Floating Photovoltaic System on Kranji Reservoir – Environmental Impact Assessment (EIA)

Volume 2 – Appendix 2.1 to 6.1

Version 1.0 (Final)

May 2024

Project No.: 0566575

Sustainability is our business

ERM

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APPENDIX 2.1 ANCHORING AND MOORING SYSTEM OPTIONS

APPENDIX 2.1: ANCHORING AND MOORING SYSTEM OPTIONS

1. DEPLOYMENT OF ANCHORING AND MOORING SYSTEM (IN-RESERVOIR)

1.1 Anchoring System Option 1

PCU/Central inverters: on fixed large piles with platform above top water level of reservoir.

O&M berthing facility: on fixed large piles with roller connections to enable it to rise and fall with the water levels.

FPV mounting system:

- Option 1.1:
  - All FPV: on 1,400 large (300-600 mm diameter) piles with roller connections that enable the FPV to rise and fall with the water levels.
  - Total of approximately 1,400 piles.
  - 300-600 mm diameter (dependent on water depth, geology, loads, and other design specifics).
  - Approximately 40 weeks duration, assuming 2 piling workstations working concurrently, enabling 6 piles a day to be installed. Assuming 24 hour works.

<u>OR</u>

- Option 1.2:
  - All FPV: with 5,000 anchor blocks and mooring lines to enable the FPV to rise and fall with the water levels.
  - Total of approximately 5,000 anchor blocks.
  - 2 m (L) x 2 m (W) x 1 m (H) dimension.
  - Approximately 70 weeks duration, assuming 4 workstations working concurrently, enabling 12 anchor blocks a day to be installed. Assuming 24 hour works.

Note: conservative case considered for surface water quality for Option 1 is piling duration from Option 1.1 = 40 weeks.

1.2 Anchoring System Option 2

PCU/Central inverters: on fixed large piles with platform above top water level of reservoir.

O&M berthing facility: on fixed large piles with roller connections.

FPV mounting system:

- Option 2.1:
  - Shallow area FPV (predominantly western waters): on 7,000 small (150-300 mm diameter) piles, with fixed frame PV connections in shallow.
  - Total of approximately 7,000 piles.
  - 150-300 mm diameter (dependent on water depth, geology, loads, and other design specifics).
  - Approximately 33 weeks duration, assuming 3 piling workstations working concurrently, enabling 30 piles a day to be installed. Assuming 24 hour works.

AND either of

- Option 2.2.1:
  - Remaining FPV: on 1,000 large piles with roller connections.
  - Total of approximately 1,000 piles.
  - 300-600 mm diameter (dependent on water depth, geology, loads, and other design specifics).
  - Approximately 23 weeks duration, assuming 2 piling workstations working concurrently, enabling 6 piles a day to be installed. Assuming 24-hour piling.

OR

- Option 2.2.2:
  - Remaining FPV: with 3,000 anchor blocks and mooring lines.
  - Total of approximately 3,000 anchor blocks.
  - 300-600 mm diameter (dependent on water depth, geology, loads, and other design specifics).
  - Approximately 42 weeks duration, assuming 4 workstations working concurrently, enabling 12 anchor blocks a day to be installed. Assuming 24 hour works.

Note: conservative case considered for surface water quality for Option 2 is piling duration from Option 2.1 + 2.2.1 = 56 weeks.

APPENDIX 2.2 EMBEDDED CONTROLS

APPENDIX 2.2: EMBEDDED CONTROLS

Table 1: Key Relevant Embedded Controls (Regulatory or Industry Standard/ Guidebooks or Planned Design/ Construction/ Operation Approach)

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
SURFACE WATER QUALITY (*SECTION 6*)	
Environmental Protection and Management Act (Chapter 94A) (Amendment), 2021 *Environmental Protection and Management (Trade Effluent) Regulations, 2011* *Environmental Protection and Management (Hazardous Substances) Regulations, 2008*	■ The Act provides for the control of air, water and noise pollution, for the safe management of hazardous waste and for the protection and management of the environment and resource conservation. Establishes NEA Allowable Limits for Trade Effluent Discharge to Watercourse or Controlled Watercourses; ■ Only trade effluent that are treated and compliant with the discharge standards for watercourses and controlled watercourses, and which do not contain prohibited materials such as pesticides, refuse, petroleum etc, will be discharged from the Project worksites; ■ Store concrete and cementitious materials according to the Material Safety Data Sheet (MSDS); ■ Carry out washout of cement and concrete mixing plant or ready-mix lorries and equipment in concrete washout areas to protect against spills and leaks; ■ Treat all trade effluent to relevant standards before it is discharged, and approval should be obtained from the Director-General of the NEA; ■ Install sampling test points, inspection chambers, flow-meters, and recording and other apparatuses for trade effluent discharged into any watercourse or land; ■ Analyse trade effluent discharged into any watercourse or land in accordance with the latest edition of "Standard Methods for the Examination of Water and Wastewater" published jointly by the American Public Health Association, the American Water Works Association and the Water Pollution Control Federation of the United States; ■ Workers will be adequately trained to handle toxic wastes stored on site, and to implement emergency action plans to deal with spills and leaks of toxic waste; and ■ Ensure that workers have received adequate instruction and training to handle any accident or emergency involving any toxic industrial waste stored or transported within the construction site.
Environmental Public Health Act (EPHA), (Amendment), 2022	■ Ensure proper storage, handling and disposal of industrial waste; ■ Prevent excessive production of toxic industrial waste; ■ Ensure provision of adequate sanitary facilities; and ■ Adequate temporary sanitary facilities will be provided for workers to ensure no public areas will be used for sanitary purposes.
Environmental Public Health (Toxic Industrial Waste) Regulations (Amendment), 2022	■ Toxic waste, such as contaminated soil from construction works must be disposed by a licensed toxic waste collector; ■ Ensure that toxic waste is stored in accordance with the approved code of practice; ■ Ensure that the toxic industrial waste is not mixed with non-toxic waste, unless it is an approved process of treatment, use or disposal; and ■ Emergency response kits will be provided at all worksites.
Environmental Public Health (General Waste Collection) Regulations (Amendment), 2019	■ Only licensed general waste collectors will collect, transport and dispose of general waste to a licensed disposal facility; and ■ Incinerable, non-incinerable and recyclable wastes will be disposed appropriately.
Fire Safety Act (Amendment), 2022	■ Petroleum or flammable materials will be stored in compliance with requirements under the relevant storage licence; ■ All practical steps will be taken to prevent the occurrence of an accident through fire, explosion, leakage or ignition of any petroleum or flammable material or vapours; ■ Firefighting equipment and other emergency response equipment will be provided at all worksites; ■ Workers will be trained in the use of available firefighting and emergency response equipment; and ■ A SCDF Plan will need to be submitted to and approved by SCDF during the final design stage.
Public Utilities (Reservoir and Catchment Areas and Waterway) Regulations 2018	The Project should: ■ Observe for prohibited activities in the Kranji Reservoir and its Catchment Area Park and obtain approval for site clearance, land-based or water-based works as necessary; ■ Implement specific safety rules, including look-out rules, speed limits, collision avoidance, navigation course control, etc;

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
Sewerage and Drainage Act (Chapter 294) (Amendment) (SDA), 2021	■ Identify location of public sewerage and drainage infrastructure near any grading, boring, excavation or ground breaking works through desktop review of drainage plan and sewerage plan prior to the commencement of the works. Subsequent to this, carry out trial trenches to confirm the location of any such public sewerage system; ■ Restrict erection of structure or object, above or across any surface water drain; ■ Prohibit works that will affect any storm water drainage system, drain or drainage reserve, directly or indirectly, without obtaining in respect of those works, a clearance certificate or approval of PUB; ■ Monitor trade effluent discharged to the public sewer and submit a monitoring record that includes the following information to PUB; - the amount of water consumed or used for the purposes of any trade, manufacture, business or building construction carried out by the persons and in the course of which the trade effluent is wholly or partly produced or of which the trade effluent is the waste or refuse; - the physical, organic and chemical nature of the trade effluent; - the raw materials and chemicals used in the trade, manufacture, business or building construction and the direction of the flow of any liquid or the trade effluent from or produced by any machinery, plant or equipment used in the trade, manufacture, business or building construction; and - such other matters relating to the trade effluent and the discharge thereof as may be required by PUB. ■ Prohibit discharge of trade effluent with characteristics that exceed the statutory limits to sewerage system; ■ Ensure that all activities involving repair, servicing, engine overhaul works, etc are carried out on a concreted area which will be bunded or provided with scupper drains to channel all wastewater into the sewerage system; ■ Trade effluent discharged to the public sewer from the worksites will be monitored and recorded; ■ Earth stockpiles will be positioned outside of the drainage reserve, and all land adjacent to drains will be turfed during general landscaping and finishing works to minimise sediment loading of stormwater drains during rainfall events; and ■ Used water will be recycled whenever practicable.
Sewerage and Drainage (Surface Water Drainage) Regulations, 2007	■ No person shall discharge or cause or permit the discharge into the storm water drainage system of Total Suspended Solids (TSS) in concentrations greater than 50 milligrams per litre of the discharge; ■ Earth control measures will be provided and maintained in accordance with the Code of Practice on Surface Water Drainage; ■ Runoff within, upstream of and adjacent to the work site will be effectively drained away without causing flooding within or in the vicinity of the work site; ■ All earth slopes adjacent to any drain will be closed turfed; and ■ Adequate measures shall be taken to prevent any earth, sand, top-soil, cement, concrete, debris or any other material to fall or be washed into the storm water drainage system from any stockpile thereof.
Sewerage and Drainage (Trade Effluent) (Amendment) Regulations, 2022	■ Any person who discharges trade effluent into any sewerage system shall, in connection with such discharge, install such sampling test points, inspection chambers, measuring devices, and recording and other apparatuses. ■ Any person who discharges trade effluent into any sewerage system shall install a pre-treatment plant if PUB so requires and shall: - use or operate the plant to treat trade effluent before discharging the trade effluent into the sewerage system; and - maintain the plant in an efficient condition at all times. ■ A person must not discharge or caused to be discharged into any public sewer any trade effluent: - which is not of a nature or type approved by PUB; - the temperature of which exceeds 45°Celsius at the point of its entry into the public sewer (NEA allowable limit for trade effluent discharge); - the pH value of which is less than 6 or more than 9 at the point of its entry into the public sewer; or - the caustic alkalinity of which is more than 2,000 milligrams of calcium carbonate per litre at the point of its entry into the public sewer. ■ A person must not discharge or caused to be discharged any trade effluent which contains any of the following substances: - any toxic industrial waste specified in the first column of the Schedule to the Environmental Public Health (Toxic Industrial Waste) Regulations (Cap. 95, Rg 11); - calcium carbide; - petroleum spirit or other inflammable substance; - any organic compound specified in the First Schedule; - any substance that either by itself or in combination or by reaction with other waste or refuse may give rise to any gas, fume, odour or substance which is or is likely to be a hazard to human life, a public nuisance, injurious or otherwise objectionable, or which prevents or is likely to prevent entry into the public sewer by workmen maintaining or repairing it; - yeast, spent or unspent molasses, crude tar, tar oil, crude oil, carbon disulfide, hydro-sulfide and poly-sulfide; - any radioactive material; - any waste or refuse liable to form a viscous or solid coating or deposit on any part of the public sewer or sewerage system; - any excessively discolouring substance; - any pesticide, fungicide, herbicide, insecticide, rodenticide or fumigant; - blood waste; or - infectious waste. ■ Prohibit discharge of trade effluent with characteristics that exceed the statutory limits to public sewerage system.
Singapore Standard SS 593: 2013 Code of Practice for Pollution Control (COPPC), 2013	■ Submit an Earth Control Management Plan endorsed by a Qualified Erosion Control Professional (QECP) to the PUB, prior to commencement of work; and ■ Implement adequate preventive measures including the provision of proper and stable barricades or screens, where deemed necessary by a QECP.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
PUB Code of Practice on Surface Water Drainage, 7th Edition December, 2018	■ Provide and maintain Earth Control Measures (ECMs) in accordance with the Code of Practice on Surface Water Drainage; ■ Submit an Earth Control Management Plan to the PUB, endorsed by a QECP prior to commencement of work; ■ Effectively drain away runoff within, upstream and adjacent to the work site without causing flooding within or in the vicinity of the site; ■ Material from any stockpile shall not be allowed to fall or be washed into the drain. Adequate preventive measures, including the provision of proper and stable barricades or screens where necessary, shall be provided; and ■ Bare surfaces (including earth stockpiles) shall be covered by concrete-lining, concrete-paving, milled waste, erosion control blankets, close turfing or other suitable materials. Access roads within the site and at exit/ entrance as well as the surfaces around the site facilities shall be covered or paved. Work areas shall be covered with canvas sheets, tarpaulin sheeting or other suitable materials during rain or before work stops every day.
PUB Code of Practice on Sewerage and Sanitary Works, 2nd Edition, 2019	■ After obtaining Temporary Occupation Permit for the development, the operator shall apply to PUB for "Written Approval to Discharge Trade Effluent"; ■ PUB may require the installation of autosampler and/ or additional monitoring of the trade effluent e.g. Volatile Organic Compound (VOC) monitoring, when granting the Written Approval; ■ All effluents that are prohibited to be discharged into a public sewer shall be disposed of by only NEA licensed toxic industrial waste collector; and ■ Animal wastes and sludge generated shall be stabilised, dewatered and disposed of as solid waste.
PUB Guidebook on Erosion and Sediment Control at Construction Sites – For Site Implementation, 2018	■ A Clearance Certificate will be obtained from the PUB, before the commencement of works; ■ Submission of an ECM proposal at the start of construction works; ■ Revision and resubmission of the ECM plans as required; and ■ The ECM and Sediment Control measures listed to be effectively implemented.
NEA's Code of Practice for Environmental Control Officers for Construction Sites, 2021	■ Provides recommended guidelines on practice measures to manage earth control measures, wastewater and sanitary facilities etc on construction sites.
Planned Design/ Construction/ Operation Approach	
Construction Earth Control Measures (ECM) Plan for Land-based Works	ECM-related embedded controls include: ■ Accumulated surface runoff from worksites will be collected by site drains to Earth Control Measures (ECMs) and discharged to the drainage system upon compliance with relevant discharge limits. No runoff into the reservoir from the proposed temporary Staging/ Launching Area will be allowed; ■ Whilst stored onsite, stockpiles will be covered by erosion control blankets or canvas or similar protective covering to minimise erosion by rainfall; ■ Silt from cut-off drains, silt traps and holding sumps should be removed regularly, with silt in holding sumps being treated and emptied within 10 hrs after a rainfall event. Content removed from the sumps should be collected by licenced waste collector for appropriate disposal/ treatment; ■ Settling ponds, where required, should be lined with impervious lining or equivalent, and designed with sufficient capacity to ensure no overflow into surrounding; and ■ Regular inspections of ECM system and discharge pipeline to ensure necessary repairs are promptly undertaken throughout the construction phase.
Construction Materials, Construction Waste and Wastewater Management (incl. Accidental Spillage and Leakage Management) for both Land-based and In-reservoir Works	■ Standard operation procedure for proper handling, storage, transfer and disposal of waste should be developed and implemented; ■ Hazardous liquid and wastewater contaminated with chemical should be stored for proper treatment and disposal offsite by approved contractor; ■ Proper storage/ bins should be provided for waste disposal. Such storage should be regularly cleaned up for offsite disposal at appropriate facilities by trained workers or contractor; ■ Provide secondary containment facilities for storage tanks/ drums containing oils and chemicals. The containment should be sized to contain the entire contents of the largest storage tank; ■ Sufficient chemical toilets (or equivalent) will be provided on site in accordance with the EPHA to serve the assembly workers for the FPV and no direct discharge of sanitary sewage would be allowed; ■ Provide appropriate equipment to prevent any leakage or discharge from containers such as portable jerry cans for ease of refuelling or handling of smaller amounts of chemicals during construction; ■ Install and operate pollution monitoring equipment to prevent and detect any leakage or discharge; ■ Ensure that emergency spill response equipment is available at appropriate worksite locations to contain and/ or absorb hazardous chemicals, fuel or oil in the event of a spillage; ■ In the event of leakage or spillage of any oil or chemicals, arrange for proper disposal of spilled product and any contaminated equipment or materials used in the response effort as TIW; ■ In the event of an accidental release, leakage or spillage of oil or chemical, immediately notify the NEA and PUB; ■ Prepare and keep up to date a Spill Prevention and Emergency Response Plan detailing how spillage, leakage or accidents involving hazardous materials will be dealt with and ensure that workers on site have received adequate training and instruction to enable them to implement the emergency action plan in the event of an emergency; ■ In the event of spillage or overflow of effluents into downstream surface waterbodies, the Spill Prevention and Emergency Response Plan will be triggered and as much of the contaminating material will be removed manually (in the case of viscous or solid material). Ensure spill control materials and protective equipment are readily accessible at the worksites and adequate training is provided to on site personnel on emergency response procedures to spill control and clean-up. Following the clean-up event, regular visual inspections and monitoring of the relevant chemical parameters will be undertaken for the affected water body until conditions return to normal; Groundwater, if any, should be discharged into the sewer with PUB's approval or disposed offsite; and ■ Trade effluent (not to be collected by ECM) should be discharged into the sewer or surface drainage systems, upon compliance with relevant discharge limits.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
Other Construction Embedded Controls for both Land-based and In-reservoir Works	■ Refuelling of work boats should be conducted at specified locations equipped with spillage control equipment (e.g. floating booms) and clean up kits to ensure any spillage can be contained and clean up swiftly. **For the proposed temporary Staging/ Launching Area:** ■ Launching ramp would be installed at the waterfront of the proposed temporary Staging/ Launching Area. The ramp would isolate disturbance from the launching activities and protect the soil/ sediment underneath and at the shoreline from wake from frequent vessel activities; ■ Silt fencing at or near the water edge to prevent on-shore sediments from washing into the reservoir; ■ Straw wattles (or equivalent) on slopes for erosion and sediment control at the launching slope; and ■ Geotextile and gravel in flat areas to prevent erosion and tracking of loose materials at the proposed temporary Staging/ Launching Area. **For firefighting:** ■ An Emergency Response Plan detailing how fires/ explosions will be managed will be prepared and agreed with SCDF, including response arrangements, and how spillage, leakage or accidents involving firefighting water and materials resulting from fire/ explosion management will be dealt with; ■ All temporary electrical installations, equipment and tools should be checked and certified for use regularly by a full-time licensed electrical worker; and ■ The hoarding for the worksite will be composed of non-combustible material to deter the spread of fire beyond the worksite. **For FPV floats:** ■ Floats to be made using a certified food-grade high-density polyethylene (HDPE) material that is recyclable, UV-resistant and corrosion-resistant. **For in reservoir navigation/ works in general:** ■ Work boats/ barges will be properly sized for the task involved and be equipped with suitable navigation safety features according to location and appropriate regulations and guidelines; ■ Speed limit of 5 knots will be implemented, particularly in shallow areas or close to the shore to minimise disturbance to the reservoir bed and erosion of the bank; ■ Regular traffic routes should be established for routine works. Offsets from shoreline as well as corridors between FPV islands allow safe navigation access, this will minimise the risk of getting into shallow water unintentionally and also minimises the risk of collision or grounding; ■ Compliance with Part IV Navigation Rules of the Public Utilities (Reservoirs, Catchment Areas and Waterway) Regulations 2006 and the International Regulations for Preventing Collisions at Sea 1972 (COLREGs); and ■ Work vessels should be well-maintained. Refuelling should be conducted at designated area equipped with spill containing equipment as well as clean up kit. **For PUB reservoir operations:** ■ Establish and agreed Standard Operating Procedures (SOPs) for works activities during tidal gate operation (e.g. works stoppage prior to tidal gate opening) with PUB; and ■ Existing aquatic vegetation management to continue, as appropriate. **For in-reservoir works:** ■ No dredging and excavation of reservoir sediment for anchoring approach or connector cable laying; and ■ Connector cables should be laid on surface of the reservoir bed, not buried.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
Good practice and planned design to be implemented during operation	■ To control the surface water quality impacts from the operation phase, the following design and operational features are taken into account. The below are further to the operational embedded controls outlined for Biodiversity (Section 7), Air Quality (Section 8), Airborne Noise and Vibration (Section 9), Soil and Groundwater (Section 10) and Vectors (Section 11). **For FPV layout design:** ■ Inclusion of the intra-island block spacing (i.e. breaking up large FPV islands with 30-40m corridors), as required for safe and viable operations, and firefighting access. Noting that whilst this is an embedded control requirement from operational perspective and SCDF, this has not been accounted for in the Water Quality Model, therefore enabling a more conservative assessment of potential surface water quality impacts in this EIA. **For maintenance:** ■ For cleaning of FPVs in reservoir, no detergent or soap would be allowed. Water (pressurised if needed) drawn from the reservoir directly would be used. **For work boats:** ■ Work boats will be properly sized for the task involved and be equipped with suitable navigation safety features according to location and appropriate regulations and guidelines; ■ Speed limit of 5 knots will be implemented, particularly in shallow areas or close to the shore to minimise disturbance to the reservoir bed and erosion of the bank; and ■ Regular traffic routes should be established for routine works. Offsets from shoreline as well as 30-40 m corridors between FPV islands allow safe navigation access, this will minimise the risk of getting into shallow water unintentionally and also minimises the risk of collision or grounding. **For handling of chemical/ hazardous waste:** ■ Workers will be adequately trained to handle chemical/ hazardous wastes stored on site, and to implement emergency action plans to deal with spills and leaks of toxic waste; ■ Appropriately licenced waste collectors to be used; ■ Emergency response kits will be provided at all Project Sites; and ■ Prepare and keep up to date a Spill Prevention and Emergency Response Plan detailing how spillage, leakage or accidents involving hazardous materials will be dealt with and ensure that workers on site have received adequate training and instruction to enable them to implement the emergency action plan in the event of an emergency. **For firefighting:** ■ Petroleum or flammable materials will be stored in compliance with requirements under the relevant storage license; ■ All practical steps will be taken to prevent the occurrence of an accident through fire, explosion, leakage or ignition of any petroleum or flammable material or vapours; ■ Firefighting equipment and other emergency response equipment will be provided; ■ Considerations should be taken into account in design of FPV layout to reduce the potential for fire propagation between FPV islands; ■ Design, installation and operation and maintenance of FPV system to be carried out to national and international standards and to manufacturers specifications; ■ A centralised monitoring system shall be implemented to observe the FPV system operations and immediately flag any faults/ issues as they occur; ■ An Emergency Response Plan detailing how fires/ explosions will be managed will be prepared and agreed with SCDF, including response arrangements, and how spillage, leakage or accidents involving firefighting water and materials resulting from fire/ explosion management will be dealt with; ■ Manual emergency shut-off system for the disconnection of the FPV modules shall be provided on land and at the inverter if it is on the water; and ■ All solar FPV strings within the array shall be differentiated and easily identifiable by responders.
BIODIVERSITY (*SECTION 7*)	
Parks and Trees Act (2021) and subsidiary legislation	■ The Act to provide for the planting, maintenance and conservation of trees and plants within national parks, nature reserves, tree conservation areas, heritage road green buffers and other specified areas. ■ The Project should strictly control any: - Activities that will damage flora, the land or cause injury to fauna within the Nature Reserves; - Cutting or damaging trees with girth of more than 1 m within a Tree Conservation Area; and - Cutting or damaging trees or plants within the heritage road green buffers. ■ The Project should also: - Provide temporary sanitary facilities and waste management areas to be provided to avoid fouling of surface water resources; and - Seek approval from NParks before carrying out restricted activities. ■ Trees with girths exceeding 1 m which are growing within any Tree Conservation Area or any vacant land, will not be cut down without approval from NParks.
Wildlife Act, 1965 (Revised edition 2020)	■ The Director-General may direct a person to implement any wildlife-related measures necessary to safeguard wildlife or health of ecosystem. ■ Workers to be trained to avoid undertaking prohibited activities such as: - The killing, taking or keeping of any wildlife; - Taking and destroying eggs of wild birds; and - Placing contraptions that are likely to cause injury to humans.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
Public Utilities (Reservoir and Catchment Areas and Waterway) Regulations 2018	The Project should: ■ Undertake measures to manage impacts to surface water quality; and ■ Ensure its activities will not lead to the damage of flora or fauna.
National Biodiversity Strategy and Action Plan (NBSAP) (NParks, 2009)	■ Fulfilment of commitments to United Nations Convention on Biological Diversity (UNCBD); and ■ Sets out goals to conserve and enhance Singapore's biodiversity.
Nature Conservation Master Plan (NCMP) (NParks, 2015)	■ The NCMP aims to systematically consolidate, coordinate, strengthen and intensify the biodiversity conservation efforts outlined in the NBSAP; and ■ Sets out biodiversity conservation plans for the following five years to achieve the Singapore's vision of a City in a Garden.
Singapore Red Data Book (2nd and 3rd edition[1])	■ List of species in Singapore which need improvement on their conservation status.
National Parks Board Guidelines on Greenery Provision and Tree Conservation for Developments (2018)	■ Set of guidelines to describe the statutory requirements on greenery provision, tree planting and conservation for development projects in Singapore, including protection of trees during construction.
Biodiversity Impact Assessment (BIA) Guidelines (NParks, 2020)	■ Provides reference for developers and industry professionals to understand the common requirements for the biodiversity component of an EIA
United Nations Convention on Biological Diversity (UNCBD, 1993)	■ Promotes conservation of biodiversity.
International Union for Conservation of Nature (IUCN) Red List of Threatened Species	■ Provides global extinction risk status of animals, fungus, and plant species.
Planned Design/ Construction/ Operation Approach	
Good practice and planned design to be implemented during construction	■ Design, installation and operation and maintenance of FPV system to be carried out to national and international standards and to manufacturers specifications, for example TR 100: 2022 Technical Reference on Floating Photovoltaic Power Plants – Design Guidelines and Recommendations, published in 2022. **For Developer/ Owner and Contractor staff:** ■ Environmental Manager to monitor, supervise and evaluate works that may impact on biodiversity (as identified in this EIA); and ■ Providing tool-box talks and training to all site personnel prior to commencement of construction to communicate the Project's commitments regarding biodiversity and how it shall be managed, including: - Ecologically sensitive areas; - Proper protocols and reporting procedures to be adopted when wildlife is encountered; - Need to be cautious when operating machinery to avoid injury/ mortality to fauna; - Need to keep all workplaces safe for wildlife (e.g. when not being actively worked on), storage and use of hazardous materials, and food/ waste management; - All workers will be prohibited from feeding animals; and - Refresher training will be provided every 6 months during the construction phase for all new and old personnel. **For tree/ vegetation clearance:** ■ Regulating contractor movements and activities to areas only within the construction and operational footprint, and prohibiting access to other areas; ■ Permit to Clear process to control and limit the clearing of vegetation to the minimum necessary, and staging vegetation clearing where practicable, e.g. seek NParks approval for felling of trees with girth >1m; ■ All terrestrial habitat clearing at the shoreline will be minimised to avoid unnecessary tree and vegetation removal to the required footprint only; and ■ Seek approval from NParks before carrying out restricted activities as outlined in the Parks and Trees Regulations, Part 2, Division 1 and 2. **For FPV Layout:** ■ Shoreline setbacks and FPV spacing: - Minimum 25 m around the reservoir edges, including for boat access; - Setback at least 100 m from the Kranji tidal gate and dam and thus SBWR and Mandai Mangroves and Mudflats to the north; - 50 m vessel corridors at prescribed water depths for PUB operations, including: o North-south vessel corridor on eastern reservoir edge (depth requirements can only be accommodated along the eastern portion of the reservoir) – resulting in generally >50 m eastern shoreline setback to FPV infrastructure; and

[1] Singapore Red Data Book status of species as of 17 January 2023. This may be subject to change.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
	○ East-west vessel corridor to PUB intake channel (the channel on the western side of Kranji bund). - O&M and fire and emergency vessel corridors, required for operational requirements and SCDF: ○ Spacing between large FPV islands; and ○ Breaking up of large FPV islands with 30-40m vessel corridors, to be incorporated in the detailed design stage by the Developer/ Owner. These measures will avoid and reduce impacts to the biodiversity-rich littoral areas, especially on the east bank, and enable some continued foraging in the western edges by birds i.e. little tern and herons. **For in-reservoir connector cables:** ■ No underwater trenching (dredging) to lay connector cables which reduces the direct loss of benthic habitat and the impacts of suspended sediments on surface water quality and biodiversity. **For night-time works on land:** ■ Use directional lighting at night to avoid lighting directed at, and minimise light spill, especially to Kranji Marshes and Sungei Kadut Forest and reservoir edges; and ■ Minimise night-time security lighting as far as practicable whilst enabling safe and secure site. **For work boats:** ■ Speed limit of 5 knots will be implemented, particularly in shallow areas or close to the shore to minimise disturbance to the wildlife. **For in-reservoir and on land works:** ■ Preventing the introduction, movement and spread of invasive species on and off site, for example through inspections and washing down of vehicles or boats / barges, and the processes for removing non-native alien species; and ■ FPV Panels to be coated with anti-reflective materials to maximise light absorption and minimise glare or reflection in order to reduce risk of bird collisions. **For on land works:** ■ Locating the proposed temporary Staging/ Launching Area and integrated Project Substation on a brownfield (previously developed) land parcel in Sungei Kadut Industrial Estate to avoid and minimise vegetation clearing for these components; ■ Integrated Project Substation to be set back from the Kranji Reservoir shoreline; ■ Integrated Project Substation to follow the principles of the Urban Design Guidelines, Guidelines on Greenery Provision and Tree Conservation, and greening/ planting, utilising native species wherever possible; ■ Shoreline adjacent of the proposed temporary Staging/ Launching Area to be re-planted after construction, where feasible; ■ Using existing roads for construction and maintenance access. No new haul road or access will be created; ■ Use only fully biodegradable erosion control blankets (ECB); ■ Maintenance of worksite hoarding and repair of damages on a timely basis; and ■ Separate storage of top- and subsoils, and reinstatement in correct order. **For emergency planning:** ■ Prepare and keep up to date a Spill Prevention and Emergency Response Plan detailing how fires/ explosions and spillage, leakage or accidents involving hazardous materials will be dealt with and ensure that workers on site have received adequate training and instruction to enable them to implement the emergency action plan in the event of an emergency.
Good practice and planned design to be implemented during operation	■ A conservative operational surface water quality modelling and assessment presented in Section 6 (Surface Water Quality) and documented in Appendix 6.1 (Water Quality Modelling Technical Appendix) covers a larger, maximum possible extent (thus more impactful) FPV coverage (of 122 ha) than that ultimately proposed by this EIA for approval (112 ha coverage, see Figure 2-4). See Table 7 18 for biodiversity mitigation recommendations related to the FPV layout. **For Developer/ Owner staff:** ■ Environmental Manager to monitor, supervise and evaluate works that may impact on biodiversity (as identified in this EIA); and ■ Providing tool-box talks and training to all site personnel prior to commencement of operation, and as part of all new staff inductions, and regular annual refresher training, to communicate the Project's commitments regarding biodiversity and how it shall be managed, including: - Ecologically sensitive areas; - Proper protocols and reporting procedures to be adopted when wildlife is encountered; - Need to be cautious when operating machinery (e.g. work boats) to avoid injury/mortality to fauna; - Need to keep all work places safe for wildlife (e.g. when not being actively worked on), storage and use of hazardous materials, and food/ waste management; - All workers will be prohibited from feeding animals; and - Biodiversity induction training should be provided for all new personnel, with refresher training provided annually during the operational phase. **For FPV Panels and Layout:** ■ Shoreline setbacks and FPV spacing:

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
	- Minimum 25 m around the reservoir edges, including for boat access; - Setback at least 100 m from the Kranji tidal gate and dam and thus SBWR and Mandai Mangroves and Mudflats to the north; - 50 m vessel corridors at prescribed water depths for PUB operations, including: o North-south vessel corridor on eastern reservoir edge (depth requirements can only be accommodated along the eastern portion of the reservoir) – resulting in generally >50 m eastern shoreline setback to FPV infrastructure; and o East-west vessel corridor to PUB intake channel (the channel on the western side of Kranji bund). - O&M and fire and emergency vessel corridors, required for operational requirements and SCDF: o Spacing between large FPV islands; and o Breaking up of large FPV islands with 30-40m vessel corridors, to be incorporated in the detailed design stage by the Developer/ Owner. These measures will avoid and reduce impacts to the biodiversity-rich littoral areas, especially on the east bank, and enable some continued foraging in the western edges by birds i.e. little tern and herons. ■ No development of the area south of the Reservoir Project Site, for fish and the terrestrial fauna they support; ■ Optimise angle of FPV panels to will allow for some light to penetrate the water surface and reduce shading, wherever feasible; and ■ FPV Panels to be coated with anti-reflective materials to maximise light absorption and minimise glare or reflection in order to reduce risk of bird collisions. **For night-time works on land:** ■ Use directional lightning at night to avoid lighting directed at, and minimise light spill, especially to Kranji Marshes and Sungei Kadut Forest and reservoir edges; and ■ Minimise night-time security lighting as far as practicable whilst enabling safe and secure site. **For work boats/ in-reservoir works:** ■ Speed limit of 5 knots will be implemented, particularly in shallow areas or close to the shore to minimise disturbance to the wildlife; ■ Preventing the introduction, movement and spread of invasive species on and off site, for example through inspections and washing down of vehicles or boats/ barges, and the processes for removing non-native alien species; and ■ Ensure good housekeeping controls such as food consumption at designated food and rest areas with storage areas and wildlife proof bins, away from natural habitat where possible, to prevent attracting wildlife to the area as a food source. **For maintenance:** ■ For cleaning of FPVs in reservoir, no detergent or soap would be allowed. Water (pressurised if needed) drawn from the reservoir directly would be used; and **For emergency planning:** ■ Prepare and keep up to date a Spill Prevention and Emergency Response Plan detailing how fires/ explosions and spillage, leakage or accidents involving hazardous materials will be dealt with and ensure that workers on site have received adequate training and instruction to enable them to implement the emergency action plan in the event of an emergency.
AIR QUALITY (*SECTION 8*)	
Environmental Protection and Management Act (Chapter 94A) (Amendment), 2021	■ This Act provides for the control of air, water and noise pollution, for the safe management of hazardous waste and for the protection and management of the environment and resource conservation.
Environmental Protection and Management (Vehicular Emissions) Regulations (Amendment), 2023	■ All motor vehicles being driven in Singapore, when using diesel or petrol, must only use Euro V diesel or petrol that conforms with the standard of using Ultra Low Sulphur Diesel (ULSD) Fuel with a maximum sulphur concentration of 10 parts per million (ppm) (0.001%) or lower to minimise SO2 emissions.
Environmental Protection and Management (Off-Road Diesel Engine Emissions) Regulations, 2012	■ Vehicles and off-road diesel engines used on site must be in compliance with emissions standards stipulated in the relevant regulations.
Environmental Public Health Act (EPHA), (Amendment), 2022	■ Control measures shall be put in place to minimise dust nuisances arising from construction works.
NEA Singapore Ambient Air Quality Targets (AAQTs), 2020	■ Recommends air quality targets, sulfur dioxide emission inventory, and industrial and vehicle emission standards for Singapore.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
NEA Code of Practice for Environmental Control Officers for Construction Sites, 2021	■ Provides recommended guidelines on practice measures to reduce dust arising from construction; ■ Open burning of construction and other wastes are not allowed at the worksite; ■ Effective measures such as water sprinklers/ spray, shielding, netting, covers/ hoarding for aggregate and sand storage should be taken to minimise dust pollution caused by construction or demolition works. The netting or barriers on the scaffolding of the construction site shall be of suitable height for effective containment of dust and debris; ■ All construction debris should be properly stored and removed for disposal quickly. They should not be left to accumulate at the site; ■ All construction equipment and machinery must be well maintained and should not emit dark smoke; and ■ Generators should be sited at locations that minimise the smell and noise nuisance affecting nearby sensitive receptors.
Guidance on Monitoring in the Vicinity of Demolition and Construction Sites (IAQM), 2018	■ Provides recommendations for the method of monitoring of concentrations of particulate matter and dust deposition in the vicinity of demolition and construction sites.
Guidance on the Assessment of Dust from Demolition and Construction (Institute of Air Quality Management, IAQM), 2014	■ Provides guidance on the assessment of dust arising from the construction and air quality impact magnitude and air receptor sensitivity criteria. ■ Provides guidelines on good practice measures to reduce dust arising from construction.
Land Use & Development Control: Planning for Air Quality Guidelines, IAQM (2017)	■ Guidance to ensure that air quality is adequately considered in the land-use planning and development control processes.
World Health Organisation Air Quality Guidelines (WHO AGS), 2021	■ Recommends levels for air quality guidelines and interim targets for common air pollutants: PM, O3, NO2 and SO2.
Planned Design/ Construction/ Operation Approach	
Good practice to be implemented during construction	■ All temporary stockpiles of spoil or backfill that have not been used for more than 3 days shall be covered with canvas sheeting or erosion control blankets; ■ Vehicular access to worksites will be paved using suitable materials such as concrete, mill waste or hardcore; ■ All cement mixer trucks must have a containment system, or a flap installed to prevent spillage of cement; ■ Provide and maintain a truck wash bay for washing vehicles leaving the worksite onto a roadway at each vehicular egress point to minimise resuspension of dust due to trackout of dirt on roadways before commencement of works on site. As part of the Earth Control Measures (ECM) Plan, obtain approval from PUB for the design of each truck wash bay; ■ Speed limits will be applied within the construction worksite; ■ All asphalt roads, pavements and public footpaths will be kept clear of dust, silt and debris; ■ Switch off machinery when not in use; ■ Ensure construction machinery used complies with the USEPA Tier 4 emission standards for NOx and PM10; ■ Maintaining all equipment and machinery, including excavators and gen-sets regularly, to minimise smoke and dust exhaust emissions; and ■ To use Ultra Low Sulphur Diesel Fuel with a maximum sulphur concentration of 10 parts per million for diesel run construction equipment.
AIRBORNE NOISE AND VIBRATION (*SECTION 9*)	
Environmental Protection and Management Act (Chapter 94A) (Amendment), 2021	■ This Act provides for the control of air, water and noise pollution, for the safe management of hazardous waste and for the protection and management of the environment and resource conservation.
Environmental Protection and Management (Control of Noise at Construction Sites) Regulations, 2011	■ Airborne noise during construction works shall comply with the limits in the legislation based on various classifications of surrounding noise sensitive receptors; and ■ No work to be carried out during the prohibited periods (i.e. 10 pm on Saturday or eve of a Public Holiday, to 7 am on the following Monday or day after the Public Holiday) for construction work at any worksite located less than 150 m away from residential and noise-sensitive premises. If work is required to be carried out during the prohibited periods, permission shall be requested from the authority (i.e. NEA).
Environmental Protection and Management (Boundary Noise Limits for Factory Premises) Regulations, 2008	■ Airborne noise during Project operation shall comply with the limits in the legislation based on the type of affected premises along the boundaries of the factory premise.
Environmental Protection and Management (Vehicular Emissions) Regulations (Amendment), 2023	■ Motor vehicles used onsite will be in compliance with noise emissions stipulated in the legislation.
Environmental Public Health Act (EPHA), (Amendment), 2022	■ Noise control measures shall be put in place to minimise noise nuisance arising from construction works to the noise sensitive receptors.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
NEA's Code of Practice for Environmental Control Officers for Construction Sites, 2021	■ Provides recommended guidelines on practice measures to manage noise on construction sites; and ■ Generators should be sited at locations that minimise the smell and noise nuisance affecting nearby sensitive receptors.
Singapore Standards SS602:2014 Code of Practice for Noise Control on Construction and Demolition Sites, 2014	■ Recommends methods of monitoring, estimation of construction equipment noise levels, noise control techniques and selection of quieter construction equipment and methods.
Singapore Standards SS593: 2013 Code of Practice for Pollution Control (COPPC)	■ Recommends noise pollution control requirements and good practices to safeguard the noise sensitive receptors.
British Standard 5228:2009+A1:2014 and Code of Practice for Noise and Vibration Control on Construction and Open Sites	■ Recommends basic methods of vibration and noise control relating to construction and open sites where work activities/ operations generate significant vibration or noise levels.
British Standard 6472-1:2008 - Part 1: Vibration sources other than blasting	■ Provides guidelines to evaluate human exposure to vibration in buildings.
International Organization for Standardization (ISO), (1996); International Standard 9613-2: Acoustics – Attenuation of Sound During Propagation Outdoors	■ Provides method for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources. The method predicts the equivalent continuous A-weighted sound pressure level (as described in ISO 1996) under meteorological conditions.
Fundamental of Acoustics, Fourth edition (2000)	■ Provides physical and mathematical concepts related to the generation, transmission and reception of acoustic waves.
Planned Design/ Construction/ Operation Approach	
Integrated Project Substation building orientation to be implemented during design	■ Louvres for the integrated Project Substation are orientated to face the public roads to the east, i.e. Sungei Kadut Drive, to minimise noise to the Kranji Reservoir and future park to the west.
SOIL AND GROUNDWATER (*SECTION 10*)	
Environmental Protection and Management Act (Chapter 94A) (Amendment), 2021	■ This Act provides for the control of air, water and noise pollution, for the safe management of hazardous waste and for the protection and management of the environment and resource conservation; and ■ Provides measures related to pollution control regarding the discharge of toxic substances or hazardous substances deemed to cause pollution of the environment including groundwater.
Environmental Protection and Management (Hazardous Substances) Regulations (Amendment), 2021	■ A record indicating the quantity of hazardous substances shall be kept; ■ Employ required practices such as proper labelling and placement of containers storing hazardous substances; ■ Ensure potentially contaminated runoff discharged to any land or watercourse complies with statutory limits and will not contain substances stipulated within the regulations; ■ Workers will be adequately trained to handle toxic wastes stored on site, and to implement emergency action plans to deal with spills and leaks of toxic waste; and ■ Ensure that workers have received adequate instruction and training to handle any accident or emergency involving any toxic industrial waste stored or transported within the construction site.
Environmental Protection and Management (Trade Effluent) Regulations, 2008	■ Only trade effluent that are treated and compliant with the discharge standards for watercourses and controlled watercourses, and which do not contain prohibited materials such as pesticides, refuse, petroleum etc., will be discharged from the Project worksites; ■ Treat all trade effluent before it is discharged into any watercourse or land, unless an exemption is specifically granted by the Director-General of the NEA; ■ Install sampling test points, inspection chambers, flow-meters, and recording and other apparatuses for trade effluent discharged into any watercourse or land; ■ Analyse potentially contaminated runoff discharged into any watercourse or land in accordance with the latest edition of "Standard Methods for the Examination of Water and Wastewater" published jointly by the American Public Health Association, the American Water Works Association and the Water Pollution Control Federation of the United States; ■ Prohibit discharge of any trade effluent, oil, chemical, sewerage or other polluting matters into any drain or land, without a license from the Director-General of the NEA; ■ Prohibit discharge of trade effluent that contains: - pesticides, fungicide, herbicide, insecticide, rodenticide or fumigant; - refuse, garbage, sawdust, timber, human or animal waste or solid matter; - petroleum or other inflammable solvent; and - any reactive substance that may give rise to hazardous fumes or odour.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
Environmental Public Health Act (EPHA) (Amendment), 2022	■ Ensure proper storage and disposal of Toxic Industrial Waste (TIW); ■ Prevent excessive production of TIW; and ■ Provide adequate sanitary facilities for workers.
Environmental Public Health (Toxic Industrial Waste) Regulations (Amendment), 2022	■ Keep a register of type, quantity and manner of disposal of TIW generated on site, date and quantity sold to TIW Collectors, and quantity held in stock and update it on a weekly basis; ■ Prepare and keep up to date an emergency action plan detailing how spillage, leakage or accidents which may arise from the storage of TIW will be dealt with and ensure that workers on site have received adequate training and instruction to enable them to implement the emergency action plan in the event of an emergency; ■ TIW such as contaminated soil from construction works must be disposed by a licensed toxic waste collector; ■ Ensure that TIW is stored in accordance with the approved code of practice; ■ Ensure that the TIW is not mixed with non-toxic waste, unless it is an approved process of treatment, use or disposal; and ■ Emergency response kits will be provided at all worksites.
Environmental Public Health (General Waste Collection) Regulations (Amendment), 2019	■ Only licensed general waste collectors shall be contracted to collect, transport, and dispose of general waste generated from the Project Site.
Fire Safety (Petroleum and Flammable Materials – Exemption) Order (Amendment), 2020	■ In the event that storage of petroleum and/or flammable materials in quantities exceeding that specified in the First Schedule of the Fire Safety (Petroleum and Flammable Materials – Exemption) Order, 2008, is required at the Project worksite, Contractors shall obtain a Petroleum & Flammable Materials Storage License from the Singapore Civil Defence Force (SCDF).
Fire Safety (Petroleum and Flammable Materials) Regulations (Amendment), 2022	■ Contractors holding a Petroleum and Flammable Materials Storage License shall implement the controls listed in the regulations for the storage of petroleum and/or flammable materials on site; ■ Keep and maintain a register of petroleum and flammable materials stored for a period of 2 years; ■ Take all practicable steps to prevent the occurrence of an accident through fire, explosion, leakage or ignition of any petroleum or flammable material or vapours; ■ Ensure that security measures are undertaken to prohibit access to the licensed storage premises by untrained personnel; ■ Provide adequate fire-fighting material and other emergency response equipment e.g. spill kits at the storage site; ■ Ensure that chemical handlers are trained to handle available equipment and are aware of the actions to be taken in the event of any fire, explosion, leakage or other similar emergencies; ■ Provide and keep updated an Emergency Response Plan to deal with any spillage, leakage, accidental discharge or emergency which may result from the storage of petroleum or flammable material stored at the premises. ■ Ensure that appropriate emergency information panels or warning labels as prescribed in the code of labelling (SS 286) are installed at the approved storage area.; and ■ In the event of any loss, theft, fire, explosion, leakage, accident or accidental discharge of any petroleum and flammable material at the worksite, take immediate action to control and contain the leakage or discharge, and inform the Commissioner of the SCDF.
Sewerage and Drainage Act (Surface Water Drainage) Regulations, 2007	■ Prohibit the discharge of silt or debris directly or indirectly into stormwater drainage systems; ■ Must not cause any obstruction to the flow of any stormwater drainage system; and ■ Prohibit works that will affect any storm water drainage system, drain or drainage reserve, directly or indirectly, without obtaining in respect of those works, a clearance certificate or approval of the PUB.

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
Singapore Standard SS593: 2013 Code of practice for pollution control (COPPC)	■ Ensure that only containers constructed and inspected in accordance with internationally acceptable standards are used for the storage of hazardous substances and affixed with approved labels; ■ Ensure that storage areas are equipped with containment as well as disposal facilities to deal with any accidental release of hazardous substances; ■ Immediate mitigation measures shall be taken to control and contain the release, leakage or spillage of any hazardous substance and to clean up any lands affected by the release, leakage or spillage. All wastes generated shall be treated and disposed of safely; ■ A full containment facility shall be provided for above ground bulk storage tanks (including skid tanks). The capacity of the containment facility shall not be less than the capacity of the largest tank; ■ For a secondary containment facility that is fully enclosed, a leak detection system with an alarm device shall be provided within the secondary containment facility. A leak test shall be conducted before the tank is put into use. The leak test shall conform to the following guidelines: - The leak test method shall be able to measure a leak rate of at least 0.19 litre per hour, and be capable of testing the entire tank system, including piping; - If the tank has a loss rate in excess of 0.19 litre per hour, the tank shall be considered to be leaking; and - The leak tests shall be carried out in accordance with an established leak test method and certified by professional engineers. The test results shall be submitted to the NEA's Pollution Control Department (PCD). ■ A contingency plan shall be developed and put in place to deal with leaks. The contingency plan shall meet the following requirements: - To appoint a competent party or person to deal with leaks from above ground tanks; - To set up guidelines to activate the contingency plan (i.e. who, when and how to contact, emergency coordinator, confirmation of leak, etc); - To inform PCD as soon as leak is detected. Singapore Civil Defence Force (SCDF) shall also be informed if the chemical/ product is flammable or combustible; - To remove chemical/ product from the tank to a temporary storage by the competent party or person; - To remove the tank for inspection; - To remove the contaminated soil for proper disposal; - To carry out soil testing to ensure that all the pollutants have been removed; and - To repair or replace the tank and re-construct the secondary containment chamber if necessary. ■ The connection point for a filling pipe of a bulk storage tank shall be provided with measures to contain spillage.
Planned Design/ Construction*/ Operation *Approach	
Phase II ESA Recommendation	■ Based on the Phase I ESA findings, it is recommended for a targeted soil and groundwater Phase II ESA (also known as an Environmental Baseline Study (EBS)) be carried out at the proposed temporary Staging/ Launching Area and integrated Project Substation worksite, (i) to determine if the identified hotspots have impacted the underlying soil, (ii) to establish the baseline soil and groundwater conditions, (iii) to recommend any remedial measures required (e.g. removal or treatment of potential contamination sources), and (iv) to inform the detailed design and construction approaches.
VECTOR (*SECTION 11*)	
Control of Vectors and Pesticides Act (Chapter 59) (Amendment), 2021	■ Ensure that no conditions favourable to breeding, propagation and harbouring of vectors are created; ■ Prevention of clearing undergrowth or vegetation on any land which may have running or standing water which may be afforded by the development of vegetation; ■ Abide by any order served to carry out vector control work or measures, as may be specified in the order, regarding the treatment, destruction or removal of anything therein as may bring the premises into a condition unfavourable to the propagation of harbouring of vectors; and ■ Abide by any notice served to carry out spraying or fogging with pesticides within the specified time frame.
Environmental Public Health Act (Amendment), 2022	■ Deal with areas or conditions that are dangerous to health, or may promote the breeding of flies or mosquitoes.
Infectious Diseases Act (Amendment), 2022	■ Prohibit any person from bringing to Singapore any vectors capable of transmitting a disease; ■ Notification of any person who is aware or suspected of being a carrier of an infectious disease; and ■ Prohibit any person for any period from carrying on any occupation, trade or business if it is conducted in such manner as is likely to cause the spread of any infectious disease.
NEA's Code of Practice for Environmental Control Officers for Construction Sites, 2021	■ Provides recommended guidelines on practice measures to manage vectors on construction sites; and ■ The Environmental Control Officer (ECO) Scheme under the Code of Practice assists contractors and site managers in identifying problems related to vector control at construction sites.
Planned Design/ Construction/ Operation Approach	
Good practice to be implemented during construction	■ Ensure good housekeeping controls such as food consumption at designated food and rest areas with storage areas and wildlife proof bins, away from natural habitat where possible, to prevent attracting wildlife to the area as a food source.
UNPLANNED EVENTS	
General industry practice for Unplanned Events	**Fire and Explosion:** ■ Design, installation and operation and maintenance of FPV system to be carried out to national and international standards and to manufacturers specifications, for example TR 100: 2022 Technical Reference on Floating Photovoltaic Power Plants – Design Guidelines and Recommendations, published in 2022; ■ A 25m setback distance from the Reservoir Project Site to the shoreline and inter-island spacing between FPV islands contains and limits the spread of fire from FPV island to FPV island, as well as to surrounding shorelines;

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
	■ Petroleum or flammable materials will be stored in compliance with requirements under the relevant storage license. In the event that storage of petroleum and/ or flammable materials in quantities exceeding that specified in the First Schedule of the Fire Safety (Petroleum and Flammable Materials – Exemption) Order, 2008, is required at the Project worksite, Contractors shall obtain a Petroleum & Flammable Materials Storage License from the SCDF; ■ All practical steps will be taken to prevent the occurrence of an accident through fire, explosion, leakage or ignition of any petroleum or flammable material or vapours; ■ Workers onsite will be properly trained to operate vessels and machinery; ■ All temporary electrical installations, equipment and tools should be checked and certified for use regularly by a full-time licensed electrical worker; ■ The hoarding for the worksite will be composed of non-combustible material to deter the spread of fire beyond the worksite; ■ A Spill Prevention and Emergency Response Plan detailing how fires/ explosions will be managed will be prepared and agreed with SCDF, including how spillage, leakage or accidents involving firefighting water and materials resulting from fire/ explosion management will be dealt with; ■ Firefighting equipment and other emergency response equipment will be provided at all worksites; ■ Workers will be trained in the use of available firefighting and emergency response equipment; ■ Considerations should be taken into account in design of FPV layout to reduce the potential for fire propagation between FPV islands; ■ Design, installation and operation and maintenance of FPV system to be carried out to national and international standards and to manufacturers specifications; ■ A centralised monitoring system shall be implemented to observe the FPV system operations and immediately flag any faults/ issues as they occur; ■ The FPV arrays, including moorings and anchors, will not be placed over the top of any existing services, such as pipelines; ■ Manual emergency shut-off system for the disconnection of the FPV modules shall be provided on land and at the inverter, if it is on the water; ■ All solar FPV strings within the array shall be differentiated and easily identifiable by responders; ■ Fire response time from SCDF will be an estimated 8 minutes from the time of call. The nearest fire station, Woodlands Fire Station, is located 8 minutes from the integrated Project Substation (and O&M Facility). Moreover, SCDF's quality service intent states that response to fire emergencies will be within 8 minutes of the call 90% of the time. This allows fires to be quickly responded to and contained within the site; and ■ Regular enforcement checks by SCDF will be conducted within industrial premises such as the integrated Project Substation (and O&M Facility) to ensure compliance with fire safety regulations. **Environmental Control Measure(s) (ECM)**[2] ■ A Clearance Certificate will be obtained from the PUB, before the commencement of works; ■ Submission of an ECM proposal at the start of construction works; ■ The ECM and Sediment Control measures listed to be effectively implemented; ■ The sizing of an ECM system with adequate capacity to cater for exceptional rainfall events such as a once in five-year storm, in accordance with PUB requirements for each worksite; ■ The sizing of an ECM with adequate capacity to cater for exceptional rainfall events, which will double up as a holding pit for firewater till collection by a third party Contractor for off-site disposal; ■ A perimeter drain will be provided to ensure that the surface runoff within the worksites will be channelled towards centralised tanks for further treatment, before discharging to the roadside drains; ■ Closed-circuit television (CCTV) cameras including Silt Imagery Detection System (SIDS) will be located at the ECM discharge points into the existing drain; ■ The construction site will also have an Environmental Control Officer (ECO) on site to ensure the implementation, maintenance and inspection of the ECM plan during the construction period; ■ Install sampling test points, inspection chambers, flow-meters, and recording and other apparatuses into the collection and treatment infrastructure at the ECM discharge point; ■ Take all adequate measures to prevent any earth, sand, top-soil, cement, concrete, bentonite slurry, debris or any other material to fall or be washed into the stormwater drainage system from any stockpile. ■ Whilst stored on site, stockpiles will be covered by erosion control blankets or canvas or similar protective covering to minimise erosion by rainfall; ■ Silt from cut-off drains, silt traps and holding sumps should be removed regularly, with silt in holding sumps should be treated and emptied within 10 hours after a rainfall event; ■ Settling pond, where required, should be lined with impervious lining or equivalent, and designed with sufficient capacity to ensure no overflow into surrounding; ■ Hazardous liquid and wastewater contaminated with chemical should be stored for proper treatment and disposal offsite by approved contractor; ■ Regular inspections of ECM system and discharge pipeline to ensure necessary repairs are promptly undertaken throughout the construction phase; ■ Ensure that adequate preventive measures are in place including the provision of proper and stable barricades or screens where necessary; ■ Effectively drain away runoff within, upstream and adjacent to the work site without causing flooding within or in the vicinity of the site; ■ Provision of adequate training to operators; ■ Revision and resubmission of the ECM plans as required; ■ Submit an Earth Control Management Plan endorsed by a Qualified Erosion Control Professional (QECP) to the PUB, prior to commencement of work; ■ Regular inspections of ECM system and discharge pipeline to ensure necessary repairs are promptly undertaken throughout the construction phase. Inspections should be done regularly and during / after any rain event. The QECP shall carry out regular audit / review for every stage of the earthworks and construction works, and revision of the ECM shall be done in accordance with the QECP advice. All inspection reports shall be kept on site and made available to the Board upon request; and ■ Establish a response plan, e.g. contaminating material will be removed manually (in the case of viscous or solid material). Following this, regular visual inspections and monitoring of the relevant chemical parameters will be undertaken for the affected water body until conditions return to normal. **Environmental Spill:** ■ All hazardous material will be stored and handled in compliance with relevant regulations;

[2] From PUB Code of Practice on Surface Water Drainage 7th Edition (2018), PUB Guidebook on Erosion and Sediment Control at Construction Sites – For Site Implementation (2018) and SS 593: 2013 Code of Practice for Pollution Control (2013)

Legislation/ Standard/ Guideline/ Planned Design & Construction Approach	Relevance to the Environmental Aspect for this EIA
	■ Standard operation procedure for proper handling, storage, transfer and disposal of waste should be developed and implemented; ■ Hazardous liquid and wastewater contaminated with chemical should be stored for proper treatment and disposal offsite by approved contractor; ■ Proper storage/ bins should be provided for waste disposal. Such storage should be regularly cleaned up for offsite disposal at appropriate facilities by trained workers or contractor; ■ Sufficient chemical toilets (or equivalent) will be provided on site in accordance with the EPHA to serve the assembly workers for the FPV and no direct discharge of sanitary sewage would be allowed; ■ All chemicals will be stored in designated storage containers within bunded areas, with drip trays provided to contain spillage. Fluids contained within the bunded areas will be removed by a licensed third party collector; ■ Provide secondary containment facilities for storage tanks/ drums containing oils and chemicals. The containment should be sized to contain the entire contents of the largest storage tank. For a secondary containment facility that is fully enclosed, a leak detection system with an alarm device shall be provided within the secondary containment facility. A leak test shall be conducted before the tank is put into use; ■ In the event of leakage or spillage of any oil or chemicals, arrange for proper disposal of spilled product and any contaminated equipment or materials used in the response effort as TIW; ■ The connection point for a filling pipe of a bulk storage tank shall be provided with measures to contain spillage; ■ The chemical storage areas will also be roofed to avoid rainwater collection within the bunded areas; ■ Ensure that all activities involving repair, servicing, engine overhaul works, etc are carried out on a concreted area which will be bunded or provided with scupper drains to channel all wastewater into the sewerage system. ■ Carry out washout of cement or ready-mix lorries and equipment in concrete washout areas to protect against spills and leaks; ■ Provide secondary containment facilities for storage tanks/drums containing oils and chemicals. The containment should be sized to contain the entire contents of the largest storage tank; ■ Provide appropriate equipment to prevent any leakage or discharge from containers such as portable jerry cans for ease of refuelling or handling of smaller amounts of chemicals during construction; ■ Install and operate pollution monitoring equipment to prevent and detect any leakage or discharge; ■ Prepare and keep up to date a Spill Prevention and Emergency Response Plan detailing how spillage, leakage or accidents involving hazardous materials will be dealt with and ensure that workers on site have received adequate training and instruction to enable them to implement the emergency action plan in the event of an emergency; ■ Ensure that emergency spill response equipment are available at appropriate worksite locations to contain and/or absorb hazardous chemicals, fuel or oil in the event of a spillage; ■ In the event of spillage or overflow of effluents into downstream surface waterbodies, the Spill Prevention and Emergency Response Plan will be triggered and as much of the contaminating material will be removed manually (in the case of viscous or solid material). Ensure spill control materials and protective equipment are readily accessible at the worksites and adequate training is provided to on site personnel on emergency response procedures to spill control and clean-up. Following the clean-up event, regular visual inspections and monitoring of the relevant chemical parameters will be undertaken for the affected water body until conditions return to normal; Groundwater, if any, should be discharged into the sewer with PUB's approval or disposed offsite; ■ In the event of an accidental release, leakage or spillage of oil or chemical, immediately notify the NEA and PUB; ■ Prepare and keep up to date an Emergency Spill Response Plan (ESRP) detailing how spillage, leakage or accidents involving hazardous materials will be dealt with and ensure that workers on site have received adequate training and instruction to enable them to implement the emergency action plan in the event of an emergency; ■ Any trade effluent treatment plant installed shall be designed with spillage containment facilities to channel any spillage back to the treatment plant; ■ Trade effluent (not to be collected by ECM) should be discharged into the sewer or surface drainage systems, upon compliance with relevant discharge limits; ■ Vessels are required to adhere to a speed limit in the reservoir. Speed limit of 5 knots will be implemented, particularly in shallow areas or close to the shore to minimise disturbance to the reservoir bed and erosion of the bank; ■ Limited work boats/ barges are to be used in the reservoir. This in addition to the speed limit and low traffic on the reservoir would reduce the chances of accidental collision; ■ Work boats/ rigs will be properly sized for the task involved and be equipped with suitable navigation safety features according to location and appropriate regulations and guidelines; ■ Regular traffic routes should be established for routine works. Offset from shoreline as well as corridors between FPV islands allow safe navigation access, this will minimize the risk of getting into shallow water unintentionally and also minimizes the risk of collision or grounding; ■ Work vessels should be well-maintained. Refuelling should be conducted at designated area equipped with spill containing equipment as well as clean up kit; ■ Workers will be adequately trained to handle chemical/ hazardous wastes stored on site, and to implement emergency action plans to deal with spills and leaks of toxic waste; ■ Provision of emergency spill clean-up kits at locations where fuel and chemicals will be stored and used; ■ Launching ramp would be installed at the waterfront of the proposed temporary Staging/ Launching Area. The ramp would isolate disturbance from the launching activities and protect the soil/ sediment underneath and at the shoreline from wake from frequent vessel activities; ■ Silt fencing at or near the water edge to prevent on-shore sediments from washing into the reservoir; ■ Straw wattles (or equivalent) on slopes for erosion and sediment control at the launching slope; and ■ Geotextile and gravel in flat areas to prevent erosion and tracking of loose materials at the proposed temporary Staging/ Launching Area.

APPENDIX 4.1 EIA SCOPING MATRIX

Table 1: Scoping Matrix

Legend

- I — An interaction with the environment or receptor which is not expected to be significant
  → To be discussed in EIA; In-place controls and standard practices will be detailed in EMMP
- S — An interaction with the environment or receptor that could be significant based on currently available information; or where no data is currently available (as a precautionary approach).
  → To be discussed in EIA; Additional mitigation measures over and above in-place controls and standard practices will be identified as necessary, and included in the EMMP
- P — Denotes a positive interaction
- (blank) — No interaction

	Project Activity	Ambient Air Quality	Global Climate	Airborne Noise	Vibration	Groundborne Noise	Light	Topography	Soil	Groundwater Quality	Water Quality (incl. reservoir bed sediment quality)	Terrestrial Habitats	Terrestrial Flora & Fauna	Aquatic Habitats	Aquatic Flora & Fauna	Protected Areas	Public Health & Safety	Transport network	Infrastructure/ Property	Public Utilities
A	**Construction Works**																			
A1	**For FPV - Construction Works on Land**																			
1	Preparation of the proposed temporary staging area and launching ramp/ area	I		S	I		I				I	I	I							
2	Assembly of the FPV system (including PV modules and transformers/ inverters), in modular sections onshore adjacent to a temporary launching point			S	I		I				I	I	I							
A2	**For FPV - Construction Works on/in Water**																			
1	Geotechnical/ Site investigation in the reservoir						I				S		S	S	S	S				I
2	Launching system into reservoir, one modular section at a time																			
3	Towing modular sections into the final position and physical connection to other section(s)																			
4	Deployment of anchors/ ballasted foundations or piles (subject to detailed engineering design), and moorling lines for newly deployed modular sections										S		S	S	S	S				I
5	Installation of ancillary equipment (e.g. connector cable)										S			S	S	S				I
A3	**For integrated Project Substation**																			
1	Geotechnical/ Site investigation at the integrated Project Substation site	I		S	I		I				I	I	I							
2	Site clearance and preparation for substation, and ancillary equipment	I		S	I						I	I	I							
3	Construction of the integated Project substation	I		S	I		I				I	I	I							
4	Installation of ancillary equipment (e.g. connector cable) to Project substation	I		I	I						I									
5	Testing and comissioning of the entire system			I	I		I				I									
B	**Operation**																			
1	Operation of the Project - Deployment of Solar panel - 24-hour operational of electricity generation		P				I				S	S	S	S	S	S				
2	Maintenance - All the maintenance/inspection/refurbishment										S	S	S	S	S					
C	**Unplanned Events**																			
1	Fire and Explosion	S									S	S	S	S	S		S			S
2	Environmental Spill								S	S	S	S	S	S	S					
3	Failue of Earth Control Measures										S									

APPENDIX 4.2 QUALIFICATION FOR LIKELIHOOD OF UNPLANNED EVENTS

APPENDIX 4.2: QUALIFICATION OF LIKELIHOOD FOR UNPLANNED EVENTS

1. INTRODUCTION

Unplanned events or emergencies that might occur during the construction or operation of the Project, may subsequently give rise to direct or indirect impacts to receptors. In accordance with the EIA methodology (see *Section 4*), the impact magnitude of an unplanned event will take into account the likelihood of such an event occurring[1]. While the impact magnitude criteria for most of the environmental topics are quantifiable to a degree, the likelihood criteria is based on a qualitative scale (see *Table 1-1* below). Given that FPV systems are relatively new in Singapore with limited information publicly available, global case studies will be used to qualify the likelihood of Project unplanned events in an objective manner. The findings and subsequent designation of likelihood for each unplanned event identified are presented herein.

Table 1-1: Definition of Likelihood Designation

Likelihood	Definition
Unlikely	The event is unlikely but may occur at some time during normal operating conditions.
Possible	The event is likely to occur at some time during normal operating conditions.
Likely	The event will occur during normal operating conditions (i.e. it is essentially inevitable).

2. UNPLANNED EVENTS

Unplanned events are defined as unintended occurrences for which engineering methods and equipment are designed to prevent during the Project construction and operational phase. During the feasibility stage, a precautionary approach was used to review the proposed activities for the Project to identify any unplanned events which may occur during the Project phases. The following unplanned events during construction and operation were identified through the scoping phase:

- Fire and Explosion;
- Failure of Erosion Control Measures (ECM); and
- Environmental Spill.

Embedded controls are measures (physical or procedural) that are planned to be put in place as part of the Project design, construction and operation from the outset to prevent or minimise the risk of the occurrence of the abovementioned unplanned events. These embedded controls are summarised in *Appendix 2.2*.

Response measures will be implemented in the event that these unplanned scenarios occur and will be incorporated into the Developer/ Owner's Spill Prevention and Emergency Response Plans. The unplanned events and the associated response measures are described in the following sections. The reasonable conservative scenario was considered in determining the consequences of the unplanned event.

2.1 Fire and Explosion

The occurrence of a fire has been identified as a risk in both the construction and operation stages of the Project. Apart from the safety implications to the workers and nearby receptors, there is a concern that a fire and the resulting firewater may adversely impact surrounding air, noise and vibration, biodiversity and surface water receptors. A summary of potential causes of fire and explosion within the Project is listed below.

On land, fire could occur within construction worksites and the integrated Project Substation as a result of:

- Electrical shortage due to wear and tear or overloading of electrical equipment; and

[1] It is noted that the occurrence of an event does not necessarily indicate that the associated impact(s) are significant.

- Accidental ignition of flammable materials or components, such as diesel fuel or combustible waste stored within the worksites/ operational site.

In the reservoir, electrical shorts within FPV systems could be caused by one of the following:

- Defects in manufacturing of the FPV;
- Defects in construction of the FPV;
- Deficiencies within the design of the FPV; and
- Extreme weather events.

A review of global case studies shows that fire incidences, while uncommon, has occurred within FPV projects. Among these, the most common sources of FPV failure resulting in fire and explosion are poor mooring design and wind resistance[2]. While there are several cases to show that FPV can be designed to withstand major storms, early projects did experience setbacks. A common cause of damage is the folding or flipping over of periphery rows due to high winds and waves. While recent designs provide better protection against wind and wave damage, including dual-pitch panel rows, perimeter windshields, and walkways (SERIS, 2019). In recent years, there are still incidences where extreme weather had caused fires in FPV systems. In Japan, Kyocera Group's FPV plant caught fire following the impact of Typhoon Faxai in 2019[3]. The fire was a result of strong winds, concentration of stresses and the failure of moorings. Strong winds had torn off FPV modules and stacked them against the ones still secured to the structure. This close contact resulted in an overheating of the modules that eventually resulted in fire.

Unlike Japan, Singapore experiences a lower mean wind speed at less than 2.5 m/s with mean speed increasing to 10 m/s or more during a northeast monsoon surge[4]. Singapore does not typically experience tropical typhoons or cyclones with the exception of Tropical Storm Vamei in 2001, which was the first and only recorded cyclone to have hit Singapore[5].

Despite the unlikely cause of fire in FPV systems from extreme weather events in Singapore, the Developer/ Owner will ensure that the enforcement of embedded controls and preventive mitigation measures to reduce the likelihood of a fire and explosion within the Project as listed below.

Embedded controls will include:

- Compliance with Fire Safety Act and the SCDF's requirements;
- Design, installation and operation and maintenance of FPV system to be carried out to national and international standards and to manufacturers specifications, for example TR 100: 2022 Technical Reference on Floating Photovoltaic Power Plants – Design Guidelines and Recommendations, published in 2022;
- A 25m setback distance from the Reservoir Project Site to the shoreline and inter-island spacing between FPV islands contains and limits the spread of fire from FPV island to FPV island, as well as to surrounding shorelines;
- Petroleum or flammable materials will be stored in compliance with requirements under the relevant storage license. In the event that storage of petroleum and/ or flammable materials in quantities exceeding that specified in the *First Schedule of the Fire Safety (Petroleum and Flammable Materials – Exemption) Order, 2008*, is required at the Project worksite, Contractors shall obtain a Petroleum & Flammable Materials Storage License from the Singapore Civil Defence Force (SCDF);

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[2] Solar Energy Research Institute of Singapore (2019). Floating Solar Handbook for Practitioners. Retrieved from https://www.seris.nus.edu.sg/doc/publications/ESMAP_FloatingSolar_Gde_A4%20WEBL-REV2.pdf

[3] https://www.pv-magazine.com/2019/09/09/japans-largest-floating-pv-plant-catches-fire-after-typhoon-faxai-impact/

[4] https://www.channelnewsasia.com/singapore/windy-weather-across-singapore-northeast-monsoon-surge-415736

[5] https://www.straitstimes.com/singapore/cyclone-unlikely-to-hit-singapore-experts-say#:~:text=A%20tropical%20cyclone%20has%20hit%20Singapore%20only%20once.,once%20every%20few%20hundred%20years%2C%22%20Prof%20Koh%20said.

- All practical steps will be taken to prevent the occurrence of an accident through fire, explosion, leakage or ignition of any petroleum or flammable material or vapours;
- Workers onsite will be properly trained to operate vessels and machinery;
- All temporary electrical installations, equipment and tools should be checked and certified for use regularly by a full-time licensed electrical worker;
- The hoarding for the worksite will be composed of non-combustible material to deter the spread of fire beyond the worksite;
- A Spill Prevention and Emergency Response Plan detailing how fires/ explosions will be managed will be prepared and agreed with SCDF, including how spillage, leakage or accidents involving firefighting water and materials resulting from fire/ explosion management will be dealt with;
- Firefighting equipment and other emergency response equipment will be provided at all worksites;
- Workers will be trained in the use of available firefighting and emergency response equipment;
- Considerations should be taken into account in the design of FPV layout to reduce the potential for fire propagation between FPV islands;
- Design, installation and operation and maintenance of FPV system to be carried out to national and international standards and to manufacturers specifications;
- A centralised monitoring system shall be implemented to observe the FPV system operations and immediately flag any faults/ issues as they occur;
- The FPV arrays, including moorings and anchors, will not be placed over the top of any existing services, such as pipelines;
- Manual emergency shut-off system for the disconnection of the FPV modules shall be provided on land and at the inverter, if it is on the water; and
- All solar FPV strings within the array shall be differentiated and easily identifiable by responders.

Regarding SCDF:

- Fire response time from SCDF will be an estimated 8 minutes from the time of call. The nearest fire station, Woodlands Fire Station, is located 8 minutes from the integrated Project Substation (and O&M Facility). Moreover, SCDF's quality service intent[6] states that response to fire emergencies will be within 8 minutes of the call 90% of the time. This allows fires to be quickly responded to and contained within the site; and
- Regular enforcement checks by SCDF will be conducted within industrial premises such as the integrated Project Substation (and O&M Facility) to ensure compliance with fire safety regulations[7].

Mitigation measures will include:

- Contractor to conduct thorough quality checks and inspections of materials prior to installation to ensure there are no manufacturing defects;
- Proper material handling practices and inspections of installed materials should be done to ensure there are no defects during construction;
- Developer/ Owner will conduct a review of past FPV design failure modes and incorporate key findings into the newer designs;
- Where possible, drains/ body of water where fire and explosion occurs should be cut off from the Kranji Reservoir. Firefighting water will be contained within the drainage system. Such water will be collected

[6] https://www.scdf.gov.sg/docs/default-source/scdf-library/publications/scdf-service-quality-handbook.pdf

[7] SCDF (2021). Annual statistics for fire, emergency medical services and fire safety enforcement checks. Retrieved form https://www.scdf.gov.sg/docs/default-source/scdf-library/amb-fire-inspection-statistics/scdf-annual-statistics-2021.pdf

and be disposed by a licensed waste collector as soon as possible to ensure the drains are empty for normal operation;

- Only non-toxic firefighting reagent (if needed) will be used for firefighting. This will minimize human health and ecological risk in case using of such reagent is needed and such reagent ends up in reservoir water. Developer/ Owner to agree with PUB on the proposed firefighting reagent to be used onsite prior to construction;
- Do not use "PVStop" chemical spray as a fire retardant to render PV panels electrically safe;
- Workers will be trained in the implementation of the Spill Prevention and Emergency Response Plan;
- Joint exercises/ drills for spillage and fire will be conducted each year by the Developer/ Owner with SDCF to ensure preparedness on spillage containment and clean up, as well as fire preventing and fighting among workers;
- In case of a fire and explosion in reservoir, a perimeter floating boom should be set up (where possible and safe) to allow containment of any floating debris from the event; and
- Establish construction and operation phase surface water quality monitoring programme in agreement with PUB prior to works commencement, to inform the Developer/ Owner on any potential deterioration of surface water quality from unplanned events.

Given the implementation of embedded controls and mitigation measures considered within the design of the FPV and Project, the likelihood of a fire and explosion occurring and impacting surface water quality, air quality and biodiversity receptors are *Unlikely*.

2.2 Failure of Erosion Control Measures (ECM)

One of the scenarios that may result in an overflow of effluents from the worksite is the failure of the ECM system during construction. The ECM system is designed to contain, channel, hold and treat surface runoff within the worksite with the objective to prevent heavily silted water from being discharged into surrounding surface waterbodies. An ECM system for a typical construction worksite would comprise perimeter storm water drains, a sedimentation basin or tank and pumps which would be designed with a holding capacity of a one in 5, 10 or 15 year storm (a one in 5 years is proposed for this Project's construction). There are a few potential causes of ECM failing, resulting in environmental impacts to nearby surface water receptors:

- During the monsoon period, there is a chance Singapore may potentially experience exceptionally heavy rainfall, which can overwhelm the ECM system and result in flooding of the worksite and subsequent uncontrolled discharge to nearby surface waterbodies;
- Failure of ECM outlet discharge pump resulting in overflow of sedimentation basin;
- Rupture due to accident or leakage due to wear and tear of ECM discharge pipeline; and
- Another cause of the failure of ECM systems would be improper inspections to ensure proper functioning of the ECM. For example, there are instances of contractors who have failed to ensure proper treatment of silty water and did not take prompt action to stop the discharge into public drains despite receiving a notification from the Silt Imagery Detection System (SIDS) by PUB[8]. As a result, the contractor was fined $10,000 for flouting ECM regulations under the *Sewerage and Drainage Act, 2021*.

For this Project, embedded controls are put in place to reduce the likelihood of an ECM failing.

Embedded controls will include:

- Meeting requirements of the *Environmental Protection and Management Act (EPMA)* as well as guidelines listed in the *PUB Guidebook on Erosion and Sediment Control at Construction Sites – For Site Implementation, 2018*;

8 https://www.pub.gov.sg/news/pressreleases/20210303AvenueEngineeringfinedforsiltydischargeandinadequateECM

- Accumulated surface runoff from worksites will be collected by site drains to Earth Control Measures (ECMs) and discharged to the drainage system upon compliance with relevant discharge limits. No runoff into the reservoir from the proposed temporary Staging/ Launching Area will be allowed;
- A Clearance Certificate will be obtained from the PUB, before the commencement of works;
- Submission of an ECM proposal at the start of construction works;
- The ECM and Sediment Control measures listed to be effectively implemented;
- The sizing of an ECM system with adequate capacity to cater for exceptional rainfall events such as a one in 5-year storm, in accordance with PUB requirements for each worksite;
- A perimeter drain will be provided to ensure that the surface runoff within the worksites will be channeled towards centralised tanks for further treatment, before discharging to the roadside drains;
- Closed-circuit television (CCTV) cameras including Silt Imagery Detection System (SIDS) will be located at the ECM discharge points into the existing drain;
- The QECP will carry out monthly monitoring to verify the ECM implementation and its effectiveness;
- The construction site will also have an Environmental Control Officer (ECO) on site to ensure the implementation, maintenance and inspection of the ECM plan during the construction period;
- Install sampling test points, inspection chambers, flow-meters, and recording and other apparatuses into the collection and treatment infrastructure at the ECM discharge point;
- Take all adequate measures to prevent any earth, sand, top-soil, cement, concrete, bentonite slurry, debris or any other material to fall or be washed into the stormwater drainage system from any stockpile;
- Whilst stored on site, stockpiles will be covered by erosion control blankets or canvas or similar protective covering to minimise erosion by rainfall;
- Silt from cut-off drains, silt traps and holding sumps should be removed regularly, with silt in holding sumps should be treated and emptied within 10 hours after a rainfall event;
- Settling pond, where required, should be lined with impervious lining or equivalent, and designed with sufficient capacity to ensure no overflow into surrounding;
- Hazardous liquid and wastewater contaminated with chemical should be stored for proper treatment and disposal offsite by approved contractor;
- Regular inspections of ECM system and discharge pipeline to ensure necessary repairs are promptly undertaken throughout the construction phase. Inspections should be done regularly and during / after any rain event. The QECP shall carry out regular audit/ review for every stage of the earthworks and construction works, and revision of the ECM shall be done in accordance with the QECP advice. All inspection reports shall be kept on site and made available to the Board upon request;
- Ensure that adequate preventive measures are in place including the provision of proper and stable barricades or screens where necessary;
- Effectively drain away runoff within, upstream and adjacent to the work site without causing flooding within or in the vicinity of the site;
- Provision of adequate training to operators;
- Revision and resubmission of the ECM plans as required;
- The Developer/ Owner is to submit an Earth Control Management Plan endorsed by a Qualified Erosion Control Professional (QECP) to the PUB, prior to commencement of work; and
- Establish a response plan, e.g. contaminating material will be removed manually (in the case of viscous or solid material). Following this, regular visual inspections and monitoring of the relevant chemical parameters will be undertaken for the affected water body until conditions return to normal.

With the implementation of these embedded controls, the likelihood of such an unplanned event occurring and resulting in notable change to surface water quality is assessed to be *Unlikely.*

2.3 Environmental Spill

Various quantities of fuel, oil, lubricants and chemicals will be stored within the construction worksites and operational areas. Of these, hazardous chemicals such as diesel stored on-site or on boats which may accidentally spill or leak to the nearby environment, impacting biodiversity, surface water, soil and groundwater receptors. In 2006, the NEA Pollution Control Department received 116 complaints, the majority of which were related to the illegal discharge or spillage of industrial wastewater or chemical/ oil into drains (Lye, 2008)[9]. There are a few potential causes of environmental spills within this Project:

- Accidental spills or leakages of fuel, oil and lubricants from the use of construction vehicles and equipment;
- Mishandling or improper storage of hazardous chemicals within fuel and chemical storage areas;
- Improper management of construction waste;
- Accidental spills or leakages from unplanned events such silty water from the failure of the ECM and firewater from responses to fire and explosion;
- Accidental spills or leakages may occur during maintenance works for example, fueling of a boat or equipment maintenance; and
- Accidental collision such as vessel to vessel, vessel to shore collision, vessel to FPV collision and vessel grounding may potentially cause fuel to leak into the reservoir.

For this Project, embedded controls are put in place to reduce the likelihood of environmental spills during the construction and operation stages.

Embedded controls include amongst others (see Surface Water Quality *Section 6* for further details):

- All hazardous material will be stored and handled in compliance with relevant regulations;
- Standard operation procedure for proper handling, storage, transfer and disposal of waste should be developed and implemented;
- Hazardous liquid and wastewater contaminated with chemical should be stored for proper treatment and disposal offsite by approved contractor;
- Proper storage/ bins should be provided for waste disposal. Such storage should be regularly cleaned up for offsite disposal at appropriate facilities by trained workers or contractor;
- Provide secondary containment facilities for storage tanks/ drums containing oils and chemicals. The containment should be sized to contain the entire contents of the largest storage tank;
- Sufficient chemical toilets (or equivalent) will be provided on site in accordance with the EPHA to serve the assembly workers for the FPV and no direct discharge of sanitary sewage would be allowed;
- Provide appropriate equipment to prevent any leakage or discharge from containers such as portable jerry cans for ease of refueling or handling of smaller amounts of chemicals during construction;
- Install and operate pollution monitoring equipment to prevent and detect any leakage or discharge;
- Ensure that emergency spill response equipment is available at appropriate worksite locations to contain and/ or absorb hazardous chemicals, fuel or oil in the event of a spillage;
- In the event of leakage or spillage of any oil or chemicals, arrange for proper disposal of spilled product and any contaminated equipment or materials used in the response effort as TIW;
- In the event of an accidental release, leakage or spillage of oil or chemical, immediately notify the NEA and PUB;

[9] Lye, L.H. (2008). A fine city in a garden – environmental law and governance in Singapore. *Singapore Journal of Legal Studies*, 68-117.

- Prepare and keep up to date a Spill Prevention and Emergency Response Plan detailing how spillage, leakage or accidents involving hazardous materials will be dealt with and ensure that workers on site have received adequate training and instruction to enable them to implement the emergency action plan in the event of an emergency;
- In the event of spillage or overflow of effluents into downstream surface waterbodies, the Spill Prevention and Emergency Response Plan will be triggered and as much of the contaminating material will be removed manually (in the case of viscous or solid material). Ensure spill control materials and protective equipment are readily accessible at the worksites and adequate training is provided to on site personnel on emergency response procedures to spill control and clean-up. Following the clean-up event, regular visual inspections and monitoring of the relevant chemical parameters will be undertaken for the affected water body until conditions return to normal; Groundwater, if any, should be discharged into the sewer with PUB's approval or disposed offsite;
- Trade effluent (not to be collected by ECM) should be discharged into the sewer or surface drainage systems, upon compliance with relevant discharge limits;
- Vessels are required to adhere to a speed limit in the reservoir. Speed limit of 5 knots will be implemented, particularly in shallow areas or close to the shore to minimise disturbance to the reservoir bed and erosion of the bank;
- Limited work boats/ barges are to be used in the reservoir. This in addition to the speed limit and low traffic on the reservoir would reduce the chances of accidental collision;
- Work boats/ rigs will be properly sized for the task involved and be equipped with suitable navigation safety features according to location and appropriate regulations and guidelines;
- Regular traffic routes should be established for routine works. Offset from shoreline as well as corridors between FPV islands allow safe navigation access, this will minimize the risk of getting into shallow water unintentionally and also minimizes the risk of collision or grounding;
- Work vessels should be well-maintained. Refueling should be conducted at designated area equipped with spill containing equipment as well as clean up kit;
- Workers will be adequately trained to handle chemical/ hazardous wastes stored on site, and to implement emergency action plans to deal with spills and leaks of toxic waste;
- Provision of emergency spill clean-up kits at locations where fuel and chemicals will be stored and used;
- Launching ramp would be installed at the waterfront of the proposed temporary Staging/ Launching Area. The ramp would isolate disturbance from the launching activities and protect the soil/ sediment underneath and at the shoreline from wake from frequent vessel activities;
- Silt fencing at or near the water edge to prevent on-shore sediments from washing into the reservoir;
- Straw wattles (or equivalent) on slopes for erosion and sediment control at the launching slope; and
- Geotextile and gravel in flat areas to prevent erosion and tracking of loose materials at the proposed temporary Staging/ Launching Area.

In addition to embedded controls, the Project has implemented further mitigation measures to mitigate the consequence of the unplanned event of an environmental spill.

Mitigation measures include:

- Preparation and implementation of vessel standard operating procedures;
- Chemicals and/ or hydrocarbons will be handled and stored in compliance with the Material Safety Data Sheet (MSDS);

- All chemical and/ or hydrocarbon wastes will be segregated into clearly marked containers prior to onshore disposal by a licensed waste management contractor, as per the relevant MSDSs. Secondary containment should also be provided for these chemicals;
- Daily inspection of boat and machinery to avoid fuel leakage;
- Practice due diligence in proper storage and handling of machinery to prevent leaching of oil or harmful materials;
- Regular maintenance of vehicles and equipment, proper training to operators to avoid fuel leakage or spillage into reservoir;
- Work boats will be refueled at specified locations following standard procedures. Refueling location(s) should be equipped with spill control kits and measures, e.g. floating booms at the perimeter, clean up kits ready to use, etc. This means any spillage from refueling would be contained and cleaned up properly;
- Provision of navigation aides and establishment of regular traffic routes would further reduce the risk of collision;
- Where possible, drains/ body of water where fire and explosion occurs should be cut off from the Kranji Reservoir. Firefighting water will be contained within the ECM system and holding pond, where appropriate. Such water will be collected and be disposed by a licensed waste collector as soon as possible to ensure normal ECM/ holding pond operation can continue;
- Spill Prevention and Emergency Response Plans to have inclusions for addressing wildlife and biodiversity concerns from events;
- Train workers in implementation of the Spill Prevention and Emergency Response Plan;
- Joint exercises/ drills for spillage and fire will be conducted each year by the Developer/ Owner with SCDF to ensure preparedness on spillage containment and clean up, as well as fire preventing and fighting among workers; and
- Establish operation phase surface water quality/ sediment quality monitoring programme in agreement with PUB prior to construction and operation, to inform the Developer/ Owner on any potential deterioration of surface water quality from unplanned events.

Given the implementation of embedded controls and mitigation measures, and the very low occurrence of severe weather conditions in Singapore which hinder navigation (such as typhoons); the likelihood of an environmental spill occurring and resulting in notable change to surface water quality and impacting biodiversity and soil and groundwater receptors are *Unlikely*.

APPENDIX 6.1 WATER QUALITY MODELLING TECHNICAL REPORT

HYDROINFORMATICS INSTITUTE

Floating Photovoltaic System on Kranji Reservoir – Environmental Impact Assessment (EIA)

Water Quality Modelling

Technical Appendix

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HYDROINFORMATICS INSTITUTE

Client	Environmental Resources Management (S) Pte Ltd
Title	**Floating Photovoltaic System on Kranji Reservoir – Environmental Impact Assessment (EIA) - Water Quality Modelling Technical Appendix**

Abstract

Water quality modelling of the Kranji Reservoir, Singapore, was conducted to feed into the Environmental Impact Assessment (EIA) of a proposed floating photovoltaic (FPV) system. The modelling effort focused on differences in water column temperature, dissolved oxygen (DO) concentrations and nutrients before and after implementation of the project for the baseline year 2019 as well as for future years 2030, 2040 and 2050. The median temperature difference with presence of FPV was within the water quality guidelines set by the Public Utilities Board (PUB) (temperature increase of not more than 0.3°C throughout the column with FPV compared to without FPV, i.e. ΔT = FPV – Non-FPV < 0.3°C) in all years. Median DO is within water quality guidelines set by PUB (DO not below 3 mg/L throughout the column, i.e. >3 mg/L) for more than 97% of time, with occurrences of DO less than 3 mg/L, ~1.3% of time in future years which is within model uncertainty. Total Nitrogen (TN), Total Organic Carbon (TOC) and Chlorophyll-a concentrations with FPV reduce when compared to the non-FPV simulation results. Total Phosphorous (TP) concentration in all scenarios exceeds water quality guidelines, consistent with TP observations in the reservoir in 2018–2019 by PUB. The potential deterioration in future water quality predicted by the water quality model is generally within the model uncertainty and conservative assumptions regarding the FPV system design and installation process. Adopting a precautionary approach, it is therefore recommended that the final design remain within the boundaries and limits assumed in this conservative water quality model.

PUB's support and collaboration in agreeing the modelling approach, model setup, calibration and validation as well as model assumptions throughout the course of this study are acknowledged and appreciated.

Contents

APPENDICES

1 Introduction

1.1 Background

Environmental Resources Management (S) Pte Ltd (ERM) has been appointed to undertake an Environmental Impact Assessment (EIA) for the potential construction and operation of a floating Photovoltaic (FPV) System on Kranji Reservoir (herein referred to as the 'Project'). Figure 1-1 shows the location and an overview of the Kranji Reservoir (blue) and the Reservoir Project Site (yellow). The Project's FPV is proposed to be located within the boundaries of the Reservoir Project Site in the north and central areas of the Kranji Reservoir. The system will be connected to an integrated Project Substation in the Sungei Kadut Industrial Estate on the eastern shoreline of the reservoir.

The large FPV islands presented in the EIA for approval are expected to cover approximately up to 112 hectares (ha) (noting as outlined in Section 5.2 a more conservative (larger) FPV layout was assessed under the surface water quality model and assessment). Figure 1-2 describes how the FPV system could be installed onto the reservoir with solar panels on top of floating pontoons which are anchored to the reservoir bed. As the presence of the FPV system could affect the water quality of the reservoir, H2i has been appointed by ERM for the catchment, hydrodynamic and water quality modelling work. The Economic Development Board (EDB) is the lead government agency for this project.

Figure 1-1 Overview of Project Area at Kranji Reservoir and Main Project Component Indicative Locations

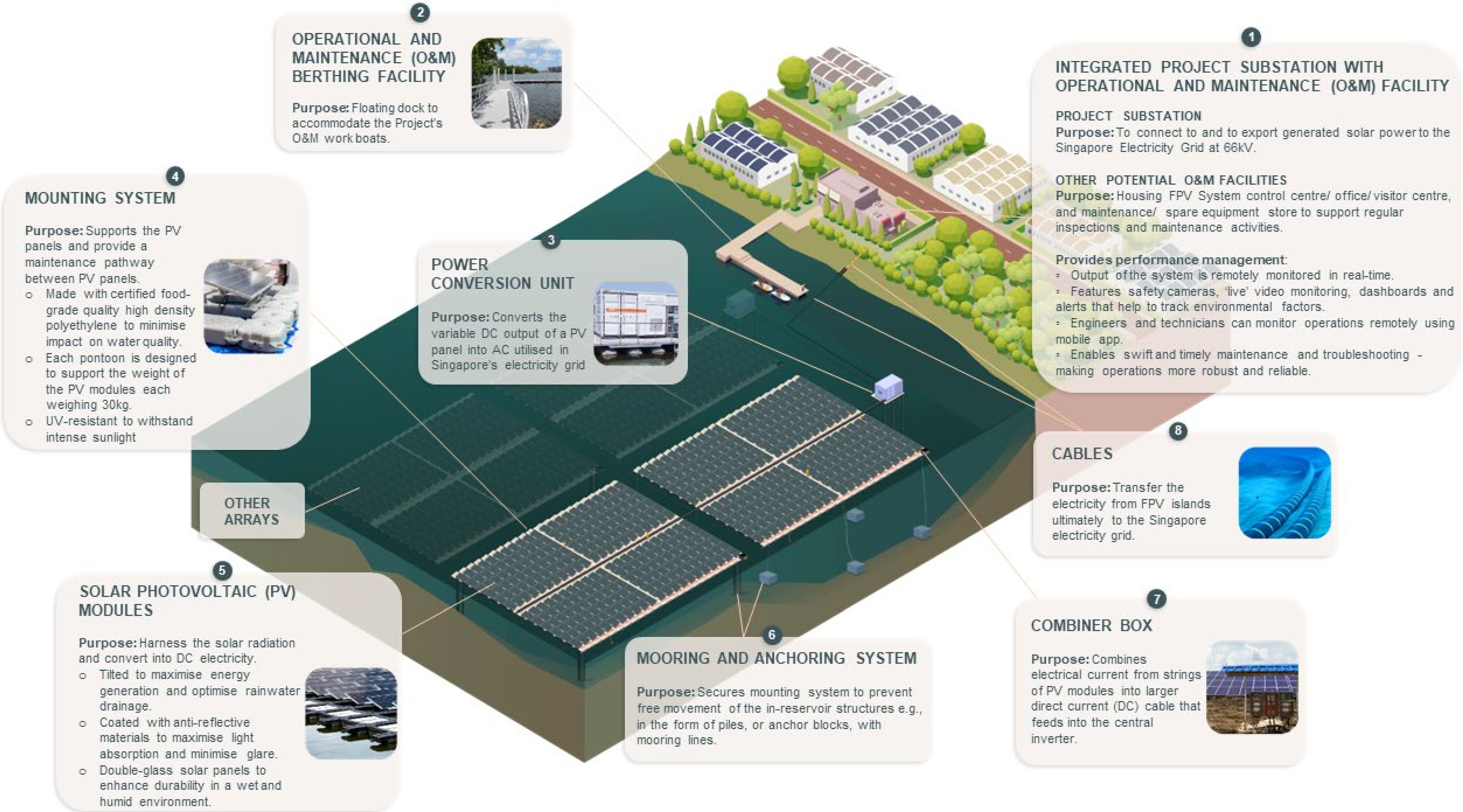


Figure 1-2 Schematic Overview of a Large-scale FPV System (adapted from Sembcorp, 2023)

1.2 Potential impacts of the presence of a floating PV (FPV) system on reservoir water quality

The presence of a FPV system directly affects several processes that may impact reservoir water quality. These processes are generally related to the changes in the thermal and kinetic energy fluxes between the atmosphere and water surface as shown in Figure 1-3. The meteorological variables that determine the heat and energy fluxes are also indicated in the figure. While it has been demonstrated that FPV panels could have positive effects on water quality by limiting algal blooms due to reduced sunlight diffusion and reduced photosynthesis (Sahu et al., 2016; Yousuf et al., 2020), FPV systems on the water surface may also give rise to adverse impacts on the biodiversity of the aquatic system as well as ecologically susceptible areas.

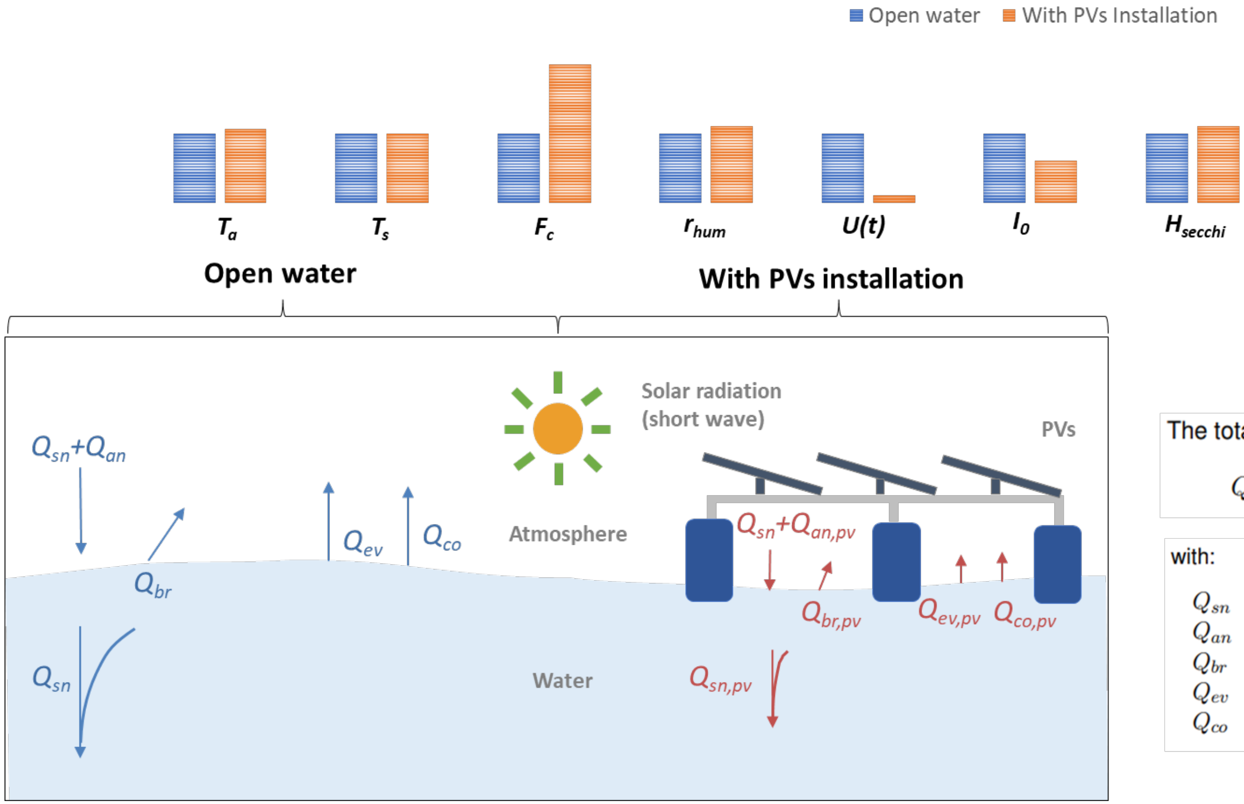
FPV systems can block solar radiation, as reported in two review studies in India (Sahu et al., 2016) and South Korea (Yousuf et al., 2020) which subsequently affects the heat balance and light penetration into the water column. The FPV systems can then reduce the surface water temperature due to shading or increase the temperature by enhanced thermal radiation from the panels and reduced evaporative heat fluxes. Therefore, there needs to be a study on the thermal structure of the reservoir with FPV system to quantify the net results of these concurrent phenomenon.

The reduction in sunlight penetration into the water column may result in less light available for primary production and hence less algae and aquatic vegetation in the water column. As a result, the dissolved oxygen (DO) concentrations in the reservoir are affected. On one hand, reduced primary production results in less oxygen input into the water column. On the other hand, the smaller quantity of algal and aquatic vegetation biomass may reduce the algae respiration rates and decomposition of detritus in the reservoir as well, thereby reducing the oxygen demand.

Dissolved oxygen concentrations are affected by the change in re-aeration, or the transfer of oxygen from the atmosphere to the water column. Reduced air-water interface dissolved oxygen exchange could lead to lower dissolved oxygen levels and as a result, a reduction in primary production, organisms and biomass (de Lima et al., 2021). Moreover, the construction and operation of an FPV system could result in leaching of substances, additives, or heavy metals to the water system, which could potentially affect the reservoir ecosystems.

In addition to the affected thermal structure, the reduction of the wind speed beneath the FPV system will reduce input of energy available for mixing in the reservoir. As a result, the vertical mixing through the water column is weakened but this may be balanced by the reduced light penetration and lower potential energy associated with daily solar warming of the near surface waters. A numerical modelling study on Tengeh and Poyan reservoirs in Singapore demonstrated that a reduction in light penetration and wind conditions lead to an increase of 0.3^{o}C in average water temperature in areas covered by FPV (Yang et al., 2022). This study also predicted a decrease in chlorophyl-a, total organic carbon, and dissolved oxygen concentration by 30%, 15% and 50% respectively and an increase in total nitrogen and total phosphorous by 10% and 30% respectively, indicating a potentially notable change in the water quality in the studied reservoir. The evaporation rate from the area covered by the FPV installation is expected to decrease by about one half depending upon the final construction of the floating structures.

The existing waters of the Kranji Reservoir are generally classified as eutrophic due to elevated levels of nutrients, TN and TP, and chlorophyll-a concentrations. In general, the reservoir is in a relatively stable, deteriorated ecological state. Occasional events of low dissolved oxygen concentrations in deeper waters and the presence of significant macrophyte biomass attest to the eutrophic status. As part of the PUB's ongoing water quality management program a significant biomass of macrophytes, and the nutrients contained within this biomass, is collected from the reservoir by mechanical harvesters and disposed offsite.



T_a	Air temperature
T_s	Water surface temperature
F_c	Cloud cover
r_{hum}	Relative humidity
$U(t)$	Wind speed
I_0	Short wave radiation
H_{secchi}	Secchi depth

The total heat flux through the free surface reads:

$$Q_{tot} = Q_{sn} + Q_{an} - Q_{br} - Q_{ev} - Q_{co},$$

with:

Q_{sn}	net incident solar radiation (short wave)
Q_{an}	net incident atmospheric radiation (long wave)
Q_{br}	back radiation (long wave)
Q_{ev}	evaporative heat flux (latent heat)
Q_{co}	convective heat flux (sensible heat).

Figure 1-3 Schematic diagram of the FPV effects on air-water exchange processes and the potential effects on the surface heat flux components (Figure created by H2i, heat balance equation and terminology from Deltares (2017))

1.3 Objective and Modelling approach

Kranji Reservoir is managed by Singapore's Public Utilities Board (PUB) and is used as a source of drinking water. Changes to the reservoir's water quality may affect the treatment of the source water or have an impact on existing water treatment processes, or affect its role in the aquatic ecosystem.

This Technical Appendix describes the potential impacts of covering a part of the reservoir surface with solar panels on reservoir water quality. As explained in Section 1.2, coverage of the water surface may result in various local changes in the governing meteorological conditions. This change in meteorological conditions was quantified based on experience from past studies and was used by numerical hydrodynamic and water quality models of the Kranji Reservoir to assess their impacts. The overall modelling approach is demonstrated in Figure 1-4.

The modelling approach, model setup, calibration and validation as well as model assumptions (e.g. changes of model inputs due to FPV) were agreed with PUB throughout the course of this study.

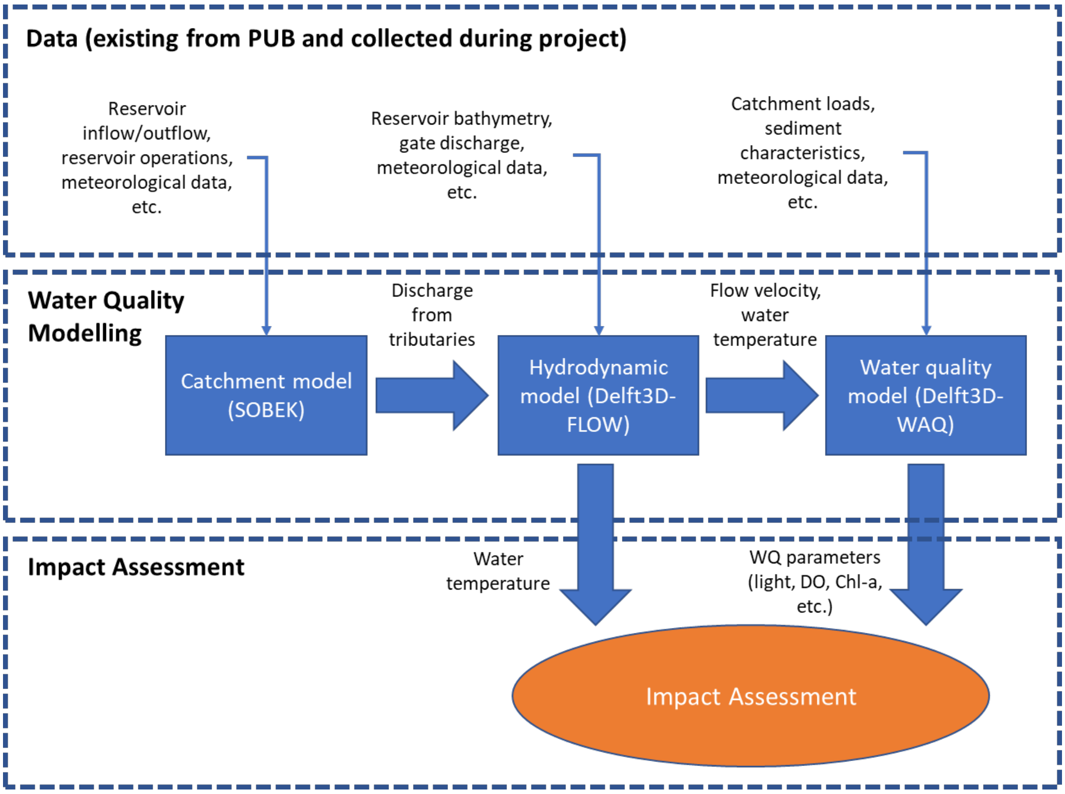


Figure 1-4 Diagram of Water Quality Modelling Technical Approach.

1.4 Guide to this Technical Appendix

This Technical Appendix documents the water quality modelling conducted in support of the overall Project EIA. After this introductory chapter, Section 2 provides a general description of the Kranji Reservoir as well as its observed water quality. Section 3 describes the selected approach to study the effects of the presence of the FPV system on reservoir water quality. Section 4 details the setup, calibration, and validation of the water quality model as well as the discussion on model uncertainties. Section 5 presents the results of the scenario simulations that were conducted to assess the potential impacts of FPV implementation. Lastly, the conclusion is provided in Section 6. References are included in Section 7. Appendix A, B, C to this Technical Appendix describe the catchment model (SOBEK), hydrodynamic model (Delft3D-FLOW) and water quality model (Deflt3D-WAQ) respectively which are parts of the modelling approach (Figure 1-4). Appendix D details the investigation on aquatic vegetation in Kranji Reservoir, and Appendix E describes the potential impacts of FPV construction activities on water quality based on preliminary construction plans. Appendix F provides additional spatial results of chlorophyll-a and dissolved oxygen in future climate scenarios.

2 The Kranji Reservoir

2.1 Reservoir and catchment

Kranji Reservoir, a tropical shallow reservoir, is located in the northwest of Singapore near the Straits of Johor (1^o25 N, 103^o44 E). Kranji dam was constructed in the early 1970s to convert the former estuary into a source of freshwater now known as Kranji Reservoir. The reservoir bathymetry is characterised by broad shallow banks and a relatively narrow and deep channel (the drowned river channel) of around 8 m depth with a local deep hole of 18 m depth, some 1,500 m upstream of the dam. The reservoir's catchment area comprises mixed land use, including residential, agricultural, industrial, and undeveloped areas (Figure 2-1, data from Urban Redevelopment Authority Master Plan 2014). The reservoir has four major tributaries, namely Sungei Kangar, Sungei Tengah, Sungei Peng Siang and Pang Sua Diversion Canal (Figure 2-1) (Yew-Hoong Gin & Gopalakrishnan, 2010). The outflow from the reservoir includes water extraction to water treatment works, whilst excess water is released to the sea (Straits of Johor) at the Kranji Tidal Gate in the north west (Xing et al., 2012).

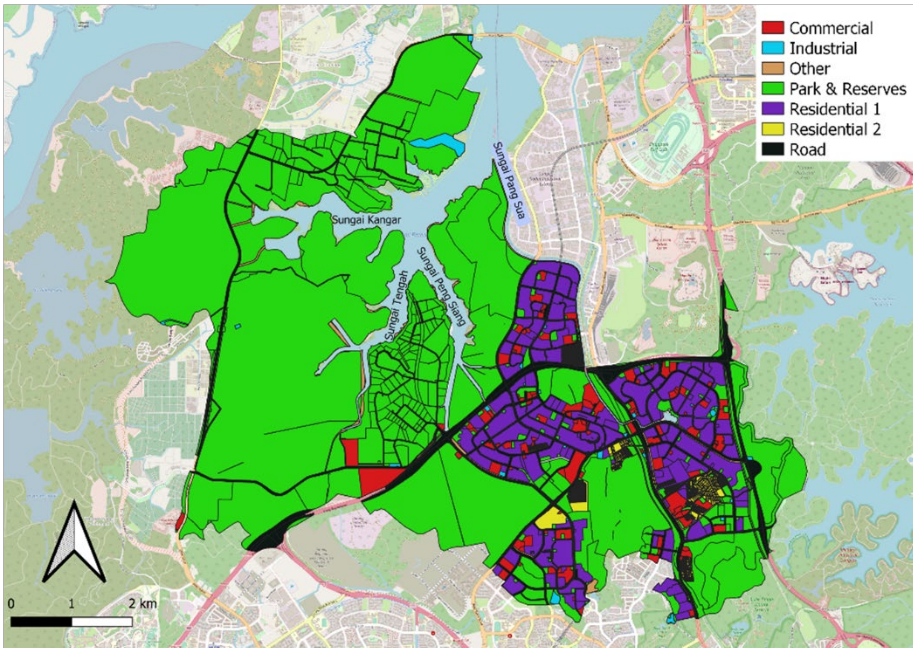


Figure 2-1 Landuse category and four tributaries to Kranji Reservoir. Original landuse categories (URA, 2014) were regrouped for this study (Note: Sungei Pang Sua is Pang Sua Diversion Canal).

2.2 Observed water quality

Figure 2-2 displays the three sampling locations namely RKR K2, H2, I2. Location RKR K2 and H2 are near the reservoir outflows to Upper Seletar Reservoir (USR) and Choa Chu Kang Waterworks (CCKWW) respectively. RKR I2 is located at an upstream location in the reservoir.

Figure 2-3 shows the observed water quality namely temperature, dissolved oxygen (DO), total organic carbon (TOC), total suspended solids (TSS), total nitrogen (TN), total phosphorous (TP) and chlorophyll-a (Chl-a) at the three locations in Kranji Reservoir from monthly sampling for two years between January 2018 and December 2019 as provided by PUB. The black dash line represents PUB's water quality guidelines for individual parameters: DO >3 mg/L, TN ≤1 mg/L, TP ≤0.06 mg/L, TOC ≤10 mg/L, Chl-a ≤50 μg/L. Temperature and DO concentration for the three locations are only available Jan.–Mar., Jun. & Aug.–Sep. 2018 and Mar.–Arp. 2019. For KRK I2 & K2, there are TSS data available only for Feb., May, Aug., Nov. in 2018 and 2019.

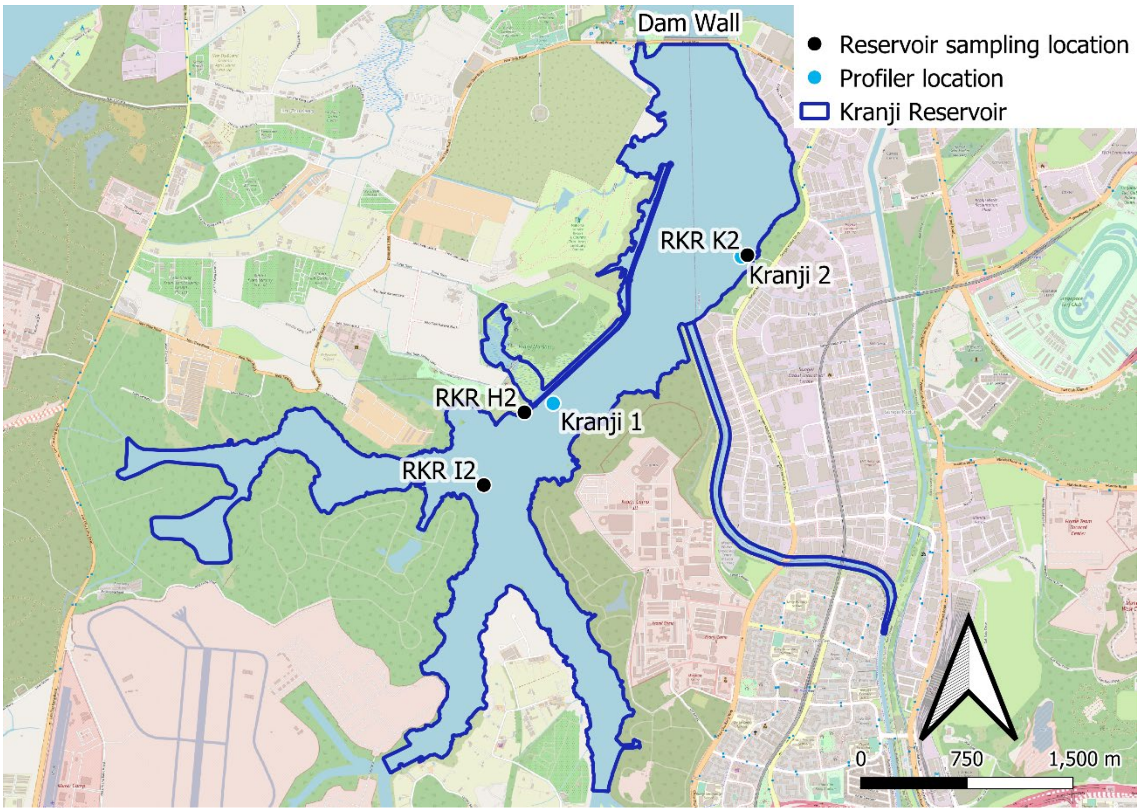


Figure 2-2 Three sampling locations in Kranji reservoir

Overall, the seasonal trends in most water quality parameters are the same at each of the three locations (Figure 2-3). Spatial differences occur occasionally, such as in June 2018 at location RKR I2 (TP and Chl-a concentrations) and November 2018 at RKR K2 (TP and Chl-a concentrations). Chl-a concentration follows the monthly trend of TN and TP where an increase in Chl-a concentration (e.g., Jun. 2018) corresponds to an increase in TN & TP concentration (Figure 2-3). However, an increase in nutrient concentration (e.g., TN in September 2018) does not necessarily lead to increase in Chl-a (Figure 2-3)[1]. TN, TP and Chl-a concentrations exceeds the recommended water quality guideline of PUB by approximately 20%, 100% and 50% of the time respectively (See Table 2-1).

Table 2-1 Summary of observed water quality from PUB sampling data in 2018-2019 for input parameters used within the water quality model (NA: Not Applicable).

Parameter	Sampling frequency	PUB Water quality guideline	Exceedance over PUB guideline in 2018-2019, over time
TOC	Monthly, weekly at RKR-H2	≤10 mg/L	8%
TSS	Quarterly	NA *	NA *
TN	Monthly	≤1 mg/L	20%
TP	Monthly	≤0.06 mg/L	100%
Chl-a	Monthly	≤50 µg/L	53%

* PUB's water quality guideline for TSS is not applicable for the assessment for this study.

[1] Algal growth in a water system can be P- or N-limited. In this instance, algal growth appears to be P-limited as the Chl-a does not increase with increased TN. However, given the temporal sparsity of the sampled nutrient data, it is noted it is difficult to fully determine the limiting nutrients.

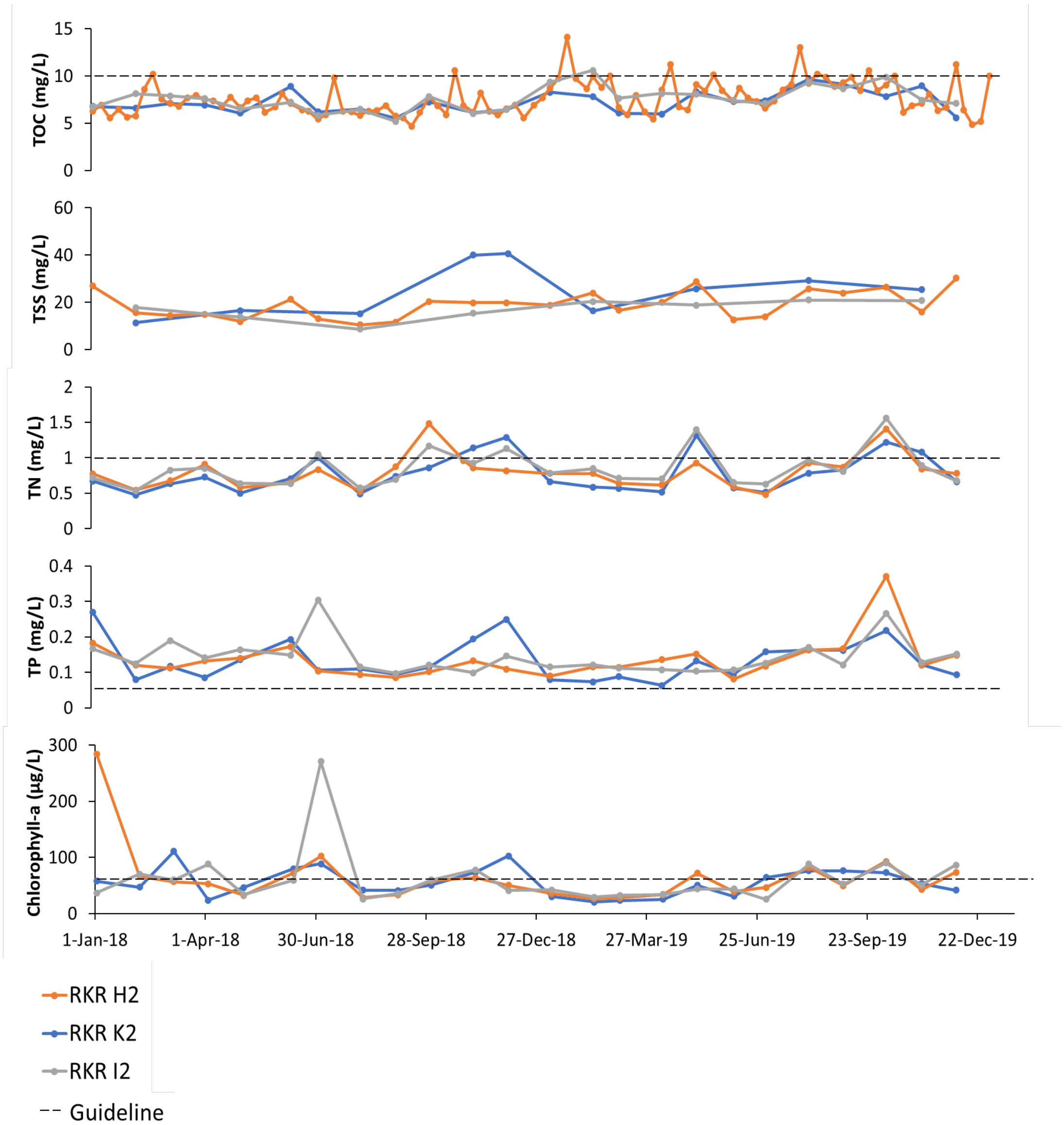


Figure 2-3 Observed water quality at three locations in Kranji reservoir. The dashed line represents water quality guideline provided by PUB.

3 Model selection

3.1 Water quality processes

As agreed with relevant Government Agencies, the water quality modelling is required to assess the changes in water column temperature, dissolved oxygen (DO), total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC), and chlorophyll-a (Chl-a) that may result from the presence of the proposed FPV system[2]. The presence of a FPV system affects several processes which either directly or indirectly affect these water quality variables. Some examples of direct impacts include: the re-aeration of oxygen which is affected by the reduction of wind and changes in the other meteorological inputs on the water surface below the FPV system; primary production is directly affected by changes in the solar radiation below the FPV system which directly affects the algal biomass (chlorophyll-a). An example of indirect impact is a change in mineralisation fluxes due to changes in the heat fluxes into and out of the reservoir that change the water column temperature. The change in mineralisation fluxes will, in turn, lead to changes in DO and nutrient concentrations in the water column below and around the FPV system.

In order to simulate the potential impacts of the presence of the FPV system on Kranji Reservoir water quality, a water quality model (Delft3D-WAQ) was setup. The overall approach for the FPV assessment is described in Figure 3-1. The catchment inflows inputs to the water quality model were derived from a catchment model (SOBEK, see Appendix A). The water quality model requires flow fields and thermal stratification that are output from the Kranji Reservoir hydrodynamic model (Delft3D-FLOW, see Appendix B). The setup, calibration and validation of the water quality model are presented in this document and Appendix C. In the water quality model, processes related to aquatic vegetation are not included as explained in Appendix D.

[2] Ammonical nitrogen and ortho-phosphate were agreed with relevant Government Agencies to be excluded during the Project's EIA Inception/ scoping phase.

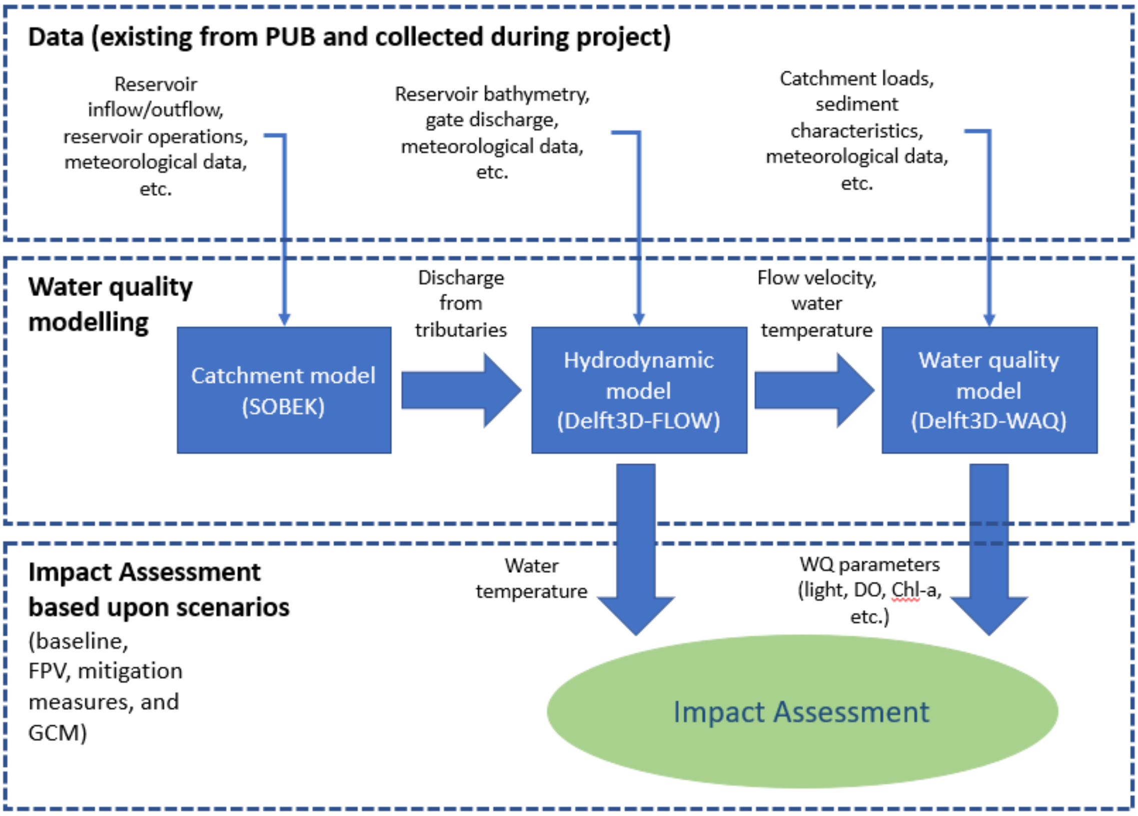
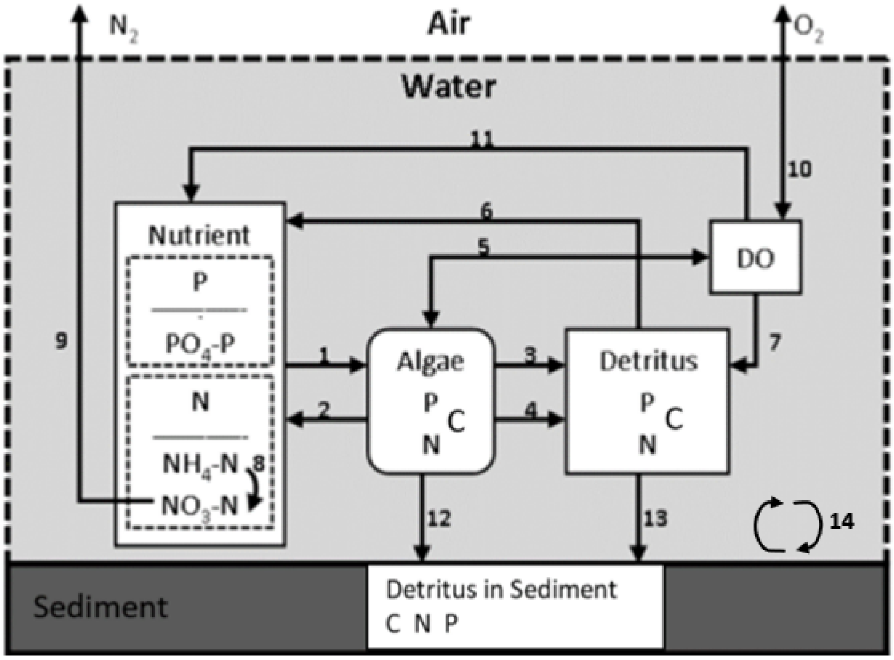


Figure 3-1 Diagram of overall water quality modelling technical approach of FPV assessment.

To represent the horizontal variation in-reservoir water quality as well as the extent of the FPV system within the numerical model, a fine 40x20 m horizontal grid (Figure B-9, Appendix B) was agreed with PUB to be used for the simulations. Due to preference for water quality modelling and large variation in the reservoir bathymetry, Z-layers were used in the vertical. The deepest sections of the reservoir (up to 18 m water depth) are represented by five vertical layers while shallow areas of 2 m water depth are represented by a two vertical layers in the water quality model (refer to section 4.1). These five vertical layers were aggregated from 20 vertical layers in the hydrodynamic model. The vertical schematisation for Kranji hydrodynamic model is detailed in Table B-3 (Appendix B). The water quality processes that were included in the modelling are shown conceptually in Figure 3-2. The calibration of the various model process coefficients is based on datasets collected during 2019 at three locations in the reservoir (RKR H2, K2 and I2) including, DO, suspended solids, total nitrogen, total phosphorous, chlorophyll-a and total organic carbon.



1. Photosynthesis
2. Respiration
3. Mortality
4. Metabolism
5. Consumption/production
6. Mineralization
7. Consumption
8. Nitrification
9. Denitrification
10. Reaeration
11. Mineralization and nitrification
12. Sedimentation of algae
13. Sedimentation of detritus
14. Resuspension

Figure 3-2 Conceptual view of water quality model process interactions

3.2 FPV Implementation in the Model

The coverage of the water surface by FPV panels introduces differences in the ambient meteorological conditions and the conditions where the solar panels are located. The affected meteorological variables and heat flux processes are shown schematically in Figure 1-3. To introduce this change in surface exchange into the water quality model, the meteorological input variables were adjusted over the area covered by the proposed FPV installation. Table 3-1 summarises the adjustment in meteorological variables over the FPV area. The assumptions detailed in Table 3-1 are based on previous studies in Singapore, which for reasons of confidentiality, cannot be cited here. Beside meteorological conditions, potential impacts of FPV construction activities based on preliminary construction plans are investigated and detailed in Appendix E.

Table 3-1 Changes in meteorological forcing due to FPV system in the model

Parameters	Remarks	Assumptions for Project with FPV
Air temperature	Assume air temperature over the panel cells affected by the FPV radiation into the water surface.	Based on the function: $Y = 0.2074\,x^2 - 10.099\,x + 148.25$ where x = ambient air temperature (°C), y = air temperature under FPV panels (°C)
Wind speed	Assumed floatation device (e.g., pontoon) completely blocks wind at water surface.	90% reduction
Solar radiation	Expected reduction in solar radiation with smaller tilt angle and larger water surface coverage.	40% reduction
Cloud cover	Assumed floatation device (e.g., pontoon) reduces cloud cover at water surface.	100%
Relative humidity	Assumed relative humidity over the panel cells affected by the FPV radiation into the water surface.	Based on the function: $y = 12.68\,e^{0.0216\,x}$ where x = ambient relative humidity (%), y = relative humidity under FPV panels (%)

4 Water quality model setup

4.1 Grid coverage and geometry

The computational grid of the Kranji Reservoir water quality model is based on the hydrodynamic model grid described in Appendix B. The hydrodynamic model uses a curvi-linear schematisation with Z-layers (constant layer thickness) in the vertical. Horizontally, the model has a resolution of 40 m in the main flow direction of the reservoir (south to north) and 20 m in the perpendicular direction. Z-layers were chosen in favour of σ-layers due to relatively steep bottom slopes and the importance of potential temperature and dissolved oxygen stratification in the Kranji Reservoir. The grid was vertically aggregated to five vertical layers for water quality modelling (i.e., first four layers of 1-m interval down to 4 meters and bottom layer from 4 m to the bed level in each cell), compared to twenty vertical layers used by the hydrodynamic model. In the shallow areas of the reservoir with depths less than the model surface layer thickness, the model consists of a single cell in vertical direction. The deeper sections of the reservoir (up to 18 m water depth) consist of all five vertical cells.

4.2 Boundary conditions

4.2.1 Meteorology

The meteorological inputs to the water quality model comprise hourly wind speed and solar radiation for the year 2019 obtained from Meteorological Services Singapore (MSS), see Appendix B, Section B.1.3 for further details on meteorological data inputs. In the water quality model wind speed mainly affects the DO re-aeration rate while solar radiation affects primary production. Figure 4-1 and Figure 4-2 show seasonality associated with the two monsoon seasons in Singapore. Solar radiation[3] is higher during the Southwest (June to September) monsoon as well as the late (dry phase) of the Northeast monsoon (December to early March). Stronger winds occur during the Northeast and Southwest monsoon periods.

[3] It is noted that the heat flux equations in Deflt3D-FLOW incorporate back (negative) radiation at night (i.e. cooling).

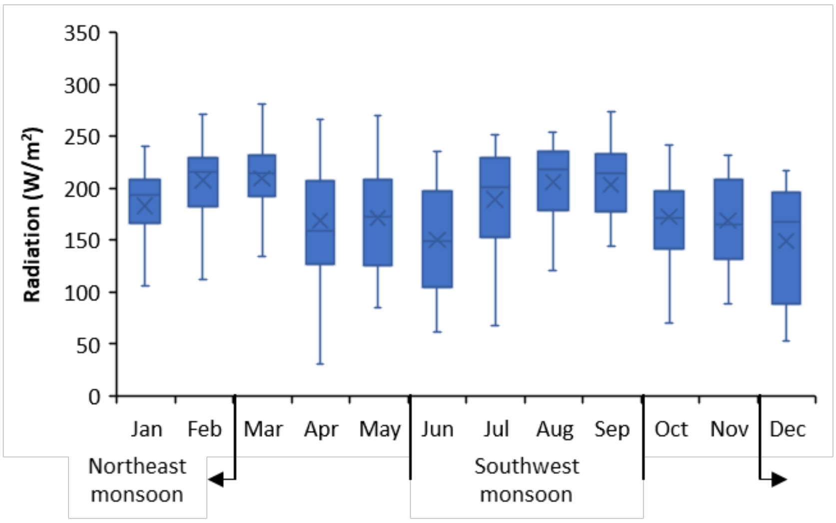


Figure 4-1 Monthly boxplots of solar radiation (W/m^2) in 2019

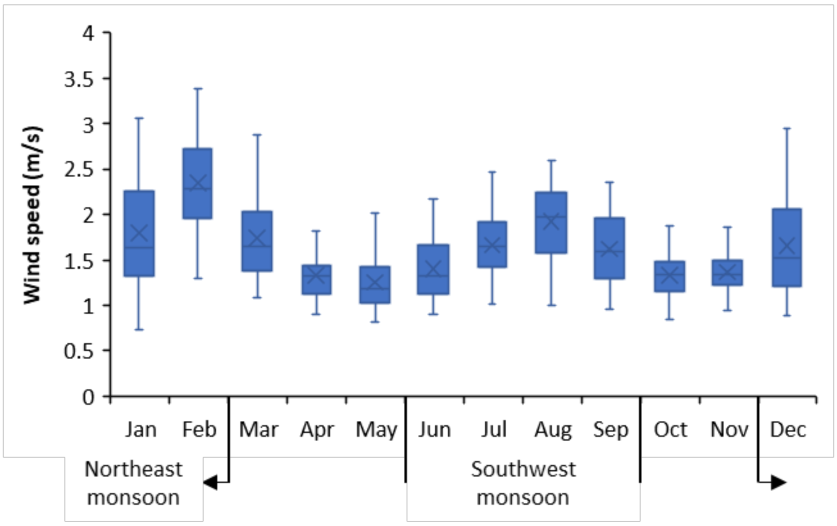


Figure 4-2 Monthly boxplots of wind speed (m/s) in 2019

4.2.2 Discharges and loads

Identified discharges and loads for Kranji Reservoir

Water in Kranji Reservoir originates from broadly three categories of sources:

- Rainfall-runoff from the catchment area of Kranji Reservoir
- Transfers from other sources, including reservoirs
- Rainfall directly on the surface of the Kranji Reservoir

Each of these water sources contribute to the reservoir loads (e.g., nitrogen and phosphorus) as well. Nutrient loads from atmospheric deposition during rainfall are also included as a source of nutrients.

Water is extracted or removed from Kranji Reservoir for drinking water supply and by evaporation at the water surface respectively. During high rainfall events excess inflow water is discharged from the reservoir to the sea (Straits of Johor) through the Kranji Tidal Gates. Figure 4-3 displays the locations of the identified inflows and outflows (note: the transfer to Murai Reservoir was at the same location as transfer to CCKWW). In the remainder of this section, more detailed information follows about the quantification of the catchment rainfall-runoff, transfers from other sources and the Kranji Tidal Gate discharge.

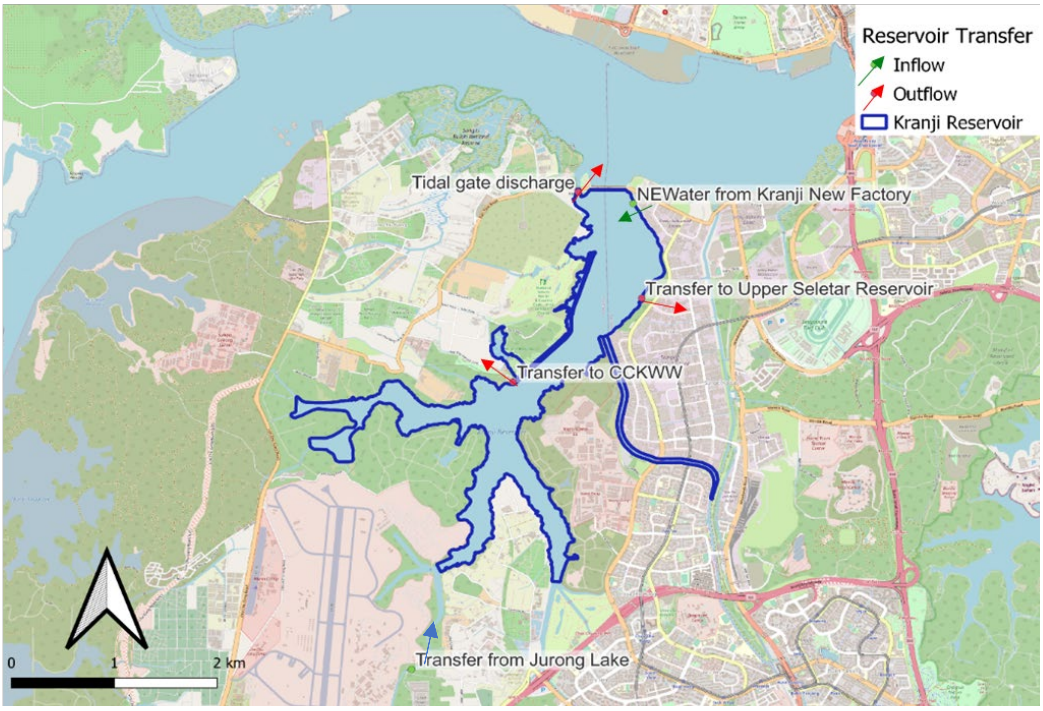


Figure 4-3 Locations of transfer inflows and outflows in Kranji reservoir.

Rainfall-runoff from the Kranji Reservoir catchment area

A rainfall-runoff model of the catchment area of Kranji Reservoir was used to calculate time-series of discharges into the Kranji Reservoir for use in the hydrodynamic and water quality models. Details on the catchment model setup, calibration and validation are described in Appendix A. Concentrations for catchment rainfall-runoff were specified based on the available observation data in the river branches and smaller tributaries leading to Kranji Reservoir.

Transfers from other sources, including reservoirs

Time series of the daily reservoir transfers were made available by PUB. The information and locations of these transfers is described in Table 4-1 and Figure 4-5. Of the two transfers into Kranji Reservoir, the volume contributed by Kranji NEWater Factory (KNF) is about 99% of the total transferred inflow volume (Table 4-1). Similarly, 99% of the water volume transferred out of Kranji Reservoir is transferred to the Choa Chu Kang Water Works (CCKWW).

Table 4-1 Water transfers from and into Kranji Reservoir

Inflow/ Outflow	Origin/ Destination	Longitude	Latitude	Average transfer (m^3/day)	Total transfer volume (m^3)	Highest daily transfer (m^3, date)
Inflow	Jurong Lake	103.71753	1.38007	103	75,260	32,014 19 Feb. 2018
Inflow	KNF[1]	103.74319	1.43678	7,175	5,237,840	43,221 19 Feb. 2018
Outflow	CCKWW[2]	103.72927	1.41507	84,317	61,552,071	153,135 15 Jan. 2019
Outflow	Murai Reservoir[3]	103.72927	1.41507	--	2148	2,148 2 Feb. 2019
Outflow	Upper Seletar Reservoir	103.74419	1.42527	708	517,092	102,730 31 Jan. 2018

[1] KNF: Kranji NeWater Factory. [2] CCKWW: Choa Chu Kang Waterworks. [3] There is only one transfer from Kranji Reservoir to Murai on 2 Feb 2019 at the same location of transfer to CCKWW.

Tidal gate discharge

During heavy rainfall the inflow volumes exceed the reservoir operational capacity and excess water is discharged from Kranji Reservoir to the sea (Straits of Johor) through the Kranji Tidal Gate on the western side of the northern Kranji Dam. Since measurements of the tidal gate discharge were not available, this quantity was instead derived through modelling. The operation of the tidal gate was simulated by assuming that when the reservoir water level exceeded 101.50 mRL, the tidal gate would effectively open and spill water from the reservoir at a constant rate of 100 m^3/s. When the reservoir level dropped below 101.47 mRL it was assumed that the tidal gate was effectively closed and spilling cease. The settings were in part derived from the tidal gate operation data provided by PUB, and in part through the calibration of the catchment model.

Water balance

Figure 4-4 shows the monthly water balance of the Kranji Reservoir for the year 2019. The monthly water balance is constructed based on the output from the catchment model (Appendix A). The dominant source of water is rainfall-runoff from the catchment area. The outflow is a combination of reservoir transfers and spilling via the Kranji Tidal Gate discharge to the Straits of Johor. The reservoir transfer ranges between $2x10^6$ and $4x10^6$ m^3 per month. Discharge of excess water through the tidal gate is low during dry months such as January and February 2019 but can be dominant during wet months (e.g., November and December 2019).

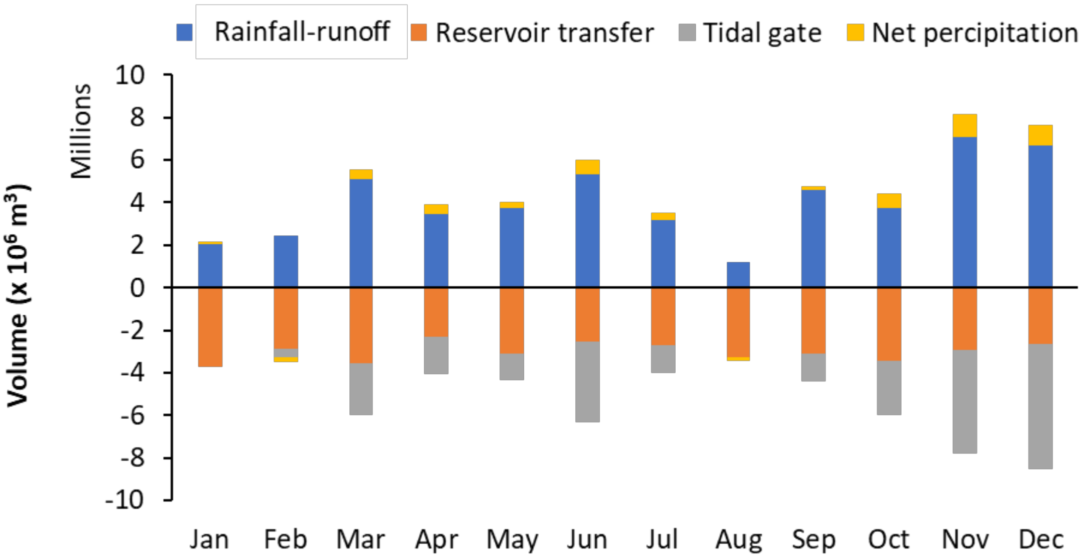


Figure 4-4 Kranji reservoir water balance in 2019

Implementation in the water quality model

Sometimes, several discharges from sub-catchments are located very near to one another. In such cases, discharges were combined into single discharge points in the water quality model. Table 4-2 summarises the grouping of individual discharges into 12 modelled discharges locations (see Figure A-3 for sub-catchments and Figure A-5 for discharge locations for each sub-catchments and reservoir transfer, in Appendix A) as implemented in the water quality model shown in Figure 4-5. All the inflows are input to the surface layer in the water quality model.

PUB sampling data were used to quantify the concentrations of the discharges in the water quality model. The typical sampling frequency of the water quality in the branches leading to the Kranji Reservoir is quarterly, except for Sungei Tengah where sampling is done monthly. Due to the frequency of the sampling, there is considerable uncertainty in the load quantification. The same holds for the quantification of loads during rainfall-runoff events. In addition, Chl-a and TSS concentrations at Sungei Tengah are determined based on the samples taken at Jurong Lake (Jurong Lake transfers to Kranji Reservoir via Sungei Tengah). Therefore, the data for Chl-a and TSS of this location were used to quantify the concentration of the other catchment discharges.

The outflows from Kranji Reservoir are the discharge from the tidal gate to the sea, the water transfers to Choa Chu Kang Waterworks, Upper Seletar Reservoir, and Murai Reservoir (Table 4-1). The water quality model uses the computed concentration in the grid cell in which the respective outflow is located to determine how much mass of each substance is removed from the reservoir.

Table 4-2 Discharge points in the water quality model

Modelled discharge	Discharge components	Description	Inflow / Outflow	Modelled discharge derived from	Modelled concentrations derived from
TidalGate	tidal_gate	Discharge through the Kranji Reservoir tidal gates to the Straits of Johor	Outflow	Catchment model	Water quality model
RTIPU	RT_IPU	NEWater from Kranji New Factory	Inflow	PUB data	PUB data
RTUSR	RT_USR	Reservoir transfer from Kranji Reservoir to Upper Seletar Reservoir	Outflow	PUB data	Water quality model
SgPsua	L_SSC-Psua1	Rainfall-runoff from Pang Sua Diversion Canal	Inflow	Catchment model	PUB data, locations CKR-J1, CKR-L1, CKR-H1
	L_SSC-Psua2		Inflow		
SgPeng	L_SSC-PS6	Rainfall-runoff from Sungei Peng Siang	Inflow	Catchment model	PUB data, locations CKR-F1, CKR-Q2, CKR-K1, CKR-Q1, CKR-Q3 and CKR-G1
	L_SSC-PS7		Inflow		
	L_SSC-PS8		Inflow		
	L_SSC-PS9		Inflow		
	L_SSC-PS10		Inflow		
	L_SSC-PS12		Inflow		
SgTengah	RT_JLake	Reservoir transfer from Jurong Lake to Kranji Reservoir	Inflow	PUB data	PUB data
	L_SSC-TG7	Rainfall-runoff from Sungei Tengah	Inflow	Catchment model	PUB data location CKR-E1
	L_SSC-TG5		Inflow		
	L_SSC-TG4		Inflow		

Modelled discharge	Discharge components	Description	Inflow / Outflow	Modelled discharge derived from	Modelled concentrations derived from
SSCNT1	L_SSC-NT1	Rainfall-runoff from SSC-NT1	Inflow	Catchment model	PUB data location CKR-A1
NT4CCKMUR	RT_Murai	Reservoir transfer from Kranji Reservoir to Murai Reservoir	Outflow	PUB data	Water quality model
	RT_CCKWW	Reservoir transfer to Choa Chu Kang Water Works	Outflow	PUB data	Water quality model
	L_SSC-NT4	Rainfall-runoff from SSC-NT4	Inflow	Catchment model	PUB data
SSCTN6	L_SSC-NT6	Rainfall-runoff from SSC-NT6	Inflow	Catchment model	PUB data location CKR-Q4, CKR-Q5 and CKR-Q7
LTKK3	L_SSC-KK3	Rainfall-runoff from SSC-KK3	Inflow	Catchment model	PUB data, location CKR-C1 and CKR-B1
LTKK4	L_SSC-KK4 L_SSC-KK5	Rainfall-runoff from SSC-KK4 and SSC-KK5	Inflow Inflow	Catchment model	PUB data, location CKR-D1
SCPS11	L_SSC-PS11	Rainfall-runoff from SSC-PS11	Inflow	Catchment model	PUB data locations CKR-J1, CKR-L1 and CKR-H1

Table 4-3 Implementation of discharges and loads in the Kranji Reservoir water quality model.

Inflow	Statistics	Discharge (m^3/s)	DO (mg/L)	TOC (mg/L)	TN (mg/L)	TP (mg/L)	Chl-a (µg/L)	TSS (mg/L)
RTIPU	Average	0.11	-	0.11	0.98	0.01	-	-
	Max	0.42	-	0.12	1.15	0.02	-	-
	Min	0	-	0.10	0.81	0.00	-	-
	No. of samples	-	-	12	2	2	-	-
SgPsua	Average	0.42	6.0	3.8	0.96	0.12	-	-
	Max	89.1	6.1	4.2	1.08	0.17	-	-
	Min	0.05	5.9	3.0	0.84	0.07	-	-
	No. of samples	-	3	4	4	4	-	-
SgPeng	Average	0.42	6.2	8.8	1.87	0.22	-	-
	Max	112	6.5	13.9	3.42	0.44	-	-
	Min	0	5.8	6.0	1.14	0.11	-	-
	No. of samples	-	3	6	6	6	-	-
SgTengah	Average	0.26	5.1	5.1	1.45	0.12	11.7	12.2
	Max	50.3	7.1	15.9	8.69	0.84	17.8	16.8

Inflow	Statistics	Discharge (m^3/s)	DO (mg/L)	TOC (mg/L)	TN (mg/L)	TP (mg/L)	Chl-a (µg/L)	TSS (mg/L)
	Min	0.02	3.9	3.1	0.72	0.04	6.0	7.7
	No. of samples	-	16	58	17	17	12	12
SSCNT1	Average	0.03	5.1	12.8	11.5	0.39	-	-
	Max	8.4	5.2	18.7	18.2	0.61	-	-
	Min	0	4.8	7.9	1.96	0.17	-	-
	No. of samples	-	3	4	4	4	-	-
SSCNT6	Average	0.04	-	9.3	0.79	0.10	-	-
	Max	12.4	-	10.1	0.96	0.12	-	-
	Min	0	-	8.6	0.63	0.08	-	-
	No. of samples	-	-	2	2	2	-	-
LTKK3	Average	0.13	5.8	8.1	0.64	0.23	-	-
	Max	37.2	6.2	9.0	0.76	0.46	-	-
	Min	0.02	5.5	7.3	0.55	0.13	-	-
	No. of samples	-	3	4	4	4	-	-
LTKK4	Average	0.1	6.2	8.7	1.97	0.22	-	-
	Max	23.4	6.3	11.0	5.34	0.53	-	-
	Min	0	6.0	6.2	0.66	0.08	-	-
	No. of samples	-	3	4	4	4	-	-
Rainfall	Average		-	2.1	1.13	0.02	-	-
	Max		-	5.2	3.04	0.02	-	-
	Min		-	0.6	0.19	0.01	-	-
	No. of samples		-	9	9	5	-	-

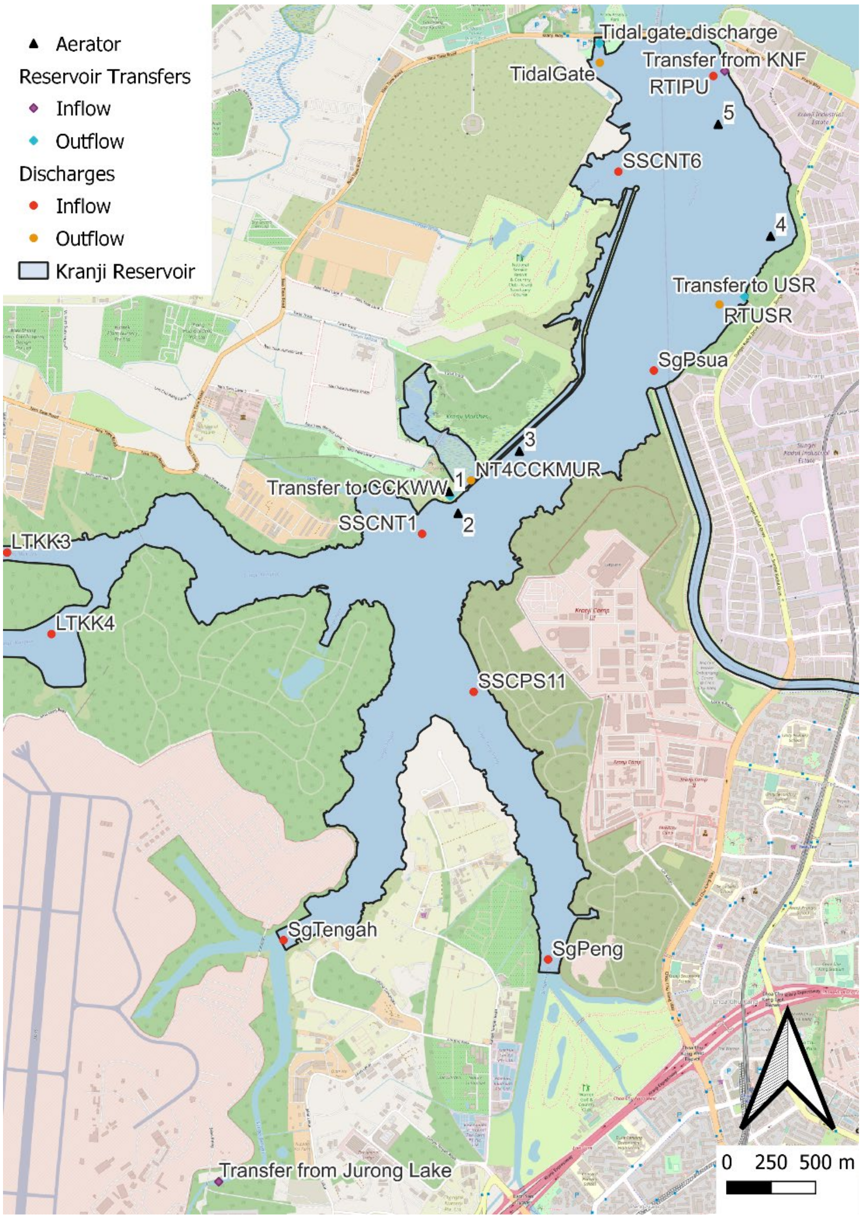


Figure 4-5 Map of 12 inflow/outflow discharges with water transfers implemented in water quality model, as well as 5 aerators (not explicitly modelled).

4.3 Thermal stratification and flow fields

The thermal stratification and flow fields in Kranji Reservoir were investigated by Xing et al. (2014) who summarise the stratification and mixing regime as follows: "In spite of the dominance of solar radiation in setting local stratification, it is shown that Kranji Reservoir is a three-dimensional system in which there can be significant variations in temperature in the vertical and along-reservoir directions, as determined by cold inflow events, differential heating, and reservoir releases. Moreover, the data suggest that the dynamical balance of the Kranji Reservoir system is sensitive to small forcing events, with the timescales of stratification and mixing as short as a day or less."

Xing et al. (2014) describe the main differences between time scales of temperate lakes where strong seasonal cycles in the solar radiation and meteorological variables drive the seasonal thermal structure, whereas tropical systems, with reduced seasonal patterns, are subject to regular diurnal variability in thermal stratification. In tropical systems thermal stratification is affected by a number of processes including solar insolation, overnight cooling and in-reservoir mixing associated with wind energy inputs and tributary inflows. Solar radiation during the day heats the near surface waters, wind mixing causes turbulent mixing of warm surface water and cooler water at depth. Overnight cooling processes cause heat loss from the water surface and convective mixing of the surface layers.

In tropical water bodies the daily cycle of solar heating causing stratification during the day and overnight cooling causing mixing means the average reservoir water temperature closely follows the average daily air temperature. The deeper reservoir waters are reasonably well mixed most nights and residence times are typically less than 24 hours. Prolonged heavy rainfall events can produce cold inflows that flow into the reservoir along the deeper river channels resulting in stratified conditions in the lower reaches (Xing et al., 2014) leading to deeper water residence times greater than a few days. As Xing et al. (2014) focused on the mixing and stratification regime, they did not address the implications for water quality of these prolonged stratified periods.

The Kranji Reservoir flow and temperature structure for 2019 are simulated by the Delft3D hydrodynamic model. The model setup and calibration are described in Appendix B. The 2019 hourly outputs from the hydrodynamic model in each cell with twenty vertical layers, along with specific water quality loads and process coefficients, form the input to the water quality model.

Figure 4-6 shows the observed temperature and DO concentrations at profiler site Kranji-2 (see Figure 2-2) at varying depths in 2019. It should be noted that there are certain periods of the year in which the DO hits ~13 mg/L. These values are likely due to sensor-related deviations and do not reflect the actual DO measurement. The data during the last two months, November to end December 2019 were reviewed closely as they appear inconsistent with general processes understanding. Upon review, the apparent inversion with bottom water showing warmer and higher dissolved oxygen than surface waters have been excluded from further interpretation.

The observed temperature data show periods when the thermal stratification persists beyond a few days (e.g., Feb. & May events as indicated by the 'black' boxes in Figure 4-6), suggesting vertical mixing is inhibited and deep water residence times increase, as described by Xing et al. (2014). During these periods DO is depleted by microbial consumption of oxygen at the sediment while the stratification inhibits vertical mixing and transport of DO from the surface layers. These processes then lead to a decrease in the deeper water DO concentration. The output of the hydrodynamic model indicates that during 2019 there were only 2 events, in May and December when the thermal stratification persisted for more than 2 days (i.e., <2% of the year 2019). The dissolved oxygen measurements (Figure 4-6) indicate similar characteristics with the deepest sampling level of 6 m below the surface, recording lower DO values (approximately 4–5 mg/L) during these events.

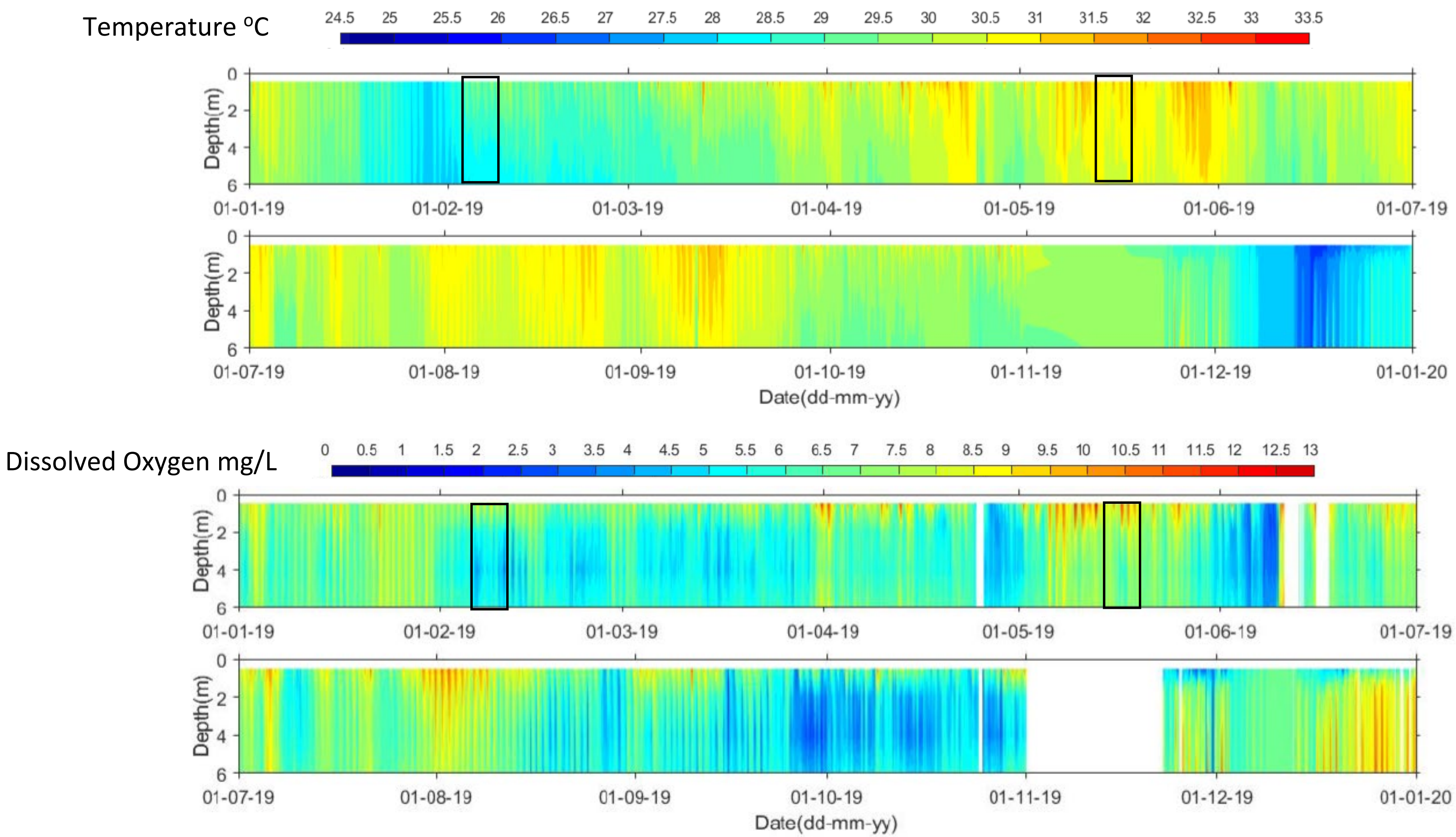


Figure 4-6 Observed temperature and dissolved oxygen variability at site Kranji-2.

4.4 Process coefficients

The model water quality processes include over 800 process coefficients that can be adjusted as part of model calibration. Based on experience with similar reservoirs, most of these process coefficients have limited effects on model results and were fixed for this application. Several main process coefficients were modified during the model calibration exercise as indicated in Table 4-4.

The values used for all the process coefficients are tabulated in Appendix C.

Table 4-4 Summary of several main process coefficents that affect the water quality model calibration

S/N	Coefficient	Tested range	Current value in the model	Parameters affected	Sensitivity (Low/Moderate/High)
1	Phosphorous adsorption and desorption rate (d^{-1})	0.1–1.5	1.5	TP, Chl-a, TOC	High
2	Adsorbed phosphorous settling rate (m/d)	0.01–0.2	0.2	TP, Chl-a, TOC	High
3	Denitrification rate ($gN/m^3/d$)	0.1–0.6	0.6	TN	High
4	Nitrification rate ($gN/m^3/d$)	0.1–0.45	0.45	TN	High
5	Extinction coefficients for Chl-a, TOC (m^2/g)	0.015–0.2	Chl-a: 0.05 TOC: 0.01	Chl-a, TOC	Low or Moderate
6	Dry matter resuspension rate ($gDM/m^3/d$)	10–1500	10	TN, TP	Low or Moderate
7	Critical bed shear stress for resuspension (N/m^2)	0.1–0.2	0.1	TN, TP	Low
8	Bloom module time step (d)	1, 2 days or 1 hour	1 day	Chl-a	Low
9	Temperature effect on mineralisation of detritus (-)[a]	1.01–1.15	1.10	TOC, TN, TP, DO	Moderate or High

[a] (-) denotes unitless.

4.5 Model calibration and validation

4.5.1 Calibration approach

Based on the data analysis and estimations of mass balance for the main water quality parameters, a select set of process coefficients (Table 4-4) were adjusted in the model calibration. The water quality model was initially run with the loading quantification based on Section 4.2.2. The preliminary results from the initial set-up were checked against the reservoir observed data in 2019 at RKR H2, K2 and I2. It was found there were significant differences between the observations and the initial model results at the mid-layer of the water column. Hence, the main calibration efforts were firstly focused on testing the impact of loading from the catchment areas on model results, given that the catchment sampling data is not frequently available for most of the inflows which brought uncertainty in incoming load estimation. This was done through a series of sensitivity simulations by using maximum/ minimum possible load (i.e., maximum/ minimum concentration observed in a year) in inflows with the largest spread in concentration. It is noteworthy that no maximum nor minimum concentration was tested for NEWater from Kranji New Factory (implemented in the model as RTIPU, Table 4-2) as it is expected that the NEWater concentration is controlled.

The calibration approach adopted the following steps:

1. Six main representative : TN, TP, TOC, TSS, DO, Chl-a - at locations RKR-H2, RKR-K2 and RKR-I2 were selected for the model calibration based on the availability of monthly sampling data. For DO, hourly profiler data was used instead of monthly sampling data.
2. A sensitivity analysis of inflow loads for each of the variables to be calibrated was carried out to assess the effects of inflow loads uncertainty on the model results.
3. Selected process coefficients of physical and chemical processes (e.g., settling, adsorption/ desorption, resuspension rates, nitrification/ denitrification) were adjusted to obtain a reasonable match between the modelled results and observed data.
4. Model performance was assessed by visual comparison of daily average model output and observed data as well as boxplots of the daily average model output and observed data. The boxplots were used to quantify the relative variability between the model results and observation data.

4.5.2 Uncertainty analysis

The deterministic Delft3D water quality model provides an approximation of the real-world dispersion and ecosystem responses to a range of inputs and coefficients that determine the rates of change, both spatially across the model grid and temporally, from one model time step to the next, of each simulated variable. Results of the water quality model simulations with and without the FPV system installed and time periods comprising the baseline scenario year, 2019, and the three future climate scenario years, 2030, 2040 and 2050, provide guidance on the likely future behaviour of the reservoir water quality if the proposed FPV system is installed. This numerical model approach involves a number of sources of uncertainties including, for example:

- The mathematical formulations used to represent complex bio-geo-chemical processes include a considerable number of assumptions about the causal relationships used to represent the natural system behaviour. These relationships may or may not apply to all systems,
- The model formulations involve hundreds of parameters, or coefficients, that vary across systems and for which little local information is available,
- Data needed to estimate parameters of the process formulae are often derived for temperate systems and may not be representative of tropical systems,
- Concentrations of water quality variables are generally measured by collecting water samples during daytime and diurnal variability of main variables is often not resolved.

The main sources of uncertainty in model process assumptions arise in the nutrient-organic matter (expressed as organic carbon) cycling and the nutrient-light-temperature-microalgae (expressed as chlorophyll-a) responses. These complex real world biogeochemical processes may involve large numbers of species and with different population dynamics are assumed to be reasonably well represented by simplified algorithms. For example, the number of different phytoplankton species that make up the microalgae population (or biomass expressed as total microalgae chlorophyll-a) are lumped into several microalgae groups with specific chlorophyll-a signature. In addition, the values of the pre-set model coefficients are generally assumed to be applicable to reservoirs in temperate and tropical environments. It is suggested that these model process assumptions contribute a significant source of uncertainty in the model outputs.

The model domain only includes the water of the reservoir with boundaries at each of the inflowing streams and water treatment plants as well as the water surface-atmosphere interface. At each boundary the model state variables need to be specified for the duration of the model simulation period. These inputs need to be derived from best available observation data specific to Kranji Reservoir. Stream inflows are derived from the catchment rainfall runoff model and the constituent loads (e.g., Nutrients, chlorophyll-a, temperature, TOC, etc.) are derived from sparse temporal measurements of concentrations in the streams. The uncertainty in the estimated loads then contributes to the simulated reservoir water quality behaviour and uncertainty in the model outputs.

Vertical thermal stratification in reservoirs may cause deterioration of the water quality and aeration systems have been installed in Kranji Reservoir for over 10 years, to reduce the potential for this effect by artificially mixing waters. During the baseline year, 2019, aerator mixing devices operated within the reservoir and the additional artificial mixing resulted in changes to the vertical distributions of the water quality variables. Since the detailed operations of the aeration devices was not known at the time when the hydrodynamic model was setup, the effects of the artificial mixing by aerators are implicitly incorporated through the calibration of the vertical and horizontal diffusion coefficients. This approach showed a reasonable match of the modelled and observed temperature structure at observation points at different locations across the reservoir.

Each of these sources of uncertainty contributes to the overall model output uncertainty. The links between variables and propagation of uncertainty through the system of equations and solution techniques make it difficult to quantify an uncertainty estimate. It is suggested that a reasonable target is that the water quality variables output from the model attain better than 60% of the variance of the observation data.

4.5.3 Model calibration results

As mentioned in the calibration approach in Section 4.5.1, the 6 main simulated water quality parameters are TN, TP, TOC, TSS, DO and Chl-a. Note that for DO, mid-depth (3-4 m below the surface) profiler data at Kranji 1 (close to RKR-H2) and Kranji 2 (close to RKR-K2) were used for comparison. Since there was no maintenance conducted between Oct 2019 to Dec 2019 for Kranji 1 and Oct 2019 to Nov 2019 for Kranji 2, data from October 2019 onwards for DO have been excluded for the analysis.

The simulated water quality is compared to the observation data by means of the box plots presented below (Figure 4-8 to Figure 4-15), as well as a time-series comparison for DO (Figure 4-7). Note that the comparison for DO (Model vs Profiler data) is shown at surface, middle and bottom layers of the water column, while for other main parameters the comparison (Model vs Sampling observation data) is shown for middle layer only. It is worth noting that as the number of sampling data points is relatively limited in reflecting the true distribution of possible concentrations in a year for all parameters except for DO, the difference in box plots elements (e.g., max, min, median) between model results and the observations may not necessarily indicate a poor performance of the model. For example, there is one outlier of 1.41 mg/L TN concentration observed at H2 (Figure 4-14) which may in fact not be an outlier if the sampling has been collected at a higher frequency. On the other hand, it was noted that as compared with the profiler data, DO estimated by the model shows more downside outliers, especially at bottom layers, which may lead to more occurrences of false positives when it comes to exceedance evaluations as compared to PUB water quality guideline (DO >3 mg/L).

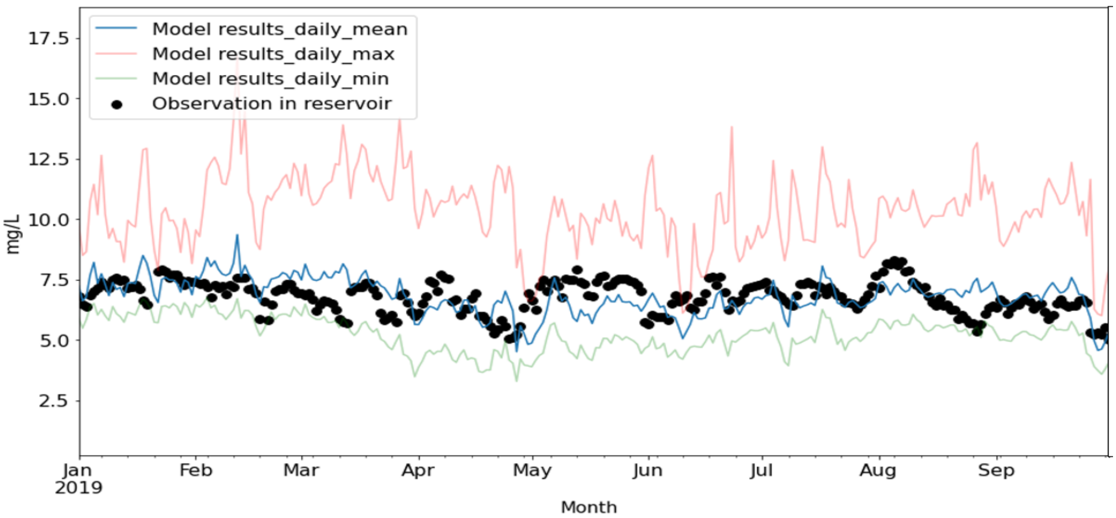


Figure 4-7 Comparison of DO between simulatedresults and observations at Location RKR H2

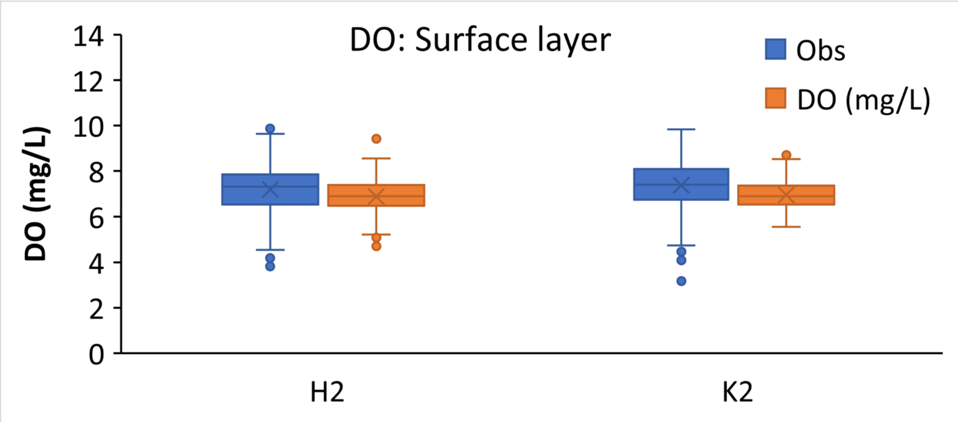


Figure 4-8 Box plot of Observation (blue) vs. Model (orange) for DO at surface layer

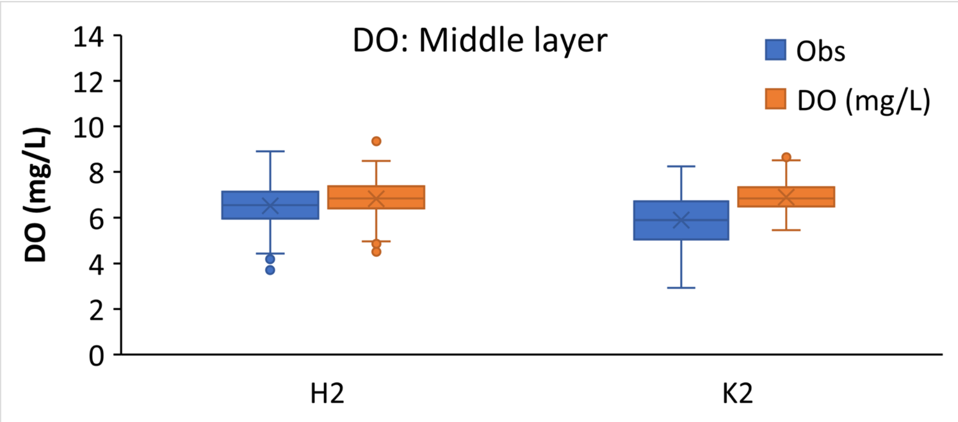


Figure 4-9 Box plot of Observation (blue) vs. Model (orange) for DO at middle layer

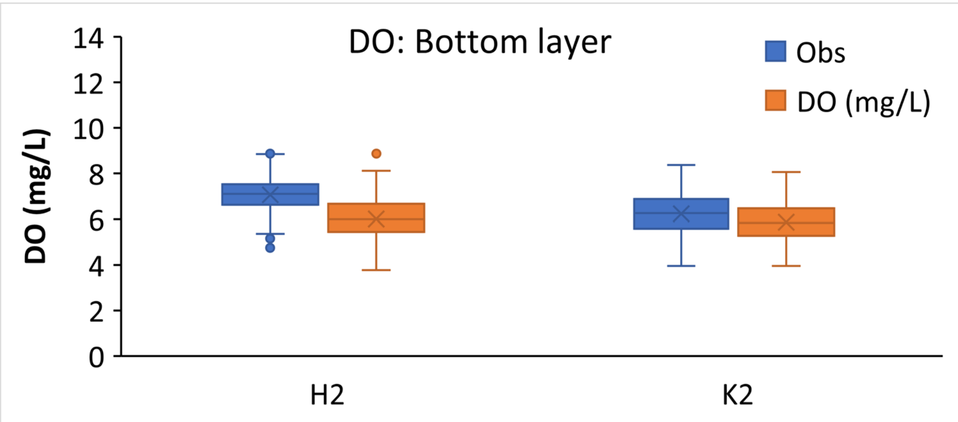


Figure 4-10 Box plot of Observation (blue) vs. Model (orange) for DO at bottom layer

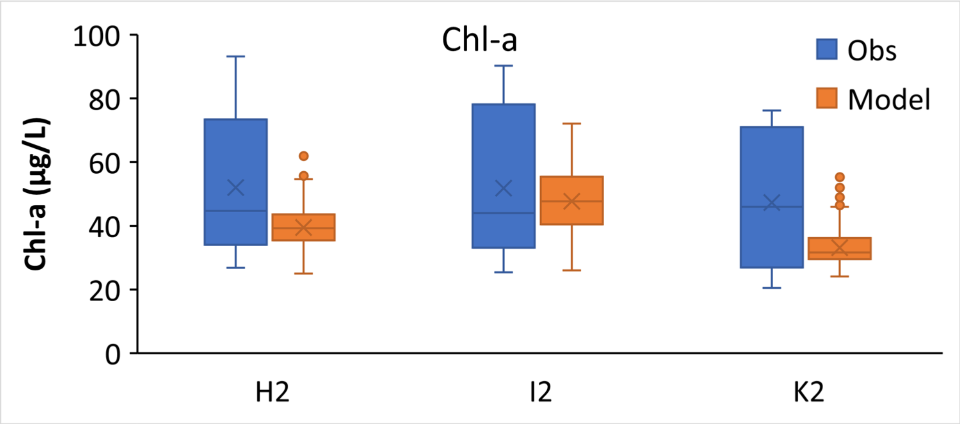


Figure 4-11 Box plot of Observation (blue) vs. Model (orange) for Chl-a

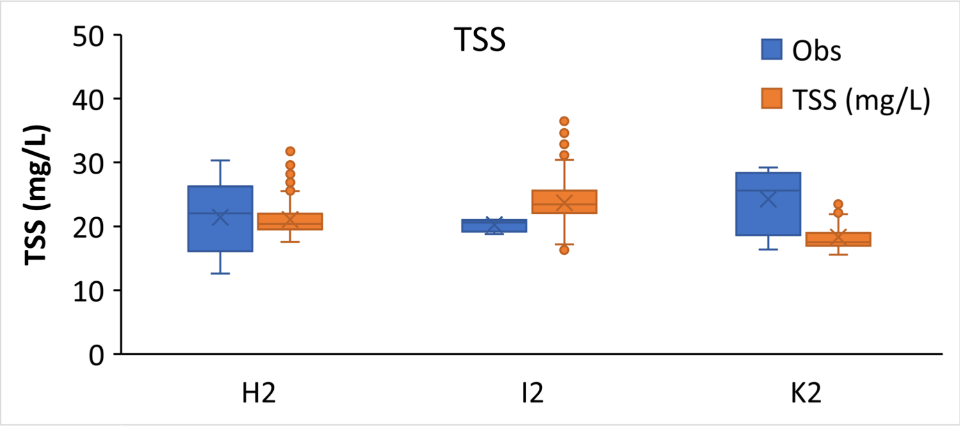


Figure 4-12 Box plot of Observation (blue) vs. Model (orange) for TSS

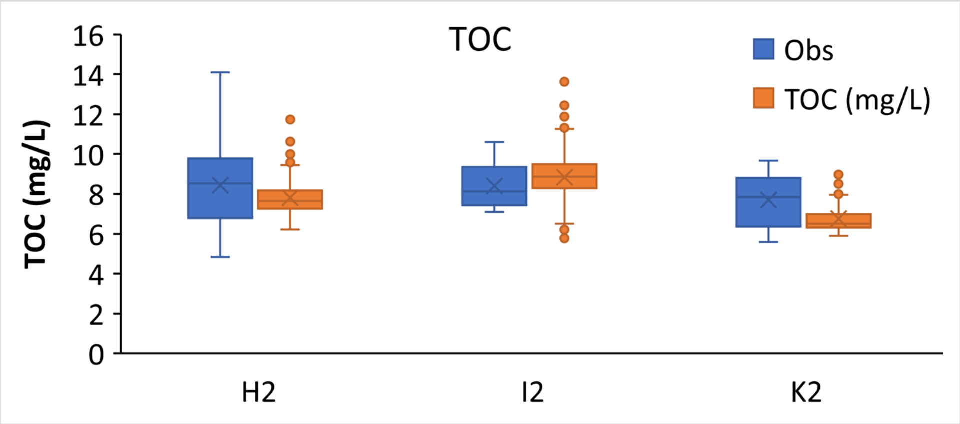


Figure 4-13 Box plot of Observation (blue) vs. Model (orange) for TOC

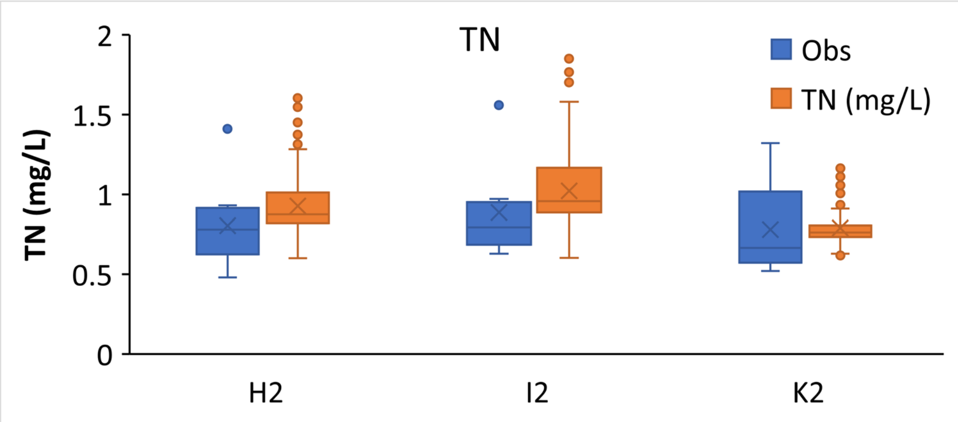


Figure 4-14 Box plot of Observation (blue) vs. Model (orange) for TN

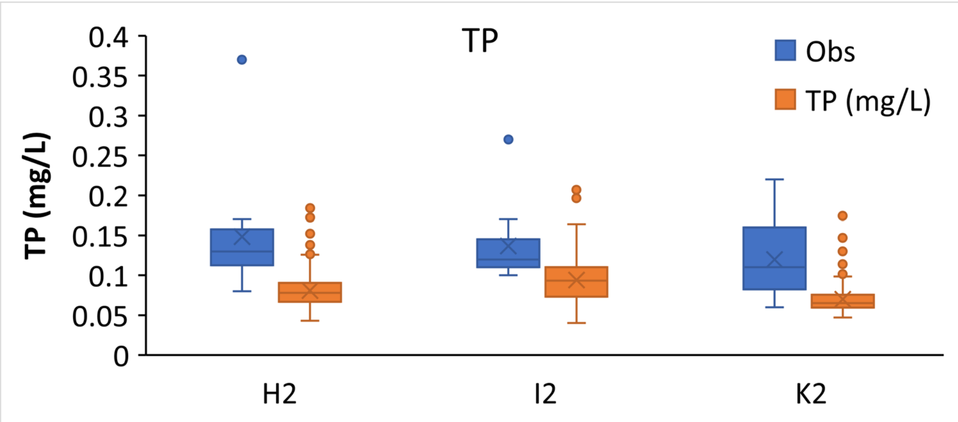


Figure 4-15 Box plot of Observation (blue) vs. Model (orange) for TP

4.5.4 Discussion of sediment oxygen demand

Sediment oxygen demand in reservoirs can vary rapidly in both space and time by a few orders of magnitude. The modelled sediment oxygen demand (SOD) was compared to results of laboratory measurements of SOD from samples taken in Kranji Reservoir (Yew-Hoong Gin & Gopalakrishnan, 2010). These authors reported measured SOD from 1.4 to 3.3 $gO_2/m^2/day$, while the SOD value used in the model ranges from 3.1 to 4.5 $gO_2/m^2/day$. Since the model values are of a similar magnitude to the available measurements no further changes were made to the coefficients affecting the modelled SOD-related processes.

5 Scenarios

5.1 Overview of modelled scenarios

To evaluate the potential effects of the proposed FPV system eight simulations of the reservoir water quality, based on current and future, projected climate meteorological conditions have been conducted. The model simulations utilise two grid setups – the existing system and the system incorporating the FPV layout – and four simulation years utilising present (i.e., 2019 baseline) and future 2030, 2040 and 2050 meteorological conditions provided by PUB and derived from Global Climate Model (GCM) projections. The simulation scenarios are summarised in Table 5-1. The first two simulations, 2019 Baseline and 2019 FPV, are baseline simulations with meteorological forcing on the 2019 existing reservoir system and FPV system, respectively. To evaluate potential water quality issues over the lifetime of the project, simulations for the years 2030, 2040 and 2050 were conducted based on meteorological forcing provided by GCMs. The FPV layout used in scenarios with the FPV system is described in Section 5.2. Also, the differences in meteorological forcing for simulation Baseline 2019 and FPV 2019 are presented in this section based on the adjustments described in Section 3.2. Details of the processing of the GCM outputs for the scenarios for the year 2030, 2040 and 2050 are described in Section 5.5.1. The simulation results for the eight scenarios listed are presented in Section 5.4 for simulations in 2019 and Section 5.5 for scenario simulations in 2030, 2040 and 2050. Section 5.5.2 discusses the results presented.

Table 5-1 Simulation scenarios to assess impact of FPV system with current and future climate forcing

Year	Reservoir with No FPV (NPV, or Non-FPV)	Reservoir with FPV (or PV) layout
2019	Baseline	2019 PV
2030	2030 NPV	2030 PV
2040	2040 NPV	2040 PV
2050	2050 NPV	2050 PV

5.2 Conservative FPV layout

A conservative approach has been carried out for water quality modelling of the FPV layout. The FPV layout modelled is of a larger FPV footprint (i.e., more impactful) than that ultimately proposed by the EIA (see EIA *Section 2 (Project Description) and Section 6.6.2.2 (Surface Water Quality)*). The conservative FPV layout includes: (i) inclusion of the Southern Extension (which ultimately was identified as a “no build” zone for biodiversity and not taken forward into the FPV layout presented in the EIA for approval, see EIA *Section 2.3*, *Project-specific Alternatives*); and (ii) the modelled layout also assumes the intra-island block spacing is also covered by FPV panels (due to limits in the model grid sizing). Thus, the layout implemented in the model does not represent the small gaps between individual FPV islands.

As a result, the conservative FPV-covered area for which meteorological conditions will be adjusted in the model is larger than the actual surface covered by the proposed FPV layout presented in the EIA for approval. This approach to assess a larger FPV footprint has been taken to provide a more conservative approach to water quality impact assessment to determine the maximum extent of FPV that is acceptable in terms of water quality. The final FPV coverage should be smaller than or equal to the assumed modelled coverage in this Technical Appendix to ensure impacts are within those assessed in the EIA. For example, the final (biodiversity mitigation) FPV layout presented in this EIA for approval (see EIA Section 2, Figure 2-4) is smaller than the maximum extent of FPV assessed in this Technical Appendix.

Figure 5-1 shows the layout of the conservative FPV layout modelled on Kranji Reservoir, where FPV (i.e., adjusted meteorological conditions) is assumed to cover a slightly larger, more conservative area of approximately 122 ha. It is noted the FPV layout presented in the EIA for approval proposes approximately 112 ha of the Kranji Reservoir total surface area to be covered (this area includes FPV islands inclusive of FPV panels, walkways, inverters, and perimeter floats; PCUs; and, other in-reservoir infrastructure which will cover the water surface, and allows for open water between FPV islands).

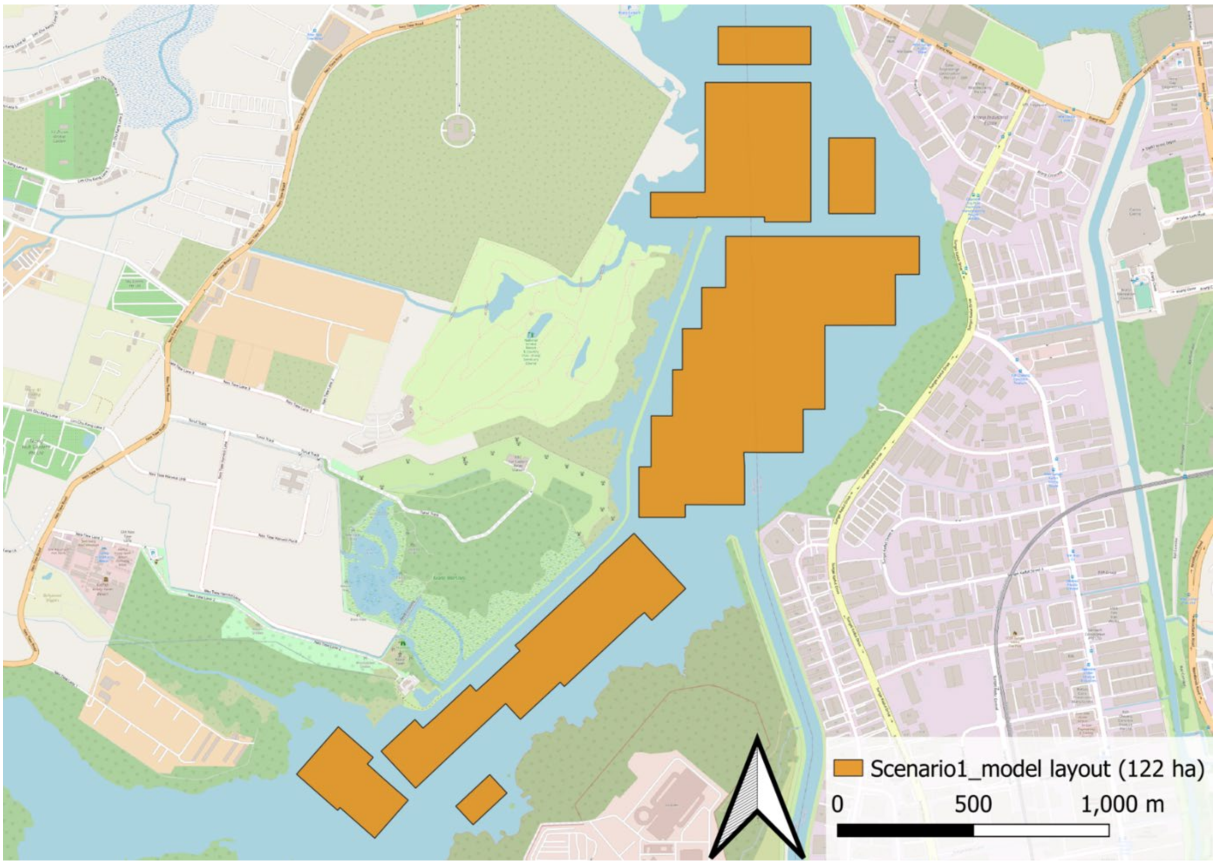


Figure 5-1 FPV Layout implemented in the model

The part of the Kranji Reservoir covered by FPV system in the model (orange colour in Figure 5-1) will induce local changes in the water-atmosphere exchange conditions at the water surface. As a result, the meteorological forcing (detailed in Section 3.2) on the area covered by the FPV system is adjusted in the model to simulate these local effects. For those areas of the reservoir that are not covered by the FPV system, no adjustment in meteorological forcing is applied. The meteorological forcing variables for January 2019, at areas without FPV (labelled NPV, or non-FPV) are compared to the areas with FPV as presented in Figure 5-2.

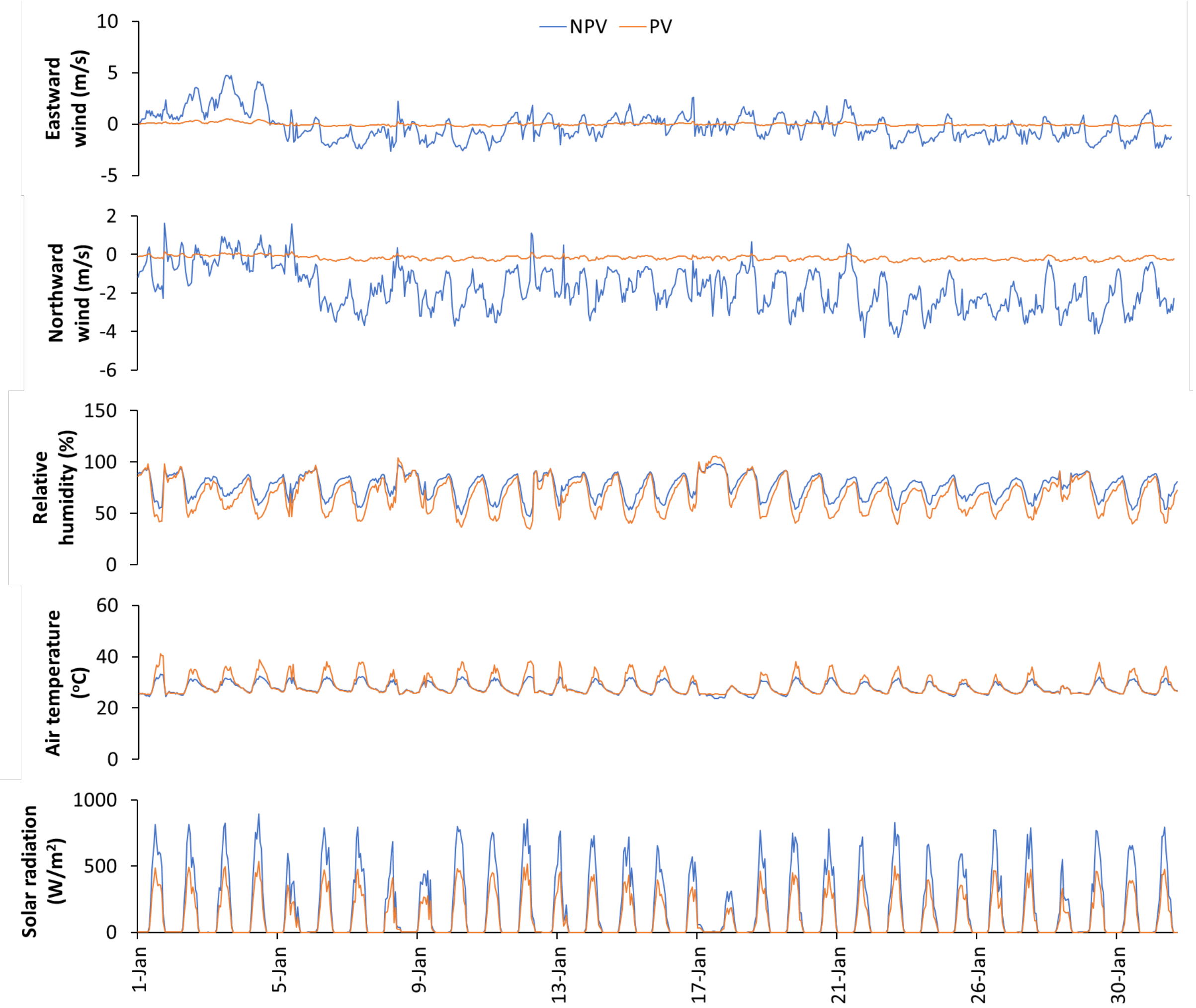


Figure 5-2 Meteorological forcings for areas without FPV (NPV, or non-FPV) and with FPV (or PV) in Jan. 2019

5.3 Assessment criteria

PUB provided water quality guidelines to comply with as detailed in Table 5-2. Observations in the reservoir demonstrate that some of the water quality variables in the current baseline exceed the concentrations listed in the guidelines (discussed in Section 2.2) for some of the time. Therefore, the assessment of modelled results assesses changes in reservoir conditions between the simulations with FPV versus the simulations without FPV (baseline, NPV or non-FPV) as well as the frequency of criteria exceedance in each scenario. For the purpose of applying the criteria, model results are averaged over the whole reservoir without distinguishing areas with and without the FPV system. Results for chlorophyll-a and dissolved oxygen concentrations are presented as annual average spatial distributions in the mid-depth, layer 3 (2-3m deep) and the bottom-most layer in each cell in Section 5.4.1 and results for the future scenario simulations for 2030, 2040 and 2050 runs are presented in Appendix F.

Table 5-2 Assessment criteria for water quality

Model Variables	Water Quality guidelines provided
Temperature change (with mitigation measures, if required)	≤0.3^{o}C (throughout water column)
DO (with mitigation measures, if required)	>3 mg/L (throughout water column)
TN	≤1 mg/L
TP	≤0.06 mg/L
TOC	≤10 mg/L
Chl-a	≤50 µg/L

5.4 Baseline year 2019 and 2019 FPV scenario

5.4.1 Annual spatial variability

Kranji Reservoir provides source water to the Choa Chu Kang Waterworks and water quality variables of concern for the water treatment processes within the Waterworks are primarily DO and Chl-a and discussion below relates to these main variables of concern. The spatial variation of the annual averages in each cell for DO and Chl-a in 2019 for simulations with and without the FPV system are presented in Figure 5-3 and Figure 5-4, respectively. The figures show the mid-depth output (Figure 5-3A and Figure 5-4A) from model layer 3 that extends from 2 to 3 m deep, and the bottom-most layer in each cell (Figure 5-3B and Figure 5-4B). Note the bottom-most layer varies from layer 5 in cells with bed level >4.5 m depth and is drawn layers 4 to 1 in cells shallower than 4.5 m.

Overall, in 2019, the annual average mid-depth DO concentration is greater than 6 mg/L throughout the reservoir and satisfies the water quality criteria (Table 5-2) with DO >3 mg/L. The lowest values occur in the deep area bottom waters and upstream in the Sungai Peng Siang tributary. The DO concentrations in the FPV scenario also satisfy the water quality criteria but indicate slightly lower values than the results without FPV.

Mid-depth chlorophyll-a annual average concentrations in the main body of the reservoir are below 40 µg/L and chlorophyll-a increases with distance upstream into the tributaries. At the upstream reaches, well upstream of the proposed FPV area, annual mean chlorophyll-a concentrations increase up to 75 µg/L (Figure 5-4A). Chlorophyll-a concentrations are generally lower in the presence of the FPV system than without the FPV. This is anticipated as a result of the reduced sunlight and primary production under the FPV area (Figure 5-4A). In general, a reduction in chlorophyll-a concentrations particularly below the water quality guideline of 50 µg/L is deemed to be an improvement in water quality.

Annual average deep water DO concentrations were derived from the bottom layer in each model cell and are presented for the 2019 non-FPV and FPV cases in Figure 5-3B. There is little difference between the results of the non-FPV and FPV simulations, with both results indicating the annual deep-water average DO is generally greater than 5 mg/L and remains above the water quality guideline of 3 mg/L throughout the reservoir.

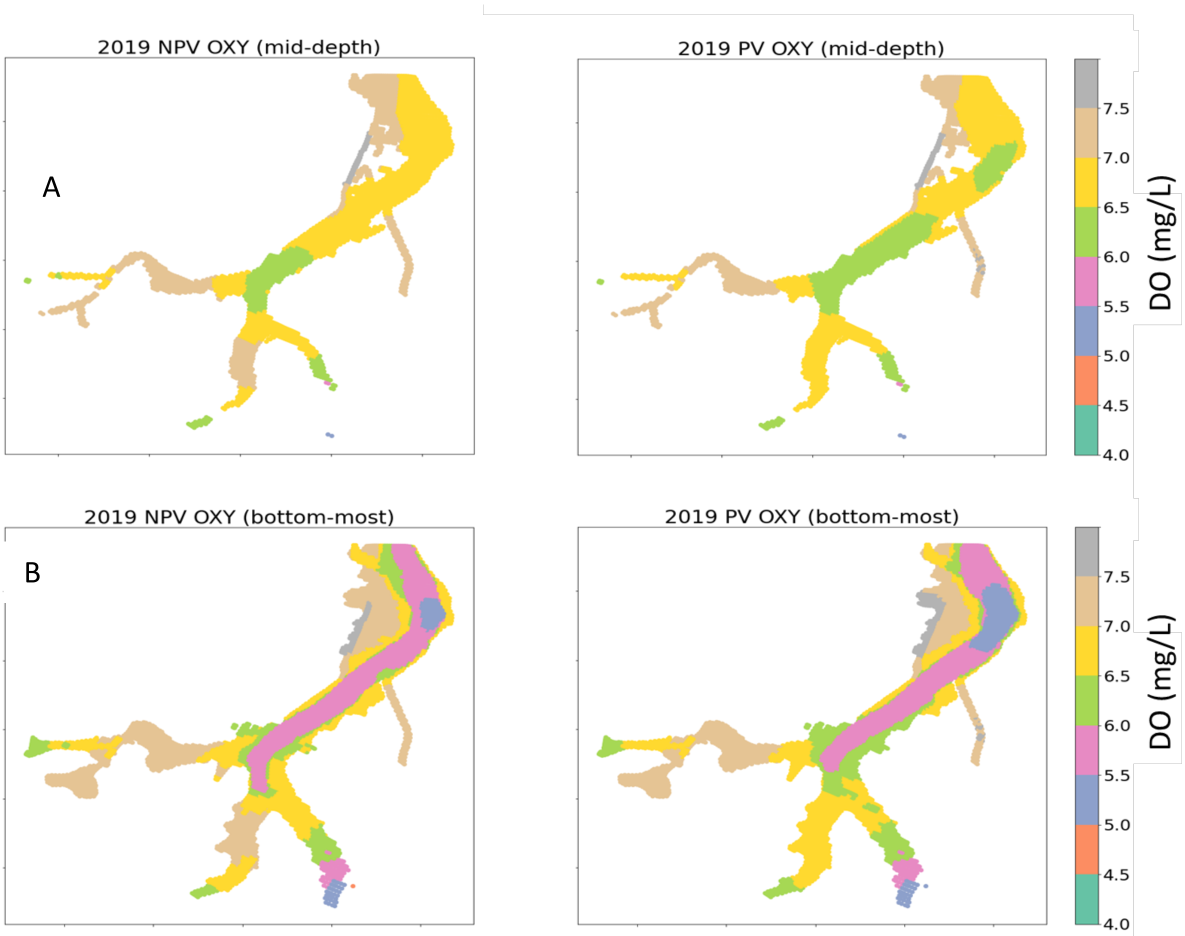


Figure 5-3 Annual average of DO concentration in 2019 for baseline (NPV, or Non-FPV) and (PV (or FPV) scenarios, A in mid-depth layer 3 (2–3 m depth) and B in the bottom most cell

Annual average deep-water (i.e., bottom-most model cells, nearest to the reservoir bed across reservoir) chlorophyll-a concentrations are presented for the 2019 non-FPV and FPV cases in Figure 5-4B. There is little difference between mid-depth and deep-water concentrations but chlorophyll-a results for the FPV simulations are slightly lower than the non-FPV results which suggests a slight improvement in chlorophyll-a concentrations with the FPV installed. The water quality guideline of 50 µg/L is generally exceeded in the upper reaches of the reservoir and the area of exceedance is reduced in the FPV simulations.

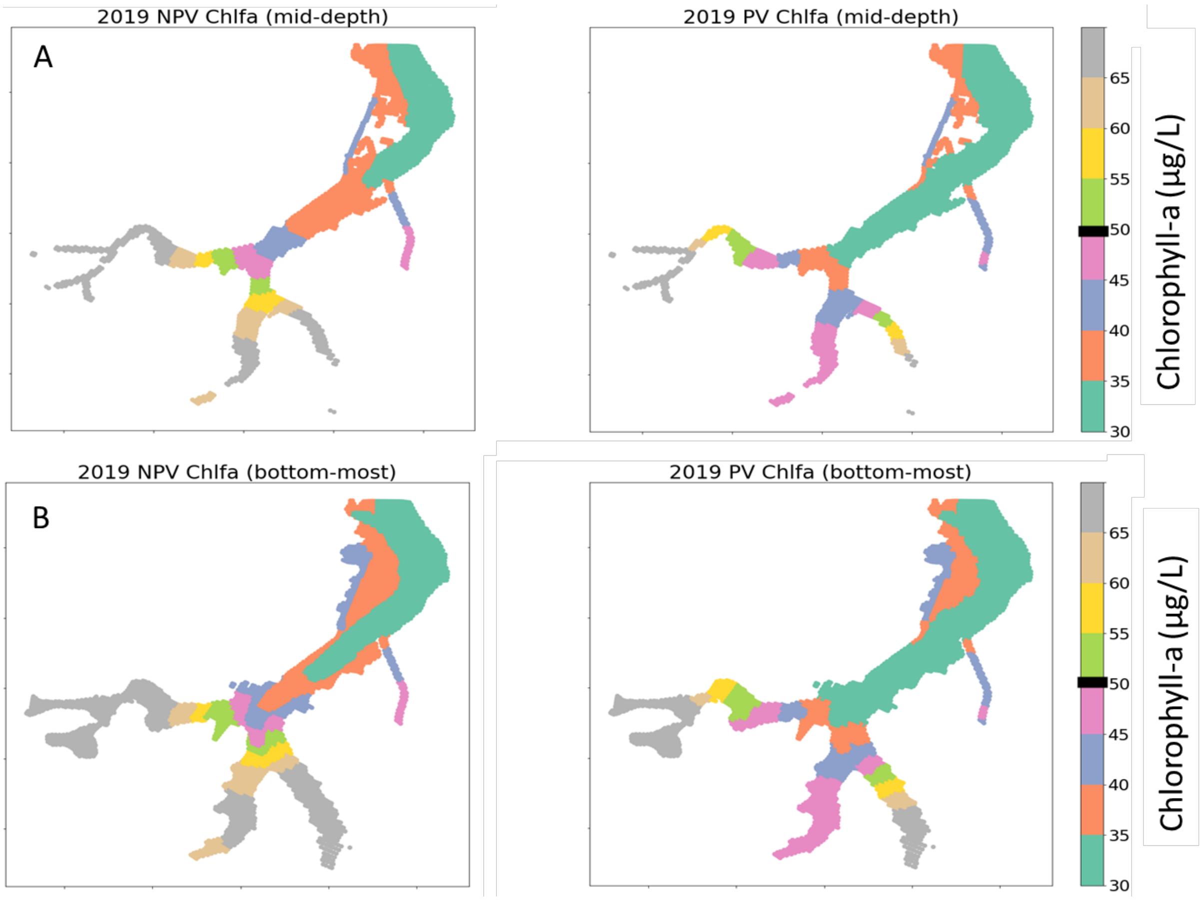


Figure 5-4 Annual average of Chl-a concentration in 2019 for baseline (NPV, or Non-FPV) and PV (or FPV) scenarios, A in mid-depth layer 3 (2–3 m depth) and B in the bottom most cell. Black line in legend indicates PUB water quality guideline

5.5 Future scenarios

5.5.1 Input preparation for climate scenarios

Future climate projections were derived from global climate models (GCM) and subsequently downscaled to regional climate model (RCM) using climate scenario Representative Concentration Pathways (RCP) 8.5 from 1 December 1950 to 1 December 2099 for Singapore (Jones et al., 2015). RCP8.5 assumes a future pathway of relatively large greenhouse gas emissions and in general results in larger changes than the other pathway scenarios. Hence adopting the RCP8.5 projection leads to more conservative estimates of future effects. The following simulation uses the meteorological forcing provided by the Geophysical Fluid Dynamics Laboratory Climate Model 3 (GFDL-CM3) with RCP8.5. The future projected meteorological inputs used to simulate climate change effects are summarised in Table 5-3.

Table 5-3 Meteorological inputs for Climate Change scenario

Required by models	Baseline model 2019	GCM output	GCM implementation
Air temperature	Hourly time-series based observation data year 2019	Daily average, min, max	Construct hourly time-series based on GCM output
Relative humidity		Daily average	Use daily average
Cloud cover		NA	Use same input as baseline model
Solar radiation		NA	Use same input as baseline model
Wind speed		Daily average	Use daily average
Wind direction		Daily average	Use daily average
Rainfall	10-min time-series based observation data year 2019	Daily total	Use same input as baseline model

Assessment of future rainfall pattern

To identify whether the future rainfall is significantly different from the past and the baseline (2019) year, the temporal variability in the rainfall data sets were analysed. The percentile distributions of annual total rainfall derived from GCM outputs for the historical period 1960-2009, at locations S23 and S66 (weather stations at Tengeh and Kranji Reservoir respectively) are presented in Table 5-4. The annual total rainfall was calculated for: 1) baseline year 2019 (based on actual data), 2) GCM outputs at locations S23 and S66 for years 2030, 2040 and 2050, and 3) the decades 2026-2035, 2036-2045 and 2046-2055 (Figure 5-5, Table 5-4). The annual total rainfall for each of these years and decades are compared with the percentile distribution of annual total rainfall for the historical period, 1960-2009 in Table 5-4.

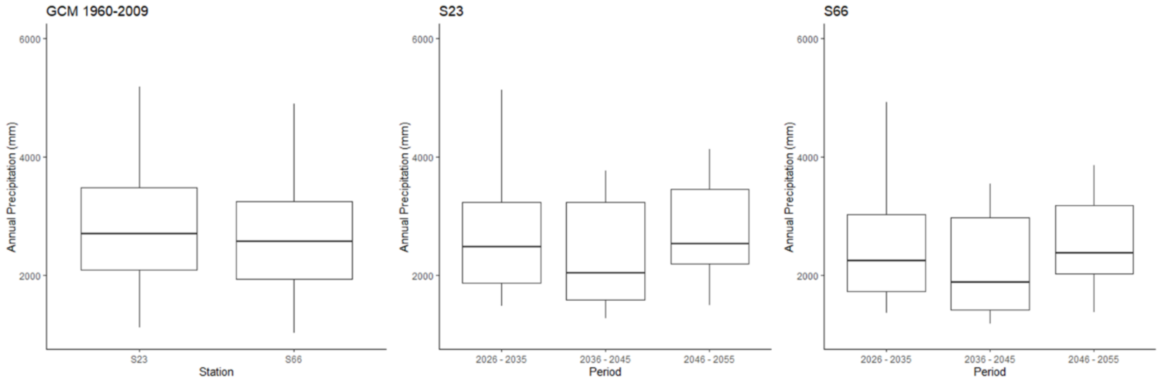


Figure 5-5 Annual total rainfall (mm) for S23 and S66 station using GCM historical & future data

Table 5-4 Annual rainfal and percentile distributionl for baseline (2019) and other periods

		S23 (Tengah)		S66 (Kranji Reservoir)	
		Average annual rainfall (mm)	Percentile GCM 1960-2010	Average annual rainfall (mm)	Percentile GCM 1960-2010
Observations	2019	2,316	30-40	1,940	20-30
GCM output	2030	2,388	30-40	2,191	30-40
	2026–2035	2,724	50-60	2,530	40-50
	2040	1,977	10-20	1,832	10-20
	2036–2045	2,336	30-40	2,162	30-40
	2050	1,671	10-20	1,525	10-20
	2046–2055	2,712	50-60	2,519	40-50

The inter-annual variability in rainfall confounds the selection of a particular representative year for the GCM scenarios (e.g., 2050) and may not yield representative rainfall forcing. Based on the annual total rainfall, there does not seem to be a shift towards drier or wetter years over the period from present to 2050. The 2019 baseline period was a drier year compared to historical (1960-2009) median rainfall (based on a historical computation by the GCM), however it was not exceptional (within the 20-30 percentile for S66 and 30-40 percentile for S23). Additionally, standard drainage infrastructure design typically uses rainfall intensity-duration-frequency (IDF) curves to compute future water drainage infrastructure requirements. The IDF curves for the years 2020 and 2050 do not show drastic shifts when compared to the historical period (Figure 5-6). Therefore, it was agreed to use the 2019 baseline rainfall as input for all future climate scenarios simulations. In this case, the climate scenarios will only be affected by changes in other meteorological variables (Table 5-3) whereas the reservoir turnover and loads stay the same. This approach enables a focus on differences between the baseline and climate scenario as a result of changes in other meteorological variables.

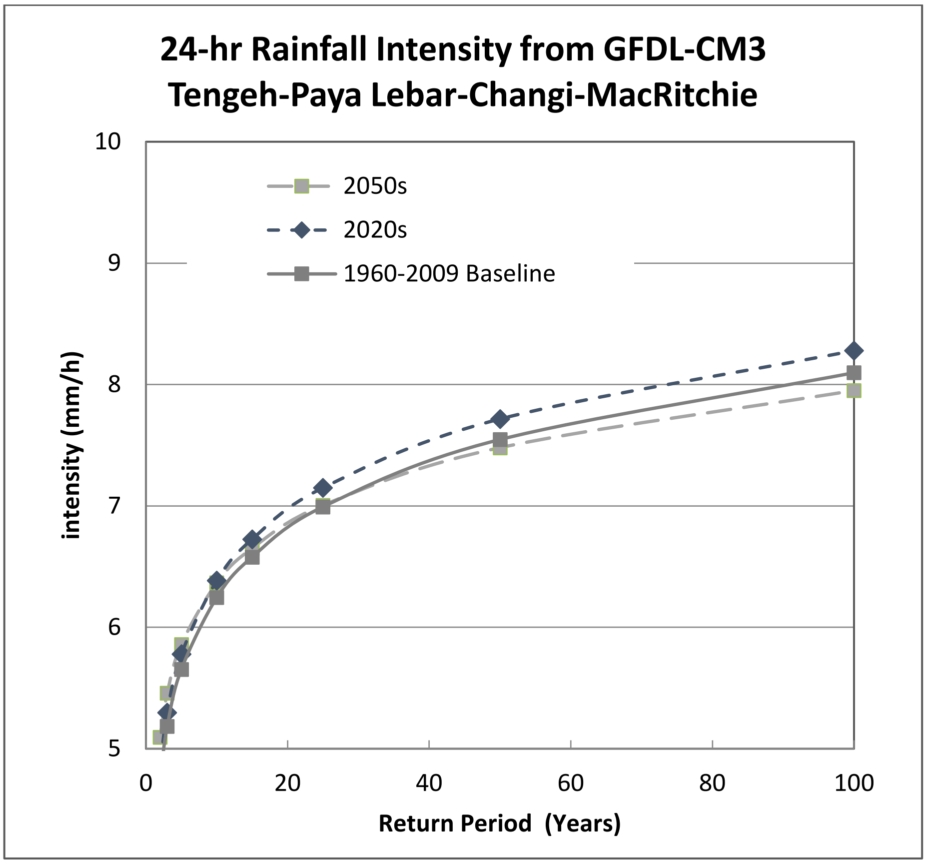


Figure 5-6 IDF curves for future rainfall using GCM data. Figure obtained from data sets provided by PUB.

Assessment of future air temperature pattern

Daily average air temperatures in 2030, 2040 and 2050 from the climate model were investigated and compared with measured air temperatures in 2019 to understand Singapore's projected air temperature pattern in future years. Figure 5-7 demonstrates that air temperature for 2040 (grey dots) is lower than in 2030 (orange dots) and that there is a clear difference between temperature in 2050 (yellow dots) compared to the other years. This is also demonstrated in the decadal changes (Figure 5-7) where the 2050 decade (2046–2056, yellow triangle) shows significantly higher air temperature than the two previous decades. The inter-annual variability in air temperature of around 1°C is observed in historical data. Singapore's air temperature increases during strong El Nino periods (MSS, 2019). This is also confirmed in the projected mean temperature for Singapore (World Bank, 2014). This indicates that even though there is inter-annual variability in air temperature in future years, there is a significant increase in temperature (>1°C) from 2019 to 2050.

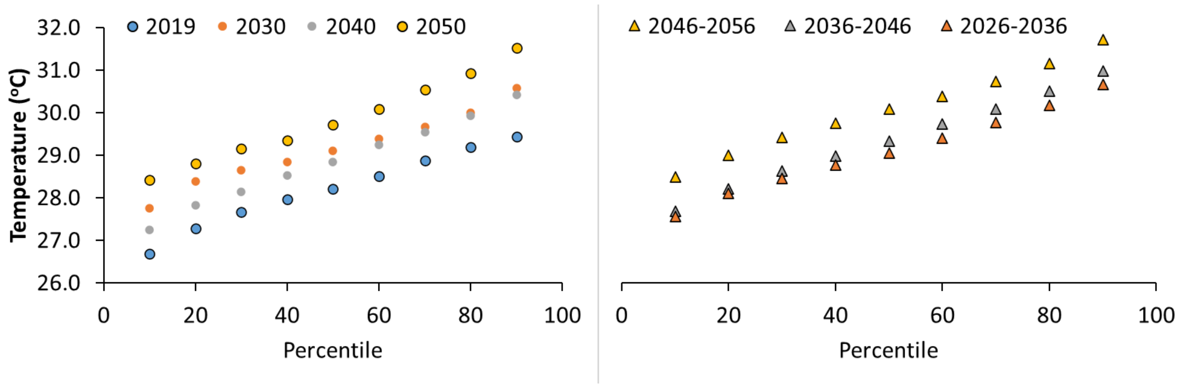


Figure 5-7 Air temperature at 10–90th percentile for each year (2019, 2030, 2040, 2050) as well as decadal changes of air temperature around the studied future year (2026–2036, 2036–2046, 2046–2056).

Hourly air temperature time-series from the GCM output

The GCM outputs are provided as daily average, maximum and minimum temperature up to 1 December 2099. To develop an hourly time series for input to the model the 2019 hourly temperature data from the baseline model was used to identify the diurnal trend in air temperature. The average temperature occurs between 09:00 and 20:00, highest at 14:00 and lowest at 07:00 (Figure 5-8). Stepwise linear interpolation was therefore used to obtain the hourly temperature. Figure 5-9 shows an example of hourly temperature in December 2049.

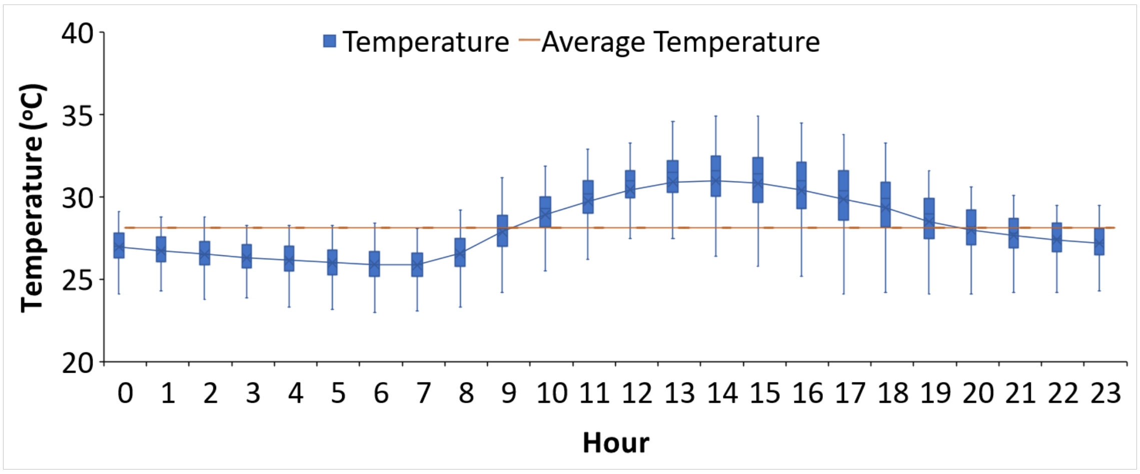


Figure 5-8 Diurnal-nocturnal trend for temperature in 2019.

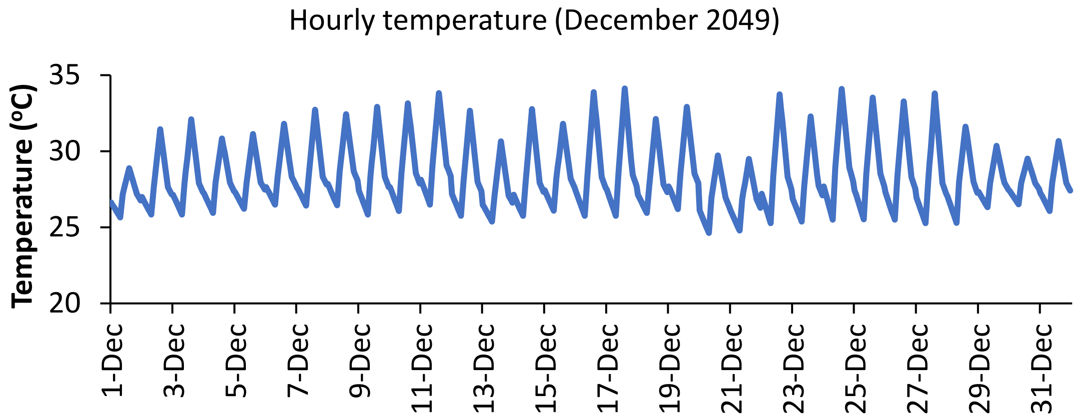


Figure 5-9 Hourly temperature in December 2049.

5.5.2 Future scenario results

Annual spatial variability[4]

Kranji Reservoir provides source water to the Choa Chu Kang Waterworks and water quality variables of concern for the water treatment processes within the Waterworks are primarily DO and Chl-a and discussion below relates to these main variables of concern. The spatial variation of the annual averages in each cell for DO and Chl-a in 2050 without FPV (NPV, or Non-FPV) and with the PV (or FPV) system are presented Figure 5-10 and Figure 5-11, respectively. The figures show the mid-depth output from model layer 3 and the bottom-most layer in each cell in the same format as Figure 5-3 and Figure 5-4 for the 2019 case. Comparing the baseline DO in 2019 (Figure 5-3A) with the 2050 Non-FPV simulation mid-depth layer (Figure 5-10A) shows the global warming of 1^{o}C temperature increase in 2050 leads to slight reduction of DO by about 0.5 mg/L in the non-FPV case. With FPV installed the DO concentrations are lower in 2050 (where FPV coverage could inhibit air-water oxygen transfer into the water column) but DO at all locations remains above the water quality guideline of 3 mg/L. Similarly for the deep waters (compare Figure 5-3B with Figure 5-10B), the annual average DO concentration is greater than 4 mg/L, above the water quality guideline.

Comparing the baseline chlorophyll-a in 2019 (Figure 5-4A) with the 2050 without FPV (NPV, or Non-FPV) simulation mid-depth layer (Figure 5-11A) shows the 2050 result is slightly lower than in 2019 for the non-FPV case. With FPV installed the annual average chlorophyll-a concentrations are lower than in 2050. Similarly for the deep waters the chlorophyll-a in deep waters shows a reduction from the 2019 case. For both the 2050 without FPV (NPV, or non-FPV) mid-depth and bottom waters show higher chlorophyll-a than the simulation results with the FPV.

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[4] Future year scenarios simulations are only changed in terms of meteorological forcings, which are air temperature, relative humidity, wind speed and direction (Table 5-3). Additionally, there are assumptions in the meteorological forcings for future year scenario (section 5.5.1). Therefore, the results for future years should be looked at as tendency of occurrences, without scrutinising specific timings. The different water quality parameters, whether they are higher or lower than in baseline year, are difficult to holistically summarise as better or worse in an objective manner.

Spatial results of the 2030 and 2040 simulations are presented in Appendix F. The trends are similar to the 2019 to 2050 although the 2030 results indicate the lowest DO and Chlorophyll-a concentrations. For DO the annual averages across the reservoir show the DO is always >3 mg/L and hence, on average the water quality guideline for DO is satisfied.

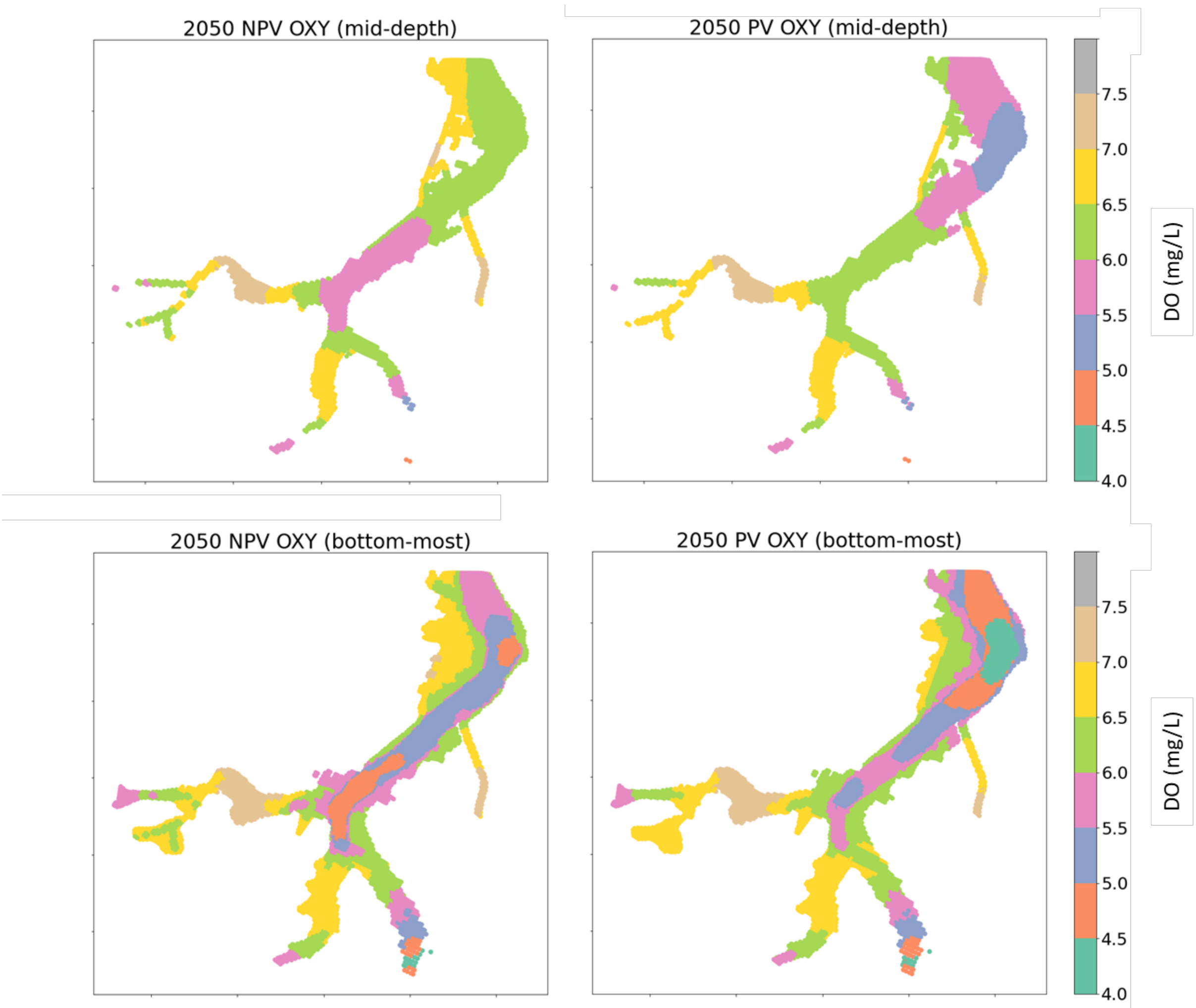

Figure 5-10 Annual average of DO concentration in 2050 for non-PV (NPV, or non-FPV)) and PV (or FPV) scenarios, A mid-depth layer 3 (2-3 m depth), and B deep water bottom layer

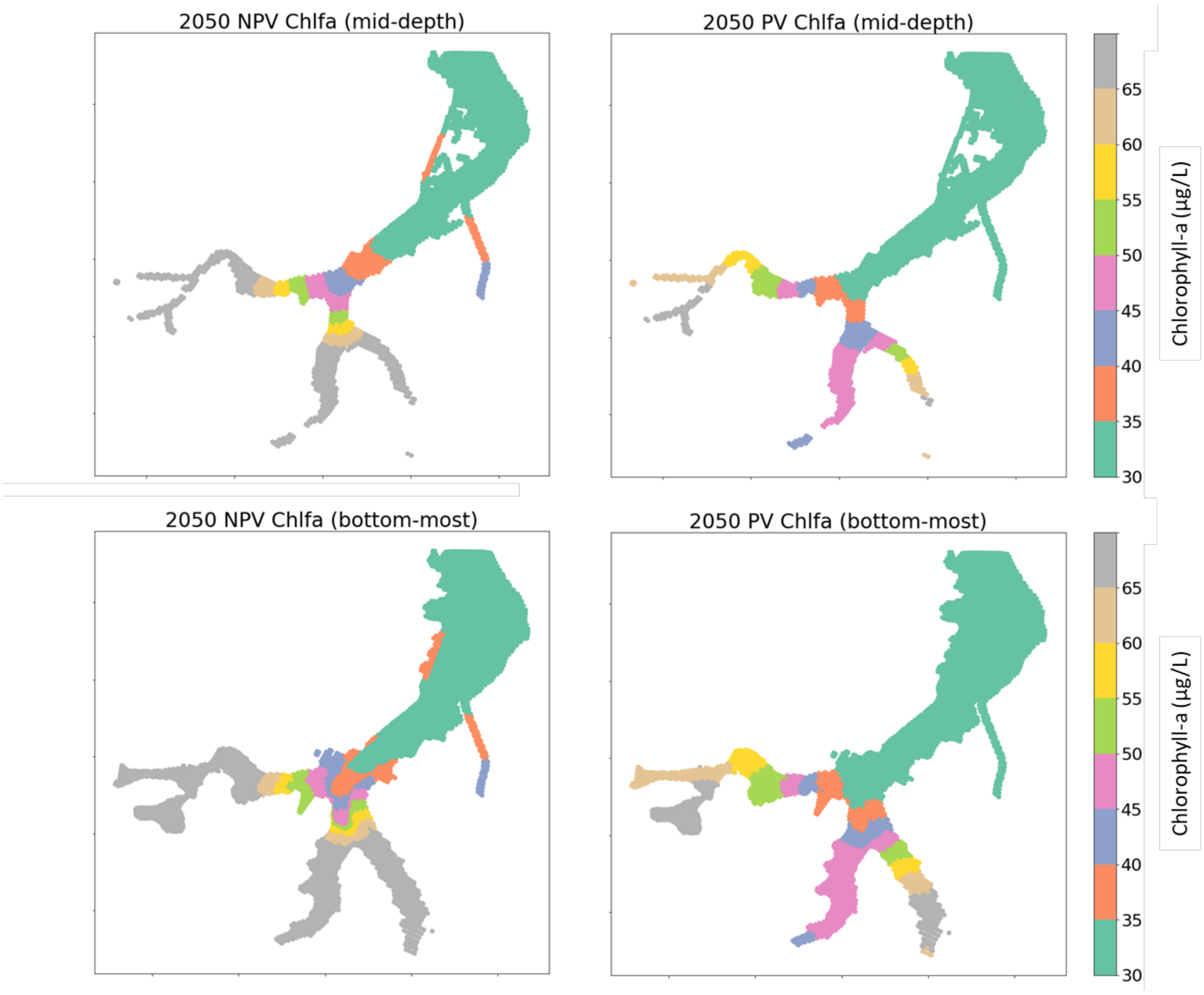

Figure 5-11 Annual average of chlorophyll-a concentration in 2050 for non-PV (NPV, or non-FPV) and PV (or FPV) scenarios, A in mid-depth layer 3 (2–3 m depth) and B in deep water bottom layer

Daily whole-reservoir averages

Figure 5-12 to Figure 5-16 present the results of the simulated daily, whole-reservoir average for each of the main water quality variables for each simulation year – 2019, 2030, 2040 and 2050 – and for the simulations without FPV (NPV, or non-FPV) and with PV (or FPV) system installed. The box plot presentation provides an overview of the statistical distribution of the data. The box plot assumes the underlying data is normally distributed and the data lies within minimum and maximum values defined as 1.5 times the interquartile range (75th percentile – 25th percentile), below and above the 25th and 75th percentiles (lower and upper quartiles). Values that lie outside the statistical maxima and minima are classed as outliers and shown as + symbols in the box plot figures. Table 5-5 summarises median values based on modelled daily average results for the entire reservoir as well as the percentage of time in a year (e.g., 0.3% represents 1 day in a year or 365 days) where the values exceed PUB guidelines in 8 scenarios.

Figure 5-12 demonstrates an increase in water temperature in future years compared to 2019 with temperature in 2030 higher than in 2040 and the highest temperature in 2050. This ties in with the assessment of air temperature in future years discussed in Section 5.5.1. Figure 5-12 also shows an increase in water temperature in the presence of the FPV system with median temperature changes ranging from 0.17–0.23°C for the four simulation years (Table 5-5). This satisfies PUB's water quality guidelines which requires a temperature change due to the FPV system of less than 0.3°C (Table 5-2). However, it is noteworthy that there is an increase in the number of days in a year where the temperature difference due to FPV system is higher than 0.3°C, with the lowest occurrence in 2019 (9% of a year, i.e. 34 days) and highest in 2050 (32% of a year, i.e. 115 days) (Table 5-5).

Table 5-5 Assessment of 8 scenarios for whole reservoir average against PUB water quality guidelines. Values in median[5].

	2019		2030		2040		2050	
ΔT (FPV – Non-FPV) (°C)	0.17		0.21		0.17		0.23	
% Exceeding ΔT >0.3°C	9%		20%		22%		32%	
	Base	**FPV**	**Non-FPV**	**FPV**	**Non-FPV**	**FPV**	**Non-FPV**	**FPV**
DO (mg/L)	6.7	6.6	6.4	5.9	6.7	6.1	6.4	6.0
% DO <3 mg/L	0.0%	0.3%	1.1%	1.4%	0.0%	3.0%	0.8%	1.4%
TN (mg/L)	0.87	0.78	0.76	0.67	0.97	0.70	0.78	0.65
% Exceeding TN >1 mg/L	23.6%	8.5%	15.3%	5.5%	32.1%	4.9%	11.2%	4.4%
TOC (mg/L)	7.9	7.0	7.7	6.4	8.2	6.8	7.6	6.3
% Exceeding TOC >10 mg/L	4.1%	1.6%	1.6%	1.1%	4.1%	1.4%	1.6%	0.8%
Chl-a (µg/L)	43	36	39	32	43	35	39	31
% Exceeding Chl-a >50 µg/L	0.5%	0.0%	2.2%	0.0%	15.1%	0.3%	11.8%	0.0%
TP (mg/L)	0.16	0.17	0.18	0.18	0.18	0.18	0.18	0.18
% Exceeding TP >0.06 mg/L	100%							

[5] Median concentration is used because statistically median concentration is used to represent a data distribution with sufficient data samples.

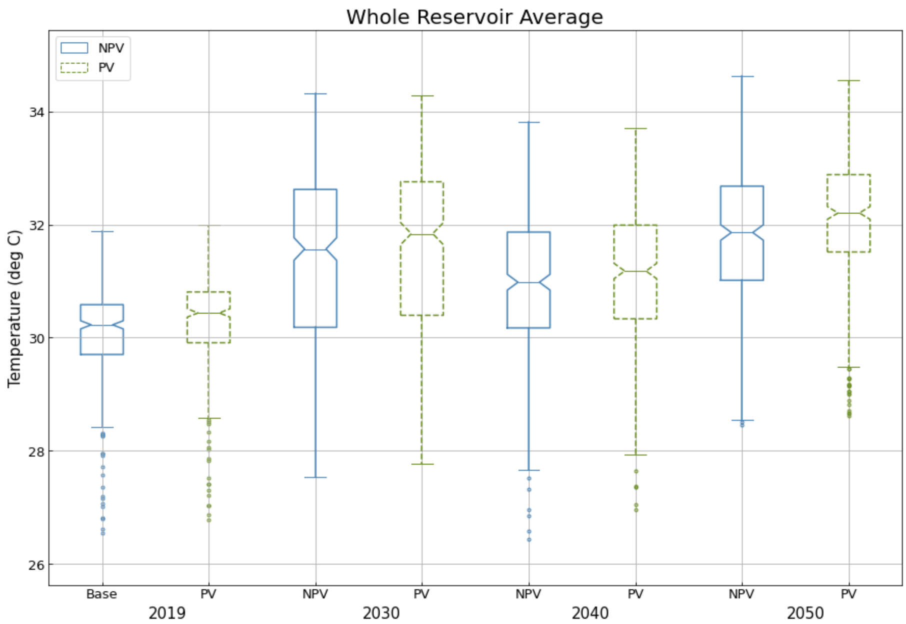

Figure 5-12 Whole reservoir average temperature in eight simulations

For DO, Figure 5-13 and Table 5-5 indicate that 97–100% of modelled results for future years with FPV system comply with the water quality guidelines (i.e., compliant for more than 354 days in a year). The median DO concentration ranges from 5.9–6.7 mg/L. Similar to water temperature, there is a slight increase in occurrences of DO concentration falling below 3 mg/L in the presence of the FPV system, especially during 2040 (3% increase, i.e., 11 more days), followed by 2050 (0.6% increase, i.e., 2 more days).

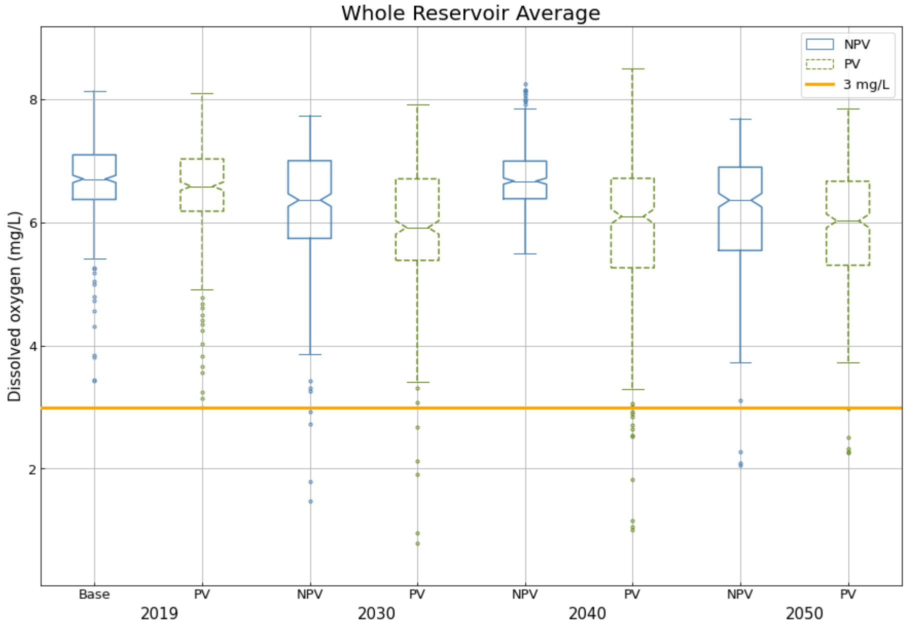

Figure 5-13 Whole reservoir average DO concentration in eight simulations

For TN, TOC and Chl-a, Figure 5-14 to Figure 5-16 and Table 5-5 show concentrations decreased for the with FPV scenario in current and future years with reduced number of days where the water quality guideline for these parameters are exceeded. On average across the 4 years (i.e., 2019, 2030, 2040 and 2050), in presence of FPV system, exceedance of TN, TOC and Chl-a water quality guideline is reduced by 54, 6 and 27 days respectively.

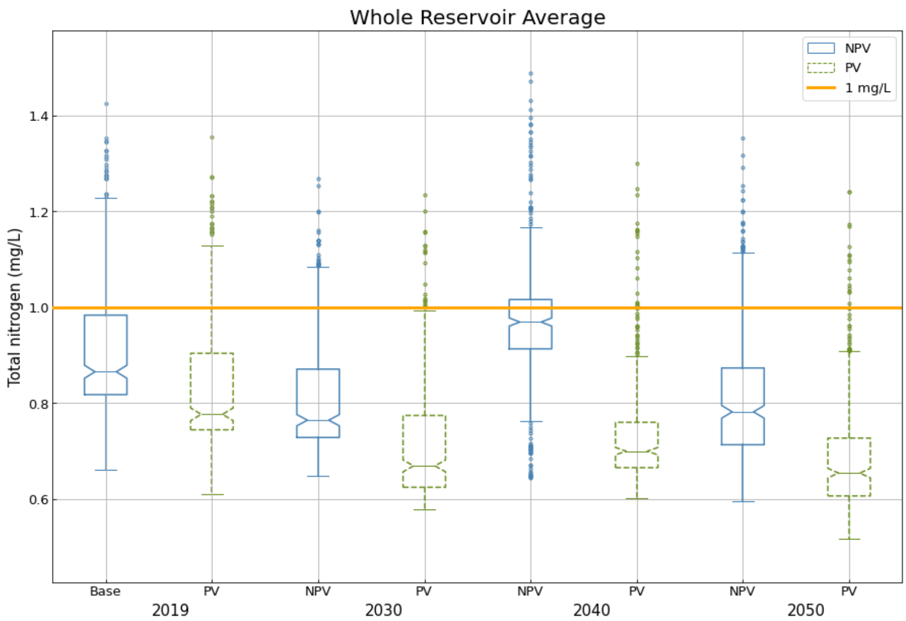

Figure 5-14 Whole reservoir average total nitrogen in eight simulations

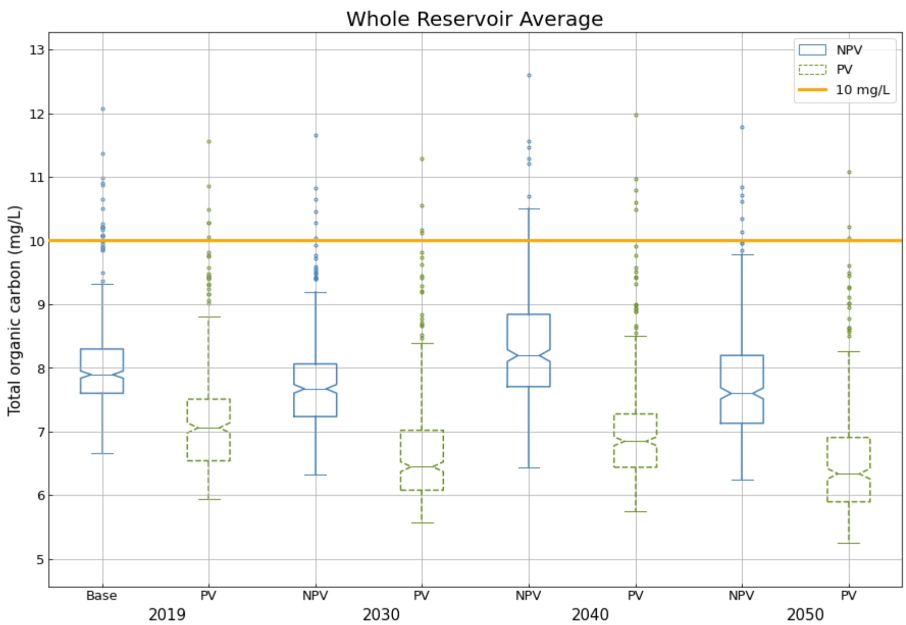

Figure 5-15 Whole reservoir average total organic carbon concentration in eight simulations

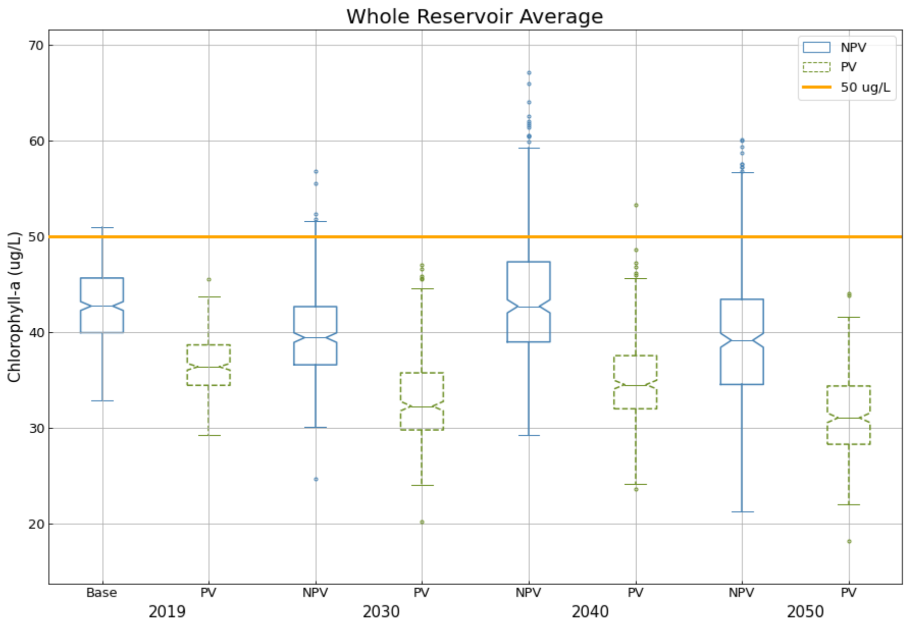

Figure 5-16 Whole reservoir average chlorophyll-a concentration in eight simulations

For TP, concentrations increased with the presence of the FPV system (Figure 5-17), but it is noted that TP always exceeds the criteria in both non-FPV and with FPV modelled concentrations (Table 5-5) which is consistent with the observed current TP concentration presented in Section 2.2.

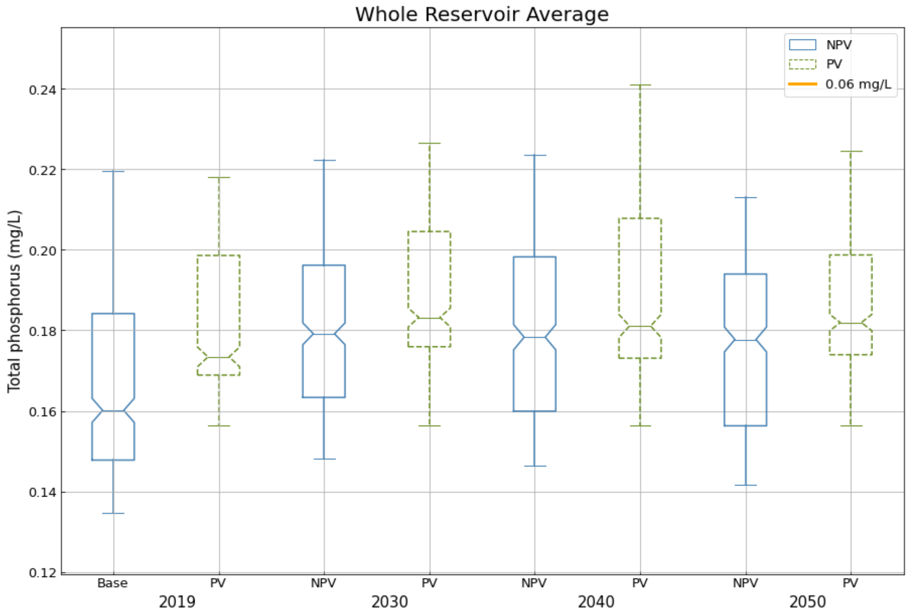

Figure 5-17 Whole reservoir average total phosphorous concentration in eight simulations. Note that the crition of 0.06 mg/L is below the minimum value in the figure.

At water intake area for CCKWW

Water at Kranji Reservoir is transferred to CCKWW for treatment; as such, it is important to understand the water quality, especially DO and Chl-a, around the point of intakes. Figure 5-18, Figure 5-19 and Table 5-6 show the concentrations of DO and Chl-a and their percentage of water quality guidelines exceedance in the year for the eight scenarios.

The median DO concentrations reduce slightly without the FPV installed and the water quality guideline exceedance increases slightly in future years up to 2050. With the FPV system installed there is a slight increase in DO concentration in the future, warmer years (Table 5-6). The increase in DO concentration with FPV for this intake area is also observed in 2030, yet the percentage of water quality guideline exceedance for scenarios with FPV (1.9%, i.e., 7 days of exceedances) is slightly higher than without FPV (1.4%, i.e., 5 days of exceedances) (Table 5-6). The model responses indicate that the FPV system introduces variability in DO concentrations at the water intake point – with more days of low DO concentrations, but overall, the DO concentration is higher in the presence of the FPV system. A possible explanation is that in the FPV scenario, there could be less chlorophyll-a concentration, which could lead to less detrital biomass, therefore less organic matter, hence less oxygen consumption).

Similar to the whole reservoir comparison, chlorophyll-a shows that in future years with FPV there is a slightly lowered Chl-a concentrations and the occurrence of water quality guideline exceedance (Table 5-6).

Table 5-6 Assessment of eight scenarios for areas around RKR H2 against PUB water quality guidelines. Median concentrations and percent of time criteria exceeded.

	2019		2030		2040		2050	
	Base	**FPV**	**Non-FPV**	**FPV**	**Non-FPV**	**FPV**	**Non-FPV**	**FPV**
DO (mg/L)	6.5	6.4	6.0	6.3	6.4	6.3	5.9	6.3
% DO <3 mg/L	1.1%	1.4%	1.4%	1.9%	0.0%	2.7%	2.5%	1.6%
Chl-a (µg/L)	40	31	36	30	41	32	35	28
% Exceeding Chl-a >50 µg/L	4.7%	0.0%	4.4%	0.8%	11.5%	1.1%	5.2%	0.0%

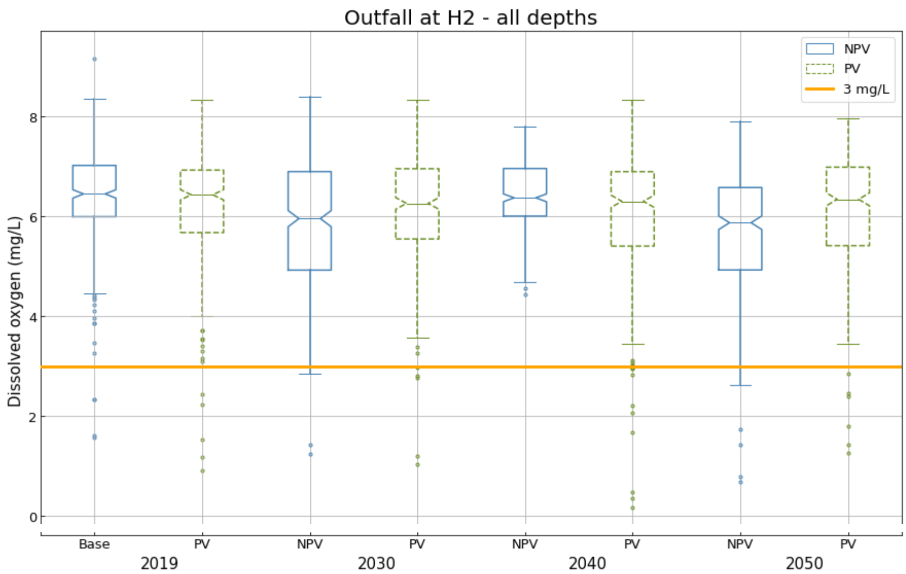

Figure 5-18 DO concentration at areas around RKR H2 for water transfer to CCKWW

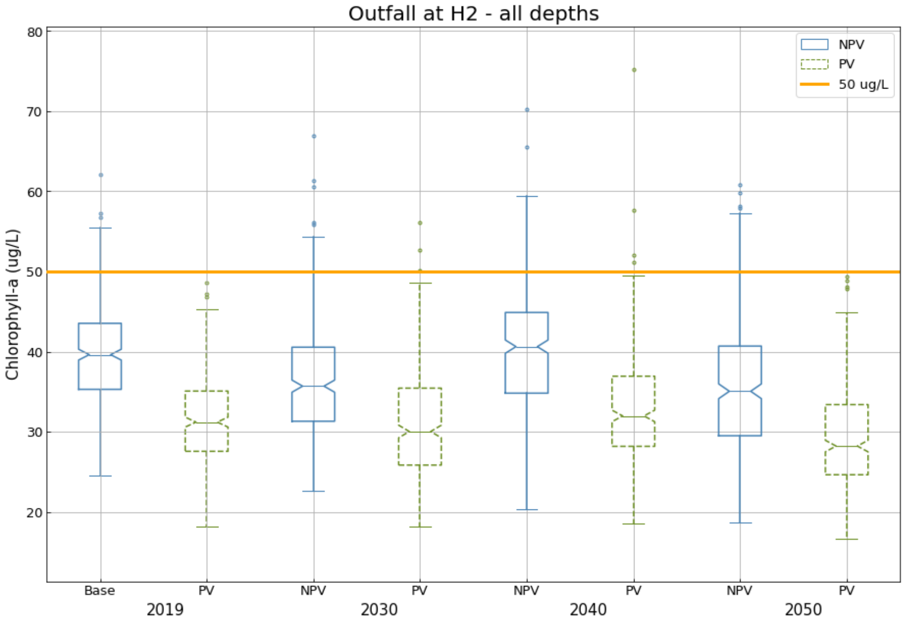

Figure 5-19 Chlorophyll-a concentration at areas around RKR H2 for water transfer to CCKWW

6 Conclusion

This Technical Appendix presents the water quality model approach and simulation results for the existing Kranji Reservoir, with no FPV installed, compared to reservoir simulation scenarios with conservative FPV layouts installed (covering 122 ha). The year-long simulations included the baseline year, 2019, and projected climate change scenarios in 2030, 2040, 2050.

Comparison of the baseline, 2019 model simulations with the lower temporal resolution observations (2018-2019) suggests the model outputs in general achieve around 60% of the variance of the observations. The assessment of the relative effects of FPV versus no FPV scenarios provides guidance as to the likely behaviour and water quality outcomes within this range of uncertainty. In general, results for all eight simulations indicate that most of the main variables (temperature, total nitrogen, chlorophyll-a, and total organic carbon) are within the expected range of variability and comply with their respective water quality guidelines. The total phosphorus concentrations generally exceed the water quality guidelines for both the existing observations and simulation results. For the future scenarios with FPV installed, dissolved oxygen shows a slight trend toward lower values with a slight increase in the occurrence of low oxygen concentrations noting, however, that the simulated increase is generally within typical DO measurement errors.

The changes in water quality parameters in future years could be attributed to the changes in meteorological forcings (see meteorological forcings assumption for future years in section 5.5.1) and their effects on the water quality. The increase in temperature in future years might affect multiple interacting processes in the water column, e.g., primary production, nutrients cycles, etc. Therefore, it is difficult to pinpoint which processes are most affected given the complexity of water quality parameters interactions. Regarding the effects of FPV panels, the changes in water quality under FPV panels could also be contributed by the changes in meteorological conditions, which has been theoretically summarised in section 3.2.

The conclusions may be summarised into two categories that assess: first, the effects attributable to the FPV through comparison of FPV simulations results with the non-FPV simulations results; and second, the effects of general climate change in future years. These findings for two categories are summarised as follows:

Effects of FPV vs. non-FPV:

- The median of the temperature difference between simulations with FPV versus without FPV (ΔT = FPV –Non-FPV) was within the PUB water quality guideline, median of $\Delta T < 0.3^{o}C$ in all years.
- Consistent with TP observations in the reservoir in 2018–2019, simulated TP concentrations for all scenarios exceed the PUB water quality guidelines. The presence of the Project leads to an increase in the median total phosphorus concentration.
- TN, TOC and Chlorophyll-a concentrations reduce and remain within the PUB water quality guidelines for a larger percent of the time, when compared to the results of simulations for the same years without FPV installed.
- The whole reservoir annual median DO is greater than 5.9 mg/L in all simulations which is well above the water quality guideline value recommended for healthy waterways. PUB's water quality guideline for dissolved oxygen, DO less than 3 mg/L, occurs slightly more often, approximately 1.3% of year, than for the corresponding years without FPV.

Effects of climate changes:

- Changes in water column temperature associated with projected changes in meteorological variables due to climate change are larger than the temperature increase associated with the Project.
- Changes in DO concentration associated with the Project are of a similar magnitude as the changes associated with the changes in meteorological conditions due to climate change.
- Changes in TP concentration associated with the Project are of a similar magnitude as the changes associated with the changes in meteorological conditions due to climate change.

The potential for slight deterioration in future water quality, particularly dissolved oxygen, predicted by the water quality model is generally within the model uncertainty and assumptions regarding both the conservative FPV system layout and proposed construction methods. It is recommended that the conservative FPV layout within this Technical Appendix be compared to the Final Design to review whether the current model results remain appropriate for the Final Design. It is noted that the current 2019 baseline includes aerator mixing devices that have been implicitly included in the model simulations. It is further recommended that appropriate monitoring be carried out and data assessed to detect any future reduction in DO attributable to the FPV installation, and to apply adaptive management measures. Since aerators and other artificial mixing devices are readily available, it is suggested that any future deterioration in dissolved oxygen could be mitigated through the installation of additional mixing devices to reduce any deleterious effects within the stipulated timeframe. Potential locations for the installation of aerators (if required) will be determined by the Developer/ Owner in consultation with PUB when the final layout is confirmed, for example during the final layout model rerun, and actual installation would be subject to ongoing monitoring results.

7 References

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APPENDIX 6.1 WATER QUALITY MODELLING TECHNICAL REPORT APPENDIX

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Floating Photovoltaic System on Kranji Reservoir – Environmental Impact Assessment (EIA)

Water Quality Modelling

Technical Appendix: Appendices

May 2024

Client	Environmental Resources Management (S) Pte Ltd
Title	**Floating Photovoltaic System on Kranji Reservoir – Environmental Impact Assessment (EIA) - Water Quality Modelling Technical Appendix - Appendices**

Abstract

This is a set of appendices to the report *Floating Photovoltaic System on Kranji Reservoir – Environmental Impact Assessment (EIA) - Water Quality Modelling Technical Appendix.* The appendices consist of additional details about the modelling studies, in particular the water balance model and hydrodynamic model which provide critical inputs to the water quality model described in the main report. On top of that, there are appendices that describe additional analysis that were done to identify further needs for modelling.

Contents

Appendix A SOBEK catchment model

An important component of the Kranji Reservoir water quality model is the water balance. Based on the reservoir water balance, time-series for the reservoir inflow and outflow quantities are determined and provided as an input to the water quality model. An important reservoir inflow is rainfall-runoff from the catchment area. In the absence of a complete set of flow rate measurements, a catchment model was set up to approximate the rainfall-runoff into Kranji Reservoir. The remainder of this Appendix A therefore first describes the overall approach taken to constructing a water balance of the Kranji Reservoir, followed by more details on the catchment model setup and calibration.

A.1 The Kranji Reservoir catchment area

The Kranji Reservoir is located in the northwest of Singapore. Its catchment area is ~51.6 km^2 in size and drains into the Kranji Reservoir through a few major rivers/ canals, namely Pang Sua Diversion Canal, Sungei Peng Siang, Sungei Tengah and Sungei Kangkar. Besides these four main branches, there are several other, smaller, catchment inflows into the reservoir.

Next to catchment runoff, the Kranji Reservoir receives water from several water transfers. Water is also transferred out from the Kranji Reservoir. Excess water leaves the reservoir by discharge through the tidal gates in the northwest to the Straits of Johor. A water balance is setup for the Kranji Reservoir taking the contributions of these various inflows and outflows into consideration.

A.2 Review of the available data

Table A-1 summarises the data that were available to construct a water balance of the Kranji Reservoir. Although the water quality modelling was only conducted for the year 2019, data were requested for the two-year period 2018–2019. By looking at a longer period, a more robust water balance could be constructed.

Table A-1 Data available for the construction of a water balance for the Kranji Reservoir.

Data	Use in water balance	Remarks
Reservoir surface area	To determine fluxes associated with rainfall on the reservoir and evaporation	N.A.

Data	Use in water balance	Remarks
Rainfall data	Boundary condition of catchment rainfall-runoff model. Direct inflow term into the reservoir.	5-minute temporal resolution rainfall data at three rain gauges in the Kranji Reservoir catchment for the period 2018–2019 provided by Meteorological Service Singapore (MSS)
Evaporation data	Outflow term in the water balance	Daily evaporation data for the period 1st January to 31st October 2018 provided by MSS
Catchment and sub-catchment delineation	Determine which area contributes to rainfall-runoff to the Kranji Reservoir	N.A.
Operation data Kranji Tidal Gates	Outflow from Kranji Reservoir	PUB provided the time of opening and closing, water level before opening and after closing as well as estimated outflow quantities. Data were not used directly as the discharge quantities are estimated from water level difference during operations. It does not consider the contribution from other discharges or precipitation during the operation.
Reservoir transfers (IPU, CCKWW, USR, Murai, Jurong Lake)	Inflows/ outflows into/ from Kranji Reservoir	Daily inflow/ outflow quantities provided by PUB. Data were used as-is in the water balance.
Reservoir water level	To verify the water balance. The water level data determine how much water is stored in the Kranji Reservoir at any given point in time	N.A.
Flow measurements in drains in the Kranji Reservoir catchment	Can be used either as a direct input to the water balance or to calibrate a catchment model which computes the rainfall-runoff. The latter approach was taken in this study.	Flow measurements at seven locations in the Kranji Reservoir catchment area provided by PUB.

A.3 Water balance approach

Based on available data, a water balance for the Kranji Reservoir was constructed as follows:

1) Reservoir transfer quantities were assumed to be accurate and implemented into the water balance as-is.

2) Rainfall and evaporation are multiplied by the reservoir surface area to estimate incoming and outgoing fluxes. In the absence of a complete set of evaporation data, additional data sources were used to estimate evaporative fluxes for periods for which data are missing.
3) In the absence of catchment flow measurements at the downstream end of each of the major branches discharging into the Kranji Reservoir, rainfall-runoff quantities were estimated using a catchment runoff model. Hydrological model coefficients were set by calibrating the model using the observed discharge data. The coefficients were then applied to other areas of the Kranji Reservoir catchment for which no observation data are available.
4) Dry weather flow quantities are estimated using a dry period without discharge through the tidal gate and minimal reservoir transfers and allocated to the sub-catchments in the catchment model according to their size.
5) Tidal gate discharge quantity is adjusted in such a manner that the modelled water level in the Kranji Reservoir most closely matches with the observed water level.

A.4 Transfers from other sources, including reservoirs

Time series of the daily reservoir transfers were made available by PUB. The information and locations of these transfers is described in Table A-2 and Figure A-1. Of the two transfers into Kranji Reservoir, the total volume contributed by Kranji NEWater Factory (KNF) is about 99% of the total inflow volume. Similarly, 99% of the water volume transferred out of Kranji Reservoir is to Choa Chu Kang Water Works (CCKWW).

Table A-2 Water transfers from and into Kranji Reservoir

Inflow/ Outflow	Origin/ Destination	Longitude Latitude	Average transfer (m^3/day)	Total transfer volume (m^3)	Highest daily transfer (m^3, date)
Inflow	Jurong Lake	103.71753 1.38007	103	75,260	32,014 19 Feb. 2018
Inflow	KNF[1]	103.74319 1.43678	7,175	5,237,840	43,221 19 Feb. 2018
Outflow	CCKWW[2]	103.72927 1.41507	84,317	61,552,071	153,135 15 Jan. 2019
Outflow	Murai Reservoir[3]	103.72927 1.41507	--	2148	2,148 2 Feb. 2019
Outflow	Upper Seletar	103.74419 1.42527	708	517,092	102,730

Inflow/ Outflow	Origin/ Destination	Longitude Latitude	Average transfer (m^3/day)	Total transfer volume (m^3)	Highest daily transfer (m^3, date)
	Reservoir				31 Jan. 2018

[1] KNF: Kranji NeWater Factory. [2] CCKWW: Choa Chu Kang Waterworks. [3] There is only one transfer from Kranji Reservoir to Murai on 2 Feb. 2019 at the same location of transfer to CCKWW.

Kranji Reservoir water transfer to other areas is represented by an "internal pump flow pipe" in SOBEK. All intake and outfall points are represented with a boundary node (see Figure A-2).

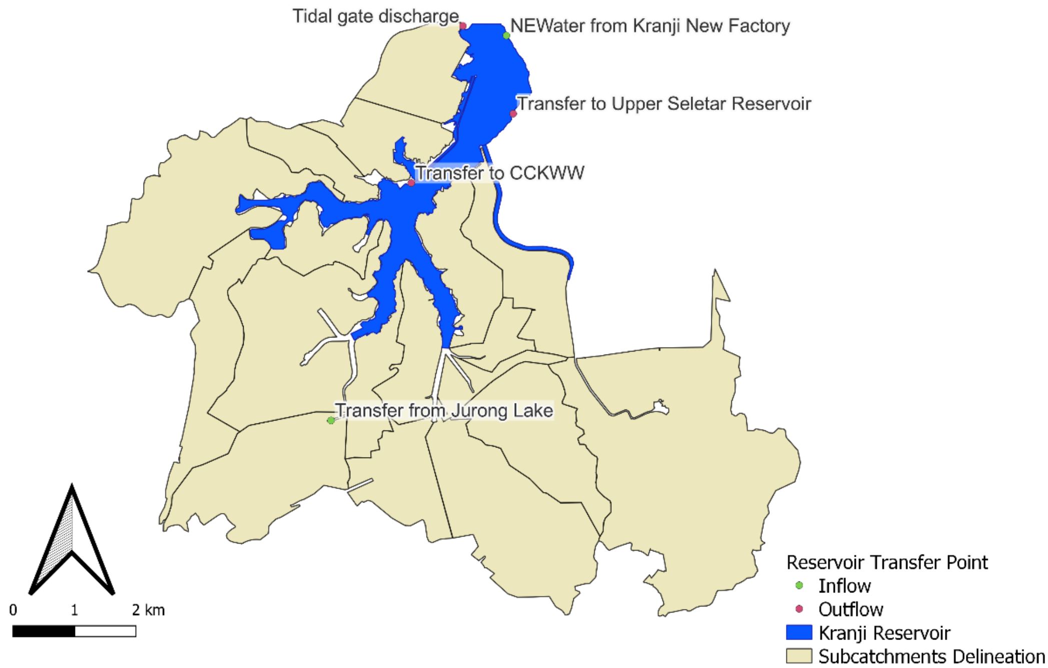

Figure A-1: Kranji Reservoir transfer locations.

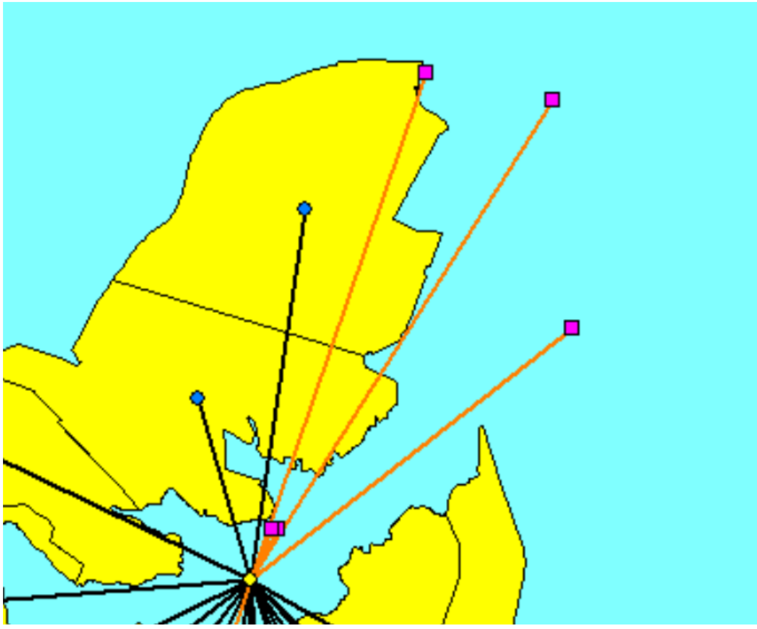

Figure A-2: Example of the reservoir transfer from Kranji Reservoir to outside catchment presented with internal pump flow pipe station. The outfall is presented with a boundary node.

A.5 Catchment rainfall-runoff model

A.5.1 Choice of hydrological model

The water balance was setup in SOBEK where, simultaneously, rainfall-runoff computations can be conducted. As the hydrological model, a method based on the rational method was adopted which is available in SOBEK. In this method, each sub-catchment is represented by a so-called “manhole with runoff”. In the remainder of this report, we will refer to these nodes as “rainfall-runoff nodes” or “RR nodes” in short. For each node, the runoff is computed by the following formula (which is the formula of the Rational Method):

$$q = c.\,h \qquad \text{(A.1)}$$

where q is the inflow into the rainfall-runoff node (in mm/min), c is the runoff factor (min^{-1}), and h is the rainfall residual water depth stored on the catchment surface (in mm). The flow in the pipe is described by the Manning formula (assuming the pipe is rectangular in cross-section):

$$Q = \frac{1}{n} b H^{5/3} I^{1/2} \qquad \text{(A.2)}$$

where *n* is the Manning coefficient, *b* is the width, *H* is the height, and *I* is the bed slope.

Each RR-node requires information about the land use in the sub-catchment it represents. For each land use separate values can be set for runoff, storage, and infiltration parameters. The setting of these parameters is done during the model calibration. The parameter values are only varied by land use. In other words, the parameter values are standard across all sub-catchments. This ensures the calibration is not an overfitting exercise.

A.5.2 Sub-catchment delineation

In order to take spatial variability in the rainfall into consideration, the catchment area was split into smaller sub-catchments. The split into smaller sub-catchments also ensures that the sub-catchment areas align with the areas downstream of flow gauges for which the catchment model could then be calibrated. The Kranji catchment was divided into 16 sub-catchments in the catchment model. Figure A-3 shows the sub-catchment delineation for the Kranji catchment.

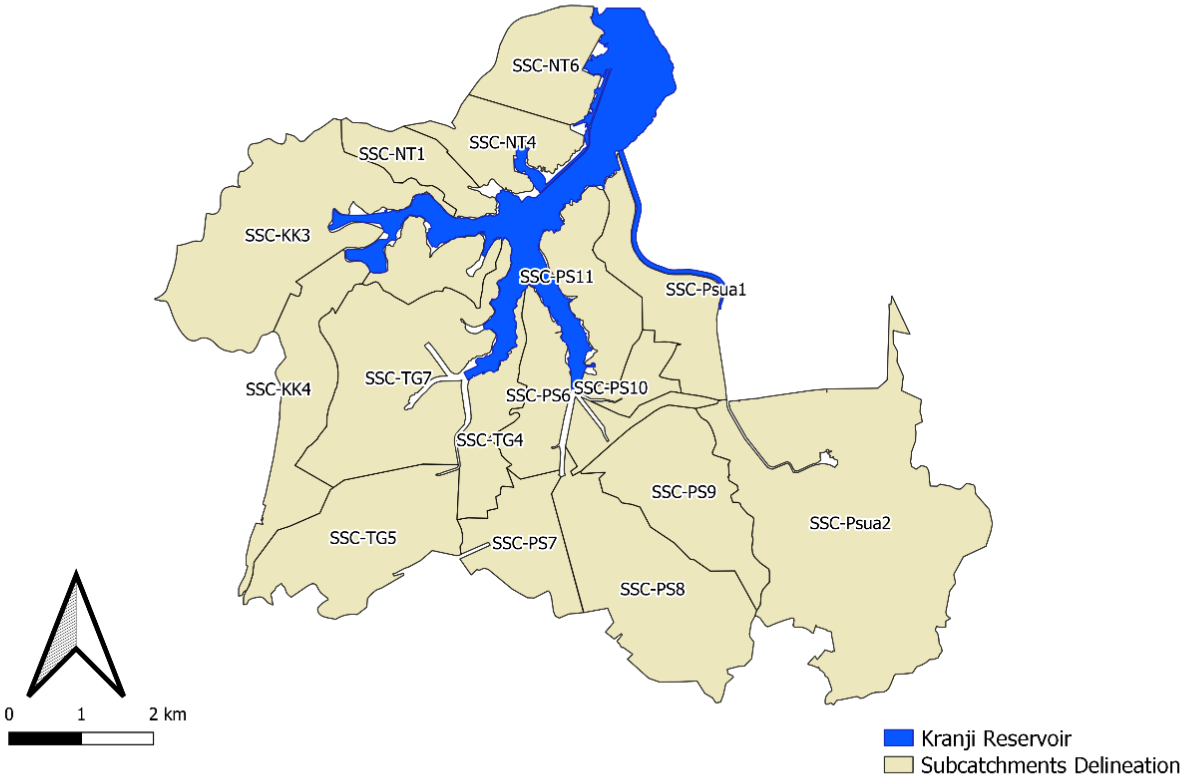

Figure A-3: The sub-catchment delineation for the Kranji catchment.

As was mentioned previously, each sub-catchment is represented by an RR-node. On each RR-node, the following characteristics needs to be specified:

- Land use
- Storage

Land use

Masterplan 2014 is used to identify the land use in the Kranji catchment. The land use in the Kranji catchment is categorised into 24 categories in the land use data from URA. The land-use categories are then merged into 7 categories, Roads, Commercial, Residential 1, Residential 2, Industrial, Park and Reserves and Other, for use in SOBEK.

The residential areas were split into Residential 1 and Residential 2 based on the assumption that the runoff characteristics from areas with landed houses will be different from areas dominated by HDB flats & condominiums. The classification of Residential 1 and Residential 2 was based on the visual interpretation of aerial images (Google Satellite).

The land use map created from Masterplan 2014 was compared with the satellite imagery. It was found that the land use category of Tengah (see sub-catchments SSC-TG4, SSC-TG5, SSC-TG7 in Figure A-3) is indicated as 'Residential' in Masterplan 2014 instead of forest. As the area covered by Tengah is relatively big and will have a large impact on the total runoff discharge of the sub-catchment in the catchment model, it was necessary to change the land use of that area to its current land use, i.e., 'Park and Reserves'. For those forest areas that were not categorised as forest in the Masterplan 2014, the land use category was also changed to 'Park and Reserves' (Figure A-4).

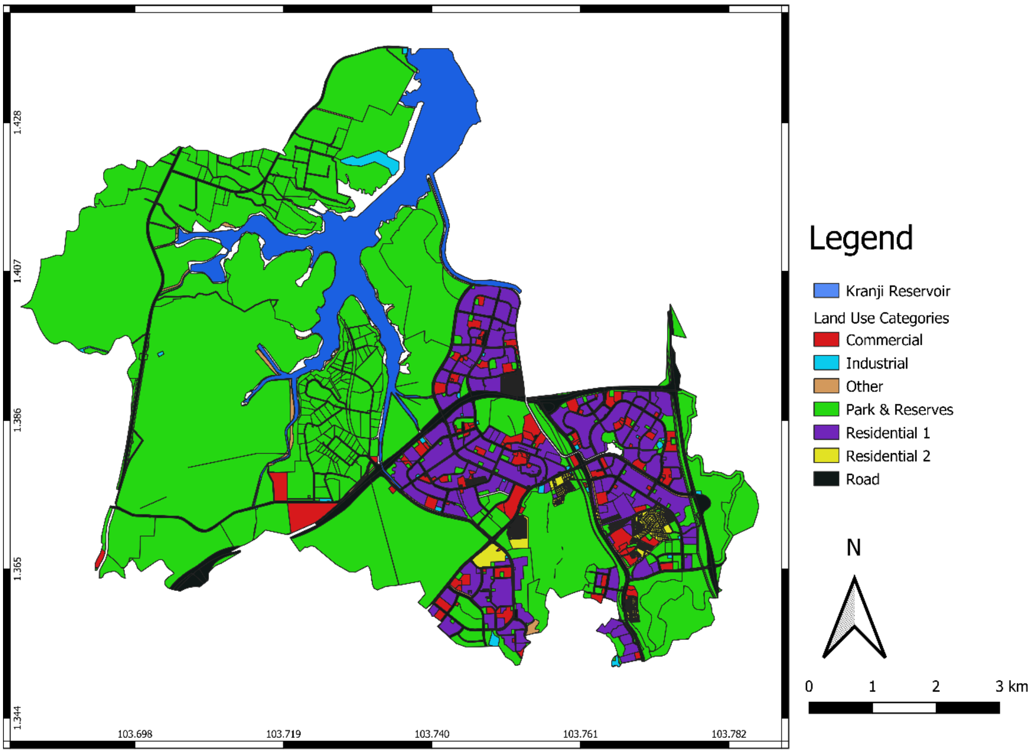

Figure A-4: Revised land use map in Kranji catchment based on Masterplan 2014, Tengah's landuse category changed to 'Park and Reserves'.

Besides differentiating land uses, the sub-catchments were further categorised as "sloped" or "flat". This is because the routing from such areas may be different. Sub-catchments with a slope of 1% on average are categorised as sloped. If the slope is <1%, a sub-catchment is considered a flat area. Table A-3 shows the matching of the SOBEK user interface terminology with the land use categories.

Table A-3: The matching of the SOBEK user interface terminology with land use categories.

	With a slope	Flat	Stretched flat
Closed paved	Roads Slope	Roads Flat	Residential 1 Slope
Open paved	Industrial Slope	Industrial Flat	Residential 1 Flat
Roof	Commercial Slope	Commercial Flat	Residential 2 Slope
Unpaved	Park & Reserves Slope	Park & Reserves Flat	Residential 2 Flat

Connection between sub-catchments and reservoir

The RR-nodes ('blue' nodes in Figure A-5) represent the connections between sub-catchments (see Figure A-3) to a storage node representing the Kranji Reservoir ('yellow' node in the centre of the reservoir in Figure A-5) with elements called rainfall-runoff pipes. Other nodes ('pink' node in Figure A-5) represents the reservoir transfer and tidal gate discharge.

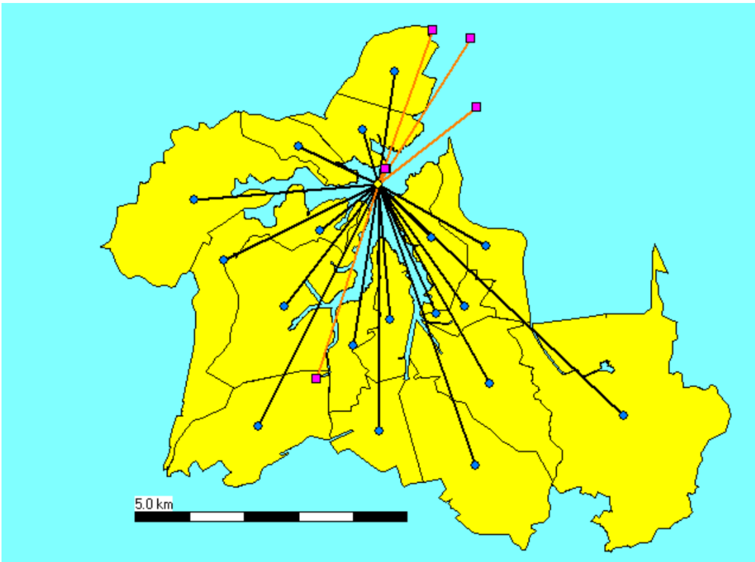

Figure A-5: RR-nodes (blue nodes) are connected to the storage node (the yellow node in the center of the reservoir) with RR pipes (the black lines).

The rainfall-runoff pipes need specifications for the invert level at the upstream and downstream end. For the downstream side, the invert levels are set to 102 mRL (Table A-4), which is slightly higher than the maximum recorded Kranji Reservoir level. This is to prevent the backflow of the reservoir water into the RR pipe which would affect the modelled discharges. The upstream invert level is a representation of the average height of the sub-catchment.

Table A-4: Invert level of RR Link

RR Link	Level Upstream (mRL)	Level Downstream (mRL)
L_SSC-KK3	113.9	102
L_SSC-KK4	113.3	102
L_SSC-NT1	109.9	102
L_SSC-NT4	103.7	102
L_SSC-NT6	105.6	102
L_SSC-PS10	112.8	102
L_SSC-PS11	111.1	102
L_SSC-PS6	110.0	102
L_SSC-PS7	112.7	102
L_SSC-PS8	121.5	102
L_SSC-PS9	120.1	102
L_SSC-Psua1	112.6	102
L_SSC-Psua2	133.6	102
L_SSC-TG4	113.4	102
L_SSC-TG5	111.3	102
L_SSC-TG7	110.9	102

A.5.3 Representation of Kranji Reservoir

The storage area of the Kranji Reservoir is represented in SOBEK by a 'Connection Node with Storage and Lateral Flow'. The storage is defined by a relationship between the reservoir level and the associated storage area at that particular level. The reservoir bathymetry was used to derive the reservoir storage curve. The direct precipitation and evaporation of the Kranji Reservoir were implemented through the lateral flow component of this node. Net precipitation (precipitation – evaporation) is applied as the rainfall boundary.

A.5.4 Dry weather flow (DWF)

In addition to rainfall-runoff, it is assumed that there is a particular quantity of baseflow (dry weather flow) which enters from the catchment area into the Kranji Reservoir. In the absence of accurate flow measurements for baseflow, the dry weather flow (DWF) was quantified by selecting a period with dry weather conditions during which the Kranji Tidal Gate stayed closed and during which there were minimal other reservoir transfers. During such periods, the change in water level can be attributed to the unknown dry weather flow. In case of the Kranji Reservoir, there typically is a reduction in water level during a dry period due to continuous water extraction to Choa Chu Kang Water Works (CCKWW). As there is always water transfer from the Kranji Reservoir to CCKWW, it was not possible to find a dry period without any reservoir transfer. To calculate the dry weather flow, seven periods without any tidal gate discharge and with a minimum number of reservoirs transfer were used to derive the most reasonable DWF value. The DWF value implemented in each RR-node is shown in Table A-5. Table A-6 shows the dry weather flow calculation for Kranji Catchment. The estimated average DWF in the Kranji catchment is 6.05 m^3/day/ha. The period August and September 2019 (the last periods stated in Table A-6) were not included in the average calculation, as the DWF values from these two periods were not regarded representative of typical conditions in the Kranji Reservoir catchment. The DWF is then converted to the unit required in SOBEK (L/hour).

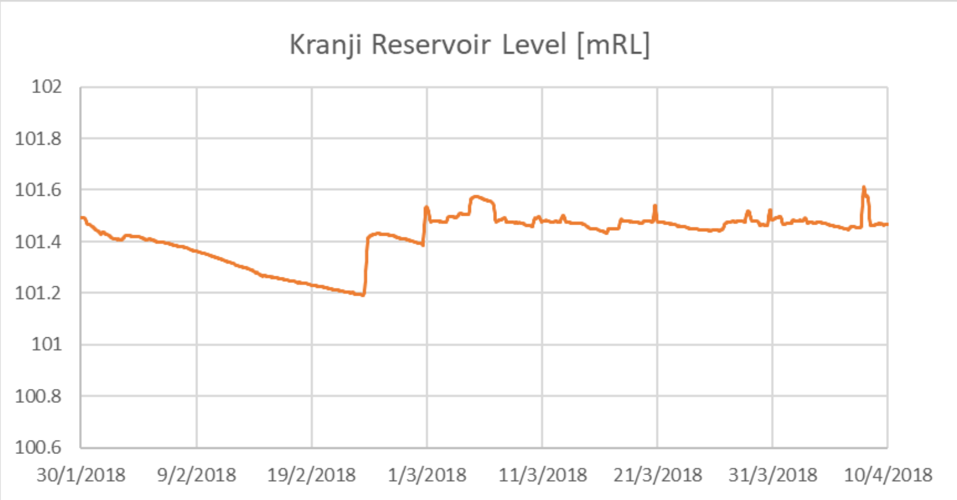

Figure A-6: Example of Kranji reservoir level that shows the continuous drop in water level in dry weather period

Table A-5: DWF (L/hr) implemented in each sub-catchment.

RR_Node	Area (m^2)	DWF (L/hr)
SSC-Psua1	2,102,385	50,873
SSC-PS11	1,901,251	46,006
SSC-PS6	1,567,141	37,922
SSC-PS10	731,604	17,703
SSC-PS9	3,911,834	94,658
SSC-Psua2	10,584,110	256,114
SSC-PS8	4,612,336	111,609
SSC-PS7	1,920,698	46,477
SSC-TG4	1,391,848	33,680
SSC-TG5	3,734,206	90,360
SSC-TG7	4,959,388	120,007
SSC-KK4	3,908,519	94,578

RR_Node	Area (m²)	DWF (L/hr)
SSC-KK3	5,522,299	133,628
SSC-NT1	1,190,218	28,801
SSC-NT4	1,652,566	39,989
SSC-NT6	1,966,871	47,594

Table A-6: Dry weather flow calculation for Kranji catchment.

Start date	End date	Duration (days)	Reservoir Transfer In (m^3)	Reservoir Transfer Out (m^3)	Net Precipitation (m^3)	Amount of Reservoir Storage Increase (m^3)	DWF (m^3)	DWF (m^3/d)	DWF (m^3/d/ha)	Remarks
5/2/2018	23/2/2018	18	347185.65	1403459.43	-460188.10	-1075924.08	440538	24474	4.74	
8/6/2018	15/6/2018	7	783.65	659327.78	-65313.44	-256172.40	467685	66812	12.93	
3/8/2018	19/8/2018	16	413174.97	1722213.13	-210175.44	-1280862.00	238352	14897	2.88	
28/9/2018	8/10/2018	10	155255.28	830092.43	-35095.92	-409875.84	300057	30006	5.81	
13/3/2019	21/3/2019	8	117411.73	1084395.58	-167637.06	-973455.12	161166	20146	3.90	
1/8/2019	26/8/2019	25	265680.12	2209023.94	-383084.93	-2305551.60	20877	835	0.16	Very small due to an extremely long dry period
11/9/2019	25/9/2019	14	296815.42	1454171.33	-180139.35	-1537034.40	-199539	-14253	-2.76	Negative DWF: not realistic. DWF may have been close to zero due to extreme dry period

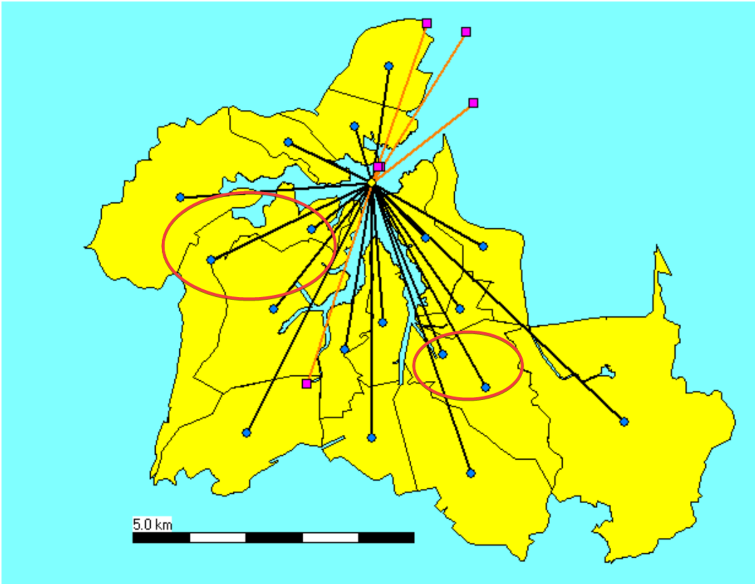

Figure A-7: Sub-catchment SSC-KK4 (left circle) and SSC-PS9 (right circle) are represented with 2 RR-nodes to improve the model calibration process. One RR-node represents the upstream area and another represents the downstream area of the flow measurement station.

A.5.5 Boundary forcing

Rainfall

Rainfall data from MSS for three rainfall stations in and around the Kranji Reservoir catchment area for the years 2018 and 2019 were available. The annual total rainfall for each station is summarised in Table A-7.

Table A-7: Total rainfall per station in and around Kranji catchment in the year 2018 and 2019.

Station ID	Total rainfall in 2018 (mm)	Total rainfall in 2019 (mm)
S23 (Tengah)	3,036	2,316
S66 (Kranji Reservoir)	1,513	1,279
S121 (Old Choa Chu Kang Road)	2,661	2,222

The rainfall data received was compared with the annual statistics found on the MSS website (Meteorological Services Singapore, http://www.weather.gov.sg/climate-climate-of-singapore). As the difference in the annual rainfall at station S66 (1,279 mm at Kranji Reservoir) was low compared to stations S23 (2,316 mm at Tengah) and S121 (2,222 mm at Old Choa Chu Kang Road), the data was verified by comparing it against information found on the MSS website. Based on data from the MSS website, the total rainfall amount observed at Station

S66 was in the range 1,000–1,500 mm, while the total rainfall amount observed was very high (>2,200 mm) at Station S23 and S121. This information is consistent with the data received. As such, the data from all three rainfall stations was used for the catchment modelling.

Figure A-8: Annual rainfall from MSS for the year 2019.

In SOBEK, a unique rainfall time-series was assigned for each sub-catchment. This was done using Thiessen polygons. Figure A-9 shows the location of each rain gauge station and the Thiessen polygons created to assign rainfall on each sub-catchment. In case a sub-catchment was at the intersect of two or more Thiessen polygons, an area-weighted rainfall time-series is derived for that sub-catchment.

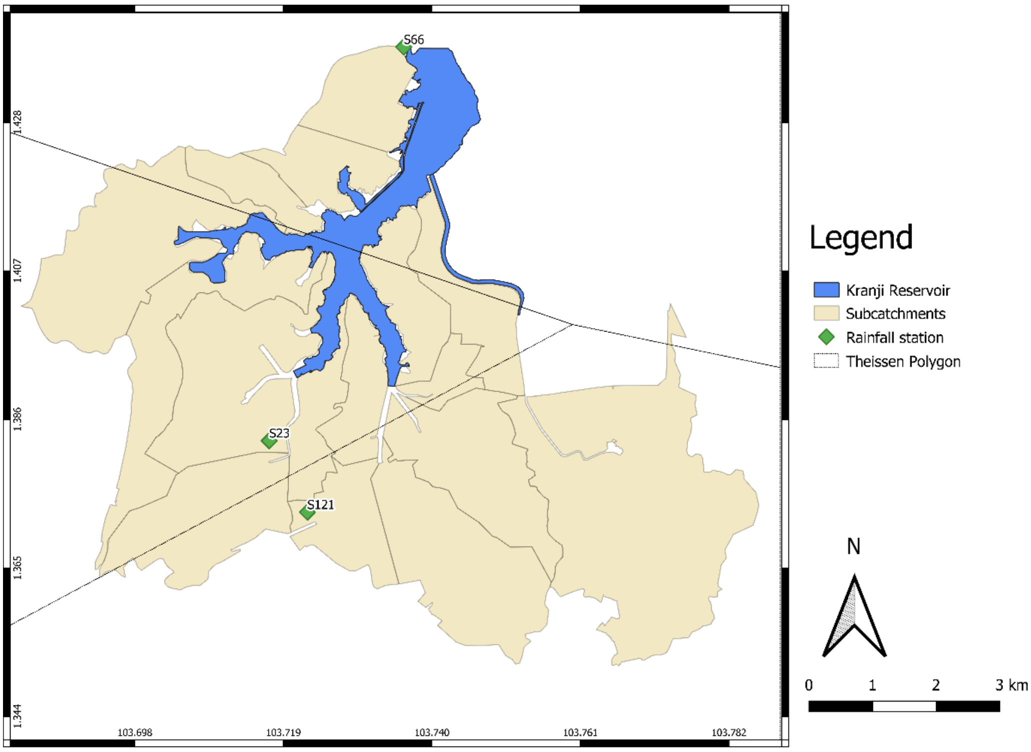

Figure A-9: Rain gauges and Theissen polygons in the Kranji catchment.

Evaporation

Evaporation data for the year 2018 was provided by MSS. However, the daily data was only available from 1 January to 31 October 2018. To fill up the missing data in the year 2018, climate re-analysis data (ERA5: https://climate.copernicus.eu/climate-reanalysis) was used to compare with the measurement data and derive the evaporation data for November and December 2018 by using the correlation.

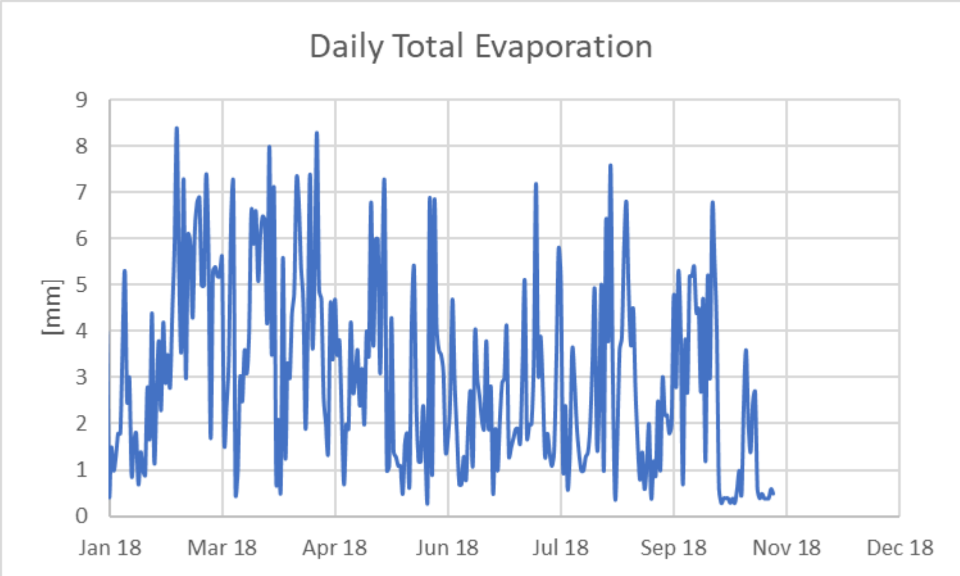

Figure A-10: Daily evaporation data (mm/d) for the period 1st January 2018 to 31st October 2018.

The daily evaporation data were used to calculate the monthly average value (see Figure A-11). The average monthly evaporation data (mm/day) of the year 2018 was used for both years 2018 and 2019 in the catchment model simulations.

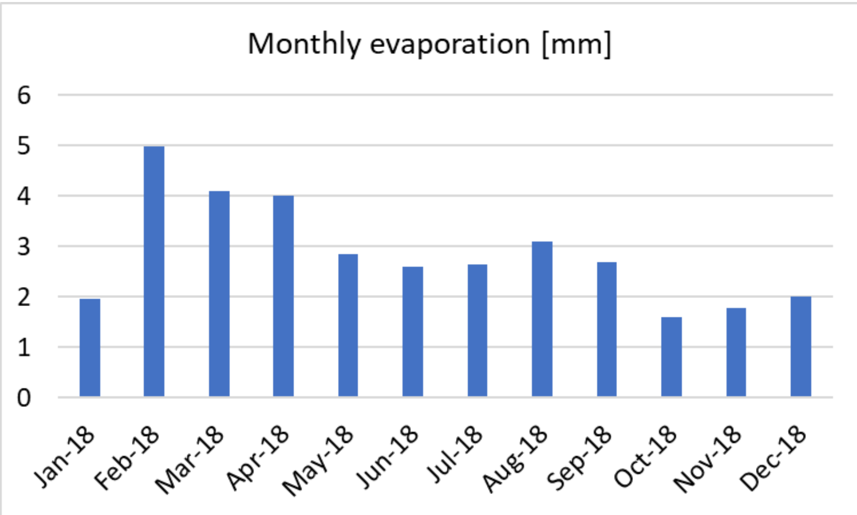

Figure A-11: Average monthly evaporation data will be used in the year 2018 and year 2019 simulations.

A.6 Calibration

A.6.1 Calibration of the catchment rainfall-runoff

The main objective of the catchment model calibration is to match the runoff volumes (specifically during rainfall events) with the measured runoff. There are seven flow measurement stations located in Kranji Catchment. Figure A-12 shows the flow measurement stations available in Kranji Catchment. Besides discharge data, reservoir water level data was used as supplementary data for the model calibration.

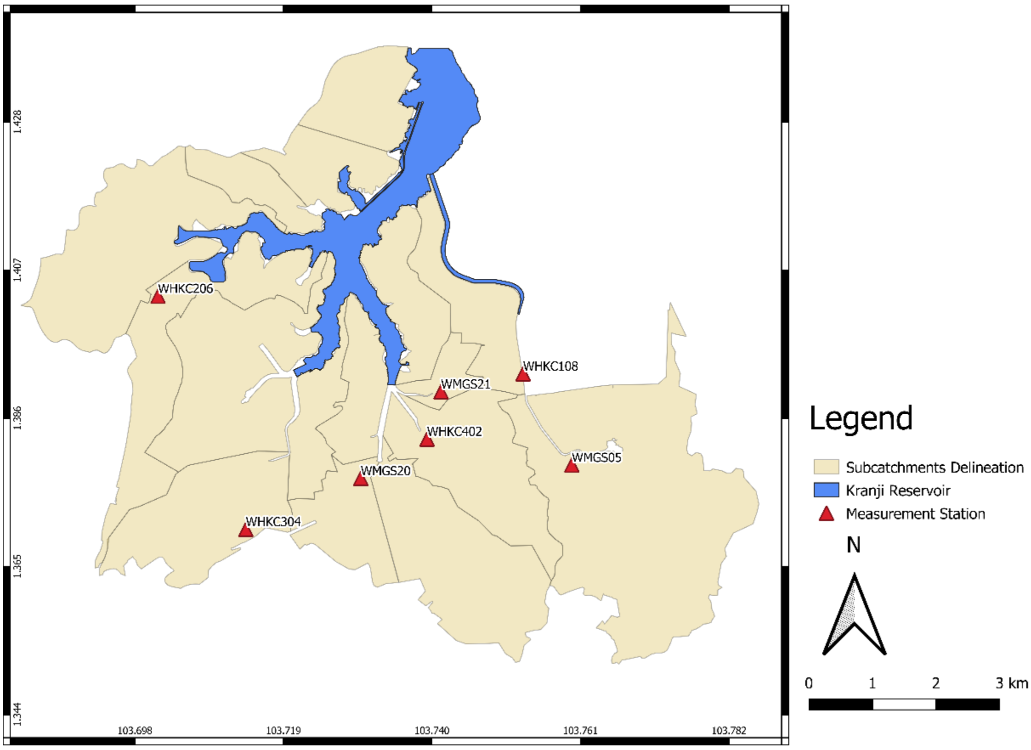

Figure A-12: Flow measurement station in Kranji Catchment.

Selection of Measurements Station and Calibration Months for Model Calibration

Stations WHKC402 and WHKC206, WHKC108 have been selected to use in model calibration. These stations were selected based on the following criteria:

1) The stations should not be located too downstream and impacted by the backflow from reservoirs. These stations may have negative readings in the discharge data.
2) The station should not be located too far upstream/ have a very small catchment area. This is because the model results would be very sensitive to errors in:
   a. Rainfall distribution errors (which is more significant for individual sub-catchment)
   b. Sub-catchment division errors
   c. Schematisation errors. As further upstream, the influence of the use of manhole pipe system (as opposed to the real micro drainage network) can have some influence on the results.
   d. Furthermore, the calibration for a relatively small section of a sub-catchment may not be representative for the overall sub-catchment or catchment response.

Therefore, preference was given to flow measurements that capture larger fractions of the sub-catchment area.

Table A-8 summarises the reasons for including or excluding particular stations for model calibration. Subsequently, three months were selected in the year 2018 and 2019 for each station. The calibration months were selected based on the availability of reliable rainfall data and discharge data. For the selected months, the runoff coefficient of the observation data was compared with those from the model. Also, observed and modelled cumulative discharge were compared for WHKC206 and WHKC402.

Table A-8: Summary of discharge measurement locations and their use for catchment model calibration.

Station	Used for calibration (Yes/No)	Reason	Selected months for calibration
WHKC108	Yes	Large catchment, varying land-uses, no negative discharges	Apr, May, Jun 2018
WHKC206	Yes	Medium-large catchment, mostly two land-uses, no negative discharges	Apr, Oct, Nov 2018
WHKC402	Yes	Medium-large catchment, varying land-uses, no negative discharges	Apr 2018, Jan, May 2019
WMGS05	No	Located in the same drain as WHKC108; the more downstream location was chosen for calibration as it captures a larger fraction of the sub-catchment and is therefore more representative for the total flow into the Kranji Reservoir	N.A.
WMGS20	No	Very small catchment, located downstream and impacted by the reservoir (negative flow)	N.A.
WMGS21	No	Very small catchment	N.A.
WHKC304	No	Located far upstream, negative flow data	N.A.

Settings of SOBEK-RR

Below are the parameters that can be set in the SOBEK rainfall-runoff module:

- Runoff coefficient (1/min)
- Surface storage (mm)
- Infiltration capacity (mm/hr) and infiltration time factors (1/h)
- Runoff pipe width (m)
- Bed friction of runoff pipe link (s.$m^{\frac{-1}{3}}$)

The runoff coefficient can be set independently for each land use. The runoff coefficient determines how fast the rainfall water is transferred into runoff. A value close to 1 means that all the rainfall runs off immediately and a value close to zero means there is a large delay between the rainfall and runoff. Surface storage represents the water that is temporarily stored on the surface. The water stored can evaporate, infiltrate, or become runoff. The infiltration capacity indicates how much water can infiltrate. Infiltrated water is a loss term in this model as the infiltrated water will not enter the drainage system. Infiltration time factors influence the infiltration capacity by increasing or decreasing the infiltration capacity during wetting and drying of the soil. The infiltration capacity and surface storage do have an impact on the total discharge reaching the drainage network, while the runoff coefficient does not have an impact on it. However, the runoff coefficient has an impact on the shape of the hydrograph (i.e., peaky, or flat). Table A-9 lists the values/ ranges of each of the mentioned parameters obtained from calibration of the SOBEK model.

The width of the runoff pipe connecting the RR-nodes to the storage node representing the Kranji Reservoir does have an impact on how fast the runoff reaches the reservoir. The larger the runoff pipe width, the lower the discharge per unit time as the wetted perimeter value increases. Runoff pipe width does not have an impact on the total runoff discharge to the drain, but it does impact the shape of the hydrograph. The smaller the runoff pipe width, the higher the peak of the hydrograph. The bed friction of runoff pipe link and cross-section impacts how fast the runoff reaches the drain. Bed friction does not impact the total runoff discharge, but only the timing of the runoff and hence the shape of the hydrograph.

Table A-9: Parameterisation of the rainfall-runoff module (SOBEK-RR) for the Kranji catchment.

Land use	Flat/ Sloped	Runoff coefficient	Storage coefficient	Infiltration capacity		Infiltration time factor	
				Max	Min	Decrease	Increase
Roads	Sloped	0.50	4	12	0	0.5	0.1
	Flat	0.40	5	12	0	0.5	0.1
Industrial	Sloped	0.50	4	12	1	0.5	0.1
	Flat	0.40	5	12	1	0.5	0.1
Commercial	Sloped	0.50	4	12	1	0.5	0.1
	Flat	0.40	5	12	1	0.5	0.1
Parks & Reserves	Sloped	0.10	8	20	1	0.5	0.1
	Flat	0.05	9	20	1	0.5	0.1
Residential 1	Sloped	0.50	4	12	0	0.5	0.1

Land use	Flat/ Sloped	Runoff coefficient	Storage coefficient	Infiltration capacity		Infiltration time factor	
				Max	Min	Decrease	Increase
Residential 2	Flat	0.40	5	12	1	0.5	0.1
	Sloped	0.50	4	12	1	0.5	0.1
	Flat	0.40	5	20	1	0.5	0.1

Table A-10: Runoff pipe width and bed friction of RR pipe defined in the catchment model.

Runoff pipe	Runoff pipe width (m)	Bed friction of runoff pipe (s.$m^{\frac{-1}{3}}$)
SSC-KK3	28	0.03
SSC-KK4	20	0.03
SSC-NT1	6	0.03
SSC-NT4	8	0.03
SSC-NT6	10	0.03
SSC-PS10	2	0.015
SSC-PS11	10	0.03
SSC-PS6	8	0.03
SSC-PS7	10	0.03
SSC-PS8	12	0.03
SSC-PS9	10	0.015
SSC-Psua1	6	0.015
SSC-Psua2	30	0.03
SSC-TG4	7	0.03
SSC-TG5	19	0.03
SSC-TG7	25	0.03

Calibration Results

In order to evaluate the calibration, the runoff coefficient based on observation data was compared to modelled runoff coefficients for the selected locations and for selected months. Furthermore, observed and modelled cumulative discharge were compared visually.

Table A-11 shows the runoff coefficient for modelled discharge per location and for the selected months. Here, the runoff coefficient is the fraction of total runoff (excluding dry weather flow) over total rainfall volume per month.

Table A-11: Runoff coefficient for modelled discharge per location and selected months.

Station	Selected months	Runoff coefficient	
		Measurement	SOBEK
WHKC206	April 2018	0.37	0.32
	October 2018	0.36	0.37
	November 2018	0.30	0.24
WHKC108	June 2018	0.38	0.50
	July 2018	0.35	0.25
	Mar 2019	0.38	0.46
WHKC402	April 2018	0.53	0.54
	January 2019	0.27	0.31
	May 2019	0.54	0.39

Cumulative discharge graphs for the two years 2018 to 2019 are shown in Figure A-13 to Figure A-15. A cumulative discharge graph for location WHKC108 was omitted because there is larger doubt about the accuracy of discharge data throughout the two years for this station. It can be seen that, the patterns in the observed and modelled cumulative discharge are similar and the cumulative discharge quantity over the entire selected period is relatively close to one another. There are intermittent periods where the observed and modelled cumulative discharge are further apart. This may be caused by inaccuracies in the spatial interpolation of rainfall data from the three gauges as the rainfall in Singapore can be highly localised. Inaccuracies in the discharge data may be another source of discrepancy.

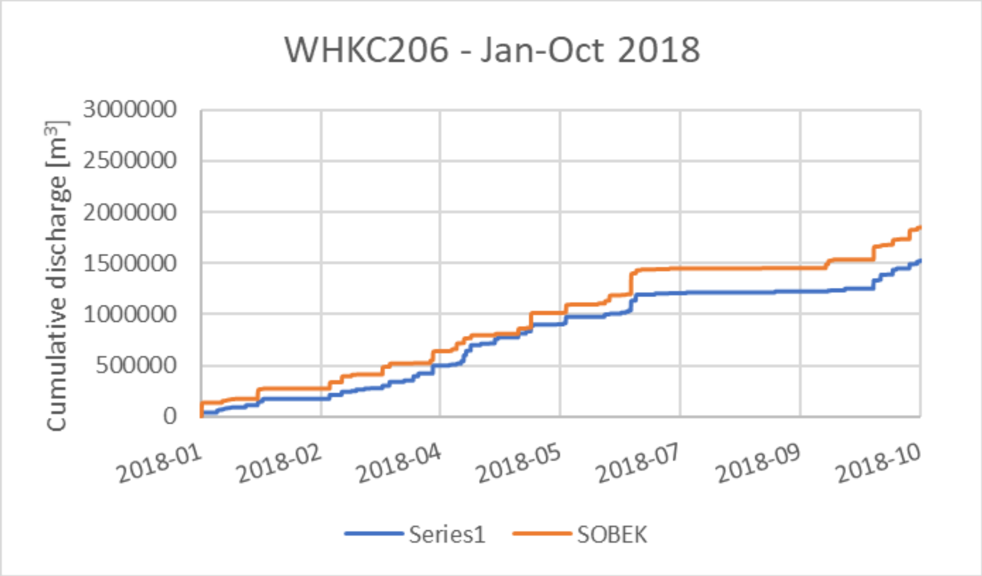

Figure A-13: Cumulative discharge for the period Jan-Oct 2018 for station WHKC206 (there was no observed discharge data for Nov and Dec 2019 and these months were hence omitted).

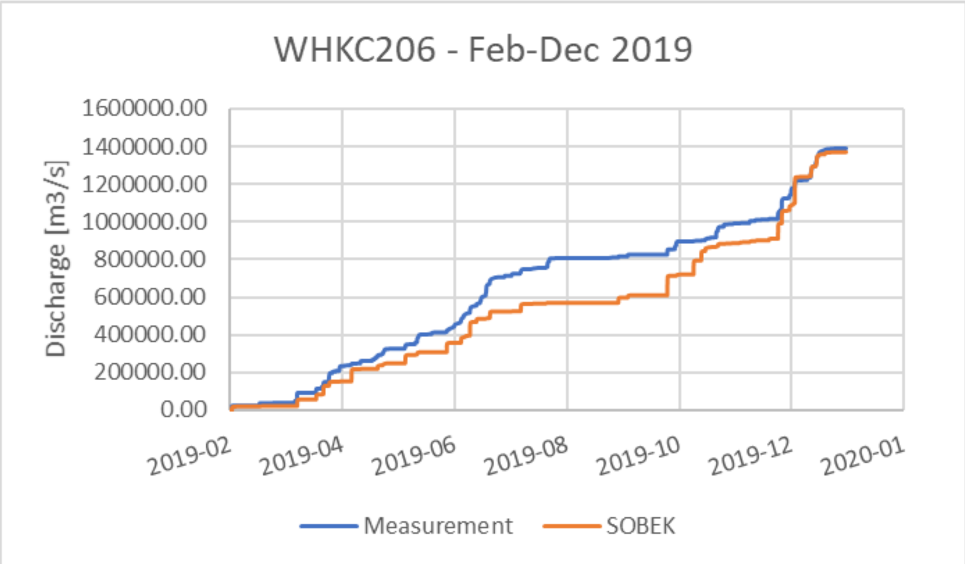

Figure A-14: Cumulative discharge for the period Feb-Dec 2019 for station WHKC206 (there was no observed discharge data for Jan 2019 and this month was hence omitted).

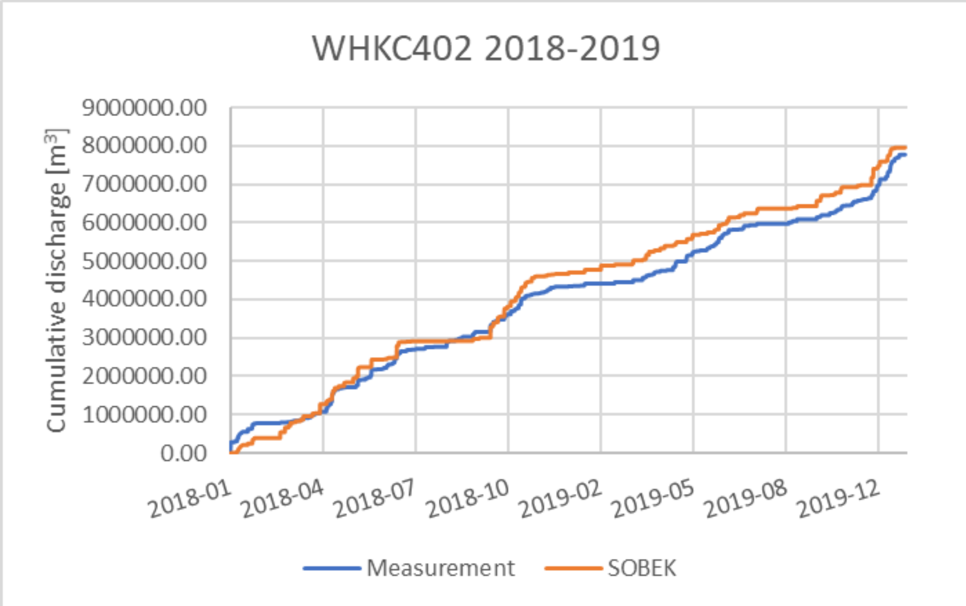

Figure A-15: Cumulative discharge for the years 2018 and 2019 for station WHKC402.

The main calibration results are:

- The observed runoff coefficients range from 0.27 to 0.54. The modelled runoff coefficients range from 0.25 to 0.50.
- There are no consistent underestimation or overestimation of the runoff coefficient in all stations.
- The observed and modelled cumulative discharge over a period of three months follow the same pattern and are relatively close to one another in the aggregate.

Tidal gate discharge

The tidal gate is represented with an internal pump flow pipe and outflow is represented with a boundary node (Figure A-16). The internal pump flow pipe is connected with the reservoir storage node (suction side) and boundary node (delivery side). The suction will switch on when the water level of the storage node is 101.50 mRL and switch off when the water level drops to 101.47 mRL. The pump setting points are determined based on the tidal gate discharge data from PUB. Figure A-17 shows the pump settings of the tidal gate.

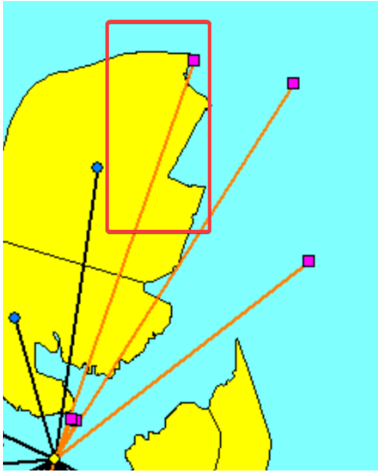

Figure A-16: Tidal gate is represented with an internal pump flow pipe and outflow is represented with a boundary node.

Stage	Capacity [m3/s]	Suction Side Switch On Level [m above datum]	Suction Side Switch Off Level [m above datum]	Delivery Side Switch On Level [m above datum]	Delivery Side Switch Off Level [m above datum]
1	100	101.5	101.47		

Figure A-17: Pump settings of the tidal gate.

A.6.2 Calibration of the reservoir water level

After calibration of catchment rainfall-runoff, all inflow and outflow quantities, except tidal gate discharge, were set. The last step in the calibration was on the settings of tidal gate discharge in the water balance model. Modelled reservoir water levels were compared with observed data in 2018-2019. The variable to change in this step is the capacity of tidal gate. In reality, the capacity of the tidal gates is a discrete value depending on the number of gates opened.

Modelled water levels were compared to the observed one (Figure A-18). The patterns in modelled water levels match well with observed one except for Jul-Sep 2018 and Aug-Sep 2019. Aug-Sep 2019 were two dry months in which the base flow may have been smaller during this period than assumed in the SOBEK model. Additionally, evaporation may have been higher (no evaporation data for 2019 were available). Both these effects may have resulted in lower observed water levels in Kranji Reservoir during Aug-Sep 2019. In Aug 2018, the model misses a large rainfall event as seen from the large water level increase in the observed data. As a result, the modelled water level deviates for a period of time after this rainfall event.

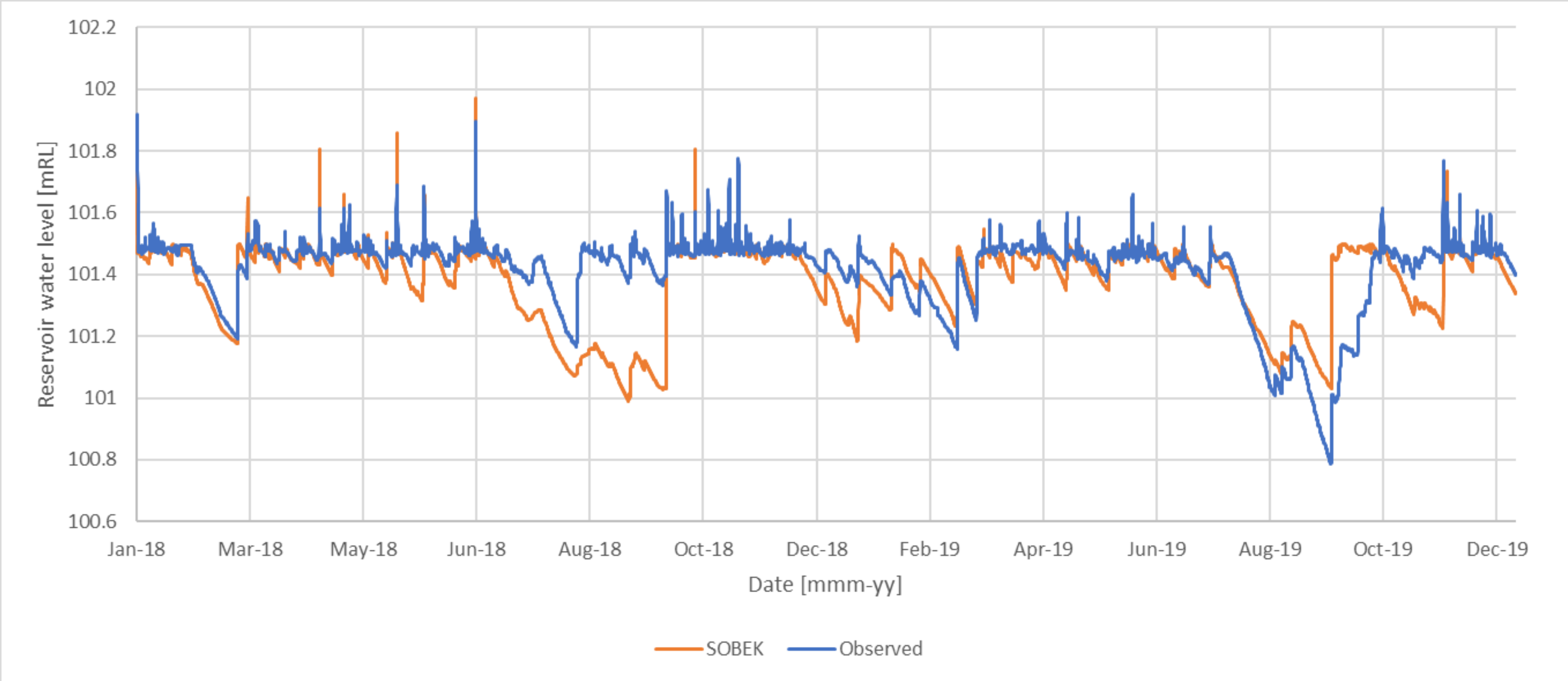

Figure A-18: Comparison of observed and modelled water level.

A.7 Conclusion

The catchment rainfall-runoff model was able to reproduce cumulative discharge quantities for the three selected observation stations. Observed and modelled runoff coefficients were within the same range. Furthermore, reservoir water levels were modelled with reasonable accuracy. While water levels deviate occasionally for periods of several weeks, this can be largely attributed to single rainfall-runoff events. In such cases it is likely that the spatial variability of the rainfall is not well captured by the three rainfall gauges. This may lead to large discrepancies in the modelled discharge into the reservoir and the actual discharge into the reservoir. Noting these issues, the 2019 water balance for the Kranji Reservoir, summarised in Table A-12 shows a water loss over the year of -0.97 x10^6 m^3 that equates to less than 5% of the total inflow or about a 0.2 m drop in the water level from the beginning to the end of the year. The water balance was considered sufficiently accurate to use the computed discharges as boundary conditions for the Kranji Reservoir hydrodynamic and water quality models.

Table A-12 Volume of inflow, outflow sources and net precipitation in 2019 (x 10^6 m^3)

Inflow in 2019 (x 10^6 m^3)			Outflow in 2019 (x 10^6 m^3)		Balance
Rainfall-runoff	Reservoir transfer in[1]	Net precipitation	Reservoir transfer out[2]	Tidal gate discharge	Sum of Inflows and Outflows
48.59	3.72	4.74	-32.49	-25.53	-0.97

[1] Reservoir transfer into Kranji Reservoir includes transfer from Jurong Lake and NEWater from Kranji New Factory

[2] Reservoir transfer out of Kranji Reservoir includes transfer to Murai, Upper Seletar Reservoir and Choa Chu Kang Waterworks

Appendix B Delft3D-FLOW hydrodynamic model

The Kranji Reservoir 3D hydrodynamic model is built using Delft3D-FLOW to simulate the water flow with the water balance established from Appendix A and the conditions of Kranji Reservoir (e.g., thermal structure) with respect to meteorological forcings such as air temperature, wind speed, solar radiation, cloud coverage, etc. This Appendix B details the Delft3D-FLOW model setup and presents the results of model calibration for the year 2019 without FPV system. Once the model was calibrated, the same setup was used for subsequent simulation scenarios.

Delft3D-FLOW solves the unsteady shallow water equations in two (depth-averaged) or in three dimensions. The system of equations consists of the horizontal equations of motion and the continuity equation, which are derived from the transportation governing equations of conservation of mass and momentum. The equations are formulated in orthogonal curvilinear co-ordinates or in spherical co-ordinates on the globe. In Delft3D-FLOW, models with a rectangular grid (Cartesian frame of reference) are considered a simplified form of a curvilinear grid. In curvilinear co-ordinates, the free surface level and bathymetry are related to a flat horizontal plane of reference, whereas in spherical co-ordinates the reference plane follows the Earth's curvature. The flow is forced by tide at the open boundaries, wind stress and heat exchange at the free surface, pressure gradients due to free surface gradients (barotropic) or density gradients (baroclinic, it means that density depends on both temperature and pressure). Source and sink terms are included in the equations to model the discharge and withdrawal of water. The flow model can be used to predict the flow in shallow seas, coastal areas, estuaries, lagoons, rivers, and lakes (Deltares, 2017).

The three-dimensional (3D) hydrodynamic modelling is of particular interest in transport problems where the horizontal flow field shows significant variation in the vertical direction. This variation may be generated by wind forcing, bed stress, Coriolis force, bed topography or density differences. This modelling approach is widely used in scenarios such as dispersion of waste or cooling water in lakes and coastal areas, upwelling and downwelling of nutrients, salt intrusion in estuaries, freshwater river discharges in bays and thermal stratification in lakes and seas (Deltares, 2017).

B.1 Data Inputs

B.1.1 Bathymetry

Bathymetry data provided by PUB was in XYZ format, with reference to Singapore Reduced Level (RL) of 101.68 mRL, as confirmed by PUB via e-mail correspondence (dated Friday, 30 Jul 2021). All the depths herein are referenced to the agreed upon established benchmark. The data are provided in reduced levels and the water depth was computed by subtracting the reduced levels from the reference level of 101.68 mRL. The bathymetry of Kranji Reservoir ranges from -0.59 m to -18.76 m with respect to the reference level of 101.68 mRL. The water depth is relatively shallow (<10 m) at most of the areas except for one location near the upstream of Kranji-2 (Profile measurement location), where a deep trench was observed.

B.1.2 Water Balance

Kranji Reservoir is a closed system with no interaction with the sea. Therefore, the water balance of the reservoir is mainly governed by reservoir storage volume, direct rainfall, catchment runoffs and controlled transfer inflow and outflow operations by PUB. This section describes the various components that play significant roles in the water balance of Kranji Reservoir.

Reservoir Level

Daily reservoir level data in RL for year 2019 was provided by PUB and is presented in Figure B-1. The reservoir level ranged between 100.79 and 101.85 mRL. A box plot of the water level is shown in Figure B-2. It is observed that there are some extreme outliers. The raw reservoir level data and filtered reservoir level data (the water level data was averaged using low pass filter to remove the extreme outliers in the raw water level data) are shown in Figure B-1. Note the box plot highlights the number of outliers shown as red crosses above and below the derived maximum and minimum values as determined assuming the data are normally distributed, and the maximum is equivalent to the 75th percentile plus the interquartile range.

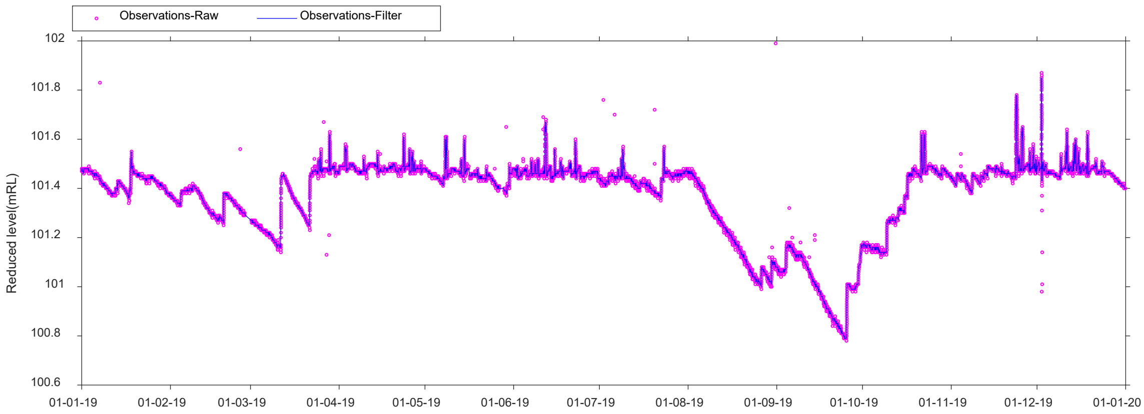

Figure B-1 Kranji Reservoir level daily time series in 2019

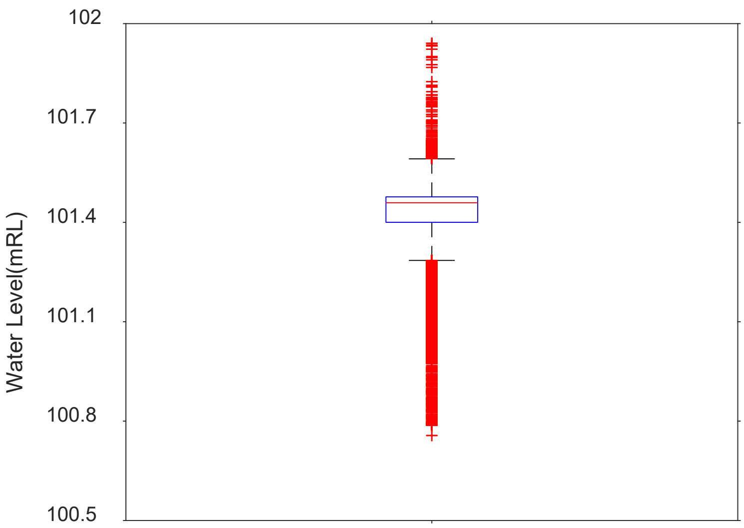

Figure B-2 Boxplot of reservoir water level

Inflow and Outflow

The water balance of the reservoir is mainly governed by reservoir storage volume, direct rainfall, surface runoff, controlled inflow, and outflow operations by PUB. Hence point source discharges rather than open boundary conditions are better representations of the catchment runoffs and reservoir transfers flowing into and out of the Kranji Reservoir.

Figure B-3 shows the setup of the 3D Kranji Reservoir hydrodynamic model which is discussed in detail in later section: setup of dry points and thin dams (section B.2.4) and operational discharges (section B.2.11). The hydrodynamic model is set up with 12 discharge locations (red cells shown in Figure B-3) based on hourly discharges computed from the SOBEK model:

TidalGate, RTIPU, RTUSR, SgPsua, SgPeng, SgTengah, SSCNT1, NT4CCKMUR, SSCNT6, LTKK3, LTKK4 and SSCPS11. The components along with the statistics of each discharge are shown in Table B-1. At each discharge location, the inputs required are discharge time series and temperature time series. The discharge time series are obtained from the SOBEK model and air temperature measurements at S121 (nearest station to Kranji Reservoir with complete set of meteorological data available) are used as the temperature inputs at all discharge locations. The time series of inflow and outflow discharges are shown in Figure B-4 to Figure B-6.

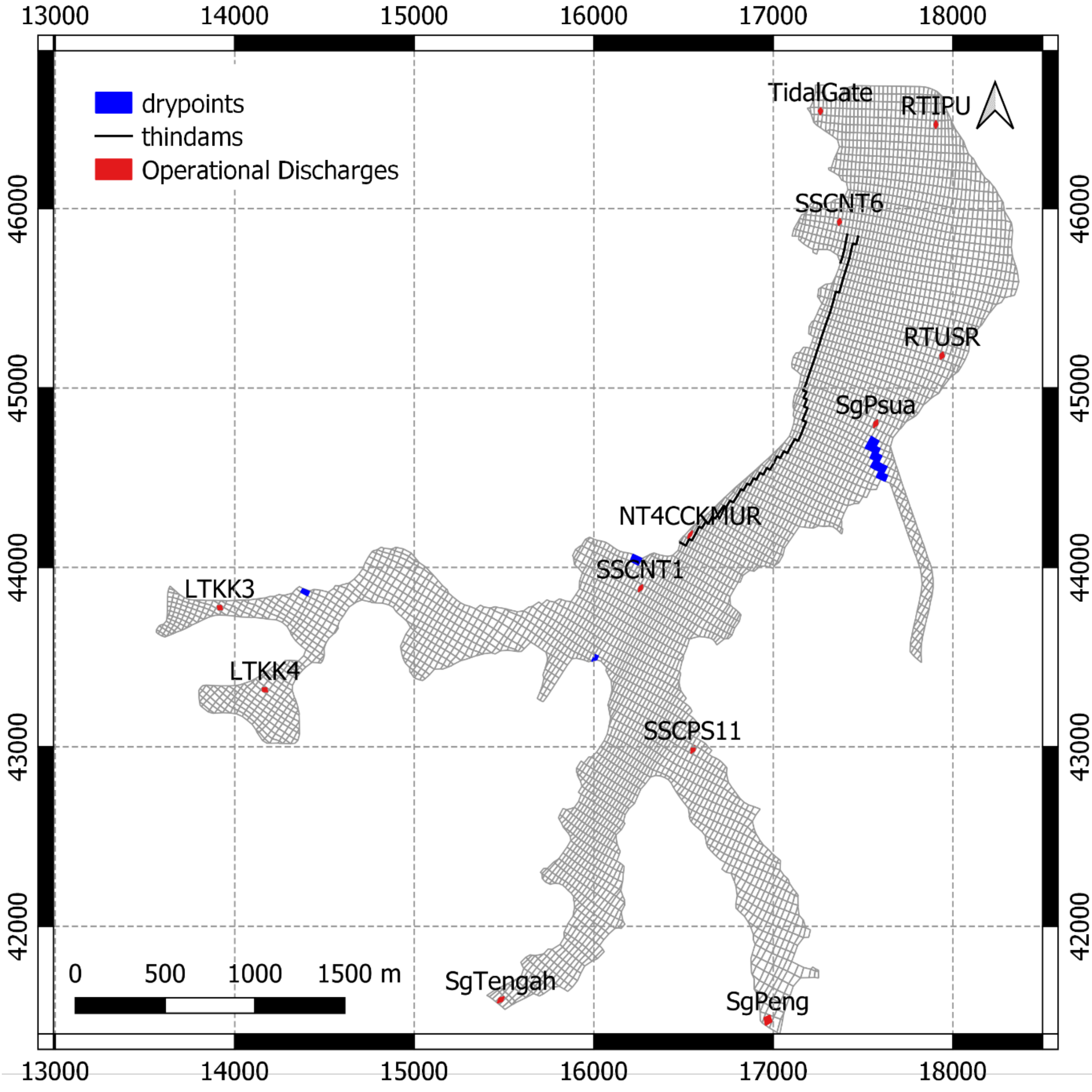

Figure B-3 Inflow and outflow discharge points, dry points and thin dams implemented in hydrodynamic model

Table B-1 Inflow and outflow (water balance) of Kranji Reservoir

Discharges	Discharge components	Inflow/Outflow	Discharge (m^3/s)			
			Min	Max	Ave	Std
TidalGate	tidal_gate	Outflow	0.00	100	0.61	6.60
RTIPU	RT_IPU	Inflow	0.00	0.42	0.11	0.15
RTUSR	RT_USR	Outflow	0.00	0.36	0.00	0.02
SgPsua	L_SSC-Psua1	Inflow	0.05	89.11	0.42	2.54
	L_SSC-Psua2	Inflow				
SgPeng	L_SSC-PS6	Inflow	0.00	112.03	0.42	2.86
	L_SSC-PS7	Inflow				
	L_SSC-PS8	Inflow				
	L_SSC-PS9	Inflow				
	L_SSC-PS10	Inflow				
	L_SSC-PS12	Inflow				
SgTengah	RT_JLake	Inflow	0.02	50.29	0.26	1.67
	L_SSC-TG7	Inflow				
	L_SSC-TG5	Inflow				
	L_SSC-TG4	Inflow				
SSCNT1	L_SSC-NT1	Inflow	0.00	8.36	0.03	0.26
NT4CCKMUR	RT_Murai	Outflow	-1.77	12.66	-0.97	0.47
	RT_CCKWW	Outflow				
	L_SSC-NT4	Inflow				
SSCTN6	L_SSC-NT6	Inflow	0.00	12.43	0.04	0.34
LTKK3	L_SSC-KK3	Inflow	0.02	37.22	0.13	0.95
LTKK4	L_SSC-KK4	Inflow	0.00	23.36	0.10	0.67
	L_SSC-KK5	Inflow				
SSCPS11	L_SSC-PS11	Inflow	0.00	17.84	0.06	0.43

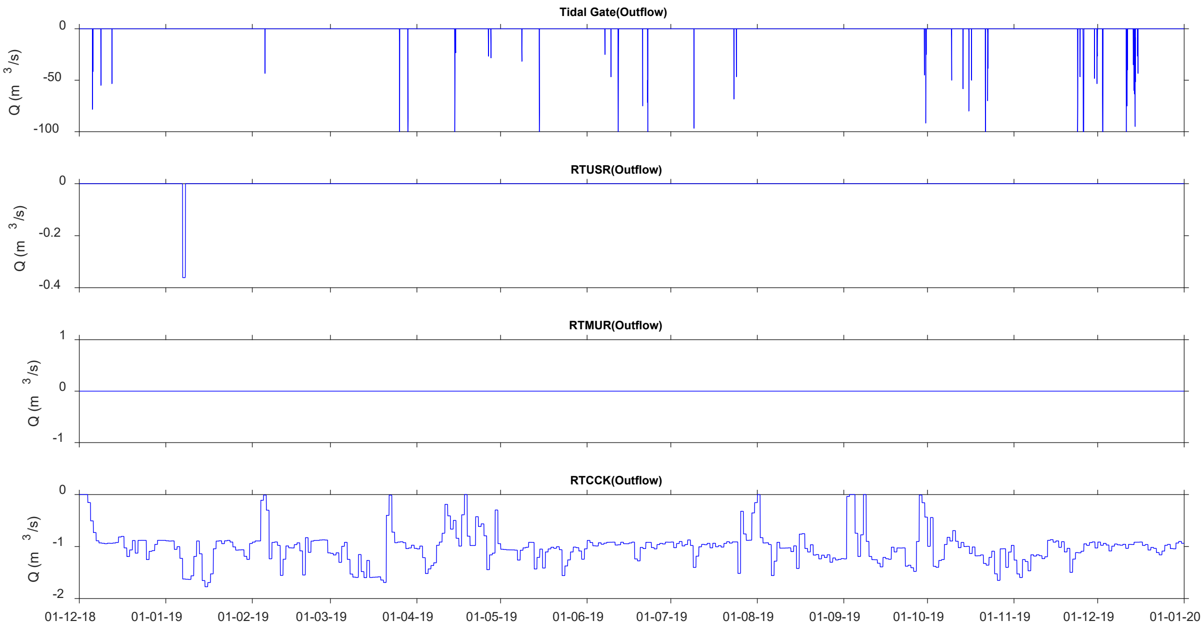

Figure B-4 Daily discharge time series at Delft3D-FLOW source and sink points tidal gate, RTUSR, RTMUR and RTCCK (in cubic metres per second) from 1 Dec. 2018 to 1 Jan. 2020

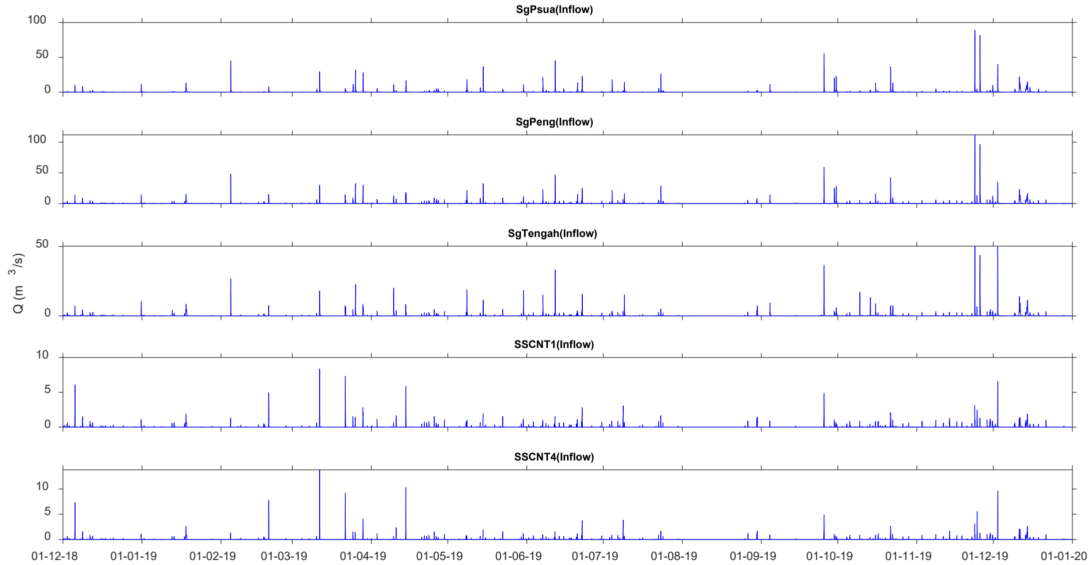

Figure B-5 Daily discharge time series at Delft3D-FLOW source and sink points SgPsua, SgPeng, SgTengah, SSCNT1 and SSCNT4 (in cubic metres per second) from 1 Dec. 2018 to 1 Jan. 2020

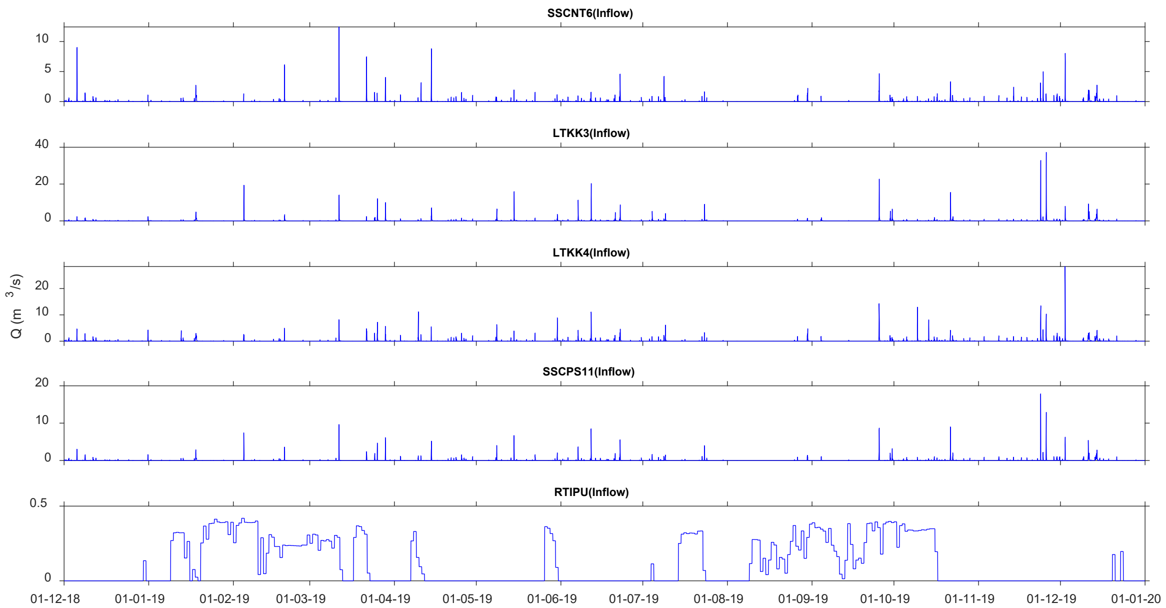

Figure B-6 Daily discharge time series at Delft3D-FLOW source and sink points SSCNT6, LTKK3, LTKK4, SSCPS11 and RTIPU (in cubic metres per second) from 1 Dec. 2018 to 1 Jan. 2020

B.1.3 Meteorological Data

Meteorological data including relative humidity, air temperature, solar radiation, wind speed and wind direction were obtained from the Station S121 (Old Choa Chu Kang Road, nearest station to Kranji Reservoir which provides meteorological data including air temperature, relative humidity, wind speed and directions) and cloudiness was taken from the Station S24 (Upper Changi Road North) (since cloudiness data is not available at S121) for ocean heat flux model. The locations of both weather stations are indicated in Figure B-7. Data gaps in raw meteorological data are filled using multi-regression linear model with the missing parameters as dependents and other meteorological parameters as independents.

The time series plots of processed x-component wind speed, y-component wind speed, air temperature, cloudiness, relative humidity, and solar radiation data are presented in Figure B-8. The statistical summary (minimum, maximum and average) of meteorological data for the period 01-01-2019 to 01-01-2020 is presented in Table B-2.

Figure B-7 Location of weather stations

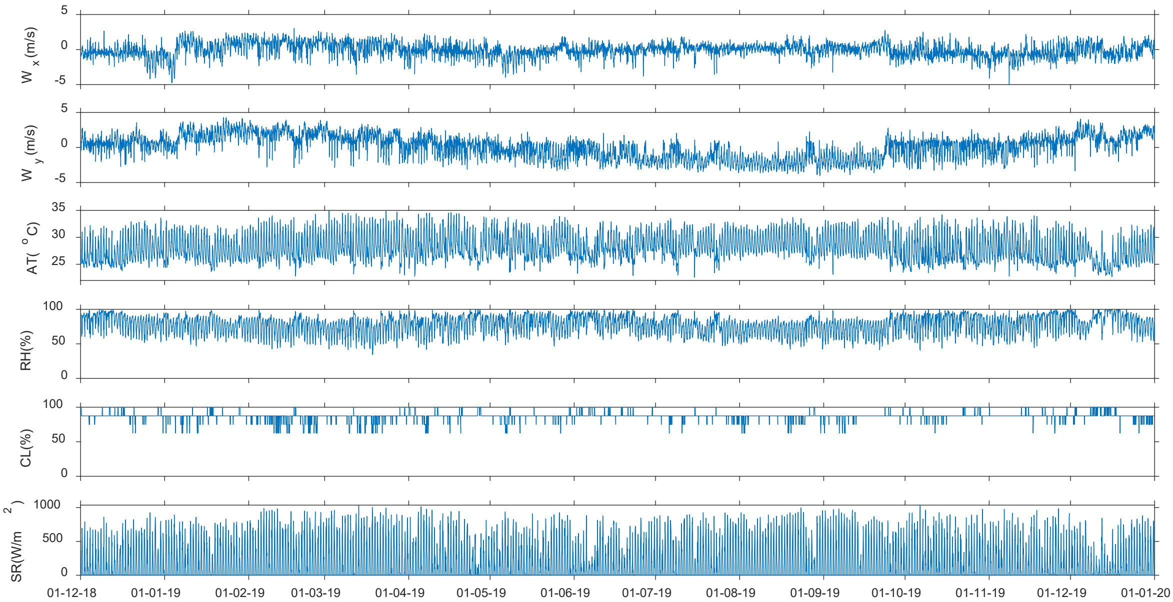

Figure B-8 Meteorological data for the period from 1 Dec. 2018 to 1 Jan. 2020 (Wx: wind speed in x direction, Wy: wind speed in y direction, AT: Air Temperature, RH: Relative humidity, CL: Cloudiness, SR: Solar Radiation)

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Table B-2 Statistical summary of meteorological data for the period 1 Jan. 2019 to 1 Jan. 2020

Meteorological Parameters	Minimum	Maximum	Average
Air Temperature (°C)			
Northeast Monsoon (Dec to early Mar)	22.7	34.9	27.64
Inter Monsoon (Late Mar to May)	22.8	34.9	28.54
Southwest Monsoon (Jun to Sep)	22.6	33.7	28.63
Inter Monsoon (Oct to Nov)	23.4	34.2	27.42
Relative humidity (%)			
Northeast Monsoon (Dec to early Mar)	41.4	99.4	77.27
Inter Monsoon (Late Mar to May)	34.3	99.4	78.60
Southwest Monsoon (Jun to Sep)	41.2	99.3	75.24
Inter Monsoon (Oct to Nov)	40.8	99.4	81.41
Cloudiness (%)			
Northeast Monsoon (Dec to early Mar)	62.5	100.0	86.5
Inter Monsoon (Late Mar to May)	62.5	100.0	86.4
Southwest Monsoon (Jun to Sep)	62.5	100.0	87.1
Inter Monsoon (Oct to Nov)	62.5	100.0	87.7
Solar Radiation (W/m^2)			
Northeast Monsoon (Dec to early Mar)	0	1030.0	183.2
Inter Monsoon (Late Mar to May)	0	1016.2	178.7
Southwest Monsoon (Jun to Sep)	0	998.5	187.5
Inter Monsoon (Oct to Nov)	0	1036.5	172.4
Wind speed (kph)			
Northeast Monsoon (Dec to early Mar)	1.2	17.6	7.7
Inter Monsoon (Late Mar to May)	1.1	14.3	5.1
Southwest Monsoon (Jun to Sep)	1.2	14.6	6.6
Inter Monsoon (Oct to Nov)	1.8	12.1	5.1

B.2 Model Setup

B.2.1 Horizontal Grid Schematization

Figure B-9 presents the horizontal grid schematisation of the 3D Kranji Reservoir hydrodynamic model. The complete model grid of the Kranji Reservoir with Waterway has about 20,234 active grid cells, with a typical grid size of 40 m by 20 m.

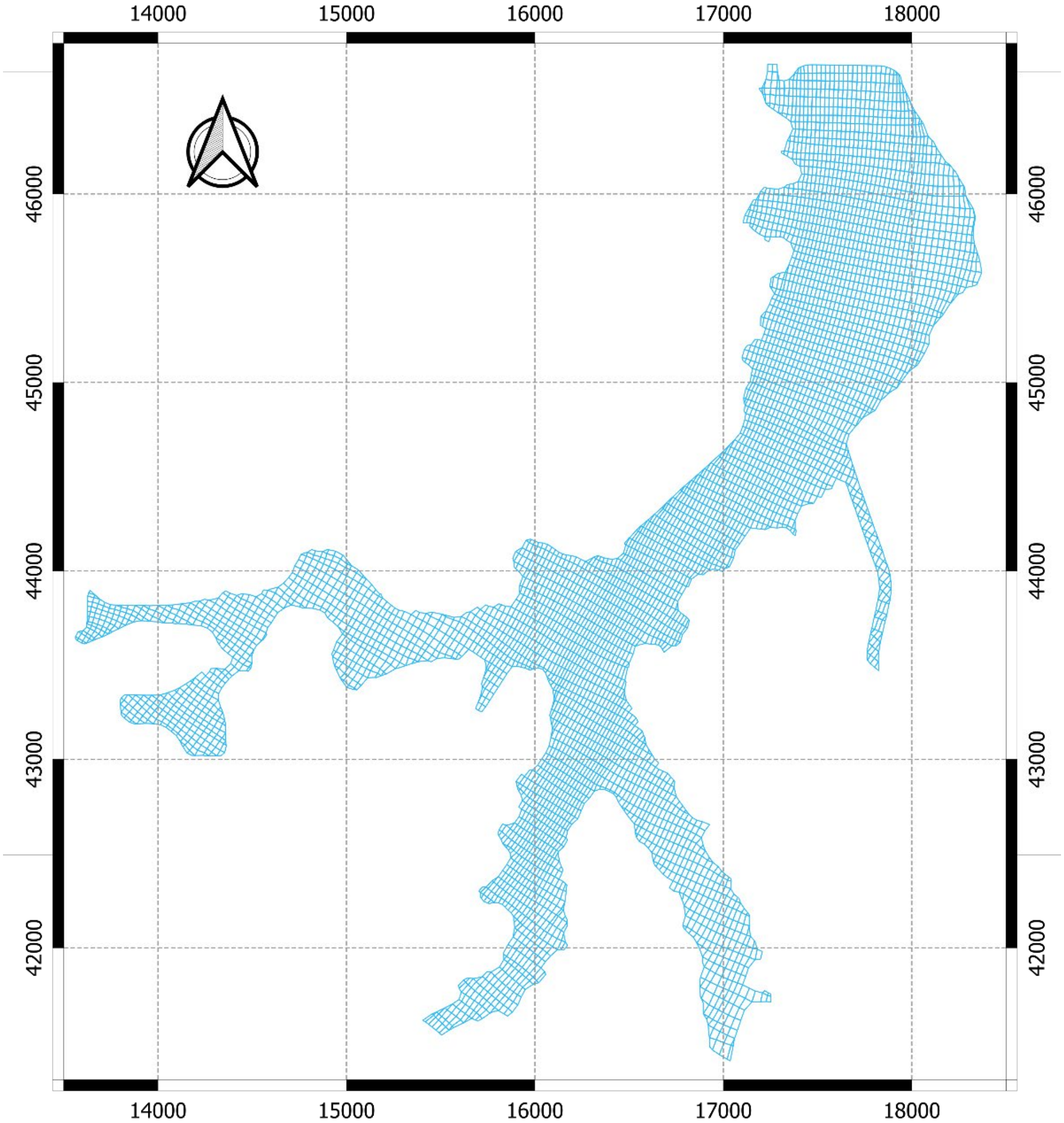

Figure B-9 Horizontal grid schematization of 3D Kranji hydrodynamic model

B.2.2 Vertical Grid Schematization

In the 3D Kranji Reservoir model, a maximum of 20 z-layers (at the deepest location) are used, with thicknesses varying between 0.5 m, 1.0 m, and 2 m (Table B-3). The computational layers are defined between -19 m and 0 m with reference to 101.68 mRL. Referring to Delft3D-FLOW manual Section 10.2 regarding vertical schematisation, sigma layer might not be sufficient to solve problems where stratified flow can occur in combination with steep topography. Z-layer has horizontal co-ordinate lines that are nearly parallel with density interfaces in regions with steep bottom slopes. This is important to reduce artificial mixing of scalar properties such as temperature, which is a crucial input from FLOW to WAQ. As, such, z-layers were chosen as it is appropriate for WAQ modelling.

Table B-3 Vertical schematization of Z-layers in Kranji Reservoir model

Water depth (m) w.r.t 101.68 mRL (=0.0m)	Layer no. in Delft3D-FLOW	Layer thickness (m)
0.0 to -0.5	20	0.5
-0.5 to 1.0	19	0.5
1.0 to -1.5	18	0.5
-1.5 to -2.0	17	0.5
-2.0 to -2.5	16	0.5
-2.5 to -3.0	15	0.5
-3.0 to -3.5	14	0.5
-3.5 to -4.0	13	0.5
-4.0 to -5.0	12	1
-5.0 to -6.0	11	1
-6.0 to -7.0	10	1
-7.0 to -8.0	9	1
-8.0 to -9.0	8	1
-9.0 to -10	7	1
-10 to -11	6	1
-11 to -12.5	5	1.5
-12.5 to -14	4	1.5
-14 to -15.5	3	1.5
-15.5 to -17	2	1.5
-17 to -19	1	2

B.2.3 Bathymetry

The bathymetry of Kranji Reservoir was implemented in the model with depths referenced to 101.68 mRL. Most of the reservoir is less than 10 m in depth.

B.2.4 Thin Dam and Dry Points

Along western side of the Kranji reservoir some earth bunds (as can be seen in Google Earth Map) were constructed to channel flows. These bunds are modelled as thin dams because the width of the earth bund is around 6 m which is less than the model grid size. Cells covering the land area are modelled as dry points. The thin dam (indicated in black) and dry points (indicated in blue) are shown in Figure B-10.

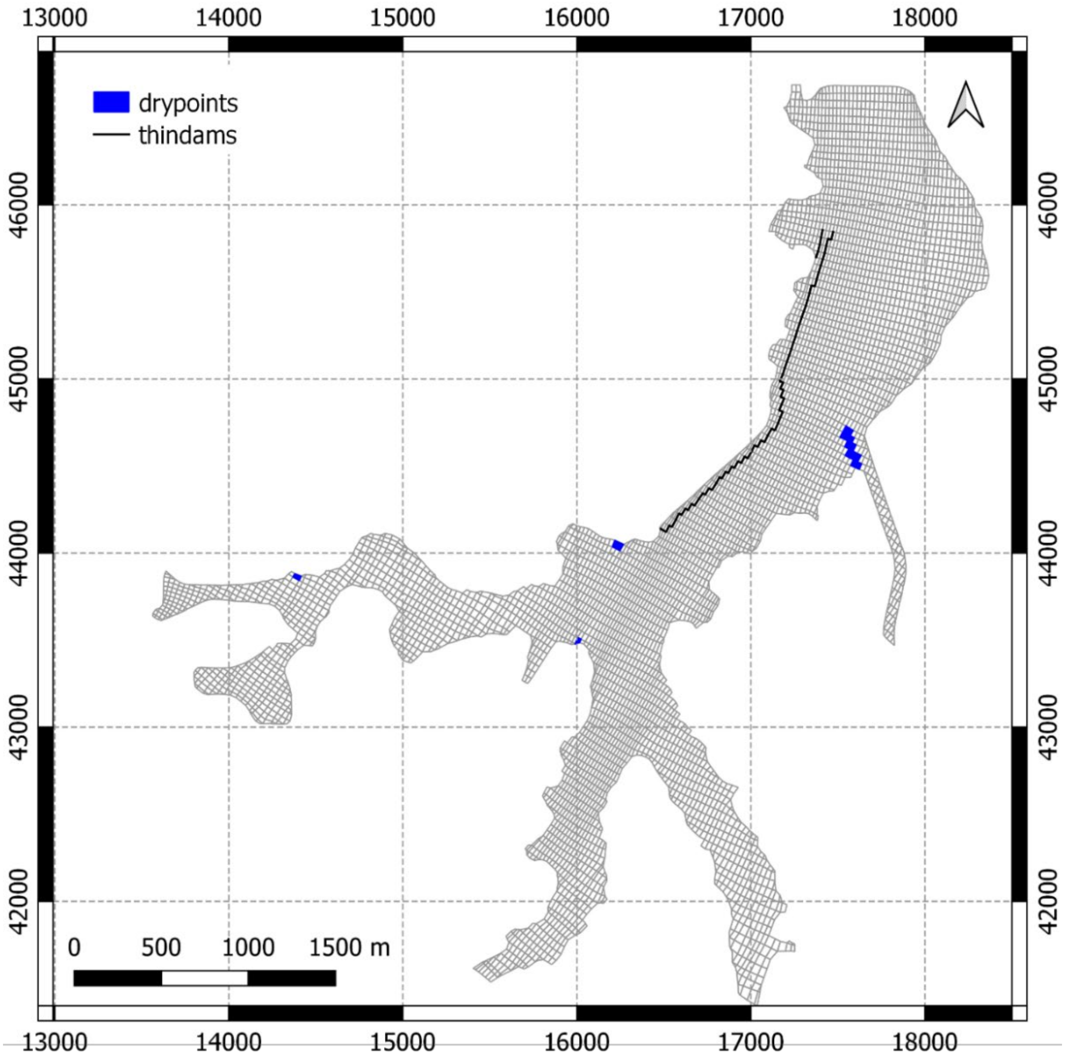

Figure B-10 Locations of thin dams and dry points of Kranji Reservoir model

B.2.5 Hydrodynamic Constants

Gravitational acceleration is specified as 9.81 m/s^2. Water and air density are specified as 996 kg/m^3 and 1.1684 kg/m^3 respectively, based on Singapore's tropical weather climate as reported on the official website of Meteorological Service Singapore (i.e., daily temperature range has a minimum usually not falling below 23-25^{o}C during the night and maximum not rising above 31-33^{o}C during the day).

B.2.6 Roughness

In terms of bottom roughness, a uniform Manning roughness coefficient of 0.021 s/m$^{1/3}$ is used. For wall roughness, the slip condition is set as “Free” meaning there is zero tangential shear stress at all lateral boundaries.

B.2.7 Horizontal Background Viscosity and Diffusivity

The background horizontal viscosity and diffusion are set to 0.5 m^2/s in this model.

B.2.8 Vertical Background Viscosity and Diffusivity, and Ozmidov Length Scale

In the k-Ɛ vertical turbulence closure model, a background value of 2 × 10^{-5} m^2/s is used for both vertical eddy viscosity and vertical eddy diffusivity, and an Ozmidov length scale of 1.5 cm is applied.

B.2.9 Heat Flux Model

To model the surface heat flux, the Delft3D-FLOW Ocean Heat Flux Model is used. This model takes spatial varying meteorological forcing such as air temperature at 2 m height, cloud cover, relative humidity, solar radiation and wind speed and direction as inputs. Other input parameters required are Stanton number, Dalton number and Secchi depth. Dalton number is used for calibration of the evaporative heat flux and Stanton number for heat convection.

Meteorological Forcing

The forcing data are provided at 3-hr interval based on measurement data from S121 station (in terms of relative humidity, air temperature at 2 m above the surface and solar radiation) and S24 station (for cloud cover). The time series plots of the meteorological data are presented in Figure B-8. The forcing is applied spatially on the water surface. For each surface grid cell, the model calculates the net surface heat flux from the atmosphere to the water and vice versa. Local meteorological effects, such as sheltering due to trees surrounding the reservoir are absent in the forcing data used.

Stanton Number

The Stanton Number is set to 1.1 x 10^{-3} in the initial model setup.

Dalton Number

The Dalton Number is set to 2.1 x 10^{-3} in the initial model setup.

Secchi Depth

A Secchi depth of 1.0 m is applied uniformly over the model domain.

B.2.10 Wind

Wind data from S121 station has been converted to wind speed in x- and y- direction and applied spatially on the Kranji Reservoir model in 300-minute interval (see Figure B-8 for input data). For the wind drag coefficient, the well-known Smith and Banke (1975) wind stress formulation has been applied, which assumes that the wind-drag coefficient changes as a function of the local wind speed (Smith and Banke, 1975).

B.2.11 Operational Discharges

The hydrodynamic model is set up with 12 discharge locations based on hourly discharges from SOBEK model: TidalGate, RTIPU, RTUSR, SgPsua, SgPeng, SgTengah, SSCNT1, NT4CCKMUR, SSCNT6, LTKK3, LTKK4 and SSCPS11. The time series of the inflow and outflow discharges are shown in Figure B-4 to Figure B-6. Table B-4 and Figure B-11 describe the locations of inflow and outflow discharges implemented in the model. At each discharge location, temperature inputs need to be provided along with the discharge inputs. The discharge time series are obtained from the SOBEK model. Net rainfall on the reservoir is distributed equally to all the operational discharge locations in addition to the catchment discharges (this is done in the SOBEK catchment model analysis). Air temperature measurements at S121 are used as the temperature inputs at all discharge locations.

Table B-4 Inflow and outflow discharge locations implemented in model

S/N	Name in Delft3D-FLOW	Inflow/ Outflow	Depth	Easting	Northing	Discharge	Temperature
1	TidalGate	Outflow	Surface	17265	46545	SOBEK	S121
2	RTIPU	Inflow	Surface	17906	46470	SOBEK	S121
3	RTUSR	Outflow	Surface	17940	45180	SOBEK	S121
4	SgPsua	Inflow	Surface	17570	44807	SOBEK	S121
5	SgPeng	Inflow	Surface	16973	41482	SOBEK	S121
6	SgTengah	Inflow	Surface	15480	41591	SOBEK	S121
7	SSCNT1	Inflow	Surface	16262	43885	SOBEK	S121
8	NT4CCKMUR	Inflow /Outflow	Surface	16538	44187	SOBEK	S121
9	SSCNT6	Inflow	Surface	17370	45930	SOBEK	S121
10	LTKK3	Inflow	Surface	13920	43779	SOBEK	S121
11	LTKK4	Inflow	Surface	14170	43319	SOBEK	S121
12	SSCPS11	Inflow	Surface	16553	42993	SOBEK	S121

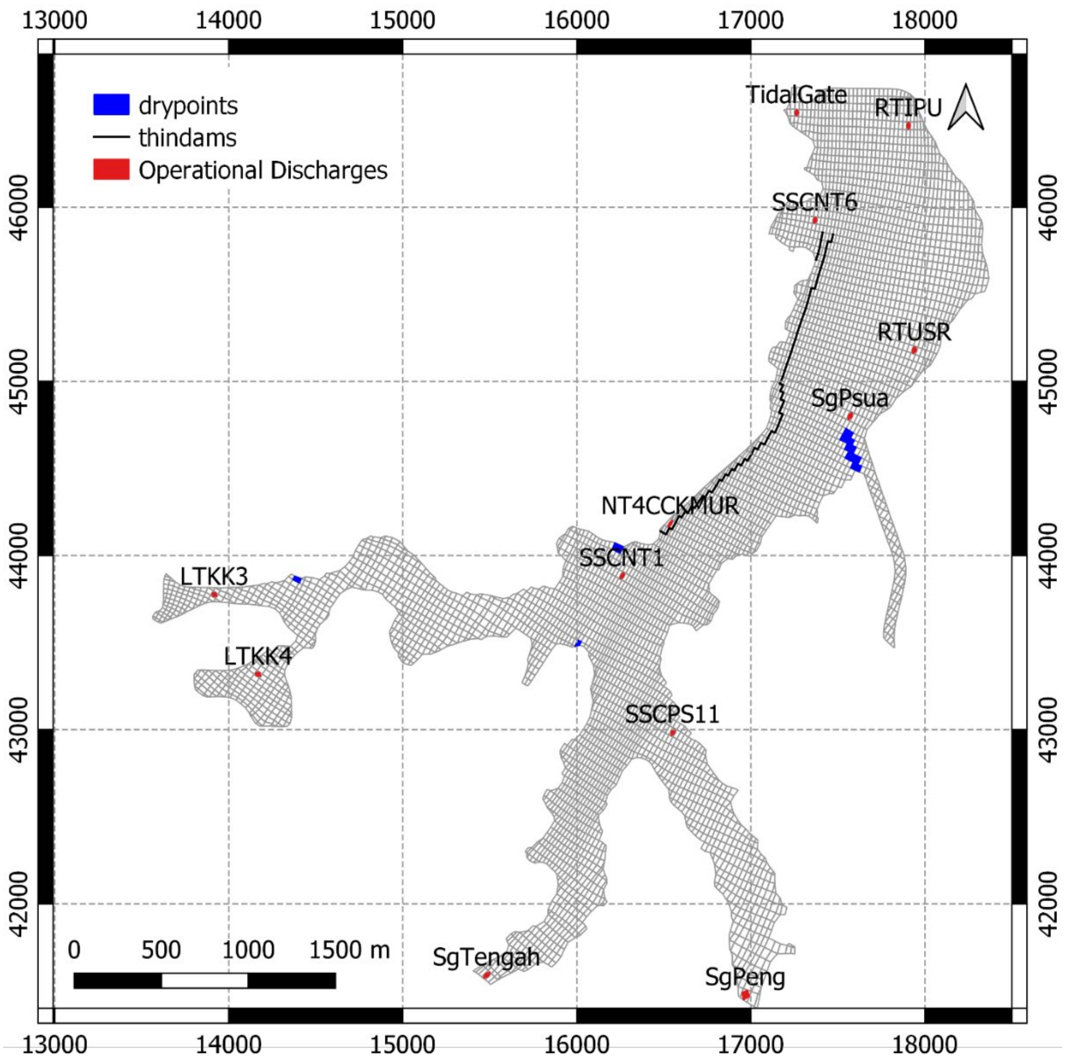

Figure B-11 Inflow and outflow discharge points implemented in model

B.2.12 Model Monitoring Points

Model output time series from 16 pre-set locations (or model monitoring points) were output from each model run. The locations and names are indicated in Figure B-12 and Table B-5. They consist of the two profile measurement stations (Kranji-1 and Kranji-2), three sampling stations (RKR H2, RKR I2 and RKR K2) and an additional eleven modelled locations for monitoring (RKRP1 to RKRP9; RKRD2; RKRTG). It is noted that observations site RKR H2 is actually located outside the model domain, and for comparison purposes the model output site is located near the observation site inside the model domain.

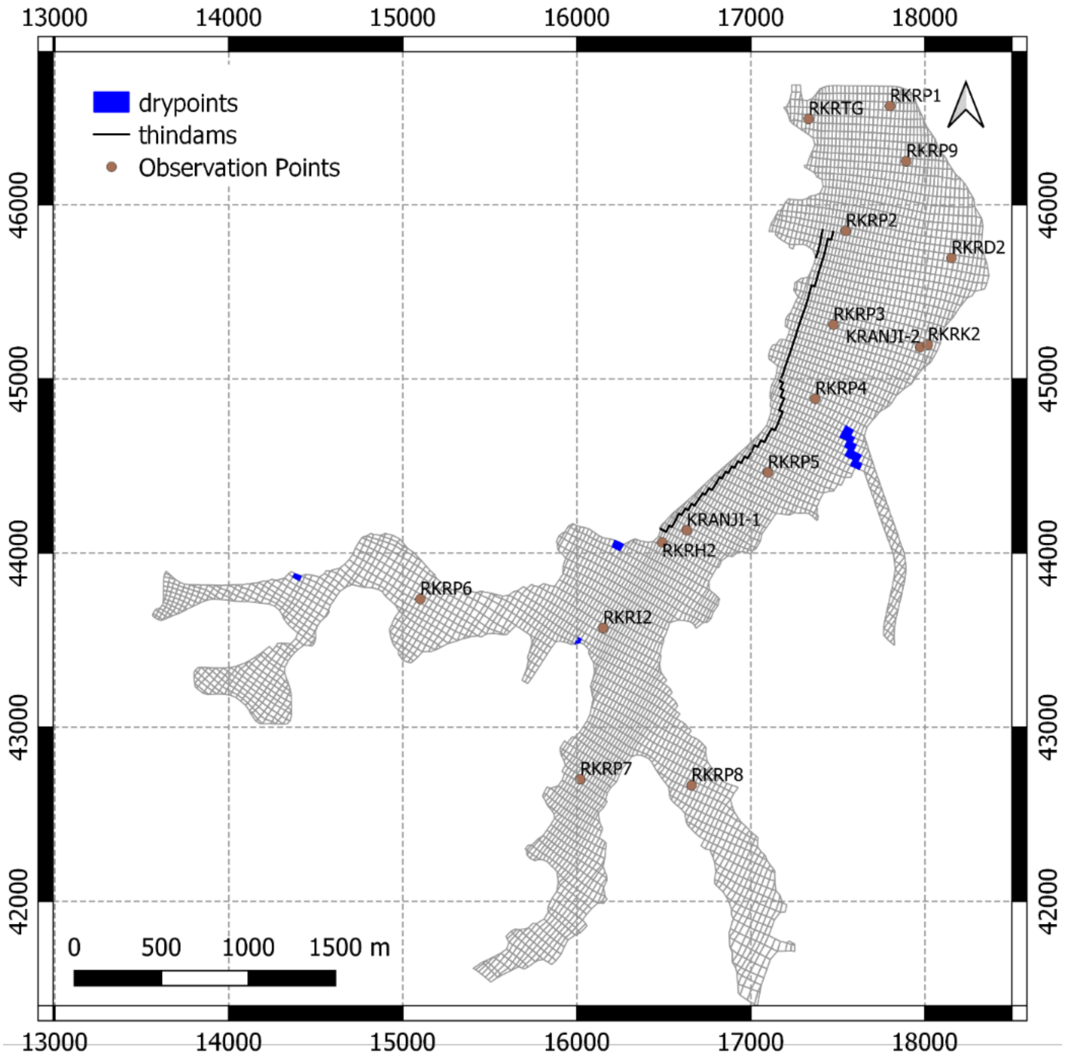

Figure B-12 Location of monitoring points (brown circles) in Kranji Reservoir model

Table B-5 Locations of monitoring stations implemented in model, following SVY21 Cartesian

S/N	Stations	Longitude	Latitude
1	RKRH2	16490.31	44061.75
2	RKRI2	16151.59	43569.66
3	KRANJI-1	16632.12	44130.99
4	KRANJI-2	17973.44	45183.03
5	RKRK2	18016.68	45196.28
6	RKRTG	17331.76	46493.85
7	RKRP1	17799.29	46566.97
8	RKRP9	17892.35	46250.12
9	RKRP2	17545.58	45850.17
10	RKRD2	18152.71	45695.06
11	RKRP3	17474.68	45312.01
12	RKRP4	17369.98	44886.02
13	RKRP5	17097.99	44462.81
14	RKRP6	15100.46	43736.03
15	RKRP7	16020.01	42701.26
16	RKRP8	16659.27	42665.8

B.2.13 Initial Condition

Based on the reservoir levels recorded by the Kranji online profiler (provided by PUB), the initial condition of the model is prescribed as follows:

- Temperature: uniform 29.0^{o}C (Recorded by Kranji-1 profiler on 1 Dec. 2018)
- Water level: uniform 0.245 m (Recorded on 1 Dec. 2018 by SOBEK model)

B.2.14 Computational Time Step

The computational time step used in the model is 1 minute. A 1-year simulation takes about 20 hours to complete on a 3.8GHz 8-core processor PC.

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B.2.15 Summary of Model Setup

Table B-6 Summary of the 3D hydrodynamic model initial setup

Parameter	Model setup
Grid Type	Curvilinear grid
Grid size	40 m by 20 m (approximately)
Number of Grid cells	20,234
Coordinate system	SVY21 Cartesian
No of layers	20 layers (Z-layers)
Time Zone	+8 GMT
Bathymetry	Water depths are referenced to 101.68 mRL (min depth =0.59 m, max depth = 18.76 m)
Initial condition	Water level at 0.245 m Temperature at 29°C
Discharges	Discharge time series are derived from SOBEK model. Temperature time series are obtained from air temperature measurements at S121
Processes	Constituent: Temperature Physical process: Wind
Gravity	9.81 m/s^2
Water density	996 kg/m^3
Roughness	Manning's coefficient: 0.021
Heat flux model	Ocean
Weather data	Spatial varying wind (S121), air temperature(S121), atmospheric pressure, cloudiness (S24), relative humidity(S121), and solar radiation(S121) **Note:** cloudiness is not available at S121 and hence took from S24. Atmospheric pressure is given as a constant value.
Advection scheme for momentum and transport	Momentum: cyclic Transport: van-Leer2
Secchi depth	1 m
Dalton number	0.0021
Stanton number	0.0011
Background horizontal viscosity/diffusivity	0.5 m^2/s
Background Vertical viscosity/diffusivity	2.1e-005 m^2/s
Model for 3D turbulence	K – Epsilon
Time step	1 minute
Additional parameters	Top and bottom water depths of Z-layers (Z_{top} = 0 m and Z_{bottom} = -19.0 m) Spatial meteorological data
Export WAQ model	Activated
Time history output	20 minutes

B.3 Model Calibration

The 3D hydrodynamic model with setup described in Table B-6 has been calibrated for 13 months (from 1 Dec. 2018 to 1 Jan. 2020) with the initial one month as the spin-up period (from 1–31 Dec. 2018). Three model simulations have been made for the calibration against temperature and water level with the details shown in Table B-7. Parameters other than ocean heat flux parameters and background horizontal viscosity/diffusivity remain the same as given in Table B-6.

Table B-7 Model simulations for calibration

Simulation	Ocean heat flux parameters	Background horizontal viscosity/diffusivity
1	Dalton number = 0.0021 Stanton number = 0.0011 Secchi Depth = 1.0 m	0.5 m^2/s
2	Dalton number = 0.0021 Stanton number = 0.0018 Secchi Depth = 1.0 m	0.5 m^2/s
3	Dalton number = 0.0021 Stanton number = 0.0021 Secchi Depth = 1.0 m	1.0 m^2/s

B.3.1 Water Level

Figure B-13 shows the computed water level by the Kranji Reservoir 3D hydrodynamic model with Simulation 1, 2 and 3 (blue), in comparison with computed reservoir water level by SOBEK catchment model (red) and recorded reservoir level in Kranji Reservoir (black), with their statistical correlation presented in Table B-8. Both the visualisation and statistics suggest that Delft3D-Flow and SOBEK generate consistent reservoir water levels in all three simulations. The SOBEK catchment model in Appendix A demonstrated a good performance between the modelled reservoir water level and recorded reservoir level in Kranji Reservoir in both magnitude and patterns. Hence the water level modelled by Delft3D-FLOW model could also be considered well calibrated against the observations.

In addition, the reservoir water level computed by Delft3D-Flow model is consistent among all three simulations, which suggests that the computed water level is not affected by ocean heat flux parameters nor background horizontal viscosity/diffusivity. Figure B-14 presents the modelled water level with Simulation 1 at 15 monitoring locations. The figure shows that water level from this hydrodynamic model is consistent at all locations of the reservoir, indicating stability of the model.

Table B-8 Statistics of reservoir level respresentation compared with observation and SOBEK model

Comparison	Mean averaged error	Mean square error	Standard deviation	Root mean square	Correlation coefficiecnt
SOBEK vs. Obs.	0.08	0.01	0.15	0.11	0.50
			Simulation-1		
Delft3D vs. Obs.	0.08	0.01	0.15	0.11	0.51
SOBEK vs. Delft3D	0.01	0.00	0.13	0.02	0.99
			Simulation-2		
Delft3D vs. Obs.	0.08	0.01	0.15	0.11	0.51
SOBEK vs. Delft3D	0.01	0.00	0.13	0.02	0.99
			Simulation-3		
Delft3D vs. Obs.	0.08	0.01	0.15	0.11	0.51
SOBEK vs. Delft3D	0.01	0.00	0.13	0.02	0.99

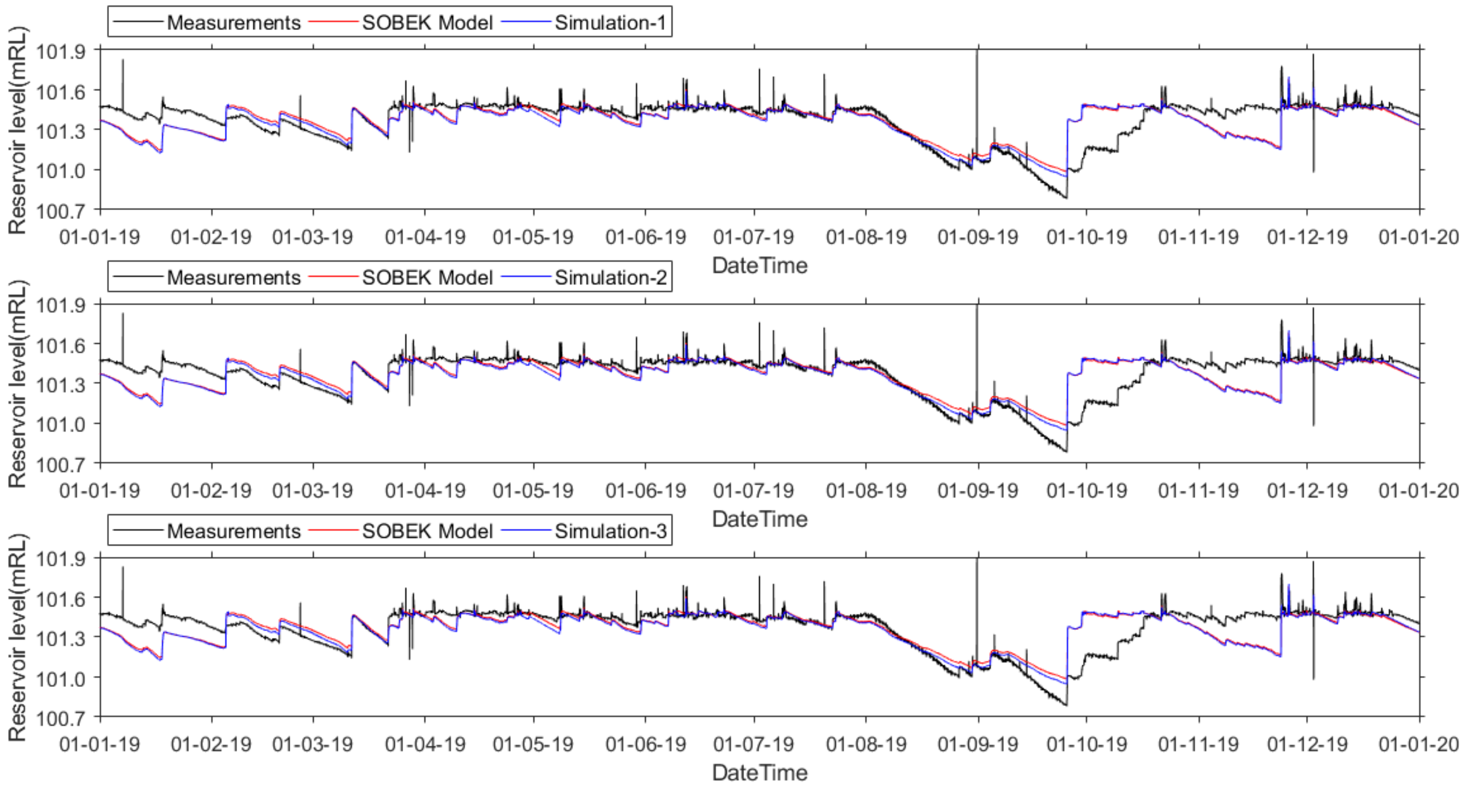


Figure B-13 Computed water level by Delft3D-FLOW model with Simulations 1, 2 and 3 (blue), in comparison with computed reservoir water level by SOBEK catchment model (red) and recorded reservoir level in Kranji Reservoir (black)

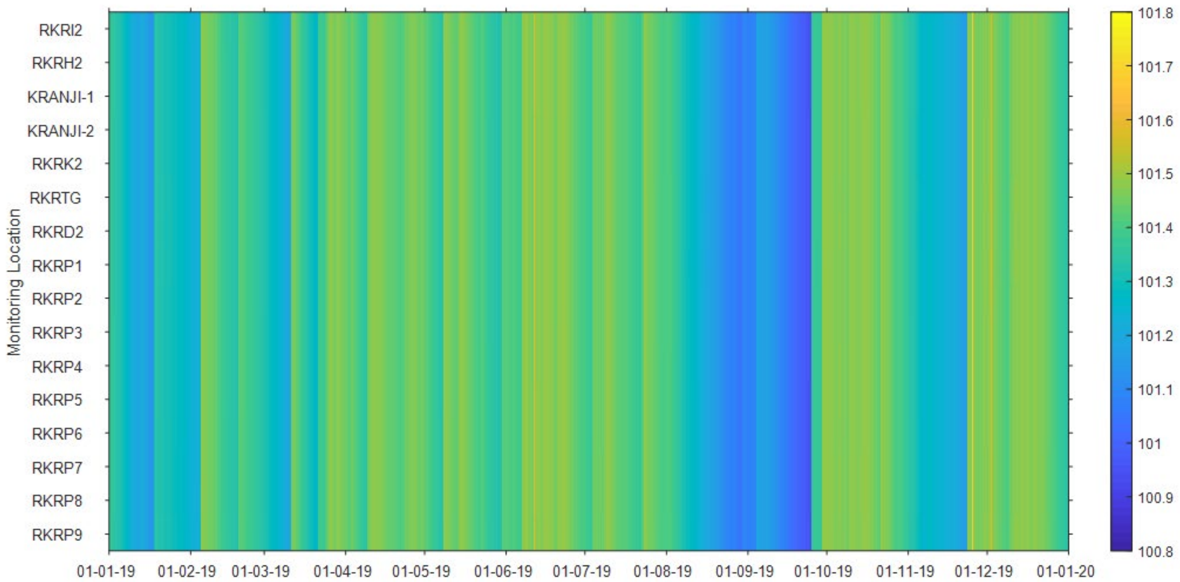


Figure B-14 Computed water level of Delft3D-FLOW model with Simulation 1 at all monitoring locations implemented in the model

B.3.2 Temperature

Kranji-1 Station

Table B-9, Table B-10, and Table B-11 present the statistics of modelled temperature with simulations 1, 2 and 3 respectively as compared with observations at Kranji-1 station. Figure B-15, Figure B-16 and Figure B-17 show time series of modelled temperature from Simulations 1, 2 and 3 (blue) in comparison with measurement (pink) at Kranji-1 station at 0.5 m, 1.0 m, 1.5 m, 2.0 m, 3.0 m and 4.0 m below water surface.

Simulation-1, which is based on the initial model setup, shows the largest deviation and overestimates the temperature compared to measurements among all three simulation cases (Table B-9). An increase in ocean heat flux parameters (Simulation-2: Stanton number increases from 0.0011 to 0.0018) effectively brings modelled temperature down to measured levels. All statistical errors of temperature are reduced with such increase in Stanton number. The overall mean averaged error (MAE) is reduced from 0.38^{o}C to 0.35^{o}C; the overall mean square error (MSE) of temperature is reduced from 0.24^{o}C to 0.20^{o}C and the overall root mean square error (RMSE) is reduced from 0.49^{o}C to 0.45^{o}C, although the correlation coefficient shows slight decrease from 0.84 to 0.83 (Table B-9, Table B-10).

When the Stanton number further increases from 0.0018 to 0.0021 and the background horizontal viscosity/ diffusivity also increases from 0.5 m^2/s to 1.0 m^2/s (Simulation-3), the MAE of modelled temperature then decrease from 0.35°C to 0.34°C, along with a decrease in RMSE from 0.45°C to 0.44°C (Table B-10, Table B-11).

Table B-9 Comparison betweem modelled temperature in Simulation-1 with observations at Kranji-1 Station

Depth (m)	Mean Averaged error (°C)	Mean square error	Standard deviation (°C)	Root mean square (°C)	Correlation coefficiecnt
0.5	0.38	0.24	1.02	0.49	0.84
1.0	0.39	0.25	0.93	0.50	0.84
1.5	0.39	0.24	0.87	0.49	0.84
2.0	0.37	0.22	0.82	0.47	0.83
3.0	0.37	0.23	0.75	0.48	0.76
4.0	0.38	0.23	0.86	0.48	0.82
Averaged	0.38	0.24	1.02	0.49	0.84

Table B-10 Comparison betweem modelled temperature in Simulation-2 with observations at Kranji-1 Station

Depth (m)	Mean Averaged error (°C)	Mean square error	Standard deviation (°C)	Root mean square (°C)	Correlation coefficiecnt
0.5	0.35	0.21	1.02	0.46	0.84
1.0	0.36	0.22	0.93	0.47	0.84
1.5	0.36	0.21	0.87	0.46	0.84
2.0	0.35	0.19	0.82	0.44	0.84
3.0	0.33	0.17	0.77	0.42	0.82
4.0	0.34	0.21	0.75	0.45	0.77
Averaged	0.35	0.20	0.86	0.45	0.83

Table B-11 Comparison betweem modelled temperature in Simulation-3 with observations at Kranji-1 Station

Depth (m)	Mean Averaged error (°C)	Mean square error	Standard deviation (°C)	Root mean square (°C)	Correlation coefficiecnt
0.5	0.35	0.21	1.02	0.45	0.84
1.0	0.36	0.21	0.93	0.46	0.84
1.5	0.35	0.2	0.87	0.44	0.84
2.0	0.34	0.18	0.82	0.42	0.84
3.0	0.32	0.17	0.77	0.41	0.82
4.0	0.34	0.20	0.75	0.45	0.77
Averaged	0.34	0.20	0.86	0.44	0.83

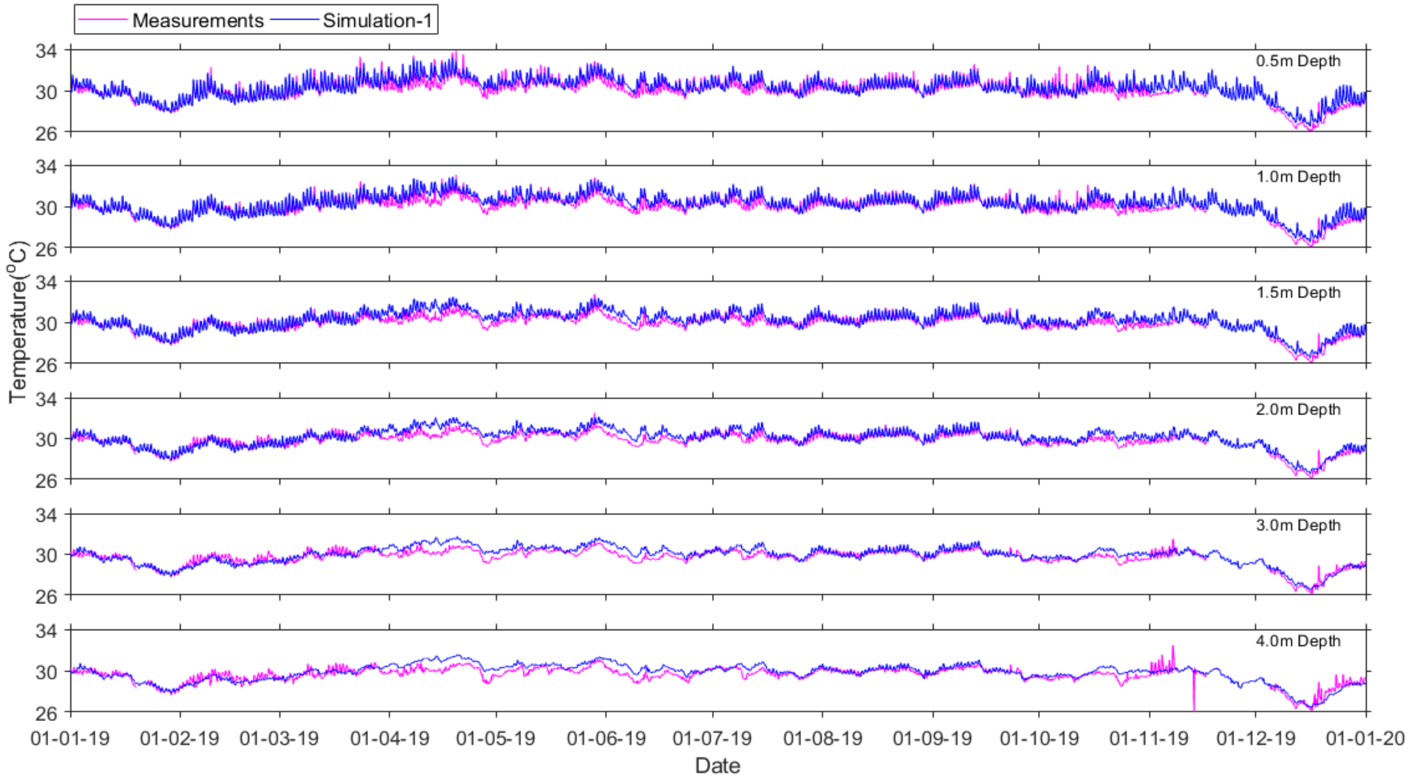


Figure B-15 Temperature in Simulation-1 and measurements at Kranji-1 Station at 0.5 m, 1 m, 1.5 m, 2 m, 3 m and 4 m below water surface during 1 Jan.–1 Jun. 2019

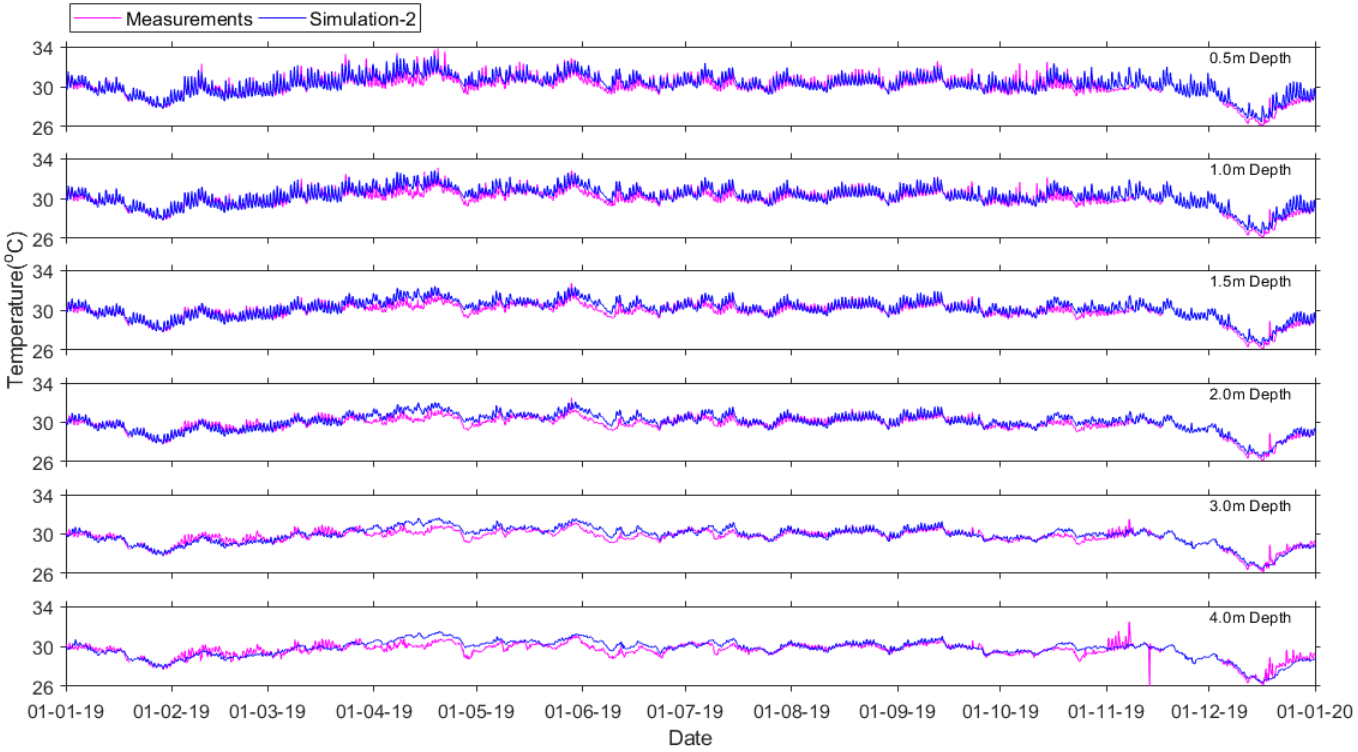


Figure B-16 Temperature in Simulation-2 and measurements at Kranji-1 Station at 0.5 m, 1 m, 1.5 m, 2 m, 3 m and 4 m below water surface during 1 Jan.–1 Jun. 2019

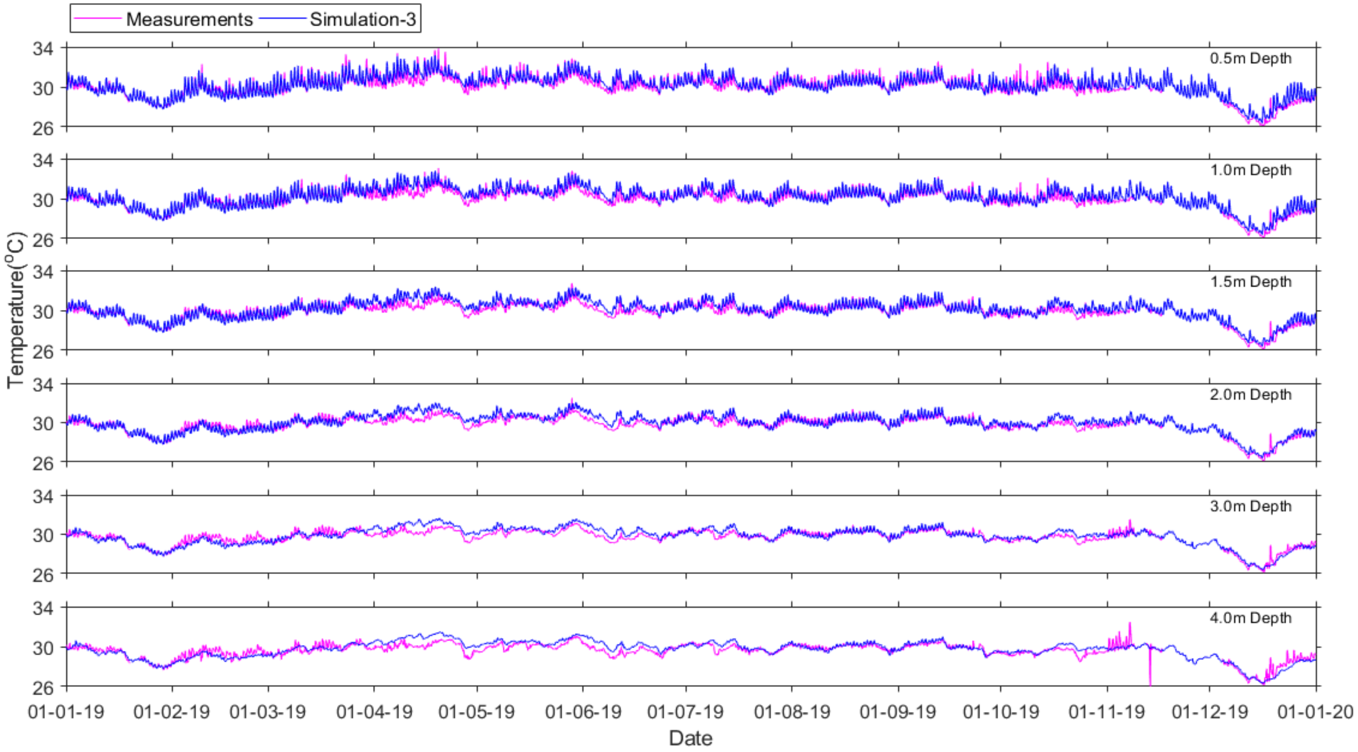


Figure B-17 Temperature in Simulation-3 and measurements at Kranji-1 Station at 0.5 m, 1 m, 1.5 m, 2 m, 3 m and 4 m below water surface during 1 Jan.–1 Jun. 2019

Kranji-2 Station

Table B-12, Table B-13 and Table B-14 present the statistics of modelled temperature with Simulations 1, 2 and 3 respectively as compared with observations at Kranji-2 Station. Figure B-18, Figure B-19 and Figure B-20 show computed temperature time series with Simulations 1, 2 and 3 (blue) in comparison with measurement (pink) at Kranji-2 Station at 0.5 m, 1.0 m, 1.5 m, 2.0 m, 4.0 m and 6.0 m below water surface.

At Kranji-2, Simulation-1 (initial model setup) also shows the greatest deviation in temperature from observations (Table B-12). An increase in ocean heat flux parameters (Simulation-2: Stanton number increases from 0.0011 to 0.0018) results in a slight decrease in modelled temperature, making it more consistent with the measurement data (Figure B-19). The overall MAE of temperature is reduced accordingly from 0.48°C to 0.46°C, MSE reduced from 0.34°C to 0.32°C and RMSE reduced from 0.58°C to 0.57°C, with correlation coefficient remained unchanged (Table B-12, Table B-13).

Simulation-3, which further increases Stanton number from 0.0018 to 0.0021 and the background horizontal viscosity/ diffusivity from 0.5 m^2/s to 1.0 m^2/s, demonstrates better model performance for temperature as compared to Simulation-2 (Table B-13, Table B-14). The overall MAE of temperature is reduced from 0.46°C to 0.45°C, MSE reduced from 0.32°C to 0.31°C and RMSE reduced from 0.57°C to 0.55°C with a slight increase in correlation coefficient from 0.69 to 0.71 (Table B-13, Table B-14).

In summary, the setup of Simulation-3 provides model outputs that best match the observed data at Kranji-2. Hence the model coefficients and setup adopted for simulation-3 is selected for baseline modelling and the following FPV testing scenarios.

Table B-12 Comparison betweem modelled temperature in Simulation-1 with observations at Kranji-2 Station

Depth (m)	Mean Averaged error (°C)	Mean square error	Standard deviation (°C)	Root mean square (°C)	Correlation coefficiecnt
0.5	0.51	0.43	1.09	0.65	0.71
1.0	0.5	0.38	0.99	0.61	0.72
1.5	0.46	0.31	0.93	0.56	0.74
2.0	0.43	0.27	0.92	0.52	0.74
4.0	0.48	0.31	0.9	0.56	0.64
6.0	0.5	0.36	0.87	0.6	0.58
Averaged	0.48	0.34	0.95	0.58	0.69

Table B-13 Comparison betweem modelled temperature in Simulation-2 with observations at Kranji-2 Station

Depth (m)	Mean Averaged error (°C)	Mean square error	Standard deviation (°C)	Root mean square (°C)	Correlation coefficiecnt
0.5	0.49	0.4	1.09	0.63	0.71
1.0	0.47	0.35	0.99	0.59	0.72
1.5	0.44	0.29	0.93	0.53	0.74
2.0	0.41	0.25	0.92	0.5	0.75
4.0	0.47	0.3	0.9	0.55	0.65
6.0	0.5	0.35	0.87	0.59	0.58
Averaged	0.46	0.32	0.95	0.57	0.69

Table B-14 Comparison betweem modelled temperature in Simulation-3 with observations at Kranji-2 Station

Depth (m)	Mean Averaged error (°C)	Mean square error	Standard deviation (°C)	Root mean square (°C)	Correlation coefficiecnt
0.5	0.48	0.38	1.09	0.62	0.72
1.0	0.46	0.33	0.99	0.57	0.73
1.5	0.43	0.27	0.93	0.52	0.75
2.0	0.4	0.24	0.92	0.48	0.76
4.0	0.45	0.28	0.9	0.53	0.67
6.0	0.49	0.33	0.87	0.58	0.6
Averaged	0.45	0.31	0.95	0.55	0.71

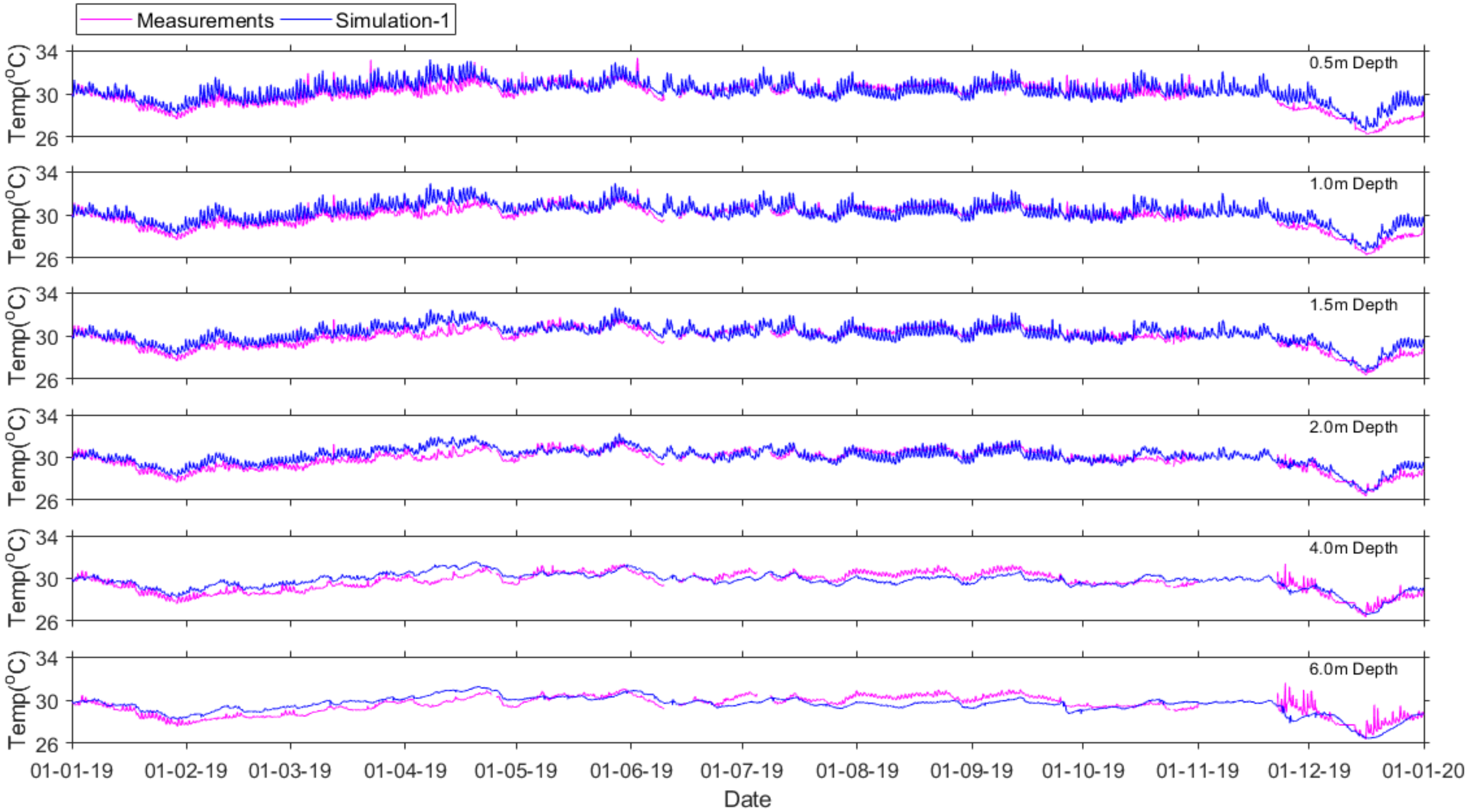


Figure B-18 Temperature in Simulation-1 and measurements at Kranji-2 Station at 0.5 m, 1 m, 1.5 m, 2 m, 4 m and 6 m below water surface during 1 Jan.–1 Jun. 2019

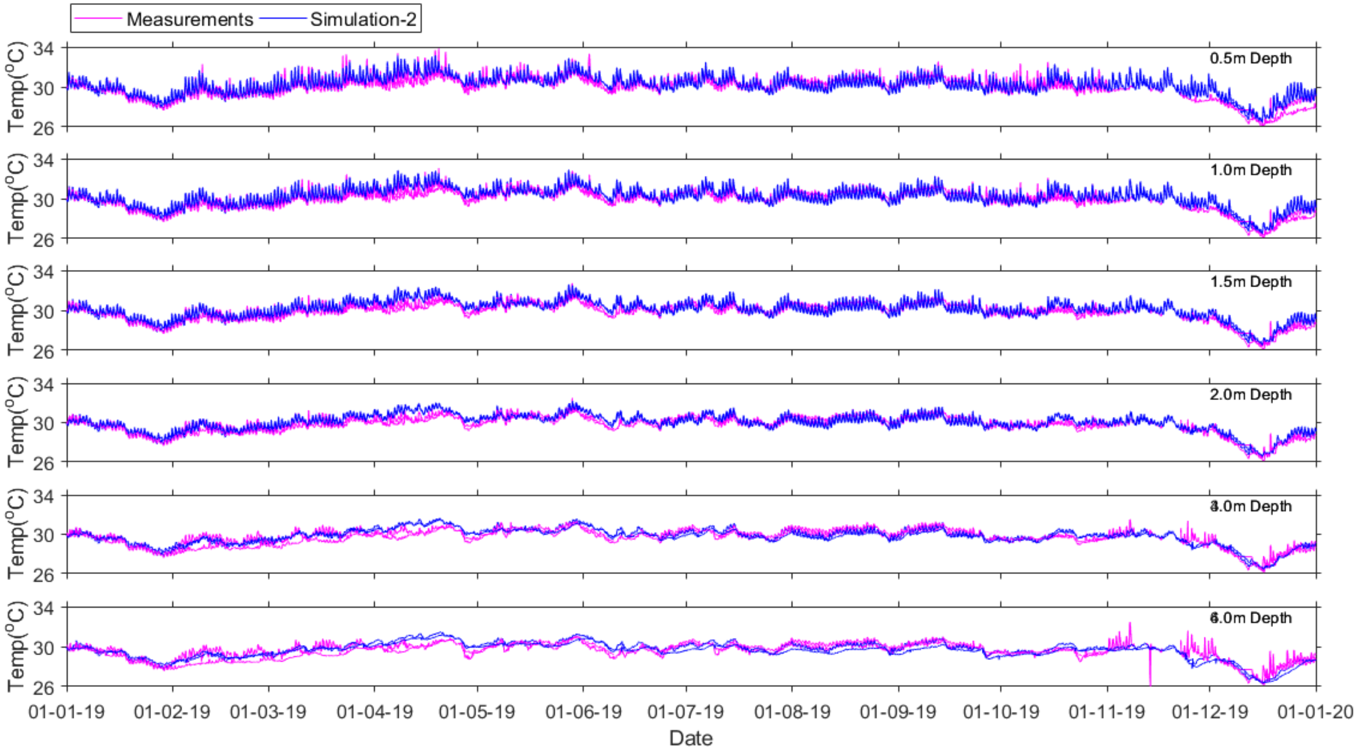


Figure B-19 Temperature in Simulation-2 and measurements at Kranji-2 Station at 0.5 m, 1 m, 1.5 m, 2 m, 4 m and 6 m below water surface during 1 Jan.–1 Jun. 2019

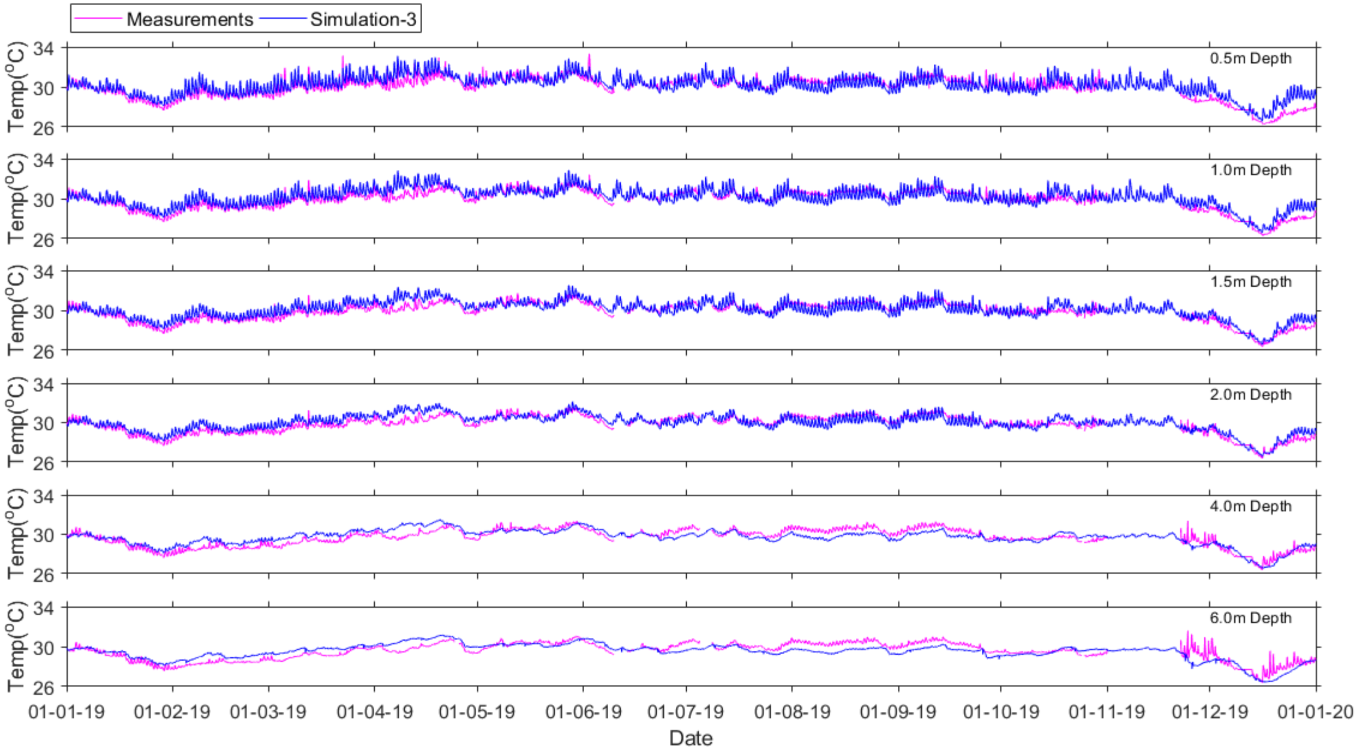


Figure B-20 Temperature in Simulation-3 and measurements at Kranji-2 Station at 0.5 m, 1 m, 1.5 m, 2 m, 4 m and 6 m below water surface during 1 Jan.–1 Jun. 2019

B.4 Conclusions

This Appendix B describes the modelling framework and information required to build the Kranji Reservoir 3D hydrodynamic model for the baseline scenario in 2019. Kranji Reservoir is modelled using a curvilinear grid with roughly 5,000 cells of 20 m x 40 m size. The model grid covers the main reservoir body and the major tributaries for baseline simulation and testing of different FPV scenarios. The orientation of the grid is aligned to the flow, and the land boundaries.

Model parameter settings used in Simulation-3 demonstrate the best model performance among all calibration cases. The Simulation-3 model results showed reasonable agreement with the temperature observations and modelled 2019 currents were in the same order as the current meter data collected in 2021. Thus, the Simulation-3 setup and model outputs are to be used as the inputs to the water quality model testing of different FPV scenarios.

Appendix C Delft3D-WAQ Model

The setup, calibration and validation of water quality model using Delft3D-WAQ has been described in the main report. This Appendix C presents additional information on the load balance and process coefficients used in the model.

C.1 Load Balance

Monthly load balance in 2019 at Kranji reservoir for TN, TP and TOC was calculated and is presented in the Figure C-1 to Figure C-3. It is assumed that the net reservoir mass change is influenced by the mass carried by inflows and outflows, and the internal change due to loadings to and from the sediment and resuspension processes, uptake by water borne algae and the mortality of algae that contributes to the detrital pool of TOC and nutrients. Hence, the mass contributed by the internal processes (i.e., negative means uptake/ settlement, positive means release) is calculated as (the net monthly reservoir mass change minus the net monthly inflow/outflow mass. The monthly mass balance helps understand whether the inflow/ outflow is the dominant source that affects the concentration/ mass in the reservoir, or whether reservoir internal loading (from sediment and biomass) makes a significant contribution.

The net mass changes of water quality parameters in the reservoir caused by inflows and outflows as well as internal loading are summarised in Table C-1 with negative values indicating net loss in loads from the reservoir. Besides the mass carried by inflows and outflows, reservoir mass storage and mass contribution by the sediment and biomass are also included in Figure C-1 to Figure C-3 for TOC, TN, TP to have an overview of the mass balance in the reservoir for each parameter. Note that the reservoir mass storage is estimated based on the reservoir sampling data and the reservoir water volume. The reservoir water volume at any time is estimated from the measured reservoir water level at that time and the storage level versus volume curve. The Chl-a load balance is not plotted because it is dominated by primary production in the reservoir. Similarly, for Total Suspended Solids (TSS), it is affected mainly by resuspension and other processes within the reservoir.

There is a net inflow of TN and TP into the reservoir from the catchment. The TN and TP concentration estimated in the reservoir (yellow lines in Figure C-2 and Figure C-3) are reasonably constant and hence the excess incoming TN and TP accumulates either in the sediment layer or in biomass (e.g., aquatic vegetation). TOC outflows are higher than catchment inflows. Therefore, the sediment layer and/ or biomass are expected to contribute to the TOC concentration in the water column.

Outflow quantities from Tidal Gate and RTUSR are summed up to get the total outflow next to the reservoir sampling data point RKR K2. Concentration data from RKR K2 is used for load estimation for Tidal Gate and RTUSR. Whereas for NT4CCKMUR, concentration data from RKR H2 is used. The outflowing loads are presented in the following section – Load Balance.

Table C-1 Net loads in the reservoir calculated from inflows and outflows in 2019 (in Kg)

Month	TOC (kg)	TN (kg)	TP (kg)	Chl-a (kg)	TSS (kg)
Jan	-1.98E+04	1.61E+03	1.21E+02	-8.59E+01	-3.17E+04
Feb	-1.10E+04	2.03E+03	1.41E+02	-3.99E+01	-3.01E+04
Mar	-8.73E+03	5.31E+03	4.52E+02	-9.56E+01	-3.61E+04
Apr	-2.55E+03	3.67E+03	1.40E+02	-8.13E+01	-3.28E+04
May	-9.94E+03	1.59E+03	-1.66E+01	-2.34E+02	-7.16E+04
Jun	-1.04E+04	2.96E+03	9.38E+01	-1.52E+02	-6.64E+04
Jul	-6.00E+03	4.32E+03	-6.69E+01	-1.47E+02	-2.50E+04
Aug	-2.01E+04	-6.72E+02	-3.43E+02	-2.20E+02	-6.16E+04
Sep	-1.00E+04	4.32E+03	8.74E+00	-1.70E+02	-4.37E+04
Oct	-1.05E+04	2.13E+03	-6.56E+02	-4.03E+02	-9.67E+04
Nov	-6.26E+02	8.20E+03	8.67E+02	-2.95E+02	-8.16E+04
Dec	-9.01E+03	5.12E+03	-2.69E+00	-3.43E+02	-1.35E+05

Note: Negative values indicate net loss in loads from the reservoir

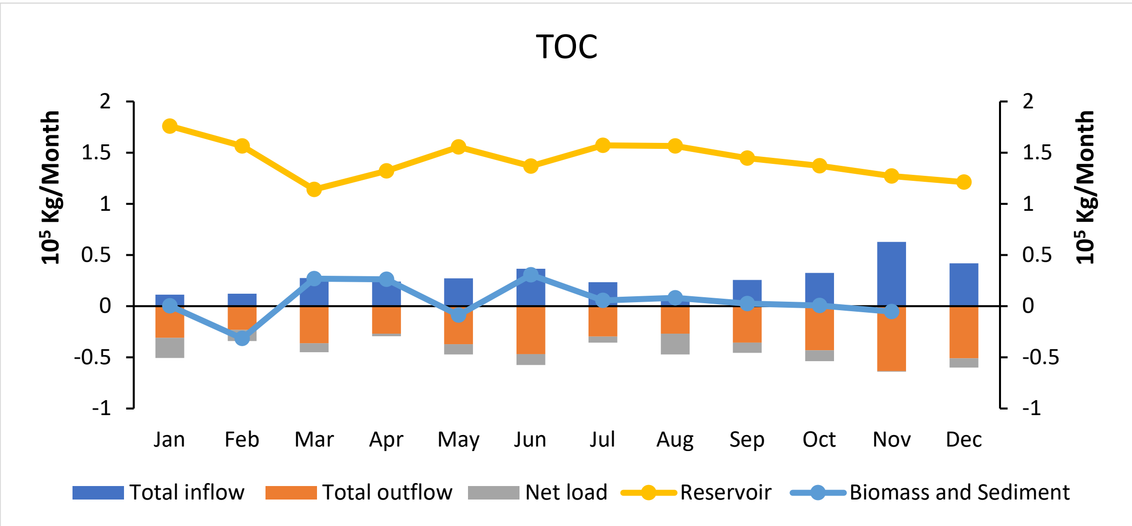


Figure C-1 Load balance for TOC in the reservoir in 2019 (right axis for line with markers)

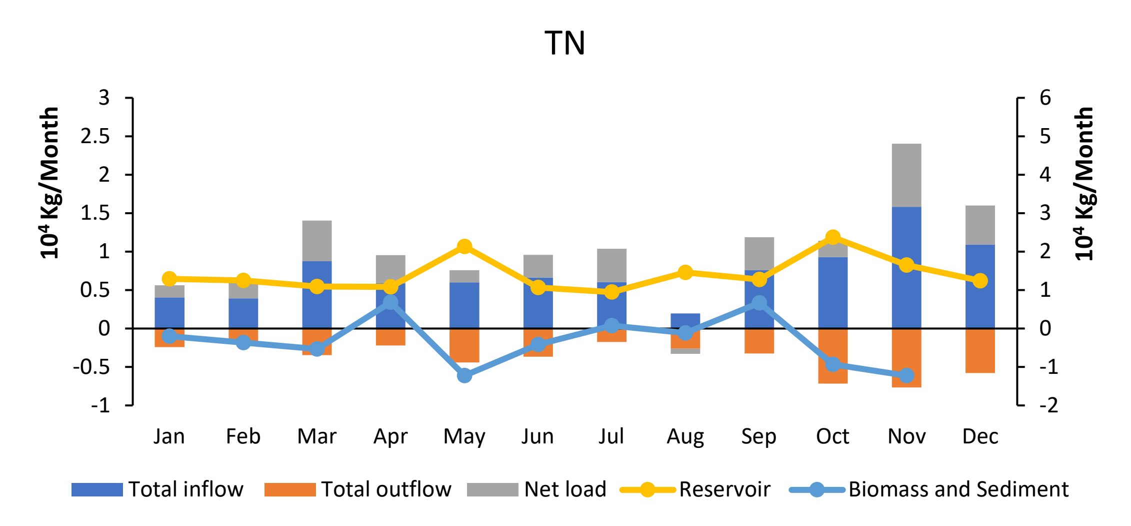


Figure C-2 Load balance for TN in the reservoir in 2019 (right axis for line with markers)

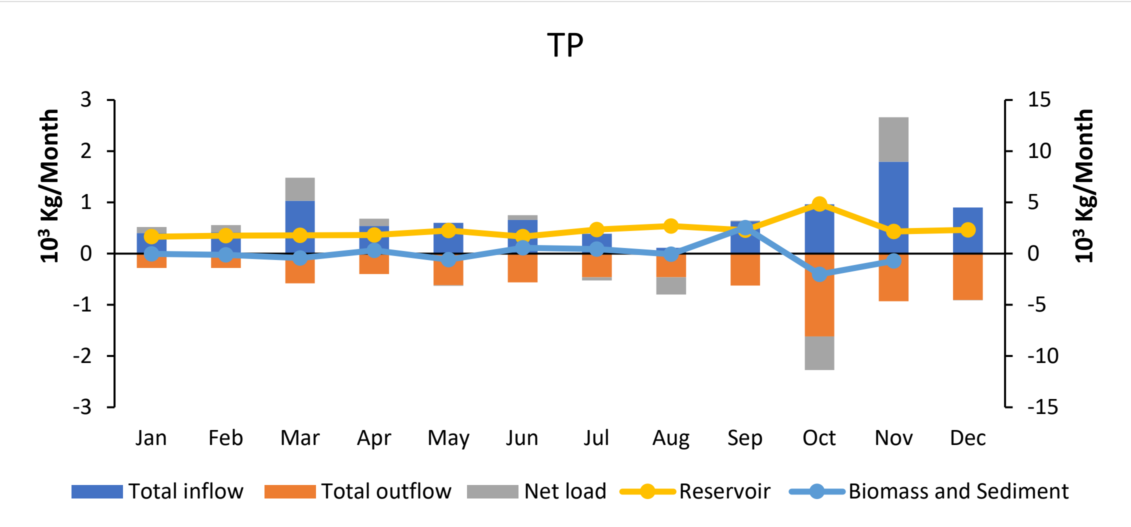


Figure C-3 Load balance for TP in the reservoir in 2019 (right axis for line with markers)

C.2 Results

Figure C-4 to Figure C-8 present the comparisons between simulated results for site RKR H2 at mid water layer and observations for the main water quality variables, TN, TP, TOC, TSS, Chl-a over the one-year baseline period (2019). Note that the model gives hourly outputs. For clearer illustration, modelled daily average, daily maximum and daily minimum are plotted in Figure C-4 to Figure C-8 to compare to the observations. The temporal variability was similar at the three sites RKR-H2, RKR-I2 and RKR-K2.

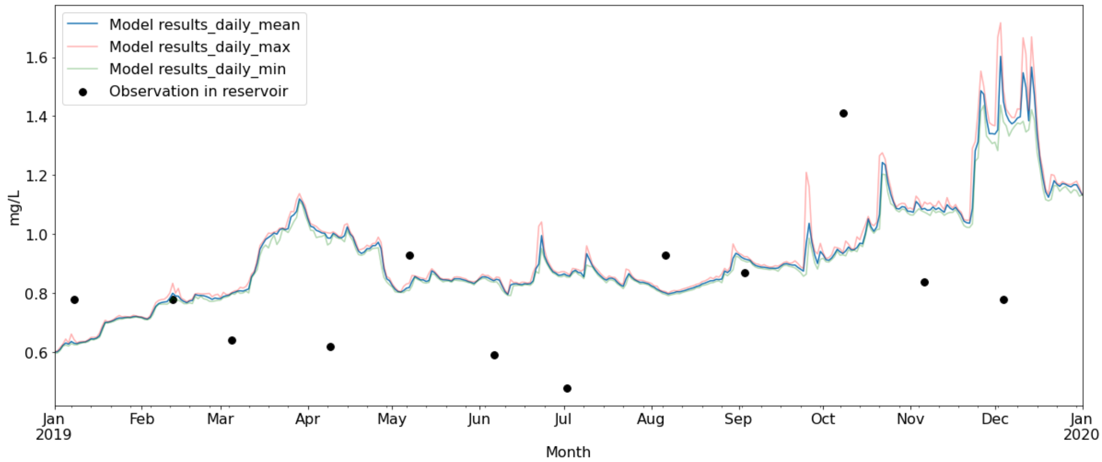


Figure C-4 Comparison of TN between Simulated and observations at Location RKR H2

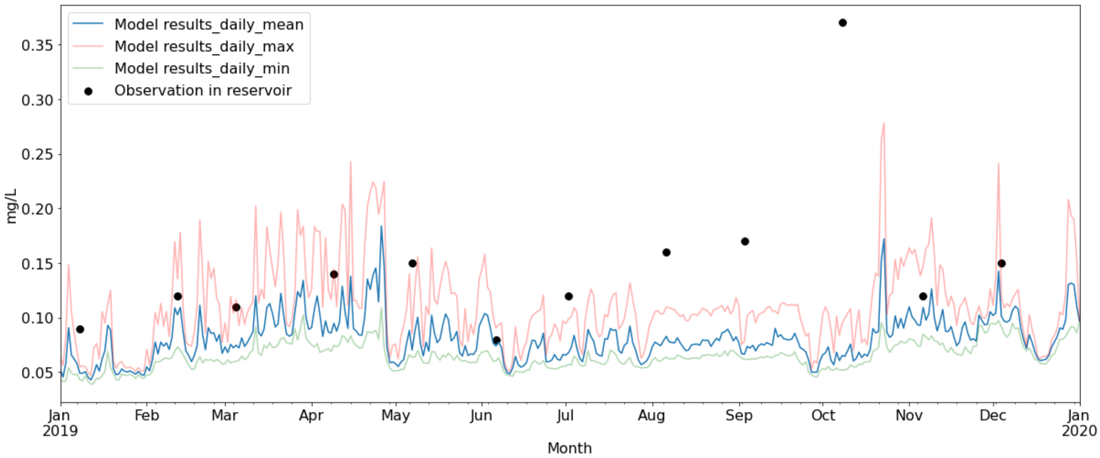


Figure C-5 Comparison of TP between Simulated and observations at Location RKR H2

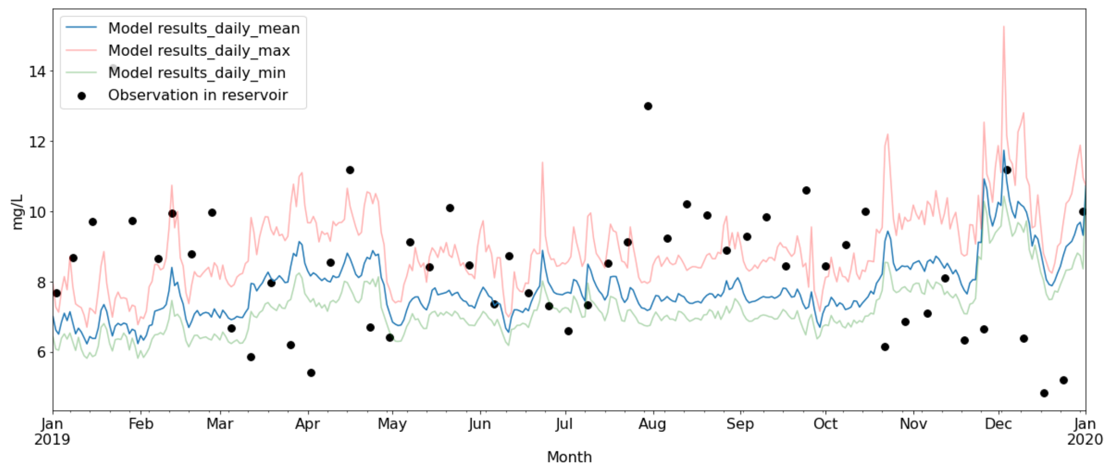


Figure C-6 Comparison of TOC between Simulated and observations at Location RKR H2

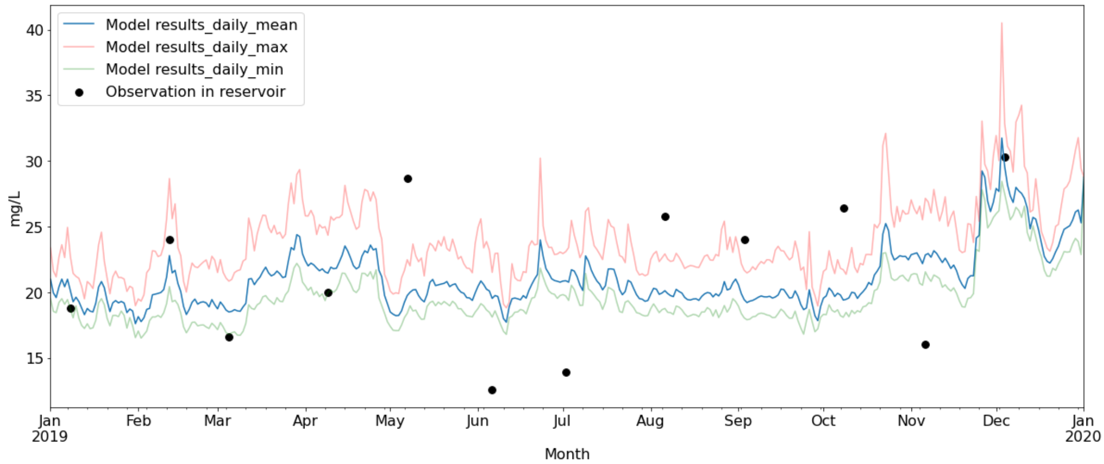


Figure C-7 Comparison of TSS between Simulated and observations at Location RKR H2

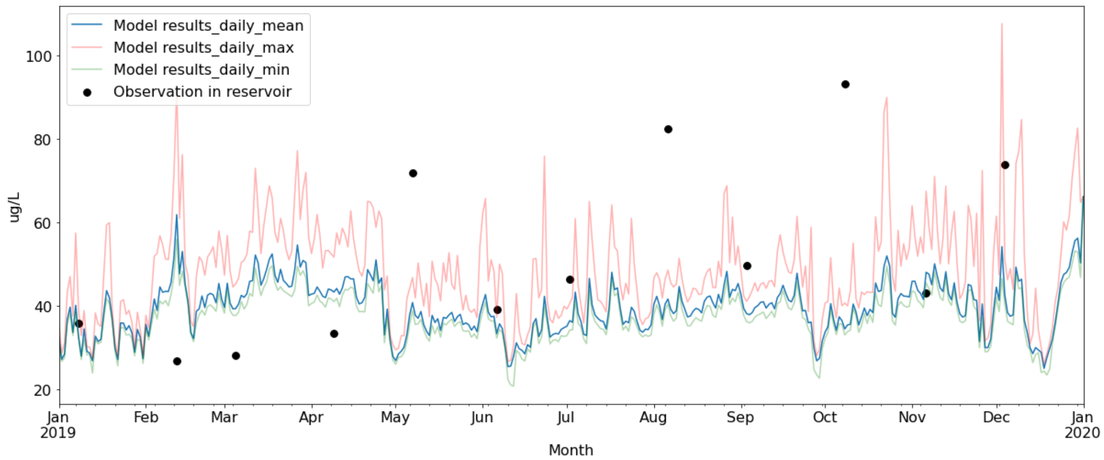


Figure C-8 Comparison of Chl-a between Simulated and observations at Location RKR H2

Appendix D Potential Issues from Aquatic Vegetation Removal

D.1 Introduction

Aquatic vegetation in Kranji reservoir may need to be trimmed to facilitate the FPV construction activities. If cut off and left in the reservoir, the cut-off vegetation (or organic matter) is likely to sink to the bottom of the reservoir and decompose, becoming an internal source of nutrients. This Appendix D discusses potential water quality issues regarding removal of aquatic vegetation using a step-by-step approach below:

1) Estimation of total nutrients mass in the reservoir based on aquatic vegetation survey conducted in March 2021.
2) Evaluation of potential release of carbon, nitrogen, and phosphorus from the cut-off vegetation in terms of availability and rate of release based on literature review.
3) Quantification of the mass/ flux of water quality parameters of concern simulated in the operation phase modelling exercise.
4) Comparison of the nutrients released from the cut-off vegetation mass against the mass/ flux in the water quality model.
5) Evaluation of the potential implications of the findings, limitation and uncertainties for the analysis, and recommendations.

The scenario presented in this appendix is a conservative scenario that assumes aquatic vegetation trimming activities (and thus, for example, construction activities) will be carried out simultaneously across the entire area covered by FPV and that vegetation will be cut-off down to 1 m below the water surface[1] all at once and left in the reservoir to decompose immediately prior to commencing construction. Furthermore, it is assumed that the decomposition process of all cut-off (including floating) vegetation will commence immediately. This scenario is an extreme case whereas actual scenario(s) are expected that the decomposition of biomass, and hence nutrient fluxes for actual scenario(s), will be of

[1] Trimming of the top 1m of aquatic vegetation was determined to be sufficient for construction activities related to deployment of the in-reservoir Project components (i.e. vessel movements). This trimming depth has been determined to be achievable based on discussion with PUB and inputs from PUB's existing aquatic vegetation management contractors.

lower magnitude. In addition, aquatic vegetation cut-off will in reality be in phases, as construction progresses. The Final Design, construction methodology and aquatic vegetation trimming schedule should be compared to the assumptions in this Appendix to review whether the current assumptions remain appropriate for the Final Design, construction methodology and aquatic vegetation trimming schedule.

This appendix also addresses the uncertainties associated with, for example, the construction method(s), because whether the aquatic vegetation requires trimming (or “cutting off” down to 1 m below the water surface) of vegetation depends on the method(s) selected. Furthermore, it is likely that the aquatic vegetation trimming activities will be phased (e.g. aligned to construction phasing) in sequence across the proposed FPV areas, resulting in small areas of vegetation needed to be trimmed at any one time. Hence, it is anticipated that the fraction of total vegetation biomass to be trimmed will generate a small increase of nutrient fluxes to the reservoir as trimming will be carried out over several months or years. It is therefore recommended that the potential change in water quality from the decomposition of cut-off/ trimmed aquatic vegetation be further evaluated once sufficient details on construction methodologies are available, thus allowing for a more substantiated estimation with fewer uncertainties. Mitigation measures, if deemed necessary, should then be recommended based on the updated evaluation findings.

In terms of potential change in water quality due to the assumed simultaneous cutting-off of aquatic vegetation from the full FPV area, and immediate commencement of decomposition of aquatic vegetation (within 1 month) deposited to the sediment layer, it is expected that there would be a resulting increase in sediment oxygen demand (SOD) and thereby reduced DO level in the affected areas, especially at the reservoir bed. The majority of vegetation cutting would likely be conducted in shallow areas, where most aquatic vegetation is observed and vertical mixing allows replenishment of bottom level DO, thus resulting in small, localised and likely insignificant levels of DO reduction.

Additionally, inclusion of this aquatic vegetation in the operation phase water quality simulation based on Delft3D’s macrophyte module is not recommended due to the lack of suitable information (e.g., biomass nutrients content, maximum depth to which specific species grow, leaf versus stem versus root biomass, temporal growth and senescence characteristics, temporal decay processes and conversion rates of leaves, stems and roots to detritus and to organic carbon) to calibrate the relevant parameters required for proper simulation. The parameterisation for the relevant Delft3D’s macrophyte module is extensive, and significant time and effort would be required to justify the selection of model calibration parameters. The inclusion of macrophyte in the simulation is also unlikely to benefit the water quality modelling exercise by reducing uncertainties in the nutrient pool. As such, further water quality modelling at this stage is considered to not yield meaningful outcomes in understanding potential water quality-related issues that may arise from the decomposition of aquatic vegetation biomass and subsequent nutrient fluxes due to aquatic vegetation cut-off and decomposition in Kranji Reservoir, e.g. during construction activities.

D.2 Aquatic vegetation biomass estimates and budget

To assess whether the decomposition of cut-off vegetation biomass may form a significant source of nutrients to the water column, the estimated nutrient mass contained in the cut-off vegetation is compared to the nutrient mass contained in other nutrient pools in the reservoir. Further, the potential flux of nutrients from decomposing cut-off vegetation is compared to the nutrient fluxes from other sources (e.g., catchment runoff, sediment exchange). It is assumed that:

1) the top 1-m of aquatic vegetation in the Reservoir Project Site area may need to be removed. This includes vegetation in ecologically sensitive areas which may be avoided in the Final Design. Aquatic vegetation removal may be required to facilitate navigation in the reservoir, however, it is noted that the construction of piles or anchor blocks is not likely to be hindered by the presence of aquatic vegetation.
2) all cut-off (including trimmed and floating) vegetation stays in the reservoir, sinks to the reservoir bed and starts decomposing all at once. In reality, it is likely that vegetation would be cut in stages (e.g. per the construction schedule) and there will be a time-lag between cutting vegetation and its sinking to the bed, or alternatively the cut vegetation may even be taken out from the reservoir (thereby limiting decomposition in the reservoir). However, as a conservative scenario, it is assumed cut-off vegetation will remain in the reservoir and not removed.
3) an extreme case where all vegetation surveyed (i.e. in whole water column) in the Reservoir Project Site area is removed and left in the reservoir to decompose all at once will be compared with the results of top 1-m vegetation cutting. It should be noted that this extreme case of all vegetation in the water column being cut is highly unlikely to be implemented as the potential disturbance to bed sediments caused by the removal of all vegetation would likely result in worsening water quality.

The total biomass of aquatic macrophyte vegetation contained in the Reservoir Project Site area was estimated by Hydrobiology based on field sampling carried out in March 2021. Nutrient mass contained in the aquatic vegetation was estimated from results of laboratory tests on grab samples in May 2021. The nutrient mass contained in the other "pools" (e.g., dissolved in the water column, phytoplankton biomass) in the reservoir were calculated from the results of a water quality model (Delft3D-WAQ) with 5 vertical layers in the reservoir. The water quality model has been set up based on the 20-layer hydrodynamic model, integrated available nutrient load data into physical, chemical, and biological processes in the water column and sediment compartments, and then calculated the temporal-spatial distribution of nutrient levels. Total nutrient mass was estimated from the model simulation results for May 2019.

The following aspects of potential issue(s) from aquatic vegetation removal are discussed:

1) Aquatic vegetation in the Reservoir Project Site area and associated nutrient mass.
2) Aquatic vegetation decomposition and potential nutrient flux into the reservoir from the decomposing vegetation.
3) Total nutrient mass in different pools in the reservoir from model estimation.
4) Comparison of nutrient flux from the cut-off (including floating) vegetation and nutrient mass in other pools in the reservoir.
5) Evaluation and recommendations.

D.2.1 Aquatic Vegetation in Reservoir Project Site Area

This section will provide a general overview of the aquatic vegetation found in the Reservoir Project Site area in Kranji Reservoir, the estimated vegetation biomass in the area of interest as well as the estimated nutrient (carbon, nitrogen and phosphorus) contents in the aquatic vegetation. More details about the biomass and nutrient content estimation are provided in section D.5.

D.2.1.1 Aquatic Vegetation Biomass Estimates

Aquatic submerged and emergent vegetation was surveyed and mapped to estimate the biomass and the total mass of nutrients contained within that biomass. A total of 112.90 ha of vegetation was mapped via sonar, while another 14 ha was inaccessible by boat due to hydrilla and lotus growth throughout the water column. However, an estimation of the biomass present in these inaccessible areas was included and accounted for in this assessment, since these locations are where biomass is expected to be greatest. Sampling sites and observed vegetation coverage are shown in Figure D-1.

Eleven types of aquatic vegetation were found in the reservoir, of which 5 types were partially submerged, 5 types were emergent aquatic vegetation, and the other one was found along banks and was considered a terrestrial rather than aquatic plant. The characteristics of the 11 aquatic plant species, along with their growth habits, are detailed in Table D-1.

D.2.1.2 Nutrient Budget in All and Top 1-m Aquatic Vegetation

Sonar measurement and imaging were used to identify areas covered with submerged vegetation and to provide estimates of the vegetation heights within the water column. It was anticipated that there will be high variability in the density of submerged vegetation due to varying light and substrate conditions at different depths. The resulting vegetated areas were separated into 5 zones, based on visual interpretation of vegetation density, bathymetry, and geographic location. These 5 zones were then the focus of ground-truthing and vegetation sampling (Figure D-1).

Sonar images were then re-analysed to interpret the maximum heights of vegetation that extended through the water column towards the surface (see example in Figure D-1), areas without vegetation in the upper 1 m of water column were excluded, leaving the map as shown in Figure D-3.

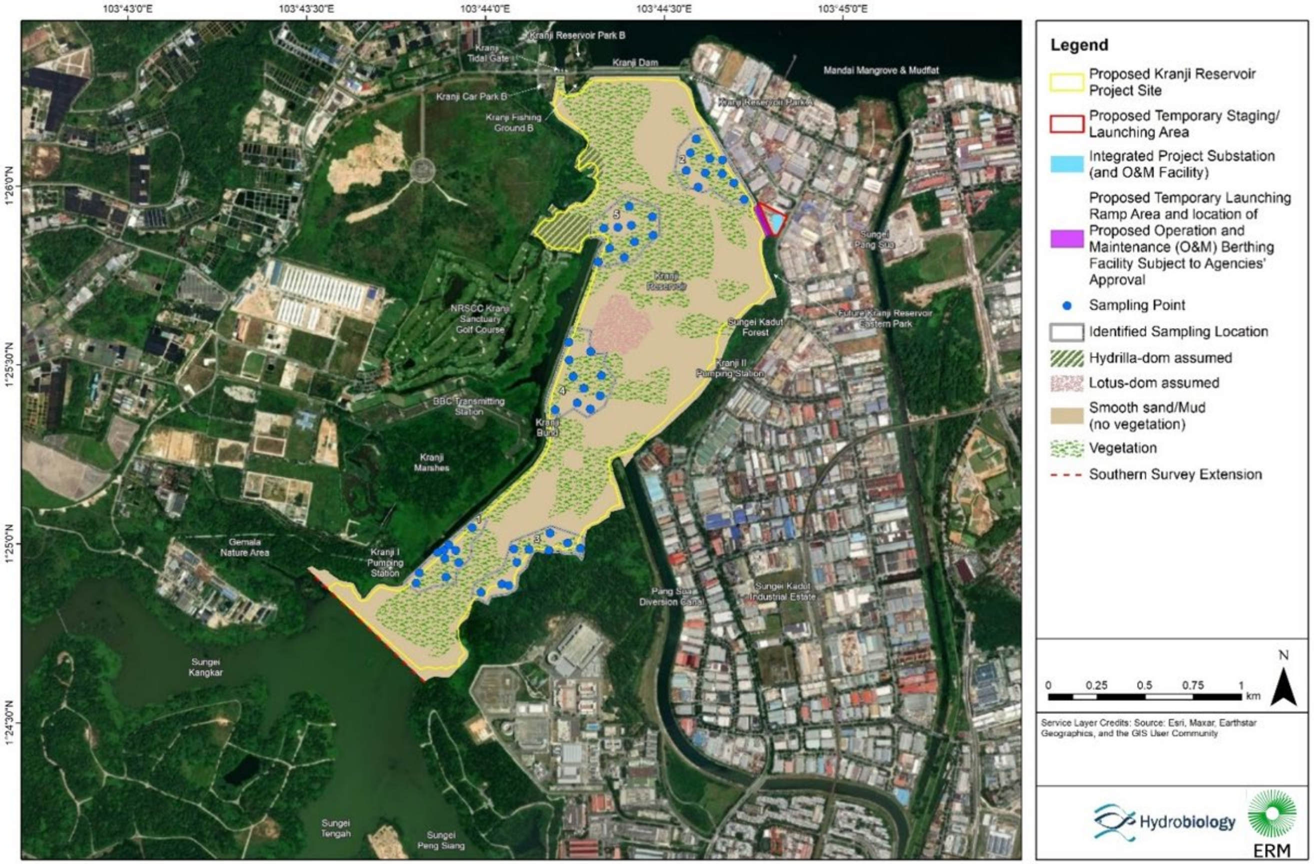


Figure D-1. Aquatic vegetation mapping in the entire water column in the Reservoir Project Site area. Numbers and different colours indicate nominal zones for biomass calculations

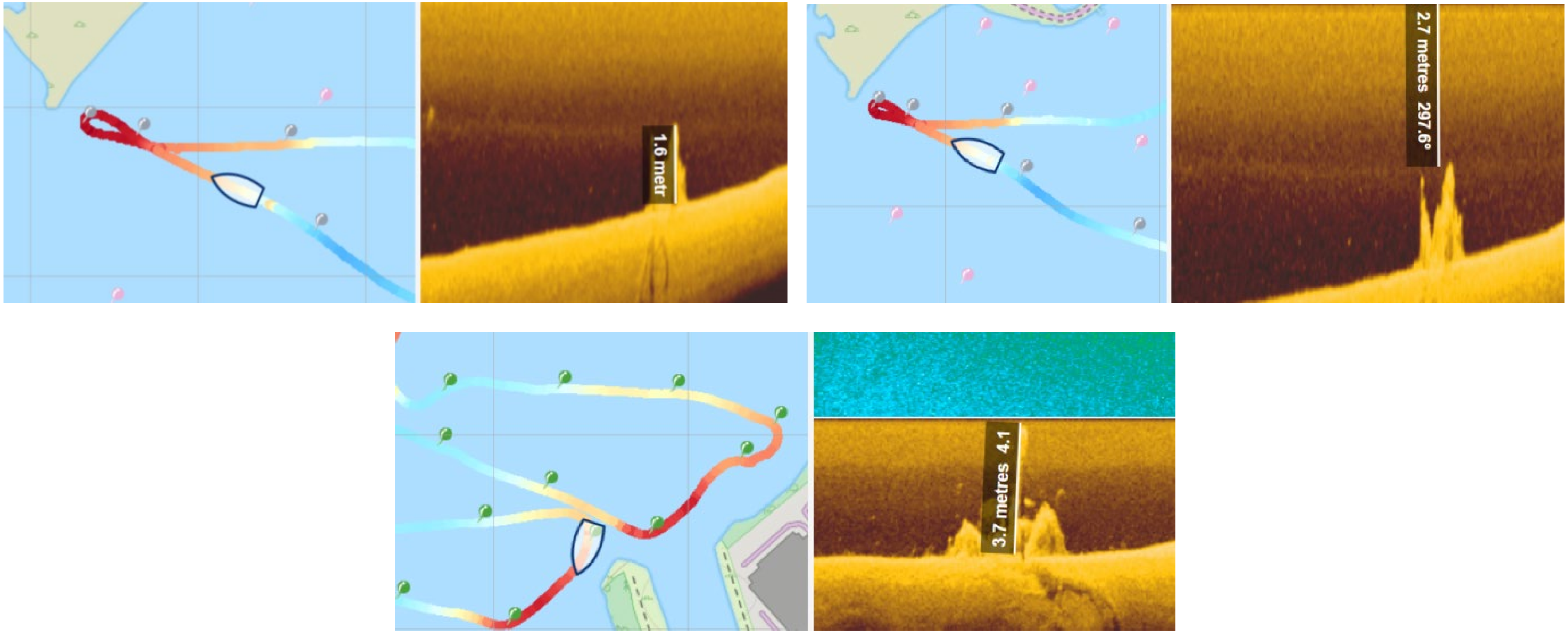


Figure D-2 . Sonar track with vegetation proud of the reservoir bed (metres are height of vegetation above reservoir bed)

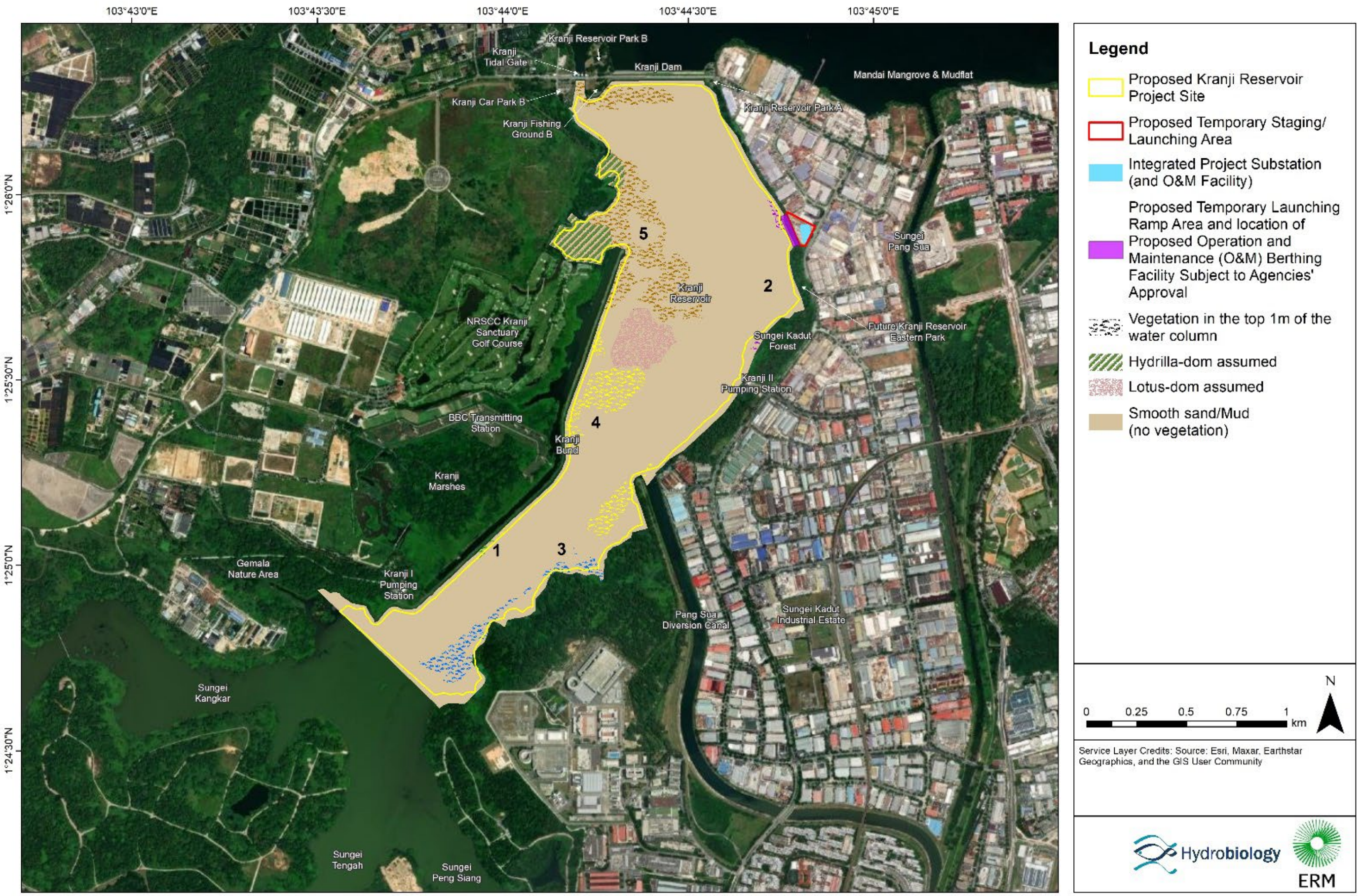
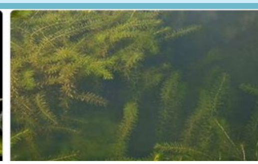


Figure D-3 Map of vegetation within top 1m of the water column in the Reservoir Project Site area. Numbers and different colours indicate nominal zones for biomass calculations

Table D-1 Submerged and emergent vegetation in Kranji Reservoir

Scientific name	Common name	Type	Notes	Examples
Hydrilla verticillata	Hydrilla	Partially submerged	Growth rate - double every 10 to 20 days. Meadows probably relatively stable in Kranji, i.e., they rapidly recover until reach self-limiting coverage. Variants can be tolerant of reduced light levels.	 
Nelumbo nucifera	Water lotus	Emergent	Seasonal development of the emergent leaf plate. Able to adjust to lower light levels (e.g., 50% reduction).	 
Pontederia crassipes	Water hyacinth	Emergent	Biomass can double in 6-14 days under conducive growth conditions. Able to grow under a broad range of light intensities.	 
Anubias lanceolata	-	Partially submerged	Grows slowly – typically takes 4-6 weeks for a new leaf to form. Preference for low to medium light conditions.	 
Philonotis spp	Green apple moss	Partially submerged	Limited data available.	 
Cabomba aquatica	Yellow Cabomba	Partially submerged	Grows fast – known to grow up to one inch a day. Requires moderate to high levels (100 µmols of PAR and above). Cannot adapt to low light conditions.	 

Scientific name	Common name	Type	Notes	Examples
Ludwigia adscendens	Water Primrose	Emergent	Fast growing. Requires full sunlight for growth.	 
Polygonum barbatum	Knotweed	Emergent	Able to grow in semi-shade or no shade.	 
Urochloa mutica	Para grass	Partially submerged	Tolerant of light shade but prefer full sun.	 
Neptunia oleracea	Water Mimosa	Emergent	Very fast growth rate. Can tolerate full sun to partial shade. Does not tolerate low levels of light.	 
Dillenia suffruticosa	Simpoh air	Not considered aquatic - found along banks	Average growth rate. Full sunlight is preferred but able to adapt to partial shade.	 

A total of 50 grabs were collected for identification and processed for loss-on-ignition and then sent to lab for TN, TP, and TC measurements. It was estimated that these vegetation samples have a total dry biomass of approximately 295 tonnes for all vegetation and 107 tonnes in the upper 1 m of vegetation in the water column. The estimated total nutrient budget for TP, TN, and TC from all submerged vegetation within the Reservoir Project Site area, and the upper 1-m in the water column are listed in Table D-2 (see section D.5 for more details).

Table D-2 Estimated total nutrient mass in aquatic vegetation in the Reservoir Project Site area

Nutrient	Total mass, all vegetation in water column (tonnes)	Total mass, vegetation in upper 1 m only (tonnes)
TP	0.57	0.15
TN	12.54	3.92
TC	101.62	36.78

Note that the estimates were based upon assumptions and extrapolation and have a high degree of uncertainty. For example, the vegetation biomass may vary seasonally but such effects are not captured with the current available data sets.

D.3 Aquatic Vegetation Decomposition and Potential Flux

D.3.1 Aquatic Vegetation Decomposition

It is assumed that most of the cut-off vegetation will sink and decompose at the bottom of the reservoir. The decomposition process involves the breakdown of dead organic plant material (leaves, stems, roots, etc.) through leaching and by microbial activity. These decomposition processes leave behind a layer of organic rich sediment and nutrients such as P and N are then available to be recycled back into the water column.

The decomposition of aquatic vegetation is largely dependent on the fibre content and C:N ratio of the plants with the general increasing resistance to decomposition being floating-leaved, submersed, and emergent species. Furthermore, it is known that the decomposition of organic matter from aquatic plants is a function of the plant species, ambient water temperature, growth form, lake/ reservoir morphology and circulation, grazing by detritivores, microbial dynamics, and other factors (Godshalk and Wetzel, 1978a; 1978b).

Laboratory and field experiments conducted for this Project found that in general, phosphorus is released during the decomposition faster than nitrogen and carbon. The concentration of

TP in water was found to increase rapidly within the first several days of plant decomposition (less than 10 days) and gradually levelled off toward the end of incubation period. Different species showed very different nutrient release rates (Li et al., 2006; Dierberg, 2009; Han et al., 2010; Wang et al., 2011, Wang et al., 2020). For example, Wang et al. (2011) observed that 30% of TP was lost within 20 days, and 50% of TP in plants was lost within 60 days for 6 types of common emergent aquatic plants, whereas Dierberg (2009) found that greater than 75% of initial P was lost after 3 weeks for *Hydrilla* and *Vallisneria*. Li et al. (2006) reported a decomposition experiment on leaves and petioles of *Nelumbo nucifera* (water lotus, emergent) and *Potamogeton maackianus* (pond weed, submerged) conducted in Lake Honghu in a temperate climate and showed that TP loss of 97.4%, 43.5%, and 78.3%, respectively at the end of a 480-day experiment.

In the decomposition process of plants, the release rate of phosphorus was observed to be much faster than that of nitrogen and organ carbon. Nitrogen release was found to be slightly faster than organic carbon (Han et al., 2010; Wang et al., 2011). TN loss of 97.2%, 21.6%, and 63.6%, from the leaves and petioles of *N. nucifera* and *P. maackianus* respectively was observed at the end of the referenced in-situ 480-day experiment above (Li et al., 2006).

Organic matter loss of 74-78% at 120 days for leaves and 87-94% at 1-year for stems was reported for 6 types of emergent aquatic plants (Wang et al., 2011). Various reports show partially submersed plant such as *Hydrilla verticillata* (Hydrilla) has a half-time of 69-156 days for the decay of organic matter (Castro et al., 2013; Wang et al., 2020). In a study in two tropical reservoirs, Castro et al. (2013) also found that 76.7% of particulate organic carbon (POC) was refractory fraction and 23.2 % was labile and soluble fraction, 11.2 % was dissolved organic carbon (DOC) for *Hydrilla verticillata*. As such one can expect a large fraction of organic matter will remain in the sediment.

Thus, compiling data on submersed and emergent species from previously mentioned research, enabled an estimate of the percentage loss for TP, TN, and TC during the first 30-day, 120-day, and a 30-day average (Table D-3). However, the decomposition process does not have a fixed pattern even for the same species because factors such as temperature, bacterial community, and oxygen levels in the surrounding environment play important roles in determining the actual decay rate of decomposing vegetation. Without detailed information on the percentage/ amount of each aquatic species, the average percentage loss figures are rough estimates assuming half of a vegetations mass was leaves and the other half was stems.

Table D-3. Estimated Percentage Loss on TP, TN, and TC Based on Published Studies

Nutrient	120 days	30 days	30 days (average)
TP	59-81%	25-75%	40%
TN	49-79%	10-40%	20%
TC	50-79%	7-47%	16%

D.3.2 Estimates of Decomposed Nutrients from Aquatic Vegetation Removal

The biomass from the top 1-m vegetation in the Reservoir Project Site area is estimated to have approximately 107 tonnes (dry weight), containing 0.15 tonnes of total phosphorus, 3.92 tonnes of total nitrogen, and 36.78 tonnes of total carbon. On average, as the vegetation decomposes at the estimated rate described in section D.2.1 the total nutrient fluxes of TP, TN, and TC from the top1-m cut-off vegetation, likely to be released into the reservoir are 0.05, 0.57, 3.17 tonnes in the first 30 days, respectively (Table D-4).

Similarly, the total nutrient fluxes of TP, TN, and TC from all aquatic vegetation in the Reservoir Project Site's water column are also calculated for reference and comparison (Table D-5).

Table D-4. Estimated Nutrient Flux from Top 1-m Cut-off Vegetation in the Reservoir Project Site area

Nutrient	Plant Mass (1-m Cut-off tonnes)	Percentage of Mass Decomposed in 30-day (Ave)	Mass released within 30 days (tonnes)
TP	0.15	40%	0.06
TN	3.92	20%	0.78
TC	36.78	16%	5.88

Table D-5. Estimated Nutrient Flux from All Vegetation in the Reservoir Project Site area

Nutrient	Plant Mass (tonnes)	Percentage of Mass Decomposed in 30-day (Ave)	Mass released within 30 days (tonnes)
TP	0.57	40%	0.23
TN	12.54	20%	2.51
TC	101.62	16%	16.26

D.4 Nutrient Mass in Other Pools in Kranji Reservoir

D.4.1 External Nutrient Flux into/out of the Reservoir

External fluxes of TP, TN, and TC into and out of the Kranji Reservoir were calculated based on collected data and the Delft3D WAQ water quality model mass balance output files.

Atmospheric deposition of PO_4, NH_4 and NO_3 were also summed for the month of May 2019. A summary of these fluxes is presented in Table D-6.

Table D-6. External flux of Nutrients tonnes into/out of Kranji Reservoir in May 2019

Fluxes	Boundary/ Load Inflow	Boundary/ Load Outflow	Atmospheric Deposition
TP	0.79	0.48	0.0042 (PO4)
TN	7.39	3.27	0.58 (NH4+NO3)
TC	140.92	33.49	-

D.4.2 Mass of Nutrient Pools in the Reservoir

Water quality model results were extracted to estimate the mass of nutrients (TN and TP) and carbon in different nutrient pools within the reservoir. The Delft3D WAQ model were integrated across the reservoir bed and within the water column to compute the concentration and total mass in each pool - in the water column, in the phytoplankton biomass, and flux from/ to the sediment pools. The total mass of nutrients in the water column pools is estimated using the modelled nutrient concentration and estimated water volume.

The sedimentation flux describes the combination of settling of suspended particles, debris, and algae from the water column to the sediment layer, and mineralisation of organic matter in the sediment. Mineralisation is the process leading to the release of dissolved inorganic nutrients from sediment layer back into the water column. The fluxes for each of these two processes were calculated from the water quality model results.

Results of the mass balance estimates are presented in the following sections for TP, TN, and TC, respectively.

D.4.3 Mass of Total Phosphorous in the Reservoir

A summary of TP concentrations and total mass in water column, in phytoplankton, and in the sediment pools for the month of May 2019 and monthly average is listed in Table D-7. According to water quality model results, the water column contains the most TP in the reservoir. Results also show data from the month of May 2019 is representative throughout the year in Kranji Reservoir.

Table D-7. Estimated TP mass in different nutrient pools in the reservoir

Parameters/Duration	TP in Water Column (excl. Algae)	TP in Phytoplankton	TP in Sediment
Month of May 2019	0.17 mg/L	0.02 mg/L	0.07 gP/m^2

	1.61 tonnes	0.18 tonnes	0.30 tonnes
Monthly Average	0.15 mg/L 1.42 tonnes	0.02 mg/L 0.19 tonnes	0.06 gP/m^2 0.25 tonnes

The sedimentation and mineralisation fluxes, 1.51 and 1.28 tonnes, respectively, were also calculated from water quality model results. These two processes are the most significant contributors (more than twice the magnitude) of all fluxes into and out of water column and hence are main factors in determining the water quality variability in the reservoir.

D.4.4 Mass of Total Nitrogen in the Reservoir

Similarly, the modelled TN results were extracted to estimate the concentrations and total mass of TN in the different nutrient pools listed in Table D-8.

Table D-8. Estimated TN mass in different nutrient pools in the reservoir

Parameters/Duration	TN in Water Column (excl. Algae)	TN in Phytoplankton	TN in Sediment
Month of May 2019	0.59 mg/L 5.59 tonnes	0.23 mg/L 1.98 tonnes	0.84 gN/m^2 3.58 tonnes
Monthly Average	0.60 mg/L 5.69 tonnes	0.24 mg/L 2.06 tonnes	0.73 gN/m^2 3.10 tonnes

The fluxes for sedimentation and mineralisation processes were also calculated to have 20.91 and 19.27 tonnes, respectively for the TN, based on water quality model results for the month of May 2019. Similar to the TP results, sedimentation and mineralisation fluxes are more than twice the magnitude of the other fluxes into and out of water column, further highlighting that these two processes could be main factors in determining the water quality variability in the reservoir.

D.4.5 Mass of Total Carbon in Water Column

The average concentrations and total mass of TC in different carbon pools in the reservoir are listed in Table D-9.

Table D-9. Estimated TC mass in different pools in the reservoir

Parameters/Duration	TC in Water Column (excl. Algae)	TC in Phytoplankton	TC in Sediment
Month of May 2019	6.89 mg/L 65.32 tonnes	1.82 mg/L 15.46 tonnes	19.53 gC/m^2 82.81 tonnes
Monthly Average	7.21 mg/L 68.35 tonnes	1.91 mg/L 16.21 tonnes	17.33 gC/m^2 73.47 tonnes

Water quality model results indicated the sedimentation and mineralisation fluxes for the month of May 2019 were 237.60 and 201.33 tonnes, respectively, and are important factors for TC in the water column.

D.5 Comparison of Nutrients in Estimated Vegetation and Other Pools

According to the in-situ survey and vegetation mapping for submerged vegetation within the Reservoir Project Site area conducted by Hydrobiology, and preliminary research on cut-off vegetation decomposition, the cut-off/ trimmed (including floating) and discarded vegetation biomass from top 1 m of the water column, potentially releases 0.06, 0.78, 5.88 tonnes of TP, TN, and TC, respectively within the first 30 days into the reservoir (last column in Table D-10).

The monthly total mass in water column (excluding algae) and phytoplankton in the reservoir, and monthly fluxes of inflows, outflows, sedimentation, mineralisation, and atmospheric deposition are also summarised in Table D-10.

These estimates indicate that nutrient budget from the cut-off vegetation in the upper 1 m of the water column is a small source of nutrients to the reservoir. The numbers are estimated upon 100% decomposition to dissolvable nutrients to the water column. Some portion of the nutrient may be refractory and is likely to be remained in the sediment, especially for the TC as indicated in the study of hydrilla in two tropical reservoirs by Castro et al. (2013).

Table D-10. Summary of total mass/fluxes of TN, TP, TC in the Month of May 2019

Nutrient	Inflow Loads (tn/month)	Outflow Loads (tn/month)	Water Column (excl. algae) (tn)	Phytoplankton (tn)	Sedimen-tation (tn/month)	Minera-lisation (tn/month)	Atmospheric Deposition (tn/month)	1-m Vegetation (30-d) (tn/month)
TP	0.79	0.48	1.61	0.18	1.51	1.28	0.0042	0.06
TN	7.39	3.27	5.59	1.98	20.91	19.27	0.58	0.78
TC	140.92	33.49	65.32	15.46	237.60	201.33	-	5.88

Schematics of mass and fluxes for TP, TN, and TC in the reservoir system (including fluxes from the decomposition of top 1-m cut-off vegetation) are presented in Figure D-4, Figure D-5 and Figure D-6 respectively for the month of May 2019, assuming the Delft3D WAQ results for May 2019 are consistent with May 2021 when the vegetation biomass sampling was carried out.

Overall, during the first 30 days, if the top-1m aquatic vegetation will be cut off all at once and it starts decomposing and releasing TP, TN, and TC, the added nutrient mass will be approximately 3%, 3%, and 2% of the existing fluxes (inflow, mineralisation, and atmospheric deposition) in the reservoir, respectively. The decomposition process slows down after the first month, and the nutrient fluxes to the water column will be released gradually and in smaller amounts than the 1st month.

In an extreme case, assuming all vegetation in the Reservoir Project Site area will be removed all at once and start decomposing and releasing nutrients to water column, the addition of TP, TN, and TC biomass in the 1st month will be approximately 11%, 9%, and 5% of the existing fluxes of the reservoir (estimated using the data in Table D-5 and Table D-10).

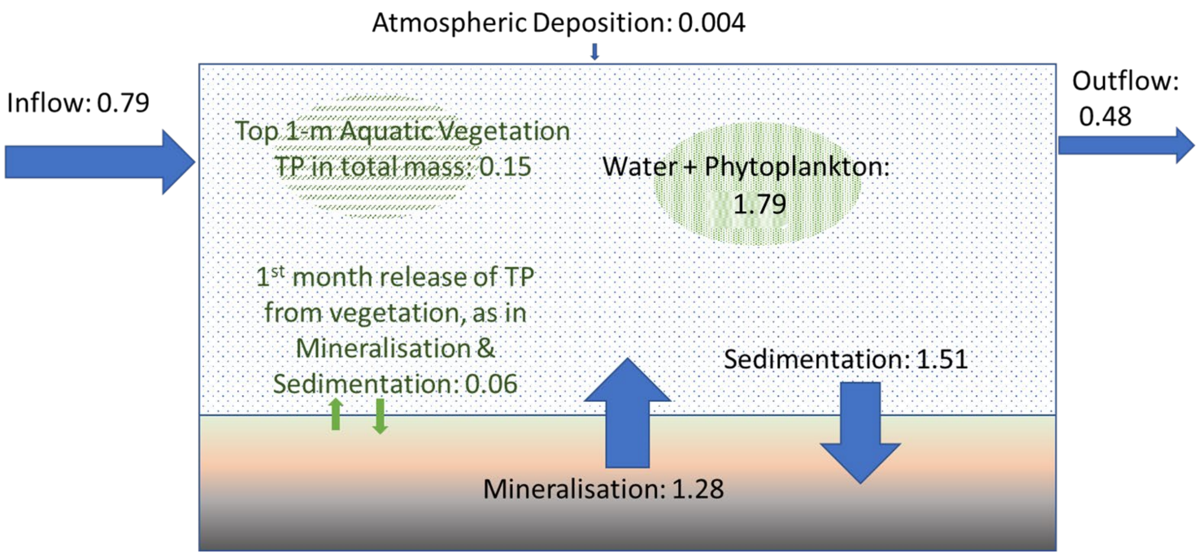


Figure D-4. Estimated TP mass and fluxes for the month of May including flux from the decomposition of top 1-m cut-off vegetation, tonnes

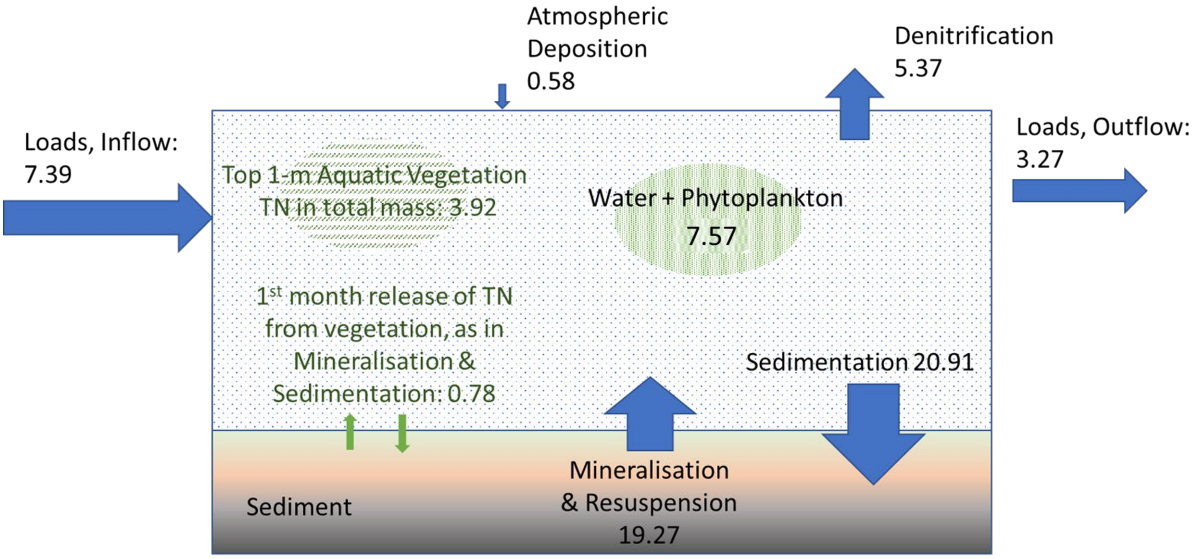


Figure D-5. Estimated TN mass and fluxes for the month of May including flux from the decomposition of top 1-m cut-off vegetation, tonnes

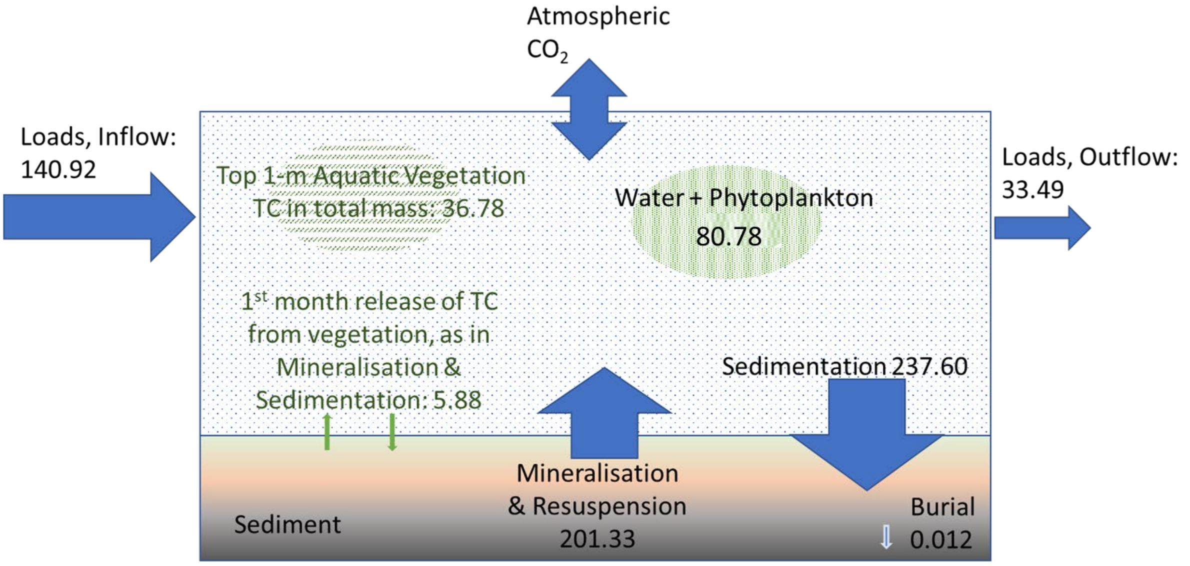


Figure D-6. Estimated TC mass and fluxes for the month of May including flux from the decomposition of top 1-m cut-off vegetation, tonnes

D.6 Conclusions

From section D.4 and D.5, assuming all TP, TN, and TC in the upper 1-m cut-off (including floating) vegetation to be released in the 1st month will be mineralised and released to the water column, the addition of nutrient mass will be approximately 3%, 3%, and 2% of the existing input fluxes (inflow, mineralisation, and atmospheric deposition) into the reservoir in

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30 days, respectively. These nutrient inputs are less than the variations in monthly fluxes for the catchment runoff (see *Appendix 6.1 Water Quality Modelling Technical Appendix*, *Appendix A* above). Daily release of nutrients from the decomposition will be very small and limited to local areas.

In an extreme case with all aquatic vegetation in the whole water column in the Reservoir Project Site area being cut off at once, decomposing and releasing nutrients to water column, the addition of TP, TN, and TC biomass in the 1st month will be approximately 11%, 9%, and 5% of the existing fluxes of the reservoir, respectively.

Further, it is noted that laboratory studies inferred that a part of the refractory biomass will likely be buried under ensuing deposition and subsequent formation of sediment layers and its slow decomposition will have negligible contribution to nutrient fluxes to the water column. Hence it is likely that the fraction of total biomass to be trimmed and left in the reservoir will generate only a very small increase the sediment fluxes to the reservoir.

The required extent of aquatic vegetation trimming depends upon the Final Design, construction methodology and aquatic vegetation trimming schedule. It is likely that only small areas would need to be trimmed in sequence as activities progress across the Reservoir Project Site area. In addition, should the aquatic vegetation trimmings, such as cut-off lotus stems and leaves, be collected and removed from the reservoir (as is the current practice by PUB) the decomposition of aquatic vegetation and contribution to nutrient fluxes will be notably reduced.

It is recommended that Final Design, construction methodology and aquatic vegetation trimming schedule be compared to the assumptions in this appendix to review whether the current assumptions remain appropriate for the Final Design, construction methodology and aquatic vegetation trimming schedule; and, if necessary, assess the potential need for mitigation measures.

Potential considerations concerning the vegetation removal estimates are of the following.

Consideration 1. Contribution of trimmed macrophyte vegetation biomass to sediment fluxes

The potential for trimmed macrophyte (predominantly hydrilla) vegetation to contribute to the nutrient load to the reservoir has been estimated using best available information with uncertainty of around 200%. The information suggests trimming could contribute to the nutrient flux from the sediment by up to 8% in the first month of trimming and decrease gradually in the following months. This is a conservative estimate that assumes all the trimmed vegetation material is available to be decomposed, when it is highly likely that a sizeable refractory fraction will be buried and take longer to contribute to flux from the sediment.

Consideration 2: Potential for the trimmed macrophyte decomposition to increase SOD and lower DO in water column

If cut-off vegetation is left in the reservoir, it will likely disperse some short distance before settling to the bed. The subsequent decomposition of the lighter cut-off organic material may lead, in the short term, to an increase in sediment oxygen demand (SOD) and a local reduction in the dissolved oxygen concentration in the near-bed waters. In the longer term, particulate refractory material is likely to accumulate in the sediments similar to the natural senescence that occurs with the annual mortality of plant biomass. Furthermore, the majority of vegetation removal is likely to be required in shallow areas where vertical mixing and replenishment of near-bed oxygen from the water surface maintains higher dissolved oxygen concentrations. This process is likely to further reduce the predicted effects of the proposed aquatic vegetation management by trimming.

D.7 References

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Sub-Appendix D-A Estimation of submerged vegetation biomass (conducted by Hydrobiology)

A combination of two methods – sonar measurement and imaging and grab/ rake dragging method were used for this survey.

Sonar measurement and imaging

The use of the sonar measurement and imaging allowed the identification of areas covered with submerged vegetation and estimates of the vegetation heights. It is anticipated that there will be high variability in the density of submerged vegetation due to varying light and substrate conditions at different depths.

The aquatic habitat assessment method involved sonar measurement of water depth, bottom roughness and bottom hardness using a side scan sonar and imaging of habitat features using the high-resolution side-scan and downward imaging sonar (Figure SD-0-1). The data collected in the field were then identified, quantified and mapped.

The vegetation mapping was done using a Humminbird Helix-9 MEGA and Transducer. The device is equipped with a combined GPS, side-scan, down-imaging, and down-beam data sources. During the side-scan sonar surveys, the transducer was attached to the side of a boat, facing vertically down towards the bed. The boat drove along transects and maintained a consistent speed of approximately 4 knots (nautical miles per hour).

The resulting vegetated areas were separated into 5 zones, based on visual interpretation of vegetation density, bathymetry and geographic location. These 5 zones were then the focus of ground-truthing and vegetation sampling (Figure SD-0-2).

Grab sampling

Samples of vegetation were collected via either an Ekman-grab or rake-dragging at identified locations/ clusters of vegetation within the reservoir based on sonar imaging maps. The map was categorised into 5 zones where 10 samples per zone was collected either by grab sampling or rake dragging of the reservoir bed (23 x 23 cm). Once a vegetated area was identified and photographed, aquatic vegetation samples were collected and subsequently washed to remove residual woody debris or other impurities. The wet and dried weight of each plant, inclusive of leaves, stems and rhizomes, was weighed and recorded. The dried sample was then sent to a laboratory for analysis of Total Nitrogen (TN), Total Phosphorous (TP) and Total Carbon (TC).

Biomass Estimates

The results of the wet and dry samples were extrapolated across each zone to provide an estimate of biomass within the water column at the time of sampling. The most heavily vegetated areas that had growth of either hydrillla or lotus throughout the water column were not able to be sampled due to boat accessibility issues. For these areas, estimates are based on the upper densities recorded from grabs in Zone 5.

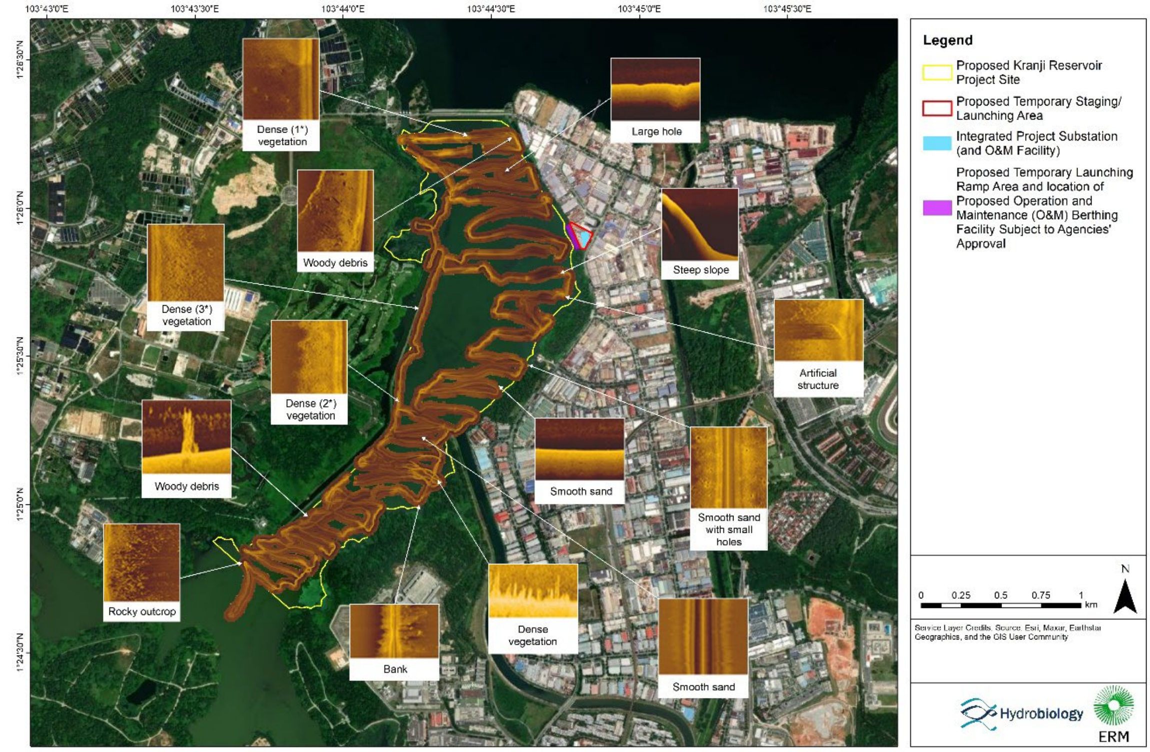

Figure SD-0-1 Sonar map with examples of reservoir-bed features

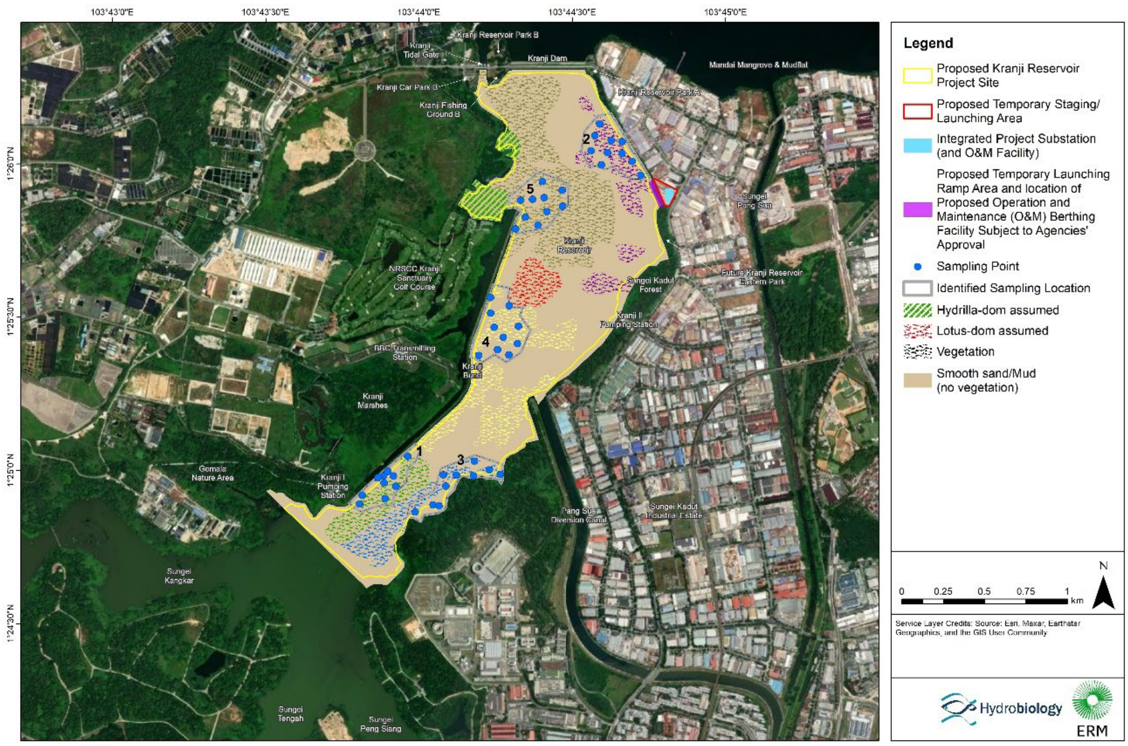

Figure SD-0-2 Submerged vegetation map, numbers and colours indicate different zones, blue points indicate sample locations.

Vegetation estimates in the upper 1m of Kranji reservoir

Sonar images were then re-analysed to produce a map with indicative heights of submerged vegetation in Kranji Reservoir. Some examples of the sonar track are provided in Figure SD-0-3. By interpreting the maximum heights of vegetation extended through the water column towards the surface, areas without vegetation in the upper 1m of water column were excluded, as shown in Figure SD-0-4. Estimates of biomass are provided in Table SD-1. The bulk of the surficial vegetation is found in the central western portion of the Reservoir Project Site area.

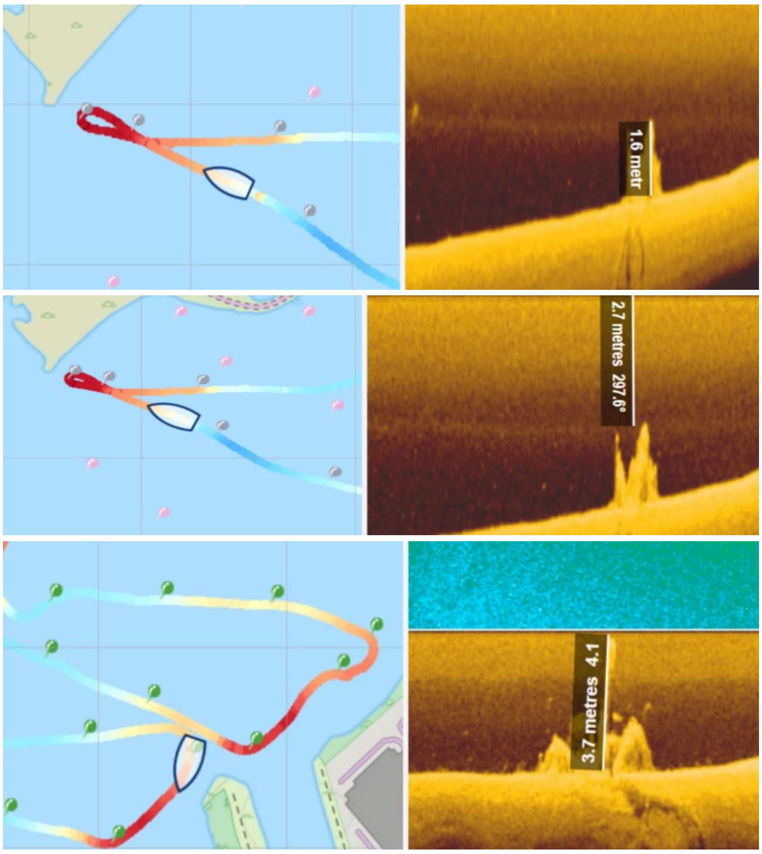

Figure SD-0-3 Sonar track with vegetation proud of the reservoir bed, latter image probably a tree stump

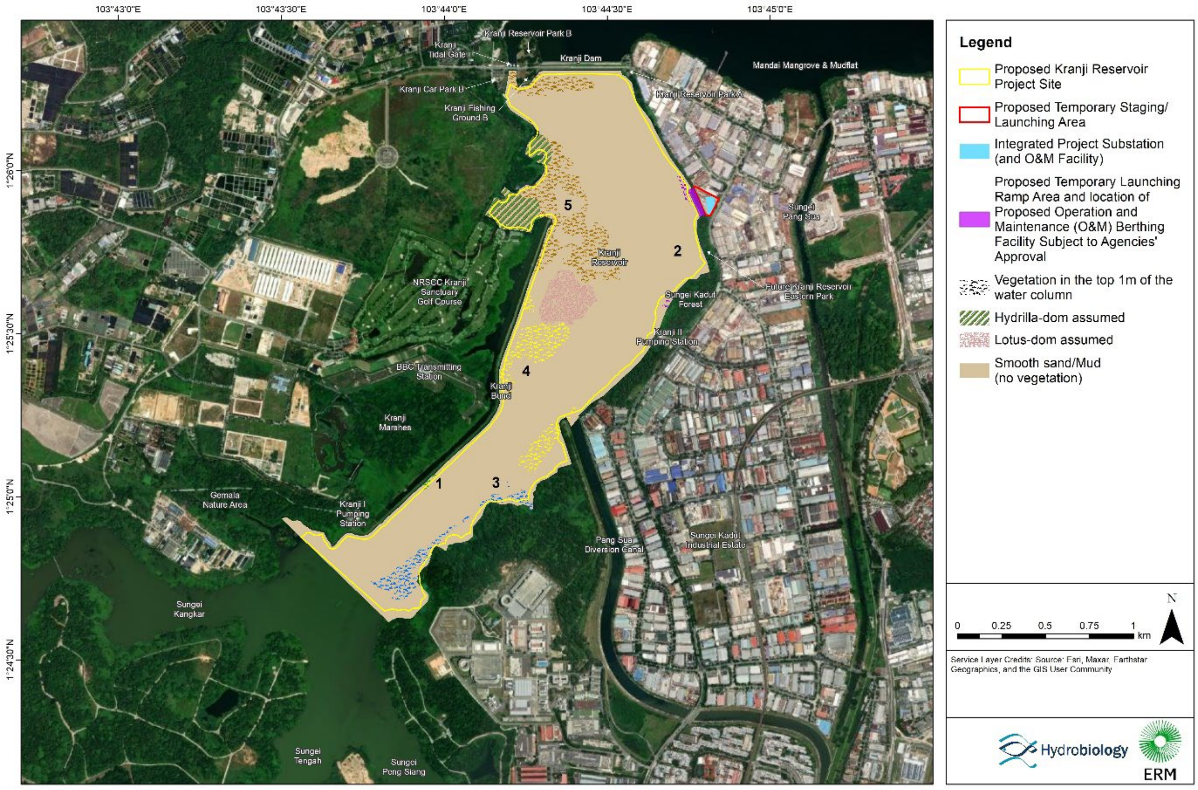

Figure SD-0-4 Map of vegetation within the upper 1m of the water column. Numbers and different colours indicate nominal zones for biomass calculations

Table SD-1 Estimate of aquatic vegetation biomass in Reservoir Project Site based on samples collected in May 2021

Zones	All aquatic vegetation in water column					Aquatic vegetation in upper 1m only				
	Area (m^2)	Total dry weight (tonnes)	TP (tonnes)	TN (tonnes)	TC (tonnes)	Area (m^2)	Total dry weight (tonnes)	TP (tonnes)	TN (tonnes)	TC (tonnes)
1	119197	26.19	0.09	0.8	8.13	1026	0.23	0.0008	0.007	0.07
2	140710	5.03	0.01	0.1	1.96	1646	0.06	0.0001	0.001	0.02
3	119813	9.27	0.01	0.3	2.84	30185	2.34	0.0031	0.070	0.72
4	271072	11.78	0.03	0.4	3.44	61418	2.67	0.0077	0.092	0;.78
5	462228	152.69	0.32	7.9	54.23	48775	16.11	0.0343	0.838	5.72
Hydrilla dominated	68220	45.07	0.01	0.7	15.05	64809	42.82	0.0116	0.688	14.30
Lotus dominated	68021	44.94	0.10	2.3	15.96	64620	42.69	0.0908	2.220	15.16
Sum	1249261.66	294.97	0.57	12.54	101.62	272479	106.92	0.15	3.92	36.78
(Ha)	124.93					27.25				
Total dry biomass / ha	2.36					3.92				

Sampling locations within each identified sampling zones are presented in Figure SD-0-5, while species and its respective wet, dry and net weights can be found in Table SD-2. While most samples could be identified, samples in Zone 3 could only be roughly differentiated by their morphology. The samples were observed to contain up to 98% of water content. Individual biomass (per grab area) per identified species and the average values and standard deviation for the aquatic vegetation were presented in Figure SD-0-6. Dried samples were further analysed for nutrients - Total Phosphorus (TP), Total Nitrogen (TN) and Total Carbon (TC). The relationship between biomass and nutrients are shown in Figure SD-0-7. The TP level was observed to be highest across all zones at 3,377 mg/kg in Zone 1 where three aquatic species were identified. The highest biomass level was, however, recorded in Zone 5 with 33.1 ± 2.22 mg/m^2, also with high TN and TC levels of 5.2 % and 35.3 %, respectively. The relationship between biomass, TP, TN and TC were distinct in Zone 2 where the lower the biomass were observed, its TP and TN levels were also low but with a high TC level observed.

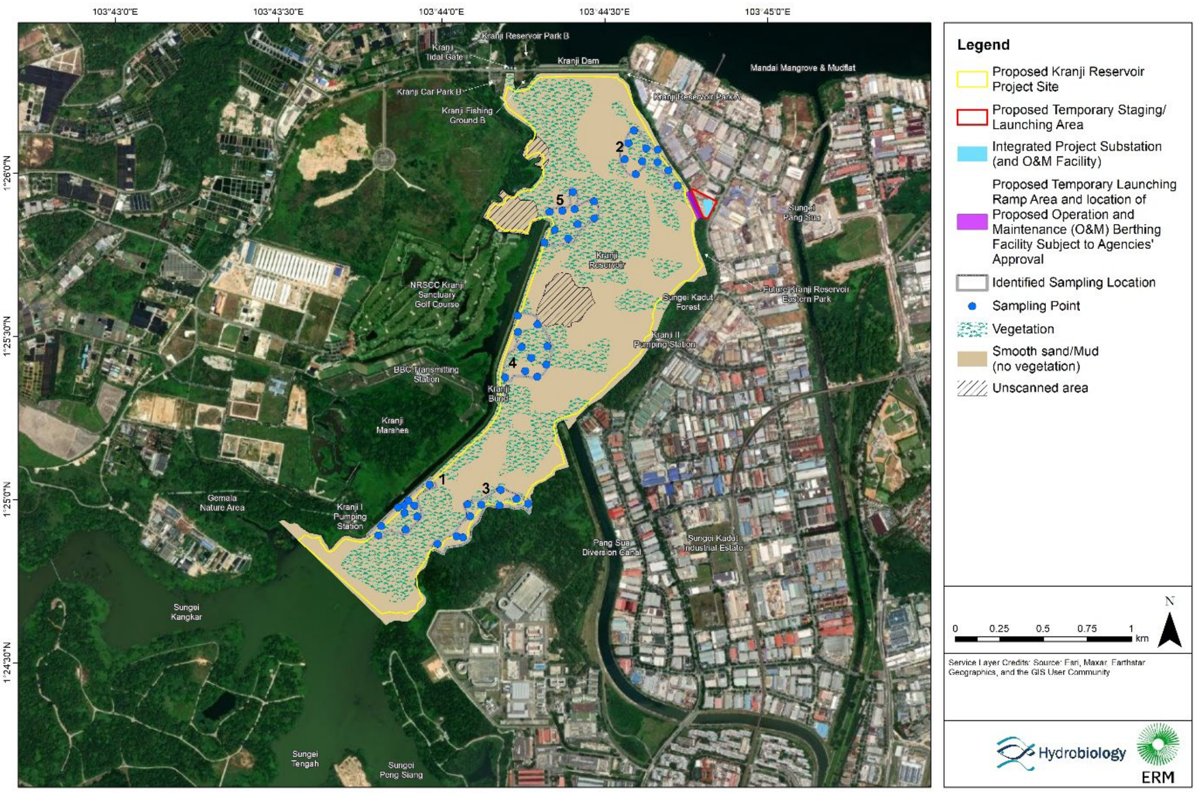

Figure SD-0-5 Aquatic vegetation sampling points based on 5 identified locations with presence of aquatic vegetation

Table SD-2 Estimate of aquatic vegetation biomass based on samples collected in May 2021. Observed aquatic vegetation and their respective wet, dry, and net weight per zone (n=10)

Zone	Scientific name	Wet weight (g)	Dry weight (g)	Net weight (g)	% Wet weight
1	*Eichhornia crassipes*	266.89	33.45	233.44	87.5
	Philonotis spp.	14.43	0.29	14.14	98.0
	Anubias lanceolata	141.55	11.5	130.05	91.9
2	*Ludwigia adscendens*	89.39	8.61	80.78	90.4
	Eichhornia crassipes	43.66	2.01	41.65	95.4
3	Unknown (decomposed)	25.6	2.6	23	89.8
	Unknown (decomposed)	0.92	0.15	0.77	83.7
	Unknown (decomposed)	29.79	3.24	26.55	89.1
	Unknown (decomposed)	18.16	2.55	15.61	86.0
4	Unknown (decomposed)	41.65	2.82	38.83	93.2
	Philonotis spp.	116.58	8.82	107.76	92.4
5	*Philonotis* spp.	397.09	100.36	296.73	74.7
	Eichhornia crassipes	142.6	6.78	135.82	95.2

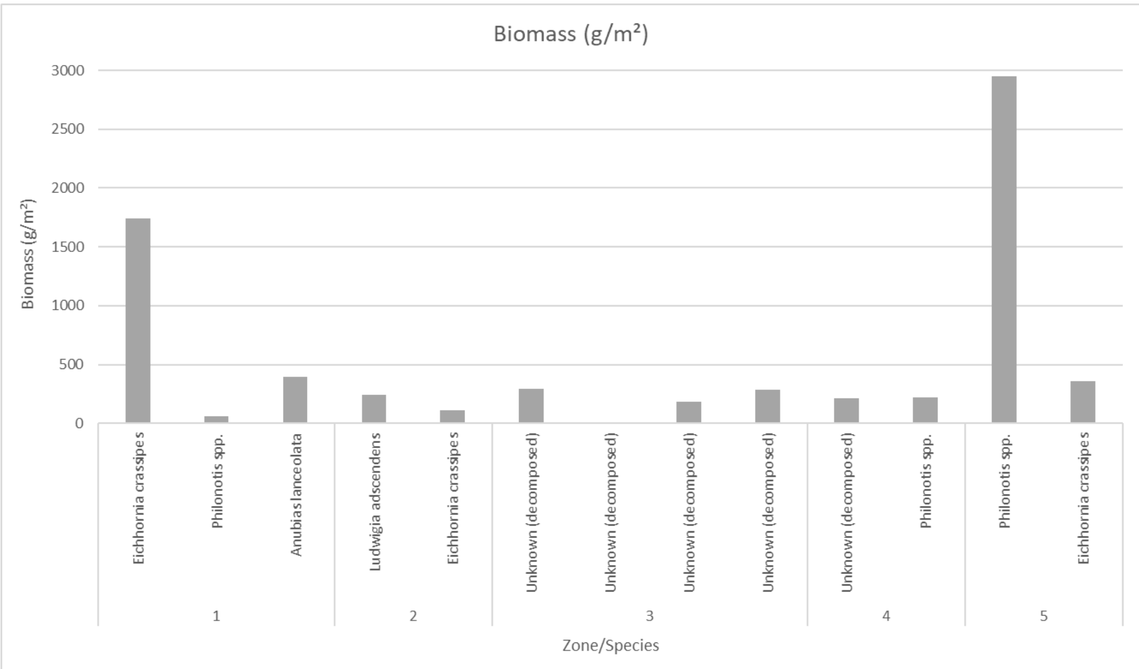

Figure SD-0-6. Species composition per zone and respective biomass of individual species and zone

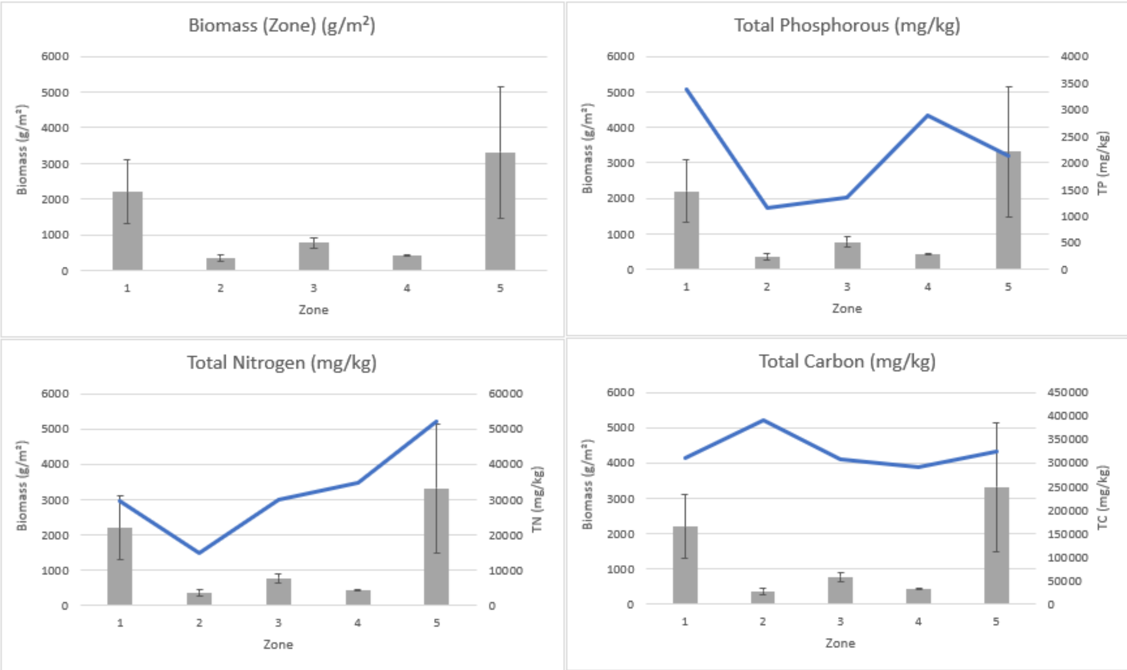

Figure SD-0-7. Relationship of nutrients (TP, TN and TC) compared to biomass per zone (+/- Std. Dev)

Appendix E Potential Impacts from FPV Construction Activities

E.1 Introduction

In a number of other reservoirs in Singapore where FPV systems have been installed, PUB has observed apparent spikes in a number of water quality parameters of concern in the vicinity of piling activities in the hours after such works were conducted. Such increases may be associated with the resuspension of sediments and release of pore water[2] into the water column. The installation of a FPV system in Kranji Reservoir may need placement of anchor blocks on the sediment bed, piling in the reservoir bed, or a combination of the two. The anchoring and/ or piling activities during construction may lead to potential increases in the concentrations of water quality parameters of concern. As part of the FPV system may be constructed near the PUB Choa Chu Kang Waterworks (CCKWW) water intake (via the intake channel behind Kranji bund), there are concerns that exceedances in water quality concentrations may affect concentrations in the source water at the water treatment plant (WTP) intake.

This Appendix E summarises the approach adopted to quantify a potential source term of FPV anchoring/ piling activities in Kranji Reservoir. The anchoring/ piling activities are assumed to form a potential source of suspended sediment, nutrients and metals. It is then further assessed whether explicit Delft3D-WAQ modelling incorporating such a source term may provide meaningful input to potential construction effects assessment. The source term is quantified by making assumptions around the FPV construction methodologies, schedules and available pore water concentration and elutriate[3] test results of sediments from Kranji Reservoir.

While the appendix focuses on the materiality of anchoring/ piling works on water quality and the need to incorporate these into the Delft3D-WAQ model, other construction impacts have also been considered for inclusion in the model. For a complete summary, please refer to the table at the end of this appendix (Table E-10).

[2] Pore water refers to the water contained in the interstices/pore space of aquatic sediments.
[3] Refers to the release of contaminants to the water column.

E.2 Quantification of source term for anchoring and piling works

E.2.1 Volume of sediment and pore water disturbed

There are two kinds of piles (cylindrical and solid) and one kind of block anchoring system considered for potential disturbance to the reservoir bed during the anchoring activity. The volume of sediment and pore water disturbed are estimated based on the equations below. For a clearer understanding of the measures of geometry used in the sediment volume estimations, please refer to Figure E-1. Sediment volume estimations are summarised in Table E-1 and Table E-2.

Volume of Sediment Disturbed:

- Cylindrical Pile: $\mathrm{Vs} = \pi(R^2 - r^2)\frac{h}{2}$
- Solid Pile: $\mathrm{Vs} = \pi R^2 \frac{H}{5}$
- Block anchor: $\mathrm{Vs} = D\left(\mathrm{L}+\frac{D}{2}\right)\left(\mathrm{W}+\frac{D}{2}\right)$

The area (radius and height) around the pile or anchor block that gets disturbed by the construction activities is based on assumptions from experience in other projects.

Volume of Pore water Disturbed:

- Cylindrical Pile: $\mathrm{Vp} = 0.5\ Vs$
- Solid Pile: $\mathrm{Vp} = 0.5\ Vs$
- Block anchor: $\mathrm{Vp} = 0.5\ Vs$

The dominant soil type in the sediment layer is silt with smaller quantities of sand and clay. We use a porosity of 50% for a silt dominant sediment[4].

[4] https://stormwater.pca.state.mn.us/index.php/Soil_water_storage_properties

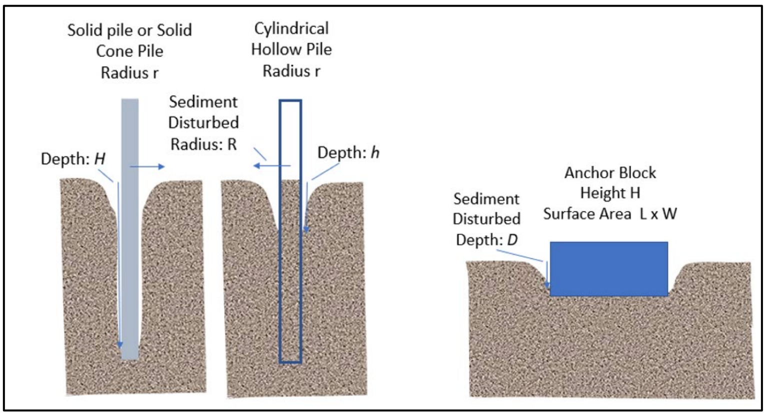

Figure E-1 Graphic illustration of the sediment disturbing situation (assumed) resulted from piling (left) and block anchoring (right) (created by H2i)

Table E-1 Estimation of sediment disturbance per pile installation

Pile Type	Cylindrical Pile			Solid Pile		
Pile Radius r (m) / Disturbance Radius R (m)	Disturbance Height h (m)	Volume Sediment Disturbed (m^3)	Volume Pore water Disturbed (m^3)	Disturbance Height H (m)	Volume Sediment Disturbed (m^3)	Volume Pore water Disturbed (m^3)
0.075/0.15	0.5	0.013	0.007	10	0.141	0.071
0.15/0.25	0.7	0.044	0.022	10	0.393	0.196
0.15/0.3	0.5	0.053	0.027	8	0.452	0.226
0.30/0.45	0.5	0.088	0.018	8	1.018	0.509

Table E-2 Estimation of sediment disturbance per block anchorage installation

Length (m) / Width (m) / Height (m)	Disturbance Depth D (m)	Volume Sediment Disturbed (m^3)	Volume Pore water Disturbed (m^3)
1/1/0.5	0.05	0.053	0.026
2/2/1	0.1	0.420	0.210

Based on the estimates shown in Table E-1 and Table E-2, the "conservative case" would likely be a solid pile construction, with pile radius 0.30 m and an estimated 0.45 m radius of disturbance. This yields a total displaced volume (sediment and pore water) of 1.5 m^3. This volume corresponds with the displacement volume of a pile of 0.3 m radius of 5.4 m length. As such, it is considered that the total displaced volume of sediment and pore water is a reasonable estimation. The calculations in the following paragraphs use the volume of sediment disturbed and the volume of pore water disturbed associated with this piling scenario.

E.2.2 Quantification of sediment source

Based on the estimation in Section E.2.1, further assumptions regarding the construction approach (Table E-3) are used to quantify the sediment source. As indicated in EIA *Appendix 2.1 (Anchoring and Mooring System Options, Anchoring System Option 1.1)* the largest proposed piles are 0.15-0.3m radius (i.e., 0.3-0.6m diameter), and it is assumed that 2 piling workstations would be working concurrently, enabling 6 piles a day to be installed. Considering a 6-day working week, 40 weeks (240 days) have been assumed required for this conservative piling option. Whilst EIA *Appendix 2.1* assumed piling over 24 hours, a condensed 10-hour timeframe is assumed in this estimation to represent a conservative case for water quality.

Table E-4 presents the details of sediment disturbance rate based on the assumptions adopted. The fine sediment fraction is defined as the smallest 10% of sediments. These sediments settle at a rate less than 1 m/day. Table E-5 shows the average fine sediment concentration generated in one model cell each hour (kg/m^3) of piling load from 6 piles (3 piles/day/by 2 workstations amounting to 6 piles/day), where the disturbed sediment is released in succession over an assumed approximate 240 days.

Table E-3 Construction assumptions used for source quantification

FPV Mooring Piles Construction schedule assumed for modelling	
Solid piles with marine coating dimensions (Length x diameter)	15 m x 0.6 m
Disturbance height (m)	8
Duration of daily work (hrs)	10
Number of piles installed per day	6

Table E-4 Sediment disturbance rate estimated

Assumptions of Sediment Disturbance	
Radius of sediments disturbed (m)	0.45
Depth of sediment disturbed (m)	8
Volume of sediment disturbed (m^3)	1.018
Sediment specific density (kg/m^3)	1,626 [1]
Total mass of sediment disturbed each day (kg)	1,655
Percent of fines (d10<1.6 µm) by number of particles (%)	10
Percent of fines (d10<1.6 µm) by mass (%)	10
Mass of fine sediment disturbed by each pile in day (10 hrs) (kg)	165.5
Mass of fine sediment disturbed by 6 piles in 10 hours each day (kg/10hr)	992.9
Fine Sediment Load (kg/s) [2]	0.028

Assumptions of Sediment Disturbance	
Fine Sediment Load (kg/hr) [2]	99.3

[1] Average particle density for samples taken from Kranji Reservoir. [2] Assume 6 piles installed simultaneously in a 40x20m area.

Table E-5 Source quantification if implemented into water quality model assuming 6 piles installed simultanously in 1 grid cell

Model Source	
Cell area (m^2) (20m x 40m)	800
Cell depth (m)	1
Average excess suspended sediment concentration in cell added each hour (mg/L)	124.1

E.2.3 Quantification of nutrient source from sediments

The quantification of the nutrient loading from the piling activities is estimated using two different methods from five sediment samples locations taken in May 2021 (Figure E-2):

1) Using the sediment pore water concentrations.
2) Using the elutriate test results.

In the elutriate test, part of the adsorbed nutrients may enter the dissolved phase. As such, the elutriate test concentrations are expected to result in a higher estimate of the nutrient release from the sediment layer as compared to using the sediment pore water concentrations. The elutriate test uses a 5-fold dilution of the sample of sediment with pore water so these elutriate concentrations presented in Table E-6 reflect this dilution and are not directly comparable to the pore water concentrations.

Figure E-2 Map of sediment sampling points

Table E-6 Pore water sampling and elutriate test data (average of five samples taken across Kranji Reservoir in May 2021)

Test Parameter	Unit	Pore water	Elutriate
Total Organic Carbon, TOC	mg/L	20.54	-
Phosphate as PO4-P	mg/L	0.10	0.04
Nitrate as NO3-N	mg/L	0.05	0.05
Total Nitrogen, TN	mg/L	21.67	7.18
Total Phosphorus, TP	mg/L	0.15	0.09
Ammonia as NH4-N	mg/L	13.18	4.04
Arsenic as As	mg/L	0.01	0.01
Cadmium as Cd	mg/L	0.000057	0.000032
Lead as Pb	mg/L	0.0016	0.0036

Estimated nutrient release to the water column using pore water concentrations

The pore water quantity released for 1 pile (m^3) (Table E-1) is multiplied by the pore water concentration (mg/L) to obtain the pore water load (gr) (i.e. the estimated load of organic carbon, total nitrogen, total phosphorus, etc. released through the piling works) and presented in Table E-6. Subsequently, the pore water load is divided by the volume of a single model grid cell to obtain the excess concentration if such a load were instantaneously released into the existing water quality model (Table E-7). The size of a model grid cell is taken as 40 m × 20 m × 1 m = 800 m^3.

Table E-7 Nutrient source quantification if implemented into water quality model using pore water concentration assuming 6 piles installed simultanously in 1 grid cell

Test Parameter	Pore water concentration (mg/L)	Pore water load (gr)	Excess concentration in model grid cell (mg/L)	
			By 1 pile	By 6 piles
Total Organic Carbon, TOC	20.5	10.5	0.013	0.078
Phosphate as PO_4-P	0.10	0.051	0.000	0.000
Nitrate as NO_3-N	0.05	0.025	0.000	0.000
Total Nitrogen, TN	21.67	11.0	0.014	0.083
Total Phosphorus, TP	0.15	0.076	0.000	0.001
Ammonia as NH_4-N	13.18	6.7	0.008	0.050
Arsenic as As	0.01	0.005	0.000	0.000
Cadmium as Cd	0.000057	0.000	0.000	0.000
Lead as Pb	0.0036	0.002	0.000	0.000

Estimated nutrient release to the water column using elutriate test concentrations

The elutriate test is conducted using ambient reservoir water to dilute the sediment and pore water sample. The concentrations obtained from the elutriate test therefore contain the background (ambient) reservoir concentrations. The minimum concentration observed in the year 2019 provided by PUB is used as background concentrations. This value is subtracted from the elutriate test concentration to obtain how much of the nutrients in the sample originate from the sediments (pore water or adsorbed nutrients released to the water column, see Table E-8). To obtain the mass released from the sediments, this concentration is multiplied by the water volume in the elutriate test. This is then divided by the sediment volume analysed in the elutriate test to understand the mass of nutrients released per bulk volume sediments. The laboratory that analysed the samples used a sediment to water volume ratio of 1:4. Lastly, multiplying this with the volume of sediments released during the piling works then gives the nutrient load associated with the piling works. The excess concentration into a model grid is again computed by dividing with the volume of a model grid. In the above analysis it is assumed that the pore water volume is minimal and there is no change to the volume of the final elutriate solution.

Table E-8 Nutrient source quantification if implemented into water quality model using elutriate test results assuming 6 piles installed simultanously in 1 grid cell.

Test Parameter	Elutriate (mg/L)	Background concentration (mg/L)	Excess concentration in test (mg/L)	Load from sediment in test (mg)	Mass (gr) released per m^3 sediment	Load (gr)	Excess concentration in model grid cell (mg/L)	
							By 1 pile	By 6 piles
Phosphate as PO_4-P	0.04	0.003	0.037	0.15	0.15	0.15	0.0002	0.0011
Nitrate as NO_3-N	0.05	0.010	0.040	0.16	0.16	0.16	0.0002	0.0012
Total Nitrogen, TN	7.2	0.40	6.8	27.1	27.1	27.6	0.035	0.207
Total Phosphorus, TP	0.09	0.050	0.040	0.16	0.16	0.16	0.0002	0.0012
Ammonia as NH_4-N	4.0	0.020	4.0	16.1	16.1	16.4	0.021	0.12
Arsenic as As	0.01	0.0025 [1]	0.008	0.030	0.030	0.031	0.0000	0.0002
Cadmium as Cd	0.000032	0.00025 [1]	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Lead as Pb	0.002	0.001 [1]	0.001	0.002	0.002	0.002	0.0000	0.0000

[1] The lowest concentrations for arsenic, cadmium, and lead in the year 2019 were below detection limit (DL), at <0.005 mg/L, <0.0005 mg/L and <0.002 mg/L respectively. The concentration DL/2 was used as background concentration.

E.3 Conclusions

The fine sediment release rate calculated in Section E.2.2 results in a source term due to the assumed construction using solid piles activities of around 165 kg/day. The Total Suspended Solid (TSS) load derived from the catchment runoff model is in the order of 330 to 3,000 kg/day. Assuming the load associated with piling 6 piles were implemented as a constant release in a single grid cell in the current model over a ten-hour period, this would translate into an excess suspended sediment concentration of 124 g/m^3 based on the loads for an hour compared to a 10 to 30 g/m^3 ambient concentration for the year 2019. However, once the fine sediment starts dispersing, the excess concentration is expected to quickly diminish. For example, if the source spreads homogeneously in an area of a 100 m radius (in a single layer of 1 m deep), then the excess concentration in that area would be diluted to 5.3 g/m^3 of fine sediment. It should be noted that these estimations are sensitive to the fraction of fine sediments.

The nutrient release rates calculated above range from 11–27 gN/pile and 0.07–0.16 gP/pile (Table E-7, Table E-8). On a daily basis, as a conservative case it was estimated 6 piles could be driven within one 40 x 20 m grid cell, translating to a load of 0.66–0.16 kgN/d and 0.00042–0.0010 kgP/d (Table E-9). The catchment loads vary from 65–530 kgN/d and 3.3–60 kgP/d (Table E-9). The estimated nutrient load associated with disturbance of the sediment layer due to piling is negligible when compared to the catchment loads.

Table E-9 Comparison of estimated load during piling and catchment load on daily basis

	Total nitrogen	Total phosphorus
Estimated load during piling (kg/d)	0.066–0.16	0.00042–0.0010
Estimated catchment load (kg/d)	65–530	3.3–60

The elutriate test results for cadmium was below the background concentration and no source term could be calculated. Arsenic and lead, although above detectable levels, do not yield a source of significance if implemented in the numerical model.

It is recommended that the Final Design, construction methodology and piling schedule etc (e.g. the number of sequential days of piling based on piling phasing and locations, proximity to water intakes etc) be compared to the assumptions in this appendix to review whether the current assumptions remain appropriate for the construction methodology and piling schedule etc; and, if necessary, assess the potential need for mitigation measures. For example, the use of silt curtains may provide a reasonable method to mitigate fine sediment dispersal to receptors such as the water intake.

In conclusion, based on the information and assumptions indicated above, the inclusion of the piling works as an additional source term in the water quality model is considered to not yield useful insights into the potential impacts associated with piling works.

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Table E-10 Construction scenarios being considered

Scenarios	Description	Assumption	Modelling approach
Anchoring: Piles	Piling may lead to sediment disturbance	The following situation is assumed: • Piles are 0.3-0.6 m diameter marine coated steel to be hammered into the bed from a barge with derrick and pile driving hammer system – lengths variable depending on water depth and sediment depth to refusal. • Six piles per 10-hours per day shift, 6 days per week. • 1,440 piles to be installed over 240 working days in five islands configuration • Fine sediment disturbed by each pile ~99.3 kg/hr • Assume work will begin near the western shore and proceed to the east towards open water. Information available to make the assumptions are described in Section E.2.1	Given the estimated sediment source, the concentrations are likely to rapidly disperse in the currents and settle to the bed in a few days, this is not likely to have any measurable impact. If modelling is required, then assumptions would be incorporated into the model as five sources operating for 30 days each in succession for the 240 days. The nutrient/heavy metals released from pore water would be estimated from the elutriate tests (details described in Section E.2.3).
Use of vessels grounding:	Vessel groundings may disturb bottom	Assume mitigation methods properly implemented	No scenario recommended
Use of vessels leakage:	Potential pollution to the water body	The potential sources of contamination due to marine construction will be mitigated for environmental protection	No scenario recommended
Launching/Staging Areas	Disturbance of the shoreline and the reservoir bed during construction	Embedded controls which may be employed to reduce sediment disturbance, erosion and sediment disbursement may include: • Straw waddles on slopes to precent sedimentation • Geotextile and gravel in flat areas to prevent erosion and tracking of loose materials. • Silt fencing at or near the water edge to prevent on-shore sediments from washing into the reservoir.	No scenario recommended

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Scenarios	Description	Assumption	Modelling approach
		Adaptive management mitigation measures may include: • In-water turbidity curtains and floating booms	

Appendix F Dissolved Oxygen and Chlorophyll-a Model Spatial

This Appendix F including Figure F-1 to Figure F-6 presents the future scenario simulation spatial results for the 2030, 2040 and 2050 runs discussed in *Appendix 6.1 (Water Quality Model Technical Appendix, Section 5.5.2)*. The chlorophyll-a and dissolved oxygen are presented as annual average spatial distributions in the mid-depth, i.e., layer 3 (2–3m deep), and deep water, taken as the result in the bottom-most layer in each cell.

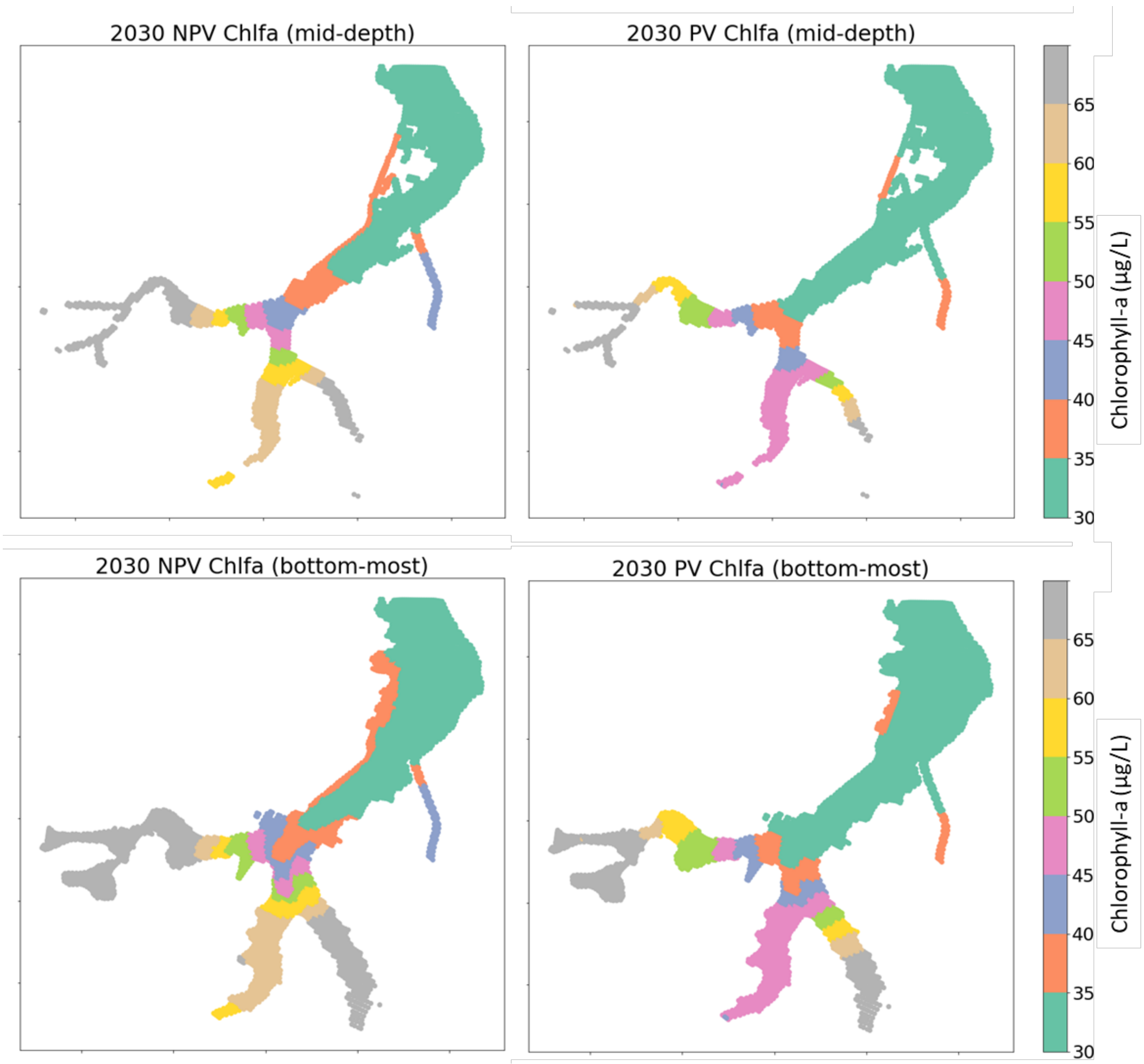

Figure F-1 Chlorophyll-a 2030 mid-depth and bottom simulation results without FPV (NPV, or non-FPV) and with FPV (or PV)

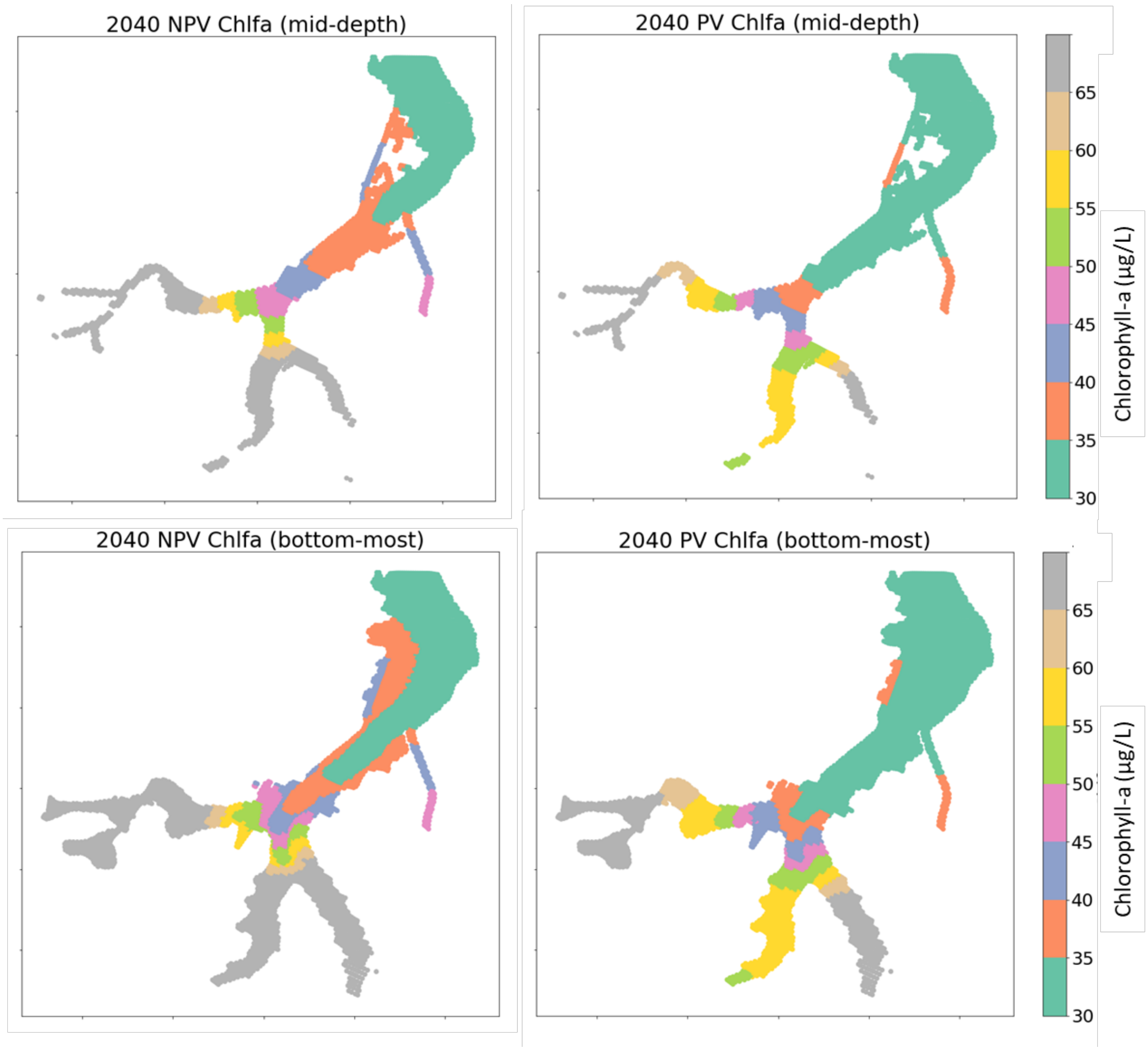

Figure F-2 Chlorophyll-a 2040 mid-depth and bottom simulation results without FPV (NPV, or non-FPV) and with FPV (or PV)

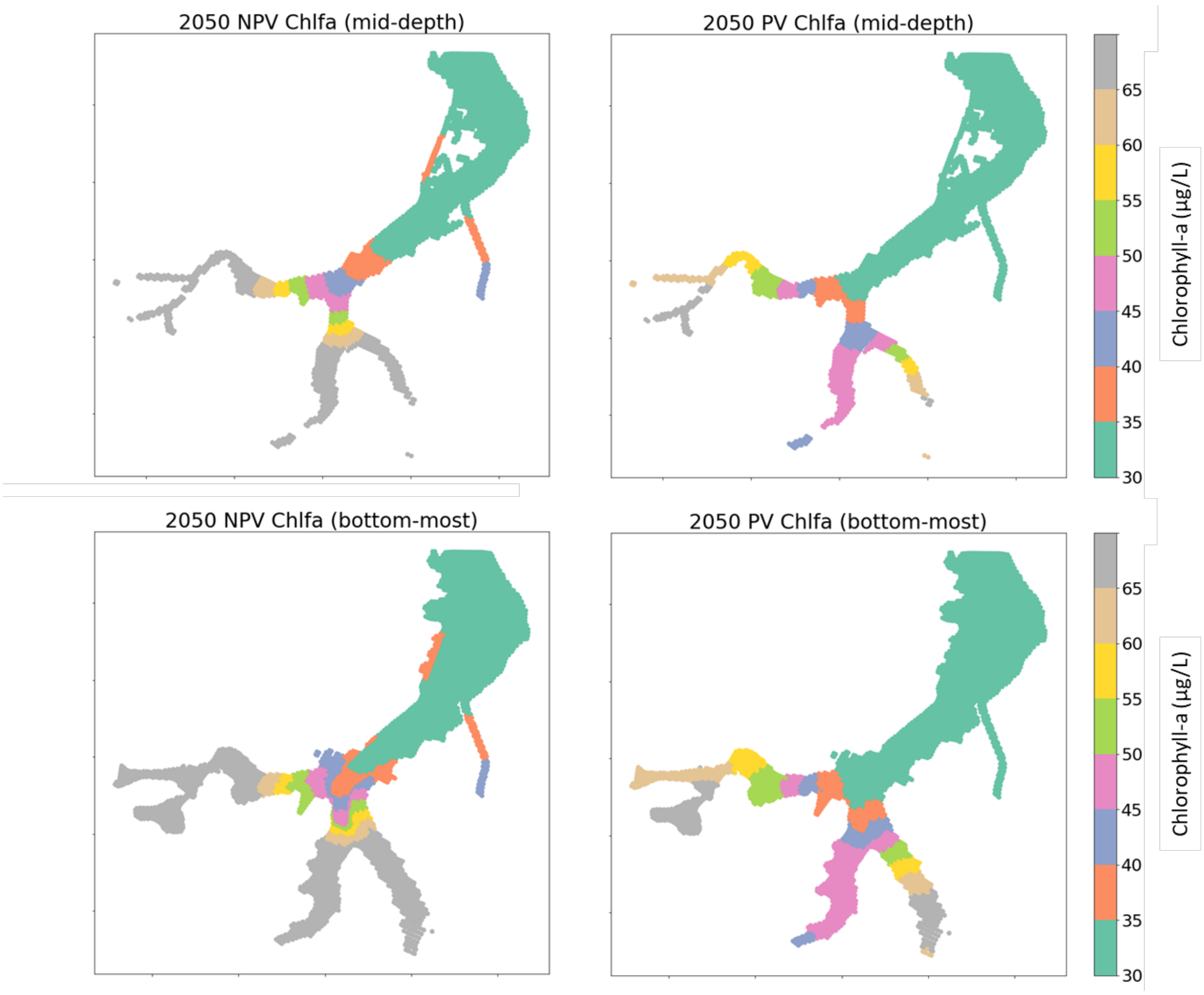

Figure F-3 Chlorophyll-a 2050 mid-depth and bottom simulation results without FPV (NPV, or non-FPV) and with FPV (or PV)

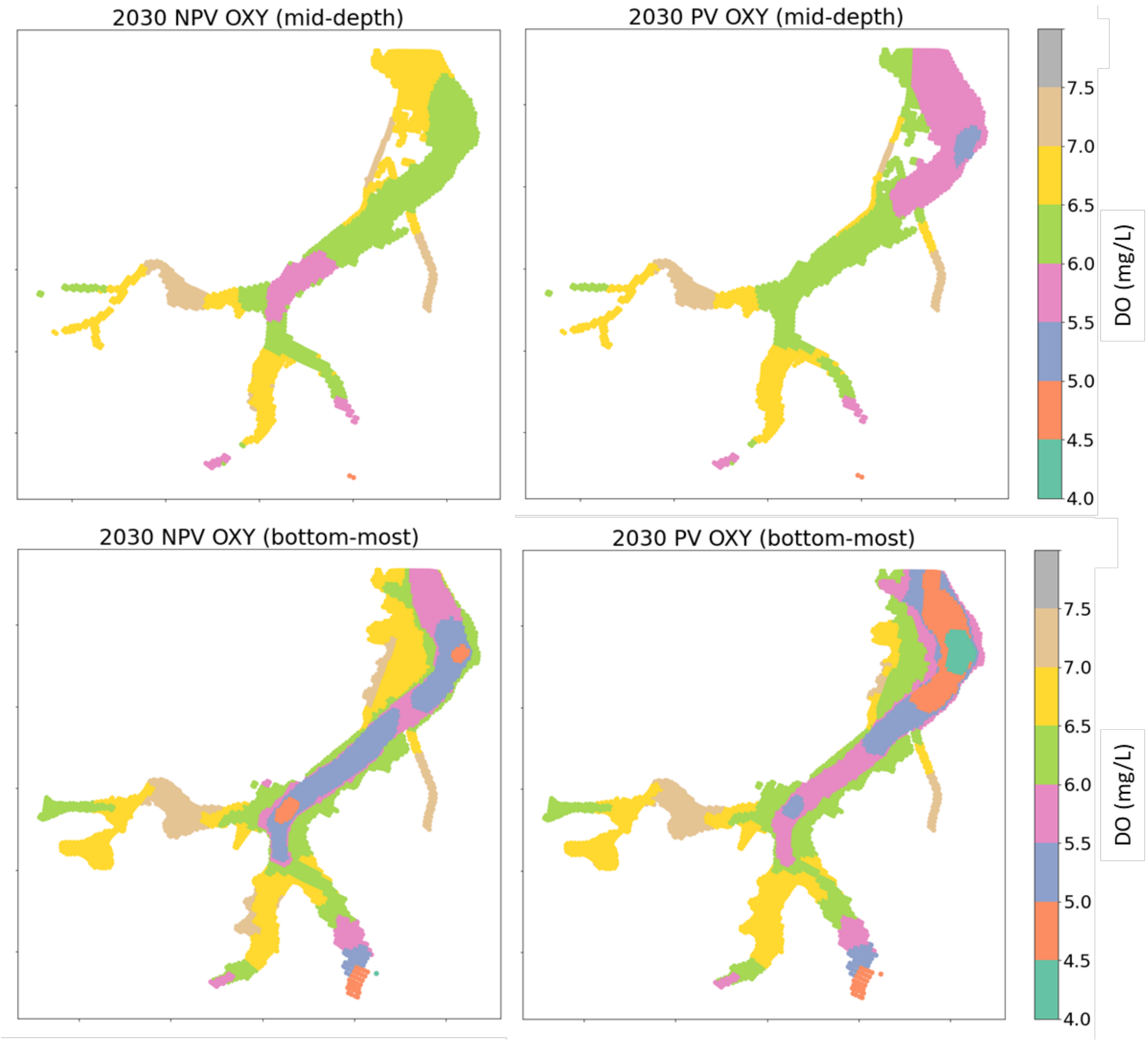

Figure F-4 Dissolved oxygen 2030 mid-depth and bottom simulation results without FPV (NPV, or non-FPV) and with FPV (or PV)

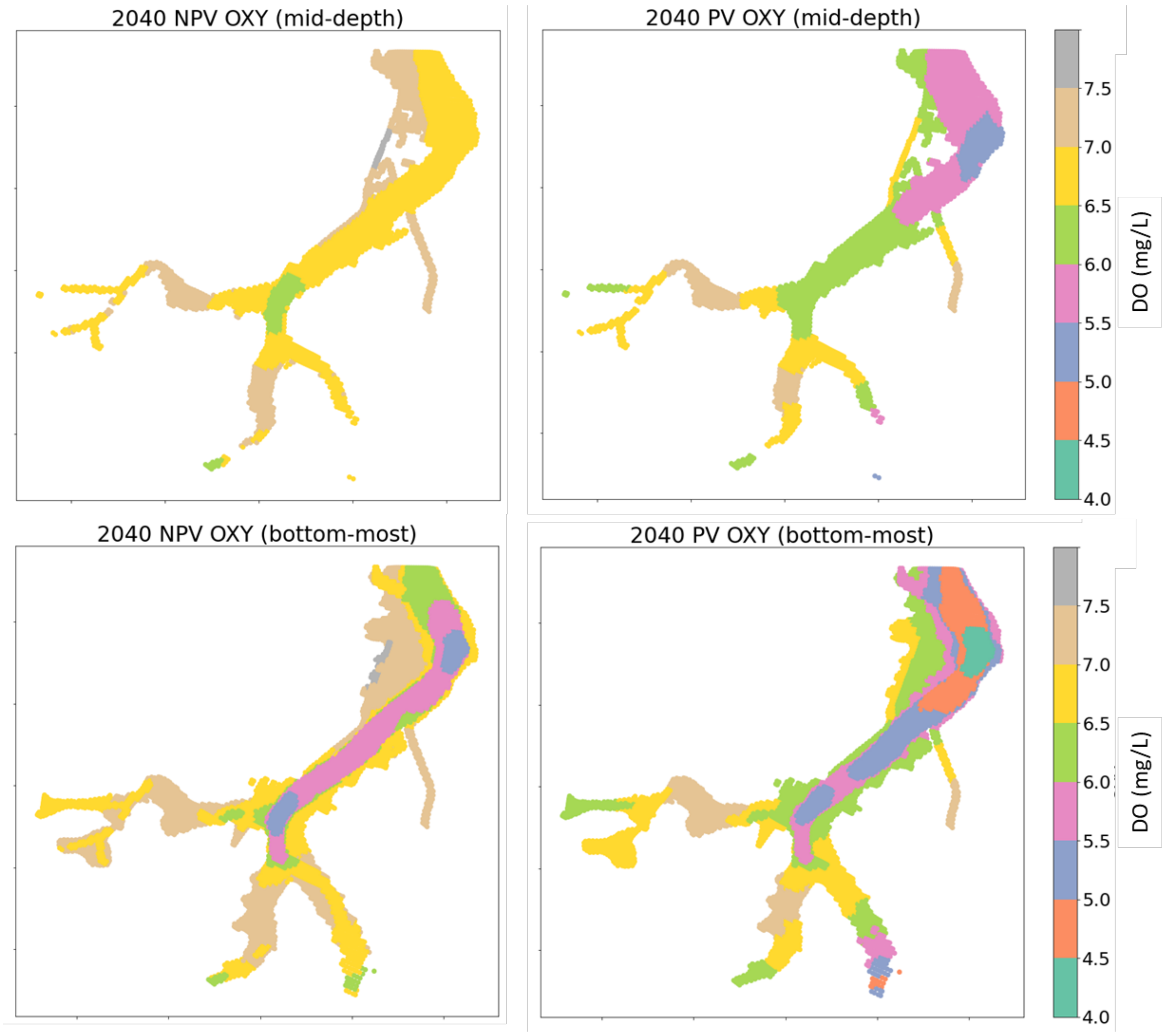

Figure F-5 Dissolved oxygen 2040 mid-depth and bottom simulation results without FPV (NPV, or non-FPV) and with FPV (or PV)

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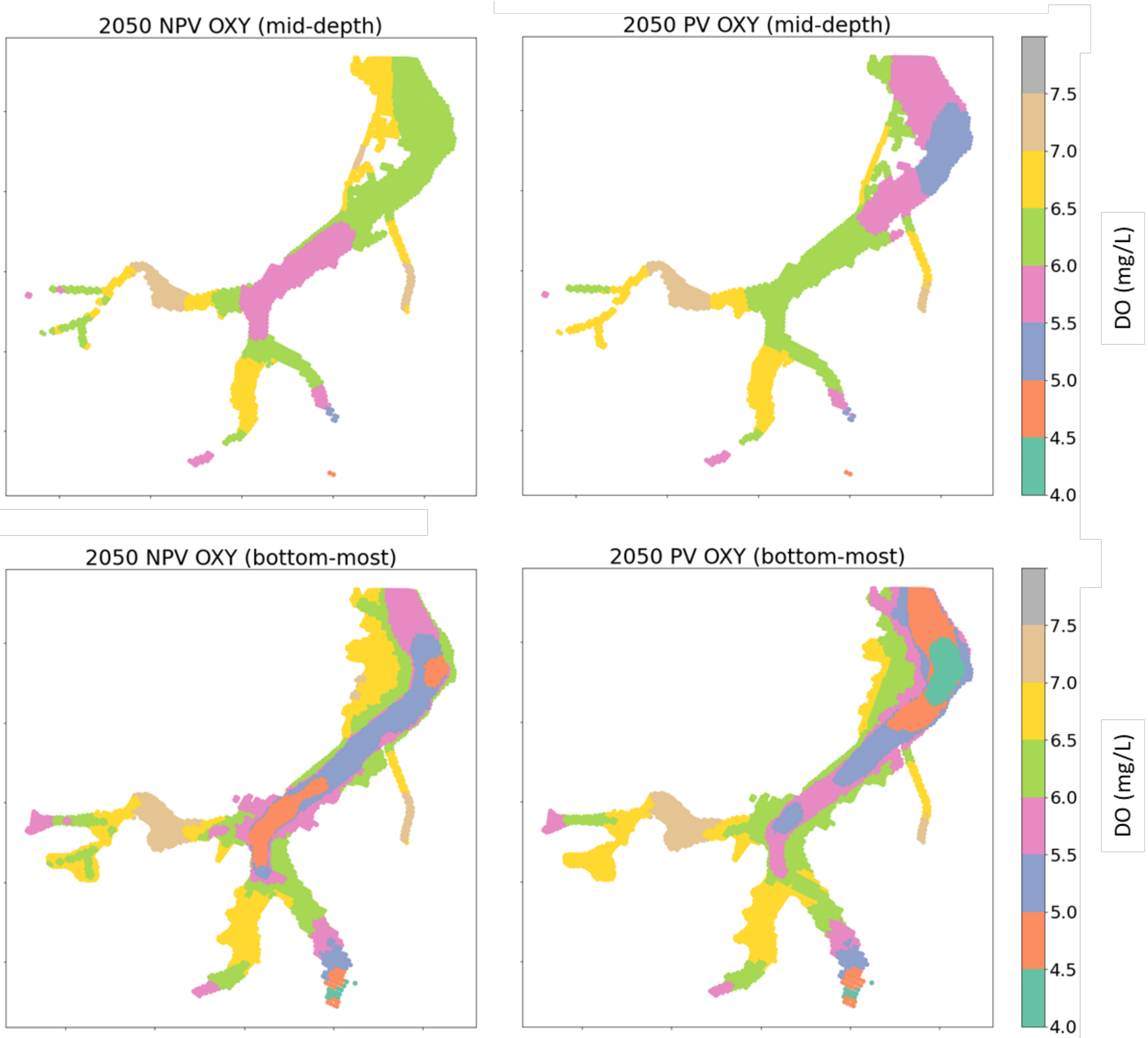
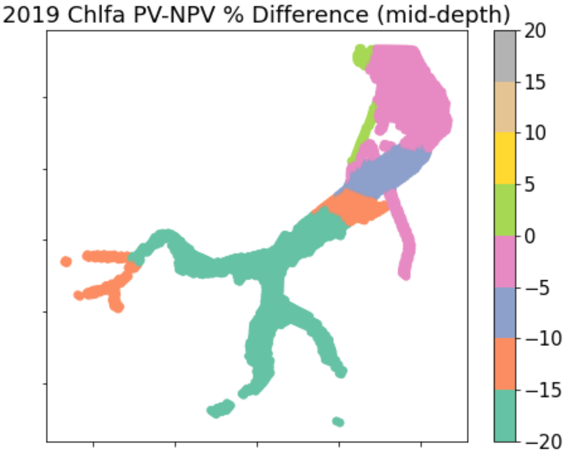
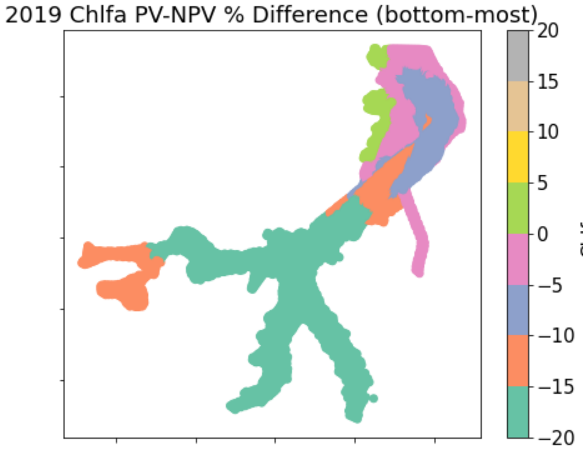
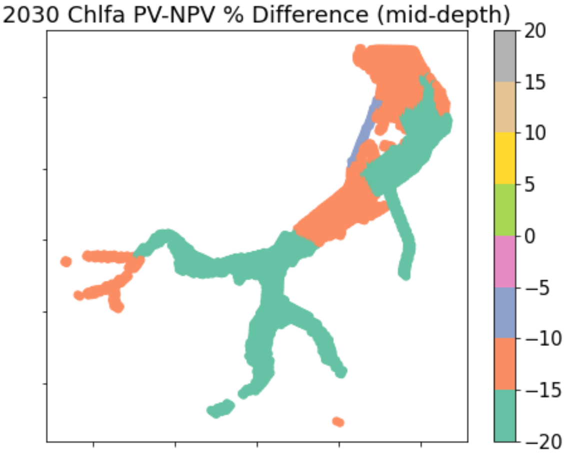


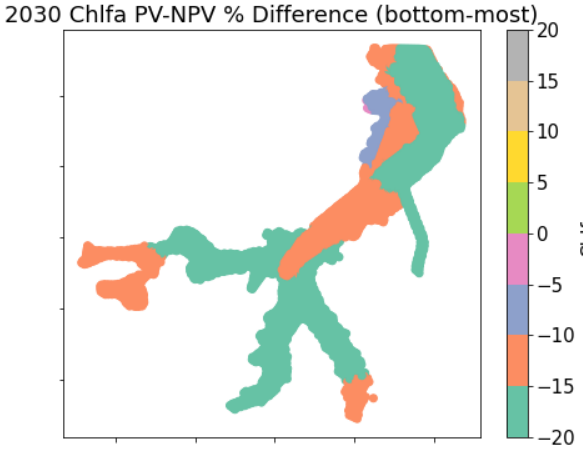
Figure F-6 Dissolved oxygen 2050 mid-depth and bottom simulation results without FPV (NPV, or non-FPV) and with FPV (or PV)

Figure F-7 and Figure F-8 display the spatial relative difference (%) based on annual average for Chl-a and dissolved oxygen in year 2019, 2030, 2040 and 2050 between simulations with and without FPV in the mid-depth, i.e., layer 3 (2–3m deep), and deep water, i.e., taken as the result in the bottom-most layer in each cell. The relative difference is calculated as $Relative\ Diff.(\%) = \frac{PV-NPV}{NPV} \times 100\%$. Negative values indicate reduction in concentration due to presence of FPV and vice versa.


2019 Chlfa PV-NPV % Difference (mid-depth)
20
15
10
5
0
−5
−10
−15
−20


2019 Chlfa PV-NPV % Difference (bottom-most)
20
15
10
5
0
−5
−10
−15
−20


2030 Chlfa PV-NPV % Difference (mid-depth)
20
15
10
5
0
−5
−10
−15
−20


2030 Chlfa PV-NPV % Difference (bottom-most)
20
15
10
5
0
−5
−10
−15
−20

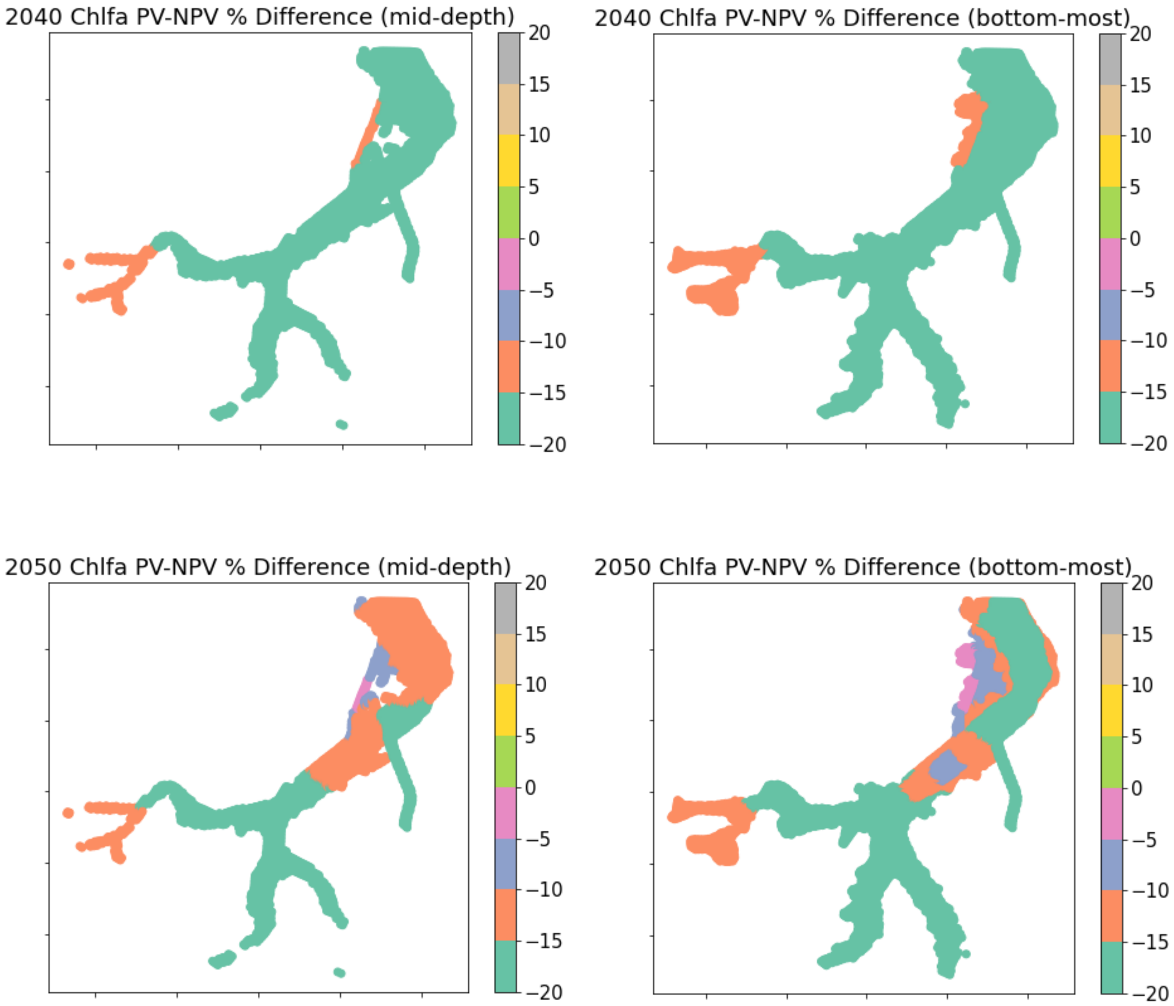
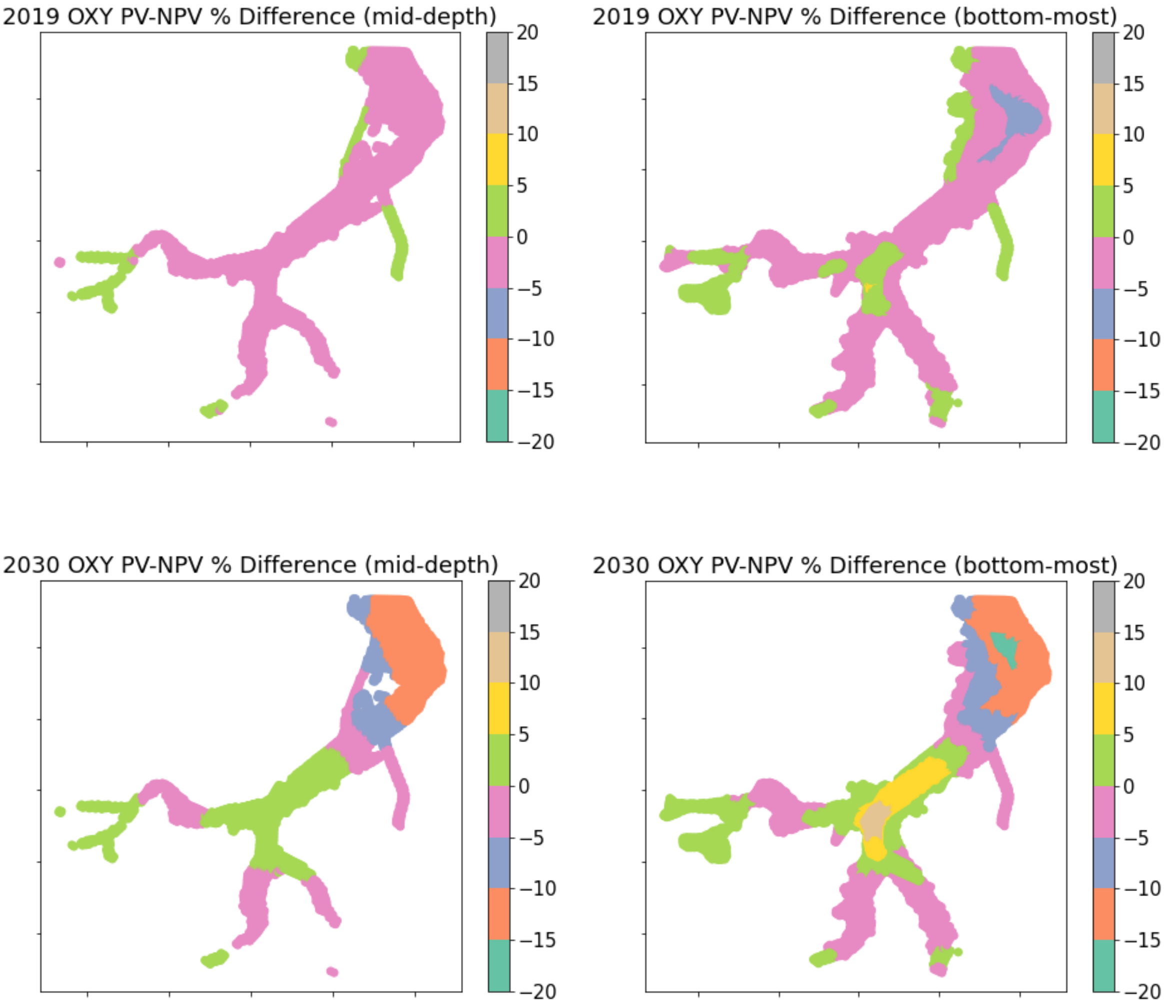


Figure F-7 Relative difference for Chl-a between PV (or FPV) and NPV (or non-FPV) simulation in 2019, 2030, 2040 and 2050 at mid-depth and bottom.



2019 OXY PV-NPV % Difference (mid-depth)
2019 OXY PV-NPV % Difference (bottom-most)
2030 OXY PV-NPV % Difference (mid-depth)
2030 OXY PV-NPV % Difference (bottom-most)
20
15
10
5
0
−5
−10
−15
−20

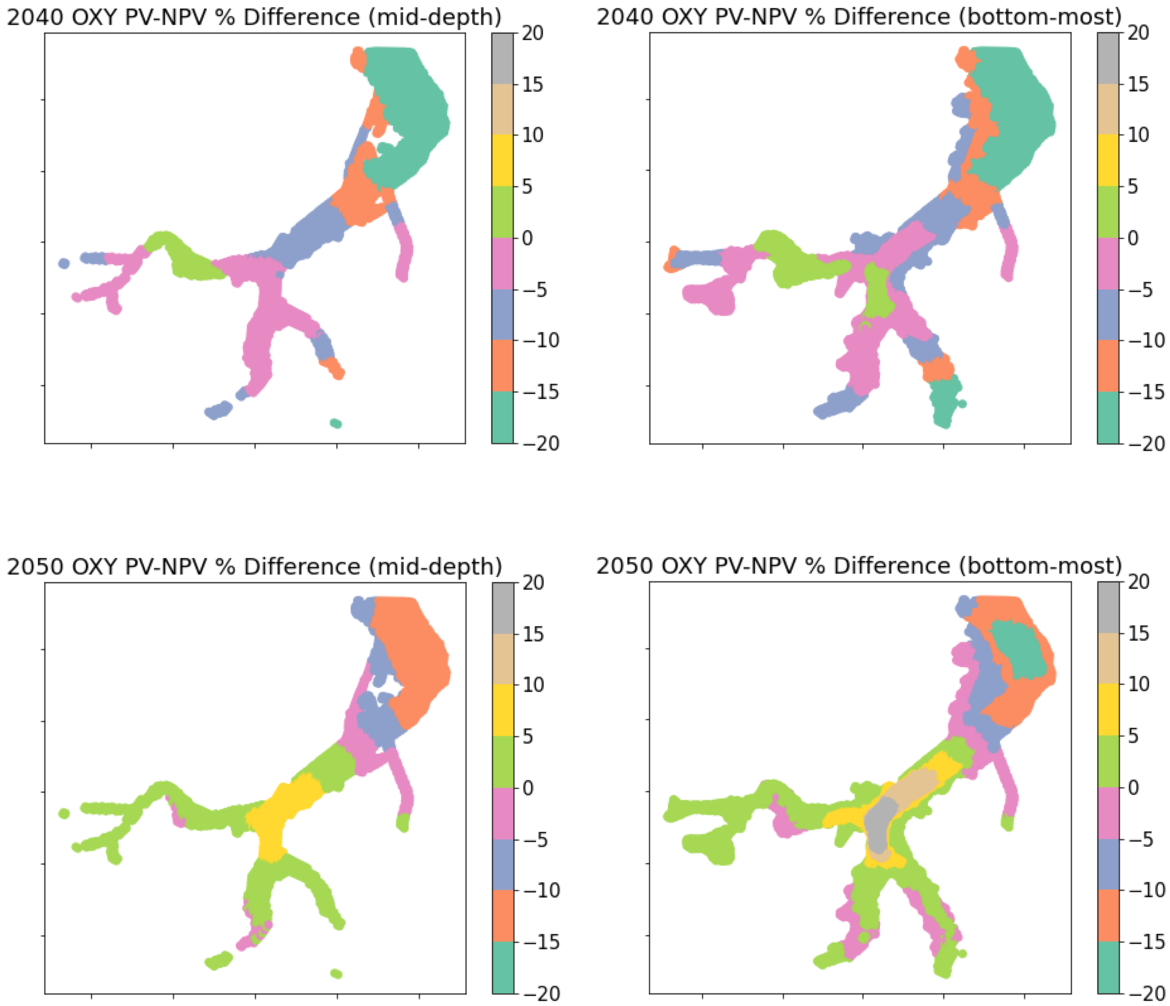


Figure F-8 Relative difference for dissolved oxygen between PV (or FPV) and NPV (or non-FPV) simulation in 2019, 2030, 2040 and 2050 at mid-depth and bottom.

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