New Catchment Models for SEQ

TUFLOW Catch

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Synopsis	This report presents a new numerical modelling platform that supports integrated whole of catchment environmental simulation. A pilot application of the new platform to Oxley Creek catchment, Southeast Queensland, is described, along with a novel framework that supports system understanding of associated numerical predictions.

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Amendment Record

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Executive Summary

The Queensland Water Modelling Network (QWMN) and Healthy Land and Water (HLW) co-commissioned the development of a new state-of-the-art numerical tool to assist with integrated catchment management across Southeast Queensland. This tool has been developed by TUFLOW (at BMT), Alluvium and Griffith University, with support from Brisbane City Council. This new tool represents a step change in the numerical modelling methods used to support integrated catchment management because it:

- Seamlessly and automatically integrates the numerical modelling of both catchment and receiving waters, which have historically been disconnected and inconsistent processes
- Uses high spatial and temporal resolution and physically based rain on grid (direct rainfall) simulation techniques to model surface and subsurface catchment hydrology. These techniques solve the equations of motion on a numerical grid (in the order of tens of metres per grid cell) rather than relying on lumped hydrology assumptions
- Uses physically based pollutant export and transport simulation techniques, in both surface and subsurface domains. These techniques solve the equations of solute and particulate transport rather than relying on event or dry weather average pollutant concentration assumptions
- Automatically converts and spatially assigns downstream predictions of catchment hydrology and pollutant export to be the inflowing boundary conditions of a linked fully three dimensional hydrodynamic and water quality receiving water model. This linkage process is entirely automated in this new tool, but has historically been manual and therefore time consuming and error prone
- Allows for the visualisation of combined catchment and receiving water quality model predictions via a free software platform
- Allows for advanced catchment-wide mass flux and balance analyses that provide new systems based insights beyond those that rely on interrogating conceptually opaque timeseries modelled-measured comparisons and associated medians and statistical goodness of fit metrics

This new tool therefore allows direct simulation of on-ground catchment processes such as gully erosion and urban runoff (amongst many others), and as an example, does not rely on spatial and temporal lumping assumptions to investigate the efficacy of proposed management interventions. Rather, this tool allows for direct and highly resolved simulation of such interventions by using first principles, and all within a seamlessly integrated modelling platform.

This report presents this new numerical tool and describes its first application, which is a pilot study of the Oxley Creek catchment, Southeast Queensland. A novel framework to exploit diagnostic and other flux outputs available within TUFLOW Catch to support systems understanding is proposed and demonstrated on this pilot model. This framework is used to explore the impact that applying daily lumped hydrology (as opposed to highly spatially and temporally resolved TUFLOW Catch hydrology) has on the predictive power of a downstream receiving water quality model of Oxley Creek.

This project was jointly funded by the Queensland Water Modelling Network and Healthy Land and Water.

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Contents

Tables

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Figures

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1 Introduction

The health of Southeast Queensland's catchments and waterways has been the subject of considerable attention since the latter part of the last century. For example, the SEQ Healthy Waterways Strategy (mid 2000s) provided a means for coordinating the development and implementation of management actions to deal with water quality and ecosystem health impacts on SEQ waterways. That strategy was built on the SEQ Regional Water Quality Management Strategy (SEQRWQMS, 2001 as described in Bunn & Smith, 2002), which in turn, built on both the Brisbane River Management Plan (1997) and the Stage 2 work of the Brisbane River and Moreton Bay Wastewater Management Study (1998).

A core focus of these strategies and plans has been the development of an understanding of the relationship between anthropogenic landscape modification and the ecological response of receiving waterways. One goal of doing so has been to provide evidenced based support to guide investment in the implementation of strategic environmental remediation and rehabilitation measures. Whilst the development of this understanding has historically used multiple complementary lines of investigation, two related lines have been widely applied in the region: data collection and numerical modelling.

Data collection has been undertaken by multiple entities over an extended period. The flagship data collection program in Southeast Queensland is the Ecosystem Health Monitoring Program (EHMP). Established more than 20 years ago, it is one of the most comprehensive freshwater, estuarine and marine monitoring programs in Australia, and it continues to play a role in related initiatives such as the annual SEQ Report Card process. Saeck et al. (2019) presents an excellent example of how this comprehensive data set is being used to better understand and manage Southeast Queensland’s waterways.

Numerical modelling has been used to support and quantitatively inform environmental management in Southeast Queensland and has often drawn on the monitoring data sets described above. Early receiving waterway modelling efforts used one- and two-dimensional schematisations of hydrodynamic and water quality processes (e.g., McKewan, 1998a; McKewan, 1998b; McKewan, 1998c; McKewan et al., 1998; Bell, 1998a; Bell, 1998b; Bell, 1999; Bell and Amghar, 2002; WBM Oceanics Australia, 2005a; WBM Oceanics Australia, 2005b; BMT WBM, 2006; BMT WBM, 2013). By the early to mid 2010s, these were superseded by models built on more advanced three-dimensional numerical platforms (CSIRO, 2014; BMT WBM, 2015; BMT WBM, 2017). Descendants of these models are currently being used as part of the SEQ Report Card process (Water Technology 2018 onwards), are highly spatially (meters) and temporally (seconds) resolved and deploy state of the art simulation techniques (such as GPU acceleration and cloud compute) to support prediction.

Catchment models have been built in parallel to provide upstream inflow boundaries to these receiving models, and whilst varying in name and appearance since the late 1990s, have essentially retained lumped (often daily) hydrology as their core simulation method. This hydrology has typically (but not always) been extended to compute daily catchment pollutant loads via multiplication of hydrologic predictions by land-use based event mean and dry weather concentrations (EMC and DWC, respectively).

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Although receiving hydrodynamic and water quality models have been coupled to catchment models for some time (with the view to using coupled models to support environmental management), the coupling has often been problematic for a range of scientific and practical reasons, including (but not limited to):

- An increasing divergence in the currency of the underlying science of the coupled models, meaning that the rigour and speed of the ever-evolving receiving model schematisation and science has not been fully exploited due to limitations in boundary forcing supplied by upstream catchment models
- The role of confounding conceptual difficulties in the linking models of materially different:
    - Time and space discretisation
    - Pollutant type predictions (e.g., total nutrients versus speciated nutrients)
- The nontrivial potential for human error in translation of results between models to delay, or even derail, modelling projects, and
- The large volume of time-consuming manual or semi-automated manipulation required to execute the linkage

Given the above, it has been identified that to better support future environmental management efforts and investment in Southeast Queensland (and further afield), an upgraded and properly integrated whole-of-system modelling platform is required. The Queensland Water Modelling Network (QWMN) and Healthy Land and Water (HLW) have therefore commissioned Alluvium, TUFLOW (at BMT) and Griffith University to develop such a modelling platform that exploits state of the art science and compute technology, and in doing so, to realign catchment and receiving water quality modelling to current best practise standards. This report describes that new platform and then presents its application as a pilot study to the Oxley Creek catchment, Southeast Queensland. A novel framework for interpreting the whole of system predictions from this pilot is presented and applied.

This project was jointly funded by the Queensland Water Modelling Network and Healthy Land and Water.

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2 Scope

The integrated modelling platform built under this commission is a combination of existing TUFLOW products: TUFLOW HPC (catchment model) and TUFLOW FV (receiving model). The integrated modelling platform is referred to as TUFLOW Catch. Development of TUFLOW Catch therefore included enhancement of TUFLOW HPC (including implementation of a new pollutant export capability) and its automated linkage with TUFLOW FV, with the following tasks.

- TUFLOW Catch development
  - Enhance TUFLOW HPC
    - Implement surface and subsurface pollutant export and simulation
    - Add simulation of the transport of pollutants through one-dimensional elements such as pipes, channel and structures (simulation of water through these features already exists)
  - Integrate TUFLOW HPC and TUFLOW FV, by automating the:
    - Identification of catchment-receiving model linkage locations
    - Preparation of all TUFLOW FV boundary condition files
  - Build TUFLOW Catch wrapper, which includes
    - Designing the text-based control file architecture for TUFLOW Catch, and
    - Having it coordinate and communicate with the underlying TUFLOW HPC and TUFLOW FV platforms
  - Pilot model delivery
    - Deliver a complete pilot model of TUFLOW Catch applied to the Oxley Creek catchment. This includes hydrologic, hydraulic and water quality components, calibrated as best as possible and to a standard acceptable for a pilot/demonstration study
  - Develop brief TUFLOW Catch user manual and documentation to support interrogation of results
- Upgrade pollutant export algorithms
  - Review of existing literature to examine suitable algorithms for implementation
  - Select appropriate constituent models
  - Adapt selected algorithms to TUFLOW Catch implementation
- Validate
  - Compare and contrast TUFLOW Catch predictions with predictions from an existing SWAT model of Oxley Creek catchment
  - Compare and contrast TUFLOW Catch predictions with predictions from an existing calibrated daily lumped hydrology and pollutant export model of Oxley Creek catchment

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In addition to the above, a novel framework that exploits the diagnostic and mass flux outputs from the TUFLOW Catch platform is proposed and applied. Although this was out of scope, it was seen as essential to the successful delivery of this project as it showcases new and innovative ways to fully exploit the latent (until now) richness of numerical data generated by the tools that have received considerable investment to date.

The above tasks are described in the following, and have been split into software development and pilot model development sections for clarity. Other sections that describe TUFLOW Catch commands, workflows and visualisations then follow.

3 Software Development

3.1 Overview

The key functional requirement of TUFLOW Catch is that it presents to the user a single, integrated and one-stop modelling interface that automates the synchronisation, linking and execution of underlying numerical engines. These underlying engines together simulate catchment scale hydrologic, hydraulic, pollutant export and advection, and receiving waterway instream processes. To do so, TUFLOW Catch draws on the power of existing (and enhanced) TUFLOW products and – most importantly – removes the user burden of manually integrating and interrogating models deployed on whole of catchment modelling projects. These two existing TUFLOW products are:

- TUFLOW HPC, that having been enhanced as part of this commission, computes:
    - Catchment surface and subsurface hydrology and routing by using rain on grid (direct rainfall) methods and a solution of the equations of motion
    - Catchment hydraulics (including one dimensional (1D) elements such as culvert and bridge flow calculations) related to hydrology by using well established methods commonly applied in flood studies for example
    - Catchment pollutant export using a first principles export model, and subsequently solving the equations of constituent transport to route pollutants with the above surface and subsurface hydrology, and through 1D hydraulic elements
    - Resultant highly temporally and spatially resolved catchment based inflow volumes and pollutant loads for delivery to a downstream receiving waterway model (TUFLOW FV)
- TUFLOW FV, that having had minimal enhancement as part of this study, computes:
    - Three dimensional in stream hydrodynamics, sediment transport and water quality dynamics, automatically using the inflow boundary conditions developed by TUFLOW HPC, and a range of other user specified boundaries

This arrangement is conceptualised below.

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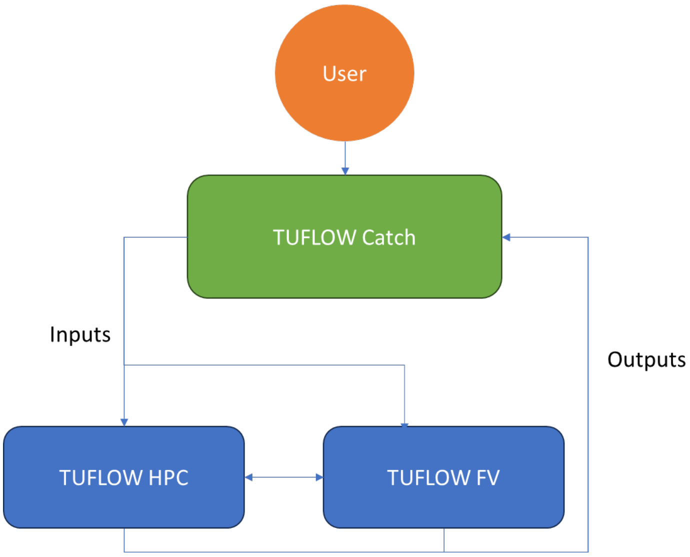

Figure 3.1 TUFLOW Catch Conceptual Arrangement

Given the above, much of the software development required by this study has taken the form of:

- Enhancing and upgrading TUFLOW HPC to execute the above functionality, and
- Developing the overarching TUFLOW Catch code base and executable to undertake unification of the underpinning TUFLOW products

These two tasks are described following. Enhancements to TUFLOW FV were minimal and are therefore not reported here.

3.2 TUFLOW HPC Enhancements

3.2.1 Pollutant Export Model

Pollutants exported from an upstream catchment often dominate the overall pollutant load delivered to receiving environments. Modelling this export is one of the core strengths of existing catchment modelling solutions and the resultant pollutant loads are typically reinterpreted for use as boundary conditions for downstream receiving water quality models. An accurate representation of catchment pollutant export is therefore crucial to support robust receiving water quality modelling analyses. Considering the shift in paradigm in TUFLOW Catch – i.e., away from lumped daily assumptions and toward a highly resolved grid-based approach to simulating hydrology and pollutant export - a literature review was conducted to explore existing approaches to grid-based catchment and pollutant simulation.

The literature review covered 68 publications that focused on catchment models that incorporated simulation of pollutant export. Of those, 46 were found to be relevant because they included water quality constituent models, erosion models, or erosion susceptibility models. The other publications focused solely on hydrological catchment modelling, stakeholder perspectives, or hydrological model formulations. Given that TUFLOW HPC executes hydrologic and hydraulic simulations within TUFLOW Catch, the latter were not pursued.

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All but two of the relevant publications were dated between 2000 and 2022 (Figure 2), and most that considered distributed (i.e., grid-based, or semi-distributed) models were published recently (2020 or later), perhaps indicating an increasing interest in distributed models in the catchment modelling space, or equally maybe an increase in accessible compute power to support these more advanced computations.

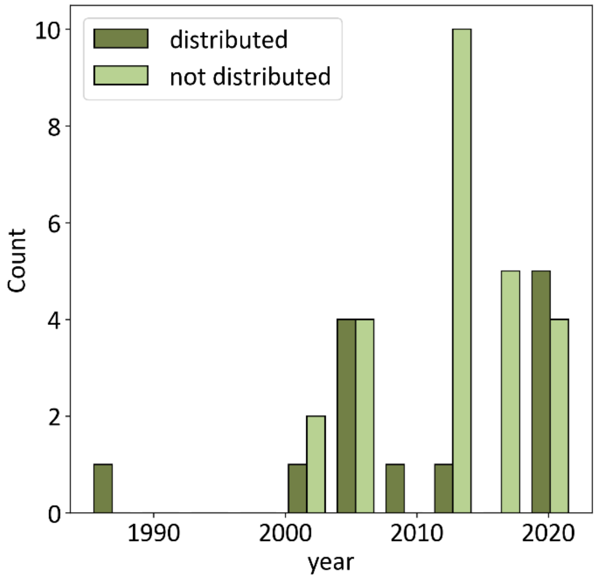

Figure 3.2 Research Articles on Catchment Modelling with Pollutant Export Modelling.

Even though the review identified the use of a variety of software suites, some common pollutant export formulations were found across most publications:

- For sediment, a version of the Universal Soil Loss Equation (USLE) was commonly used,
- For nutrient species, pathogens, and pesticides a formulation involving EMCs and DWCs was used

Both approaches are tied to land use in some manner. For example, USLE formulations include information about soil, cover and practice, typically averaged over a functional unit which is defined by land use (Ellis, 2018), and EMC/DWC formulations are typically applied to specific land uses or management strategies (Bartley, et al., 2012).

To utilise the information users may already have available or are familiar with, pollutant export in TUFLOW Catch was also built based on common pollutant export approaches and land use. However, to make full use of the TUFLOW HPC grid-based approach, the EMC/DWC approach was reformulated from first principles as a mass accumulation and release per unit area model, referred to as an accumulation/washoff model. Accumulation/wash-off models are common in urban water management (Hossain & Imteaz, 2015). This type of model conceptualises pollutant accumulation on impervious surfaces during no-flow or low-flow conditions and wash off during high-flow conditions (Gaut, et al., 2019; Barbé, et al., 1996). Typically, a proportion of the accumulated material runs off if a threshold flow is reached (i.e., enough energy is available for liberation of mass). This mechanism is generally based on a non-linear function for the runoff (Bonhomme & Petrucci, 2017). A variety of models in the urban water space (e.g., SWMM, STORM (Obropta & Kardos, 2007)) are commonly used to this end, pointing to the robustness of the approach.

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Despite the above, the literature also suggests that upscaling of accumulation/wash-off models from the experimental to (generally urban) catchment scale can lead to problematic interpretation of associated parameters. However, it was expected in this commission that due to the discretised nature, increased model complexity and formulation as accumulation/wash-off per unit area, the reported problems will affect less the TUFLOW Catch implementation within TUFLOW HPC (Bonhomme & Petrucci, 2017). Testing this assumption was one motivation for building a pilot TUFLOW Catch model of the Oxley Creek catchment.

In light of the above, two parameters were proposed for the generation of each pollutant considered in the catchment:

- Areal accumulation rate (kg/ha/yr), and
- Areal wash-off/release rate (also in kg/ha/yr)

Areal Accumulation Rate

Areal accumulation rates were estimated from literature values for a range of pollutants (Table 3.1). The literature was found to mostly report total pollutant loads in the case of nutrients and carbon rather than speciated loads of e.g., organic and inorganic species (Fletcher, 2014; Bartley et al., 2012; Eyre, 2002; Alvarez-Cobelas, 2010). Since speciated loads are required by the receiving water quality model component of TUFLOW Catch, they were estimated from total loads and EMCs for speciated pollutants where available.

For nutrients (nitrogen and phosphorus species) and carbon, the following mass sums were assumed (i.e., neglecting the very small contribution from phytoplankton, and noting that D, P and O represent Dissolved, Particulate and Organic, respectively):

- Total Nitrogen (N): $TN = (NH_4+NO_x+DON+PON)$
- Total Phosphorus (P): $TP = (PO_4+DOP+POP)$
- Total Organic Carbon (C): $TOC = (DOC+POC)$

With the concentrations of TN, TP and TOC, and the concentrations of NH_4, NO_x, DON, PO4, DOP, and DOC reported in the literature (Fletcher, 2014; Bartley et al., 2012; Eyre, 2002; Alvarez-Cobelas, 2010), the missing PON, POP, and POC concentrations were inferred based on the mass sums above. Areal accumulation rates of each speciated component were inferred from the total load and the fraction of the speciated concentration.

The areal accumulation rates for two land use classes (forest and urban) (Table 3.1) were used for the Oxley Creek catchment pilot model of TUFLOW Catch. Although associating these rates with land uses was adopted in the pilot study, doing so is not mandatory, and if users have sufficient information and/or knowledge of their system, they can use any other appropriate categorisation (including slope, proximity to waterways, known eroding gullies etc.) to spatially define these rates: they are not confined to being land use based, and the degree of detail to which they are set is entirely up to the user. This approach has been adopted specifically with model scenario execution in mind, where spatially explicit and modifiable pollutant export parameterisations are often needed to properly investigate matters such as nutrient offsetting and targeted land remediation.

The adopted areal accumulation rates are presented in Table 3.1.

Table 3.1 Adopted Areal Accumulation Rates (all in kg/ha/year)

Pollutant	Areal pollutant export rate	Land use	Reference
Sediment	55.000	Forest	Fletcher, 2014
	300.000	Urban	Fletcher, 2014; Bartley, 2012
Ammonium	0.273	Forest	Fletcher, 2014; Bartley, 2012
	2.171	Urban	Fletcher, 2014; Bartley, 2012
Nitrate+Nitrite	0.662	Forest	Fletcher, 2014; Bartley, 2012
	2.364	Urban	Fletcher, 2014; Bartley, 2012
FRP	0.010	Forest	Fletcher, 2014; Bartley, 2012
	0.022	Urban	Fletcher, 2014; Bartley, 2012
DON	1.021	Forest	Fletcher, 2014; Bartley, 2012
	2.194	Urban	Fletcher, 2014; Bartley, 2012
DOP	0.009	Forest	Fletcher, 2014; Bartley, 2012
	0.005	Urban	Fletcher, 2014; Bartley, 2012
PON	1.044	Forest	Fletcher, 2014; Bartley, 2012
	3.271	Urban	Fletcher, 2014; Bartley, 2012
POP	0.061	Forest	Fletcher, 2014; Bartley, 2012
	0.623	Urban	Fletcher, 2014; Bartley, 2012
DOC	21.446	Forest	Fletcher, 2014; Eyre, 2002; Alvarez-Cobelas, 2010
	71.486	Urban	Fletcher, 2014; Eyre, 2002; Alvarez-Cobelas, 2010
POC	12.154	Forest	Fletcher, 2014; Eyre, 2002; Alvarez-Cobelas, 2010
	40.514	Urban	Fletcher, 2014; Eyre, 2002; Alvarez-Cobelas, 2010

Areal Wash-Off Rate

A wash-off model has been developed for use in conjunction with the above areal accumulation rates and is presented conceptually in Figure 3.3. The model tracks and increments a dry store and wet store for every TUFLOW HPC 2D cell, with:

- α_{dry} being the mass per unit area of the dry store of each constituent
- α_{wet} being the mass per unit area of the wet store (dissolved) of each constituent

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At each timestep *dt* the dry and wet areal masses are updated for all constituents for all active TUFLOW HPC 2D cells. The wet store constituents are also transported according to the progression of surface hydraulic flows, which is done as a separate calculation step to the generation update. Under wet weather conditions, the dry store is dissolved into the wet store at a rate given by a user defined time constant (also referred to as a time of concentration), T_c. This dissolution only occurs once user-specified minimum rain rates and surface water depths have both been exceeded. Otherwise, i.e. during dry weather, the dry store accumulates at the rates specified in Table 3.1, up to a user specified limiting areal mass.

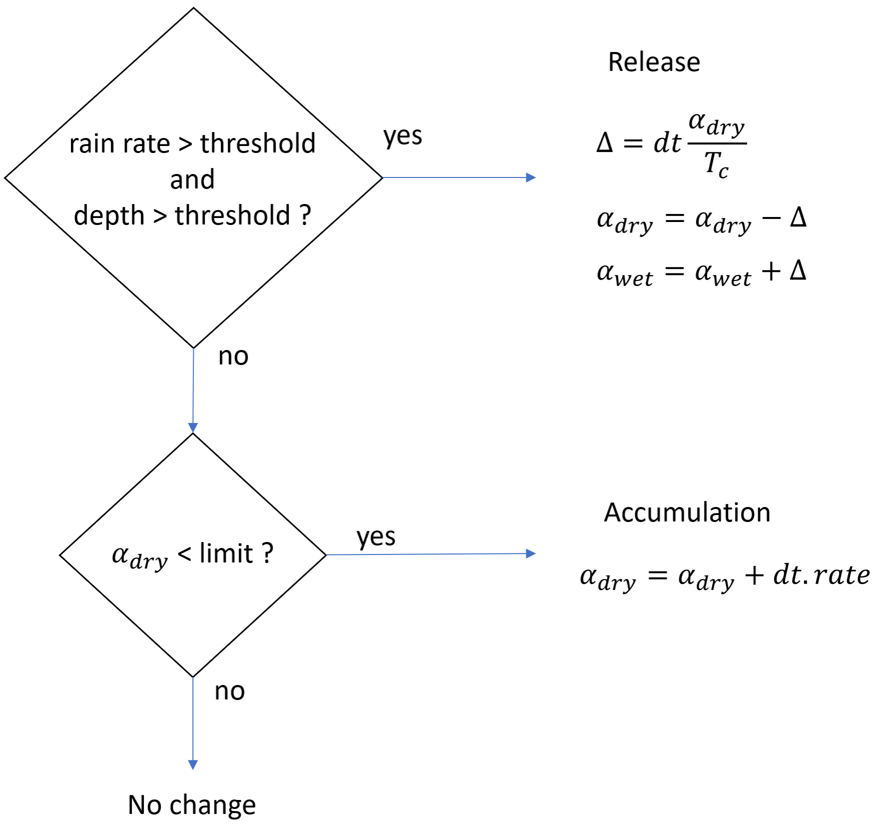

Figure 3.3 Areal Wash-Off Model, Executed at Each Timestep, Constituent and 2D TUFLOW HPC Cell

3.2.2 Other Enhancements

TUFLOW HPC is an existing product that has been enhanced as part of this commission, as follows:

- With the 2023-03-AA release, TUFLOW HPC introduced several new features that were necessary for developing TUFLOW Catch:
  - Introduced groundwater advection using a soil horizontal hydraulic conductivity and a calculation of in-groundwater table slope. Refer to the 2023-03-AA TUFLOW release notes for the details of the mathematical implementation
  - Introduced support for up to 10 vertical groundwater layers

- Introduced evapotranspiration (removal) of water from the top-most groundwater layer
- Increased the number of allowable constituent tracers from 1 to 20, including tracking of these through all groundwater layers

• Additional to the above commercial release, new features were required within TUFLOW HPC specifically for TUFLOW Catch:

- Material based surface generation of constituents. A runoff properties file allows for the user to specify the choice of generation model and required input parameters (for example Tc and α_{dry} described above) for each constituent within each surface material used in the 2D catchment model. This is carried out in a way that allows for assigning a set of generation models as a global default, and then overriding one or more surface materials with new generation models (and parameters) for one or more constituents. This allows for very fine-grained control of land-based constituent generation, down to specific sites that may be significant sources of certain constituents such as known gully erosion areas. This approach is also very useful for setting up and executing management scenarios where spatially explicit interventions are proposed – they can be implemented in this framework without recourse to spatial averaging or lumping assumptions

- Accumulation of constituents. As described above, a new dry store surface layer for constituent simulation was introduced to allow for the creation of constituents. A generation model can then choose, based on user request, whether it generates a constituent during dry weather only, wet weather only, or both, and whether the created constituent is assigned to the dry store, or the wet (already dissolved) surface field (as described in Section 3.2.1)

- Wet weather release of constituents. The generation model also determines how the dry store field is converted to the wet field. Once in the wet field, the constituent will advect with the surface water and may (see next point below), infiltrate to groundwater. User defined minimum rainfall intensity (mm/hr) and minimum cell depth (m) can be defined, both of these need to be exceeded before the dry store is released to the wet field (also as described above)

- Selective infiltration of constituents. Constituents can be selectively prohibited from infiltrating into the groundwater layers (for example particulate based constituents such as PON), and therefore will only be exported as surface-borne pollutants during rain events. Soluble constituents may be allowed to infiltrate into the groundwater layers and eventually exported as emergent base flow

The above functionality is intended to enable modelling of water and constituent fate and transport as illustrated in Figure 3.4.

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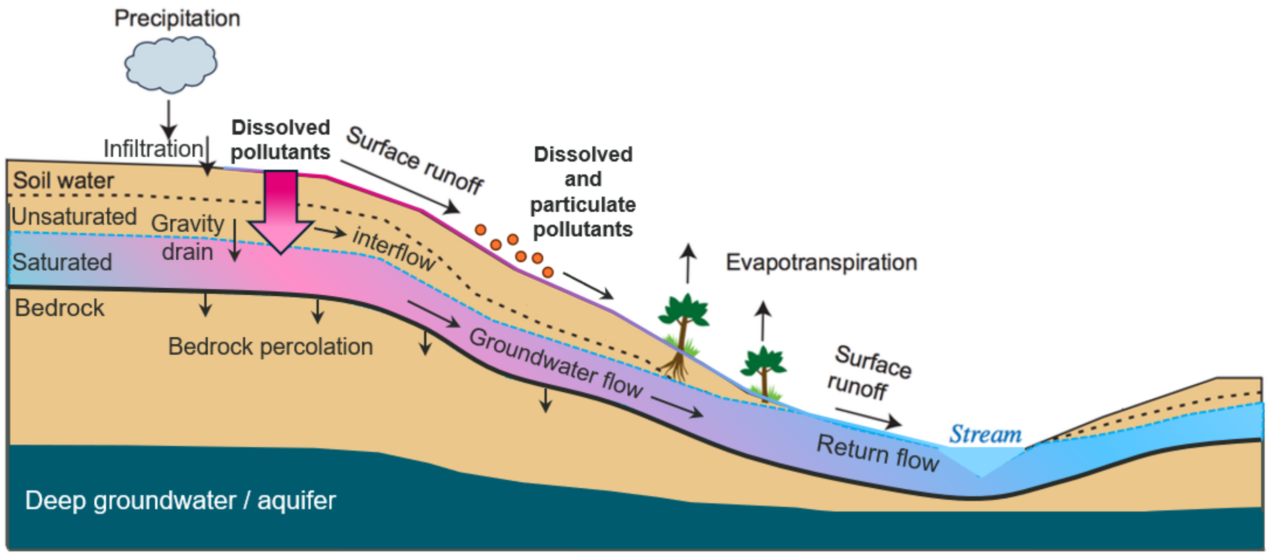

Figure 3.4 Water and Constituent Generation, Fate and Transport

Both constituent concentrations (as they advect through surface and/or subsurface waters) and accumulating dry stores are available as map (2D) outputs from TUFLOW HPC (see Section 6.4).

3.2.3 Boundary Export

Linking of catchment and receiving water models can potentially be a time-consuming manual process. Experience has shown that this linkage between models can be a source for errors, potentially requiring rework and therefore adversely influencing project timelines and budgets. TUFLOW Catch undertakes this task automatically.

TUFLOW HPC boundaries prepared for TUFLOW FV are one of two types: nodestrings or lateral inflows. Nodestring boundaries are applied as a ‘Q’ type boundary at the TUFLOW FV nodestrings and include allowance for momentum and are typically applied at mainstream waterway locations where momentum transfer is important. Lateral inflows are applied as a cell inflow (TUFLOW FV boundary type ‘QC’) which does not include any transfer of momentum, but is still mass conservative.

TUFLOW Catch removes this as a source of error by automating the process in three steps:

1. Initialisation of the TUFLOW FV model to generate the required constituent variables, spatial and temporal configurational information for HPC
2. Simulation of the TUFLOW HPC catchment model and writing of downstream boundaries for TUFLOW FV
3. Simulation of TUFLOW FV receiving water model using these inflow boundaries

At stage 1, the following are determined by TUFLOW HPC:

- TUFLOW FV mesh location, geometry and intersection with TUFLOW HPC grid

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- The location of any (optionally user specified) TUFLOW FV boundary inflow nodestrings. If none have been specified, TUFLOW HPC will assume all boundary inflows to TUFLOW FV are lateral (rather than nodestring) inflows
- The constituents required for simulation in the TUFLOW HPC pollutant export model and therefore inclusion in boundary condition headers and boundary data files to be written

To determine the boundaries between the TUFLOW HPC and TUFLOW FV models, the FV mesh file is processed to determine the HPC cells that fall within the mesh. Boundary linkages from the HPC model are then resolved.

If a TUFLOW FV mesh element does not contain one or more TUFLOW HPC cell centres, then the TUFLOW HPC cell that contains the TUFLOW FV element centroid is selected. After all mesh elements and boundary nodestrings are processed, the TUFLOW HPC cells at the perimeter of the TUFLOW FV mesh are selected as transfer cells, and any cells entirely within the TUFLOW FV mesh are deactivated in TUFLOW HPC computations.

These TUFLOW HPC transfer cells track the surface and groundwater flow volumes and constituent masses between boundary output times. Each transfer cell's outflows are converted into timeseries of flow rates and concentrations and exported into the comma delimited (.csv) format expected by TUFLOW FV. Boundary data for TUFLOW FV is written with date (dd/mm/yyyy hh:mm:ss, rather than hour) format.

This automated selection of linkage cells is sufficiently robust to handle differences in mesh/grid resolution between TUFLOW HPC and TUFLOW FV, including in cases where the TUFLOW HPC model is higher resolution than the (local) TUFLOW FV model mesh, and vice-versa. Some typical cases are presented in Figure 3.5.

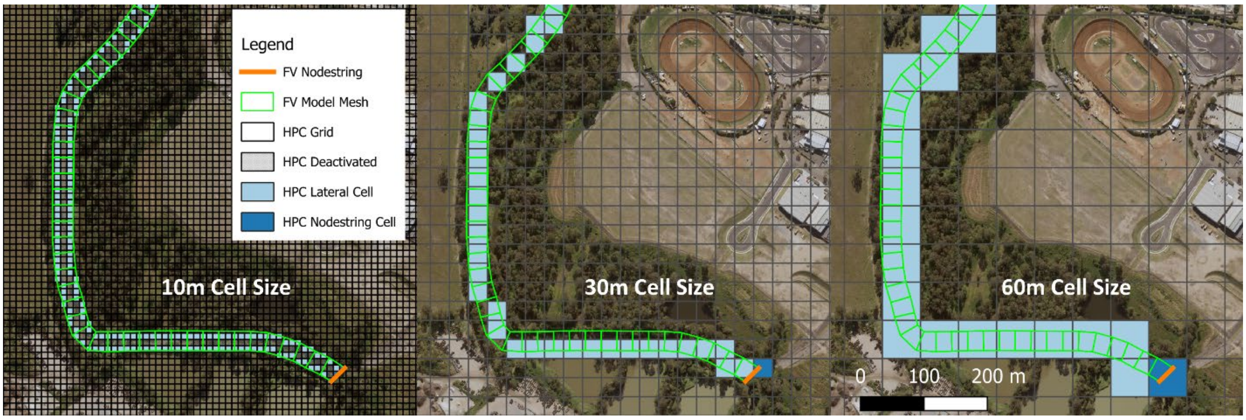

Figure 3.5 TUFLOW HPC Linkage Cells at Various Relative TUFLOW HPC/TUFLOW FV Grid/Mesh Resolution Combinations

A range of options are being considered to continually enhance this linking approach, including:

- Grouping lateral cells together (e.g., within a user specifiable radius) to reduce the number of TUFLOW FV lateral boundaries produced
- Allowing different boundary export interval times for lateral and nodestrings boundaries (e.g., three hourly for lateral inflows and at 15 minutes for nodestrings)

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- Using a different output format instead of .csv, e.g., NetCDF
- Dynamically linking the catchment and receiving models so that they run together allowing data transfer via memory rather than file writing

3.3 TUFLOW Catch Development

The manner in which TUFLOW Catch seamlessly integrates TUFLOW HPC and TUFLOW FV is via user construction and interaction with only one overarching TUFLOW Catch control file. The control file is subdivided into four sections:

1. Global commands
2. TUFLOW HPC hydraulic model commands
3. TUFLOW HPC pollutant export model commands
4. TUFLOW FV receiving model commands

It is important to note that the contents of sections 2 and 4 above are nothing other than that which would be otherwise contained within standard TUFLOW HPC and TUFLOW FV control files, respectively (except for a small number of additional TUFLOW Catch commands described below). This is a deliberate design choice, and it means that:

- Users can directly draw on their previous experience and familiarity with constructing TUFLOW HPC and TUFLOW FV models – almost no new commands are needed to populate these sections
- The TUFLOW Catch control file replaces the individual TUFLOW HPC (.tcf) and TUFLOW FV (.fvc) control files. The latter are no longer needed to be separately built by the user: TUFLOW Catch takes the content of sections 2 and 4 above and automatically writes out the respective TUFLOW HPC and TUFLOW FV control files in the locations required, without the user needing to worry about file or folder structures
- Combining the above two features means that users can construct both their TUFLOW HPC and TUFLOW FV models as a single TUFLOW Catch model, directly through the TUFLOW Catch control file interface. In other words, the TUFLOW Catch control file becomes the single point of truth and construction for the underlying TUFLOW suite of models. This ensures that the user has only one point of interaction with all models and platforms and therefore supports the seamless under-the-hood execution of the TUFLOW suite. This includes specification of all relative paths from the TUFLOW Catch control file – TUFLOW Catch reinterprets these for subsequent writing of the subordinate .tcf and .fvc files. If a file sharing platform such as SharePoint is used to house modelling input (not output) files then this arrangement allows multiple users to collaborate on a single TUFLOW Catch control file, each editing different sections that relate to different roles/skill sets

More broadly, if users follow the recommended approach and use the TUFLOW Catch plugin available at no cost in the free QGIS software (see Section 6.4) then this TUFLOW Catch control file structure will be generated as a template automatically on project commencement and setup. This alleviates the need to recreate (or worse, copy from previous projects) a new TUFLOW Catch control file for each application. The template includes all relevant commands for TUFLOW Catch, with prompts for tailoring.

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The four sections of the TUFLOW Catch control file are described below.

3.3.1 Section 1: Global Commands

These commands relate to model parameters that encompass all aspects of the simulation, including (but not limited to):

- Simulation start and end time
- Hardware specifications (GPU or CPU)
- GIS projection
- Output directories for results and check files
- Other miscellaneous commands (see user manual)

An example from the Oxley Creek catchment TUFLOW Catch model is presented following.

```
!
! TUFLOW CATCH GLOBAL COMMANDS

! Hardware
Hardware == GPU

! GIS integration
SHP Projection == ..\model\gis\projection.prj

! Simulation times
date format == ISODATE
start date == 01/01/2020 00:00:00
end date == 02/01/2020 00:00:00

! Output and check files
output directory == ..\output
write check files == ..\check
log folder == ..\log

! Boundary condition configuration
Catch output folder == ..\bc_dbase
Catch output interval == 900
CSV write frequency day == 7
```

Figure 3.6 TUFLOW Catch Control File Example: Section 1

3.3.2 Section 2: TUFLOW HPC Hydraulics Commands

These commands are those of a TUFLOW HPC .tcf file, with the addition of the following TUFLOW Catch commands:

- The location to which TUFLOW Catch should write the subordinate .tcf file
- The location of the TUFLOW HPC executable to be used
- Possible (optional) overwrites of the commands issued in Section 1

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3.3.3 Section 3: TUFLOW HPC Pollutant Export Commands

These commands are new and are used to configure the catchment pollutant export models run with TUFLOW HPC. They allow for specification of:

- Constant concentrations for any number of constituents, e.g., phytoplankton being 5 µg/L, or dissolved oxygen being a fixed concentration
- Which pollutants are prevented from entering the groundwater (see Section 3.2.1)
- A constant or timeseries of inflow water temperatures, or other constituents wishing to be specified as timeseries
- Pollutant export methods and parameters for every constituent simulated (see Section 3.2.1)
- Spatial variation of these models and parameters via 'materials', at a spatial resolution down the computational grid size. This allows for high spatial resolution of pollutant export features and does not resort to spatial lumping

An example from the Oxley Creek catchment TUFLOW Catch model is presented below.

```
!
! POLLUTANT EXPORT

catchment pollutant export model == mass accumulation release
  ! Constant concentrations
  Constant Salinity == 0
  Constant WQ_DISS_OXYGEN_MG_L == 6.5
  Constant WQ_SILICATE_MG_L == 20
  Constant WQ_FRP_ADS_MG_L == 0
  Constant WQ_PHYTO_GREEN_CONC_MICG_L == 0

  ! Prohibited infiltrations
  Infiltration SED_FINES == Off
  Infiltration WQ_POC_MG_L == Off
  Infiltration WQ_PON_MG_L == Off
  Infiltration WQ_POP_MG_L == Off

  ! Temperature
  Time-series Temperature == temperature

  ! Pollutnat export properties
  ! Rates are in kg/(ha.yr), Limits are in kg/ha Set limit to same as yearly rate
  ! timeConstant is in s, rainThreshold is in mm/hr, depthThreshold is in m

  Material == ALL ! assume all forested
    SED_FINES,        method==rate, rate==55.00,  limit==55.00,  timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_AMMONIUM_MG_L,method==rate, rate==0.273,  limit==0.273,  timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_NITRATE_MG_L, method==rate, rate==0.662,  limit==0.662,  timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_FRP_MG_L,     method==rate, rate==0.010,  limit==0.010,  timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_DOC_MG_L,     method==rate, rate==21.446, limit==21.446, timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_DON_MG_L,     method==rate, rate==1.021,  limit==1.021,  timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_DOP_MG_L,     method==rate, rate==0.009,  limit==0.009,  timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_POC_MG_L,     method==rate, rate==12.154, limit==12.154, timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_PON_MG_L,     method==rate, rate==1.044,  limit==1.044,  timeConstant==3600, rainThreshold==1, depthThreshold==0.002
    WQ_POP_MG_L,     method==rate, rate==0.061,  limit==0.061,  timeConstant==3600, rainThreshold==1, depthThreshold==0.002
  end material

  Material == 20,21,22,23,24,25,26,27
    SED_FINES,        method==rate, rate==300.0,  limit==300.0,  timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_AMMONIUM_MG_L,method==rate, rate==2.171,  limit==2.171,  timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_NITRATE_MG_L, method==rate, rate==2.364,  limit==2.364,  timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_FRP_MG_L,     method==rate, rate==0.022,  limit==0.022,  timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_DOC_MG_L,     method==rate, rate==71.486, limit==71.486, timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_POC_MG_L,     method==rate, rate==40.514, limit==40.514, timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_DON_MG_L,     method==rate, rate==2.194,  limit==2.194,  timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_DOP_MG_L,     method==rate, rate==0.005,  limit==0.005,  timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_PON_MG_L,     method==rate, rate==3.271,  limit==3.271,  timeConstant==600, rainThreshold==1, depthThreshold==0.001
    WQ_POP_MG_L,     method==rate, rate==0.623,  limit==0.623,  timeConstant==600, rainThreshold==1, depthThreshold==0.001
  end material
```

Figure 3.7 TUFLOW Catch Control File Example: Section 3

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3.3.4 Section 4: TUFLOW FV Commands

These commands are those of a TUFLOW FV .fvc file, with the addition of the following TUFLOW Catch commands:

- The location to which TUFLOW Catch should write the subordinate .fvc file
- The location of the TUFLOW FV executable to be used
- Possible (optional) overwrites of the commands issued in section 1

3.3.5 Executable

TUFLOW Catch is a Windows executable file and was written in Fortran using Visual Studio. It is not yet available on linux or iOS. A linux release is planned for 2024.

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4 Pilot Model Development

On completion of the development described above, and following execution of the usual TUFLOW product QA/QC protocols, TUFLOW Catch was applied to the Oxley Creek catchment as a pilot study for this commission. The study area is presented below, with indicative TUFLOW HPC and TUFLOW FV model extents.

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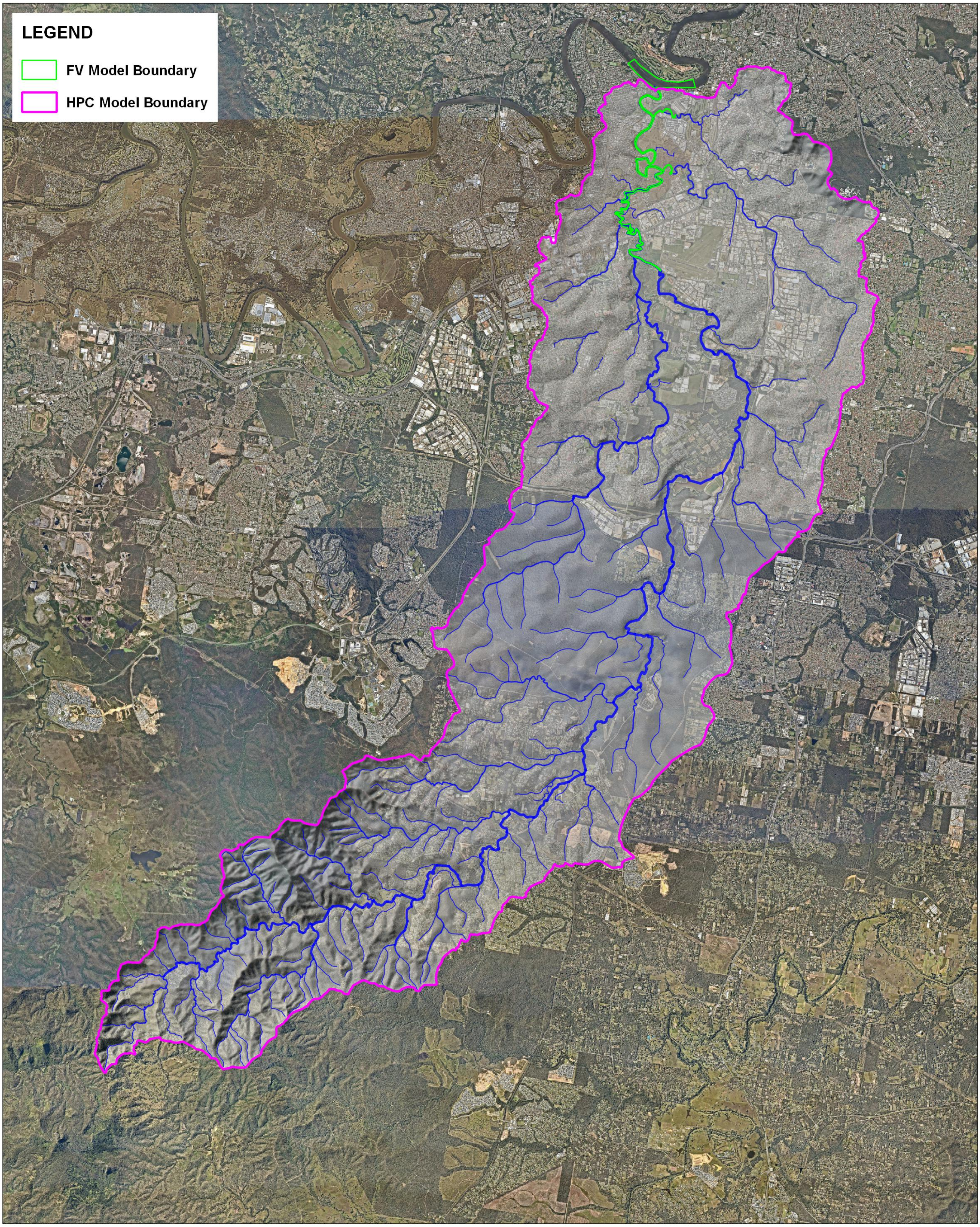

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Study Area and Model Domain

Figure: 4.1

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Constructing the TUFLOW Catch pilot entailed building three models, using the TUFLOW Catch control file interface:

- TUFLOW HPC hydraulic model
- Pollutant export model
- TUFLOW FV three dimensional receiving hydrodynamic and water quality model

These model builds are described below.

4.2 TUFLOW HPC Hydraulic Model

4.2.1 Overview

There are numerous approaches available for modelling the hydrologic processes that generate catchment runoff flows from rainfall. Australian Rainfall and Runoff (ARR) Book 4 (Ball et al., 2019) describes approaches based on the spatial resolution as lumped, semi-distributed or distributed, shown in Figure 4.2. TUFLOW HPC direct rainfall hydraulic modelling (also referred to as rain on grid modelling above) is a distributed assessment approach. In this approach, rainfall runoff is simulated using a hydraulic model for each model grid cell, and is computed based on the cell area, rainfall volume applied, soil infiltration losses and evapotranspiration. TUFLOW HPC routes flow associated with surface runoff, based on the adjacent cell geometry and associated flows, groundwater infiltration (vertical) and in-cell horizontal flow.

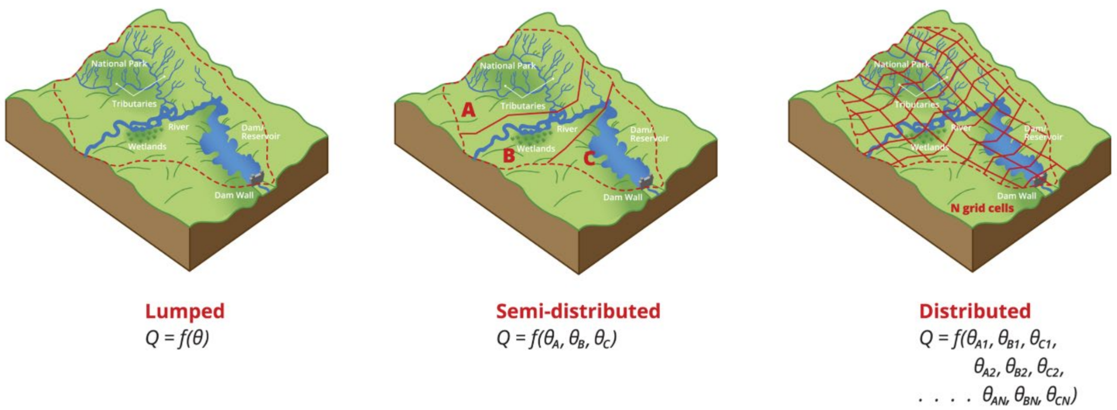

Figure 4.2 Catchment Rainfall Runoff Modelling Approaches (ARR 2019, Book 4 Figure 4.2.5)

Advantages of the TUFLOW HPC direct rainfall modelling distributed assessment approach (as compared to lumped or semi-distributed approaches) are numerous, and include:

- Higher resolution representation of spatially varying catchment features and associated hydrologic processes (typically at a grid resolution finer than 100m-by-100m per cell, across an entire catchment). Examples of rainfall/runoff significant catchment features include: ground slope, land use type, pervious/impervious surface, soil type and condition
- No time consuming manual sub-catchment delineation is required. This removes the potential for human error and catchment delineation difficulties in flat areas

- Dynamically linked hydraulic analysis of surface water and groundwater interactions. This linkage is essential for the accurate estimate of streamflow conditions during non- and low-rainfall periods when surface flows in ephemeral streams and creeks are predominantly generated by groundwater origin base flows and contribute to the delivery of falling limb hydrologic features, which are explored as part of this pilot model application

Historically, the high computational demand associated with direct rainfall distributed modelling made the option often unsuitable for long duration (multiple years) continuous simulation at whole of catchment scales. In more recent times, hardware and software advances have dramatically improved simulation efficiency, increasing simulation speeds by over 1000 times compared to circa 2010 modelling. These computational advances alleviate the historic limitations, now meaning the higher resolution and accuracy results associated with direct rainfall distributed modelling are available for use by applications requiring multi-year continuous simulation assessment: simulations that were considered intractable a decade ago are now comfortably within reach. This project is a demonstration of this technology: the TUFLOW HPC model can provide flow estimates for all locations within the Oxley Creek catchment at a 60m-by-60m resolution (to a total of 71,615 2D surface cells, and the same number of subsurface cells for each groundwater layer) hydrologically enforced through the use of sub-grid sampling at a 1 metre resolution, which is the same as the underlying DEM. The model simulation time using off the shelf GPU hardware was 3.45 hours per year simulation. The flow estimate result accuracy from the analysis is excellent, as presented in Figure 4.16 to Figure 4.27.

It is noted that this modelling approach is a fundamental paradigm shift from the traditional daily lumped hydrology rainfall runoff modelling that has been widely adopted and applied in Southeast Queensland (and elsewhere) since the last century. It represents an exciting new development in the continued evolution and maturation of catchment modelling to support informed catchment management decision making. Some benefits associated with the new approach include:

- Significantly increased catchment rainfall/runoff flow estimation accuracy. The increased accuracy is the result of many factors including, although not limited to:
  - More detailed mathematical representations of the on-ground physical forcings associated with rainfall/runoff processes and routing of flows – these fine scale physical forcings are lost in a lumped hydrology model. For example, routing of flow is accurately estimated using the Shallow Water Equation form of the Navier Stokes equations, not a user defined lag parameter
  - Greater resolution definition of the upstream contributing sub-catchment and spatial variations in rainfall intensity
  - Greater temporal resolution of rainfall inputs (15 minutes increment instead of daily)
  - Hydrological enforcement of the sub-cell topography through use of TUFLOW HPC's powerful sub-grid sampling (SGS) feature.
  - Improved estimation of groundwater baseflow recharge to the surface water creeks

These assessment methodology improvements increase the accuracy of rising limb, peak and (especially) falling limb flow hydrograph estimates during wet periods. The estimation of baseflow recharge to the surface water creeks also improves flow estimations during dry (non-rain) periods.

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Accurate estimation of these hydrologic behaviours is essential for accurate receiving water hydrodynamic and water quality modelling: catchment flows have a direct impact on both the delivery of pollutants to downstream waterways, and the hydrodynamic control of tailwater ingress to tidal creeks/estuaries (and therefore estuarine salinity/recovery and water quality). This impact of falling limb hydrology prediction on downstream water quality modelling predictive power is explored in detail in this pilot study.

4.2.2 Data Collation

Oxley Creek Flood Model

Modelling files associated with the Oxley Creek Flood Study (BCC, 2014) have been provided by Brisbane City Council. The TUFLOW model developed for the Flood Study has been used as the foundational dataset for the TUFLOW HPC catchment model used in this pilot. The Oxley Creek Flood Study included:

- XP-RAFTS semi-distributed hydrology model comprising 249 sub-catchments, with an average area of 100ha. The hydrology model used a fixed initial (mm) and continuing (mm/h) loss model for the rainfall runoff loss approach
- TUFLOW Classic hydraulic model covering the lower half of the Oxley Creek catchment. Johnson Road, Goodna represents the upstream extent of the 2D hydraulic model. Topography data in the model comprises Airborne Laser Survey, flown in 2009, and creek cross-section information amalgamated from numerous datasets surveyed in the prior 40 years

The XP-RAFTS hydrology and TUFLOW Classic hydraulic model were calibrated to significant historical events in 1996 and 2009.

Numerous updates have been made to the Oxley Creek Flood Study TUFLOW model for the purpose of this study. The updates have configured the model for compatibility with the latest TUFLOW HPC software version, accessing recent advances in computational hydraulics, and utilising features necessary for efficient, accurate whole of catchment direct rainfall hydraulic modelling. The updated model configuration is detailed in Section 4.2.3. Hereon in the updated model will be referred to as the TUFLOW HPC catchment model.

Rainfall Data

The TUFLOW HPC catchment model has been calibrated to three one-year periods, 2022, 2020 and 2019. Rainfall data is an essential data input from historic event model calibration. Fortunately, the Oxley Creek catchment and its surrounds includes a high density of rainfall gauges. Rainfall gauge data used for this pilot have been provided by Brisbane City Council (BCC) and purchased from the Australian Bureau of Meteorology (BoM). Table 4.1 provides a summary list of the rainfall gauge stations. The gauge locations are shown in Figure 4.3.

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Table 4.1 Rainfall Gauge Summary

Rainfall Gauge Name	Station ID	Source
Beaudesert Rd, Calamvale	40784	BCC
Blunder Ck at Richlands	40785	BCC
Johnson Road, Forestdale	40788	BCC
Blunder Ck Inala	540029	BCC
Dulcie St, Salisbury	540470	BCC
Jingle Downs Alert	40786	BoM
Lyons Alert	40793	BoM
Greenbank (Thompson Rd) Alert	40794	BoM
Oxley Ck Alert	540646	BoM
Brisbane Road Alert	40874	BoM
Romani Alert	40934	BoM
Maclean Bridge Alert	40935	BoM
Bellbird Park (Purser Rd) Alert	40985	BoM
Jindalee Alert	540192	BoM
Washpool Alert	540195	BoM
Underwood (Millers Rd) Alert	540233	BoM
Stretton (Gowan Rd) Alert	540234	BoM
Hillcrest (Wine Glass) Alert	540235	BoM
Spring Mt Alert	540665	BoM
Goodna Alert	540670	BoM
Redbank Plains Alert	540671	BoM
Flagstone Ck (Jimboomba) Alert	540689	BoM
Kilmoylar Rd Alert	540690	BoM
Waller Rd Alert	540692	BoM
Bellbird Park (Eugene St) Alert	540728	BoM
Park Ridge (Stoney Camp Rd) Alert	540787	BoM

Water Level Data

Water level gauges are also an essential data input from historic event model calibration. Water level gauge recording represent the dataset that is used to assess a model’s ability to reproduce the real-world flow behaviour in a catchment.

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Water level gauge recordings within the Oxley Creek catchment have been provided by BCC and BoM. Table 4.2 provides a summary list of the water level gauge stations. The gauge locations are shown in Figure 4.3.

Table 4.2 Water Level Gauges

Water Level Gauge Name	Station ID	Source
Durack King Ave Alert	40789	BCC
Musgrave Rd, Coopers Plains	40791	BCC
Beatty Road, Acadia Ridge	40796	BCC
Corinda High School Alert	540071	BCC
New Beith Alert	540097	BCC
Oxley Creek Mouth Alert	540274	BCC
Marshall Road Alert	540432	BCC
Lakeside Crescent Alert	540535	BCC
Oxley Ck Alert (at Goodna Rd)	540646	BoM

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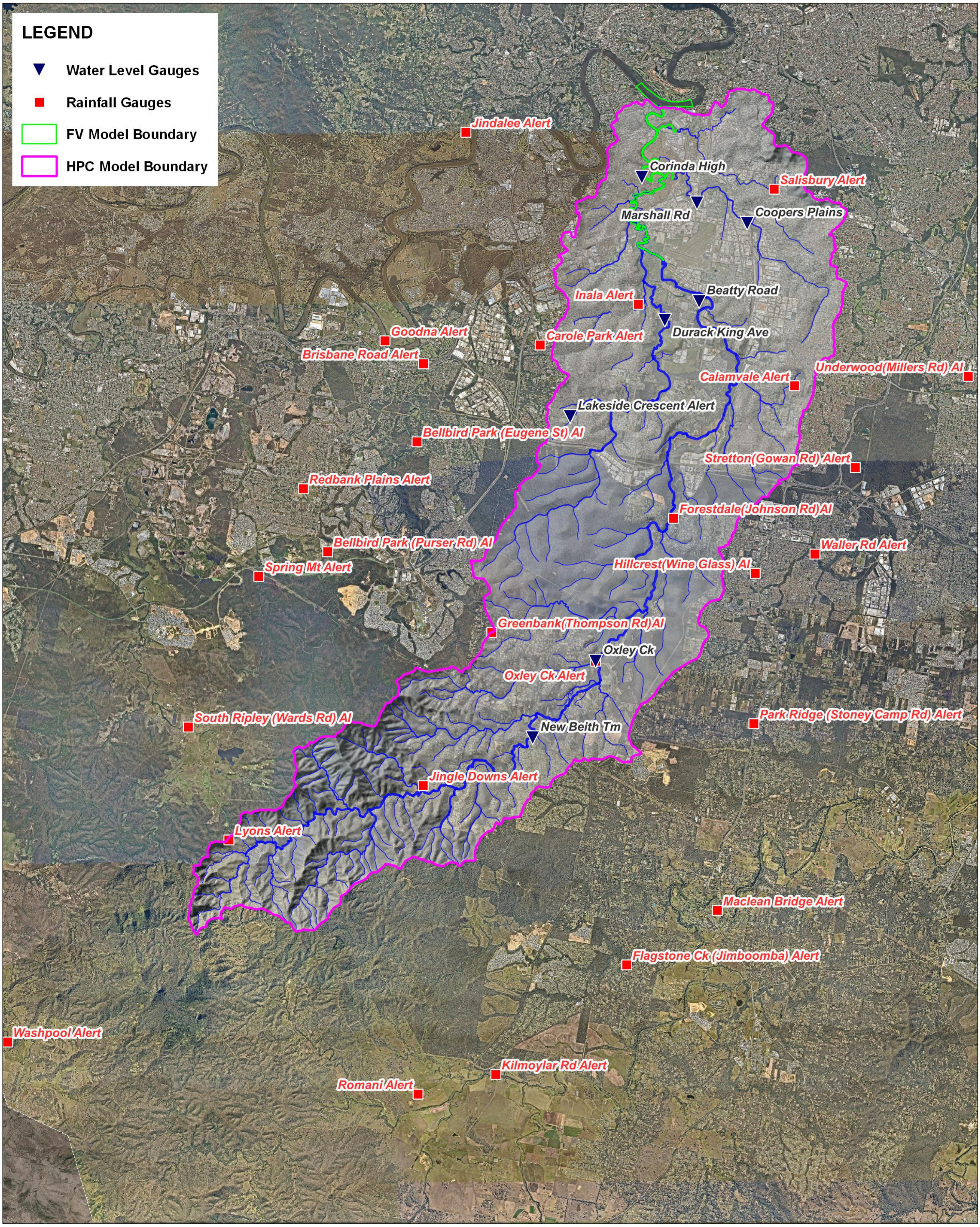

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Rainfall and Water Level Gauges Locations

Figure: 4.3

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Site Visit

BMT conducted a multi-stop catchment site visit to gain familiarity with the study area on 31st May 2023. This included measuring dimensions of key structures (such as culverts) for subsequent direct inclusion the TUFLOW HPC catchment model as 1D features. Some pictures from the site visit follow.

Spring Mountain Drive

Goodna Rd Oxley Bridge

Topsoil Observation (near New Beith Water Level Gauge)

Figure 4.4 Site Visit Photos

4.2.3 Model Development

The TUFLOW model developed for the Oxley Creek Flood Study (BCC, 2014) has been used as the foundational dataset for the catchment model developed for this project. Significant updates to the model are summarised in the following sections.

TUFLOW Solution Scheme

The Oxley Creek Flood Study (BCC, 2014) TUFLOW model utilised TUFLOW Classic as the numerical solver. TUFLOW Classic uses a finite difference implicit solution. In 2014, at the time of the Flood Study, TUFLOW Classic was the most accurate and fastest commercially available shallow water equation solver. Hydraulic modelling technology has improved significantly since 2014. The TUFLOW Classic model has been upgraded to TUFLOW HPC. TUFLOW HPC is a finite volume explicit solution, specifically designed for parallel compute on Graphical Process Units (GPU). Using current off-the-shelf NVIDIA GPU hardware, TUFLOW HPC is over 100 times faster than the TUFLOW Classic 2014 CPU

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solver. TUFLOW HPC development began in 2011, with its first commercial release in 2017 (after completion of the Oxley Creek Flood Study (BCC, 2014)). Since TUFLOW HPC's initial release, continual enhancements have been published year on year, as documented in the TUFLOW Classic/HPC release notes (TUFLOW, 2017, 2019, 2020, 2022, 2023). TUFLOW HPC's superior accuracy and speed have helped it become the most popular and widely used solution today, with most TUFLOW Classic models now using the HPC solver.

Sub-Grid Sampling of Elevation Data

Sub-grid Sampling (SGS) of terrain data was added as a new feature to the 2020 release version of TUFLOW HPC. SGS is an update to Traditional Cell Sampling methods used by TUFLOW Classic and other shallow water equation solvers. A conceptual design illustration comparing the Traditional Cell Sampling and SGS methods is presented in Figure 4.5.

In both the Traditional and SGS topography sampling approaches, Digital Elevation Model (DEM) topography data is typically available at a finer resolution than the hydraulic model computational grid resolution. In these instances:

- Traditional topography sampling sets the cell elevation as either the DEM elevation at the cell centroid or the average elevation within the cell. The resulting grid is a series of flat-bottomed cells with linear relationships between water surface elevations and cell water volume (cell water depth multiplied by cell area). Furthermore, connections between adjacent cells and the cell faces are rectangular in shape, with linear relationships between water surface elevation and the face flux area used to convey flow

- SGS topography sampling extracts sub-grid data from an underlying DEM to develop a non-linear relationship between the water surface elevation and the cell's volume to describe the cells' storage capacity. SGS also generates a non-linear relationship between the water surface elevation and the cell face area and cell width (or wetted perimeter) to improve the representation of the fluxes across the cell faces as flow is conveyed throughout the model domain. The SGS approach still computes a single water level for each cell, but the computations to determine the cell volume and cell face fluxes utilise the higher resolution underlying terrain data

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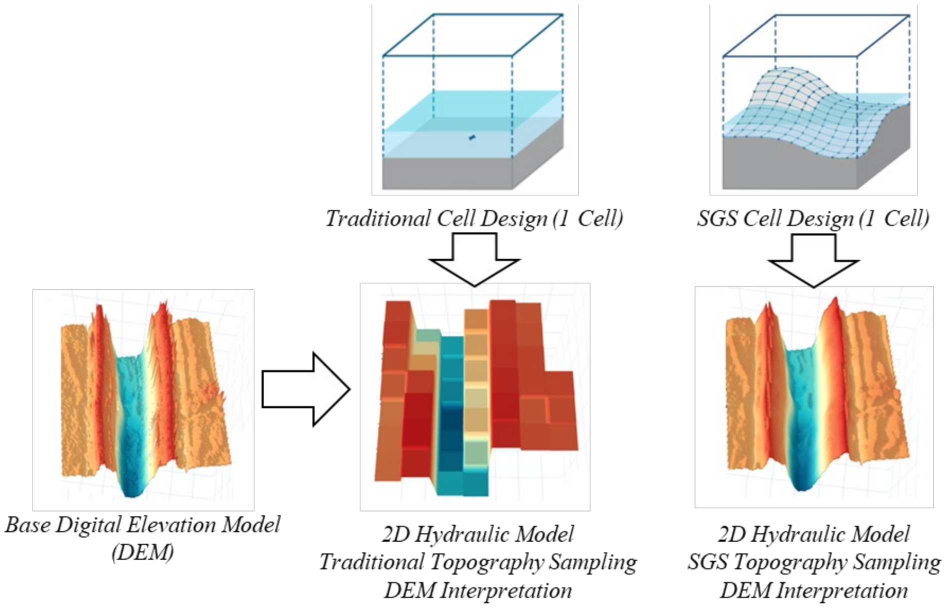

Figure 4.5 2D Topography Sampling and DEM Interpretation of Traditional Cell Sampling and Sub-grid Sampling Models

Numerous publications describe the solution accuracy and simulation speed benefits associated with SGS (Kitts *et al,* 2020, Ryan *et al,* 2022, Huxley *et al*, 2022). A summary of the key findings relevant to catchment direct rainfall modelling include:

- SGS removes artificial numerical loss artefacts common in grid shallow water equation solutions when the flow direction is oblique to the grid orientation. As a result, SGS improves solution accuracy. Models can be developed using a grid orientation at any angle relative to the flow direction with no loss of solution fidelity. (Kitts *et al,* 2020)

- Compared to the Traditional Cell Sampling approach, SGS hydrologically enforces the runoff by enabling transmission of flow between adjacent cells when the flow scale is proportionally significantly smaller than the modelled cell resolution. This SGS behaviour significantly improves modelling accuracy by removing unphysical depression storage artefacts, as commonly occurs when using Traditional Cell Sampling for direct rainfall modelling applications. As a result, superior reproduction of the rise and fall water level and flow behaviour at gauged hydrographs during model calibration has been demonstrated when using SGS. (Ryan *et al,* 2022)

- Cell size result convergence testing demonstrates that consistent results are achieved at a much larger cell size using SGS, compared to Traditional Cell Sampling. Modelling at a larger cell size, reduces computational load and increases simulation speed. (Huxley *et al,* 2022). On average, doubling of cell size increases simulation speed by a factor of eight

The use of SGS has enabled the TUFLOW HPC Catchment model to operate using a 60m 2D cell resolution without an adverse impact on flow estimation accuracy, as compared to results associated with finer cell resolution versions of the same model, as demonstrated by the calibration statistics (for the 60m 2D cell grid) presented in Section 4.2.4.

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Model Extent

The Oxley Creek Flood Study (BCC, 2014) TUFLOW model covered the lower half of the Oxley Creek catchment. It extended from the Oxley Creek Mouth to Johnson Road, Goodna. For this pilot, and to apply a direct rainfall modelling methodology to support the generation of catchment runoff flows and associated water quality constituents, the model extent has been increased to include the entire Oxley Creek catchment, as shown in Figure 4.3.

Model Topography Data

The TUFLOW HPC catchment model has been updated using the latest available Council topography datasets. New Airborne Laser Survey (ALS) datasets added to the model include:

- 2014 Brisbane Council Digital Elevation Model (1m resolution)
- 2017 Logan Council Digital Elevation Model (1m resolution)
- 2019 Ipswich Council Digital Elevation Model (1m resolution)

Bathymetry data was also updated between the Oxley Creek Mouth and Sherwood Road, based on creek cross-section survey data provided by BCC.

1D and 2D Hydraulic Structures

Major 1D and 2D structures, such as bridges and culverts, present in the Oxley Creek Flood Study (BCC, 2014) TUFLOW model were included in the TUFLOW HPC catchment model.

The design water level / flow relationship for the Forest Lake Spillway has been added to the TUFLOW HPC catchment model. The design details were sourced from the *Emergency Action Plan Forest Lake Dam Referable Dam ID: # 0651* (BCC, 2022) report.

Land use and Manning's n

Land use data definition and parameterisation have been updated in the TUFLOW HPC catchment model to upgrade the model for direct rainfall hydraulic modelling. The updated dataset covers the entire catchment, shown in Figure 4.6, and includes the Manning's *n* and fraction impervious parameterisation listed in Table 4.3.

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Table 4.3 Land Use and Manning's *n* Parameterisation

Landuse Type	Manning's n	Fraction Impervious
Estuary	0.022	0.0
Non-Tidal Waterway	0.040	0.0
Waterbodies	0.025	0.0
Upstream Creek / Overbanks – Clean	0.045	0.0
Upstream Creek / Overbanks – Rocky, medium Vegetation	0.070	0.0
Upstream Creek / Overbanks – Rocky Dense Vegetation	0.100	0.0
Grass (maintained)	0.035	0.0
Light Vegetation (sparse trees)	0.050	0.0
Medium Vegetation (brush)	0.070	0.0
Dense Vegetation (trees with no undergrowth)	0.100	0.0
Very Dense Vegetation (trees with dense undergrowth)	0.150	0.0
Cropping (low density)	0.040	0.0
Cropping (medium density)	0.080	0.0
Cropping (high density)	0.120	0.0
Roads/Car parks	0.025	0.9
Low density urban	0.060	0.1
Medium density urban block	0.100	0.1
High density urban Block	0.200	0.1
Commercial/Industrial	0.100	0.9
Buildings	1.000	1.0
Mining Area	0.040	0.0
Rural Residential	0.070	0.1

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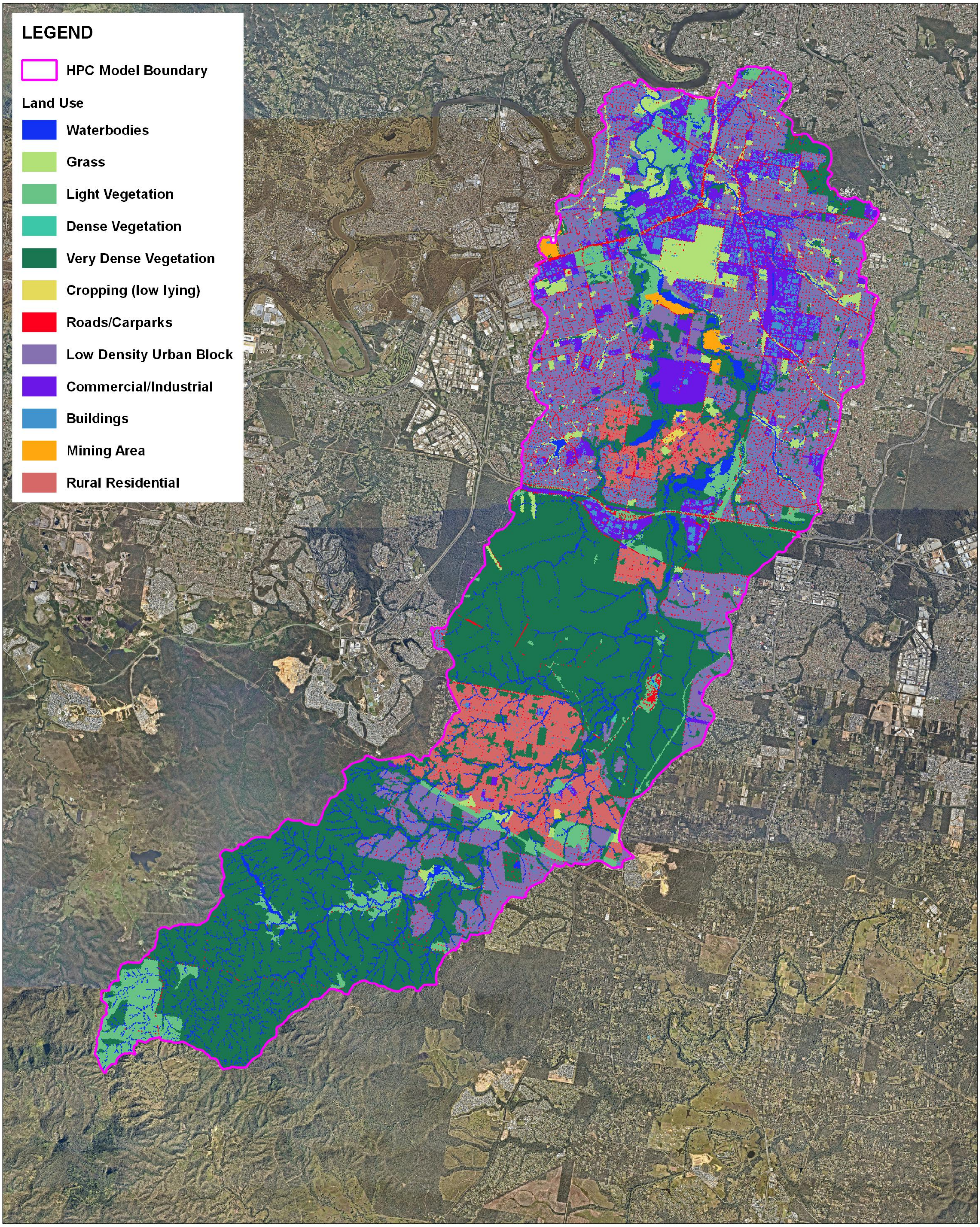

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TUFLOW HPC Catchment Model Land use Delineation

Figure: 4.6

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Boundary Conditions

The Oxley Creek Flood Study (BCC, 2014) utilised a linked hydrology / hydraulic modelling methodology. Direct rainfall (rain-on-grid) modelling, used by the updated TUFLOW HPC catchment model, excludes the need for separate hydrologic modelling. Instead, rainfall boundary conditions are applied directly to all 2D cells in the hydraulic model. Flows and pollutants are subsequently also routed by the hydraulic model (through both 1D and 2D computational elements), defining the above and below ground flow behaviour.

Three 12-month periods have been selected for rainfall /runoff calibration of the TUFLOW HPC catchment model: 2022, 2020 and 2019. These periods were selected in recognition of:

- **Recency:** Changes in catchment state associated with urban development or major infrastructure upgrades, which could alter the catchment rainfall runoff behaviour
- **Data Availability:** The selected periods are extremely data rich in terms of rainfall and stream gauge information. Twenty-eight rainfall gauges have been used to estimate the spatial and temporal variation of rainfall over the Oxley Creek catchment. Nine stream gauges have been used to assess the flow estimation performance of the model
- **Catchment Moisture and Rainfall Runoff Event Magnitude Variation:** Model validation using a wide range of rainfall conditions is necessary to test and confirm a developed model is an accurate representation of reality. The annual average rainfall at Archerfield Airport, within the Oxley Creek catchment, is 1056.1mm (BoM, 2023). The selected calibration periods are representative of the full range of rainfall/runoff behaviours
    - 2022 is representative of an extremely wet period. The annual rainfall at Archerfield Airport was 1711mm (BoM, 2023)
    - 2019 is representative of an extremely dry period. The annual rainfall at Archerfield Airport was 595mm (BoM, 2023). 2019 includes numerous extended (multiple month long) periods when the upper catchment ephemeral reaches of the Oxley Creek were dry
    - 2020 was a slightly below average year. The annual rainfall at Archerfield Airport was 913mm (BoM, 2023)

12-month cumulative rainfall totals used during the project rainfall/runoff calibration modelling are summarised in Figure 4.7 to Figure 4.9, and presented as contoured totals in Figure 4.12 to Figure 4.10.

The rainfall data has been applied as a direct rainfall boundary using TUFLOW's Inverse Distance Weighted (IDW) Interpolated Method. TUFLOW's IDW rainfall processing feature was specifically chosen for this task because of its ability to deal with missing data within rainfall input datasets (i.e., when a gauge is not operational for a period, though rain is occurring). Missing data is ignored from the instantaneous IDW interpolation during data processing. During such periods, surrounding gauge information supplements the missing data. This processing avoids under estimation of the rainfall volume by accidental inclusion of erroneous null value inputs. Use of this feature meant the partial datasets identified in Figure 4.7 to Figure 4.9 could be used when data was available, and were ignored when data was missing.

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Recorded water level data from the Oxley Creek Mouth (540274) gauge was applied as downstream water level boundary in the TUFLOW HPC catchment model calibration process.

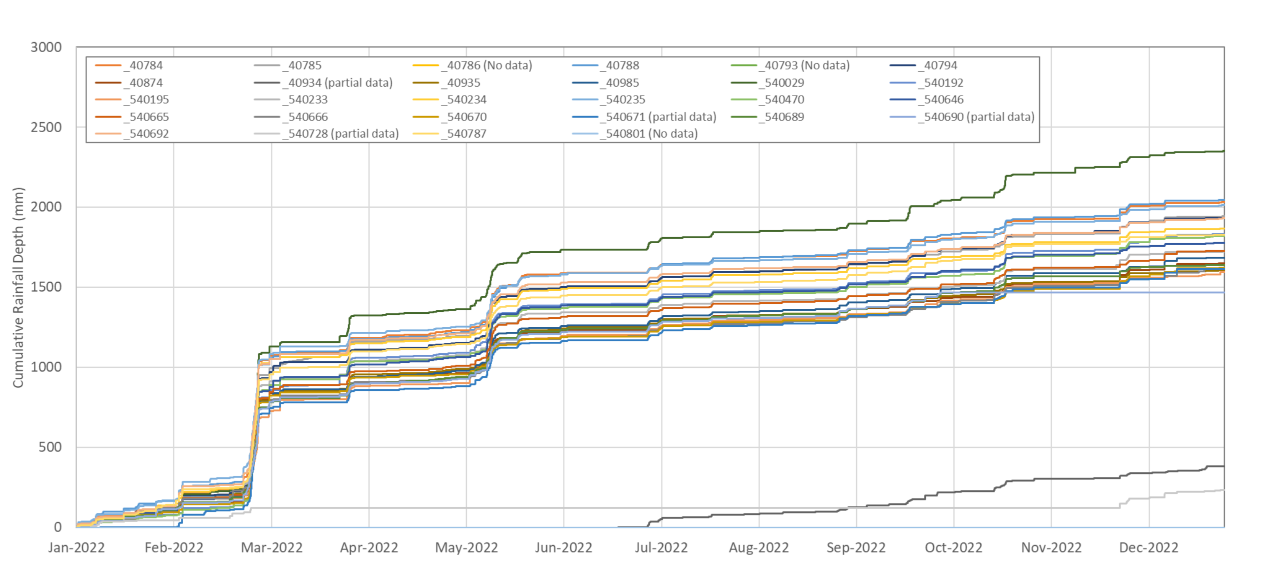

Figure 4.7 2022 Recorded Cumulative Rainfall Graph

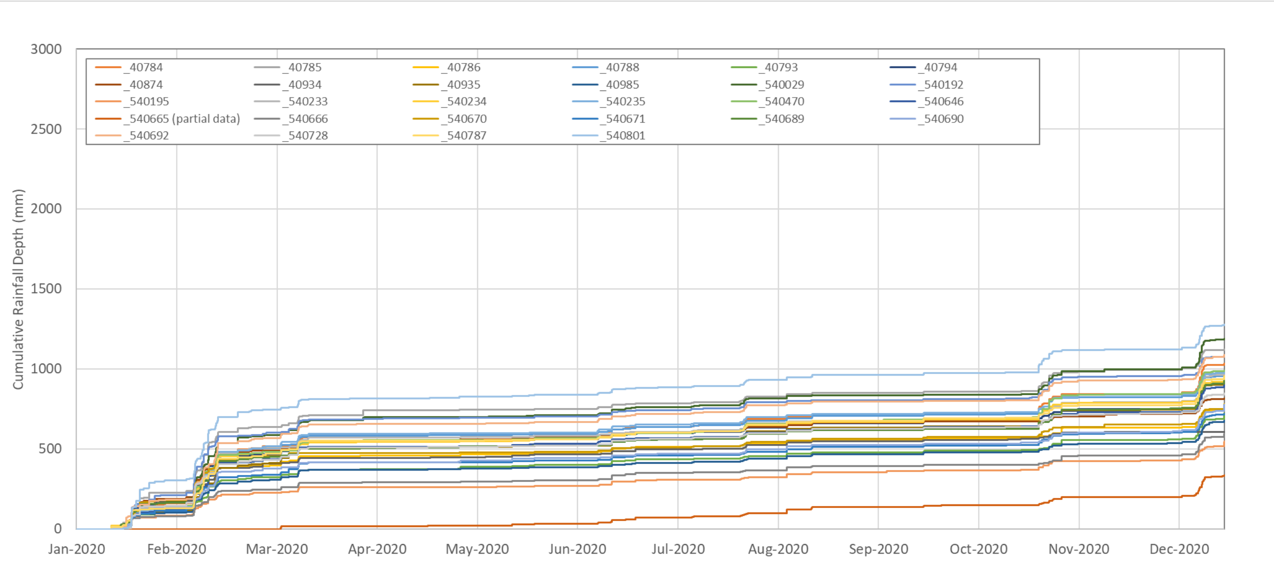

Figure 4.8 2020 Recorded Cumulative Rainfall Graph

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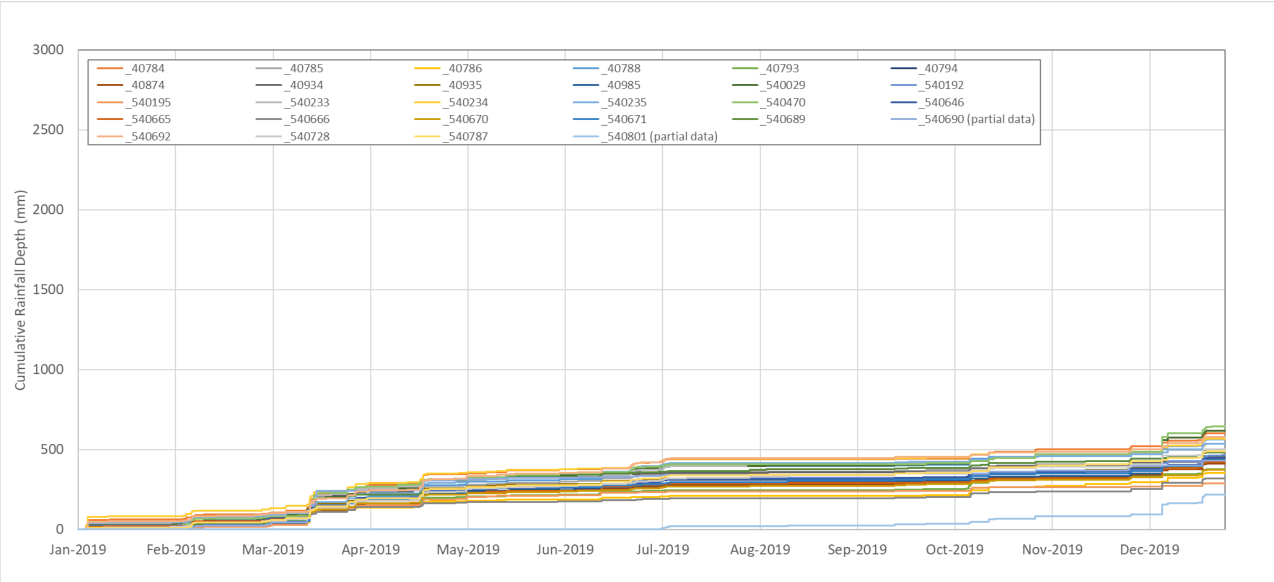
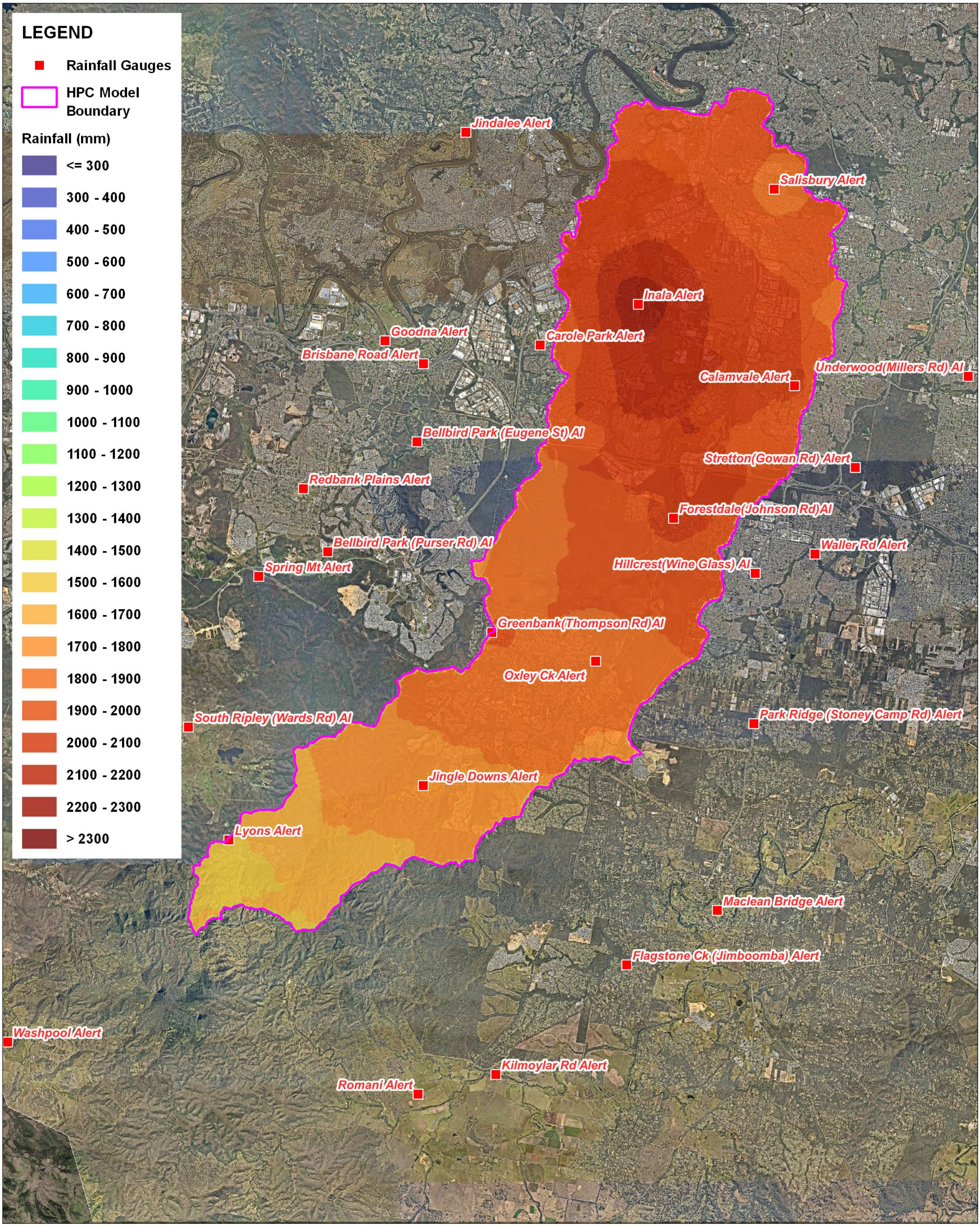


Figure 4.9 2019 Recorded Cumulative Rainfall Graph



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2022 Recorded 12 Month Cumulative Rainfall Distribution

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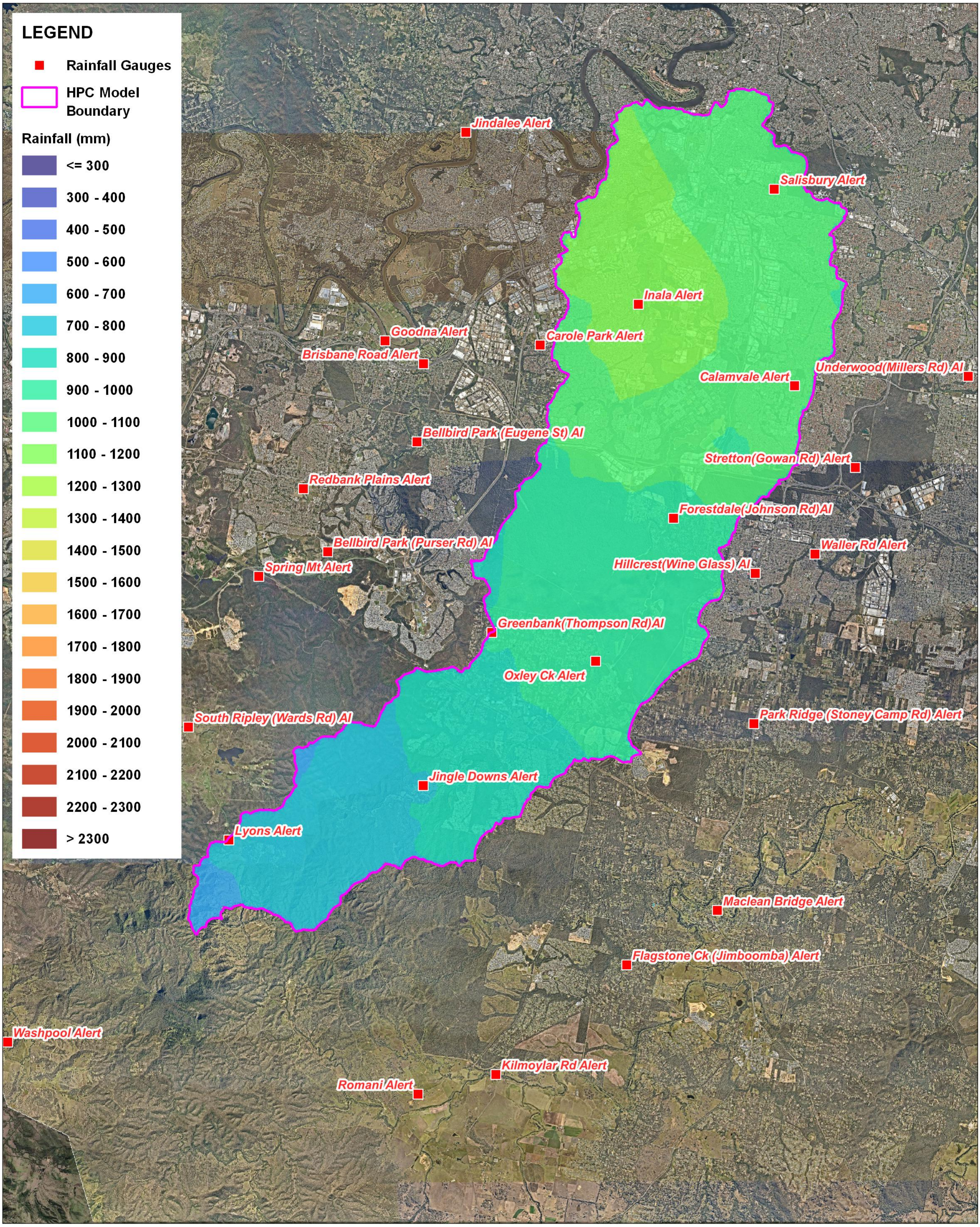

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2020 Recorded 12 Month Cumulative Rainfall Distribution

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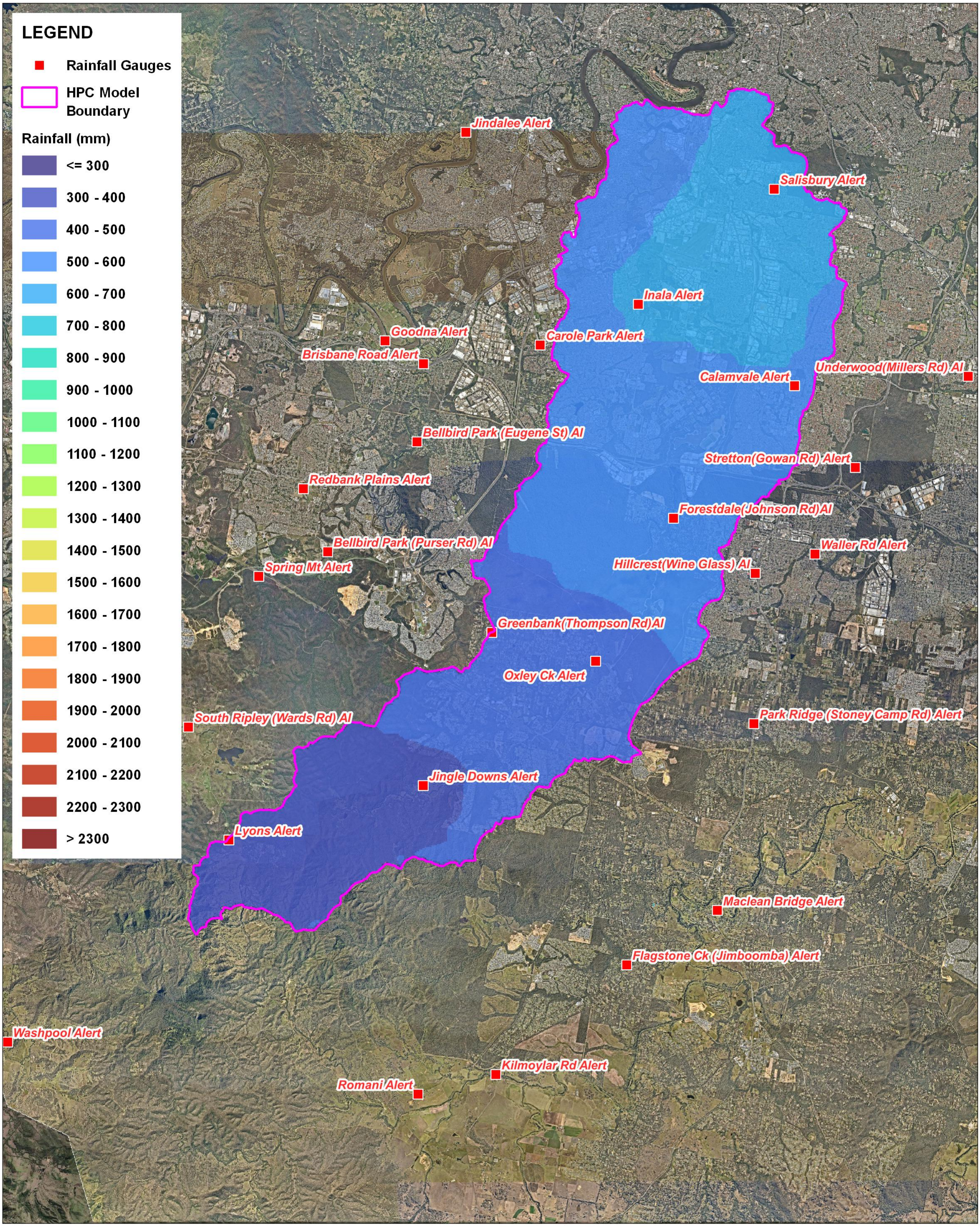

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2019 Recorded 12 Month Cumulative Rainfall Distribution

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Groundwater Parameterisation

Physically, the upper soil layers attenuate rainfall runoff by infiltrating the surface water, creating groundwater that may later recharge downstream channels, thereby generating base flow. A proportion of the groundwater may also infiltrate into deeper soil layers or be removed from the soil layer via evapotranspiration, and may subsequently not re-enter as surface flow. For long term continuous catchment simulations, consideration of soil infiltration and groundwater movement is critical to accurately replicate the timing, magnitude, and rising and falling limbs of catchment runoff events.

Soil infiltration and groundwater movement has been added to the TUFLOW HPC catchment model. Green-Ampt infiltration has been adopted as the vertical soil infiltration approach. The Green-Ampt approach varies the rate of infiltration over time based on the soil's hydraulic conductivity, suction, porosity and initial moisture content.

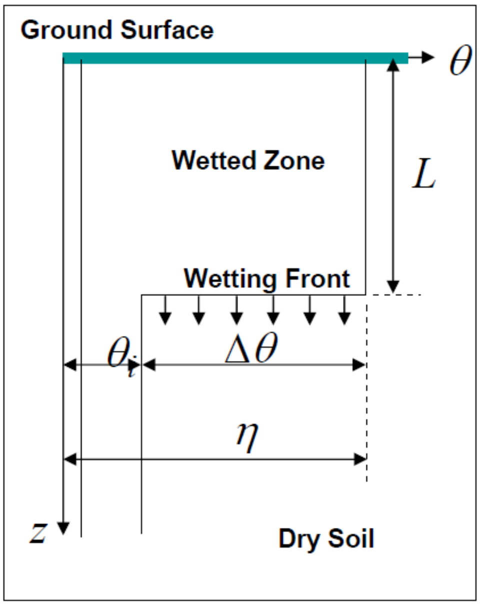

Figure 4.13 Green-Ampt Infiltration Conceptual Design

The basic form of the Green-Ampt equation is:

$$f(t) = K\left(1 + \frac{\Delta\theta(\varphi + h_0)}{F(t)}\right)$$

Where:

t = time
K = saturated vertical hydraulic conductivity
$\Delta\theta$ = defined as the soil capacity (the difference between the saturated and initial moisture content)
φ = soil suction head
h_0 = depth of ponded water
$F(t)$ = cumulative infiltration calculated from:

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$$F(t) - \Delta\theta(\varphi + h_0)\ln\left(1 + \frac{F(t)}{\Delta\theta(\varphi + h_0)}\right) = Kt$$

The horizontal movement of sub-surface groundwater is defined via a 2D implementation of Darcy's law. The vertical flux between the soil layers (Q_z) and the horizontal flux between sub-surface cells (Q_x and Q_y) are modelled as:

$$Q^z = -K_z A$$

$$Q^x = -K_h h\theta \frac{de}{dx} dy$$

$$Q^y = -K_h h\theta \frac{de}{dy} dx$$

Where:

K_z = vertical hydraulic conductivity (mm/hr)
K_h = horizontal hydraulic conductivity (mm/hr)
A = cell area (m^2)
h = depth or water in the soil layer (m)
θ = porosity
e = groundwater pressure elevation (m)

For cells that are unsaturated the groundwater pressure level is exactly the groundwater elevation within that layer (see Figure 4.14). For cells that are fully saturated, the groundwater pressure level is that of the cell in the layer above (or the water surface elevation if the layer above is the surface layer). For cells that are nearly saturated the groundwater pressure level is transitioned between these two limits. The threshold at which the transition begins is called the groundwater blending threshold ϕ:

$$\varepsilon = \frac{\frac{h}{dz} - \phi}{1 - \phi}$$

$$e_i = (1 - \varepsilon)(z_i - h_i) + \varepsilon e_{i-1}$$

$$e_0 = WSE_{surface}$$

Where:

dz = vertical thickness of the layer
z_i = bottom elevation of layer *i*
e_i = resulting groundwater pressure level for the layer *i*

The layer ordering is such that the surface water layer is 0, the interflow layer is 1, and any additional groundwater layers increase from 2, from top to bottom.

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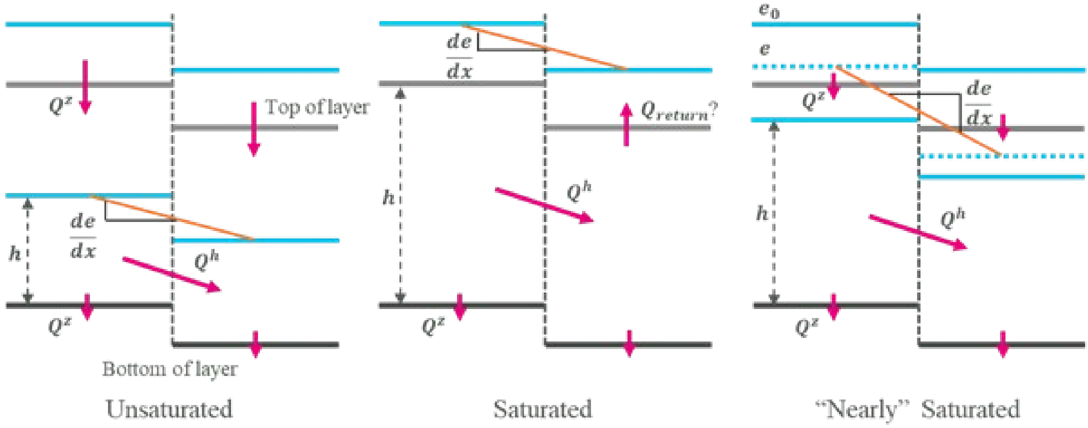

Figure 4.14 Dacy Law Gound Water Fluxes and Pressure Gradient Conceptual Design

The soil parameters in the Oxley Creek TUFLOW HPC Catchment model were sourced from the Australian Soil Atlas (CSIRO, 2013). The predominant soil types in the catchment are hard acidic yellow (Dy3.41) and red (Dr3.41) mottled soils. The texture of the Horizon A soil is categorised as Sand, Sandy Loam or Loam. Although this could vary spatially, a median texture of Sandy Loam has been adopted.

Australian Soil Atlas (CSIRO, 2013) reports a thickness of the Horizon A soil from 0.1~0.6m with a median value of 0.3m in the study area. Soil thickness sensitivity testing was undertaken during the model calibration exercise. A thickness of 0.3m was selected as the final modelled value. Below Horizon A soil, the Horizon B soil type is clay, with low hydraulic conductivity. Accordingly, only one layer of soil was applied in the TUFLOW HPC catchment model.

Australian Soil Atlas (CSIRO, 2013) reports the median vertical hydraulic conductivity in the study area to be 30mm/hr, with a possible range of 3mm/hr ~ 300mm/hr. A vertical hydraulic conductivity of 30mm/hr has been adopted. Horizontal hydraulic conductivities (K_h) are significantly larger than vertical hydraulic conductivities due to soil anisotropy (Barwell and Lee, 1981) and the formation of piping within the soil layer (Bell 2005). A horizontal hydraulic conductivity value of 100 mm/hr was used in urban areas, and 10,000mm/hr in undisturbed areas.

Evapotranspiration

Evapotranspiration represents a loss of water from the soil, both by evaporation from the soil surface and by vegetative transpiration. Evapotranspiration contributes to the drying of soil between rainfall events. Reduction in soil moisture during dry periods subsequently affects the infiltration capacity of the soil during and following rainfall events. Evapotranspiration has been included in the TUFLOW HPC catchment model. Modelled values were sourced from BoM (2023). The monthly potential evapotranspiration values used are presented in Figure 4.15.

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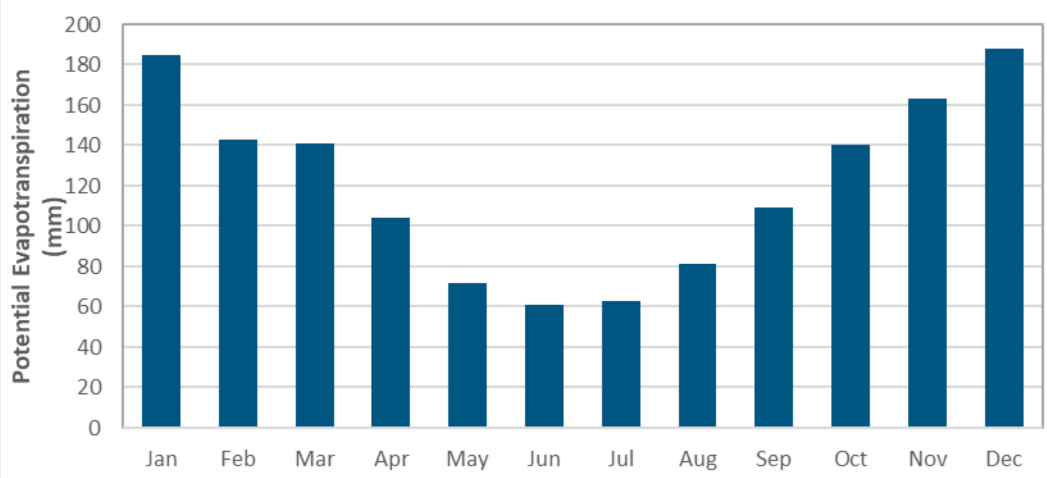

Figure 4.15 Potential Evapotranspiration (mm) per Month.

Pollutant Inputs

The pollutant export parameterisation described in Section 3.2.1 was applied directly and unchanged to the Oxley pilot model.

4.2.4 Model Calibration

Model calibration plots, comparing model results against recorded data, for 2022, 2020 and 2019 at the nine stream gauge locations listed in Table 4.2 and shown in Figure 4.3 are presented in the following section. The results are ordered from upstream to downstream gauge locations.

Oxley Creek Main Channel Gauges:

- New Beith: Figure 4.16 to Figure 4.18. In addition to the recorded gauge data, flow estimates calculated from an existing calibrated daily lumped rainfall runoff model are available for New Beith Gauge (Alluvium, 2023). Daily lumped hydrology flow estimates have been included in plotted results at that gauge.
- Goodna Road: Figure 4.19 to Figure 4.21
- Beatty Road: Figure 4.22 to Figure 4.24
- Corinda High School: Figure 4.25 to Figure 4.27

Oxley Creek Tributary Gauges:

- Lakeside: Figure 4.28 to Figure 4.30
- Durack: Figure 4.31 to Figure 4.33
- Coopers Plains: Figure 4.34 to Figure 4.36
- Marshall Road: Figure 4.37 to Figure 4.39

Some observations from the calibration results include:

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- The TUFLOW HPC catchment model is producing flow estimates comparable to the real world recorded data at all gauge locations in the catchment and for the full range of catchment moisture and rainfall intensity conditions during 2022, 2020 and 2019
- Peak flow estimates during the major and moderate flood events in 2022 and 2020 are accurately estimated by the TUFLOW HPC catchment model
- The inclusion of soil infiltration and horizontal sub-surface flow in the TUFLOW HPC catchment model has multiple benefits in terms of representing the physical rainfall/runoff and groundwater processes, and their interactions, including:
  - Storage of water in the sub-surface soil is enabling the modelling of surface water recharge from the groundwater to the creeks (i.e. base flow) for extended periods following rainfall events (weeks to months), reproducing the observed falling limb signatures in gauged data. The groundwater to surface water recharge is successfully reproducing the attenuated falling limb hydrograph shape present in the recorded datasets. This is a significant improvement compared to the flow estimates of the existing lumped catchment model, as shown in Figure 4.16 to Figure 4.18
  - Available soil infiltration capacity varies temporally based on soil moisture content. Soil moisture content is affected by the rainfall infiltration into the soil, sub-soil groundwater movements within the interflow zone and evapotranspiration. The TUFLOW HPC catchment model is reproducing the physical variations in rainfall / runoff response due to changes in soil moisture content and associated infiltration capacity. Long duration, multiple-peak rainfall/flood events, such as occurred in February and March of 2022, are demonstrating a model behaviour where the initial wetting associated with the event experiences a significantly greater soil infiltration capacity compared to later periods during the same rainfall event when the soil is fully saturated. Following the rainfall event, when dry conditions prevail, the soil infiltration capacity gradually increases again due to the above-mentioned groundwater movement and evapotranspiration. This dynamic soil infiltration capacity behaviour is providing a framework to support accurate modelling in a continuous simulation mode, for yearlong durations including any combination of wet and dry periods
- The high-resolution spatial data inputs in the TUFLOW HPC catchment model (i.e. on a 60m x 60m grid) enables the accurate representation of site-specific flow conditions catchment wide. 2019 was an extremely dry year. The recorded and model results for the 2019 period demonstrate the drastically different flow behaviours that can occur in rural and urban areas because of contrasting pervious / impervious surface characteristics during dry low flow water years:
  - The catchment upstream of Beatty Road gauge is predominantly rural or forested. The recorded gauge data and model results indicate there were extended no flow periods in Oxley Creek upstream of Beatty Road gauge (see Figure 4.21, Figure 4.24 and Figure 4.27). This result suggests there was insufficient rainfall for much of the year to generate significant runoff. Much of the rainfall that fell was infiltrated to the soil
  - The catchment upstream of Coopers Plains gauge is predominantly urbanised, with a significant proportion of the surface being impervious. The impervious surface has resulted in substantially greater runoff from the Coopers Plains section of the catchment (see Figure 4.36), compared to upstream of the Beatty Road gauge (see Figure 4.27), even though the contributing catchment area is substantially smaller in the case of the former gauge

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Flow exceedance plots, calculated from the above recorded and modelled flow estimates, are provided in Figure 4.40 to Figure 4.45. Hourly sampling (rather than daily or monthly) has also been used for the calculation of all Nash-Sutcliffe Efficiency (NSE) and % Bias (PBIAS) goodness of fit performance statistics. Results from the analysis are presented in Table 4.4

Table 4.4 Modelled Flow / Record Flow Goodness of Fit Statistics

Gauge Location (Gauge ID)	Nash Sutcliff Efficiency	% Bias
New Beith Alert (540097)	0.85	11.75
Oxley Ck Alert (at Goodna Rd) (540646)	0.85	19.75
Beatty Road, Acadia Ridge (40796)	0.81	6.34
Lakeside Crescent Alert (540535)	0.58	0.11
Durack King Ave Alert (40789)	0.83	-4.04
Musgrave Rd, Coopers Plains (40791)	0.85	9.89

Taking the D-M-A timescale benchmarks for these statistics from Moriasi et al. (2015) (hourly benchmarks are not presented therein), all NSE statistics above are classified as ‘very good’ other than Lakeside which was ‘satisfactory’. Similarly, PBIAS metrics are generally ‘good’, with Durack King Avenue and Lakeside being ‘very good’ and Goodna Road and New Beith being ‘satisfactory’.

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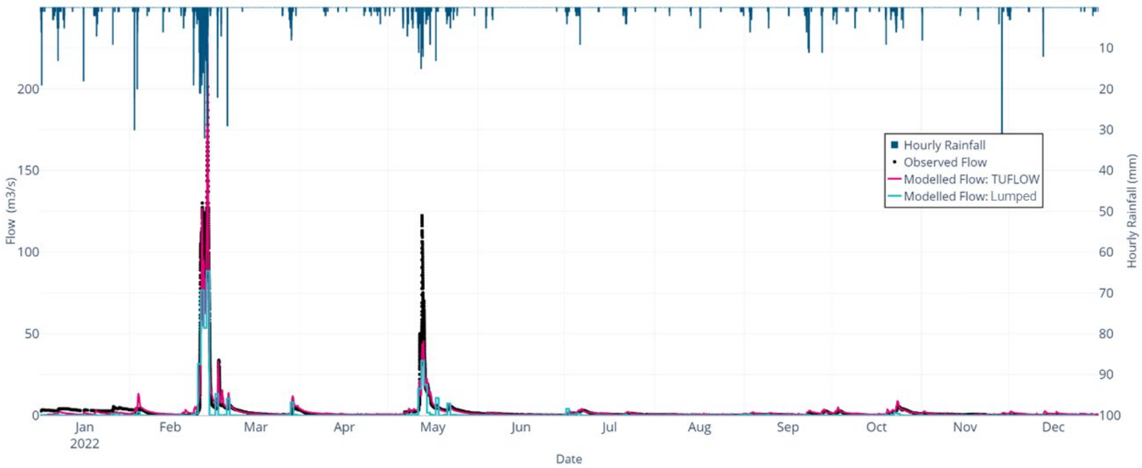

Figure 4.16 New Beith Gauge (540097): 2022 Model Calibration

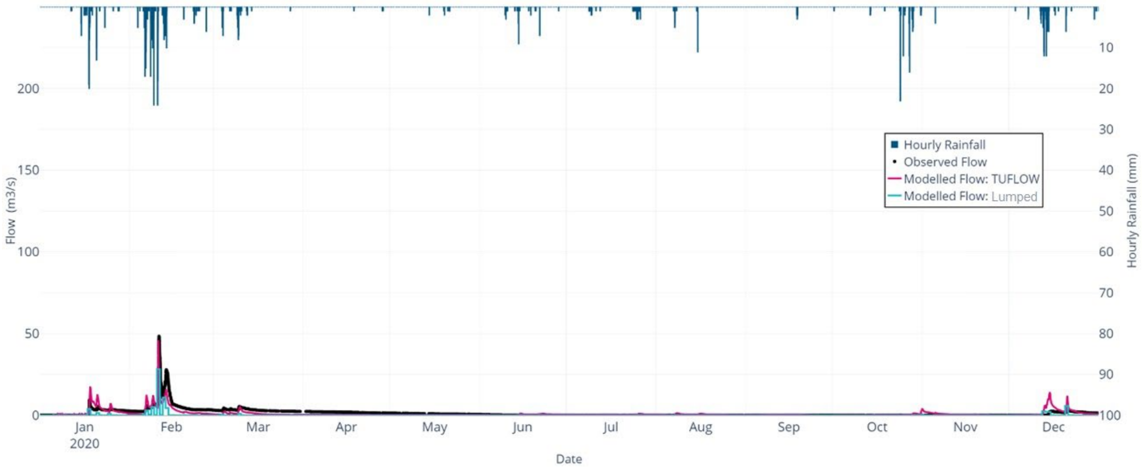

Figure 4.17 New Beith Gauge (540097): 2020 Model Calibration

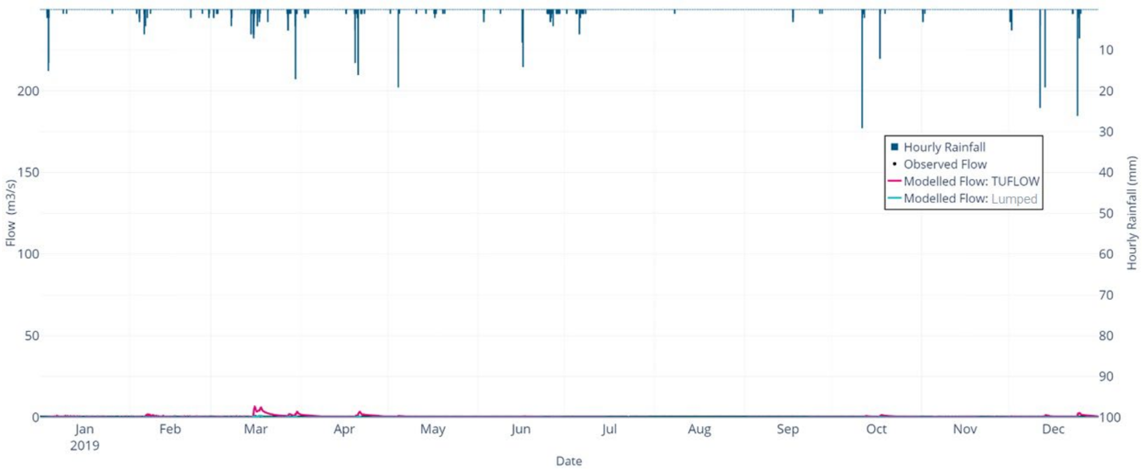

Figure 4.18 New Beith Gauge (540097): 2019 Model Calibration

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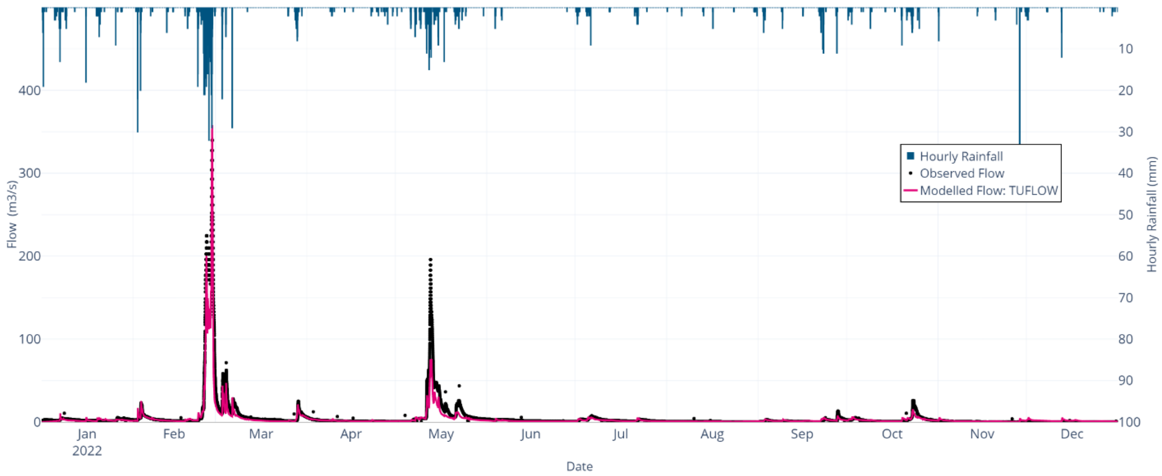

Figure 4.19 Goodna Rd Gauge (540646): 2022 Model Calibration

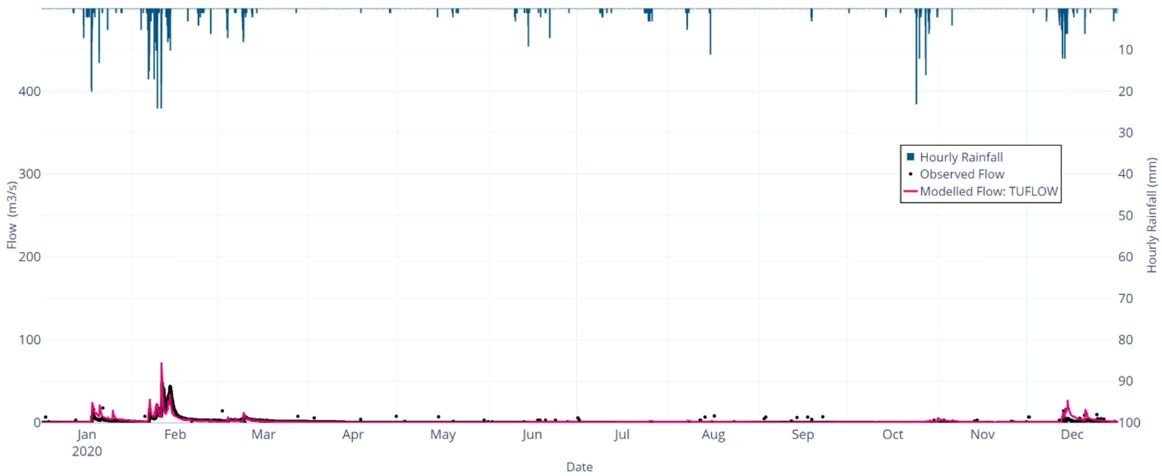

Figure 4.20 Goodna Rd Gauge (540646): 2020 Model Calibration

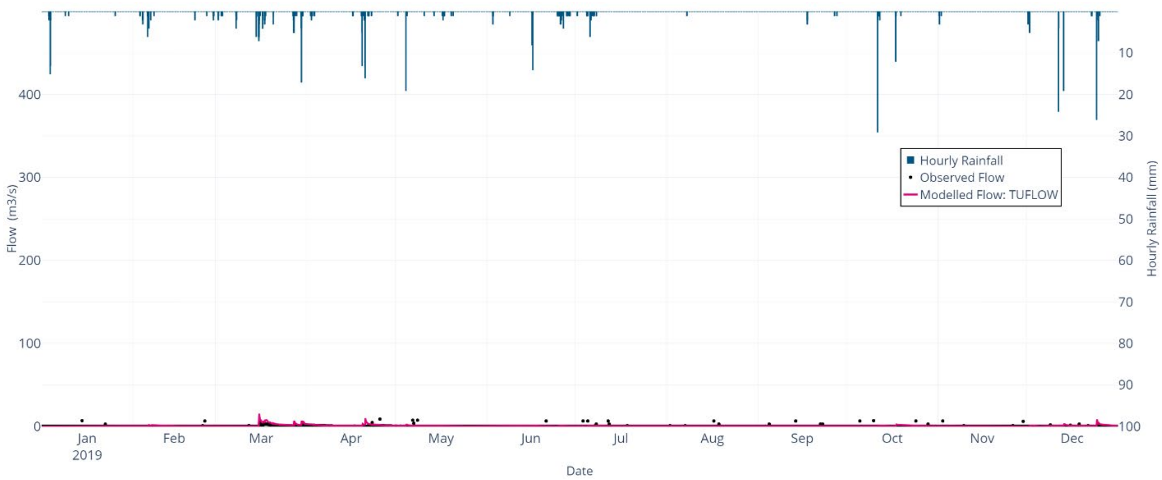

Figure 4.21 Goodna Rd Gauge (540646): 2019 Model Calibration

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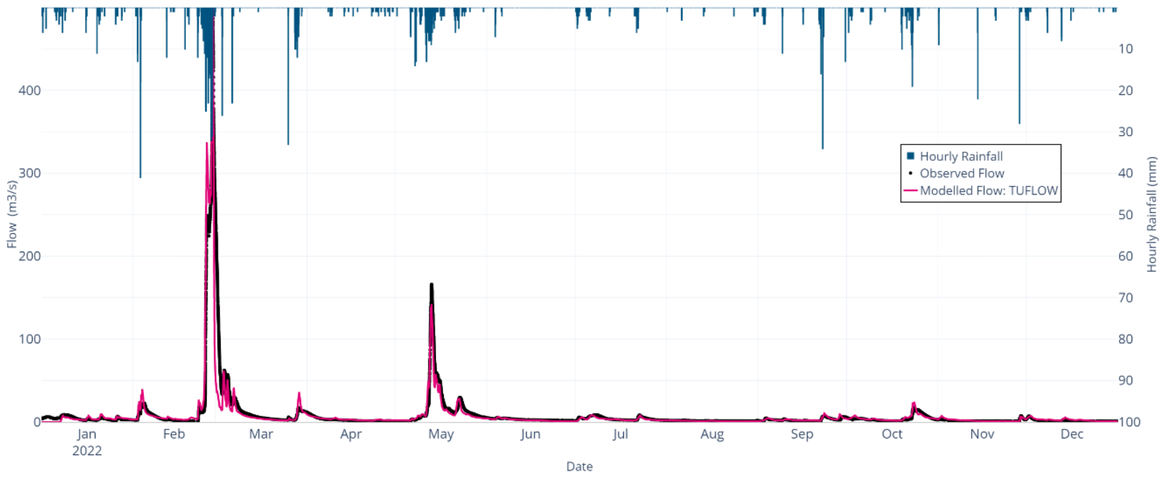

Figure 4.22 Beatty Rd Gauge (40796): 2022 Model Calibration

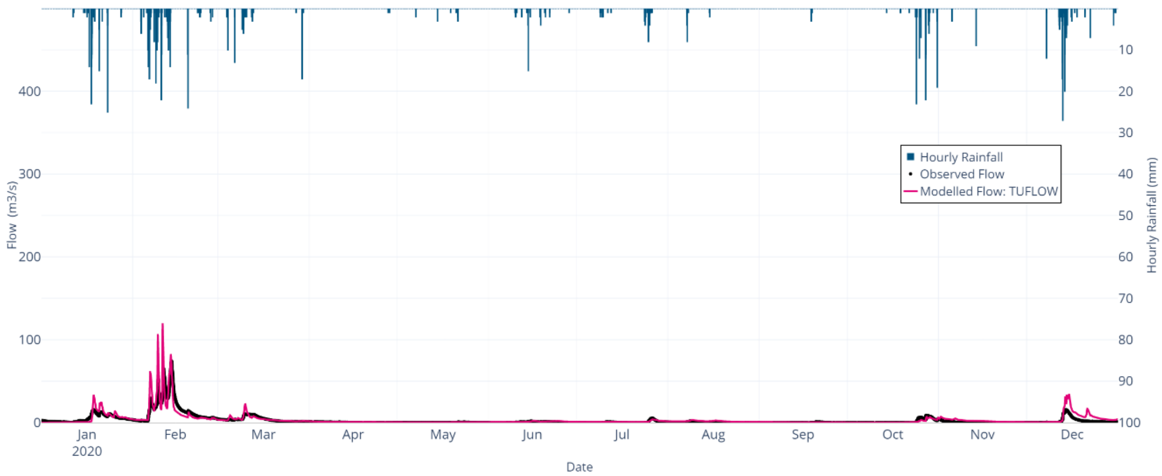

Figure 4.23 Beatty Rd Gauge (40796): 2020 Model Calibration

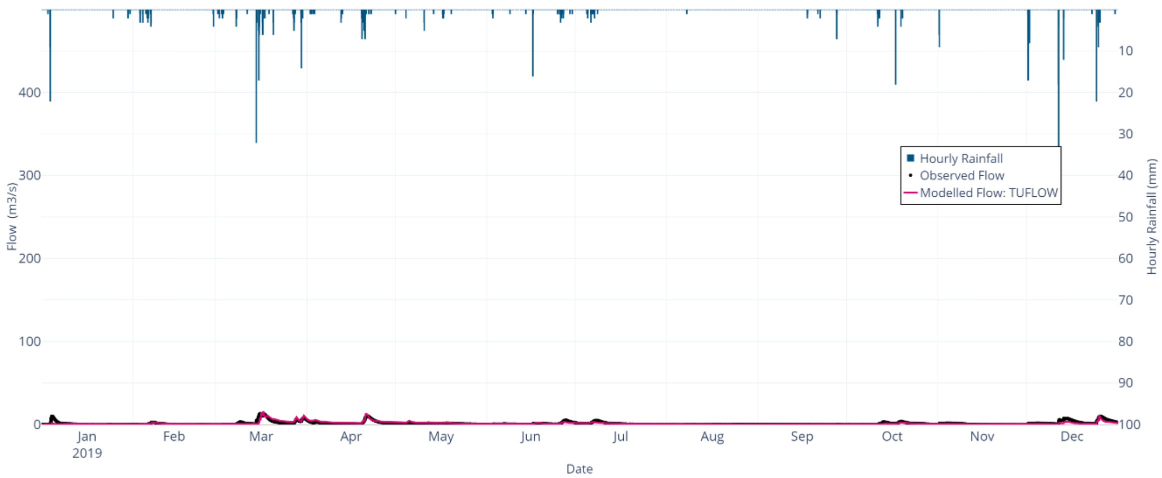

Figure 4.24 Beatty Rd Gauge (40796): 2019 Model Calibration

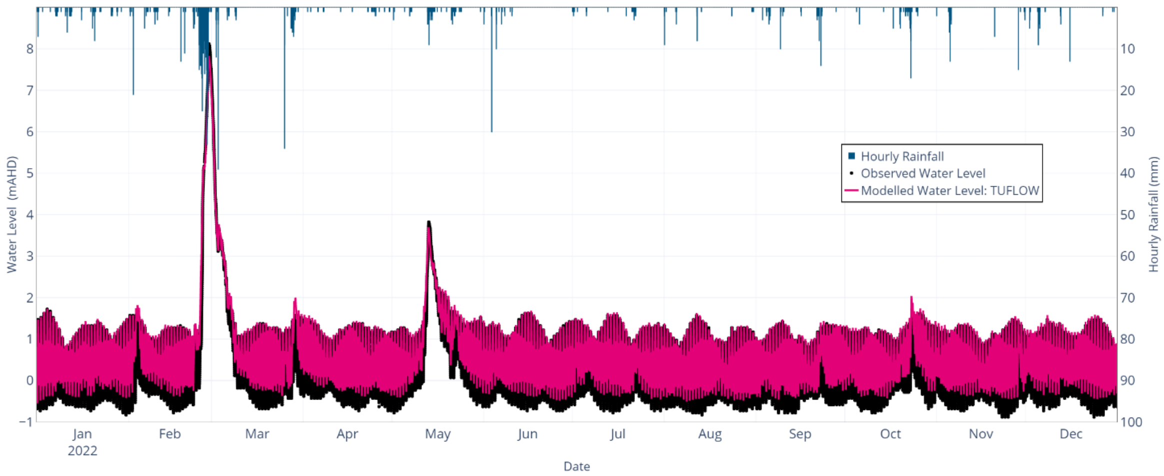

Figure 4.25 Corinda State High Gauge (540071): 2022 Model Calibration

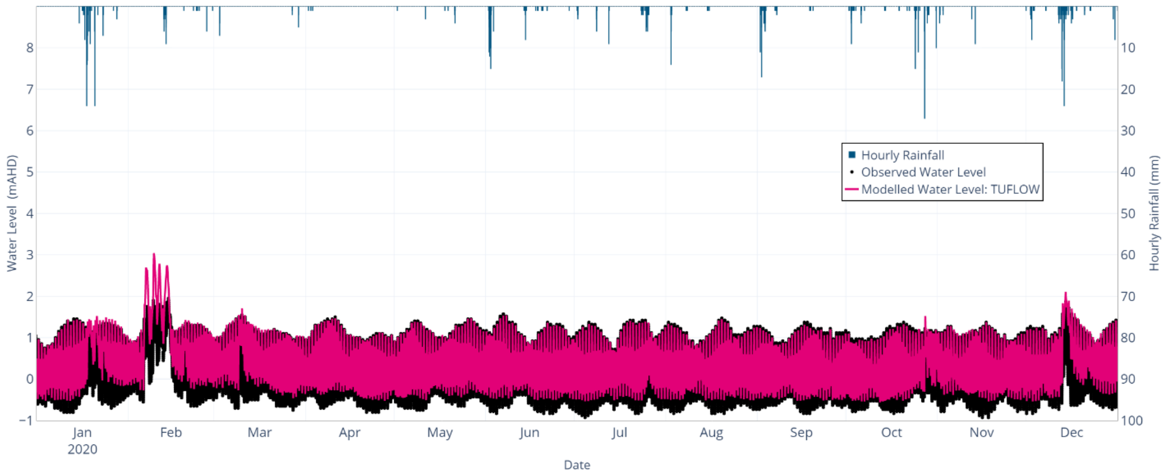

Figure 4.26 Corinda State High Gauge (540071): 2020 Model Calibration

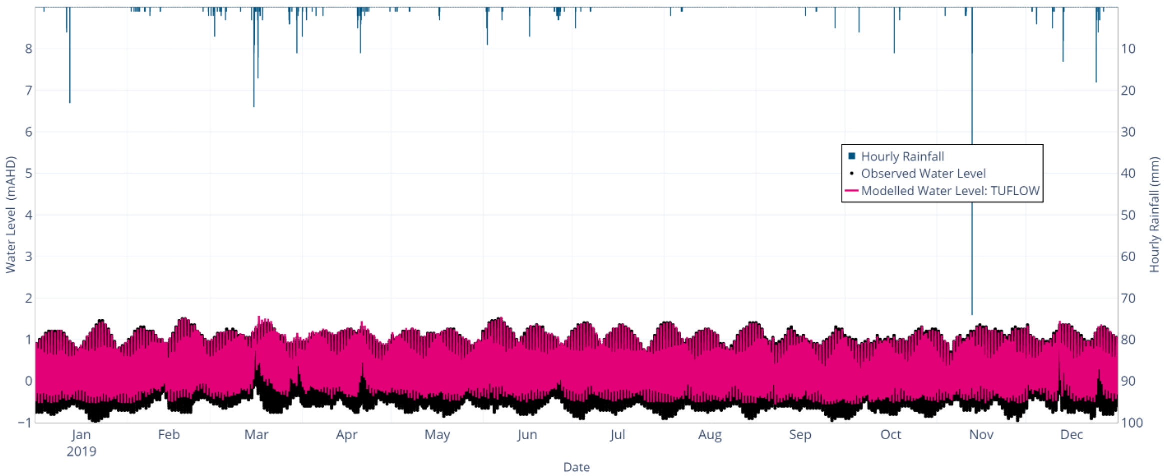

Figure 4.27 Corinda State High Gauge (540071): 2019 Model Calibration

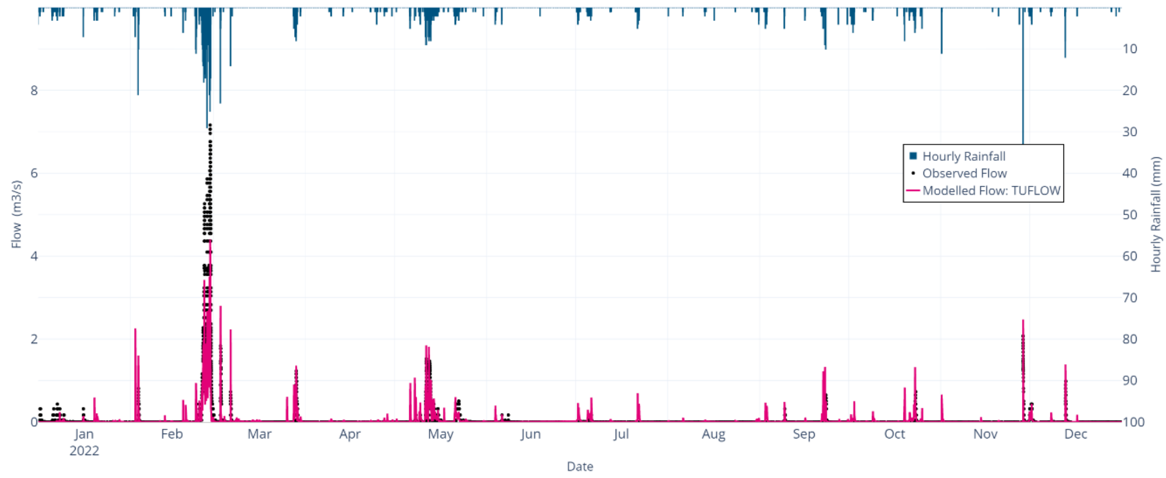

Figure 4.28 Lakeside Gauge (540535): 2022 Model Calibration

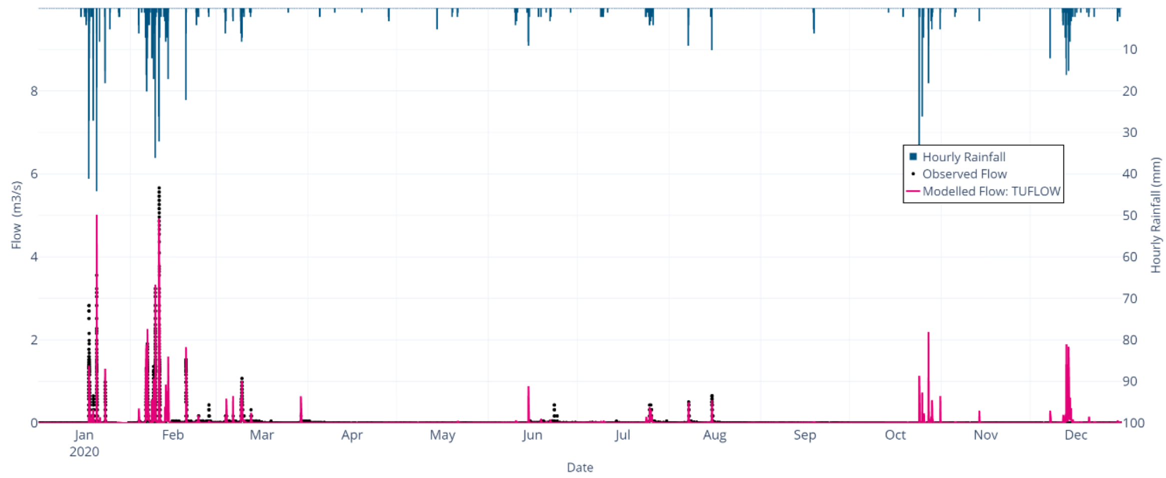

Figure 4.29 Lakeside Gauge (540535): 2020 Model Calibration

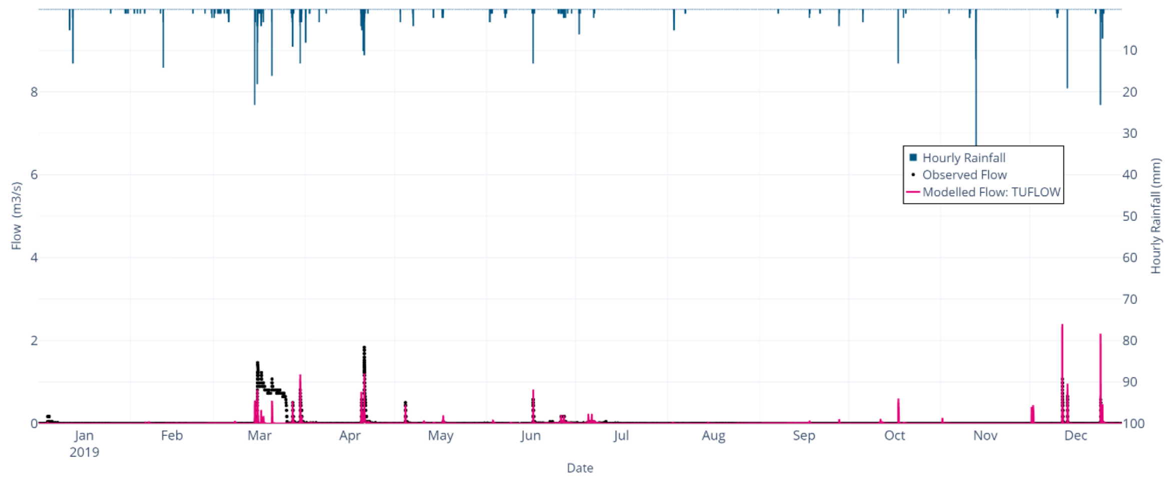

Figure 4.30 Lakeside Gauge (540535): 2019 Model Calibration

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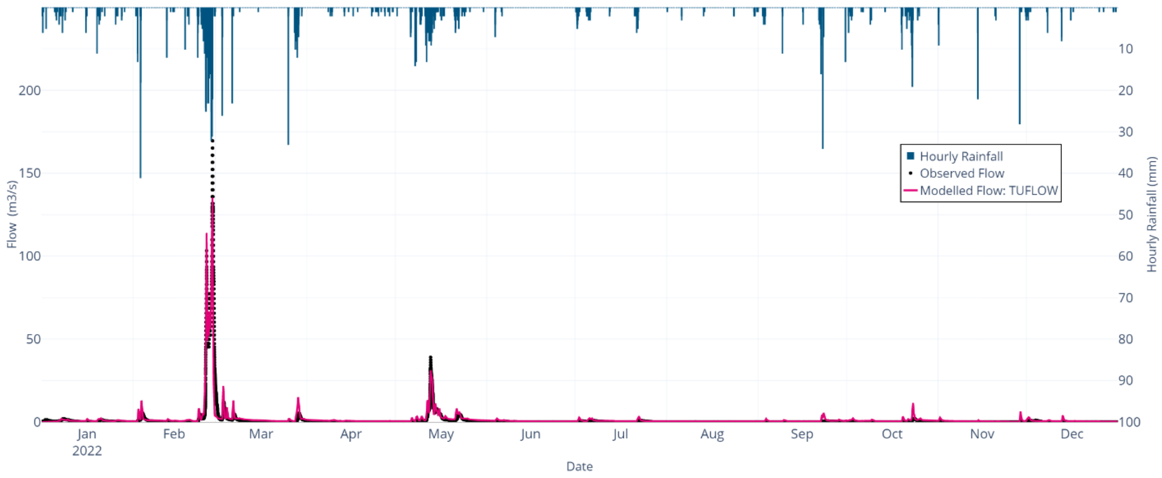

Figure 4.31 Durack Gauge (40789): 2022 Model Calibration

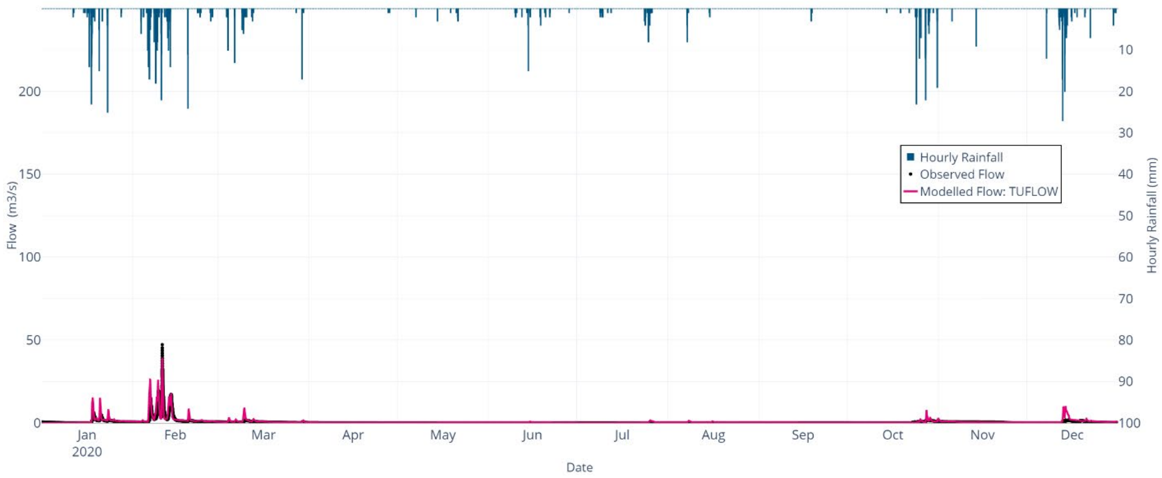

Figure 4.32 Durack Gauge (40789): 2020 Model Calibration

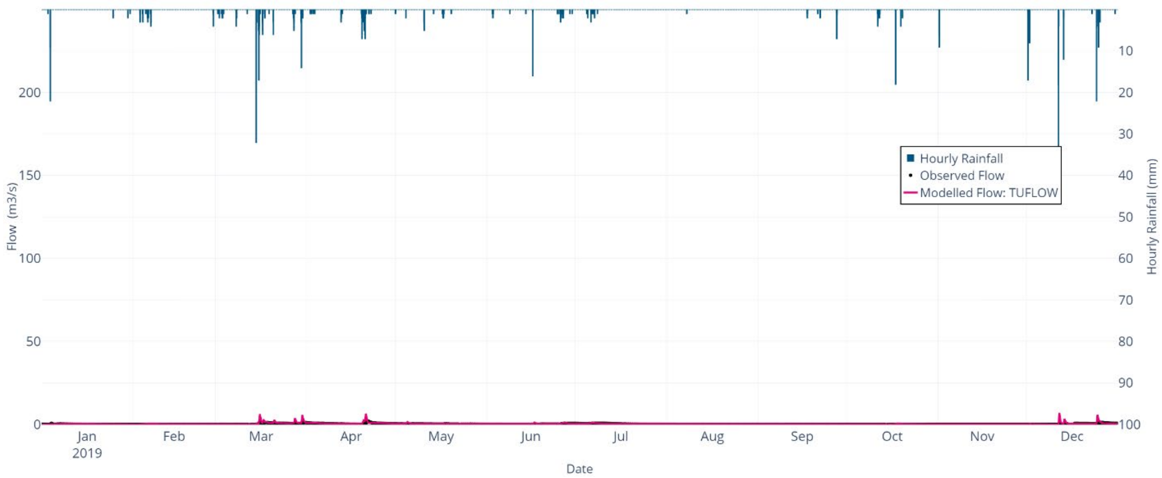

Figure 4.33 Durack Gauge (40789): 2019 Model Calibration

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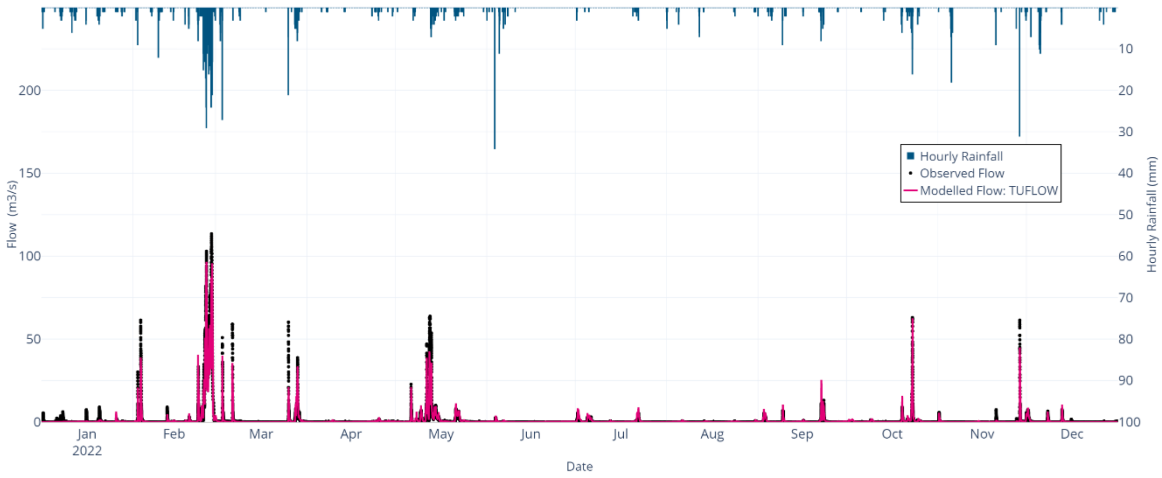

Figure 4.34 Coopers Plains Gauge (40791): 2022 Model Calibration

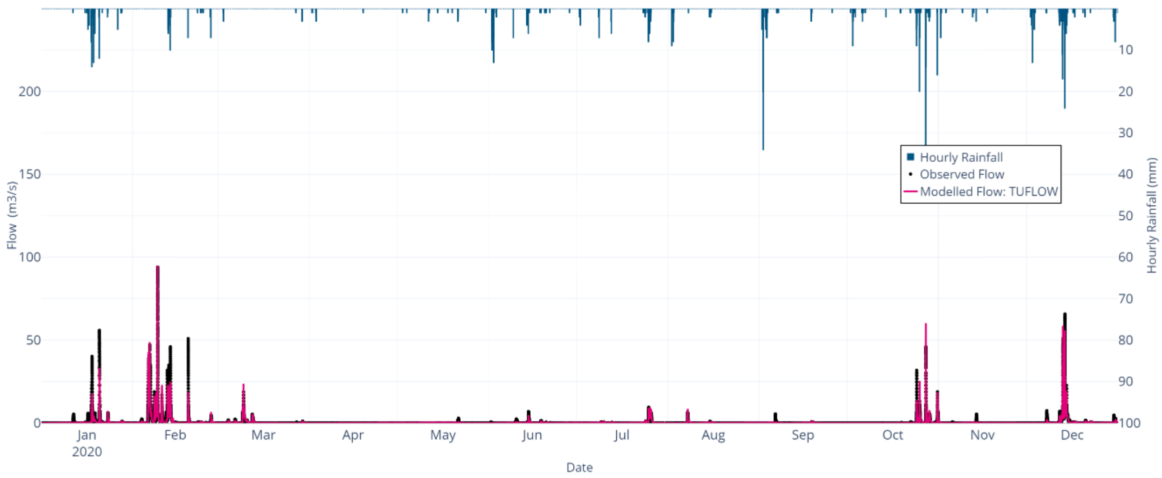

Figure 4.35 Coopers Plains Gauge (40791): 2020 Model Calibration

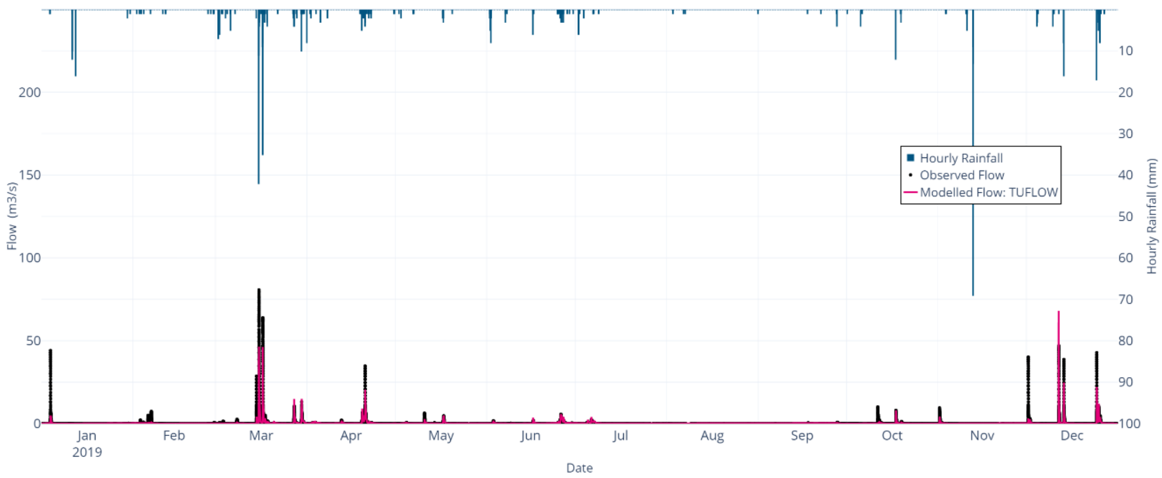

Figure 4.36 Coopers Plains Gauge (40791): 2019 Model Calibration

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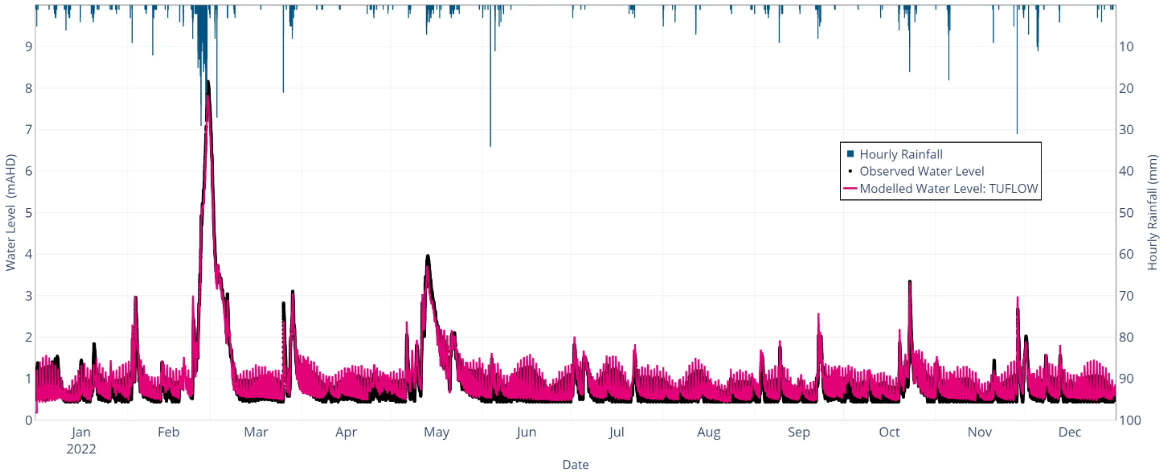

Figure 4.37 Marshall Rd Gauge (540432): 2022 Model Calibration

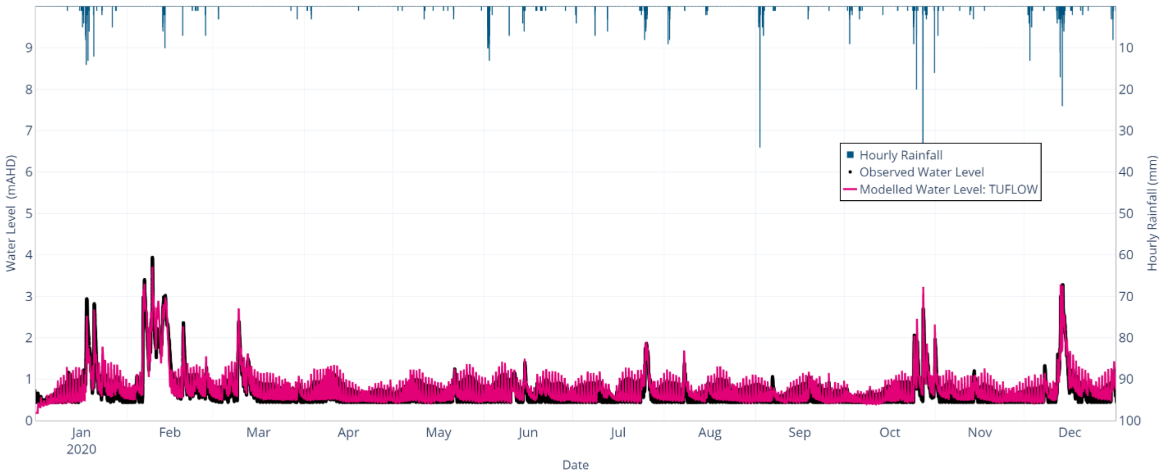

Figure 4.38 Marshall Rd Gauge (540432): 2020 Model Calibration

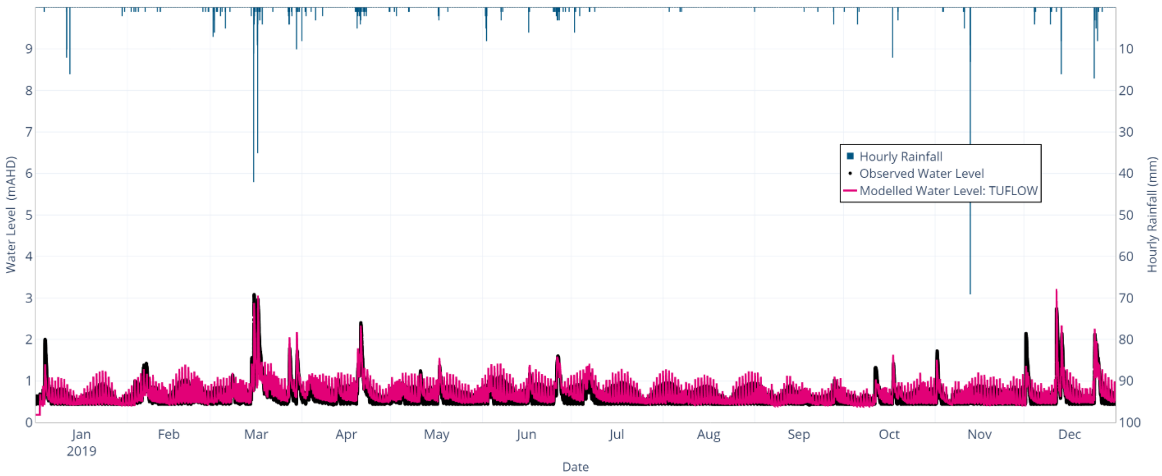

Figure 4.39 Marshall Rd Gauge (540432): 2019 Model Calibration

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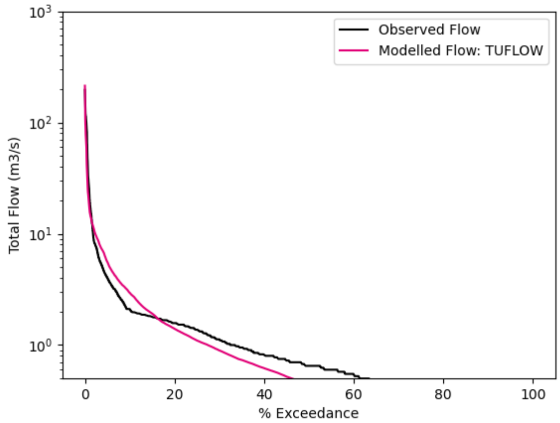

Figure 4.40 New Beith Gauge (540097): Flow Exceedance Result

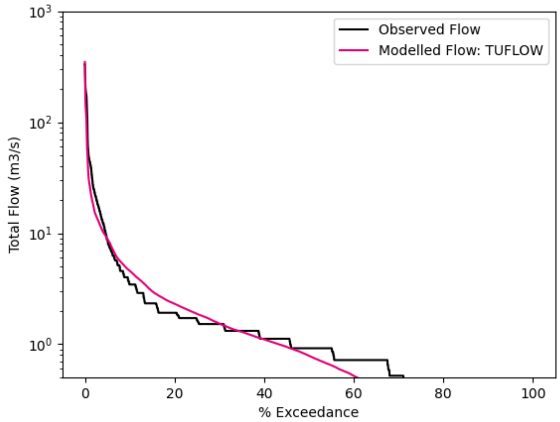

Figure 4.41 Goodna Rd Gauge (540646): Flow Exceedance Result

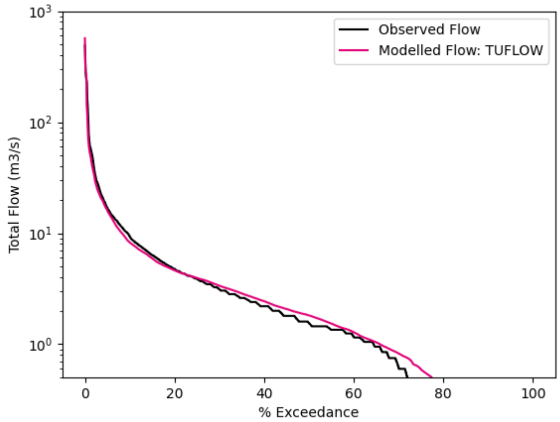

Figure 4.42 Beatty Rd Gauge (40796): Flow Exceedance Result

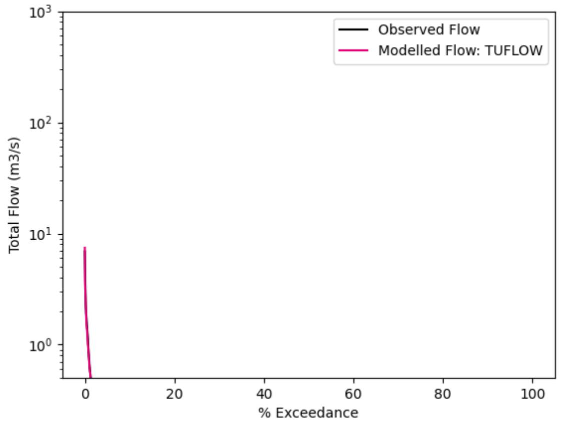

Figure 4.43 Lakeside Gauge (540535): Flow Exceedance Result

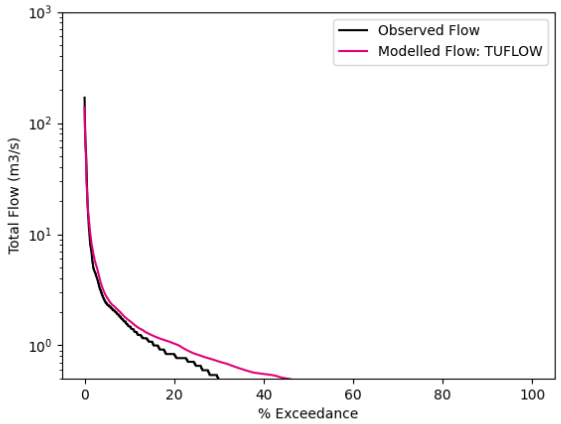

Figure 4.44 Durack Gauge (40789): Flow Exceedance Result

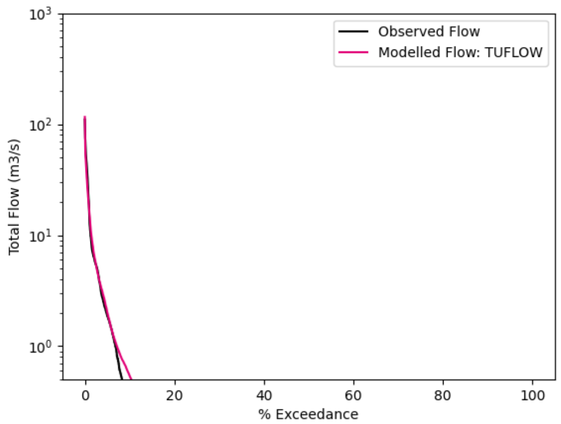

Figure 4.45 Coopers Plains Gauge (40791): Flow Exceedance Result

4.3 Pollutant Export Model

Deployment of this model is a fundamental shift in the way that simulation of pollutant export from catchments has historically been undertaken in Southeast Queensland. In this new approach, no longer are event mean or dry weather concentrations multiplicatively applied to lumped hydrology to compute mass loads: rather, a first principles approach has been taken to allow simulation of processes as they occur on the ground – not through application of averages. This paradigm shift is a substantial departure from previous methods and means that:

- Mass build-up and release of pollutant constituents is being physically represented in the model at the true location of occurrence. This more physically realistic representation is a major improvement to the event mean concentration assumptions used by traditional daily lumped hydrology tools
- The parameterisation of pollutant constituent transport is being disaggregated in the new modelling approach to differentiate between movement of dissolved constituents and those associated with suspended particles

Together with the improved flow prediction methods described above, these pollutant export methods coupled with the spatially distributed discretisation of model inputs and assessment results, provide catchment managers with the opportunity to assess intervention options in new ways. It creates a framework to support user friendly assessment of site specific land use or catchment changes, and their subsequent impact on receiving waterway hydrodynamics and water quality. Example applications could be the assessment of gully erosion impacts and mitigation on receiving water quality, road runoff water quality assessment and nutrient offset trading.

Catchment based (i.e., not within Oxley Creek itself) water quality monitoring data was not available to this study.

4.4 TUFLOW FV Receiving Model

4.4.1 Overview

The receiving hydrodynamic and water quality model component of the Oxley TUFLOW Catch pilot study was constructed using TUFLOW FV.

TUFLOW FV is a 1D/2D/3D flexible mesh solver that computes hydrodynamics (including atmospheric heat exchange), advection dispersion, sediment transport, particle tracking and water quality dynamics. It is the same modelling platform that has been applied for some time to estuaries throughout Southeast Queensland as part of the Healthy Land and Water Report Card process. The platform is familiar to local practitioners.

Importantly for this pilot study, TUFLOW FV permits use of freely oriented triangular and quadrilateral solution elements, combined into a model mesh, to simulate environmental processes. This allows models to be tailor made to conform to nature's shapes, which (in contrast to the requirements of the upstream TUFLOW HPC model where fixed grid is sufficient), allows smooth resolution of sinuous bathymetric features without loss of solution rigour or succumbing to excessive runtimes. This is especially important in the Oxley Creek receiving model because the creek is characterised predominantly by oxbows and meanders – unless constructed at an intractable spatial resolution, a fixed grid model would likely not resolve correctly the key instream features that control tidal and intertidal dynamics within the creek.

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Five TUFLOW FV modules were deployed to simulate the receiving waters of Oxley Creek: hydrodynamics (HD), advection-dispersion (AD), three-dimensional computation (3D), sediment transport (ST) and water quality (WQ). The combinations of these modules are referred to in subsequent sections of this report simply as TUFLOW FV and are described below.

Hydrodynamics (HD)

TUFLOW FV solves the nonlinear shallow water equations (NLSWE), including viscous flux terms and various source terms on a flexible mesh comprised of triangular and quadrilateral elements. It uses a **f**inite **v**olume scheme to do so (hence the platform name TUFLOW **FV**).

The NLSWE is a system of equations describing the conservation of fluid mass/volume and momentum in an incompressible fluid, under the hydrostatic pressure and Boussinesq assumptions. The standard form of the NLSWE, which relates the time-derivative of the conserved variables to flux-gradient and source terms, is given below.

$$\frac{\partial \boldsymbol{U}}{\partial t} + \nabla \cdot \boldsymbol{F}(\boldsymbol{U}) = \boldsymbol{S}(\boldsymbol{U}) \tag{1}$$

The finite volume schemes are derived from the conservative integral form of the NLSWE, which are obtained by integrating the standard conservation equation over a control volume, Ω.

$$\int_\Omega \frac{\partial \boldsymbol{U}}{\partial t} d\Omega + \int_\Omega \nabla \cdot \boldsymbol{F}(\boldsymbol{U}) \mathrm{d}\Omega = \int_\Omega \mathbf{bv}\boldsymbol{S}(\boldsymbol{U})\mathrm{d} \tag{2}$$

Gauss' theorem is used to convert the flux-gradient volume integral into a boundary-integral:

$$\frac{\partial}{\partial t}\int_\Omega \mathbf{bv}\boldsymbol{U}\,\mathrm{d}\Omega + \oint_{\partial\Omega}(\boldsymbol{F}\cdot\boldsymbol{n})\mathrm{ds} = \int_\Omega \mathbf{bv}\boldsymbol{S}(\boldsymbol{U})\mathrm{d} \tag{3}$$

Where $\int_\Omega d$ represents volume integrals, $\oint_{\partial\Omega} d\,s$ represents boundary integrals and $\boldsymbol{n}$ is the boundary unit-normal vector.

The NLSWE conserved variables are volume (depth), x-momentum and y-momentum:

$$\boldsymbol{U} = \begin{bmatrix} h \\ hu \\ hv \end{bmatrix} \tag{4}$$

where $\boldsymbol{h}$ is depth, $\boldsymbol{u}$ is x-velocity and $\boldsymbol{v}$ is y-velocity.

The x, y and z components of the inviscid flux ($\boldsymbol{F}^I$) and viscous flux ($\boldsymbol{F}^V$) terms in the NLSWE are given below.

$$\boldsymbol{F}_x^I = \begin{bmatrix} hu \\ hu^2 + \frac{1}{2}gh^2 \\ huv \end{bmatrix}, \boldsymbol{F}_x^V \approx \begin{bmatrix} 0 \\ -hK_v\frac{\partial u}{\partial x} \\ -hK_v\frac{\partial v}{\partial x} \end{bmatrix}$$

$$\boldsymbol{F}_y^I = \begin{bmatrix} hu \\ huv \\ hv^2 + \frac{1}{2}gh^2 \end{bmatrix}, \boldsymbol{F}_y^V \approx \begin{bmatrix} 0 \\ -hK_v \frac{\partial u}{\partial y} \\ -hK_v \frac{\partial v}{\partial y} \end{bmatrix} \tag{5}$$

$$\boldsymbol{F}_z^I = \begin{bmatrix} hw \\ hwu \\ hwv \end{bmatrix}, \boldsymbol{F}_z^V \approx \begin{bmatrix} 0 \\ -\nu_t \frac{\partial u}{\partial z} \\ -\nu_t \frac{\partial v}{\partial z} \end{bmatrix}$$

Some of the various source terms to the NLSWE are provided below.

$$\boldsymbol{S} = \begin{bmatrix} 0 \\ gh\frac{\partial z_b}{\partial x} + fvh - \frac{h}{\rho_0}\frac{\partial p_a}{\partial x} - \frac{hg}{\rho_0}\int_z^\eta \frac{\partial \rho}{\partial x}dz - \frac{1}{\rho_0}\left(\frac{\partial s_{xx}}{\partial x} + \frac{\partial s_{xy}}{\partial y}\right) + \frac{\tau_{sx}}{\rho_0} - \frac{\tau_{bx}}{\rho_0} \\ gh\frac{\partial z_b}{\partial y} - fuh - \frac{h}{\rho_0}\frac{\partial p_a}{\partial y} - \frac{hg}{\rho_0}\int_z^\eta \frac{\partial \rho}{\partial y}dz - \frac{1}{\rho_0}\left(\frac{\partial s_{yx}}{\partial x} + \frac{\partial s_{yy}}{\partial y}\right) + \frac{\tau_{sy}}{\rho_0} - \frac{\tau_{by}}{\rho_0} \end{bmatrix} \tag{6}$$

where:

- $\frac{\partial z_b}{\partial x}, \frac{\partial z_b}{\partial y}$ are the x- and y-components of bed slope
- f is the Coriolis coefficient
- ρ is the local fluid density, ρ_0 is the reference density and p_a is the mean sea level pressure
- $\boldsymbol{s}_{ij}$ is the short-wave radiation stress tensor, and
- $\boldsymbol{\tau}_s$ and $\boldsymbol{\tau}_b$ are respectively the surface and bottom shear stress terms (where applicable)

Other source terms not included above include inflow/outflow to/from the water column and evaporative fluxes.

The Oxley Creek TUFLOW FV model was constructed to simulate the following within the HD module:

- Water surface elevation (and therefore water depth)
- x, y and z water speed and direction
- Salinity, and
- Temperature (see discussion on the 3D module below)

Additional detail on the HD module equations, solutions and capabilities is provided in chapters 2 and 4 of the TUFLOW FV Science Manual.

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Advection Dispersion (AD)

TUFLOW FV solves the scalar conservation equations for the transport of scalar constituents in the water column.

$$\mathrm{U} = [hC] \tag{7}$$

where C is a constituent concentration. The flux components of the scalar conservation equation (that are a parallel to the flux form of the NLSWE equations presented above) are:

$$\begin{gathered} F_x^I = [huC],\; F_x^V \approx \left[-h\left(D_{xx}\frac{\partial C}{\partial x} + D_{xy}\frac{\partial C}{\partial y}\right)\right] \\ F_y^I = [hvC],\; F_y^V \approx \left[-h\left(D_{yx}\frac{\partial C}{\partial x} + D_{yy}\frac{\partial C}{\partial y}\right)\right] \\ F_z^I = [hwC],\; F_z^V \approx \left[-h\nu_t'\frac{\partial C}{\partial z}\right] \end{gathered} \tag{8}$$

The source components may include scalar decay and settling:

$$\mathrm{S} = [-K_d hC - w_s C] \tag{9}$$

where K_d is a scalar decay-rate coefficient and w_s is a scalar settling velocity.

In direct support of the HD module, the Oxley Creek TUFLOW FV model was constructed to simulate the following within the AD module:

- Salinity
- Temperature (see discussion on the 3D module below)
- Sediment (see discussion on the ST module below)
- All water quality constituents (see discussion on the WQ module below)

Additional detail on the AD module equations, solutions and capabilities is provided in chapter 3 of the TUFLOW FV Science Manual.

Three-Dimensional Computation (3D)

The TUFLOW FV 3D module allows for the three-dimensional simulation of hydrodynamics, advection dispersion, sediment transport and water quality. Typically (but not always) an upgrade from two dimensions to three requires simulation of water temperature and the potential for the evolution of the vertical thermal stratification of the water column. This in turn requires inclusion of atmospheric heat exchange processes within calculations. As such, TUFLOW FV offers a range of different atmospheric heat exchange models for inclusion in simulations, the basic components of which are presented below. The Oxley Creek TUFLOW FV model included atmospheric heat exchange, primarily because it supports simulation of water temperature, which is required by the water quality module.

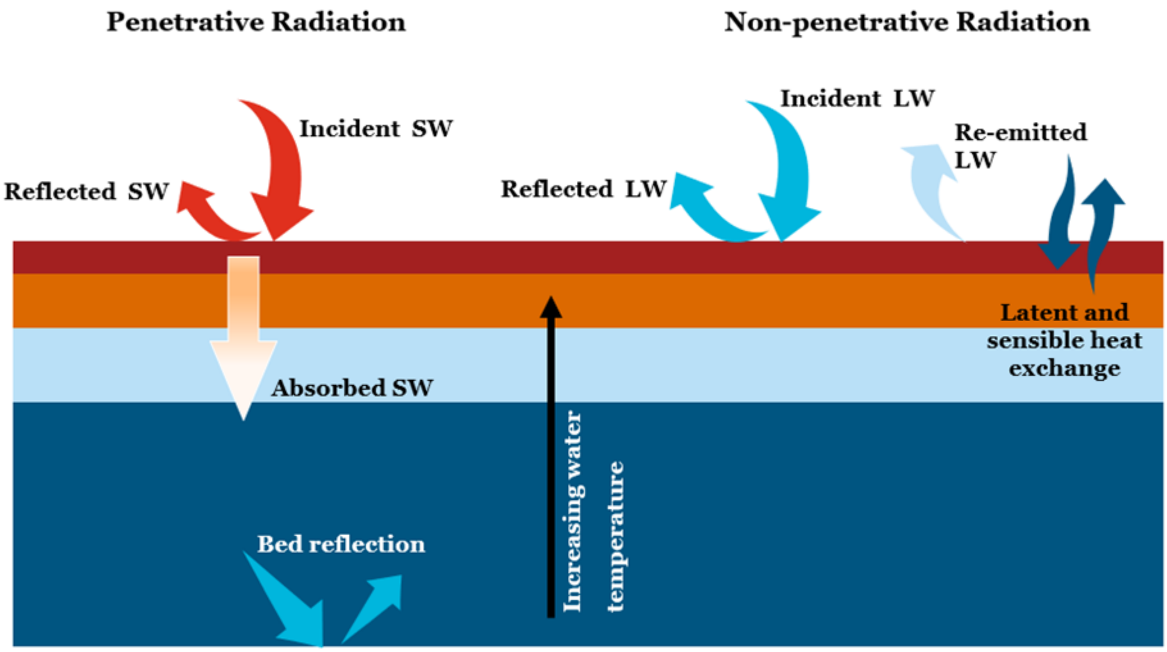


Figure 4.46 Atmospheric Heat Exchange Simulation Conceptual Model

In direct support of the HD and AD modules, the Oxley Creek TUFLOW FV model was constructed to simulate the following within the 3D module:

- Salinity
- Temperature (see discussion on the 3D module below)
- Sediment (see discussion on the ST module below)
- All water quality constituents (see discussion on the WQ module below)

Additional detail on the 3D module equations, including descriptions of the various heat exchange model options, is provided in chapter 5 of the TUFLOW FV Science Manual.

Sediment Transport (ST)

The TUFLOW FV sediment transport module is a flexible and sophisticated bed load and suspended load sediment transport model that enables the 2D or 3D simulation of:

- Sediment transport in creeks, rivers, reservoirs, estuaries, coastal and ocean environments,
- Sediment transport due to currents and/or wave driven processes,
- Morphological evolution with hydrodynamic feedback,
- Sediment exchange between the water column and the bed (deposition and erosion),
- Advection and dispersion of suspended sediment,
- Bed load transport, bed slumping, bed consolidation and sediment sorting/armouring processes

One or more sediment fractions can be simulated as they are distributed within the bed and transported as bed or suspended load. The figure below provides a conceptual model of the discrete sediment transport process modelled by the ST Module.

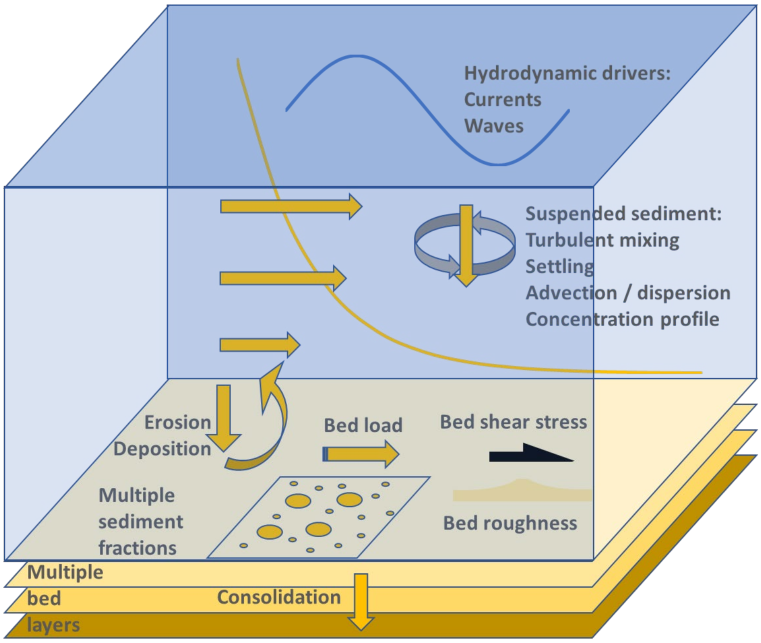


Figure 4.47 Sediment Transport Module Conceptual Model

The ST Module is an Eulerian solver and tracks sediment mass across discrete control volumes defined by the hydrodynamic model mesh or grid.

The HD module controls the overall simulation and communicates the hydrodynamic response such as currents and waves (with the latter not included in the Oxley model) to the ST Module. The HD, AD and ST modules work together to calculate the horizontal and vertical turbulent mixing, settling, advection, dispersion and concentration profiles of suspended sediment within the water column. Multiple suspended sediment fractions can be simulated and individually tracked as scalar constituents by the AD Module.

Provided with hydrodynamic and suspended sediment conditions, the ST Module is responsible for resolving the current-bed boundary layer including potential bed forms and resultant bed shear stresses. The ST module calculates bed load transport potential and sediment erosion-deposition exchanges at the bed and tracks the resultant change in sediment mass in the bed.

The ST module conceptualises the bed as consisting of multiple vertically stratified bed layers. Each layer comprises a mixture of the defined multiple sediment fractions. The mass (kg/m^2) of each sediment fraction within an individual cell's bed layer is tracked by the ST module. The total quantity of sediment in each bed layer (kg/m^2) and the associated dry density (kg/m^3) are used to calculate the layer thickness (m).

Each sediment transport process is calculated on a timestep specified via the ST module. This timestep will typically be much larger than the HD timestep, for example, the HD timestep may be sub-second to seconds and the ST timestep be five to fifteen minutes. The purpose of this approach is to speed up simulations which are run over the larger timescales (such as within TUFLOW Catch) which morphological changes typically occur.

Additional detail on the ST module equations, solutions and capabilities is provided in chapter 1 of the TUFLOW FV STM/PTM User Manual.

Water Quality (WQ)

The TUFLOW FV Water Quality (WQ) Module enables the three-dimensional simulation of water quality and ecological processes in natural and constructed waterways such as (but not limited to) lakes, tidal estuaries, river systems and coastal oceans. The module's design is flexible to support tailoring of its setup to meet individual application demands and complexity.

Several key features have been included in the design of the WQ Module to support its efficient and effective use by practitioners. These include:

- Simulation units. The units of simulation (including specification of initial conditions, boundary conditions and computed variable parameters) can be selected as either the commonly used mg/L (and μg/L for phytoplankton) system, or the mmol/m^3 system
- Library defaults. The WQ Module comes packaged with a fully populated library of default settings for all computed variable parameters. This means that users can quickly set up water quality simulations that automatically draw on these library defaults, with a view to then progressively overriding these defaults and therefore customising simulations to suit
- Command syntax. The WQ Module uses familiar TUFLOW style command == argument(s) syntax that has a long established pedigree within other TUFLOW products
- Log file user feedback. WQ Module simulations generate a log file that reports all simulation configuration details for review
- Output computed variable names. The WQ Module output variable names are descriptive and include the units used, for example WQ_DISS_OXYGEN_MGL
- Output diagnostic variable names. The WQ Module output diagnostic variable names are descriptive and include the units used, for example WQ_DIAG_O2_ATMOS_EXCHANGE_MG_M2_D
- Specification of concentration limits. The WQ Module allows users to optionally specify minimum and maximum concentration limits for each computed variable, and the WQ Module will reset concentrations to these limits if exceedances are detected. All instances of resetting are optionally reported to the WQ Module log file as continuous commentary
- Inbuilt guidance on parameter specification. The WQ module checks all user specified parameters and compares them to typical ranges. If a parameter's specified value falls outside a typical range, then a warning is reported to the WQ module log file

The science underpinning the WQ module is that developed at the School of Agriculture and Environment's Oceans Institute at The University of Western Australia. The WQ module has wrapped this world class science into a form that is easily accessed via familiar TUFLOW style commands and workflows, and offers the additional features described above.

The WQ module can be executed in one of three (fixed, but customisable) simulation classes that, in order of increasing complexity are:

- Dissolved oxygen
- Inorganics
- Organics

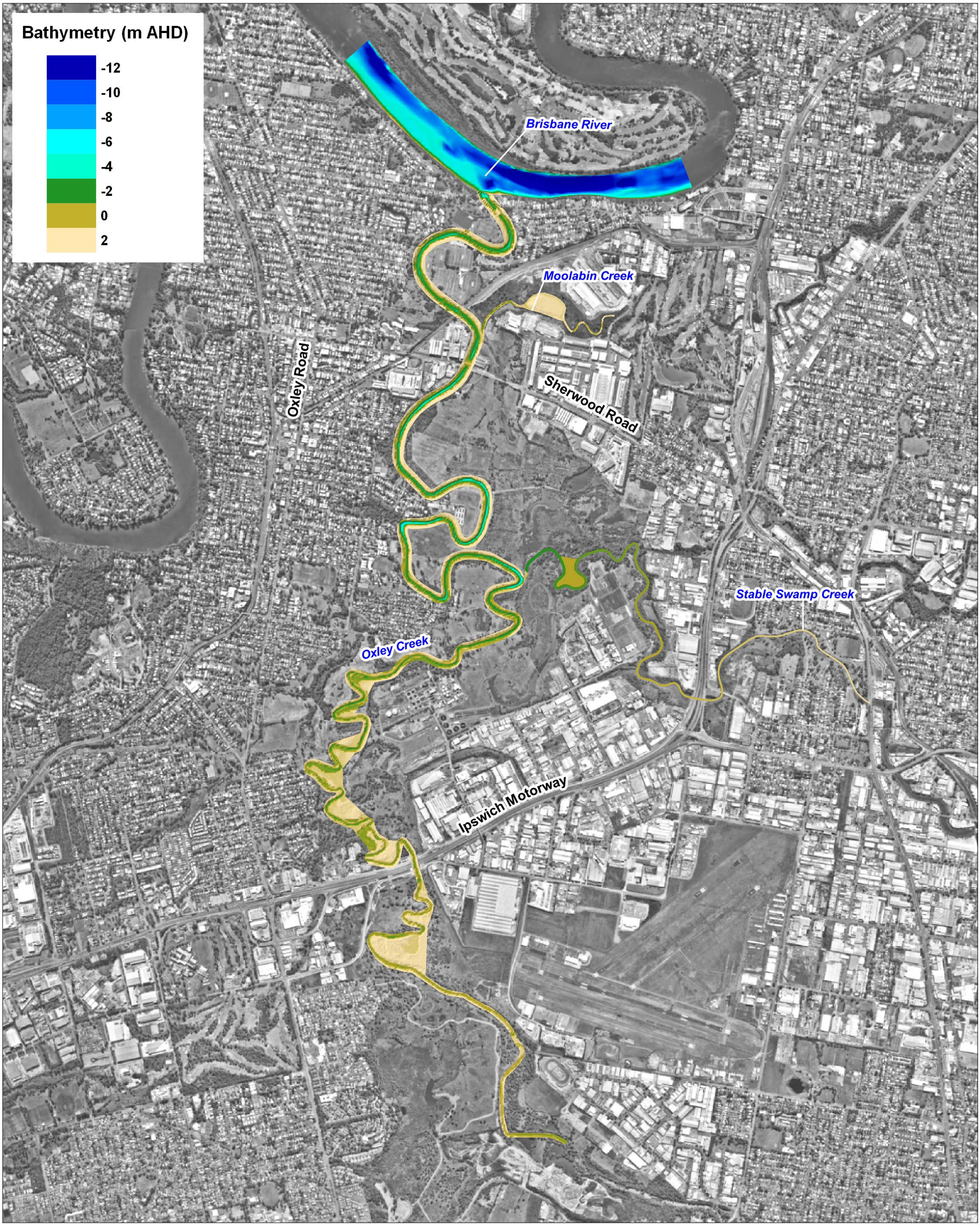
Additional detail on the WQ module solutions and capabilities is provided in Chapter 3 of the TUFLOW FV WQ Module User Manual. The equations used for all process calculations are presented in appendices D to N in the same manual so are not repeated here.

4.4.2 Data Collation

The primary data provider for the TUFLOW FV component of this pilot model was Brisbane City Council (BCC). The study team is grateful for BCC's contribution to the modelling in this regard, and notes that the quality of the TUFLOW FV model that would have been built without BCC's data would be substantially compromised.

Bathymetry

Bathymetric data covering Oxley Creek from its mouth to tidal limit (and slightly beyond) was sourced from the hydraulic model provided to the project by BCC and is presented in Figure 4.48. It was provided in flt format and converted to ascii grid format for reading and inclusion in the TUFLOW FV model as the base bathymetry. Bathymetry for the immediate downstream reach of the Brisbane River included in the model (see Figure 4.52) was sourced from legacy data used in previous Brisbane River modelling studies.



Title:

Oxley Creek and Brisbane River Bathymetric Data

Figure: 4.48

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TUFLOW

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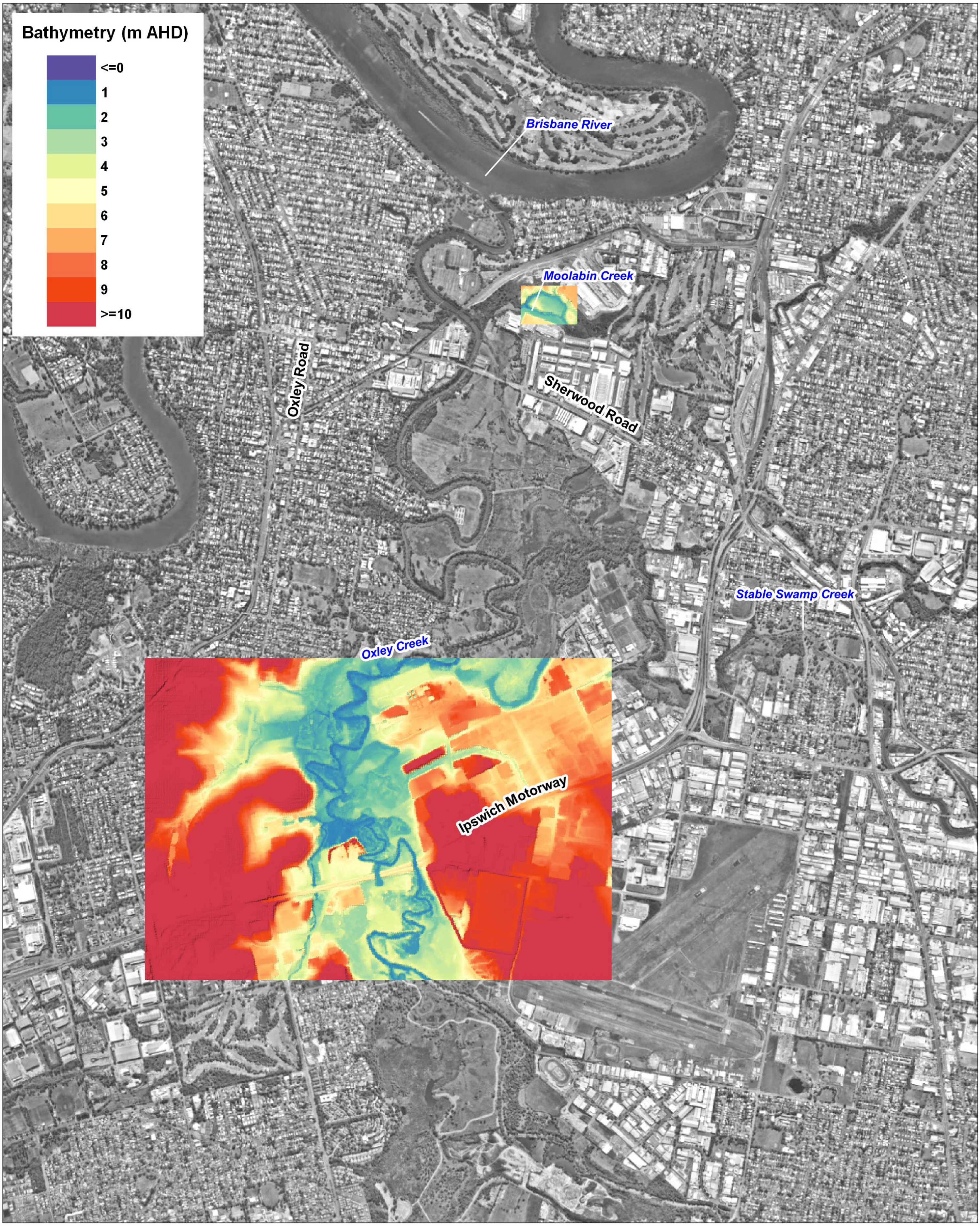
Some sections of Oxley Creek are flanked by low lying intertidal areas that were found to be outside the extents of the data presented above. Five metre derived Light detection And Ranging (LiDAR) data was sourced from AusMaps (via QGIS) to fill these areas and extracts used are presented in Figure 4.49.



Title:

Oxley Creek Intertidal Bathymetric Data

Figure: **4.49**

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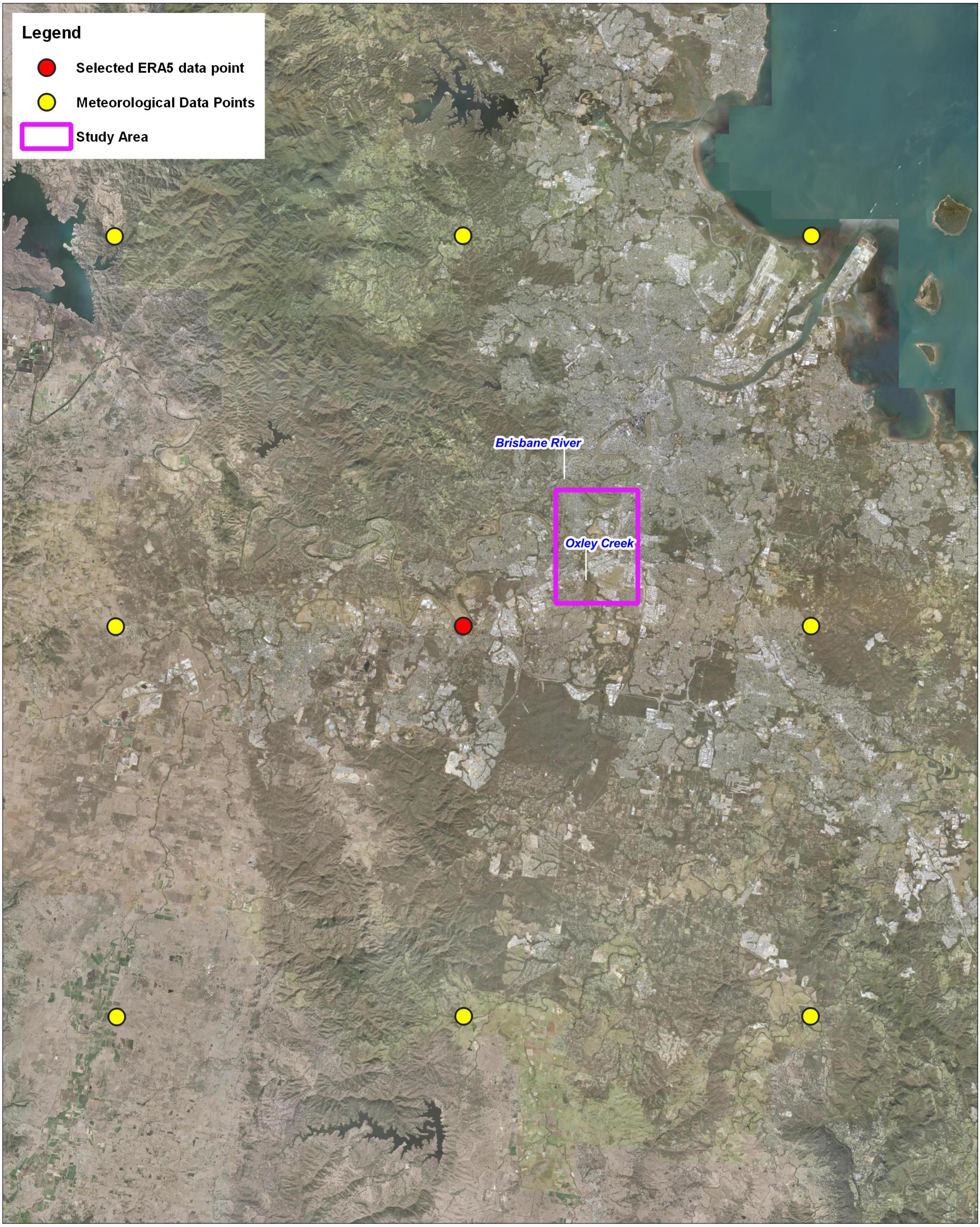
Meteorology

Meteorological forcing was required to support atmospheric exchange (heat flux) calculations within the TUFLOW FV model, and therefore the simulation of water temperature. TUFLOW FV's freely available data pre-processing tools were used to automatically source and format these data. Specifically, the Get Atmos tool was used to automatically:

- Extract hourly meteorological data from the ERA5 global circulation model only for:
  - The spatial extents of Southeast Queensland
  - The years 2019 and 2020 (the years selected to calibrate the TUFLOW FV model, see Section 4.4.3)
- Post process the data into NetCDF files readable by TUFLOW FV
- Construct all the necessary TUFLOW FV meteorological boundary condition header text files required for subsequent simulation

The locations extracted for this study from the ERA5 database are presented in Figure 4.50.



Title:

Oxley Creek ERA5 Meteorological Data Points

Figure: 4.50

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Data was extracted from the ERA5 database and applied to TUFLOW FV as gridded binary data at hourly time increments. Extracted data included the following:

- Wind speed (azimuthal x and longitudinal y) at ten metres elevation
- Mean sea level pressure
- Downwards longwave radiation
- Downwards shortwave radiation
- Air temperature
- Relative humidity

The gridded data applied to the TUFLOW FV Oxley model is presented in Figure 4.51, at a representative location denoted as the central red point in Figure 4.50.

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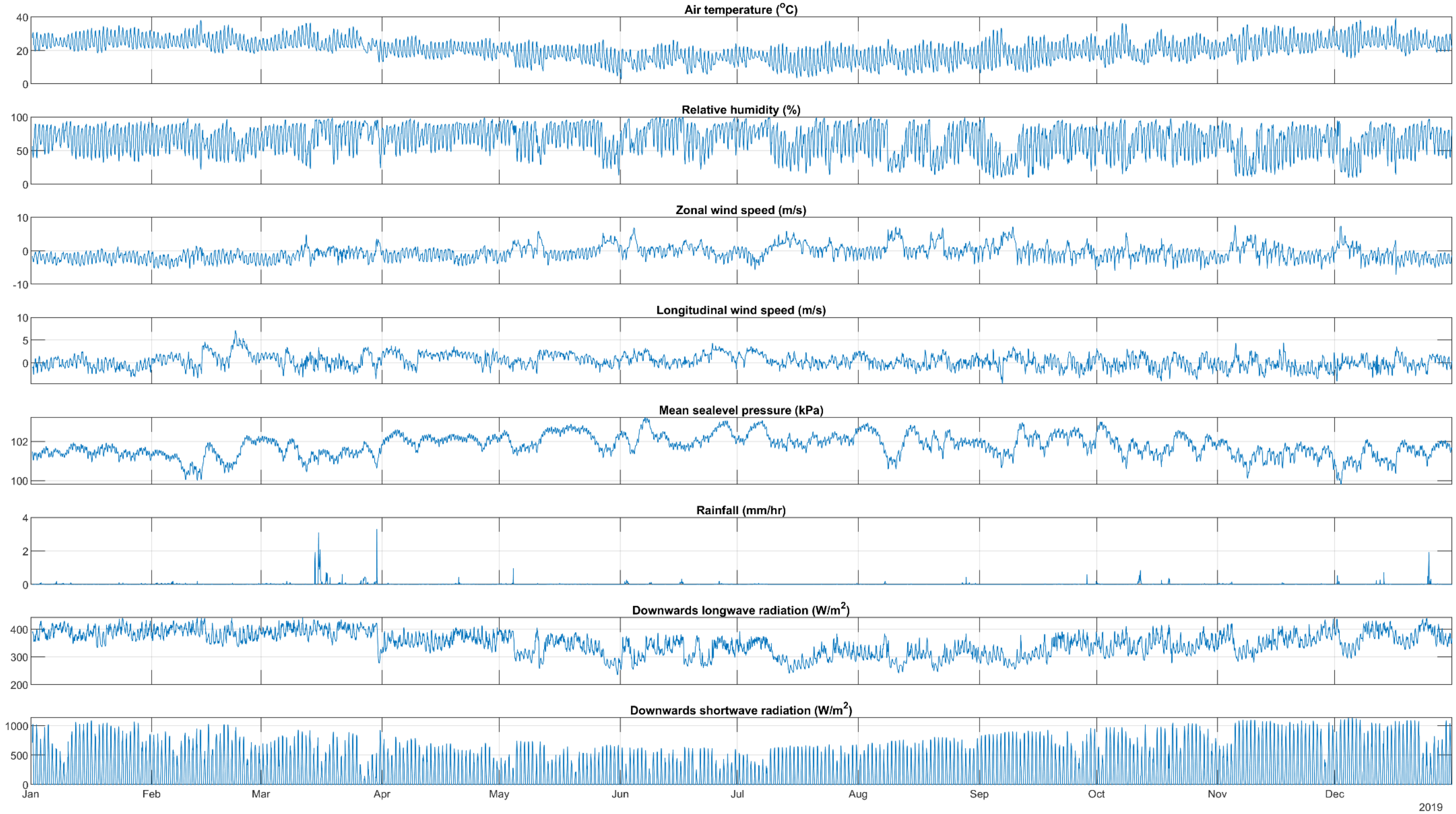

Figure 4.51 Oxley Creek ERA5 Meteorological Example Data

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Downstream Tidal Water Level Boundary

BCC tidal water level data collected at the mouth of Oxley Creek (station 540274_OXA588) were used to force the Oxley model tidal elevation boundaries.

Downstream Tidal Water Quality Boundary

BCC water quality data collected at the mouth of Oxley Creek (also at station 540274_OXA588) was used to set water quality at the Oxley Creek model tidal boundaries within the Brisbane River. By necessity this involved interpolating between spot measurements to provide a continuous boundary condition.

Catchment Inflows

Catchment inflows (both volume and concentrations) were sourced directly from TUFLOW HPC predictions, via the TUFLOW Catch modelling framework.

Calibration Data

The TUFLOW FV receiving hydrodynamic and water quality model component of the pilot model required calibration to available in-creek data. The key provider of calibration data was BCC, and on review of all available information, it was determined that the period 01/01/2019 to 01/01/2021 was most suitable for model calibration because it:

- Is relatively recent and therefore consistent with other data sets such as bathymetry and rainfall
- Included one of the densest temporal and spatial coverages of in situ hydrodynamic and water quality data

4.4.3 Model Development

Model Mesh

It is of central importance that a robust and efficient model mesh be constructed to support effective TUFLOW FV simulations. Key features of a well-constructed mesh include:

- Smooth resolution of waterway sinuosity
- Absence of wagon wheel style element connections that have many triangles pivoted at a single central node
- Stable inclusion of intertidal areas, and
- Appropriate capture of key bathymetric features

To build an efficient mesh to support Oxley Creek TUFLOW FV simulations, state of the art mesh generation techniques available in SMS13.3.1 were used. These are new approaches to mesh generation that greatly improve mesh computational efficiency and stability, but also save the modeller considerable time and effort across mesh construction tasks. This is particularly the case in systems such as Oxley Creek that include repeated and complex oxbow style bends that historically have been problematic to mesh (primarily manually) effectively and efficiently. New techniques now allow this previously cumbersome task to be automated and completed within (in the case of Oxley Creek, at least) a matter of hours rather than days.

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These techniques are designed to generate a robust map coverage from which a model mesh is then automatically generated . The intent is that the map coverage sets the framework and structure for a mesh, without constructing the mesh itself. This map is then the foundation for consistent, fast and reproducible regeneration of a model mesh. In this way, changes to the map can be made efficiently, and a new mesh rapidly generated without recourse to excessive manual mesh manipulation (which is time consuming and difficult to reliably replicate).

The map coverage for Oxley Creek was built and the resultant mesh is presented in Figure 4.52.

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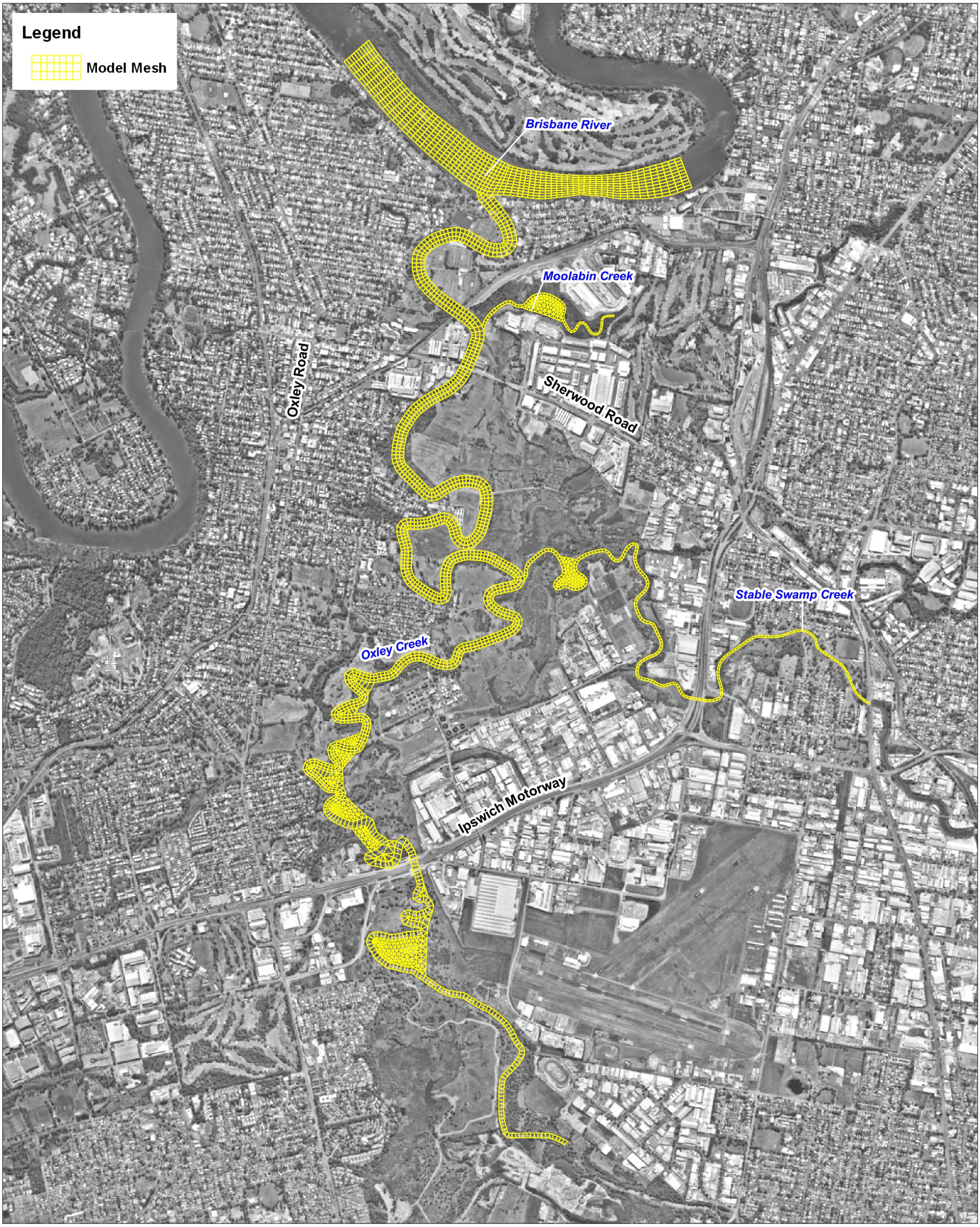

Title:

Oxley Creek TUFLOW Mesh

Figure: **4.52**

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This model mesh was used by the HD, AD, 3D, ST and WQ modules equally.

Vertical discretisation

The TUFLOW FV model of Oxley Creek is a three-dimensional model that has:

- Six fixed height z layers up to and including -1.1m AHD, and
- Five overlying sigma layers

The fixed height layer faces are at -16m, -10m, -6m, -4m, -3m, -2m and -1.1m. The sigma layers wet and dry (and expand and contract) in response to changes in water level.

Bathymetry

Bathymetric data is applied by TUFLOW FV (and not directly within SMS). As part of doing so, some minor bathymetric modifications were made to the collated data described above to ensure that the thalwegs of Oxley Creek's main channel and sidearms were resolved correctly within the TUFLOW FV model. This was achieved through application of paired 2d_zln_L | 2d_zln_P breakline features within TUFLOW FV, with the location and elevation of these breaklines being determined by the BCC bathymetric data. Importantly, application of these breaklines ensured that there were no unintended unphysical bathymetric blockages within the Oxley Creek model mesh, from its mouth right to its tidal limit.

In addition, a small number of bathymetric modifications were made to individual model cells located primarily within intertidal areas. This was undertaken so that these cells did not become artificially isolated during simulations – such isolated cells are unphysical and can lead to model stability issues under periods of extended evaporative losses.

The order in which bathymetric data is specified within a TUFLOW FV control file is important because it determines the hierarchy with which bathymetric data is applied to the model mesh. Specifically, data that is specified first in a simulation is overwritten by data specified subsequently, where spatial overlap occurs. This typically means that higher quality and detail-refining bathymetric data sets are specified last. As such, the following specification order was applied to the Oxley Creek model build:

1. AusMaps LiDAR (5m gridded)
2. Brisbane River bathymetry (irregular spacing)
3. BCC flood model bathymetry (5m gridded)
4. Thalweg breaklines (vector layers)
5. Minor manual intertidal region changes (vector layers)

The final bathymetry applied to the Oxley Creek TUFLOW FV model mesh is presented in Figure 4.53.

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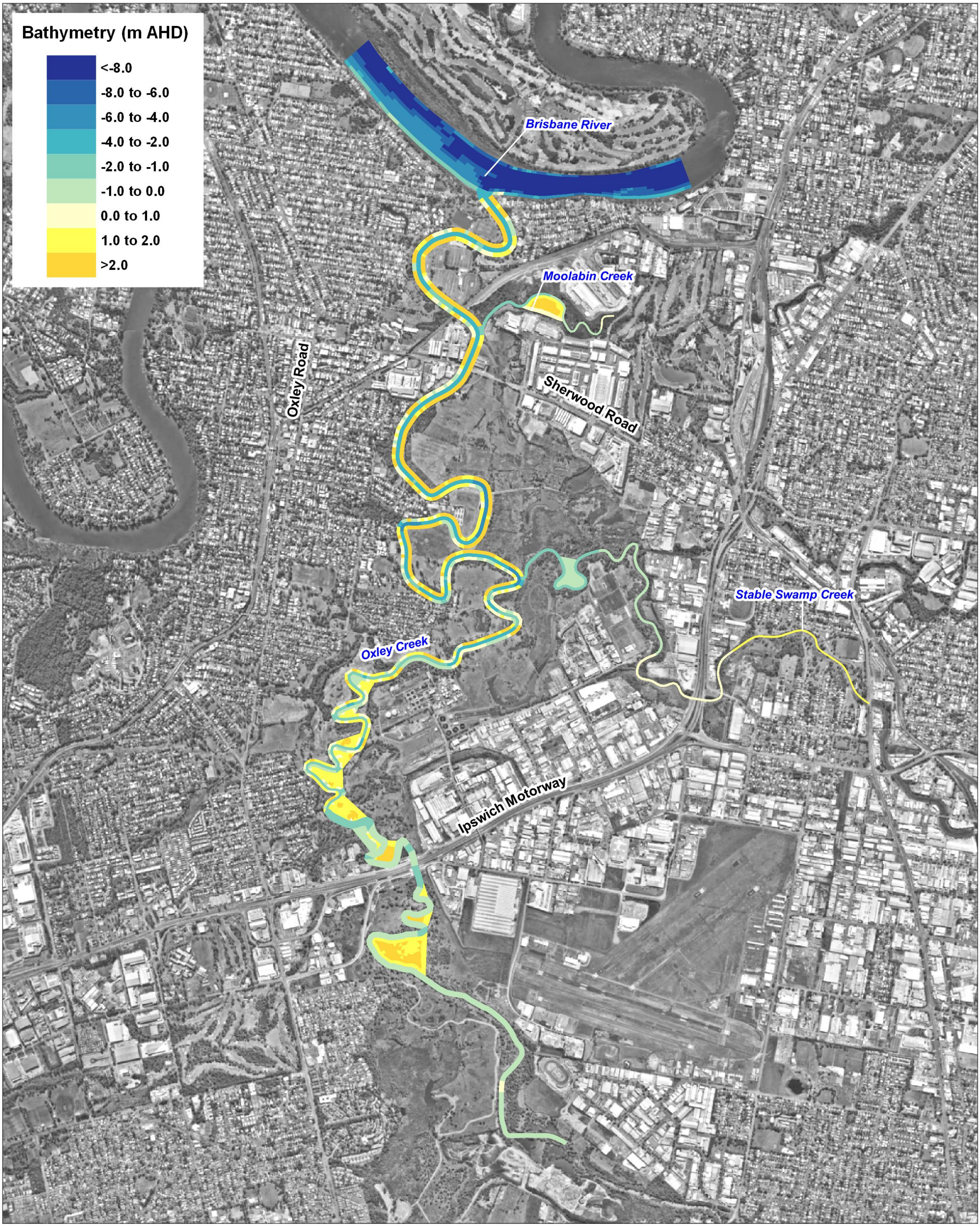

Title:

Oxley Creek TUFLOW Mesh, With Bathymetry

Figure: 4.53

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Bottom Roughness

For simplicity in this pilot study, a single Manning's roughness of 0.012 was applied to the entire domain. This can be easily updated if sufficient supporting data comes to hand.

Horizontal Momentum Model

Again, for simplicity, the Smagorinsky momentum mixing was applied throughout the model domain with a global horizontal eddy viscosity coefficient of 0.2. The exception to this was in parts of the Brisbane River domain where high fringing velocities were observed. A slightly larger eddy viscosity was applied in these regions as a gradient damper. This did not influence mass transport through the domain.

Horizontal Scalar Model

Similarly, the Smagorinsky scalar mixing was applied throughout the model domain, again with a global horizontal scalar diffusivity coefficient of 0.2.

Vertical Mixing Model

The General Ocean Turbulence Model (GOTM) was used to compute vertical mixing.

Tidal Water Level Boundary

The tidal water level data collected at station 540274_OXA588 was used to force the TUFLOW model at the Brisbane River boundaries. On close inspection, the measurements at that site were found to be truncated vertically at approximately -0.62m AHD. This meant that the lower tidal levels were omitted from the data. As such, the following remedial steps were taken (using MATLAB) to correct this anomaly:

- Read raw tidal
- Fit raw tidal data to a spline on a regular five minute timestep
- Take fast Fourier transform of spline data and extract spectral power (amplitude) and phases
- Reconstruct timeseries from full array of Fourier amplitudes and phases

The spectral power (amplitudes) and phases are presented in Figure 4.54 (against period for ease of interpretation).

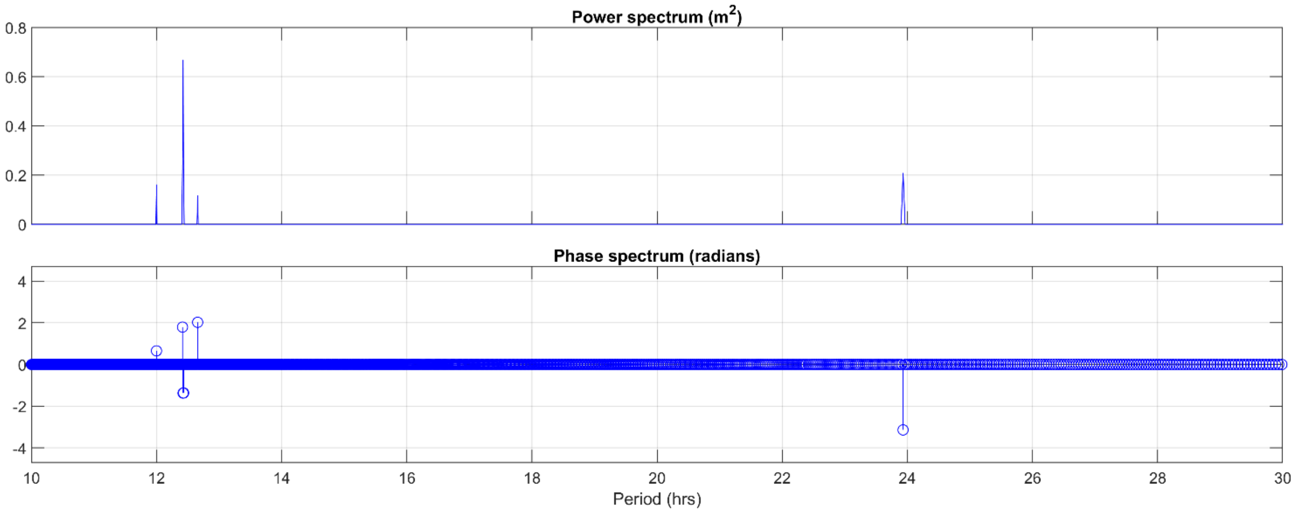

Figure 4.54 Oxley Creek Fourier Analyses

The Fourier periods are as expected, with the dominant power and phase signals at approximately 12 (12.00, 12.41, 12.42, 12.66) and 24 (23.93) hours, with localised modifications. The 12.42 hour period is the most energetic. The reconstructed timeseries is presented in Figure 4.55 for one location on the Brisbane River model boundary.

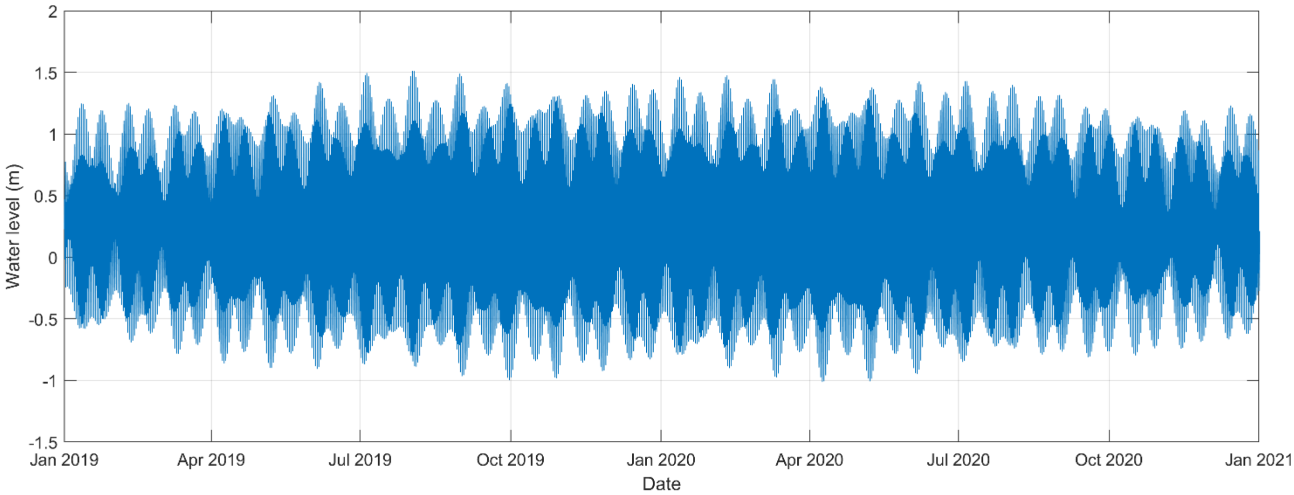

Figure 4.55 Oxley Creek Reconstructed Tidal Water Level Boundary

Ideally the corrections above would be avoided, but for the purposes of this pilot study (which is not a formal model calibration study), this approach was deemed suitable.

Once reconstructed, simple shallow water wave calculations were used to temporally offset the reconstructions to allow their spatial shifting from the point of measurement at the Oxley Creek mouth to the upstream and downstream TUFLOW FV model boundary locations within the Brisbane River (see the model mesh in Figure 4.52). This provided for an approximate 4 minute and 30 second lag between the two Brisbane River tidal water level boundaries.

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Catchment Volumetric Inflows

Catchment inflows were computed by TUFLOW HPC. They were delivered to the TUFLOW FV model as:

- Three nodestring inflows, specified at a frequency of 15 minutes
  - Oxley Creek at the Ipswich Motorway
  - Oxley Creek at Rocklea, and
  - Oxley Creek at the Brisbane Markets
- 454 lateral inflows along the fringes of Oxley Creek, specified at a frequency of 3 hours

These locations are presented in Figure 4.56 and Figure 4.57. The figures show that the spatial distribution of the lateral inflows (whose locations have been automatically determined by TUFLOW Catch) offer a far higher spatial resolution to describe the interconnectivity of a catchment and its receiving waterways than has been historically possible. In addition to this spatial resolution increase, the user-specifiable temporal resolution of 15 minutes and 3 hours for nodestring and lateral inflows, respectively, is well beyond that previously accessible using legacy modelling platforms that often operated on a daily timestep. It is noteworthy that setting this high spatial and temporal resolution comes at no time or effort cost to the modeller, which is a key feature of this new modelling platform.

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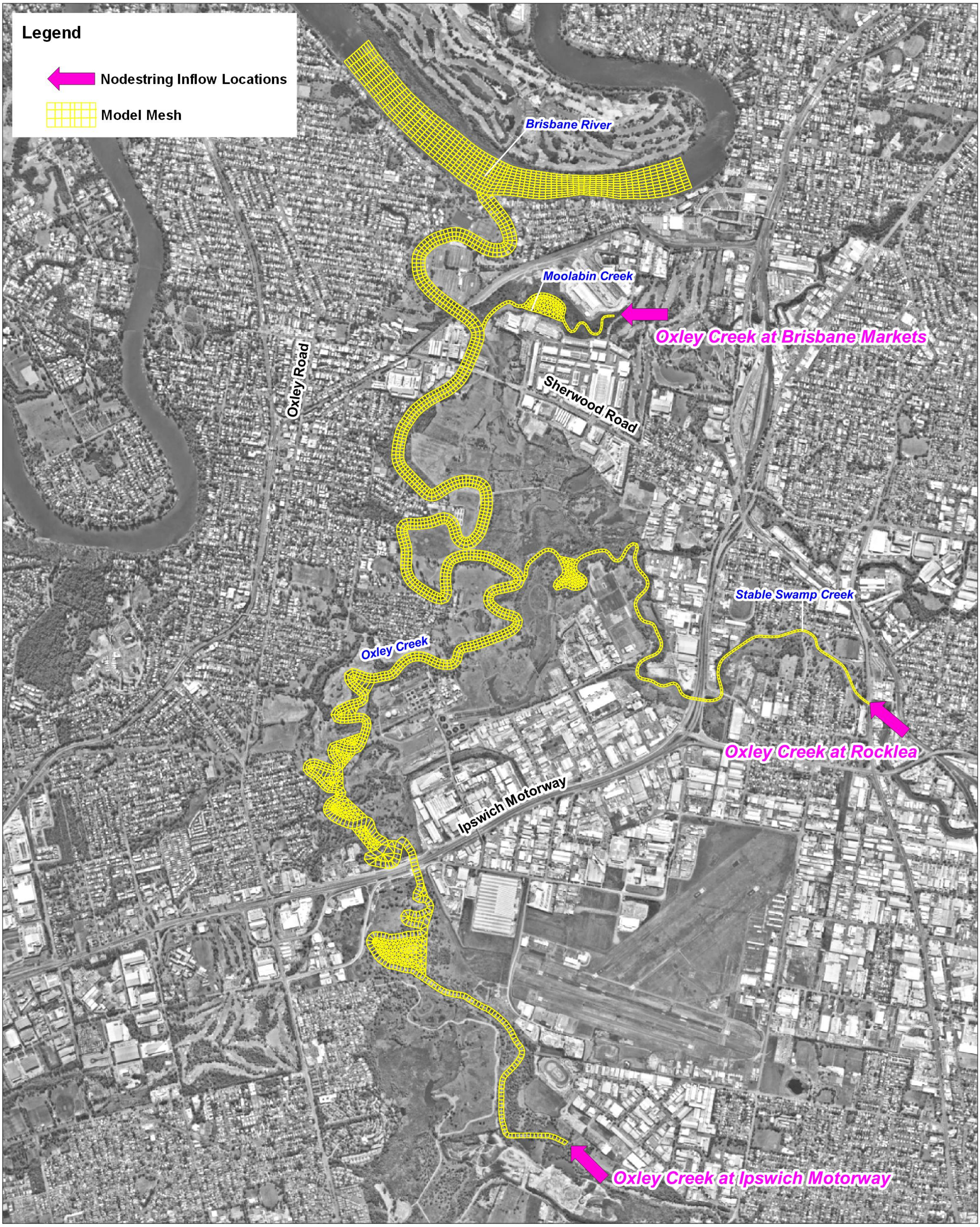

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Oxley Creek Nodestring Catchment Inflow Locations

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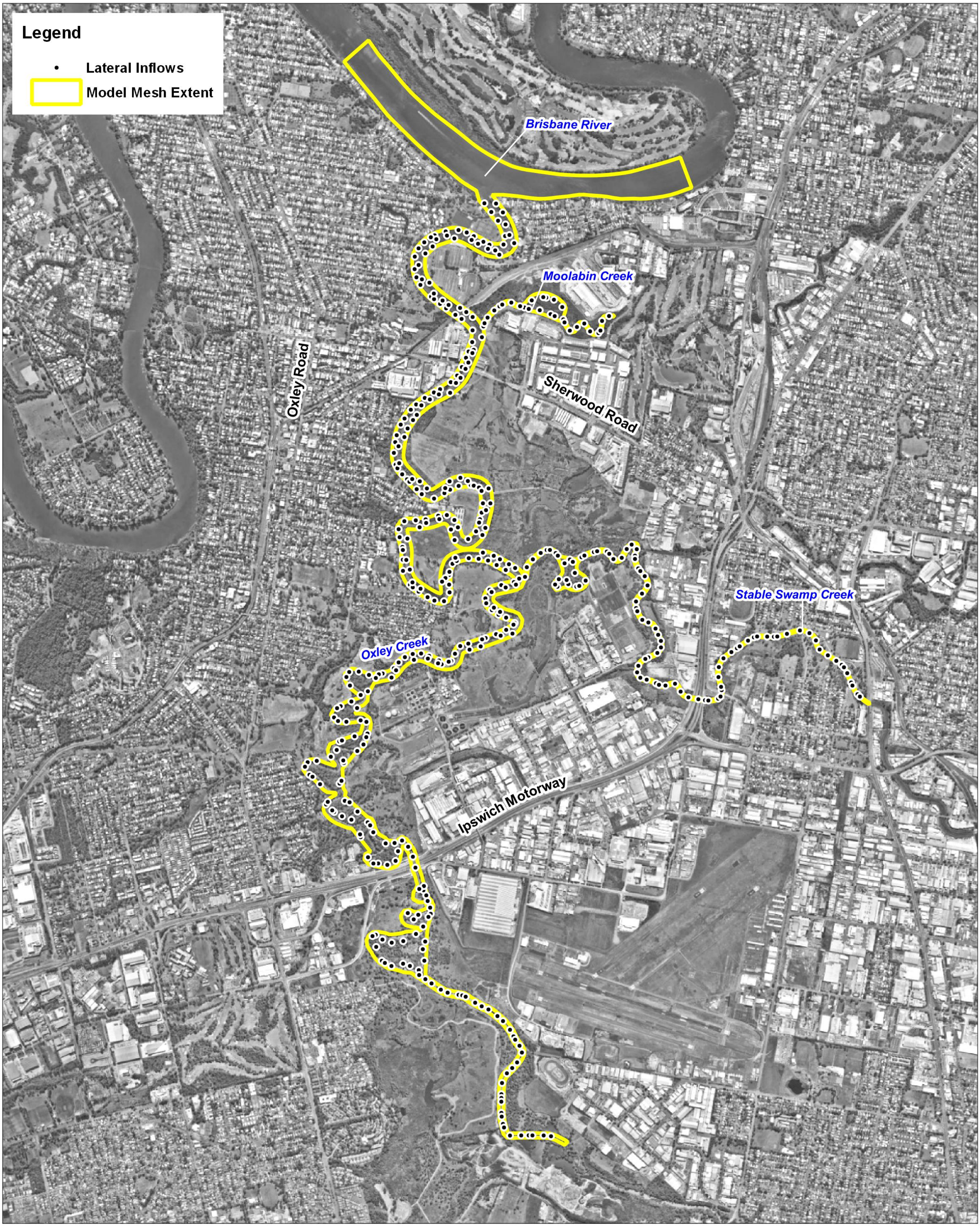

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Oxley Creek Lateral Inflow Location

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Water Quality Module Configuration

The Oxley Creek TUFLOW FV model deployed the organics simulation class to simulate the following constituents within the WQ module:

- Dissolved oxygen
- Silicate
- Inorganic nitrogen
  - Ammonium
  - Nitrate
- Inorganic phosphorus
  - Filterable reactive phosphorus
  - Adsorbed filterable reactive phosphorus
- Organic matter (labile and refractory)
  - Particulate organic carbon
  - Dissolved organic carbon
  - Particulate organic nitrogen
  - Dissolved organic nitrogen
  - Particulate organic phosphorus
  - Dissolved organic phosphorus
- Phytoplankton
  - One basic group (excludes internal nutrient simulation), that is limited by light, temperature, nitrogen and phosphorus

The processes that govern the simulation of these constituents are presented in Figure 4.58.

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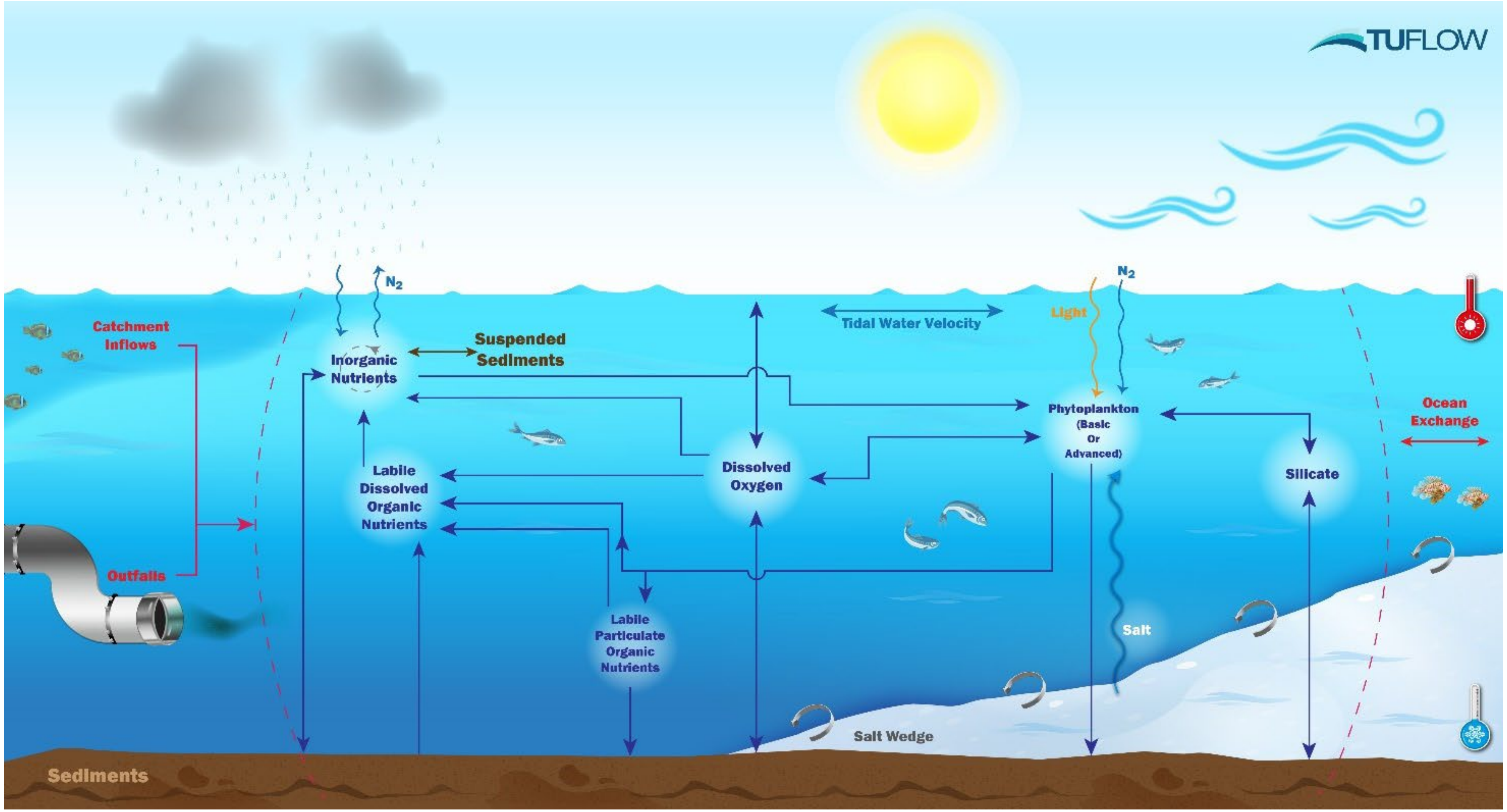

Figure 4.58 Water Quality Constituents and Related Processes Conceptual Model

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Tidal Water Quality Tidal Boundary

The data used to construct the water quality boundary within the Brisbane River were temporally sparse and were therefore interpolated to provide the full downstream water quality conditions. This interpolation (whilst being a common occurrence and practise) can lead to boundary specifications that are sometimes difficult to interpret. Should water quality data that is more finely resolved become available then it can easily be applied to this TUFLOW FV model if required. For the purposes of this pilot study, the interpolation approach was pursued.

Water quality data was available for:

- Salinity
- Temperature
- Total suspended sediment
- Dissolved oxygen
- Ammonium
- Nitrate
- FRP
- Chlorophyll *a*

These were applied as interpolated spot measurements across 2020 and 2021, to both Brisbane River boundaries equally and without alteration. Particulate and organic carbon, nitrogen and phosphorus measurements were not available so were assumed to be:

- Dissolved and particulate organic carbon: 10.0 mg/L and 2.0 mg/L respectively
- Dissolved and particulate organic nitrogen: 0.8 mg/L and 0.2 mg/L respectively
- Dissolved and particulate organic phosphorus: 0.05 mg/L and 0.01 mg/L respectively

These values were assumed to be constant and can be easily updated in the model if additional data comes to hand.

Catchment Water Quality Inflows

Water quality concentrations attached to catchment inflows were computed by TUFLOW HPC, using the methods described elsewhere in this report. In a significant departure and advancement from legacy catchment-receiving water quality modelling studies, speciation of catchment model-derived total nutrient concentrations was not required because these constituents (e.g. nitrate) were simulated explicitly in the pollutant export processes described in Section 3.2.1. This removes a significant shortcoming of previous standard practise, and (supported by the automation of TUFLOW Catch) reduces errors and the time taken to manually undertake this historically cumbersome speciation process.

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Temperature was not simulated directly in TUFLOW HPC catchment runoff. Rather, it was assigned a user specified timeseries at all inflow locations equally, where this timeseries had been constructed *a priori* from the ERA5 meteorological data described previously. In this pilot model application, water temperature was computed from ERA5 air temperature data as a four day antecedent rolling average. This rolling average was specified as a csv input file to TUFLOW Catch and assimilated by TUFLOW HPC accordingly.

Other constituents that were not directly simulated as exported pollutants were assigned user specifiable constant values as follows, using typical values from available in stream monitoring data:

- Dissolved oxygen: 5.5 mg/L
- Silicate: 20.0 mg/L
- FRP adsorbed: 0.0 mg/L
- Phytoplankton:
  - Oxley main channel and sidearms: 11.5 µg/L
  - Localised lateral inflows: 4.5 µg/L

It is noted that these were chosen to be specified as constants in this pilot model application. They could have, however, been provided as timeseries, as was the case with temperature. Such a timeseries specification is currently possible and could be implemented should sufficient data be available. Alternative constant values can also be specified if desired.

The phytoplankton constant values noted above are likely larger than might typically have been applied within previous catchment-receiving numerical model systems in Southeast Queensland. The higher value for the main creek branches was selected based on the presence of extensive ecologically active standing waterways upstream of Oxley Creek's tidal limit. A brief survey of online mapping data reveals that these waterways extend for several kilometres upstream and include biologically active marshes and wetlands that support obvious phytoplanktonic growth. It is reasonable to assume therefore that on delivery of catchment flows and concentrations to the Oxley Creek TUFLOW FV model, a signature of this elevated biological activity remains – hence the specifications assumed above. One example of such an upstream area is presented in Figure 4.59. This assumption can easily be revisited as additional data comes to hand.

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Figure 4.59 Oxley Creek Upstream Biologically Active Area

As described in Section 3.2.1, TUFLOW HPC was enhanced to account for the expected difference in transport behaviour between dissolved and particulate constituents. This enhancement allowed for the user to set any constituent's transport to either allow or prohibit infiltration once released from its store, thus differentiating between, for example, how particulate and dissolved organic nitrogen might migrate through the landscape. The qualitative influence this enhancement has on the downstream TUFLOW HPC pollutant export timeseries predictions of particulate and dissolved organic nitrogen is presented in Figure 4.60. The corresponding predictions from the same existing lumped catchment model introduced in Section 4.2 are presented in Figure 4.61 for comparative purposes. Mass fluxes are presented.

The spikes in particulate organic nitrogen mass flux (and less so for dissolved) predicted by TUFLOW HPC correspond to rainfall wash-off events and reflect the expected behaviour of a constituent that is confined to surface transport. The qualitative behaviour of particulate and dissolved organic nitrogen mass fluxes is not differentiated in the predictions of the existing lumped model, and this is likely because they were computed from applying respective constant speciation factors to the existing model's prediction of total nitrogen mass flux.

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Also of note is the dominance of the dissolved organic nitrogen mass flux predicted by TUFLOW HPC during dry time falling limbs. This mass flux is associated with baseflow, and is qualitatively the reverse of the dominant particulate mass flux that occurs during times of surface flow.

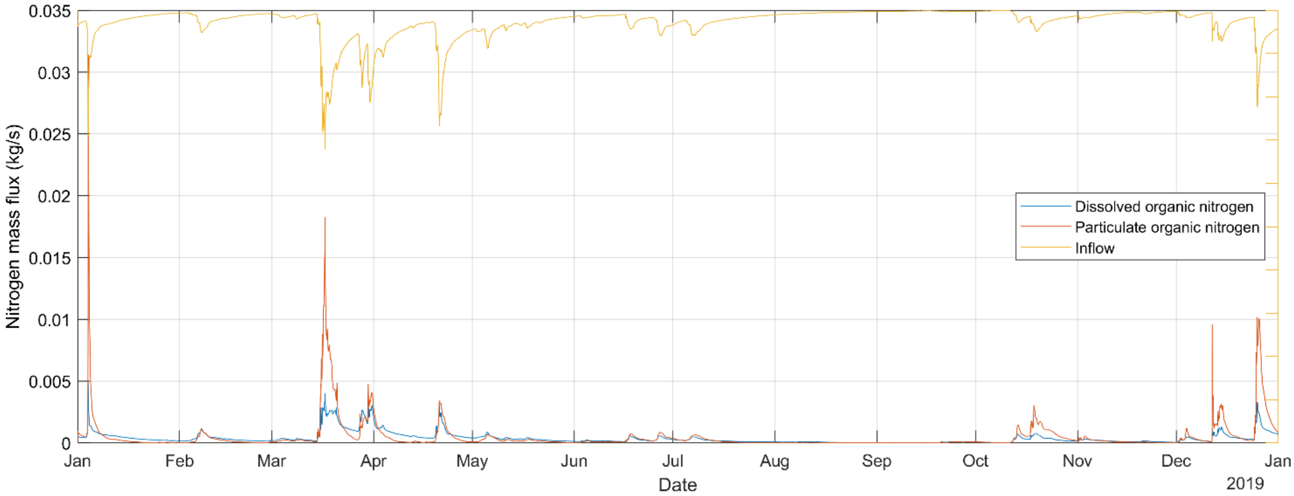

Figure 4.60 Example Particulate and Dissolved Organic Nitrogen Mass Flux Prediction, TUFLOW HPC. Inflows Shown on the Reversed Axis

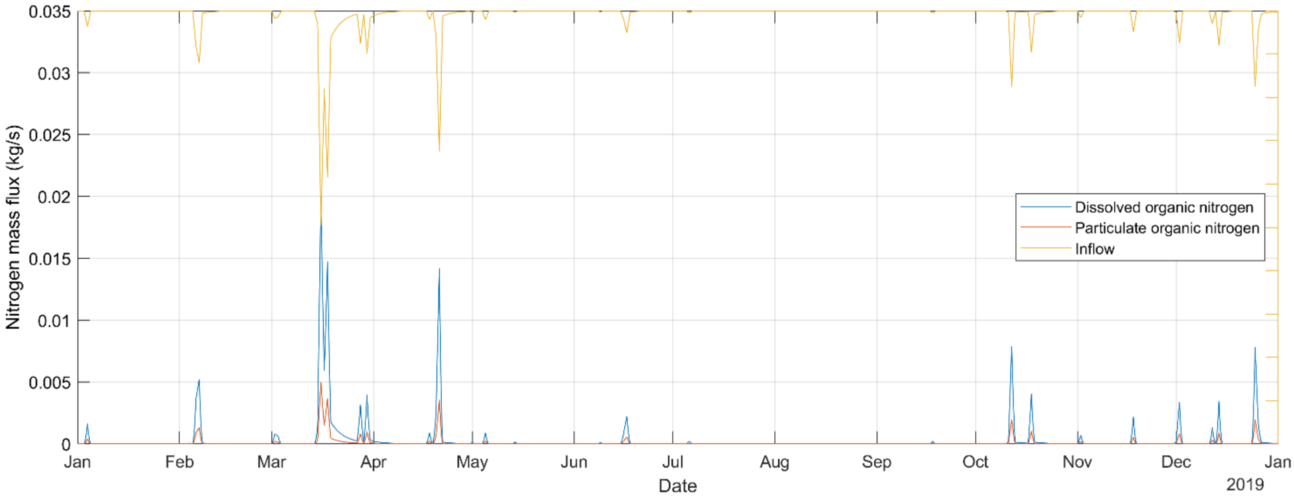

Figure 4.61 Example Particulate and Dissolved Organic Nitrogen Mass Flux Prediction, Existing Model. Inflows Shown on the Reversed Axis

Water Quality Sediment Fluxes

In the interests of simplicity for this pilot model, the flux of water quality constituents across the sediment water interface was set to be spatially invariant. Typical fluxes were assigned to each constituent, and allowed to vary with temperature and dissolved oxygen concentrations as described for dissolved oxygen in Appendix D of the TUFLOW FV Water Quality Manual (and similar Chapters for other water quality constituents).

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Water Quality Parameters

The TUFLOW FV WQ module was parameterised using typical values for all processes. One generic phytoplankton group was simulated.

Sediment Transport Module Configuration

The TUFLOW ST Module was deployed with a single fraction configured to reflect fine sediment. The fraction was allowed to settle and resuspend.

Simulation Period

Three simulation periods were set for the pilot model. These periods were chosen to:

- Best exploit the available calibration data provided by BCC
- Span a multiannual contiguous period
- Have sufficient data to set up and execute TUFLOW HPC simulations to provide catchment inflows to TUFLOW FV, and
- Include a range of climatic conditions

With these criteria, the following periods were chosen:

- A warmup period of 7 days from 01/01/2019 00:00:00 to 08/01/2019 00:00:00. This period was used to gradually draw down a fully wetted model to the starting water level of the subsequent simulation. This technique is often used and is a convenient way to allow the FV model to establish areas of wet and dry cells in preparation for subsequent simulation of actual conditions. A restart file was saved at the end of this period, and used as the input (with timestamp override) to the next simulation period
- First annual period from 01/01/2019 00:00:00 to 01/01/2020 00:00:00. This is a drier (but nonetheless hydrologically important) annual period, with total annual rainfall at Archerfield airport of 595mm, compared to the annual average of 1056mm at the same location. The restart (with timestamp overridden) from the warmup simulation was used to initialise all hydrodynamic and water quality computed quantities for this first annual simulation
- Second annual period from 01/01/2020 00:00:00 to 01/01/2021 00:00:00. This is a wetter annual period, with total annual rainfall at Archerfield airport of 913mm, again compared to the annual average of 1056mm at the same location. The restart (without the timestamp being overridden) from the first annual simulation was used to initialise all hydrodynamic and water quality computed quantities for this second annual simulation.

4.4.4 Model Calibration

Period of Presentation

Although the simulated periods noted above span two years, only results from the 2019 calendar year are presented in this report, for the following reasons:

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- The 2019 calendar year is a drier year than average. As such, the influence of catchment inflows (especially volumes) on the receiving waters can be more closely assessed in relation to responses to subtle hydrologic features such as the shape of rising and falling limbs of predicted catchment inflows. This contrasts to a wetter year (2020 or 2022) where large catchment inflow volumes swamp Oxley Creek in a short period of time and potentially mask the hydrologic boundary condition subtleties of interest in this pilot study

- Although including some intertidal areas, the Oxley Creek TUFLOW FV pilot model was not designed to simulate substantive overbank / breakout flows, of which there are many in this well-known low-lying area, especially during wetter periods. In-channel model predictions are therefore less reliable during significantly wetter times compared to those of drier times (such as 2019) where flows are constrained to being largely in-bank. For example, superelevated water levels and unphysically high mouth exit velocities have been observed in the 2020 TUFLOW FV HD model predictions during these times. A potential extension of this pilot might include the simulation of bank overflows in the TUFLOW FV model domain

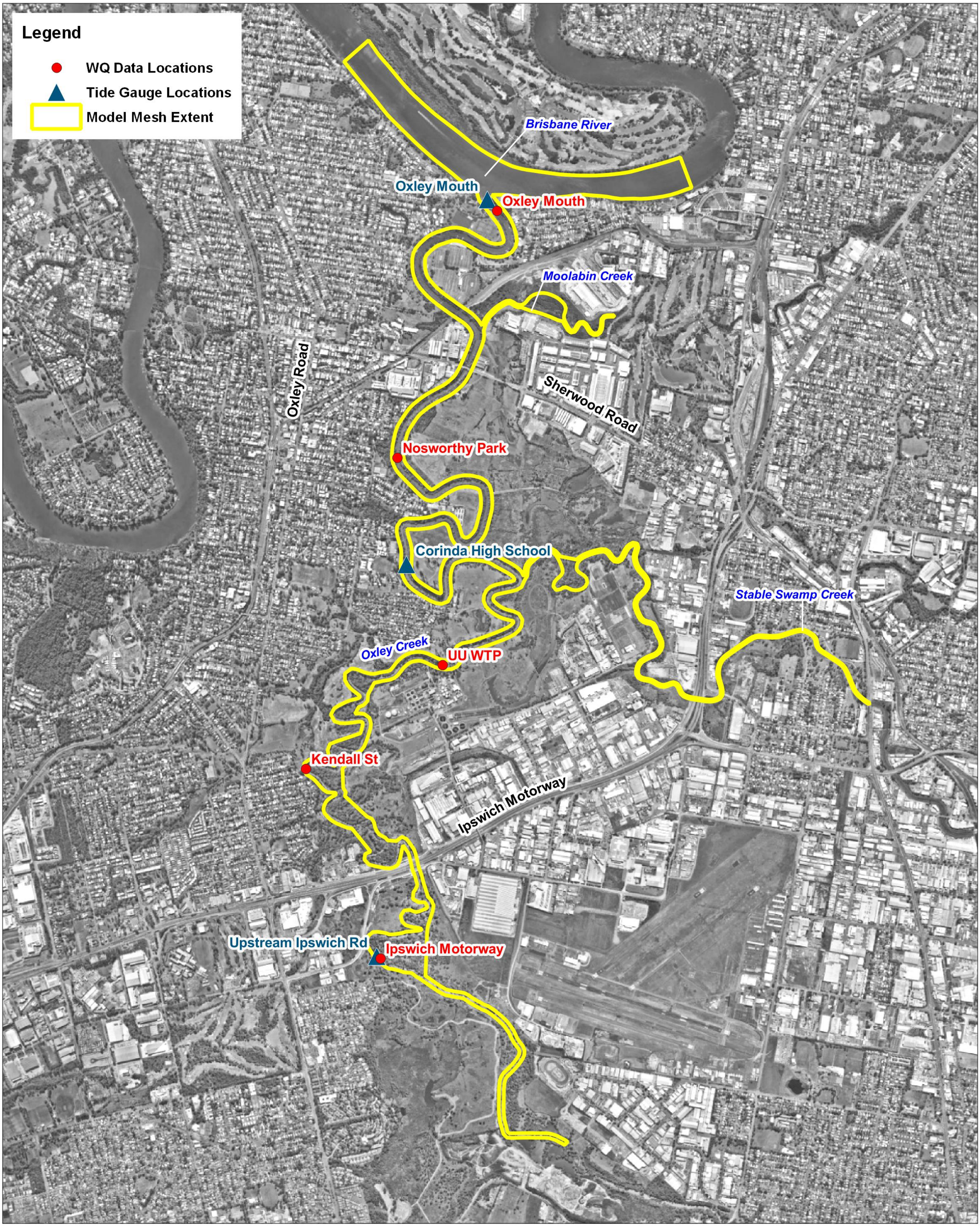
- The material to be presented in subsequent sections of this report is already voluminous and would be unwieldy and lack focus if predictions from both 2019 and 2020 were included

Data Availability

The core data used to assess model performance during calibration were those provided to this study by BCC, and comprised measurements taken at the following locations (see Figure 4.3):

- Water levels
  - Oxley Creek mouth (site 540274_OXA588)
  - Corinda High school (site 540071 - OXA023)
  - Upstream of Ipswich Rd (site 540805 - OXA1890)
- All other data
  - Oxley Creek Mouth
  - Nosworthy Park
  - Urban Utilities Water Treatment Plant
  - Kendall St
  - Ipswich Motorway

Not all sites included all data, but data that was collected over the selected TUFLOW FV modelling period was extracted from the BCC database and included where possible in model comparisons. The location of sites listed above are presented in Figure 4.62.



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Oxley Creek Monitoring Sites

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Calibration Approach and Metrics

It has been a long standing practice to rely on presentation of concentration timeseries and/or annual median thalweg plots to compare model predictions with measurements, and therefore (with calculation of some goodness of fit metric/s such as those proposed in Moriasi et al, 2015) attempt to assess water quality model predictive power. One of the understandable motivations for doing so is the need to compare model predictions to scheduled water quality objectives, which are often expressed as annual medians. Whilst it is likely that such timeseries and statistically-based assessment techniques will continue to play some future role in model – measurement comparisons, the integrated modelling framework offered by TUFLOW Catch now allows progression of model assessment beyond sole reliance on these approaches.

Specifically, TUFLOW Catch allows modellers to fully exploit the power of its diagnostic model outputs (as opposed to concentration outputs). These diagnostics report the environmental fluxes of volume and/or mass that occur within a model, because of its user-specified configuration. It is these fluxes that capture the transfer of volume and mass throughout a system, and therefore are the true descriptors of the inner workings of a numerical model and its user-configured representation of an environmental system. Even for the simplest of environmental indicators, this is an important step forward because reporting of fluxes reveals the reasons why timeseries predictions are as they are: timeseries alone cannot offer this insight because they are the integrated result of the combined action of any number of underlying fluxes, whose relative influence on concentration predictive skill cannot be retrospectively isolated from timeseries inspection or statistical analysis alone.

Said plainly: given the potential multitude of parameters that can be tuned in a numerical model configuration, it is entirely possible to set these parameters so that models appear to correctly predict concentration timeseries; it is also entirely possible that these concentration predictions appear correct but are arrived at for the wrong reasons, i.e. the underlying environmental fluxes are incorrect. The only way to ascertain whether timeseries predictions are meaningful is to therefore interrogate and report the underlying fluxes that generate these timeseries predictions: the diagnostic outputs of the TUFLOW Catch suite of products support this approach.

The above can be illustrated by way of the simple example of the prediction of nitrate concentrations in a waterway. In a relatively standard water quality model setup (including that of the current pilot model of Oxley Creek), the mass flux pathways of nitrogen that combine to generate a timeseries prediction of nitrate at a point are:

- Tidal boundary exchange (source or sink)
- Catchment inflows (source)
- Point source discharges (source)
- Irrigation/other extractions (sink)
- Sediment fluxes (source or sink)
- Atmospheric fluxes, wet (rainfall) and dry (dust) (sources)
- Uptake by phytoplankton (sink)
- Nitrification (source)
- Mineralisation (sink)

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- Denitrification (sink)
- Anaerobic oxidation of ammonium (sink), and
- Dissimilatory reduction of nitrate to ammonium (sink)

All the rates that govern these processes are user specifiable, and some have multiple parameters that govern fluxes, such as phytoplankton uptake. It is therefore possible to tune the set of model parameters that dictate the operation of the above fluxes to then have a model produce a timeseries prediction at a point that looks plausible when compared to spot measurements. However, without interrogating diagnostic outputs and subsequently reporting the underlying fluxes that generate this final timeseries prediction, a modeller has no means to know that the underlying mass flux balance accords with expectation, and therefore when model scenarios are set up and run that adjust these fluxes, that meaningful future predictions are necessarily made.

Most importantly, and well beyond disputing the value of a goodness of fit metric generated from a timeseries analysis, it is the presentation of these fluxes that allows wide and meaningful engagement in assessing model performance and therefore predictive capability. For example, fluxes of mass and volume presented on a conceptual diagram are easily interpreted by a wide range of non-modelling stakeholders and are much more accessible than timeseries and statistical analyses. Such conceptual diagrams of fluxes offer a means of engagement with those who have a valuable non-modelling understanding of the systems being simulated, with individual insights extending beyond the purview of a numerical modeller.

Given the above, the presentation of the Oxley Creek model calibration, whilst still including timeseries comparisons, focuses more on provision of an understanding of environmental fluxes and their pathways. It is hoped that this method of presentation supports active and wider discussion around whether the model is correctly parameterised from an environmental flux perspective (and therefore assess its utility as a predictive tool), rather than whether model concentration timeseries predictions pass through each and every measured spot data point.

In light of the above, the method of presentation of predictions from the Oxley Creek pilot model is as follows (for each simulated quantity, see following subsection):

1. A conceptual diagram of the final values of all relevant cumulative system fluxes, over the entire year period (2019). Sub-annual (e.g. seasonal) periods could equally be selected and interrogated in subsequent analyses if seen to be useful. These fluxes vary in nature and number between simulated constituents (e.g. the flux pathways of dissolved oxygen are different to those of ammonium), and conceptual diagrams are tailored as such. An example is presented in Figure 4.63. The numbers are final cumulative fluxes over the period noted in the bottom left hand corner. Some interpretive notes:

    a. Fluxes are presented over the 2019 calendar year
    b. Fluxes are those occurring throughout the entire TUFLOW FV model domain
    c. Positive values mean that over the period presented, a nett flux into the domain has occurred for the constituent considered
    d. Negative values mean that over the period presented, a nett flux out of the domain has occurred for the constituent considered
    e. The three fluxes of largest magnitude are coloured red

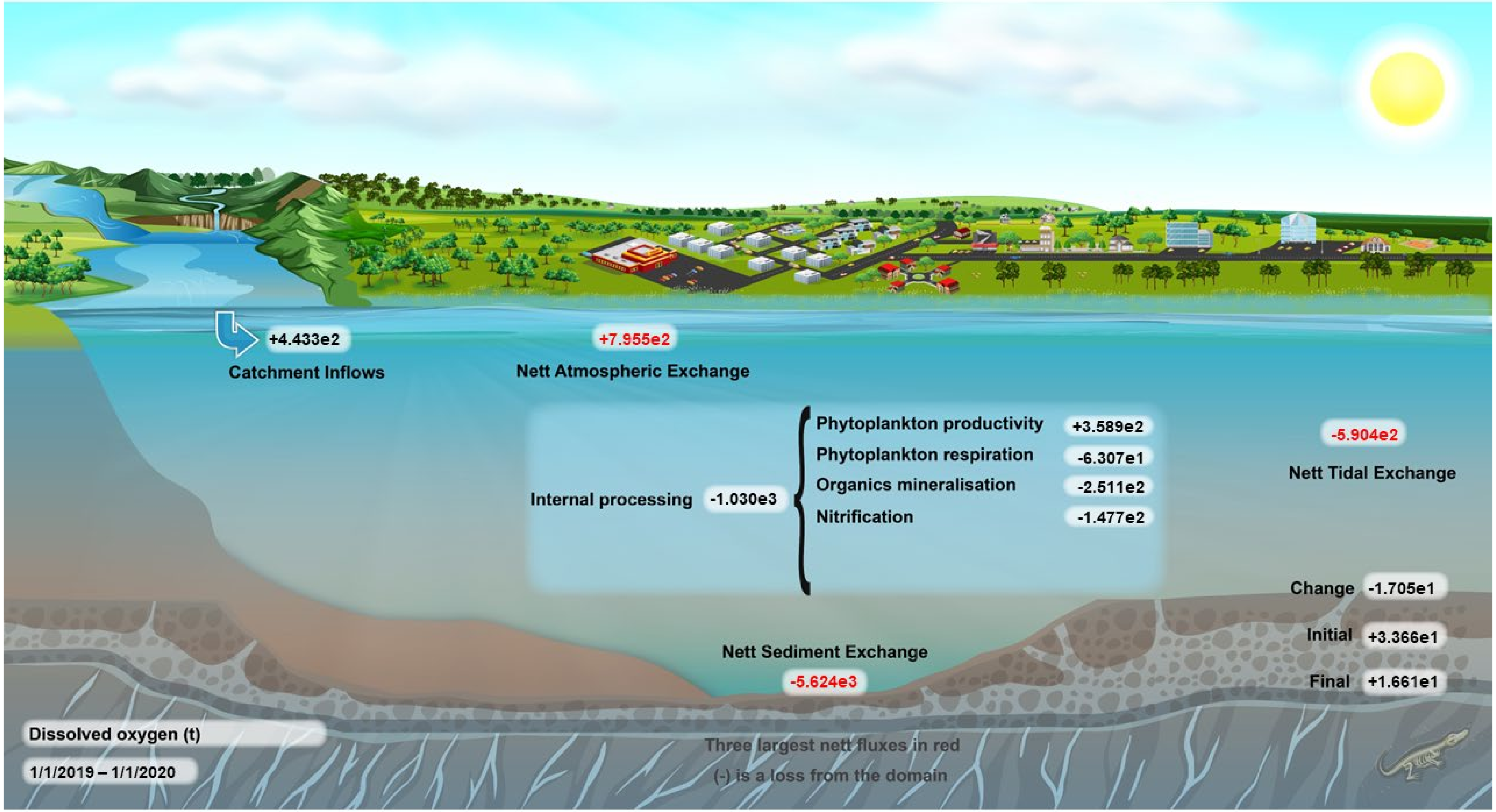

Figure 4.63 Oxley Creek Example Conceptual Diagram of Fluxes – Dissolved Oxygen

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2. Two mass and flux (not concentration) timeseries plots that support and complement the conceptual diagram. These are presented on the same figure in two panes:

    a. Upper pane. The total instantaneous mass (or volume) of a constituent within the entire model domain as it evolves in time. The horizontal axis is time and the vertical axis is mass (or volume) of the constituent considered. This pane allows the reader to inspect the mass/volume timeseries and make statements such as "On the 12th of January, the Oxley Creek model predicted that the creek held a mass of 450 tonnes of dissolved oxygen". Often (but not always) these timeseries have an obvious tidal signal, reflecting the fact that exchange of mass occurs across tidal boundaries. Some interpretive notes:

        i. Masses and volumes are presented over 2019 to match the conceptual diagram period
        ii. All masses and volumes are positive quantities
        iii. A positive (increasing) slope of the mass timeseries line means the model-wide mass or volume is increasing
        iv. A negative (decreasing) slope of the mass timeseries line means the model-wide mass or volume is decreasing

    b. Lower pane. The temporal evolution across the simulated annual period of the cumulative fluxes of mass or volume throughout the entire model domain, for the constituent considered. These fluxes are both across boundaries (e.g., tidal exchange or catchment inflows) and internal transformations (e.g., the production of dissolved oxygen by phytoplankton productivity). This pane allows the reader to inspect the cumulative flux timeseries and make statements such as "The flux of dissolved oxygen into the model via atmospheric exchange is roughly balanced by the flux of oxygen leaving the model via benthic consumption." It is these sorts of statements that are at the heart of this presentation framework: they provide systems understanding of how a model is balancing underlying fluxes and therefore arriving at its prediction of a concentration timeseries at a point. The flux timeseries values at the right hand end of each timeseries are the final cumulative fluxes predicted by the model for each pathway or boundary and correspond to the numbers presented in the preceding conceptual diagram. An example is presented below for dissolved oxygen fluxes. The horizontal axis is time, and the vertical axis is cumulative flux (as a mass or volume) over the period considered. The timeseries are not concentrations or instantaneous fluxes – they are cumulative fluxes. Some interpretive notes:

        i. Cumulative fluxes are presented over 2019 to match the conceptual diagram period
        ii. Mass and volumes cumulative fluxes can be positive or negative quantities. A positive quantity at any point in time means that to that time, more constituent mass or volume has entered the domain than has left, and vice versa
        iii. A positive (increasing) slope of the cumulative mass timeseries line at any point in time means the model-wide instantaneous mass or volume flux is positive (into the domain) at that time
        iv. A negative (decreasing) slope of the cumulative mass timeseries line at any point in time means the model-wide instantaneous mass or volume flux is negative (leaving the domain) the domain) at that time

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v. The sum of the final cumulative fluxes across all timeseries equals the difference in mass or volume from the start to end of the simulation (i.e., the difference in the final and initial values of the mass timeseries presented in the upper panel)

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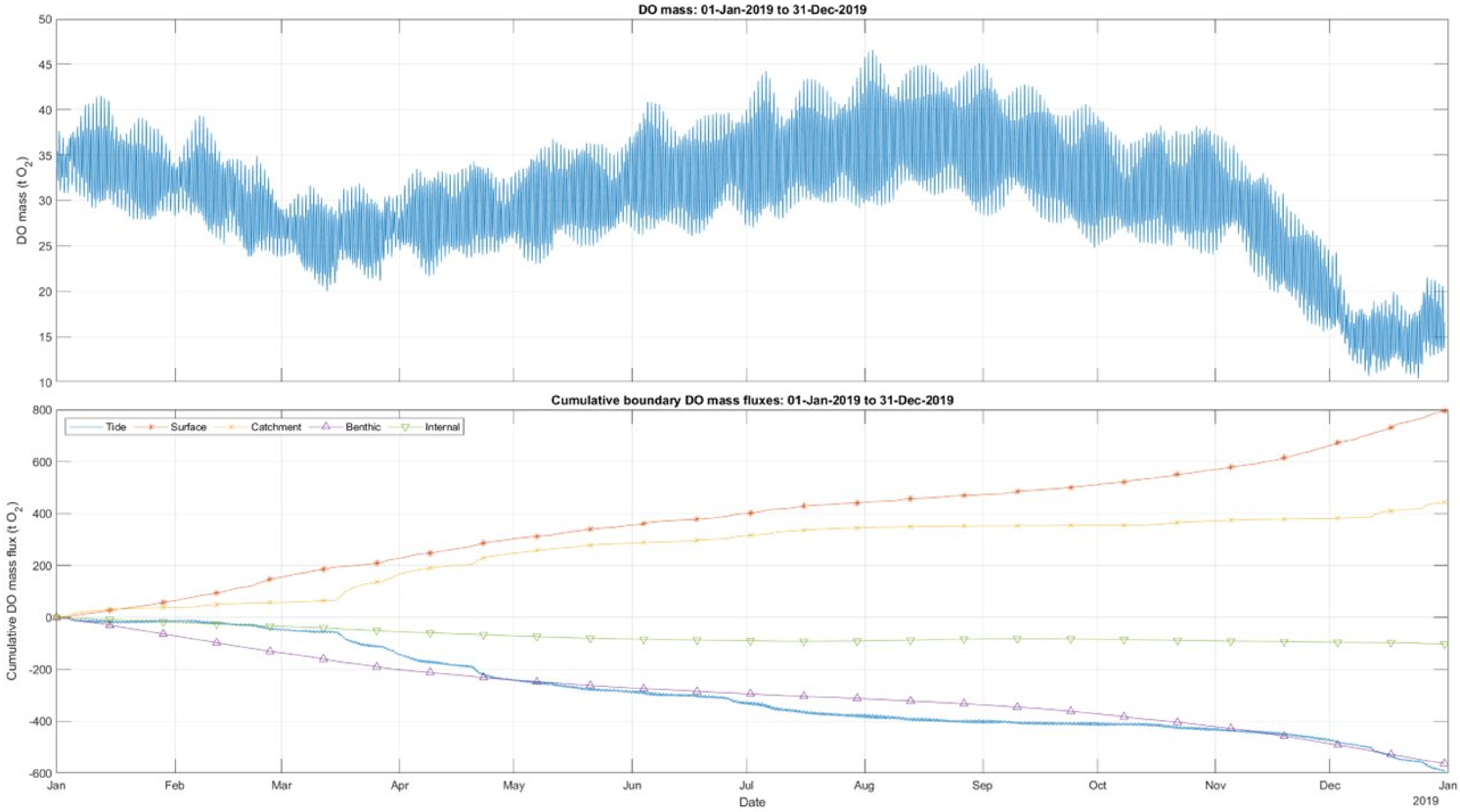

Figure 4.64 Oxley Creek Example Cumulative Fluxes – Dissolved Oxygen

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3. Traditional timeseries comparisons of modelled predictions against available spot monitoring data. Each figure reports a single constituent comparison and has multiple panes, where each pane corresponds to one of five sites at which spot sampling occurred. An example is presented below for dissolved oxygen concentrations. Some interpretive notes:

    a. Model data are extracted at the surface in each instance. This can be adjusted to present other locations in the water column if required

    b. Timeseries are presented across 2019 to match the conceptual diagram and flux periods

    c. Not all constituents always have measurements at every location, and as such some panes will have limited (or no) measured data presented, and will include only model concentration predictions

    d. The bottom pane in each timeseries figure has the inflows to Oxley Creek at the Ipswich Motorway coplotted as a thin solid line, with the view to supporting timeseries interpretation within the context of the timing of catchment inflows

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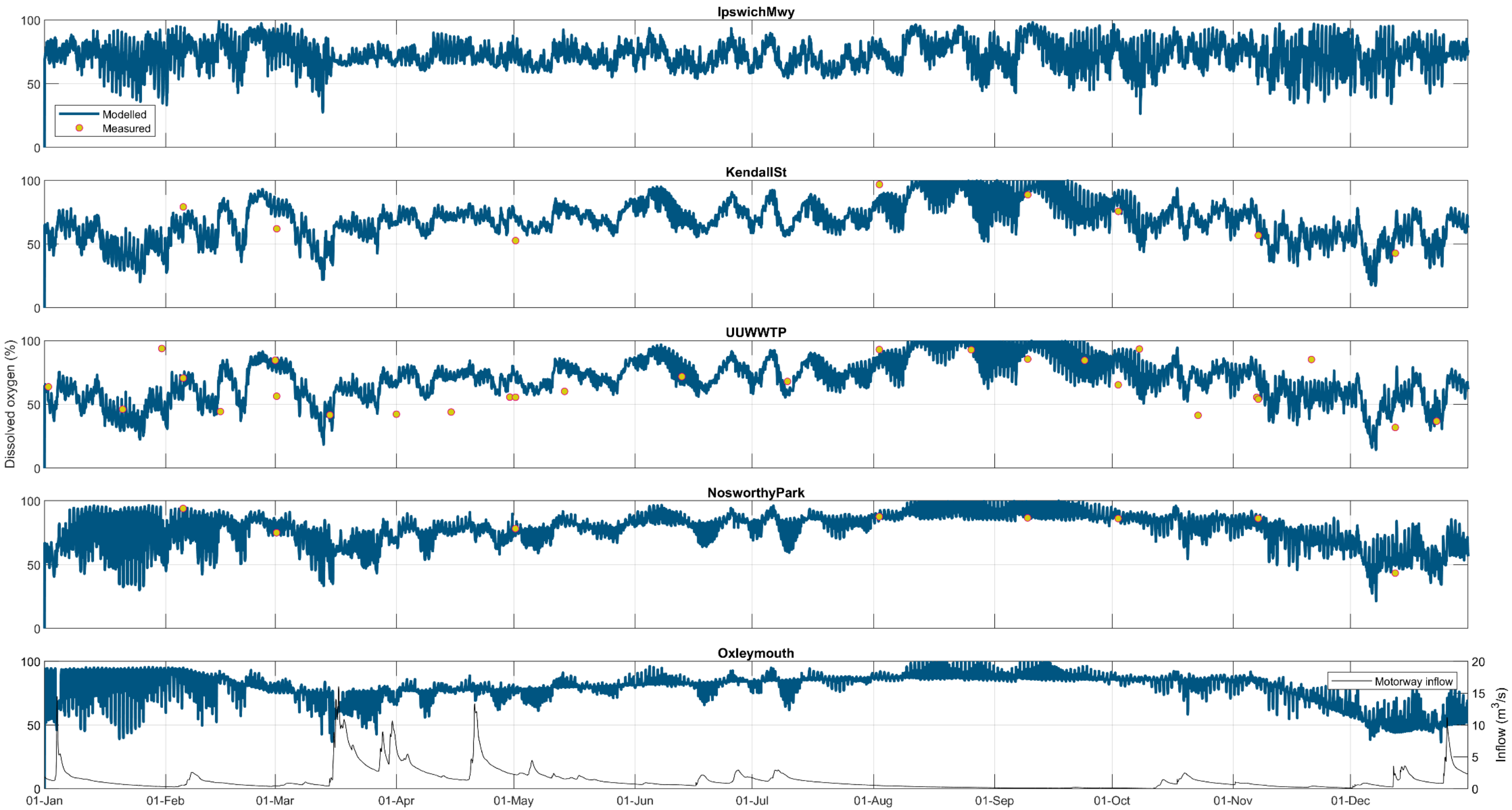

Figure 4.65 Oxley Creek Example Concentration Timeseries – Dissolved Oxygen

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4. Interpretation of system behaviour for the relevant constituent, drawing on the above presentation of modelled and measured data. These are typically brief but are intended to illustrate the combined value of presenting this chosen suite of model metrics. It is hoped that these interpretations will generate discussion around model performance from the position of having developed a flux-based systems understanding of Oxley Creek

Constituents Presented

In the main body of the report, the modelled constituents presented in the way described above are:

- Volume
- Salt
- Sediment (i.e., total suspended sediment)
- Dissolved oxygen
- Total nitrogen
- Total phosphorus, and
- Total chlorophyll a.

The water quality-related constituents have been chosen given their frequent use as comparison points to water quality objectives (WQOs). These totals were not simulated in their own right within TUFLOW FV, but have been post processed as sums of their respective components.

4.4.5 Calibration Results

The calibration of the TUFLOW FV model was undertaken in three stages:

- Hydrodynamics
- Sediment transport, and
- Water quality

These are presented following, using the metrics described above, where possible and appropriate.

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Hydrodynamics

A complete hydrodynamic calibration exercise would typically include consideration of model performance in the prediction of:

- Water surface elevation (i.e., comparing predicted water surface elevation at a location/s where water level gauge measurements have been made). This assesses a model's ability to reproduce surface wave propagation throughout a domain
- Discharge (i.e., comparing predicted cross-sectional discharge/s (flow/s) or point velocity field/s with acoustic doppler current profiler measurements). This assesses a model's ability to convey water volumes (and hence masses) throughout a domain
- Water temperature (i.e., comparing predicted water temperatures at a location/s where water temperature measurements have been made). This assesses the model's ability to assimilate and correctly apply atmospheric heat exchange, and to advect heat through a model domain. It is therefore dependant on the performance of the above
- Salinity (i.e., comparing predicted salinities at location/s where salinity measurements have been made). This assesses a model's ability to transport dissolved constituents throughout a model domain, both in response to barotropic (two dimensional external) and baroclinic (three dimensional internal) processes. The recovery of an estuarine salt wedge following a fresh flushing event is often used as an indicator as to the ability of a model to appropriately transport dissolved constituents

Combinations of these comparisons might also include considering a model's predictive capability over both spring and neap tidal periods.

Although having good temporal and spatial coverage, and generally being very informative, the data provided by BCC to this modelling study was not able to support all the above comparisons. The comparisons that were possible included:

- Fluxes:
  - Conceptual diagram volume fluxes
  - Cumulative volume flux timeseries
  - Conceptual diagram salt fluxes
  - Cumulative salt flux timeseries
- Timeseries
  - Tidal water level comparisons to continuous data. Given the vertical truncation of the boundary forcing data and the required data manipulation described previously, comparisons were most meaningful in frequency space and are therefore presented as such
  - Salinity comparisons to spot (campaign) data, and
  - Water temperature comparisons to spot (campaign) data

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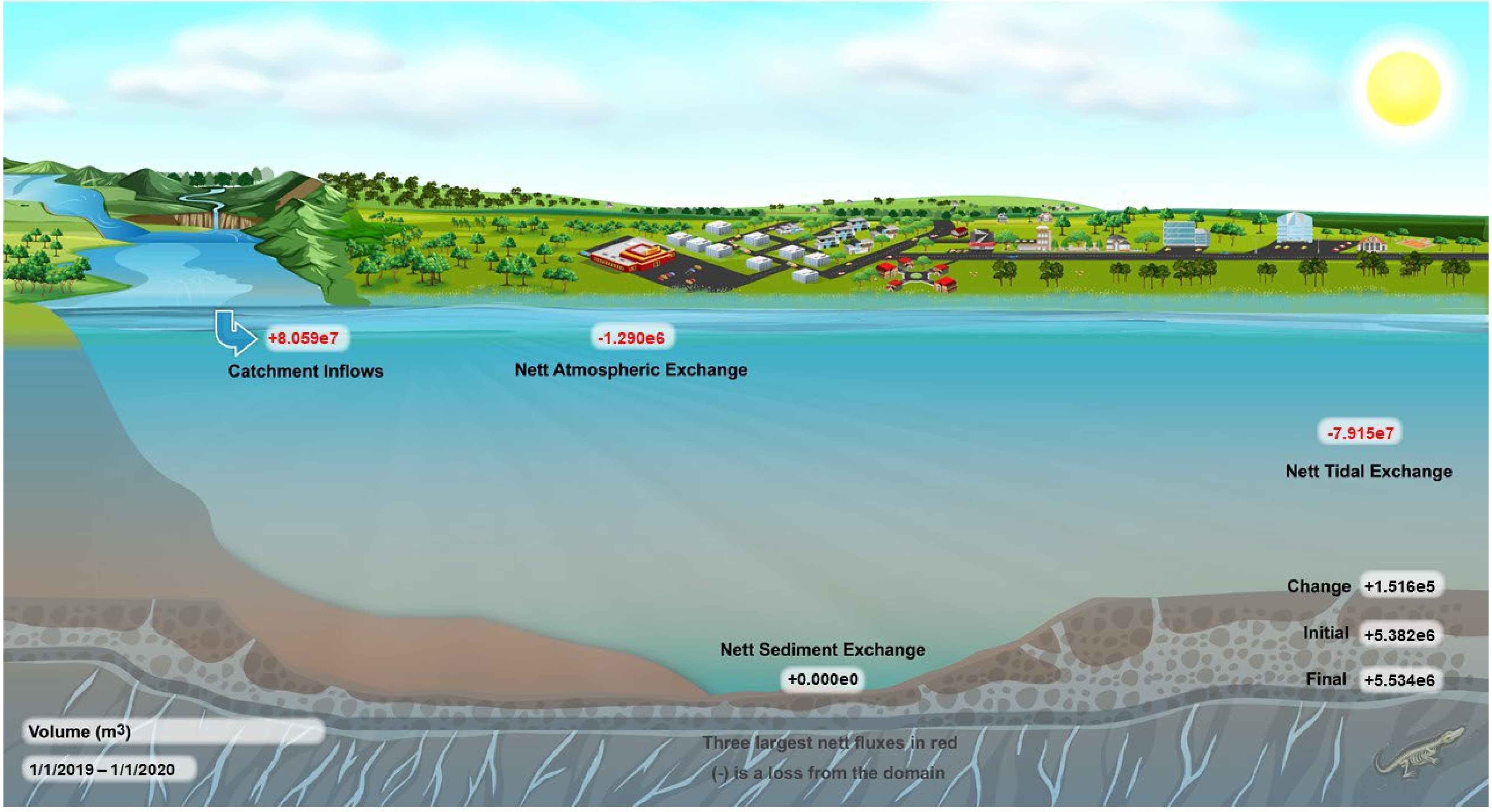

Figure 4.66 2019 Conceptual Diagram: Volume

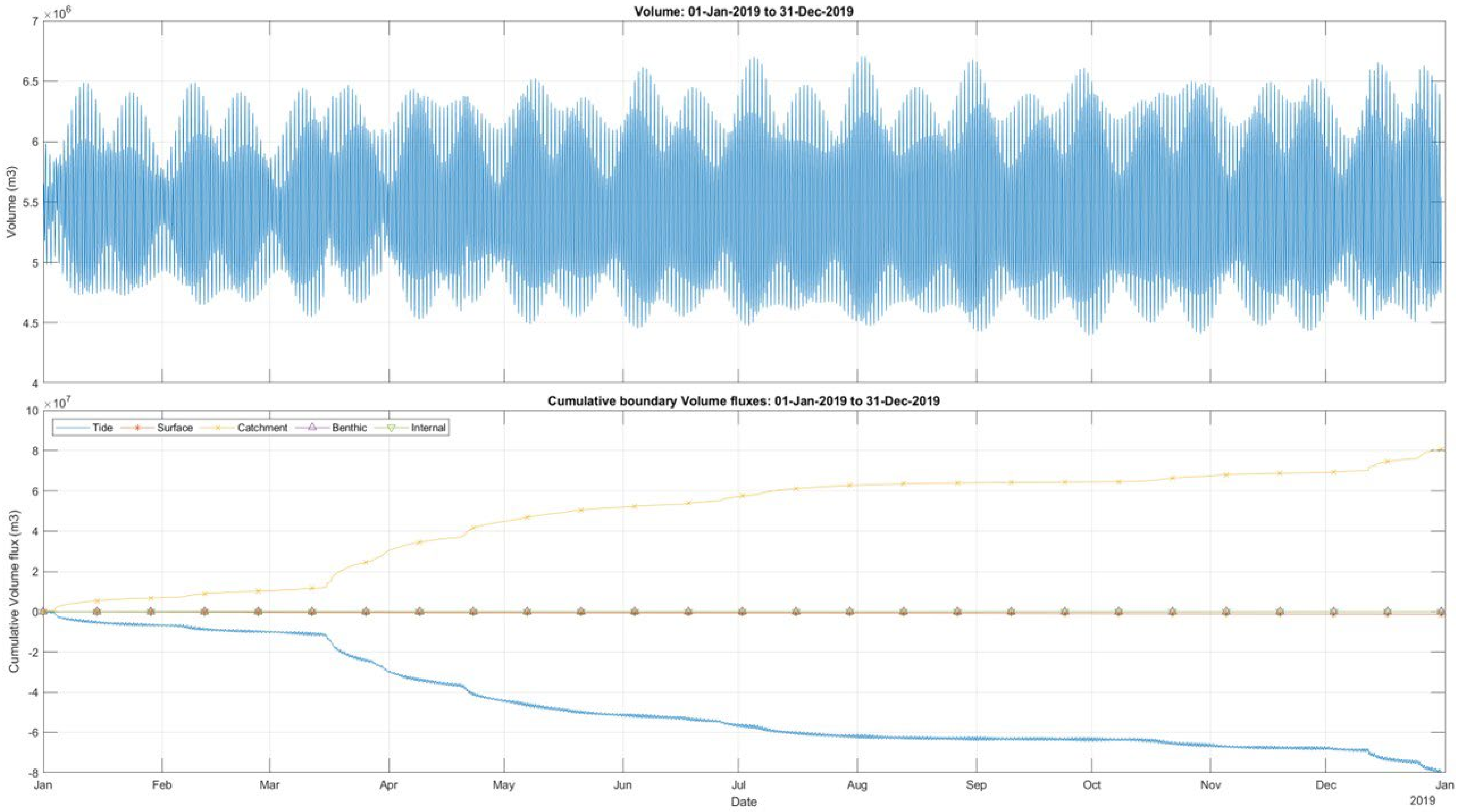

Figure 4.67 2019 Mass and Cumulative Flux Timeseries: Volume

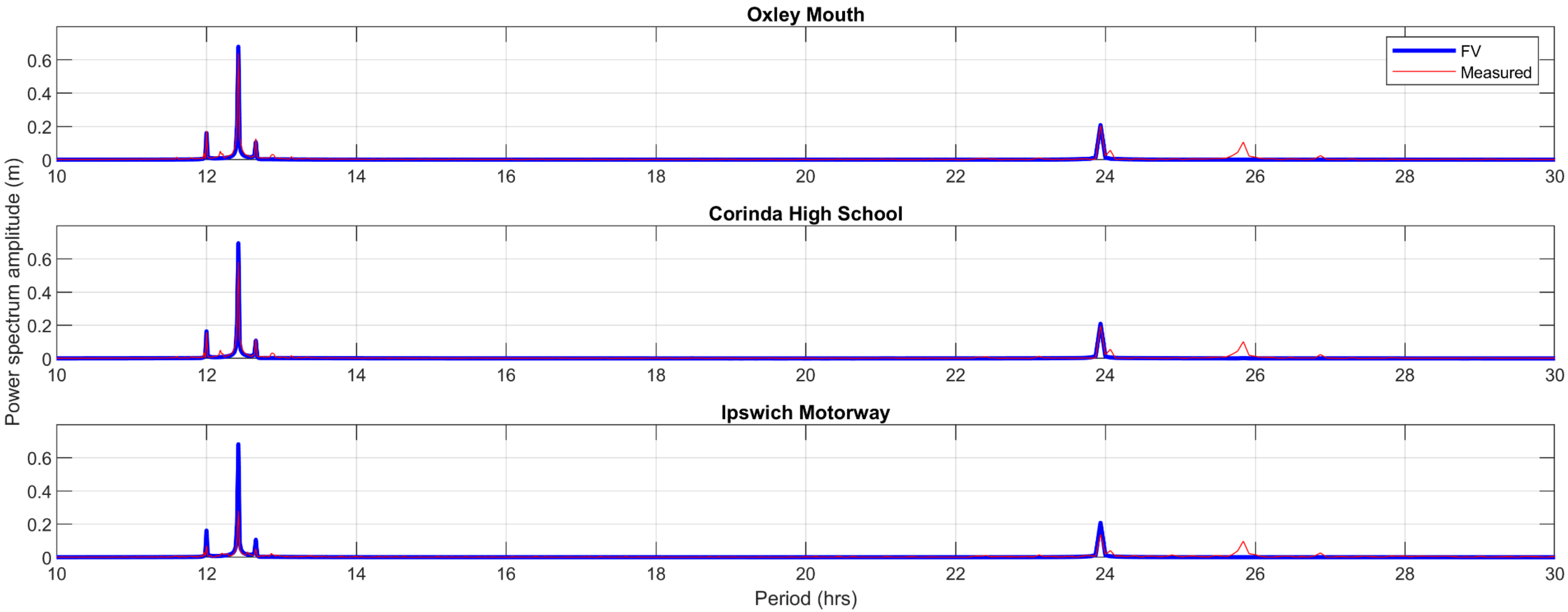

Figure 4.68 2019 Water Level Fourier Power Spectra

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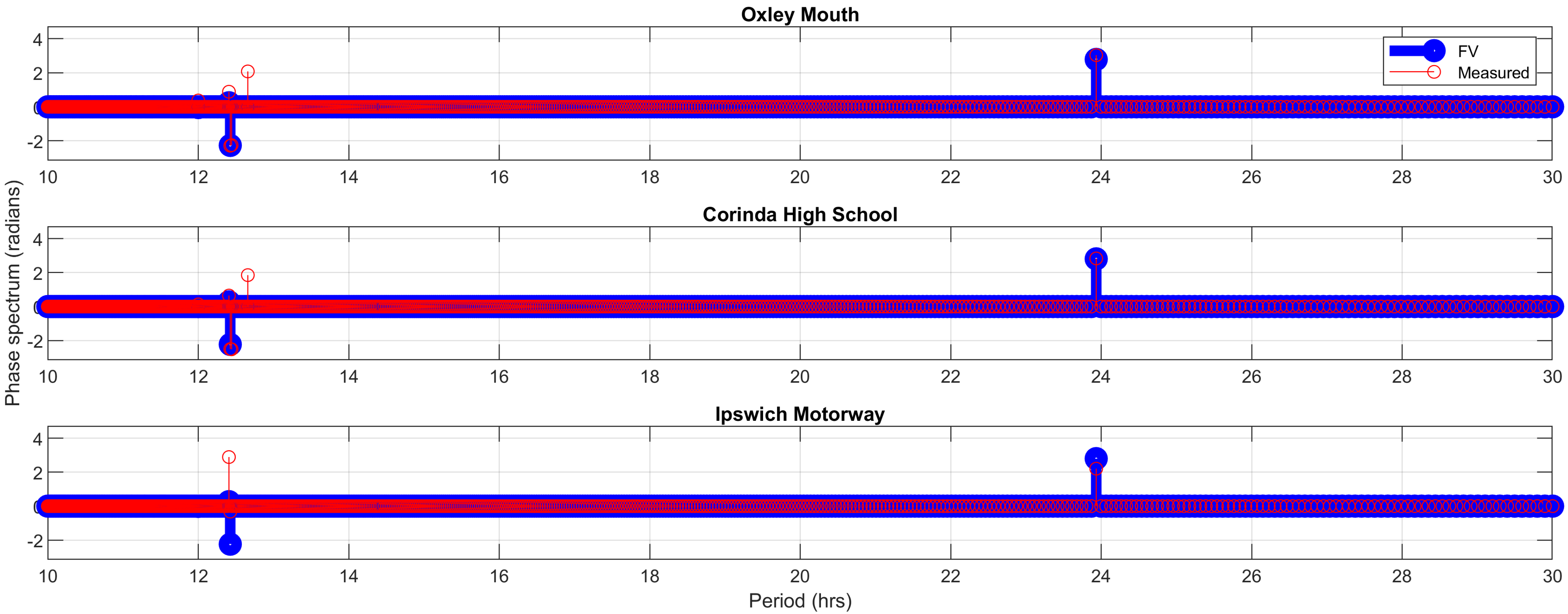

Figure 4.69 2019 Water Level Fourier Phase Spectra

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The previous figures are consistent with first order expectation in that the two dominant boundary fluxes of water volume (mass) are catchment inflows and tidal outflows. The Oxley creek system has these fluxes approximately balanced in the longer term (Figure 4.66 and lower pane of Figure 4.67), and the high frequency signature of tidal fluxes is evident in the total volume timeseries (upper pane of Figure 4.67). Evaporative loss of volume is a second order process.

The mass and flux assessments above reveal that the standing water volume of Oxley Creek (5.5e6 m^3) is approximately 7% of the volume of water delivered by catchment inflows in one year (8.0e7 m^3). This means that the volume of Oxley Creek, even in a relatively dry year such as 2019, is replaced more than 15 times under the influence of catchment inflows. In the main, these inflows pass out into the Brisbane River.

Finally, the spectral plots of power and phase show good agreement, especially at Oxley Mouth and Corinda High School. The modelled tidal signal at Ipswich Motorway has slightly more spectral power (amplitude) than measured, but its peaks are correctly located in period space. The apparently opposite phases at Ipswich Motorway (at periods slightly greater than 12 hours, Figure 4.69) exaggerate the actual difference: the presented phase shifts at that period are both close to having magnitudes of pi (3.14 radians), with measured and modelled being close to +3.14 and -3.14 radians, respectively. The plotted phases are therefore close in reality: a phase shift of +3.14 radians is the same as a phase shift of -3.14 radians.

The same suite of figures is presented below for salt.

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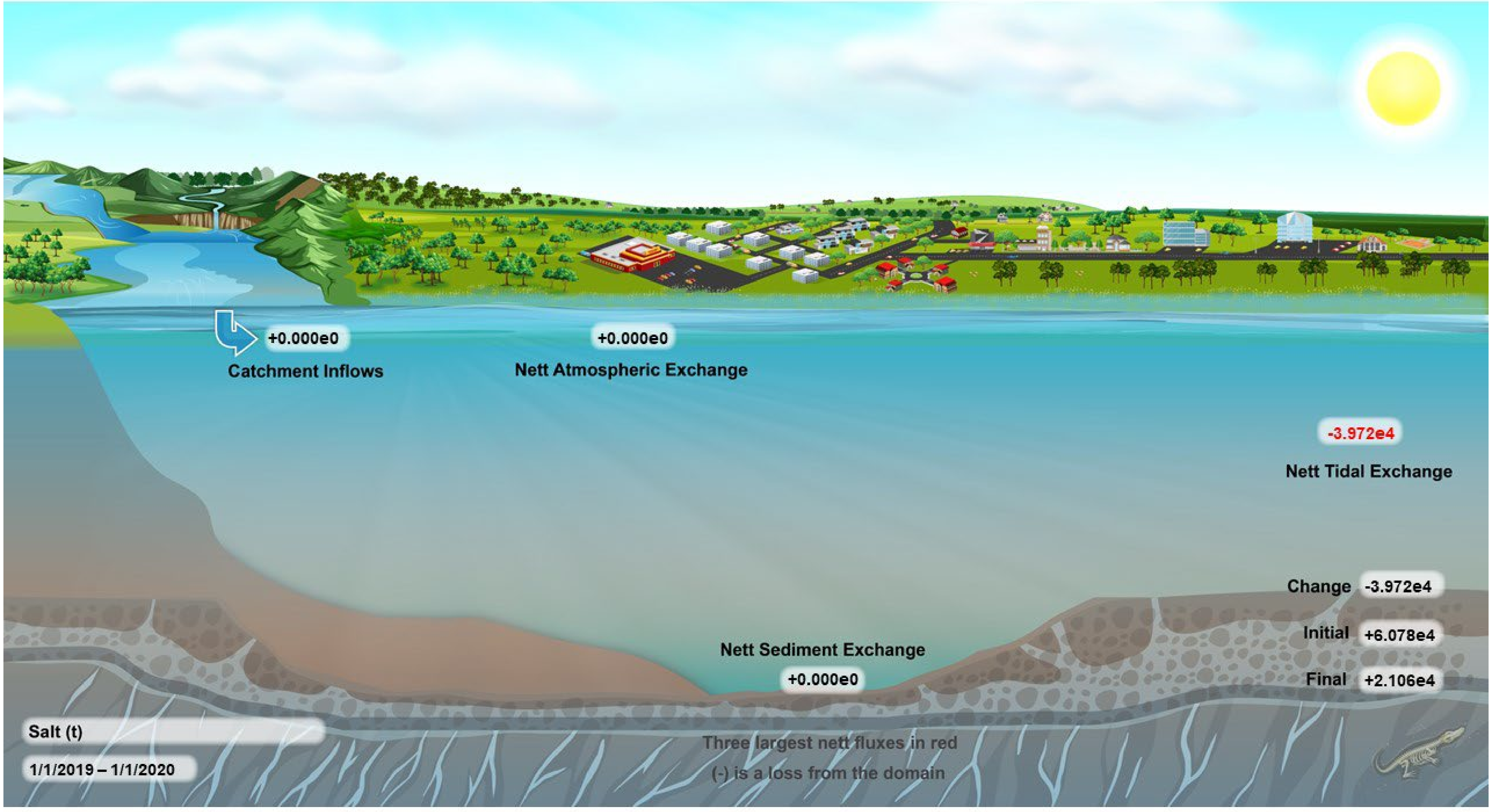

Figure 4.70 2019 Conceptual Diagram: Salt

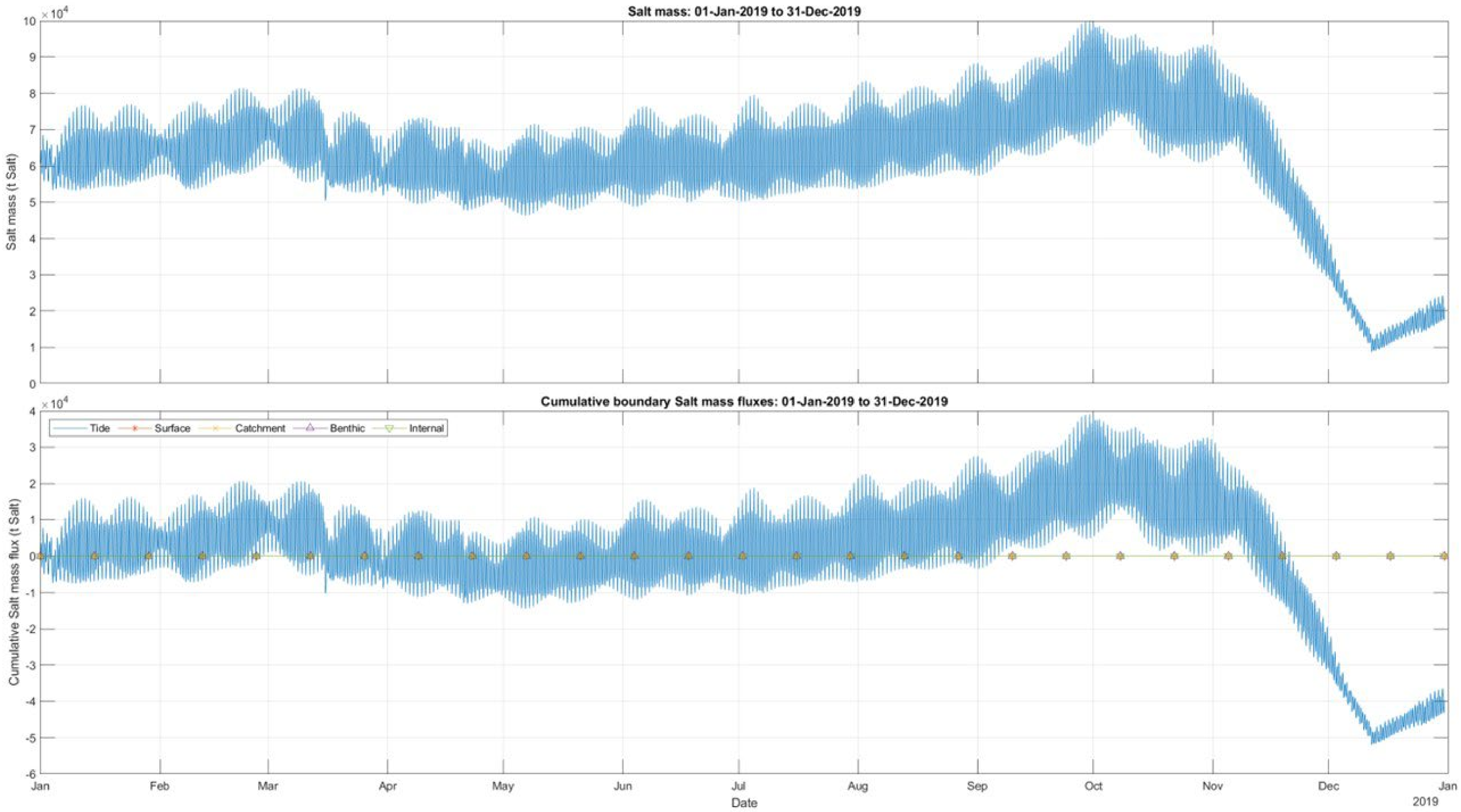

Figure 4.71 2019 Mass and Cumulative Flux Timeseries: Salt

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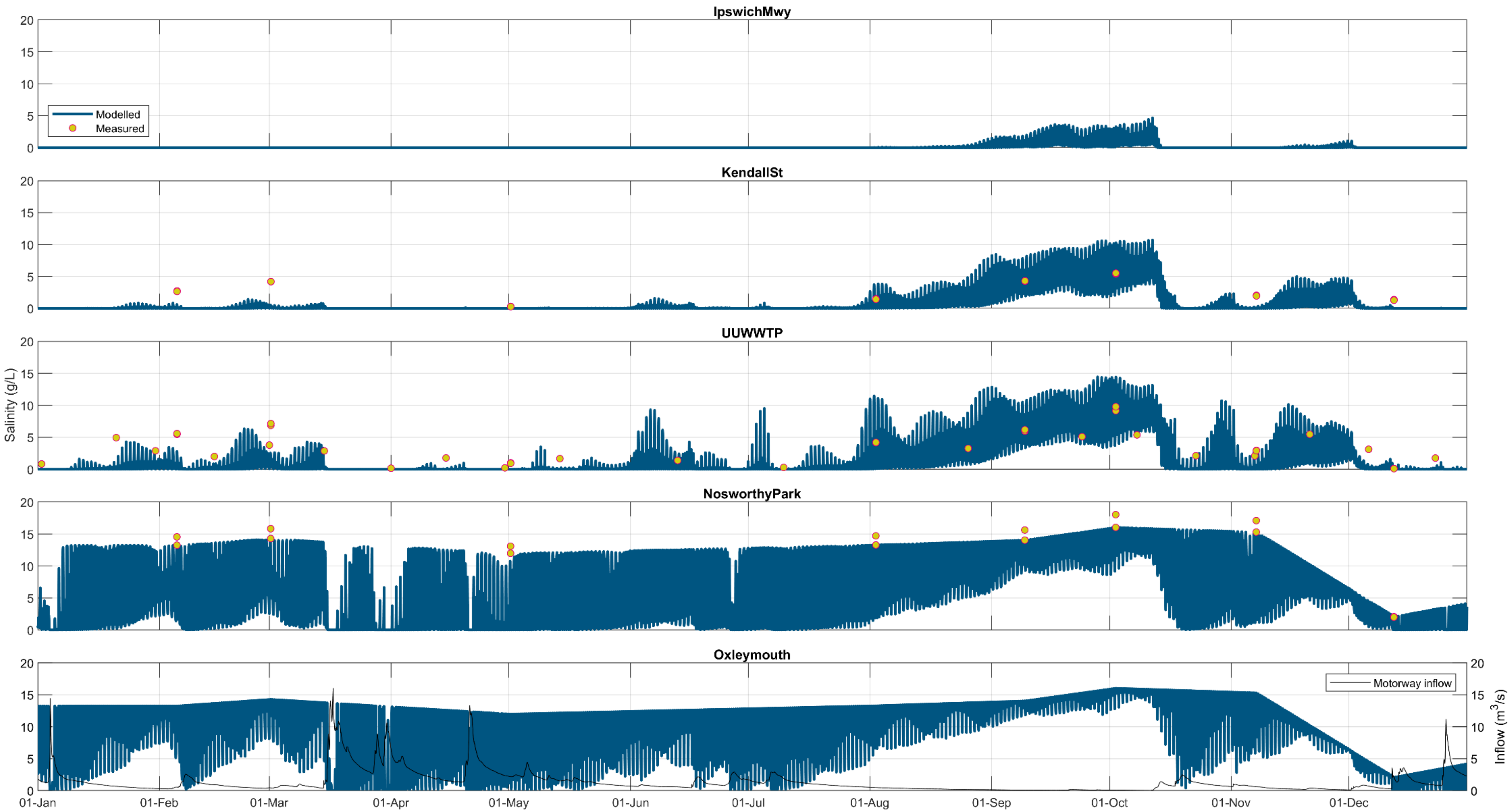

Figure 4.72 2019 Salinity Timeseries

Oxley Creek has a typical standing mass of salt of 60 to 70 thousand tonnes. During drier periods where catchment inflows are less (but not zero), this tonnage increases, and this is evidenced by the predicted salt mass increase from August to November. At around November, a drop in the downstream Brisbane River salinity (from an event outside the model domain) sees almost the entire standing load of salt leave Oxley Creek – this is evidenced by the negatively sloped tidal mass flux after November 2019 (Figure 4.71).

The above reflects the well-known processes that dictate the salt balance of any estuary. The only source of salt is the downstream boundary, and in this instance, its ingress from that boundary to Oxley Creek is supported by tidal pumping and retarded by the flushing action of opposing freshwater catchment inflows. This balance drives entirely the salinity profile along the creek, and in particular the recovery of salt back up the creek after a substantial freshwater flush. The TUFLOW FV model correctly predicts this recovery on several occasions throughout 2019 (Figure 4.72), most notably between August and November. This robust prediction of salinity by the TUFLOW FV model is a strong indicator that both the pumping and flushing processes are well simulated. Importantly, the flushing process is driven entirely by the catchment inflow boundaries applied to the model – in this instance they were the hydrologic predictions of TUFLOW HPC, delivered via TUFLOW Catch's automated and highly resolved catchment-receiving water linking process.

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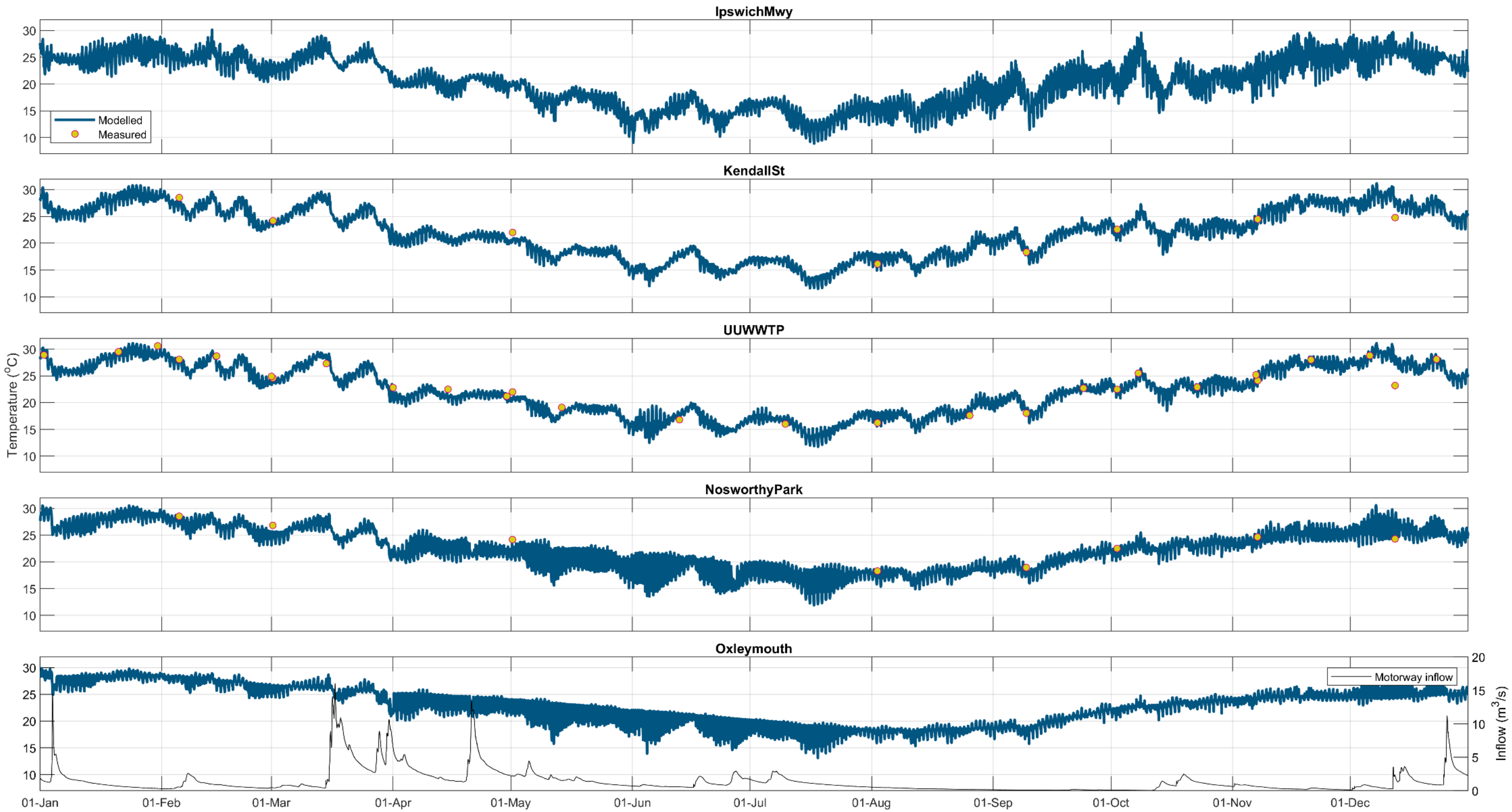

Figure 4.73 2019 Temperature Timeseries

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The temperature timeseries above show that TUFLOW FV accurately predicts water temperatures throughout the domain. It is worth noting that this result was achieved by use of an automated TUFLOW FV preprocessing tool that took less than half an hour to set up for Oxley Creek. Following execution (which could be left unattended for the time it took to download data, which varies with internet speed), the preprocessor produced meteorological boundaries in the format expected by TUFLOW FV. These boundaries were applied unchanged to the model to produce the simulation performance presented in Figure 4.73.

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Sediment Transport

A complete sediment transport calibration exercise would typically include consideration of multiple sediment fractions and the fate and transport of these through a model domain. Current data justifies simulation and assessment of only one sediment fraction (which is therefore the same as TSS). The comparisons that were possible included:

- Fluxes:
  - Conceptual diagram sediment mass fluxes
  - Cumulative sediment mass flux timeseries
- Timeseries
  - Total suspended sediment comparisons to spot (campaign) data at some sites

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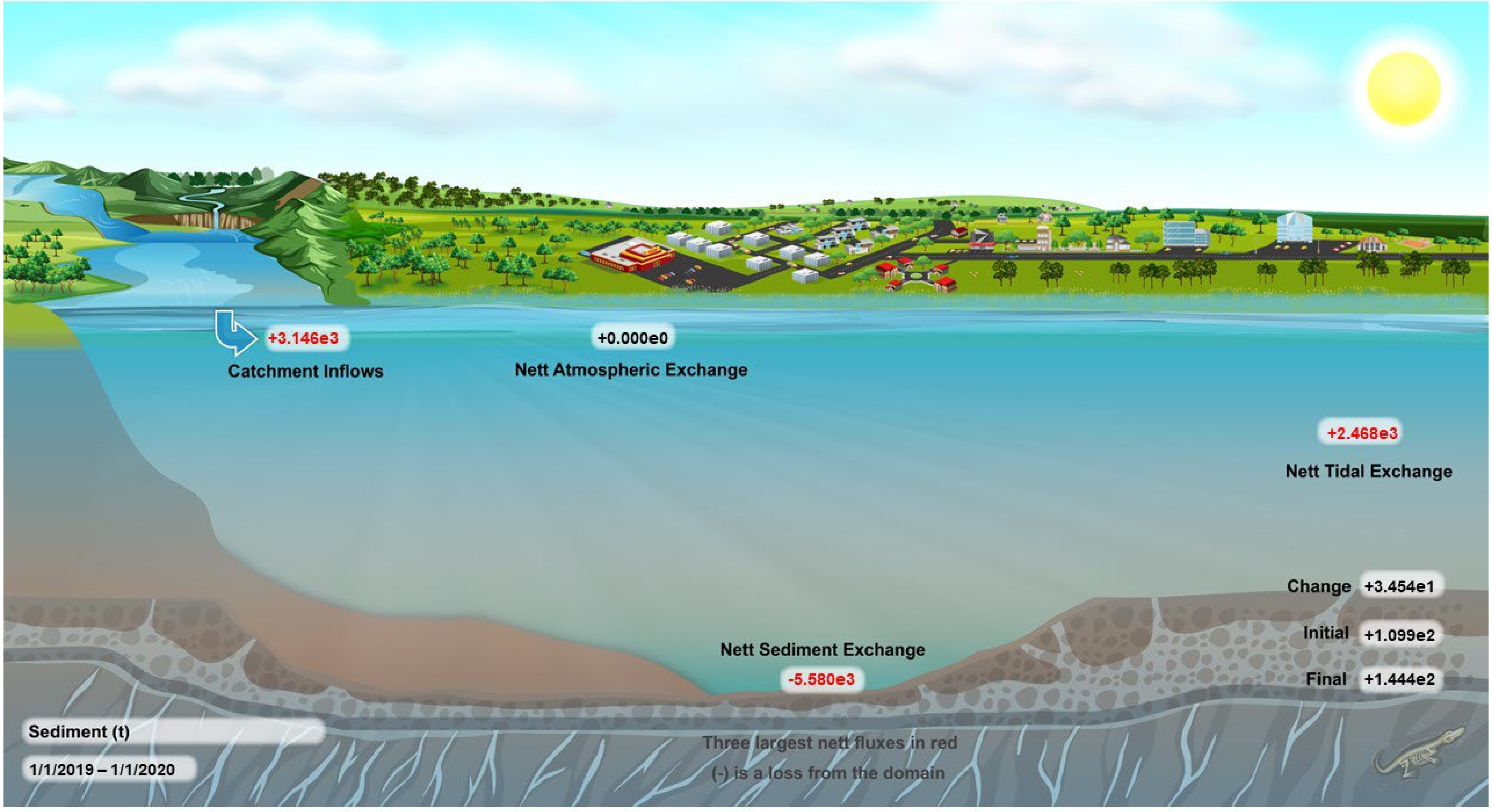

Figure 4.74 2019 Conceptual Diagram: Sediment

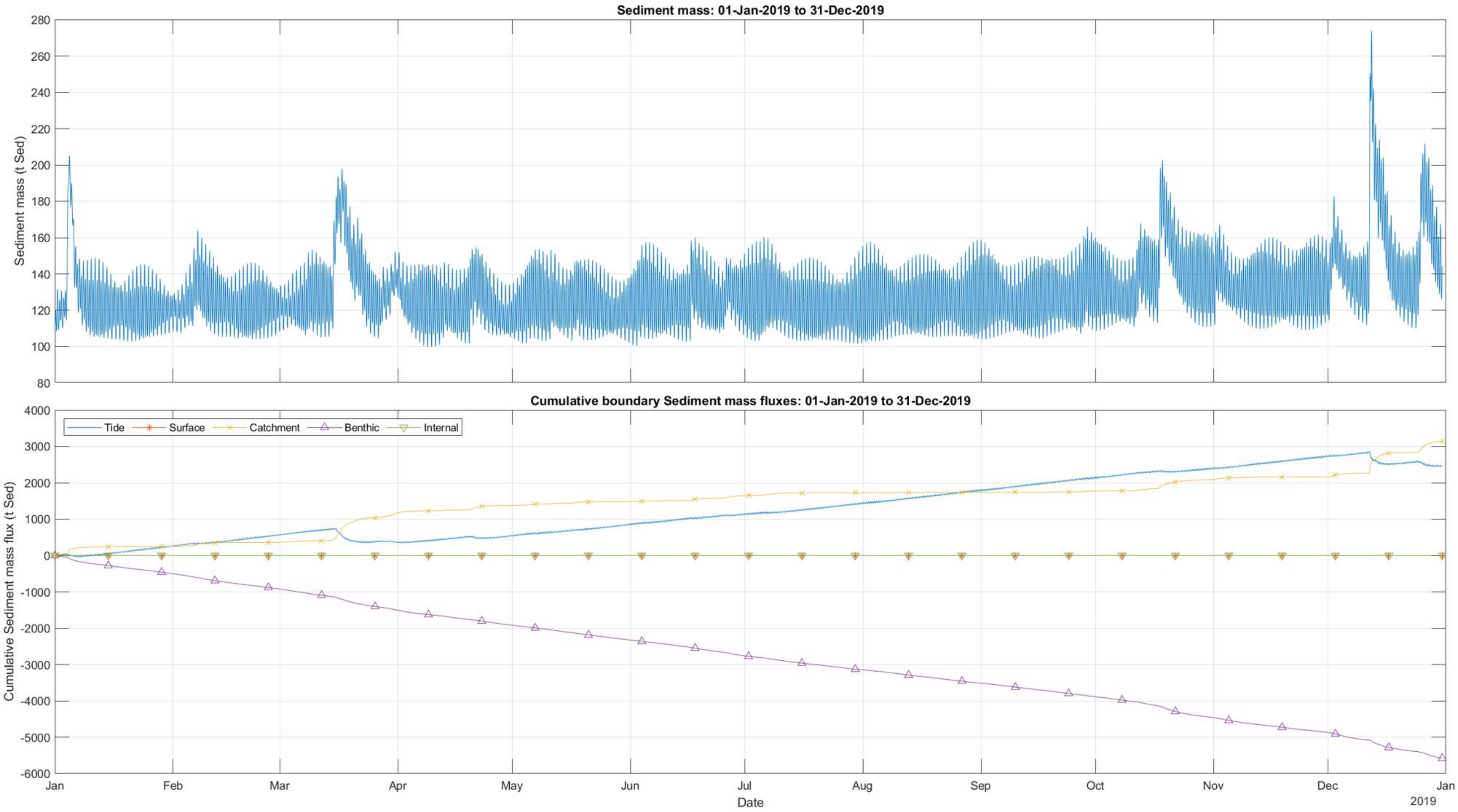

Figure 4.75 2019 Mass and Cumulative Flux Timeseries: Sediment

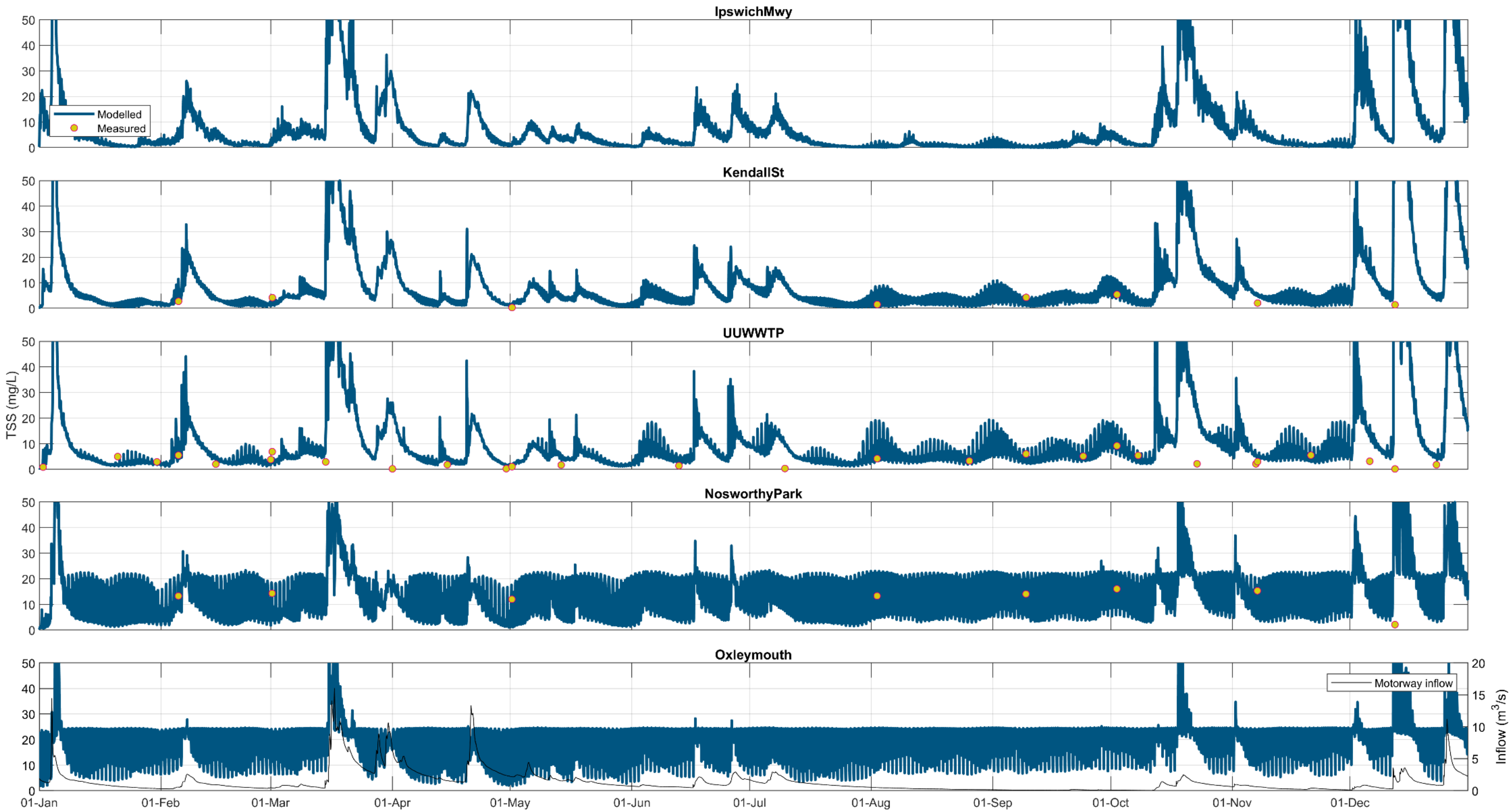

Figure 4.76 2019 Sediment Timeseries

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Figure 4.74 and Figure 4.75, which describe sediment mass fluxes, together demonstrate that the configuration of the Sediment Transport module in the Oxley Creek TUFLOW FV pilot model has the creek as a depositional environment that receives sediment almost equally from upstream (catchment inflows) and downstream (tidal boundary). Over the longer term, this sediment settles as a benthic loss from the system, although instantaneous fluxes are both to and from the bed, deposition outstrips resuspension.

Furthermore, the figures demonstrate that the standing mass of sediment in Oxley Creek is approximately 100 to 140 tonnes (Figure 4.75). Of interest, is that the total tonnage of sediment delivered from the catchment and tidal boundaries, and removed via settling is some 6,000 tonnes – 50 to 60 times the standing suspended sediment mass. This result resonates with the volumetric turnovers noted previously, which were in the order of 15 times per year. Both these insights point to Oxley Creek feeling the influence of its boundaries, and even its catchment boundaries in a relatively dry year.

This system understanding is not obvious from consideration of the suspended sediment timeseries presented in Figure 4.76 alone, although the model predictions generally compare well with spot measurements. The question then arises as to whether the additional mass flux information available to the modeller would warrant a reconfiguration of the ST module parameterisation, regardless of the goodness-of-fit of the timeseries predictions to spot measurements (determined by some statistical metric). Specifically, is the prediction of Oxley Creek as a depositional environment (at least over the relatively dry 2019 year) correct in the expert view of stakeholders? Regardless of the answer to this question, the information now available through exploitation of model diagnostic and flux outputs supports these significantly more meaningful conversations.

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Water Quality

A complete water quality calibration exercise would typically include consideration of all simulated constituents. This is possible in the current study in terms of presenting dissolved oxygen, total nitrogen, total phosphorus, and total chlorophyll a mass fluxes and timeseries in the form described above:

In addition to the above, further diagnostic outputs are available with the TUFLOW FV WQ Module. These are phytoplankton related diagnostics and are timeseries that describe the evolution of the following:

- The limitation on phytoplankton primary productivity due to the key drivers of temperature, nitrogen and phosphorus. These limitation diagnostics are all single valued outputs (at each TUFLOW FV cell and timestep, for each of the above) that vary between 0.0 and 1.0 (other than temperature, for which the limitation diagnostic can exceed 1.0). These values reflect the constraint on primary productivity in space and time for each limiter, with a value of 0.0 meaning complete constraint, and a value of 1.0 meaning no constraint. For example, if, at a particular time and location, the nitrogen limitation diagnostic had a value of 0.05 and the temperature limiter had a value of 0.8, then nitrogen scarcity is (much) more strongly limiting phytoplankton productivity than temperature. These limitation diagnostics are presented as timeseries at each monitoring location, in the same multi-panelled figure as the chlorophyll a concentration timeseries
- Ambient temperatures superimposed on the temperature limitation function. These are the actual water temperatures predicted by TUFLOW FV, plotted on top of the user defined temperature limitation function. The limitation function is the same at each of the five sites considered (and for the entire model), but the ranges of ambient temperatures computed by TUFLOW vary across sites. Plotting these actual temperatures on top of the limitation function provides an indication as to how the simulated phytoplankton group is evolving with respect to temperature
- The mass fluxes of phytoplanktonic chlorophyll a that result from:
  - Primary productivity
  - Respiration
  - Excretion
  - Mortality
  - Sedimentation

  Again, these flux timeseries support elucidation of the magnitude and balance of growth and loss processes occurring within a given phytoplankton group – such elucidation is not possible by considering chlorophyll a concentration timeseries alone. These phytoplanktonic mass flux diagnostics are presented as timeseries at each monitoring location, in the same multi-panelled figure as the chlorophyll a concentration timeseries.

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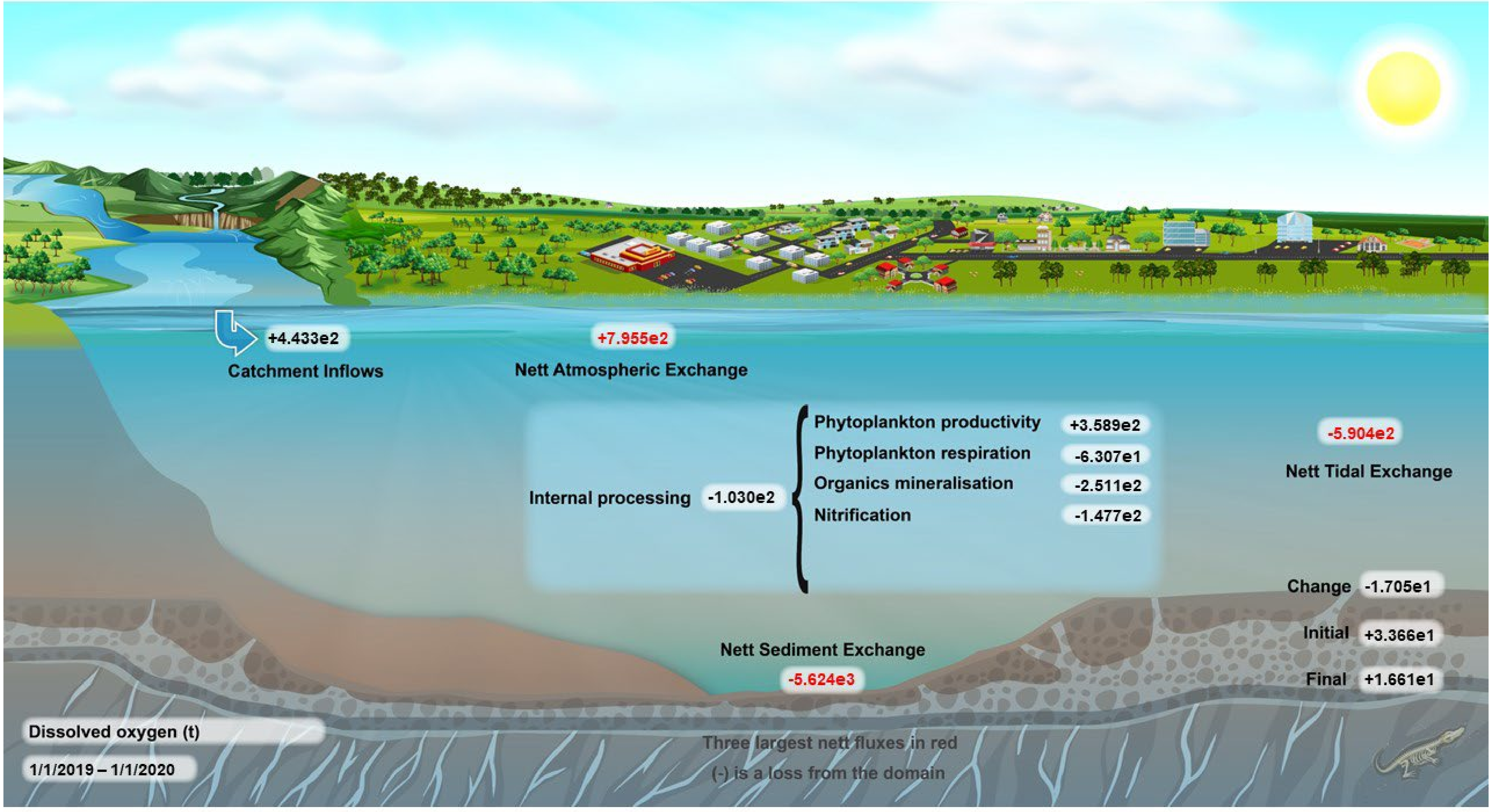

Figure 4.77 2019 Conceptual Diagram: Dissolved Oxygen

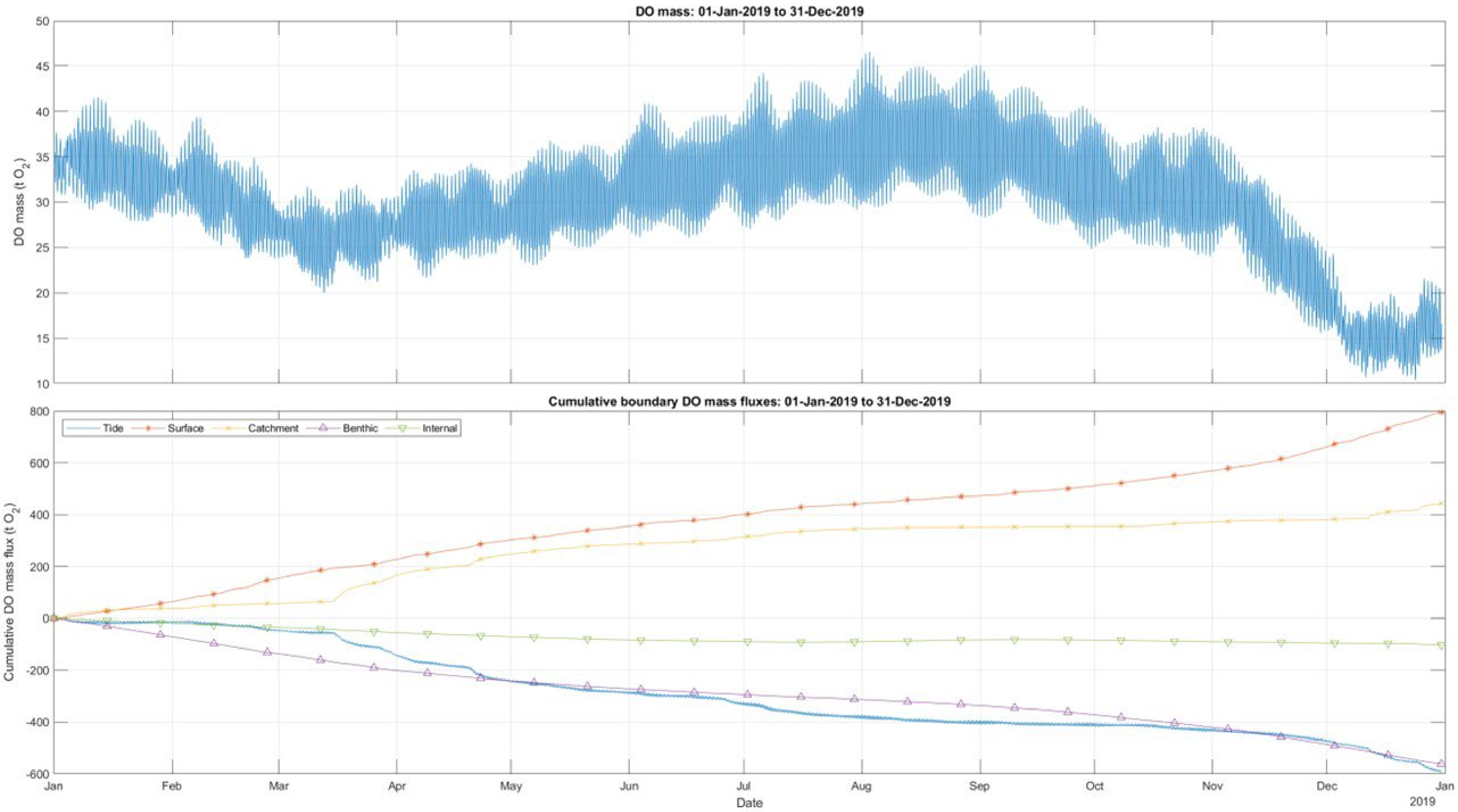

Figure 4.78 2019 Mass and Cumulative Flux Timeseries: Dissolved Oxygen

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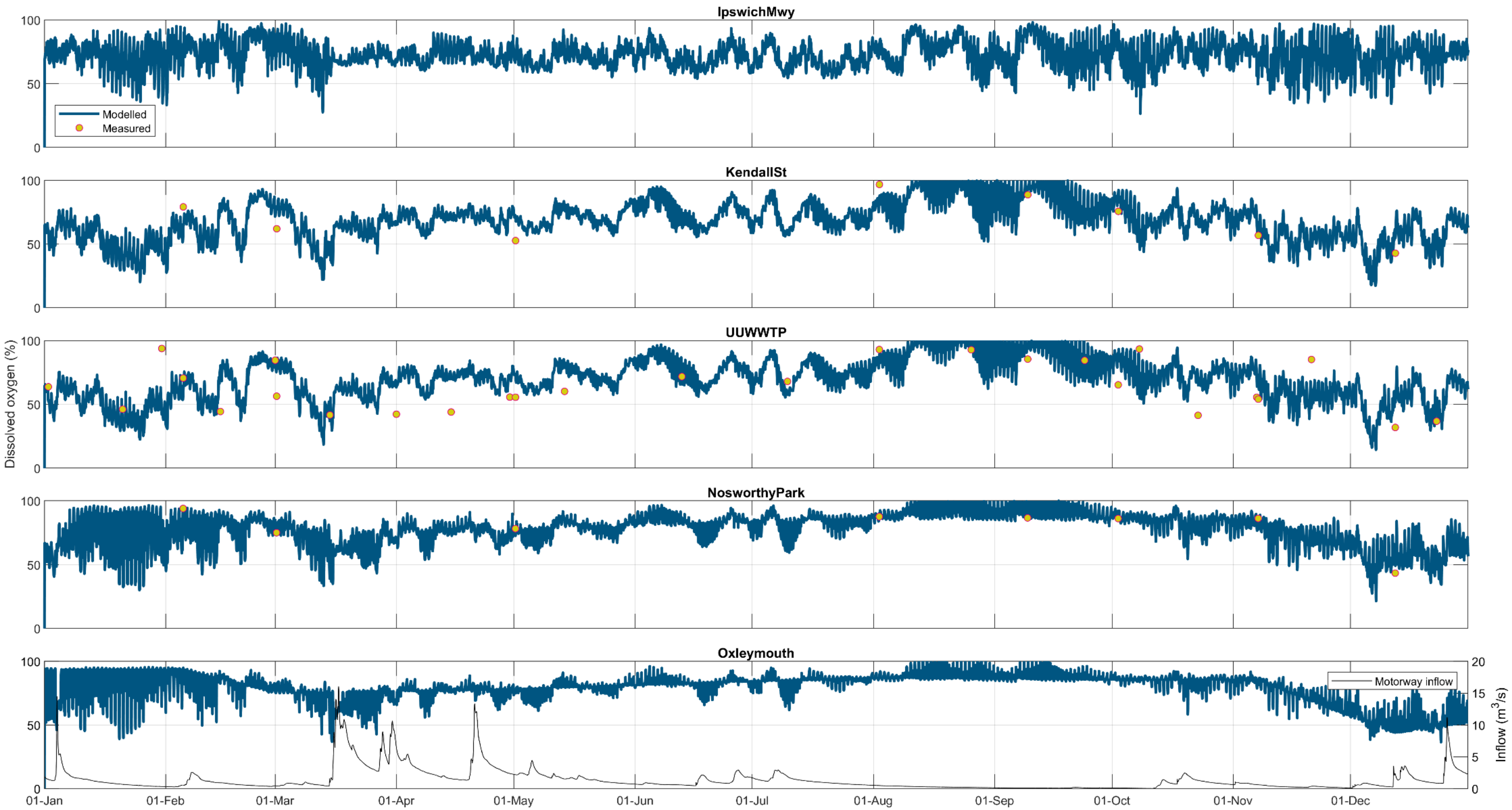

Figure 4.79 2019 Dissolved Oxygen (mg/L) Timeseries

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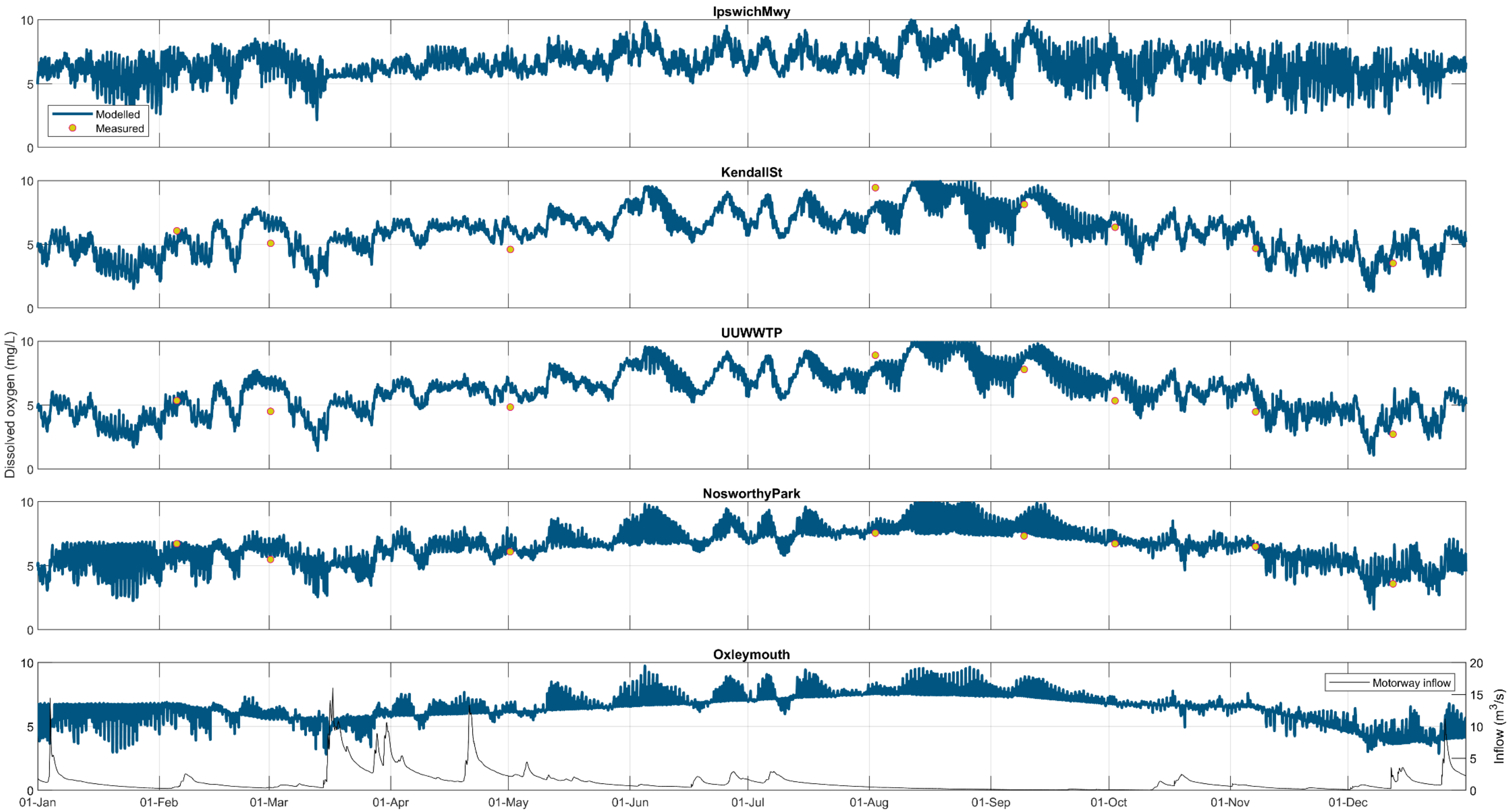

Figure 4.80 2019 Dissolved Oxygen (% Saturation) Timeseries

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Figure 4.77 and Figure 4.78 reveal that the dissolved oxygen mass balance in the Oxley Creek TUFLOW FV model has the dominant influxes of surface aeration and catchment inflows being offset by a combination of sediment consumption and tidal egress. A second order mass flux is the nett loss of dissolved oxygen through mineralisation of organics, nitrification and phytoplankton respiration, which are offset partially by oxygen production due to primary productivity. Of note is that the latter flux (productivity) is of the same order of magnitude as catchment inflow oxygen delivery and about 50% of the oxygen flux due to reaeration. This points to it being an important process to capture well.

The standing mass of dissolved oxygen in Oxley Creek is approximately 40 tonnes, and yet the magnitude of summed influxes and summed losses of oxygen total approximately 1,000 tonnes each. Again, this points to a system that is rapidly exchanging oxygen with its boundaries, and recycling oxygen through its internal processes, to a similar extent that the mass fluxes of sediment and volume found – turnover of the standing oxygen mass occurred approximately 25 times in 2019. Such oxygen turnover might well be characteristic of a highly organic and modified system such as Oxley Creek.

It is not possible to gain such a system understanding from examination of timeseries concentrations and spot measurements alone – this analysis has shown that these concentrations are the result of the action of a number of fluxes, and that these fluxes turn over the standing oxygen mass repeatedly.

Notwithstanding the above, the TUFLOW FV model does predict well the dissolved oxygen concentrations and percent saturations measured in the creek, other than perhaps a short period during April 2019 when an inflow event was occurring. But this may well be of secondary importance to engaging stakeholders in a discussion as to the model's predictive power in accurately reflecting the expected relative magnitudes of dissolved oxygen mass flux pathways in Oxley Creek.

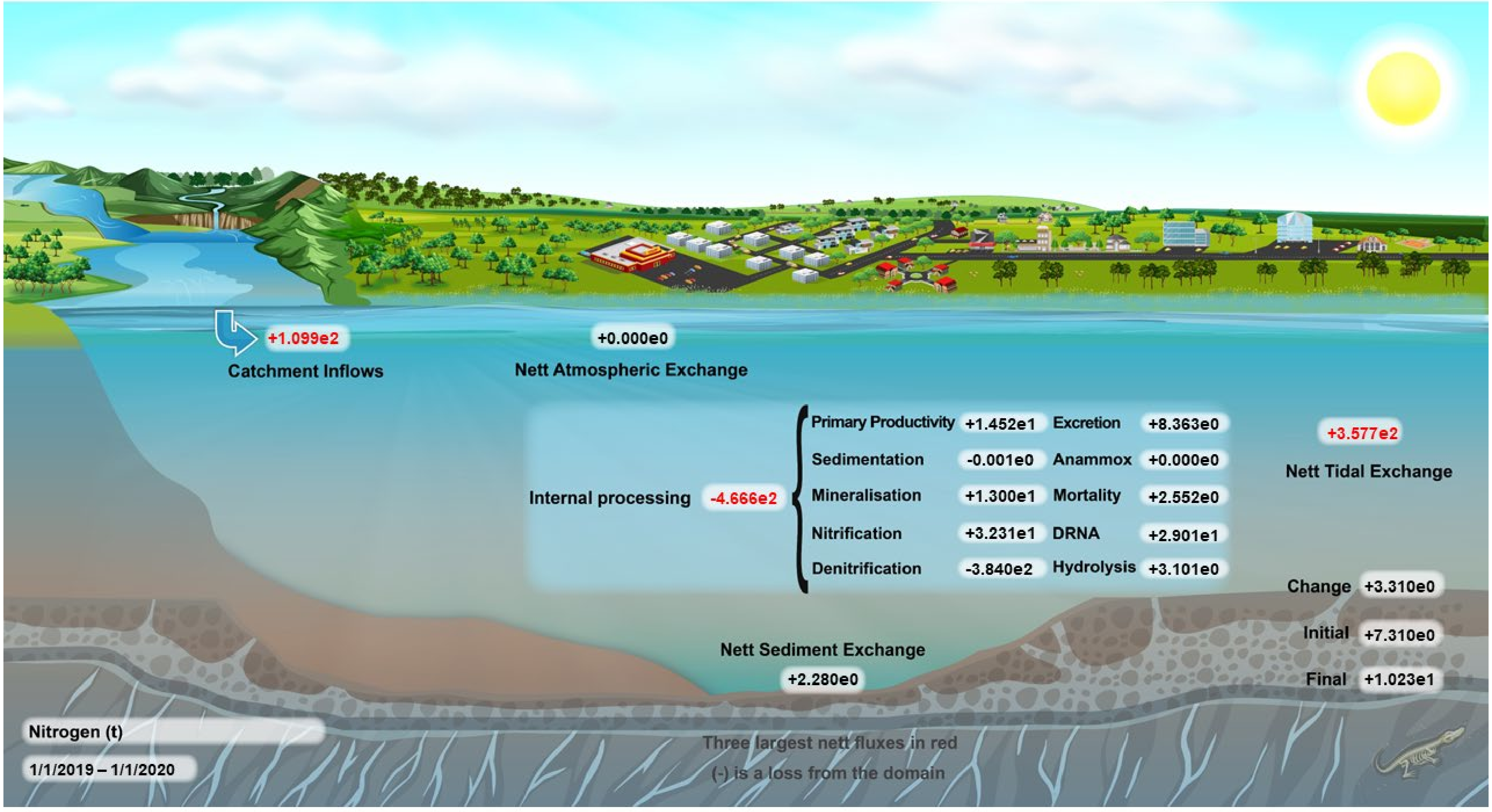

Figure 4.81 2019 Conceptual Diagram: Total Nitrogen

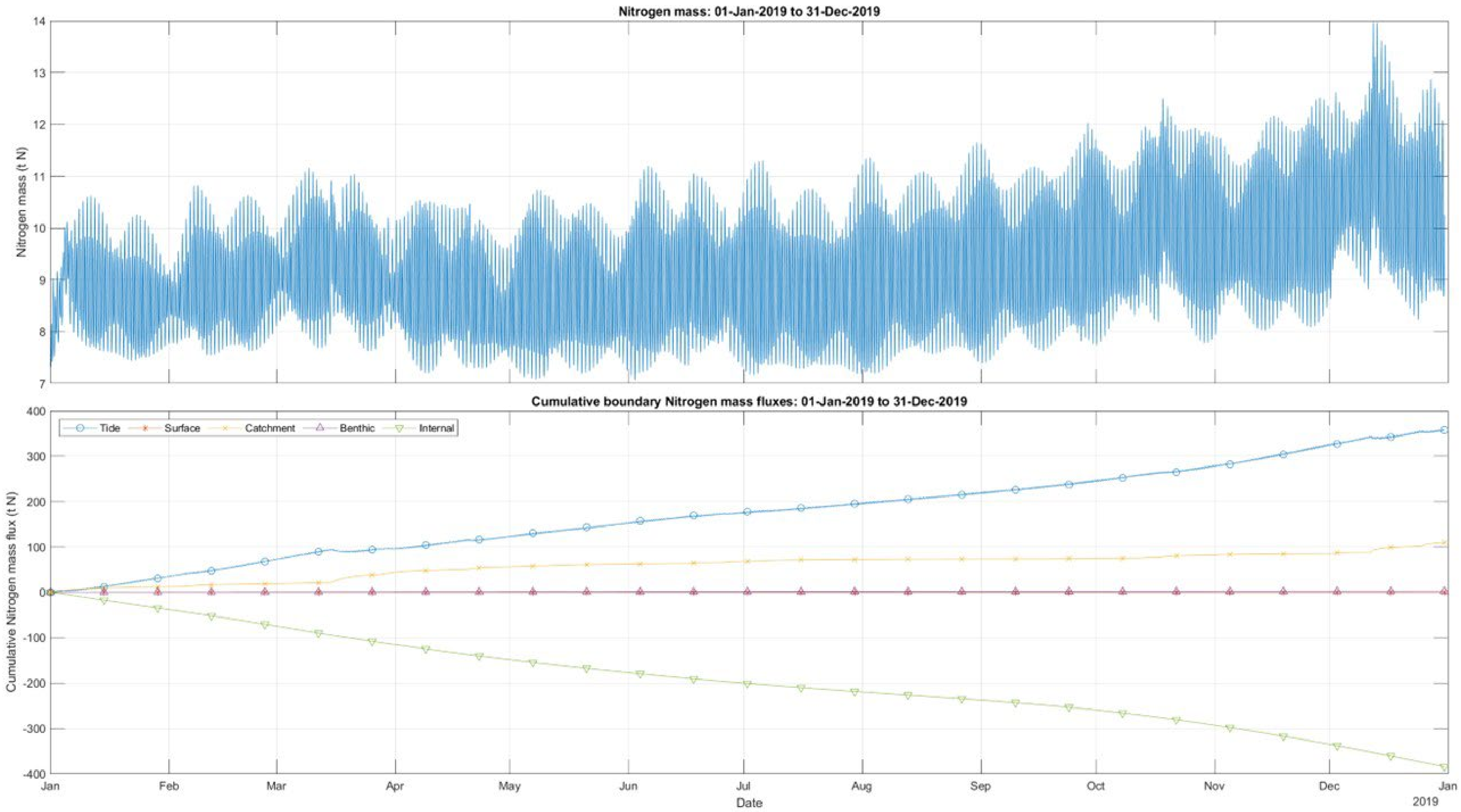

Figure 4.82 2019 Mass and Cumulative Flux Timeseries: Total Nitrogen

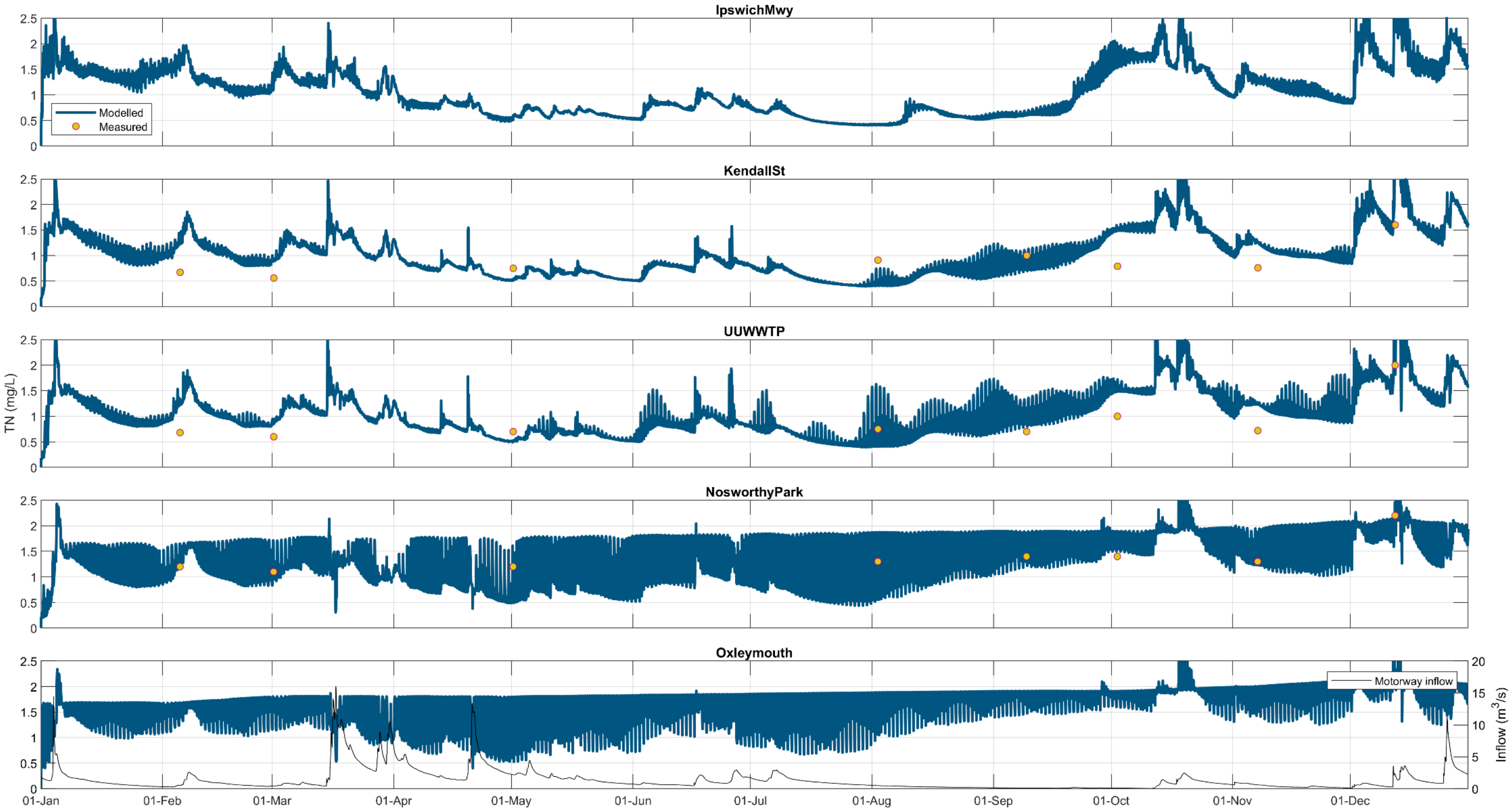

Figure 4.83 2019 Total Nitrogen Timeseries

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It is noted that the list of internal fluxes in Figure 4.81 cannot be summed to give the nett internal flux, as presented. This is because several of the fluxes included in the conceptual diagram's internal flux breakdown are from one form of nitrogen to another (e.g. primary productivity or nitrification), so do not represent a nett flux of total nitrogen. The nett flux of total nitrogen shown (-4.666e2 tonnes) is correct and is a net loss of total nitrogen due to internal processing.

The mass balance for nitrogen has different primary mass flux pathways to the quantities previously considered. Notwithstanding that nitrogen is the most complex of all simulated quantities (see Figure 3.16 in the TUFLOW FV WQ Manual, for example), Figure 4.81 and Figure 4.82 reveal that the dominant influxes of nitrogen are from the catchments and tides, and that this is offset primarily by denitrification, which is the reduction of nitrate to free nitrogen gas as a result of biological oxygen stripping. Such stripping is typical of environments that are highly organic and/or biologically active. Given the previous observation that the standing dissolved oxygen mass in Oxley Creek is rapidly turned over, it may accord with expectation that biological activity seeks alternative oxygen sources such as nitrate.

Related to this, Figure 4.81 and Figure 4.82 show that the magnitude of the positive and negative nitrogen mass fluxes are again 30 to 40 times the standing mass of nitrogen in Oxley Creek. This is consistent with previous observations and reflects a dynamic and evolving system. The question again arises as to whether this an accurate reflection of the expected flux pathways in Oxley Creek. It may, or it may not be, but these fluxes provide an accessible point of contact and engagement for wider discussions of model performance.

As an aside, Figure 4.83 shows that the TUFLOW FV model represents reasonably well the total nitrogen concentrations in Oxley Creek, and this could be assessed using some form of goodness-of-fit metric. It might be best undertaken once the relative magnitudes of the nitrogen flux pathways predicted by the model within Oxley Creek are settled.

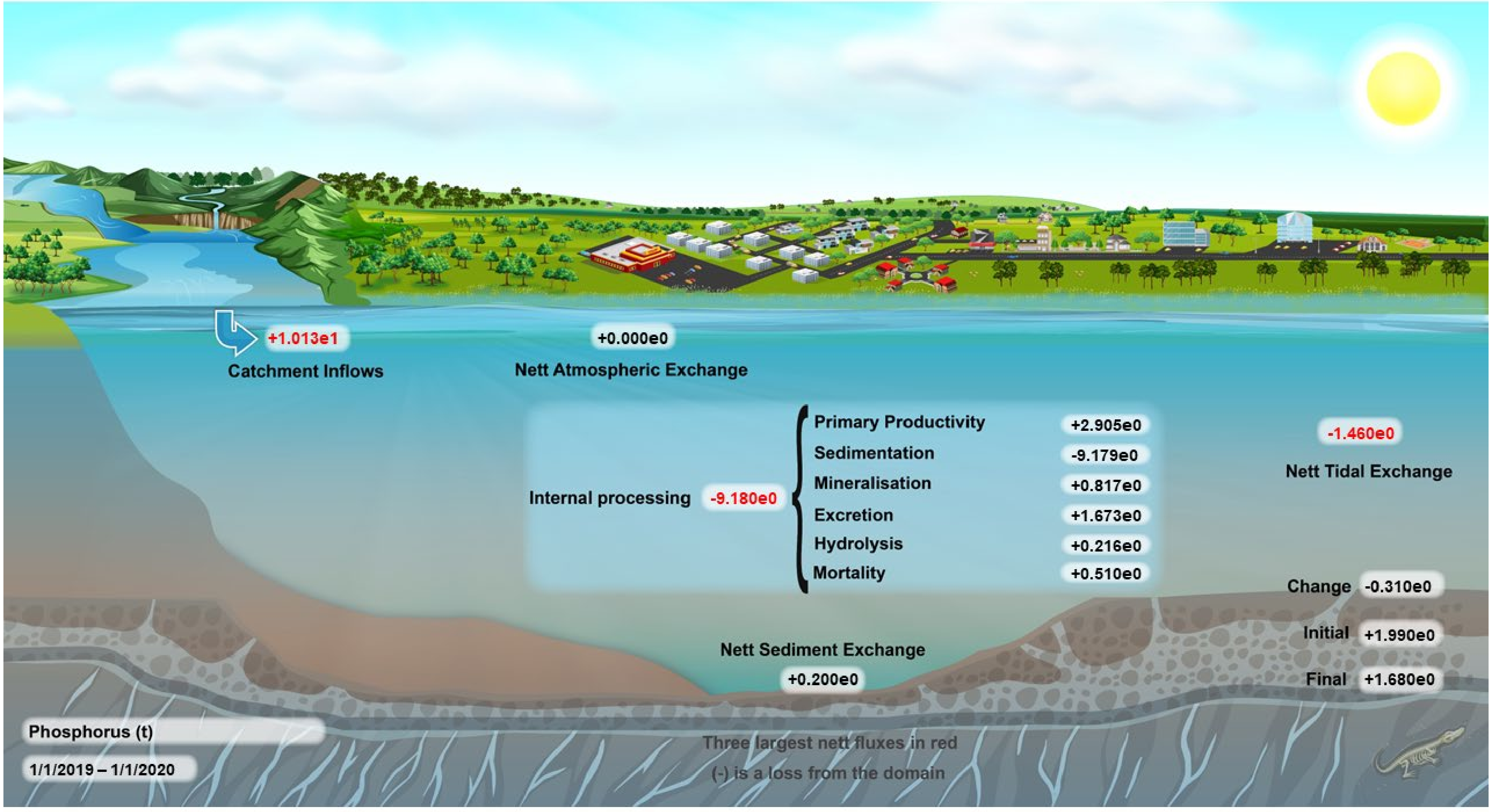

Figure 4.84 2019 Conceptual Diagram: Total Phosphorus

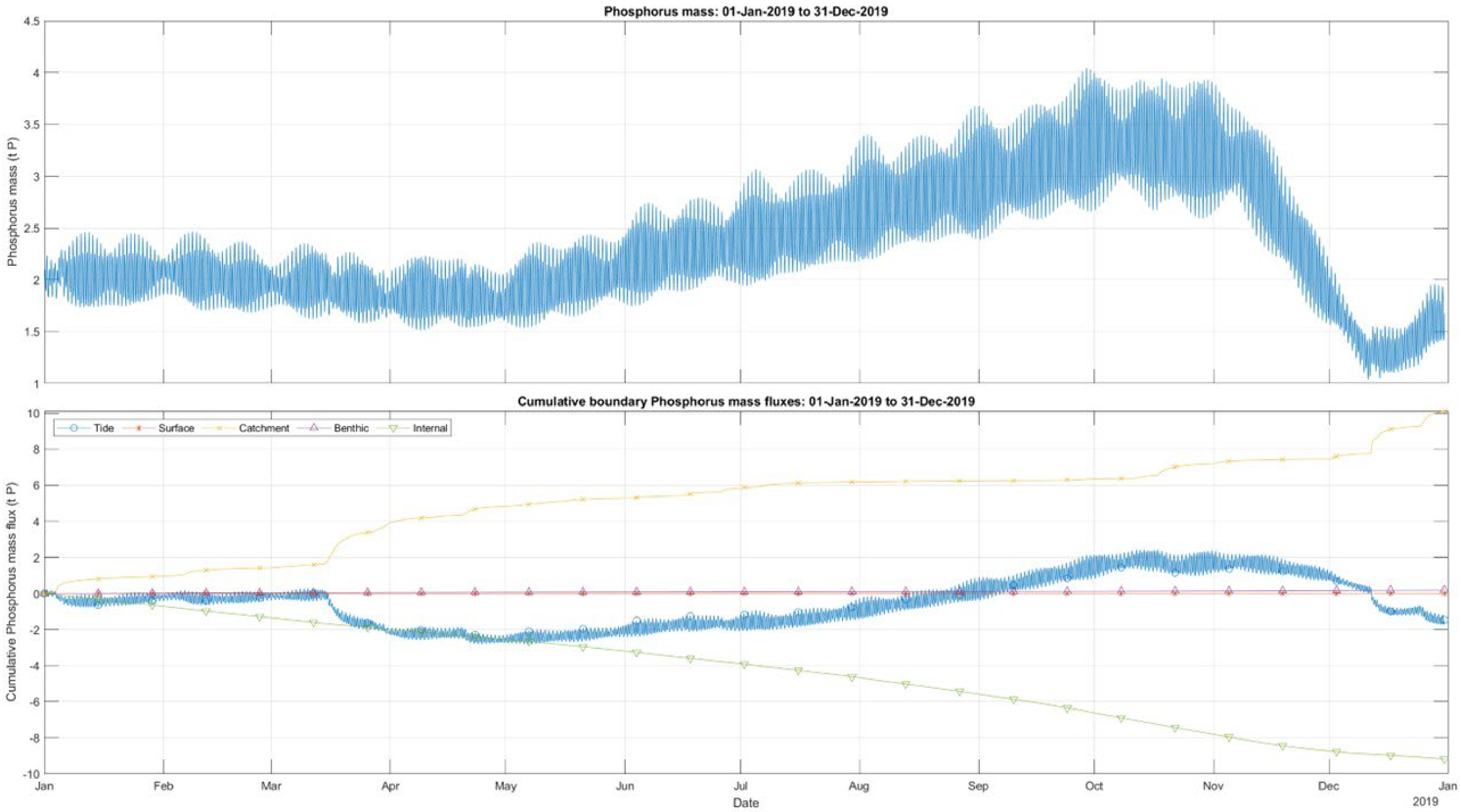

Figure 4.85 2019 Mass and Cumulative Flux Timeseries: Total Phosphorus

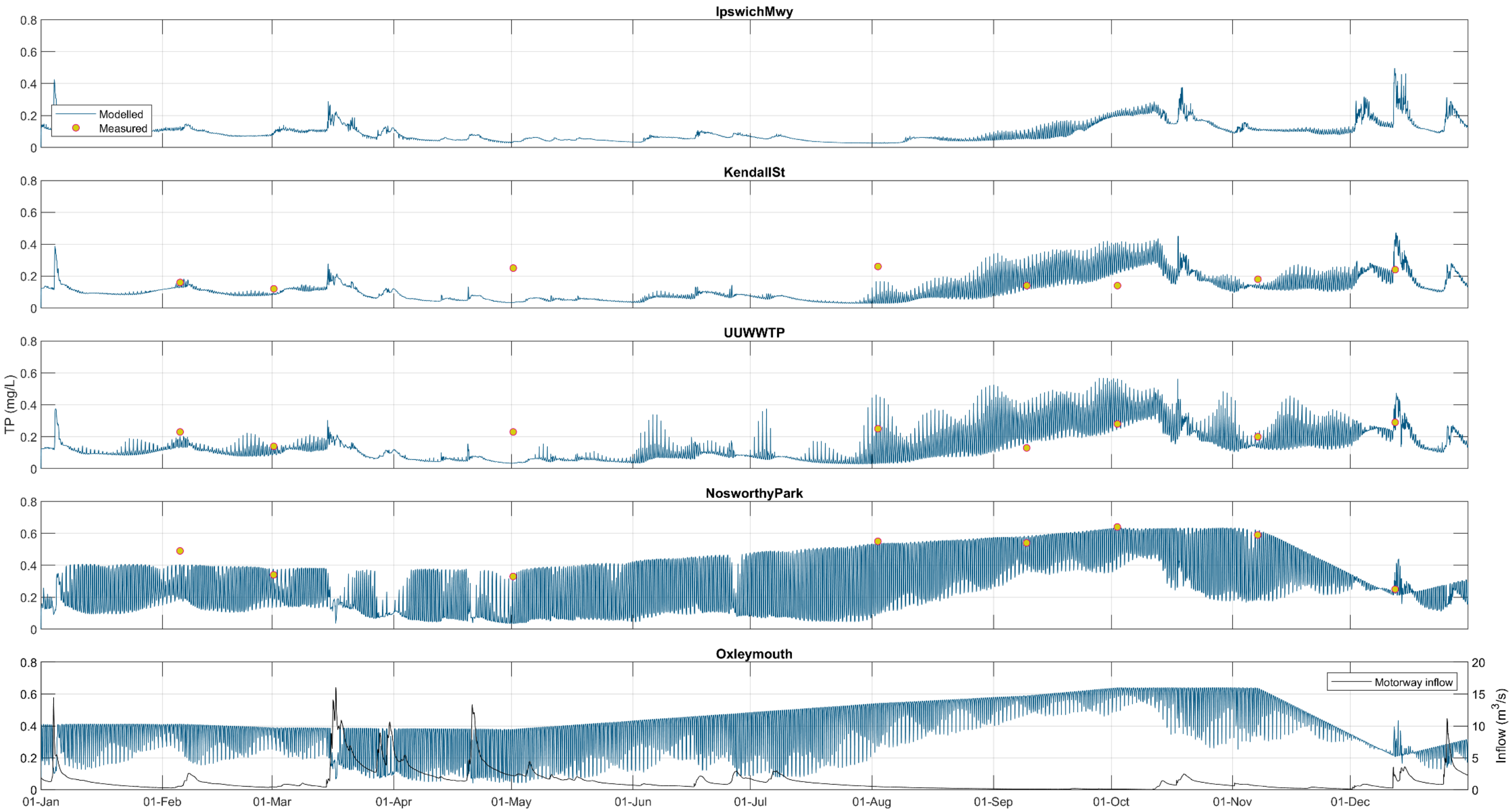

Figure 4.86 2019 Total Phosphorus Timeseries

It is noted that the list of internal fluxes in Figure 4.84 cannot be summed to give the nett internal flux, as presented. This is because several of the fluxes included in the conceptual diagram's internal flux breakdown are from one form of phosphorus to another (e.g. primary productivity), so do not represent a nett flux of total phosphorus. The nett flux of total phosphorus shown (-9.180e0 tonnes) is correct and is a net loss of total phosphorus due to internal processing.

The suite of figures for total phosphorus reveals a mass balance that is dominated by catchment inflows over the course of 2019. This does point to the need to accurately simulate these catchment loads. Although this pollutant load is offset by tidal egress of phosphorus, the dominant loss is sedimentation of FRP that is attached to sediment. This is entirely consistent with the previous finding regarding suspended sediment flux pathways: Oxley Creek acts as a sink for sediment and its attached FRP, at least in 2019.

Notwithstanding this, the cumulative mass flux of phosphorus from the tidal boundary oscillates about zero but does take on a positive gradient around August 2019 (Figure 4.85), which lasts until November. This positive gradient indicates a nett accumulated influx of phosphorus over this period. This accords well with the observed salinity influx discussed previously: over this period, catchment flows predicted by TUFLOW HPC are low (but not zero) and as such they allow ingress of the signature of the tidal boundary (as salt or phosphorus) to Oxley Creek. This suggests that not only is the balance of inflows and tidal pumping important for salinity prediction, but it is also important for correctly simulating phosphorus mass fluxes.

Once again, the standing mass of phosphorus in Oxley Creek is approximately 5-fold less than the magnitude of the mass fluxes applied to the system over the course of a year. This is consistent with previous observations.

As with nitrogen, the TUFLOW FV model represents the total phosphorus concentrations in Oxley Creek, and this could be assessed using some form of goodness-of-fit metric. It might be best undertaken once the relative magnitudes of the phosphorus flux pathways predicted by the model within Oxley Creek are decided.

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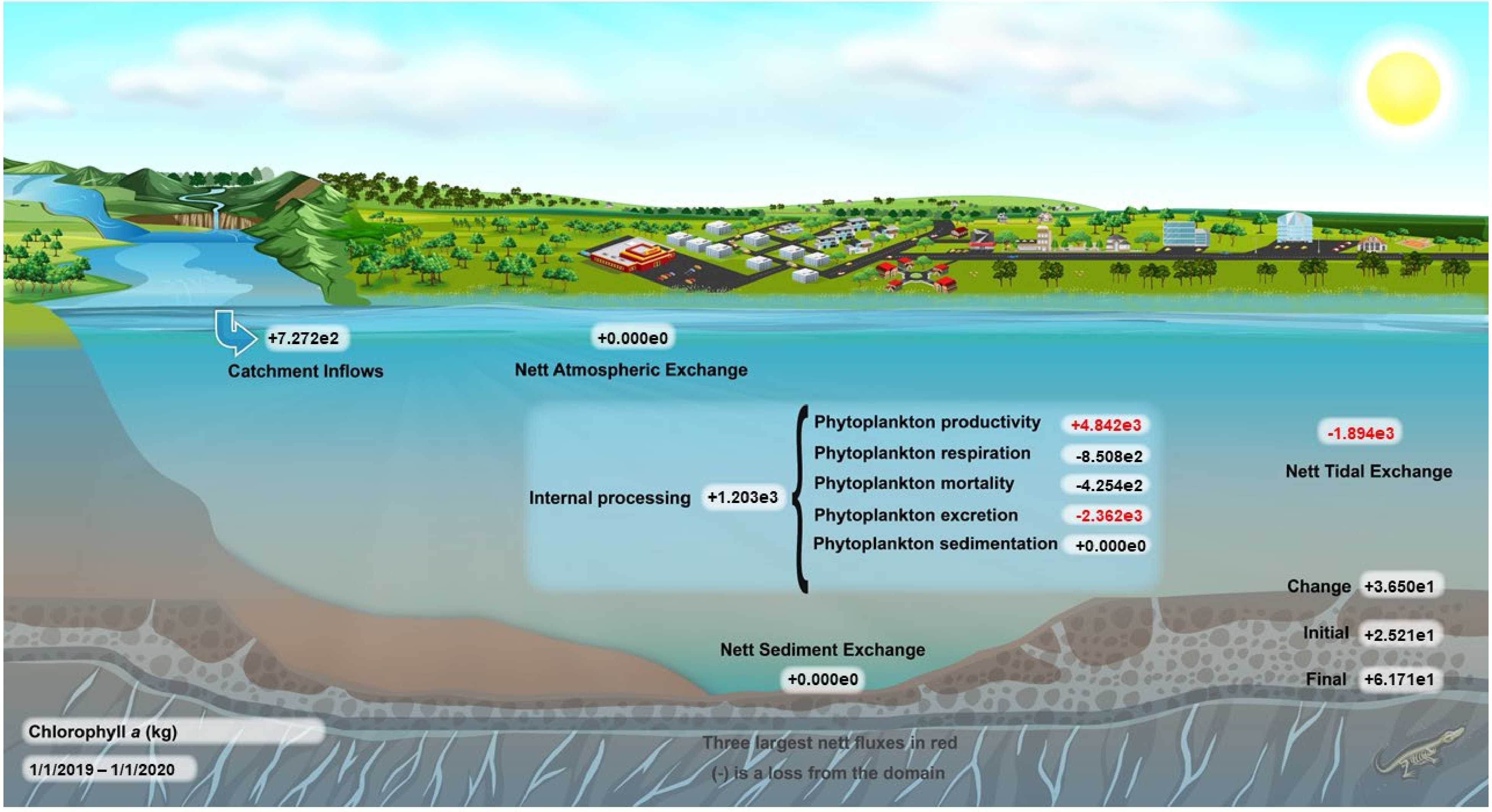

Figure 4.87 2019 Conceptual Diagram: Total Chlorophyll *a*

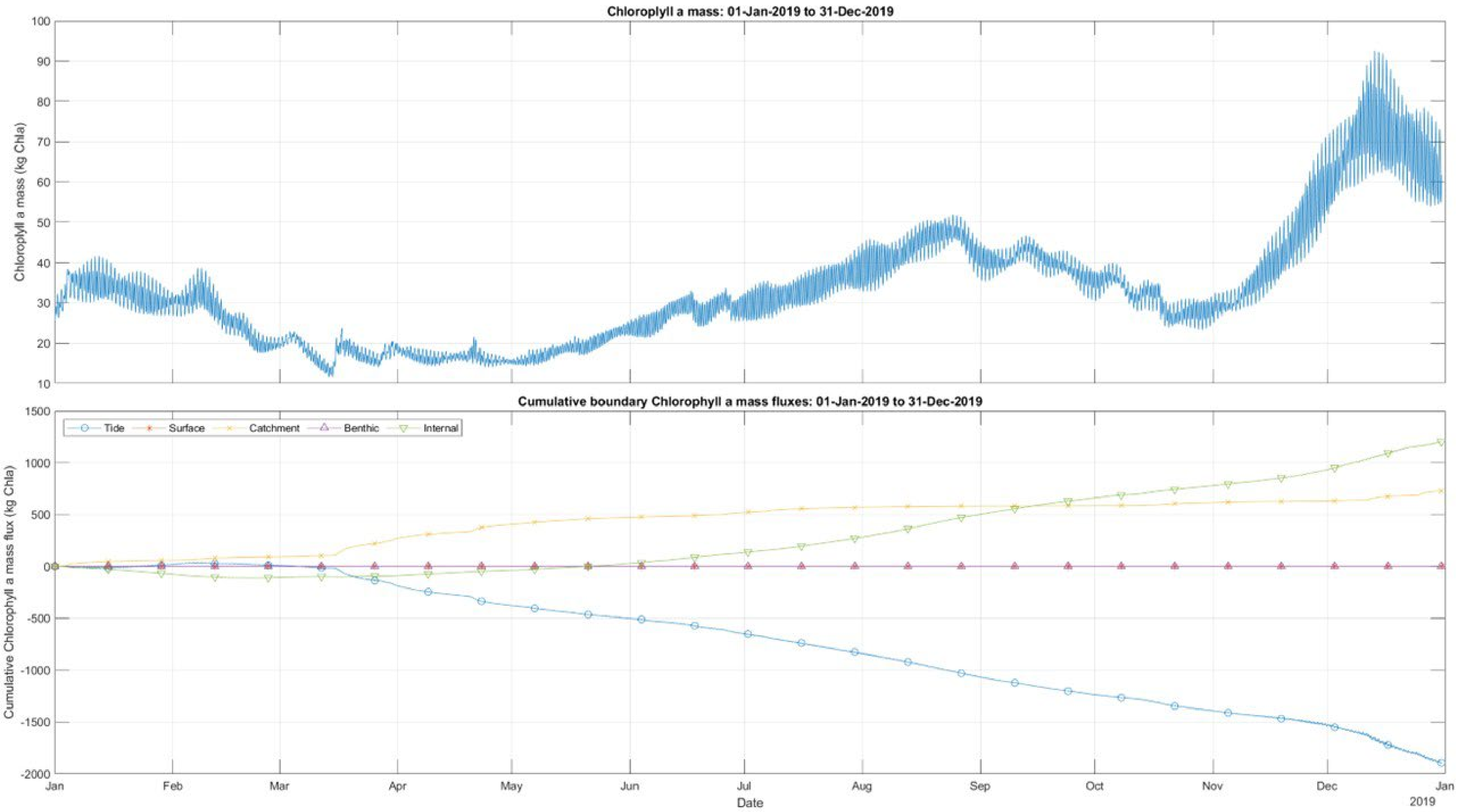

Figure 4.88 2019 Mass and Cumulative Flux Timeseries: Total Chlorophyll *a*

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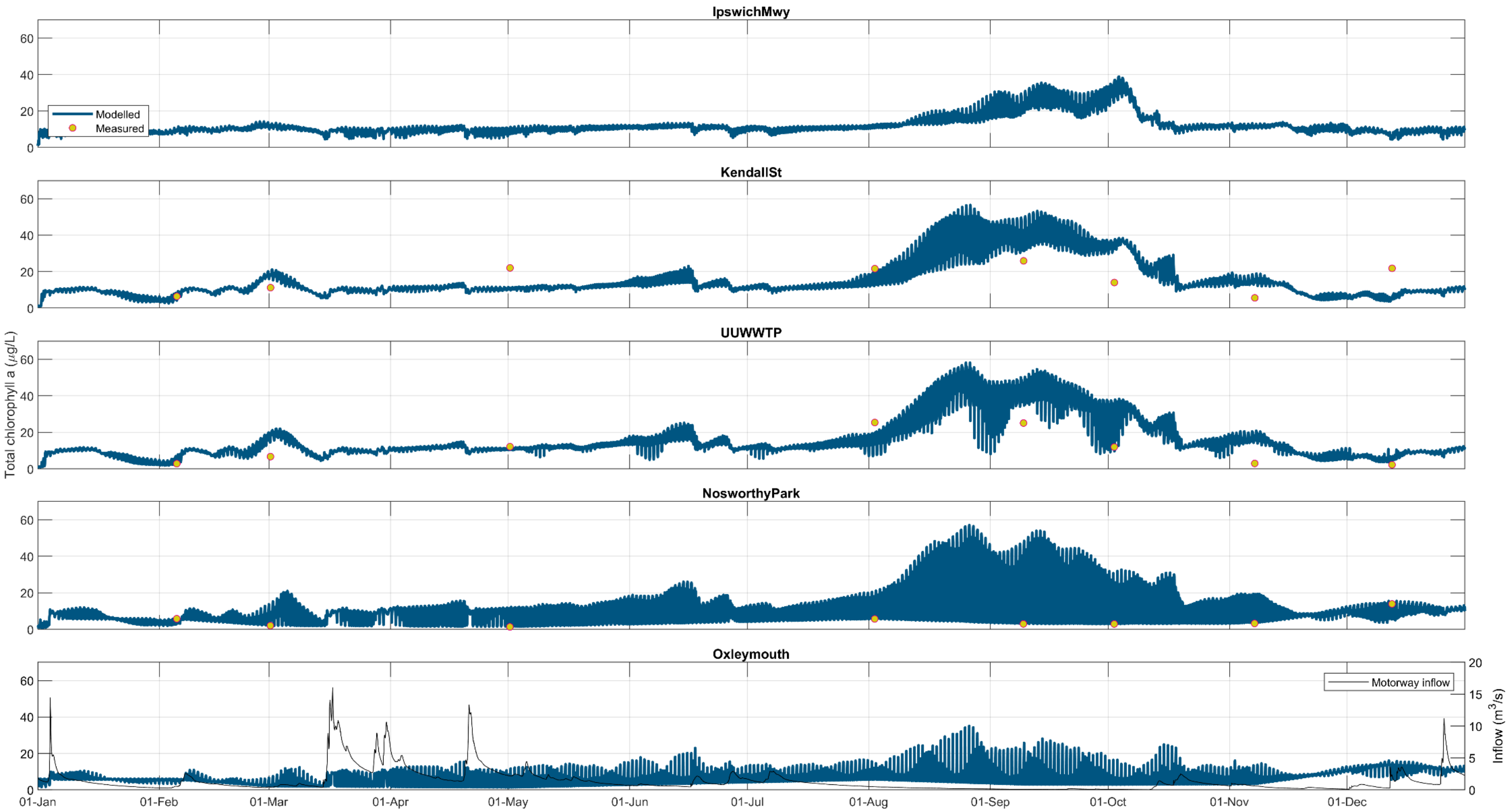

Figure 4.89 2019 Total Chlorophyll *a* Timeseries

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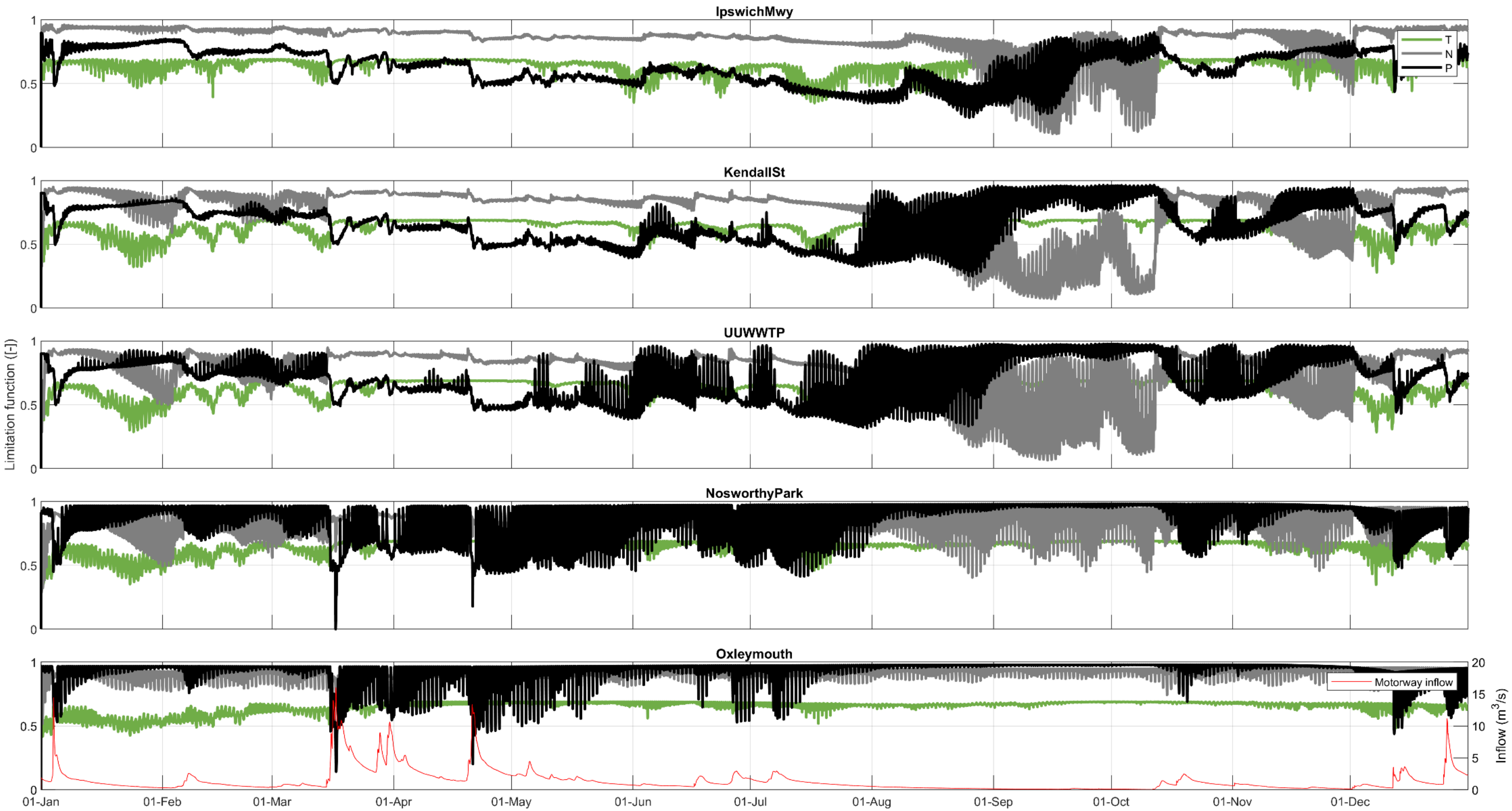

Figure 4.90 2019 Total Chlorophyll *a* Timeseries: Limitation Functions

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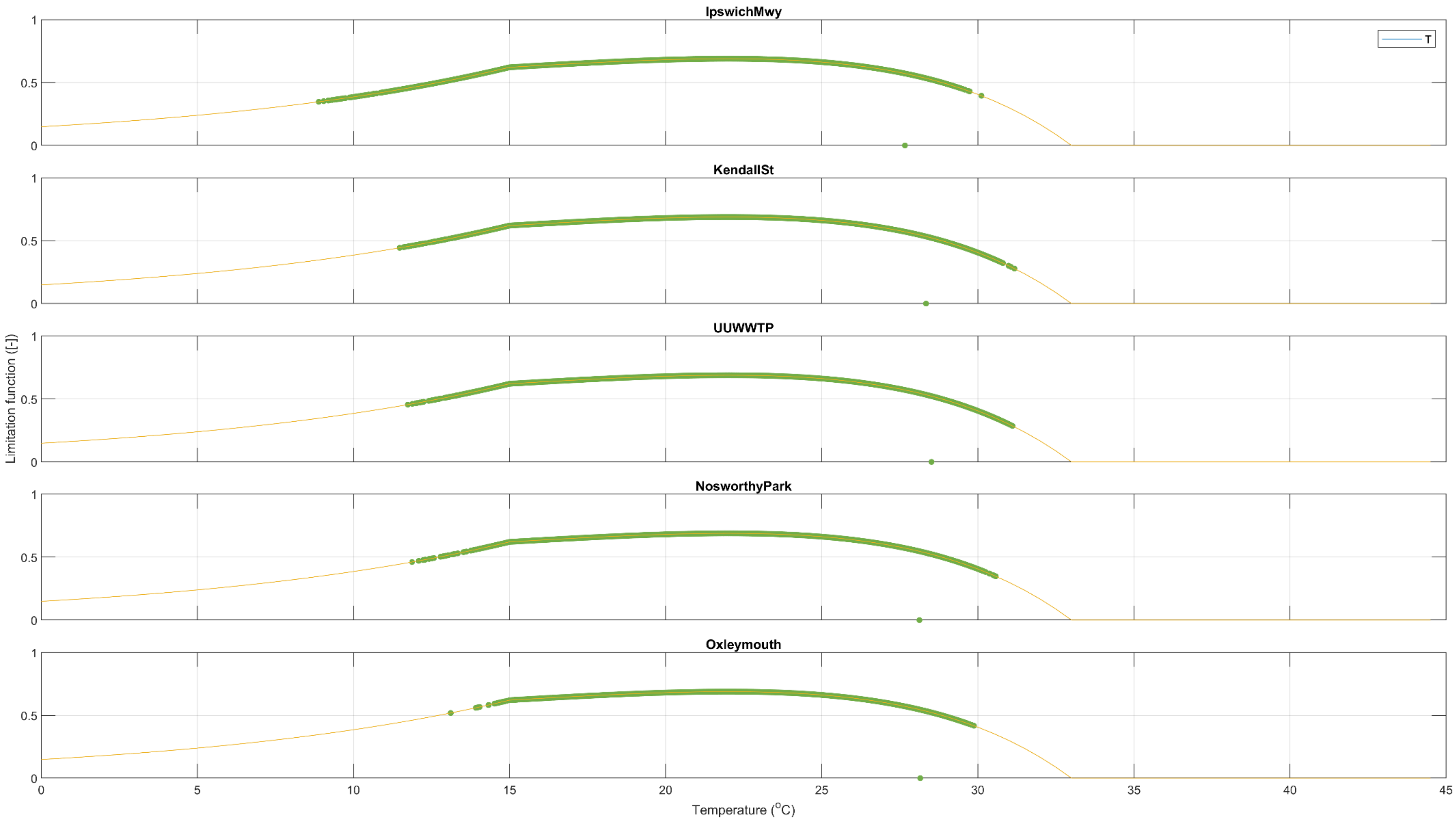

Figure 4.91 2019 Total Chlorophyll *a* Timeseries: Temperature Limitation Function Values

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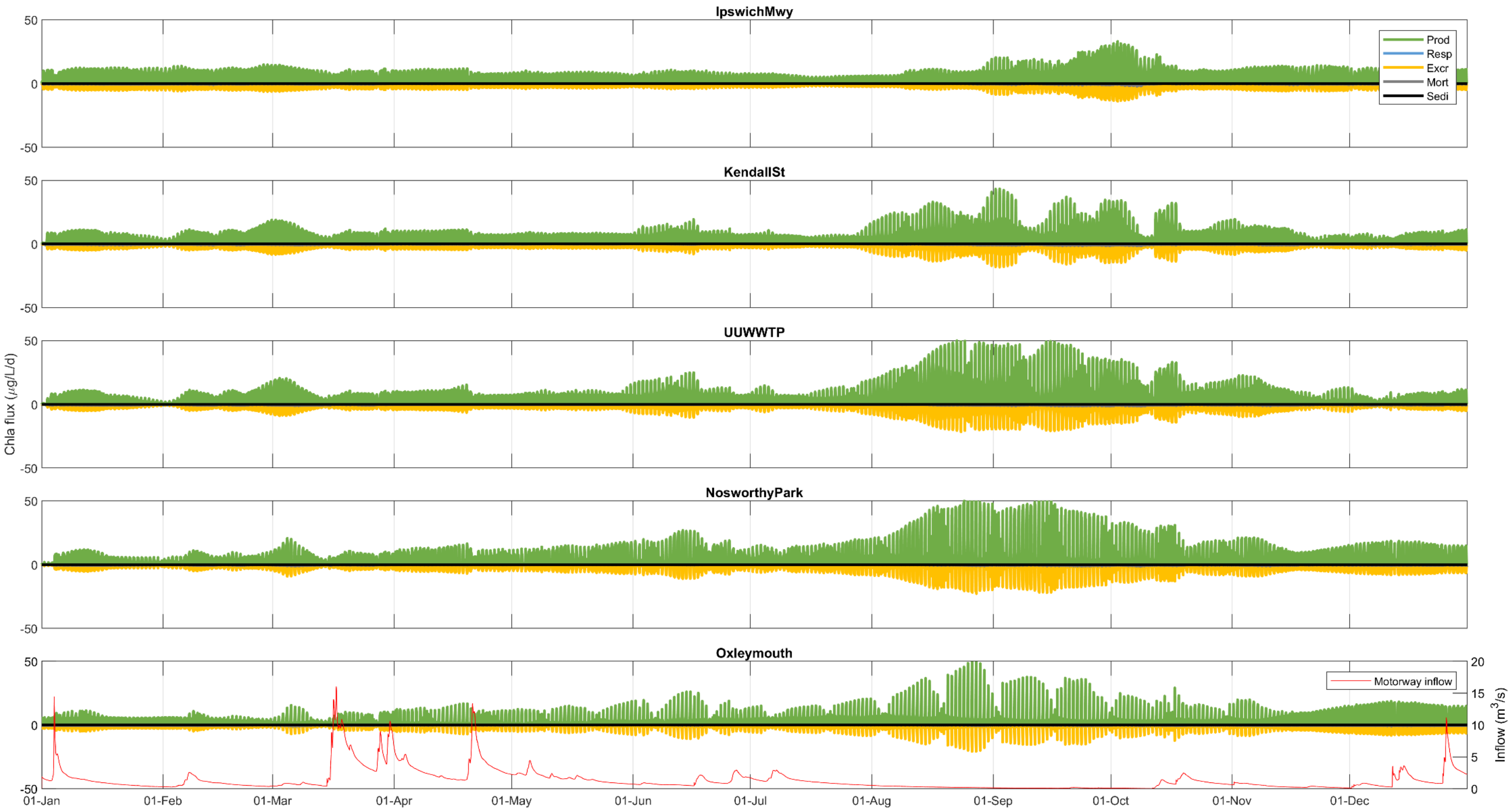

Figure 4.92 2019 Total Chlorophyll *a* Timeseries: Growth and Loss Fluxes

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Chlorophyll *a* – a proxy for phytoplankton biomass – is unique in the suite of quantities considered to this point, by virtue of it being created in situ via primary productivity, without the need for direct delivery via a boundary. Similarly, chlorophyll *a* is consumed not by the influence of a boundary, but by respiration, exudation and other related phytoplanktonic loss processes. Figure 4.87 and Figure 4.88 reveal that the dominant positive flux of chlorophyll *a* in the Oxley Creek model is due to primary productivity, with a lesser flux from catchment inflows. The dominant loss flux pathways are excretion and tidal egress. Figure 4.92 shows this balance between primary productivity gains (green line) and excretive losses (yellow line). As such, the TUFLOW FV model predicts that over the course of 2019, chlorophyll *a* is produced in-creek and that this production is balanced by in-creek excretion and tidal loss. This is consistent with a system that has previously been shown (through examination of mass flux pathways of oxygen and nutrients) to be biologically active.

The phytoplankton limitation values presented in Figure 4.90 describe which of temperature, nitrogen and phosphorus are limiting phytoplankton growth at any point in time (across the five locations presented). The lower the limitation value, the more limiting is being imposed. In broad terms, the figure shows that from January to mid-March, temperature is the most limiting phytoplankton growth. Following a series of inflows, phosphorus becomes limiting (especially in the mid creek reaches) until nitrogen becomes limiting at approximately (from downstream to upstream site):

- August at Nosworthy Park
- September at UUWWTP
- September at Kendall St, and
- October at Ipswich Motorway

The question then arises – what causes the transition from phosphorus limitation to nitrogen limitation across this period? The mass flux assessments presented above have shown that over August to October 2019 the downstream tidal boundary delivers phosphorus back into Oxley Creek (Figure 4.88). This occurs over a low (non-zero) catchment inflow period where tidal pumping works against catchment inflows and delivers mass upstream. Accordingly, as phosphorus is delivered to these progressively upstream sites over these drier months, phytoplankton in these reaches are provided with the phosphorus they need, and nitrogen becomes limiting. This in turn supports the bloom observed in October/November in the phytoplankton concentrations presented in Figure 4.89.

Understanding the nature and cause of the phytoplankton bloom predicted by TUFLOW FV in autumn 2019 relied on reporting and assessing mass fluxes through Oxley Creek. This understanding is not possible from examining a timeseries alone, even if it is does have acceptable goodness of fit statistics when compared to measurements. Notwithstanding this, Figure 4.89 does show that both the TUFLOW FV predictions and measurements of chlorophyll a increase over this autumnal period.

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4.5 Summary

TUFLOW Catch has been applied to the Oxley Creek catchment as a pilot study. This integrated and automated modelling platform, with its enhancements and augmentations, has encouraged and supported development of a systems understanding of the creek. Although many strands of understanding have evolved from this pilot study, an important one that has emerged is the need to use diagnostic (not concentration) outputs to quantify, understand and validate the relative magnitudes of the mass flux pathways that are predicted by a numerical model. This does not involve computing goodness of fit metrics in concentration timeseries – measurement comparisons. Rather, it involves coming to an understanding and agreement amongst stakeholders as to whether a numerical model is appropriately capturing the mass flux pathways of a system it is attempting to simulate. Without this understanding and agreement then it is entirely possible that numerical models can be configured to deliver the right answers (concentration timeseries with acceptable goodness of fit metrics) for the wrong reasons (incorrect distribution of mass flux pathways).

The above pilot analysis and holistic approach offered by TUFLOW Catch support moving away from concentration timeseries comparisons to assess model predictive power, and towards taking a mass flux based, catchment wide view of environmental systems being modelled. This is the novel and innovative approach to model validation proposed in this report.

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5 Discussion

5.1 Summary

This report has described a new numerical platform – TUFLOW Catch – that uses a high degree of automation to support the integrated simulation of catchment-wide hydrologic and water quality processes. This platform uses first principles techniques to predict highly spatially and temporally resolved surface and subsurface catchment runoff and pollutant loads, and automatically links these predictions with a downstream three-dimensional receiving hydrodynamic and water quality model. This is a major step forward in the whole-of-catchment simulation of environmental systems and will support assessment of the efficacy of real world management interventions (such as environmental offsets), and all within a single integrated platform that exploits state of the art scientific rigour and compute power.

The new platform has been applied to the Oxley Creek catchment, where the excellent hydrologic predictive power of the TUFLOW HPC rain on grid (direct rainfall) method has been demonstrated. This predictive performance is in large part due to TUFLOW HPC using high-resolution spatially and temporally resolved boundaries and inputs to solve the equations of motion for both surface and subsurface flows. This has included both 1D (e.g., pipes and bridges) and 2D solution elements. TUFLOW HPC has not relied on temporal or spatial lumping assumptions but has sought to simulate on-ground catchment hydrology conditions.

The new platform computes the generation, advection and dispersion of dissolved and particulate pollutants throughout the catchment. New, first principles, approaches were taken to achieving this, and these have been shown to support robust prediction of subsequent receiving water quality dynamics in Oxley Creek. This is in large part due to the novel accumulation wash-off style pollutant export model developed being built to simulate environmental processes as they occur on-ground, and then by routing these pollutants by solving the transport equations at high spatial and temporal resolutions. The export model does not rely on spatial or temporal lumping methods or the associated assumptions, nor does it mandate that accumulation wash-off model parameterisation be linked to land use. One advantage of this highly spatially resolved approach is that is allows direct simulation of potential on-ground remediation works, where these might be planned (down to tens of metres accuracy), rather than attempting to lump up fine scale changes or management interventions into larger scale and less physically meaningful functional units.

Finally, the new numerical platform automatically determines, links and populates a downstream 3D TUFLOW FV model's boundary conditions with the hydrologic, hydraulic and pollutant export predictions of TUFLOW HPC. This automated linking technique was shown to work efficiently and smoothly, and produce TUFLOW FV boundaries at much higher spatial and temporal resolutions. This translated directly to an efficient TUFLOW FV WQ calibration process, with less than 5 iterations being required to prepare the model to the standard reported. In this light, it is worth noting that despite adopting entirely new hydrologic and pollutant export models that were populated with parameters from the literature, the resultant predictions of hydrodynamics and water quality in Oxley Creek were remarkable in their reproduction of measurements, with little need for iterative and time-consuming calibration processes.

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In addition to the above, the integrated nature of TUFLOW Catch has allowed for the proposal of a refreshed reporting framework with which to assess receiving water quality model predictive power. This framework moves beyond the presentation of concentration timeseries and/or annual median thalweg plots alone. Rather, it encourages the presentation and assessment of the magnitude and direction of the volume and mass fluxes that occur within a model's parameterisation. Doing so allows for development of a systems understanding of a model's behaviour, and therefore enables a clear view (by all stakeholders) of whether a model is reproducing the hierarchy of expected flux pathways, or: direct addressing the question "Is the model achieving the right answers for the right reasons, or not?" Such flux-based insights are simply not possible from considering concentration timeseries or thalweg medians alone: this is primarily because timeseries are one-way integrations of any number of underlying environmental fluxes that cannot be retrospectively disentangled.

It is hoped that this new modelling platform and method of results presentation, assists environmental professionals throughout Southeast Queensland to better understand and manage our precious natural resources. Outputs from the TUFLOW Catch modelling platform are currently available to support this approach.

5.2 Comparison with an Existing Model

As described in this report's introduction, a great deal of high quality and groundbreaking numerical modelling has been undertaken in Southeast Queensland since late last century. This includes whole of catchment linked modelling studies, and as such it is important that the predictive capability of TUFLOW Catch be reviewed in the context of previous relevant work. Doing so is the subject of this section.

Given that the majority of the scientific and compute related enhancements offered by TUFLOW Catch centre around the prediction of catchment hydrology and associated pollutant export, attention is focussed here on comparing the predictions of TUFLOW HPC with those of an existing calibrated lumped daily hydrologic and pollutant export model of Oxley Creek catchment. The TUFLOW FV model built in this study is also used to assess changes in water quality predictive power within Oxley Creek that result from being forced by the hydrologic and pollutant export predictions from TUFLOW HPC and the existing lumped model.

5.2.1 Existing Catchment Model

The existing lumped daily catchment hydrology and pollutant export model has been prepared as part of a separate commission (Alluvium, 2023). The key features include use of:

- A daily timestep, forced by daily rainfall and monthly average evapotranspiration
- Lumped hydrology, with the Oxley Creek catchment divided into two subcatchments – one upstream and one downstream of the New Beith gauge (see Figure 4.3 for the gauge location)
- A node-link network to route flows and loads
- EMC/DWC approaches to compute pollutant loads from flows

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The model was calibrated to flow gauge data at New Beith and simulates flow, sediment, total nitrogen and total phosphorus and spans the 2019 and 2020 calendar years (amongst others), so was directly applicable here.

5.2.2 Model Comparisons

The comparison of predictions, and associated impacts on downstream receiving water quality modelling outcomes was separated into two stages:

1. Comparison of predicted flows and loads entering Oxley Creek
2. Impacts on water quality predictions within Oxley Creek

The comparison was undertaken over both the 2019 and 2020 years, given their previously noted contrasting hydrology. These comparisons are presented below.

Flow and Load Comparison

The existing model did not simulate explicitly the 457 (i.e., 3 mainstem and 454 lateral) tributaries and inflow points to Oxley Creek that were resolved by TUFLOW Catch. As such, the spatially resolved TUFLOW Catch inflow volume and load predictions were summed to a single whole-of-creek timeseries, to match the nature of the predictions from the existing catchment model. In addition, the existing lumped model's daily data was interpolated onto the higher temporal resolution of the TUFLOW HPC predictions to allow for like-to-like statistical comparisons.

Comparisons of the (spatially aggregated) catchment flow rates, and mass flux rates of total suspended sediment, total nitrogen and total phosphorus for 2019 and 2020 are presented in Figure 5.1 and Figure 5.2, respectively. Each panel presents (from top to bottom), TUFLOW HPC (blue) and existing lumped model (red) flow rate (m^3/s), total suspended sediment (TSS) flux (kg/s), total nitrogen (TN) flux (kg/s) and total phosphorus (TP) flux (kg/s). These are presented on the same vertical scale between 2019 and 2020 for each quantity, for ease of comparison.

For context of interpretation of the figures the total volumes and pollutant masses predicted by TUFLOW HPC, and the existing lumped model are presented in Table 5.1 for each of 2019 and 2020.

Table 5.1 Total Flow Volumes and Pollutant Masses Predicted by TUFLOW HPC and the Existing Model

Constituent	TUFLOW HPC		Existing model	
	2019	2020	2019	2020
Flow volume (m^3)	8.090×10^7	1.875×10^8	1.405×10^7	6.630×10^7
TSS (tonnes)	2001	2927	1517	7044
TN (tonnes)	66	104	22	108
TP (tonnes)	6	9	3	15

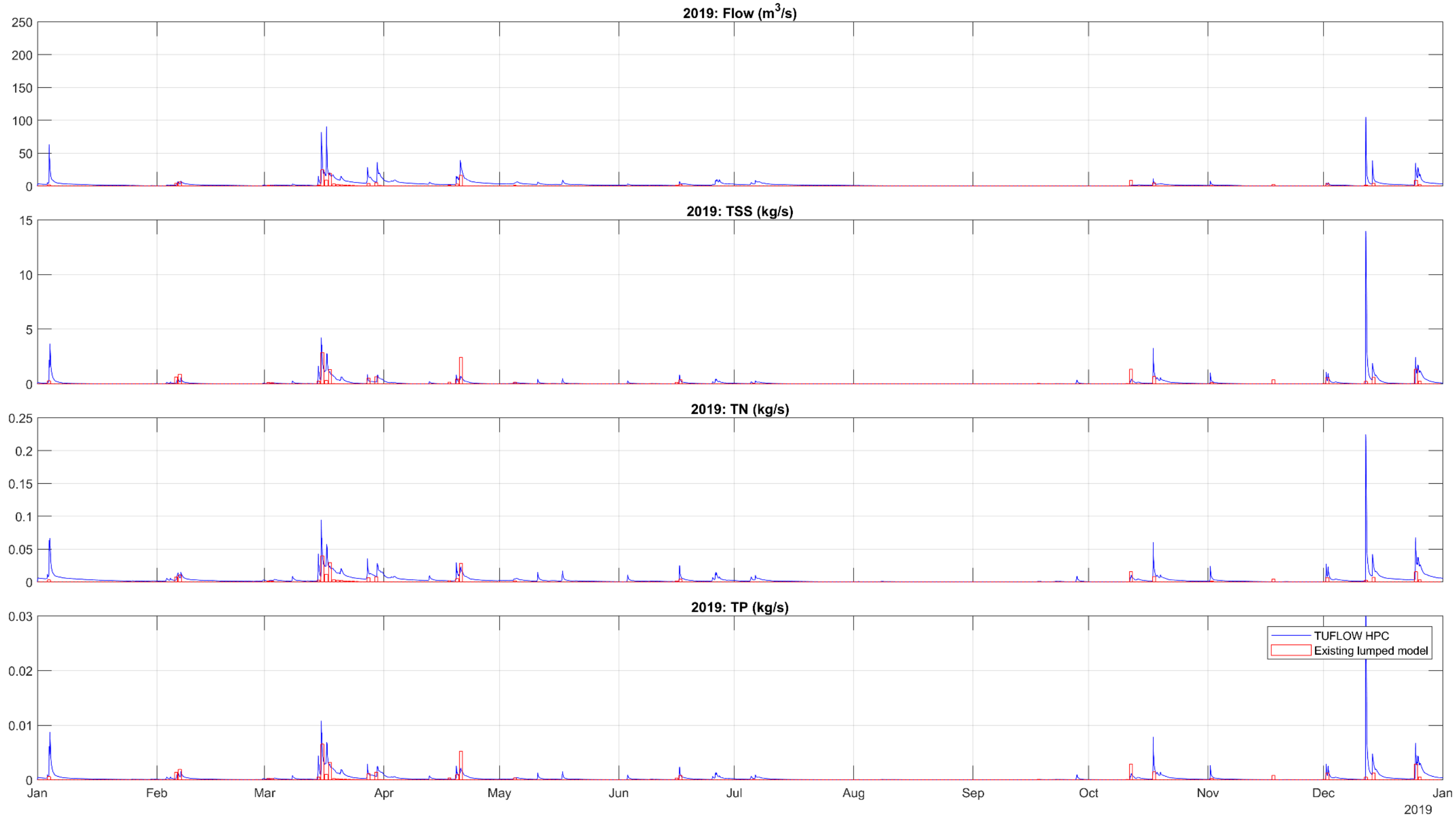

Figure 5.1 2019: Total Incoming Flow, TSS, TN and TP to the TUFLOW FV Model - TUFLOW HPC and Existing Model Timeseries

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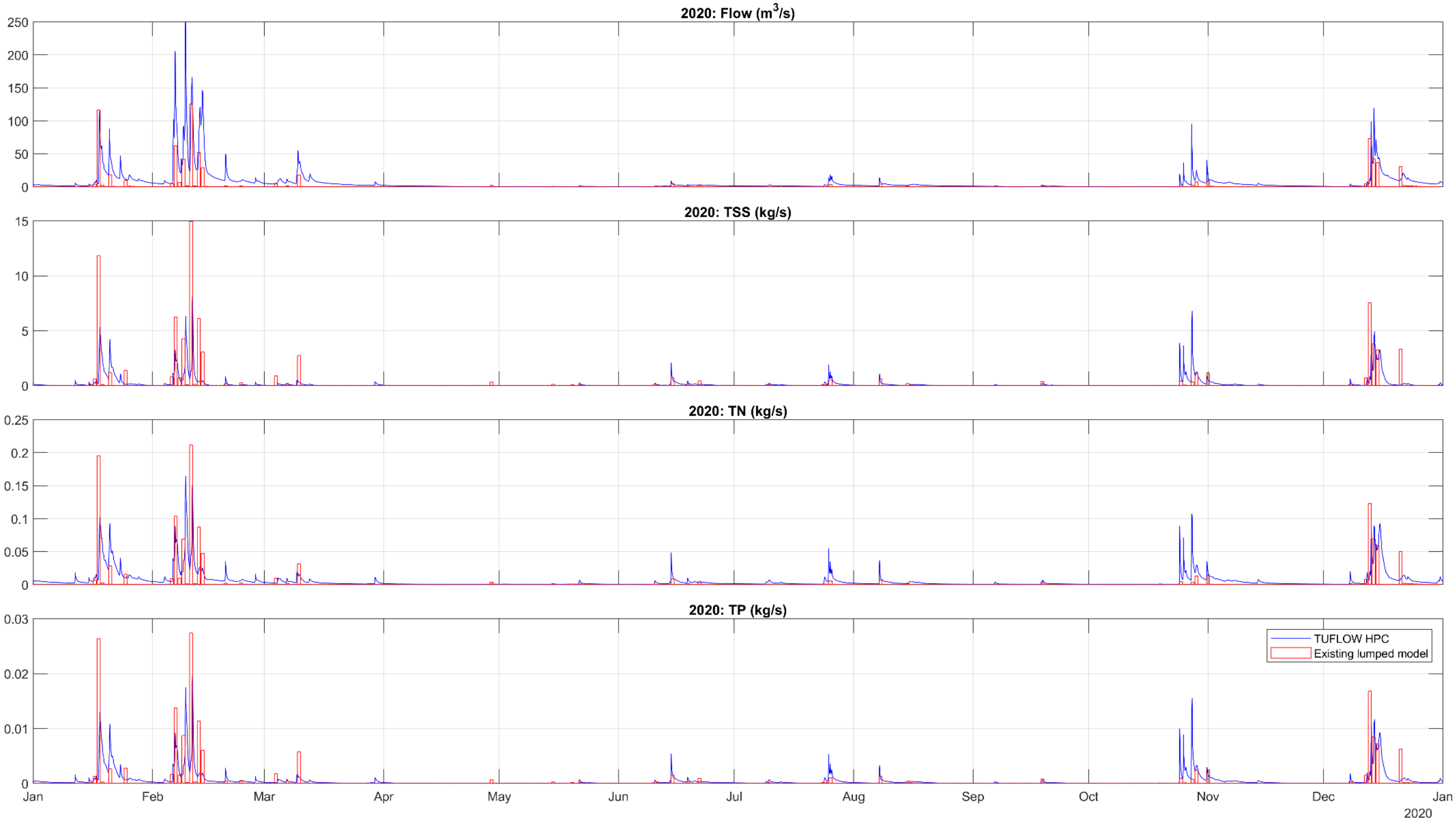

Figure 5.2 2020: Total Incoming Flow, TSS, TN and TP to the TUFLOW FV Model - TUFLOW HPC and Existing Model Timeseries

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In broad terms, the two sets of predictions show some high level feature similarities such as the prediction of elevated flows and mass fluxes at similar times. These rates are often comparable in peak magnitude, although they vary in duration and in some instances, the existing model shows a limited response at times when TUFLOW HPC predicts large peaks (e.g. December 2019 and October 2020).

To provide further insight, Figure 5.3 provides a zoomed period in 2020 that compares these flow rates and mass fluxes more closely. The panels and line colours are unchanged from the previous figures.

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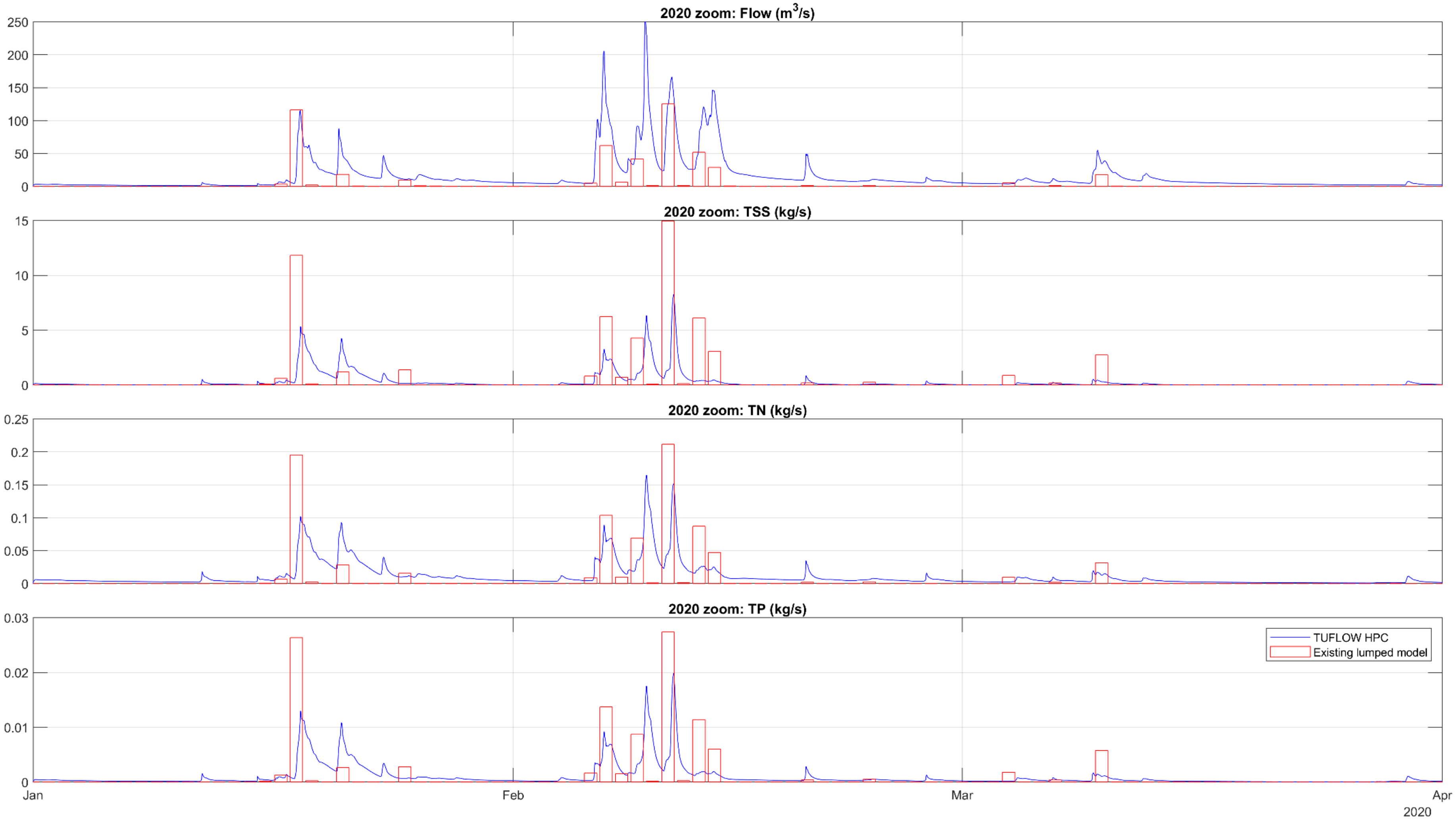

Figure 5.3 2020: Zoomed Total Incoming Flow, TSS, TN and TP to the TUFLOW FV Model - TUFLOW HPC and Existing Model Timeseries

Figure 5.3 confirms the previous interpretation, that whilst superficially similar in some high level forms, there remain material differences between the TUFLOW HPC and existing model hydrology and pollutant export predictions. On closer examination of Figure 5.3, one striking difference between the two responses is the presence of substantive falling limbs in the TUFLOW HPC predictions of flow rate and mass flux. These limbs last for extended periods (up to months) and are largely absent in the existing model’s predictions. Gauge data used in the calibration of the TUFLOW HPC hydrology model showed the presence of these falling limbs at almost all sites, and that TUFLOW HPC reproduced these limbs – as such they are real. If catchment model predictions are to be used to force downstream receiving water quality models, these falling limb features require resolution. For example, one might argue that the peak flows predicted by the two models over 2020 are similar – but that the falling limbs differ substantially. Referring to Table 5.1, these limbs could contribute the same order of magnitude of water as the peak flows: TUFLOW HPC with falling limbs has an annual volume more than four times the corresponding volume of the existing lumped model.

To further explore this matter, the timeseries presented previously have been converted to exceedance curves. These are presented in Figure 5.4 and Figure 5.5 for 2019 and 2020, respectively. Axis limits are the same between each figure’s corresponding panels, and the line colours are the same as previous figures.

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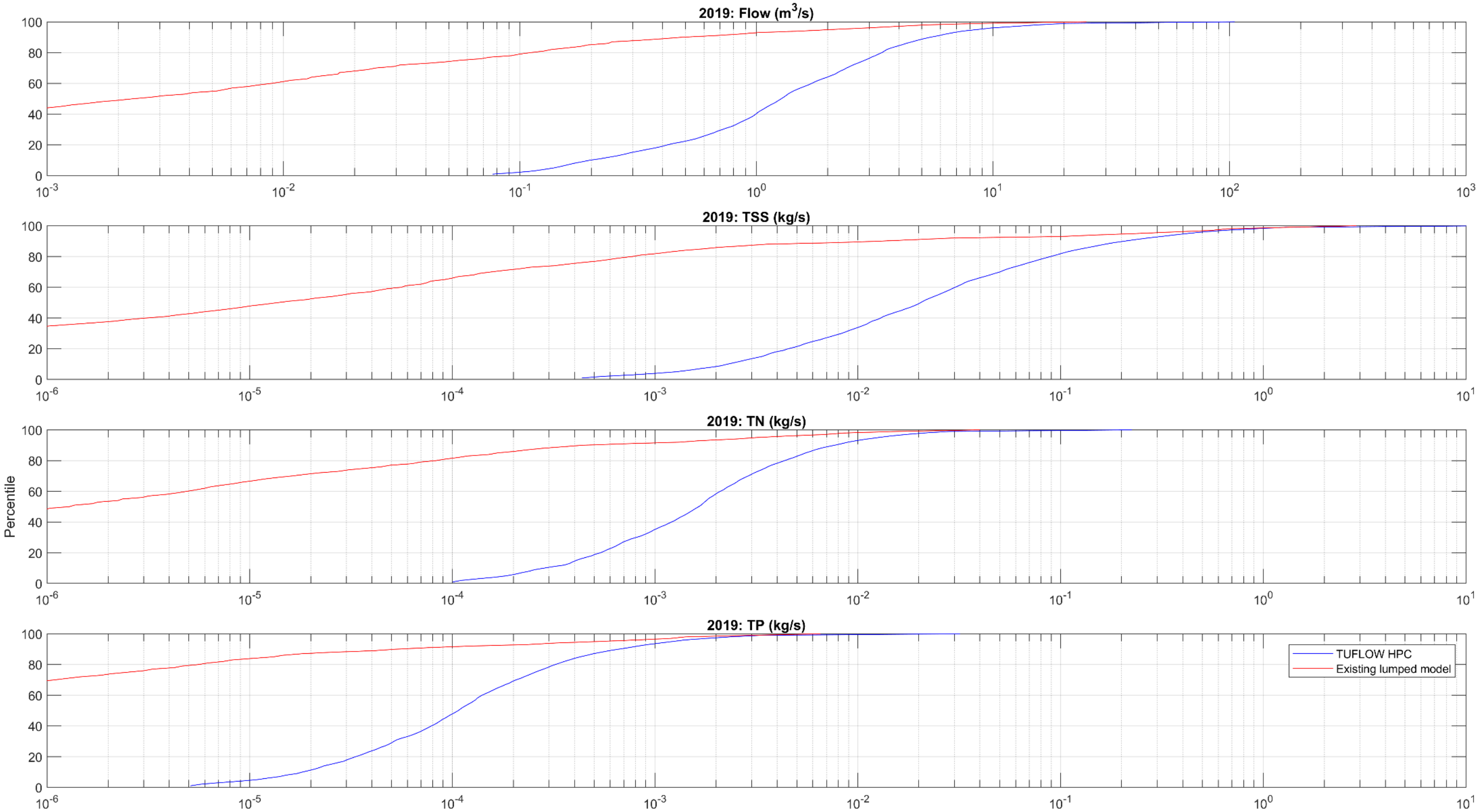

Figure 5.4 2019: Total Incoming Flow, TSS, TN and TP to the TUFLOW FV Model - TUFLOW HPC and Existing Model Exceedance Curves

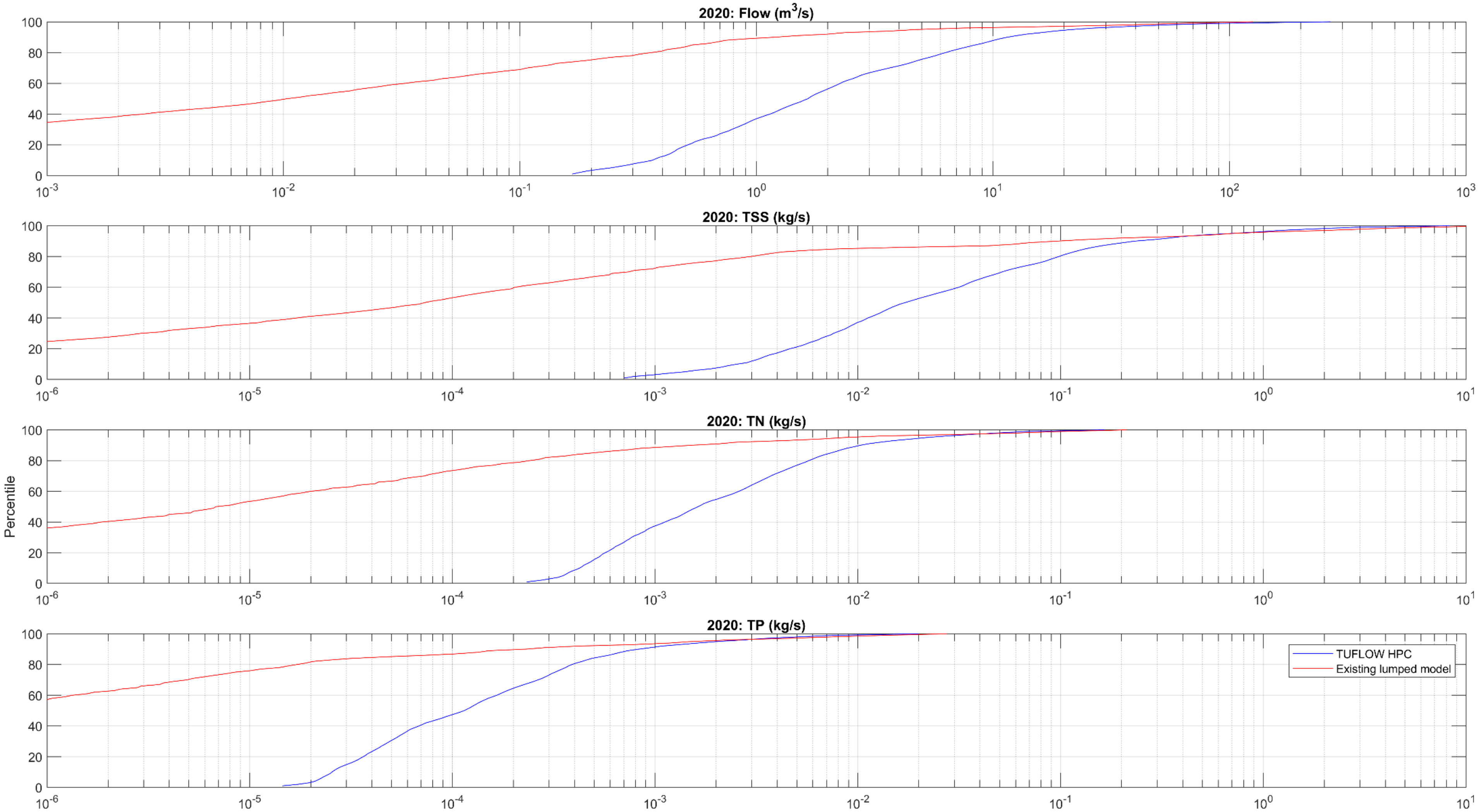

Figure 5.5 2020: Total Incoming Flow, TSS, TN and TP to the TUFLOW FV Model - TUFLOW HPC and Existing Model Exceedance Curve

The influence of the falling limb (or its absence) is clear in the figures. The TUFLOW HPC distributions are tight because they reflect a smaller range of values due to the presence of the falling limbs keeping predicted flows (and mass fluxes) away from persistently small values. Conversely, the exceedance curves of the existing model are widely spread because of the underlying data incorporating large counts of small flows and mass fluxes.

Although there are other potential features of significance that differentiate the hydrologic and pollutant export predictions of TUFLOW HPC and the existing model, this presence/absence of falling limbs will be pursued here. Specifically, the potential of this difference to influence downstream receiving water quality modelling predictive power is explored.

Impacts on Downstream Water Quality Model Predictions

To explore potential downstream impacts of this difference in falling limb prediction between the models, the TUFLOW FV model described in Section 4.4 was redeployed but with the highly resolved TUFLOW HPC generated inflow boundaries replaced with those of the existing lumped model. No other changes were made to the TUFLOW FV model or its parameterisation.

Because the existing model's predictions were not spatially resolved, they were applied as a single inflow at the southern tidal limit of Oxley Creek, this being the creek's primary tributary. No other inflows were applied.

Because the existing model's pollutant export predictions were of total nutrients, they required manual speciation. A speciation typical of that applied to other Southeast Queensland estuaries was therefore applied manually. That speciation is presented in Table 5.2. The same suite of constant boundary condition concentrations described in Section 4.4 were applied, as well as the time varying water temperature condition.

Table 5.2 Manual Speciation of Pollutants Predicted by the Existing Model

Constituent					Partition Percentage
Total Nitrogen	Organic	62.5%	Dissolved	80%	50.0%
			Particulate	20%	12.5%
	Inorganic	37.5%	Ammonia	9.3%	3.5%
			Oxidised Nitrogen	90.7%	34.0%
Total Phosphorus	Organic	30%	Dissolved	80%	24.0%
			Particulate	20%	6.0%
	Inorganic	70%	Phosphate		70.0%

The presentation of TUFLOW FV's predictions under the forcing of the existing catchment model's boundary conditions follows the intent of the framework described in Section 4.4 (i.e. masses and fluxes that support system understanding) are presented first, followed by concentration timeseries, where helpful. Timeseries of masses and cumulative fluxes are always presented. The mass and cumulative

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flux timeseries are presented in pairs, with each pair comprising predictions from the TUFLOW FV model forced by the TUFLOW HPC model (upper pane) and existing catchment model (lower pane). This presentation method means that there are four panes per page, these being predictions from the TUFLOW FV model:

- Forced by TUFLOW HPC boundaries: mass timeseries
- Forced by TUFLOW HPC boundaries: cumulative flux timeseries
- Forced by the existing model boundaries: mass timeseries
- Forced by the existing model boundaries: cumulative flux timeseries

Vertical axis limits on all related figure pairs are the same to support easy comparison. These may be different limits to those applied to figures presented previously, but the underlying data is unchanged.

Concentration timeseries are presented in one multi-pane figure for each quantity. The predictions from both TUFLOW FV models are coplotted in each pane, with the models driven by TUFLOW HPC and the existing catchment model presented in dark and light blue, respectively. Where available, monitoring data is also included as points.

Only TUFLOW FV predictions from 2019 are presented.

Given that the intent of this exploration is the downstream impact of inflowing falling limbs, volumes are presented initially.

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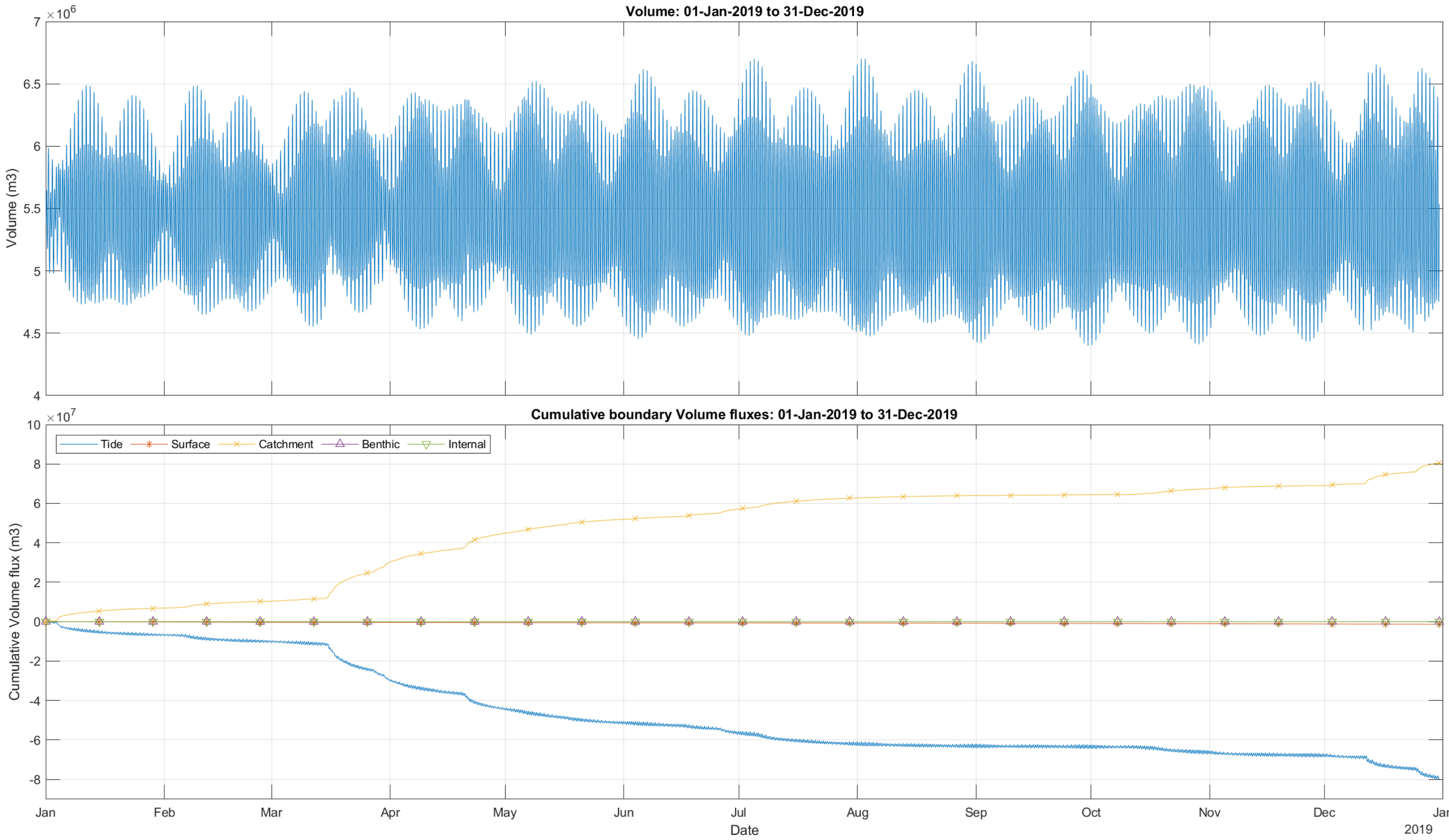
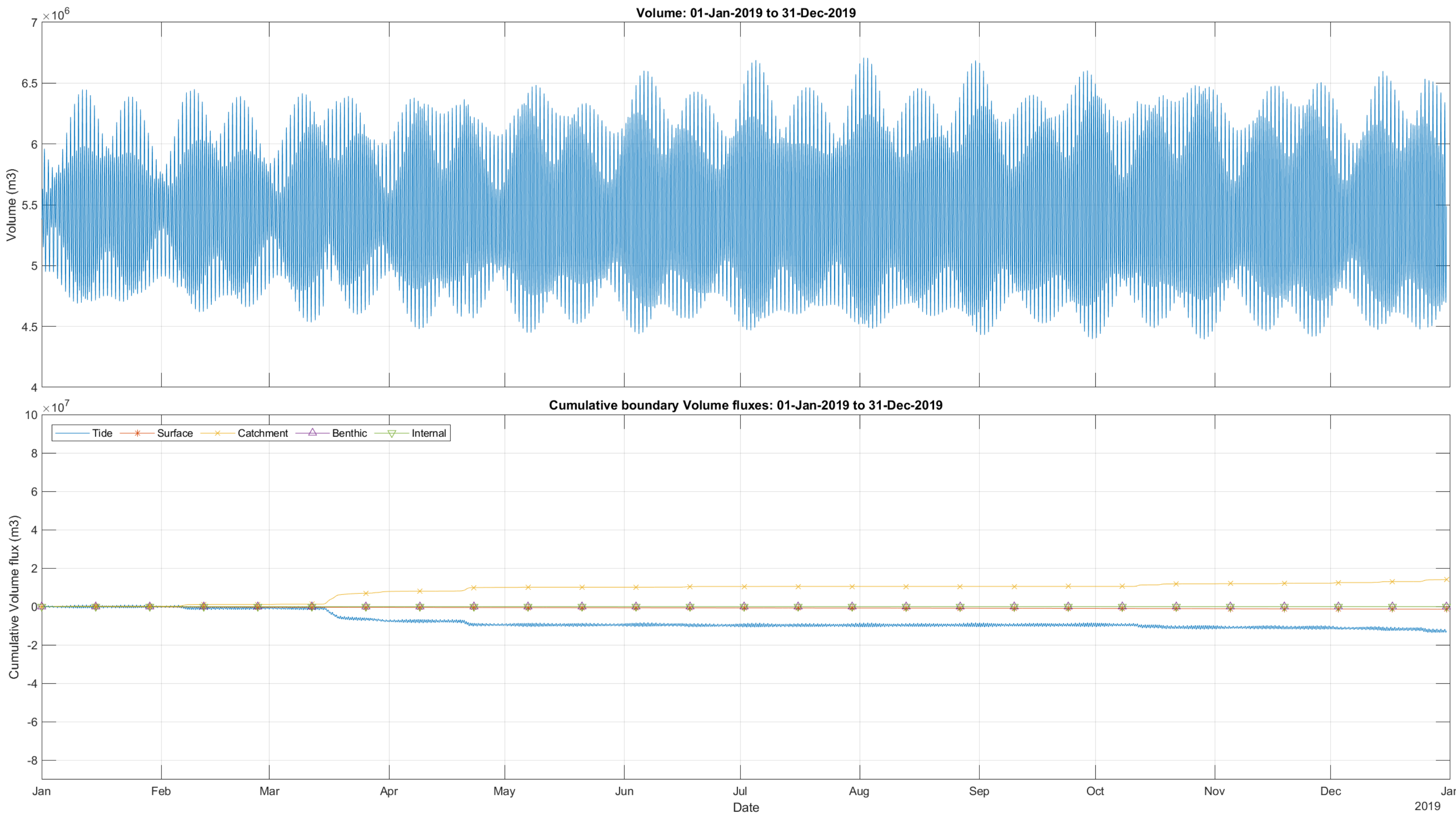


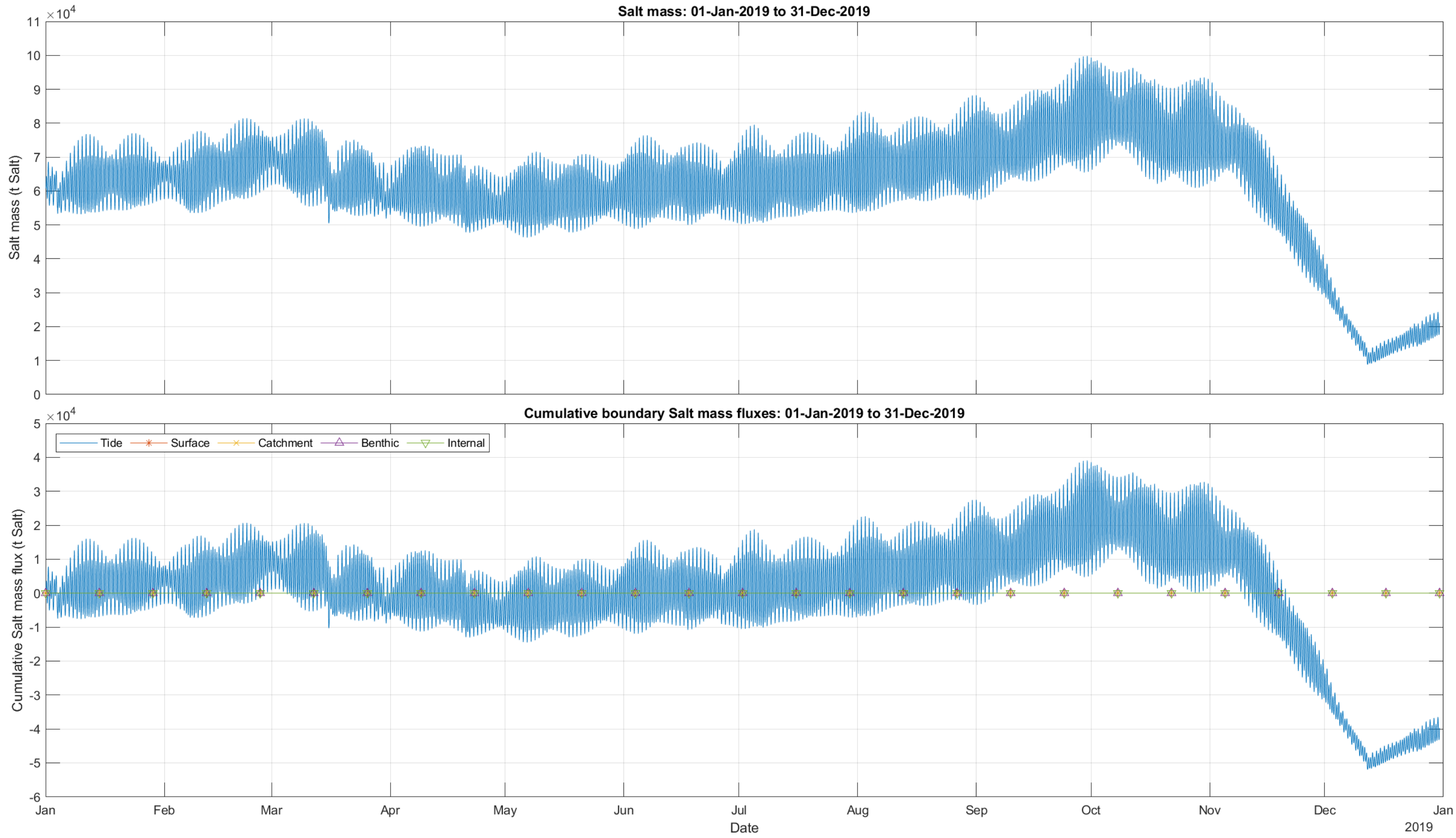
9: Mass and Cumulative Flux Timeseries (TUFLOW HPC Boundaries): Volume



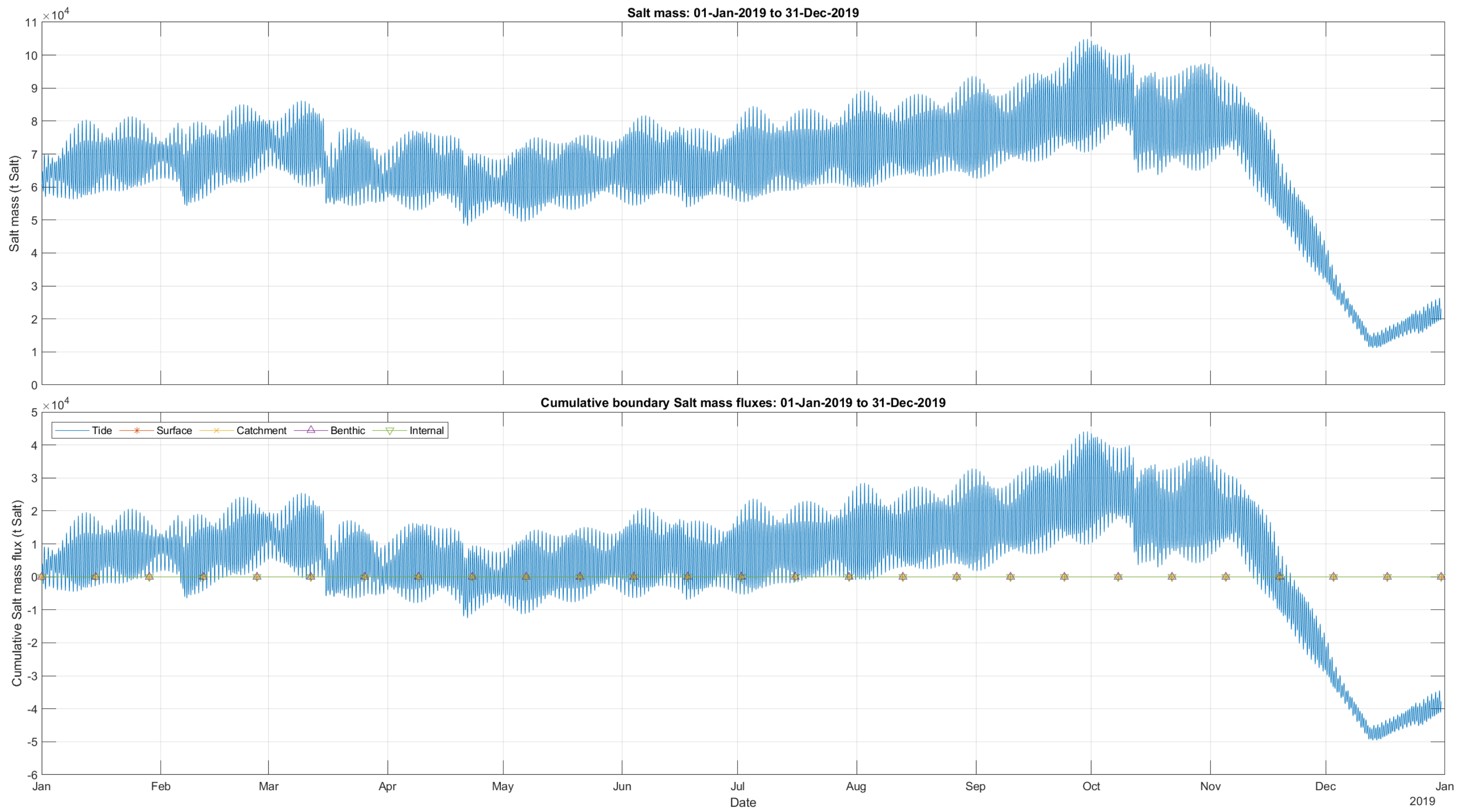
9: Mass and Cumulative Flux Timeseries (Existing Model Boundaries): Volume

The mass flux figures show that, as expected, catchment inflows approximately balance tidal outflows and evaporative mass losses are of second order. A comparison of Figure 5.6 and Figure 5.7 is consistent with expectation and previous results in that the cumulative volumetric fluxes delivered by the existing catchment model are smaller than those generated by TUFLOW HPC.

Salt masses are presented below.



9: Mass and Cumulative Flux Timeseries (TUFLOW HPC Boundaries): Salt



9: Mass and Cumulative Flux Timeseries (Existing Model Boundaries): Salt

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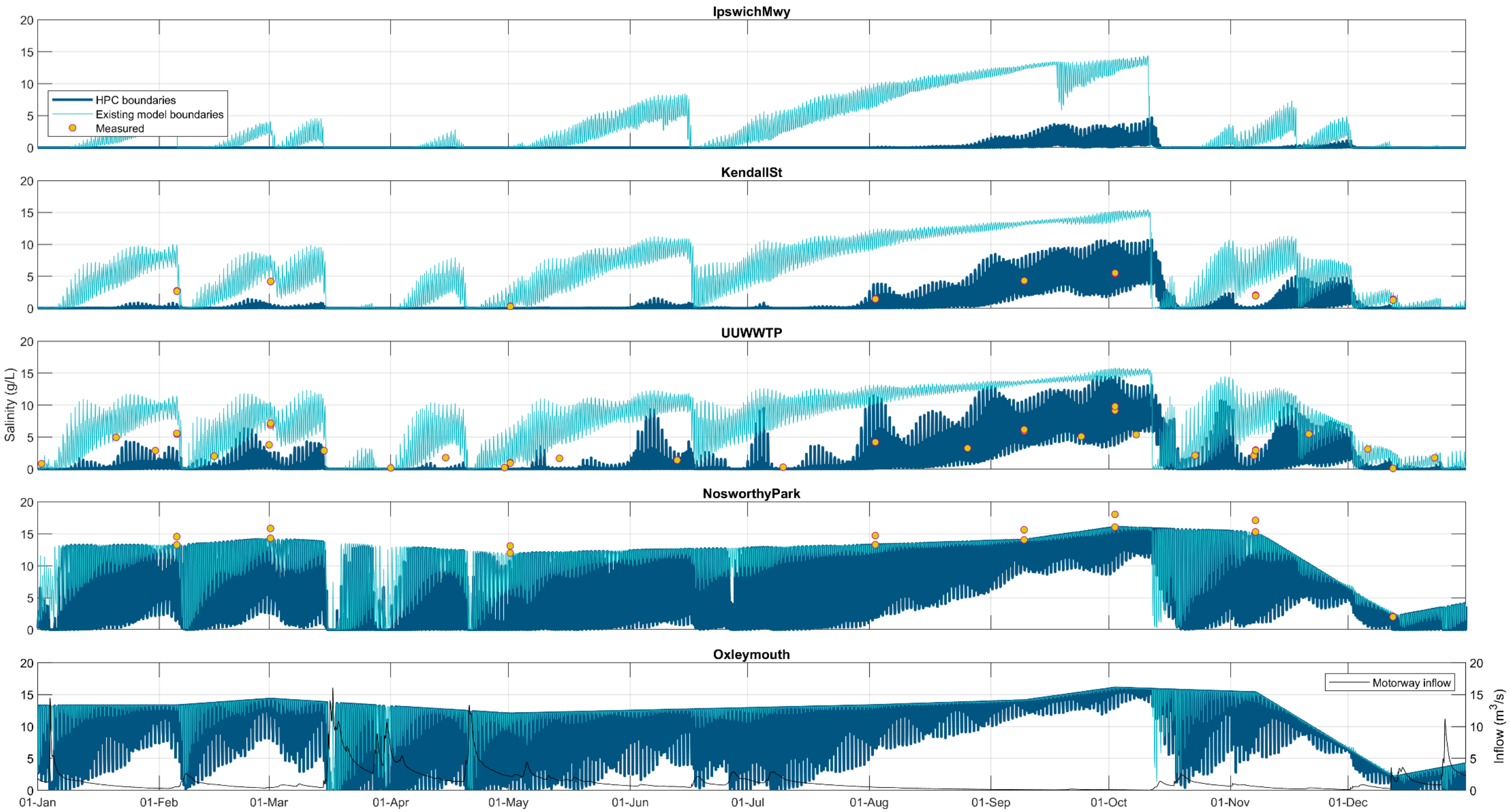

Figure 5.10 2019 Salinity Timeseries

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Figure 5.8 and Figure 5.9 again are consistent with the expectation that the tidal boundary provides the only flux of salt mass to Oxley Creek, and that this mass influx increases during drier periods. Closer inspection of these figures shows that over the previously noted drier period (from mid-year to November) the salt mass ingress to the creek is greater in the case of the TUFLOW FV model forced by the existing lumped model boundaries. The difference appears subtle, but is present to the extent that at the peak of the ingress in October, the creek holds an additional 5,000 tonnes of salt under the action of the existing model's boundaries. This is a direct result of the lower inflows predicted by the existing catchment model, and the different salt balance that develops in the creek.

This difference in the creek's salt balance, although it appears subtle on initial inspection, has a profound impact on the prediction of salinities (i.e. concentrations) in Oxley Creek. The corresponding timeseries presented Figure 5.10 underscore how sensitive this system is to differing boundary forcing, with salinity recovery rates being materially different under the two boundary forcing cases considered. In particular, the salinity recoveries predicted by TUFLOW FV under forcing of the existing lumped catchment model are much more rapid than when forced by TUFLOW HPC boundaries, and more rapid than spot measurements suggest. Conversely, salinity recovery under the boundary forcing of TUFLOW HPC predicts the spot measurements well.

Sediment masses are presented below.

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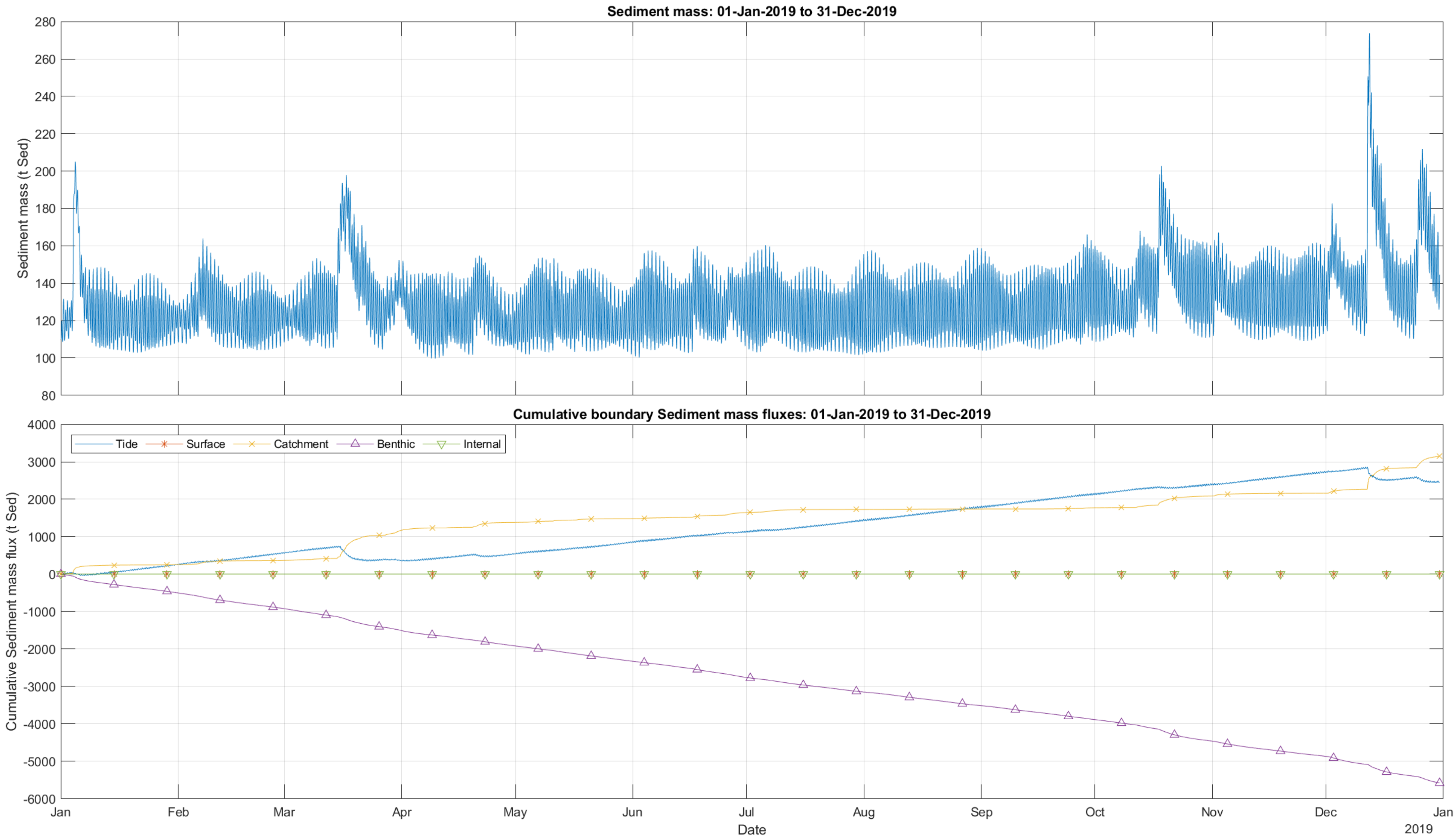
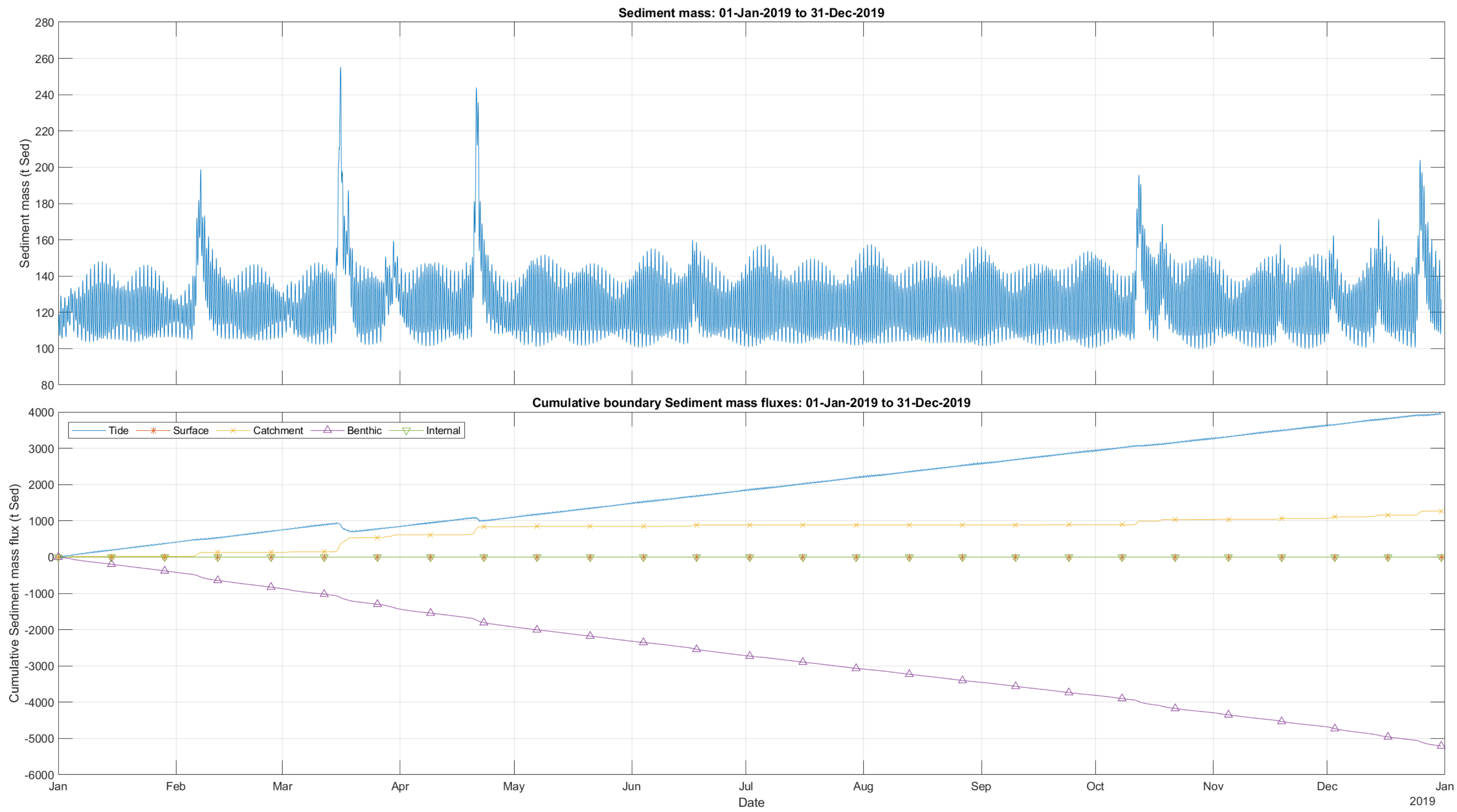
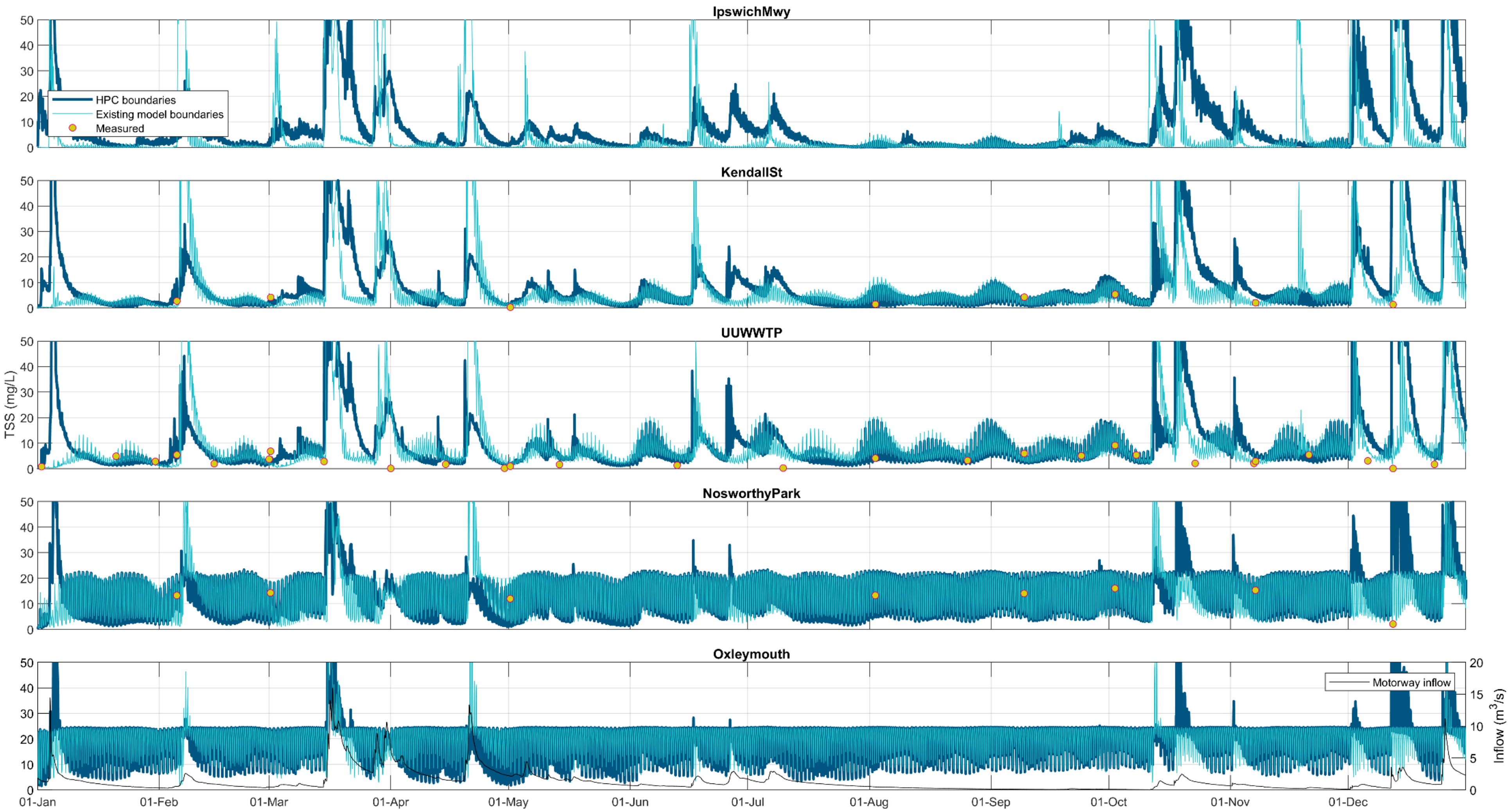


19: Mass and Cumulative Flux Timeseries (TUFLOW HPC Boundaries): Sediment



19: Mass and Cumulative Flux Timeseries (Existing Model Boundaries): Sediment



re 5.13 2019 Sediment Timeseries

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The cumulative mass flux timeseries demonstrate that the two TUFLOW FV models are operating in fundamentally different manners in terms of sediment flux pathways. For instance, the TUFLOW FV model forced by TUFLOW HPC has catchment and tidal fluxes of sediment being of a similar magnitude, and their sum balanced by settling losses. Conversely, the TUFLOW FV model forced by the existing lumped model has considerably less catchment sediment flux (due at least in part to its lower predicted inflows), to the point that catchment influxes of sediment are almost of second order importance – tidal influxes of sediment dominate sediment delivery to the creek.

This is not at all obvious from the timeseries presented in Figure 5.13 – they are not materially different to the eye other than the magnitude of sediment concentration peaks predicted during a small number of inflow events. Indeed, they both mirror well the available spot measurements, but for different underlying reasons. As such, discerning such a shift in underlying mass flux pathways is difficult from considering concentration timeseries alone.

Annual median sediment concentrations have been computed from each TUFLOW FV model's predictions at the five sites presented above and are presented in Table 5.3.

Table 5.3 Annual Median Suspended Sediment Concentrations, TUFLOW FV Models Forced by TUFLOW HPC and the Existing Model

Monitoring site	TUFLOW HPC boundaries	Existing model boundaries
Ipswich Motorway	3.2	0.5
Kendal St	4.9	4.1
UU WWTP	6.0	5.6
Nosworthy Park	14.8	16.9
Oxley Mouth	21.9	21.9

These medians are not significantly different between the two TUFLOW FV model predictions, at all five sites considered, and yet the relative magnitudes of the underlying mass flux pathways that generated these medians are indeed materially different. This outcome points directly to the potential interpretation difficulties that might be encountered when assessing model performance by considering timeseries and medians alone.

One common use for linked catchment and receiving water models is investigation of the efficacy of proposed catchment management intervention, i.e. to use the models to assess changes in receiving waterways under the influence of catchment management works. If in the case of the Oxley Creek pilot model it was determined that (for example) a 20% reduction in annual catchment sediment loads could be achieved via implementation of a specific management intervention, then these changes could be applied to the TUFLOW FV model catchment boundaries and the associated in-creek benefits assessed. If these changes were applied to the TUFLOW FV model forced by TUFLOW HPC boundaries, it would be reasonable to expect an outcome of measurable positive changes in the creek's sediment mass – this is because catchment sediment loads are half the total sediment loads to the system (Figure 5.11). Conversely, if the same reduction in catchment sediment loads was applied to the TUFLOW FV model forced by the existing lumped catchment model, a significantly lesser in-creek benefit would likely be seen. This is because in that model's configuration, the mass flux assessment

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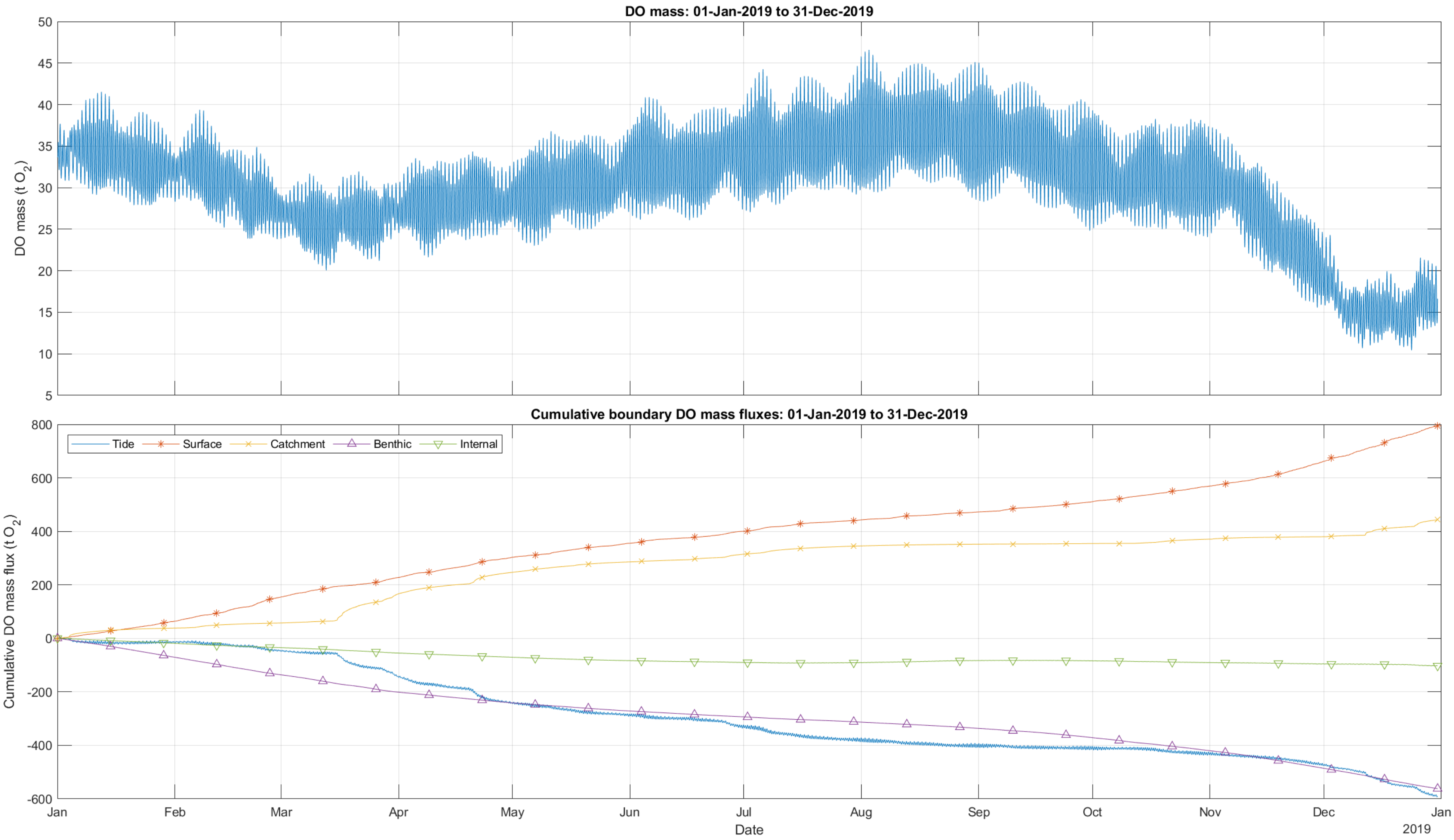
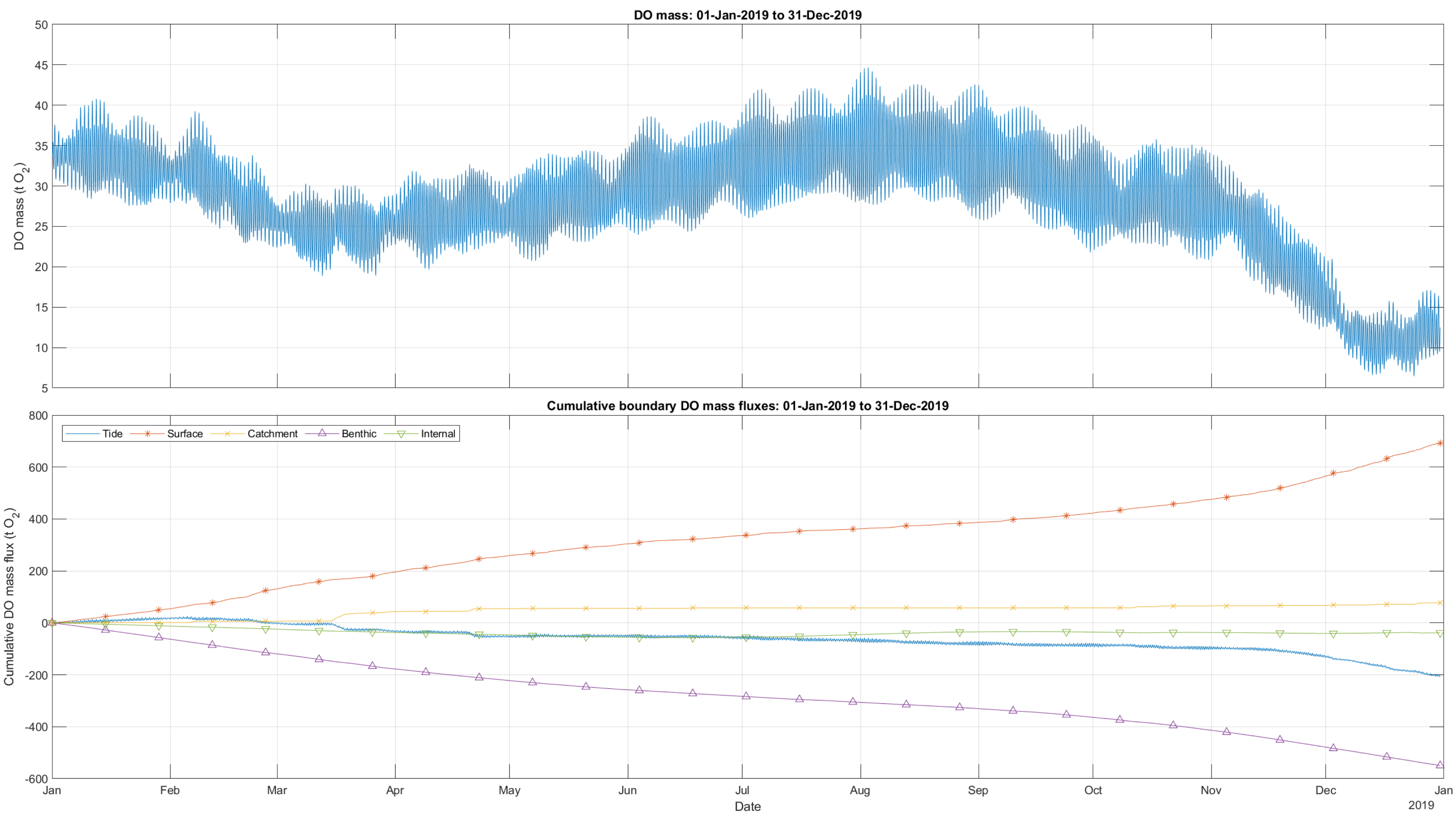
presented in Figure 5.12 shows that tidal influx of sediment from the Brisbane River (not catchment fluxes of sediment mass) dominates the overall delivery of sediment to Oxley Creek. As such, even 100% reduction of catchment derived sediment loads would have limited influence on the TUFLOW FV model's predictions of in-creek sediment concentrations – but this systems insight is only possible via examination of mass fluxes. Indeed, it is this style of insight that could save environmental modellers (and their customers) considerable time and cost by avoiding setting up and executing hypothetical scenarios that can be shown in advance to be of limited value. Rather, targeted scenarios that focus on modifying the identified dominant mass flux pathways could be meaningfully constructed and valuable resources expended judiciously.

Dissolved oxygen masses are presented below.



19: Mass and Cumulative Flux Timeseries (TUFLOW HPC Boundaries): Dissolved Oxygen



19: Mass and Cumulative Flux Timeseries (Existing Model Boundaries): Dissolved Oxygen

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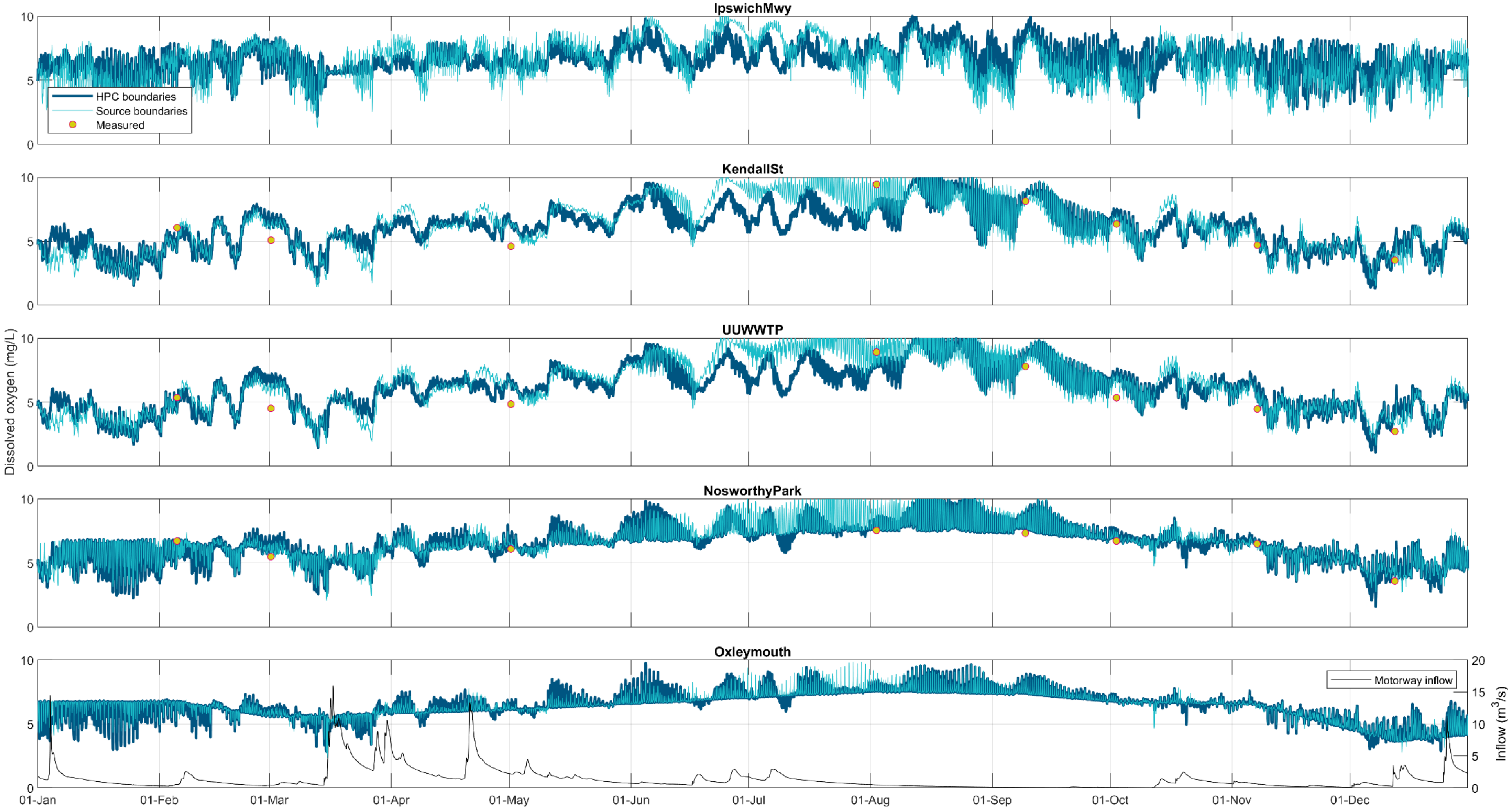

Figure 5.16 2019 Dissolved Oxygen (mg/L) Timeseries

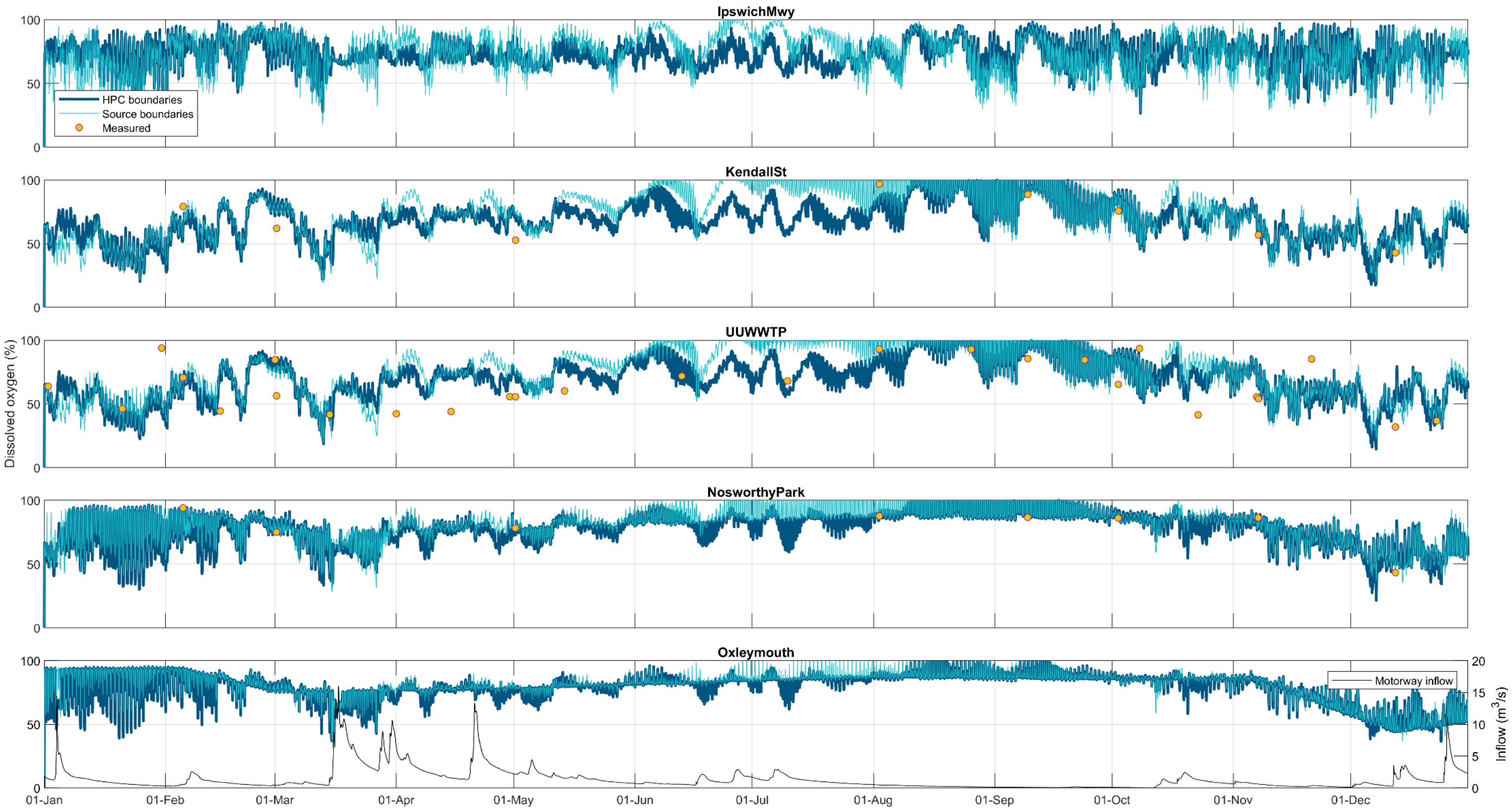

Figure 5.17 2019 Dissolved Oxygen (% Saturation) Timeseries

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The cumulative flux timeseries presented above demonstrate that the two TUFLOW FV models considered are operating differently in terms of oxygen dynamics, with the TUFLOW FV model forced by the existing lumped model showing a smaller order of magnitude of catchment and tidal fluxes (as expected based on lesser catchment inflow volume predictions discussed previously), and interestingly, much smaller internal losses. The latter points to a rebalancing of internal dissolved oxygen loss processes compared to the TUFLOW FV model forced by TUFLOW HPC boundaries, and again this is not obvious from considering the timeseries in Figure 5.16 alone.

As for sediment, the annual median dissolved oxygen concentrations between the TUFLOW FV simulations are not materially different (Table 5.4), despite having been computed from timeseries derived from different underlying dissolved oxygen flux balances.

Table 5.4 Annual Median Dissolved Oxygen Concentrations, TUFLOW FV Models Forced by TUFLOW HPC and the Existing Model

Monitoring site	TUFLOW HPC boundaries	Existing model boundaries
Ipswich Motorway	6.52	6.46
Kendal St	6.10	6.23
UU WWTP	6.22	6.32
Nosworthy Park	6.63	6.62
Oxley Mouth	6.60	6.60

Nitrogen masses are presented below.

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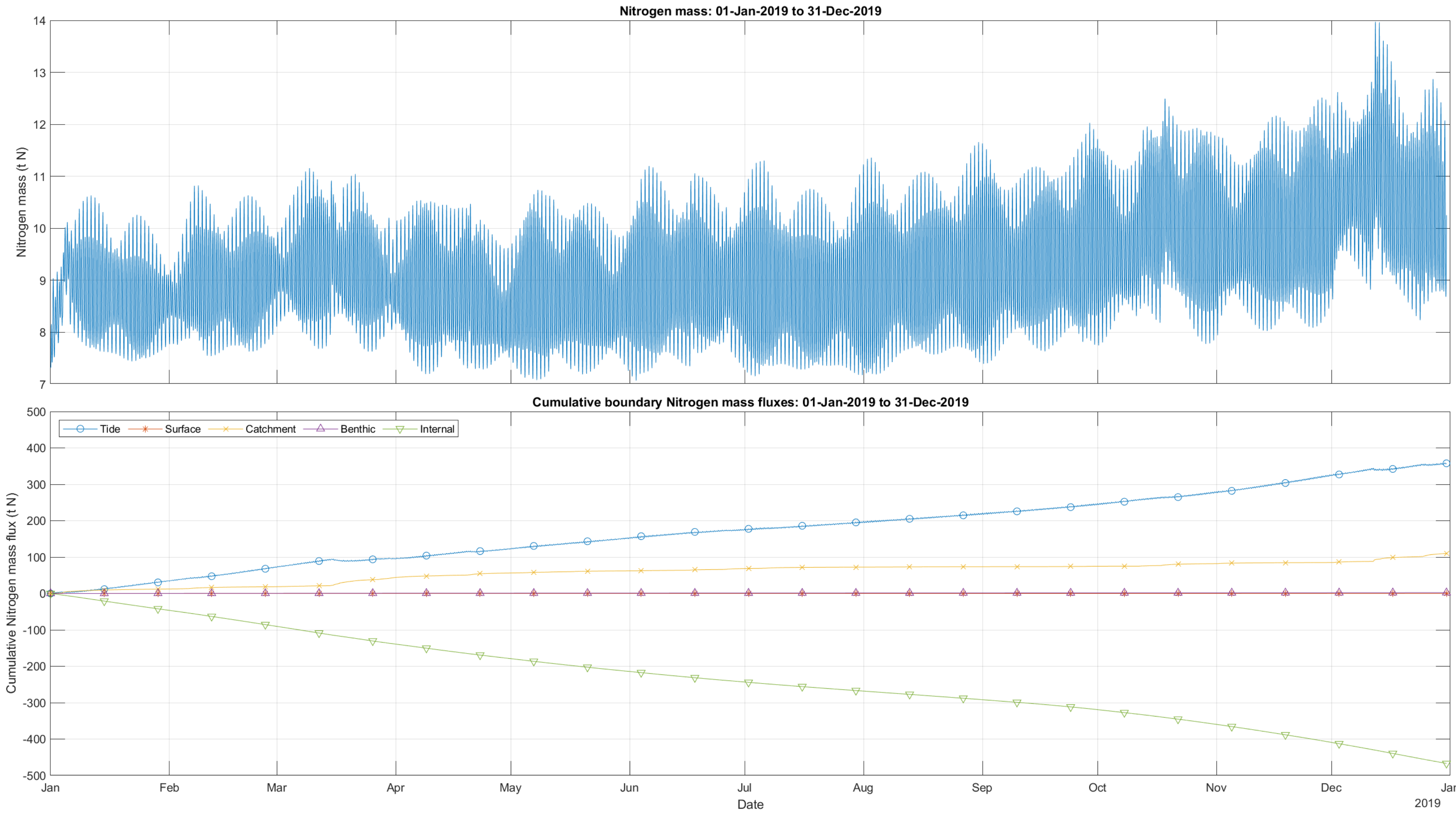

Figure 5.18 2019: Mass and Cumulative Flux Timeseries (TUFLOW HPC Boundaries): Total Nitrogen

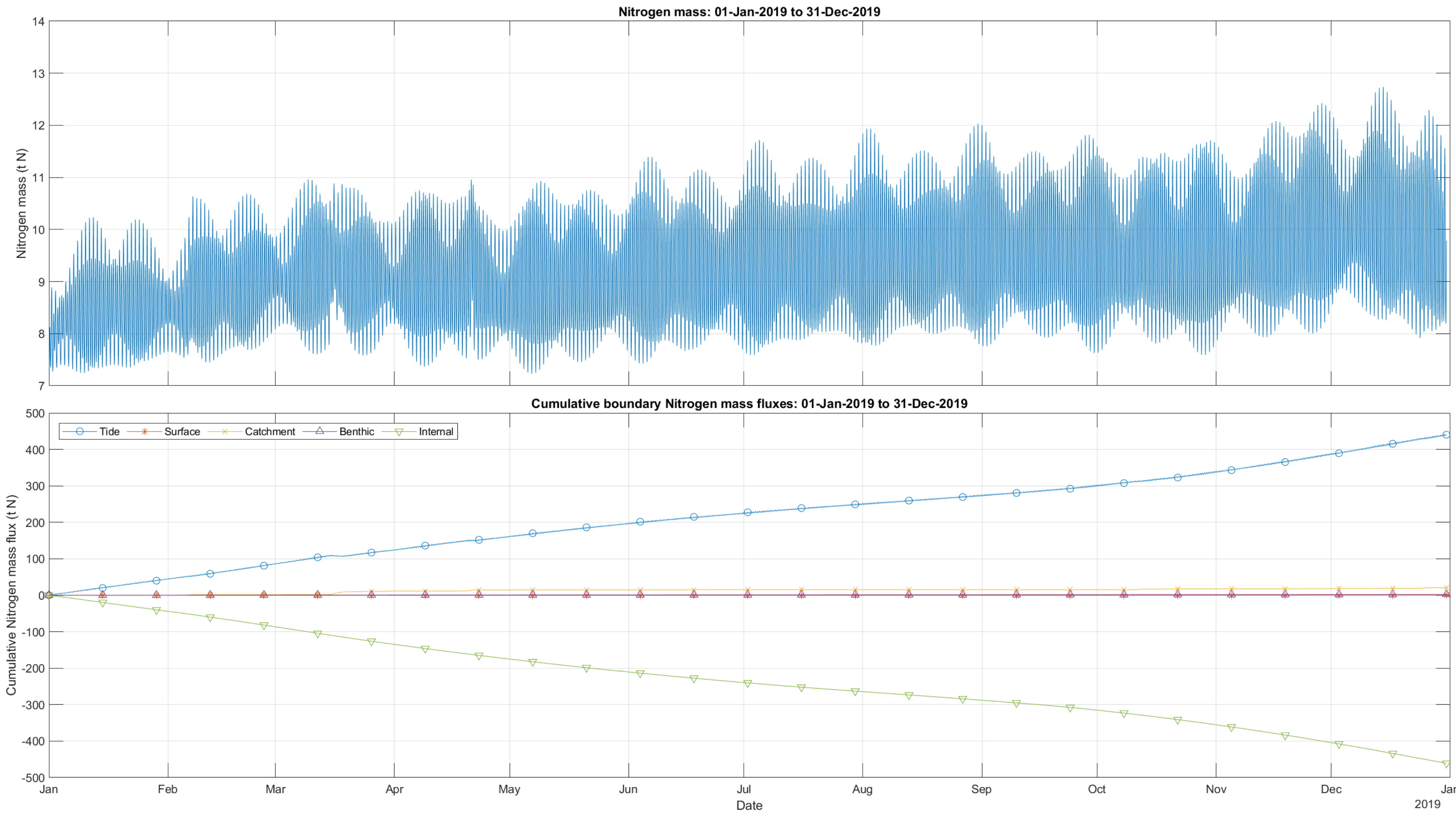

Figure 5.19 2019: Mass and Cumulative Flux Timeseries (Existing Model Boundaries): Total Nitrogen

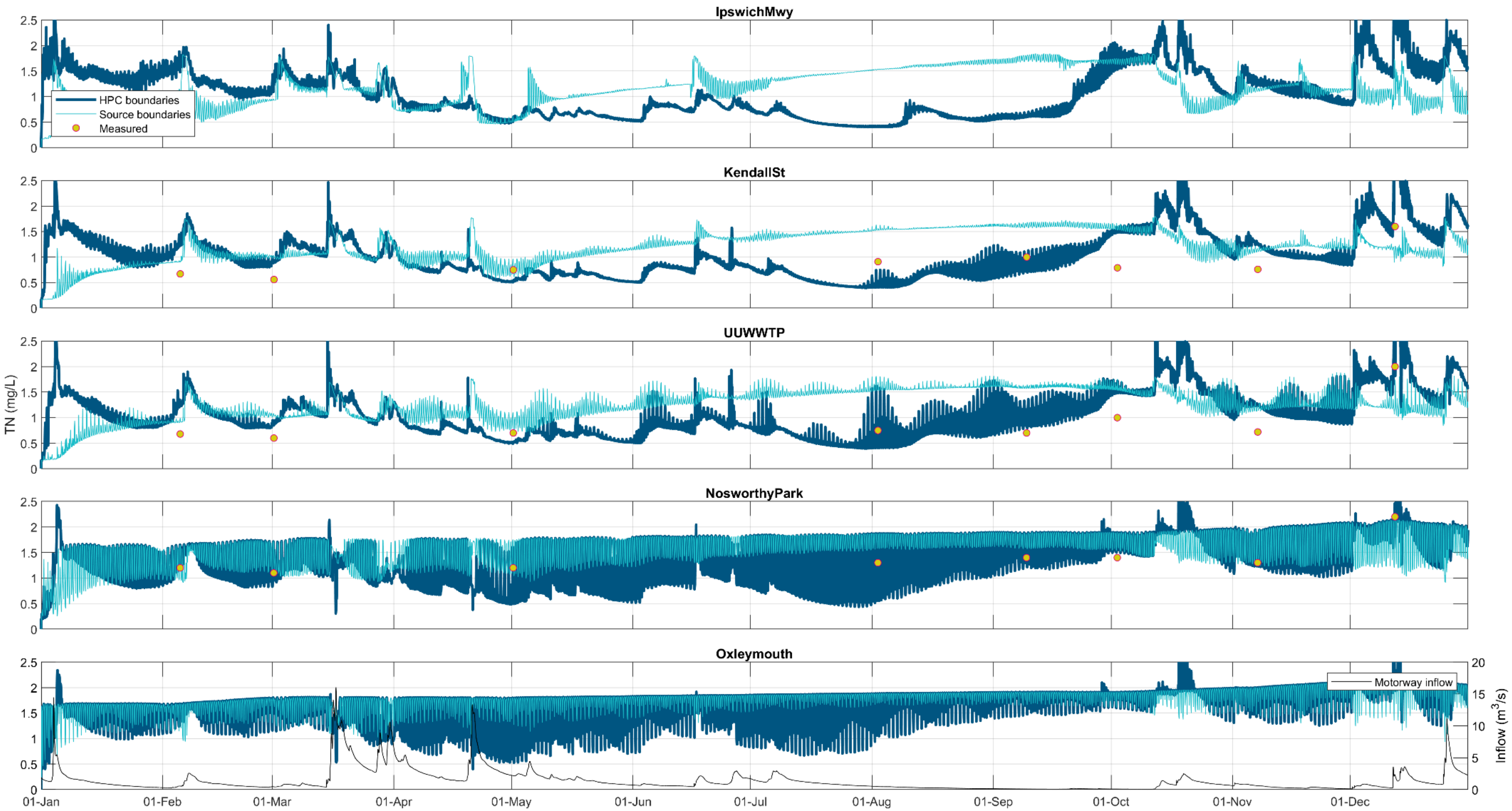

Figure 5.20 2019 Total Nitrogen Timeseries

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The above figures present a similar scenario to sediment: tidal influx of nitrogen dominates in both models, and rather than being balanced by settling (as was the case for sediment), internal consumption of nitrogen is the primary balancing flux. Of these internal fluxes, denitrification dominates (Figure 4.81). Although there is a measurable catchment influx of nitrogen in the TUFLOW FV model forced by TUFLOW HPC, the corresponding catchment fluxes in the other TUFLOW FV model are negligible. As for sediment, this a priori knowledge can assist greatly in constructing meaningful management intervention scenarios, or indeed more broadly determining whether this balance of fluxes is a reasonable reflection of the environmental system under consideration.

As was the case for salinity, the change in nitrogen mass flux balance between the two TUFLOW FV simulations allows for additional ingress of nitrogen from the tidal boundary back into Oxley Creek. This is a direct result of the lesser volumetric catchment influx predicted by the existing lumped model compared to TUFLOW HPC’s inflow boundary predictions. This increase in the standing mass of nitrogen in the creek is again evident in the above figures, with the standing mass being greater over the August to November period in the TUFLOW FV model forced by the existing catchment model. As was the case for salinity, this increase in standing mass has a profound impact on the prediction of nitrogen concentrations in Oxley Creek: during the mid year drier period, the TUFLOW FV model forced by the existing lumped model substantially overpredicts in-creek total nitrogen concentrations and the mass flux analysis reveals that this overprediction is due to the influence of the tidal boundary. Conversely, the other TUFLOW FV model captures well the measured total nitrogen concentrations.

Phosphorus masses are presented below.

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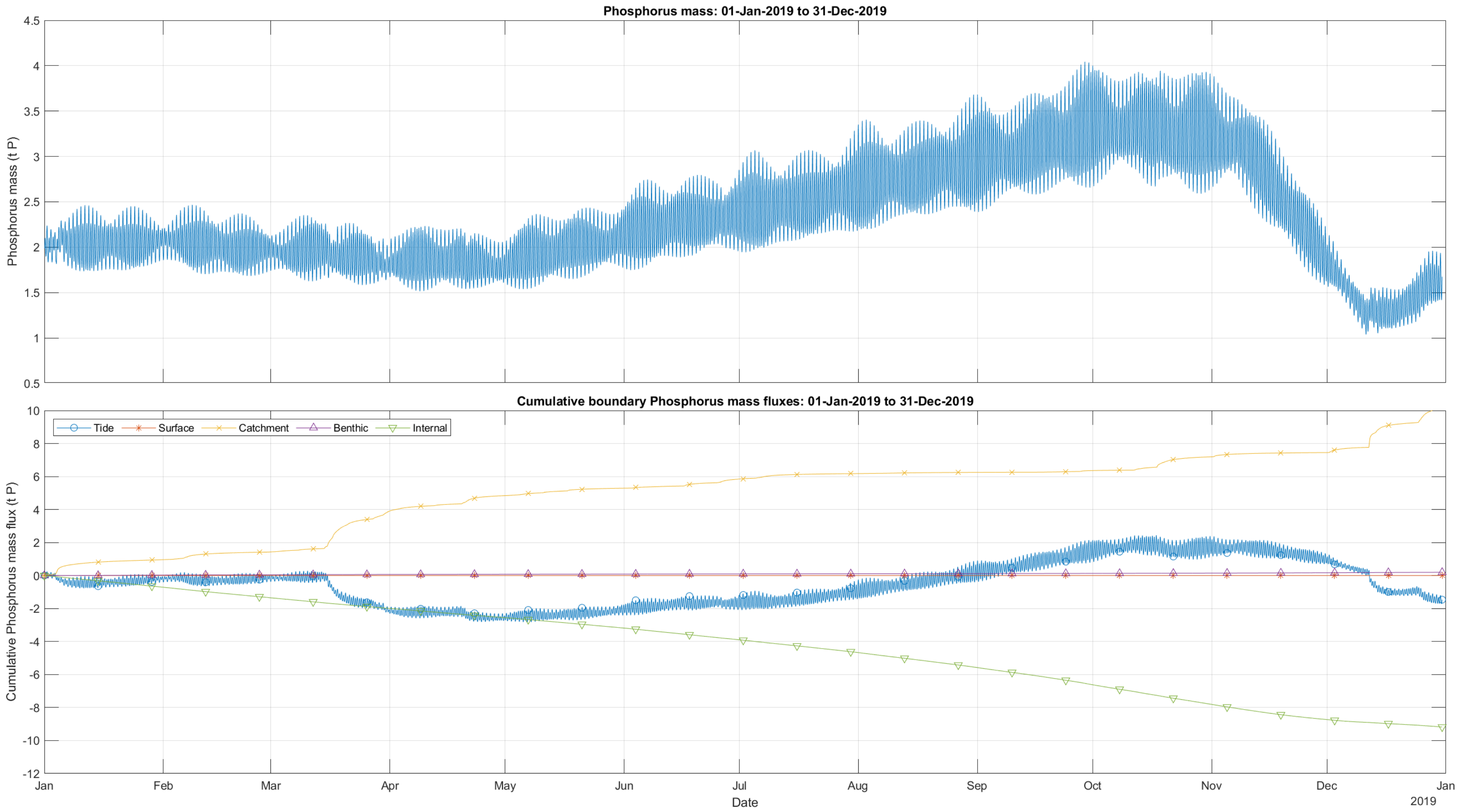

Figure 5.21 2019: Mass and Cumulative Flux Timeseries (TUFLOW HPC Boundaries): Total Phosphorus

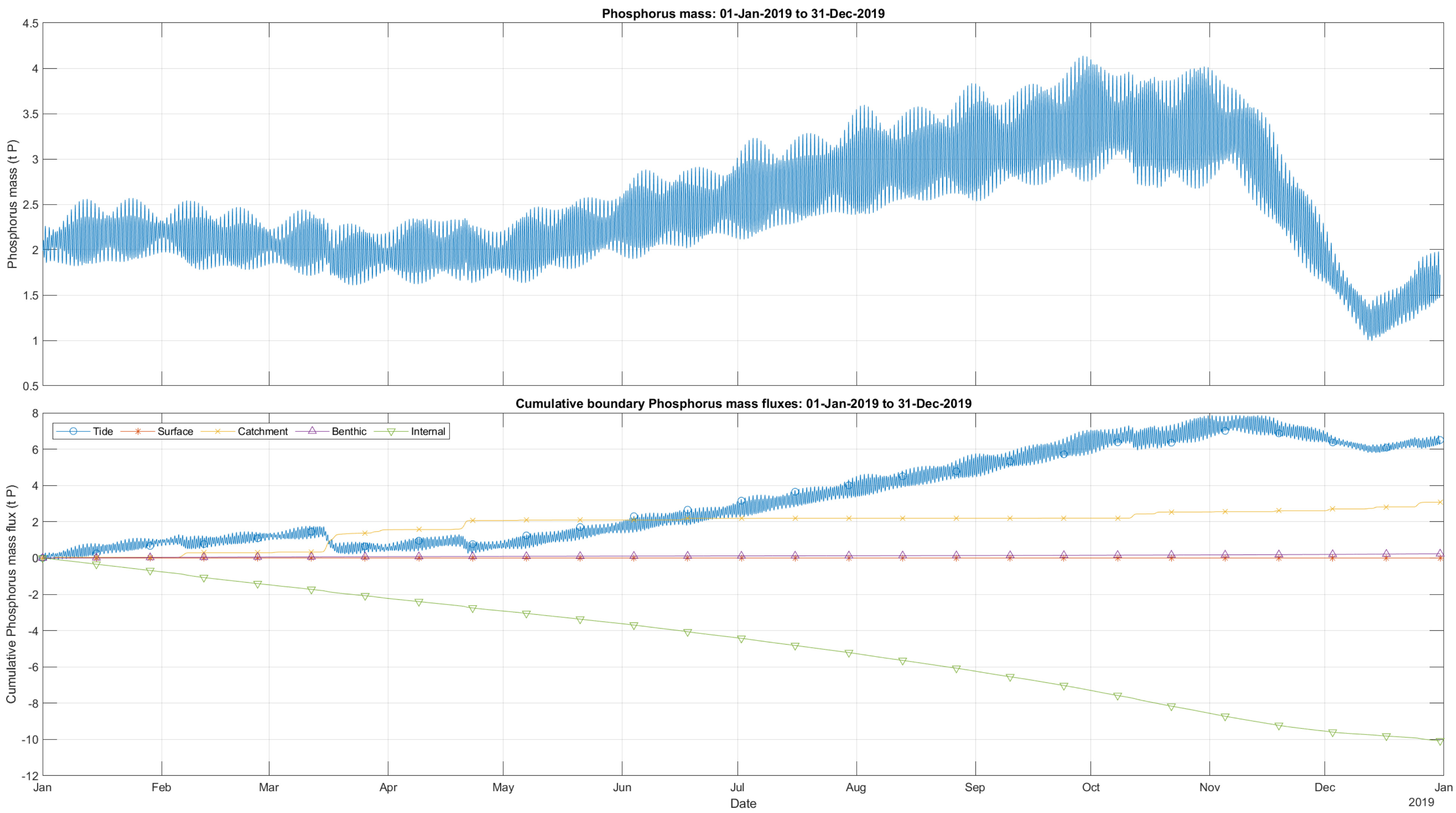

Figure 5.22 2019: Mass and Cumulative Flux Timeseries (Existing Model Boundaries): Total Phosphorus

BMT (UNOFFICIAL)

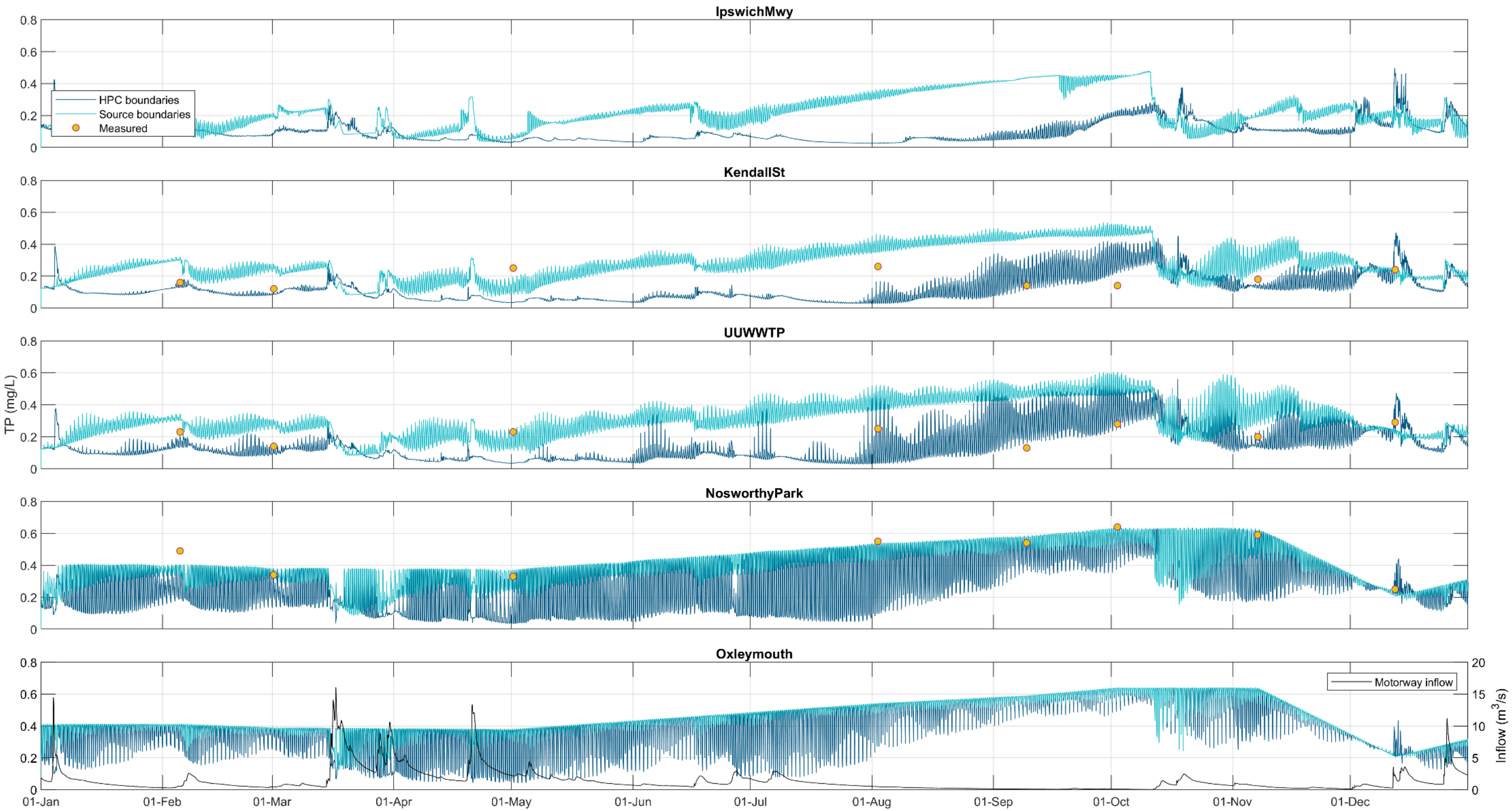

Figure 5.23 2019 Total Phosphorus Timeseries

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The figures above present a shift in underlying phosphorus mass fluxes that directly parallels those previously described, so will not be laboured here. In short: the reduced catchment inflow volumes predicted by the existing lumped model compared to those predicted by TUFLOW HPC allows for excessive ingress of phosphorus upstream into Oxley Creek, and therefore tidal phosphorus mass fluxes dominate.

This behaviour is however, accentuated in the case of phosphorus. Figure 5.22 reveals that at no stage throughout the annual TUFLOW FV simulation under the forcing of the existing catchment model boundaries does the cumulative tidal flux of phosphorus become negative. This is to say that the tidal boundaries represent an ongoing cumulative positive flux of phosphorus into Oxley Creek under these boundary conditions. This is in direct contrast to the parallel cumulative tidal mass flux timeseries presented in Figure 5.21, which oscillates in sign throughout the year, thus allowing net phosphorus transport in both directions across the tidal boundary.

The above process translates again to an increased standing mass of phosphorus in the TUFLOW FV predictions forced by the existing lumped model, and a subsequent substantial overprediction of in-creek total phosphorus concentrations (Figure 5.23), compared to measurements. This overprediction commences during drier times, as early in the year as late May, and becomes more pronounced as the drier period progresses.

The implications for prediction of phytoplankton dynamics are presented below.

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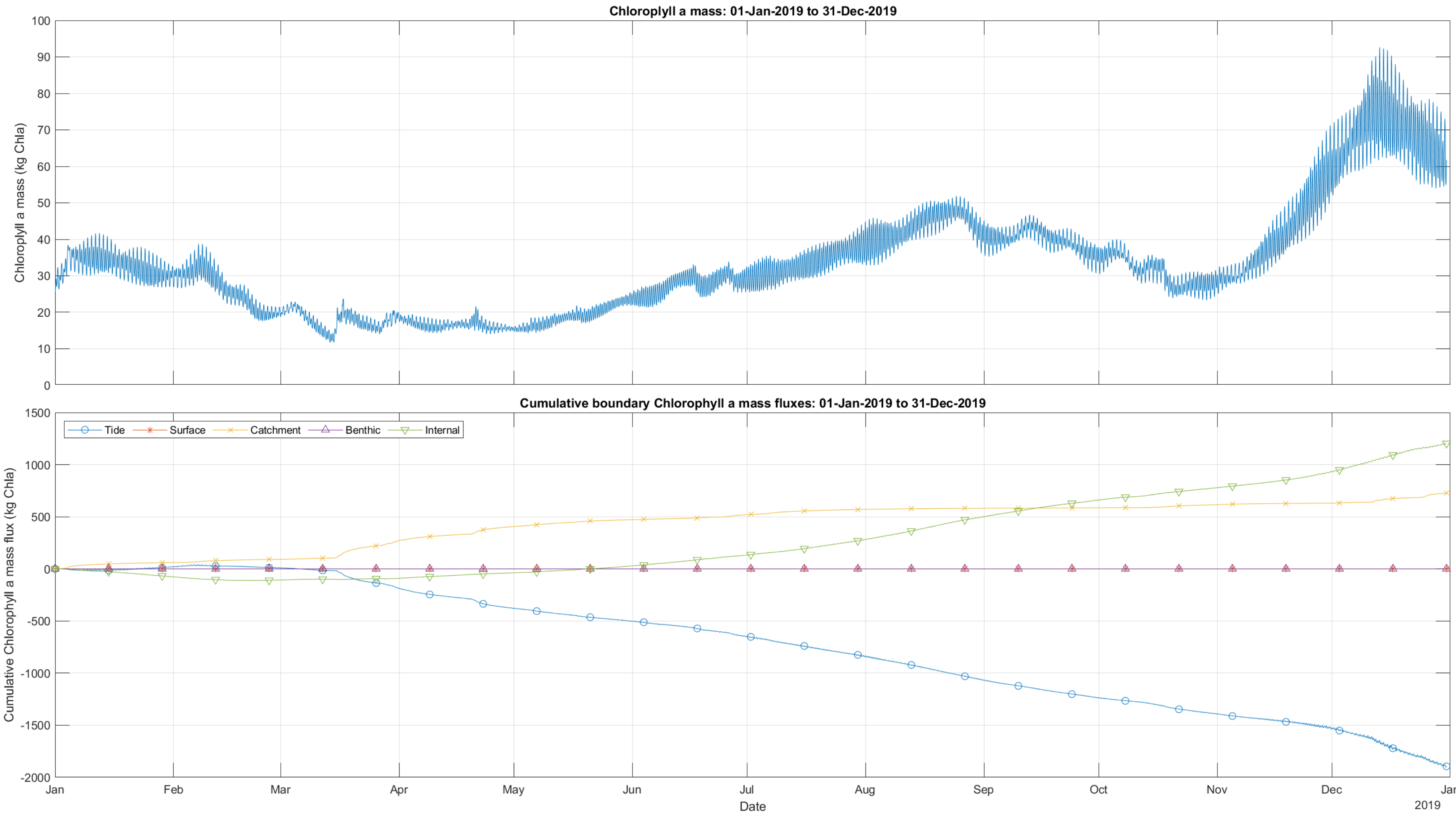

Figure 5.24 2019: Mass and Cumulative Flux Timeseries (TUFLOW HPC Boundaries): Total Chlorophyll *a*

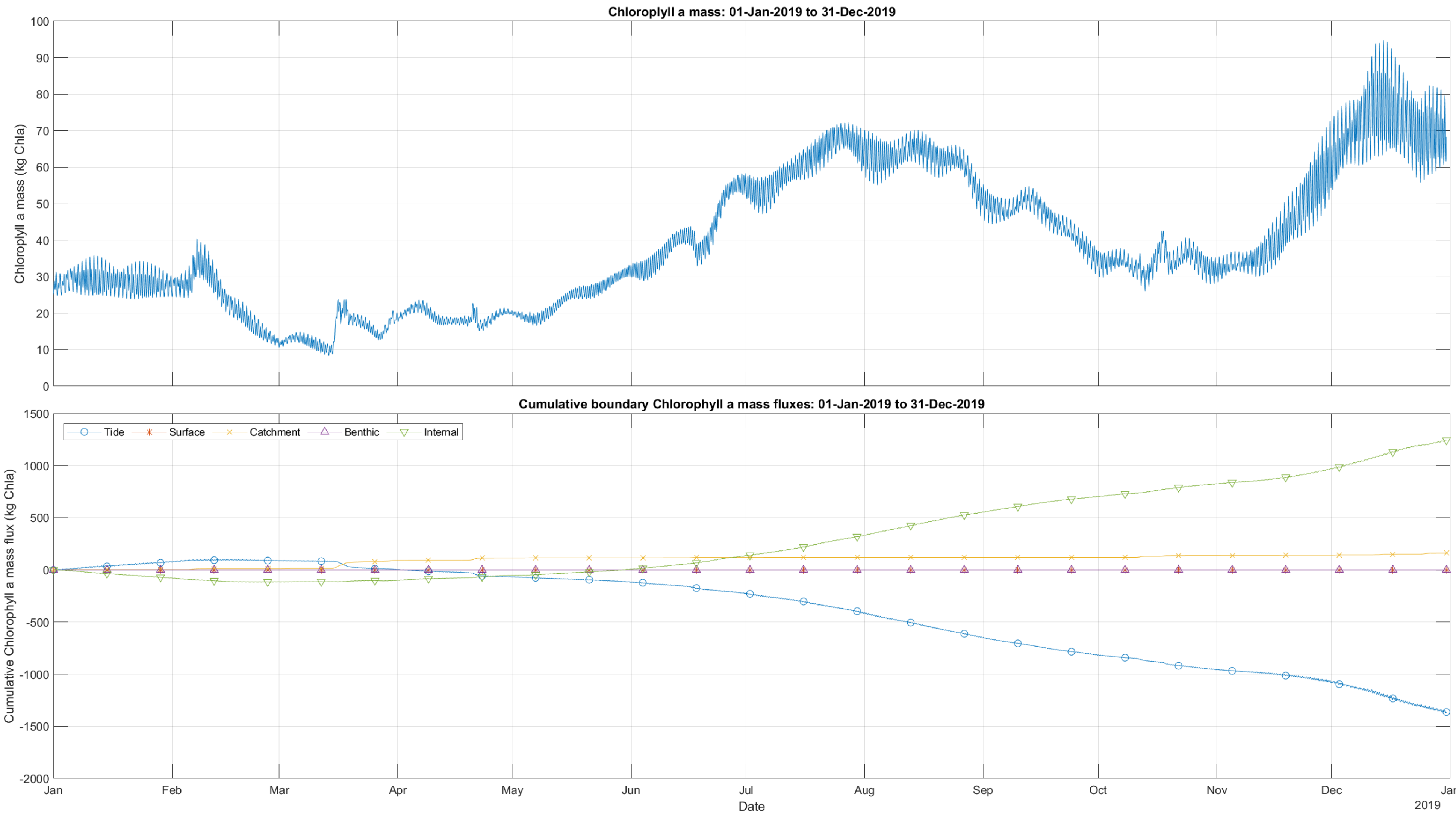

Figure 5.25 2019: Mass and Cumulative Flux Timeseries (Existing Model Boundaries): Total Chlorophyll *a*

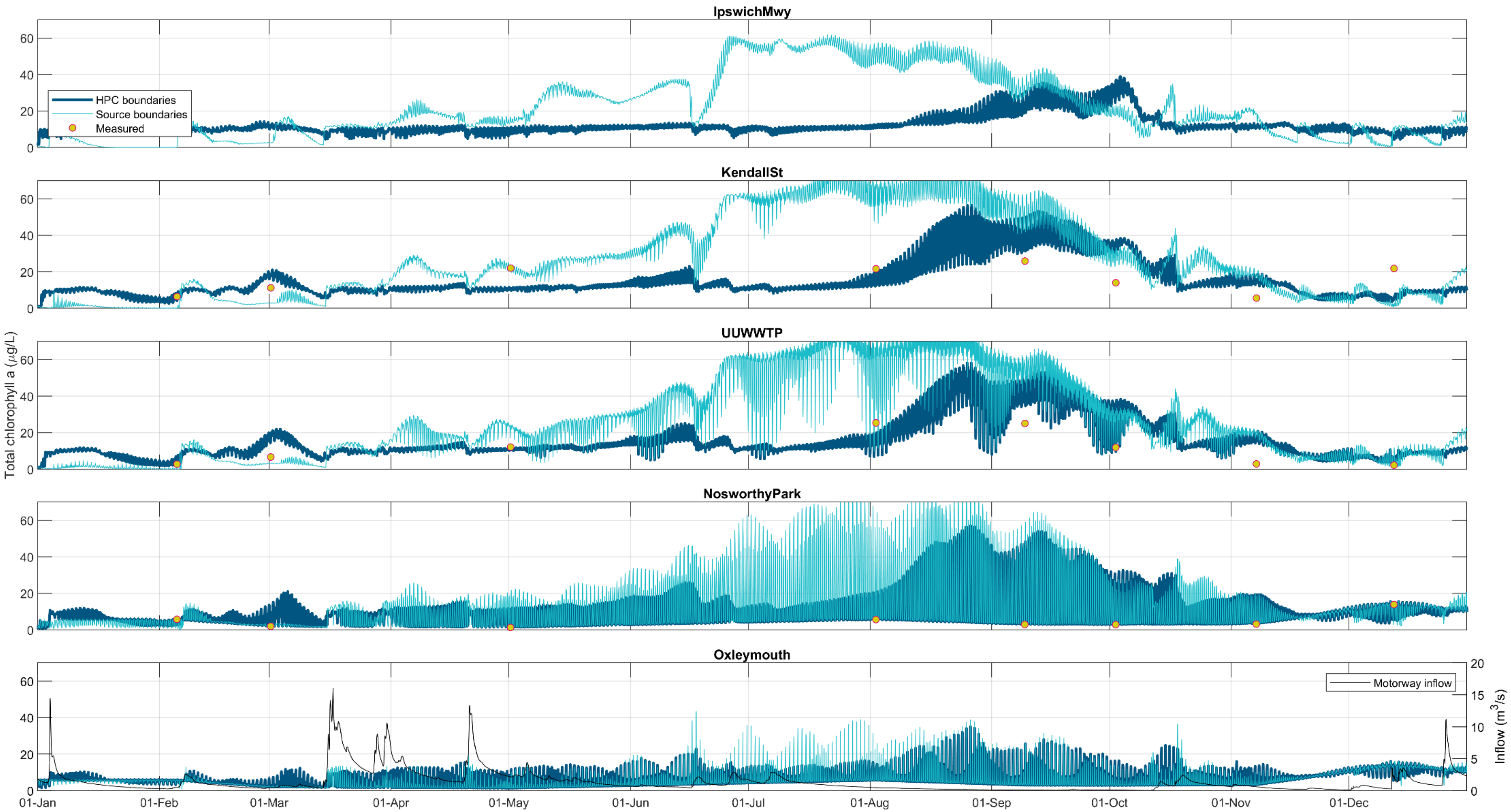

Figure 5.26 2019 Total Chlorophyll *a* Timeseries

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Figure 5.24 and Figure 5.25 present chlorophyll a mass flux pathways that are broadly similar, i.e. that phytoplankton undergoes primary production in-creek, and is advected downstream and out of the system. The relative magnitudes of these key fluxes do however vary between the two TUFLOW FV simulations, with the TUFLOW FV simulation forced by the existing lumped model demonstrating generally lesser downstream flushing (and system exit) and greater in-creek primary productivity. This is consistent with previous mass flux analyses:

- Lesser downstream flushing of chlorophyll *a* is a result of lesser catchment inflow volumes available to advect phytoplankton out of the system, and
- Greater in-creek primary productivity is a result of the introduction of both nitrogen and phosphorus to the creek from the downstream tidal boundary (which in turn is also a response to reduced catchment inflows predicted by the existing catchment model)

The above shift in mass flux pathways results in a substantial mid-year overprediction of chlorophyll *a* concentrations in the TUFLOW FV model forced by boundary conditions from the existing lumped model (Figure 5.26). At their peak, the associated chlorophyll *a* masses are accordingly some 20 kg greater in this model (Figure 5.25).

Further insight into the exact mechanism by which this occurs can be found by interrogating the limitation function diagnostic outputs produced by the TUFLOW FV WQ Module for both TUFLOW FV simulations. These are presented below, for only temperature, nitrogen and phosphorus, for clarity. Limitation functions of 0 and 1 indicate complete suppression and no suppression of primary productivity, respectively.

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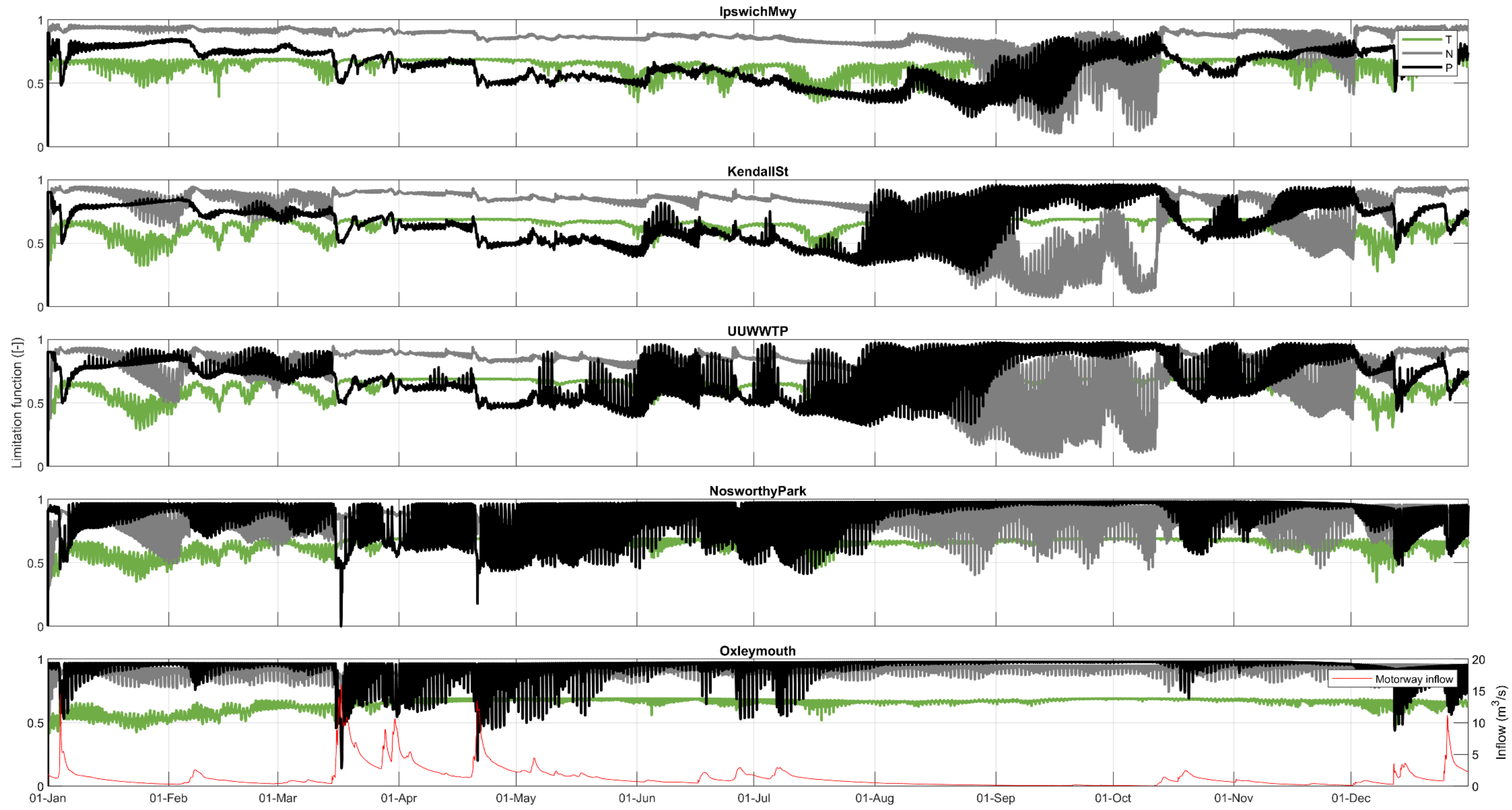

Figure 5.27 2019: Phytoplankton T, N and P Limitation Function Timeseries (TUFLOW HPC Boundaries)

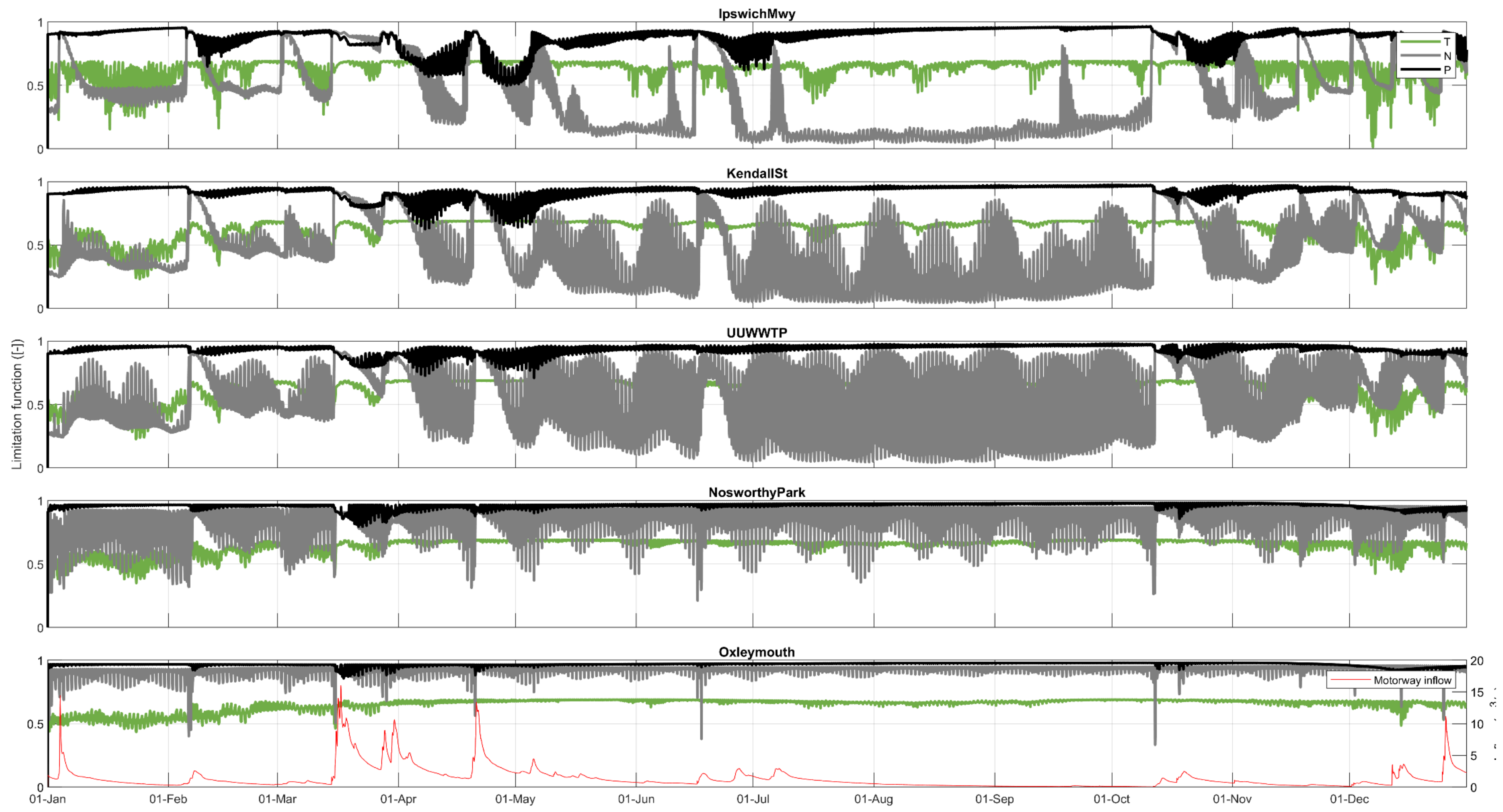

Figure 5.28 2019: Phytoplankton T, N and P Limitation Function Timeseries (Existing Model Boundaries)

The figures show that:

- Temperature limitation (green line) is essentially unchanged between the two simulations, as expected
- Phosphorus limitation (black line):
  - Almost entirely controls primary productivity in the TUFLOW FV simulation forced by TUFLOW HPC boundaries, as would reasonably be expected in such a fresh-estuarine system. This phosphorus limitation is progressively relaxed over the course of the year as the nett influx of phosphorus from the downstream boundary ingresses
  - Almost never controls primary productivity in the TUFLOW FV simulation forced by the existing lumped model
- Nitrogen limitation (grey line):
  - Only controls primary productivity in the TUFLOW FV simulation forced by TUFLOW HPC boundaries when the phosphorus limitation is relaxed (above)
  - Almost always control primary productivity in the TUFLOW FV simulation forced by the existing catchment model

Whilst in this instance, differences in the predicted chlorophyll *a* concentration timeseries are easily identified by eye, and these differences are attributable to variations in underlying flux pathways, the above limitation function timeseries are by far the most illuminating resource. In short, they reveal that:

- When TUFLOW HPC hydrologic predictions are used to force the Oxley Creek TUFLOW FV model, phytoplankton behave as a phosphorus limited species, which typifies fresh-estuarine phytoplankton groups, but
- When the existing lumped model is used to force the same (and identically parameterised) TUFLOW FV model, a structural change in the simulated phytoplankton community is induced, and the phytoplankton behave as nitrogen limited, which are less associated with waterways such as Oxley Creek, and more commonly associated with marine environments.

In short, different hydrologic forcing of the Oxley Creek TUFLOW FV model produces diametrically opposed phytoplanktonic responses in the receiving waterway.

5.2.3 Analysis

Substantial insight and system understanding has been gained through analysis of mass flux pathways in the Oxley model, under two different catchment boundary forcings. This, in combination with phytoplankton limitation function analysis, has revealed the underlying mechanisms that control water quality prediction in Oxley Creek – it has been demonstrated that such insight is not offered readily by examination of concentration timeseries and annual medians alone.

The analysis presented above was able to identify and describe mass flux pathway modifications that occurred when a TUFLOW FV model forced by TUFLOW HPC had this boundary forcing replaced with those from an existing lumped catchment model. The common thread running through almost all these modifications, either directly or indirectly, was the substantial difference in the prediction of the basic hydrologic regime. This was:

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- The existing catchment model predicted approximately six times less total flow volume entering Oxley Creek in 2019 compared to the TUFLOW HPC predictions (Table 5.1), and yet
- The peak (spot) flow rates predicted by the two hydrologic models during events were generally not too dissimilar (Figure 5.2 uppermost pane), but
- That the TUFLOW HPC model predicted long and smooth falling limbs after each inflow event (where these falling limbs were also observed in gauge data to which TUFLOW HPC calibrated well using hourly statistics), and
- That these falling limbs were almost entirely absent in the predictions of the existing catchment model (Figure 5.1, Figure 5.2 and Figure 5.3, uppermost panes)

It seems therefore most likely that the existing catchment model's inability to predict these falling limbs is of first order importance in accounting for the divergence in total flow delivered to Oxley Creek in 2019. If this is the case, then the analysis presented in this section provides a direct causal link between poor hydrologic prediction (i.e. an absence of known falling limbs, and even before considering pollutant export) and induced phytoplanktonic assemblage modifications in downstream receiving water quality models. The intermediate steps in this linkage for Oxley Creek are:

- Absence of falling limbs causes underestimation of water volumes delivered to a receiving model as catchment inflows
- This allows for too rapid nutrient recovery up Oxley Creek after flushing rain
- This releases phosphorus limitation of phytoplankton primary productivity and replaces it with nitrogen limitation, which is a fundamental shift in assemblage dynamics

All this is to say that it has become clear in this pilot modelling study, and comparative mass flux analysis, that accurate and robust prediction of catchment hydrology – right down to details such as accurate falling limb prediction – is likely essential for providing the foundations for similarly robust downstream receiving water quality modelling to be executed.

This pilot model has demonstrated that with its enhancements and features, TUFLOW Catch is a platform that now offers the level of rigour required to drive holistic catchment modelling and management forwards.

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6 Intended Workflow

6.1 General Process

The generally intended process for constructing a TUFLOW Catch simulation is as follows:

1. Use the QGIS tool described in Section 6.2 to automatically construct the standard folder structure and have it populated with template and empty files

2. Use the TUFLOW Catch (*.tcc) template file generated above to commence constructing the simulation, and specifically:

    a. Set the simulation details in the Global Commands block (see Section 3.3.1)

    b. Commence construction of the TUFLOW HPC model in the second *tcc block (see Section 3.3.2). Typically this would be the first model to be built and calibrated (because it drives the downstream TUFLOW FV model) and this TUFLOW HPC model should be run directly through the TUFLOW Catch control file, independently of other construction work that may be occurring. This is achieved simply by commenting out the other blocks (pollutant export and TUFLOW FV) in the *tcc file. When this is done, TUFLOW Catch will run only the TUFLOW HPC component of the TUFLOW Catch simulation

    c. Commence construction of the pollutant export model in the third *.tcc block (see Section 3.3.3). This can be undertaken independently of the TUFLOW HPC and TUFLOW FV modelling and calibration process, but will be needed when pollutant export is turned on in TUFLOW Catch (by uncommenting the pollutant export block in the *.tcc control file)

    d. Commence construction of the TUFLOW FV model in the final *.tcc block (see Section 3.3.4). Again, many of the tasks associated with constructing a TUFLOW FV model can be undertaken independently of the TUFLOW HPC and pollutant model set up and calibration. These tasks include, for example, mesh construction and testing, atmospheric data assignment, application of tidal / downstream boundaries, assignment of extractions, and general speed and stability testing. This process should also be undertaken through the TUFLOW Catch *.tcc control file, with the TUFLOW HPC and pollutant export command blocks commented out.

3. Calibrate the TUFLOW HPC hydrologic/ hydraulic model to available data and finalise model

4. Finalise pollutant export model construction (although this can be altered at any time subsequent)

5. Run TUFLOW Catch with all command blocks turned on. This will:

    a. Execute the calibrated TUFLOW HPC model (with hydrology, hydraulics and pollutant export turned on)

    b. Automatically locate, configure and write all the boundary condition data expected by TUFLOW FV

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   c. Execute TUFLOW FV, using the boundary conditions produced by TUFLOW HPC and the pollutant export model

6. Review the calibration performance of TUFLOW FV, and then commence calibration of that HD, (ST) and WQ model. There is no need to rerun the TUFLOW HPC model each time a TUFLOW FV calibration run is required – the *.tcc control file should be used with the TUFLOW HPC and pollutant export blocks commented out. This will just run TUFLOW FV, using the latest boundary condition files generated by TUFLOW HPC.

6.2 Initiation

The following instructions describe how to access the TUFLOW Catch QGIS tool and use it to setup and configure a TUFLOW Catch simulation.

6.2.1 QGIS / Plugin Installation

A set of GIS tools have been developed specifically for TUFLOW Catch as part of this study to help setup, edit, and view results of TUFLOW Catch models. The tools have been developed inside a plugin framework for the QGIS software package. QGIS is an open source (free) GIS program that is widely used by many sectors, however specifically it is already used by the majority of TUFLOW modellers as part of their modelling workflow.

The 'TUFLOW Catch Plugin' is a distinct plugin and separate to the existing 'TUFLOW Plugin', however there are some overlaps between the tools and existing TUFLOW/QGIS users should find the TUFLOW Catch plugin familiar. The following sections act as interim documentation for the TUFLOW Catch Plugin until such a time that the plugin is publicly released.

The latest QGIS version can be downloaded from the following location. The TUFLOW Catch plugin requires **QGIS v3.30 or later**.
https://qgis.org/en/site/forusers/download.html

It can also be installed via OSGeo4W, which has many benefits over installing via the binary (exe) package installer (either installation method is suitable):
https://wiki.tuflow.com/QGIS_Tips#Installation_via_OSGeo4W

To install the TUFLOW Catch plugin:

7. Download the plugin from the following location:
   https://downloads.tuflow.com/Private_Download/tuflow_catch_plugin/tuflow_catch_plugin.zip

8. Open the 'Plugin Manager' in QGIS (Plugins >> Manager and Install Plugins)

9. Navigate to 'Install from ZIP', point it to the downloaded zip file, press 'Install Plugin'

10. Navigate to 'Installed Plugins' and ensure that 'TUFLOW Catch' is checked on

The TUFLOW Catch plugin is made up of a toolbox (located in the QGIS Processing Toolbox) and a toolbar. The following tools can be found in the toolbox:

- Create TUFLOW Catch Project

- Import Empty File

The following tools can be found in the toolbar:

- Open Result
- Time Series Plot
- Cross-section Plot
- Curtain Plot
- Vertical Profile Plot

One other tool can be found in the context menu after right clicking a vector layer in the Layers Panel:

- Increment Layer
- TUFLOW Styling
- Correct GPKG Name (only available for GPKG layers)

For more information on the Processing Toolbox please see the following links:

- QGIS - Processing Toolbox

6.2.2 Project Configuration and Setup

The 'Create TUFLOW Catch Project' toolbox should be used to initialise a TUFLOW Catch project. As part of its the configuration, the tool will:

- Create the TUFLOW Catch folder structure
- Generate TUFLOW HPC and TUFLOW FV empty input files
- Create a series of template control files for running TUFLOW Catch
- Saves the configuration for use with other TUFLOW Catch toolbox tools

For a description on the inputs, please read the tooltip located inside the toolbox. The inputs for this example workflow should be:

11. **Project Name:** oxley
12. **Project Folder:** <modelling folder directory>

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13. **Project CRS:** EPSG:28356 – GDA94 / MGA zone 56

14. **TUFLOW HPC Executable:** <file location of TUFLOW Catch HPC exe>

15. **TUFLOW FV Executable:** <file location of TUFLOW Catch FV exe>

16. **Default GIS Format:** GPKG

17. **All additional options checked on**

6.2.3 Importing Empty Inputs

During the model build process empty files should be used to create GIS input into both the catchment HPC model and the receiving FV model. The 'Import Empty' tool can be used to automate this step by giving the user easy access to all the different empty types (with descriptions) and then, once run, the new GIS layer will be saved into the appropriate folder with the desired name and opened in QGIS.

Please see the tooltip in the tool dialog for more information on the specific input parameters. An example of importing a 2d_code for the TUFLOW HPC model is given below:

18. **Project Folder:** <modelling folder directory> *(Note: this should be pre-populated if the 'Create TUFLOW Catch Project' tool has been run).*

19. **Empty Type:** '2d_code'. If the list of empty types is blank, then potentially the empty files were not created properly, and it's recommended to check if they exist within their respective gis/empty folders.

20. **Geometry Type:** 'Region'

21. **Run ID:** 'oxley' (or a run number can also be included i.e. 'oxley_001')

22. ***Other Options:*** *Can be customised by the user*

6.2.4 Incrementing Layers

It is common practice to increment layers before editing them if they were used on a previous model run. The old layers then provide a backup and ability to wind back model changes to a previous state. The TUFLOW Catch plugin offers a tool to automate the incrementing steps as described below.

The increment tool can be initialised by right clicking a layer in the Layers Panel and selecting the increment layer option (TUFLOW Catch >> Increment Layer). The available options will depend on whether the layer is a Shapefile or a GPKG.

- **Shapefile:**
  - 'Increment Layer' - saves the current shapefile into a new file and opens it in QGIS.
- **GPKG:**

- ‘Increment Layer and Database’ - saves chosen layers into a new (or existing) GPKG database and opens the new layers.
- ‘Increment Layer’ – saves the chosen layer into a superseded location (as a backup) and allows the current layer to safely be edited.

Please see the tooltips on the given tool for more information.

6.2.5 Styling Layers

The TUFLOW Catch plugin offers a tool to quickly style (via pre-set defaults) input layers, log outputs, check files, and results. The styling tool can be found by right clicking the open layer in the Layers Panel in QGIS and selecting ‘TUFLOW Styling’ (TUFLOW Catch >> TUFLOW Styling). This tool is only available for vector layers currently.

6.2.6 Correcting GeoPackage Layer Names

The TUFLOW Catch plugin offers a tool to correct GeoPackage layer names in the Layers Panel in QGIS. This may be required on occasion as QGIS will sometimes add the database name to the open layer name. This tool can be found by right clicking the open GeoPackage layer in the Layers Panel in QGIS and selecting ‘Correct GPKG Name’ (TUFLOW Catch >> Correct GPKG Name).

6.3 Execution

The steps outlined in Section 6.1 should be followed to execute the various stages of a TUFLOW Catch simulation. In all instances however, TUFLOW Catch is called (regardless of which command blocks it is running) by issuing a command line instruction that directly parallels the execution of existing TUFLOW products, that is (with the example control file Oxley_001.tcc):

```
C:\>"C:\TUFLOW\TUFLOWCatch.exe" -pu0 Oxley_001.tcc
```

A batch file can also be used to initiate a TUFLOW Catch simulation, and in this file the standard TUFLOW commands can be used to specify parameters such as executable path and GPU ID.

```
set exe="C:\TUFLOW\TUFLOWCatch.exe"     ! Sets path of TUFLOWCatch executable
set OMP_NUM_THREADS=6                   ! Sets number of threads to use in CPU portion of calculations

%exe% -pu0 Oxley_001.tcc                ! Initiates a TUFLOW Catch simulation using GPU 0
```

6.4 Visualisation

This section describes the steps involved in visualising the results of TUFLOW Catch in QGIS.

6.4.1 Opening Results

Before loading any layers into a QGIS workspace, it is generally good convention to ensure that the workspace Coordinate Reference System (CRS) is set correctly. This can be done via the project properties (Project >> Properties >> CRS). This example uses GDA 94 / MGA zone 56 (EPSG:28356).

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For more information on projections in QGIS, please see the following link:
[QGIS - Working with projections]

Clicking the ‘Open Results’ tool on the TUFLOW Catch toolbar will prompt the user to select the result to load. The file with the extension “.tuflow.json” should be selected to import the results into QGIS. Note, the results from TUFLOW catch do not have the CRS natively specified in the output format (although they are spatially in the correct position) and the CRS may be required to be set for the layer once loaded in QGIS.

6.4.2 Changing Result Type and Styling

Switching between result types can be done via the ‘Layer Styling’ panel. The quickest way to open this is by pressing F7 and by default it should appear on the right-hand side of the QGIS window (note F7 will toggle this window, i.e. if it is already open, F7 will close it).

If there are multiple layers open in QGIS, the ‘Layer Styling’ panel will show what is currenting selected in the ‘Layers’ panel. Changing result types, colour ramps, vector options, mesh rendering, and how 3D results are depth averaged are all controlled within the ‘Layer Styling’ panel.

For more information on the ‘Layers’ panel and ‘Layer Styling’ panel, please see the following links:

- QGIS - Layers panel
- QGIS - Mesh layer properties

6.4.3 Changing Output Time

The output time can be changed by using the native ‘Temporal Controller’ in QGIS. The temporal controller can be viewed by clicking the ‘Temporal Controller Panel’ icon in the QGIS toolbar (it is part of the ‘Map Navigation’ toolbar). Another method of viewing the temporal controller is by right clicking anywhere in the QGIS toolbar and under the ‘Panels’ section, check on ‘Temporal Controller Panel’.

Selecting ‘Animated Temporal Navigation’ will turn on the temporal controller. Clicking ‘Set to Full Range’ should set the temporal controller to the appropriate start time, end time, and timestep.

For more information on the temporal controller, please see the following links:

QGIS - The temporal controller panel

6.4.4 Plotting

Plotting directly from the map outputs can done via the TUFLOW Catch plugin. Note, plotting time series outputs from TUFLOW HPC or TUFLOW FV is not currently supported in the plugin.

The TUFLOW Catch plugin supports 4 plot types:

- Time series plot – extracts a given 2D depth averaged result for a single location over the full temporal output range
- Cross-section plot – extracts a given 2D depth average result sampled along the cross-section line for a single temporal output
- Curtain plot – extracts a given 3D result sampled along the cross-section line for a single temporal output
- Vertical profile plot – extracts a 3D result for a single location for a single temporal output

Initialising a Plot

The steps below outline how to initialise a plot:

23. Ensure the result layer is selected (highlighted) in the QGIS 'Layers' panel

24. Use the drop-down arrow next the plot icon to select:

    a. Whether to plot from a New Location (user can draw a new point/line anywhere on the map) or From Layer (this is an existing vector layer already in the QGIS workspace). If From Layer is selected, the layer must be also checked-on in the From Layer sub-menu and a feature from the layer must also be selected on the map already.

    b. Which result types to plot. Multiple options can be selected. Time series and cross-section plots also support a number of custom depth averaging types.

25. Click the plotting button (so that it becomes indented). If plotting a New Location, the user should now select a location in the QGIS map window to plot from. For time series and profile plots, this will be a single point which can be placed by left clicking. For cross-section and curtain plots, a line should be drawn by left clicking to add a vertex and right click to finish (the line should contain at least 2 vertices).

Once initialised, all the plotting options can be found in the right click context menu.

Plotting Menu Options

Add/Remove (Ctrl+Alt+A) menu options:

- Add Location – user can add a new location from the map window

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- From Layer – user can add a location from an existing vector layer (features in layer must already be selected in QGIS map window)
- Model Results – user can toggle on/off which model results should be plotted
- Result Types – user can toggle on/off which result types should be plotted
- Locations – user can toggle on/off which (already plotted) locations should be plotted

Subplots (Ctrl+Alt+S) menu options:

- Add Subplot Right – Adds a subplot to the right of the current plot
- Add Subplot Below – Adds a subplot below the current plot
- Move To Secondary Axis – Available if the user has right clicked a line using the primary axis. Moves the selected line to the secondary axis
- Move to Primary Axis – Available if the user has right clicked a line using the secondary axis. Moves the selected line to the primary axis
- Remove Secondary Axis – Available if a secondary axis exists. Removes the secondary axis and moves any lines that are using the secondary axis to the primary axis
- Move to Subplot – Available if the user has right clicked a line and multiple subplots exist. Moves the line to the desired subplot
- Remove Subplot – Available if multiple subplots exist. Removes the selected subplot from the figure

Depth Averaging Plots (Ctrl+Alt+D) menu options – *Available only for 2D depth averaged plots (time series, cross-section). Located under 'Result Types' sub-menu.*

- https://fvwiki.tuflow.com/Depth_Averaging_Results

Show Current Time – *Available only for time series plots.* Shows the current time as a vertical line in the plot window (temporal controller must be initialised).

Show Vectors – *Available only for curtain plots.* Shows vectors in relation (aligned) with the drawn line (if available).

Interpolate – *Available only for profile plots.* Toggles vertical interpolation of results between linear and stepped in the plot window.

Vertical Levels – *Available only for profile plots.* Toggles on the locations of the vertical levels (drawn as dashed horizontal lines).

Navigation Options – Plotting library specific navigation options. *Note, not all options are available and keyboard shortcuts may not work.*
https://matplotlib.org/3.2.2/users/navigation_toolbar.html

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Copy menu options:

- Copy Data to Clipboard – Copies all figure data to the clipboard so that it can be pasted into another program e.g. MS Excel
- Copy Selected to Clipboard – Available if the user has right clicked a line. Copies the data associated with the selected line to the clipboard so that it can be pasted into another program e.g. MS Excel
- Copy Image to Clipboard – Copies the figure as an image (as it currently appears) to the clipboard so that it can be pasted into another program
- Copy to Memory Layer – Copies all user drawn objects connected to the plot into a new QGIS memory vector layer
- Copy Selected to Memory Layer – Available if the user has right clicked a line. Copies the drawn object that is associated with the selected line into a new QGIS memory vector layer

Export menu options:

- Export Data to CSV – exports all figure data into a CSV
- Export Selected to CSV – Available if the user has right clicked a line. Exports the data associated with the selected line to a CSV
- Export Image – Saves the figure as an image file
- Export Vector Layer – Saves the user drawn objects connected to the plot into a GIS vector file
- Export Selected to Vector Layer – Available if the user has right clicked a line. Export the drawn object associated with the selected line to a GIS vector file

Plot Customisation

Many plot customisation options are not currently available (axis range, axis labels, line styling etc.). There are a couple of workarounds that can be used to get around some of these limitations:

- Freeze the axis limits – if the pan or zoom navigation tools are used, the axis limits are frozen (and colour ramp scale on curtain plots). Subsequent updates (e.g. using the temporal controller to update the output time) will not update the axis limits. This can be reversed by clicking the 'home' plot navigation tool
- Custom colours – custom colours for different locations can be achieved by using an existing layer to plot from. The existing layer should have a character attribute field called 'colours' which is populated by the desired colour as either a hexadecimal (e.g. "#1ABDC9"), RGB (e.g. "26,189,201"), or a common colour name (e.g. "cyan"). Note this customisation is only possible for different locations and not for different result types

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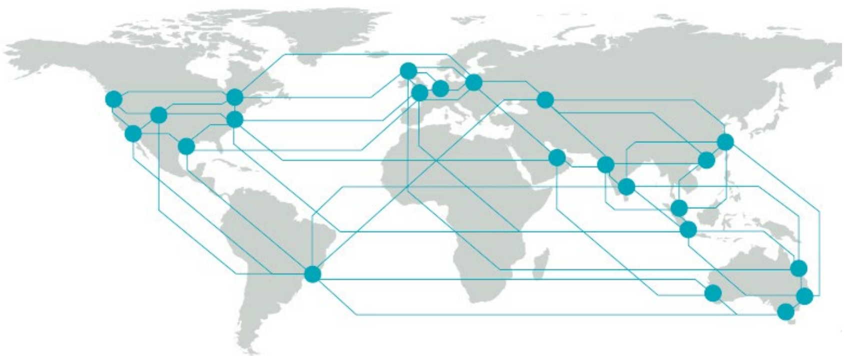

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