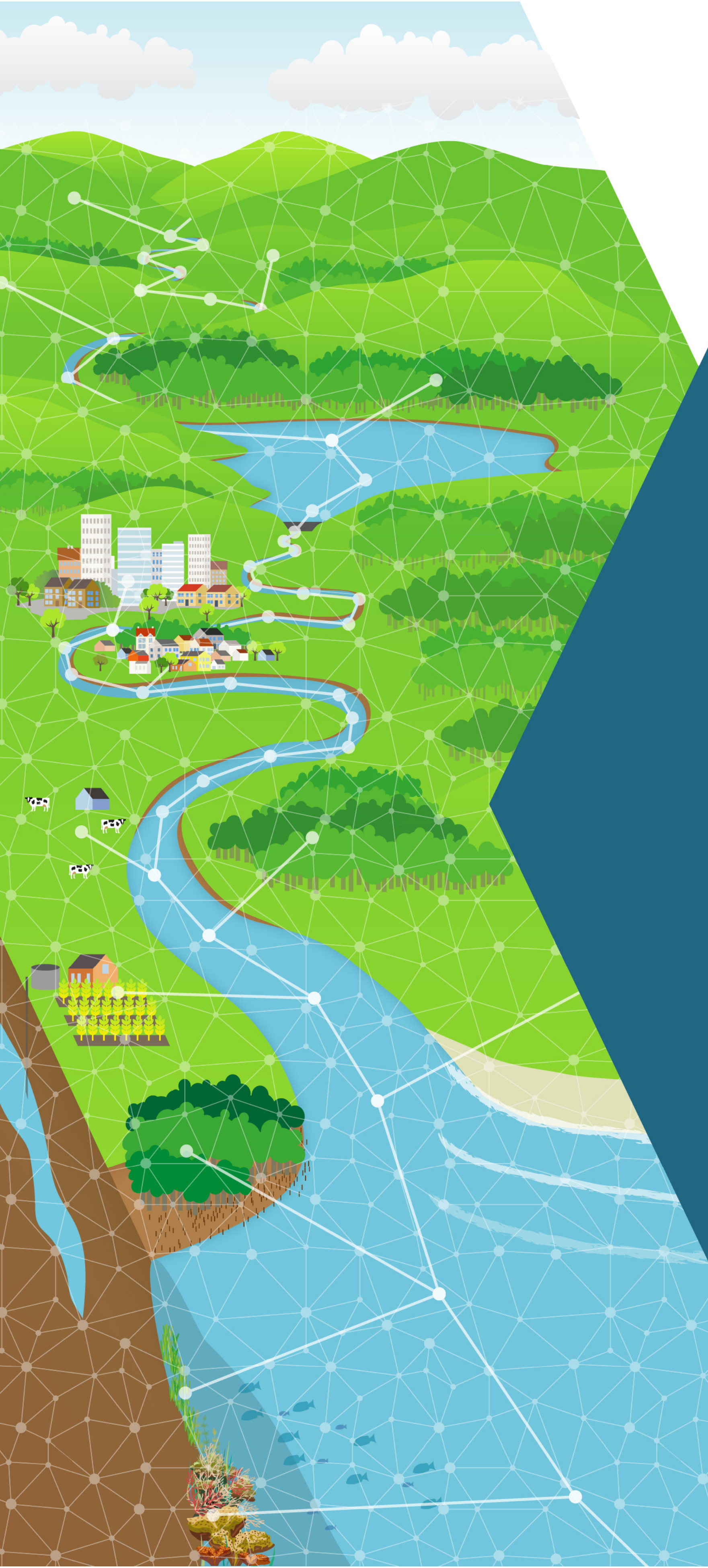
QUEENSLAND WATER MODELLING NETWORK



QWMN Wetland Hydrology Models Review

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For Queensland Water
Modelling Network

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The Queensland Water Modelling Network (QWMN) is an initiative of the Queensland Government that aims to improve the state's capacity to model its surface water and groundwater resources and their quality. The QWMN is led by the Department of Environment and Science with key links across industry, research and government.

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Summary

The aim of this project was to evaluate the suitability of different models that can be used to simulate the ability of wetlands to mitigate pollution, particularly nitrogen removal, in downstream receiving waters. Reliable and defensible models are also needed to document and demonstrate environmental licence and water quality offset requirements are met. Of particular concern is deterioration of the World Heritage listed Great Barrier Reef (GBR) and nationally significant Moreton Bay. The Great Barrier Reef marine ecosystems and their associated catchments are part of a dynamic, interconnected system. The condition of all parts of the system, including the catchment, is important for the long term health of the Great Barrier Reef. Each part has its own inherent ecosystem and biodiversity values and provides ecosystem services such as water quality improvement and carbon storage that benefit the receiving marine environment. Coastal freshwater wetlands continue to be affected by a range of chronic and acute pressures such as excess nutrient, sediment and pesticide loads; loss of connectivity; changes in hydrology and invasive species (Waterhouse et al 2017).

Wetlands can also play a vital role in protecting these systems, but models are required to ascertain the effectiveness of the wetlands for removing pollutants, the size and location of the wetlands, and whether the costs of establishing and/or managing wetlands provide value for money associated with good water quality outcomes. For the purpose of this report, a range of wetland types was considered, including constructed treatment wetlands (which are palustrine wetlands), and natural, palustrine, lacustrine and estuarine wetlands.

One of the main findings of this report is that model users should first ask whether the wetland model is suitable for the questions being asked. Important questions relate to the spatial resolution, temporal resolution and the biogeochemical processes. Wetland models can be box models (zero dimensional), one-dimensional (horizontally averaged), two-dimensional (vertically averaged) or three dimensional. Zero dimensional models can be dynamic with time-varying biogeochemical or steady state (static) processes. Higher dimensionality is associated with greater levels of complexity, requiring increased levels of modeller skill and more detailed topographic and bathymetric information about the catchment and wetland respectively. Most of the spatially resolved models (1D, 2D and 3D) are dynamic and provide detailed temporal information which can result in increased computation times, particularly for a 3D model. Wetlands can have high spatial variability, meaning that a modeller should consider carefully the consequences of using models of reduced spatial complexity. For example, a horizontally averaged 1D model may not be suitable for a long, shallow wetland that does not stratify but has large longitudinal gradients. On the other hand, a highly resolved 3D model may require too much computational time to be practical for doing multi-year simulation runs, if required.

Wetland hydrodynamic models vary in whether they are coupled with biogeochemical/ecological models and, for coupled models, in the complexity of the biogeochemical process representations. Some models include only the hydrological/hydrodynamic component while others have a relatively complete biogeochemical process representation. Modeller skill becomes important with increasing levels of biogeochemical process representation because there can be many rate and stoichiometric parameters that require calibration against field data. The modeller needs to consider carefully which biogeochemical variables to simulate and the extent of calibration required to produce a satisfactory match of model output to observations. Nitrogen submodels are likely to be a critical component of most wetland models and the nitrogen submodels embedded in wetland models should be carefully scrutinised to ensure they satisfactorily address the needs of the modeller in terms of flux representations (e.g., for processes like denitrification), variable selection (e.g., total and/or dissolved nitrogen) and interactions with other variables (e.g., dissolved oxygen, phytoplankton).

Eleven modelling packages were assessed in this report, exploring their capacity, treatment logic, usability and applicability for use within the GBR, regulatory, offsets and water quality improvement contexts, including stand-alone, site/local assessment and catchment scale integration. Of these, there are a few modelling frameworks that may provide further ongoing benefit if adapted or developed further for use in the GBR context, summarised below:

- The MUSIC modelling software would benefit from further development of treatment algorithms to better represent nutrients of interest, especially nitrogen, or including recent knowledge of wetland processes (e.g., Adame et al. 2019).
- The hydrodynamic models coupled with biogeochemical modules (i.e. GLM AED and TUFLOW FV AED models) may be used to refine design components for treatment wetlands, or evaluate which existing wetlands are likely to be of more benefit for nutrient removal. Additional benefit could be garnered through development in conjunction with other models that describe landscape processes (e.g. those which simulate the relationship between rainfall, runoff generation and transportation, such as MUSIC, Source or SWMM models)
- SWMM has the adaptability to simulate the hydrologic, hydraulic and water quality processes of wetlands. Given its use worldwide, many literature studies could be used for developing and refining it for further use in the GBR context.
- The Source framework (widely applied in the Reef context) could benefit from coupling with a higher speed wetland hydrodynamic models, or the development of a specifically designed wetland plugin. Given recent updates to the MUSIC framework (i.e. MUSIC X), this could be embedded in Source to provide a comprehensive whole of catchment understanding of wetlands at the landscape scale (given updates to treatment algorithms in MUSIC).

In the context of site-based/localised assessment of wetland features, there is no single method or model available that could be considered as 'industry standard', as MUSIC is considered such a standard for Urban Storm Water design and assessment throughout Queensland. The diversity of wetland types, locations and functionality will make provision of single, user-friendly model (with appropriate support) difficult to achieve. However, in the short term it is clear that there are some potential developments that could be supported, and these are complimentary to the broader R&D principles previously outlined for a GBR context. Some of these model development activities could include:

- Collation and documentation of existing box models, with online access to allow distribution throughout Queensland
- Collation of relevant measured/experimental data to begin formulating a 'database' of useful parameters and pollutant reduction rates (similar to regional MUSIC parameter sets and recommendations that are utilised by LGAs and similar, acknowledging that many stakeholders are not familiar with scientific literature, and indeed may not have the resources to search and make sense of this)
- Formalise development, maintenance and support of industry standard tools (if sufficient stakeholder demand is demonstrable) for site-based/localised assessment. This would require long term commitment from industry and government. It would appear logical to modularise this development, targeting specific assessments representing a limited number of wetland types and environments (ie performance of constructed wetlands/bioreactors within a sugarcane enterprise in the Wet Tropics region). Without modularisation and targeting of specific processes, it is difficult to build models that contain all of the necessary drivers, internal operations, and reporting tools required (as this report has concluded with regards to broader R&D).

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1 Introduction

The ability to quantify the performance of wetland systems through predictive modelling tools is a key need to understand how best to use both natural and constructed treatment wetlands to improve water quality outcomes. This study seeks to identify and evaluate models which can be used to improve our understanding of wetland hydrology and nitrogen removal. Additionally, it presents a review of model applications for different wetland scales (i.e., sizings) and types (i.e. constructed treatment wetlands, and natural palustrine, lacustrine and estuarine wetlands). These features are important in selecting models that are appropriate for the system under consideration. Other pertinent selection factors are the scale at which processes or areas within a wetland are simulated.

No single model is likely to answer all of the questions that may be asked about wetland function, processes and performance. Some models will act at fine scale (e.g., to resolve processes within the wetland), broad scale (e.g., to examine wetland performance at whole of catchment scale) or may be used to provide comparative information (e.g., which wetland type would be most suitable for a particular situation such as reducing nitrogen loads to receiving waters from farming activities).

This report evaluates models that can be used to assess wetland performance in terms of contaminant removal (e.g., nutrients, suspended sediment, pesticides). The models selected have been identified through previous assessments and models documented in the literature, projects for the Queensland Water Modelling Network (QWMN) and applications the authors are aware of across Australia. This report is not intended to be a comprehensive list of wetland models but instead provides a summary of different tools and models which may have applicablity, credibility and usability for assessing the role of wetlands in improving water quality, especially in contexts such as the Great Barrier Reef (GBR) catchments, regulatory assessents, nutrient offsets and site-scale assessment of wetlands. Site-based assessment of individual wetland features can still inform at a broader, GBR-wide scale, however these assments do not need to be fully embedded within the broader models to inform. For many stakeholders and applications, it is advantageous if the wetland assessment is not embedded within a complicated modelling framework.

The GBR is of world renown and an important feature of the Australian landscape, from environmental, social, cultural and economic perspectives. Scientific studies have identified that the health of the Great Barrier Reef is declining. Of particular concern is a recommendation of a change in its world heritage status to 'in danger' by United Nations officials reporting to UNESCO. Consequently, concerted efforts are required to improve the scientific understanding of the drivers of poor water quality on the Reef so that catchment management actions can be targeted appropriately to the contaminants and areas of concern.

Wetlands, whether they be constructed treatment wetlands, or natural wetlands in the landscape, are one of the important treatment system elements that form part of the strategy for water quality improvement. Wetland models, if appropriate to the landscape, climate and context of the Reef catchments, form part of the decision framework for managers in their efforts to achieve the water quality targets of the Reef 2050 Water Quality Improvement Plan 2017-2022 (State of Queensland, 2018). Wetlands are also an integral part of land management strategies throughout Australia and Queensland, including in South East Queensland where there is also an urgent need to reduced land-based contaminant inputs to estuarine and coastal waters. Further understanding of catchment pollutant generation and wetland treatment performance is required in tropical and subtropical areas in particular, for example the Wet Tropics, where there may be periods of high flow that result in rapid pollutant flow through wetlands (Adame et al. 2019, DeBose et. al. 2014).

To fulfill the objectives of synthesising and evaluating the available wetland models, this report is structured as follows:

a) A brief overview of each model evaluated (Section 2)
b) Outline of the key processes that affect water quality and the models that represent these processes (Section 3)
c) Model classification and usability in accordance with the QWMN model classification structure, and an assessment of model usability (Section 4)
d) Model applicability based on which models are suitable to simulate different processes within a wetland (e.g. nitrogen transformation and removal) and demonstrated applications in the literature (Secton 5)
e) Assessment of model suitability, focusing on which models may address questions about process rates, efficiency and design of wetlands (Section 6)
f) Recommendations to outline which models are most appropriate for future use, improvement and development (Section 7)

2 Model Review

2.1 What is a model?

Water modelling is the process of developing mathematical and logic-based representations of real-world relationships between different variables (e.g. the spatial and temporal relationships between water quality pollutants, stream hydrology, plant life and other chemical components of river water), then using these representations to understand how processes (e.g. pollutant dispersal and fate in rivers and coastal areas) will operate under different conditions (QWMN 2021a). In the context of this assessment, a model provides relationships among numerous wetland forcing factors (factors exerting external influence on the wetland e.g. climatic inputs, inflow into the wetland etc.). It also provides that relationship with wetland variables (processes occurring within the wetland e.g., relationships between climatic variables, water quality and quantity, chemical and biological processing within the wetland, etc.). This is done so for several wetland types (constructed treatment wetlands (which are palustrine (vegetated) wetlands), and natural palustrine, lacustrine and estuarine wetlands). These water modelling tools are used in a myriad of applications, including informing policy, planning and decision making about wetland implementation and optimising functionality and performance.

2.2 Potential modelling issues

The capability and accuracy of a wetland model to represent hydrological and biogeochemical processes depends on the scientific representation of the relationships between variables, and a robust dataset (as forcing data input or to calibrate and validate the model). Where issues occur is when relationships are not well understood or defined (or the logic of the model does not represent the processes being investigated), or a dataset (e.g., data obtained from a field or experimental study) is poor or limited. When this is the case, it is important to understand the uncertainty in the model output, and what steps need to be taken to reduce model uncertainty. One method to quantify uncertainty involves adjusting model parameters using upper and lower bounds of values from the literature or theory, to provide a band of model output that is highly likely to encompass the future observations. The process of altering parameters in the model to examine their effect on the model outcome is known as a sensitivity analysis.

2.3 Model technical terms

In the following introduction of modelling, a number of technical terms have been used. We provide a context of, and explanation for these terms.

- **One Dimensional (1D) vs. Two Dimensional (2D) vs. Three Dimensional (3D)** –refers to the spatial dimension used to model the wetland. In this context, a 1D (vertically resolved) model is represented by a node and link network structure with wetland volume represented by a storage curve. A 2D vertically integrated model represents the two horizontal dimensions but disregards changes in depth. Some 2D models which are best suited for long narrow wetlands represent the depth dimension and the longest horizontal dimension. A 3D model represents the two horizontal dimensions and the depth. A schematic of these is presented in Figure 1.

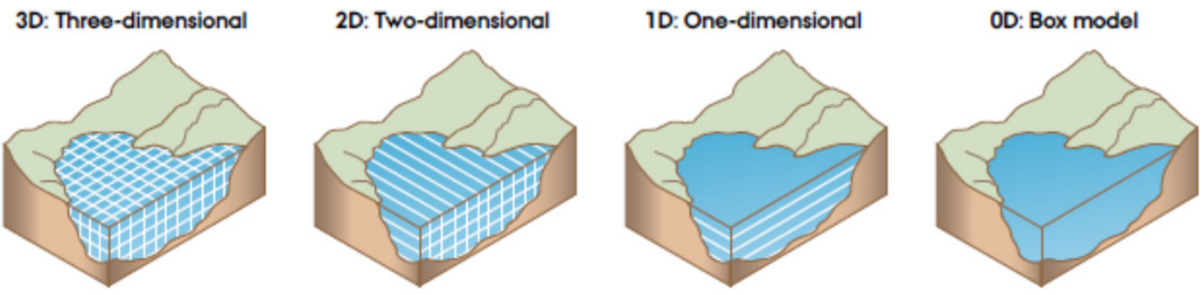

Figure 1. *Model domain dimensions (Hipsey, M., et al, 2013)*

- **Zero dimensional (0D)** – refers to a model with no dimensions, that is the wetland is represented as a volume only. An example of this is a spreadsheet-based box model, with no dimensional values. An example of this is present in Figure 1.
- **Mesh, flexible mesh** – the geometry of the landscape or wetland bathymetry is represented by a network of uniformly sized cells within a model, with each cell representing an elevation. A flexible mesh differs to a mesh in that the cells can be of variable sizes (e.g. larger cells where little to no (or inconsequential) change occurs over that cell through the duration of the model, and smaller cells where there is consequential change over the model time period). The smaller the cell size of the mesh, the finer the spatial resolution of the model.
- **Finite element** – A finite element is a small section of a total model (a mesh cell) to which a set of differential equations can be applied to represent model behaviour at that cell. These equations are carried out over each finite element in the entire model domain, and combined to represent the entire system behaviour.
- **Rate and stoichiometric parameters** – in this instance, the rate parameter refers to the process or rate in which biological transitions occur within the wetland's biogeochemical processes, while stoichiometry refers to the mass balance of these transitions.
- **Forcing factors** – forcing factors are those which exhibit external influence on the wetland (e.g. climatic inputs such as rain and potential evapotranspiration, catchment inflow quantity and quality etc.)
- **Variables** – parameters inside the wetland that describe and influence the wetland processes (e.g. effect of the climatic factors on the wetland (e.g. water warming, circulation), biogeochemical processing within the wetland etc.)
- **Component plug-in (plug-in) model** – a component plug-in model is a modelling tool which has been developed to be utilised and integrate into part of a larger modelling framework (e.g. a wetland processing tool as part of a framework which also represents the landscape processes).
- **Exponential decay** – exponential decay is the decay of a quantity in an exponential function relative to its initial value. In terms of wetland modelling, this is a representation of a constituent/pollutant decay as a function of inflow concentration, with consideration of treatment area, treatment distance along a wetland or residence time. Dissolved inorganic nitrogen concentrations, for example, have been observed as decaying exponentially along a wetland, from high levels at the source to low where water leaves the wetland (Kadlec, R. H., Wallace, S. D., 2009, p323).

Further terms are defined in Section 4 in relation to model classification.

As previously stated in Section 1, several models were reviewed to demonstrate their conceptual framework, wetland treatment logic, and usability and applicability to different wetland types. The following provides a brief overview of the different models (including box models and plugins). Additional information around the categorisation of these models is provided in Attachment A.

2.4 Box Model

All models require some physical dimension, either as a box (zero dimensional) or in one, two or three dimensions, but equally importantly, they provide a water balance that accounts for known sources and sinks, including water level, and an unknown component that is not measured (e.g. groundwater is usually not measured). When all the sources and sinks of water are accounted for, the model is said to be acting conservatively. A feature of all good hydrological/hydrodynamic models is that they act conservatively with respect to water mass (i.e. inputs equal outputs).

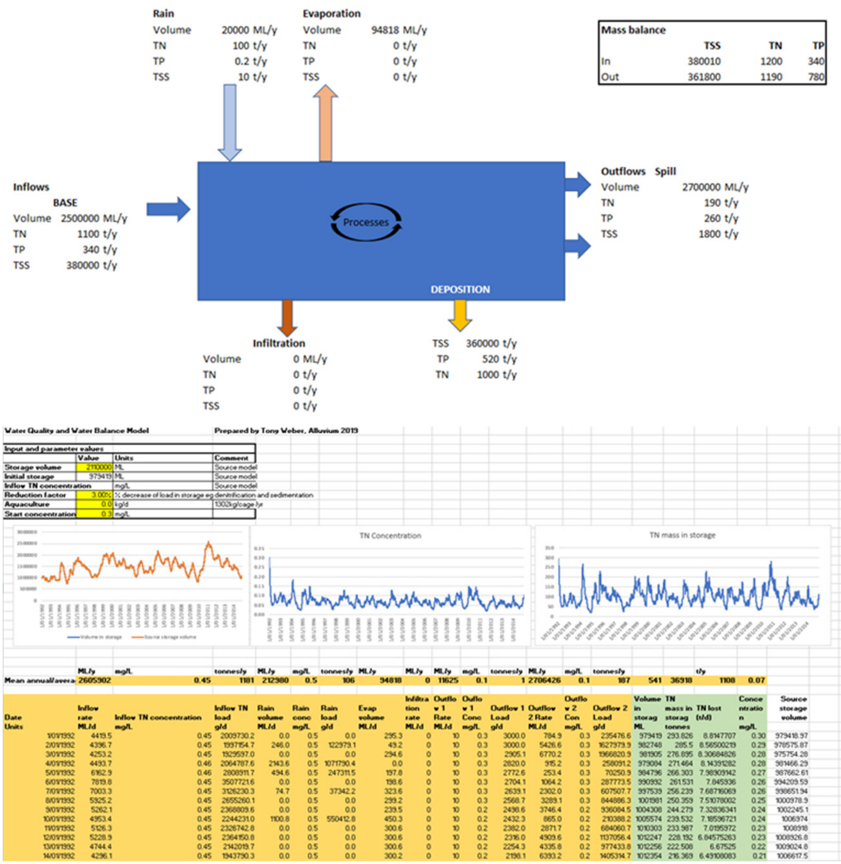

Figure 2. *Box model example (Alluvium, 2018)*

A box model refers to a tool that does not have any spatial dimension, unlike the 1D, 2D and 3D models mentioned above. Box models for wetlands treat the whole wetland water volume as homogeneous, with inflows instantaneously mixed through the water volume (Adame et al. 2019). This can be a disadvantage if the rates of processes vary with location or distance through the wetland. The box model often takes the form of a spreadsheet. The box model approach is straightforward in that simple surface area-depth-volume relationships and inflow and outflow volumes can be used to describe the hydrology without complex additional internal mixing and transport processes. The simulation of treatment within the wetland can be represented by a range of approaches, from simple reduction factors to complex interactions representing nutrient cycling processes that take place over the time that the water is contained within the wetland.

The representation of wetlands (of any typology) with box models can provide a simple way of developing a predictive model for wetland function and performance that because of the model simplicity, allows for ease of understanding of cause (e.g., anoxic conditions) and effect (e.g., discharges of reduced compounds such as ammonium and sulfides). The simplicity and familiarity of typical spreadsheet based box models makes them a useful site-based assessment tool that can be applied and interpreted by a varied stakeholder base. The potential for user-error to alter box model outcomes, and impact associated decisions, must be considered when these are used as part of a distributed assessment tool suite. Box models can provide a useful complement to more complex, spatially resolved models because of fast run times and simplicity but they can also potentially be a resource drain if they cannot be set up and run quickly. Additionally, they can have limited usability where they do not adequately represent the key processes. Because box models tend to be highly individualised applications (e.g., ranging from spreadsheets to mathematical equations in a computer program), we do not provide further details about them here.

2.5 Component plugin

Component plugin models are usually separately developed algorithms or scripts that work within another modelling framework. The Source modelling framework allows such plugins to be developed and applied within the broader model, and can consist of a fully developed model with interface features to assist in inputs, parameterisation and result definition, or as simple as a formula or equation much like those in spreadsheet applications. The component plugin is a logical extension of the box model concept. It allows for software controls to minimise user-error, however it also constrains the flexibility and applicability of the model. Once embedded in, or plugged-in to, a modelling framework, the opportunities to vary inputs and drivers, or modify internal operation, make this a difficult model to apply to many diverse situations. This phenomenon is demonstrated by considering the evolution of the Source modelling framework and it's precursors. The inclusion of water quality components, even down to the definition of individual pollutant names, remains a user responsibility. Source provides just the necessary 'shell' to allow for pollutants to become an identifiable feature within the model. Beyond the most rudimentary generation and transport options, all water quality considerations (pollutant generation, transformation and transportation) need to be supplied by the user, often as plugin components.

A concerted effort was made to identify any component plugin models which may be suitable for modelling wetlands. We did not identify any tool that was specifically associated with a wetland model. Consequently, the 'component plugin' modelling tool has not been assessed in this report.

2.6 External landscape model

Among the wetland hydrology models reviewed, many of these models, including MIKE 21, GLM AED, HEC RAS, RMA, TUFLOW FV AED, and BOX MODEL (Table 3), do not have the capacity to generate inflow forcing on their own and thus rely on external landscape or hydrological models to provide the inflow.

Although models such as Source, MUSIC or SWMM can be used to simulate the rainfall-runoff relationship and generate inflows, this process inevitably introduces complexity and additional computational cost. This means that in general, these models will be more applicable to assessments of water quality outcome in larger wetland features (estuaries, wetlands associated with frequent flooding), and often applied at a temporal scale that may not be particularly informative for localised assessment of small wetland features. The smaller wetland features may need to represent fluxes and transformations over critical hours, not days or weeks. The recently developed Australian National Water Balance Model – Australian Water Resources Assessment Landscape (AWRA-L) model from the Bureau of Meteorology and CSIRO can be used to obtain landscape-scale runoff. AWRA-L is a daily grid-based (5 × 5 km) distributed landscape model. For each grid cell, the model simulates the flow of water through the landscape from rainfall entering the grid cell, through the vegetation and soil moisture stores, and then out of the grid cell through evapotranspiration, runoff or deep drainage to the groundwater. The model provides simulation outputs of evapotranspiration, runoff, and deep drainage over a period from 1911 to present. Importantly, these outputs are freely available to the public (http://www.bom.gov.au/water/landscape) and can be used to provide inflows to wetland hydrology models by converting runoff to discharge. As AWRA-L is a national model, it has simulation outputs available to all of Australia, including the Great Barrier Reef catchment.

There are two caveats to applying AWRA-L outputs for wetland projects. The first is that AWRA-L has been calibrated on a large domain (i.e. spatial extent) that covers multiple climate conditions, providing an 'average' response but potentially being less accurate for specific climate domains. This issue can be circumvented by calibrating AWRA-L outputs to local streamflow measurements. AWRA-L does not include water quality information and consideration could be given to developing of a suitable plug-in or coupled model to simulate water quality constituents. Consequently, this model is not included in the analysis of the subsequent sections.

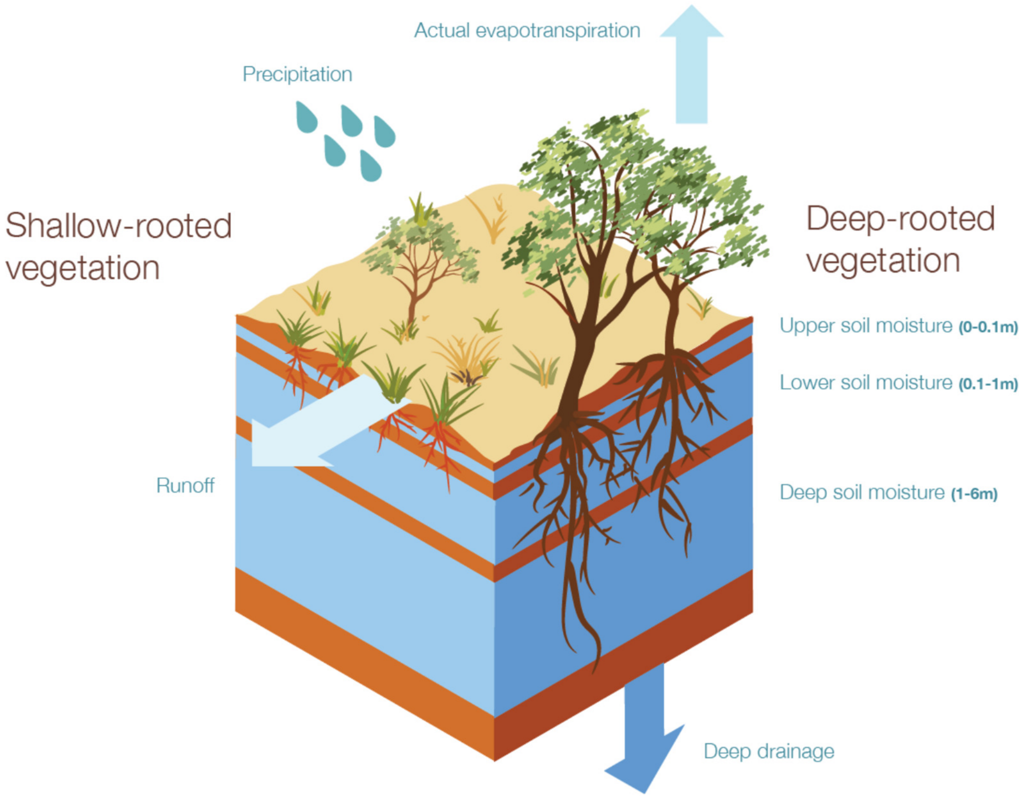

Figure 3. *AWRA-L Conceptual hydrologic model (Frost et al, 2018)*

2.7 Geospatial models

The literature review identified several types of geospatial models. Examples of wetland geospatial tools are described in US. Fish & Wildlife Services (2020), Sutter (2000) and Martínez-López et. al. (2012) and Blackmore D., Chang., H, (2015). The tools identified through this assessment use a combination of geospatial analyses and analytical methods (e.g. Normalised difference vegetation indexing (NDVI), image classification, buffering, dissolving, clipping, density, frequency etc.) to describe numerous wetland physical characteristics. The characteristics include wetland location, size, typology, catchment area, vegetation and health (using vegetation as a proxy indicator). The geospatial models do not include nutrient processing within wetlands. Consequently, geospatial modelling tools have not been assessed and are not referenced further in this report.

2.8 GLM AED

GLM (General Lake Model) is a vertically resolved one dimensional (1D) lake water balance and stratification model. The model computes vertical profiles of physical variables (including temperature, salinity and density). It accounts for inflows/ outflows, mixing and surface heating and cooling. It is well suited to long-term investigations ranging from seasons to decades as it is computationally efficient and operates in only one dimension. GLM can be coupled with an ecological modelling library to support simulations of lake water quality and ecosystems processes. For this assessment, the ecological modelling library assessed is AED2/AED2+ (see below).

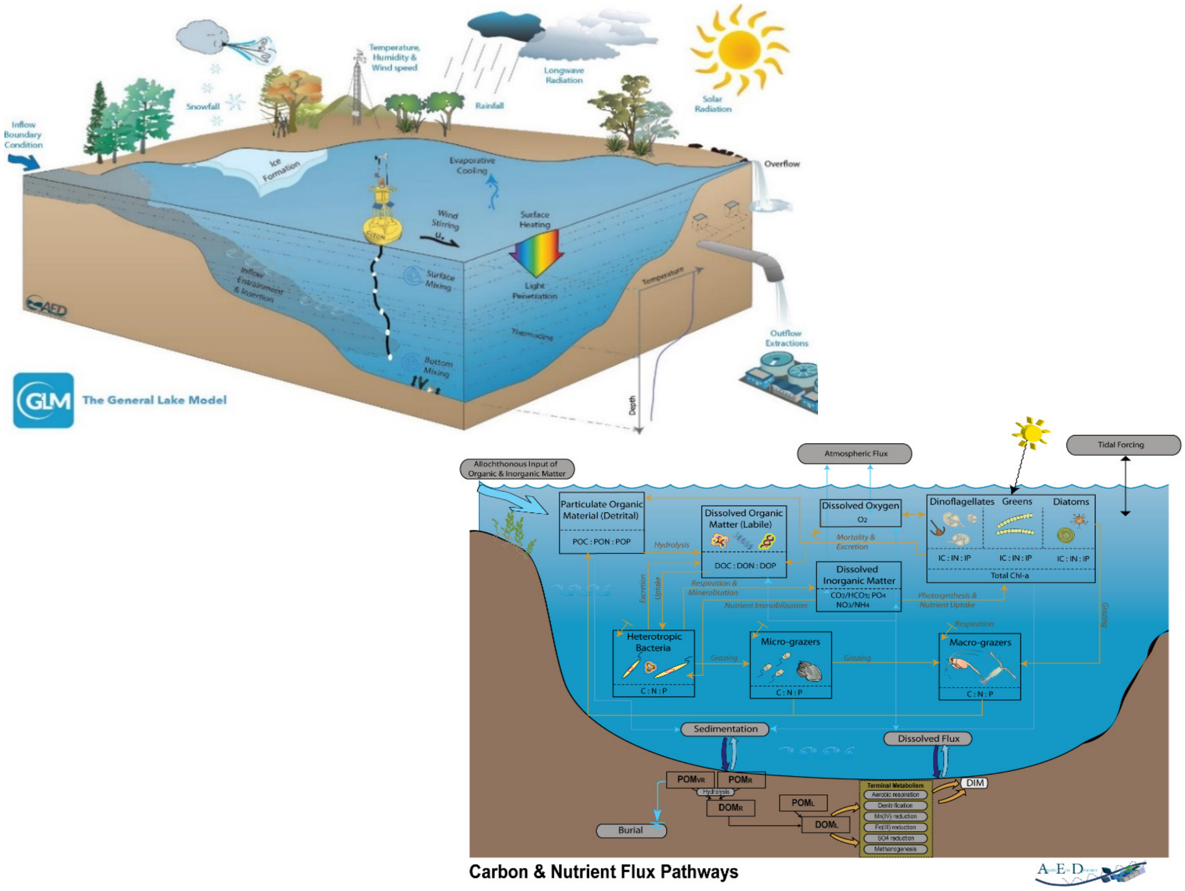

Figure 4. *GLM and AED conceptual models (AED-UWA, 2016, 2017)*

AED (Aquatic Ecodynamics) is a modelling library of components used to describe water quality, habitat, and aquatic ecosystem dynamics. There are two versions of this modelling library, AED2 and AED2+, the difference in each being the components included. AED2 includes components such as oxygen, inorganic nutrients, organic matter and phytoplankton, while AED2+ includes components such as sediment quality, benthic vegetation and benthic macroinvertebrates. For ease of reference (as components from either of these can be adopted in wetland modelling), the remainder of this report will simply reference AED.

Each of the components can be configured to suit the application (simple or complex). The user can apply any number of modules to customise the variables they wish to simulate their dependencies with other modules. Module components can consider carbon, nitrogen, phosphorus and oxygen and their interactions. Outflow concentrations and loads are simulated using the full GLM-AED model.

For the same reason that the box model simplifies the throughflow and exponential decay processes of water constituents, the 1D model also simplifies these processes by averaging in the horizontal dimension. This means that it may not be a suitable tool for evaluating changes in water constituents where there are substantial longitudinal gradients. On the other hand, where the wetland is a circular lake, has long residence times and undergoes vertical stratification, GLM may provide a highly suitable hydrological/hydrodynamic framework for wetland modelling due to the ability to resolve all of these elements.

The GLM-AED coupled model would provide significant insight into wetland processes of any constructed treatment wetland or natural palustrine, lacustrine or estuarine wetland, as these could be individually represented and accounted for, though again, no specific wetland module exists and the emphasis would be on the user to configure the details of wetland processes. If coupled to landscape models such as Source, MUSIC or SWMM, there is the potential to provide data on inflows (volume and composition) for running the GLM-AED model or to embed GLM-AED within a catchment modelling framework. The latter may be quite complex and resource intensive and, in the first instance, it is likely to be easier to use model inputs and outputs from the respective catchment and wetland models for catchment-scale applications.

2.9 HEC RAS

HEC RAS (Hydrologic Engineering Centre's River Analysis System) is a modelling software tool for performing either one dimensional (1D) steady or unsteady flow, two dimensional (2D) unsteady flow hydraulics, sediment transport/mobile bed computations, water temperature modelling and generalised water quality modelling (albeit in testing phases, commented on further below). The water quality model consists of algal, dissolved oxygen, nitrogen, phosphorus and benthic algal processes.

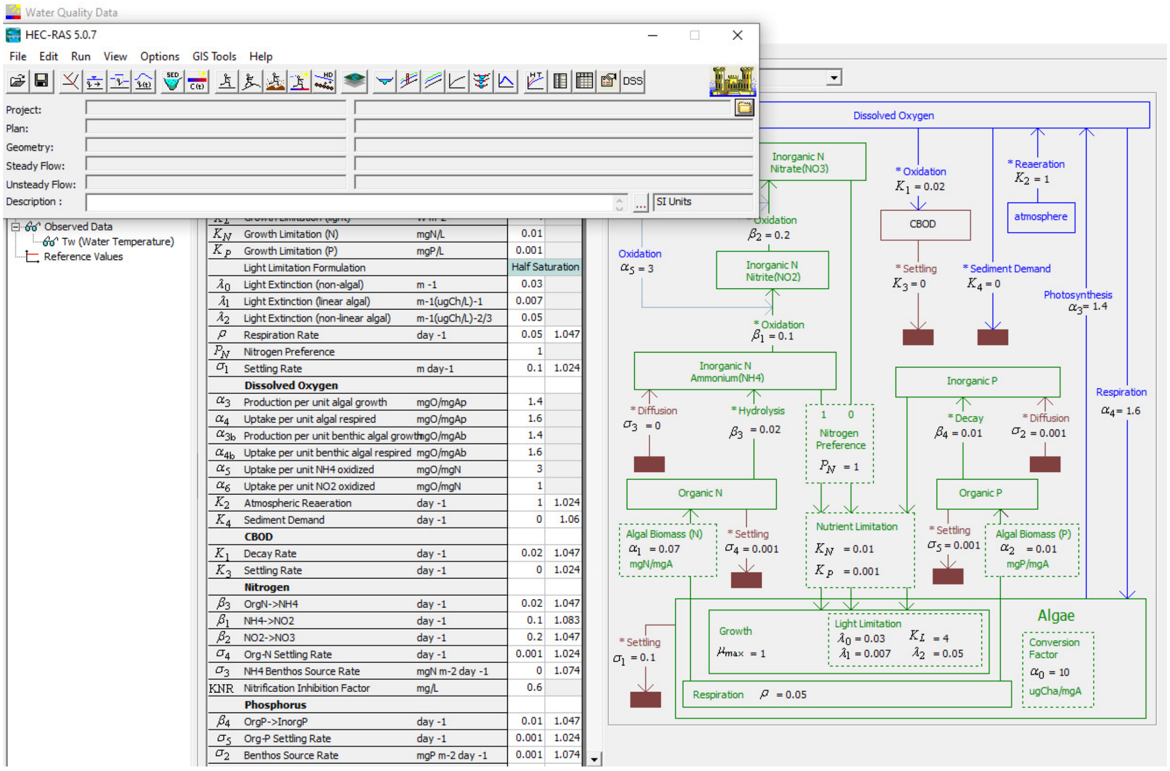

Figure 5. *HEC-RAS model screenshot (US-ACE, 2019)*

The 1D hydraulic regime is based on a reach (link) system and user supplied cross sections, while the 2D regime is based on a flexible mesh replicating the site topography. The hydraulic regime forms the basis of any of the additional modelling computations (i.e. sediment, temperature and water quality). At the time of writing, it is understood that the most recent version of HEC RAS (version 6) allows sediment, temperature and water quality analysis on 2D hydraulic models, however this is still in beta testing phase.

Wetland representation (of constructed, palustrine and lacustrine typologies) in HEC RAS would therefore be limited to only evaluating hydraulic and hydrologic processes at this stage, which may be useful in understanding wetland connectivity to other aquatic networks. The understanding of wetland connectivity enables better assumptions to be made when seeking to inform catchment scale water quality models from site-based assessments of wetland features, as well as the individual wetland performance as the connection of the pollutant source to the wetland is essential to understanding how a wetland at a site operates. In 2D form this model has capability to adjust accurately to the topography, which would make it particularly suitable for terrain with low relief.

2.10 MEDLI

MEDLI (Model for Effluent Disposal using Land Irrigation) is a model designed for analysing effluent disposal systems for intensive rural industries, agri-industrial processors (e.g. abattoirs), and sewerage treatment plants using land irrigation.

MEDLI uses a modular style structure to outline the processes which can be adopted in a model, including (but not limited to) waste estimation, pre-treatment, pond water chemistry, and water balance and interactions with soils. The pond module consists of mass balances for water and nutrients, employing empirically derived relationships to represent processes such as nitrogen volatilisation.

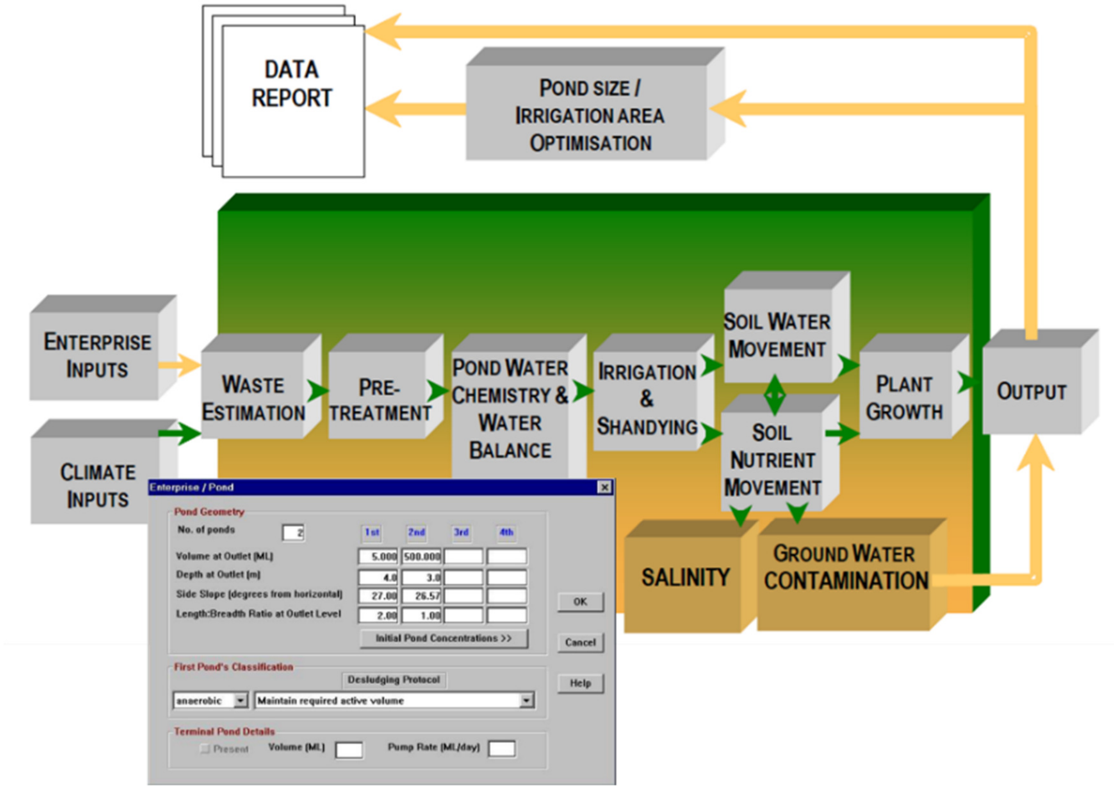

Figure 6. *MEDLI conceptualisation (Vieritz, A., 2012)*

For wetland assessments (typically constructed), MEDLI is likely to evaluate nutrient treatment performance in subsurface flows well but it may not adequately account for surface flow processes. Reference material indicates that representing subsurface flows and nutrient treatment is given more precedence than surface water flow processes, indicating the latter may be inadequately represented. MEDLI in its current form may not be the most relevant tool for site-based assessment of wetland processes, however its commercialisation, maintenance, support and distribution (and acceptance as an industry standard tool) could provide some insight into future development considerations of similar tools specifically for wetlands.

2.11 MIKE HYDRO

MIKE HYDRO (previously MIKE 11) is an overarching model framework developed by the Danish Hydraulic Institute (DHI) group, which incorporates both Basin and River module frameworks, both suited for different applications. The river module is adopted for modelling one dimensional (1D) river models and has numerous applications including water quality assessment in wetlands. For this purpose an additional module, MIKE ECO, is required.

MIKE HYDRO considers runoff from catchments, calculated by selecting one of a suite of different rainfall-runoff models, and transported into a river system using a *River link*. A number of processes are represented in the river system including routing, structures, controls and storages. Additionally, the model can consider water and solute transport and mixing (advection/dispersion) and decay of constituents as water travels through the river system. In modelling a wetland, the MIKE ECO module is required as part of the MIKE HYDRO framework.

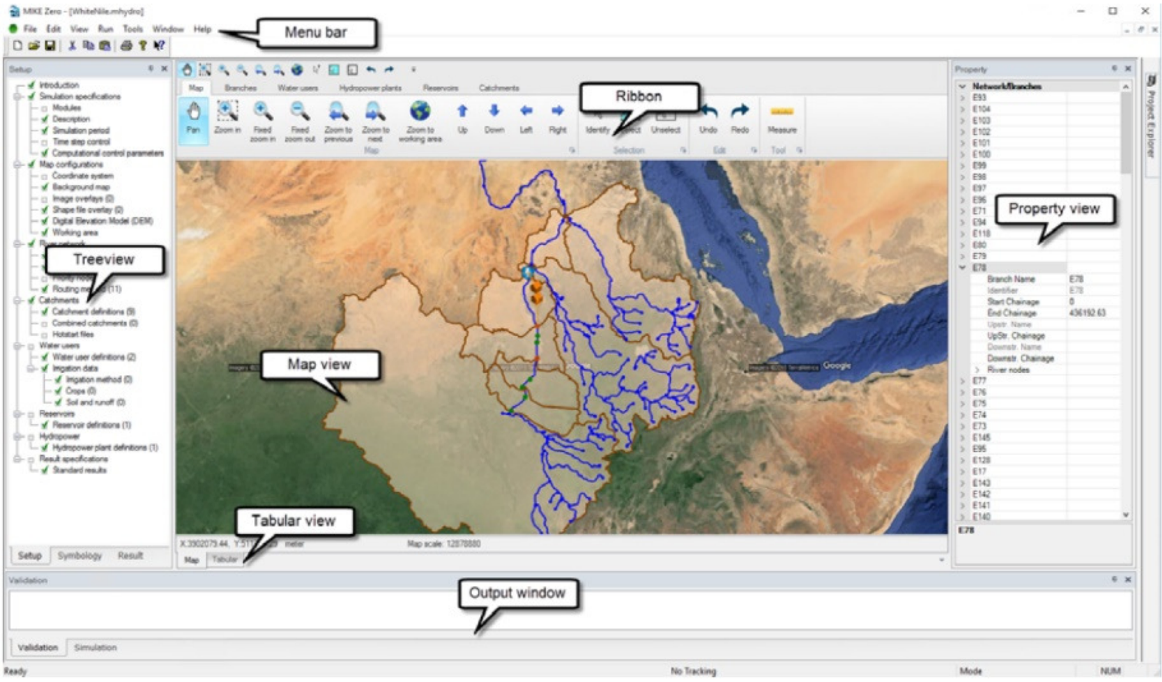

Figure 7. *MIKE HYDRO screenshot (DHI, 2017a)*

MIKE ECO is used to mathematically describe chemical, biological and ecological processes, interactions between state variables (e.g. dissolved substances, particulate matter, etc.) and physical processes (i.e. sedimentation). The model can either adopt predefined mathematical representations of these processes or user defined processes.

The MIKE ECO model can be adapted to represent the functionality of all wetland types, but again would require user knowledge and input to configure it appropriately.

2.12 MIKE 21

MIKE 21 is a modelling framework which houses a range of modules including MIKE HD (hydrodynamics), MIKE AD (advection-dispersion), MIKE ST (sediment tracking), MIKE PA (particle tracking) and MIKE ECO (environmental module). Using these modules, MIKE 21 is capable of modelling two dimensional (2D) free surface flows applicable to the simulation of hydraulic and environmental phenomena in wetlands, lakes, estuaries, bays, coastal areas, and seas.

The framework adopts a bathymetric surface (translated to a mesh) of the area being modelled and adopts forcing functions (e.g., meteorological conditions) on the model to represent real world conditions. For the hydrodynamic model base, this includes (amongst others) various stresses and forces acting on the water, energy dispersion and wetting/drying.

The additional modules add processes to simulate erosion of sediment, transport and deposition of sediment as well as other variables, and any other chemical, biological and ecological processes that are relevant to the state variables (e.g. dissolved substances, particulate matter etc.).

As per MIKE HYDRO, the model can be configured through the MIKE ECO module, to represent all wetland types.

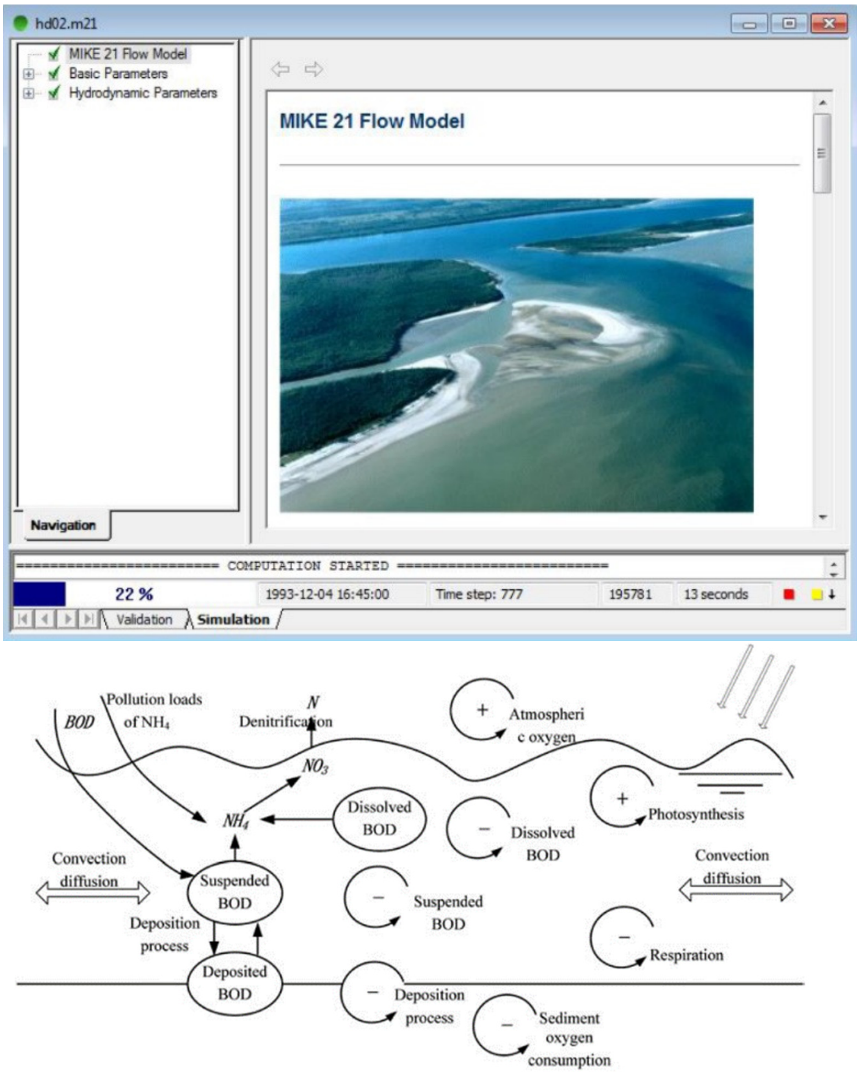

Figure 8. *MIKE 21 screenshot (DHI, 2017b) and conceptualisation (Yan, Q. 2015)*

2.13 MUSIC

MUSIC (Model for Urban Stormwater Improvement Conceptualisation) is software used for stormwater management and Water Sensitive Urban Design (WSUD). MUSIC is used to simulate urban development impacts and other land use changes on waterways. It can simulate a wide range of treatment devices to identify the best way to capture and reuse stormwater runoff, remove contaminants, as well as reduce runoff frequency. MUSIC allows evaluation of treatment devices associated with Water Sensitive Urban Design and Integrated Water Cycle Management (IWCM) goals.

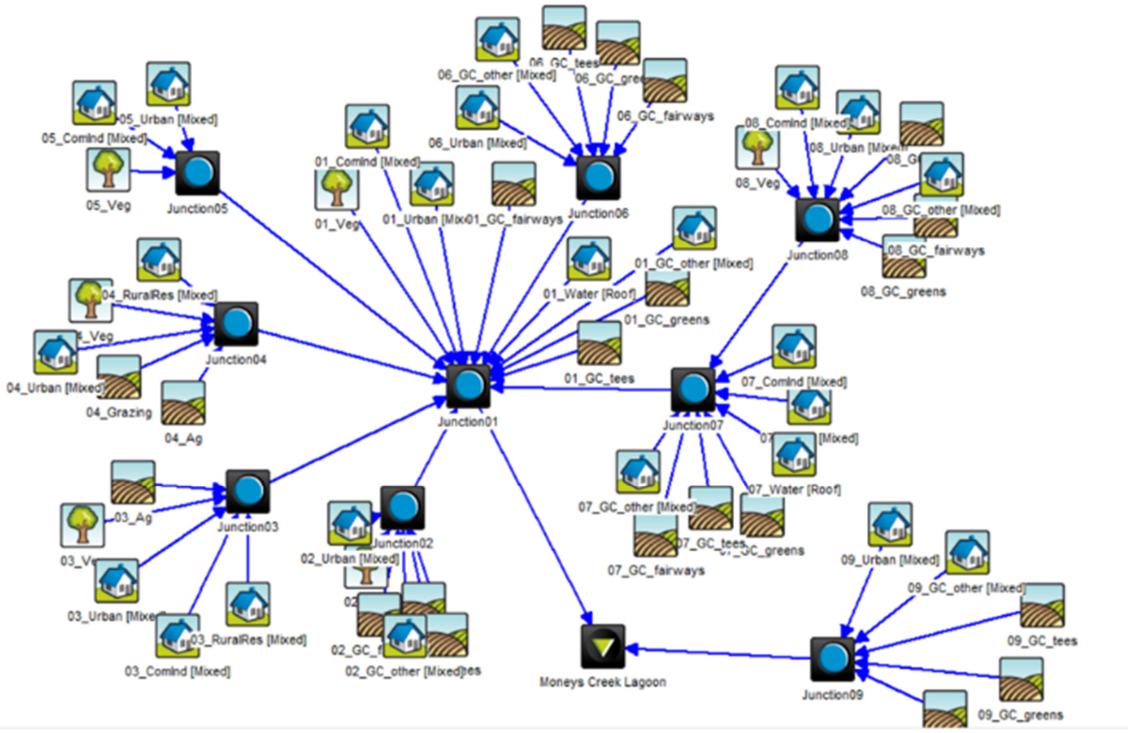

Figure 9. *MUSIC model example (Alluvium, 2021)*

As of 2020, a new iteration of the MUSIC software, MUSIC X, has been made publicly available. In addition to a myriad of software architectural changes, this iteration has enabled greater interaction with the Source software as a plugin, as discussed in Section 2.15.

MUSIC is conceptualised through a link and node approach and contains specific treatment nodes that are preconfigured, including a specific wetland node. This wetland node was based on the outcomes of research from the former CRC for Catchment Hydrology and evaluated hydrologic and water quality performance, associated with Total Suspended Solids (TSS), Total Nitrogen (TN) and Total Phosphorus (TP), using an exponential decay type function (the Universal Stormwater Treatment Model – USTM – Wong et al 2002). This considered how the hydraulic efficiency of the wetland (in terms of wetland shape and propensity for mixing) influenced the decay of each constituent. These were only derived for total nutrients, not dissolved fractions, so further work would be needed to refine these to be applicable to dissolved forms. That being said, much of the research underpinning the development of the USTM concurred with research in the US on treatment wetlands, especially in the removal of nitrate, so it is likely that a decay curve approach for DIN is possible as a way of adapting MUSIC for treatment wetlands focusing on this constituent.

This model can be applied to constructed, palustrine and lacustrine wetlands. The way in which MUSIC has become the accepted industry standard for assessment of urban water design (with coupled documentation and guidelines) has the potential to shape a similar concept for wetland water quality decision support tools. The level of investment required should not be underestimated, and the diversity of wetland types, and likely applications, means that it is likely that similar wetland tools would be necessarily modular, and limited in transferability.

2.14 RMA

RMA (Resource Management Associates) represents a number of modelling tools. For the purpose of this report, two of relevance are RMA2 and RMA4.

RMA2 is a 2D depth averaged finite element hydrodynamic model. It computes water surface elevations and horizontal velocity components for subcritical flow (where water depth is less than critical depth, commonly 'slow flow') and free-surface (flow only subject to gravity, commonly 'open channel flow') 2D flow fields.

The model adopts a mesh to represent the bathymetric and topographical features of the modelled system and employs a number of boundary conditions and internal equations to determine the finite element solution for both steady and unsteady flows.

RMA4 is a finite element water quality transport model, which utilises the hydrodynamics of the associated RMA2 model to compute the transport and mixing of constituents. The constituent types are specified by the user in either the 1D or 2D computational mesh domain. The model adopts an advection-diffusion process to evaluate processes in an aquatic environment. It can model suspended and/ or dissolved substances within the water column and can compute the physical processes of migration and mixing.

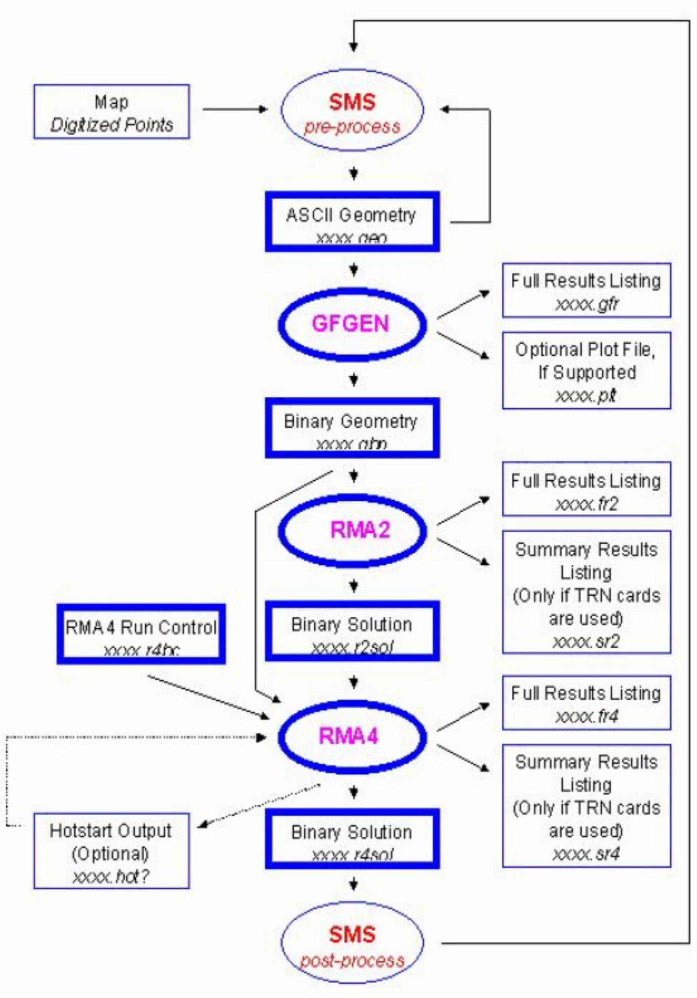

Figure 10. *RMA model flow chart (Donnell et al, 2008)*

A coupled model suite of RMA2 and RMA4 would be suitable for evaluating wetland processes (of all typologies) but as with other hydrodynamic and water quality process models (e.g. GLM AED, TUFLOW AED), it requires significant effort involved in user configuration to represent these processes. The RMA model, however, has a wealth of literature to support the set up and configuration of the model.

2.15 Source modelling framework

Source is a modelling platform mostly used for river systems (including planning of water resources) or catchments (including catchment response to rainfall). It is not a model on its own but rather a framework for a group of models, including rainfall-runoff generation and transport models, constituent generation and fate model, and any additional models which may explain different processes in the landscape (primarily included through component plugins). By pulling these models together, the Source modelling framework can be configured in different combinations to suit a particular problem or answer specific modelling questions.

The software has three basic components: generation, delivery and transport (of numerous constituents which could include sediment, nutrients, pathogens, or any other which is required to be modelled), and each of these can be configured independently for specific catchment land uses, topographies or processes. Under each of these components, there are several models to choose from to allow for the best representation of the catchment processes. The primary driver of Source is rainfall-runoff, with generated runoff being used to derive a constituent generation model. The runoff and subsequent generated constituent (any which is required to be modelled) are delivered though a link and node system, which can be configured to represent numerous conditions (including stream wetting, storage, water demand etc.).

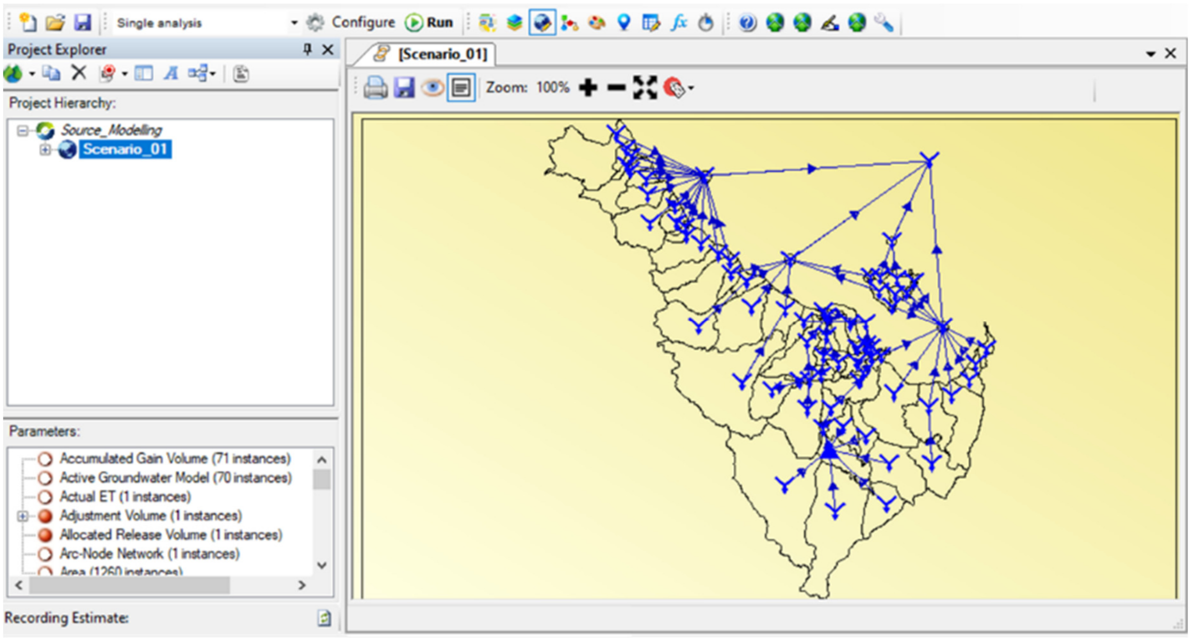

Figure 11. *Source model screenshot (Alluvium, 2021)*

There are no specific modules or models within the Source framework directly configured for wetlands in water quality improvement, however a number of modules could be used (e.g. the USTM model noted in the MUSIC section above is available), but all need to be user-configured. Source also has the ability to link directly to MUSIC through MUSIC X and has the flexibility to incorporate plug in component models, though none are currently available which are specifically associated with wetlands. A wetland node is available in Source to evaluate their relationship with storage and connectivity in river systems, especially where their role in river system management (e.g. water accounting) is required.

Source can be adopted to represent any type of wetland, given input data is suitably parameterised. In general, Source operates on a daily timestep (although this is not a rigid model constraint). Many pollutant transformation processes will require consideration of transport and concentration at a much finer time scale. The explicit coupling of site-based assessment tools to Source representations is likely to remain an application-specific consideration.

2.16 SWMM

SWMM (Storm Water Management Model) is a dynamic rainfall-runoff simulation model used for single event or long-term simulation of runoff quantity and quality, primarily from urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of nodes and links (representing pipes, channels, storage/treatment devices, etc.). SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in nodes and links during a simulation period comprised of multiple time steps.

Storage/treatment devices such as wetlands are represented by a node with user inputs defining the storage curve (i.e. relationship between surface area and depth/ volume) for hydraulics, and through specified expressions for treatment processing as specified by the user from a suite of processes supplied in the model (e.g. EMC treatment, constant removal treatment, n^{th} order reaction kinetics, the k-C* model etc.).

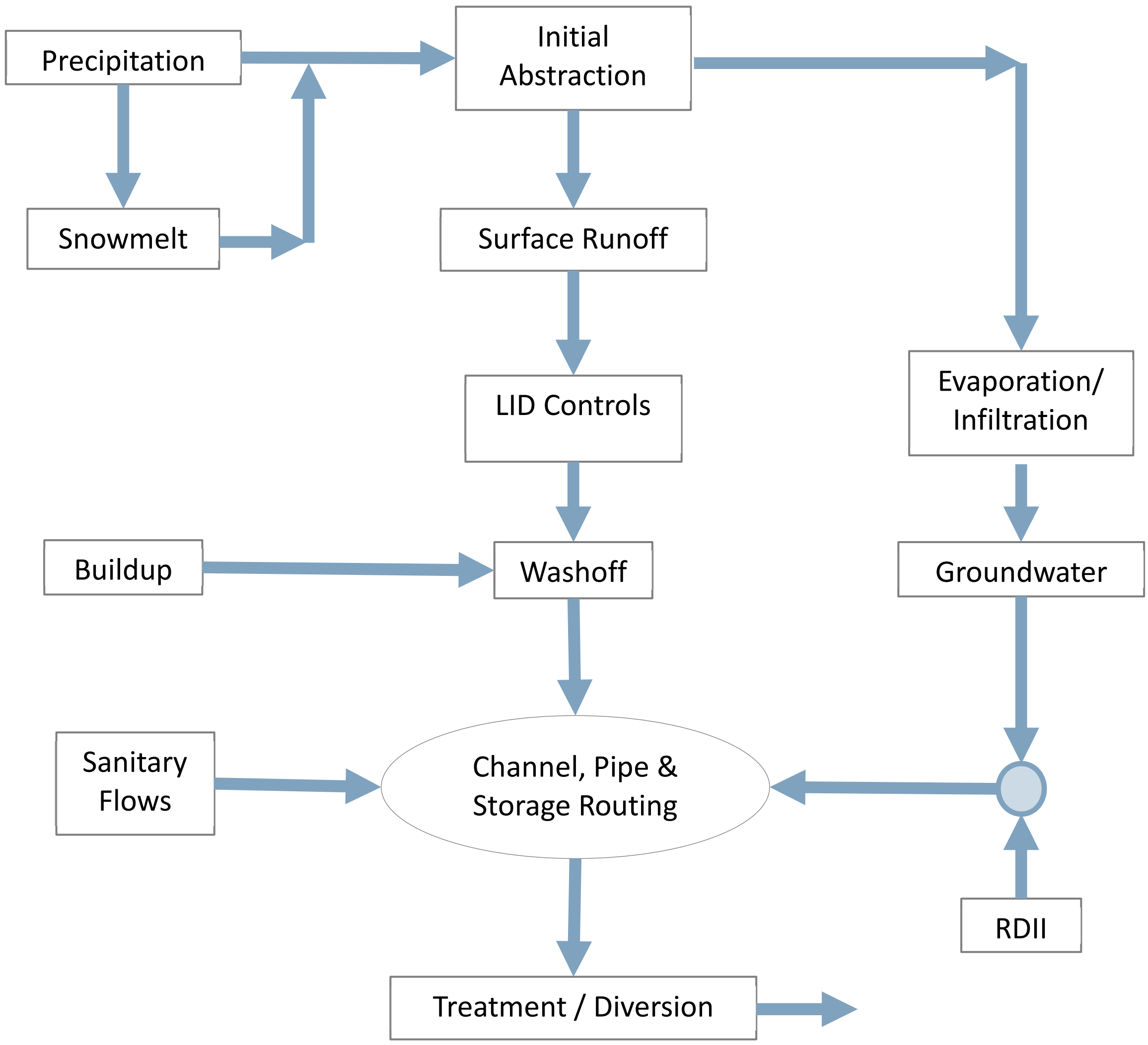

Figure 12. *SWMM model conceptualisation (Rossman, L., Huber, W., 2016)*

Wetlands (specifically constructed wetlands and natural palustrine and lacustrine wetlands) could therefore be simulated within SWMM to a moderate level of sophistication but would need further development of applicable relationships to simulate wetland performance, especially in the GBR context.

2.17 TUFLOW FV AED

TUFLOW (Two-dimensional Unsteady FLOW) is a modelling program for simulating depth-averaged, one (1D) and two dimensional (2D) free surface flows. The 1D engine uses a series of links and nodes as a conceptualised model, while the 2D represents the modelled area through a mesh grid of elements (either gridded squares with TUFLOW classic and HPC or flexible mesh with TUFLOW FV).

The TUFLOW Classic and HPC 2D model solves the full two-dimensional, depth averaged, momentum and continuity equations for free-surface flow using a 2nd order semi-implicit matrix solver. That is, a second order Alternating Direction Implicit (ADI) finite difference solution of the 2D shallow wave equations (additional information can be found in BMT (2018)). At the time of this investigation, it appears that this modelling package is not fully adapted for modelling water quality.

TUFLOW FV is a numerical hydrodynamic model for one dimensional (1D), two dimensional (2D) and three dimensional (3D) Non-Linear Shallow Water Equations (NLSWE). Using this hydrodynamic model as a base, TUFLOW FV also has the ability to include optional modules that provide advection dispersion, sediment transport and morphology, particle tracking, water quality and three-dimensional modelling capabilities.

TUFLOW FV can be coupled with the AED module (similar to GLM AED - see section 2.8) to be able to simulate aquatic biogeochemical and ecological dynamics[1].

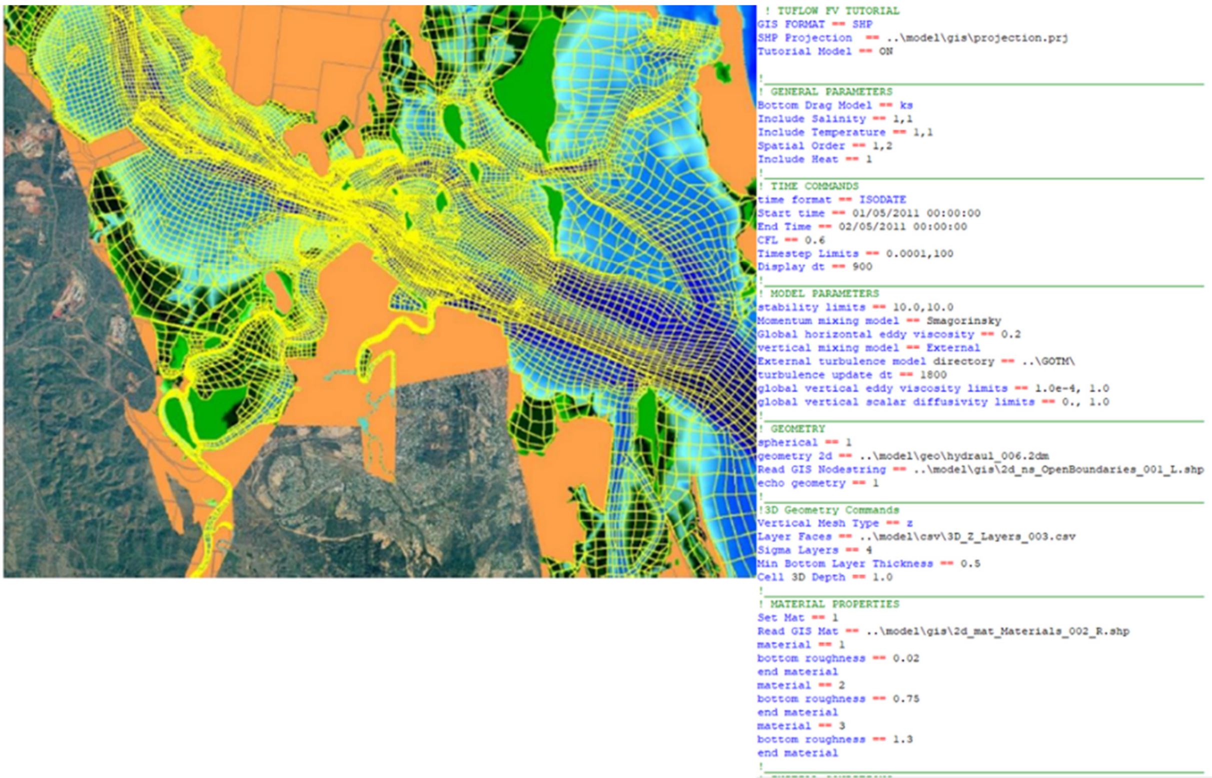

Figure 13. *TUFLOW model example and parameterisation (BMT, 2019)*

Given that TUFLOW is a hydrodynamic and ecosystem process modelling suite when coupled with a module such as AED, the ability to simulate any typology of wetland processes (e.g., nitrogen and phosphorus cycling processes) in detail would be possible, again with considerable user knowledge and configuration required. There is also the potential to link to models such as Source, TUFLOW classic and other landscape models that may provide both fine scale detailed process assessment and evaluation of landscape performance and connectivity. The required data and user competency is likely to limit the application of this modelling suite to large organisations, more suitable to a GBR-context than a site-based assessment.

[1] It is understood that BMT are currently in the process of creating an in-house water quality module to couple with TUFLOW FV.

3 Wetland Treatment Logic

An important aspect in determining suitability of modelling tools for wetland representation is understanding the treatment logic applied within the model. This assists in demonstrating the scientific credibility of each model, such that we can evaluate which model or models are suitable to representing wetlands in specific scenarios or for specific purposes.

The following section provides an overview of the current processes occurring within a wetland and provides identification of which models have the ability to replicate different processes. Figure 14 represents the processes considered during the modelling review.

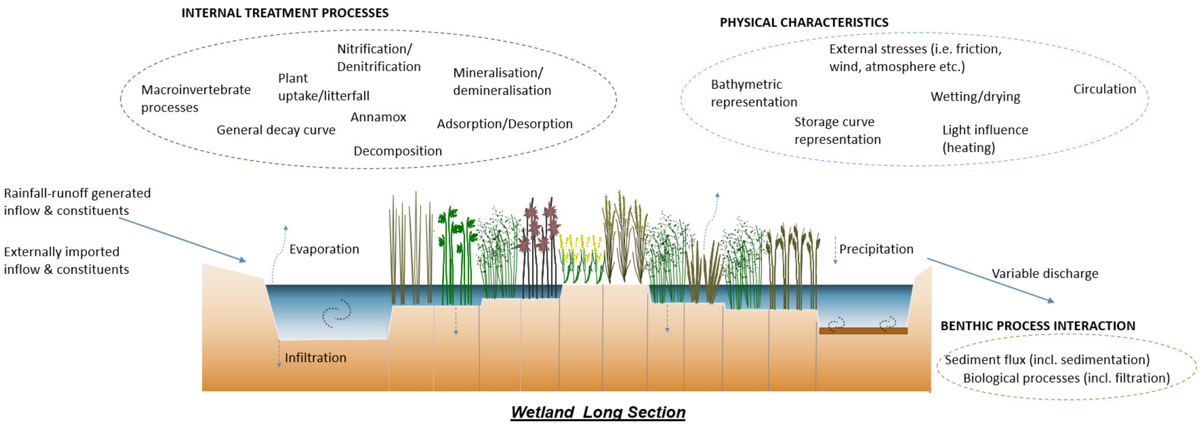

Figure 14. *Conceptual schematic of wetland processes*

In addition to the physical characteristics of the wetland such as the bathymetry, surface storage and hydrologic control configurations, the performance of a wetland can be then determined by the key process components that will be in operation once the wetland has captured and retained flow. In this context, the main processes experienced by wetlands have been briefly discussed in Table 1.

Table 1. Wetland processes considered

Process group	Process	Summary description as it relates to wetland modelling
Boundary conditions	Catchment inflows	Describes the inflows (in terms of quantity & quality) required for modelling of the wetland.
	Precipitation	The rainfall which falls directly onto the wetland
	Infiltration	The infiltration/seepage of a wetland
	Evaporation/evapotranspiration	The evaporation/evapotranspiration of a wetland.
	Discharge	Water discharge from a wetland, through both controlled and uncontrolled means.
Treatment processes	Nitrification/denitrification	Refers to the change in nitrogen-based substances through biological processes that respectively convert ammonium to nitrate, and nitrate to gaseous nitrogen within a wetland.
	Annamox	Refers to the change in NO to N2 through biological processes.
	Macroinvertebrate processes	Refers to nutrients consumed during feeding or excreted by macroinvertebrate within the wetland.
	General decay curve	Refers to the general decay curve of nutrients and sediment within the wetland, meant to represent the summation of all relevant processes.

	Decomposition	Refers to the breakdown processes that convert organic matter, including nutrients) to inorganic forms within a wetland.
	Plant uptake/litterfall	Refers to the flux of nutrients from vegetation uptake and litterfall, respectively.
	Mineralisation	Conversion of nutrients in organic form to inorganic form as a result of bacterial activity.
	Adsorption	The process of nutrients attaching to inorganic sediments.
Waterbody physical characteristics	Waterbody representation	How the wetland is represented in the model, either through an explicit topographic and hydrologic representation or as a simple storage curve.
	External stresses	Refers to any external stresses that may impact upon the wetland, including wind, bed friction, atmospheric pressure, solar radiation, etc.)
	Wetting/drying	Refers to the influence of wetland wetting and drying, primarily around the outermost extents of the wetland.
	Light influence	Influence of light (heating, photosynthesis) on the treatment processes occurring within the wetland.
	Circulation	Associated with the processes that induce vertical and horizontal mixing of wetland waters.
Benthic interactions	Sediment flux (particulates)	Refers to the movement of sediment (and associated attached nutrients) between the lake bed and water column, including processes of settling (i.e. sedimentation) and resuspension.
	Biological processes	Refers to the process of filtration of particulate matter through deposition on or interception by macrophytes.

The logics applied within each of the models in dealing with the above processes have been reviewed in detail and are available in Attachment B. Figure 15 represents a schematised wetland and its processes. The numeric identification allows for a detailed evaluation of each model's treatment logic. A summary of the information provided in this figure is also presented in Table 2.

Table 2. Summary of models adopting identified processes

Model ID	Model
1	BOX MODELS
2	GLM AED
3	HECRAS
4	MEDLI
5	MIKE HYDRO
6	MIKE 21
7	MUSIC
8	RMA
9	SOURCE
10	SWMM
11	TUFLOW FV AED

Process	Models adopting processes
Catchment inflows	4,5,7,9,10
Precipitation	1,2,3,4,5,6,8,9,10,11
Infiltration	1,2,3,4,5,6,7,8,10,11
Evaporation/evapotranspiration	1,2,3,4,5,6,7,8,9,10,11
Discharge	1,2,3,4,5,6,7,8,9,10,11
Nitrification/denitrification	2,5,6,11
Macroinvertebrate processes	2,3,11
General decay curve	1,2,3,5,6,7,8,9,10,11
Decomposition	2,11
Plant uptake/litterfall	2,11
Mineralisation	2,11
Adsorption	2,11
Bathymetric representation	3,6,11
Storage curve representation	1,2,3,4,5,7,8,9,10
External stresses	2,6,11
Wetting/drying	6,8,11
Light influence	2,11
Circulation	2,11
Sediment flux	2,3,4,5,6,11
Biological processes	2,3,11

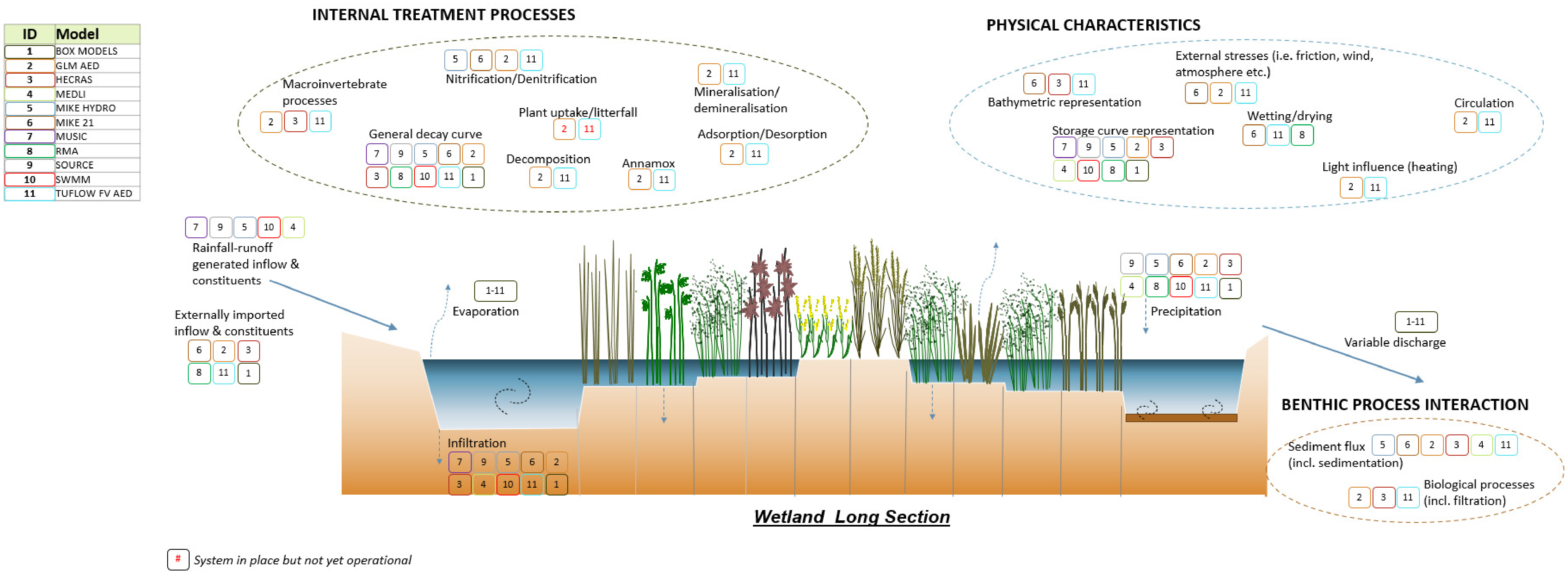

Figure 15. *Schematic representation of processes adopted in reviewed models*

From Table 2 and Figure 15, a number of conclusions can be made, the first of which is that almost all models can simulate the generic high level processes of a wetland system. Relevant inputs include inflows, storage (volume) details, decay/decomposition of pollutants and outflows. Only a few models (e.g. GLM AED and TUFLOW AED) represent more detailed processes that include both the physical processes of transport and mixing, as well as desorption, adsorption and settling, and the biogeochemical processes (e.g. nitrification/denitrification).

The second observation is that no model alone can represent all of the processes that occur in a wetland nor can any model include fully embed a detailed wetland model implicitly within a catchment model.

4 Model classification and usability

To assist in comparison of the models reviewed from a usability perspective, a broad classification system is required. Through previous works, QWMN have developed a series of classification themes as part of reviewing 18 major water models currently used by the Queensland Government, as presented in the Strategic Review of Models (QWMN, 2021b).

These themes were generally adopted for assessing each of the models reviewed from a usability perspective. By their nature, some themes have the potential to be somewhat subjective. To aid in impartiality, the responses informing these themes have been reviewed by experts in the field of wetland modelling. Additional information has been obtained through the public domain (i.e. internet).

A summary of the assessment is presented in Table 3, whilst the full assessment is present in Attachment A. Where possible, a rating scheme describing required effort has been adopted to aid in describing the model themes (e.g. setup & post processing effort, calibration requirements, etc). For instances where this isn't feasible (discrete classifiers), a numeric value has been adopted (e.g., interface, spatial/temporal scale etc.). The following may aid in the classification:

- **Deterministic vs. stochastic vs. mixed**. Most process-based models tend to be deterministic, i.e., for a given set of inputs there is no variation in the model output. This contrasts with a stochastic model that generates variability in the model output, often using a statistical approach. Hybrid approaches are increasingly used, for example by using repeated model runs where parameters are adjusted repeatedly (see e.g., 'sensitivity analysis' above) or an ensemble of models that because of variations in their process descriptions, generate different output.
- **Static vs**. **dynamic.** Most process models are dynamic as they represent changes in concentrations of variables through time. By contrast, static models (or steady state models) provide an equilibrium condition and therefore have no time component. Static models are usually computationally simple and can be set up easily but give no scope to examine the evolution of wetland systems.
- **Discrete vs**. **Continuous**. Discrete models represent a single event, whist continuous models represent a continuous timeseries.
- **Temporal Scale** – represents the temporal extent of the modelled period (e.g. a hours, days, months, years etc.). Temporal scale is of relevance to dynamic models.
- **Spatial Scale** – represents the spatial extent that the model cover (e.g. small scale may relate to a small wetland system, medium scale is a wetland and river reach, large scale is at a landscape and catchment/s extent).

When considering usability, and the information presented in Table 3, it can be considered that a model such as the MUSIC software has a high level of usability (e.g. conceptual process understanding for basic use, medium setup and post processing effort required, well supported and easily and readily achievable knowledge transfer). However, this can come at the expense of detailed process modelling (e.g. nutrient cycles, influence of external forces etc.), as identified in Figure 15.

In contrast, a modelling tool such as GLM AED, while having in-depth modelling process capabilities (see Figure 15), has been classified as one of the models with lower usability. It requires extensive setup and post processing effort, a comprehensive process understanding for calibration of biogeochemical parameters, is only moderately supported and requires moderate effort for knowledge transfer.

Table 3 Model classification overview

Theme	Classifier	BOX MODELS	GLM AED	HECRAS	MEDLI	MIKE HYDRO	MIKE 21	MUSIC	RMA	SOURCE	SWMM	TUFLOW FV AED
Model type	• Deterministic (1) v stochastic (2) v mixed (3) • Static (4) v dynamic (5) • Discrete (6) v continuous (7)	1*,5,7	1*,5,7	1*,4,6	1,4,7	1*,4,6	1*,5,6	3,4,7	1*,5,6	1*,4,7	3,4,7	1*,5,6
Model licence & cost	• Open source (1) v proprietary (2) v public (3) v not specified (4) • Relative cost ($ - $$$)	4($)	1(-**)	1(-)	2($$)	2($$$)	2($$$)	2($$)	2($$)	2($$$)	2($$$)	2($$$)
Spatial/temporal scale	• Small temporal scale (1) • Medium temporal scale (2) • Large temporal scale (3) • Small spatial scale (4) • Medium spatial scale (5) • Large spatial scale (6)	3,1	3,1	3,5	3,6	1,6	1,6	3,6	1,2	3,6	3,6	1,6
Process understanding & expertise required for use *(Basic use/ detailed use)*	• Comprehensive (🟥🟥🟥) • Partial (🟧🟧🟧) • Conceptual (🟧🟧) • Very little (black box) (🟩) • None (□)	🟧🟧/ 🟥🟥🟥	🟥🟥🟥/ 🟥🟥🟥	🟧🟧/ 🟥🟥🟥	🟧🟧/ 🟥🟥🟥	🟧🟧/ 🟥🟥🟥	🟧🟧/ 🟥🟥🟥	🟧🟧/ 🟥🟥🟥	🟥🟥🟥/ 🟥🟥🟥	🟧🟧/ 🟥🟥🟥	🟥🟥🟥/ 🟥🟥🟥	🟥🟥🟥/ 🟥🟥🟥
Interface	• GUI (1) • Text (2) • Mixed (3)	2	2	1	1	1	1	1	3	1	1	3
Setup/post processing effort *(Setup/ post processing)*	• Extensive (🟥🟥🟥) • Medium (🟧🟧) • Little (🟩) • None (□)	🟥🟥🟥/ 🟩	🟥🟥🟥/ 🟥🟥🟥	🟧🟧/ 🟧🟧	🟧🟧/ 🟧🟧	🟧🟧/ 🟧🟧	🟥🟥🟥/ 🟥🟥🟥	🟧🟧/🟧🟧	🟥🟥🟥/ 🟥🟥🟥	🟥🟥🟥/ 🟥🟥🟥	🟥🟥🟥/ 🟥🟥🟥	🟥🟥🟥/ 🟥🟥🟥
Calibration requirements	• Extensive (🟥🟥🟥) • Medium (🟧🟧) • Little (🟩) • None (□)	🟥🟥🟥	🟥🟥🟥	🟥🟥🟥	□	🟥🟥🟥	🟥🟥🟥	🟩	🟥🟥🟥	🟥🟥🟥	🟥🟥🟥	🟥🟥🟥
Level of support	• Well supported (🟩) • Moderate support (🟧🟧) • Poorly supported (🟥🟥🟥) • Not supported (□)	🟧🟧	🟧🟧	🟧🟧	🟧🟧	🟩	🟩	🟩	🟥🟥🟥	🟩	🟩	🟩
Stakeholder communication and knowledge transfer	• Easily and readily achievable (🟩) • Easily but not readily achievable (🟩🟩) • Moderate (🟧🟧) • Difficult (🟥🟥🟥) • Not required (□)	🟩	🟧🟧	🟧🟧	🟩	🟧🟧	🟩🟩	🟩	🟥🟥🟥	🟩🟩	🟩🟩	🟩🟩
Uncertainty testing	• Comprehensive (🟩) • Partial (🟧🟧) • Non-existent (🟥🟥🟥)	🟥🟥🟥 For all models, the modeller needs to be cognizant of input uncertainties. Additionally, any embedded uncertainty in the modelling framework requires comprehensive knowledge to understand.										
Currency	• Year updated • Frequency of updates	Variable	2020 Intermitent	2020 unknown	2015 unknown	Annual*** Intermitent	Annual*** Intermitent	2021 Intermitent	2005 unknown	2021 Intermitent	2005 Intermitent	2020 Intermitent

** Although deterministic, computing power and batching allows for many runs, resulting in a quasi-stochastic nature if the modeller desired.*
*** No model acquisition cost, however costs may be associated with learning tools (e.g. tutorials, webinars etc.)*
**** Licencing agreement may not allow for updates to be implemented.*

5 Model applicability

Each of the models in this review has the ability to represent wetlands and the complexity of their internal processes to a lesser or greater extent. Through investigating the validity of these models for this purpose, several references have been identified in which the modelling tool has been used to represent wetlands. Table 4 presents these references for each model and provides a description of how the model was used. As anticipated, this is not a comprehensive list of all instances where these models have been used for wetland (or related) description, rather a subsample of publicly sourced information (papers sourced from the internet).

Table 4 Model reference list

Model	Reference	Locality	Description	Relevant aspects of wetland modelled
BOX MODELS	Alluvium, 2018	Sarawak, Borneo, Malaysia	A box model was constructed of the Batang Ai reservoir in Sarawak, Borneo, Malaysia, to incorporate catchment model inputs into storage hydrodynamics (zero dimensional) and water quality processes. While not specifically wetland related, it shows the flexibility of using a spreadsheet style box model for simulating storage related processes.	• Hydrodynamics • TSS, TN, TP
GLM AED	Hipsey, M., et. al., 2019	Upper Swann, Western Australia	This paper summarises the scientific basis and numerical implementation of the model algorithms, including details of sub-models that simulate surface heat exchange and ice cover dynamics, vertical mixing, and inflow–outflow dynamics. It additionally demonstrates the suitability of the model for different lake types that vary substantially in their morphology, hydrology, and climatic conditions. Further it investigates the dynamic coupling with biogeochemical and ecological modelling libraries (i.e. AED) for integrated simulations of water quality and ecosystem health.	• Hydrodynamics • Numerous quality modules considered in one lake, including (sediment tracers, oxygen, carbon, silica, nitrogen, phosphorus, organic matter, phytoplankton, zooplankton)
	Bruce, L., et. al., 2018	Worldwide	This paper develops and analyses 32 one dimensional GLM lake models from a global observatory network. The data set was varied over latitude, climatic zones, size, residence time, mixing regime and trophic level. This paper did not however consider the dynamic coupling with biogeochemical and ecological modelling libraries (i.e. AED).	• Hydrodynamics
	Fenocchi, A., et. al., 2018	Northern Italy/Southern Switzerland	Long term (approx. 17 year) calibration and validation of Lake Maggiore (Northern Italy/Southern Switzerland), focusing on reproduction of both deep-water chemistry and phytoplankton biomass and succession	• Lake hydrodynamics • Speciation of nutrients • Carbon consideration • consideration of phytoplankton
HECRAS	Xiao, L., et. al., 2020	Edmonton, Canada	The performance of a constructed wetland is assessed as it impacts on nutrient discharges into the receiving waterway.	• Hydrodynamics • Nitrate, organic phosphorus
	Rogers, J., Wu, C., 2007	Southern Wisconsin, North America	Assessment of a 44.9 ha wetland, with reference to hydrodynamics and sediment and phosphorus reduction.	• Hydrodynamics • Sediment, phosphorus
MEDLI	Ash, R., Truong, P., 2004	Toogoolawah, Queensland, Australia	Modelling of wastewater effluent treatment through Vitiver Grass wetlands for pH, DO, BOD, SS, TN and TP.	• Hydrodynamics • pH, DO, BOD, SS, TN, TP
MIKE HYDRO	Liang, J. et. al., 2015	Beijing, China	Scenario assessment of lake water quality using a number of techniques, including a 'Wetland Landscape' (which appears to be a wetland treatment train).	• Hydrodynamics • BOD, COD, ammonia, TP

MIKE 21	Qiao, H, et. al., 2018	Liao River estuary, China	Utilises MIKE 21 hydrodynamic and salinity modelling to simulate the hydrodynamic characteristics and salinity transport processes in the Pink Beach wetlands of the Liao River estuary	• Hydrodynamics • Salinity
	Somes, H., Bishop, W., Wong, T., 1999	Strzelecki Ranges, Victoria, Australia	Undertakes numerical simulation of flow hydrodynamics within a constructed wetland (however does not consider quality, anticipated to be due to lack of availability at time of assessment).	• Hydrodynamics
MUSIC	Alluvium, 2019, DPI 2009	Queensland, Australia	MUSIC was used to assess the performance of wetlands for nutrient management across a range of reef catchments as part of an evaluation into cost-effectiveness of management options for reef investment. The above work was developed using previous guideline development conducted for the former Qld Department of Primary Industries in using MUSIC to evaluate on farm wetland performance. It used concentrations for each constituent (including DIN) based on Queensland Paddock to Reef (P2R) monitoring data but simulated their decay consistent with the decay functions for the existing similar constituents (e.g. DIN was simulated using the decay functions for TN)	• Hydrodynamics • Fine sediment (as Total Suspended Solids) • DIN (as Total Nitrogen) • Total Nitrogen • Total Phosphorus
	Wong, T,. et. al., 2002	Australia	Along with outlining the MUSIC modelling framework, this paper presents a case study of a stormwater quality improvement study using MUSIC to model various treatment approaches, including wetlands. This paper presents the percentage reduction in TSS, TN and TP from these options and how they comply with location specific water quality objectives.	• Hydrodynamics • Total Suspended Solids • Total Nitrogen • Total Phosphorus
	Mohd Noor, N., et. al., 2014	Malaysia	MUSIC was used to assess the WSUD components of a development in Malaysia, of which included a constructed stormwater wetland. This assessment has identified that the modelling indicates 'significant' reduction of TSS, TN and TP from existing land use to future in the study area. This assessment identified that MUSIC is suitable for prediction over a long term period, however not well established for simulations for short term periods or event based rainfall.	• Hydrodynamics • Total Suspended Solids • Total Nitrogen • Total Phosphorus
RMA	Ajiwibowo, H., 2018	Sumatra Island, Indonesia	Represents lake hydraulics and water quality (TSS and phosphate). It utilises an RMA2 for flow modelling and RMA4 for contaminant transport modelling.	• Hydrodynamics • BOD, DO, phosphate
	Hasab, H., et. al., 2015	South Eastern Iraq	Simulation of the Mesopotamia marshlands in southern Iraq using RMA 2 and RMA 4 to determine hydrodynamics, TDS, TSS and salinity concentrations and movement.	• Hydrodynamics • TDS, TSS, Salinity
	Koskiaho, J., 2011	Southern Finland	Two-dimensional hydraulic simulation and TSS simulation of constructed wetlands.	• Hydrodynamics • TSS
SOURCE	Rassam et al, 2005.	Australia wide	Used the precursor to Source, the E2 modelling framework, to develop the Riparian Nutrient Model, which was designed to simulate the transient flow of stream flow into riparian zones where nutrient removal (including dissolved fractions) was simulated. With adaptation, this could readily represent wetland zones.	• Hydrodynamics • Nitrate
SWMM	Pittman, J., 2011	Villanova, Pennsylvania, North America	Utilisation of SWMM to analyse the hydrodynamics and water quality (TSS, TDS, chlorides, NO2 and NO3) of a constructed stormwater wetland.	• Hydrodynamics • TSS, TDS, chlorides, nitrite, nitrate
	Gamache, M., et. al., 2013	Boston, Massachusetts, North America	A uniquely detailed SWMM computer model was adapted from an existing system-wide 4,000 node hydraulic model (which includes all ponds and wetland located along modelled conduits), and used to assess sources, loads, and mitigation alternatives for 13 pollutants discharging from the city's drain systems to its receiving waters. It simulates pollutant conveyance through open and closed conduit systems, first-order decay of oxygen demand, bacteria	• Hydrodynamics • TSS, BOD, COD, TKN, NOx, NH_3, TP, PO_4, Cu, Zn, faecal coliforms, E. coli, Enterococcus

			die-off, bacteria resuspension from sources in sediment bed load and pollutant removal through natural and constructed detention/treatment systems.	
	Lee, S., et. al., 2010	Han River Basin, South Korea	Assesses the applicability of the watershed scale hydrologic and water quality simulation model SWMM to simulate the hydrology of a small watershed in the Han River Basin.	• Hydrodynamics
TUFLOW	Zhang, L., et. al., 2017	Jilin, Northeast China	The coupled TUFLOW-FV and Aquatic Ecodynamic AED2 models were used to simulate the hydrodynamic and water quality of Chagan Lake, and propose the water diversion scheme that could improve the water quality to reach Chinese Grade III quality and maintain the ecological water level.	• Hydrodynamics • NH_3, TN, TP

6 Assessment of Model Suitability

All models within this assessment are likely to have merit when they have been applied in contexts for which they were specifically designed for. When consideration is given to modelling wetlands, some may be more suited for specific purposes or modelling questions that may be of interest in understanding wetlands in the GBR context. That is, there is unlikely to be one model can be the most suited for all situations; rather the situation will dictate the model (or models) applied. Table 5 presents a range of typical scenarios which models may be required to answer, including which model could be applied, the pros and cons of this, and (where possible) an example of this having been accomplished.

Important additional considerations when setting up a model may be the quality of the input data; sparse or incomplete input data may necessitate simpler modelling approaches because of the amount of data filling, interpolation and extrapolation that is required. Additionally, model capability can dictate adoption for different scenarios (e.g. the model should be able to represent detailed internal treatment processes if this is what's required). Modeller 'skill' is another important consideration. The models with relatively complex biogeochemical modules require considerable time and effort to calibrate numerous biogeochemical parameters. Theory, literature, measurements and experimental work are often used in combination to select values of these parameters, and modeller skill has an important part to play in the accuracy of the model simulations. Autocalibration is also sometimes used but will not circumvent modeller skill. Lastly, a strict process of model calibration followed by validation on an independent dataset is required (e.g., corresponding to when some feature in a wetland has changed, or even a different, nearby wetland).

Some models have well developed visualisation tools, which can be an important consideration depending on the intended audience for the model output. Consideration could be given to producing wetland model visualisation tools that can be readily adapted to different models as well as data assimilation tools that would enable input data to be automatically formatted for multiple models, potentially opening up opportunities for ensembles of models.

Table 5 Typical modelling requirement scenarios

Scenario	Model	Pros	Cons	Examples
Requirement for a detailed understanding of processes occurring within a wetland (i.e. sources & sinks of nutrients)	BOX MODELS	• Highly customisable • Potentially simple set up, fast run times and easy interpretation	• Generally simplistic representation of wetland hydrodynamics (i.e., a mixed box).	Alluvium, 2018
	GLM AED	• In-depth nutrient processing • Detailed representation of wetland hydrodynamics • Highly customisable setup	• Considerable effort required in model setup • Comprehensive understanding required for appropriate use • External sources of data required as inputs into model • Extensive calibration of biogeochemistry required	Fenocchi et. al., 2018
	HECRAS	• Consideration of in-depth nutrient processing	• Considerable effort required in model setup • Only considers a 1D representation of wetland hydrodynamics*	Xiao et. al., 2020 Rogers, Wu 2007
	MIKE 21	• In-depth nutrient processing • Detailed representation of wetland hydrodynamics • Highly customisable setup	• Considerable effort required in model setup • Comprehensive understanding required for appropriate use • External sources of data required as inputs into model • Extensive calibration of biogeochemistry required	Qiao, H, et. al., 2018

Requirement for a detailed understanding of processes occurring within a wetland (i.e. sources & sinks of nutrients), *cont.*	RMA	• Customisable wetland hydrodynamic setup	• Considerable effort required in model setup • Minimal level of support • Only considers model decay rate, no in-depth nutrient processing	Ajiwibowo, 2018
	SWMM	• Moderate effort required for model setup • Variable wetland treatment processes with speciation considered	• No nutrient cycle representation • Simple wetland hydrodynamic representation	Gamacheet. al., 2013
	TUFLOW FV AED	• In-depth nutrient processing • Detailed representation of wetland hydrodynamics (including 3D capabilities) • High level of hydrodynamic setup support • Highly customisable setup	• Considerable effort required in model setup • Comprehensive understanding required to appropriately use • External sources required as inputs into model	Zhang et. al., 2017
Assessment of the suitability of different wetland types for nutrient removal	GLM AED	• Highly customisable wetland hydrodynamic setup to represent various wetland types • Highly customisable treatment/ processing parameters to replicate various in-wetland processes.	• Considerable effort required in model setup • Comprehensive understanding required to appropriately use • Moderate support	Hipsey et. al., 2019
	MIKE 21	• Highly customisable wetland hydrodynamic setup to represent various wetland types • Customisable treatment/ processing parameters to replicate various in-wetland processes.	• Considerable effort required in model setup • Comprehensive understanding required to use appropriately	Qiao et. al., 2018 Somes et al. 1999
	TUFLOW FV AED	• Highly customisable wetland hydrodynamic setup to represent various wetland types • Highly customisable treatment/ processing parameters to replicate various in-wetland processes. • High level of hydrodynamic setup support	• Considerable effort required in model setup • Comprehensive understanding required to appropriately use	Zhang et. al., 2017
Assessing wetland designs for an approvals process^	BOX MODELS	• Highly customisable • Most transparent • Easily adapted to new applications • Familiar to non-modellers	• Generally simplistic representation of wetland hydrodynamics and nutrient processing (although could adopt complex nitrogen cycle processing).	Alluvium, 2018
	GLM AED	• Highly customisable wetland hydrodynamic setup to represent various wetland types • Highly customisable treatment/ processing	• Considerable effort required in model setup • Comprehensive understanding required to appropriately use • Moderate support	Hipsey et. al., 2019

	parameters to replicate various in-wetland processes.		
HECRAS	• Consideration of in-depth nutrient processing	• Considerable effort required in model setup • Only considers a 1D representation of wetland hydrodynamics*	Xiao et. al., 2020 Rogers, Wu 2007
MEDLI	• Well referenced representation of treatment for one wetland type (i.e. constructed wetlands)	• Poor representation of wetland hydrodynamics • Not versatile for wetland types.	Ash, Truong., 2004
MIKE HYDRO	• Good integration between catchment and wetland representation within the same model	• Simplistic representation of wetland hydrodynamics • Only has consideration of two rainfall runoff models	Liang et. al., 2015
MIKE 21	• Highly customisable wetland hydrodynamic setup to represent various wetland types • Customisable treatment/ processing parameters to replicate various in-wetland processes.	• Considerable effort required in model setup • Comprehensive understanding required to use appropriately	Qiao et. al., 2018 Somes et al. 1999
MUSIC	• Relatively usable software • Incumbent modelling tool for a high number of regulatory authorities in approvals process • Quick to run • Considers high level wetland hydrodynamics	• Only considers decay of total nutrients (and TSS), no speciation or nutrient cycle consideration	DPI 2009.
RMA	• Customisable wetland hydrodynamic setup	• Considerable effort required in model setup • Minimal level of support • Only considers model decay rate, no in-depth nutrient processing	Ajiwibowo, 2018
SOURCE	• Highly customisable representation of catchment • High level of variability in rainfall runoff model choice • Incumbent modelling tool for catchment representation in Australia • Can easily modify bulk parameters using text file integration	• Considerable effort is required for setup, including setting up of treatment trains • May require input from alternate models representing wetlands	Rassam et al, 2005.
SWMM	• Relatively usable software • Considers high level wetland hydrodynamics • Variable wetland treatment processes with speciation considered	• Moderate effort required for model setup	Gamache et. al., 2013
TUFLOW FV AED	• Highly customisable wetland hydrodynamic setup to represent various wetland types	• Considerable effort required in model setup • Comprehensive understanding required to appropriately use	Zhang et. al., 2017

		• Highly customisable treatment/ processing parameters to replicate various in-wetland processes. • High level of hydrodynamic setup support		
Landscape (catchment) assessment of wetland influence on water quality (i.e. catchment scale understanding of wetland influence)	MIKE HYDRO	• Good integration between catchment and wetland representation within the same model	• Simplistic representation of wetland hydrodynamics • Only has consideration of two rainfall runoff models	Liang et. al., 2015
	MUSIC	• Easy to represent a treatment train approach, and numerous treatments within numerous catchments • Relatively usable software with quick setup time • Quick to run	• Only considers one type of rainfall runoff model • Difficult to alter parameters on a bulk level	Alluvium, 2019.
	SOURCE	• Highly customisable representation of catchment • High level of variability in rainfall runoff model choice • Incumbent modelling tool for catchment representation in Australia • Can easily modify bulk parameters using text file integration	• Considerable effort is required for setup, including setting up of treatment trains • May require input from alternate models representing wetlands	Rassam et al, 2005.
	SWMM	• Considers surface build up of pollutants within the catchment • Good integration between catchment and wetland representation within the same model Considers first flush processes Easy for seamless integration between landscape scale and treatment scale	• Simplistic representation of wetland hydrodynamics	Gamache et. al., 2013

**2D modelling of water quality currently in beta version*
^ Model choice highly dependent on detail called for in legislative documents; the models adopted are highly dependent on the questions needing to be answered.

7 Conclusions and recommendations

From the findings of this review, it is concluded that there is no 'one size fits all' approach to wetland modelling. Consideration needs to be given to the questions needing answers. For some questions, several models may be required (e.g. process understanding in the catchment may require SOURCE, which can provide the input into a process detailed wetland model represented in GLM AED). The questions therefore include:

(i) what level of integration is required with other models to extend to reach or catchment scale,
(ii) what is the length of the simulation (e.g., days…decades),
(iii) what is the spatial representation of the model (0D, 1D, 2D or 3D) and
(iv) what level of model complexity is sought (e.g., a water balance, a mixing and transport model, or a fully coupled hydrodynamic-ecological model)?

When considering the question to be answered, attention should also be paid to how current/up to date the modelling tool is (often related to the level of support for the user), the scientific rigour that underpins the modelling processes and the level of documentation available to assist the user with running the model and understanding the model conceptualisation and formulation. A catalyst for future investment of modelling tools could be if the tool is not sufficiently current or the scientific rigour is deemed unacceptable or unsuitable, but a decision should not be made to resurrect a model that is considered to have become obsolete or outdated – and would require a major investment

From the analyses within this report, there are a few modelling frameworks that may provide further ongoing benefit if adapted or developed further for use in the GBR, regulatory context, nutrient offsets and natural wetland management context.

The MUSIC model has been applied previously to assess different wetland configurations in the Reef, however it has been applied "as is" without further adaptation of the treatment algorithms to specifically address the likely performance of wetlands in the tropics in terms of nutrient removal. MUSIC has the advantage of being widely applied across Australia and is relatively easy to use, but without tailoring the treatment algorithms to better represent the nutrients of interest (e.g., dissolved inorganic nitrogen), or the recent knowledge around wetland processes (e.g., Adame et al. 2019), the outputs of the model are likely to lack credibility. We therefore suggest that if some development of the treatment algorithms (the k-C* and CSTR configurations of the USTM components of the wetland node) were undertaken, MUSIC would have wide applicability to the assessment of wetlands (e.g., assessment of new constructed treatment wetlands) in Reef applications. This is unlikely to be a significant component of work, with most being completed through review of existing monitoring data.

The GLM-AED framework and the TUFLOW FV-AED coupled modelling suite have the ability to represent wetland processes in a high degree of detail and the ability to be used to evaluate the optimisation of wetland performance, existing wetland processes and the connectivity of wetlands in a hydrodynamic environment. The hydrodynamic environment should, however, be considered carefully because any reduction in model dimensionality may render the model less effective and potentially not fit for purpose (e.g., horizontally averaged GLM where a wetland has substantial horizontal variation). GLM-AED and TUFLOW FV-AED are computationally intensive and require a high degree of modelling skill to implement, hence their use in assessing different wetland types quickly is likely to be limited, though they may be used to refine design components, or evaluate which existing wetlands are likely to be of more benefit for nutrient removal. Given they have already been used in this context, further development and application of them is warranted in terms of applications to specific case studies, especially where monitoring data is available, and perhaps in conjunction with other models that describe landscape processes, such as SWMM, Source or MUSIC.

The SWMM model has considerable potential to provide a simulation tool of intermediate complexity between the MUSIC and GLM-AED models, given that it is readily adaptable to simulate the hydrologic, hydraulic and water quality processes of wetlands, and can represent these at different levels of detail, rather than at a high level such as MUSIC (i.e. just using exponential decay), or the detailed hydrodynamic representations in GLM-AED. SWMM has not seen wide application in Queensland, though it is used extensively across the world and literature studies are available which may assist in developing and refining it further for use in the Reef space.

It also has the advantage of being free in some cases (i.e. using the command line version with no interface), but this will limit its usability.

Finally, the Source modelling framework is widely applied in the Reef context and across Australia. It is also eminently flexible given that plug-in modules can be developed for it, though none exist currently to describe wetland performance. Coupling the Source model with a higher speed wetland hydrodynamic model that operates at a similar computational speed to Source (comparatively a Source model run lasts from a few seconds up to a couple of hours, depending on the size of the model and the computational power, whereas wetland hydrodynamic models can run from a few seconds to many days), may be useful to consider to describe wetlands at the catchment scale, or alternatively, developing a wetland plugin specifically for Source may also provide the appropriate level of functionality. These would require a significant level of investment to develop given that there is no existing component plugin model that could be easily adapted here, it would need to be developed from “scratch”. With the development of MUSIC X, if MUSIC was to be configured to be more representative of wetlands in the Reef context, MUSIC X models can be embedded within Source such that a more comprehensive whole of catchment understanding of wetlands at the landscape scale could be undertaken. In a similar vein, the Riparian Nutrient Model may have some components that may be adaptable to wetlands, though currently this focuses on subsurface processes only and has not been considered for surface flow wetlands.

In the site-based assessment (or legislative) context, there is no currently available wetland model that could be considered ‘industry standard’, as both MUSIC and MEDLI are recognised for urban stormwater and land disposal respectively. Where appropriate stakeholder demand is demonstrable, a robust business case for formalised development of wetland-specific decision support tools could be presented to government and industry to seek support. The development of new modelling tools, or adaptation of existing models, is a long-term commitment and requires not only software development, but also scientific input and support. The diversity of wetland types and pollutant processes that might need consideration for different applications and activities again reinforces the continued theme of this report: there is not one solution that will suit all needs. A strategic and prioritised approach to explicit tool development would need to be managed. Even without a formalised plan to build commercial-standard wetland models like MUSIC and MEDLI, there are some activities that could take place in the short term to assist the assessment and comparison of water quality outcomes from small scale wetland features, and these do no impede R&D continuing at the landscape and catchment scale. Some of these are:

- Collation and documentation of existing box models, with online access to allow distribution throughout Queensland
- Collation of relevant measured/experimental data to begin formulating a ‘database’ of useful parameters and pollutant reduction rates (similar to regional MUSIC parameter sets and recommendations that are utilised by LGAs and similar, acknowledging that many stakeholders are not familiar with scientific literature, and indeed may not have the resources to search and make sense of this)
- Use the thorough review of model capability provided in this report to launch a formal process of model development for an identified, critical purpose. Provision of an intuitive model that can help assess the impact of palustrine (vegetated) wetlands on nitrogen processes at a local/farm scale is one priority activity already identified by several organisations.

While we have not specifically identified other models for further development, there are possibilities that proprietary tools such as DHI HYDRO, DHI ECOlab and TUFLOW FV could be further developed in collaboration with their developers, but this has not been explored further in this report and remains an opportunity that could be investigated.

We found that the models examined provide the opportunity to explore wetland processes and roles in more depth, but further work is likely to be required to enable the models to be improved and to investigate specific applications in more detail. No one model has been identified which suits all wetland modelling questions but rather, it is a case of “horses for courses” according to the questions being raised. We suggest that several models be maintained as ‘user ready’ and consideration be given to additional investment so that applications are available for use in the Reef context. Further, we would suggest that once an approach for modelling has been established that a set a modelling guidelines and review processes documentation also be established. This will ensure a consistency in preparation and evaluation of models created.

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Attachment A
Model Classification

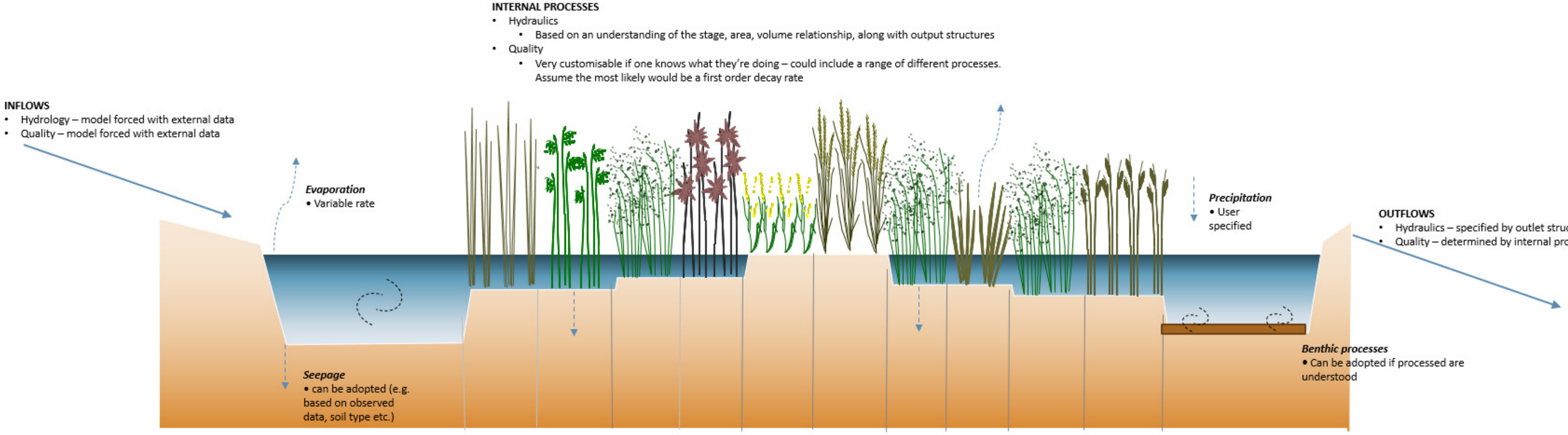
Theme	Classifier	Models BOX MODELS	GLM AED	HECRAS (1d & 2d)
Key area of use	• Farming and agricultural systems assessment • Water planning and supply • Water balance modelling • Water quality modelling • River hydraulic modelling • Catchment policy • Flooding • Aquaculture • Mine decommissioning and discharge • Other • Policy formation • Regulation/permitting • Planning • Impact assessment	• Water balance modelling • Water quality modelling • Planning • Impact assessment	• Water balance modelling • Water quality modelling • Aquaculture • Other • Regulation/permitting • Planning • Impact assessment	• Flooding • Water quality modelling • Other • Policy formation • Regulation/permitting • Planning • Impact assessment
Model type	• Deterministic v stochastic v mixed • Static v dynamic • Discrete v continuous	• Deterministic • Dynamic • Continuous	• Deterministic • Dynamic • Continuous	• Deterministic • Static • Discrete
Model licence & cost	• Open source • Proprietary • Public • Not specified	• Open source • ~$350*	• Public • Free	• Public • Free
Spatial/temporal scale	Models are often able to operate over a relatively wide range of spatial and temporal scales. This information is provided in graphic form to facilitate identification of models and scales.	• Minimal temporal/spatial scale**	• Very wide temporal/spatial scale*	• Very wide temporal/spatial scale*
Process understanding & expertise required for use	• Comprehensive • Partial • Conceptual • Very little (black box) • None	• Conceptual for basic use • Partial for detailed use	• Comprehensive for basic use • Comprehensive for detailed use	• Partial for basic use • Comprehensive for detailed use
Interface	• Graphical User Interface (GUI) • Text • Mixed	• Text	• Text	• GUI
Setup/post processing effort	• Extensive • Medium • Little • None	• Extensive setup • Minimal post processing	• Extensive setup • Extensive post processing**	• Medium setup** • Medium post processing
Calibration requirements	• Extensive • Medium • Little • None	• Extensive***	• Extensive***	• Extensive***
Level of support	• Well supported • Moderately supported • Poorly supported • Not supported	• Moderately supported****	• Moderately supported****	• Moderately supported****
Stakeholder communication and knowledge transfer	• Easily and readily achievable • Easily but not readily achievable • Moderate • Difficult • Not required	• Easy and readily achievable*****	• Easy but not readily achievable*****	• Moderate
Uncertainty testing	• Comprehensive • Partial • Non-existent	• Need to be cognizant of input uncertainties. User to specify testing to determine influence • The imbedded uncertainty in the model framework requires comprehensive knowledge to understand.		
Currency	• Year updated • Frequency of updates	• Varied******	• GLM - 2020, AED - 2019 • Intermittently	• Dec 2020
Additional notes	Additional notes provided, expanding upon classifiers mentioned above.	* cost of a Microsoft Office suite including Excel ** only designed for a specific waterbody element (i.e. wetland) *** against all lines of truth (e.g. water level, quality data etc.) **** depending on the box model and the creator of the model ***** only if originally set up well ****** depending on the box model	* determined by input data and practically limited by computing power ** can be scripted for iterative runs *** against all lines of truth (e.g. water level, quality data etc.) **** tutorials and examples available online ***** anticipated to be moderate to set up initially, but easy for iteration once set up	* determined by input data and practically limited by computing power ** dependant on modelling complexity adopted *** against all lines of truth (e.g. water level, quality data etc. often this information does not exist) **** no paid support from developer but commercial courses available at a cost. Moderate online community and tutorials in manual.

Theme	Classification	Models		
		MEDLI	**Mike HYDRO**	**MIKE 21**
Key area of use	• Farming and agricultural systems assessment • Water planning and supply • Water balance modelling • Water quality modelling • River hydraulic modelling • Catchment policy • Flooding • Aquaculture • Mine decommissioning and discharge • Other • Policy formation • Regulation/permitting • Planning • Impact assessment	• Water balance modelling • Water quality modelling • Other • Planning • Regulation/permitting • Impact assessment	• Flooding • Water quality modelling • River hydraulic modelling • Other • Policy formation • Regulation/permitting • Planning • Impact assessment	• River hydraulic modelling • Flooding • Water quality modelling • Other • Policy formation • Regulation/permitting • Planning • Impact assessment
Model type	• Deterministic v stochastic v mixed • Static v dynamic • Discrete v continuous	• Deterministic • Static • Continuous	• Deterministic • Static • Discrete	• Deterministic • Dynamic • Discrete
Model licence & cost	• Open source • Proprietary • Public • Not specified	• Proprietary • Unknown*	• Proprietary • ~$1100 per licence per month*	• Proprietary • ~$970 per licence per month*
Spatial/temporal scale	Models are often able to operate over a relatively wide range of spatial and temporal scales. This information is provided in graphic form to facilitate identification of models and scales.	• Moderate temporal/spatial scale**	• Very wide temporal/spatial scale**	• Very wide temporal/spatial scale**
Process understanding & expertise required for use	• Comprehensive • Partial • Conceptual • Very little (black box) • None	• Partial for basic use • Comprehensive for detailed use	• Partial for basic use • Comprehensive for detailed use	• Partial for basic use • Comprehensive for detailed use
Interface	• Graphical User Interface (GUI) • Text • Mixed	• GUI	• GUI	• GUI
Setup/post processing effort	• Extensive • Medium • Little • None	• Moderate setup • Moderate post processing***	• Extensive to medium setup • Extensive to medium post processing	• Extensive setup • Extensive post processing
Calibration requirements	• Extensive • Medium • Little • None	• None****	• Extensive***	• Extensive***
Level of support	• Well supported • Moderately supported • Poorly supported • Not supported	• Moderately supported*****	• Moderately supported****	• Moderately supported****
Stakeholder communication and knowledge transfer	• Easily and readily achievable • Easily but not readily achievable • Moderate • Difficult • Not required	• Easy and readily achievable******	• Moderate*****	• Easy*****
Uncertainty testing	• Comprehensive • Partial • Non-existent	• Need to be cognizant of input uncertainties. User to specify testing to determine influence • The imbedded uncertainty in the model framework requires comprehensive knowledge to understand.		
Currency	• Year updated • Frequency of updates	• 2015 • Unknown	• 2020 (annually) • Intermittently******	• 2020 (annually) • Intermittently******
Additional notes	Additional notes provided, expanding upon classifiers mentioned above.	* licence cost not specified, but considered low (Vieritz, A., 2011) ** determined by input data and practically limited by computing power *** can be set up initially for ease of iterative runs **** as understood without model use ***** paid support available ****** once reporting within the model has been set up	* comes as package deal with additional modules (i.e. Hydrology/hydraulics package) ** determined by input data and practically limited by computing power *** against all lines of truth (e.g. water level, quality data etc.) ****paid support available, poorly supported online community ***** not readily achievable, generally 1D timeseries outputs at specified computational points ****** user contract may not allow for unpaid updates	* comes as package deal with additional modules (i.e. Urban flooding package) ** determined by input data and practically limited by computing power *** against all lines of truth (e.g. water level, quality data etc.) ****paid support available, poorly supported online community ***** not readily achievable, generally 2D mapping ****** user contract may not allow for unpaid updates

Theme	Classification	Models		
		MUSIC	**RMA**	**SOURCE**
Key area of use	• Farming and agricultural systems assessment • Water planning and supply • Water balance modelling • Water quality modelling • River hydraulic modelling • Catchment policy • Flooding • Aquaculture • Mine decommissioning and discharge • Other • Policy formation • Regulation/permitting • Planning • Impact assessment	• Water planning and supply • Water quality modelling • Water balance modelling • Other • Policy formation • Regulation/permitting • Planning • Impact assessment	• Flooding • Water quality modelling • River hydraulic modelling • Other • Policy formation • Regulation/permitting • Planning • Impact assessment	• Farming and agricultural systems assessment • Water planning and supply • Catchment policy • Water quality • Other • Policy formation • Regulation/permitting • Planning • Impact assessment
Model type	• Deterministic v stochastic v mixed • Static v dynamic • Discrete v continuous	• Mixed • Static • Continuous	• Deterministic • Dynamic • Discrete	• Deterministic • Static • Continuous
Model licence & cost	• Open source • Proprietary • Public • Not specified	• Proprietary • ~$5000 per licence	• Proprietary • ~$3410 per licence*	• Proprietary • ~$8000 per licence*
Spatial/temporal scale	Models are often able to operate over a relatively wide range of spatial and temporal scales. This information is provided in graphic form to facilitate identification of models and scales.	• Very wide temporal/spatial scale*	• Very wide temporal/spatial scale**	• Very wide temporal/spatial scale**
Process understanding & expertise required for use	• Comprehensive • Partial • Conceptual • Very little (black box) • None	• Partial for basic use • Comprehensive for detailed use	• Comprehensive for basic use • Comprehensive for detailed use	• Partial for basic use • Comprehensive for detailed use***
Interface	• Graphical User Interface (GUI) • Text • Mixed	• GUI	• Text***	• GUI
Setup/post processing effort	• Extensive • Medium • Little • None	• Medium to little setup • Medium to little post processing	• Extensive setup • Extensive post processing	• Extensive setup • Extensive post processing
Calibration requirements	• Extensive • Medium • Little • None	• Little to none**	• Extensive****	• Extensive ****
Level of support	• Well supported • Moderately supported • Poorly supported • Not supported	• Moderately supported***	• Poorly supported*****	• Moderately supported*****
Stakeholder communication and knowledge transfer	• Easily and readily achievable • Easily but not readily achievable • Moderate • Difficult • Not required	• Easy and readily achievable	• Difficult	• Easy but not readily achievable
Uncertainty testing	• Comprehensive • Partial • Non-existent	• Need to be cognizant of input uncertainties. User to specify testing to determine influence • The imbedded uncertainty in the model framework requires comprehensive knowledge to understand.		
Currency	• Year updated • Frequency of updates	• 2021 • Intermittently	• 2005 • Unknown	• Feb 2021 • Intermittently
Additional notes	Additional notes provided, expanding upon classifiers mentioned above.	* determined by input data and practically limited by computing power ** numerous guidelines for different areas available, typically only in urban settings. Model should encompass representative wet and dry periods *** paid support available, poorly supported online community	* price when combined with Aquevo SMS software. Limited community version available, however not very comprehensive ** determined by input data and practically limited by computing power *** can be interfaced with Aquevo SMS to provide a GUI experience **** against all lines of truth (e.g. water level, quality data etc.) ***** list of frequent issues have been identified in the manual	* limited community version, relatively comprehensive ** determined by input data and practically limited by computing power ***can be scripted for iterative runs **** against all lines of truth (e.g. water level, quality data etc.) ***** paid support available, moderate online wiki

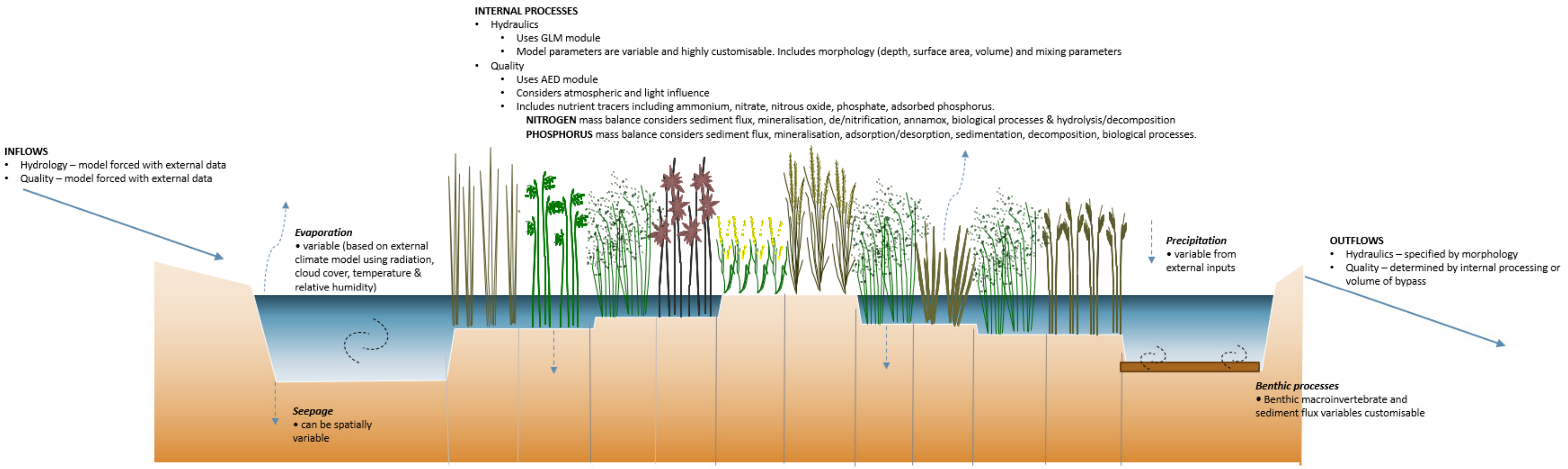
Theme	Classification	Models	
		SWMM	**TUFLOW FV AED**
Key area of use	• Farming and agricultural systems assessment • Water planning and supply • Water balance modelling • Water quality modelling • River hydraulic modelling • Catchment policy • Flooding • Aquaculture • Mine decommissioning and discharge • Other • Policy formation • Regulation/permitting • Planning • Impact assessment	• Water planning and supply • Catchment policy • Flooding • Water quality modelling • Other • Policy formation • Regulation/permitting • Planning • Impact assessment	• Flooding • River hydraulic modelling • Water quality modelling • Other • Regulation/permitting • Planning • Impact assessment
Model type	• Deterministic v stochastic v mixed • Static v dynamic • Discrete v continuous	• Mixed • Static • Continuous	• Deterministic • Dynamic • Discrete
Model licence & cost	• Open source • Proprietary • Public • Not specified	• Proprietary • ~$1440-2160 per licence per annum	• Proprietary • ~$9,900 per licence*
Spatial/temporal scale	Models are often able to operate over a relatively wide range of spatial and temporal scales. This information is provided in graphic form to facilitate identification of models and scales.	• Very wide temporal/spatial scale*	• Very wide temporal/spatial scale**
Process understanding & expertise required for use	• Comprehensive • Partial • Conceptual • Very little (black box) • None	• Comprehensive for basic use • Comprehensive for detailed use	• Comprehensive for basic use • Comprehensive for detailed use
Interface	• Graphical User Interface (GUI) • Text • Mixed	• GUI	• Text***
Setup/post processing effort	• Extensive • Medium • Little • None	• Extensive setup • Extensive post processing	• Extensive setup • Extensive post processing
Calibration requirements	• Extensive • Medium • Little • None	• Extensive**	• Extensive****
Level of support	• Well supported • Moderately supported • Poorly supported • Not supported	• Moderately supported***	• Well supported*****
Stakeholder communication and knowledge transfer	• Easily and readily achievable • Easily but not readily achievable • Moderate • Difficult • Not required	• Easy but not readily achievable	• Easy but not readily achievable
Uncertainty testing	• Comprehensive • Partial • Non-existent	• Need to be cognizant of input uncertainties. User to specify testing to determine influence • The imbedded uncertainty in the model framework requires comprehensive knowledge to understand.	
Currency	• Year updated • Frequency of updates	• 2005. • Intermittently ****	• TUFLOW FV - 2020, AED - 2019
Additional notes	Additional notes provided, expanding upon classifiers mentioned above.	* determined by input data and practically limited by computing power ** against all lines of truth (e.g. water level, quality data etc.) *** Paid support available, with online training materials. Minimal online community with online video tutorials. **** potential support from TUFLOW sources (SWMM adopts TUFLOW 2D engine) ***** regular software updates with free subscription	* for 1 licence & 1 quality add on module – however can link to AED for no cost ** determined by input data and practically limited by computing power *** options for 3rd party GUI or Geographic Information System (GIS) interface **** against all lines of truth (e.g. water level, quality data etc.) ***** paid support available, online training materials, comprehensive online community and wiki

Attachment B
Wetland Treatment Logics



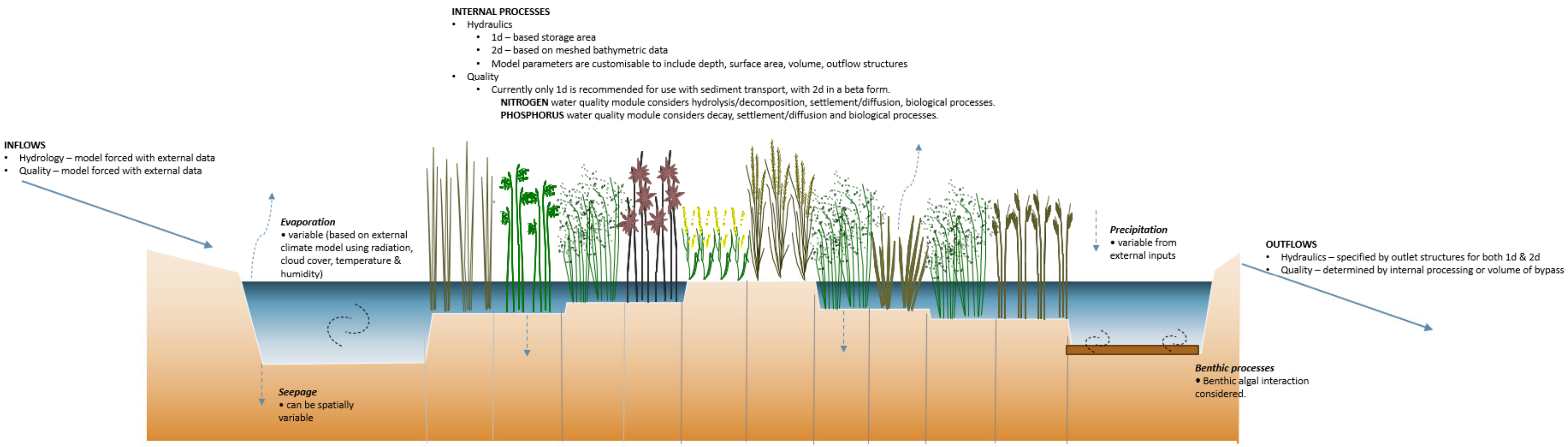
Wetland Long Section

BOX MODEL SCHEMATISATION



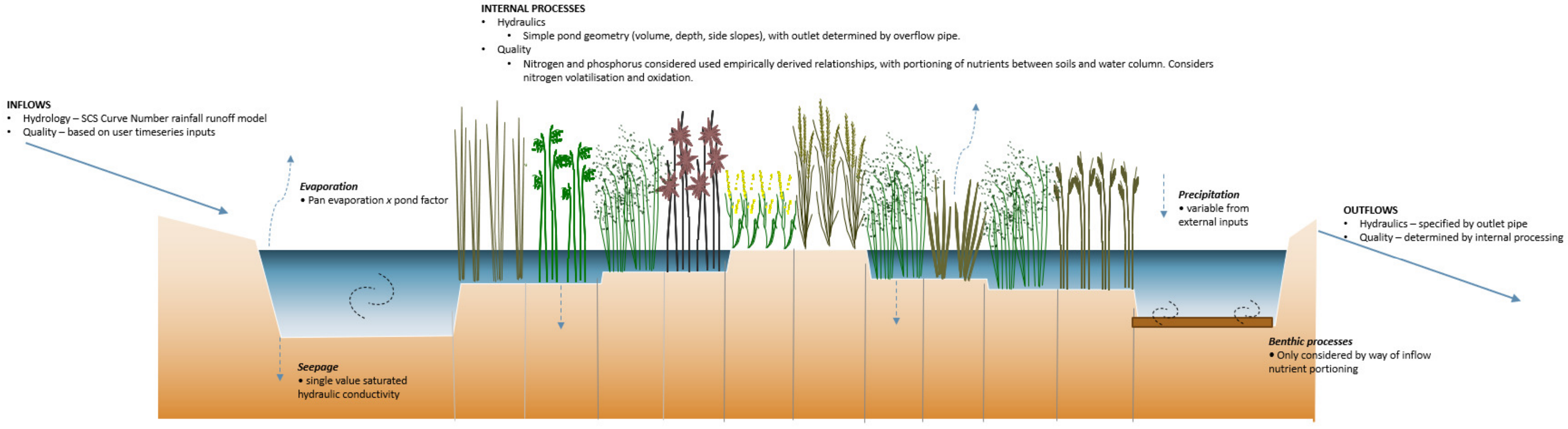
Wetland ("Lake") Long Section

GLM AED SCHEMATISATION



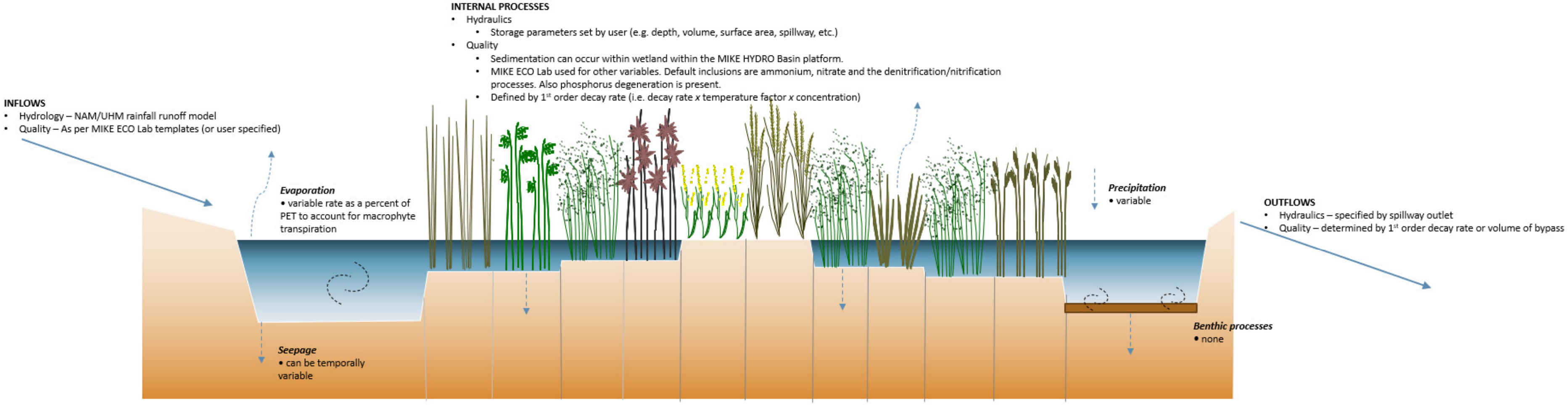
Wetland Long Section

HECRAS SCHEMATISATION



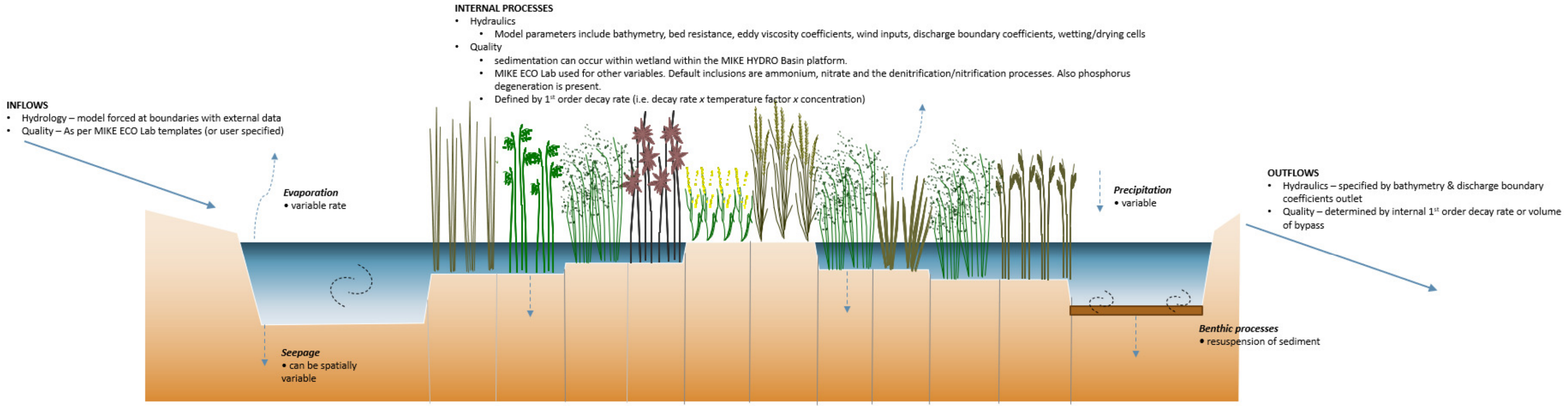
Wetland ("Pond") Long Section

MEDLI SCHEMATISATION



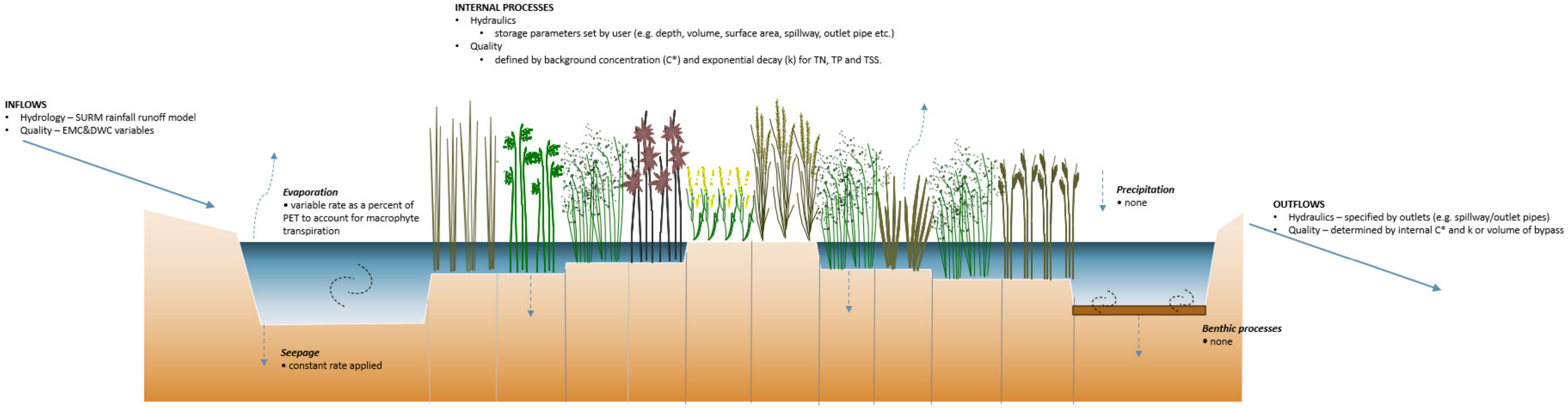
<u>Wetland ("Reservoir Lake") Long Section</u>

<u>MIKE HYDRO SCHEMATISATION</u>



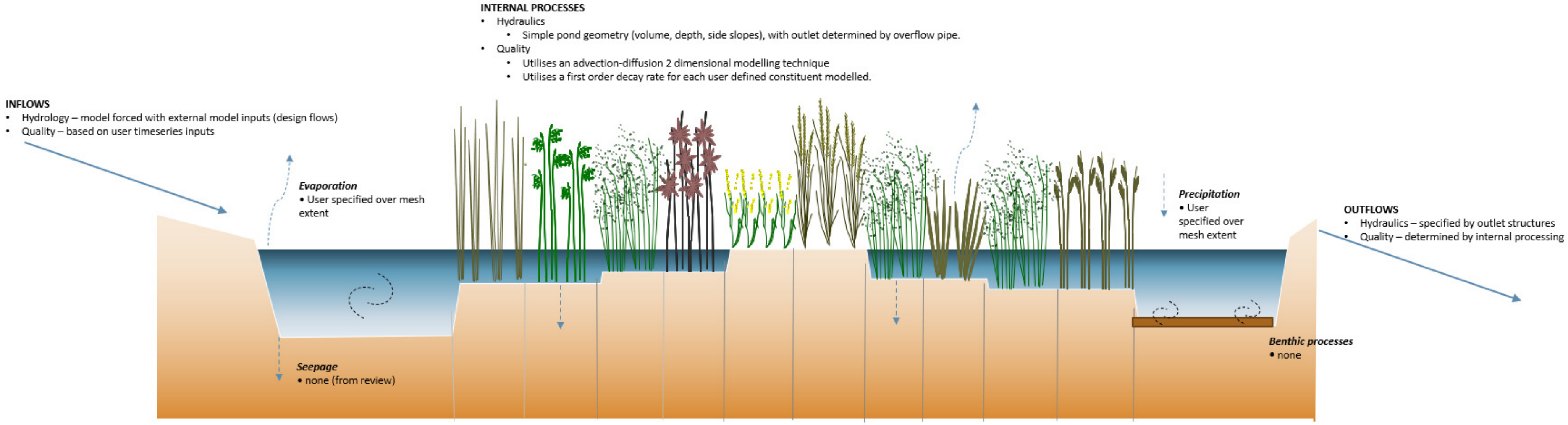
Wetland Long Section

MIKE 21 SCHEMATISATION



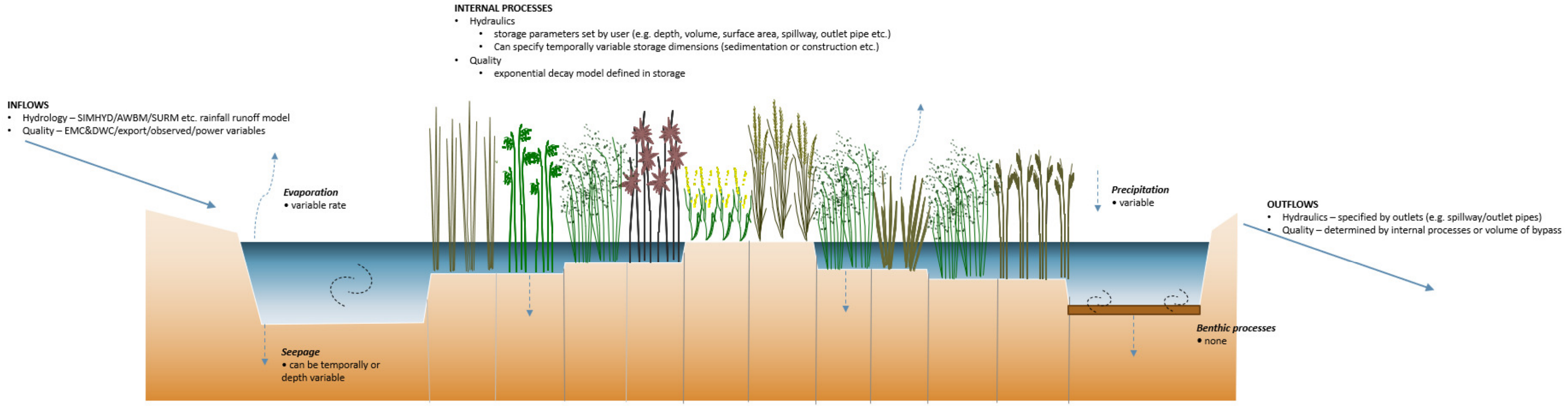
Wetland Long Section

MUSIC SCHEMATISATION



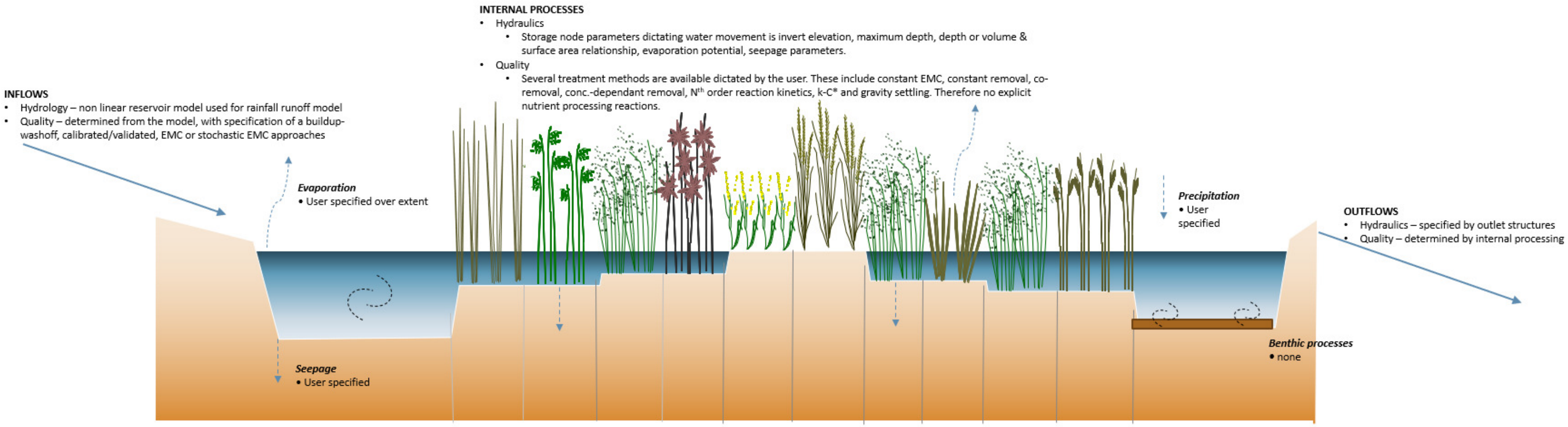
Wetland Long Section

RMA SCHEMATISATION



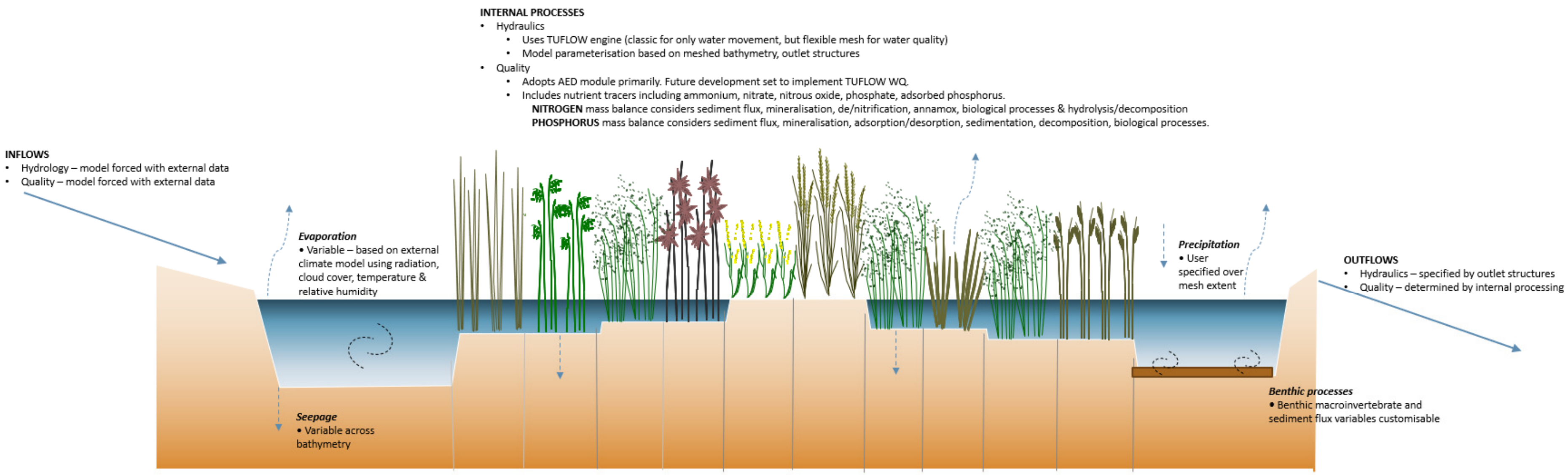
Wetland ("Storage Node") Long Section

SOURCE SCHEMATISATION



Wetland Long Section

SWMM SCHEMATISATION



Wetland Long Section

TUFLOW FV AED SCHEMATISATION