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The Development of Wetland Conceptual Models for the Semi-Arid Zone

Final report

January 2009

Price A. & Gawne B. (2009)
The Development of Wetland Conceptual Models for the Semi-Arid Zone – Final Report. A report prepared for the Murray-Darling Basin Authority by the Murray-Darling Freshwater Research Centre.

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Cover Photo: Back Lake, Narran Lakes Complex, NSW. Photo Credit: Ben Gawne

ISBN: 978-1-921557-09-5

Publication no.: 04/09

The Murray-Darling Freshwater Research Centre is a joint venture between the Murray Darling Basin Authority, CSIRO Land and Water and La Trobe University, that aims to answer locally relevant research questions to help guide water managers, and ultimately improve the health of our rivers, lakes and wetlands.

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A. Price & B. Gawne
A Report prepared for the Murray-Darling Basin Authority
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1. PROJECT BACKGROUND

The Northern Murray-Darling Basin Program ('The Program') is an initiative of the Murray-Darling Basin Authority (MDBA) aimed at providing advice on the sustainable management of the water resources of the Darling River and its associated tributary river systems. The Program is guided by a Working Group made up of representatives from state agencies, the Australian Government and the community.

The Program is concerned with the water resources in the Darling River basin including the following valleys: the Border Rivers; Moonie; Gwydir; Namoi-Peel; Macquarie; Castlereagh; Condamine-Balonne; Nebine; Warrego; Paroo; Barwon-Darling and the Lower Darling.

The Program has been engaging the assistance of a range of organisations to bring an integrated approach to the development of a strategic action plan. This work includes projects in areas such as the ecology of northern wetlands and rivers; the provision of socio-economic information that provides an understanding of the links between water resources and people as well as on-going studies of the hydrology of the region.

The Northern Murray-Darling Basin Program recognised the need for a long-term ecological monitoring framework for wetlands in the Northern Murray-Darling Basin to complement the Sustainable Rivers Audit. In 2007, the Northern-Basin Working Group contracted the Murray-Darling Freshwater Research Centre (MDFRC) to undertake a scoping study investigating the current monitoring arrangements for wetland monitoring in the northern basin and identifying options for progressing the development of a monitoring framework. This study reported that although wetland monitoring is required at several jurisdictional levels, current monitoring arrangements are at best ad-hoc and to-date, there has been very little investment in the development of wetland monitoring programs. Thus wetland monitoring is often incomplete and inconsistent at both regional and state levels. This has resulted in a paucity of information regarding wetland condition that compromises our capacity to sustainably manage wetlands across much of Australia.

The scoping study further identified that the National Land and Water Resources Audit (NLWRA), the National Water Commission (NWC), the Department of Environment, Water, Heritage and the Arts (DEWHA), the NRM Ministerial Council, the Wetlands and Waterbirds Taskforce and all state governments have accepted the need for the development of wetland monitoring programs and the need for a consistent approach across jurisdictions. In response, the NLWRA, in conjunction with state agencies, undertook the National Wetland Indicators Review which developed a framework for monitoring wetland extent, distribution and condition. The National Wetland Indicators Review undertook an extensive review of the different programs, indicators and frameworks currently used to monitor wetlands in Australia and overseas, and held jurisdictional workshops and national workshops to develop and reach national agreement on a set of indicators and guidelines for extent, distribution and condition of lacustrine and palustrine wetlands. The NLWRA framework has the support of federal, state and regional jurisdictions and the proposed framework has been agreed to by the Wetlands and Waterbirds Taskforce and by the Aquatic Ecosystems Taskforce for consideration. In light of this, the MDBA is working collaboratively with the state and federal jurisdictions in the development of the NLWRA framework rather than independently developing a separate framework.

The NLWRA framework proposes that managers should utilise their system understanding to develop conceptual models of wetlands and utilise these models to select appropriate indicators rather than mandating a single set of condition indicators for all wetlands. Thus, the development of conceptual models that synthesise our understanding of the ecological functioning of wetlands is a vital step in the development and implementation of the framework.

2. CONCEPTUAL MODEL DEVELOPMENT WITHIN THE MURRAY-DARLING BASIN

Conceptual modelling is currently being undertaken collaboratively by New South Wales, Queensland and South Australian agencies and the MDBA. The conceptual models being developed by these jurisdictions are aimed at identifying the key components, processes and drivers of the different wetland types and will form the basis for indicator selection/development for future monitoring programs (Figure 1). Responsibility for the development of conceptual diagrams is being shared between the jurisdictions with Queensland taking responsibility for developing conceptual models for the wetland types in the tropics and sub-tropics; NSW developing conceptual models for the temperate areas, South Australia developing conceptual models for the arid zones and the MDFRC (on behalf of the MDBA) is developing models for wetland types in the semi-arid zone. Specifically the models will be used for:

- Synthesis of knowledge and to identify knowledge gaps.
- Identification of key links between drivers, stressors, and system responses.
- Understanding of how the processes, threats and system dynamics differ between wetland types.
- Facilitate in the selection and justification of indicators.
- Interpretation of monitoring data (specific to different wetland types) and identification of acceptable levels of change.
- Education and communication tools.

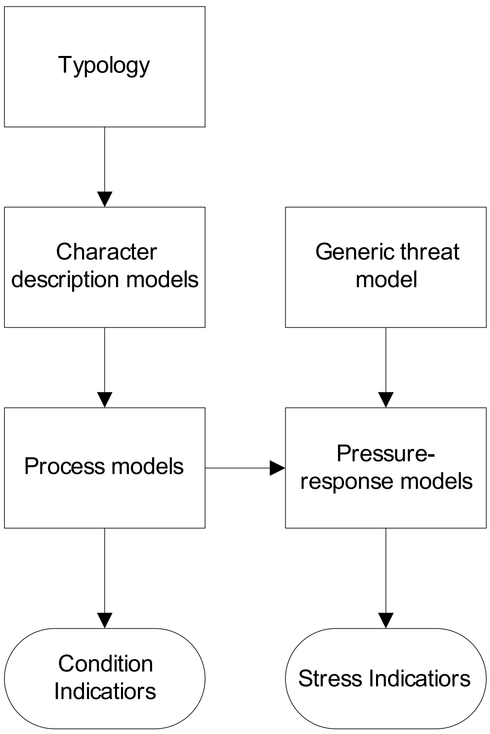


Figure 1. Illustration of the process for developing wetland indicators starting with the development of a wetland typology then wetland character descriptions, conceptual models of wetland processes, threats and pressure response relationships which underpin indicator selection.

3. MODEL DEVELOPMENT PROCESS

3.1 Wetland Classification/Typology

Conceptual models are being developed for a number of wetland types. These wetland types are derived from 'The Wetlands Description Tool', developed by the Queensland Environment Protection Agency (EPA) which was developed through a series of national workshops and expert panels. 'The Wetlands Description Tool' allows for wetlands to be classified based on a number of attributes at increasingly specific spatial scales (continental, ecosystem, landscape and local) (Table 1). Definitions of the attributes used in this classification system may be found on the Queensland EPA WetlandInfo website http://www.epa.qld.gov.au/wetlandinfo/site/WetlandDefinitionstart/WetlandDefinitions/Typologyintro/Typology.html.

Table 1. Queensland EPA typology used to classify wetlands across the Murray-Darling Basin (table adapted from Queensland EPA, 2008: http://www.epa.qld.gov.au/wetlandinfo/site/WetlandDefinitionstart/WetlandDefinitions/Typologyintro/Typology.html.

Scale	Category	Attribute used in Wetland Habitat Typology
Ecosystem	Wetland system	Lacustrine and Palustrine
Continental	Climate	1. Coastal (Equatorial and Tropical, Subtropical and Temperate) 2. Inland (Semi-Arid and Arid)
Landscape	Geomorphology / topography	1. Floodplain 2. Non-floodplain (depressional) 3. Non-floodplain (springs)
	Soils	1. Rock 2. Soil 3. Sand
Local	Water type	1. Saline 2. Fresh
	Water regime	1. Commonly wet 2. Periodic inundation
	Dominant vegetation structure	1. Tree 2. Shrubs (Heath) 3. Grasses/Sedges/Herbs
	Dominant Vegetation Community	Dominant vegetation community is used for the tree wetlands to divide: 1. Melaleuca and Eucalypt swamps 2. Palm swamps

For wetlands in the semi-arid zone, wetland typology was also based on 'The Wetlands Description Tool'. After consultation with the NSW, Queensland and South Australian jurisdictions, it was decided that models for seven major semi-arid wetland types would be developed. These are:

- Commonly wet freshwater lakes
- Periodically-inundated floodplain freshwater lakes
- Periodically-inundated non-floodplain (depressional) freshwater lakes
- Floodplain freshwater swamps
- Non-floodplain (depressional) freshwater swamps
- Saline lakes
- Saline swamps (developed by the Queensland EPA).

Wetlands in the semi-arid zone were not classified on the basis of dominant vegetation community as no palm swamps occur in the semi-arid zone. In addition, semi-arid wetlands were not classified on the basis of soils as this attribute was not thought to be important in distinguishing between major wetland types in this climatic zone. The saline swamp models developed by the Queensland EPA are thus not presented in this report but are available on the Queensland EPA's WetlandInfo website http://www.epa.qld.gov.au/wetlandinfo/site/ScienceAndResearch/ConceptualModels.html.

3.2 Model Types

Following discussions with the jurisdictions, it became clear that they wanted to use the models for both the selection of indicators and as a communication tool for communities. To achieve these objectives it was agreed that both box and arrow conceptual models and pictorial character description models would be produced (Figure 2). Given the complexity of wetlands, the clearest way of depicting key components, drivers and processes was to develop a nested suite of models comprising three types of conceptual model that would capture our system understanding (Figure 2). The types of conceptual model produced are:

1. Overarching Component Models
2. Generic Key Driver Model
3. Wetland-type specific Character Description Models
4. Wetland-type specific Inundation Models for all wetland types that are temporary.

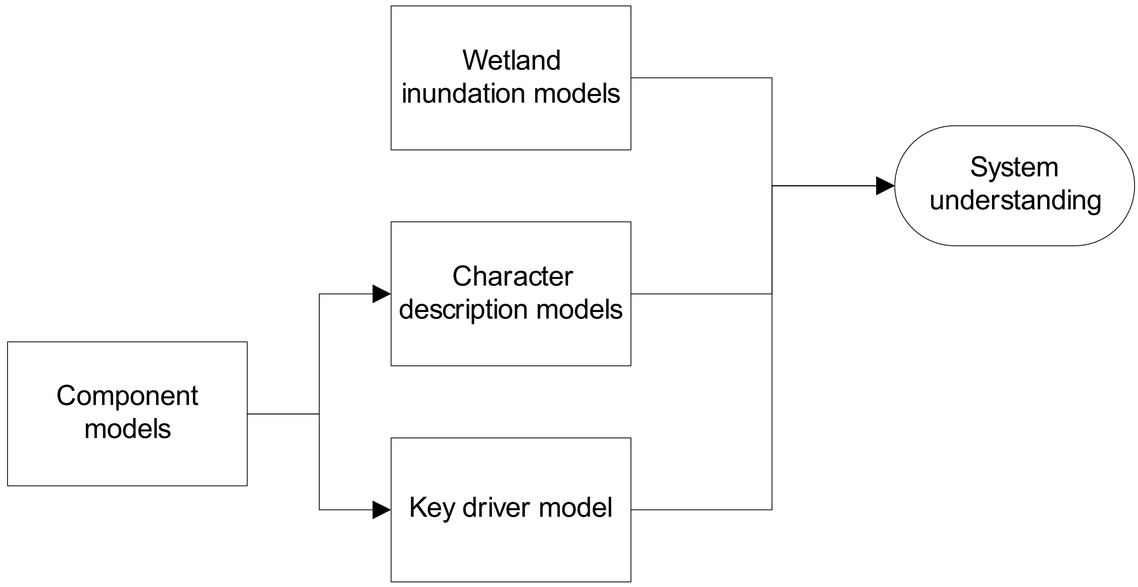


Figure 2. The relationship between the four types of conceptual models developed.

3.2.1 Wetland Component Models

The majority of wetland components (e.g., fish, invertebrates, aquatic vegetation and water quality parameters) are common across all wetland types. Component models have been developed to describe the drivers of these overarching components. These models provide a basis for understanding key processes and drivers for individual wetland types. Component models were developed for:

- Wetland geomorphology
- Wetland hydrology
- Water quality: pH, turbidity, dissolved oxygen, temperature and salinity
- Dissolved nutrient loads
- Dominant vegetation
- Dominant form of primary production
- Microbial production
- Invertebrates
- Fish
- Waterbirds
- Frogs.

3.2.2 Wetland Key Driver Model

Wetland type specific key driver models were originally developed for all wetland types. These models were designed to illustrate the relationships within and among key components and processes for that wetland type. However, following feedback from the expert panel workshop (see section 3.3.2), the key driver models were amalgamated into a single generic model that may be used as a template for the development of key driver models for individual wetlands or for wetland types classified at a finer scale than that used in the current project.

3.2.3 Character Description Models

The character descriptions consist of an annotated diagram describing the essential features and processes for each wetland type. Character description models were developed for:

- Commonly wet freshwater lakes
- Periodically-inundated freshwater floodplain lakes
- Shrub/Lignum swamps
- Eucalypt swamps
- Sedgeland/Grassland swamps
- Periodically-inundated freshwater non-floodplain (depressional) lakes
- Saline lakes.

3.2.4 Wetland Type Inundation Models

These models are designed to illustrate the changing condition of a specific wetland type as they undergo cycles of filling and draining or drying. Inundation models were developed for:

- Commonly wet freshwater lakes
- Periodically-inundated freshwater floodplain lakes
- Periodically-inundated freshwater non-floodplain (depressional) lakes
- Freshwater floodplain swamps
- Freshwater non-floodplain (depressional) swamps
- Saline lakes.

Freshwater floodplain swamps were not broken up into vegetation types (as was done for the character description models) as there was insufficient information regarding the inundation processes of these wetland types to differentiate among them.

3.3 Expert Panel Workshop

3.3.1 Workshop Participants

The draft models were presented at an expert panel workshop that was held in Sydney on the 28th and 29th October 2008. Participants are listed in Table 2.

3.3.2 Feedback from the Conceptual Model Workshop

The approach taken to the development of the models was strongly endorsed by the workshop participants and overall the feedback received was very positive. An overview of the feedback received and our response to the feedback for each of the model types is summarised in Table 3.

In addition to feedback regarding the specific models, there was discussion about the need for recognition of values around artificial and modified wetlands as these wetland types are outside the scope of the work currently undertaken by NSW, Queensland, South Australia or the MDBA. The need for incorporation of a broader landscape context into conceptual model development was also discussed in the context of:

- The importance of mosaics of different wetland types within the landscape.
- The difficulty in classifying large wetlands or wetland complexes as a single wetland type.
- The spatial scale at which birds utilise the landscape.
- The importance of connectivity between rivers, wetlands and the floodplain proper.

While it was agreed it is vital to consider the broader landscape when conceptualising wetland functioning and processes, it was suggested this would need to be undertaken as a complementary but separate process to that of developing conceptual models at the wetland scale.

Table 2. List of workshop participants and their organisation.

Invitee	Organisation
Harry Balcombe	Griffith University
Ryan Breen	Department of Environment, Water, Heritage and the Arts
Margaret Brock	Private Consultant
Sam Capon	University of Canberra
Sonia Claus	NSW Department of Environment and Climate Change
Patrick Driver	NSW Department of Water and Energy
Ben Fee	SA Department of Water, Land and Biodiversity Conservation
Neal Foster	NSW Department of Water and Energy
Lana Heydon	Qld Environmental Protection Agency
Sarah Imgraben	NSW Department of Environment and Climate Change
Kim Jenkins	University of New South Wales
Mike Maher	NSW Department of Environment and Climate Change
Mike Ronan	Qld Environmental Protection Agency
David Scheltinga	Qld Environmental Protection Agency
Glen Scholz	SA Department of Water, Land and Biodiversity Conservation
Fran Sheldon	Griffith University
Martin Thoms	University of Canberra
Brian Timms	Private Consultant
Maria Van Der Gragt	Qld Environmental Protection Agency

Table 3. Summary of feedback and responses from the conceptual model workshop held in Sydney, October 2008

Model	Feedback	Response
Component Models		
General	Three additional component models need to be developed. 1. A geomorphology model to describe the processes that determine wetland shape. 2. A microbiology model to describe the factors that influence bacterial and fungal communities. 3. A frog model to describe key processes that determine frog community composition	These additional models have been developed in consultation with an appropriate expert in that field.
Hydrology	Suggestions were made regarding the modification of the water source model and it was suggested that the duration of inundation, frequency of inundation and inundation regime models be combined into a single model.	A singe model for wetland hydrology has been developed.
Water chemistry and character (WQ and nutrients)	Some minor changes were proposed to the water quality and nutrient models, however, overall these models were generally accepted as is.	The suggested minor changes to these models have been made.
Dominant vegetation and dominant form of primary production	There was discussion around whether separate vegetation and primary production models are needed, however consensus was not reached.	The two models have been left separated.
Invertebrates, fish and waterbirds	Some minor changes were suggested and it was recommended that within-wetland recruitment processes be explicitly incorporated into the models for fish and invertebrates.	Within-wetland recruitment has been incorporated into these models and the suggested minor changes have been made.
Key Driver Models		
General	The workshop group recommended that an overarching generic key driver model be developed which could then be modified for individual wetlands or for specific wetland types.	A generic key driver model has been developed.

Table 3.(continued)

Model	Feedback	Response
Character Description Models		
General	A claypan model should be developed	We also recommend that a claypan model be developed, however, it was outside the scope of the current project.
	More emphasis needs to be placed on dry phase processes and components	We recommend that dry-phase models be developed, however, it is outside the scope of the current project.
	The reasons for variability in water quality parameters should be explicitly stated	This information has been incorporated into models.
	Greater details should be added regarding the distribution of waterbirds	This has not been done due to the amount of information that would need to be included
	Detail around aquifer types and groundwater processes needs to be verified	This has not been done as generalisations are difficult.
	A number of minor changes were suggested for each of the character description models	The suggested minor changes to these models have been made.
Inundation Models		
General	Overall, these models were accepted as is and only a few very minor changes were suggested.	The suggested minor changes to these models have been made.

4. CONCEPTUAL MODELS

4.1 Wetland Component Models

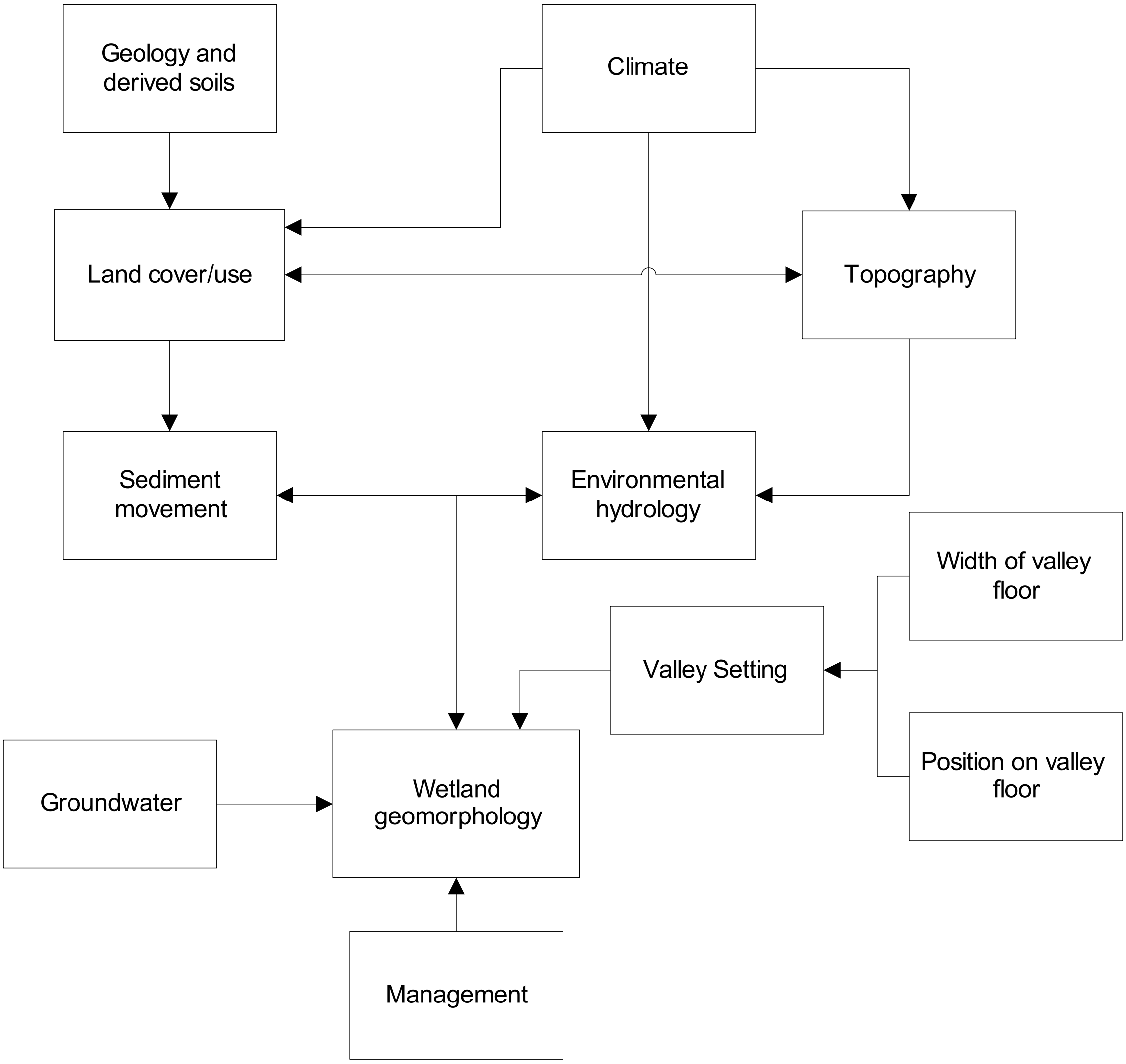


Figure 3. Component Model 1: Wetland geomorphology

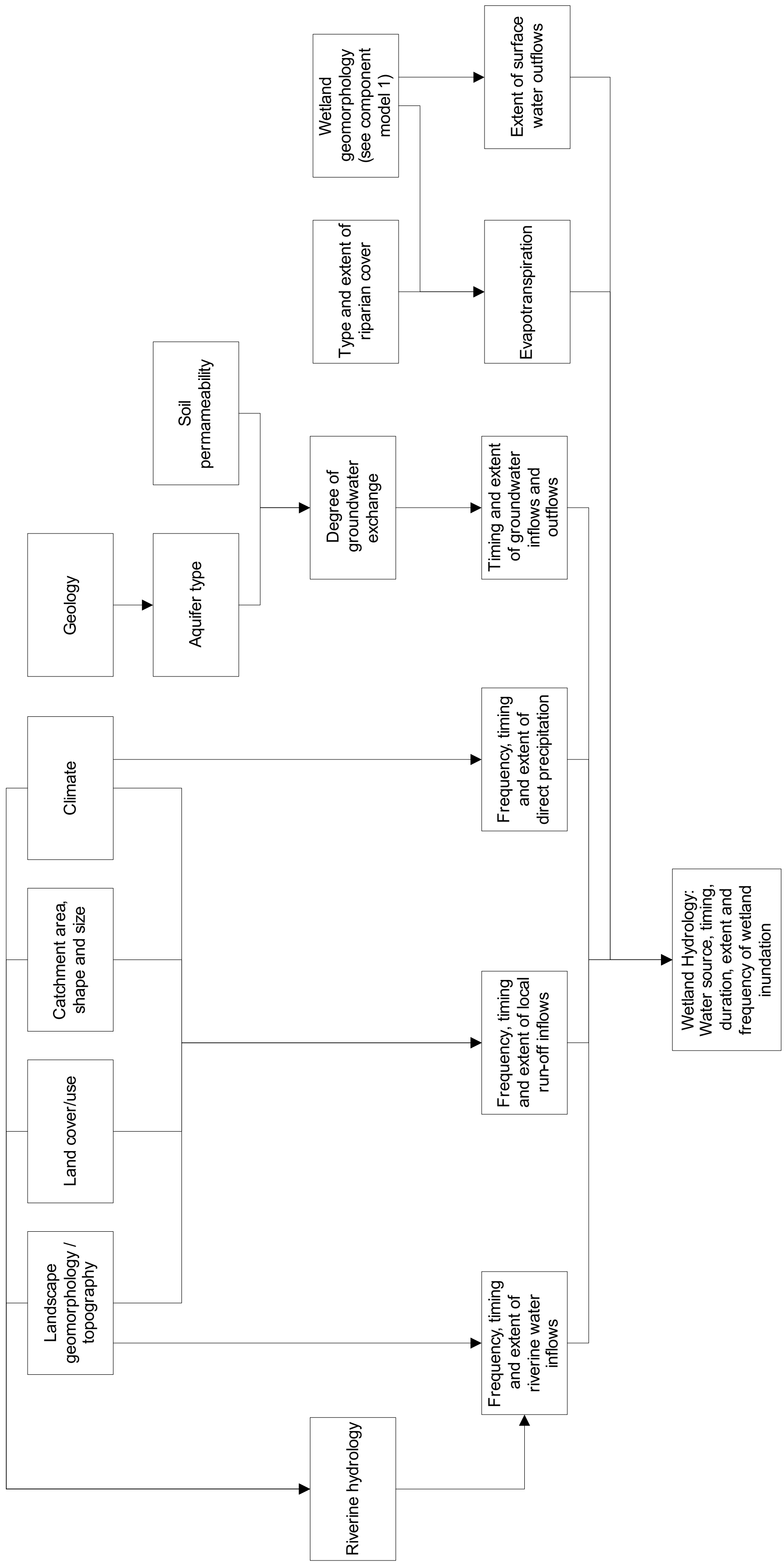


Figure 4. Component Model 2: Wetland hydrology

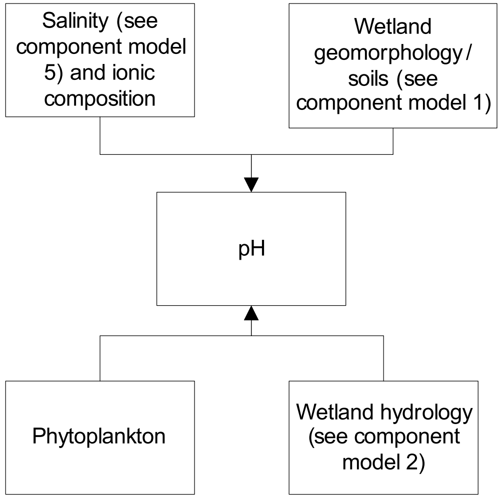


Figure 5. Component Model 3: pH

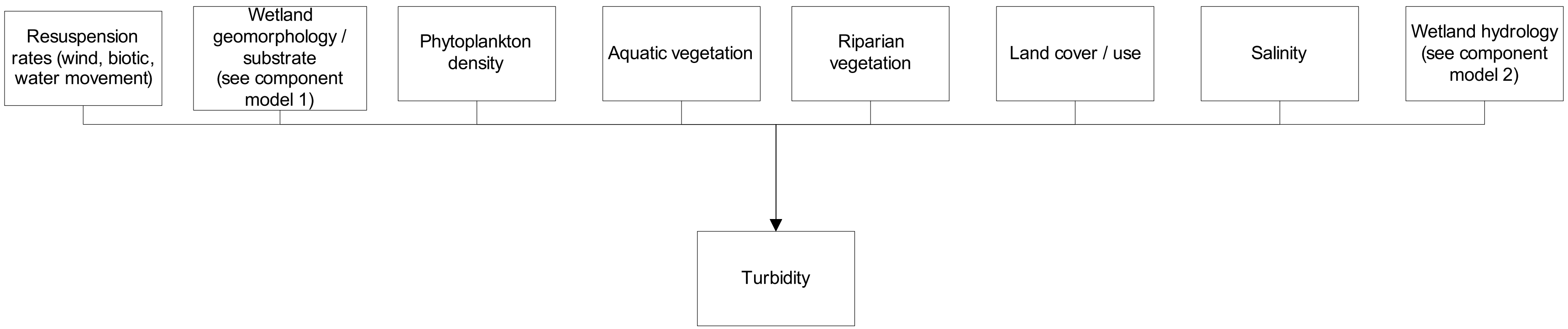


Figure 6. Component Model 4: Turbidity

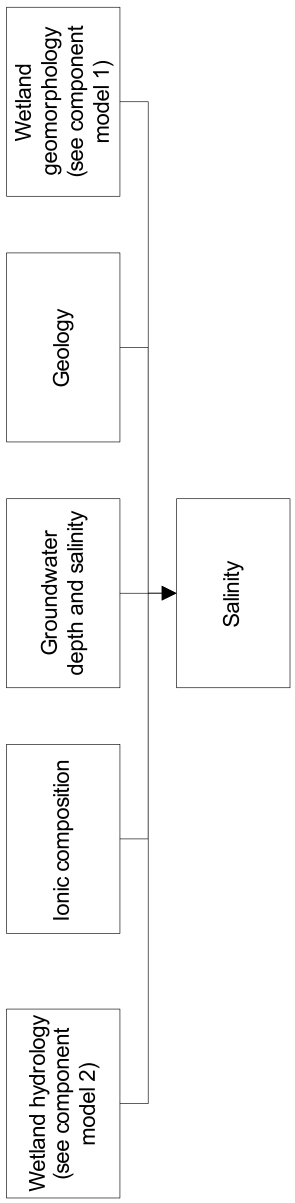


Figure 7. Component Model 5: Salinity

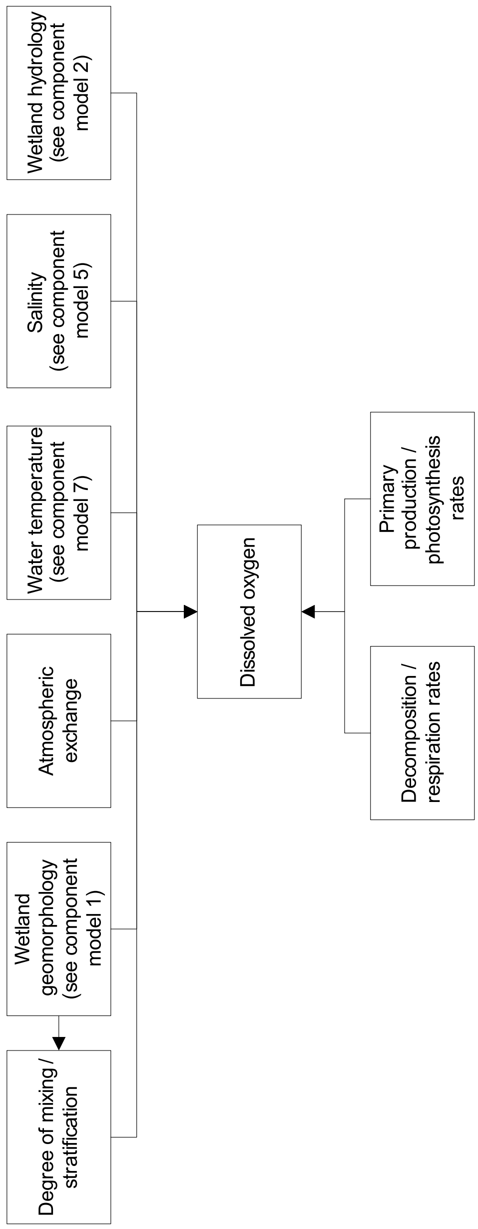


Figure 8. Component Model 6: Dissolved Oxygen Concentrations

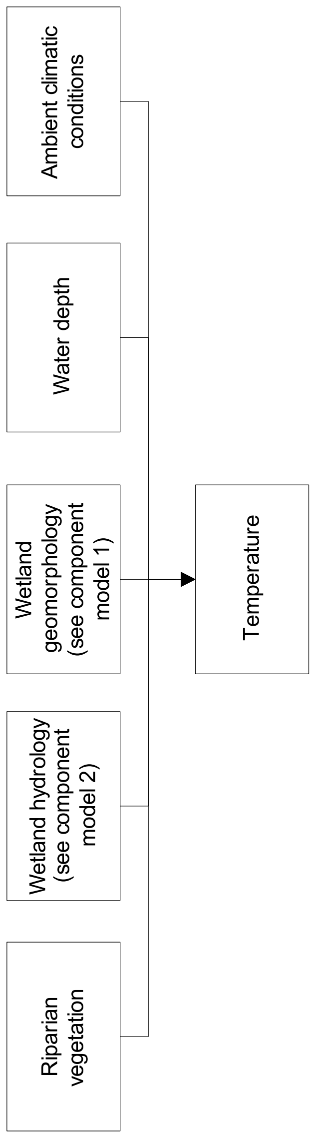


Figure 9. Component Model 7: Water temperature

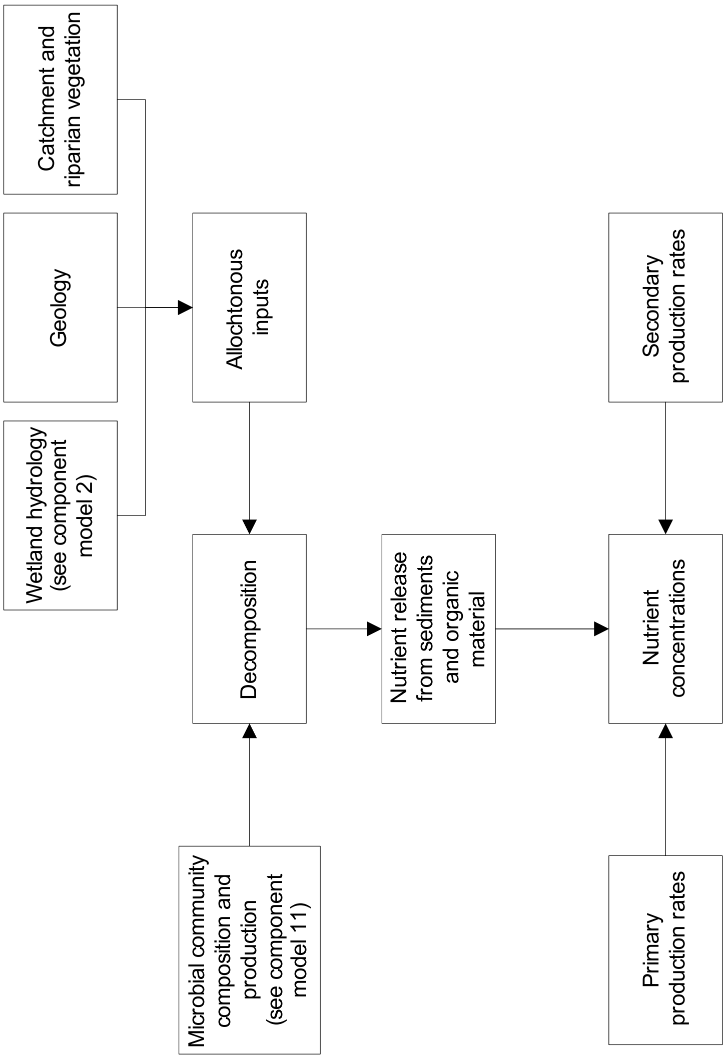


Figure 10. Component Model 8: Nutrient Concentrations

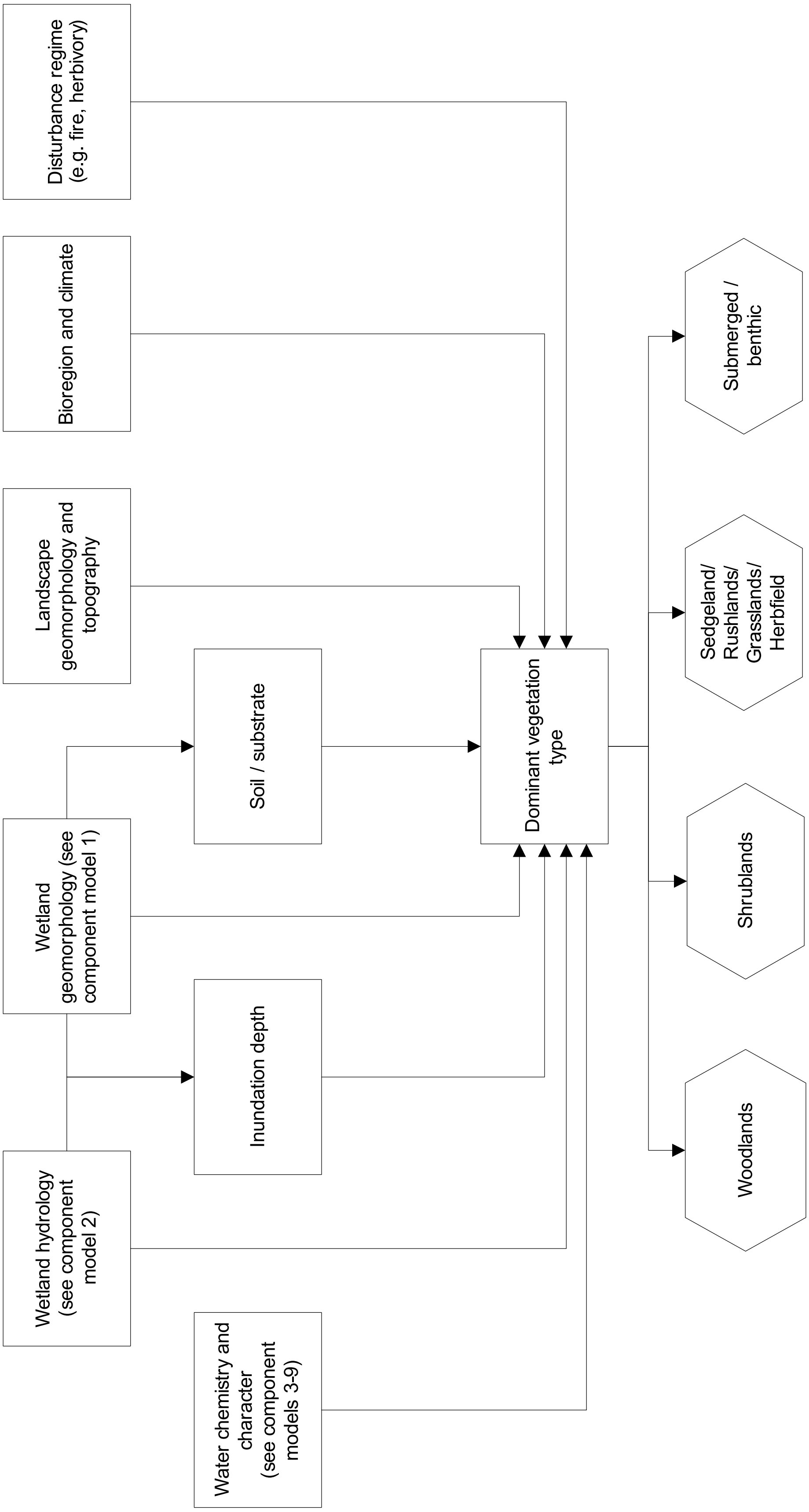


Figure 11. Component Model 9: Dominant Wetland Vegetation Components

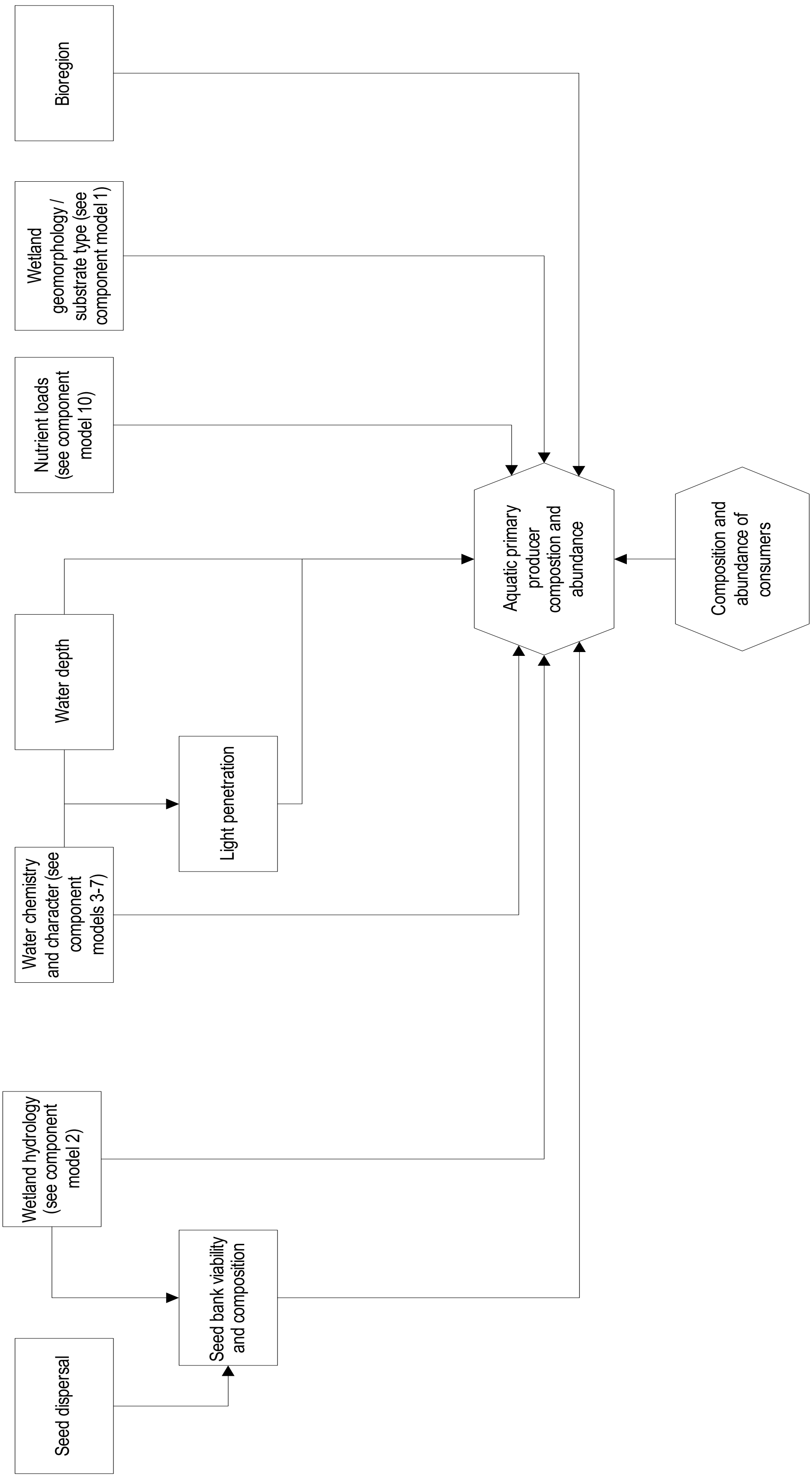


Figure 12. Component Model 10: Dominant Aquatic Primary Production

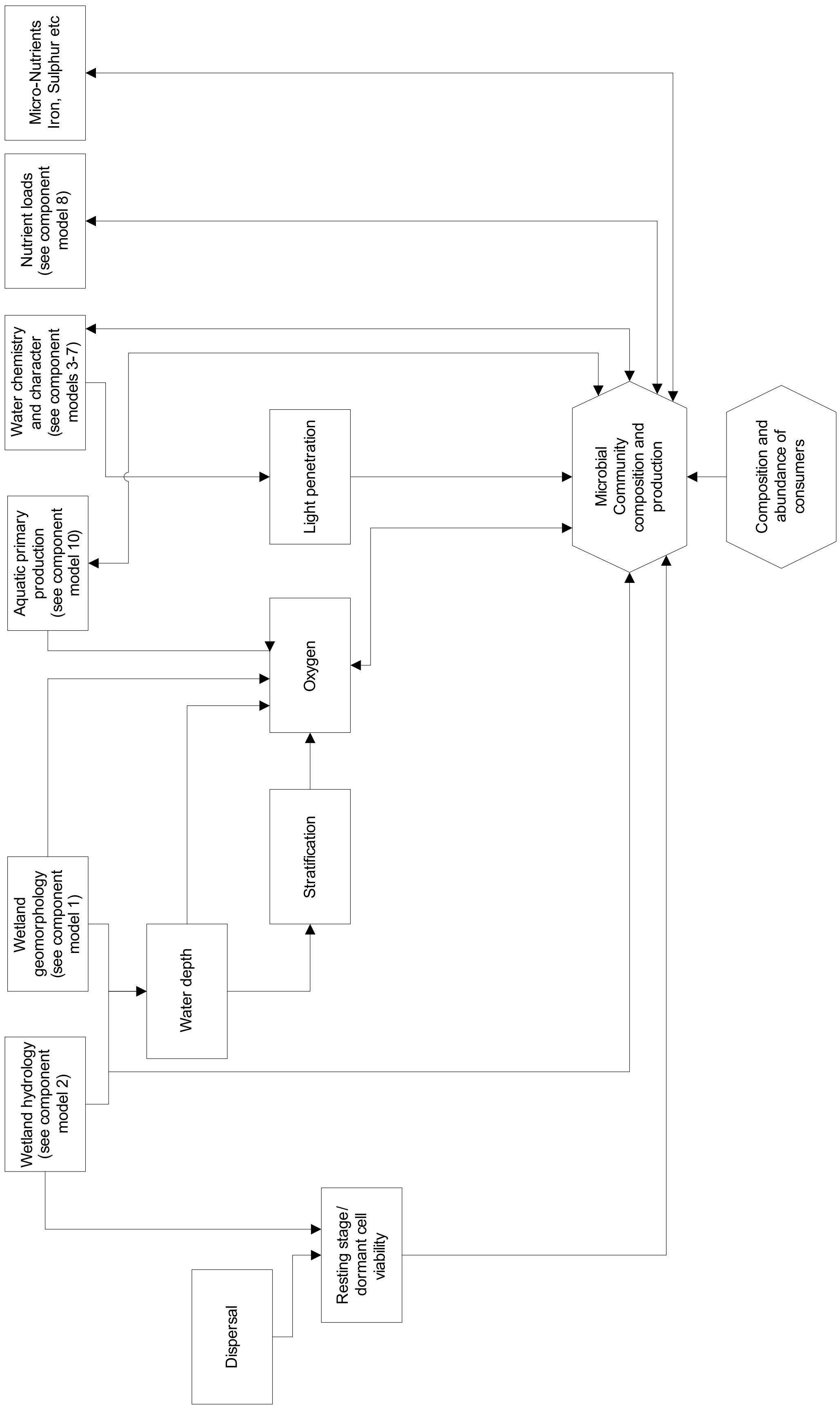


Figure 13. Component Model 11: Microbial Production

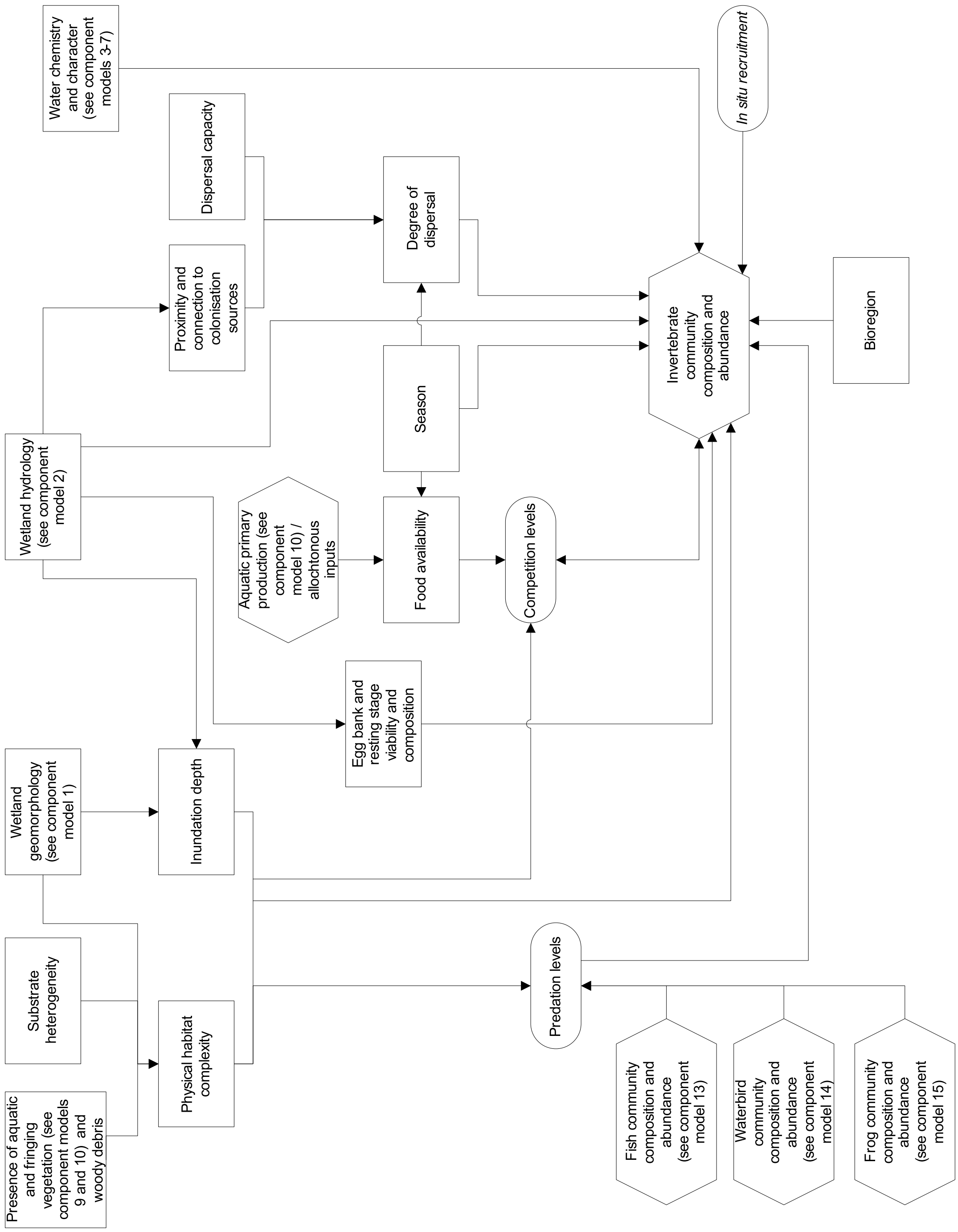


Figure 14. Component Model 12: Invertebrate Community Composition and Abundance

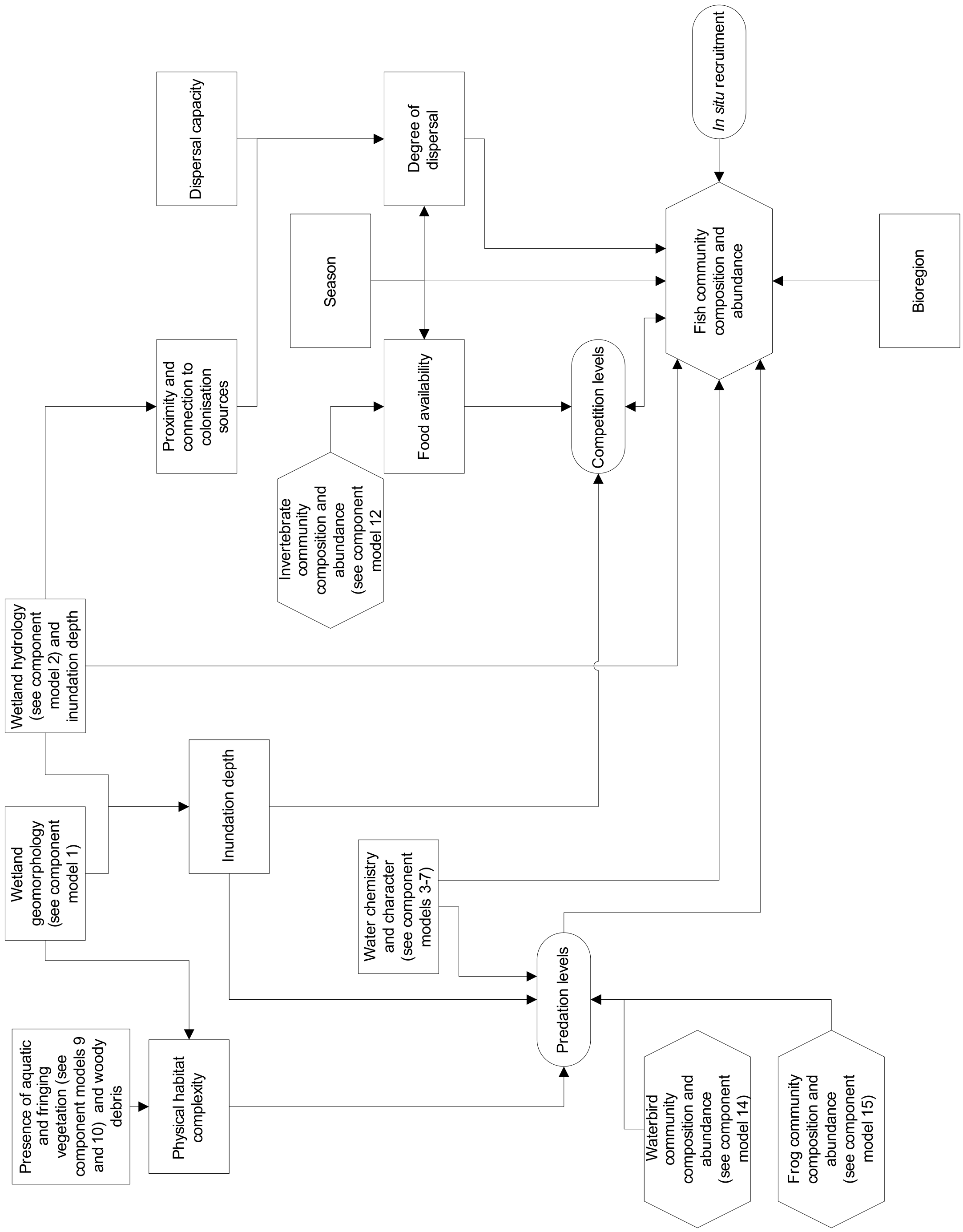


Figure 15. Component Model 13: Fish Community Composition and Abundance

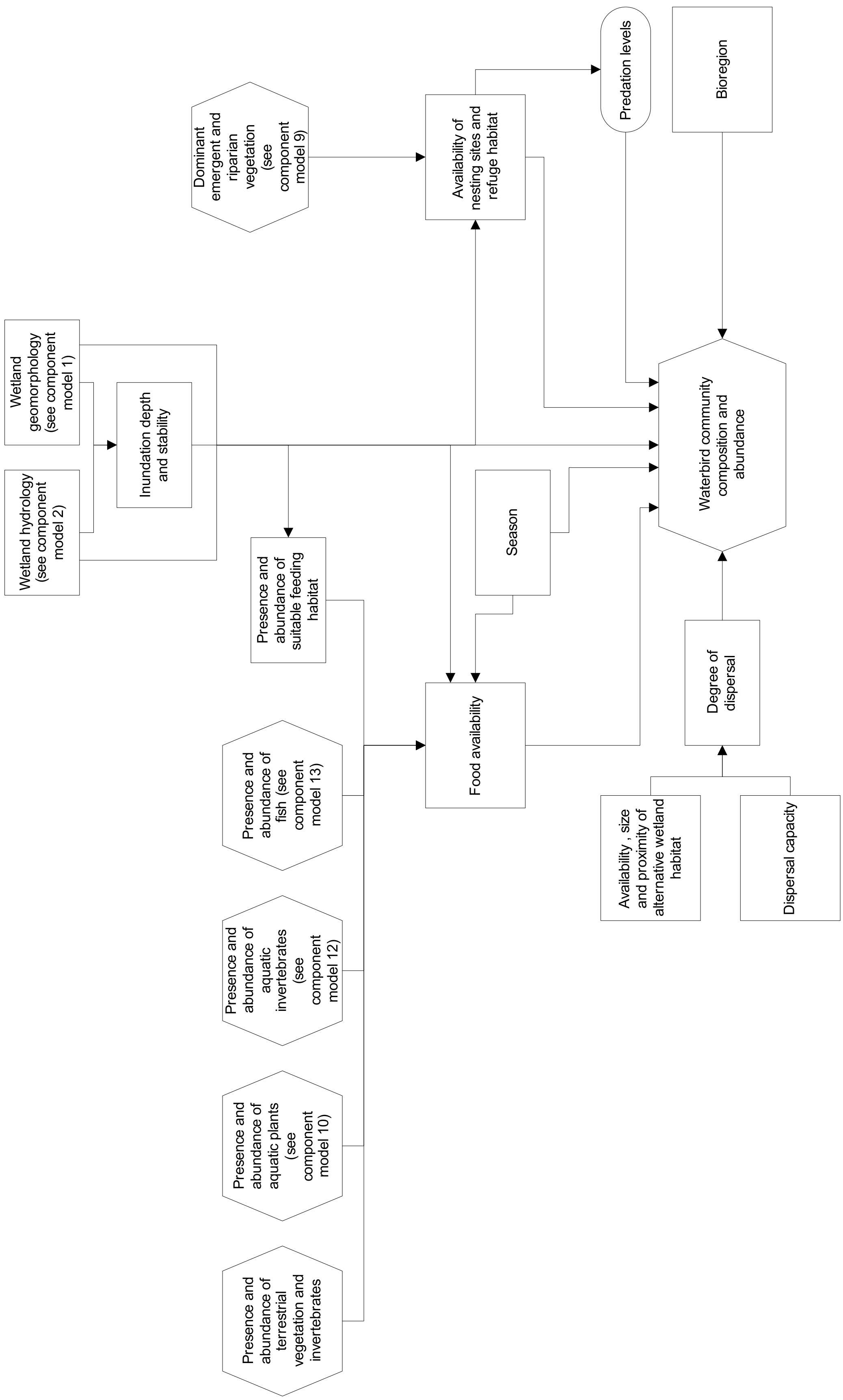


Figure 16. Component Model 14: Waterbird Community Composition and Abundance

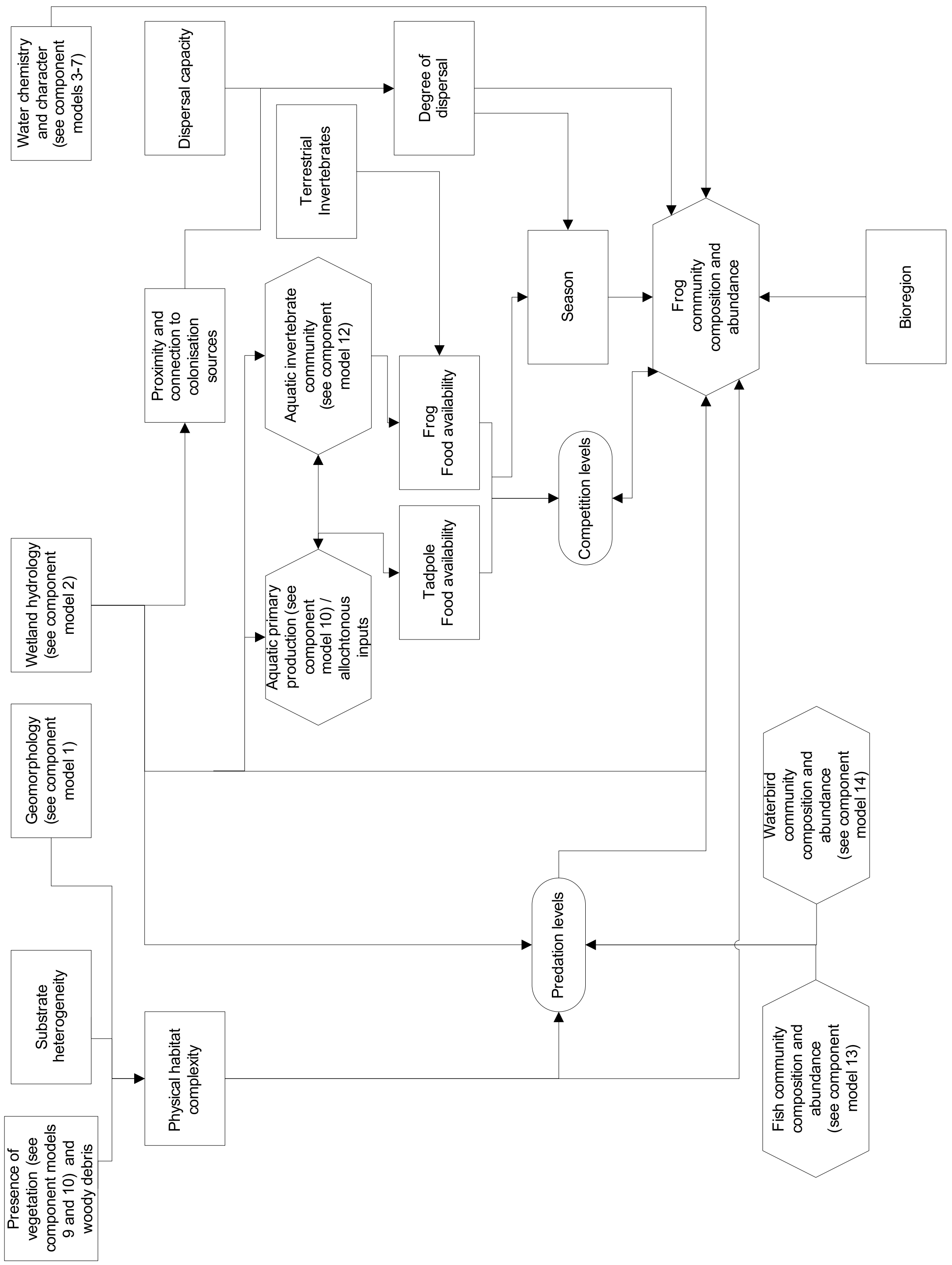


Figure 17. Component Model 15: Frog Community Composition and Abundance

4.2 Wetland Key Driver Model

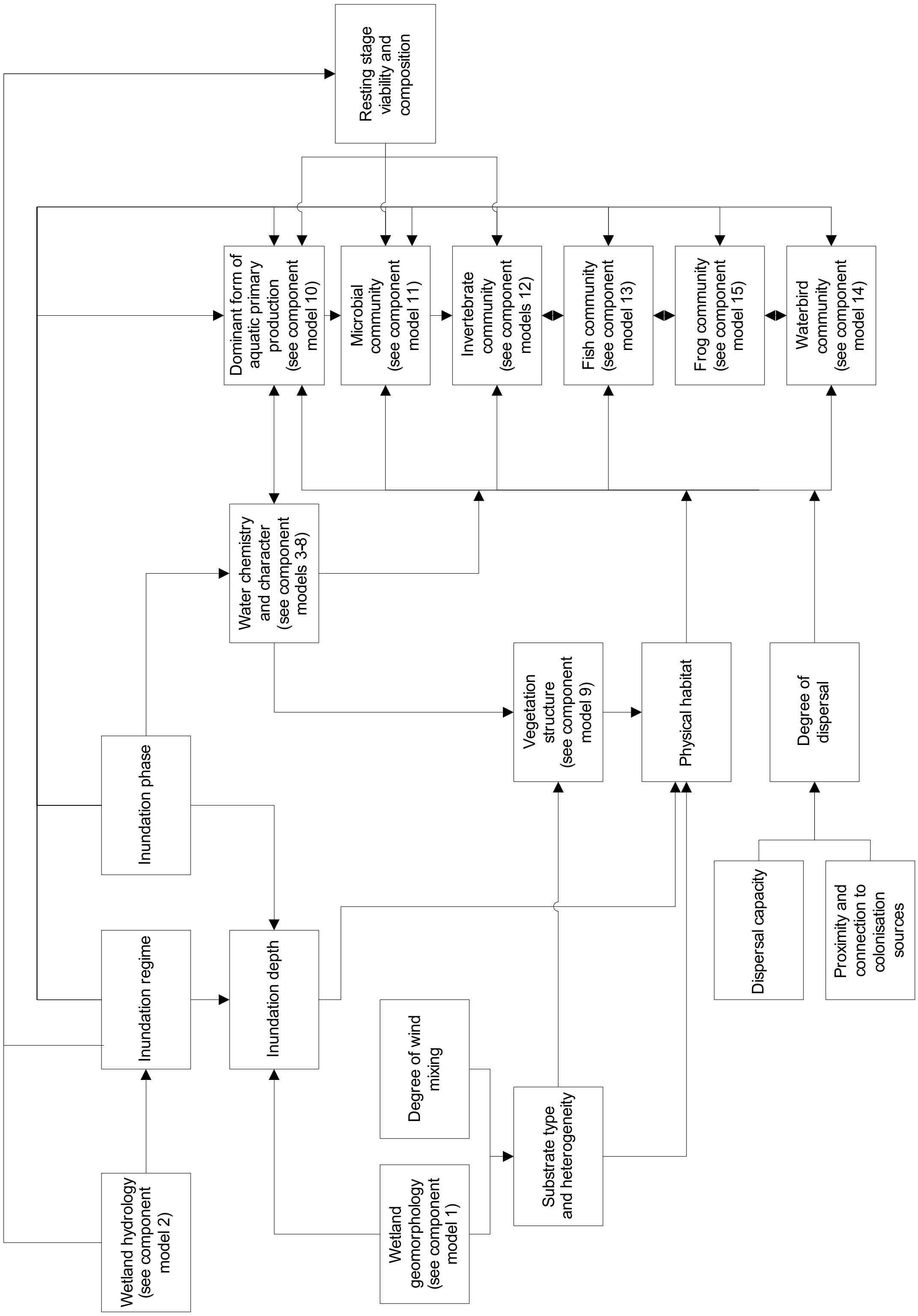


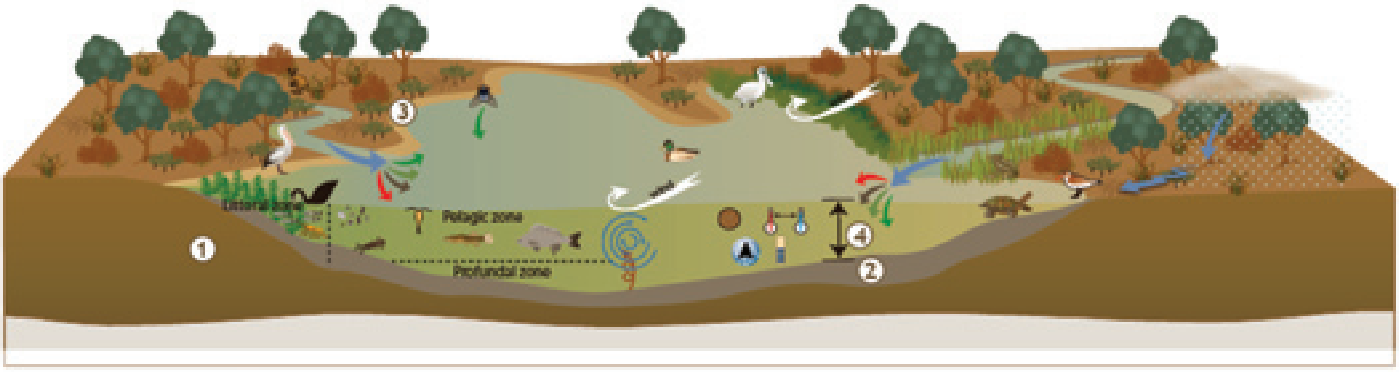
Figure 18. Generic Wetland Key Drivers Model

COMMONLY WET FRESHWATER LAKES

Commonly Wet Freshwater Lakes

Lacustrine

Examples include: Lake Numalla, Bulloo Lake, Lake Bindegolly, Lake Broadwater, Llangothlin lagoon



Components / Features

① Soil types vary but may include brown and grey clays, red and yellow earths.

② Grey clay substrates which may be deep and/or cracking.

③ Large beaches may be present where water levels are relatively static and inflowing streams deliver sediment.

④ Water depth may shallow to deep (generally up to 5 m) depending on lake morphology and inflows and may fluctuate widely over time.

Water Quality

Water temperature is temporally and spatially variable among and within lakes depending on depth and riparian vegetation (see component model 7).

Dissolved oxygen concentrations are temporally and spatially variable among and within lakes (see component model 6).

pH is generally alkaline and may vary spatially within the lake. pH varies in response to productivity, sediments and microbial activity (see component model 3).

Water is fresh, however electrical conductivity is temporally and spatially variable among and within lakes (see component model 5).

Turbidity levels can be moderate to high depending on input water quality, salinity and the inundation stage (see component model 4).

Flora

Riparian and fringing vegetation: Lake margins are typically fringed by forests, woodlands, shrublands or grasslands. Species composition varies according to topography, soil salinity levels and geographic location.

Emergent macrophytes: Commonly wet freshwater lakes may be fringed by dense stands of emergent macrophytes that can influence primary production within the lake (see component model 9). Presence, density and composition of emergent macrophytes varies spatially and temporally and is dependant on a number of factors with long term persistence dependent on the seed bank (see component model 10). Lake drying provides additional habitat for many macrophytes and amphibious species

Presence, abundance and spatial distribution of submerged macrophytes is highly variable among lakes. Submerged and floating macrophytes may be present depending on a variety of factors including, water quality, water depth, and light penetration (see component model 10). When present submerged macrophytes influence patterns of primary production both directly and through their influence on algal production (see component model 8).

Algae: Algal production typically includes a diverse range of macro- and microscopic species which occupy a range of habitats. Macroscopic algae includes charophytes and filamentous algae. Microscopic algae includes phytoplankton which predominates in open water and periphyton which are grow attached to the sediment, plants and to particles of organic and inorganic matter. Algal production may be the dominant form of primary production depending on variables such as nutrient loads and the degree of light penetration (see component model 10).

Processes

Commonly wet freshwater lakes fill primarily from inflowing streams and distributary channels and local runoff. Direct precipitation, groundwater seepage, overbank and overland flow contribute minor inputs into lakes. Seasonal variation in water levels are important in maintaining habitat for plants.

Sediments, dissolved nutrients and allochtonous material are transported into lakes via inflowing streams and overbank and overland flow.

Biota disperse into and out lakes via inflowing creeks and channels, overland flow from flooded rivers and aerial dispersal.

Lake morphology, wind and sediment type combine to drive a number of processes. In shallow lakes, wind action mixes the water and may cause sediment resuspension. The direction of the prevailing wind will influence the distribution of sediments and plants around the lake through wave mediated disturbance. In the semi-arid zone, lakes are generally too shallow for stratification to occur.

Aquatic Ecology

The aquatic ecology of commonly wet lakes is largely driven by three variables: water depth, water clarity and nutrient loads which interact to strongly influence primary and secondary production (see component model 10).

Water depth is a major determinant of the diversity of habitats available to aquatic organisms. In deep lakes, three distinct depth-related habitats or zones are recognised:

1) the **littoral zone** occurs around the edge of the lake and is characterised by shallow water, warmer water and coarser sediments. Wind action may have an important effect on both water quality and on the distribution of vegetation in this zone. If present, emergent macrophytes are concentrated in this zone and, depending on water clarity, rooted submerged macrophyte species also occur in this zone. The presence of emergent and submerged macrophytes provides a highly complex habitat for invertebrates and fish and consequently, species diversity and abundances in this zone may be high. Vegetated littoral zones are particularly important for larval and juvenile fish and for small-bodied species of fish as macrophytes provide cover from larger predatory fish

2) the **pelagic or limnetic zone** occurs in the upper layers of the interior of the lake where there is sufficient light penetration for photosynthesis to occur. In the pelagic zone, primary production is dominated by phytoplankton (although some floating macrophytes may occur). Larger species of fish occur in the pelagic zone, where deeper water provides protection from waterbird predation.

3) The **profundal zone** occurs below the pelagic zone where there is little light penetration. The sediments in this zone are finer and production in this zone is dominated by decomposition of organic matter that falls to the bottom of the lake.

Shallow lakes are dominated by littoral zone habitats.

Water clarity and **nutrient loads** are also majors determinant of the dominant form of primary production (see component model 10) and thus, the diversity and abundance of aquatic fauna. High levels of turbidity and high dissolved nutrient loads favour phytoplankton dominance in lakes. In turn, high phytoplankton biomass further reduces water clarity, further disadvantaging submerged vegetation.

Commonly wet lakes are often associated with smaller ephemeral lakes and swamps that may be connected during periods of high water. These associated wetlands may represent important habitats for fish and birds.

Fauna

Aquatic Invertebrates: Commonly wet lakes may contain a diverse invertebrate community comprising of freshwater micro- and macroinvertebrate species. Community composition and abundance will vary depending on a number of factors including water quality and food and habitat availability (see component model 12).

Fish are likely to be absent or present in high to low abundances depending on a number of factors including water quality and food and habitat availability (see component model 13). Deeper lakes may represent important refuge habitat and may contain higher diversity than shallow with larger-bodied species utilising the deeper water habitats and larvae, juveniles and small-bodied species utilising the littoral zones.

Other fauna: Commonly wet lakes can be important refuge habitat for frogs (see component model 15) and turtles. During dry periods lakes represent an important source of water and lake bed vegetation can be an important food resource for terrestrial birds and

Waterbirds

A variety of waterbirds including herbivores, piscivores, waders, shorebirds, ducks and grebes, may be absent or present in low to high abundances depending on food and habitat availability (see component model 14). Most birds have specific depth requirements and so many species are confined to the edges of deep lakes. Due to the extended duration of inundation, lakes can represent important refuges for some species. Some lakes may also be important breeding sites.

Herbivores | Ducks and grebes | Shorebirds | Large wading birds | Piscivores

Key Threats

Changes to inundation regime, sedimentation, increased nutriant loads/eutrophication, land clearing and grazing, introduced species

Figure 19. Character description model for semi-arid commonly wet freshwater lakes

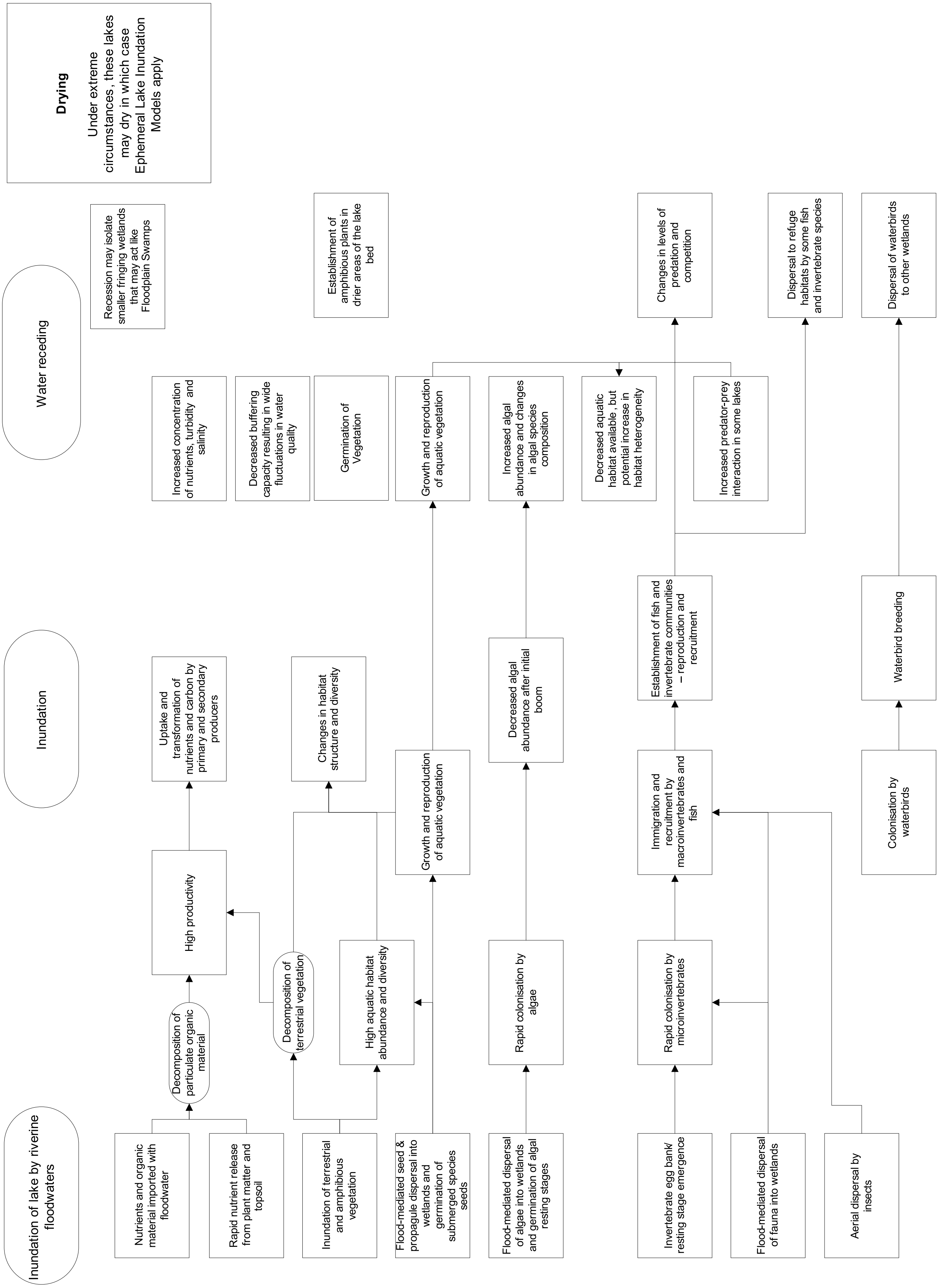


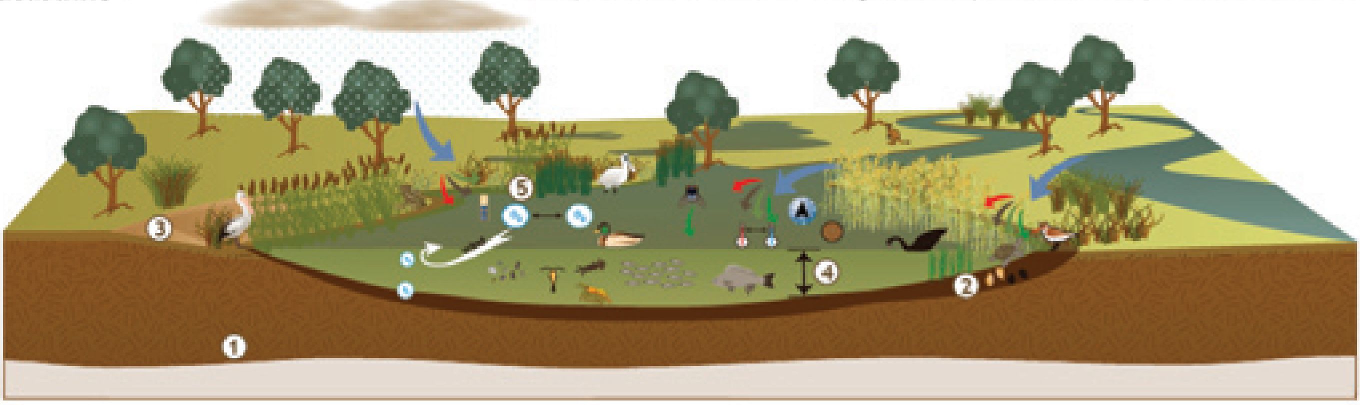
Figure 20. Inundation model for semi-arid commonly wet freshwater lakes

PERIODICALLY-INUNDATED FRESHWATER FLOODPLAIN LAKES

Periodically-Inundated Freshwater Floodplain Lakes

Lacustrine

Examples include: Narran Lake, Yantabangee Lake, Peery Lake, Lake Goran, Gilpoko Lake and some Menindee Lakes.



Components / Features

1. Soils: alluvial heavy cracking clays.
2. Heavy cracking clay substrates.
3. Lunette dunes may be present around eastern lake shores in lakes where deflational processes have operated.
4. Water depth may be shallow (0.5 m - 1 m) to deep (3 m) depending on lake morphology and inundation phase.
5. In lakes with high turbidity levels, primary production may be confined to a narrow littoral zone.

Water Quality

Water temperature is temporally and spatially variable among and within lakes (see component model 7).

Dissolved oxygen concentrations are temporally and spatially variable among and within lakes (see component model 6).

pH is generally alkaline but may vary depending on inundation phase (see component model 3).

Water is fresh but may become hypersaline when drying. Lake salinity will also vary depending on location in catchment with downstream lakes tending to be more saline (See component model 5).

Turbidity levels are moderate to high depending on source-water, sediment type and depth (See component model 4)

Fauna

Aquatic Invertebrates: Periodically-inundated floodplain lakes may contain a diverse and abundant invertebrate community comprising of micro- and macroinvertebrates. Early invertebrate colonisers of periodically-inundated floodplain lakes are desiccation-resistant species of microinvertebrate which emerge from egg banks and resting stages to rapidly colonise newly-inundated wetlands. Typically riverine species of invertebrates, which lack a desiccation-resistant stage, colonise lakes via aerial dispersal and from via inflows from adjacent creeks and rivers. Community composition and abundance will vary depending on a number of factors including inundation phase, water quality and food and habitat availability (see component model 12).

Fish are likely to be absent or present in high to low abundances depending on a number of factors including inundation phase, water quality and food and habitat availability (see component model 13).

Other fauna: Frogs may be present (see component model 15). As the lakes dry the development of vegetation on the lake bed will provide habitat for a variety of reptiles, birds and mammals.

Key Threats

Changes to inundation regime, sedimentation, increased nutrient loads/eutrophication, land clearing and grazing, blue-green algal blooms, introduced species

Processes

Lakes fill primarily from inflowing creeks and distributary channels and from overland flow and backflow from flooded rivers. Local runoff, direct precipitation and groundwater seepage may contribute to the duration and frequency of inundation but are generally insufficient for complete filling of lakes.

Sediments, dissolved nutrients and allochtonous material are transported into lakes from adjacent rivers and the floodplain.

Biota disperse into lakes via inflowing creeks and channels, overland flow from flooded rivers and aerial dispersal.

Seed and egg banks within the lake sustain communities through internal regeneration and recruitment.

Once full, periodically-inundated lakes are likely to function similarly to commonly wet lakes (see character description and key driver models for commonly wet lakes). Large lakes are often associated with swamps that may be connected during periods of high water.

Flora

Riparian and fringing vegetation: Lake margins are typically fringed by forests, woodlands, shrublands and grasslands. Species composition varies according to floodplain inundation regime, soil salinity levels and geographic location and typically includes trees, shrubs, grasses, sedges and herbs.

Emergent macrophytes: Periodically-inundated floodplain lakes may be fringed by dense stands of emergent macrophytes, however, these lakes can also be characterised by large areas of bare shoreline. Presence, density and composition of emergent macrophytes varies spatially and temporally and is dependant on factors such as sediment and water level stability, wave exposure, frequency of inundation and inundation phase and the presence and composition of viable seed banks (see component model 9).

Submerged macrophytes are uncommon, however in lakes with low turbidity, they may be present depending on other factors such as the presence and composition of viable seed banks and of shallow water (see component model 10).

Algae: Algal production in periodically-inundated floodplain lakes typically includes a diverse range of macro- and microscopic species that occupy a range of habitats. Macroscopic algae includes filamentous algae and species which are attached to the sediments. Microscopic algae includes phytoplankton which predominates in open water and periphyton which are grow attached to the sediment, plants and to particles of organic and inorganic matter. Algal production may be the dominant form of primary production depending on variables such as nutrient loads and the degree of light penetration (see component model 10).

Waterbirds

A variety of waterbirds including herbivores, piscivores, waders, shorebirds, ducks and grebes, may be absent or present in low to high abundances depending primarily on water depth and food (see component model 14). Periodically-inundated freshwater floodplain lakes represent important refuge habitat and in some cases may be used as breeding sites.

Herbivores — Ducks and grebes — Shorebirds — Large wading birds — Piscivores

Figure 21. Character description model for semi-arid periodically-inundated freshwater floodplain lakes

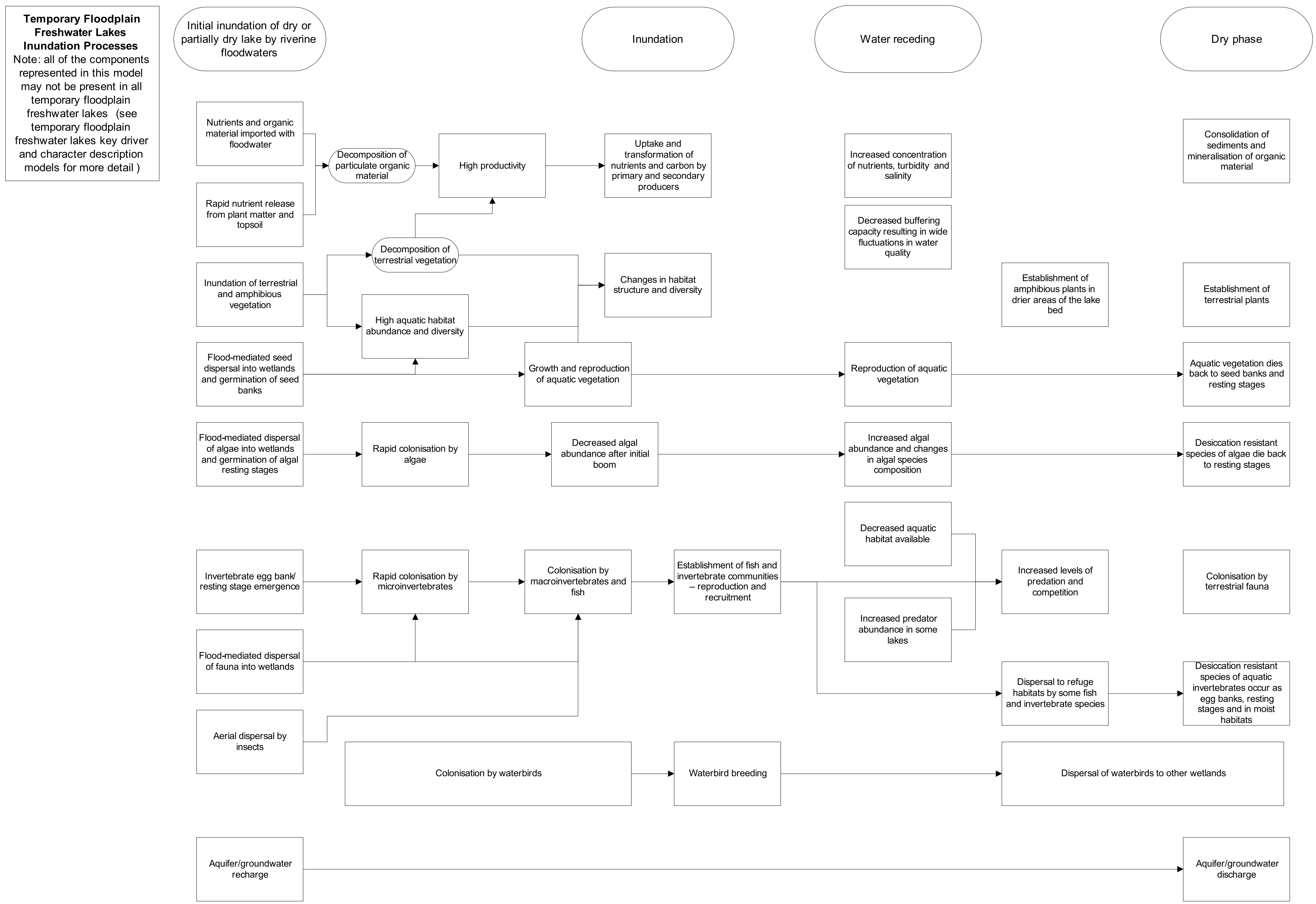


Figure 22. Inundation model for semi-arid periodically-inundated freshwater floodplain lakes

PERIODICALLY-INUNDATED FRESHWATER NON-FLOODPLAIN (DEPRESSIONAL) LAKES

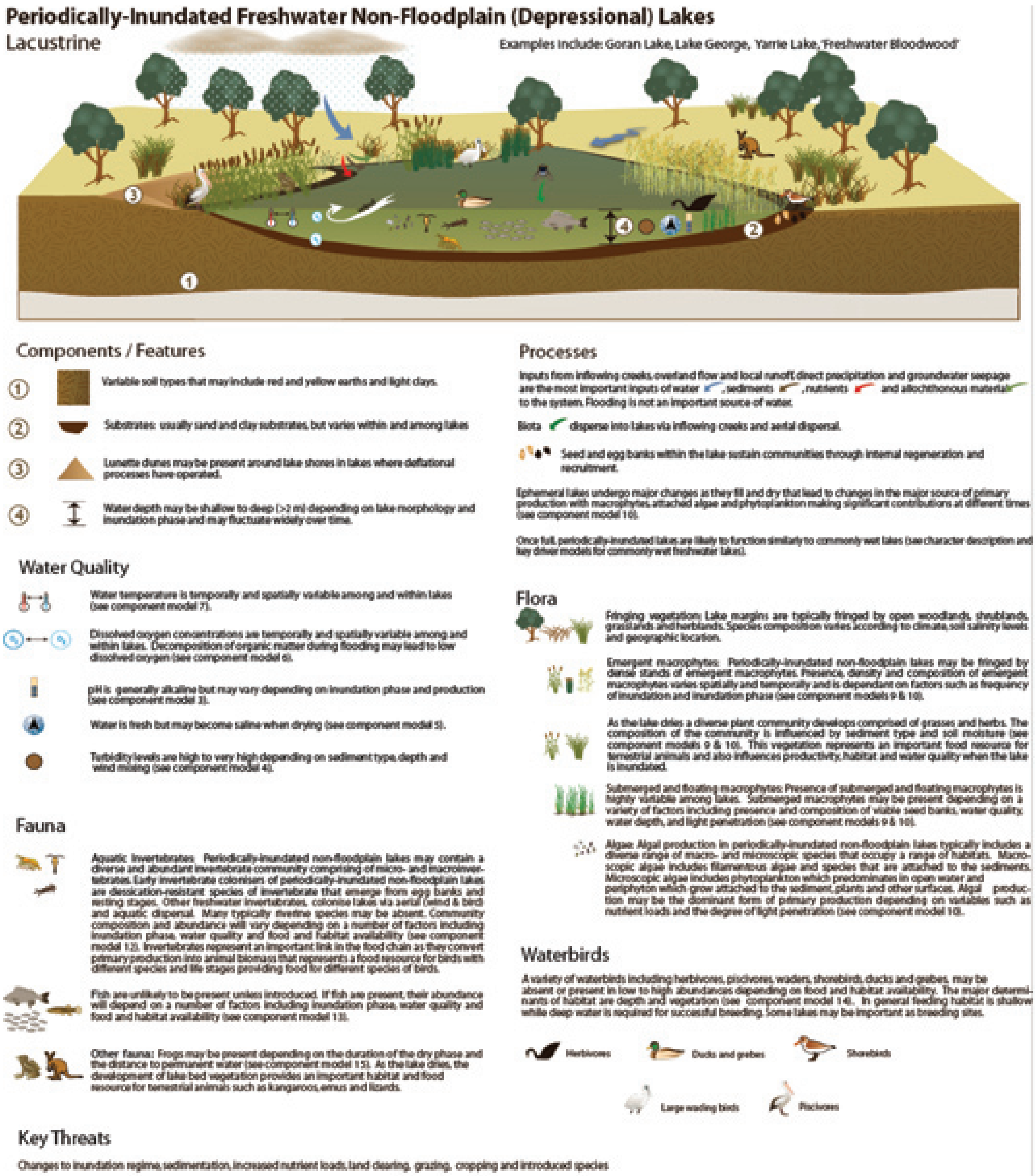


Figure 23. Character description model for semi-arid periodically-inundated freshwater non-floodplain (depressional) lake

Figure 24. Inundation model for semi-arid periodically-inundated freshwater non-floodplain (depressional) lakes

FRESHWATER SWAMPS

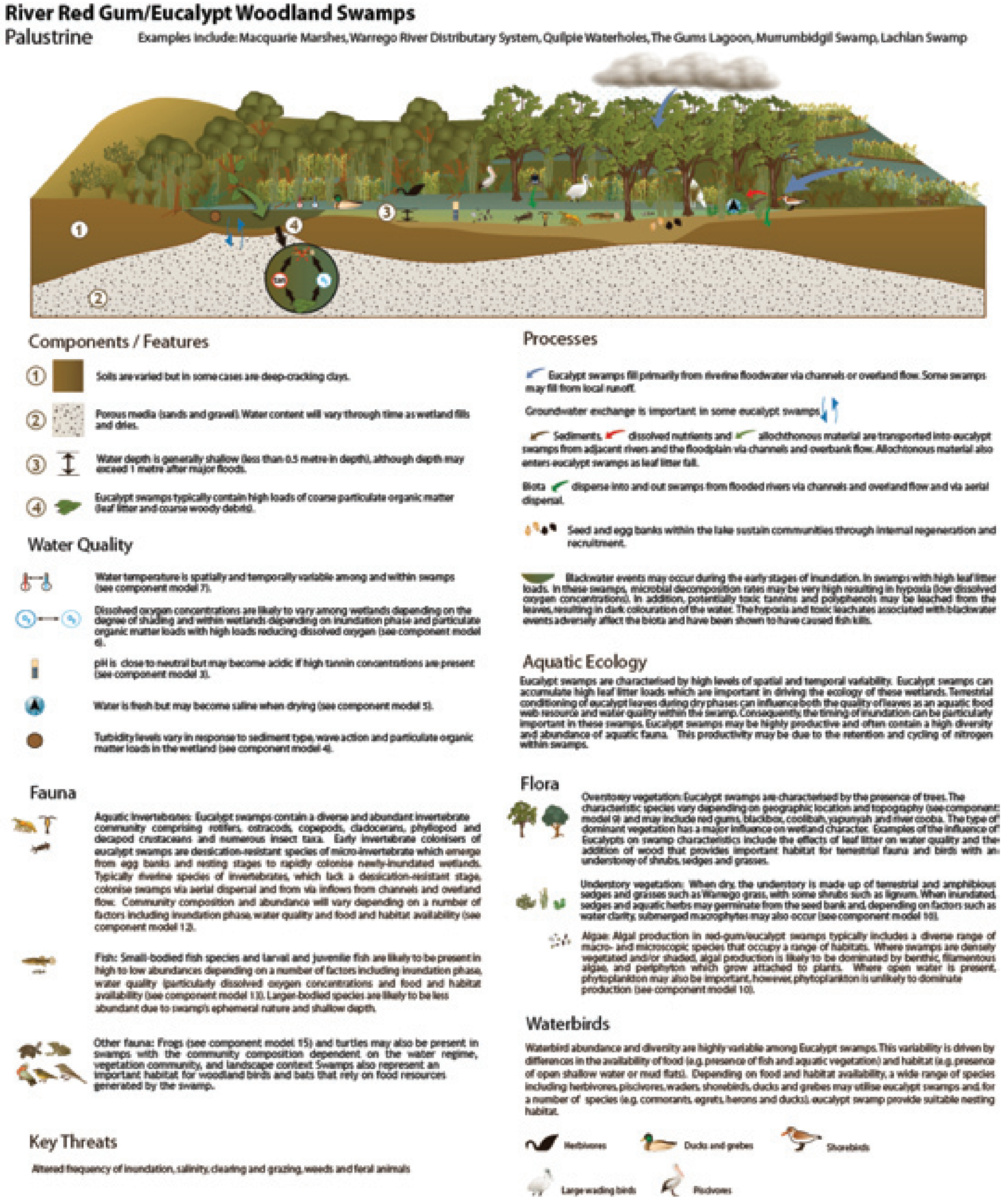
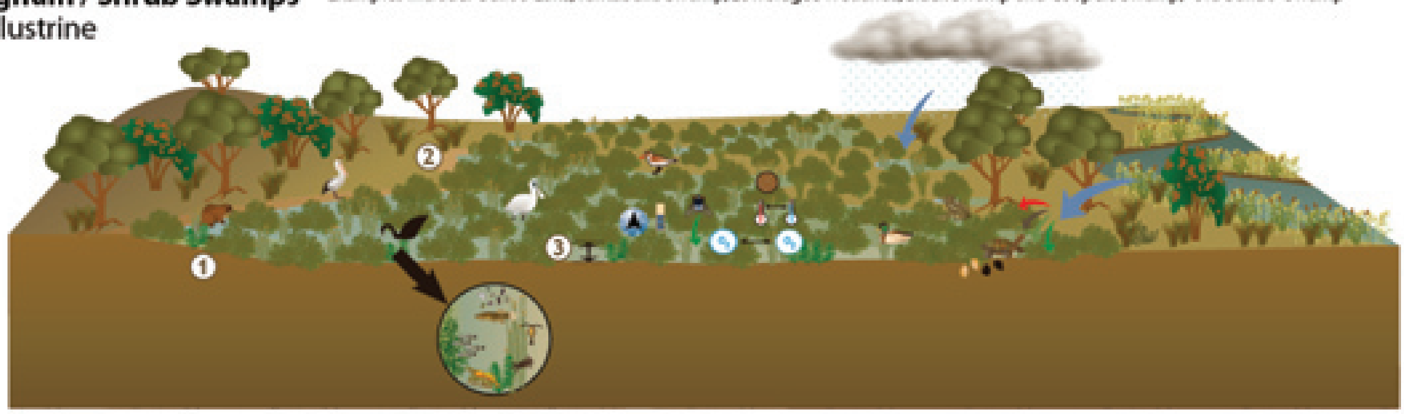


Figure 25. Character description model for semi-arid river red gum/eucalypt woodland swamp

Lignum / Shrub Swamps

Palustrine

Examples include: Bulloo Lake, Yantabulla Swamp, Lowbidgee Wetlands, Black Swamp and Coopers Swamp, "Old Bando" Swamp



④ ④

Components / Features

1. Soils and substrates are deep cracking brown and grey clays which may be up to 10 m deep.
2. Well developed beaches may be present where swamps were formed by deflation.
3. Water depth is shallow (less than 1 metre in depth), although depth may exceed 1 metre after major floods.

Water Quality

Water temperature is spatially and temporally variable among and within swamps (see component model 7).

Dissolved oxygen concentrations are likely to vary depending on inundation phase (see component model 6).

pH is generally alkaline but may vary depending on inundation phase (see component model 3).

Water is fresh but may become hyposaline when drying (see component model 5).

Turbidity levels are variable among swamps (low to high - see component model 4).

Fauna

Aquatic Invertebrates: Lignum swamps contain a diverse and abundant invertebrate community comprising phyllopod crustaceans, ostracods, copepods, cladocerans, decapod crustaceans and insects. Early invertebrate colonisers of lignum swamps are desiccation-resistant species of microinvertebrates which emerge from egg banks and resting stages to rapidly colonise newly-inundated wetlands. Typically riverine species of invertebrates, which lack a desiccation-resistant stage, colonise swamps via aerial dispersal and from via inflows from channels and overland flow. Community composition and abundance will vary depending on a number of factors including inundation phase, water quality and food and habitat availability (see component model 12).

Fish: Small-bodied fish species and larval and juvenile fish are likely to be present in high to low abundances depending on a number of factors including inundation phase, water quality and food and habitat availability (see component model 13). Larger-bodied species are likely to be absent if water depths are shallow.

Other fauna: Frogs (see component model 15), turtles and water rats may be present in lignum swamps.

Key Threats

Changes to inundation regime, sedimentation, increased nutrient loads, land clearing and grazing, introduced species

Processes

Lignum swamps fill primarily from riverine floodwater via channels or overland flow. Some swamps may fill from local runoff. Lignum swamps are regularly inundated (every 2-8 years) for 3 to 5 months in southern areas and 6 to 12 months in northern areas. Swamps dry completely between inundation events.

Sediments, dissolved nutrients and allochtonous material are transported into lignum swamps via channels and overbank flow.

Biota disperse into and out of swamps from flooded rivers via channels and overland flow and via aerial dispersal.

Seed and egg banks within the lake sustain communities through internal regeneration and

-

Aquatic Ecology

Lignum swamps provide a highly structurally complex habitat that traps organic matter, and provides abundant substrates and resources for epiphytic and benthic communities of micro-algae, bacteria and fungi. The major sources of aquatic primary production are aquatic vegetation and attached algae (see component model 10). In turn, this provides diverse and abundant food resources and habitat for invertebrates and fish.

Flora

Riparian and fringing vegetation: Lignum swamps may be sparsely fringed by floodplain eucalypts and acacias.

Aquatic vegetation: Most floodplain shrub swamps are dominated by lignum, although other shrubs such as nitre goosefoot may also be present. The density and size of the lignum is variable. Where inundation is frequent and prolonged (up to 3-4 months) the density of shrubs may be very high and the lignum may reach 2-3 metres in height. When the swamp is inundated, sedges and aquatic herbs may recruit from the seedbank and grow between the lignum bushes (see component model 9).

Algae: Algal production in lignum swamps typically includes a diverse range of macro- and microscopic species which occupy a range of habitats. Where swamps are densely vegetated with lignum and sedges, algal production is likely to be dominated by benthic, filamentous algae, and periphyton which grow attached to plants. Where open water is present, phytoplankton may also be important.

Waterbirds

Lignum swamps support a diverse suite of waterbirds including herbivores, piscivores, waders, shorebirds, ducks and grebes that depend on dense cover for breeding and shelter. Lignum provides suitable breeding habitat for a number of species including ibises, spoonbills and other colonial waterbirds and is also known to support breeding colonies of ducks, rails and waterhens. Species requiring open water habitats (e.g. large piscivores) or large areas of mud flats (e.g. a number of shorebird species) may not be present in swamps where lignum is very dense.

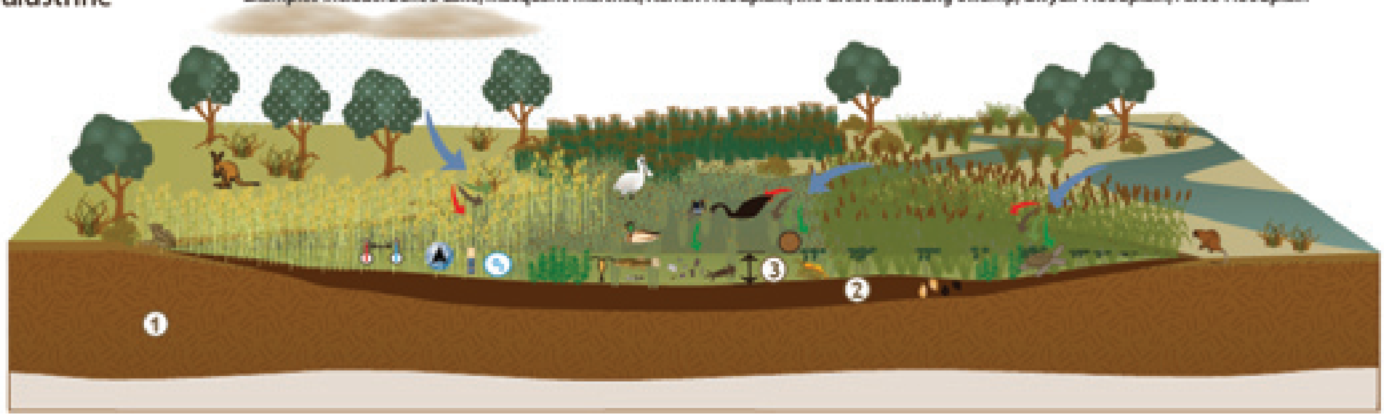
Herbivores — Ducks and grebes — Shorebirds — Large wading birds — Piscivores

Figure 26. Character description model for semi-arid lignum/shrub swamps

Grassland, Sedgeland and Herbland Swamps

Palustrine

Examples include: Bulloo Lake; Macquarie Marshes; Narran Floodplain; the Great Cumbung Swamp; Gwydir Floodplain; Paroo Floodplain



Components / Features

(4)

(1) Soils: Alluvial soils.

(2) Brown and grey cracking clay substrates.

(3) Water depth may be shallow to moderate depending on wetland morphology and inundation phase.

Water Quality

Water temperature is spatially and temporally variable among and within swamps (see component model 7).

Dissolved oxygen concentrations are likely to vary depending on inundation phase (see component model 6).

pH is generally alkaline but may vary depending on inundation phase (see component model 3).

Water is fresh but may become hyposaline when drying (see component model 5).

Turbidity levels are vary from high in some swamps to low very low in others where vegetation density is high (see component model 4). Turbidity levels may be highly temporally variable.

Fauna

Aquatic Invertebrates: For swamps that are connected to rivers, aquatic invertebrate community composition may be similar to that found in lignum swamps and the invertebrate fauna may comprise of phyllopod crustaceans, ostracods, copepods, cladocerans, decapod crustaceans and insects. Unless structural diversity is high, invertebrate abundances and diversity may be lower than those found in lignum swamps. For swamps that have no direct connection to rivers, invertebrate communities may be dominated by phyllopod crustaceans and species that have desiccation-resistant stages. Community composition and abundance will vary depending on a number of factors including inundation phase, water quality and food and habitat availability (see component model 12).

Fish: There is little information regarding the fish fauna of grassland, sedgeland and herbland swamps. Fish may be absent or present in high to low abundances depending on a number of factors including dispersal capacity, inundation phase, water quality and food and habitat availability (see component model 13).

Other fauna: Frogs (see component model 15) and turtles may be present in grassland, sedgeland and herbland swamps . As the swamp dries, swamps provide habitat and food for a variety of reptiles, birds and mammals.

Key Threats

Changes to inundation regime, sedimentation, increased nutrient loads, land clearing and grazing, introduced species

Processes

Grassland, sedgeland and herbland swamps fill primarily from inflowing channels, from overland flow and backflow from flooded rivers and from local runoff.

Sediments, dissolved nutrients and allochthonous material are transported into swamps from inflowing channels, adjacent rivers and the floodplain.

Biota disperse into lakes via inflowing channels, overland flow from flooded rivers and aerial dispersal.

Seed and egg banks within the lake sustain communities through internal regeneration and recruitment

Aquatic Ecology

Grassland, sedgeland and herbland swamps are highly variable in relation to dominant species composition and density of cover (see component model 9 & 10). Where the density of plants is high, organic matter may be trapped during dry phases, providing abundant resources for decomposers and consumers. High plant density also provides a large surface area for colonisation by epiphytic and benthic communities of micro-algae, bacteria and fungi. In turn, this provides diverse and abundant food resources and habitat for invertebrates and fish. In comparison to shrub swamps, the structural habitat provided by the emergent vegetation of sedgeland and grassland swamps may provide relatively low structural complexity, (depending on vegetation structure and density), potentially reducing the diversity and abundance of invertebrates and fish. As swamps dry, habitat and food becomes available for terrestrial animals as the vegetation undergoes a succession that depends on germination of seeds from the seed bank

Flora

Riparian and fringing vegetation: The margins of sedgeland and grassland swamps may be characterised by grasses and herbs, few trees and the occasional presence of shrubs such as lignum. The vegetation of the surrounding landscape varies according to floodplain inundation regime, soil salinity levels and geographic location and typically includes trees, shrubs, grasses, sedges and herbs (see component model 9). As the swamp dries the lake bed vegetation will change from aquatic vegetation to amphibious species and terrestrial grasses and herbs.

Aquatic vegetation: Grassland, sedgeland and herbland swamps may be dominated by one or several species of grasses, sedges and rushes with species composition being determined by the interaction of a number of variables including inundation regime, water depth, substrate and biogeography (see component model 10). Typical species include *Eleocharis* and *Cyperus* sedge species, Cumbungi (*Typha* spp.), club and giant rush species (*Bolboschoenus* and *Juncus* spp.), the common reed *Phragmites australis*, and grasses such as spiny mudgrass (*Pseudoraphis spinescens*) and canegrass (*Eragrostis australasica*). Species composition is highly temporally and spatially dynamic, with shifts occurring with changes in inundation regime and/or phase of inundation. When the swamp is inundated, aquatic herbs may grown between the emergent vegetation and in open water areas. Seed banks are often highly diverse.

Algae: Algal production in grassland, sedgeland and herbland swamps typically includes a diverse range of macro- and microscopic species which occupy a range of habitats. Where swamps are densely vegetated with emergent vegetation, algal production is likely to make a relatively minor contribution to primary production (see component model 10) and will be dominated by benthic, filamentous algae, and periphyton which grow attached to plants.

Waterbirds

Grassland, sedgeland and herbland swamps provide important feeding grounds for large wading birds such as the brolga and ibises. Some species of ducks and grebes and herbivores are also known to utilise these swamps. Species requiring open water habitats (e.g. large piscivores) or large areas of mud flats (e.g. a number of shorebird species) may not be present where emergent vegetation is very dense (see component model 14).

Herbivores — Ducks and grebes — Shorebirds — Large wading birds — Piscivores

Figure 27. Character description model for semi-arid grassland, sedgeland and herbland swamps

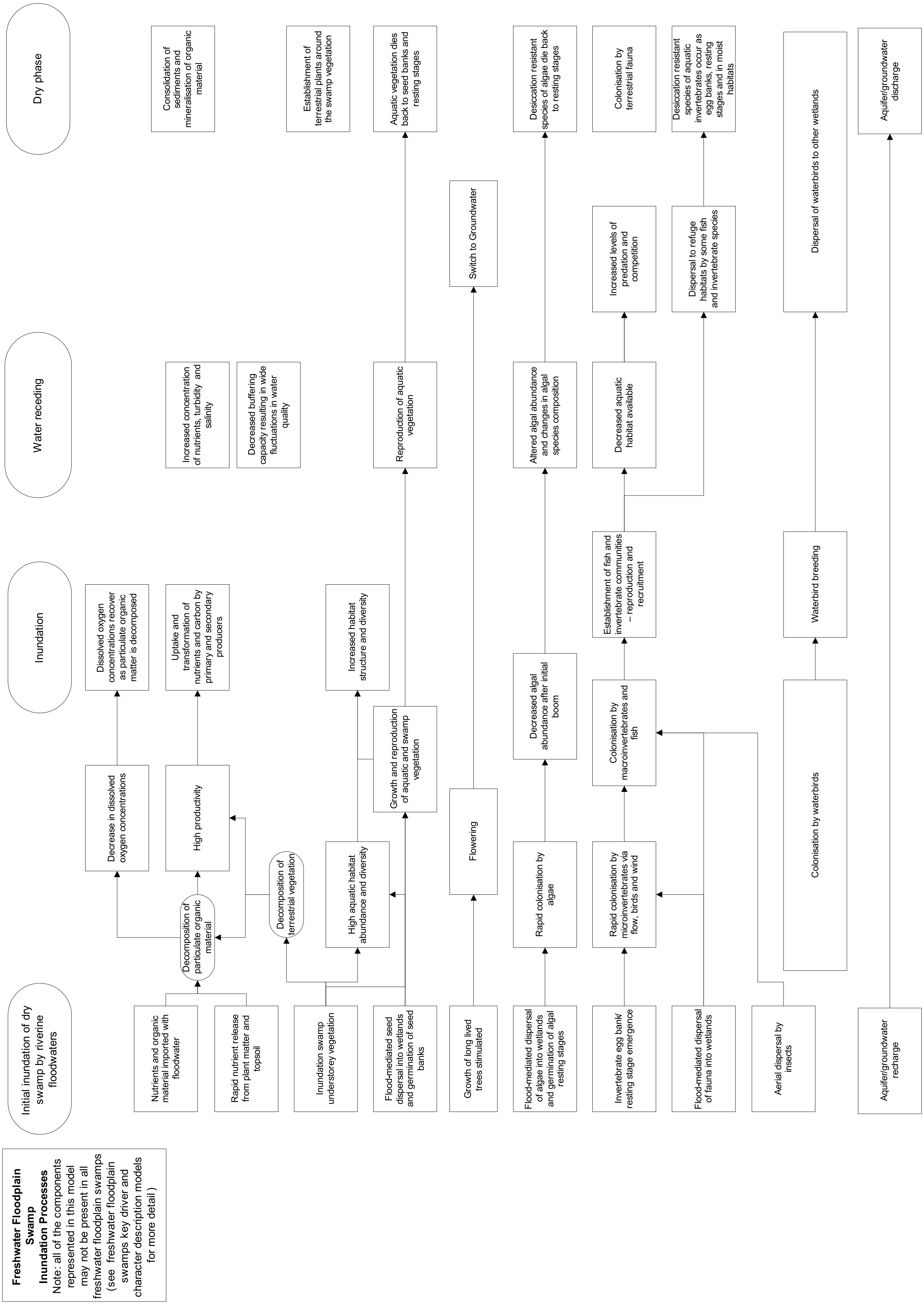


Figure 28. Inundation model for semi-arid freshwater floodplain swamps

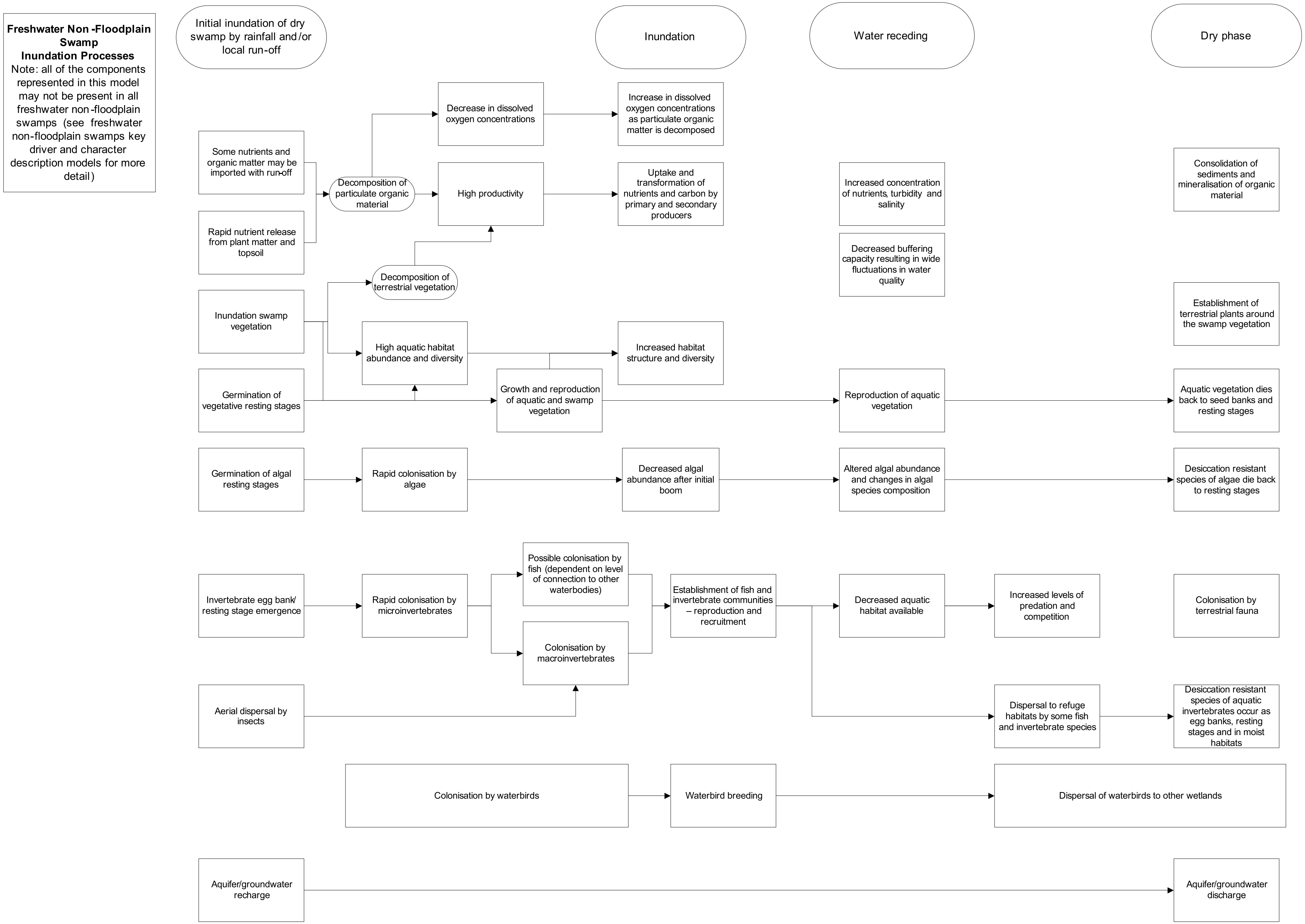
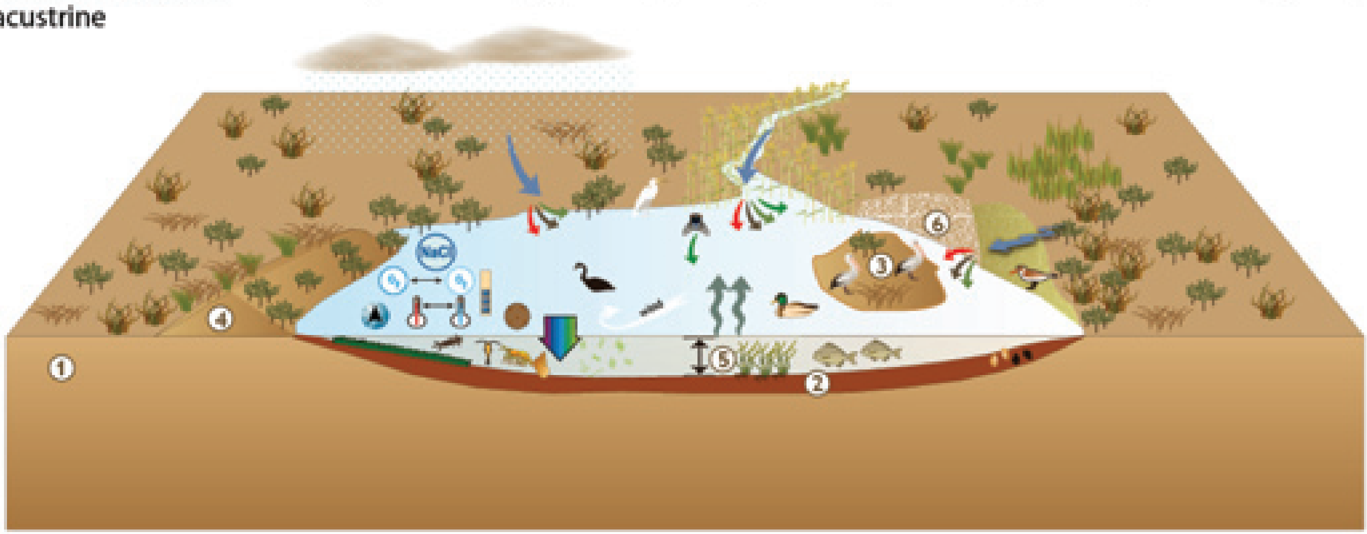


Figure 29. Inundation model for semi-arid freshwater non-floodplain (depressional) swamps

SALINE LAKES

Inland Saline Lakes
Lacustrine

Examples include: Lake Wyara, Lake Frome, Lake Galilee, Lake Burkanoko, Lake Nichebulka, Lake Buchanan, Horshoe Lake, Taylors Lake, Mulga Down:



Features

① Soils: soil types vary but may include red and yellow earths, duplexes, sands and texture contrast soils

② Clay substrates

③ Larger lakes are often characterised by islands, stranded beaches and spits. These may provide breeding habitat for waterbirds.

④ Many smaller lakes have old gypseous lunette dunes and younger clay lunette dams

⑤ Water depth is shallow (less than 2 m)

⑥ Salt and algal mat crusts can form in areas where the lake bed has dried out

Water Quality

The water temperatures of saline lakes are highly temporally and spatially variable (see component model 7). Within individual lakes, water temperatures fluctuate widely on both a daily and a seasonal basis (daily ranges of up 15 °C; seasonal ranges of up to 8-38 °C).

Dissolved oxygen levels are highly variable in saline lakes but are generally lower than in freshwater systems. In saline lakes, dissolved oxygen levels are determined by the interaction between salinity, temperature, ionic composition and air pressure (see component model 6).

pH values are highly variable in saline lakes with pH ranges of 3.0 to 11 having been recorded (see component model 3). In the northern semi-arid zones, pH is generally alkaline ranging from 8-10.

Salinity levels are highly temporally and spatially variable and may range from hyposaline (∼3 g/L) to hypersaline (> 50 g/L). Salinity levels vary as a result of a number of factors including surface area to volume ratio, evaporation rate, the degree of groundwater interaction and inundation phase (see component model 5).

The water in saline lakes is generally clear. However, turbidity levels may rise following major inflows or due to wind mixing in very shallow wetlands (see component model 4).

Fauna

The community composition, diversity and abundances of aquatic fauna are regulated by a number of factors including the frequency of wetting and proximity to colonisation sources; water quality variables including salinity levels, dissolved oxygen levels and pH ; biotic interactions such as predation; biogeography ; food availability; the presence and abundance of macrophytes and algae and substrate homogeneity.

Aquatic Invertebrates may include insects and crustaceans. At very high salinities (>∼150 g/L) the invertebrate fauna is restricted to brine shrimps and a few ostracod species.

Fish only occur in salt lakes with low to moderate salinities (<∼35 g/L). In these lakes, abundances can be very high and the presence of an abundant fish fauna is important in supporting piscivorous birds. In intermittent and episodic systems, fish species survive dry times in waterholes of inflowing creeks and have good dispersal and high fecundity when lake water is present.

Processes

Lakes fill primarily from inflowing creeks, local runoff, direct precipitation and groundwater seepage.

Sediments, dissolved nutrients and allochtonous material are transported into saline lakes via inflowing creeks and overland flow

Biota disperse into lakes via inflowing creeks and aerial dispersal

Evaporation rates are very high

Saline lakes are typically well mixed by the wind resulting in no stratification and well sorted, homogenous substrates.

Seed and egg banks within the lake sustain communities through internal regeneration and recruitment.

Aquatic Ecology

The aquatic communities of saline lakes are comprised of a diverse range of biota including archaeobacteria or halobacteria, eubacteria, cyano bacteria, algae, Macrophytes, crustaceans, insects, non-arthropod invertebrates and vertebrates including fish and birds. The aquatic ecology of saline lakes is primarily influenced by the interaction of three main drivers: salinity levels, frequency of inundation and nutrient loads.

Salinity levels: The composition of biological communities in salt lakes is different from that in freshwaters with differences in composition becoming more pronounced as salinity increases. As a general rule, both species richness and diversity in inland saline waters decreases with increasing salinity. The relationship between salinity and species richness is particularly clear at the upper end of the salinity spectrum. The number of species is greatest in subsaline waters, decreases dramatically at low salinities, and then continues to decrease gradually with increasing salinity. However, as a determinant of community structure, salinity levels appear to have minimal impact in highly saline systems and is of greatest importance when salinities are less than approximately 50 g/L. In hyposaline waters (between 3 and 20 g/L), most taxa present, at all taxonomic levels, are also found in freshwaters. The biota essentially comprises halotolerant freshwater forms. In mesosaline waters, (between 20 and 50 g/L), there are few halotolerant freshwater taxa and most of the biota comprises taxa restricted to inland saline waters of moderate salinity. In hypersaline waters (greater than 50 g/L), the biota is almost entirely restricted to highly saline waters with only a few genera and even fewer species also found in less saline waters. Since salinity often exceeds 50 g/L (up to 350 g/L and beyond in certain lakes), throughout most of the range of salinity in salt lakes, the biota of salt lakes is quite different from that of freshwaters.

Frequency of inundation: The frequency of inundation is important in determining species composition with occurrence patterns varying between commonly wet, intermittent (water is present on a seasonal basis) and episodic (water is present only after unpredictable rainfall events) saline lakes.

Nutrient levels: In combination with salinity and inundation regimes, nutrient levels are important in determining the dominant form of primary production, which in turn is an important driver of diversity and abundance patterns of the aquatic fauna

Flora

Riparian and fringing vegetation: species composition varies according to soil salinity levels and geographic location (see component model 8) but salt lakes are typically fringed by low open shrublands comprised of salt-tolerant species such as samphire (*Halosarcia* spp.) and salt bush (*Atriplex* spp.).

Salinity and frequency of inundation are the primary drivers of macrophyte growth in saline systems. Macrophytes can occur in high densities in permanent and intermittent hyposaline and mesosaline lakes. In hyposaline waters, some essentially salt tolerant freshwater emergent species can occur in the littoral zone (e.g. *Potamogeton pectinatus*, *Phragmites australis*). In lakes with higher salinity levels, only submerged species confined to salt lakes such as species of *Ruppia*, *Chara*, *Nitella* and *Lepilaena* are present.

Algae: There is little data available regarding algal production in saline lakes. It is likely that phytoplankton is the dominant form of algal production and phytoplankton may be the dominant form of primary production in lakes with low to moderate salinity levels and high nutrient loads

Benthic microbial mats comprising mostly of halophyllic cyanobacteria - however eukaryotic algae, particularly diatoms, unicellular and filamentous green algae and photosynthetic and heterotrophic bacteria may also be present - occur in both permanent and seasonal/episodic hypersaline lakes (∼<100 g/L). Microbial mats support fewer species of aquatic invertebrates than submerged macrophytes.

Waterbirds

Saline lakes are important feeding and breeding sites for a variety of water-bird species including herbivores, piscivores, waders, shorebirds and ducks and grebes. Large numbers of waterbirds have been found on a number of saline lakes. All species are nomadic so lakes are usually colonised quickly after filling. Species composition and abundance are dependent on food and habitat availability, and inundation phase (see component model 14).

Herbivores — Ducks and grebes — Shorebirds — Large wading birds — Piscivores

Key Threats

Changes to inundation regime, sedimentation and deflation, surface flow diversions, weeds and feral animals.

Figure 30. Character description model for semi-arid saline lakes

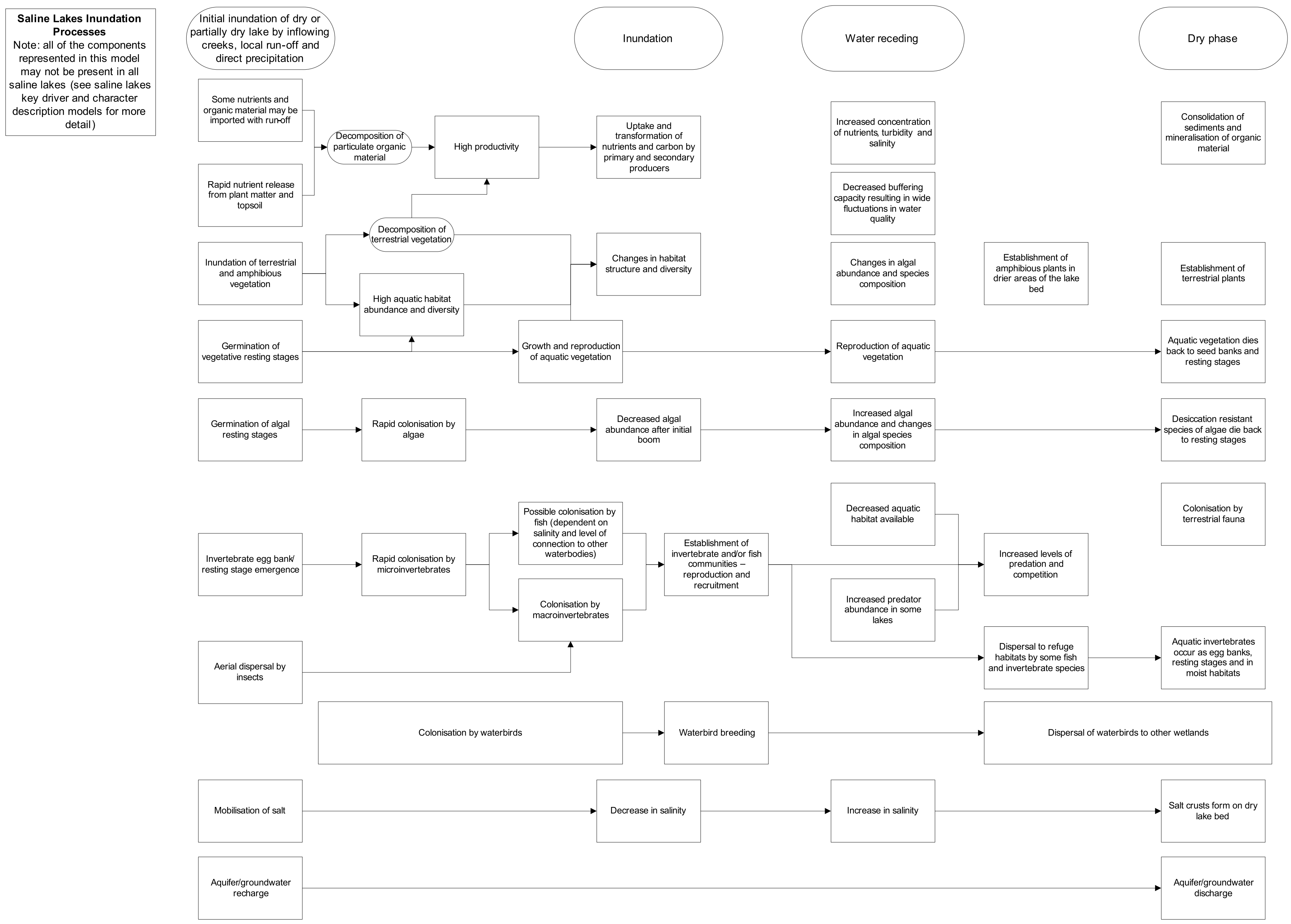


Figure 31. Inundation model for semi-arid saline lakes

Australian Government

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BASIN AUTHORITY