QUEENSLAND WATER MODELLING NETWORK

Climate change and variability

Making our water models climate change ready: Are they up to the task?

An evaluation guideline for water models needing to incorporate climate variability and/or climate change.

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Queensland Government

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Background

The use of water models in understanding the impacts of climate change is of key interest to government agencies, industry, academia and the community. Many existing water models and water related models have the potential to incorporate aspects of climate change, however it can be a challenge to understand how well they may be suited to this task.

This guideline outlines a series of evaluation criteria and a scoring system to help assess the readiness of water models to account for or incorporate climate change in their use. These criteria were developed from assessing a range of case studies as part of the Critical review of Climate Change and Water Modelling in Queensland (Alluvium *et al*. 2019). The intent is to provide a ready reckoner for modellers and decision makers to understand the ability of particular models to answer key questions associated with ***existing climate variability*** and ***future climate change***.

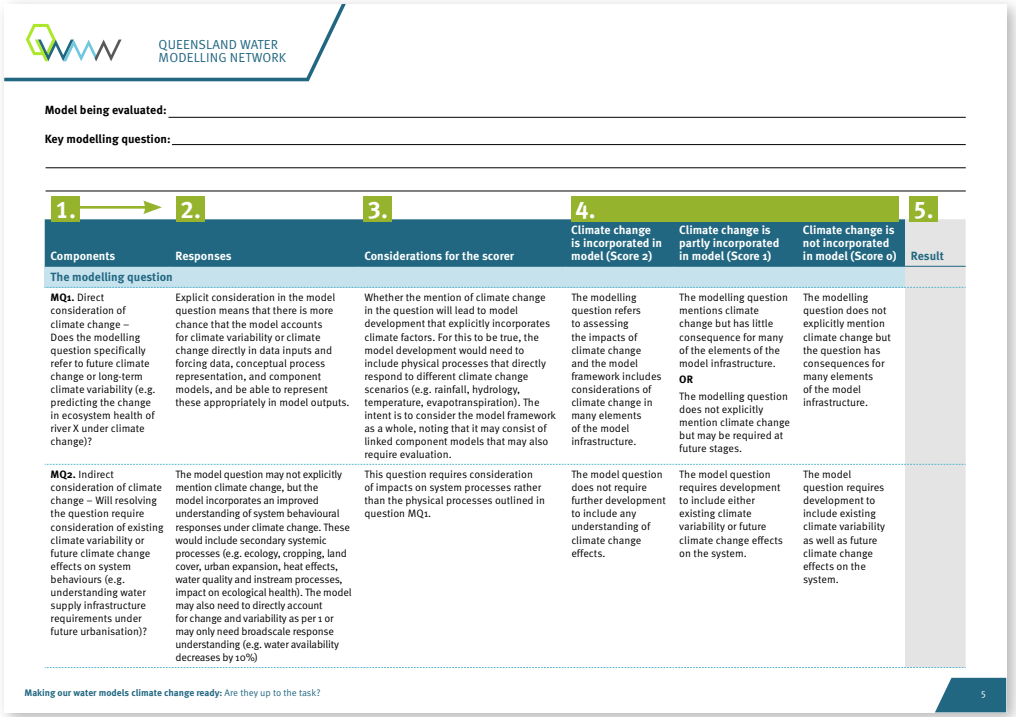
The reference to ***existing climate variability*** means the representation of variability in a range of climate factors that may be present not just in the last 120 years of recorded data, but also from improved understanding of past climate patterns, sequences and influences determined through paleoclimate research.

In this guideline, ***future climate change*** means the representation, either at global, regional or local scales, of the impacts of climatic shifts as a result of increased greenhouse gas emissions in the atmosphere. These are likely to cause changes to a range of climate factors in addition to existing climate variability and may further add to that variability (e.g. through increases in frequency and/or intensity of climatic events). Therefore, the reference to future climate change in this report can mean both accounting for trends in climate factors (such as increases in temperature or changes in rainfall) and changes to existing climate variability in future years.

How to use these evaluation criteria

A series of six overall criteria have been developed and these are described in the following page. From these, a scoring rubric has been developed which explores each of the criteria in more detail under separate component criteria and provides a numeric score to allow the user to evaluate the suitability of the models. The approach will therefore provide an indication of where the models may or may not be useful for answering questions associated with climate change and will also indicate where further work is required to improve their usability.

1. To use the criteria, read through the component to understand the relevance to the model being evaluated.
2. From there, work horizontally across to the responses column, which provides some more information around the component and how it may relate to the evaluation of the model.
3. Considerations are then provided in how to score the model against the component using the rubric in the last three columns.
4. A rubric is simply a statement-based scoring system, similar to school report cards, which help the scorer understand which is most applicable.
5. The result is then added to the final column.



QUEENSLAND WATER
MODELLING NETWORK

Model being evaluated: _____

Key modelling question: _____

1. → Components	2. Responses	3. Considerations for the scorer	4. Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	5. Result
The modelling question						
MQ1. Direct consideration of climate change – Does the modelling question specifically refer to future climate change or long-term climate variability (e.g. predicting the change in ecosystem health of river X under climate change)?	Explicit consideration in the model question means that there is more chance that the model accounts for climate variability or climate change directly in data inputs and forcing data, conceptual process representation, and component models, and be able to represent these appropriately in model outputs.	Whether the mention of climate change in the question will lead to model development that explicitly incorporates climate factors. For this to be true, the model development would need to include physical processes that directly respond to different climate change scenarios (e.g. rainfall, hydrology, temperature, evapotranspiration). The intent is to consider the model framework as a whole, noting that it may consist of linked component models that may also require evaluation.	The modelling question refers to assessing the impacts of climate change and the model framework includes considerations of climate change in many elements of the model infrastructure.	The modelling question mentions climate change but has little consequence for many of the elements of the model infrastructure. **OR** The modelling question does not explicitly mention climate change but may be required at future stages.	The modelling question does not explicitly mention climate change but the question has consequences for many elements of the model infrastructure.	
MQ2. Indirect consideration of climate change – Will resolving the question require consideration of existing climate variability or future climate change effects on system behaviours (e.g. understanding water supply infrastructure requirements under future urbanisation)?	The model question may not explicitly mention climate change, but the model incorporates an improved understanding of system behavioural responses under climate change. These would include secondary systemic processes (e.g. ecology, cropping, land cover, urban expansion, heat effects, water quality and instream processes, impact on ecological health). The model may also need to directly account for change and variability as per 1 or may only need broadscale response understanding (e.g. water availability decreases by 10%)	This question requires consideration of impacts on system processes rather than the physical processes outlined in question MQ1.	The model question does not require further development to include any understanding of climate change effects.	The model question requires development to include either existing climate variability or future climate change effects on the system.	The model question requires development to include existing climate variability as well as future climate change effects on the system.	

What the results mean

The results of the scoring should indicate to the user where the majority of focus should be placed in improving model suitability to address climate variability and or climate change and so shouldn't be considered as pass/fail type scores. They are provided to help the user identify where efforts may be best placed to improve model suitability and to provide a consistent framework for evaluating existing and future water models around this issue.

Generally, if a model scores 10 or less overall, it is likely that it is unsuitable in its current form and will need significant improvement to enable climate change to be properly evaluated. Scoring between 11-20 indicates that the model may be suitable in some circumstances, but further efforts may be needed to adapt it to better answer the question. Those that score above 20 may be generally suitable for evaluation, but care should still be taken as some component criteria may be essential to score highly in order to properly answer the modelling question.

Worked example

At the end of the table, a worked example is provided using the Paddock to Reef Case Study from the Critical Review of Climate Change and Water Modelling in Queensland. It shows how the criteria were considered and the scores obtained. It is provided as an example only, and should not be considered indicative of current Paddock to Reef modelling associated with incorporating climate change, as this has progressed since the development of the Case Study.

The modelling question

Does the key question that the model needs to answer require improved representation of climate change or variability? For example, understanding changes in water infrastructure operations, changes in human systems which use water, changes in processes that rely on water.

Data inputs and forcing data

Consider how the inputs, or forcing data, for the model may change. This may be as straightforward as climate variables such as rainfall, evapotranspiration, temperature, humidity, solar radiation, wind, seasonality, intensity, duration, but it also may need to evaluate whether other inputs may be affected by change or variability, such as streamflow data, agricultural cropping requirements, economic data or even social information (e.g. how will land use representation change under different climate outcomes). Also consider the availability and representativeness of the forcing data that accounts for climate change or variability. Do the data sets have the same indicators or parameters, does there need to be further verification or derivation to make it suitable for use and if so, what are the implications in doing so?

Conceptual process representation

Do the conceptual processes that the models are based on have the ability to account for different climatic sequences and at relevant scales? Models may account for broadscale systems such as looking at city water supplies, or fine scale processes such as changes in water column ecological response under altered temperature or flow conditions. Primarily this is about understanding the system process or processes that the model is simulating, such as rainfall-runoff, water consumption, ecological response, crop water use, overland flow pathways. Consider whether the system processes will be affected as initial responses to climate change or variability such as changes in runoff from changes in rainfall, or “downstream” processes, such as how should a crop model change if there is less runoff to harvest.

Component models

Models are typically made up of a series of component models, so there is a need to identify where climate inputs or representation may alter under aspects of those component models under different climatic sequences. This can include rainfall-runoff, vegetation growth, water demands (both human and industry), ecological response and sociology-economic models. It is important to understand the sensitivity of these component models and whether they will be significantly affected by alternative climate sequences, or even if they may no longer be representative of the process under climate variability or change.

Model outputs

Can a model be used in an exploratory mode, such that multiple scenarios can be run to evaluate different climate sequences, with large amounts of data output, or is it more that the model is run to evaluate the “most likely” scenario? The latter will have implications for how well the forcing data and system processes are able to represent the overall system response, whereas the former approach allows for “stress testing” to see where the model is best and worst suited to evaluating the model question under change or variability. Are there enough computer resources to allow models to be used in this way?

Decision frameworks

Consider how models that account for future climate change will be used in decision making. What decision frameworks will be best suited to considering multiple realisations of future climate, how is risk and uncertainty able to be accounted for, what alternative decisions may be possible or what future forcing conditions may have implications for the results?

Model being evaluated: _____

Key modelling question: _____

_____

_____

Components	Responses	Considerations for the scorer	Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	Result
The modelling question						
MQ1. Direct consideration of climate change – Does the modelling question specifically refer to future climate change or long-term climate variability (e.g. predicting the change in ecosystem health of river X under climate change)?	Explicit consideration in the model question means that there is more chance that the model accounts for climate variability or climate change directly in data inputs and forcing data, conceptual process representation, and component models, and be able to represent these appropriately in model outputs.	Whether the mention of climate change in the question will lead to model development that explicitly incorporates climate factors. For this to be true, the model development would need to include physical processes that directly respond to different climate change scenarios (e.g. rainfall, hydrology, temperature, evapotranspiration). The intent is to consider the model framework as a whole, noting that it may consist of linked component models that may also require evaluation.	The modelling question refers to assessing the impacts of climate change and the model framework includes considerations of climate change in many elements of the model infrastructure.	The modelling question mentions climate change but has little consequence for many of the elements of the model infrastructure. **OR** The modelling question does not explicitly mention climate change but may be required at future stages.	The modelling question does not explicitly mention climate change but the question has consequences for many elements of the model infrastructure.	
MQ2. Indirect consideration of climate change – Will resolving the question require consideration of existing climate variability or future climate change effects on system behaviours (e.g. understanding water supply infrastructure requirements under future urbanisation)?	The model question may not explicitly mention climate change, but the model incorporates an improved understanding of system behavioural responses under climate change. These would include secondary systemic processes (e.g. ecology, cropping, land cover, urban expansion, heat effects, water quality and instream processes, impact on ecological health). The model may also need to directly account for change and variability as per 1 or may only need broadscale response understanding (e.g. water availability decreases by 10%)	This question requires consideration of impacts on system processes rather than the physical processes outlined in question MQ1.	The model question does not require further development to include any understanding of climate change effects.	The model question requires development to include either existing climate variability or future climate change effects on the system.	The model question requires development to include existing climate variability as well as future climate change effects on the system.	

Components	Responses	Considerations for the scorer	Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	Result
MQ3. Timeframes – Is the question likely to need resolution of short-term or long-term climate change responses?	The period over which the model question needs to be evaluated determines the type of climate change factors that should be incorporated. For short term responses (5-20 years), improved understanding of existing climate variability is likely to be more important than future climate change. For longer term (20 years +), future climate change in addition to better representation of existing climate variability will need to be accounted for.	Models that run over longer evaluation periods require more consideration of future climate change factors. If the model evaluation periods are short term, it won't require consideration of future climate change factors.	Answering the model question requires longer evaluation periods so future climate change factors are incorporated. **OR** Answering the model question requires shorter evaluation periods and more frequent updates so future climate scenarios aren't incorporated but existing climate variability is.	Answering the model question requires shorter evaluation periods and more but the model is unlikely to be updated frequently so climate change factors may need to be considered.	The inclusion of climate change factors is unsuitable given the required evaluation period.	
MQ4. Temporal patterns – Does the modelling question require an understanding of changing temporal patterns in the future (e.g. evaluating frequency of extreme rainfall events)?	Answering the model question includes forcing data that are suitable to represent the changes, or that the component models are able to resolve changing temporal dynamics (e.g. some models will have static parameters over an entire modelling period and may not be suitable).	Does the model forcing data include the temporal variability consistent with predictions of climate change? Examples of forcing data that would need to take account of climate change factors include: future land use layers, changes in hydrologic response, predictions of human movements due to changing climate etc.	The models' forcing data incorporates temporal variability predicted to be influenced by climate variability.	The model's forcing data incorporates some temporal variability but isn't comprehensive enough to explicitly assess the impacts of climate change.	The model's forcing data does not incorporate any temporal variability so can't represent impacts of climate change of that model input.	

Components	Responses	Considerations for the scorer	Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	Result
Data inputs and forcing data (Purpose – Do we have access to the data required to answer the model questions as per the first criteria).						
DI1. Does the model require climatic forcing data e.g.: ► temperature ► rainfall ► evaporation/ evapotranspiration ► solar radiation ► wind ► humidity and is that data available over the time and space scales needed to answer the modelling question?	The forcing data required to answer the model question needs to be sufficient to account for existing climate variability or future climate change, i.e. the model will need climate data as direct input to drive the model response. The scale of the data over temporal and spatial extents needs to also be considered to ensure that sufficient data is available and at the appropriate scale.	The reviewer needs to determine if the forcing data accounts for existing climate variability or future climate change: Understand which GCMs have been used to derive the data, what RCPs they represent and whether these may be relevant to the question (e.g. exploring ranges of outcomes or medians) Are the data available at an appropriate scale (both temporal and spatial)? Will the data need to be derived from other indicators or are they directly available? Not all climate indicators may be available, and some might require calculation using available inputs (e.g. evapotranspiration).	The data input required are available or easily calculated or derived from other available datasets and are at sufficient scales to evaluate the modelling question.	Not all of the data inputs required are available, but most are able to be derived from other datasets. **OR** The data input required are available but not at sufficient scales to properly answer the modelling question.	The data input required are not available and can't be calculated or derived from other datasets.	

Components	Responses	Considerations for the scorer	Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	Result
DI2. Will other data inputs be influenced by existing climate variability or future climate change?	For the model to fully incorporate climate change factors, the other baseline datasets required to run the model need to be assessed. Data that relates to the system behaviours may be influenced by climate factors and may need to be updated to reflect how this may alter the inputs. Where model outputs may be applicable to projects with long lifetimes (e.g. Water Plans are usually updated after 20 years), the underlying science may change and therefore those datasets may not be relevant over the full period the project is intended to cover.	Assess the baseline data sets other than the forcing data that are required to run the model. Datasets that should be assessed include: ▶ Potable water demands ▶ Crop water demands ▶ Crop types ▶ Harvesting regimes ▶ Vegetative cover ▶ Soil properties ▶ Stream flows ▶ Economic activity (e.g. farming intensity, coal production) ▶ Social responses (e.g. population growth, tourism activity) ▶ Ecological responses (e.g. algal blooms, changes in groundwater dependent ecosystems, blackwater event frequencies).	The baseline datasets incorporate climate change or variability and are likely to be relevant over the life of the project. **OR** The baseline datasets are not influenced by climate change or variability.	Some, but not all, of the baseline datasets have the ability to incorporate climate change variability or the datasets may change over the life of the project.	The baseline datasets do not incorporate climate change variability, but should in order to adequately represent climate change factors. **OR** The baseline datasets incorporate current science but will not be updated for the life of the project and therefore may become outdated or unsuitable to evaluate climate variability and change.	
DI3. Will spatial and/ or temporal patterns of data inputs change?	To fully incorporate climate change factors, the data inputs need to account for predicted changes in frequency, seasonality, intensity, multi-year variability (ENSO, IPO etc.), orographic effects. These changes also vary spatially.	Consider all of the data inputs used to run the model and assess if each dataset needs to change spatially or temporally to fully account for climate change variability.	The data inputs account for spatial/ temporal patterns of changes in climate. **OR** The data inputs do not need to account for predicted changes in climate.	Some, but not all of the data inputs account for spatial/temporal patterns of changes in climate.	The data inputs do not account for spatial/temporal patterns of changes in climate. OR The update frequency is not sufficient to account for this.	

Components	Responses	Considerations for the scorer	Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	Result
DI4. Does answering the model question require consideration of historical measured data or future climate projections?	Models may be required to use historical climate sequences to represent management approaches over time (e.g. water resource models). Assessing the impacts of future climate change may therefore need to consider whether the retention of the historical climate sequence is still required or if future climate change predictions can be directly used.	Evaluate whether there is a strong need to maintain the historical climate sequence and how this needs to be reflected in incorporating future climate change.	The model retains characteristics of historical climatic sequences in evaluating future climate change. **OR** The model does not need to account for historical climate sequences when predicting future climate change impacts.	The model incorporates some components of the historical sequence but full representation of frequency, intensity and period are not reflected directly in the climate change input data.	The model needs to reflect historical climate sequences in assessing future climate change but has not considered this in application of future climate change data.	
Conceptual process representation						
CP1. Do the conceptual models that underpin the numerical model properly represent or allow for climate change or variability and are the parts of the conceptual model most sensitive to climate change identifiable?	Conceptual models are the basis for general understanding of the processes expressed in the numerical model. So assessing models for suitability to incorporate climate change or variability requires the evaluation of the conceptual models. Specific aspects that may change under different climate regimes, such as increased temperatures or changes in rainfall, are typically well accounted for in most water related models, however other aspects, such as changes in soil infiltration, increased moisture uptake by plants or improved productivity due to increased CO_2 concentrations may not be catered for.	Assess if the conceptual models depict explicitly the necessary elements of climate change in all inputs and outputs. It is likely that as models are improved to better incorporate climate variability and change, the conceptual models are likely to improve also.	The conceptual models explicitly depict the necessary elements of climate change.	Some of the necessary elements of climate change are depicted in the conceptual models.	The conceptual models do not depict the necessary elements of climate change.	

Components	Responses	Considerations for the scorer	Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	Result
Component models						
CM1. Do the component models have sufficient parameters to account for changes in climate inputs?	Typically, water models can be made up of a number of different component models (e.g. a rainfall runoff model, an ecosystem response model, a pollutant generation model). Examining these will be needed to understand if and how they may resolve different forcing conditions under altered climates.	Assess the component models based on the evaluation criteria. Depending on the level of details needed, each component model may require separate evaluation under these criteria.	The component models have sufficient parameters to account for changes in climate inputs.	Only some of the component models have sufficient parameters to account for changes in climate inputs.	The component models do not have sufficient parameters to account for changes in climate inputs.	
Model outputs						
MO1. Temporal variability – Does the model show results that can assess long-term changes in climate?	Models can be run over different time steps (hours, days, months) and for different periods (1 year, 30 years, 100 years). Do the model outputs cover the period where altered climate patterns will show an influence? For example, a model that is calibrated and validated over a short time period may not be able to represent the changes of an altered climate regime easily without significant work to update the model calibration under the likely future conditions.	Assess the outputs of the models for sufficient temporal resolution and parameterisation to account for predicted temporal climate variability (e.g. do the model outputs cover periods of >30 years or for timeframes >20 years into the future).	The model outputs cover the period where climate patterns would show an influence.	Only some of the model outputs cover the period where climate patterns would show an influence.	The model outputs do not cover the period where climate patterns would show an influence.	
MO2. Spatial variability – Does the model have sufficient spatial scale or in locations where different climate realisations can be used?	Model outputs that represent single points or land parcels may not show the full range of variability that may be possible due to different climate outputs. Current datasets are available at larger spatial scales and consideration of whether the input data sets will match the scale of the outputs will need to be made.	Assess the outputs of the models for sufficient spatial resolution and parameterisation to account for spatial climate variability.	The model outputs cover appropriate spatial scales where climate patterns would show an influence.	Only some of the model outputs cover appropriate spatial scales where climate patterns would show an influence.	The model outputs do not cover appropriate spatial scales where climate patterns would show an influence or at the scale at which climate risks are expected.	

Components	Responses	Considerations for the scorer	Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	Result
MO3. Scenario testing – Can the model evaluate multiple scenarios or operate in a stochastic fashion?	Exploratory modelling may require hundreds or thousands of scenarios to be evaluated, maybe coupled to stochastic variation of parameters. As such the model will need to provide outputs that can be used in statistical analyses or be able to be run in "batch modes" through scripting or other methods to generate the outputs required.	Assess the capacity of the models to run multiple scenarios and enable the necessary statistical differentiation between the outputs and the computing resources needed to both run the models and evaluate the outputs.	The model can run multiple scenarios and allow statistical analysis to be run that can resolve changes against inherent uncertainty.		The model cannot run multiple scenarios and does not allow statistical analysis to be run that can resolve changes against inherent uncertainty.	
Decision frameworks						
DF1. Model flexibility – Is the model able to be altered easily to account for different actions, inputs or parameters (e.g. for exploratory modelling or multiple scenarios)?	Run times, ability to be rerun or changed quickly will provide more flexibility in assessing multiple options or be used in different decision frameworks more easily. For example, having a large model that takes weeks to run may not be conducive to short-term decision making or producing alternate scenarios, or it may not provide enough understanding of how different inputs can affect model results. Considering how the model may be used in the decision-making process will improve its usefulness and function in the decision process when assessing climate change impacts.	Assess the ability to adjust and re-run the models at timeframes matching decision making requirements.	The model can be adjusted and re-run at timeframes matching decision making requirements.	There is a mismatch between the model set up and run time and the decision-making requirements but is not significant enough to impact the decision.	The model cannot be adjusted and re-run at timeframes matching decision making requirements.	
DF2. Trajectories – does the model represent not just the result of different climates (static assessment), but also the processes of change (dynamic assessment)?	Depicting climate variability often requires an understanding of not only the "book ends" (e.g. best case/worst case), but also the transition process (i.e. what happens during change) to best understand whether decisions that address book ends result in undesirable outcomes.	Assess the model to see if dynamic changes can be incorporated over the modelling period.	The model can represent dynamic changes in the system as a result of climate change during the evaluation period.	The model can only partially represent dynamic changes in the system as a result of climate change during the evaluation period.	The model cannot represent dynamic changes in the system as a result of climate change during the evaluation period.	

Components	Responses	Considerations for the scorer	Climate change is incorporated in model (Score 2)	Climate change is partly incorporated in model (Score 1)	Climate change is not incorporated in model (Score 0)	Result
DF3. Visualisation – can the model present results in ways that are easily communicated or can the model outputs be easily incorporated into communication tools?	Many models simply generate data or information. Once run, the user (modeller/decision maker/ stakeholder) needs to contextualise that information to allow the implications of the model results to be understood in the decision process. Models that produce results that can be visualised easily (e.g. graphs, maps etc) may provide better inputs into decision frameworks than those which require significant post processing.	Assess if the model outputs can be easily visualised for the required decision-making process and the post processing requirements are able to be resourced appropriately if needed.	Model outputs can be easily visualised for required decision making process.	Model outputs can be visualised but not easily enough to be entirely useful for the required decision making process.	Model outputs cannot be visualised for required decision making process and require significant post processing to visualise climate change impacts.	

Worked Example

Introduction

This worked example reviews the application of the eWater Source Model in the P2R Catchment Loads Modelling program with a view to understanding how this modelling could incorporate (if required) the impacts of future climate change and existing climate variability on the modelling process and the results obtained.

Modelling Question

The primary modelling question to be answered is evaluating and reporting progress towards the Reef 2050 Water Quality Improvement Plan (see https://www.reefplan.qld.gov.au/) through the ongoing analysis of baseline condition and application of improved management practices in a range of agricultural industries including targeted treatment options and investment prioritisation relative to a baseline year.

Role

Models have been developed for each of 6 NRM regions (Cape York, Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays, Fitzroy and Burnett Mary) as shown below. The models are used to compare changes in management practice implementation against a baseline scenario (nominally 2013) by simulating different agricultural industries and their associated management at the paddock and landscape scales. These are completed in component models such as APSIM, and HowLeaky outside of Source and in a dynamic SedNet model within Source at the landscape scale through changes in cover.

This coupling of component models approach means that there are a wide range of model inputs and parameters that may be influenced by the need to better account for future climate change and existing climate variability. A screenshot of the Wet Tropics P2R model is shown in the figure right.

The Source model is run every year incorporating the new practice adoption layer, with major updates to the model and input data sets every 5 years (last update 2018).

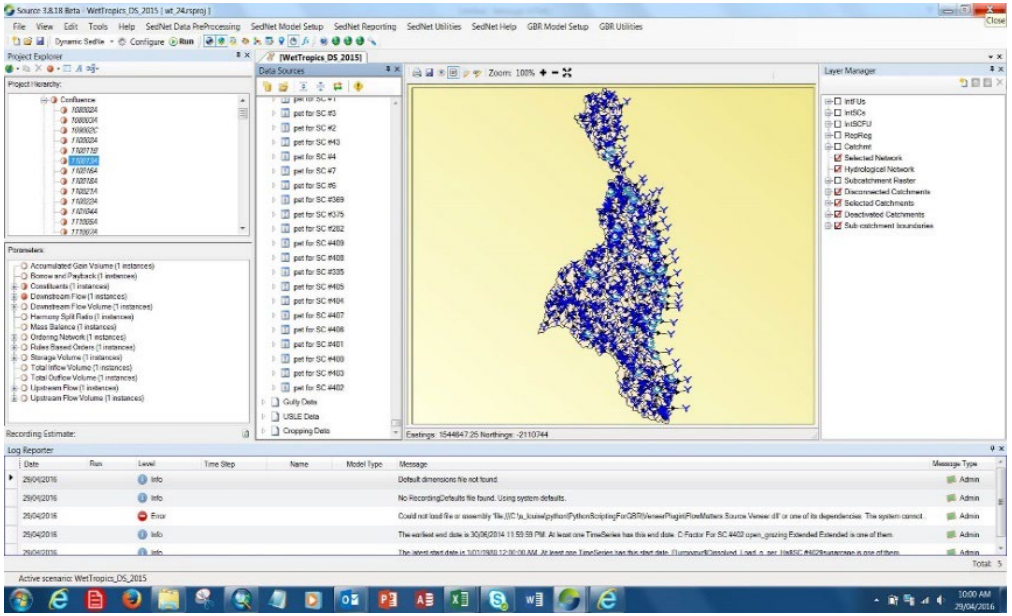


Figure 22 Wet Tropics P2R Source Model

Model being evaluated: Source Paddock to Reef Modelling Framework

Key modelling question: Evaluating and reporting progress towards the Reef 2050 Water Quality Improvement Plan through the ongoing analysis of baseline condition and application of improved management practices in a range of agricultural industries relative to a baseline year.

Components	P2R modelling assessment	Result
The modelling question		
MQ1. Direct consideration of climate change – does the modelling question specifically refer to future climate change or long-term climate variability (e.g. predicting the change in ecosystem health of river X under climate change)?	**No** – Currently this is not required under the P2R program but may be a future need.	**1** – The modelling question does not explicitly mention climate change but may be required at future stages.
MQ2. Indirect consideration of climate change- will resolving the question require consideration of existing climate variability or future climate change effects on system behaviours (e.g. understanding water supply infrastructure requirements under future urbanisation)?	**Yes** – The majority of focus would be on future climate change representation to understand changes in pollutant loads to the reef.	**1** – The model question requires development to include either existing climate variability or future climate change effects on the system.
MQ3. Timeframes – Is the question likely to need resolution of short-term or long-term climate change responses?	**Long Term** – The models will be required to evaluate the changes over longer time frames (e.g. 20-50 years) and the model doesn't include incorporation of these factors as yet.	**0** – The inclusion of climate change factors is unsuitable given the required evaluation period.
MQ4. Temporal patterns – Does the modelling question require an understanding of changing temporal patterns in the future (e.g. evaluating frequency of extreme rainfall events)?	**Yes** – changes in events such as cyclones, monsoonal patterns etc will need to be accounted for in future climate change assessments but this is dependent on input data. The model currently has a seasonably variable cover factor that can therefore incorporate the likely impacts of future climate change on this aspect.	**2** – The model's forcing data incorporates temporal variability predicted to be influenced by climate variability.
Data inputs and forcing data		
DI1. Does the model require climatic forcing data e.g.: ▸ temperature ▸ rainfall ▸ evaporation/evapotranspiration ▸ solar radiation ▸ wind ▸ humidity and is that data available over the time and space scales needed to answer the modelling question?	**Yes** – In the existing P2R models, rainfall and evapotranspiration are the primary climate forcing data.	**2** – The data input required are available or easily calculated or derived from other available datasets and are at sufficient scales to evaluate the modelling question.

Components	P2R modelling assessment	Result
DI2. Will other data inputs be influenced by existing climate variability or future climate change?	**Yes** – Other components such as vegetation cover and land use may need to be changed to account for issues such as increased temperature, sea level rise, changed agricultural practices. The models have sufficient datasets that can incorporate climate variability or change.	**1** – Some, but not all, of the baseline datasets have the ability to incorporate climate change variability or the datasets may change over the life of the project.
DI3. Will spatial and/or temporal patterns of data inputs change?	**Yes** – Changes in rainfall spatial patterns are accounted for as the climate data is spatially derived. Extreme event frequency are not a current focus of the program, but are likely to be needed in the future and this will require better assessment of changes in temporal patterns.	**2** – The data inputs account for spatial/temporal patterns of changes in climate.
DI4. Does answering the model question require consideration of historical measured data or future climate projections?	**Possibly** – the model currently evaluates baseline and change management scenarios over the same historical sequence. For understanding future climate change impacts, perhaps only the two scenarios need to be directly comparable, so historical sequence may not be important, but running both scenarios through the same future climate sequence will be needed.	**2** – The model does not need to account for historical climate sequences when predicting future climate change impacts.
Conceptual process representation		
CP1. Do the conceptual models that underpin the numerical model properly represent or allow for climate change or variability and are the parts of the conceptual model most sensitive to climate change identifiable?	**Possibly** – The conceptual processes of rainfall runoff and constituent generation do allow for climate influences to be represented, however some elements such as changed vegetation cover etc are not currently represented (but could be relatively easily).	**1** – Some of the necessary elements of climate change are depicted in the conceptual models.
Component models		
CM1. Do the component models have sufficient parameters to account for changes in climate inputs?	**Yes** – In most cases the current Sacramento rainfall runoff model, HowLeaky and APSIM agricultural models, and the dSedNet constituent generation models can account for changes in climatic conditions on the direct processes they are simulating.	**2** – The component models have sufficient parameters to account for changes in climate inputs.
Model outputs		
MO1. Temporal variability – Does the model show results that can assess long-term changes in climate?	**Possibly** – The models are run over a 28-year consistent climate period to allow for comparison against baseline scenarios. Altering the climate of this 28 year period may have implications for assessing changes against a baseline condition with a different 28 year climatic period. This period may also not represent the full variability likely to be experienced across the GBR region if accounting for the extent of variability possible from the paleo and recorded climate regimes.	**2** – The model outputs cover the period where climate patterns would show an influence.

Components	P2R modelling assessment	Result
MO2. Spatial variability – Does the model have sufficient spatial scale or in locations where different climate realisations can be used?	**Yes** – The models run at a scale that uses broad scale climatic inputs such as SILO gridded rainfall and therefore are at the optimal scale to use climate change data products currently available.	**2** – The model outputs cover appropriate spatial scales where climate patterns would show an influence.
MO3. Scenario testing – Can the model evaluate multiple scenarios or operate in a stochastic fashion?	**Yes** – the models can run multiple scenarios but run times may prevent use in stochastic assessments.	**2** – The model can run multiple scenarios and allow statistical analysis to be run that can resolve changes against inherent uncertainty.
Decision frameworks		
DF1. Model flexibility – is the model able to be altered easily to account for different actions, inputs or parameters (e.g. for exploratory modelling or multiple scenarios)	**Yes** – the models are quite flexible to adjust parameters and run different scenarios and are commonly used in this form.	**2** – The model can be adjusted and re-run at timeframes matching decision making requirements.
DF2. Trajectories – does the model represent not just the result of different climates (static assessment), but also the processes of change (dynamic assessment)?	**No** – currently this is not easily represented without some adjustment to input data sets (e.g. running models over shorter time frames) as some of the input data is static (e.g. land use). The use of dynamic cover in the models does allow for some representation of one component of trajectory to be simulated.	**1** – The model can only partially represent dynamic changes in the system as a result of climate change during the evaluation period.
DF3. Visualisation – can the model present results in ways that are easily communicated or can the model outputs be easily incorporated into communication tools?	**Possibly** – The current outputs are typically post-processed to provide for different visualisations, though some work is occurring to improve this process.	**1** – Model outputs can be visualised but not easily enough to be entirely useful for the required decision-making process.

Overall result = 24 – the model is likely to be suitable for assessing existing climate variability or future climate change with only limited changes needed.