Queensland Government

QWMN

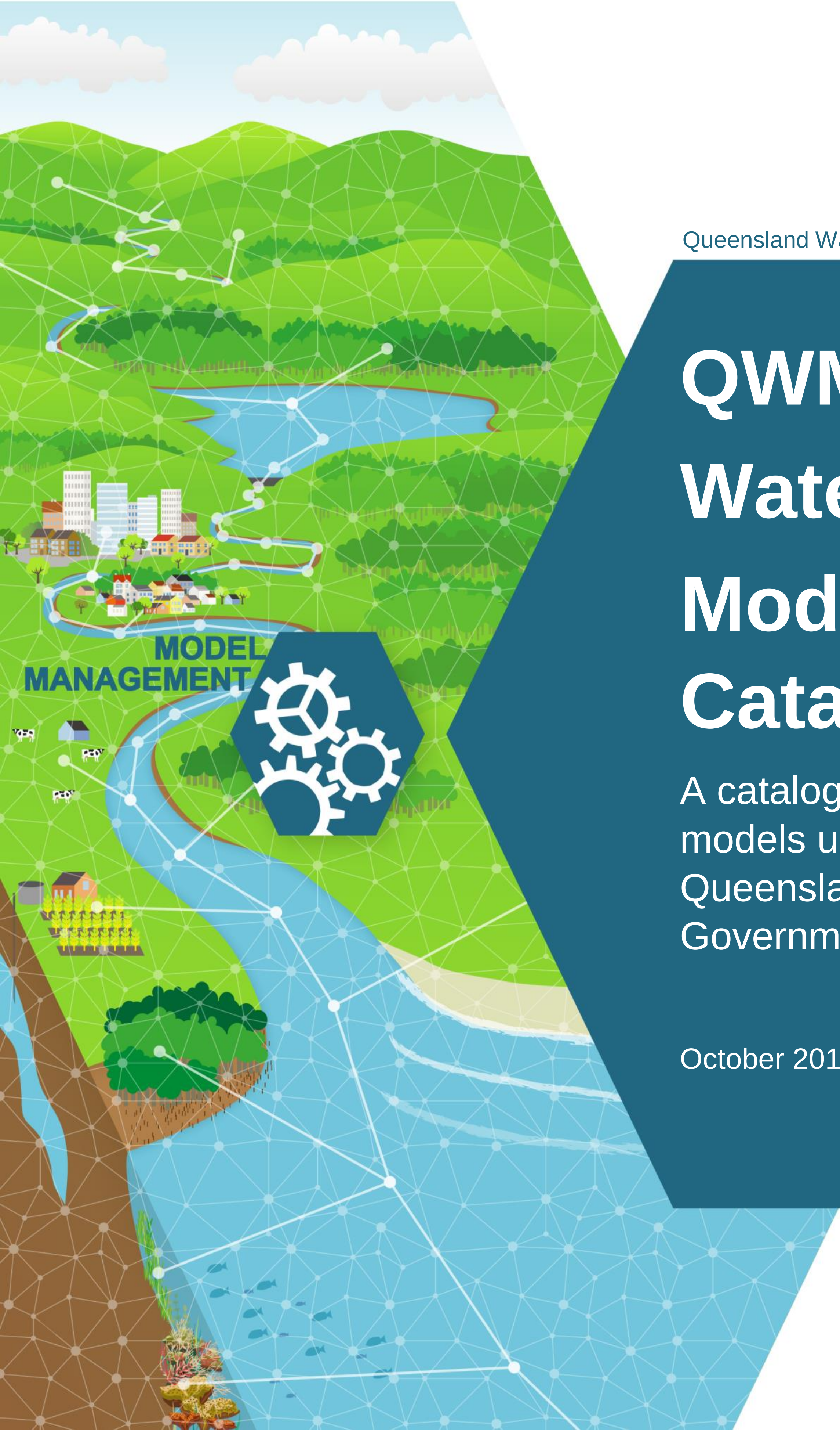
Griffith University

Queensland Water Modelling Network

QWMN Water Model Catalogue

A catalogue of water models used by the Queensland Government

October 2017



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Executive summary

The purpose of the Queensland Water Modelling Network (QWMN) Water Model Catalogue is to provide a concise overview and collation of the major water models currently used by the Queensland Government. The catalogue is a resource for researchers and students to better understand the scope and range of models being applied by Queensland Government agencies and utilise these tools and applications for teaching and collaborative research projects.

18 water models have been identified through consultation with Queensland Government modelling, planning and policy representatives and are documented in this catalogue. The water models have a wide and diverse range of uses within government and provide support for: land-holder decision making; agricultural systems assessments; water planning decision making; framing catchment and groundwater policy making and reporting; and for receiving waters and coastal water quality reporting.

The water models catalogued cover a wide range of hydrologic processes and simulate and/or predict water quantity and quality at different temporal and spatial scales. They also deal with complex water allocation processes and the management of water infrastructure. It is important to note that a vast amount of experience exists within the Queensland Government in using these models and interpreting their results.

The catalogue uses three water model classifications to broadly identify the most likely research and development modelling opportunities:

1. Mature and well-developed models that have little research and development (R&D) opportunities because they are 'off-the-shelf' type models.
2. Global and complex models—often proprietary software—where R&D and changes to the model occur largely in response to the needs and requirements identified by a wide community of model users.
3. Queensland Government developed models where intellectual property and capital exists within the Queensland Government. These models are most likely to have the greatest potential for R&D and collaboration with universities.

The catalogue contains a companion spreadsheet that summarises the key attributes for each model within these three classifications.

The two key recommendations from the Water Model Catalogue are:

- A searchable meta-database be developed to allow different model user groups to select water models based on model functionality, complexity, cost, and model applications in Queensland; and
- Organise user engagement workshops to identify areas for strategic improvement of 'Classification 3' water models in Queensland. Users could include policy and decision makers; model operators, model developers, model trainers and educators.

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Introduction

In March 2017 the Queensland Government established the interdepartmental Queensland Water Modelling Network (QWMN). The state-wide network focuses on modelling research and development (R&D) and innovation to improve the efficiency and effectiveness of operational water modelling activities in Queensland.

Computer-based models are seen as valuable tools to inform water allocation decisions, water quality investments, and objectively assess the impacts of industry development and the implementation of planning initiatives on the availability, movement and quality of water resources. The QWMN identified a need to create a catalogue that outlines the major water models used by government; serves as a reference document for new users and non-experts; and helps facilitate broader and appropriate use of water models in policy and decision-making, inside and outside government.

Addressing these needs, this Water Model Catalogue provides a concise overview of the major water models used by the Queensland Government, outlining their policy applications, key characteristics, functional capabilities, spatial and temporal operations, assumptions, as well as their strengths, weaknesses and opportunities to support policy, planning and risk assessment programs. The Water Model Catalogue also provides metadata on water models to enable informed discussions of future model development and dissemination for the benefit of modellers and other end users.

An additional purpose of the Water Model Catalogue is to expose university researchers and students to the scope and range of models being applied by Queensland Government agencies, and highlight opportunities to utilise these tools and applications for teaching and collaborative research projects. The Water Model Catalogue also helps bound discussions with universities and research organisations on model development, focusing future investment into enhancing rather than re-inventing existing modelling tools.

The Water Model Catalogue illustrates the large variety of models used by the Queensland Government. Models range from tools for farmers to make farm management decisions, researchers to assess alternative agricultural systems and sustainability outcomes, and integrated catchment planning and assess effluent reuse, through to policy and planning support in surface water and groundwater management. Increasingly, an ensemble of water models is being used to evaluate and address a diverse range of environmental issues including land salinity risk; water quality discharged from catchments adjacent to the Great Barrier Reef; and reporting on progress in meeting reef water quality targets.

The models are organised in the Water Model Catalogue based on their uses:

Model use	Model name
Farmer decision support	SoilWater App
Agricultural systems assessments	Howleaky, APSIM, Grasp – AussieGrass
Planning support	MEDLI, 2CSalt
Catchment policy	Sacramento, SIMHYD, IQQM, eWater Source - Quantity, eWater Source - Quality, MIKE 11, HEC-RAS, WATHNET
Groundwater policy	MODFLOW, BC2C
Receiving water and coastal water quality reporting	eReefs, TUFLOW

SoilWater App (SWApp)

Summary

Conducting dryland and irrigation farming within a variable rainfall climate and on a diverse range of soils remains a challenge to Australian farmers. Grain production in Australia is limited, in most seasons, by the amount of rainfall received during a fallow and during crop growth, and by how much water is stored in the soil. Soil water stored during fallow periods and early season maintains crop water supply especially towards the critical time around anthesis (Freebairn et al. 2017).

SoilWaterApp (SWApp) is an iOS App that has been developed for dryland and irrigation decision makers to provide ready estimate of current soil water levels during both fallow and cropping periods. The app’s irrigation component allows users to explore a range of irrigation approaches, from flood to drip, and provides a forward look at water needs using historic rainfall data.

SWApp provides ‘water-balance simulation’ using in-field weather data and available soil water measures from a range of devices and estimates to provide readily available, real-time estimates of soil water that famers can use to make informed management decisions.

Policy application

The Australian Government’s National Soil Research, Development, Extension Strategy identifies improving water use efficiency for dryland and irrigated agriculture as a means to enable farmers to adapt to climate change and plan and manage for climate risk (National Soil RDE Strategy, 2014).

Functionality, capability

SWApp estimates daily evaporation, transpiration, infiltration, runoff, deep drainage and soil water using the same computer code embedded in Howleaky? (McClymont et al. 2016). Howleaky? and APSIM (McCown et al. 1996) share much of their water balance code and agreement between the two models was confirmed in model testing (Freebairn et al. 2017).

SWApp uses long-term weather data from ‘Silo’ (https://www.longpaddock.qld.gov.au/silo/) to provide the climatic context for the current season and probabilistic estimates of future water status. Starting conditions are specified by the user and can be adjusted with information collected from field estimates based on observation (e.g. very wet or dry); soil push probe depths; and independent sensors. Input data is securely stored in the cloud and can be accessed from multiple devices.

Initially a SWApp user enters a property and paddock name and a relevant climate station. Since SWApp operates on GPS-equipped ‘smart’ devices, it automatically presents the user with the five nearest climate stations from the 4,500 climate stations across Australia. More locally relevant rainfall data can be entered to replace Bureau of Meteorology data. User can then select a soil type that best represents the site from a list covering the major soil types in each Australian state.

A model start date and its starting soil water and distribution parameters are set by the user. Starting soil water can be estimated using ‘push probe’ measurements and local rain data selected or added. The user then selects soil cover condition (crop residue) for the fallow and cropping periods, and fallow or crop type, and adjusts the plant and maturity dates.

Operating Skills

SWApp runs on Apple iPhone and iPad (iOS) devices and is relatively simple to run. Text and graphics show the percentages of PAWC and millimetres of water available; the water balance, where the water is in the soil profile; and the pattern of water accumulation, soil and crop cover.

Custodianship

SWApp was developed for the Grain Research and Development Corporation led project ‘new tools to measure and monitor soil water’ (USQ 00014) conducted by the University of Southern Queensland. The SWApp is freely available for download in the Apple App Store and supporting documentation is provided at http://www.soilwaterapp.net.au/.

Key contacts

David Freebairn (University of Southern Queensland): david.freebairn@usq.edu.au

Training

Training is provided via a help system, YouTube video and a library of reference material, which are all available at http://www.soilwaterapp.net.au/Library.

Research and development priorities

Additional functions soon to be added to SWApp include:

- soil type selection based on a 'national soil grid'; and
- evaluation of user behaviour.

Other capabilities planned include:

- expand SWApp to operate on more operating platforms (1.Web App 2.Android);
- link to more data sources such as Victoria's weather/soil water station network; Tasmania's Sense-T data network; and private weather station networks with built in data quality control;
- add a crop stress index and simple yield estimator;
- add a soil nitrogen mineralisation and nitrogen calculator to facilitate fertiliser decision making and timing;
- enact wider data sharing, mapping, and area wide management in addition to improving links to third party software (i.e. farm management software);
- evaluate user behaviour and value propositions of users;
- build a data collection and archive system to collate and store key experimental and farmer datasets that are often unpublished and disappear after their primary use; and
- add a temperature sensing capability to the app's hardware and an application to aid with frost risk and sowing decision making.

Key publications and links

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The National Soil Research, Development, Extension Strategy 2014, Securing Australia's soil, for profitable industries and healthy landscapes. www.daff.gov.au/natural-resources/soils.

HOWLEAKY

Summary

Howleaky (www.howleaky.net) (McClymont et al., 2011) is a one-dimensional, daily time-step model that estimates soil water balance, runoff, erosion and constituent loads for an area that is assumed uniform in soil, vegetation and climate (typically several to tens of hectares in size). Howleak*y* is derived from the model PERFECT (Littleboy et al., 1992) and has been extensively validated with hydrology data for cropping systems in Queensland.

Howleaky allows the evaluation of alternative land uses and land management strategies in terms of:

a) runoff and erosion;

b) drainage below root zone (salinity risk);

c) phosphorus and nitrogen losses in runoff; and

d) pesticide mass balance and losses in runoff.

Interim modules also exist for solute mass balance (Freebairn 2017) and DIN loss in deep drainage (Rattray et al. 2017).

One of the key strengths of HowLeaky is its advanced graphical user interface (GUI) that provides instant visualisation and comparison of results through customisable reports and times-series analyses. The Howleaky software tool provides the ability to build broader understanding of paddock scale water and soil dynamics and implications of land use and management; capture the interrelationships between climate, soils, vegetation type, management and biophysical responses at the paddock scale; and facilitate transparent communication between technologists and land managers (Rattray et al., 2004). Howleaky can also run many simulations in a batched project, such as a simulation matrix of many soils, climates and management levels.

Policy Application

Howleaky has been used in the ‘paddock to reef monitoring, modelling and reporting program’ (Carroll et al., 2012) to evaluate improvements in water quality through the adoption of improved land management practices—as defined under an ABCD practice management framework—and by linking the paddock model time series outputs to catchment models (Shaw and Silburn 2016). Doing so appropriately represents the complex interactions between climate, soils and management actions across the broad and diverse Great Barrier Reef catchments.

Functionality, Capability

Howleaky is a ‘daily time step physically based model’ with the following basic components: 1) a soil water, soil solute and crop residue balance; 2) a leaf area index driven or green/dead cover pattern crop model; 3) a modified USDA curve number approach to estimate runoff; and 4) a USLE (Freebairn cover-concentration/Universal Soil Loss Equation) for predicting soil loss. This approach has been adopted to facilitate the exploration of the effects of land use change and land management decisions on water balance and soil loss using physically measurable parameters and processes that have a physical basis.

HowLeaky also has a phosphorous module, developed by Robinson et al. (2007) based on the approach of Sharpley (1995; 2007), that models phosphorous transported in two forms, dissolved and particulate. Dissolved phosphorous loads are calculated from the functions reported in Sharpley (1995) where dissolved phosphorous concentrations are dependent on the degree of saturation of the soil components that sorb phosphorous. The loss of particulate phosphorous is based on erosion-generated sediment concentrations in runoff and soil total phosphorous content. The module has been amended to include alternate methods for estimating dissolved reactive phosphorous and particulate phosphorous fractions (Robinson et al. 2011). The model’s nitrogen module estimates nitrate-nitrogen and total nitrogen (particulate) in runoff and nitrate-nitrogen in water leached below the plant rooting depth.

The pesticide module in HowLeaky is based on algorithms from the CREAMS (Knisel 1980) and GLEAMS (Leonard et al 1987) models and further developed by Shaw et al. (2011). A central concept is the application of an extraction coefficient to estimate concentrations of chemicals in runoff as a function of soil concentration, as demonstrated for a wide range of chemicals in Australian conditions by Silburn (2003) and Silburn and Kennedy (2007). The pesticide applied is calculated as a function of product concentration, product rate and application efficiency. The module accounts for pesticide application onto the crop, crop residue or directly to the soil. Pesticide wash-off is added to the soil and crop residues. A temperature dependant half-life is included and first order degradation rates are assumed. Pesticide concentration in surface soil is calculated after leaching losses, with an extraction coefficient used to estimate the total runoff loss and a partitioning coefficient used to proportion the chemical into dissolved and particulate phases.

Operating skills

Howleaky provides the ability to interrogate model input and output files in a simple and transparent manner. The model has an additional ability to compare multiple simulations at one time and features to import user defined data to compare with model simulation outputs to provide an efficient means of calibration.

Custodianship

The Queensland Department of Environment and Science (DES) is custodian of the HowLeaky software, and it is distributed via a Creative Commons licence. The software is available online (www.howleaky.net) and has been supported by a range of Australian organisations, including Queensland and Victorian Governments, and DHM Environmental Software Engineering.

Through the QWMN, the University of Southern Queensland (USQ) has commenced a project to enhance the model's algorithms, governance arrangements, model documentation and access. The project is being led by USQ's Dr Keith Pembleton, Senior Lecturer (Plant Agricultural Sciences) School of Agricultural, Computational and Environmental Sciences, Faculty of Health, Engineering and Sciences.

Key Contacts

David McClymont (DHM Environmental Software Engineering Pty Ltd), David Freebairn (USQ), and Mark Silburn (Department of Natural Resources, Mines and Energy: info@howleaky.net

Training

Online tutorials are available at: www.howleaky.net/index.php/tutorials

Research and development priorities

- Continued development of a module for DIN loss in deep drainage (Rattray et al. 2017); and
- The development of DIN runoff model.

Key publications and links

Carroll, C, Waters, D, Vardy, S, Silburn, DM, Attard, S, Thorburn, PJ, Davis, AM, Schmidt, M, Wilson, B, Clark, A 2012, 'A paddock to reef monitoring and modelling framework for the Great Barrier Reef: paddock and catchment component', *Marine Pollution Bulletin, 65,* 136–149.

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Shaw, M, Silburn, DM, Thornton, C, Robinson, JB, McClymont, D 2011, 'Modelling pesticide runoff from paddocks in the Great Barrier Reef using HowLeaky', *19th International Congress on Modelling and Simulation*, Perth, Australia, 12–16 December 2011. (http://mssanz.org.au/modsim2011).

Shaw, M and Silburn, M (Eds) 2016, *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program, Paddock Scale Modelling Technical Report*. Queensland Department of Natural Resources and Mines.

Silburn, DM 2003, Characterising Pesticide Runoff from Soil on Cotton Farms using a Rainfall 797 Simulator. Unpublished Ph.D, Faculty of Agriculture, Food and Natural Resources, University of Sydney.

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Agricultural Production Systems Simulator (APSIM)

Summary

The Agricultural Production Systems Simulator (APSIM) is a modular modelling framework that was developed to simulate biophysical process in farming systems, particularly where there is interest in the economic and ecological outcomes of management practice in the face of climatic risk (Keating et al., 2003). APSIM was developed by the Agricultural Production Systems Research Unit (APSRU), which commenced in 1991 and is made up of a collaborative group from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Queensland Government agencies.

The development of APSIM addressed a need for modelling tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factors, whilst also addressing long-term resource management issues in farming systems. APSIM was designed at the outset as a farming systems simulator that sought to combine accurate yield estimation in response to management. APSIM can be used to predict the long-term consequences of farming practice on soil resources, such as soil organic matter dynamics, erosion, and acidification; and on water quality from sugarcane production in Great Barrier Reef (GBR) catchments.

APSIM is undergoing continual development and new capabilities have been regularly added to the model. The current version is 7.9.

Policy application

The APSIM modelling framework has been used to explore components of the water balance for a range of farming systems in the Murray-Darling Basin (MDB) of Australia. Water leaking below the root zone of annual crops and pastures in the MDB is leading to development of dryland salinity and delivery of salt to waterways (Huth et al. 2003).

APSIM has also been used in GBR catchments where sugarcane is grown to explore losses of nitrogen fertiliser via both runoff and leaching; and inform water quality target setting (Thorburn et al., 2013).

Functionality, capability

The APSIM modelling framework is made up of:

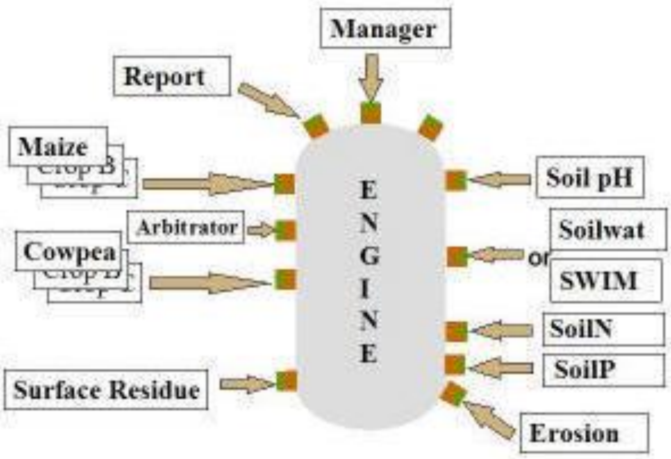
a) biophysical modules that simulate biological and physical processes in farming systems;
b) management modules that allow the user to specify the intended management rules that characterise the scenario being simulated and control the conduct of the simulation (these can be coded through an external ‘manager’);
c) modules to facilitate data input and output to and from the simulation; and
d) a simulation engine that drives the simulation process and facilitates communication between the individual modules (Keating et al. 2003).

APSIM provides a choice of two water balance modules, SoilWater or SWIM. SoilWater is a tipping bucket method using a USDA curve number and SWIM is based on a numerical solution of the Richard’s infiltration equation. Plant modules are available for a wide range of crops and simulate the key physiological processes including phenology, organ development, water and nutrient uptake, carbon assimilation, biomass and nitrogen partitioning between organs, and responses to abiotic stresses.

APSIM has a soil erosion module and erosion productivity function that use the Freebairn concentration-cover and USLE factors. A soil carbon/nitrogen model simulates nitrification and denitrification, including emissions of nitrous oxide. DIN loss in deep drainage is simulated based on a modified version of the CERES equations. Other water quality modules, such as DIN runoff and pesticide runoff, are not available through APSIM v7.9 but are able to be coded in the manager—as was done in the paddock to Reef Program (Carroll et al., 2012, Shaw and Silburn 2016).

The APSIM framework also includes:

- various user interfaces for model construction, testing and application;
- various interfaces and association database tools for visualisation and further analysis of output; and
- various model development, testing and documentation tools.



Operating skills

APSIM can be run through the user interface or through command line. The manager module enables a user to modify existing modules or add additional algorithms as required. An extensive set of training manuals that comprehensively facilitates the introduction and use of APSIM are available at: www.apsim.info/

Custodianship

APSIM is freeware software available, with registration, at www.apsim.info/Products/Downloads.aspx The APSIM Initiative was established in 2007 to promote the development and use of the science modules and infrastructure software of APSIM. As a result, APSIM development, maintenance and commercialisation are now the responsibility of the APSIM Initiative, which operates separately from the APSRU—a research-oriented, informal collaborative network based out of Toowoomba, Australia. The APSIM Initiative is managed by a steering committee, with a reference panel providing advice on matters relating to APSIM development, in particular science quality and software development.

The foundation members of the APSIM Initiative are CSIRO, the Queensland Government and the University of Queensland. AgResearch Ltd. New Zealand became a party in 2015 and other organisations may apply to join at any time.

Key contacts

APSIM contact: apsim@daf.qld.gov.au

Training

The APSIM help and support forum contains training manuals and periodic training and is available at: www.apsim.info/

Research and development priorities

- development of a pesticide module;
- representation of DIN lost to runoff ; and
- representation of irrigation generated runoff in furrow irrigated systems.

Key publications and links

Carroll, C, Waters, D, Vardy, S, Silburn, DM, Attard, S, Thorburn, PJ, Davis, AM, Schmidt, M, Wilson, B, Clark, A 2012, 'A paddock to reef monitoring and modelling framework for the Great Barrier Reef: paddock and catchment component', *Marine Pollution Bulletin, 65,* 136–149.

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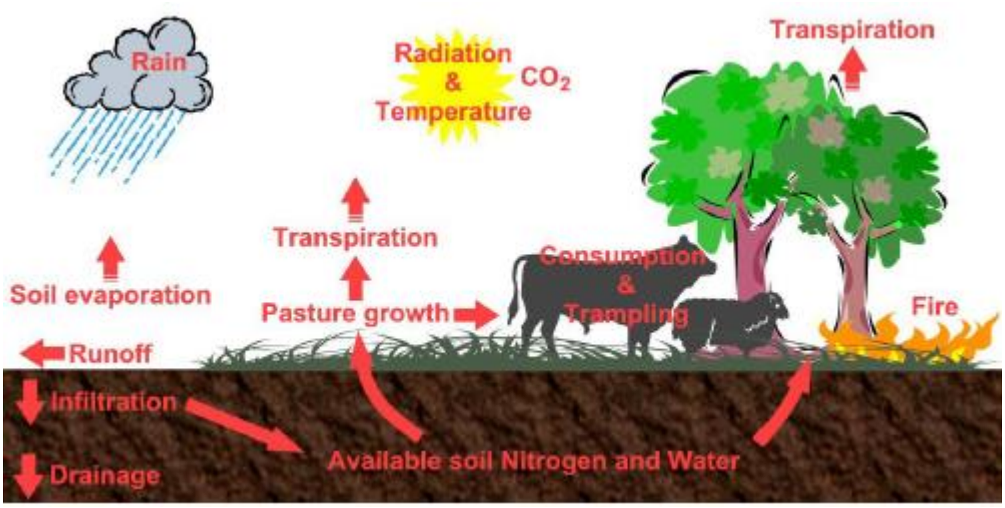
GRASP & AussieGRASS

Summary

GRASP (Rickert et al. 2000) is a model of the climate-soil, plant-animal-management interactions in the perennial grasses of northern Australia. It is a daily time step model that uses daily climate data including rainfall, temperature, evaporation, radiation and vapour pressure. Other model inputs include soil data (e.g. field capacities and wilting points), plant growth, cover, temperature responses, nitrogen, senescence, litter breakdown and animal intake. It is a one-dimensional model that simulates a point on the landscape, but can be used spatially in the AussieGRASS model and a number of other products where output is averaged across spatial zones such as paddocks, land types, and 5km pixels. The model has a management component that includes management records for decisions such as stocking rates and burning. Within the management records, observations of features such as total standing pasture and pasture can be input to calibrate the model.



GRASP predicts the effects of various soil, climate, pasture and management inputs on:

- water balance (runoff, infiltration, soil evaporation, transpiration and drainage);
- pasture growth (green growth, death and detachment); and
- animal intake (diet selection, utilisation and live weight gain).

GRASP model components relevant to water quality modelling:

Model Component	Description/Reference
Water movement through soil	Soil storage bucket or GLEAMS or CREAMS
Rainfall intensity	Scanlan et al. 1996, Fraser et al. 2011
Runoff	Scanlan et al. 1996, Owens et al. 2003, Fraser 2013
Plot scale soil erosion	Scanlan et al. 1996
Nitrogen and phosphorus movement in runoff/drainage	Not represented
Grass growth	Limited by soil water, nitrogen, radiation and temperature
Grass biomass - cover relationship	User defined for species
Tree water use	Derived from user input of tree basal area or foliage projected cover
Animal intake	Range of feed intake models (e.g. Stone 2012)
User defined management options	Stocking rate, burning
Climate file input	P51 from SILO on Long Paddock
Running model	Either single or batch from DOS prompt. Single in windows user interface.

AussieGRASS is a spatial implementation of the GRASP model on a 5km by 5km grid across Australia (Carter et al. 2000, 2003). AussieGRASS output is available online at: www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/index.html

The AussieGRASS web-based tool:

- is a spatial implementation of the GRASP grass production model;
- is updated monthly based on the Southern Oscillation Index (SOI) phase;
- provides relative rainfall and pasture growth maps; and
- provides experimental forecasts up to 12 months ahead based on the International Research Institute's consensus forecasts of El Niño state.

Policy application

Climate is the single largest driver of variability of agricultural production and accounts for one-third to two-thirds of annual global crop yield variability (Managing for Climate). GRASP and AussieGRASS have been used to support primary producers and natural resource managers manage the risks, and exploit the opportunities, resulting from Australia's variable and changing climate. For example, the GRASP model has been used to study potential changes to livestock carrying capacity under climate change (McKeon et al., 2009).

AussieGRASS was initially developed as a tool to assess drought conditions and has been used extensively for this purpose. Other developments and policy uses include grass fire risk products for rural fire services; reporting on rangeland condition change to the Australian Collaborative Rangelands

Information System (ACRIS); analysis of greenhouse gas emissions; and the provision of information to the Queensland Rural Leasehold Land Strategy (Delbessie Agreement) process (Stone et al., 2010).

Functionality, capability

GRASP has a four-layer soil water budget. Runoff can be calculated using two methods: the Scanlan method and a modified USDA Curve Number approach. The original Scanlan method is an empirical function of groundcover, daily rainfall, rainfall intensity and soil moisture deficit (Scanlan et al., 1996). More recently a modified USDA Curve Number approach has been incorporated into GRASP (Owens et al., 2003).

The model calculates the soil water balance and pasture growth on a daily time-step and requires daily climate inputs (rainfall, temperature, radiation, humidity, evaporation and vapour pressure deficit) for each grid cell (Jeffrey et al. 2001) as well as parameter layers for soil and pasture types. Variables such as tree basal area and animal numbers are also required for each grid cell.

The application of the GRASP model in the Queensland Government's Paddock to Reef program has been primarily to ascertain the impact of four management scenarios on groundcover. Long-term simulations of management effects on cover were undertaken for a variety of grazing land types and climate locations. From this process, the relative change in cover was defined when moving from one management scenario to another. These relativities were used to account for the impact of management changes on the cover layer component of the Universal Soil Loss Equation. The Universal Soil Loss Equation was used to model grazing land soil erosion in the Paddock to Reef program.

AussieGRASS requires spatial meteorological, soil, vegetation and stock management data. The daily grids of rainfall, minimum and maximum temperature, pan evaporation, solar radiation and vapour pressure deficit required by AussieGRASS (Carter et al., 2000) are available through SILO PPD. Soil type and associated parameters are required for four soil layers including layer thickness, bulk density and soil water content (at air dry state, wilting point and field capacity). The upper limit to daily soil evaporation must also be specified.

Operating Skills

The GRASP model can be run from a DOS prompt in single or batch modes. There is also a Windows interface version which can perform single runs. Documentation of the model includes a technical manual, calibration manual and tutorials, which are available as a complete package.

Custodianship

The development of GRASP was funded by the Queensland Government Department of Agriculture and Fisheries and a number of other agencies have contributed to its ongoing development. Dr Greg McKeon was the model's prime developer, with contributions made from many other researchers. There is now a GRASP model version coded in FORTRAN90 known as Cedar GRASP that allows programmers to make changes and add new sub-models.

The Queensland Department of Environment and Science (DES) is the custodian of the GRASP and AussieGRASS models.

Key contacts

Ramona Dalla Pozza, DES: ramona.dallapozza@des.qld.gov.au

Training

Funding from Meat and Livestock Australia (MLA) facilitated extensive workshops, which were attended by DES staff.

Research and development priorities

As per MLA's 2008 report research and development priorities for GRASP and AussieGRASS are:

- dynamic nitrogen uptake/dilution;
- runoff models for land-types;
- dynamic trees/shrubs;
- browse availability;
- carbon/nitrogen flow, phosphorus;
- soil erosion (wind and water);
- grazing feedbacks on productivity; and
- detachment/decomposition process, species composition change.

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Model for Effluent Disposal using Land Irrigation (MEDLI)

Summary

Model for Effluent Disposal using Land Irrigation (MEDLI) is a daily time step biophysical model that quantifies the water, nutrient and salt balance of pasture and crops irrigated with treated effluent. It uses historical climate data, enterprise data, storage pond geometry, soil hydraulic properties and agronomy rules to simulate the main processes that determine the fate of the water, nitrogen, phosphorus, and soluble salts in the effluent stream, from its production through to the disposal area. MEDLI was developed in the mid-1990s by the Queensland Government Department of Agriculture and Fisheries, the Cooperative Research Centre for Waste Management and Pollution Control, and the CSIRO. Since development, it has been used by consultants and regulators to assess the environmental impact of irrigation schemes using effluent from sewage treatment plants, onsite sewerage systems, and intensive rural industries including feedlots, piggeries, dairies, abattoirs, tanneries, landfill leachate, and coal seam gas process water.

An updated version of MEDLI (V2) was released for Windows by the then Queensland Department of Science, Information Technology and Innovation (DSITI) in June 2015. This version currently supports sewage treatment plants, on-site sewerage systems and any user-defined waste stream (e.g. abattoir effluent) that defines effluent volume time series and its chemical composition. Version 2 is a substantial upgrade on version 1 and has a completely rebuilt software package to suit modern computer operating systems; a more intuitive user interface; an additional microbiological health risk assessment module; and a detailed interactive summary report with comprehensive text and graphical outputs informed by prior users. Further software development is ongoing.

Policy application

MEDLI has become accepted as the design tool in the Queensland Government's effluent reuse guidelines for both sewage treatment plants and animal industry enterprises (EPA 2005). MEDLI is commonly used for environmental evaluations of environmentally relevant activities (e.g. ERA 25 – Meat processing and ERA 63 – Sewage treatment).

Functionality, capability

MEDLI uses a 'medley' or integration of a number of models to simulate the effluent stream from its production through to disposal area (Gardner et al. 1996). It was designed as a top-down model, in that the major processes were included in the model but processes considered of secondary importance were excluded. This approach was considered appropriate for a planning tool designed to predict outcomes for irrigation schemes that were 'within a manageable divergence of reality'. Importantly, however, such as simplified model structure means that few parameter inputs are required, allowing the model to be used by a wide range of users.

Waste estimation: MEDLI V2 contains a waste stream estimation module for sewage treatment plants only. The 'generic waste estimation module' uses measured waste stream characteristics for defining a representative year of daily waste generation.

Climate: MEDLI requires daily rainfall, temperature (minimum and maximum), class A pan evaporation and solar radiation data. These data can be obtained for Australian locations directly from the SILO database (www.longpaddock.qld.gov.au/silo/). Long climate sequences (e.g. ≥40 years) are needed to capture the effect of climatic variability on the long-term performance of an effluent irrigation scheme design.

Pond chemistry and water balance: MEDLI's pond module consists of mass balances for hydraulic, nitrogen, phosphorus, and total dissolved salts components. It uses a number of empirically derived relationships to model pond chemistry but does not attempt model the complex nitrogen transformations that occur with the exception of ammonia volatilisation loss. The user is required to supply the likely ammonium-nitrate-organic nitrogen partitioning of total nitrogen in the storage pond. The model allows for up to four effluent ponds in series, the first of which may be simulated as anaerobic to incorporate the effects of sludge accumulation and removal on the pond nutrient balances. The last pond defined in the pond series is always the wet weather storage pond from which irrigation water is supplied.

Irrigation and shandying: The irrigation module simulates the operator's effluent irrigation management, allowing both time-based and soil water deficit-based irrigation trigger options, which are then combined with a fixed application depth (mm) or a soil water-deficit replenishment option. However, irrigation can be overridden by other factors such as the occurrence of rainfall on the scheduled irrigation day. These options allow the designer to explore non-standard irrigation practice for disposing of the effluent. Availability of water is usually determined by the volume of water in the wet weather storage pond. However, if the effluent has a high salinity or nitrogen concentration, dilution with a fresh water source is an option, provided an external water source is available for shandying the irrigation water.

Soil water movement: Soil water movement is simulated as a one-dimensional (vertical) water balance, averaged over the irrigation paddock. Water (and nutrient and salt) movement down the soil profile is represented by three to four user-defined soil layers and modelled using the 'cascading bucket' approach. Rainfall runoff, deep drainage, soil evaporation and plant transpiration are predicted using algorithms from a number of well-tested models including PERFECT (Littleboy et al. 1989) and EPIC (Sharply and Williams, 1990). When a saturated profile cannot transmit all the predicted infiltration as saturated drainage, the excess is routed as irrigation runoff. No vertical upward water flow is modelled so MEDLI is not well suited for modelling situations with a shallow water table. Lateral subsurface water flow (interflow) is also not modelled by MEDLI, so the effect of surface slope on water movement is ignored.

Soil nutrient movement: The transformation of organic nitrogen, ammonium and nitrate from one form to another is modelled by first order kinetics and/or the Michaelis-Menten equation. The transformation rates are modified by the daily temperature and soil moisture status of the soil. To simplify nitrogen inputs, adsorption/ desorption of ammonium and immobilisation of ammonium and nitrate are considered to be of minor importance for effluent irrigation, particularly since effluents are expected to have a low carbon to nitrogen ratio (e.g. <25). This simplifies the soil nitrogen module to include only mineralisation, denitrification, nitrification, plant uptake and ammonium volatilisation during irrigation. Ammonium and organic nitrogen are considered to be immobile within the soil profile. Leaching of nitrate is linked to water movement down the soil profile. Phosphorus adsorption and desorption is modelled using the empirical Freundlich adsorption isotherm algorithm to describe the sorption capacity of the layers within the soil profile and predict the sustainable phosphorus storage life of the soil. Transformation of phosphorus between organic and inorganic forms are not modelled. Plant nitrogen (ammonium and nitrate) and phosphorus uptake is based on algorithms from EPIC (Sharpley and Williams 1990) with the inclusion of the option for luxury nutrient uptake by plants.

Soil salinity: The effect of soil profile salinity under a given irrigation/climate regime on plant yield is determined using steady-state soil salinity leaching algorithms from SALF (Shaw and Thorburn 1985). To use in the steady-state algorithms, daily time step values are averaged over a user-defined number of years (usually 5-10 years) required to reach steady-state following commencement of irrigation.

Crop growth: User defined monthly plant green cover for a representative year can be used for a water balance-based assessment of a scheme's design. To estimate the quantities of nitrogen and phosphorus that are removed from the effluent irrigation site by the export of harvested material (i.e. cut and carry), dynamic crop and pasture growth modules are provided. Both modules assume that the plant canopy increases over thermal time (degree days), with biomass accumulation a function of daily solar radiation intercepted by the plant canopy, discounted by any nitrogen, water, waterlogging or temperature stress calculated using algorithms from EPIC, GRASP (McKeon et al. 1982) and PERFECT models. The pasture is harvested by mowing when a set biomass is reached. The crop is always resown after harvest. High stress can trigger a forced harvest, requiring the pasture or crop to be resown when favourable conditions for plant growth return.

Groundwater transport: The groundwater model allows for mixing (dilution) of leachate with the groundwater flowing beneath the irrigation area, and dispersion of leachate in the direction of flow, as well as in the vertical direction. Nitrate concentrations downgradient of the wastewater irrigation area are calculated, but only along a transect in the direction of groundwater flow, passing through the centre line of the wastewater irrigation area, where peak concentration values are expected.

Pathogen health risk: The pathogen risk assessment module estimates the ingested dose of viral, bacterial, or protozoan pathogens from liquid ingestion, aerosol inhalation or contact with plant surfaces irrigated with effluent. These estimates, along with the frequency of exposure and dose-response relationships sourced from the literature, provide an estimate of human health risk using deterministic Quantitative Microbial Risk Analysis methodologies.

Operating skills

Users require a sound understanding of plant-soil-water relationships, irrigation strategies, and pond management to design an effluent irrigation scheme using MEDLI. There are a number of tools within MEDLI to assist the user, such as the ‘Multi-run option’ that helps identify the optimal irrigation area and pond volume combination for a scheme; and the ‘Reliability of Supply option’ that determines the potential irrigation demand of a scheme.

Custodianship

The Queensland Government Department of Environment and Science (DES) is the custodian of the custodian of MEDLI.

Key contacts

MEDLI contact: medli@qld.gov.au

Training

MEDLI is maintained and continuously improved using funds from software sales and MEDLI training workshops. Licenced users have access to detailed system documentation and receive upgrades automatically. Technical support is available as part of licence agreements. Training workshops are provided subject to demand (currently twice a year).

Research and development priorities

- Extend MEDLI V2 to intensive rural industry and rainfall-dependent waste streams;
- fully release the pathogen module; and
- expand MEDLI to multiple paddocks with one pond system.

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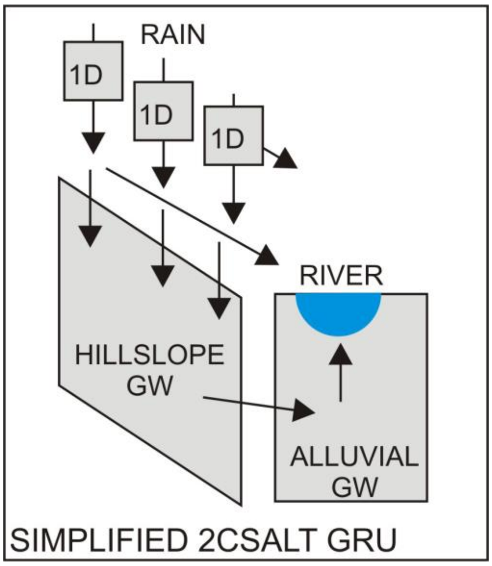
2CSalt

Summary

The 2CSalt model (Stenson et al., 2005) predicts both the quantity and timing of water and salt export from upland catchments. It was developed to explore changes in water and salt generation under various land-use scenarios. Importantly, it provides a consistent approach that can be applied quickly over a large number of catchments, whilst still producing results that are directly comparable between catchments.

2CSalt divides a catchment into multiple units based on topography. These form the fundamental modelling units, which can be aggregated to provide totals at the catchment outlet. Separating the catchment into many separate units allows the impacts of management options (such as land-use change) to be variable across the catchment, depending on the hydrological and salt store properties of each of the units (Gilfedder and Littleboy, 2005). It achieves this through the use of broadly available data sets such as Groundwater Flow Systems (GFS) and Digital Elevation Models (DEMs), and through the use of a limited number of model parameters.

Pre-run water balance modelling of land use or land management scenarios from one dimensional (1D) models, such as APSIM (McCown et al., 1996) or PERFECT (Littleboy et al., 1992), generate soil water balance outputs. The daily time-series outputs of 1D soil water balance are then lumped to monthly and used as input to 2CSalt. The 2CSalt model monthly outputs of water and salt can then be fed into river routing models such as IQQM to provide an insight into management and impacts on basin salt yields.



A simplified diagram of the basic structure of each groundwater response unit (GRU) in the 2CSalt model (from Gilfedder et al., 2007).

Policy application

2CSalt was designed to allow state agencies operating within the Murray-Darling Basin to model upland unregulated catchments in a consistent and comparable manner and meet salinity reporting obligations to the Murray Darling Basin Commission.

Functionality, capability

The core of 2CSalt is the Three Stores Model (TSM). The TSM is a monthly time step mass balance model for water and partial mass balance for salt. The ‘three stores’ are the hillslope groundwater store, alluvial groundwater store, and the soil water balance layer. The TSM takes the four input fluxes (recharge, runoff, evapotranspiration and lateral flow) and moves them between the hillslope and alluvial stores, eventually discharging water and salt to the stream.

The 2CSalt model quantifies surface and subsurface contributions to stream flow and salt export and predicts the impacts of land-use change (Stenson et al. 2005, Littleboy 2005).

2CSalt was designed to use existing regional data such as topography (DEM) and GFS maps (Coram et al. 2000), including attributes for groundwater salinity, hydraulic conductivity, specific yield, aquifer depth and depth to water table. Outputs include monthly water and salt contribution to streams from several water pathways. The catchment is divided into Groundwater Response Units (GRUs) with hillslope and alluvial groundwater stores. These are allocated parameters from the GFS map and analysis of the DEM. Maps of soils, climate and land use are used to derive unique combinations referred to as Hydrologic Response Units (HRUs). A soil water balance model is used to calculate monthly recharge, runoff, lateral flow and evapotranspiration for each HRU. These are then summed for the surface sub-catchment or underlying GRU as appropriate. A monthly salt balance is calculated using rainfall and groundwater salinity. Scenarios are built by changing land use and rerunning the model. The model does not account for routing, pumping, river regulation, storages and diversion, losing streams or groundwater flow into or outside the catchment (i.e. regional GFS). (Silburn et al., 2006).

Operating skills

2CSalt is a reasonably simple model, and runs on Windows 2000 or XP operation systems, with .NET runtime installed. It requires an Intel x86 based PC with at least 512 Mb of RAM and 200 Mb of disk space.

Custodianship

2CSalt is part of the eWater Toolkit as a prototype model. Access to the model can be arranged by contacting the eWater CRC directly at: www.ewater.com.au/

Key contacts

Matthew Stenson, CSIRO Land and Water: matthew.stenson@csiro.au

Training

2CSalt is part of the eWater Toolkit as a prototype model. Access to the model can be arranged by contacting the eWater CRC directly at: www.ewater.com.au/

Research and development priorities

No research and development priorities identified.

Key publications and links

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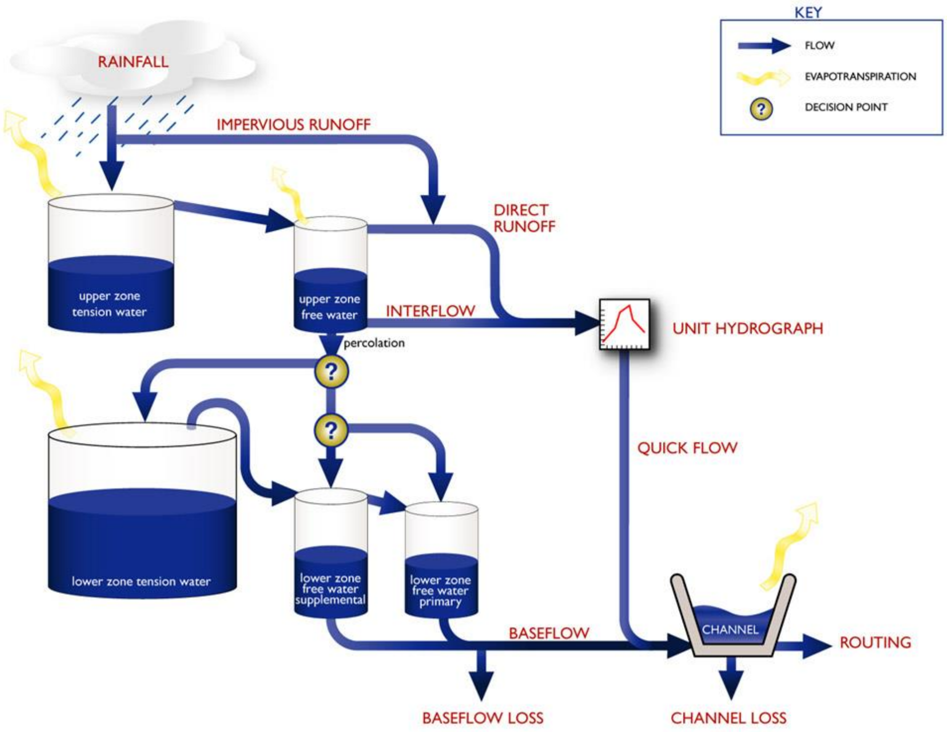
Sacramento

Summary

The Sacramento model was developed to simulate daily stream flows in the 1970s (Burnash et al. 1973). This conceptual hydrologic model, also known as SAC-SMA which stands for SACramento Soil Moisture Accounting model, is used by National Weather Service (NWS) for river flow forecasting in the United States (Burnash, 1995).

Input to the Sacramento model includes daily rainfall and potential evaporation (PE). Daily rainfall data can be prepared using gauge data for sites in relation to the catchment. Increasingly, rainfall data are prepared using SILO grid data for the catchment and for PE daily values are taken to be the mean monthly potential evaporation divided by the number of days for the month. In effect, only 12 distinct PE values are inputs for the Sacramento and other similar conceptual models. The Sacramento model has 16 distinct parameters that need to be calibrated using observed stream flow data (Podger, 2003). These parameters are used to define moisture store capacities, lateral outflows, flow between stores, and losses (see figure below).



A schematic diagram showing conceptual storage and flow pathways used in Sacramento (Source: RRL training material, 2004)

Policy application

The Sacramento model is extensively used in conjunction with IQQM and Source Rivers for water resources assessment in New South Wales and Queensland, and in the Source Catchments modelling framework for flow simulation for Great Barrier Reef catchments.

Functionality, capability

The Sacramento model is primarily used to simulate daily flows for gauged catchments in Australia. Sacramento is most useful to backfill missing flow data and to extend the period of flow record once the model is calibrated. The latter function of flow extension is particularly useful because, for most gauged catchments, rainfall records are usually much longer than the flow record. A conceptual hydrologic model like Sacramento can be used to estimate daily flows from recorded daily rainfall to represent climate variations and the effect such variations have on stream flows over a period that is much longer than the available flow record.

Operating skills

Manual model calibration in Sacramento is time consuming and subjective, with significant variability in the quality of the resulting simulated runoff dependant on the skill of the modeller. Software tools, such as those available within the Rainfall-Runoff Library, improve manual calibration to some extent.

Recently, advances in computation capability has made automated calibration feasible, using various parameter optimisation techniques. Global optimisation algorithms, such as Shuffled Complex Evolution (SCE) and Covariance Matrix Adaptation Evolution Strategy (CMA-ES) have been shown to produce excellent Sacramento calibrations with significantly increased consistency in quality, when given suitably defined objective functions.

Data custodianship

Numerous implementations of SAC-SMA exist within state government departments and organisations, such as the Queensland Government Department of Environment and Science (DES), the New South Wales Government Department of Primary Industries, and eWater.

Key contacts in Queensland

Chas Egan: Chas.Egan@des.qld.gov.au, Maria Greer: Maria.Greer@des.qld.gov.au, Matthew Gooda: Matthew.Gooda@des.qld.gov.au, Department of Environment and Science (DES)

Training

Training is often provided to employees of organisations conducting Sacramento modelling, making use of a specific implementation of the model.

The Sacramento model is one of five rainfall-runoff models hosted in the Rainfall Runoff Library (RRL), a collection of conceptual hydrologic models sharing the same input data requirement, developed by the CRC for Catchment Hydrology. The RRL is readily available for registered users through the eWater web site with a user guide and some training materials provided (Perraud et al. 2003; Podger 2003).

Research and development priorities

No research and development priorities identified.

Key publications and links

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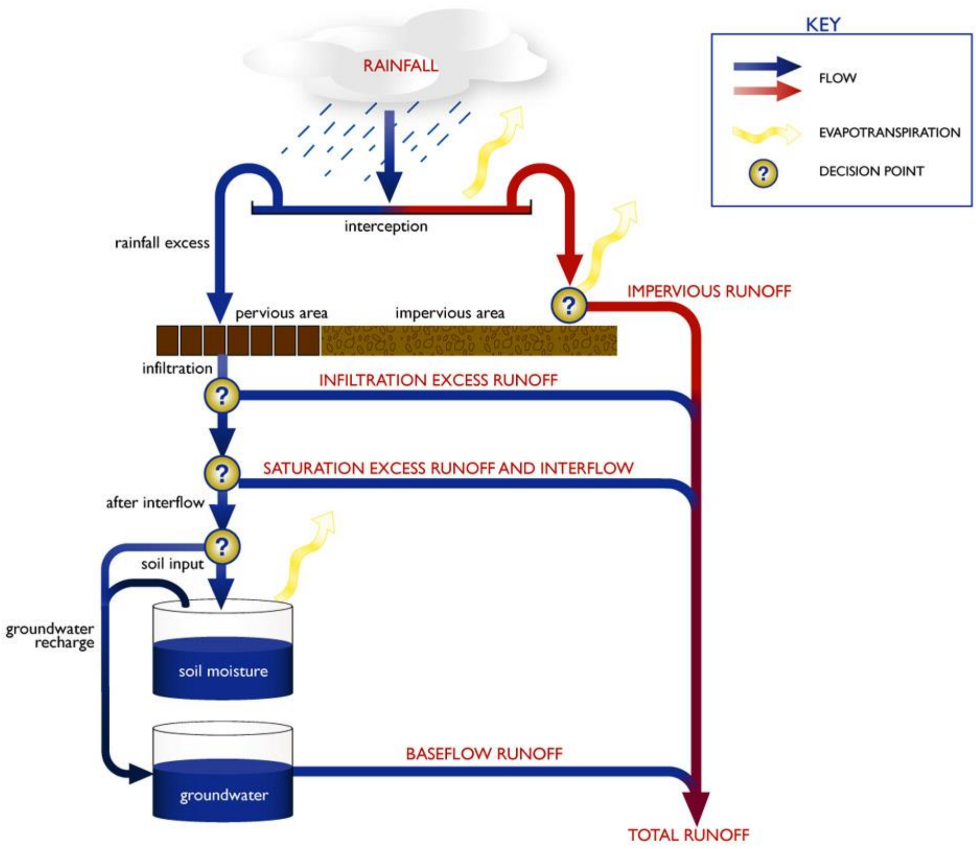
SIMHYD

Summary

SIMHYD, which stands for Simplified Hydrologic model, is a conceptual hydrologic model that simulates daily stream flows (Chiew et al. 2002). It is a simplified version of HYDROLOG (Porter and McMahon, 1975) with a reduction in model parameters from the original 17 to nine (Chiew et al. 2002).

Inputs to SIMHYD include daily rainfall and potential evaporation (PE). Daily rainfall data can be prepared using gauge data for sites in relation to the catchment. Increasingly, rainfall data are prepared using SILO grid data for the catchment and for PE daily values are taken to be the mean monthly potential evaporation divided by the number of days for the month. In effect, only 12 distinct PE values are inputs for SIMHYD and other similar conceptual models. Model parameters need to be calibrated using observed stream flow data. Calibration is essential because there were no reliable relationships between parameter values and catchment characteristics based on an extensive analysis for more than 300 catchments around Australia (Chiew et al. 2002).



Schematic diagram showing conceptual storage and flow pathways used in SIMHYD (Source: RRL training material, 2004)

Policy application

SIMHYD was used widely in the Source Catchments modelling framework for flow simulation for Great Barrier Reef catchments. More recently, the Sacramento model has been used instead of SIMHYD for consistency with tools used for developing water resources management plans in Queensland.

Functionality, capability

SIMHYD is primarily used to simulate daily flows for gauged catchments. SIMHYD is most useful to backfill missing flow data and to extend the period of flow record once the model is calibrated. The latter function of flow extension is particularly useful because for most gauged catchments, rainfall records are usually much longer than the flow record. A conceptual hydrologic model like SIMHYD can be used to estimate daily flows from recorded daily rainfall to represent climate variations and the effect such variations have on stream flows over a period that is much longer than the available flow record.

The critical assumption that underpins this approach is that the calibrated parameter values for conceptual models such as SIMHYD remain unchanged over long periods of time. This is often a questionable assumption given considerable changes in land use and land management practice for catchments in Queensland over periods in excess of 10-20 years.

Operating skills

SIMHYD is fairly easy to use, especially within the Rainfall Runoff Library (RRL) with robust calibration and simulation tools (Perraud et al. 2003).

Data custodianship

SIMHYD is a member model within the RRL hosted by eWater. SIMHYD has been implemented by the CSIRO, universities, and overseas-based institutions. SIMHYD is one of the hydrologic models that can be used for flow simulations within the Source Catchments framework.

Key contacts in Queensland

David Waters: David.Waters@dnrme.qld.gov.au (Department of Natural Resources, Mines and Energy)

Training

SIMHYD is one of five rainfall-runoff models hosted in the RRL, a collection of conceptual hydrologic models sharing the same input data requirements developed by the CRC for Catchment Hydrology. RRL is readily available for registered users through the eWater web site with a user guide and some training materials provided (Perraud et al. 2003; Podger 2003).

Research & Development Priorities

No research and development priorities identified.

Key publications and links

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WATHNET

Summary

Making decisions for the management of water supply systems is a complex and difficult task. Typically, water supply systems not only have requirements from multiple users (including urban, irrigation, and environmental) with different, often conflicting objectives; but also multiple sources with different levels of quality. This complexity in allocating water gives rise to a very large number of infrastructure and operating policy options. The solution to this complex decision making requires the use of mathematical techniques that are formulated to take simultaneous consideration of conflicting objectives (Cui et al., 2011).

The WATHNET water simulation model was developed by George Kuczera of the University of Newcastle (Kuczera, 1997) and is capable of representing a system of storages, transfer links (including natural rivers, pipes and pumps) and demand centres serving urban, rural and environmental customers. WATHNET is widely used in New South Wales and Queensland and is continually being improved (Varley, 2016).

WATHNET is a generalised simulation model that, unlike the traditional approach to system operation, uses a network linear program (NetLP) to simulate the operation of a wide range of water supply headworks configurations. Instead of using explicit rules to make water assignments, it uses information about the current state of the system, as well as forecasts of streamflow and demand, to formulate a network linear program. In a single time step, the NetLP determines the water allocation for given streamflow and demand in accordance with the following hierarchy of objectives (Cui et al., 2011):

- satisfy demand at all demand zones;
- satisfy all instream flow requirements;
- ensure that reservoirs are at their end-of-season target volumes;
- minimise delivery costs; and
- avoid unnecessary spill from the system.

Policy Application

Following the 2011 flood event in the Brisbane River catchment the Queensland Floods Commission of Inquiry recommended that a comprehensive plan to manage Brisbane River flood risk be established (Qld FCoI, 2012). To this end, the WATHNET model has been used to evaluate the impacts various operating scenarios for the Wivenhoe Dam have on the South East Queensland Water Supply Strategy (2010) (see figure below). WATHNET modelling scenarios were used to assess the short and long-term water supply security for South East Queensland (SEQ) if Wivenhoe Dam levels were lowered below the deemed full operating supply level (i.e. 100% dam level for water supply purposes). The effects of lowering the full supply level for Baroon Pocket and Hinze Dam were also assessed (DEWS, 2014a).

Similarly, the North Pine Dam Optimisation Study (NPDOS) was initiated in response to the recommendations of the Queensland Floods Commission of Inquiry (QFCoI, 2012) to investigate potential alternative operations of North Pine Dam during flood events. Four operational alternatives for operating North Pine Dam were assessed using WATHNET (DEWS, 2014b):

1. existing situation with the dam at Full Supply Volume (FSV);
2. lowered dam levels with flood release trigger at the current FSV;
3. lowered dam and flood release trigger levels; and
4. gates lifted to the fully open position (i.e. no gate control).

Functionality, capability

WATHNET is a suite of programs capable of simulating the operation of a wide range of water supply headworks and transfer systems serving urban, industrial, irrigation and in-stream demands. The model contains assumptions about infrastructure, such as pipeline capacities, storage capacities and behaviour (including evaporation), manufactured water from desalination and recycling, and water demands across a region.

WATHNET can use synthetically generated inflow sequences that have the same statistical characteristics as the historical flow records to assess supply system storages. In the NPDOS water supply modelling assessment, 10,000 synthetic inflow sequences each 117 years in length were modelled along with the historic record. Demand projections can be modelled based on the 'most likely' forecast demand scenarios. For NPDOS, modelling scenarios were generated for a planning horizon of 20 years to 2033. In addition, companion studies on the impacts to environmental and infrastructure assets can be used to assess the Net Present Costs (NPCs) of each operational scenario conducted. NPCs can use WATHNET modelling scenarios to assess impacts on dam operations, flood risks, water supply security, and impacts on infrastructure (road, rail, and river crossings).

Operating skills

Very specific technical skills and experience in both hydrology modelling and water supply management are required to use the WATHNET model.

Custodianship

A SEQ-specific version of WATHNET, the SEQ Regional Water Balance Model, resides with the Queensland Government Department of Natural Resources, Mines and Energy.

Key Contacts

Matthew Gooda: Matthew.Gooda@des.qld.gov.au, Department of Environment and Science.

Training

No formal training in the use of WATHNET is currently available.

Research and development priorities

No research and development priorities identified.

Key publications and links

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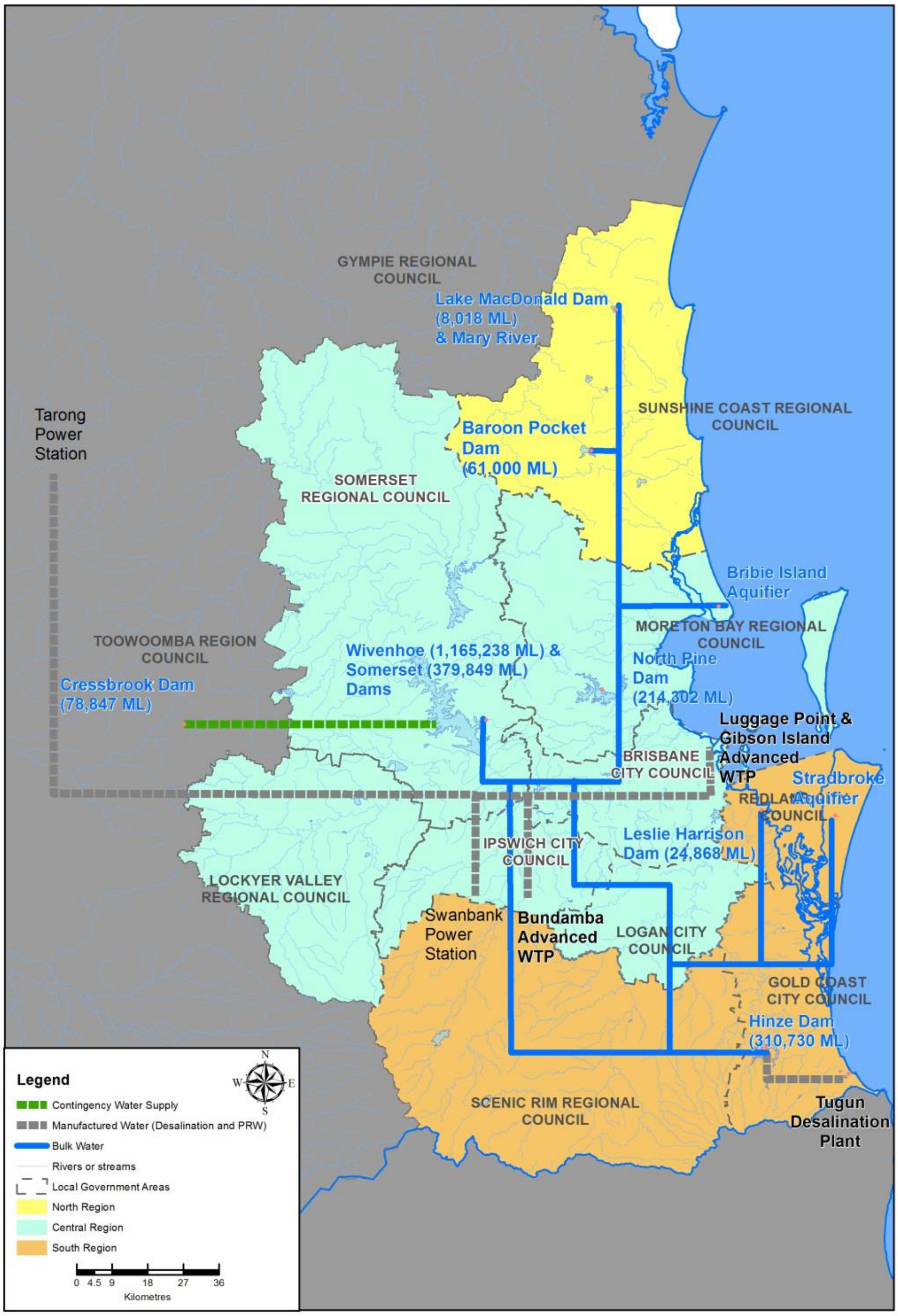

South East Queensland (SEQ) bulk water supply system.

Integrated Quantity and Quality Model (IQQM)

Summary

The Integrated Quantity and Quality Model (IQQM) is a hydrologic modelling tool developed by the New South Wales Government, with collaboration from the Queensland Government. Its prime purpose is to simulate the impacts of water resource management strategies on flows, so the impacts of various water diversion scenarios can be assessed and incorporated in Water Resource Plans (WRPs) (Simons, 1996, Hameed and Podger, 2001, Hameed and O'Neill, 2005).

Rainfall/runoff modelling is provided within the IQQM shell by the Sacramento Model (Burnash et al., 1973). IQQM has been subject to widespread and rigorous scientific reviews and is well regarded for its capability to estimate flow volumes (Cullen et al., 2003). The model provides a daily simulation of water flows by representing river systems and flow paths using a series of nodes and links. The nodes represent points of significance of the particular river system (e.g. gauging stations, diversion sites, stream junctions, etc.), and the links simulate flow paths and stream characteristics. IQQM is a rules-based model that includes a large number of 'routines' to simulate different types of diversions. It is also flexible in its range of applications. Outputs from the model include simulated hydrographs and a wide range of flow analyses such as histograms and flow duration curves.

River managers and modellers use long-term planning models to inform river operators and planners on how to best operate regulated river systems with multiple supply options. Complex multiple water supply problems occur when water can be sourced from storages in parallel, in series or delivered by parallel distribution paths. In Queensland, IQQM is used to solve multiple supply path problems for long-term water resource planning.

Policy application

The Council of Australian Governments (COAG) adopted a Water Reform Framework that required the states to adhere to legislative reforms that: cap the average annual total diversions; meet environmental water needs; separate land title and water entitlements; allow more water trading; and contain a stronger regulatory framework for the delivery of water services. IQQM is the modelling tool used in Queensland and New South Wales to address the COAG Water Reform Framework.

IQQM has also been used in the Murray-Darling Basin to assess the impact of dryland salinity on instream salinity.

Functionality, capability

The water quantity module of IQQM simulates all the processes and rules associated with the movement of water through a river system. Hameed and O'Neal (2005) outline the major processes:

a) system inflows and flow routing;
b) on and off-river reservoir modelling;
c) harmony rules for reservoir operation (operational management of multiple reservoirs i.e., what and when to release from which reservoir);
d) crop water demands, orders and diversions;
e) town water and other demands;
f) hydropower modelling;
g) effluent outflow and irrigation channels;
h) wetland demands and storage characteristics;
i) water sharing rules for both regulated and unregulated river systems;
j) resource assessment and water accounting; and
k) interstate water sharing agreements.

The model applies hydrologic flow routing for the simulation of the different ranges of flow conditions. There are a variety of options available to model the different operating procedures of both on- and off-river storages. The model can also simulate fixed demands (e.g. urban water supplies and power stations), riparian and minimum flow requirements, flood plain storage behaviour, wetland and environmental flow requirements, distribution of flows to effluent streams, and transmission losses. It is also capable of simulating water quality processes such as salinity, temperature and other constituents (Hameed and O'Neal, 2005).

IQQM has been designed for examining long-term behaviour under various management scenarios. The model's code uses a shell structure incorporating a number of modules, including instream water quantity, instream water quality and rainfall-runoff modules. The coding design of IQQM allows new modules to be easily incorporated into the existing structure. River systems are modelled in IQQM by a series of nodes connected by links, which allow the model to be configured to simulate any river system (Simons, Podger, Cook 1996).

The available node types include tributary and pumped inflows, on- and off-river storages, fixed demands with monthly patterns and environmental constraints (e.g. town water supplies), in-channel losses, irrigation extractions, industrial extractions, anabranches, environmental and riparian targets, channel capacity constraints, river confluences, and wetlands and floodplain storage. Water sharing rules, including interstate agreements, and water use accounting procedures can also be simulated.

For routing of river flows, two hydrologic routing procedures are available: Muskingum routing (Miller and Cunge, 1975) and Laurenson's non-linear routing with lag (Laurenson, 1986). Multiple stage routing of river flow is possible and can be used to take into account the differences in flow behaviour between low and high flow conditions.

The water quality component of IQQM has been predominately used to assess the impact of dryland salinity on basin-wide instream salinity. IQQM can be used to understand how salt is transported within river systems. It is also capable of being used to integrate basin scale salt exports, and as a planning tool to support in-stream salinity management (Javam et al., 2000).

Operating skills

IQQM is a specialist water resource planning tool that requires detail understanding of basin-wide hydrology and water management for operation.

Custodianship

The New South Wales Government maintains the IQQM codes and a register of all model holders/users. The custodianship of the IQQM version used by the Queensland Government for water resource planning resides with the Queensland Government Department of Environment and Science (DES).

Key contacts

Matthew Gooda: Matthew.Gooda@des.qld.gov.au Craig Johansen: Craig.Johansen@des.qld.gov.au, DES.

Training

No formal external IQQM training is currently provided.

Research and development priorities

IQQM is a platform that has been applied across Queensland and New South Wales and internationally for over 20 years and the capability of the platform has been fine-tuned during this time. There are currently no R&D priorities identified for IQQM.

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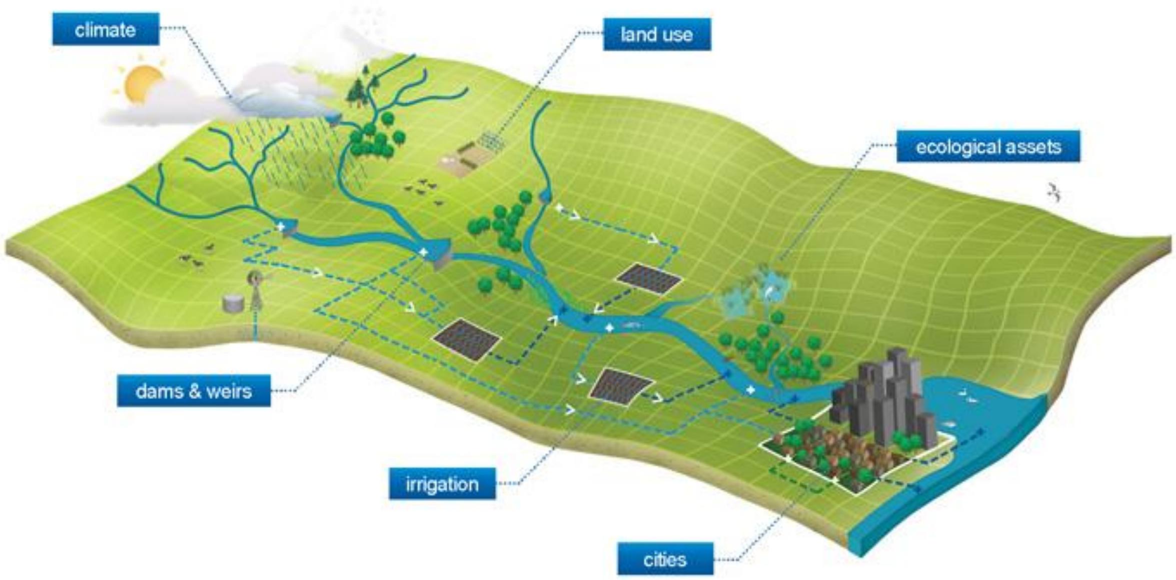
eWater Source – Water Quantity

Summary

Many of Australia's large river systems are highly regulated, both physical by flow control and storage structures, and legally by water sharing rules and regulations. Regulated rivers systems provide resources for a range of water needs including irrigation, urban use, and aquatic ecosystems such as wetlands. These competing needs often lead to a complicated balance and management of socio-ecological requirements.

This complexity is magnified when dealing with transboundary river systems, where different parts of a basin fall under different political jurisdictions, and where different modelling tools (rainfall-runoff models and river system models) are used to guide water resource management. The Murray-Darling Basin (MDB) is an Australian example of such a transboundary river system. The New South Wales and Queensland state agencies responsible for managing the basin's water resources use the daily Integrated Quantity and Quality Model (IQQM) with the Sacramento rainfall-runoff model. However, the Victorian state agency uses the REALM model at daily, weekly and monthly time steps. The Murray-Darling Basin Authority (MDBA) uses the Monthly Simulation Model (MSM, monthly) with BigMod (daily) to model river flow regulation in the Murray River system (Welsh et al., 2012). This makes combining individual models for the whole basin cumbersome, as downstream models require the outputs of upstream models as inputs, and these models are often run at different time steps (Welsh and Podger, 2008).

The National Water Initiative (NWI, 2004) was established by the Commonwealth of Australia with the main objective of achieving a nationally compatible market. This includes a regulatory and planning-based system for managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes. The commonwealth and the various state jurisdictions required a transparent, robust and repeatable tool to underpin water planning and management. To meet these needs, the eWater Source framework was developed in collaboration with research and industry partners by eWater Limited (Ltd), which in-turn evolved from the eWater Cooperative Research Centre (CRC). eWater Source is Australia's national hydrological modelling platform endorsed by the Council of Australian Governments (COAG) (see figure below).



A schematic diagram of the eWater Source conceptual modelling approach, available at http://ewater.org.au/products/ewater-source/

Policy application

The water planning component of eWater Source has been trialled in Queensland in the Macintyre Brook system in the northern region of the Murray Darling Basin by the Queensland Government Department of Environment and Science (DES). The focus of the trial was to apply the planning mode of Source to the modelling of a river system with a continuous sharing water resource assessment and allocation system. The aim was to improve water management, resource assessment and delivery in the Macintyre Brook system.

Functionality, Capability

eWater Source combines integrated water resources management with water policy and governance capabilities.

In the water planning mode, eWater Source runs at a daily time-step and is designed to assess the long-term impacts of water resources policy on system storages, flows, and water shares. In the operations mode, eWater Source is designed to support the operation of regulated river systems and forecast inflows on a daily or seasonal basis. The eventual aim is to achieve a consistent modelling approach across different catchments and state boundaries, such as in the MDB.

The components used to model regulated rivers within eWater Source encompass and enhance the key functionalities of the three widely used river system modelling tools in Australia: IQQM, REALM and MSMBigmod, as well as new scientific research, and engagement with key stakeholders (Welsh and Black, 2010).

eWater Source enables:

- integrated water resource assessments, including agricultural, hydropower, urban, industrial and environmental requirements;
- water balance studies from catchment to river basin scale;
- water accounting and analysis of supply/demand balances;
- inflow forecasting and multi objective reservoir operations;
- resource assessment and allocation policy development and planning;
- trade-off analysis to balance sharing and equitable use of scarce water resources;
- low flow and drought management;
- water quality analysis based on catchment land use scenarios;
- impacts of climate change and transboundary transfers;
- bulk water systems optimisation, planning and operations including multiple supply options (reservoir/recycling/desalination); and
- conjunctive groundwater-surface water use analysis.

eWater Source has a range of capabilities. Users are able to simultaneously answer catchment management and river modelling questions, including the ability to handle complex policy and management rules at a system-wide scale. Key features include the ability to:

- model water sharing and accounting using a selection of resource assessment systems dealing with water sharing plans in place in different catchments and jurisdictions;
- assign, track, manage and reassign an owner's (such as a state or 'the environment') share of water as it moves through the river system;
- support both rules based and optimised solutions to manage the delivery of water from multiple supply storages via multiple paths;
- track the concentration of salinity and other 'conservative constituents' through the river system;

- take explicit account of fluxes between the river and the groundwater aquifer along entire river reaches at any time step;
- predict inflows from rainfall and runoff using a collection of available models; and
- select from a range of water user demand models, including urban, environmental and irrigation demand, to inform storage releases.

eWater Source's capabilities can be extended through the use of plugins, which can modify or replace many of the standard tools within the model. They can be new component models, such as rainfall runoff or water user demand, and data processing tools.

eWater Source is built using a Microsoft .NET-based technology stack, with TIME (Rahman et al., 2003) as a base modelling framework and E2 (Argent et al., 2009) providing the base simulation system. The TIME environment of the software caters for future expansion of the tool to include additional functionalities, new scientific knowledge and modelling methods.

Operating skills

The major strength of eWater Source is its flexible software architecture, which makes it easily expandable and enables users to create and link their own custom functions.

eWater Source is available in two versions. The full version provides access to the complete range of governance functionality, and the complete set of Integrated Water Resource Management (IWRM) functions such as water sharing, accounting and capacity sharing methods. The free, publically-available version of eWater Source provides limited functionality that includes hydrological, water balance and water quality modelling capabilities to promote transparent decision making and knowledge sharing. The free version is an ideal entry point for IWRM research and transboundary studies.

Custodianship

The custodian of eWater Source is eWater Limited (Ltd), a public incorporated limited guarantee, not-for-profit Australian company. Its members include:

- Murray-Darling Basin Authority (representing the Commonwealth);
- Queensland Government Department of Natural Resources, Mines and Energy;
- New South Wales Government Office of Water;
- Victorian Government Department of Environment and Primary Industries; and
- South Australian Government Department of Environment, Water and Natural Resources.

Key Contacts

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Training

eWater provide a wide range of web-based and video training packages around the functional operation of eWater Source. eWater encourages a collaborative approach to development and knowledge sharing within the eWater Source user community and maintains a collection of online community resources including best practice modelling guidelines—a series of quality assurance principles and actions to ensure implementation and application are the best achievable. Available training can be found at: http://ewater.org.au/products/ewater-source/source-training/

Research and development priorities

No research and development priorities identified.

Key publications and links

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eWater Source – Water Quality

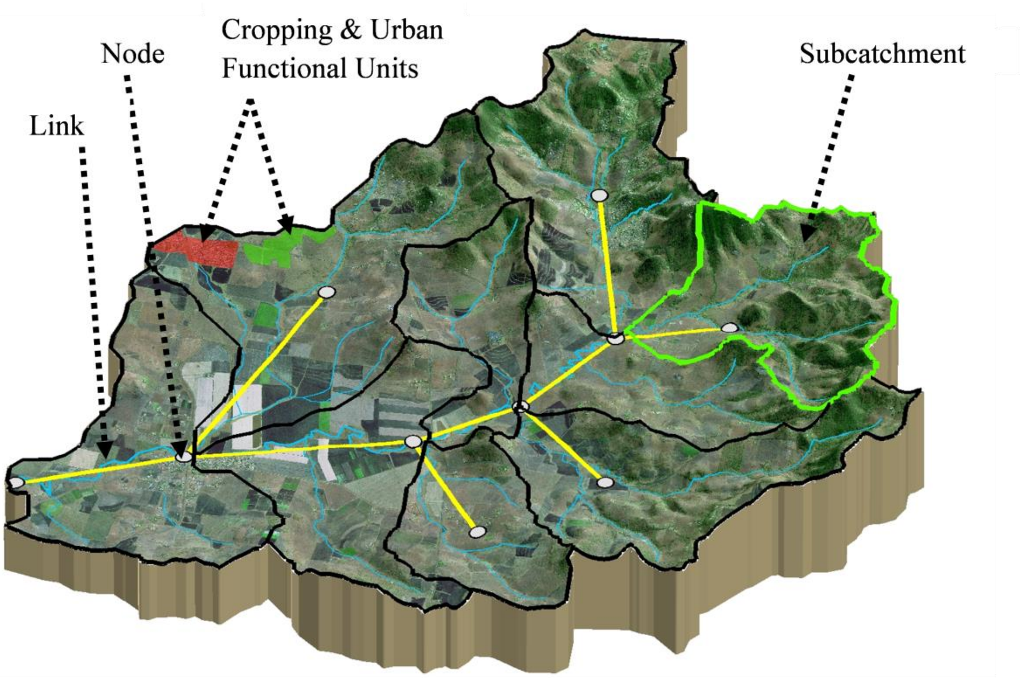
Summary

eWater Source Catchments is an integrated modelling framework. It has been developed out of the E2 node-link modelling system to model the routing and transformation of flow and constituents in streams, water storage and use, and land use differences in sediment loss (Argent et al., 2009).

The eWater Source water quality modelling component uses Functional Units (FU) to represent differences in hydrological responses between land uses. There are two modelling components assigned to each FU to represent the processes of runoff generation and constituent generation. There are a range of basic constituent generation models in eWater Source and the most frequently used is a simple Event Mean Concentration/Dry Weather Concentration (EMC/DWC) model.

A daily runoff time-series for each FU in each sub-catchment is predicted, which is then accumulated to predict daily flow and discharge. Runoff and constituents are routed from a sub-catchment through the stream network via nodes and links with a range of filter and decay models available through the stream network (see figure below). The inputs for runoff are grids of daily rainfall and potential evapotranspiration (Jeffrey et al., 2001). For constituent generation, when using the EMC/DWC, concentrations for each FU type are required.

eWater Source is not a single hydrological model and constituent generation model. Rather, it is a range of component models that have been incorporated into an adaptable framework that recognises the practical, political and technical issues in developing water policy and support land management planning and the need for transparency. In addition, eWater Source can be customised using plug-ins to address specific policy questions.



***An** example of a functional unit (FU) and node-link network generated in eWater Source Catchments. These components represent the sub-catchment and stream network (Waters et al., 2013).*

Policy application

The eWater Source water quality modelling framework has been used to simulate sediment, nutrient and herbicide loads entering the Great Barrier Reef (GBR) lagoon from adjacent catchments (covering 420,000 km^2), and report on progress towards meeting reef water quality targets.

An eWater Source water quality model has also been developed for the Queensland section of the Murray Darling Basin (MDB). This model is being used to develop water quality guidelines for the MDB Plan.

Functionality, capability

During the GBR Source Catchment modelling the SIMHYD water balance model (Chiew et al., 2002) was initially used to conceptualise the effect of interception, soil moisture and groundwater stores on total daily runoff and evaporation. In the second phase of reporting, an improved hydrological calibration performance was achieved using the Sacramento rainfall-runoff model, particularly for calibrating high flows. Furthermore, the Sacramento model is used by the Queensland Government in water planning models, thus allowing calibration tools and algorithms used for hydrology calibration to be developed in partnership.

Runoff model parameters are calibrated using the Parameter Estimation Simulation Tool to minimise a user-defined objective function representing the discrepancy between predicted and measured monthly and long-term runoff at multiple unregulated stream gauging stations across the river basin (PEST; Doherty, 2009). The accumulated unregulated stream flow includes water transmission losses and human extractions as daily time-series for relevant stream nodes, based on available flow data.

For the constituent generation component, SedNet modelling functionality was incorporated into eWater Source to provide estimates of gully and streambank erosion and floodplain deposition (Ellis and Searle 2014). Two paddock models, HowLeaky (Rattray et al., 2004 ab) and APSIM (Keating et al., 2003), were used to calculate loads and reduction in loads due to the adoption of land management practices for cropping and cane areas respectively. For grazing areas, the Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) was used to generate daily loads. The grazing systems model GRASP (Rickert et al., 2000) was used to derive changes in ground cover (C-factor) to represent reductions in loads for different grazing management practices. An Event Mean Concentration (EMC) approach was used to generate loads for conservation areas and the remaining minor land uses. In order to reduce the effect of climate variability, a static climate period was used (1986–2014) to produce average annual loads and the relative change in loads due to industry and government investments in improved land management practices.

Operating Skills

eWater Source features a wide range of data pre-processing and analysis functions that allow users to create and compare multiple scenarios, assess the consequences, and report on the findings.

eWater Source is available in two versions. The full version provides access to the complete range of governance functionality, and the complete set of Integrated Water Resource Management (IWRM) functions such as water sharing, accounting and capacity sharing methods. The free, publically-available version of eWater Source provides limited functionality that includes hydrological, water balance and water quality modelling capabilities to promote transparent decision making and knowledge sharing. The free version is an ideal entry point for IWRM research and transboundary studies.

Custodianship

The custodian of eWater Source is eWater Limited (Ltd), a public incorporated limited guarantee, not-for-profit Australian company. Its members include:

- Murray-Darling Basin Authority (representing the Commonwealth);
- Queensland Government Department of Natural Resources, Mines and Energy (DNRME);

- New South Wales Government Office of Water;
- Victorian Government Department of Environment and Primary Industries; and
- South Australian Government Department of Environment, Water and Natural Resources.

Key contacts in Queensland

David Waters: David.Waters@dnrme.qld.gov.au (DNRME), Rob Ellis: Robin.Ellis@des.qld.gov.au, Department of Environment and Science

Training

eWater deliver basic training for new users to build a water balance model within the eWater Source framework for specific modelling objectives. In addition, through the GBR Source Catchment modelling there is extensive capacity from the Queensland Government to provide insights into the use of eWater Source.

Research and development priorities

The research and development priorities for the eWater Source water quality component are:

- speed up model run time through use of python script to enable bulk runs for future scenarios, such as stochastic generated future climate change scenarios
- coupling of visualisation software to aid calibration and support web-based GBR reporting
- spatial derivation of rainfall (I5) and peak runoff (Qp) to run MUSLE erosion model
- improved algorithms to represent streambank and gully erosion, including alluvial gullies
- improved gully mapping
- increased pool of field data to validate/calibrate various components of both paddock and catchment models including gully & streambank parameters (and consideration of a spatial approach to parameterisation), DIN in deep drainage, and soil physical and chemical properties.

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MIKE

Summary

The Danish Hydraulic Institute (DHI) has developed a suite of models that have been used by a number of government departments around the world. MIKE 11 is one such DHI-developed model. It is a fully dynamic, one-dimensional modelling package that includes comprehensive facilities for modelling complex river channel networks, lakes and reservoirs. With a hydrodynamic engine as a core module, MIKE 11 offers a variety of add-on modules and large selection of hydraulic structures, including ‘dam break’ structures and operational structures allowing the user to define complex control strategies. Additional application areas include rainfall-runoff, flood modelling, real-time forecasting, pollutant transport, ecology and water quality as well as sediment transport and river morphology assessments.

The hydrodynamic (HD) module is the nucleus of the MIKE 11 modelling system and forms the basis for most modules including flood forecasting, advection-dispersion, water quality and non-cohesive sediment transport modules.

Data requirements for MIKE 11 include:

- definition of the watercourse network schematic;
- cross-sectional information at various locations along the reach of the watercourse;
- surface roughness values;
- definition of upstream and downstream boundary conditions; and
- inflow hydrographs at various locations along the reach of the watercourse.

MIKE 11 has now been superseded by MIKE HYDRO River for river applications, along with a suite of other applications including MIKE FLOOD for surface water flooding, MIKE SHE for integrated catchment hydrology, MIKE HYDRO Basin for water resources planning and MIKE 21C for river sediments and morphology applications.

Policy application

In the Lower Fitzroy River Infrastructure Project of 2015 a MIKE 11 one-dimension (1D) hydrodynamic model was used on the Lower Fitzroy River—the Fitzroy River downstream from the Mackenzie and Dawson Rivers junction to approximately 15 km downstream of the existing Eden Bann Weir. The lower reaches of the Mackenzie and Dawson Rivers were assessed using a MIKE 21 two-dimensional (2D) model. Hydraulic modelling was undertaken to estimate the peak water levels for the existing river and as a result of raising Eden Ban Weir and constructing a new weir at Rookwood. MIKE 21 has also been used at Woodleigh on the Dawson River to assist with an ecological risk assessment for the Fitzroy Water Resource Plan. MIKE FLOOD has been used for the East Trinity Acid Sulphate Soils remediation project near Cairns in north Queensland.

Functionality, capability

MIKE11 covers the entire phase of surface hydrology and river routing. Five files are required to create a MIKE11 hydrodynamic model: a river network file, a cross-section file, a boundary file, a hydrodynamic parameter file, and a simulation file.

The MIKE11 HD module uses an implicit, finite difference scheme for the computation of unsteady flows in rivers. The complete non-linear equations of open channel flow (Saint-Venant) can be solved numerically at all grid points at specified time intervals for given boundary conditions.

The MIKE 11 HD module has the capability to undertake:

- flood analysis and flood alleviation design studies;

- real time flood, drought or water quality forecasting;
- dam break analysis;
- optimisation of reservoir and river structure operations;
- ecology and water quality assessments in rivers and wetlands;
- sediment transport and long-term assessment of morphology changes;
- salinity intrusion in rivers and estuaries;
- wetland restoration studies; and
- tidal and storm surge studies in rivers and estuaries

Operating skills

MIKE 11 can be used on Windows 7 Professional Service Pack 1 (32 and 64 bit), Windows 8.1 Pro (64 bit), Windows 10 Pro (64 bit) and Windows Server 2012 R2 Standard (64 bit). Experience and knowledge of river systems, hydrology, hydrodynamics and numerical modelling is required to maximise MIKE 11 capabilities.

Custodianship

MIKE 11 was developed by DHI and is proprietary software protected under copyright.

Key contacts

DHI has three offices in Australia in Sydney, Gold Coast and Brisbane dealing with MIKE products. Email: mike.au@dhigroup.com

Training

DHI provide online training from introduction through to advance courses at: https://www.theacademybydhi.com/training

MIKE 11 User Guide, Reference Manual, and online help are available at: http://www.dhi.dk

Research and development priorities

No identified research and development priorities.

Key publications and links

Lower Fitzroy River Infrastructure Project 2015, Surface water resources supporting material: Part 4 Hydraulic modelling and references. https://www.statedevelopment.qld.gov.au/assessments-and-approvals/lower-fitzroy-river-infrastructure-project-draft-eis-documents.html.

TUFLOW

Summary

TUFLOW (Two-dimensional Unsteady FLOW) is the product of a research and development project jointly funded by BMT WBM Pty Ltd and The University of Queensland. TUFLOW is based on the solution scheme documented in Stelling (1984). It is a finite difference, alternating direction implicit (ADI) scheme solving the full two-dimensional (2D) free surface flow equations. Additional features were incorporated by Syme (1991). Up until 1997 it was used extensively used by BTM WBM Pty Ltd for estuarine and coastal studies, with the occasional flood study. Since 1997, considerable improvements in flood modelling capabilities and Geographic Information Systems (GIS) linkages have been developed, resulting in extensive and wide-ranging applications to flood investigations worldwide. TUFLOW was made commercially available in 2001.

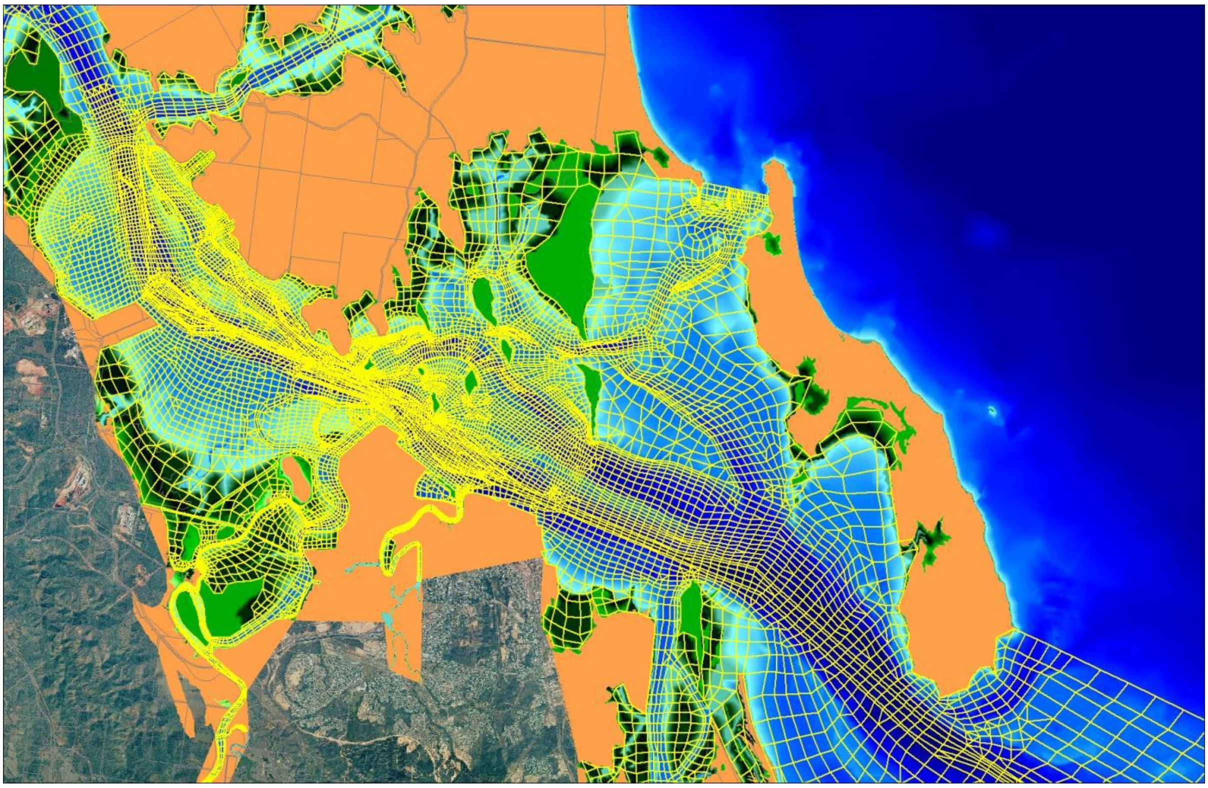
TUFLOW has been further developed to include a suite of numerical engines and supporting tools for simulating free-surface water flow for urban waterways, rivers, floodplains, estuaries and coastlines (see image below). TUFLOW uses 1D, 2D and 3D solutions to represent the physical processes.

At the core of TUFLOW are three numerical engines:

- TUFLOW
- TUFLOW GPU Solver
- TUFLOW FV

Each of these engines has a range of additional modules and free utilities to suit a wide range of applications and study requirements.

A Graphical User Interface (GUI) and GIS are used to provide the modelling environments, which provide significant gains in flexibility and efficiency for users, and reduces overall software costs to the user.



An example of TUFLOW FV Mesh, Port Curtis estuary, Queensland, Australia (Figure 4.2, from TUFLOW User Manual, 2013).

Policy Application

Following the 2011 flood event in the Brisbane River catchment the Queensland Floods Commission of Inquiry recommended that a comprehensive plan to manage Brisbane River flood risk be established (Qld FCoI, 2012). In response, the Queensland Government instigated the Brisbane River Catchment Floodplain Study (BRCFS) with a Comprehensive Hydraulic Assessment component.

The magnitude of a flood event is dependent on the complex interactions of number of factors, some of which are highly variable including depth and duration of rainfall, spatial and temporal distribution of rainfall, antecedent catchment conditions, downstream boundary conditions, the initial water levels in the Wivenhoe Dam, and the operation of the dam.

To account for a high degree of variation and interaction of these variables and complex catchment conditions that include backwater effects, a Monte Carlo Simulation approach was used for the hydraulic modelling. For the hydraulic assessment, two TUFLOW hydraulic models were developed and used in a two-stage process:

1. Fast Model – a 1D model, developed as a networked 1D or quasi-2D scheme, designed for speed and more suited to computationally demanding Monte Carlo Simulation applications; and

2. Detailed Model – a 2D model with some in-bank sections modelled in 1D.

The probability approach used allowed for more confident estimates of design events that properly accounted for catchment-wide rainfall variations and operation of the Wivenhoe Dam flood gates.

The TUFLOW FV model was also used to produce a 3D hydrodynamic and water quality receiving water model for the Maroochy River in south east Queensland (McAlister et al, 2013). The Framework for Aquatic Biological Modelling (FABM) was linked to TUFLOW FV to specifically provide an Aquatic Ecosystems Dynamics module for the receiving water model and simulate aquatic biogeochemical and ecological dynamics.

Functionality, capability

TUFLOW Classic is a 1D network and 2D fixed grid-based software for simulating flood and tidal flow. The1D/2D hydrodynamic computational engine has a wide range of functionalities and is ideally suited for modelling the flooding of rivers and creeks with complex flow patterns; overland and piped flows through urban areas; estuarine and coastal tide hydraulics; and inundation from storm tides and tsunami.

TUFLOW GPU is a 2D fixed grid software package. The software uses a computer graphic card for its computations instead of its central processing unit (CPU). This change has significantly improved model run times and simulations in TRUFLOW GPU run between 10 to 100 times faster than in TUFLOW Classic (www.tuflow.com). TUFLOW GPU is limited to 2D applications and, as such, has limited functionality compared to TUFLOW Classic. The runtime benefits of this software are however extremely powerful for broad-scale regional assessments, which may have otherwise been too computationally intensive to model using a CPU type model.

TUFLOW FV is a numerical hydrodynamic model for 2D and 3D Non-Linear Shallow Water Equations (NLSWE). The model is suitable for simulating a wide range of hydrodynamic systems ranging in scale from open channels and floodplains, through to estuaries, coasts and oceans.

The Finite-Volume (FV) numerical scheme employed by TUFLOW FV is capable of solving NLSWE on both structured rectilinear grids and unstructured meshes comprised of triangular and quadrilateral elements. The flexible mesh allows for seamless boundary fitting along complex coastlines or open channels, as well as accurately and efficiently representing complex bathymetries with a minimum number of computational elements. The flexible mesh capability is particularly efficient at resolving a range of scales in a single model without requiring multiple domain nesting.

The flexible mesh model structure allows users to modify mesh resolution spatially, thus seamlessly increasing the model resolution in areas of interest. This modelling approach reduces the number of computation cells in a model and hence reduces simulation times. Additionally, TUFLOW FV has been parallelised, which means users can fully capitalise on the computing power of multiple processor/thread computers.

The TUFLOW FV model with FABM capacity allows users to simulate interactions between biogeochemical variables including oxygen, carbon, nutrients (organic and inorganic), sediment, light, temperature and a single alga species.

Operating skills

TUFLOW Tutorials are provided for new users to learn how to develop and view models. The tutorials are intended to be used during training sessions, however it is possible to self-train by working through the tutorials independently. It should be notes, however, that inexperienced modellers with no prior hydraulic modelling experience, may have difficulties with some steps and concepts in the tutorials. A TUFLOW licence is not required to run the tutorial/demo models. The complete model input files are provided, allowing the user to cross-check and compare their files to help identify any problems.

Custodianship

BMT WBM Pty. Ltd. is the custodian of the TUFLOW models. TUFLOW Software can be used through a license agreement with BMT WBM and product prices are available at: www.tuflow.com/Prices.aspx

Key contacts

Email: info@tuflow.com; and sales@tuflow.com

Training

TUFLOW in-house training and web-based tutorials are available at: training@tuflow.com

Additional support is provided by developers and users of the software at: support@tuflow.com

Research and development priorities

There is an overall research and development gap in water modelling of ecological and water quality of lakes and standing waters.

Key publications and links

McAlister, T, Barry, B, Holmes, R, Peille, C, Faivre, G, Cooke, T, Jorissen, J 2013, Three-dimensional Receiving Water Quality Modelling for the Maroochy River. Calibration Report. www.emg.cmar.csiro.au/www/dms/software/shoc/untitled/.../Maroochy_final.pdf

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Syme, WJ 1991, *"Dynamically Linked Two-Dimensional / One-Dimensional Hydrodynamic Modelling Program for Rivers, Estuaries & Coastal Waters"*, William Syme, M.Eng.Sc (Research) Thesis, Dept of Civil Engineering, The University of Queensland, 1991.

TUFLOW 2012, TUFLOW FV Science Manual - Flexible Mesh Modelling. www.tuflow.com

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Hydrologic Engineering Center-River Analysis System (HEC-RAS)

Summary

The Hydrologic Engineering Center-River Analysis System (HEC-RAS) was developed by the U.S. Corps of Engineers Institute of Water Resources (CEIWR-HEC) Hydrologic Engineering Center, HEC-RAS was designed to perform one and two-dimensional hydraulic calculations for a full network of natural and constructed channels. The following is a description of the major capabilities of HEC-RAS.

The latest version of HEC-RAS (v5.0) was released in March 2016 and includes two-dimensional (2D) flow simulation. This is widely regarded as the most significant development of HEC-RAS in recent years.

HEC-RAS software includes graphical user interface (GUI), hydraulic analysis, data storage and management, and 1D and 2D graphics capabilities.

Data requirements for the HEC-RAS 11 model include:

- definition of the watercourse network schematic;
- cross-sectional information at various locations along the reach of the watercourse;
- surface roughness values;
- definition of upstream and downstream boundary conditions;
- inflow hydrographs at various locations along the reach of the watercourse; and
- sediment particle size and water quality-related parameters if additional capability for sediment transport and water quality analysis is invoked.

Policy application

HEC-RAS has been widely used for flood mapping and flood risk assessment, and for assessing the impact of infrastructure development on river stage and flow velocities, mostly around low-lying coastal areas.

Functionality, capability

The HEC-RAS system consists of four main areas:

1) steady flow water surface profile;
2) one- and two-dimensional unsteady flow simulation
3) sediment transport computations; and
4) water quality analysis.

In addition to these river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

Water surface profile
Water surface profiles are calculated for steady, gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach. The basic computational procedure is based on the solution of the 1D energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head).

One and two-dimensional unsteady flow simulation
This component of the HEC-RAS modelling system is capable of simulating 1D; 2D; and combined 1D/2D unsteady flow through a full network of open channels, floodplains, and alluvial fans. The unsteady flow component can be used to performed subcritical, supercritical, and mixed flow regime

(subcritical, supercritical, hydraulic jumps, and draw-downs) calculations in the unsteady flow computations module.

Sediment transport
This component of the modelling system is intended for the simulation of 1D sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods (typically years, although applications to single flood events are possible). The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring. Major features include the ability to model a full network of streams, channel dredging, various levee and encroachment alternatives, and the use of several different equations for the computation of sediment transport.

Water quality analysis
This component of the modelling system is intended to allow the user to perform riverine water quality analyses. An advection-dispersion module is included with the current version of HEC–RAS, adding the capability to model water temperature. Transport and fate of a limited set of water quality constituents is now also available in HEC-RAS. The currently available water quality constituents are: Dissolved Nitrogen (NO3-N, NO2-N, NH4-N, and Org-N); Dissolved Phosphorus (PO4-P and Org-P); Algae; Dissolved Oxygen (DO); and Carbonaceous Biological Oxygen Demand (CBOD).

Operating skills

HEC-RAS can currently be used on: Windows XP, Vista, 7, 8, 8.1, and 10 both 32-bit and 64-bit. Experience and knowledge of open-channel hydraulics, hydraulic design, and river systems is highly desirable to appreciate HEC-RAS capabilities and to interpret model outputs.

Custodianship

The HEC-RAS software was developed with U.S. Federal Government resources and is freely available in the public domain.

Key contacts

Hydrologic Engineering Center, U.S. Corps of Engineers Institute of Water Resources (CEIWR-HEC): www.hec.usace.army.mil/contact/

Training

HEC-RAS Version 5.0 User's Manual, Two-Dimensional Modelling User's Manual, Application Guide, and Hydraulics Reference Manual are all available on line at: www.hec.usace.army.mil/software/hec-ras/documentation.aspx

Training workshops are readily available. A 3-day training workshop on 1D and 2D flood modelling with HEC-RAS is offered through KUSTOM Engineering in Sydney: http://www.kustomengineering.com.au/?page=upcoming-workshops-nsw-hecras

A 5-day workshop on 1D and 2D flood models using HEC-RAS is offered through ICE WaRM in Brisbane: http://www.surfacewater.biz/brisbane/

Research and development priorities

HEC-RAS is free software, used widely in the U.S. and Australia, and in many other locations around the world. Software bugs and improvement suggestions can be emailed to the Hydrologic Engineering Center. More information can be found here: http://www.hec.usace.army.mil/software/support_policy.aspx

Key publications and links

The website for HEC-RAS: http://www.hec.usace.army.mil/software/hec-ras/

HEC-RAS Application Guide: http://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%20Applications%20Guide.pdf

MODFLOW

Summary

MODFLOW is a three-dimensional (3D) finite difference modular groundwater model (Harbaugh 2005). The groundwater flow domain is organised into rectangular or cubic block elements. MODFLOW was developed by the US Geological Survey (USGS) for the description and prediction of the behaviour of groundwater systems that solves a volume-averaged form of the governing 3D flow equation which combines Darcy's Law and the principle of conservation of mass. The finite-difference approach involves the replacement of a set of partial differential equations for water movement by a large matrix equation in which spatial and temporal differentials are replaced by discrete differences. Therefore, a study area must be organised into cells within rectilinear grids resulting in layers consisting of rows and columns. Like most numerical models, MODFLOW can accommodate an almost unlimited degree of heterogeneity within the model domain. Layers representing aquifers can be simulated as confined, unconfined, or a combination of both, for which hydraulic parameters (hydraulic conductivity, aquifer storage etc.) and boundary conditions are specified. Flows from external stresses such as pumping, rainfall recharge, evapotranspiration, seepage outflow, and groundwater interaction with streams can also be simulated. For transient simulations, the flow equations are temporally discretised through time steps. A time-period considered in MODFLOW for an aquifer remains constant and is defined as a stress period, with a stress period usually divided into smaller time steps (Reading et al. 2012)

Policy application

MODFLOW was used in the National Water Commission Raising National Water Standards Program's Lower Burdekin Groundwater project with the purpose of developing an integrated and holistic package of modelling tools to support the decision-making process for water management in the Lower Burdekin.

Functionality, capability

MODFLOW was first published in 1984 and originally conceived solely as a groundwater-flow simulation code with a modular structure that provided a robust framework for the integration of additional simulation capabilities. The family of MODFLOW-related programs now includes capabilities to simulate coupled groundwater/surface-water systems, solute transport, variable-density flow (including saltwater), aquifer-system compaction and land subsidence, parameter estimation, and groundwater management.

Many commercial products have been developed to provide a user-friendly graphical user interface in MODFLOW for pre- and post-processing of data. Many other models have been developed to work with MODFLOW inputs and outputs, such as SEAWAT (Guo et al 2002) and GSFLOW (Markstrom et al 2008). The modular nature of MODFLOW facilitates the creation of linked models that are able to simulate several hydrologic processes, such as flow and transport models, surface water and groundwater models and chemical reaction models.

Operating skills

MODFLOW may be used for either 2D or 3D applications. Input procedures have been designed so that each type of model input data may be stored and read from separate external files. User-specified formatting allows input data for the grid to be read in almost any format without modification to the program. The output of model results is also flexible and the user can select which data to output, the frequency of output, and for some data, the format of the output (Harbaugh 2005).

MODFLOW-2005 is written in the Fortran 90 (American National Standards Institute, 1992) programming language and is therefore highly portable. Use of non-standard features has been avoided so that MODFLOW-2005 will run, without modification, on most computers. Minor modification, however, may be necessary or desirable on some computers (Harbaugh 2005).

Custodianship

MODFLOW source code is public-domain, which provides opportunities for comprehensive verification of the code. It has worldwide acceptance as the industry standard (Middlemis et al., 2000), with the USGS and other organisations/researchers regularly upgrading the capability of MODFLOW, thus ensuring that the code contains contemporary capabilities.

MODFLOW 6 is likely to become the standard platform as it consolidates MODFLOW-USG, MODFLOW-NWT and MODFLOW-2005 etc. into a single platform. The other main motivation for this version is an 'object-oriented' style framework in the sense that multiple models within the same simulation can be tightly coupled at the matrix level by adding them to the same numerical solution, or they can be iteratively coupled until convergence is attained between them. So, data is transferred between 'silo' models, or so-called 'exchange objects', while still allowing models to be developed and used separately. There are also a number of new features, while some older MODFLOW packages have been deprecated.

Key contacts

Mark Gallagher: Mark.Gallagher@dnrme.qld.gov.au (Department of Environment and Science contractor), Lucy Reading: Lucy.Reading@qut.edu.au (QUT)

Training

MODFLOW has been used by the Queensland Government Department of Environment and Science, (DES) in a number of groundwater flow modelling projects, and is therefore a high-level of expertise and capacity for the Queensland Government to provide insights into the use of MODFLOW. Online training is also available at: https://water.usgs.gov/ogw/modflow/MODFLOW.html

Research and development priorities

The research and development priorities for MODFLOW are:

- for MODFLOW 6 an operational management package (which is already a scheduled activity for the Border Rivers groundwater model project);
- particle transport applications; and
- evaluation of the efficiency of GPU parallel solvers.

Key publications and links

Harbaugh, AW 2005, 'MODFLOW-2005, the U.S. Geological Survey modular ground-water model -- the Ground-Water Flow Process', *U.S. Geological Survey Techniques and Methods 6-A16*.

Harbaugh, AW, Langevin, CD, Hughes, JD, Niswonger, RN, and Konikow, LF 2017, MODFLOW-2005 version 1.12.00, the U.S. Geological Survey modular groundwater model: U.S. Geological Survey Software Release, 03 February 2017, http://dx.doi.org/10.5066/F7RF5S7G

Middlemis, H, Merrick N, and Ross, J 2000, 'Murray-Darling Basin Commission groundwater flow modelling guideline', *Project No, 125*, Aquaterra Consulting Pty Ltd, Perth.

Reading, L, Wang, J, Lenahan, MJ, Gallagher, M and Foy, Z 2012, Development of a hydrological modelling toolkit to support sustainable development of the Lower Burdekin groundwater system: Review of modelling methods. Brisbane: Department of Science, Information Technology, Innovation and the Arts, Queensland Government.

Biophysical Capacity to Change (BC2C)

Summary

The Biophysical Capacity to Change (BC2C) model (Dawes *et al*. 2004) is an annual time-step model that uses a simple water balance approach and groundwater response time theory to estimate the impacts of changes in forest cover on stream volume and salt load.

BC2C divides the modelled area into sub-catchments, based on a user-identified area threshold applied to land-surface topography information. These Groundwater Response Units (GRUs) are the fundamental modelling unit within BC2C. Water and salt generation from each of the GRUs are then summed to the area of interest, such as a gauging station. Each modelled area has tens to hundreds of individual GRUs.

Gilfedder et al., (2007) compared and outlined the differences between the BC2C and 2CSalt models. BC2C is essentially a top-down approach that uses generalised relationships to estimate the impact of afforestation. In contrast, 2CSalt obtains its water balance by aggregating the individual results from more detailed one dimensional (1D) water balance modelling, and includes both a hill-slope and an alluvial groundwater store to produce monthly stream flow and salt load estimates.

Both BC2C and 2CSalt assume a gaining stream, with no ability to drain water back into the groundwater system. This restricts the scope of the model to upland areas where this assumption is more likely to be valid (Gilfedder et al., 2007).

While there is an overlap in the scale of applicability of the BC2C and 2CSalt models (1000-2000 km^2), each is suited to addressing different questions (Gilfedder et al., 2007). BC2C is intended for regional prioritisation across large catchments, and for examining the variation in possible impacts of afforestation scenarios between catchments. Whereas 2CSalt operates at a scale finer than BC2C, and although being more computationally intensive it can model a broader range of land-use scenarios and examine seasonal impacts. BC2C also has the ability to be calibrated to measured gauged data, and has outputs that can feed into river routing models.

Policy Application

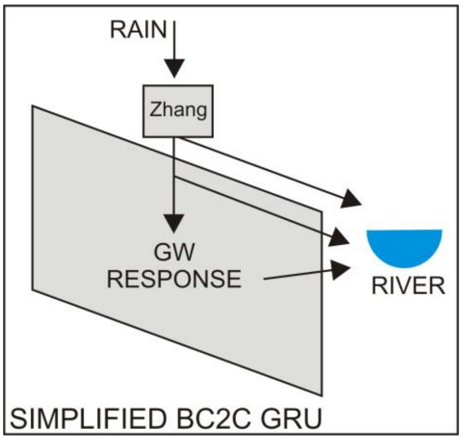
BC2C was used in the Fitzroy Salinity Risk Assessment project to support community investment in land management actions (Chamberlain et al., 2007).

Functionality, capability

BC2C is intended for regional prioritisation across large catchments, and for examining the variation in possible impacts of afforestation scenarios between catchments.

BC2C uses the mean annual water balance relationship developed by Zhang et al. (2001). Excess water is then partitioned into quick and slow flow components. The quick flow component is directed into the stream, while the slow flow is delayed according to a groundwater response function. Groundwater Flow Systems (GFS) maps are used to map hydrogeological parameters across the modelled area. Variability in aquifer slope, transmissivity, and flow length affects the timing of groundwater discharge to stream.

BC2C uses a mean annual water balance input, and its output shows the change in mean annual water and salt using an annual time-step. The figure below shows a simplified version of the conceptual model for a GRU.



A simplified diagram of the basic structure of each groundwater response unit (GRU) in the BC2C model (from Gilfedder et al., 2007)

Operating skills

BC2C is designed to be easily used by a range of users. However, it requires knowledge of processes affecting flow of water through catchments, along with supporting data to run the model. BC2C can be run with a user-friendly interface that allows changes to surface vegetation to reflect the change in water and salt yield over time. A GIS version is also available when greater control of parameters or a more detailed description of the spatial patterns are required (www.toolkit.net.au/bc2c).

Custodianship

The BC2C model is available through the Catchment Modelling Toolkit (www.toolkit.net.au/bc2c), which is documented in Gilfedder *et al*. (2005).

Key contacts

Matt Gilfedder: mat.gilfedder@csiro.au, CSIRO

Training

Support and model training is available from eWater at:
https://toolkit.ewater.org.au/training/default.aspx and via: support@ewater.com.au

Research and development priorities

No research and development priorities identified.

Key publications and links

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Dawes, W, Gilfedder, M, Walker, G, Evans, R, Stenson, M, Dowling, T, Austin, J and Best, A 2004, BC2C Technical Documentation, Technical Report 36/04, CSIRO Land and Water, Brisbane.

Gilfedder, M, Stenson, M, Walker, G, Dawes, W, and Evans, R, 2005, *BC2C, Biophysical Capacity to Change – User Guide*, Cooperative Research Centre for Catchment Hydrology, Canberra.

Gilfedder, M, Stenson, M, Dowling, T, van Dijk, A, and Walker, GR 2006, 'Salinity impacts of future forestry scenarios for the MDB', in *Proc 2006 MDB Groundwater Workshop*, September 2006, Canberra, [published as CDROM].

Gilfedder, M, Littleboy, M, and Stenson, M 2007, 'Two Modelling Approaches for Predicting Water and Salt Generation to Upland Streams: BC2C & 2CSalt', In: Oxley. L, Kulasiri, D (eds). *MODSIM*

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Zhang, L, Dawes, WR and Walker, GR 2001 'The response of mean annual evapotranspiration to vegetation changes at catchment scale', *Water Resources Research*, 37, 701-708.

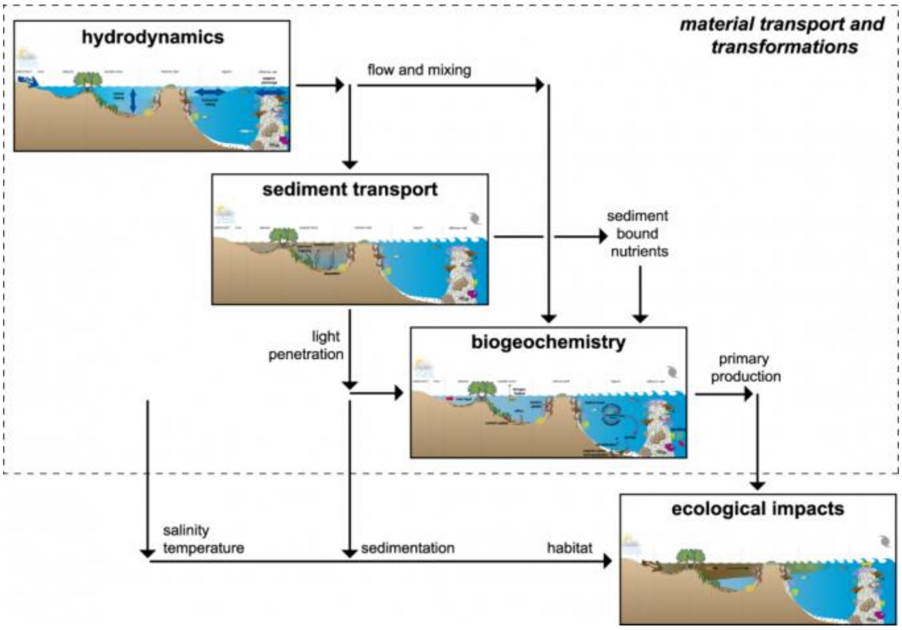
Receiving Water & Coastal Models

Summary

The eReefs initiative focusses on the protection and preservation of the Great Barrier Reef (GBR). The overall aim of eReefs is to improve communication and decision support tools for the management of the GBR. eReef Marine modelling covers catchments, estuaries, reef lagoon and the open ocean. The objective is to collate data and latest technologies to develop integrated marine models that produce enhanced visualisation, communication and reporting tools for the GBR.

There are three major components of the eReefs Marine models (see figure below):

1) a hydrodynamic model to predict the physical state of the system
2) a sediment transport model to predict the fate of suspended fine sediments
3) a biogeochemical model for water column and benthic production, water quality and nutrient cycling simulations.



Primary components of a material transport and transformation models (inside box), showing internal linkages between sub models and linkage to ecological impacts models (from Webster et al. 2008)

The eReefs Marine modelling uses a nested approach. A regional 4 km resolution model is nested within a global general circulation model, with a 1 km resolution model subsequently nested within the 4 km model. These models provide outputs of sea level, currents, temperature, salinity, suspended sediment, primary and secondary production, nutrients and optical characteristics throughout the GBR domain. The models operate in near real-time, such that current conditions may be monitored, and a hind-cast archive exists back to September 2010 for the 4 km model and December 2014 for the 1 km model. The archive is kept up-to-date by continuously appending the near real-time outputs.

A Relocatable Coastal Ocean Model (RECOM) has been developed which is an automated re-locatable modelling system capable of generating high resolution models of hydrodynamics, waves, sediment transport and biogeochemistry (BGC) that are nested within the 4 km or 1 km regional models. This package is designed for non-specialist users, whereby the user simply and intuitively interacts with the models via a graphical workflow interface.

Both regional models extend along the Queensland coast from Papua New Guinea to the New South Wales border, and offshore to beyond the continental slope. The 4 km model encompasses some of the Coral Sea, whereas the 1 km model is limited to the shelf regions.

Policy application

The Reef Water Quality Protection Plan goal is to protect the health of Great Barrier Reef ecosystems. The combined eReef Marine Modelling provides a single integrated and consistent platform to predict changes in water quality in space and time in response to land use and load scenarios for any or all Great Barrier Reef catchments.

Functionality, capability

The hydrodynamic model SHOC (Sparse Hydrodynamic Ocean Code; Herzfeld et al., 2008), is used for both the regional and shelf model applications.

Hydrodynamic models at the 4 km and 1 km scale are respectively operating in near real-time within the CSIRO real-time framework (TRIKE). These model outputs are routinely posted online (http://www.emg.cmar.csiro.au/www/en/emg/projects/eReefs/Results.html) and are available to CSIRO users via OpenDAP. The 4 km model has been currently running routinely in near real-time since September 2010, and a hind-cast archive suitable for scenario simulations exists back to that date. This period encompasses a range of forcing conditions imposed by the seasonal cycle, including extreme conditions of flood and cyclones. The 1 km model began routine operation in December 2014.

Both the sediment transport and BGC models do not operate efficiently when fully coupled to the hydrodynamic model (runtime is too slow) and must use an offline transport model as the driver.

The sediment model is initialised with the observed distribution of gravel, sand and mud. Catchment sediments discharged into the GBR are represented in the model by two classes of particles having varying settling velocities. There exist four benthic layers in sediments. The model is intended as a decision support tool to estimate GBR-wide distribution of fine sediments and it also supports biogeochemical model simulations and provides input to nested fine-resolution relocatable model RECOM.

The BGC model is organised as three ‘zones’: pelagic, epibenthic and sediment. The epibenthic zone overlaps with the lowest pelagic layer and shares the same dissolved and suspended particulate material fields. The sediment is modelled in multiple layers with a thin layer of easily resuspended material overlying thicker layers of more consolidated sediment. Pelagic processes include phytoplankton and zooplankton growth and mortality, detritus remineralisation and fluxes of dissolved oxygen, nitrogen and phosphorus. Macroalgae and seagrass growth and mortality are included in the epibenthic zone whilst further phytoplankton mortality, microphytobenthos (benthic diatom) growth, detrital remineralisation and fluxes of dissolved substances are included in the sediment layer. Also included are the augmentation of nitrogen fixation, reef metabolism, filter feeders, radiative transfer, carbon chemistry including reef calcification and alkalinity models, air-sea exchange including atmospheric deposition, rain nutrients and dust, benthic iogeochemistry including links with substrate boulders reef etc., bioturbation and burial, seagrass.

The eReef Marine modelling provides a capacity to predict impacts of catchment loads on water quality under acute flood event conditions, and chronic post-flood and dry season conditions. Further, ecological response models can employ output from the water quality model to simulate, for example, coral cover, coral recruitment, habitat community composition, macroalgae and COTS as indicators of reef health (Herzfeld et al. 2016).

Operating Skills

A re-locatable model, RECOM, is an automated re-locatable modelling system capable of generating high resolution models of hydrodynamics, waves, sediment transport and biogeochemistry that are nested within the 4 km or 1 km regional models. This package is designed for non-specialist users, whereby the user simply and intuitively interacts with the models via a graphical workflow interface.

Custodianship

The eReefs Marine modelling components reside with the Coastal Environmental Modelling (CEM) team with the Marine Biogeochemistry Program within the CSRIO Marine & Atmospheric Research group. A modelling platform Environmental Modelling Suite (EMS) houses the suite of core functionality (hydrodynamics, sediment transport, biogeochemistry and waves) and supporting libraries for CEM.

Key contacts

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Training

No formal training is provided. SHOC sediment transport and biogeochemistry user guide manuals are available at: http://www.emg.cmar.csiro.au/www/en/emg/software.html

Research and development priorities

No research and development priorities identified.

Key publications and links

Herzfeld, M, Andrewartha, J, Baird, M, Brinkman, R, Furnas, M, Gillibrand, P, Hemer, M, Joehnk, K, Jones, E, McKinnon, D, Margvelashvili, N, Mongin, M, Oke, P, Rizwi, F, Robson, B, Seaton, S, Skerratt, J, Tonin, H, Wild-Allen K 2016, *eReefs Marine Modelling: Final Report*, Jan. 2016, CSIRO, Hobart, 497pp.

Herzfeld, M 2015, 'Methods for freshwater riverine input into regional ocean models', *Ocean Modelling,* 90**,** 1-15.

Herzfeld, M, Waring, J, Parslow, J, Margvelashvili, N, Sakov, P, Andrewartha, J 2008, *SHOC: Sparse Hydrodynamic Ocean Code Science manual*. CSIRO internal document. http://www.emg.cmar.csiro.au/www/en/emg/software/EMS/hydrodynamics.html

Webster, IT, Brinkman, R, Parslow, J, Prange, J, Stevens, ADL, Waterhouse, J 2008, *Review and Gap Analysis of Receiving-Water Water Quality Modelling in the Great Barrier Reef*, CSIRO Water for a Healthy Country Flagship. 137 p.

Conclusion

The water models presented in this catalogue cover a wide range of hydrologic processes and simulate and/or predict water quantity and quality at different temporal and spatial scales.

A large number of diverse water models are being extensively used by the Queensland Government for policy making in the area of natural resources management (NRM). It should also be noted that there is a vast amount of experience and expertise within Queensland Government departments in using these models and interpreting their results, including an acute awareness of model limitations.

The water models used in Queensland could be classified in a number of different ways. Conceptually, they can be grouped into lumped, e.g. Sacramento, or distributed, e.g. AussieGrass, models. Some are run for individual runoff or flood events such as HEC-RAS and MIKE 11, while others run using daily time steps continuously. From the perspective of future research and development, however, all water models can be effectively classified into three categories:

I. Models that are mature and well established:
   a. SIMHYD
   b. Sacramento
II. Models that are complex, still evolving and widely used in Queensland and elsewhere:
   a. HEC-RAS
   b. MIKE11
   c. MODFLOW
   d. TUFLOW
   e. WATHNET
III. Models that are developed largely in Queensland to address policy issues that are uniquely or particularly relevant to Queensland and their use and adoption beyond Queensland are so far limited by comparison:
   a. Howleaky
   b. GRASP-AussieGRASS
   c. APSIM
   d. MEDLI
   e. Implementation of eWater Source for Reef catchments

For Category I models, there is little research and development potential as they are essentially ‘off-the-shelf’ models, and any change or improvement would simply lead to a new and different model with similar and well-defined functionalities.

For Category II models, much of the research and development needs are addressed by model developers in response to large user communities. QWMN and the Queensland Government are not able to effectively influence the direction of these models’ development and improvement.

Water models in Category III are largely developed in Queensland to address issues of importance to the state. The Queensland Government has invested considerable amount of resources in testing and implementing these water models and owns their intellectual capital and intellectual property. Research and development needs should be most effectively sought and identified among Category III water models because improvement in these models can be readily and efficiently implemented and tested for Queensland river basins.

Recommendations

This report recommends that:

- a searchable meta-database be developed for different model user groups to select information on water models based on model functionality, complexity, cost, and model applications in Queensland; and

- user engagement workshops be held to identify areas for the strategic improvement of Category III water models in Queensland, where users would broadly include policy and decision makers; model operators, model developers, model trainers and educators.

SUMMARY TABLE - Attributes of Water Models used by Qld Government

WATER MODEL	Category	Custodianship	User Base	R & D Potential	Mode (Continuous/ Event-based)	Lumped/ Distributed	Model Complexity (1-5)	Functionality (M-U)	License Cost	Modelling Skills	Data Requirements	Computer Requirements	Training Availability	Visualisation	Scale	Representation scheme
Soil Water App (replaced HowWet)	III - developmental potential in Qld	USQ	DAF, Farmers	High	C	L	2	S	Free	Low	Climate, soil, soil water, transpiration	IPhone, iPad (iOS)	Online Tutorials	Yes	Paddock	point
Howleaky	III - developmental potential in Qld	DES	DNRME, DES, Farmers, USQ	High	C - daily	L	2	M	Free	Medium	Climate, soil, soil water, Curve number, Crop/Irrigation management, leaf area, erodibility	Windows	Online Tutorials	Yes	Paddock	point
ApSim	III - developmental potential in Qld	APSIM Initiative	CSIRO, DAF, DNRME, DES, UQ, AgResearch Ltd.	High	C - daily	L	2	M	Free	Medium	Climate, soil, soil water, Curve number or SWIM, Crop/Irrigation management, leaf area, erodibility	Windows	Online Tutorials	Yes	Paddock	point
GRASP-AussieGrass	III - developmental potential in Qld	DES	DES, DNRME, DAF	High	C - daily	L	3	M	Free	Medium	Climate, soil, land type, vegetation, stock management	Windows through to High Performance Computer	Manuals, CD Tutorials	Yes	Paddock through to Landscape on 5k x 5k grid	raster
MEDLI	III - developmental potential in Qld	DES	EHP, DES	High	C - daily	L	2	S	Free	Medium	Climate, soil, soil water, Curve number, Crop/Irrigation management, plant green cover	Windows	Periodic workshops	Yes	Paddock	point
2CSalt	III - developmental potential in Qld	eWater Ltd	CSIRO, DNRME, DES	Medium	E	L	2	S	Free	Medium	Pre-run water balance land use modelling from APSIM or HOWLEAKY. Groundwater Flow System Maps and attributes, DEM, Land use	Windows	Online Tutorials	Yes	Groundwater Flow units - Paddock through to Catchment (1000 - 2000km^2)	point
BC2C	III - developmental potential in Qld	eWater Ltd	CSIRO, DNRME, DES	Medium	C	L	3	S	Free	Medium	Climate, Flow, Evapotranspiration, DEM, Groundwater Response Units, Land Use	Windows	Online tutorials	Yes	Catchment - Basin	point
eWater - Quality	III - developmental potential in Qld	eWater Ltd	DNRME, DES, Commonwealth & State Gov. NRM Groups	High	C - daily	D	4	M	Free - Public Version	Very High	Sacramento Rainfall/Runoff modelling, DEM, soils, vegetative cover, APSIM, HOWLEAKY, GRASP, RUSLE, Crop/Grazing Management	Windows through to High Performance Computer	Online tutorials	Yes	Catchment - Basin	node-link
IQQM	III - developmental potential in Qld	DES	DES, DNRME	Med-Low	C - daily	D	3	S	Free	Very High	Sacramento Rainfall/Runoff modelling. Comprehensive set of rules for movement of water through river system	High Performance Computer	No formal training	Limited	Catchment - Basin	node-link
eWater Source – Quantity	III - developmental potential in Qld	eWater Ltd	DES, DNRME	Medium	C	D	4	M	Proprietary	Very High	Choice of Rainfall/Runoff model. Comprehensive set of rules for movement of water through river system	Windows through to High Performance Computer	Online Training	Yes	Catchment - Basin	node-link
Receiving Water & Coastal Models	III - developmental potential in Qld	CSIRO CEM	NRM Groups, Commonwealth & State Gov.	Medium	C	D	4	M	Free - RECOM Ver.	Medium to Very High	In automated Relocatable Coastal Ocean Model RECOM package a graphical user interface can be used	Windows through to High Performance Computers	User Manuals. No formal training	Yes	Regional scale 5km resolution nested within global circulation model. And 1km resolution nested within 4km model	raster
TUFLOW	II - Global	BMT WBM	State & Local Government	Med-Low	C	D	4	M	Proprietary Tutorials free	Medium to Very High	Definition of watercourse network schematic, river reach cross-sections at multiple locations. Surface roughness, upstream/downstream boundary conditions, inflow at multiple locations.	Windows through to High Performance Computers	Online Tutorials	Yes	Floodplain- Receiving Water	raster
WATHNET	III - developmental potential in Qld	DES, DNRME	DNRME	Med-Low	C	D	4	M	Free	Very High	Pipeline capacities, storage capacities and behaviour (including evaporation), and manufactured water (from desalination, recycled) and water demands across a region.	Windows through to High Performance Computer	No formal training	Limited	Catchment - Basin	raster
HEC RAS	II - Global	US Army	US Army	Low	Event	D	3	M	Free	Medium	Definition of watercourse network schematic, river reach cross-sections at multiple locations. Surface roughness, upstream/downstream boundary conditions, inflow at multiple locations. Sediment particle size, WQ parameters.	Windows	Periodic Workshops	Yes	Catchment - Basin	river reach
MODFLOW	II - Global	USGS	USGS	Low	C	D	3	M	Free/Proprietary (GUI)	High	Define Groundwater Flow domain. Aquifer layers (confined, unconfined, both), hydraulic parameters, boundary conditions. Rainfall recharge, pumping, evapotranspiration.	Windows through to High Performance Computer	Online tutorials	Yes	Catchment - Basin	raster
MIKE	II - Global	DHI Group		Med-Low	Event	D	2	S	Proprietary	Medium	Definition of watercourse network schematic, river reach cross-sections at multiple locations. Surface roughness, upstream/downstream boundary conditions, inflow at multiple locations.	Windows	Online Training	Yes	Catchment-Basin	river reach
Sacramento	I - mature & established	US Weather Service		Low	C - daily	L	1	S	Free	Medium	Daily rainfall, flow, & potential evaporation	Windows	Online Tutorials	Yes	Catchment - Basin	point
SIMHYD	I - mature & established	CSIRO		Low	C - daily	L	1	S	Free	Medium	Daily rainfall, flow, & potential evaporation	Windows	Online Tutorials	Yes	Catchment - Basin	point

Clarification

Model Complexity - is the number of processes modelled and the range of scales the model is able to handle	From single process (1) to multiple processes (4)
Modelling Skills - are the skills required to run and use the model proficiently and competently	Low; Medium, High, Very High
Functionality	M - multiple; S - single