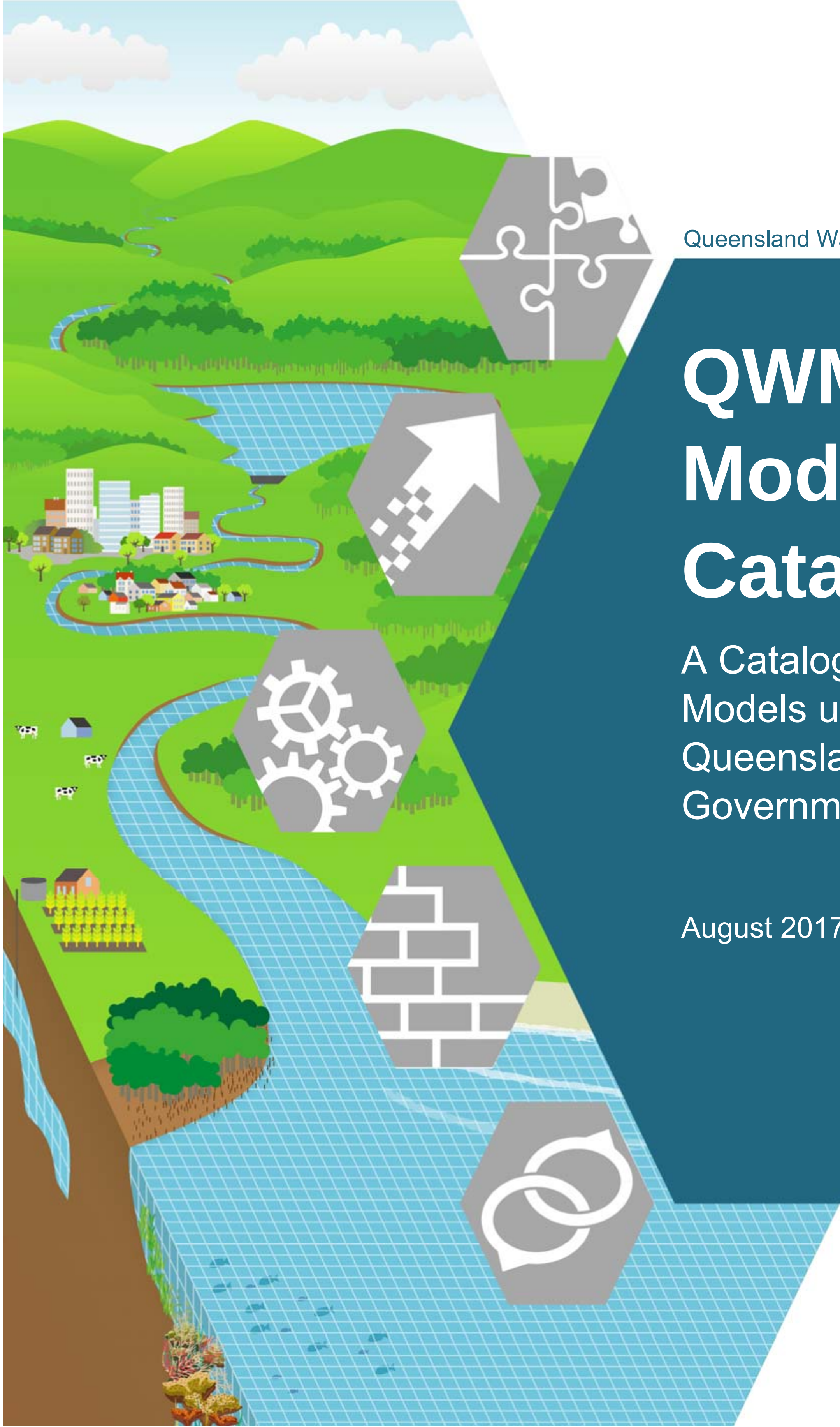

Queensland Water Modelling Network

QWMN Model Catalogue

A Catalogue of Water Models used by the Queensland Government

August 2017

A Catalogue of Water Models Used by the Queensland Government

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Introduction

The Queensland Government recently established an interdepartmental Queensland Water Modelling Network (QWMN). The state-wide Network will focus on modelling R&D and innovation to improve the efficiency and effectiveness of operational water modelling activities.

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

The purpose of the Water Modelling Catalogue is to provide a concise overview of the major water models used by the Queensland Government, outlining their policy application, key characteristics, functional capabilities, spatial and temporal operations, assumptions, as well as other strengths, weaknesses and opportunities to support policy, planning and risk assessment programs. The Water Modelling Catalogue 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 Modelling Catalogue is to expose university researchers and students to the scope and range of models being applied by Queensland Government agencies, and the potential opportunities to utilise these tools and applications for teaching and collaborative research projects. The Water Modelling Catalogue will also help bound discussions with universities and research organisations on model development going forward, focusing future investment into enhancing rather than re-inventing existing modelling tools.

The Water Modelling Catalogue illustrates the large variety of models used ranging from tools for farmers to make farm management decisions, researchers to assess alternative agricultural systems and sustainability outcomes, integrated catchment planning and assess effluent reuse, through to policy and planning support in surface and groundwater water management. Increasingly, an ensemble of water models is being used to evaluate and address a diverse range of environmental issues from land salinity risk to 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 Modelling Catalogue to reflect how the models are used for: Farmer Decision Support (SoilWater App), Agricultural Systems Assessment (Howleaky, Apsim, Grasp – AussieGrass), Planning Support (MEDLI, 2CSalt), Catchment Policy (Sacramento, Simhyd, IQQM, eWater Source, Source Catchments, MIKE 11, HEC-RAS), Groundwater Policy (MODFLOW, BC2C), and Receiving Water &Coastal water quality reporting.

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, how much is stored in the soil and the amount received during crop growth. Soil water stored during the fallow and early season maintains crop water supply especially toward 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 as a ready estimate of current soil water status during fallows and crops. The 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, with the aim to provide readily available, real-time estimates of soil-water that famers can use to make informed management decisions.

Policy Application

In the National Soil Research, Development, Extension Strategy improving water use efficiency for dryland and irrigated agriculture is identified, 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 specified by the user can be adjusted with inputs from: field estimates based on observation (e.g. very wet or dry); soil push probe depths; 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 is a smart device, it presents the user with the 5 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. A soil type that best represents the site is selected from a list covering the major soil types in each state.

A start date and starting soil water and distribution is set by the user. Starting soil water can be estimated from a push probe and local rain data selected or added. Then the user selects soil cover condition (crop residue) for the fallow and crop period, and fallow or crop type, and adjusts plant and maturity dates.

Operating skills

SWApp runs on iPhone and iPad (iOS) devices and is relatively simple to run, text and graphics show: the percentages of PAWC and mm 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 project “New tools to measure and monitor soil water” (USQ 00014) by the University of Southern Queensland. The SWApp is freely available for download at the App Store with documentation at www.soilwaterapp.net.au.

Key Contacts

David Freebairn: david.freebairn@usq.edu.au

Training

Training is through a help system, YouTube video and a library of reference material (http://www.soilwaterapp.net.au/Library).

Research & Development Priorities

Additional functions to be added in next 12 months include:

- Soil type selection based on a "national soil grid"
- Evaluation of user behaviour

Other capabilities planned include:

- Expand SWApp to operate on more platforms (1. Web App 2.Android)
- Link to more data sources e.g. Victoria's weather/soil water station network; Tasmania's Sense-T data network, 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 N calculator to facilitate fertiliser decision making and timing;
- Enact wider data sharing, mapping, area wide management along with better 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 for key experimental and farmer datasets to start the process of value adding to the many datasets that disappear after their primary use (often not published!)
- Add temperature sensing capability to hardware and App to aid with frost risk and sowing decisions.

Key Publications and Links

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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). *Howleaky* is derived from 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 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, enable a greater understanding and access to an analysis tool that captures the interrelationships between climate, soils, vegetation type, management and biophysical responses, at the paddock scale, and create more transparency and communication between technologists and land managers (Rattray et al., 2004). Howleaky is also able to run many simulations in a batched project, i.e. 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 the improvements in water quality through the adoption of improved land management practices, as defined under an ABCD practice management framework, and by linking ‘paddock’ model time series outputs to ‘catchment’ models (Shaw and Silburn 2016). This is undertaken to appropriately represent the complex interactions between climate x soils x management across the large expanse of GBR catchments.

Functionality, Capability

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

Robinson et al. (2007) has developed a phosphorous module in *HowLeaky* based on the approach of Sharpley (1995; 2007). Phosphorous is transported in two forms, dissolved and particulate phosphorous. 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. This module was later amended to include alternate methods for estimating dissolved reactive phosphorous and particulate phosphorous fractions (Robinson et al. 2011). The 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. These were further developed by Shaw et al. (2011). A central concept is application of an extraction coefficient to estimate concentrations of chemicals in runoff as a function of soil concentration, 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. There is 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 Department of Science, Information Technology and Innovation (DSITI) is custodian of the HowLeaky software, and distributed via a Creative Commons licence. The software is also available at (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 has commenced a project to enhance the model algorithms, governance arrangements, model documentation and access to the Howleaky model. The project is being led by 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, Mark Silburn DNRM, and through: info@howleaky.net

Training

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

Research & Development Priorities

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

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

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APSIM

Summary

The Agricultural Production Systems Simulator (APSIM) is a modular modelling framework that was developed to simulate biophysical process in farming systems, in particular 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 made up of a collaborative group from CSIRO and Queensland State Government agencies.

APSIM addressed a perceived need for modelling tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factors, whilst 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 with prediction of the long-term consequences of farming practice on the soil resource, such as soil organic matter dynamics, erosion, acidification; and more recently on water quality from sugarcane production in the Great Barrier Reef catchments.

APSIM is undergoing continual development, with new capability added to regular releases of official versions, current version being 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 this region is leading to development of dryland salinity and delivery of salt to waterways (Huth et al. 2003)

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

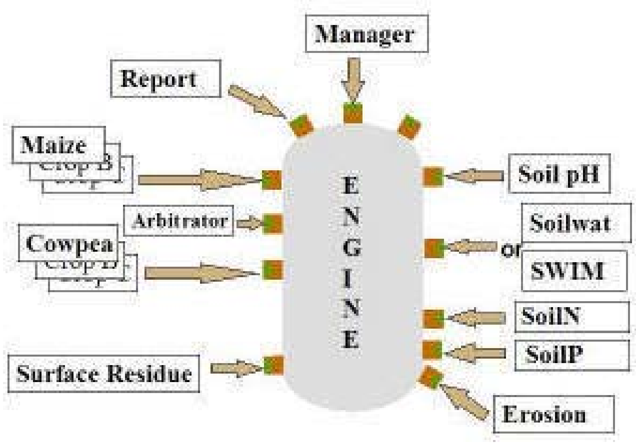
Functionality, Capability

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 that 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,
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 water balance modules; SoilWater which is a tipping bucket method using a USDA curve number or SWIM which 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 using the Freebairn concentration-cover, and USLE factors, and an erosion productivity function and calculates. A soil carbon/nitrogen model simulates nitrification and denitrification, including emissions of N_2O. 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, for example as 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.
- Various model development, testing and documentation tools.

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.

Operating skills

There are an extensive set of training manuals that comprehensively facilitates the introduction and use of APSIM at: http://www.apsim.info/

Custodianship

APSIM is freeware software available, with registration at (https://www.apsim.info/Products/Downloads.aspx). An APSIM Initiative was established in 2007 to promote the development and use of the science modules and infrastructure software of APSIM. APSIM development, maintenance and commercialisation are now the responsibility of the APSIM Initiative and are now separate from the research-oriented Agricultural Production Systems Research Unit (APSRU). APSRU is now an informal collaborative network based out of Toowoomba, Australia. 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 State of Queensland 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 is through: apsim@daf.qld.gov.au

Training

An APSIM help and support forum has been established, with training manuals and periodic training outlined at: http://www.apsim.info/

Research & Development Priorities

- Development of a pesticide module
- Representation of DIN lost to runoff
- Representation of irrigation generated runoff in furrow irrigated systems

Key Publications and Links

Carroll, C., Waters, D., Vardy, S., Silburn, D.M., Attard, S., Thorburn, P.J., Davis, A.M., 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 of perennial grasses of Northern Australia. It is a daily time step model which 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, simulating a point on the landscape but is used spatially in AussieGRASS and a number of other products where output is averaged across spatial zones (e.g. paddocks, land types, 5km pixels). There is a management component of the model that includes management records for decisions such as stocking rate and burning. Within the management records, observations of features like total standing pasture and pasture can be input to calibrate the model.

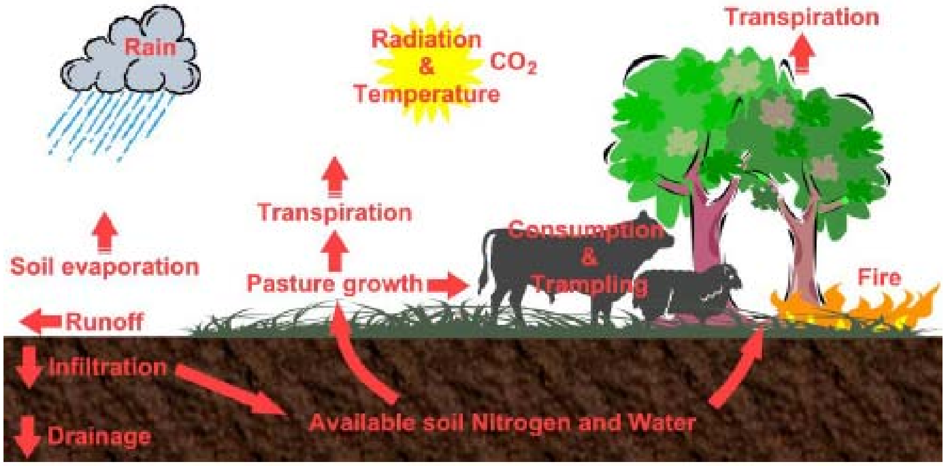

Figure 1 Simplified Grazing Model

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

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

GRASP model components relevant to water quality modelling:

Model Component	Description
Water Movement Through Soil	Soil storage bucket / GLEAMS / 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 / 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 / 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 https://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 phase
- provides relative rainfall and pasture growth maps
- 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 with the aim to support primary producers and natural resource managers manage the risks, and exploit the opportunities, resulting from Australia’s variable and changing climate. The GRASP model has recently 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 use include grass fire risk products for rural fire services; reporting on rangeland condition change to ACRIS (Australian Collaborative Rangelands Information System); analysis of greenhouse emissions; and 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 Paddock 2 Reef program has been primarily to ascertain the impact of management (four managements ‘A’, ‘B’, ‘C’ and ‘D’) 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 to another (e.g. from ‘D’ to ‘C’ management). 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 Paddock 2 Reef.

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 run single runs. Documentation of the model includes a technical manual, calibration manual and tutorials which are available as a complete package.

Custodianship

Development of GRASP was funded by Queensland Primary Industries and Fisheries. Various funding agencies have contributed to its ongoing development. Dr Greg McKeon was the prime developer with contributions from many other researchers. There is now a GRASP model version coded in FORTRAN90 known as Cedar GRASP with aim that coding will allow future programmers to make changes and add new sub-models

The Queensland Department of Science Information Technology Innovation (DSITI) are custodians of the GRASP and AussieGRASS models.

Key Contacts

Ramona Dalla Pozza, DSITI: ramona.dallapozza@dsiti.qld.gov.au

Training

Under previous MLA funding extensive workshops were conducted, and are periodically undertaken by DSITI staff.

Research & Development Priorities

Refer MLA Report (2007)

- 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
- detachment/decomposition process, species composition change.

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MEDLI

Summary

MEDLI (Model for Effluent Disposal using Land Irrigation) is a daily time step biophysical model to quantify the water, nutrient and salt balance of pasture & 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 by the Queensland Department of Primary Industries, the CRC for Waste Management and Pollution Control, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in the mid 1990's. Over the last 2 decades, 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 the Windows operating system (Windows 7+) by the Department of Science, Information Technology and Innovation (DSITI) in June 2015. It 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 represented a substantial upgrade on Version 1 with a completely rebuilt software package to run on modern computer operating systems, a more intuitive user interface, the addition of a microbiological health risk assessment module, and a detailed interactive summary report with comprehensive text and graphical output informed by prior users. Software development is on-going.

Policy Application

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

Functionality, Capability

MEDLI is a "medley" or integration of a number of models to simulate the effluent stream from its production through to the disposal area (Gardner et al. 1996). It was designed as a "top-down" model, in that the major processes were included in the model, whilst 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". But just as importantly, the simplified model structure was parsimonious in the parameter input requirements, so that the model could 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: Daily rainfall, temperature (minimum and maximum), Class A pan evaporation and solar radiation data are required by MEDLI. They can be obtained for Australian locations directly from the SILO database (http://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 & water balance: MEDLI's pond module consists of mass balances for the hydraulic, nitrogen, phosphorus, and total dissolved salts components. It uses a number of empirically derived relationships to model the 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 & 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 3 to 4 user-defined soil layers, 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 C:N (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 N and P that are removed from the effluent irrigation site by the export of harvested material (i.e. cut & 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 Multirun option to help identify the optimal irrigation area and pond volume combination for a scheme and the Reliability of Supply option to determine the potential irrigation demand of a scheme.

Custodianship

DSITI is the custodian of MEDLI.

Key Contacts

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 & Development Priorities

Current development priorities are to extend MEDLI V2 to intensive rural industry and rainfall-dependent waste streams, fully release the pathogen module, and to expand MEDLI to multiple paddocks with one pond system.

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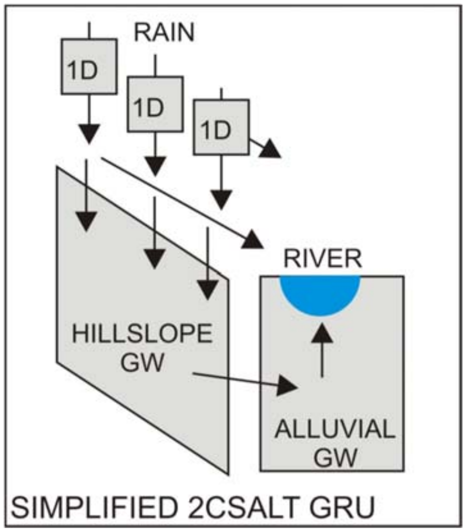
2CSALT

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. By separating the catchment into many separate units, this 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 1-D 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 1-D 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 within the Murray-Darling Basin to model upland unregulated catchments in a consistent and comparable manner, to 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).

It was designed to use existing regional data such as topography (digital elevation models) and Groundwater Flow Systems (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 landuse 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. Requires 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 through contacting the eWater CRC directly (http://www.ewater.com.au/).

Key Contacts

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Training

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

Research & Development Priorities

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 is also known as SAC-SMA which stands for SACramento Soil Moisture Accounting model 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. As to the potential evaporation, oftentimes, the daily value was taken to be the mean monthly potential evaporation divided by the number of days for the month. In effect, only 12 distinct PE values as input 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 (Figure 1).

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 the GBR 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 record is usually much longer than the flow record. A conceptual hydrologic model like the Sacramento can be used to estimate daily flows from recorded daily rainfall to represent climate variations and the effect of such variations on stream flows over a period that is much longer than the available flow record.

Operating skills

Manual calibration 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 the manual calibration experience 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 DSITI in Queensland, Department of Primary Industries in NSW and eWater.

Key contacts in Queensland

Chas Egan

Maria Greer

Matthew Gooda

Training

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

The Sacramento model is one of 5 rainfall-runoff models hosted in the RRL, a collection of conceptual hydrologic models sharing the same input data requirement, developed through CRC Catchment Hydrology.

RRL is readily available for registered users through the eWater web site with user guide and some training materials (Perraud et al. 2003; Podger 2003).

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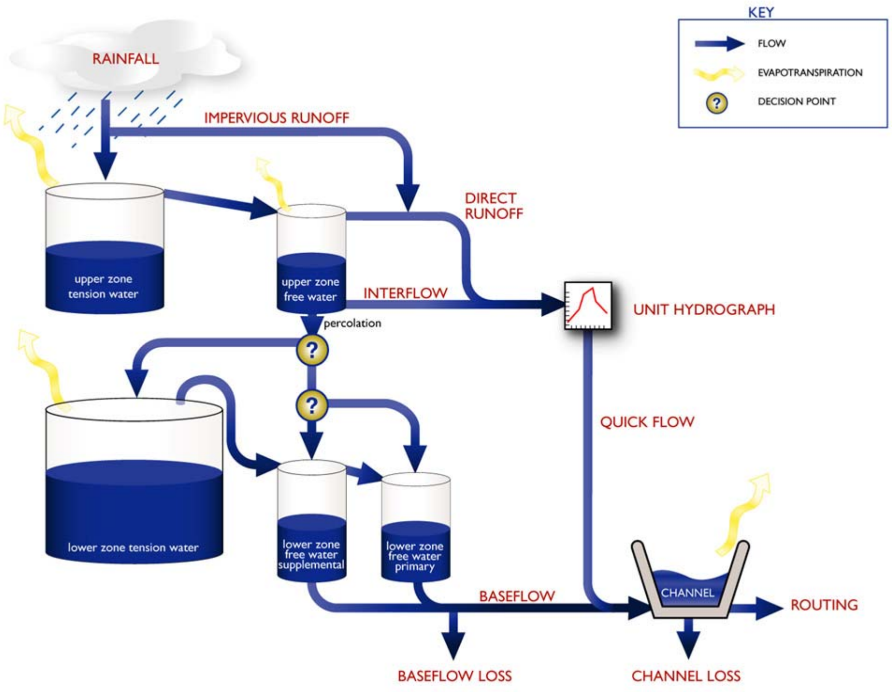

Figure 1. Schematic diagram showing conceptual storage and flow pathways used in Sacramento (Source: RRL training material, 2004).

SIMHYD

Summary

SIMHYD, which stands for Simplified Hydrologic model, is a conceptual hydrologic model to simulate daily stream flows (Chiew et al. 2002). This model is a simplified version of HYDROLOG (Porter and McMahon, 1975) with a reduction in model parameters from the original 17 to 9 (Chiew et al. 2002).

Input to SIMHYD 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. As to the potential evaporation, oftentimes, the daily value was taken to be the mean monthly potential evaporation divided by the number of days for the month. In effect, only 12 distinct PE values as input for SIMHYD and other similar conceptual models. Model parameters need to be calibrated using observed stream flow data. Calibration is most necessary because there were no reliable relationships between parameter values and catchment characteristics based on an extensive analysis for about 300+ catchment around Australia (Chiew et al. 2002)

Policy Application

SIMHYD was used widely in the Source Catchments modelling framework for flow simulation for GBR 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 record is 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 of such variations 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 RR with robust calibration and simulation tools (Perraud et al. 2003).

Data Custodianship

SIMHYD is a member model within Rainfall-Runoff Library - RRL hosted by eWater. Implementation of SIMHYD can be found in other organisations such as CSIRO and universities, and institutions overseas. SIMHYD is also one of hydrologic models that could be used for flow simulation within the Source Catchments framework.

Key contacts in Queensland

David Waters, DNRM

Training

SIMHYD is one of 5 rainfall-runoff models hosted in the RRL, a collection of conceptual hydrologic models sharing the same input data requirement, developed through CRC Catchment Hydrology.

RRL is readily available for registered users through the eWater web site with user guide and some training materials (Perraud et al. 2003; Podger 2003).

Key publications and links

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https://toolkit.ewater.org.au/Tools/RRL

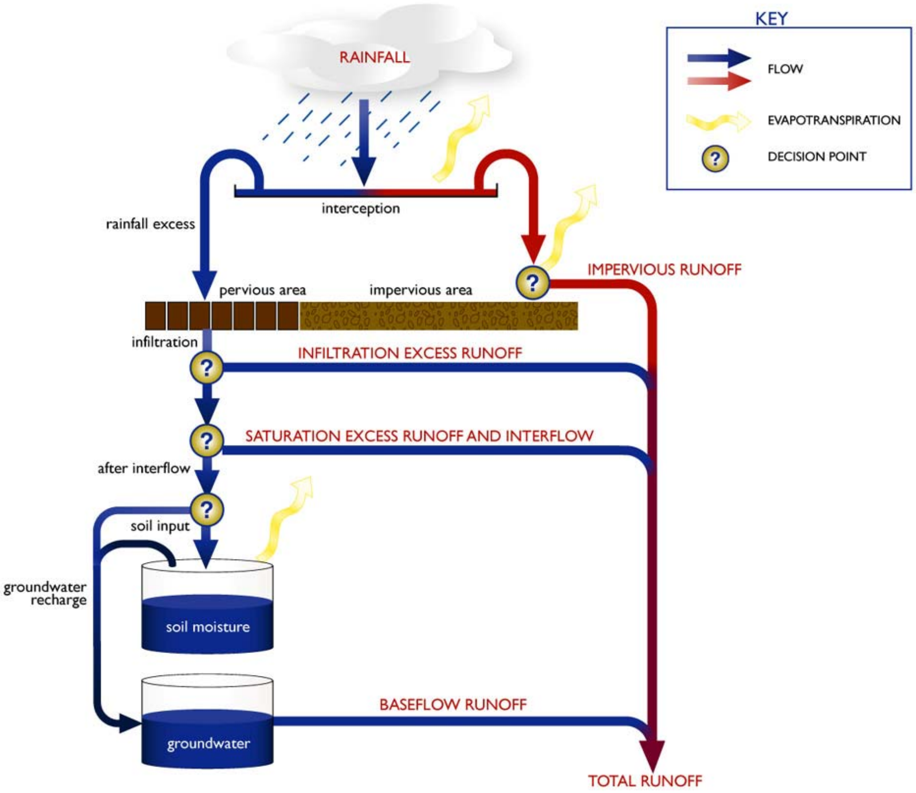

Figure 1. Schematic diagram showing conceptual storage and flow pathways used in SIMHYD (Source: RRL training material, 2004)

IQQM

Summary

The IQQM (Integrated Quantity and Quality Model) is a hydrologic modelling tool developed by the NSW Department of Land and Water Conservation, with collaboration from the Queensland Department of Natural Resources and Mines. Its prime purpose is to simulate the impacts of water resource management strategies on flows, so the evaluation of the impacts of various water diversion scenarios can be assessed and incorporated in Water Resource Plans (WRP's) (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 for representation of the particular river system (e.g. gauging stations, diversion sites, stream junctions, etc.), 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, and is flexible in its range of application. Output from the model includes 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, where there are often multiple supply options. Complex multiple water supply problems occur when water can be sourced from storages in parallel, storages 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; 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 in-stream 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 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 allows the model to be configured to simulate any river system. (Simons, Podger, Cook 1996)

Node types available 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, wetlands and floodplain storage. Water sharing rules, including interstate agreements, and water use accounting procedures may 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 may 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 in-stream salinity. IQQM can be used to understand how salt is transported within river systems, and is 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

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

Custodianship

New South Wales maintains the IQQM codes and maintains register of all of the model holders/users. The custodianship of the IQQM version used by Queensland Government for Water Resource Planning resides with DSITI.

Key Contacts

Matthew Gooda, Craig Johansen (DSITI).

Training

No formal external IQQM training is conducted.

Research & Development Priorities

IQQM is a platform that has been applied across Queensland and New South Wales and overseas for over 20 years and capability of the platform has been fine-tuned during this time. There are no research and development priorities identified for IQQM by Queensland and New South Wales.

Key Publications and Links

Cullen, P., Marchant, R., Mein, R. (2003). Review of Science Underpinning the Assessment of the Ecological Condition of the Lower Balonne System. Report to the Queensland Government Independent Scientific Review Panel. ISBN 0 7345 2448 XQNRM03025

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eWater Source

Summary

Many of Australia's and Queensland's large river systems are highly regulated, with physical flow control and storage structures, as well as a range of water sharing rules and regulations. Regulated rivers systems provide resources for a range of water needs: irrigation, urban use, and aquatic ecosystems such as wetlands leading 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 falls under different political jurisdictions, and where different modelling tools are used to guide water resource management. The Murray-Darling Basin (MDB) is an example of such an Australian transboundary example where state agencies responsible for management of water resources within the basin use different models (rainfall-runoff models and river system models). The New South Wales and Queensland state agencies use the daily Integrated Quantity and Quality Model (IQQM) with the Sacramento rainfall- runoff model. The Victorian state agency uses the REALM model at daily, weekly and monthly time steps. The Murray-Darling Basin Authority uses the Monthly Simulation Model (MSM, monthly) with BigMod (daily) to model river flow regulation in the Murray 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, regulatory and planning based system for management of 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).

Policy Application

The planning component of Source has been trialled in Queensland in the Macintyre Brook system in the northern region of the MDB with the Queensland Department of Science, Information Technology, and Innovation (DSITI). The focus of the trial has been 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 is 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 capability.

In the planning mode, Source is designed to assess the long-term impacts of water resources policy on system storages, flows, and water shares. In the operations mode, Source is designed to support the operation of regulated river systems and forecast inflows, on a daily or seasonal basis. The eventual aim of Source is to provide the ability to use a consistent modelling approach across different catchments and state boundaries, such as the Murray Darling Basin.

The components used to model regulated rivers within the 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/desal)
- conjunctive groundwater-surface water use analysis.

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
- select from a range of 'water user' demand models, including urban, environmental and irrigation demand, to inform storage releases.

Source's capabilities can be extended through the use of plugins, which can modify or replace many of the standard tools within Source. They can be new component models (e.g. new rainfall runoff or Water User demand model) and data processing tools.

eWater Source is built on top of 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 the eWater Source is its flexible software architecture, which makes it easily expandable, enabling users to create and link their own custom functions.

Source is available in two versions – the free public version, which is a fully featured IWRM modelling platform, and the full version, which provides access to the complete range of governance functionality, such as water sharing, accounting and capacity sharing methods

The free Source (public version) is a fully featured hydrological, water balance and water quality modelling platform, which promotes transparency and knowledge sharing. It allows sharing of models across governments, NGOs and the wide range of stakeholders necessary to engage in IWRM. It is an ideal entry point for IWRM research and transboundary studies.

Custodianship

eWater Limited (Ltd) are the custodians of Source and is a public incorporated limited guarantee, not-for-profit Australian company. Members include:

- Murray-Darling Basin Authority (representing the Commonwealth)
- Queensland Department of Science, Information Technology and Innovation
- New South Wales Department of Primary Industries Water
- Victorian Department of Environment, Land, Water and Planning
- South Australian Department of Environment, Water and Natural Resources

Key Contacts

Matt Gooda, Craig Johansen (DSITI) and at: http://ewater.org.au/contact-us/

Training

eWater provide a wide range of web-based and video training packages around the functional operation on Source. eWater encourages a collaborative approach to development and knowledge sharing within the Source user community, and maintain 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 is found at: http://ewater.org.au/products/ewater-source/source-training/

Research & Development Priorities

Key Publications and Links

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Source Catchments

Summary

The eWater CRC Source Catchments is an integrated modelling framework. This modelling framework was developed out of the E2 node-link modelling system to model 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 Source integrated modelling system uses Functional Units (FUs) to represent differences in hydrological responses between land uses. There are two modelling components assigned to each FU representing the processes of: Runoff generation and Constituent generation. Event Mean Concentration/Dry Weather Concentration (EMC/DWC) model, which is a standard constituent generation model in Source. Runoff and constituents are routed from a sub-catchment through the stream network via nodes and links.

A daily runoff time-series for each FU in each sub-catchment is predicted, which is then accumulated to predict daily flow, or discharge, in each stream link. The inputs are grids of daily rainfall and potential evapotranspiration (Jeffrey et al., 2001).

Source is not a single hydrological model. It is a range of models that have been incorporated into an adaptable framework that recognises the practical, political and technical issues in developing water policy and the need for transparency and sustainability. Source can be customised using ‘plug-ins’ to address specific policy questions.

Policy Application

The Source Catchments modelling framework was used to generate sediment, nutrient and herbicide loads entering the GBR lagoon from adjacent catchments (420,000 km^2) and reporting progress towards meeting Reef Water Quality targets.

Functionality, Capability

Initially in the GBR Source Catchment modelling the SIMHYD water balance model (Chiew et al., 2002) was used to conceptualise the effect of interception, soil moisture and groundwater stores on total daily runoff and evaporation. In the second phase reporting an improved hydrological calibration performance was achieved using the Sacramento Rainfall-Runoff model particularly for calibrating high flows, which was identified through previous calibration that needed to be improved. 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. The model parameters are calibrated 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, using the Parameter Estimation Simulation Tool (PEST; Doherty, 2009). The accumulated unregulated stream flow is then modified by the modeller to include water transmission losses and human extractions as daily time-series for relevant stream nodes, based on available administrative and stream-gauge records.

For the constituent generation component SedNet modelling functionality was incorporated into Source to provide estimates of gully and streambank erosion and floodplain deposition (Ellis & Searle 2014). Two locally developed paddock models, HowLeaky (Rattray et al. 2004 ab) and APSIM (Keating et al. 2003) were used to generate 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 has invested and evaluated the usability of their software through extensive stakeholder engagement. Source features a wide range of data pre-processing and analysis functions that allows users to create and compare multiple scenarios, assess the consequences, and report on the findings.

Data Custodianship

The Source Catchment modelling framework resides with eWater and has released a free public version of Source, which is suitable for IWRM studies and development of customised Decision Support Systems. Source (public version) is a fully-featured hydrological, water balance and water quality tool, an ideal entry point for Transboundary Integrated Water Resource Management studies and research based on the leading hydrological and water quality foundations of Source.

Key contacts in Queensland

David Waters DNRM, Rob Ellis DSITI

Training

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

Research and Development Priorities

Key publications and links

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Renard K.G., Forster, G.A., Weesies, D.K., McCool, D.K., Yoder, D.C. (1997). Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation. Agricultural Handbook 703. (United States Department of Agriculture: Washington, DC).

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Waters DK, Carroll C, Ellis R, Hateley L, McCloskey G, Packett R, Dougall C, Fentie B (2014). Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR, Technical Report, Volume 1, Queensland Department of Natural Resources and Mines, Toowoomba, QLD (ISBN: 978-1-7423-0999).

MIKE 11

Summary

MIKE 11 was developed by the Danish Hydraulic Institute (DHI). MIKE 11 is a fully dynamic, one-dimensional modelling package. It includes comprehensive facilities for modelling complex river channel networks, lakes and reservoirs. With the 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 you 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 the MIKE 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; and,
- Inflow hydrographs at various locations along the reach of the watercourse.

Policy Application

Lower Fitzroy River Infrastructure Project (2015). MIKE 11 (version 2010) one-dimension (1D) hydrodynamic model was undertaken on Lower Fitzroy River, covering 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 MIKE 21 a 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.

Functionality, Capability

The 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 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.

MIKE 11 hydrodynamic model 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
- Tidal and storm surge studies in rivers and estuaries

Operating skills

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

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 Group and is proprietary software protected under copyright.

MIKE 11 has now been superseded by MIKE HYDRO River for river applications, along with a suite of other applications: 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.

Key Contacts

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

Training

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

Research & 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.

HEC-RAS

Summary

HEC-RAS stands for Hydrologic Engineering Center-River Analysis System. The software was developed at the Hydrologic Engineering Center, U.S. Corps of Engineers Institute of Water Resources (CEIWR-HEC). 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 HEC-RAS system contains several river analysis components for: (1) steady flow water surface profile computations; (2) one- and two-dimensional unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. A key element is, that all four components use a common geometric data representation and common geometric and hydraulic computation routines. 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.

The latest version 5.0 of HEC-RAS release in March 2016 includes 2-dimensional 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, 1-D and 2-D 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; and,
- Inflow hydrographs at various locations along the reach of the watercourse
- 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 4 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 one-dimensional 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 one-dimensional; two-dimensional; and combined one/two-dimensional 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 one-dimensional 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 Version 5.0 User's Manual, Two-Dimensional Modelling User's Manual, Application Guide, and Hydraulics Reference Manual are available on line.

HEC-RAS currently is able to 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 freely available in the public domain.

Key Contacts

Hydrologic Engineering Center, U.S. Corps of Engineers Institute of Water Resources (CEIWR-HEC)

Training

Training workshops are readily available. For example, a 3-day training workshop run by K Engineering on 1 and 2-dimensional 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 1-D and 2-D flood models using HEC-RAS is offered through ICE WaRM in Brisbane in September 2017: http://www.surfacewater.biz/brisbane/

Key Publications and Links

The web-site 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

Research & Development Priorities

HEC-RAS is a free software, used widely in the U.S. and Australia, and in many other locations around the world. There is an email address for reporting bugs and improvement suggestions.

MODFLOW

Summary

MODFLOW is a three-dimensional finite difference model groundwater model (Harbaugh 2005). The groundwater flow domain is organised into rectangular or cubic block elements. MODFLOW is a modular groundwater model 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 three-dimensional 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. Thus 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 Lower Burdekin Groundwater project with the purpose to develop an integrated and holistic package of modelling tools to support the decision-making process for water management in the Lower Burdekin. The project was funded by the National Water Commission under the Raising National Water Standards Program.

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 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 with MODFLOW for pre- and post-processing of data. Many other models have been developed to work with MODFLOW input and output such as SEAWAT (Guo et al 2002) and GSFLOW (Markstrom et al 2008), making linked models which simulate several hydrologic processes possible (flow and transport models, surface water and groundwater models and chemical reaction models), because of the modular nature of MODFLOW.

Operating skills

MODFLOW may be used for either two- or three-dimensional 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; the user may 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 thus 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, so 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.

This is likely to become the standard platform in the near future, given that 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 (DSITI contractor), Lucy Reading QUT

Training

MODFLOW has been used by the QDSITI in previous groundwater flow modelling projects, thereby allowing a high-level of expertise and capacity for internal training. In addition there is on-line training at: **https://water.usgs.gov/ogw/modflow/MODFLOW.html**

Key Publications and Links

Harbaugh, A.W. (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, A.W., Langevin, C.D., Hughes, J.D., Niswonger, R.N., and Konikow, L. F., (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., N. Merrick 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, M.J., Gallagher, M. & 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.

Research & Development Priorities

- For MODFLOW 6 an operational management package (which is already a scheduled activity for the Border Rivers GW Model project) is required.
- Particle transport applications, and
- Evaluating the efficiency of GPU parallel solvers.

BC2C

Summary

The BC2C (Biophysical Capacity to Change) Model (Dawes *et al*. 2004) is an annual time-step model which uses a simple water balance approach, and groundwater response time theory to estimate the impact 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 is then summed to the area of interest (e.g. 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, with BC2C 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 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) they are suited to address 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 is computationally more intensive it can model a broader range of land-use scenarios, and examine seasonal impacts; with the ability to calibrate to measured gauged data, and outputs that can feed into river routing models.

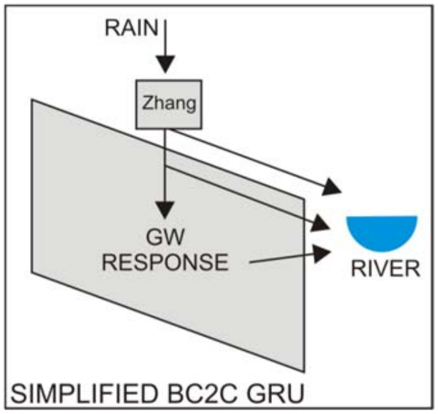

Figure 1. Simplified diagram of the basic structure of each groundwater response unit (GRU) in the BC2C model (from Gilfedder et al., 2007).

Policy Application

Fitzroy Salinity risk assessment 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).

The 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 mean annual water balance input, and its output shows the change in mean annual water and salt using an annual time-step. Figure 1 shows a simplified version of the conceptual model for a GRU.

Operating skills

BC2C is designed to be simply 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 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 is required, or more detailed description of the spatial patterns are required (www.toolkit.net.au/bc2c).

Custodianship

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

Training

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

Research & Development Priorities

Key Publications and Links

Chamberlain, T., Silburn, D.M., Forster, B.A., Wearing, C.H., Moss, J.B., Reading, L.P., Owens, J.S., Pearce, B.R. (2007). Salinity risk assessment for the Fitzroy Basin, Queensland. Department of Natural Resources and Water, Indooroopilly.ISBN:9311662172020

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

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

Gilfedder, M., M. Stenson, T. Dowling, A. van Dijk, and Walker, G.R. (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 2007 International Congress on Modelling and Simulation; December 2007; Modelling and Simulation Society of Australia and New Zealand 2007 p1478 – 1484.

Zhang, L., W.R. Dawes, and Walker, G.R. (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 intitiative 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 (Figure 1); a hydrodynamic model to predict the physical state of the system; a sediment transport model predicting the fate of suspended fine sediments, and; a biogeochemical model for water column and benthic production, water quality and nutrient cycling.

The eReefs Marine modelling uses a nested approach, with a regional 4 km resolution model nested within a global general circulation model and a 1 km resolution model subsequently nested within the 4km 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 4km model and December 2014 for the 1km 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 1km 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 4km and 1km scale are respectively operating in near real-time within the CSIRO real-time framework (TRIKE). These model outputs are routinely posted on the web (http://www.emg.cmar.csiro.au/www/en/emg/projects/eReefs/Results.html), and are available to CSIRO users via OpenDAP. The 4km 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 1km model began routine operation in December 2014.

Both the sediment transport and biogeochemistry 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; 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 EMS (Environmental Modelling Suite) houses the suite of core functionality (hydrodynamics, sediment transport, biogeochemistry and waves) and supporting libraries for CEM.

Key Contacts

Mike Herzfeld CSIRO

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 & Development Priorities

Key Publications and Links

Herzfeld, M., J. Andrewartha, M. Baird, R. Brinkman, M. Furnas, P. Gillibrand, M. Hemer, K. Joehnk, E. Jones, D. McKinnon, N. Margvelashvili, M. Mongin, P. Oke, F. Rizwi, B. Robson, S. Seaton, J. Skerratt, H. Tonin, K. Wild-Allen (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, I.T., Brinkman, R., Parslow, J., Prange, J., Stevens, A.D.L., 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.

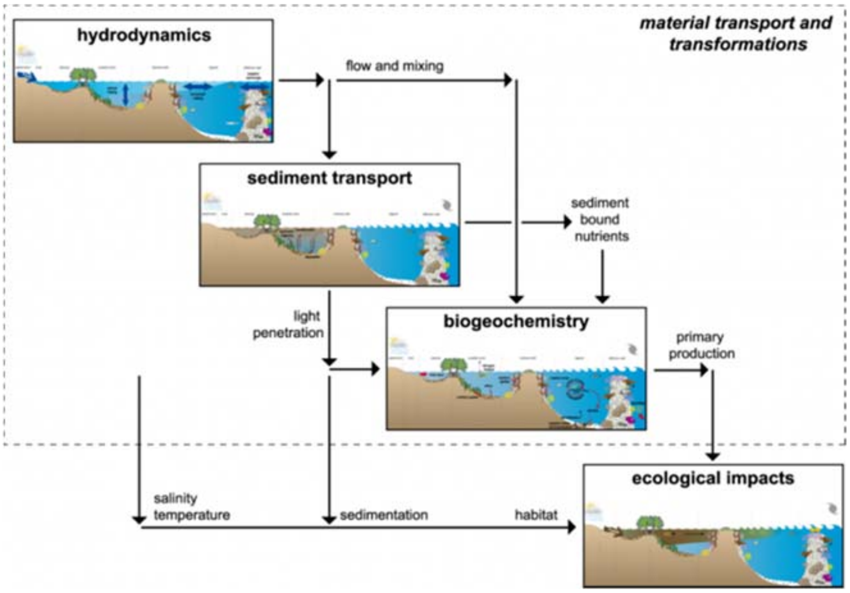

Figure 1. Primary components of a material transport and transformation models (inside box), and showing internal linkages between sub models and linkage to ecological impacts models (from Webster et al. 2008).

Conclusion

A large number of diverse water models are being used extensively in Queensland government for policy making in the broad area of natural resources management. These water models cover a wide range of hydrologic processes, and simulate and/or predict water quantity and quality at different temporal and spatial scales. There is also a vast amount of experience with and expertise within Queensland government departments in using these models and interpreting modelling 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, e.g.
    a. SIMHYD
    b. Sacramento
II. Models that are complex, evolving and widely used in and well beyond Queensland, e.g.
    a. HEC-RAS
    b. MIKE11
    c. MODFLOW
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 quite limited by comparison
    a. Howleady
    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 a large user community. QWMN and Queensland government are not in a position to effectively influence the direction of model development and improvement over next few years. Water models in the third category were largely developed in Queensland to address issues of importance in Queensland. Queensland government has invested considerable amount of resources in testing and implementing these water models and owns the intellectual capital and Intellectual Properties associated with water models in this category. It is also clear and obvious that research and development needs should be most effectively sought and identified among these water models because improvement in models in this category can be readily and efficiently implemented and tested for river basins around Queensland.

Recommendations

- That QWMN develop a searchable meta-database for different model user groups to select water models for information based on model functionality, complexity, cost, and model applications in Queensland;
- That QWMN organise user engagement workshops to identify areas for strategic improvement of Category III water models in Queensland. Users here are interpreted broadly to include policy and decision makers; model operators, model developers, model trainers and educators.