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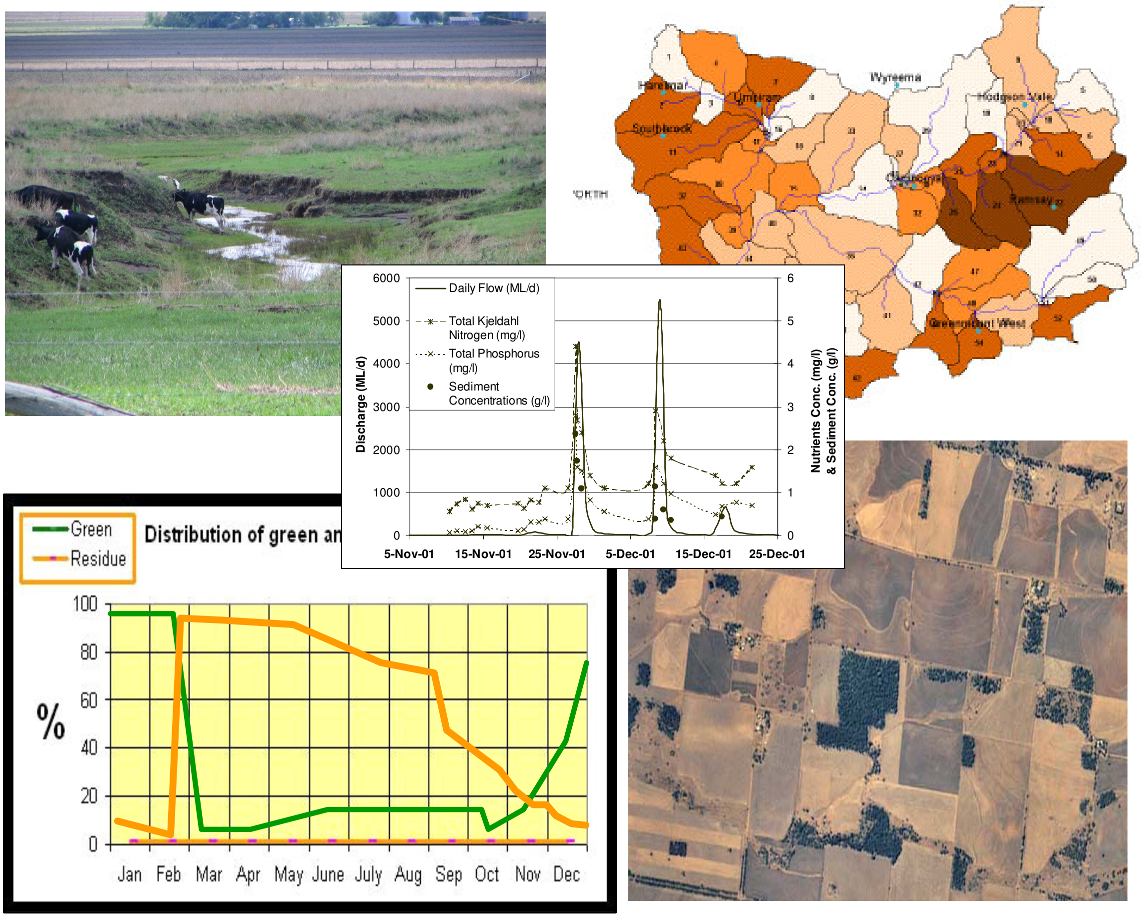

University of Western Australia

Final Report

Review of Water Quality Modelling Tools for the Investment Framework For Environmental Resources (INFFER)

May 2008

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1.0 BACKGROUND

The INFFER, the Investment Framework for Environmental Resources, is a new asset-based approach to natural resource management. The core aim of INFFER is to help natural resource management (NRM) investors to achieve the highest value NRM outcomes (water quality, salinity and biodiversity) that are possible with the available resources (Pannell and Ridley, 2008). The aim of the framework is to integrate biophysical, social and economic information to identify how best to respond in different circumstances.

This report provides an assessment of the state of model development available to support the biophysical understanding of water quality. The assessment is intended to be used by a range of stakeholders, and details a sample of water quality models currently available in Australia, their benefits and limitations, and essentially, describes what these models are useful for.

1.1 FUNDAMENTAL WATER QUALITY MODEL PROCESSES

While there are numerous water quality models, the fundamental concepts on which they are based are relatively few and are generally quite simple. There are three basic components of most water quality models – generation, delivery and transport (CRCCH, 2005).

1.1.1 Generation

Estimating how much sediment, nutrient or pollutant is produced in a catchment. In approximate order of complexity, approaches to generation are:

1. Average annual rate of generation per land use (mass/area/year), from studies average long term pollutant loads for particular land uses are derived;
2. Event mean concentration (mass/volume) from studies average long term pollutant concentrations for particular land uses are derived ;
3. Separate processes of generation, separate processes are used for generation rates from each major source i.e. hillslope, gully, streambank; and
4. Process based approaches, to represent the processes involved in soil/water and other interactions.

1.1.2 Delivery

Modelling how sediment, nutrient or pollutant loads gets from the source of generation to a stream. Once material is generated, it must be delivered to a stream via some pathway from the land unit or sub-catchment. The delivery phase is often where management actions can be represented such as the use of riparian filter strips/buffers, dams for trapping material, alterations to surface cover (that will affect both generation and delivery), wetlands, detention ponds etc. There are several basic approaches to dealing with delivery:

1. Net generation, no explicit process of generation represented;
2. Delivery ratio, assumes a proportion of what is generated makes it to stream; and
3. Explicit pathways/process based, the detailed pathways of movement from source of generation to stream are explicitly modelled.

1.1.3 Transport

Modelling how sediment, nutrient or pollutant loads are transported downstream in a catchment. Once material makes it to a stream, it is available for transport through the stream network. Again there are several basic approaches:

1. No explicit transport, all the material that makes it to a stream is assumed to make it out of the catchment;
2. Routing with water, allows for the time it takes for a flood wave to move through a stream network;
3. Routing allowing for transformations, material may deposit or be re-suspended, nutrients may alter form, decay, enrich etc,
4. Routing in managed systems, used to replicate the behaviour of highly managed systems and a large proportion of the modelling effort is in establishing the appropriate rules of operation of the managed system.

1.2 MODEL COMPLEXITY

Model complexity refers to the extent to which a model attempts to represent the various processes at work. There are three major classifications of model complexity commonly used, empirical, conceptual and process based.

1.2.1 Empirical

Models that simply calibrate a relationship between inputs and outputs. There is no attempt to describe the behaviour caused by individual processes. An example is: **Runoff = a. (rainfall)^{b},** where parameters a and b is derived via a regression between measured rainfall and runoff.

1.2.2 Conceptual

Basic processes such as interception, infiltration, evaporation, surface and subsurface runoff etc. are separated to some extent. However, the equations that are used to describe the processes are essentially calibrated input-output relationships.

1.2.3 Process Based (or complex conceptual)

Provide a deeper understanding of hydrological processes based on the fundamental physics and governing equations of water flow over and through soil and vegetation. They are intended to minimise the need for calibration by using relationships in which the parameters are, in principle, measurable physical quantities. However in practice obtaining parameters can prove difficult.

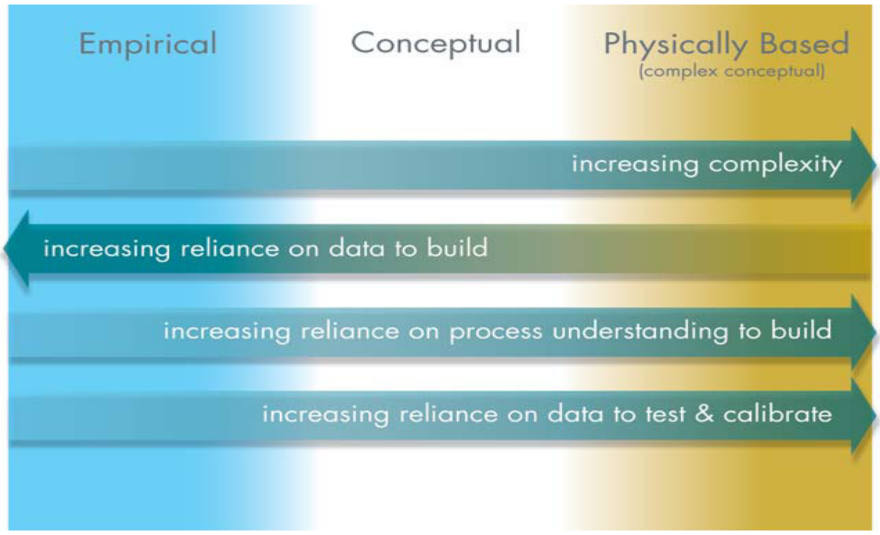

Figure 1 Some features of the different classifications of models. Note that classifications are not distinct but operate over a continuum. (Source CRCCH, 2005)

1.3 FRAMEWORKS FOR CHOOSING A MODEL

Model users need to be realistic about the role of models in decision making:

- A perfect answer a year late is useless;
- A model which is too simple or uncertain or inflexible to deal with the real objective/s is useless;
- Modelling is as much an art as a science, and the skill of the modeller is at least as important as the quality of the model;
- Models integrate data and knowledge of processes; they cannot invent knowledge where none exists.

From a technical perspective:

- Modellers must understand the principles on which the model is based;
- Model time and space scales must match objectives and available data;
- Formal uncertainty estimation is likely to be impossible but an appreciation of uncertainty must be considered at each stage of the modelling and conveyed to users;
- Availability of data for testing and expertise for interpretation must be considered up front. (CRCCH , 2005)

Generally, the choice of model should be made by selecting the least complex model that will provide the desired outputs (Hamill and Trevor, 2008).

2.0 REVIEW OF MODELS

2.1 SHORTLISTING MODELS FOR REVIEW

A qualitative analysis of forty-nine models was undertaken using a survey of books, journals, websites and personal communications. Particular sources of information included; the CRC for Catchment Hydrology toolkit website (www.toolkit.net.au), Merritt et al, 2003, and Hammill and Trevor (2008). A summary of the forty-nine (49) listed models is presented in Appendix A.

A process of short listing was then undertaken, with consideration of criteria such as; Usability, Support, Acceptance, Robustness and Fit for Purpose. The short list of twelve (12) models includes:

- AusRivAS;
- CatchMODS and iHacres;
- CMSS;
- E2/WaterCAST;
- Howleaky?;
- LASCAM;
- MUSIC;
- PIA;
- RAPUP;
- SedNet and ANNEX;
- SWAT; and
- USLE and modifications (RUSLE).

Each model was considered with regards to the processes modelled, model complexity, potential uses of the model, limitations, and expertise and data needs. The short list was based on choosing a range of models that covers the types/complexities, rather than reviewing numerous models which are a variation on the same theme. We also chose models that we considered have been widely used and are readily available or have the potential for widespread application.

3.0 MODEL REVIEW SUMMARY

3.1 AUSRIVAS: AUSTRALIAN RIVER ASSESSMENT SYSTEM

Short description: AUSRIVAS is a rapid prediction systems used to assess the biological health of Australian rivers. There are four bioassessment themes: macroinvertebrates; diatoms; macrophytes; and riparian vegetation and two physical assessment themes: physical and chemical; and benthic community metabolism.

The underlying philosophy is a model that predicts the biological health that can be expected to occur at a site in the absence of environmental stress, such as pollution or habitat degradation, to which data (such as flora/fauna) collected at the site can be compared. Various (sub) models have been developed for each state for the main habitat sites found (riffles, edge, pools, and bed habitats).

Processes modelled: Biological health (as defined by a range of methods in the “River health assessment toolbox”). By way of example, using macroinvertebrates in AusRivAS as the basis upon which to assess the ecological condition of river sites. Macroinvertebrates are collected from reference sites, which are defined as sites representing least impaired conditions. Reference site information forms the template against which test sites are compared to assess their ecological condition. Macroinvertebrates are collected at the test sites, along with a suite of physical and chemical information that includes the predictor variables chosen for use in the AusRivAS model. These predictor variables are used to place test sites into the reference site groups formed on the basis of the biota. The model then calculates the probability of occurrence of each taxon at a test site, based on the occurrence of each taxon within the corresponding reference site groups. The number of taxa predicted to occur at a test site is compared against the number of taxa that were actually collected at the test site, with the difference between the two being an indication of the ecological condition of the site.

Model complexity, opportunities and limitations: Complex and requires considerable field data and ecological expertise to construct. The model is not intended as a “cause and effect” model”, i.e. *x* change upstream land management will result in *y* change in river health. Rather it is intended to provide a comparative tool for river health.

Potential and known uses of the model: All states and territories were involved in the AUSRIVAS program through the National River health program (NRHP) (1996-2001). Method and models have been incorporated into the Murray Darling Basin Commission’s (MDBC) ongoing Sustainable Rivers Audit (SRA) program.

Expertise and data needs: Considerable field data and ecological expertise required. Key issue with using the state/territory AUSRIVAS models at the national and state level is reference site condition reporting. Currently the models treat all reference sites equally. There are variations in the degree of human impact on reference sites within states (e.g. WA wheat belt versus Kimberly), as well as between states.

Summary: There may be some potential to use AUSRIVAS methods for discriminating between “high value asset” sites with regards to their current ecological condition. However the model does not predict cause and effect in ecological conditions of assets due to on-ground investment.

3.2 CATCHMODS & IHACRES : CATCHMENT SCALE MANAGEMENT OF DIFFUSE SOURCES MODEL

Short description: CatchMODS is a model framework designed to simulate the effects of catchment-scale management activities on water quality. It enables users to trade-off investment in remediation and land use change against water quality improvements (in the form of pollutant load reductions). CatchMODS integrates several sub-models: hydrologic (based on the IHACRES rainfall-runoff model); sediment (substantially modified from the SedNet model); nutrient; economic cost; and in-reservoir plankton-response model (for Ben Chifley Dam catchment only).

CatchMODS is structured as a network of linked river reach and associated subcatchment areas. Upstream tributaries provide input for downstream reaches and enable routing of pollutants. The model enables identification of critical pollutant source areas (i.e. subcatchments) and management recommendations can extend down to individual river reaches and subcatchment scales.

A range of improvements to CatchMODS are in progress. They include: a capacity to simulate the effects of pollutant inputs from urban areas; improvements to process representation for the effects of riparian and gully zone remediation; a capacity to predict pathogen source, transport and fate; and a capacity to estimate inputs from intensively farmed areas.

Processes modelled: Daily streamflow, several summary hydrologic variables, annual average loads of suspended sediment, total nitrogen and total phosphorus and the cost (ongoing and fixed) of management scenarios. The model is coded in the ICMS (Interactive Component Modelling System). ICMS enables a variety of model inputs including temporal and summary spatial data and for application across a range of catchments with minimal modification

Model complexity, opportunities and limitations: Hydrologic model (iHacres) is a simple conceptual model. The water quality model is more complex and requires data to populate the hillslope and gully erosion components; little information is required for streambank erosion as it is driven by hydrology. The primary limitation to the approach is having sufficient data (particularly for gully erosion) to be able to confidently discriminate between sources of sediment in a catchment.

Potential and known uses of the model: CatchMODS was originally developed as a tool for improving the management of diffuse source pollutants in the Ben Chifley Dam catchment. Prototypes of the model have also been developed for several other catchments including the Moruya River and Colia Lake catchments, NSW, the Cox Creek catchment, SA and the Avon-Richardson catchment in VIC.

Expertise and data needs: The concept is that a developed model should be able to be run by stakeholders to test scenarios; however expert users are required to develop each new model project. Data needs include digital elevation model (DEM) climate and streamflow data, land use and ULSE parameters, and gully activity.

Summary: Catchmods captures many of the key processes at work at a sub-catchment scale (with respect to pollutant sources and sinks), meaning model users can discriminate between various pollutant sources (gullies or land management) allowing an understanding to be developed as to the impact various on-ground investments may have. However this comes at a cost, which is developing a new model, requires considerable data (and confidence in that data) for the discrimination to be valuable. While constructing a new model can be a reasonably complex process, the user interface (including economics) allows for easy interaction with stakeholders at point of delivery.

3.3 CMSS : CATCHMENT MANAGEMENT SUPPORT SYSTEM

Short description: CMSS is a useful first-cut tool for any catchment pollutant load investigation. The model inputs are a pollutant loading rate for each landuse. You can investigate landuse contributions to total load by catchment and sub-catchment and explore what happens if land use areas are modified.

Processes modelled: The model is a simple conceptual model where each land use is assigned a pollutant (Nitrogen and Phosphorus) loading rate. The predictive module calculates nutrient loads by summation of total area per land use within the catchment with nutrient generation rate per unit area. There is also allowance for point sources.

Model complexity, opportunities and limitations: CMSS is extremely simple, and provide coarse spatial representation of outputs. It does not model the hydrology of the catchment which is a major limitation of this model, given the importance of flow when estimating nutrient exports and understanding the release and transport of nutrients. However, more accurate representation can be gained by using measured loads, and then comparing loads derived from CMSS. When the CMSS stream routeing and assimilation functions are not used, CMSS can overestimate nutrient loads. CMSS is basically a spreadsheet model that provides a visual representation of loads derived from a table of land use- export values.

Potential and known uses of the model: The primary use of the model is to assess the effects of land use and management policies on long-term nutrient loads delivered to rivers. CMSS has been widely used in Australia as an initial planning tool because of its simplicity, ease of use and ease of results presentation

Expertise and data needs: Expertise required to construct and run a model is low. Data needs are low; however users may find it difficult to obtain locally relevant export loading rates for various land uses/ land management scenarios.

Summary: A useful first cut tool for estimating the load of pollutants. However as this is an empirical approach the loading rates for various land management scenarios would need to be provided. These loading rates would need to be researched in some way (experimentally or use inputs from another modelling approach).

3.4 E2 / WATERCAST: WATER AND CONSTITUENT SIMULATION PRODUCT

Short description: E2 is a software product for whole-of-catchment modelling. It is designed to allow modeller to construct models by selecting and linking component models from a range of available choices.

E2 will be “re-badged” to WaterCAST in near future, with enhancements that include: ability to handle large data sets; stochastic climate module; and will comprise a suite of integrated databases and decision support tools for regional water and constituent accounting, developed and promoted as national benchmarks.

Processes modelled: Primary outputs are water balance, sediment and nutrients (Total N and P). E2 currently uses an event mean concentration approach (EMC) for constituent generation at a subcatchment scale for each functional unit or land use. It can apply simple filtering prior to exporting from subcatchment. It has no detailed in stream sediment transport algorithm as yet, this is in development. Surface / groundwater interaction for flow and constituents are currently being developed. There is an ecological module, the ecological response model (ERM) (or ecological modeller).

The new features of WaterCAST include: Stochastic climate capability - allows you to run scenarios under the full range of possible predicted climatic conditions; Capacity to model the effects of small distributed storages (farm dams) on water yield (effects on water quality are also possible but rudimentary at this stage); urban water demand, supply and receiving water quality.

Improvements in usability of the model in large catchments; improvements in the interface and greater ease in running and reporting on different scenarios; within a year, the capacity to model groundwater and surface water conjunctively will be added; within two years. WaterCAST will become more spatially explicit, such that the location of patches of forest, pasture, point-sources of pollution etc within subcatchments will be explicitly modelled.

Ecological modeller is a Beta sub-model that can transform input time series into output series such as days meeting habitat suitability criteria. At present only the impact of flow can be modelled.

Model complexity, opportunities and limitations: E2 adopts a conceptual structure upon which integrated catchment models are built. This structure may not be the most appropriate for some types of problems. The predictive power of E2 is a function of the available component models, so if the available models are not appropriate to the problem or available data, predictive performance will be reduced. Development of new component models is a complex process requiring specialist knowledge, so the capacity for some users or their agents to develop new component models may be limited.

Potential and known uses of the model: Currently E2 is being applied in Victoria (GMW), South Australia EPA, Fitzroy Qld, Burnett Qld, Mackay Whitsunday, Barron River Qld, Condamine – Balonne Qld, Is currently used by a number of NRM groups (such as the Queensland Murray Darling Committee) to assess the water quality impacts of on ground works investment.

Ecological modeller has been applied at Werribee VIC and Okaparinga SA, with plans for applications in the Murray Darling Basin Commission (icon sites) and south east QLD post July 2008.

Expertise and data needs. High level expertise required. Data needs vary on modelling approach taken and sub-model modules used.

Summary: E2 is well supported nationally through e-water and its greatest strength lies in the 'total package' it provides by being able to link many model components together. However development of new component models is a complex process requiring specialist knowledge. The model does not come with a sufficient database to be able to assign event mean concentrations for various land management systems, as these are empirically derived some research would be required to derive them. Neither does it explicitly define the relative impacts of different sources of pollutants (i.e. gullies vs. hillslope erosion). The concept of Ecological modeller (E2 sub-model) is potentially a useful way for linking biophysical outputs to ecological outcome and could possibly be adapted if the entire E2 platform is not adopted.

3.5 HOWLEAKY?

Short description: HowLeaky? is a rebuilding of the PERFECT V3 model, with an interface designed to be useful to a wider range of non-modellers. Useful to explore the implications of alternative land-uses on water balance, runoff, erosion, and drainage. The primary purpose of HowLeaky? is to explore implications of: different land uses (including crops, pasture and trees); climates; soil types; management (tillage, crop rotation, herbicide strategies) on hydrology; production index; erosion; sediment loss off site; phosphorus and pesticide movement.

Processes modelled: Productivity, soil column hydrology, runoff, deep drainage, erosion, sediment, phosphorus and pesticides. It is a point (or paddock) scale model but has been applied to catchment scale problems through integration with Geographical Information Systems (GIS).

Model complexity, opportunities and limitations: Howleaky? is a complex conceptual model. Limitations include its one-dimensional nature (a single point in a landscape) and does not consider partial area runoff processes or lateral movement of water. It is designed to be applied at a field-sized area with homogeneous soils, topography and climate unless it is run for multiple land units (see Rattray *et al*, 2006).

Potential and known uses of the model: Potential uses include: Evaluate effects of cropping systems on runoff, recharge, erosion and yield; evaluate surface management options; evaluate the effects of crop and pasture rotations on runoff, erosion and recharge. PERFECT (on which Howleaky? is fashioned) has been widely applied in Australia. Howleaky has been applied in a number of salinity and pesticide projects in Queensland and Victoria, in development best management practices for the grains industry and to inform NRM investment in 3 QLD NRM regions.

Expertise and data needs: Requires soils and agronomic expertise. Data needs can be high in new areas where soils data is not available. Experience has been that agronomy of new land use systems can be developed relatively quickly with the assistance of local experts.

Summary: Howleaky? allows the consideration of land use, soils, climate and land management on hydrology and water quality at the paddock scale. It is now integrated with the catchment scale modelling approach adopted in Catchmods, extending it range of usefulness in addressing catchment questions. There are risks associated with uncertainty when applied to new regions where input or validation data sets are not readily available (common to all models).

3.6 LASCAM: LARGE SCALE CATCHMENT MODEL

Short description: LASCAM can be used to predict the long-term impact of land use and climatic changes on the daily trends of stream flow and water quality (represented by salt, sediments and nutrients). It was developed by the Centre for Water Research at the University of WA. The basic building blocks are subcatchments organised around the river network. All hydrological and water quality processes are modelled at the subcatchment scale; the resultant flows and loads are aggregated via the stream network to yield the response of the catchment at the main outlet and at any number of intermediate points on the stream network.

Processes modelled: Runoff, erosion, salt and nutrients. LASCAM is a complex conceptual model with a daily time step. The inputs to the model are daily rainfall and potential evaporation, landscape attributes relating to the A and B soil horizons, leaf-area index, percentage of deep rooted vegetation and percentage of impervious area, for each of the subcatchments. The quantities and application dates of fertiliser in each subcatchment are also required. Phosphorus and nitrogen are modelled in both dissolved and particulate forms. In the case of nitrogen, the soluble component is further discriminated into nitrate-nitrogen and ammonium-nitrogen. The soluble nutrients are transported in surface and subsurface water fluxes, and once in the stream they are routed conservatively. Particulate nutrients, which are assumed to be either organic, or inorganic components attached to eroded sediment material (derived from upslope erosion, or from bank and bed erosion in the stream channel), are transported non-conservatively. The model also incorporates a complex salinity modelling approach.

Model complexity, opportunities and limitations: LASCAM would appear to be highly complex, which may prove to be its greatest limitation based on experience with models such as SWAT. However there are possibly opportunities to adapt components of the model if applying a modelling approach in Western Australian conditions.

Potential and known uses of the model: Has been applied by model developers in Western Australian Catchments (Swan River Basin) to model the effects of climate and land use change on flow and water quality in receiving water bodies. Also applied in a Malaysian study.

Expertise and data needs: The model requires a large amount of data to run; and can only be used by experience modellers.

Summary: While this model appears interesting in that it has applied land use information applicable to understanding farming systems effects on salinity and water quality, there is limited information available on the success or otherwise of the approach.

3.7 MUSIC: Model for Urban Stormwater Improvement Conceptualisation

Short description: MUSIC is an aid to decision-making enabling users to evaluate conceptual designs of stormwater management systems to ensure they are appropriate for their catchments. MUSIC will simulate the performance of a group of stormwater management measures, configured in series or in parallel to form a “treatment train”.

Processes modelled: Runoff, sediment, nutrients. The runoff model is simple and requires a definition of the impervious area and two soil moisture stores. The water quality model is a simple conceptual model built on empirical data. The model runs on either a continuous or event basis, allowing analysis of the merits of a proposed strategy over the short term and long term.

Model complexity, opportunities and limitations: The model is not complex, however there is a considerable amount of background knowledge required to consider how treatments may be fitted into an urban development design (i.e. location and area). The primary limitation is that the model is designed primarily for use in urban environments.

Potential and known uses of the model: Widely used in south east Queensland and Victoria by local government and consultants. It is considered the benchmark method for determining “treatment train” requirements for water sensitive urban design.

Expertise and data needs: Expertise is required regarding urban planning to ensure the recommendations from the model can be incorporated into the final designs appropriately. Data needs are topography, land use and climate for the development area which are usually available for a development project.

Summary: Model is primarily aimed at urban development proposals and would not be well suited to large scale areas involving rural industries. However, this model provides a good demonstration how a simple conceptual model has been developed and implemented across an industry group (to facilitate adoption of water sensitive urban design) with the model outputs used to set targets for on ground works. Importantly, while the development team have taken an empirical modelling approach, they are supporting this with ongoing field research to extend their modelling capabilities and validate model predictions.

3.8 PIA: Policy Impact Assessment

Short description: Based on a macro-economic modelling approach, PIA is a computational general equilibrium modelling approach where environmental variables (i.e. fish) are linked to economic production processes at a catchment scale.

Processes modelled: Economic production with intermediates based on price sensitive substitution of input factors. Water quality changes are based on production changes and links to ecological impacts (i.e. fish) based on water quality changes. Provides feedback from ecology to economic activity. The PIA model quantifies the impact of policy interventions that target changes in land use and land management on economic indicators (i.e. Gross Regional Product) and environmental indicators (i.e. fish abundance). The PIA model quantifies climate change impacts on the sectoral structure of catchment economies and flow-on effects on environmental variables such as fish abundance.

Model complexity, opportunities and limitations: It appears to be a highly complex approach (linking production to water quality to ecology to economics). Most other modelling approaches considered in this report bridge over only one of these links (i.e. production to water quality). Unfortunately at the time of this report little information was available on the model and the developers could not be contacted.

Potential and known uses of the model The PIA model allows comparing different policy interventions (such as instruments to achieve different targets) quantifying their environmental and economic outcomes (catchment scale) to support the development of scenarios for target-setting. Applied to GBR catchments in order to simulate cross catchment consequences of policy interventions or climate change.

The SEPIA (Single Entity Policy Impact Assessment) model simulates land-use decision making (LUDM) enacted by agents involved in agricultural production. The current application includes sugar cane, tree fruit, and beef cattle (grazing) producers, and is applied in the Douglas Shire, north Queensland.

Expertise and data needs: Expert system for economists. May require a lot of data that is not readily available.

Summary: While this model looked interesting in that it linked water quality, ecology and economics, little information appears to be available on the success or otherwise of the approach.

3.9 RAPUP: Risk Assessment, Prioritisation and Understanding Process

Short description: RAPUP uses local and expert knowledge and readily available GIS technology to structure decision making around priorities. It allows sub-catchment groups to assess the impacts of their actions and to understand and visualise what is happening in their local catchment, as it can accommodate any model (simple conceptual through to analytic) and expert opinion to provide an overview of catchment responses to management. It represents a pragmatic amalgamation of water balance modelling, local knowledge and uses GIS to do the arithmetic and graphical presentation at a catchment scale. . RAPUP is a process or philosophy rather than a model.

Processes modelled: Runoff, erosion, sediment and nutrients, although processes modelled are limited only by users imagination. GIS is used to integrate data for a catchment based on estimates for each class of land use * soil type * topography. HowLeaky? has been used to provide estimates of water balance, erosion and chemical movement from management units although any model or estimate can be used.

Model complexity, opportunities and limitations: RAPUP typically requires access to data and modelling skills that may not always be available. RAPUP is partially documented and the experience base is narrow, although it relies on the range of skills typically found within NRM agencies and regional bodies. The process relies on users being able to accept data from different sources, and having people skilled in working with community groups.

Potential and known uses of the model: The RAPUP process has been applied in sub-catchments on the Darling Downs, Qld. Readily available skills (within regional bodies) and local information were used to analyse the spatial distribution of risks of poor water quality, salinity occurrence and biodiversity. Enriching data layers such as land management were acquired from land use maps and local knowledge. This data and enhanced analysis provides a benchmark for the catchment to assess impacts of investments on catchment outcomes.

Expertise and data needs: Requires soil science and agronomic expertise, and GIS capacity. Data needs can be high in new areas where soils data is not currently available. Experience has been that agronomy of new land use systems can be developed relatively quickly with the assistance of local experts.

Summary: RAPUP represents an inclusive approach to catchment modelling with less reliance on any one style of model. The focus of applying the philosophy of RAPUP is to provide an overview of catchment behaviour to land managers, and exploration of impacts of changes in management on end of valley outcomes.

3.10 SedNet and ANNEX: Sediment River Network model and Annual Network Nutrient Export

Short description: SedNet constructs sediment and nutrient (phosphorus and nitrogen) budgets for regional scale river networks (3,000 - 1,000,000 km^2) to identify patterns in the material fluxes. This can assist effective targeting of catchment and river management actions at the regional scale, to improve water quality and riverine habitat.

SedNet can also be used to identify the many opportunities for deposition of sediment in the stream network, recognising that not all areas of erosion result in export of sediment for the catchment.

Processes modelled: Erosion, sediment and nutrients. SedNet is a steady-state model (delivers long term average annual results) developed for estimating sediment generation, transport and deposition. Sediment is generated from hillslopes, gullies and riverbanks and transported through a river network with deposition occurring in floodplains and dams.

Model complexity, opportunities and limitations: The model outputs should be interpreted as indicating patterns across the region, rather than accurate estimates of sediment supply in each particular sub-catchment (smallest individual sub-catchment that should be modelled is in the order of 1000 km^2). The comprehensive data for the large number of river links in the catchment and the cumulative parameters can be difficult to obtain raising uncertainty in range of parameter values and limiting confidence in outputs.

Potential and known uses of the model: Specific features are provided for catchment change scenarios such as: Riparian vegetation change; Gully stabilisation; Landuse change; and flow regulation and modification.

SedNet has been widely applied in conjunction with ANNEX. The National Audit was a broad scale assessment of sediment sources and sinks, more recently projects such as the Short Term Modelling Project have applied SEDNET for the Great Barrier Reef catchment.

Expertise and data needs: Expert system requiring considerable training and understanding or geomorphology. Data needs are high for a regional analysis.

Summary: The model is aimed at regional scale assessment, which has been conducted in the National Land and Water Audit. Various groups have re-applied SEDNET regionally (with improved data sets and higher spatial resolution). However, this model is not an appropriate tool for INFFER as it does not operate at an appropriate scale.

3.11 SWAT: Soil Water Assessment Tool

Short description: Comprehensive catchment based model deals with water sediment, nutrient s and chemicals. The Soil and Water Assessment Tool (SWAT) was developed by the USDA (United States Department of Agriculture) to predict the impacts of land management on water, sediment and agricultural chemical yields in large catchments. It is designed to evaluate likely long term impacts of land use and management changes.

Processes modelled: SWAT simulates physical processes of plant growth, soil column water balance, runoff, drainage, groundwater, stream routing, erosion, sediment, nutrients, pesticides, algae and dissolved oxygen dynamics, and in-stream nutrient cycling. SWAT can run at either a sub daily or daily time step. The conceptual framework for SWAT consists of a two stage modelling approach; the first is constituent generation (runoff, sediments, nutrients, pesticides) and the second is transportation of the constituents through a stream network.

Model complexity, opportunities and limitations: Highly complex physically based model. However there are many opportunities to learn from the many publications on SWAT that provide insights into those processes that may work well and those that don't. The theory manual for SWAT (Neitsch *et al*, 2001) provides many useful algorithms and reference across the many processes modelled.

Potential and known uses of the model: The published literature includes many papers where SWAT has been tested against observed data from around the world. This testing has covered a large range of scales and landscapes. Most papers show an ability to adequately predict streamflow on a monthly basis. Varying success is reported for constituent transport. SWAT has been tested in Australia with limited success; considerably more work has been done in the United States than elsewhere.

Expertise and data needs: Highly complex and very large data needs are required to run the model. While all model components have default values, the use of these defaults may introduce large uncertainty where local data is not available. SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed.

Summary: While SWAT has been widely applied internationally, its perceived greatest asset of including many of the important physical processes driving water quality in a catchment results in a model that is overly complex and unwieldy. Testing of the model in Australian conditions has tended to show it not well suited to our environment. This may be due to the complexity of the environment rather than any intrinsic deficiencies. In developing a modelling approach for INFFER it is worth keeping in mind the problems of uncertainty with regards to model predictions that arise from highly complex models such as SWAT. While they may operate adequately for the developer, problems with extension to other regions may be problematic.

3.12 USLE: Universal Soil Loss Equation

Short description: Estimates long term annual average erosion at the paddock scale. USLE is based on statistical analyses of more than 10,000 plot-years of erosion data collected from runoff plots located at 49 erosion research stations in the United States.

Processes modelled: There are a number of variations on the USLE, however the key equation is: A = R x K x C x LS x P , where A (t ha^{-1} yr^{-1}) is average annual soil loss over the area of a hillslope that experiences net loss, R (MJ mm hr^{-1} ha^{-1} yr^{-1}) is rainfall erosivity, K (t hr MJ^{-1} mm^{-1}) is soil erodibility, L (unitless ratio) is the slope length factor, S (unitless ratio) is the slope steepness factor, C (unitless ratio) is the cropping factor, and P (unitless ratio) is the conservation practices factor. Many models utilise the USLE in its original form, however many other use a similar form but introduce runoff into the equation. The most widely recognised of these being the RUSLE (Revised USLE).

Model complexity, opportunities and limitations: While the model appears simple, it can be complex to apply as calculating the factors can prove difficult. It has proven reliable in the few tests against measured data. That the USLE does not include hydrology means that it is a one purpose model (erosion) thus can not utilise higher level information that has become commonplace when using water balance models.

Potential and known uses of the model: Probably the single most widely applied method internationally for providing soil erosion estimates. This is certainly true when all the revised forms of the model are considered.

Expertise and data needs: Considerable expertise is required to derive many of the parameters for the model. Once parameter values are derived/ available the model is simple to apply as it is a simply empirical model.

Summary: The USLE estimates annual average erosion from hillslopes. A key to the methods success is that it considers land condition, management practices, soils types and climate using a set of empirical relationships. There is less confidence that the model will be useful in areas well beyond its empirical roots, although it has been adapted to be a key part of hydrology driven erosion/water quality models. As such, it is a sub model in common use rather than a stand alone model.

4.0 CONCLUSIONS

This report reviews a broad cross section of water quality models available in Australia. The focus of the review was water quality models that consider such things as hydrology, sediments and nutrients, however more contemporary views of water quality now include ecological condition. This report has touched on some models that deal with ecology, primarily E2 and AusRivAS, however the original intent of this report was not an extensive review of these types of models. While every effort was made to identify as many water quality models as possible for inclusion, the author acknowledges that there will inevitably be some models that have been overlooked.

Good practice for choosing a model

While selection of a model for a task might appear to be a technical issue based on factors such as the question to be answered, and spatial and temporal information requirements, model selection often comes down to the expertise available and timeframe in which an answer is required. While the final model chosen will integrate expert knowledge and information, it is often the process of gathering data and constructing a model that proves to as useful as the final model developed.

In the data gathering process, a key criterion to success is to have a process in which the modelling group conduct on ground investigations (with local experts) of the catchment and decide what are the dominant processes at play and what potential solutions exist for intervention or management? It is often useful to conceptualise the system to be modelled and, in the case of INFFER, identity how the “high value asset” links with the broader landscape. This information will form the basis for deciding what processes will need to be understood and modelled. This is a melding of local knowledge and scientific disciplines to create a richer picture than would be possible with a purely technical approach.

It is also worth considering that in any modelling process community engagement specialist are vital parts of the team, this is often overlooked in many modelling approaches. The engagement of key stakeholders and local experts who have spent many years working and living in catchment will provide insights and information that may not be documented and may allow you to quickly develop an understanding of how the landscape and farming systems may have evolved with time, allowing an understanding of how water quality processes are operating.

Models and methods recommended for investigation (or ongoing testing) for INFFER are:

The most apparent modelling option is the **Catchmods and Howleaky** combination with which the INFFER team has had previous experience. The approach has a demonstrated capacity to provide erosion and water quality estimates for land use and management, including major sources and sinks of sediment (i.e. includes gullies) and alibility to model the catchment scale response to changes in management practices. The trial application of the model has demonstrated a capacity to develop new components (using specialists). A disadvantage to the approach appears to be the time taken for data gathering, model development and validation, a problem shared with most modelling activities. It would be anticipated that subsequent applications of the model would be carried out more quickly.

The foremost alternative would be to use **E2/WaterCAST** which will provide a large package of models and approaches in one toolkit. While a high level expertise is required for this approach, as the flagship model of the e-water CRC opportunities for training occur frequently. An advantage of the model(s) is they are being used by a number of groups nationally, which may facilitate transferring the INFFER method more widely if the approaches were aligned. Some of the challenges in using this approach are the current E2 model(s) do not discriminate sources of pollutants (gullies vs. hillslope) and it is unlikely that data sets will be available for land management scenarios. These limitations may be able to be addressed through either the development of new component models or collecting data for land management practices of interest. It should be noted that developing new component models is a complex process requiring specialist knowledge.

It is also worth considering an approach such as **RAPUP, w**hich is a process of integrating local and expert knowledge and readily available GIS technology to structure decision making around priorities rather than a 'coded' model. The philosophy is to allow sub-catchment groups to assess the impacts of their actions and to understand and visualise what is happening in their local catchment. The process can accommodate any model (simple conceptual through to analytic) and expert opinion to provide an overview of catchment responses to management. RAPUP uses generic GIS platforms to integrate data present this data graphically at a catchment scale. The disadvantage of this approach is that it is currently not well documented.

The INFFER team have also shown interest in extending water quality modelling to include more contemporary notions of water quality that include ecological outcome. E2 has an 'Ecological modeller' module that can link hydrology and chemical outputs to ecological outputs, however this is a highly specialised and complex model. A primary tool in the Australian market place for assessing ecological condition of a riverine site or asset is **AusRivAS** This is not strictly 'a model' in the same sense as the other models reviewed here, however as part of the INFFER process involves selecting "high value asset" in a landscape, the AusRivAS approach may provide a tool for prioritising riverine sites. It should be noted that it is not a cause and effect model, and will not provide answers on the effect that land management will have on ecological condition/outcomes at a site. It should also be noted that while AusRivAS provides an assessment of condition of an asset, the value of an asset will include other factors such as how representative or unique an asset is.

Models and methods that would appear unlikely to prove useful for INFFER are:

CMSS: This is a very simple approach to estimate catchment pollutant loads. We suggest it will not provide the necessary level of information INFFER requires. It is also unlikely that loading rates for land management scenarios will be available.

LASCAM: Western Australian developed model with limited information available to assess, suggesting it is not readily available.

MUSIC: Is a good example of simple empirical approach being applied for urban water quality being supported by field research to derive parameters. As it is focused on urban development it is not directly applicable to the INFFER program.

PIA: Links water quality, ecology and economics, however only limited information available to assess, suggesting it is not readily available.

SedNet and ANNEX: Only suitable for regional assessments and will not provide the spatial resolution required for INFFER.

SWAT: While this has been applied widely internationally the model tends to be overly complex and unwieldy. However there are many useful references (model development and application) associated with the model that may prove useful for sub-model component development.

USLE: Commonly used as an erosion sub-model at the paddock or hill-slope scale. We regard it as too narrow in focus for application with INFFER.

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APPENDIX A Long List Of Models

MODEL ACRONYM	FULL MODEL NAME	DEVELOPER/ CUSTODIAN	TYPE OF MODEL	SPATIAL SCALE	PROCESSES	'WHAT IS TOOL USEFUL FOR?
AusRivAS	Australian River Assessment System	http://ausrivas.canberra.edu.au/index.html		Subcatchment	Biological health	AUSRIVAS consists of mathematical models that can be tailor made for use in different aquatic habitats and for different times of the year. These models predict the aquatic macroinvertebrate fauna expected to occur at a site in the absence of environmental stress, such as pollution or habitat degradation.
CMSS	Catchment Management Support System	e-water CRC. http://www.toolkit.net.au/	Conceptual	Region	Pollutant loading rates	It is a useful first-cut tool for any catchment pollutant load investigation. The model inputs are a pollutant loading rate for each landuse. You can investigate landuse contribution to total load by catchment and sub-catchment and explore what happens if land use areas are modified.
CatchMODS and iHacres	Catchment scale management of diffuse sources model	iCAM, Australian National University. http://icam.anu.edu.au/products/catchmods.html	Conceptual	Catchment	Daily streamflow, several summary hydrologic variables, annual average loads of suspended sediment, total nitrogen and total phosphorus loads and the cost (ongoing and fixed) for management scenarios	CatchMODS is a model framework designed to simulate the effects of catchment-scale management activities on water quality. It enables users to trade-off investment in remediation and land use change against water quality improvements (in the form of pollutant load reductions)
Howleaky?	Howleaky?	APSRU Qld, www.apsru.gov.au	Physical	Paddock	Productivity, water balance, erosion, sediment, phosphorus and pesticides	Useful to explore the implications of alternative land-uses on water balance, runoff, erosion, and drainage. It represent the dynamics between weather, soils and vegetation in so far as these impact on water use and water and sediment flows
LASCAM	Large Scale Catchment Model	Centre for Water Research University of Western Australia, CSIRO. http://www.cwr.uwa.edu.au/	Conceptual	Catchment	Runoff, erosion, salt and nutrients	LASCAM (Large-scale catchment model) can be used to predict the long-term impact of land use and climatic changes on the daily trends of stream flow and water quality

MODEL ACRONYM	FULL MODEL NAME	DEVELOPER/ CUSTODIAN	TYPE OF MODEL	SPATIAL SCALE	PROCESSES	'WHAT IS TOOL USEFUL FOR?
		services/models.php?mdid=7				(represented by salt, sediments and nutrients).
PIA	Policy Impact Assessment	CSIRO Sustainable Ecosystems, Water for a Healthy Country	Conceptual	Catchment	Economic production with intermediates based on price sensitive substitution of input factors. Water quality changes based on production changes. Ecological impacts (i.e. fish) based on water quality changes. Feedback from ecology to economic activity	Based on a macro-economic modelling approach, Computational General Equilibrium modelling, environmental variables (i.e. fish) are linked to economic production processes at a catchment scale.
RAPUP	Risk Assessment, Prioritisation and Understanding Process	QLD Department of Natural Resources and Water. http://www.nrw.qld.gov.au/salinity/publications.html	Conceptual	Sub-catchment	Runoff, erosion, sediment and nutrients	The Risk Assessment, Prioritisation and Understanding Process (RAPUP) uses local and expert knowledge and readily available GIS technology to structure decision making around priorities. It allows sub-catchment groups to assess the impacts of their actions and to understand and visualise what is happening in their local catchment. More of a process than a model
USLE and modifications (RUSLE)	Universal Soil Loss Equation	Various	Empirical	Paddock	Erosion	Estimate annual average erosion at paddock scale
CAT	Catchment Assessment Tool	VIC Department of Primary Industries. http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_cat	Physical / Complex conceptual	Catchment - spatially distributed	Water balance, salt.	Catchment hydrology, biodiversity, water quantity and quality
EMSS	Environmental Management Support System	Has been superseded by E2	Conceptual	Catchment	Pollutant loads	Uses hydrology by an event mean concentration to develop loading rates for land uses/sub-catchment/catchments. Can investigate the impact of intervention of land use change or filtering. Has been superseded by E2

MODEL ACRONYM	FULL MODEL NAME	DEVELOPER/ CUSTODIAN	TYPE OF MODEL	SPATIAL SCALE	PROCESSES	'WHAT IS TOOL USEFUL FOR?
GUEST	Griffith University Erosion System Template	Griffith University	Physical	Plot	Runoff, erosion, sediment	Is a steady-state, process-based model developed to interpret temporal fluctuations in sediment concentration from bare soil in single erosion events
HSPF	Hydrological Simulation Program - FORTRAN	Centre for Exposure Assessment Modelling (CEAM) (EPA)	Physical	Catchment	Instream component includes not only nutrient processes such as nitrogen and phosphorus movement, but also benthic algae, phytoplankton, and zooplankton.	HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical.
IQQM	Integrated Quality and Quantity Model	NSW Department of Land and Water Conservation	Conceptual (some physical)	Region	Water resource management and instream water quality	Runoff is modelled using the conceptual Sacramento model, while the in-stream water quality module is based on the QUAL2E model. Focus on system water allocation
ICMS	Interactive Component Modelling System	iCAM, The Australian National University. http://www.clw.csiro.au/products/icms/index.html	Conceptual	User defined	Water balance and water quality	A framework for building catchment models in.
LISEM	Limburg Soil Erosion Model	University of Utrecht http://www.geog.uu.nl/lisem/	Physical	Sub-catchment	Runoff, erosion, sediment transport	Simulates the hydrology and sediment transport during and immediately after a single rainfall event in a small catchment
MIKE 11	MIKE 11	Danish Hydrologic Institute (DHI) http://www.dhigroup.com/Software/WaterResources/MIKE11.aspx	Conceptual (some physical)	Catchment	Runoff, erosion and sediment	Flood risk analysis, water quality assessment, sediment transport
MEDLI	Model for effluent disposal using land irrigation	Department of Primary Industries and Fisheries. http://www2.dpi.qld.gov.au/environment/5721.html	Physical / Complex conceptual	Sub-catchment	Water balance, nutrients, salt	MEDLI models the effluent stream from its production in an enterprise through to the disposal area and predicts the fate of the water, nitrogen, phosphorus, and soluble salts

MODEL ACRONYM	FULL MODEL NAME	DEVELOPER/ CUSTODIAN	TYPE OF MODEL	SPATIAL SCALE	PROCESSES	'WHAT IS TOOL USEFUL FOR?
MAMA	Modelling and Monitoring Assessments Decision Support Tool	CRC for Coastal Zone, Estuary and Waterway Management. http://www.coastal.crc.org.au/3M	Physical / Complex conceptual		Simple transport; Sediment transport; Sediment-Water column interaction; DO (Dissolved Oxygen); NPZ (nutrient-phytoplankton-zooplankton); CNPZ (NPZ plus carbon); NPZM (NPZ plus macrophytes); Contaminant; Pathogen; Phytoplankton (Population); Population; Foodweb.	The DSS is designed for state government officers involved with Environmental Impact Assessment.
PERFECT	Productivity Erosion Runoff Functions to Evaluate Conservation Techniques		Physical	Paddock	Productivity, runoff, erosion and sediment	Implications of tillage and crop sequences on water balance, erosion
Q-Scape	Q-Scape	Department of Natural Resources and Water	Conceptual (some physical)	Catchment	Water balance, erosion, sediment and nutrients	Hasn't been fully developed, but planned as primary tool for Great Barrier Reef Catchments for water quality assessment
SEPIA	Single Entity Policy Impact Assessment	CSIRO Sustainable Ecosystems	Conceptual	Catchment		The SEPIA model simulates the impact of policy interventions and climatic changes on sediment generation at a paddock scale. Based on bio-physical processes and economic indicators agents change their behaviour. This allows testing how an incentive change (i.e. market based instrument) impacts on land management outcomes. Nutrients and pesticides are planned for the next two steps.
SCAR		La Trobe University	Empirical	Paddock		Has been applied in a number of research projects at La Trobe University to evaluate the economics of dryland salinity and erosion control in Victoria, new south Wales and South Australia
Production focussed models						

MODEL ACRONYM	FULL MODEL NAME	DEVELOPER/ CUSTODIAN	TYPE OF MODEL	SPATIAL SCALE	PROCESSES	'WHAT IS TOOL USEFUL FOR?
APSIM	Agricultural Production Systems Simulator	APSRU Qld, www.apsru.gov.au	Physical	Paddock	Crop growth, water balance	Implications of crop sequences on water balance, production focus, flexible and complex
SGS model	Sustainable Grazing Systems model	Ian Johnson, Armidale	Physical	Paddock	Water balance , pasture production, animal production	Pasture focused model, comprehensive water balance linked to soil and animal production
APSFARM	Agricultural Production Systems Simulator	APSRU Qld, www.apsru.gov.au	Physical	Multi-paddock	Crop growth, water balance	Implications of crop sequences, whole farm management on water balance, production focus, complex
AussieGRASS	Australian Grassland and Rangeland Assessment by Spatial Simulation	QLD Department of Natural Resources and Water. http://www.longpaddock.qld.gov.au/	Conceptual	Region	Pasture growth and soil moisture estimates	Designed for medium term tactical operations i.e. planning de-stocking or re-stocking operations to support environmental sustainability and avoid land degradation
GRASP	GRASs Production	QLD Department of Natural Resources and Water. http://www.longpaddock.qld.gov.au	Empirical	Region	Pasture growth and soil moisture estimates	Uses daily climate inputs to simulate the water balance (runoff, infiltration, soil evaporation, transpiration, and drainage), pasture growth (green growth, death, and detachment) and animal intake (diet selection, utilisation and live weight gain).
e-water CRC, main water quality models						
E2	E2	e-water CRC. http://www.toolkit.net.au/	Conceptual	Catchment	Water balance, sediment and nutrients	E2 is a software product for whole-of-catchment modelling. It is designed to allow modellers and researchers to construct models by selecting and linking component models from a range of available choices. E2 enables a flexible modelling approach, allowing the attributes and detail of the model to vary in accordance with modelling objectives.
MUSIC	Model for Urban Stormwater Improvement Conceptualisation	e-water CRC. http://www.toolkit.net.au/	Conceptual	Sub-catchment (Urban)	Runoff, sediment, nutrients	Urban stormwater focus

MODEL ACRONYM	FULL MODEL NAME	DEVELOPER/ CUSTODIAN	TYPE OF MODEL	SPATIAL SCALE	PROCESSES	'WHAT IS TOOL USEFUL FOR?
SedNet and ANNEX	Sediment River Network model and ANNEX (Annual Network Nutrient Export)	e-water CRC. http://www.toolkit.net.au/	Conceptual	Region	Erosion, sediment and nutrients	SedNet constructs sediment and nutrient (phosphorus and nitrogen) budgets for regional scale river networks (3,000 - 1,000,000 km2) to identify patterns in the material fluxes. This can assist effective targeting of catchment and river management actions at the regional scale, to improve water quality and riverine habitat.
CLASS	Catchment Scale Multiple-Landuse Atmosphere Soil Water and Solute Transport Model	e-water CRC. http://www.toolkit.net.au/	Physical / Complex conceptual	Catchment - spatially distributed	Water balance, solute balance and vegetation growth modelling, terrain modelling, recharge, discharge and lateral flow modelling and streamflow routing	Physically based distributed eco-hydrological modelling framework that can be used to predict land-use effects at paddock, hillslope and catchment scales
WaterCAST	Water and constituent simulation product	e-water CRC. http://www.toolkit.net.au/	Conceptual	Catchment	Water balance and constituents	WaterCAST will comprise a suite of integrated databases and decision support tools for regional water and constituent accounting, developed and promoted as national benchmarks.
Water balance						
AgET	AgET	WA Department of Food and Agriculture. http://www.agric.wa.gov.au	Empirical	Paddock	Water balance for crop rotations, water table changes	Watertable changes associated with different crop and pasture rotations, WA focus, to explore changes in rotation impacts on drainage and water table depth
Aquacycle	Aquacycle	e-water CRC. http://www.toolkit.net.au	Conceptual	Sub-catchment (Urban)	Water balance	Aquacycle is a daily urban water balance model
Catcher	Catchment Rainfall, Runoff and Recharge Calculator	WA Department of Agriculture and Food. http://www.agric.wa.gov.au/content/lwe/water/catcher.htm	Empirical	Catchment	Water balance	Allows users to see how much effect different crop plantings in different areas of a catchment can have on the catchment water balance.
HowWet?	HowWet?	APSRU Qld, www.apsru.gov.au	Conceptual	Paddock	Soil column water balance	Uses farm rainfall records to estimate how much plant available water and nitrate has been stored in the soil during a fallow, and erosion -not probabilistic, short period

MODEL ACRONYM	FULL MODEL NAME	DEVELOPER/ CUSTODIAN	TYPE OF MODEL	SPATIAL SCALE	PROCESSES	'WHAT IS TOOL USEFUL FOR?
						estimates
RRL	Rainfall Runoff Library	e-water CRC. http://www.toolkit.net.au/	Conceptual	Catchment	Water balance	A collection of water balance tools (rainfall-runoff relationships)
USA models						
SWAT	Soil Water Assessment Tool	United States Department of Agriculture. http://www.brc.tamus.edu/swat/swatmod.html	Runoff, erosion, sediment, nutrients, pesticides		Runoff, erosion, sediment, nutrients, pesticides	Comprehensive catchment based model deals with water sediment, nutrient s and chemicals. Can be applied at wide range of scales, has GIS linkages
AGNPS	AGricultural Non-Point Source Pollution Model	United States Department of Agriculture - Natural Resources Conservation Services. http://www.wsi.nrcs.usda.gov/products/w2q/h&h/tools_models/agnps/index.html	Physical / Complex conceptual	Catchment - spatially distributed	Water balance, sediment, nutrients, pesticides	Erosion and WQ estimates for USA
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation		Physical / Complex conceptual	Catchment - spatially distributed	Runoff, erosion, nutrients	Detailed process model to estimate erosion, landform specific capacity
CREAMS /GLEAMS	Chemical Runoff and Erosion from Agricultural Management Systems model	United States Department of Agriculture. skaggs@eos.ncsu.edu	Physical / Complex conceptual	Sub-catchment	soil erosion, runoff, water quality, pollutant transport	CREAMS is a field scale model for predicting runoff, erosion, and chemical transport from agricultural management systems. It is applicable to field-sized areas. GLEAMS is a revisit of CREAMS but with a groundwater and pesticide focus
EPIC	Erosion-Productivity Impact Calculator	United States Department of Agriculture. http://www.brc.tamus.edu/	Physical	Paddock	Runoff, erosion, sediment, nutrients, pesticides	Is a mechanistic simulation model used to examine long-term effects of various components of soil erosion on crop production
QUAL2E	The Enhanced Stream Water Quality	EPA Environmental Research Laboratory. http://www.epa.gov/ceampu	Physical	Catchment	nutrient cycles, algal production, benthic and carbonaceous demand,	

MODEL ACRONYM	FULL MODEL NAME	DEVELOPER/ CUSTODIAN	TYPE OF MODEL	SPATIAL SCALE	PROCESSES	'WHAT IS TOOL USEFUL FOR?
	Model	bl/			atmospheric re-aeration, dissolved oxygen balance	
SWMM	Storm Water Management Model	U.S. Environmental Protection Agency. http://www.epa.gov/ceampubl/	Physical / Complex conceptual	Sub-catchment	urban runoff, pollutants	SWMM is a dynamic rainfall-runoff simulation model, primarily but not exclusively for urban areas, for single-event or long-term (continuous) simulation.
SWRRB/SWRRB-WQ		Has been superseded by SWAT	Runoff, erosion, sediment, nutrients, pesticides	Runoff, erosion, sediment, nutrients, pesticides	Runoff, erosion, sediment, nutrients, pesticides	SWRRBWQ was developed to simulate hydrologic, sedimentation, and nutrient and pesticide transport in a large, complex rural watershed.
TOPOG		Canadian Centre for Climate Modelling and Analysis. http://www.cccma.bc.ec.gc.ca/~varora/	Physical / Complex conceptual	Catchment - spatially distributed	Water balance, salt, erosion and sediment	TOPOG describes how water moves through landscapes; over the land surface, into the soil, through the soil and groundwater and back to the atmosphere via evaporation. Conservative solute movement and sediment transport are also simulated.
WEPP	Erosion Prediction Model	USDA- ARS. National Soil Erosion Research Laboratory	Physical	Sub-catchment	erosion, runoff	Is applicable to hillslope erosion processes (sheet and rill erosion), as well as simulation of the hydrologic and erosion processes on small watersheds
XP -AQUALM		http://www.xpsoftware.com/products/xpaqualm.htm	Conceptual	Sub-catchment (Urban)	Runoff, sediment, WQ	