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SKM

Ecomarkets *Ensym* Model

METHODS FOR INCORPORATING WITHIN SUBCATCHMENT ROUTING AND LATERAL FLUXES OF WATER AND CONSTITUENTS WITHIN THE *ENSYM* FRAMEWORK

- Final
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1. Introduction

1.1. Ecomarkets project objectives

ecoMarkets is the term used to describe a range of market-based systems that are being developed and applied by the Victorian Government that aim to address environmental decline. The main function of ecoMarkets is to provide incentives for private landholders, who own 65 per cent of Victoria's land, to manage their land in ways that conserve and enhance the environment. Landholders will be able to earn income from ecoMarkets if they are able to provide environmental improvements in a cost-effective way. (DSE, 2008)

"ecoMarkets work by creating opportunities for providers of environmental benefits, such as private landholders, to engage in partnerships with willing buyers of these benefits. Willing buyers may be the Government seeking to obtain environmental improvements on behalf of the Victorian public or they may be private companies or individuals such as developers seeking to offset environmental damage through remedial actions elsewhere. They may also be ethical investors or philanthropic organisations seeking to invest in interventions that contribute to the improved health of the Victorian environment." (DSE, 2008) Three pilot projects have already been undertaken by DSE in implementing the ecoMarkets approach.

1.2. Existing *Ensym* and *Biosym* frameworks

Assessment of the worth of environmental outcomes to be delivered by ecoMarkets has been conducted using the *Ensym* modelling framework. *Ensym* works by comparing the proxy statistics for environmental outcomes from different scenarios: a baseline or reference scenario representing existing conditions, against scenarios that represent the acceptance of one or more of the offers put forward by private landholders. Individual offers by landholders are ranked according the cost effectiveness of the environmental outcomes delivered, i.e. the measure of overall environmental return per dollar of investment.

The current forumulation of *Ensym* includes a biophysical modelling component that is known as *Biosym*. The *Biosym* component model subdivides Victoria using a horizontal grid into 20 m squares. On each 20 m square, a one-dimensional water and constituent flux balance is solved on a daily time step. The one-dimensional hydrological model is based upon the *CAT* model, which was first derived from the *PERFECT* model (Baker et al. 2001; Beverly et al. 2003).

The current *Ensym* and *Biosym* framework does not explicitly allow for horizontal redistribution of water or constituent fluxes via surface, groundwater or subsurface flow paths. Instead, the total runoff from a subcatchment is simply computed on a daily basis by adding the surface runoff computed from all of the grid cells that are deduced to be upstream of that subcatchment outlet.

1.3. Ultimate objectives of routing and lateral fluxes within *Biosym*

Many of the environmental outcomes that *Ensym* seeks to predict are related to the health of streams, floodplains, riparian zones and estuaries. Other environmental outcomes may relate to health of the landscape itself or capture / reductions in production of greenhouse gasses.

In order to connect actions in the landscape to environmental outcomes in the stream, along floodplains and in riparian zones, it is necessary for *Biosym* to represent how landscape elements (20 m grid cells) are connected to each other and ultimately to streams.

Ecologists will ultimately provide guidance on how modelled changes in flows and/or constituent fluxes along streams are related to environmental outcomes. There are currently no ecological models linked into the *Biosym* framework at present to explicitly make this assessment but such models may be incorporated in future.

The mathematical structure of the ecological models that might later be incorporated into Biosym are not yet defined. However, ecological response models that are currently used in freshwater systems typically relate changes in environmental health to changes in flow regime and sometimes to changes in other constituents including sediment, salinity, nutrients (TN and TP), dissolved Oxygen and temperature. Until the ecological models are incorporated in the *Ensym* framework, the constituents and temporal resolution required to assess scenarios cannot be defined. This lack of clarity around the final constituents, temporal resolution and metrics required makes it problematic to provide a firm recommendation on the model framework for lateral flow redistribution.

1.4. Definitions of key terms: constituents, routing and lateral flow redistribution

Constituent is a general term for any material that is transported (in either suspended or dissolved form) with the flow of water. Constituent is a more general term than pollutant or contaminant that by contrast with the other two terms does not carry an assumption that the material being transported is detrimental to catchment or stream health. Examples of constituents include sediment, Nitrogen (Total Nitrogen and species of Nitrogen), Phosphorus (Total Phosphorus and species of phosphorus), salinity, dissolved Oxygen, Biochemical Oxygen Demand and indicator pathogens such as *e-Coli*.

The current *Biosym* framework includes one-dimensional hydrological models, which represent the landscape as a large number of square elements formed by a 20 m by 20 m horizontal grid. Flows and constituents in real catchments do not only travel in one vertical dimension but move horizontally across the catchment via various flow pathways.

Lateral flow redistribution is the general term that is used in this report to describe the horizontal movement of water through the catchment. Lateral flow redistribution can occur via:

- Overland surface flow across hillslopes,
- Flow in groundwater aquifers,
- Flow in the vadose or unsaturated zone, and
- Routing of flows via rivers, creeks, gullies or other overland stream channels.

Routing is the specific term for the change in magnitude, speed and shape (height and duration) of a flow hydrograph as it moves downstream via a river, creek, gully or other overland stream channel, due to channel and floodplain storage and frictional effects.

1.5. Scope and objectives of SKM project

The objectives of this project are to:

- Assess the ability of existing *Ensym* and *Biosym* framework to produce flows and constituent fluxes, given that it currently does not include subcatchment routing and lateral fluxes; and
- Recommend an approach for incorporating within subcatchment routing and lateral fluxes of water and constituents within the *Ensym* framework.

Our review and recommendations are limited to hydrological routing approaches for water and constituents, whereby fluxes move strictly in a “downhill” direction and the rates of movement are controlled only by inputs of water and constituents. There are some situations where more sophisticated hydrodynamic routing schemes would be required to represent fluxes that are controlled by both upstream and downstream conditions, such as estuaries and large reservoirs and lakes. Estuaries are subject to inflows from both the upstream catchment and from the sea. Modelling of flows and constituent fluxes in estuaries therefore requires a hydrodynamic model of the estuary to represent the complicated bi-directional flows that occur. It would be impractical to establish such complicated hydrodynamic models of estuaries within a widescale framework like *Biosym*. Estuaries are therefore out of scope for the remainder of this discussion paper. However, *Biosym* may be used to estimate flows into the upstream extent of an estuary. Similarly, changes in flow and water quality within large reservoirs, which would also require a hydrodynamic model of the estuary to be adequately represented, are also out of scope for this discussion paper. We have also not explicitly considered regulated systems, such as reaches that are downstream of large water supply dams.

1.6. Approach to the project and available information

This report has been written on the basis of a relatively limited consultation with the *Biosym* project team:

- A two-hour meeting between SKM and the DSE project team
- Publications describing the high level structure of ecoMarkets, *Ensym* and *Biosym*
- Available literature on *PERFECT* and *CAT*

1.7. Report structure

Section 2 discusses the capability and heritage of the existing *Biosym* framework to meet the stated objectives of DSE.

Section 3 provides a brief review of approaches applied within other hydrological modelling frameworks to lateral flow redistribution and routing.

Section 4 provides a recommended development pathway on the basis of our understanding of the current *Biosym* framework and from the review of other modelling approaches.

2. Capability and heritage of existing *Biosym* component

2.1. Model structure

Ensym uses Matlab to build the overall front end for integrating models. The framework incorporates economic and biophysical component models. Each of those models are then linked in as compiled dynamic link libraries (dll). Individual dll code files are built in a number of different coding languages, including C and FORTRAN.

The biophysical modelling components in *Ensym* are known as *Biosym*. The current *Biosym* component is a grid based 1D biophysical model that implements the *PERFECT* model composition. The one-dimensional models are not explicitly coupled to groundwater in the current version of *Ensym*.

The model requires GIS layers that describe landuse and soils. We did not review the adequacy of these layers for the modelling task but we understand that these have been obtained by DSE and are used for a number of related modelling purposes within *Ensym*.

2.2. Groundwater modelling

Work is currently underway on development of regional groundwater models using the Modflow framework. These regional groundwater models will receive recharge inputs as the drainage from the *Biosym* grid models.

2.3. Existing data inputs

The model uses daily climate data for a model run period from 1975 through 2005. The daily rainfall and pan evaporation data is obtained at several climate stations across Victoria from the SILO climate database. The climate data is then allocated to the 20 m grid cells on the basis of the nearest neighbour to one of the climate data stations.

Topography is represented in the model using the Victorian statewide Digital Elevation Model (DEM), which has 20 m horizontal resolution. The DEM that is currently included within *Ensym* was extracted only from contour and spot height information that was based upon topographic mapping. The DEM is not hydrologically corrected and therefore drainage pathways identified using the DEM in many places will not map the horizontal position of drainage pathways that could be identified from an independent data source, such as stream layers from topographic mapping, aerial photography or satellite imagery.

Ensym implements a model knows as DFLOW, which is a simple D8 pointer model that derives a flow accumulation matrix for every point in the DEM. The flow accumulation values are then used to derive the outline of the drainage catchment to any particular point in the landscape. A "pit filling" algorithm is used to overcome the presence of spurious "pits" and "dams" in the DEM that are not actually present in the landscape to adjust the flow accumulation and therefore the drainage catchment extents.

Several other projects, including definition of the Australian Water Resources Council Basin boundaries, the Sustainable Diversion Limits project undertaken by SKM and DSE and the Bureau of Meteorology's geospatial fabric project have developed or are in the process of developing boundaries for hydrological catchments and subcatchments. Considerable effort has been employed in all of these projects to define boundaries of catchments and subcatchments so that surface water drainage paths have been correctly represented.

Since the *Biosym* uses its own independent DEM, there is no independent verification of subcatchment boundaries against known subcatchment boundaries mapped from other projects. This is a considerable weakness that should be addressed by using a hydrologically corrected DEM that has been stream enforced using a stream network of reasonable resolution. It is likely that a DEM of this type could be obtained easily from other projects that are already being undertaken by DSE, Geoscience Australia and the Bureau of Meteorology. The subcatchment boundaries mapped using *Biosym* should also be compared against the boundaries determined from the Bureau of Meteorology Geospatial fabric and possibly the Sustainable Diversion Limits project and where necessary adjustments made to ensure consistency.

2.4. Assessment of existing capability of *Ensym* and *Biosym* to meet the stated objectives

As a one-dimensional, point scale model, the existing *Ensym* and *Biosym* model structure is likely to be appropriate for estimating flow and constituent export hydrographs from small scale subcatchments, in the range up to 500 ha. The model is appropriate for these small catchments areas because:

- there is generally an absence of hydrological gauging station data for catchments of this small scale that could be used to prove that the point scale models are producing inappropriate outputs;
- at a daily scale, there is likely to be sufficient consistency in the spatial and temporal pattern of rainfall for catchments of this size so that this should not be a major source of error;
- catchment landscape properties, such as vegetation and soil properties are likely to be relatively consistent across catchments of this scale and therefore lateral redistribution of surface and subsurface flows and constituent fluxes is less likely to cause appreciable error in the outputs.

As catchments approach the larger end of this scale range (i.e. 100 to 500 ha), hydrographs of flows and constituent loads from real catchments would start to appear attenuated when compared to a direct summation of the runoff from individual grid elements within the catchment. The existing *DFlow* algorithm used in Biosym that sums runoff from individual grid cells without allowing for attenuation is likely to produce hydrographs that are too peaky than observed catchment runoff hydrographs. Simulation of this attenuation behaviour may be achieved simply by implementing a simple linear store at the end of the catchment. The delay parameter for the linear store (i.e. the proportion of the stored volume in the conceptual store that is released on each day) would need to be determined by calibrating the parameter on a number of catchments in this size range that have streamflow gauging and then regionalising the parameter for ungauged catchments by fitting a regression relationship to readily accessible catchment characteristics, such as catchment area, slope and/or drainage density. To our knowledge, no direcly applicable "off the shelf" relationships are available in the literature and a study would need to be conducted.

As catchment areas increase in size, lateral redistribution of water and constituent fluxes within the catchment becomes an increasingly important feature of the landscape hydrology. Lateral redistribution occurs in the saturated groundwater system, within the soil layers of the unsaturated zone, along the ground via surface overland flow paths and within surface water courses. The existing model structure of unconnected 1D grid models with groundwater models of the saturated groundwater aquifer systems only represent the first of these redistribution mechanisms (groundwater fluxes) but does not represent any of the others.

The simplest approach to representing lateral redistribution would be to sum the generated surface runoff and associated constituent loads from all of the grid cells within a catchment and therefore to effectively ignore other lateral redistribution processes. The problem with such an approach is that it cannot explicitly account for lateral flow within the unsaturated zone, infiltration of runoff (and constituents) as it moves along surface flow pathways or generation of saturation excess runoff at near the bottom of hillslopes as water accumulates there.

Furthermore, the loads of some constituents that are generated and delivered to streams are likely to vary considerably, depending upon which part of the catchment the runoff is generated from. If lateral redistribution is not considered then the grid cells where the model is generating runoff may be very different from the parts of the catchment where runoff is actually generated and this in turn is likely to adversely affect the accuracy of the constituent loads generated by the model and delivered to the stream.

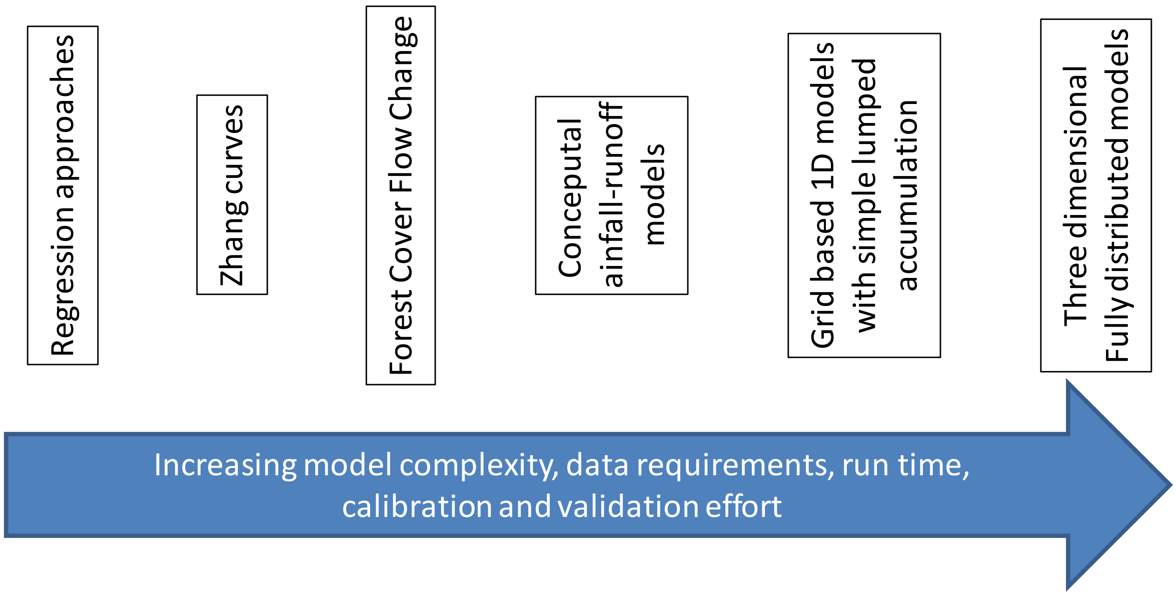
All of these problems created by the lack of representation of lateral fluxes within the existing *Ensym* model would become more serious at increasing catchment scales (above 500 ha) because climatic drivers (rainfall, evapotranspiration and temperature) become increasingly non-uniform as catchment size increases and most of this climatic variation will not be represented by the climatic data entered within the model; vegetation, landuse, soil and geology become increasingly variable as catchment size increases; and streamflow gauging and water quality monitoring data becomes more plentiful for catchments in this size range, thereby providing evidence of the deficiencies in the proposed simple approach.

Biosym must therefore be adjusted to represent processes for lateral redistribution of water and constituent fluxes. There are a great variety of approaches that have been used in numerous previous catchment hydrology models over previous decades that are considered in the following chapter.

3. Approaches applied within other modelling frameworks for routing and lateral water redistribution

Development of models to represent catchment processes has been an ongoing activity in hydrology over the last four decades. In order to adequately represent flows and fluxes of constituents at the catchment outlet, these models need to cater for within catchment redistribution of flows and constituents in some manner – either implicitly or explicitly. There are hundreds of different models that have been developed and there is insufficient capacity or resources to adequately address them all here. However, catchment models fall along a continuum spanning simple functional relationships, through lumped conceptual models, semi-distributed modelling approaches through to fully distributed models.

Figure 1 shows this continuum, with examples of the more common models of each type that are known by the authors to have been applied within Australia in recent years. A brief discussion then follows of each of the models, explaining their model structure, level of complexity and procedures required for calibrating and verifying model parameter selection.



- **Figure 1 Conceptual diagram of possible hydrological modelling approaches**

3.1. Lumped models of mean annual flow: Regression Approaches and Zhang curves

The simplest approaches to estimating catchment runoff are the regression approaches that have been applied to estimating mean annual runoff. Regression approaches were used in the Victorian and South West Western Australian Sustainable Diversion Limits projects (Sinclair Knight Merz, 2003, 2009) to estimate mean annual runoff for unregulated catchments. The equation for mean annual runoff per unit of catchment area in Victoria (Sinclair Knight Merz, 2003) is:

$$MAF\_KM = 365.25\ \mathbf{exp}(-19.73 + 2.77\ \mathbf{ln}(RAIN\_ANN) + 0.003\ TREE) \qquad (1)$$

where, MAF_KM = mean annual flow (ML/km²) $RAIN\_ANN$ = mean annual rainfall (mm) and $TREE$ = proportion of woody vegetation Cover (%).

An alternative simple approach to estimating the mean annual runoff is the approach adopted by Zhang et al. (2001, 2004) and based upon the much earlier work of Budyko (1958). Zhang et al. (2001, 2004) have fitted equations to catchments from around the world that predict the mean annual flow from the catchment on the basis of mean annual rainfall, mean annual potential evaporation and the proportion of tree cover of the catchment.

Whilst the regression and Zhang curve type approaches can be reliably applied to ungauged catchments, they only provide estimates of mean annual runoff from subcatchments and do not provide any guidance on variations in flows at shorter time steps. This may be insufficient for assessing outcomes for environmental assets that may require an understanding of seasonal, monthly or daily variability in flows or constituent fluxes to predict response.

3.2. Lumped catchment models producing flows on daily to annual time step

The *Forest Cover Flow Change* tool (Best et al., 2003) extended the Zhang curve approach to derive daily flow time series for gauged catchments only. This model analyses the daily time series of observed flows to identify those aspects of the flows that respond to changes in forest cover – either an increase in forest cover due to new timber plantations or a decrease due to deforestation. The method then uses the Zhang algorithm along with the daily flow analysis to modify the timeseries of flows from the lumped catchment. The method does not provide guidance for ungauged catchments or for individual streams or subcatchments within a gauged catchment, since it is a lumped model.

At the next level of complexity are lumped conceptual rainfall runoff models. These models have successfully and widely applied to many catchments across Australia and internationally over the past several decades. These models represent runoff processes using conceptual “stores” of water, with transfers between stores and production of deep drainage and runoff fluxes controlled by equations. Conceptual rainfall runoff models are most commonly implemented using daily rainfall and potential evaporation data, since climate data with daily resolution is the most widely available.

The most commonly applied conceptual rainfall runoff models that have been applied in Australia in recent years include *AWBM* (Boughton, 2004), *Hydrolog* (Porter & McMahon, 1975), *SimHyd* (Chiew et al., 2002)and *Sacramento* (Burnash et al., 1973), although many other models have also been applied in Australia and overseas. All four of the models listed in the previous sentence have been demonstrated to provide daily flow hydrographs that provide good matches to observed flow hydrographs at the catchment outlet, provided that care is taken in the process of calibrating the rainfall runoff models. Model parameters can be regionalised from gauged to ungauged catchments but this generally results in a reduction in the ability of the model to accurately predict mean annual runoff and daily flows in the ungauged catchments, when compared to the gauged catchments (Viney et al., 2009).

The eWater CRC's *Source Catchments* modelling framework, which has previously been referred to as *Watercast* and *e2*, is an overall framework that allows for a variety component models to represent generation of runoff and constituent fluxes. *Source Catchments* operates using functional units, that represent different hydrological responses from different parts of the catchment. Each functional unit then normally implements a conceptual rainfall runoff model (as described in the previous paragraphs) and normally a relatively simple model for generation and delivery of each constituent to the stream network.

3.3. Grid based one-dimensional models with simple flow accumulation

A number of relatively simple water balance models have been applied to predict how climate, vegetation, soils and land management influence the water balance as part of a wider flow and constituent modelling activity. Some applications include *AgET* in Western Australia (Argent 1999), *GRASP* pasture production model in Queensland (Owens et al. 2003), *PERFECT* cropping systems model in Queensland (Owens et al. 2003), New South Wales (Littleboy et al. 2003) and Victoria (Baker et al. 2001; Beverly et al. 2003), *APSIM* cropping systems model (e.g. Asseng et al. 2001; Baker et al. 2001), and the *GRASSGRO* pasture production model in Victoria (Baker et al. 2001; Beverly et al. 2003).

Although these are five different models, they share many conceptual similarities with each other and also with *Biosym*. All are bucket-type models that simulate the 1-dimensional or paddock scale water balance. They do not simulate lateral flow or hydrological connectivity within a catchment. More complex models that account for sub-daily infiltration processes based on soil physics (e.g. Richards Equation) have been applied to predict recharge in smaller, focus areas and subcatchments. Some examples include *HYDRUS* as part of the *CATSALT* model in New South Wales (Tuteja et al. 2003ab), *SoilFlux* in Victoria (Daamen et al. 2002) and the *TOPOG* model to investigate the accumulation of salt in the root zone of a tree plantation over a shallow water table (Silberstein et al. 1999). These more complex models have more demanding data requirements that often prevent widespread application. Lateral connectivity also significantly increases the number of parameters and the complexity involved in calibrating the models so that they produce reliable estimates of flow at the catchment outlet.

3.4. Catchment groundwater models

The major groundwater models used for salinity and water quality modelling in Australia are *FLOWTUBE* (Dawes et al. 2000) and *MODFLOW* (McDonald and Harbaugh 1988). The *MODFLOW* model is a complex 2-dimensional model of groundwater flow. In Australia, it has been widely applied but primarily for groundwater allocation and contamination modelling. It evaluates the effects of management options on aquifer behaviour including effects of water usage patterns and changes in recharge regime due to land use changes. The Murray-Darling Basin Commission undertook a major study using *MODFLOW* to improve the understanding of the groundwater flow systems and assess the associated water resources. Five major modelling studies covered the regions of the Lachlan Block, the Southern Riverine Plain, the Lower Murrumbidgee, the Lower Darling, and the South Australian and Victorian Mallee. These studies assessed land and water management options and estimated impacts on groundwater resources, river and aquifer interaction and salinity. Other examples of the use of *MODFLOW* for salinity modelling include the comparison of different land management options in terms of their effects on crop productivity, stream flow, stream salt load, and stream salinity (Daamen et al,. 2002) and as one component of the Victorian Catchment Assessment Tool model.

The Cooperative Research Centre for Catchment Hydrology developed the *2CSalt* model as a means of integrating outputs from one-dimensional grid based models with a relatively simple semi-distributed representation of the groundwater response to derive monthly timeseries of flow and salt load exported from catchments. It has been applied across the Murray Darling Basin to analyse and predict the influence of vegetation change induced salinity inputs to the Murray from upland fractured rock aquifer catchments.

Existing activities such as the CSIRO Biophysical Capacity to Change Model or *BC2C* (Dowling et al. 2003), the New South Wales Department of Infrastructure, Planning and Natural Resources (DIPNR) *CATSALT* model (Tuteja et al. 2003ab), the Victorian Department of Primary Industries (DPI) *CAT* model (Beverly et al. 2003) and the Queensland Department of Natural Resources and Mines (QDNRM) salinity hazard/risk mapping (Moss et al. 2002) are examples of salinity models that are currently under development. These different approaches have evolved from previous research activities and reflect data availability, skills within those organisations and organisational priorities. *2CSalt* was developed as a salt balance model that would provide consistent output across different state government agencies by integrating the independent grid based hydrological modelling initiatives that differed between states with a common framework for representing subcatchment routing and groundwater connectivity. A recent application of *2CSalt* to estimating catchment scale outputs of flows and constituent loads for ungauged catchments is documented by Littleboy et al. (2009) for coastal New South Wales.

3.5. Three-dimensional fully distributed grid-based models

The most mathematically complicated modelling frameworks attempt to solve three dimensional equations for the fluxes of flows and constituents through the catchment. Examples of such models include *Topmodel* (Beven et al., 1984), *Topog* (O'Loughlin, 1986; Vertessy e t al., 1994; Short, et al., 1995) and *SHE* (Abbott et al., 1986; Bathurst et al., 1991). These models implement a similar framework to *Biosym* but they can solve for redistribution of water horizontally in addition to the vertical distribution of water that is only implemented within *Biosym*. A difficulty in implementing such models is that they can have thousands or even millions of independent parameters, which makes it extremely difficult to identify an optimum set of parameter values and to have confidence in the performance of the model to predict flows and constituent fluxes.

Bevan (1993) is strongly critical of distributed hydrological models for a number of reasons. The key points that Bevan (1993) makes are that physical properties of catchments, on which these models are based, cannot be measured everywhere across a catchment of interest. This requires the introduction of model parameters that average out sub-grid variability in the parameters of interest and introduces the requirement for calibration of model parameter values. Bevan (1993) goes on to state that, "These arguments for the invalidation of current physically-based distributed models suggests that belief in the predictions of such models is an act of faith, resting insecurely on scientific principles. Because of differences in measurement and element scales of parameter values and variables, it is unlikely that the modelling process can be redeemed satisfactorily by calibration."

3.6. Summary assessment of modelling options

Whilst DSE could consider implementing one of these "three dimensional" catchment modelling frameworks, drawing from the criticisms of Bevan (1993) they are not appropriate at this time for use within a statewide modelling framework like *Biosym* because:

- Three dimensional catchment models have only ever previously been applied in small research catchments, where the intensive computations required are not a limiting factor. Applying such models on a CMA region or statewide basis is likely to be prohibitive in computational terms.
- Even where good performance can be demonstrated from a three-dimensional model in a gauged catchment, translation of the large number of parameters to ungauged catchments, so that the level of performance of the model is kept at an acceptable level, is extremely difficult.
- Distributed hydrological models, due to their structure, introduce a very large number (thousands or millions) of parameters for each subcatchment. The large number of parameters creates the problem of equifinality (Bevan, 1993), which is the situation where there are a very large number of different sets of parameter values that could produce equally acceptable predictions of flows and constituent loads. Adding complexity to the model structure (and

increasing the number of parameters) does not therefore increase confidence in predictions of the model over adoption of a much simpler and less parameterised model structure.

4. Recommendation of approach

4.1. Recommended approach

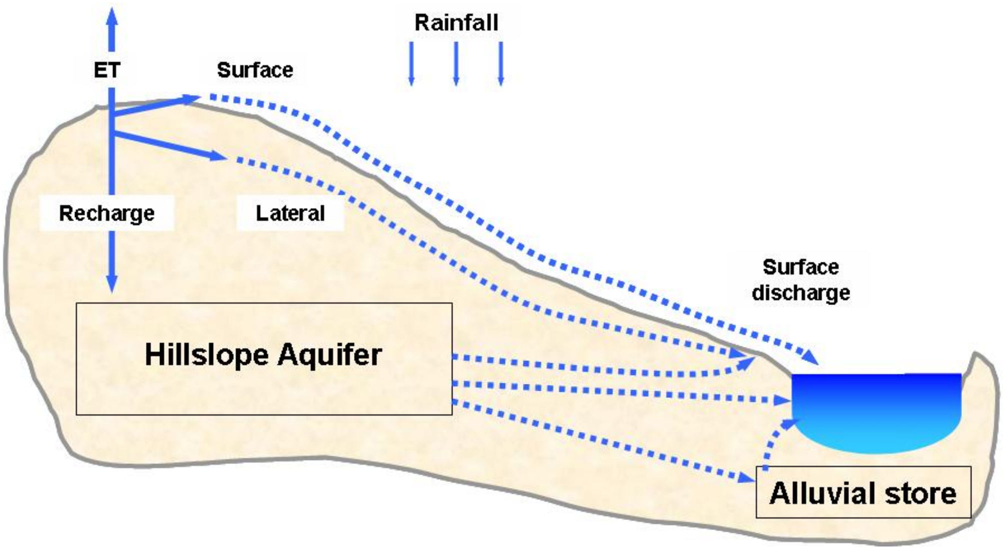
Given all of the difficulties listed above with three-dimensional catchment water quality models and *Biosym*'s existing implementation of one-dimensional grid based models, we recommend that *Biosym* adopts a relatively simple lumped modelling framework at the subcatchment level that integrates the outputs from the one-dimensional grid based models. Our recommendation is that *2CSalt* provides a good template for this that, with some modification, will allow for either monthly or daily timeseries of flow, sediment and nutrient loads to be generated from subcatchments across Victoria. The *2CSalt* framework could be modified to integrate the MODFLOW groundwater modelling as a replacement for the simple "three stores" groundwater models from the original *2CSalt* model.

SKM believes that this approach would capitalise on the existing models that have been developed in *Biosym* whilst avoiding the considerable problems (with no improvement in model performance) that would be associated with implementing one of the three-dimensional model algorithms.

4.2. *2CSalt* conceptual structure

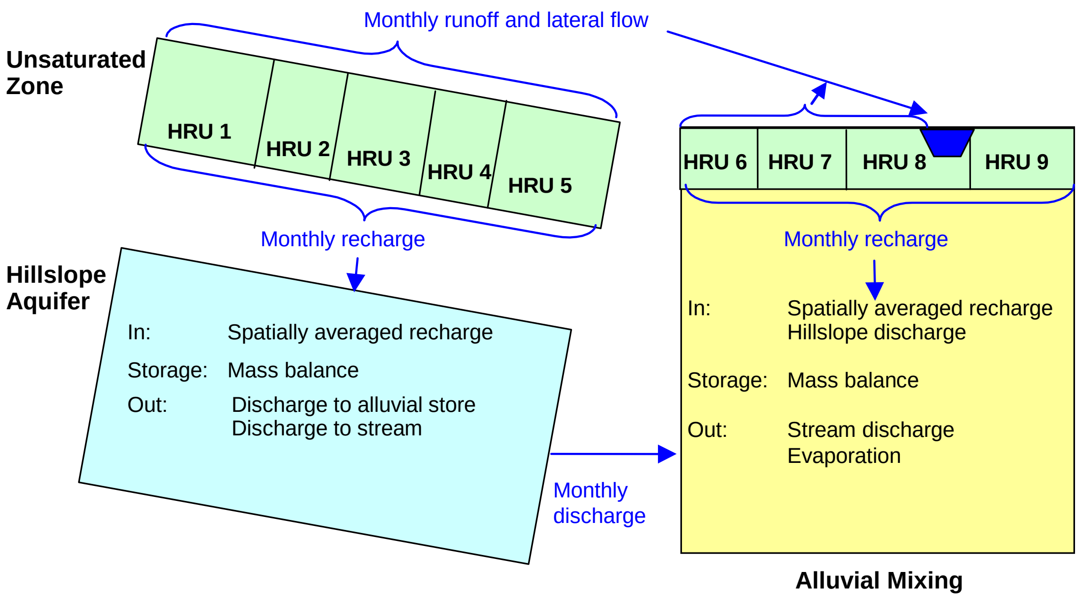
The following section has largely been extracted from the *2CSalt* user manual (CRC for Catchment Hydrology, 2005). The reader is referred to this user manual for further details on the concepts or implementation of the model.

2CSalt quantifies surface and groundwater contributions of salt to catchment scale salt export, and predicts the impacts of land use change on hydrology and salt export at a catchment scale. The pathways of water and salt to stream simulated by *2CSalt* are depicted in Figure 4.1. Water or salt can enter the stream via surface runoff, shallow lateral flow, discharge from hill slope aquifers and discharge from alluvial stores.



- **Figure 2 Simplified representation of water and salt pathways to stream**

The idealised cross-section depicted in Figure 2 is represented in *2CSalt* as a three-stores model (Figure 3). The unsaturated zone is split into Hydrological Response Units (HRU) to represent combinations of climate zone, soil type and land use. This is completely consistent with the grid based approach that is currently implemented within *Biosym*. Both the hill slope aquifer and the alluvial store are represented by simple buckets. A mass balance of water is maintained on a monthly time-step. For the hillslope aquifer, water enters via recharge and can exit by discharge to either the alluvial store or direct to stream. For the alluvial store, water enters via recharge or from hill slope discharge and can exit by discharge to stream or evaporation.



- **Figure 3 Three stores model**

The major components of *2CSalt* are:

- “Terrain Analysis” that defines the spatial units of *2CSalt*
- “Unsaturated Zone Model” to define the unsaturated zone water balance (this is equivalent to the existing *Biosym* framework)
- “Groundwater Flow Systems” to provide parameters to define the volume and potential discharge of the hill slope and alluvial stores
- “Three Stores model” to simulate water and salt for each GRU on a monthly time step.

Further details on the model algorithm, including full descriptions of the equations used and the input data are provided in the *2CSalt* User Manual (CRC for Catchment Hydrology, 2005).

4.3. Availability of source code

The source code for *2CSalt* is owned by the eWater CRC. However, the model algorithm is relatively simple and all of the information on the model algorithm is made available in publications that are in the public domain. It would therefore be relatively simple to translate the published algorithms into the *Biosym* modelling framework.

Translation of the *2CSalt* modelling framework into *Biosym* is most likely to be a relatively modest effort in terms of model coding compared to what has been achieved to date. There may be some considerable effort however in calibrating and validating the routing model to observed flow responses from gauged subcatchments.

4.4. Data layers to be obtained or included

The existing *Ensym* modelling framework uses a DEM that is not stream enforced to follow known drainage paths in the landscape. This is a major deficiency of the model inputs that should be corrected. The *Biosym* framework should adopt a DEM that has been stream enforced and hydrologically corrected. The DEM should also be tested, and where possible adjusted, to match the boundaries of catchments defined from hydrological modelling initiatives, such as the sustainable diversion limits project and the Bureau of Meteorology's geospatial fabric.

4.5. Calibration and validation of model parameters

Littleboy (2009) provides an example on the application of *2CSalt* for the estimation of flows from ungauged catchments. To provide confidence in the predictions from the model, flows and constituent loads should be validated against observed data collected at flow gauging and monitoring locations. The routing model possesses some parameters that can be tuned so that the model can more closely represent the time series of flows produced from subcatchments.

The Sustainable Diversion Limits data set includes estimates of mean annual flow for each SDL subcatchment within Victoria, which were derived from application of Equation (1). These estimates could potentially be used as a basis for validation or calibration of the parameters of the routing model so that the mean annual runoff produced from each subcatchment at least match the independent SDL data set for the existing (or reference) landscape conditions. This at least would reduce the potential bias in the estimates of mean annual flow from what would otherwise be an uncalibrated model.

5. Conclusions

This is an initial discussion paper into the incorporation of a scheme for lateral flow redistribution and routing within the *Biosym* model framework.

A review was conducted of the theoretical performance of the existing *Ensym* and *Biosym* model structure. As a one-dimensional, point scale model, the existing *Ensym* and *Biosym* model structure is likely to be appropriate for estimating flow and constituent export hydrographs from small scale subcatchments, in the range up to 500 ha. The model is appropriate for these small catchments areas because of relatively consistency that is typically observed in catchment properties and climatic drivers. As catchment areas increase in size, lateral redistribution of water and constituent fluxes within the catchment becomes an increasingly important feature of the landscape hydrology and a more sophisticated model for lateral redistribution of flow and constituent fluxes is required.

A brief review was conducted of catchment modelling frameworks that could be considered for incorporation within *Biosym*. Following this review, we have recommended the adoption of a semi-distributed framework that is based upon the *2CSalt* modelling framework developed by the CRC for Catchment Hydrology. Adoption of such a routing scheme would capitalise on the existing models that have been developed in *Biosym* whilst avoiding the considerable problems (with no improvement in model performance) that would be associated with implementing one of the three-dimensional model algorithms.

The algorithms used in the *2CSalt* model framework are readily available in publically available reports. With a relatively modest investment in coding this model framework, it could be adopted within *Biosym* as a means of representing lateral flow movement and redistribution. Further details on the implementation of *2CSalt* are included in CRC for Catchment Hydrology (2005).

Finally, we recommend that DSE consider modifying the digital elevation model (DEM) that is used to one that is stream enforced and consistent with boundaries of subcatchments produced by other projects that have adopted stream enforced DEM, such as the Sustainable Diversion Limits project and the Bureau of Meteorology’s geospatial fabric.

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