Dynamic SedNet Component Model Reference Guide: Update 2017

Concepts and algorithms used in Source Catchments customisation plugin for Great Barrier Reef catchment modelling

Queensland Government

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This report has been prepared by the Department of Environment and Science. The update to the reference guide is required as some important modifications and additions have been made to the modelling customisations.

December 2017

Contents

1. Introduction

This technical document contains conceptual basis, algorithms and application information for the Dynamic SedNet plugin for Source Catchments (eWater CRC 2010a), as applied in the Great Barrier Reef (GBR) water quality modelling program (Waters *et al*. 2014). Knowledge of the structure and application of Source Catchments is essential to interpret this document, and to utilise the Dynamic SedNet plugin appropriately. Some of the component models described in this document are only available in the complimentary plugin, 'GBR Dyn SedNet Extension'. These models are indicated by a 'GBR Only' addition to the relevant heading.

A thorough description of the major project driving the development of the Dynamic SedNet (and GBR Dyn SedNet Extension) plugin for Source Catchments is available in Waters *et al*. (2014), where the need to report individual constituent generation and transport processes for the entire Great Barrier Reef required significant customisation of Source Catchments. In contrast to the holistic narrative provided by Waters *et al*. (2014), this document (Dynamic SedNet Component Model Reference Guide) seeks only to provide readers with the technical details necessary to understand how each algorithm and process is appropriately interpreted by a modeller, or implemented programmatically.

Many of the algorithms/concepts are from Wilkinson *et al.* (2014) and eWater CRC (2010b). Wilkinson *et al.* (2014) should be referred to for further information and explanation. However, there are many instances where the desired concept was unable to be applied or tested adequately, so variations may have been implemented (resulting in the need for this document).

Without altering the Source Catchments framework it is possible to design and run simple water quality models that can be used to inform stakeholders on broad land use and landscape change impacts. However, new data relating to land use and landscape change is being generated all the time, at varying spatial and temporal scales. In addition, the algorithms and concepts described by Wilkinson *et al*. (2014) are not available in Source Catchments as it is provided in its most basic form. To utilise this evolving data in a water quality modelling environment, thus enhancing the service provided to stakeholders, it is necessary to alter the data pre-processing environments, the data input mechanisms for Source Catchments, the reporting environments, and the internal algorithms used to generate and transport pollutant loads. The Source Catchments modelling framework has been designed with this flexibility in mind, and the Dynamic SedNet (and GBR Dyn SedNet Extension) plugin demonstrates how far this adaptation can be taken when applied to a region as large and variable as the Great Barrier Reef catchments.

1.1 Summary Of Major Changes

Since publication of the Dynamic SedNet Reference Guide (Ellis and Searle 2014) there have been some significant changes to the internal operation of the Dynamic SedNet customisation of Source Catchments. These are described in this reference guide with the major changes highlighted, so that modellers will be aware of the likely implications when comparing to previous versions.

1.1.1 Changes To Particulate Nutrient Generation

The most significant change is associated with the calculation of particulate nutrient loads (nitrogen and phosphorus) from the related eroded soil mass. In the previous (2014) version, soil nutrient concentration values were applied to only the relevant fine sediment component of the total eroded soil mass from hillslope, gully and stream bank sources (i.e., the coarse sediment component was excluded). On further review of the original specification documents, and based on the measurements used to inform soil nutrient concentration, it became apparent that particulate nutrient generation should consider the total eroded soil mass, not just the fine sediment component. The calculations within the plugin haven't changed significantly, however the use of 'total eroded soil mass' is now apparent in the algorithms of sections 4.13 and 5.3 of this report. In most cases these changes would result in a gross increase in generation of particulate nutrients (in an un-altered Dynamic SedNet scenario), thus a re-calibration is likely to be necessary.

1.1.2 Changes To Dissolved Inorganic Nitrogen (DIN) From Time Series

A minor change to the (GBR specific) reporting of Dissolved Inorganic Nitrogen (DIN) TimeSeries Load Model outputs has been incorporated to provide more clarity to the modeller (section 4.10). Briefly, the entire amount of DIN lost below the crop root zone is reported as "Leached" in summary outputs. This "Leached" load is not considered a "supply" of pollutant to the stream. However, a portion of the "Leached" load may be transferred to the stream as "supply" (determined by a user specified seepage delivery ratio) via the slow flow mechanism. This load may also be combined with the Dry Weather Concentration (DWC) derived load, with the combined load labelled as "Seepage" supply (representing DIN entering the stream from below the root zone). To assist modellers, the relative contributions of "TimeSeries Contributed Seepage" and "DWC Contributed Seepage" are presented separately in relevant summary outputs. These changes impact the amount of information returned to the modeller, however they will not change generated or transported DIN loads between versions.

1.1.3 Changes To USLE Derived Sediment Generation

A "Maximum Fine Sediment Allowable Runoff Concentration" parameter has been introduced (section 4.5.3), allowing modellers to limit the generated eroded soil mass when the relevant rainfall runoff model has provided a relatively small runoff volume for pollutant transportation. The USLE model is highly sensitive to rainfall, and under special conditions can calculate a large eroded soil mass when the independent rainfall runoff model does not calculate a large runoff event. Experiments were made (around 2014) to apply a 'Maximum Annual Erosion Load' (implemented in a daily time step), however this approach did not allow for daily runoff differences to be reflected in transported sediment masses.

1.1.4 Changes To Reporting And Run Time

The ability to report various summary outputs that don't necessarily alter generated or transported pollutant loads has been enabled by the inclusion of an 'Alternative Processes Abstract Model' class, described in section 4.9. There have also been enhancements made to the Dynamic SedNet customisation to decrease model run time and to couple with command line utilities (Section 2.6).

1.1.5 Changes To The Reference Guide

To reflect the most recent GBR applications of the Dynamic SedNet modelling approach, the schematic representations of sub-model components in section 2.5 have been altered to indicate that the Sacramento rainfall runoff model (Burnash *et al.* 1973) has been implemented in place of SimHyd (Chiew *et al.* 2002).

2. Modelling and programming context

2.1 Long term time series analysis

One of the concepts that has been grappled with in many of the parameterisation routines required for these component models is the need to analyse long term time series data that are not always be stored internally by a Source Catchments scenario, such as daily Functional Unit (FU) runoff or daily link outflow. In order to supply these required time series files, one of the utilities provided in the Dynamic SedNet plugin is the command to “Run Model And Output Time Series”. This will run the full model period (or truncated if specified) with recording of all runoff (quick + slow flow), base flow (slow flow only) and link outflows turned on – at the end of the model run these recorded time series data sets will be written to a user specified directory on disk as CSV files. The files (and the sub-directories) use a naming convention that allows them to be imported by relevant parameterisers for long term analysis as needed. The modeller must be aware that any change to the scenario that will alter runoff and/or flow will necessitate the repetition of this procedure, and probably the re-parameterisation of most models.

2.2 Concept of a Wrapper model

At the initial time of plugin development, Source Catchments was unable to accommodate multiple generation models (representing different processes) assigned to each constituent and Functional Unit (FU) combination represented throughout a scenario. In order to represent multiple generation processes like ‘hillslope’ and ‘gully’ for each constituent and FU combination, whilst maintaining independence of each component model, we have introduced a ‘wrapper’ model. The ‘wrapper’ model itself is assigned to a particular constituent/FU combination, and links to one or more component sub-models that each represent a process of interest. The use of ‘wrapper’ models allows the use of a single component model representing a process (e.g. gullies) to be combined with many alternative component model representations of other processes (e.g. hillslope), without modifying the internal structure of the Source Catchments platform.

2.3 Concept of an Abstract class

The most accurate definition of an abstract class (in terms of Object Oriented Programming) can be found in numerous other publications. However in the context of this reference document and the plugin that it describes, an abstract class is a ‘parent’ object that will provide its members (methods, parameters, properties etc.) to every instance of a ‘child’ object that it is related to. The use of abstract classes to define ‘parent’ constituent generation models allows programmers to write reporting tools that, after each model run, can gather information on common parameter and property values throughout the Source Catchments scenario, without having to know all of the individual characteristics of each ‘child’ generation model.

The ability to employ generic abstract classes, allowing ‘child’ objects to identify with a ‘parent’ class, lets the core functionality of the Dynamic SedNet plugin expand through complimentary plugins, like the ‘GBR Dyn SedNet Extension’ plugin. The extension of Dynamic SedNet can introduce even more variability in the generation and transport processes represented, but remain compatible with the customised reporting tools.

2.4 Customised reporting

The Dynamic SedNet plugin also provides enhanced reporting features, in addition to the existing Source Catchments reporting facilities. With the assistance of eWater, the Source Catchments core program was modified to provide 'totalisers' for every instance of generation and transport model associated with every Functional Unit or Link based representation of each constituent. This allows access to variables representing the total constituent load leaving each FU or Link (and entering each Link) for every complete model run, without the need for Source Catchments to explicitly record a daily time series representation of each of these. This has given Source Catchments the ability to provide a more comprehensive data base of constituent mass balance without comprising model run time or memory requirements.

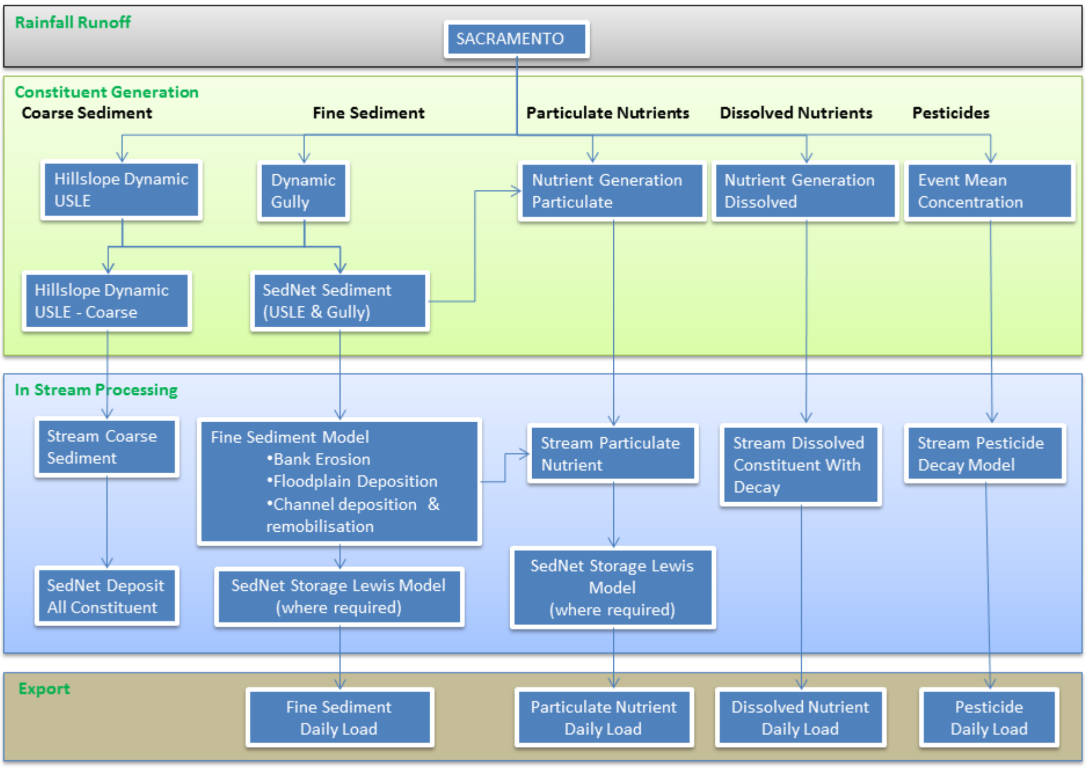
To further enhance the capabilities provided by the inclusion of constituent 'totalisers', Dynamic SedNet uses these variables as well as others specifically programmed into the plugin to summarise model predictions into a series of tables that replicate many of the original SedNet reporting facilities. Additional reports and summarising features have been added to address specific requirements of the project described by Waters *et al*. (2014). All summary tables, and a large 'raw results' table from which all summaries are built, are saved to a user-defined location on completion of a Dynamic SedNet model run, allowing analysis without having to run models again.

2.5 Model structure and interdependence

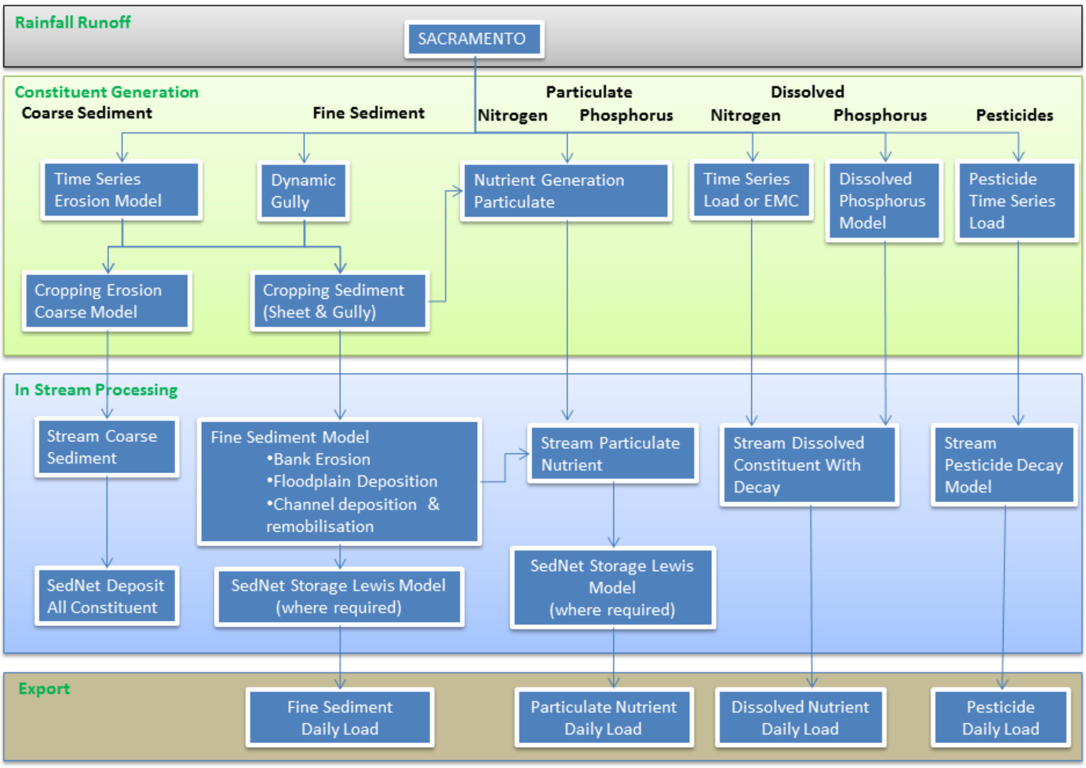
The catchment-node-link structure of Source Catchments is described in eWater CRC (2010a). Generation of constituents is represented within this structure by assigning generation models for each constituent to each 'Functional Unit' described in the scenario, a unique instance of which occurs within each sub-catchment. The Dynamic SedNet plugin requires interdependence between the constituent generation models assigned to specific land uses, representing FUs. This interdependence allows the daily generation of specific constituent (e.g. particulate nitrogen) to be a function of the daily generated load of another, related constituent (e.g. sediment). Each of the generation models included in the Dynamic SedNet plugin is described more fully in this document, however the relationship and interdependence of the specific generation and transport models is depicted graphically below for three land use implementations: grazing, sugar cane and cropping.

The three land use implementations depicted in the diagrams have differing model designs because the data and supporting models available to adequately represent these 'industries' was different at the time of model design. Sugar cane and cropping had very advanced APSIM and Howleaky? (respectively) modelling environments, data inputs and modellers available to provide reliable interpretations of land use impact. Most regions dominated by grazing land uses had access to satellite-derived estimates of ground cover that could inform erosion models of spatial and temporal changes in cover. No single generation model could be used to incorporate these disparate concepts, hence the derivation of the complicated matrix design presented.

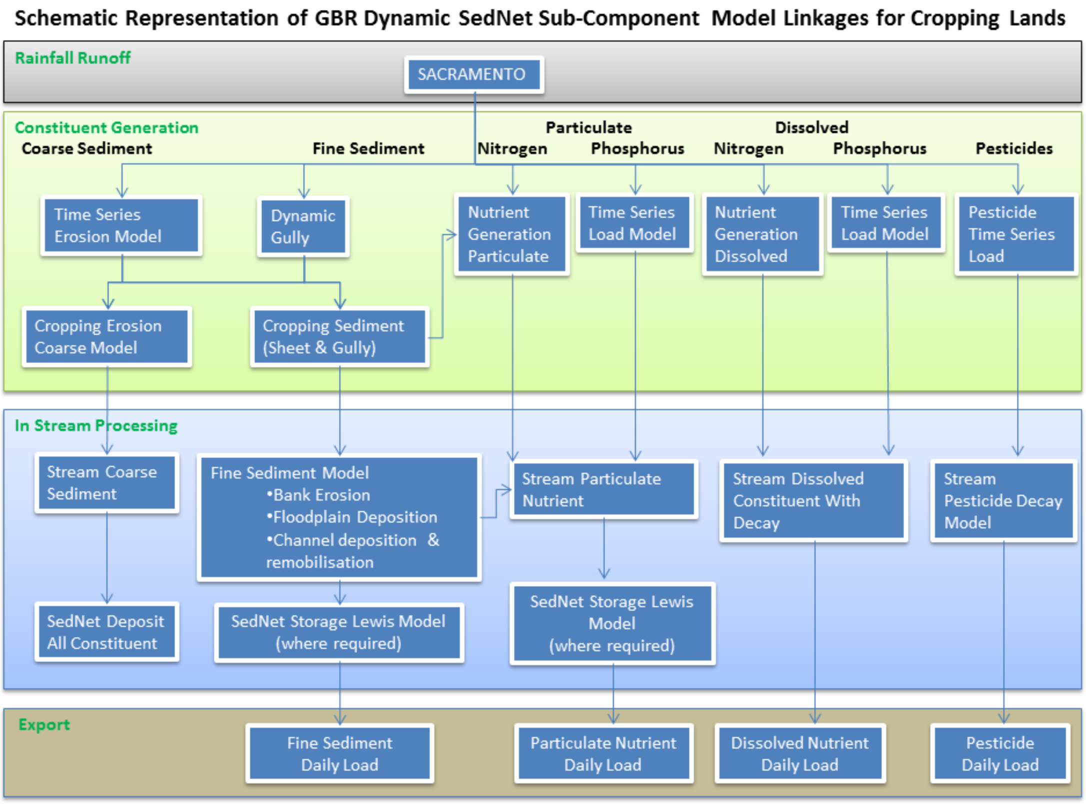
2.5.1 Model structure for grazing


Schematic Representation of GBR Dynamic SedNet Sub-Component Model Linkages for Grazing Lands

2.5.2 Model structure for sugar cane


Schematic Representation of GBR Dynamic SedNet Sub-Component Model Linkages for Sugar Lands

2.5.3 Model structure for cropping



2.6 Model running and configuration

In order to reduce model run time, Source Catchments scenarios operating a Dynamic SedNet running configuration can now (post 2014) opt to “Pre Run Catchments”, whereby all FU based rainfall runoff and constituent generation models are run in their entirety during the first modelling timestep. This enhancement uses efficient data access mechanisms and also utilises parallel processing. Once the Pre Run Catchments process is complete, the model run continues as normal. It is important to note that using this running configuration removes the ability to record and output some time series variables that modellers might like to review when fine tuning a calibration.

The Dynamic SedNet customisation is compatible with command line operation using Source Catchments’ “RiverSystem.CommandLine.exe” utility. A complete Dynamic SedNet model run using RiverSystem.CommandLine.exe will result in 2 outputs:

- The expected Dynamic SedNet summary outputs as saved in the running configuration
- The specific RiverSystem.CommandLine.exe as determined by command line arguments

RiverSystem.CommandLine.exe output file inclusions can be modified by the use of a ‘configuration’ file (see Source Catchments Help for instructions). The Dynamic SedNet plugin will assist with application of this configuration by ‘turning on’ recording of elements included in the configuration file, alleviating the need to modify this via the Graphical User Interface (GUI) beforehand.

To alter individual parameter values for a RiverSystem.CommandLine.exe run of Dynamic SedNet, it is recommended to use a file-based Input Set structure (see Source Catchments Help for instructions).

3. Rainfall Runoff Models

3.1 Rainfall Runoff Model Shell - SedNet

This Rainfall Runoff model serves as a ‘wrapper’ to house a standard rainfall runoff model as a ‘base’, such as SimHyd (Chiew *et al.* 2002) or Sacramento (Burnash *et al.* 1973), whilst providing additional 'State' variables that allow reporting of some variables of interest in the custom Dynamic SedNet results report:

- Cumulative Total Rainfall (over model run period)
- Cumulative Total PET (over model run period)
- Cumulative Total Runoff (QuickFlow + SlowFlow) (over model run period)
- Cumulative Total Baseflow (over model run period)

The ‘base’ rainfall runoff model must be of a type that expects 2 time series inputs, one representing daily rainfall and the other representing daily potential evapotranspiration. From daily climate inputs the ‘base’ rainfall runoff model estimates ‘quick flow’ and ‘slow flow’. It is assumed in the Dynamic SedNet suite of models that ‘quick flow’ is representative of high energy overland flow (runoff), and that ‘slow flow’ may be a combination of low energy overland flow and subsurface seepage (perhaps even ground water contribution). This distinction is important when considering appropriate parameterisation and operation of constituent generation models.

This Rainfall Runoff model also includes two parameters that record the file location of climate inputs that were used to populate the models. The custom built Climate Collation utility for this model actually writes rainfall and potential evapotranspiration (PET) time series CSV files to disk, using a consistent naming convention, prior to importation to Source Catchments. This allows users to supply updated CSV climate inputs without going through the typical raster based collation if they choose to do so.

The naming convention assumes that the same climate time series input is used for each Functional Unit within each sub-catchment, and the files are therefore named:

- rainfall for SC #XX.csv
- pet for SC #XX.csv

with 'XX' the relevant sub-catchment number.

Note: Even though this Rainfall Runoff model records the file location of climate inputs, it DOES NOT read the files from disk during model run time, the climate inputs are stored internally, in the usual Source Catchments manner.

4. Constituent Generation Models

4.1 Constituent definition

In order to replicate SedNet reporting functionality, but to also utilise the flexibility of the Source Catchments modelling environment, 8 constituents (pollutants) are created by the Dynamic SedNet scenario creation ‘wizard’, and a series of tools is also included to apply these constituents to a Source Catchments scenario that may have been created using methods other than the ‘wizard’.

The constituents defined represent a comprehensive range of sediment and nutrient types, allowing differentiation for generation, transport and loss modules. The 8 constituents defined are:

- Sediment – Fine
- Sediment – Coarse
- Particulate Phosphorus (P_Particulate)
- Dissolved Organic Phosphorus (P_DOP)
- Filterable Reactive Phosphorus (P_FRP, also known as 'Dissolved Inorganic Phosphorus')
- Particulate Nitrogen (P_Nitrogen)
- Dissolved Organic Nitrogen (N_DON)
- Dissolved Inorganic Nitrogen (N_DIN)

The primary reason for separating fine and coarse sediment is to allow different in-stream transport and deposition models to be applied, with the transport of coarse material in-stream considered to more like 'bed load' transport rather than 'suspended sediment' transport). The data (and concept) used to separate any land-based eroded soil mass into fine and coarse components (prior to delivery to the stream network) will be different for every application. Typically a modeller will utilise a spatially variable representation of particle size fraction that suits their purpose, understanding that their choice of particle size categories for partitioning into fine and coarse components will affect the manner in which transport and deposition algorithms operate (an effect that is easily managed through many adjustable model parameters). The choice of particle size categories for differentiation will also have some effect on the direct comparison of model predictions with observed data or previous modelling projects, considerations that modeller must make (and be prepared to explain).

The 'GBR Dyn SedNet Extension' plugin allows the modeller to introduce up to eight additional constituents into the model design, representing pesticides/herbicides which were specific to the reporting requirements of the major project considered during the time of this plugin development. Whilst not of critical importance to the operation of either plugin described in this document, the list of constituents available via the 'GBR Dyn SedNet Extension' plugin is:

- 24-D
- Ametryn
- Atrazine
- Diuron
- Glyphosate
- Hexazinone
- Paraquat
- Tebuthiuron

Further pesticides/herbicides were added to the available list post 2014, these are: Aciflurofen, Chlorsulfuron, Diquat, Fluroxypyr, Haloxyfop, Imazapic, Imazethapyr, Isoxaflutole, MCPA, Metribuzin, Metsulfuron-methyl, Pendimethalin, S-metolachlor, Simazine, Terbuthylazin, and Trifluralin.

4.2 Combining Hillslope (sheet) and Gully Contributions

This plugin provides the capability to model the hillslope and gully contribution of sediment loads, as previously represented in the SedNet model. In recognition of the fact that some users may want to build their own generation models representing these processes, a generic 'abstract' model is utilised to provide the reporting framework necessary to fit within the Dynamic SedNet reporting summaries. The 'SedNet_Hill_And_Gully_Abstract_Model' expects that it will be utilised by models that supply a hillslope and gully contribution. This design element allows users to provide their own plugin models that ‘extend’ Dynamic SedNet, and have the calculated loads included in the summary results.

The abstract model has no parameters, just state variables that must be populated by the inheriting models after each timestep of the simulation: the abstract model does NOT populate any of these variables (i.e. the variables are not set to zero at the beginning of each simulation timestep), as this appeared to significantly affect model run time in complex scenarios. The abstract model DOES reset the running total (cumulative) variables at the start of each model run. These variables supply data for the Dynamic SedNet summary reports.

Daily state variables to supply Source Catchments constituent generation mechanisms:

- Daily Sheet Fine Sediment Supply Load
- Daily Sheet Coarse Sediment Supply Load
- Daily Gully Fine Sediment Supply Load
- Daily Gully Coarse Sediment Supply Load
- Daily Quick Flow Sheet Fine Sediment Rate after SDR
- Daily Quick Flow Gully Fine Sediment Rate after SDR
- Daily Quick Flow Sheet Coarse Sediment Rate after SDR
- Daily Quick Flow Gully Coarse Sediment Rate after SDR
- Daily Slow Flow Sheet Fine Sediment Rate after SDR
- Daily Slow Flow Gully Fine Sediment Rate after SDR
- Daily Slow Flow Sheet Coarse Sediment Rate after SDR
- Daily Slow Flow Gully Coarse Sediment Rate after SDR

Running total (cumulative) generation variables used by Dynamic SedNet result summaries:

- Total Quick Flow Fine Sediment From Sheet Model
- Total Quick Flow Fine Sediment From Gully Model
- Total Slow Flow Fine Sediment From Sheet Model
- Total Slow Flow Fine Sediment From Gully Model
- Total Quick Flow Coarse Sediment From Sheet Model
- Total Quick Flow Coarse Sediment From Gully Model
- Total Slow Flow Coarse Sediment From Sheet Model
- Total Slow Flow Coarse Sediment From Gully Model

4.3 Sediment Generation (EMC & Gully)

This is a 'wrapper' model that allows the combination of the common ‘Event Mean Concentration' model and the 'Dynamic Gully Model', representing hillslope and gully contributions to sediment supply respectively. It implements the abstract model ‘SedNet_Hill_And_Gully_Abstract_Model’.

By using a ‘wrapper’ model, we can house more than one sub-model under the guise of a single generation model. This particular 'wrapper' model allows us to keep the hillslope and gully models as distinct entities with identifiable contributions, making this distinction available for post model run analysis.

4.4 SedNet Sediment (USLE & Gully)

This is a 'wrapper' model that allows the combination of the 'Hillslope Dynamic USLE' model and the 'Dynamic Gully Model', representing hillslope and gully contributions to sediment supply respectively. It implements the abstract model ‘SedNet_Hill_And_Gully_Abstract_Model’.

By using a ‘wrapper’ model, we can house more than one sub-model under the guise of a single generation model. This particular 'wrapper' model allows us to keep the hillslope and gully models as distinct entities with identifiable contributions, making this distinction available for post model run analysis.

4.5 Hillslope Dynamic USLE

This constituent generation model requires that the operating Source Catchments scenario has distinct constituents defined that represent Fine and Coarse components of the eroded soil mass, and that the constituent 'load' to be applied to the 'quick flow' runoff component is the Fine Sediment load. Under this assumption, the Coarse Sediment load will be calculated, but to be applied to a 'quick flow' runoff component, a partner generation model must be employed to transfer the Coarse Sediment load to the stream network (‘Hillslope Dynamic USLE – Coarse’).

This model implements a spatially distributed form of the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.* 1997, Lu *et al.* 2001), and predicts the amount of soil lost from the hillslope according to:

$$A = R * K * S * L * C * P$$

Where

A = soil erosion per unit area (t/ha)

R = Rainfall erosivity EI30 (MJ.mm/ha.h.day)

K = Soil erodibility (t.ha.h/ha.MJ.mm)

S = Slope Steepness (dimensionless)

L = Slope Length (dimensionless)

C = Cover management factor (dimensionless)

P = Practice factor (conservation measures) (dimensionless)

In terms of RUSLE application, this generation model assumes that the Practice factor (P) is static at a value of 1, so is not considered in calculations. In the context of catchment scale water quality models, this is often justified due to paucity of management practice data.

4.5.1 Calculation of landscape inputs

The operation of this model relies on time series files representing these variables for each Functional Unit:

- K * L * S * C
- K * L * S * C * (fine sediment proportion of the total eroded soil mass)

The choice of algorithm/process for calculating K, L and S factors is not dictated by this generation model. Typically, however, the K factor would be calculated according to Loch and Rosewell (1992) or Loch *et al.* (1998), with L and S factors calculated according to methods outlined in McCool *et al.* (1989) – or a GIS based variation of this. Continuous raster representations of these factors give the model its ability to model erosion processes spatially.

Raster analysis of RUSLE factors provides a spatially detailed approach to populating the requisite parameter values, however Source Catchments would run very slowly if the required raster analysis was conducted for each Functional Unit at each time step of the operating scenario. This is why a pre-generated time series approach has been taken, and a purpose built spatial parameteriser is used to produce these time series files, with the assumption that K, L and S factors are temporally static and represented by a single raster (K*L*S), and that C factor is also available in raster format, as either a single static representation or varying temporally at a user defined time step. This application of RUSLE requires R and K factors in ‘S.I. units’, not ‘metric’ as originally used in RUSLE and its precursors. Thus, the units of R factor are MJ.mm/ha.h.day, and K factor are t.ha.h/ha.MJ.mm.

By default, the parameteriser calculates the K*L*S*C * (fine sediment proportion) product for every pixel for each temporal representation of C factor (currently an annual estimate), and spatially averages these values across a Functional Unit to produce the input time series files.

Additionally, the parameteriser also captures FU-averaged values of K, L and S, and a time series of FU-averaged C factor. The modeller can choose to operate the erosion model using the FU-averaged values, allowing for faster re-population with adjusted C factor inputs for scenario analysis. This option is simpler than the pixel-by-pixel approach, but yields slightly different (and less spatially explicit) results.

4.5.2 Calculation of rainfall erosivity

The Rainfall erosivity factor (R) is calculated daily at model runtime using the relationship with daily rainfall amount documented by Yu (1998).

$$EI30 = \alpha * (1 + \eta * \text{Time Of Year Factor}) * R^{\beta}, \text{ when } R >= R_0$$

Where:

EI30 is daily rainfall erosivity (MJ.mm/ha.h)

R is daily rainfall amount (mm)

R_0 is the threshold rainfall amount (usually 12.7mm)

$\eta = 0.29$

$\beta = 1.49$

α = a calculated constant (could also be supplied as raster)

The 'Time Of Year' factor included in the daily R factor calculation is substituted by a variation of the 'Time Of Year' factor given in Scanlan *et al.* (1996):

$$\text{Time Of Year Factor} = \cos (2 * \pi * ((\text{Day Of Year} - 15)/365))$$

The variation here is using 'Day Of Year - 15' to peak intensity mid-January, the Scanlan *et al*. (1996) original uses 'Day Of Year + 30'

The purpose built RUSLE parameteriser will calculate α for each Functional Unit based on the rainfall time series available, according to (Yu 1998):

$$\alpha = 0.395 * (1 + 0.098 * e^{(3.29 * S/P)})$$

Where:

S = mean summer rainfall (mm), November – April

P = mean annual rainfall (mm)

Another approach provided by the parameteriser is to supply a spatial representation of the required α parameter, giving the modeller some control over the impact of this parameter.

4.5.3 Operation of USLE model

On each day of simulation a total potential eroded soil mass is calculated by $R * K * L * S * C$. Using the appropriate fine sediment proportion and the available quick flow volume, a potential fine sediment concentration is calculated. If this concentration exceeds the “Maximum Fine Sediment Allowable Runoff Concentration” parameter value, available loads of fine and coarse sediment are reduced based on the maximum fine sediment concentration.

Available fine and coarse sediment loads are then scaled by specific Sediment Delivery Ratios before being assigned to the quick flow delivery mechanism, representing sediment ‘filtering’ from within the generation model.

This model requires the user to specify concentrations of Fine and Coarse sediment to be applied to the 'slow flow' output, i.e. a Dry Weather Concentration (mg/L) value.

4.6 Dynamic Gully Model

This constituent generation model assumes that the operating Source Catchments scenario has distinct constituents defined that represent Fine and Coarse components of the eroded soil mass, and that the constituent 'load' to be applied to the 'quick flow' runoff component is the Fine Sediment load. Under this assumption, the Coarse Sediment load will be calculated, but to be applied to a 'quick flow' runoff component, a partner generation model must be employed to transfer the Coarse Sediment load to the stream network (‘Hillslope Dynamic USLE – Coarse’ or ‘Cropping Soil Erosion Model – Coarse’).

The purpose built parameterisation routines will populate each Functional Unit’s model with values and time series inputs to run both a CSIRO (Wilkinson *et al.* 2014) and DERM gully model type. Both model types use a simple linear model to derive an Annual Average Sediment Supply (AASS - tons per year) based on the calculated gully volume (from gully density, cross sectional area and Functional Unit area) over a known time period (calculated from Year Of Gully Raster and a known time of volume estimate) and a supplied soil bulk density value.

$$\text{AASS (t/year)} = (Ps * \alpha_{XS} * GD_{FU} * A_{FU}) / \text{Age}$$

Where:

Ps = Dry soil bulk density (t/m^3 or g/cm^3)

α_{XS} = Gully cross sectional area (m^2)

GD_{FU} = Gully density (m/m^2) within Functional Unit

A_{FU} = Area of Functional Units (m^2)

Age = Years of activity to time of volume estimation (e.g., year of disturbance to year of estimation)

The method used to then apportion the Annual Average Sediment Supply to the daily generation model differs for the CSIRO and DERM options.

4.6.1 CSIRO gully model

The CSIRO model uses a 'Daily Runoff Factor' (DRF), the ratio of a daily runoff (runoff raised to designated power) to long term runoff (average of runoff raised to designated power, determined during parameterisation by analysing each Functional Unit's runoff time series) and constant of 1/365.25 to calculate a daily gully soil load from the Annual Average Sediment Supply.

$$\mathrm{DRF} = \frac{Q_i^{\,b}}{\frac{1}{n}\sum_{i=1}^{n} Q_i^b} * \frac{1}{365.25}$$

Where:

DRF is the Daily Runoff Factor

Q_i is daily Functional Unit runoff (mm)

Q_t is the long-term runoff (mm)

n is the number of days in the long-term runoff time series

b is an adjustable runoff power parameter, by default set to 1.4

The Daily Runoff Factor is then used to create a daily eroded mass of fine and coarse sediment, by direct multiplication with the Annual Average Sediment Supply value:

Daily Fine Sediment Load (kg) = $(AASS * 1000)$ * DRF * Clay and Silt proportion

Daily Coarse Sediment Load (kg) = $(AASS * 1000)$ * DRF * (1 – Clay and Silt proportion)

4.6.2 DERM gully model

The DERM model uses the ratio of annual runoff amount to long term annual runoff amount to calculate an annual time series of Runoff Weighted Annual Sediment Supply (kg) from the Annual Average Sediment Supply during parameterisation.

$$RWASS_i = \left(\frac{QT_i}{\frac{1}{n}\sum_{i=1}^{n} QT_i} \right) * (AASS * 1000)$$

Where:

$RWASS_i$ is the Runoff Weighted Annual Sediment Supply (kg) for year i

QT_i is total runoff for the Functional Unit for the year i

n is the number of years in the long-term runoff time series

The relevant Runoff Weighted Annual Sediment Supply value is then apportioned to a daily eroded mass of fine and coarse sediment using the ratio of daily runoff to annual runoff for the Functional Unit.

Daily Fine Sediment Load (kg) = $RWASS_i * \left(\frac{Q_j}{QTi}\right)$ * fine sediment proportion

Daily Coarse Sediment Load (kg) = $RWASS_i * \left(\frac{Q_j}{QT_i}\right)$ * (1 – fine sediment proportion)

Where:

$RWASS_i$ is the Runoff Weighted Annual Sediment Supply (kg) for year i

Q_j is the daily runoff amount for the Functional Unit for the jth day of simulation

QT_j is the total runoff amount for the Functional Unit for year i

4.6.3 Gully load processing common to CSIRO and DERM models

Both models also alter the daily fine sediment load by multiplication of Management and Activity factors (value range 0-1, default 1). Coarse sediment loads are not affected by activity factor.

Adjusted Daily Fine Sediment Load (kg) = $DFSL * M_f * A_f$

Adjusted Daily Coarse Sediment Load (kg) = $DCSL * M_f$

Where:

$DFSL$ is the Daily Fine Sediment Load (kg) calculated from runoff analysis

$DCSL$ is the Daily Coarse Sediment Load (kg) calculated from runoff analysis

M_f is the Management factor

A_f is the activity factor

Fine and coarse sediment loads are also scaled by specific Sediment Delivery Ratios before being assigned to the quick flow delivery mechanism, thus representing sediment ‘filtering’ from within the generation model.

The 'Year Of Gully Full Maturity' parameter is NOT used in calculating the total gully volume. However, the 'Year Of Gully Full Maturity' parameter is now coupled with the 'Average Activity Factor', such that the Activity Factor is applied as 1 (i.e., no impact) until after the 'Year Of Gully Full Maturity' is surpassed in the model run time, when the supplied Activity Factor is applied (allowing the modeller to alter the load into the future). This is simply a linear application of this factor.

4.7 Hillslope Dynamic USLE - Coarse

This model relies on the 'SedNet Sediment (USLE & Gully)' wrapper to combine the Coarse Sediment loads calculated by the 'Hillslope Dynamic USLE' and 'Dynamic Gully Model' models, and provide this combined load to the quick flow output for the Coarse Sediment constituent model. To do this, the Fine Sediment constituent MUST be named according to the Dynamic SedNet conventions (Sediment - Fine), and this Fine Sediment constituent MUST employ the 'SedNet Sediment (USLE & Gully)' wrapper model.

4.8 Cropping Sediment (Sheet & Gully) – GBR Only

This is a 'wrapper' model that allows the combination of the 'Cropping Soil Erosion Model' model and the 'Dynamic Gully Model'. It implements the abstract model 'SedNet_Hill_And_Gully_Abstract_Model'.

4.9 Cropping Soil Erosion Model (Erosion Load TimeSeries Model) – GBR Only

This model is setup specifically to take time series loads of daily soil loss in T/Ha generated from sheet erosion, as calculated by external models like HowLeaky? and APSIM (see Waters *et al.* 2014 for descriptions). The importation of time series files from HowLeaky? and APSIM require different processes, and there are specific parameterisers to handle this within the Dynamic SedNet suite of tools.

This constituent generation model assumes that the operating Source Catchments scenario has distinct constituents defined that represent Fine and Coarse components of the eroded soil mass, and that the constituent 'load' to be applied to the 'quick flow' runoff component is the Fine Sediment load. Under this assumption, the Coarse Sediment load will be calculated, but to be applied to a 'quick flow' runoff component, either a partner generation model must be employed to transfer the Coarse Sediment load to the stream network, or this transfer must be undertaken by a 'wrapper' model that is housing an instance of this Cropping Soil erosion Model.

This model will apportion the daily load of eroded soil into Fine and Coarse components based on a user-supplied proportion (similar, but not restricted to, the proportion of clay and silt in the soil matrix of the eroded soil). Other user-supplied parameter values are Sediment Delivery Ratios for the Fine and Coarse sediment components of the daily soil load.

This model also allows the user to specify concentrations of Fine and Coarse material to be applied to the 'slow flow' output, i.e. a Dry Weather Concentration (mg/L) value.

Note: Even though this generation model records the file location of time series inputs, it does NOT read the files from disk during model run time, the time series are stored internally, in the usual Source Catchments manner.

4.10 Alternative Processes Abstract Model

This abstract class can be utilised by plugins to provide tailored pollutant generation models that will be recognised by, and contribute to, Dynamic SedNet summary results. The abstract class provides two abstract 'string' properties that must have values supplied by the plugin code (not by the modeller) that identify what the ‘quick flow’ and ‘slow flow’ constituent supply loads will be labelled as in the ‘BudgetElement’ column of the Dynamic SedNet summary results.

Accompanying this is an abstract ‘dictionary’ property (named ‘alternativeOtherProcessMap’) which can be populated with as many key/value ‘pairs’ of string objects as the programmer desires. The ‘key’ of each record will determine what descriptor will be placed in the ‘BudgetElement’ column of the Dynamic SedNet summary results with the ‘Process’ always labelled ‘Other’. The ‘value’ of each dictionary record will need to match the exact name of the variable from the plugin model that will give access to the total constituent load over the relevant model period, in units of kilogram per second. All records in the Dynamic SedNet summary results labelled as ‘Other’ in the ‘Process’ column will NOT be considered in any summaries related to generation, supply, loss or export of the system. They are used only to provide supporting information to the modeller.

For convenience of recording, three state variables are provided that modellers can access:

- Quickflow Total Constituent Supplied To Stream
- Slowflow Total Constituent Supplied To Stream
- Combined Total Constituent Supplied To Stream

4.11 TimeSeries Load Model

This model is setup specifically to take daily time series loads (T/Ha) of any constituent, possibly as calculated/supplied by external models. The importation of time series files is not catered for in the standard Dynamic SedNet suite of tools.

Delivery ratio is also user-supplied, as is a 'Load Conversion Factor' that allows the same time series to be interpreted differently for specific purposes. For instance a calculated load might need conversion to reflect generation from only a proportion of the total FU area.

This model also allows the user to specify concentrations of constituents to be applied to the 'slow flow' output, i.e. a Dry Weather Concentration (mg/L) value.

Note: Even though this generation model records the file location of time series inputs, it does NOT read the files from disk during model run time, the time series are stored internally, in the usual Source Catchments manner.

4.12 Dissolved Nitrogen TimeSeries Load Model– GBR Only

This model implements the Dynamic SedNet ‘Alternative Processes Abstract Model’. The ‘quick flow’ total constituent supply load will be labelled ‘Hillslope no source distinction’ in the summary results, the ‘slow flow’ total constituent supply load will be labelled ‘Seepage’. One alternative process labelled ‘Other’ has been included: the total amount of DIN ‘Leached’ into ground water over the model run period will be represented.

This model is setup specifically to take daily time series loads (g/Ha) of surface-supplied DIN, as calculated by APSIM or occasionally HowLeaky. A ‘Delivery Ratio – Surface’ parameter determines how much of this time series is delivered to the stream each day if a quick flow volume is available. An additional time series representing the daily amount of DIN leached below the root zone (into ground water) can also be supplied (g/Ha). A proportion of this leached time series (determined by the ‘Delivery Ratio - Leached To Seepage’ parameter) may be delivered to the stream via the ‘slow flow’ pathway (if available), and will also be combined with any load calculated from the ‘Dry Weather Concentration’ parameter. The relative contributions of these sources to the ‘slow flow’ derived constituent load will be included in the summary results.

A 'Load Conversion Factor' allows the constituent load to be interpreted differently for specific purposes, for instance a calculated load might need conversion to reflect generation from only a proportion of the total area. The Load Conversion Factor may be altered during parameterisation to consider the ratio of point-source derived runoff (APSIM for GBR models) and Source Catchments runoff for the same Functional Unit.

Note: Even though this generation model records the file location of time series inputs, it does NOT read the files from disk during model run time, the time series are stored internally, in the usual Source Catchments manner.

4.13 Dissolved Phosphorus Nutrient Model – GBR Only

This model is written specifically to calculate dissolved phosphorus loads from Phosphorus Saturation Index, which itself may be calculated from 'Colwell P' and 'Phosphorus Buffer Index'. This model is used primarily when external models can supply time series inputs of other critical constituents (like sediment or dissolved nitrogen), but can't supply time series inputs of Dissolved Phosphorus (e.g. APSIM).

The concentration of total dissolved phosphorus is calculated from the Phosphorus Saturation Index (PSI) according to:

$$\text{P conc. (mg/L)} = \frac{7.5 * PSI}{1000} \qquad \text{when PSI < 10, or}$$

$$\text{P conc. (mg/L)} = \frac{-200 + (27.5 * PSI)}{1000} \qquad \text{when PSI >= 10}$$

A ‘Proportion of Total P’ parameter allows the user to define how much of the calculated Total Dissolved Phosphorus load should be assigned to the particular constituent being considered. For example, Dissolved Organic Phosphorus and Filterable Reactive Phosphorus may be inferable from the Total Dissolved Phosphorus load by multiplication of a simple factor.

A 'Load Conversion Factor' allows the constituent load to be interpreted differently for specific purposes, for instance a calculated load might need conversion to reflect generation from only a proportion of the total area. The Load Conversion Factor may be altered during parameterisation to consider the ratio of point-source derived runoff (APSIM for GBR models) and Source Catchments runoff for the same Functional Unit.

The dissolved phosphorus load is then calculated by (with appropriate units conversions where required):

Diss. P = runoff * P Conc * Proportion of Total P * Load Conversion Factor * Delivery Ratio

There is no mechanism for supplying a slow flow constituent load in this model.

4.14 Nutrient Generation Dissolved

This model replicates the original SedNet (Wilkinson *et al.* 2004) approach to dissolved nutrient generation, applying user-supplied Event Mean Concentrations (EMC) (mg/L) to quick flow and Dry Weather Concentrations (DWC) (mg/L) slow flow.

The EMC and DWC values are rapidly assigned to each Functional Unit specifically on a 'Land Use Concentration' basis via Dynamic SedNet parameteriser input controls.

An alternative approach to varying the concentration of dissolved nutrient by ‘decaying’ after application has not been implemented.

4.15 Nutrient Generation Particulate

This model replicates the original SedNet (Wilkinson *et al*. 2004) approach to (hillslope and gully) particulate nutrient generation, where user-supplied concentrations (kg/kg) are applied to the total eroded soil mass (fine and coarse sediment, prior to application of any sediment delivery ratio), with enrichment potentially occurring as specified by the user. **The use of ‘total eroded soil mass’ is an important change implemented early in 2017:** previously, particulate nutrient loads were calculated according to the clay proportion of the eroded soil mass only (refer to section 1.1 of this document).

User supplied soil nutrient concentrations (kg/kg) are needed for both surface and sub-surface use, with surface concentrations used to calculate hillslope particulate nutrient supply, and sub-surface concentrations used to calculate gully particulate nutrient supply.

There is no process of enrichment applied to the calculated gully particulate nutrient supply. This is due to the assumed high delivery ratio of gully sediment in SedNet (Wilkinson *et al*. 2004). This leaves the calculation of particulate nutrient supply from gullies as:

Gully Supply (kg) = Gully Sed. Load (kg) * Sub-Surface Soil Nut. Conc.

Hillslope particulate nutrient supply can be enriched in one of 2 ways:

- Application of a simple nutrient enrichment ratio, or;
- Calculation of a phosphorus specific enrichment based on the CREAMS model (Knisel 1980), using a relationship varying with fine sediment supply and area.

The CREAMS enrichment calculation takes the form:

Enrichment Factor = 1.2 * (2.4 – 0.27 * ln(sediment load (kg/ha)))

The GBR Dynamic SedNet models have only had the CREAMS enrichment enabled for Functional Units whose fine sediment supply has been taken from the APSIM model outputs, i.e. sugar cane. All other Functional Units use the simple enrichment approach.

The application of both forms of enrichment is a simple multiplication by a factor, the difference between the methods is simply the derivation (and dynamism) of the factor.

Hillslope Supply (kg) = Hillslope Sed. Load (kg) * Surf. Soil Nut. Conc. * Enrichment Factor

The particulate nutrient loads from hillslope and gully sources are each altered by a specific delivery ratio before being combined for transport to the stream via the ‘quick flow’ mechanism.

This model also allows the user to specify concentrations of material to be applied to the 'slow flow' output, like a Dry Weather Concentration (mg/L) value.

4.16 Pesticide TimeSeries Load Model – GBR Only

This model implements the Dynamic SedNet ‘Alternative Processes Abstract Model’. The ‘quick flow’ total constituent supply load will be labelled ‘Hillslope no source distinction’ in the summary results, the ‘slow flow’ total constituent supply load will be labelled ‘Seepage’. No alternative ‘Other’ processes have been included.

This model is setup specifically to take daily time series loads (g/Ha) of pesticide constituents, as calculated by HowLeaky? or APSIM . Time series loads are expected for both the particulate and dissolved components. The particulate component is adjusted by the fine particle percentage as well as a delivery ratio when being transferred to the stream network, the dissolved component is adjusted only by a specific dissolved delivery ratio.

The particulate and dissolved components are combined when delivered to the stream, and are therefore unable to be distinguished once in the stream network. A 'Load Conversion Factor' allows the constituent load to be interpreted differently for specific purposes, for instance a calculated load might need conversion to reflect generation from only a proportion of the total area.

This model also allows the user to specify concentrations of material to be applied to the 'slow flow' output, like a Dry Weather Concentration (mg/L) value.

Note: Even though this generation model records the file location of time series inputs, it does NOT read the files from disk during model run time, the time series are stored internally, in the usual Source Catchments manner.

5. In Stream Processing Models

It is necessary to give some background on the structure and nomenclature of the Source Catchments modelling environment. Without this information it is impossible to communicate the operation and assumptions of the Dynamic SedNet In Stream Processing Models, and the calculations performed would not be able to be validated in alternative assessments.

There has been some separation of constituent handling in the links and nodes comprising a Source Catchments network – there are now ‘Constituent Provider’ and ‘Constituent Output’ classes written for specific routing and node model options, and in addition to this there is the potential for any link to made up of more than one ‘division’. The Dynamic SedNet In Stream Processing Models have been designed under the assumption that each link has a single ‘division’ to consider.

All of the Dynamic SedNet In Stream Processing Models implement 'Source Sink Model', an interface that provides the ability to 'lose' constituents, however the lost constituent load is not made available as a variable that may be accessed in subsequent model time steps. In addition to this complication, the Source Catchments terminology is confusing. Source Catchments’ use the terms below to identify key constituent transport properties of each instance of a ‘Source Sink Model’ and the associated Constituent Provider and Constituent Output:

- *StoredMass* is the material remaining in the link's 'water column/storage', (kg)
- *DownstreamFlowMass* is the material exiting the link with the Outflow (kg)
- *InitialMass* is the material in the link's 'water column/storage' at the start of a time step (kg)

As stated earlier, 'Bed' storage of constituents (or any continuing measure of 'lost' constituent load) is not a property of Source Sink Models, you must account for it yourself within your plugin-provided in stream processing model. In order and to be able to 'lose' and 'gain' constituent material (i.e., remobilise from stream beds) we created a 'channel store' state variable in relevant models, because no such variable is provided for material not suspended in the water column.

And, very importantly,

- In Stream Processing Models should return a 'working mass' that the constituent provider will apportion to StoredMass and DownstreamFlowMass via a fully-mixed concentration transfer

5.1 SedNet Stream Fine Sediment Model

This model combines the concepts of bank erosion, flood plain deposition and channel deposition/remobilisation (Wilkinson *et al.* 2014).

The bank erosion calculation assumes that the operating Source Catchments scenario has distinct constituents defined that represent Fine and Coarse components of the eroded soil mass, and that the constituent 'load' to be applied to the StoredMass and DownstreamFlowMass components is the Fine Sediment load. Under this assumption, the Coarse Sediment load will be calculated, but to be applied to a DownstreamFlowMass (or StoredMass) component, a partner in stream model must be employed to represent or 'carry' the calculated Coarse Sediment ('SedNet Stream Coarse Sediment Model').

Floodplain deposition and channel deposition/remobilisation do not consider other constituents in the system, just the constituent to which this model is applied (Fine Sediment).

The components of this model are executed in this order:

1. Bank erosion
2. Floodplain deposition
3. Channel deposition/remobilisation

5.1.1 Bank erosion

The bank erosion component of this model relies on the daily disaggregation of a Mean Annual Bank Erosion load, which is calculated during parameterisation. However, the Mean Annual Bank Erosion load is also recalculated during each day of the model run – this allows parameters like Riparian Vegetation and Bank Full Flow to be changed by the user and have an immediate effect, without running a full re-parameterisation.

Mean Annual Bank Erosion (MABE) (t/y) is calculated by:

MABE (t/y) = Retreat Rate (m/y) * Mass Conversion * Bank Erodibility

Retreat Rate (RR) (m/y) is calculated by:

RR (m/y) = $k * p_w * g * S_l * Q_{bf} * M_f$

Where:

k is bank erosion 'calibration' coefficient (0.00004 by default)

p_w is density of water (1000 kg/m^3)

g is acceleration due to gravity (m/s^2)

S_l is the river bed slope (m/m)

Q_{bf} is the bank full flow/discharge (m^3/s)

M_f is the bank erosion management factor, a linear multiplier allowing modellers to adjust retreat rate according to implied management actions.

Mass Conversion (to ultimately convert Retreat Rate to a Mass) is calculated by:

$$\text{MC} = p_s * h * L_l$$

Where:

P_s is sediment dry bulk density (t/m^3)

h is bank height (m), the 'bank' being that which the modeller considers the erosion contributing feature (not necessarily 'channel' height or depth).

L_l is length of river represented by the link (m)

Bank Erodibility (BE) is calculated by:

BE = (1 - MIN(*RipVeg*, *MaxVegEffectiveness*)) × *SoilErod*

Where:

RipVeg is the proportion of intact riparian vegetation (1 for complete coverage, 0 for none)

MaxVegEffectiveness is a 'cap' on the effectiveness of the riparian vegetation

SoilErod is the erodibility of the soil material adjacent to the stream (0 for rock, 1 for erodible soil, spatial analysis may result in values anywhere within this range)

Mean Annual Bank Erosion is disaggregated to a daily load using a Link Discharge Factor, which is the relationship of daily outflow to long term average daily flow, and a constant:

$$\text{Daily Bank Erosion (kg)} = \frac{1}{365.25} * LDF * MABE * 1000$$

Where:

MABE is Mean Annual Bank Erosion (t/y)

LDF is Link Discharge Factor

Link Discharge Factor is calculated on a daily basis according to:

$$\text{LDF} = \frac{Q_i^{\,b}}{\frac{1}{n}\sum_{i=1}^{n} Q_i^b}$$

Where:

Q_i is the daily flow rate (m^3/s)

Q_t is the long-term historical daily flow record (m^3/s)

n is the number of days in the long term historical daily flow record

b is the adjustable Daily Flow Power Factor, default 1.4

The Daily Bank Erosion load (kg) is then apportioned to Fine and Coarse Sediment according to the supplied fine particle proportion (clay + silt).

5.1.2 Floodplain deposition

The mass of fine sediment deposited on the floodplain (FD_{fs}) of each link is determined on a daily basis by:

$$FD_{fs}\ (\text{kg}) = I_f * \left(\frac{Q_f}{Q_L}\right) * \left(1 - e^{-\left(v_p * A_f / Q_f\right)}\right)$$

Where:

Q_L is daily discharge (m^3/s)

Q_{bf} is Bank Full Flow (determined during parameterisation) (m^3/s)

$Q_f = Q_L - Q_{bf}$ (m^3/s)

I_f is daily fine sediment supply (kg)

A_f is floodplain area (m^2)

V_p is settling velocity (m/s), default 0.0007

5.1.3 Channel deposition/remobilisation

The amount of material that can be deposited in each link (‘channel store’) is capped at an upper limit, currently represented as a proportion of the bank height parameter. Once the channel store is 'full', no more deposition can occur unless remobilisation removes some material from the store first. By setting the available depth for deposition to zero, modellers can effectively ‘turn off’ deposition (and hence remobilisation).

Fine sediment supply is calculated as:

Fine Sediment Supply I_f (kg) = Lateral Load (kg) + Inflow Load (kg) + Residual Load (kg)

Lateral Load includes supply from bank erosion, hillslope, gullies, and any other FU generated sediment loads, from within the sub-catchment associated with the link. Associated with daily fine sediment Supply (I_f) are daily fine sediment Deposition (D_f) and daily fine sediment Yield (Y_f), both in units of kilograms.

The maximum channel store of deposited fine sediment (kg) is $S_{f\ max}$ and is determined geometrically from the channel width (m), length of stream (m), available depth for deposition (m) and sediment bulk density (t/m^3, default 1.5). The mass of sediment residing in the channel store (kg) at any given time is denoted S_f.

The deposition/remobilisation model requires the daily calculation of two Sediment Transport Capacity values for each link:

$$STC_{dep} = \frac{1}{10}\left(\frac{Q_L^{1.4} S_L^{1.3}}{\omega_{dep} w^{0.4} \eta^{0.6}}\right)$$

$$STC_{mob} = \frac{1}{10}\left(\frac{Q_L^{1.4} S_L^{1.3}}{\omega_{mob} w^{0.4} \eta^{0.6}}\right)$$

Where:

STC_{dep} is the Sediment Transport Capacity (kg) for deposition (of fine sediment)

STC_{mob} is the Sediment Transport Capacity (kg) for remobilisation (of fine sediment)

Q_L is daily discharge (m^3/s)

S_L is slope of stream represented by link (m/m)

ω_{dep} is the (adjustable) average terminal fall velocity (m/s) for fine sediment (default 0.0007)

ω_{mob} is the (adjustable) terminal fall velocity (m/s) for larger particles (default 0.1)

ω_{dep} must be less than ω_{mob} (ie., $\omega_{dep} < \omega_{mob}$)

w is channel width (m)

η is Manning's channel roughness factor (default 0.04)

Once the Sediment Transport Capacity values have been calculated, deposition/remobilisation is determined according to these rules:

1. If $I_f > STC_{dep}$ then $Y_f = STC_{dep}$ and $D_f = I_f - STC_{dep}$, limited by $D_f \le S_{f,\max} - S_f$;
2. If $I_f < STC_{mob}$ then $D_f = I_f - STC_{mob}$ (D_f will be < 0, indicating remobilisation), limited by $D_f \ge -S_f$ .It follows then that $Y_f = I_f - D_f$, although Y_f will be apportioned between outflow and residual fluid;
3. If $STC_{mob} \le I_f \le STC_{dep}$ then $D_f = 0$, S_f remains unchanged.

5.2 SedNet Stream Coarse Sediment Model

This model combines the concepts of bank erosion and channel deposition/remobilisation. It relies on the existence of a 'SedNet Stream Fine Sediment Model' for a Fine Sediment constituent, whose name must use the Dynamic SedNet naming convention (Sediment - Fine).

The bank erosion calculation (and contribution) is actually performed by the associated in stream processing model for Fine Sediment. At time of development, the Dynamic SedNet programmers were unable to implement the ‘bed material’ storage and/or transport models as defined in the specification document. For this reason, the channel deposition model for coarse sediment deposits ALL supplied constituent, with no upper limit to deposition. No remobilisation occurs.

5.3 SedNet Stream Particulate Nutrient

This model combines the concepts of bank erosion, flood plain deposition and channel deposition/remobilisation, and relies on the existence of a 'SedNet Stream Fine Sediment Model' for a fine sediment constituent, whose name must use the Dynamic SedNet naming convention (Sediment - Fine). The components of this model are executed in this order:

1. Bank erosion
2. Floodplain deposition
3. Channel deposition/remobilisation

The total available particulate nutrient load (I_{nut}) for deposition/transport is calculated by:

$$I_{nut} \text{ (kg)} = \text{Lateral Load (kg)} + \text{Inflow Load (kg)} + \text{Residual Load (kg)} + \text{Bank Load (kg)}$$

Lateral Load includes total (fine and coarse) sediment supply from hillslope erosion and gullies. If the associated fine sediment lateral load is zero, yet the particulate nutrient lateral load is greater than zero, the particulate nutrient lateral load is removed from I_{nut} to minimise the likelihood of fine sediment based deposition/remobilisation creating disproportionate particulate nutrient loads.

In an attempt to achieve a similar outcome, the particulate Bank Load contribution to I_{nut} is adjusted by the proportion of fine sediment assumed to be in the Daily Sediment Bank Load.

5.3.1 Bank erosion (particulate nutrients)

Stream bank generation of particulate nutrients applies a user-supplied (often from raster analysis) nutrient concentration value to the total sediment bank erosion load (not just ‘fine’ sediment as was the case prior to 2017 updates):

$$\text{Daily Bank Particulate Load (kg)} = \text{Daily Sed. Bank Load (kg)} * \text{Concentration (kg/kg)}$$

The particulate nutrient concentration is calculated from a raster data set of sub-surface concentrations, analysed during parameterisation of the ‘SedNet Stream Fine Sediment’ model.

5.3.2 Floodplain deposition (particulate nutrients)

Floodplain deposition is calculated by using the proportion of fine sediment deposited in this manner:

$$FD_{nut} \text{ (kg)} = \left(\frac{FD_{fs}}{I_f}\right) * I_{nut}$$

Where:

FD_{fs} is the floodplain deposited fine sediment load (kg)

I_f is the fine sediment supply load for the relevant time step (kg)

I_{nut} is the particulate nutrient supply load for the relevant time step (kg)

5.3.3 Channel deposition/remobilisation (particulate nutrients)

Channel deposition/remobilisation of particulate nutrients operates in the same conceptual manner as floodplain deposition, i.e. based on the fine sediment proportion of deposition/remobilisation with regard to supply. Conceptually it is important to note that as the model is currently implemented, the available suspended load for deposition (i.e. I_f) is not updated after floodplain deposition is calculated. This implementation has been intentional, and is consistent with the way that the proportion of fine sediment deposition/remobilisation has been calculated.

Channel deposition/remobilisation is calculated according to the proportion of fine sediment deposition/remobilisation:

$$D_{nut} = \left(\frac{D_f}{I_f}\right) * I_{nut}$$

Where:

D_f is the channel deposited fine sediment load (kg). May be negative for remobilisation.

I_f is the fine sediment supply load for the relevant time step (kg)

I_{nut} is the particulate nutrient supply load for the relevant time step (kg)

If D_{nut} is less than zero, remobilisation has occurred, with the relevant material added to the suspended load for apportioning to outflow and residual loads.

5.4 SedNet Stream Dissolved Constituent With Decay

This model is intended for use with dissolved nitrogen constituents, and applies a decay based on 'travel time', which is calculable from flow velocity if that is available. Flow velocity is significantly affected by stream width and height parameters, and in fact there is currently no comprehensive flow velocity calculation for periods of 'over bank flow'. The uncertainty surrounding the physical parameterisation of this model, and also uncertainties of its applicability in situations where the travel time of most links is less than 1 day, means that the 'decay' option for this model is currently recommended to be 'switched off' in GBR models.

This in stream model is also ‘unusual’ in that it directly calculates an outflow load, whereas most other in stream models calculate a load to be apportioned between outflow and residual water storage.

The operation of this model when decay is selected requires the calculation of ‘travel time’ (seconds), t_c:

$$t_c = \frac{v_i}{L_l}$$

Where:

v_i is the velocity of flow (m/s)

L_l is the link length (m)

Link length is determined during Source Catchments network delineation, and can also be updated manually for each link. Flow velocity, however, is not provided as a standard Source Catchments output variable. The concept that we have used to calculate flow velocity is to try to determine an average cross sectional area for the link, and use this to convert outflow rate (m^3/s) to a flow velocity (m/s).

To determine cross sectional area of the link, this model inherits link length, width and heights parameter values from the ‘SedNet Stream Fine Sediment Model’ attached to the fine sediment constituent. Caution needs to be taken to ensure ‘link height’ represents the geometric channel and not necessarily the erodible bank height (as used by the fine sediment bank erosion model). The average channel width could also be different from that used to define the fine sediment deposition area. This is an obvious area for further improvement.

The cross sectional area of the water body, however, is not directly determined by channel height, but by the ‘depth’ of the water mass in the identified ‘Storage’ of each time step. In this implementation, if a Storage volume for the previous time step is available, then the average value is calculated. If not, the Storage volume used for ‘depth’ calculations is the Storage on the given day:

If S_{i-1} exists: $S_{av} = \frac{S_i + S_{i-1}}{2}$

Else: $S_{av} = S_i$

Where:

i is the ith day of the model time series

S_i is the water storage volume (m^3) on the ith day of the model time series

S_{av} is the average water storage volume (m^3) to be used to calculate depth

Depth of the water storage for each link at any time step, D_i (m) is calculated as:

D_i = Min $\left(ch_l,\left(\frac{S_{av}}{L_l * W_l}\right)\right)$

Where:

ch_l is the channel height (m), inherited from fine sediment model ‘Channel Depth’

S_{av} is the average volume of water in the link storage for time i (m^3)

L_l is the length of the link (m)

W_l is the width of the link (m), currently inherited from fine sediment model ‘Channel Width’

This approach obviously ‘caps’ the depth of the storage volume being represented, so is not representing over bank flow (floods).

Once average depth of water storage for time step *i* is determined (D*i*), the cross sectional area (m^2) is calculated by:

CS_i = $D_i * W_l$

Where:

CS_i is cross sectional area of water storage (m^2) on the *i*th day of the model time series

D_i is the average depth (m) of the water storage volume on the *i*th day of the model time series

W_l is the average width of the channel

With cross sectional area calculated, flow velocity is then determined from the outflow rate of the time step:

v_i = $\frac{Q_i}{CS_i}$

Where:

v_i is the flow velocity (m/s) on the *i*th day of the model time series

CS_i is cross sectional area of water storage (m^2) on the *i*th day of the model time series

Q_i is the outflow rate (m^3/s) on the *i*th day of the model time series

With flow velocity calculated, travel time can then be estimated:

t_c = $\frac{v_i}{L_l}$

Where:

t_c is the estimated travel time (s)

v_l is the velocity of flow (m/s)

L_l is the stream length (m)

Having calculated water storage depth (or 'stage height') as D_l (m), we can also calculate the decay coefficient k_1:

$$k_1 = \frac{v_f}{D_l}$$

Where:

k_1 is the decay coefficient

v_f is the nutrient uptake velocity (m/day), default 0.096

D_i is the average depth (m) of the water storage volume on the *i*th day of the model time series

Eventually, the decay of the dissolved nitrogen load can begin, according to the relationship of calculated travel time (t_c) to model time step (t_s).

When $t_c \leq t_s$:

$$Mout_i = \left(Mlat_i + Mr_{i-1} + Min_i\right) * e^{(-k_1 t_s)}$$

$$M_{ri} = 0$$

When $t_c > t_s$:

$$Mout_i = \left(Mlat_i + Mr_{i-1}\right) * \frac{t_s}{t_c} * e^{(-k_1 t_s)}$$

$$Mr_i = \left[\left(Mlat_i + Mr_{i-1}\right) * \left(\frac{t_c - t_s}{t_c}\right) + Min_i\right] * e^{(-k_1 t_s)}$$

Where:

$Mout_i$ is the load of dissolved nitrogen (kg) to be assigned to the outflow

Mr_i is the remaining load to be assigned to the water storage

Mr_{i-1} is the remaining load from the previous time step

$Mlat_i$ is the supply of dissolved nitrogen (kg) from lateral sources (hillslope etc)

$Mini$ is the supply of dissolved nitrogen (kg) from upstream sources

k_1 is the decay coefficient

t_c is the link travel time in days (d)

t_s is the model time step in days (d)

5.5 SedNet Stream Pesticide Model – GBR Only

This model copies the functionality of the Source Catchments 'Decay' model, as it existed in early 2011. It is likely this model will become more complicated under future development, hence its inclusion as a standalone model.

The decayed load (kg) is calculated as:

$$Decay_i = Csu_i - \left(Csu_i * 2^{\left(-\frac{t_s}{h}\right)} \right)$$

Where:

$Decay_i$ is the decayed load (kg) for the *i*th day of the model time series

Csu_i is the total constituent supply load (kg) for the *i*th day of the model time series

t_s is the model time step in seconds (s)

h is the half life in seconds (s)

The constituent load after decay is then apportioned between outflow and the residual water storage.

With t_s = 86400 for a daily model and h an adjustable parameter, if h is also set to 86400, half of the load is decayed in each in link in each day of the model run.

5.6 SedNet Deposit All Constituent

As the name suggests, this model simply drops all constituent from the water column, meaning that StorageMass and DownstreamFlowMass are both zero at the end of each time step. This model does tally up the material lost over the model run period for reporting, but it is not available for remobilisation. This model is a convenient option to employ when the modeller wants to ensure there are no exports loads of a particular constituent.

5.7 SedNet Storage Lewis Model – GBR Only

This model is intended for use on links operating as Storage models, and removes supplied constituent using a 'trapping' algorithm based on reservoir capacity, length and discharge rate. Any material that does not make it to the Outflow component is considered trapped for ever, and hence removed from the 'suspended' constituent storage.

The trapped daily percentage of supplied fine sediment is calculated as (Lewis *et al*. 2013):

$$T_i = S - \left[M * \left(\frac{Cap^2}{LDF * Len * Q_i^{\,2}} \right)^{LDP} \right]$$

Where:

T_i is the percentage of supplied fine sediment trapped on the *i*th day of the model time series

Cap is reservoir capacity, or ‘full supply volume’ (m^3)

Len is reservoir length (m) (wall to longest impounded length at capacity *Cap*)

Q_i is daily total inflow (m^3/s) on the *i*th day of the model time series (an option exists to use outflow)

S is an adjustable parameter (‘subtractor’), default 112

M is an adjustable factor (‘multiplier’), default 800

LDF is an adjustable length/discharge factor, default 3.28

LDP is an adjustable length/discharge power factor, default -0.2

The model then assumes that any material not trapped is passed out in the daily outflow;

$$\text{Daily Outflow Load (kg)} = \left[1 - \left(\frac{T_i}{100} \right) \right] * \text{Daily Supply Load (kg)}$$

Daily Residual Load (kg) = 0

5.8 Reservoir Dissolved Constituent Decay - SedNet

This model is an implementation of the dissolved nutrient loss model described in Wilkinson *et al.* (2004), and is intended for use on links operating as Storage models. It relies on Bank Full Flow and Median Flood Residence Times to lose/decay material over time. Conceptually, Bank Full Flow is difficult to determine in Storage links, so for now we have provided a boolean parameter that can ‘turn off’ decay, resulting in no constituent decay.

When decay is selected to occur, each day’s outflow is compared to the Bank Full Flow value. If the outflow rate is less than the Bank Full Flow value, all constituent is decayed under the assumption that residence time is greater than five days. If outflow is greater than or equal to Bank Full Flow, the proportion of decay is scaled linearly from 100% of supplied (and residual) constituent when ‘Residence Time’ is greater than or equal to five days, to 0% when ‘Residence Time’ is zero.

$$\text{Proportion Decayed} = Min\left(1, \frac{RT}{5}\right) \qquad \text{when } Q_i \geq Q_{bf}$$

$$\text{Proportion Decayed} = 1 \qquad \text{when } Q_i < Q_{bf}$$

Where:

RT is Median Flood Residence Time in days (d)

Q_i is daily outflow/discharge (m^3/s) on the ith day of the model time series

Q_{bf} is Bank Full Flow or Overbank Flow (m^3/s) (determined during parameterisation)

Median Flood Residence Time is calculated during parameterisation according to:

$$RT = \frac{V_{fsl}}{V_{bf}}$$

Where:

V_{fsl} is volume (m^3) of storage at full supply level

V_{bf} is volume (m^3) of median flood (Median Over Bank Flow as calculated during parameterisation)

After the decay load has been calculated, the remaining load is apportioned between outflow and the remaining water mass.

5.9 Reservoir Particulate Trapping Deposition Model - SedNet

This model is an implementation of the Reservoir Deposition model described in Wilkinson *et al.* (2004), and is intended for use on links operating as Storage models. It relies on knowledge of the reservoir capacity and Mean Annual Inflow.

Trapped constituent is dropped permanently from the suspended constituent load, non-trapped constituent is re-apportioned to Storage and Outflow components according to volume.

The particulate trapping efficiency, TE_i (%), is calculated according to:

$$TE = -22 + \left[\frac{119.6 * \left(\frac{C}{MAI} \right)}{0.012 + 1.02 * \left(\frac{C}{MAI} \right)} \right]$$

Where:

C is the total reservoir capacity (m^3)

MAI is the mean annual inflow (lateral + upstream) (m^3)

The trapped amount of particulate is tallied for reporting, but is not made available for remobilisation.

6. Conclusion

The successful application of plugin adaptations to the Source Catchments modelling framework has been demonstrated in the Great Barrier Reef catchment modelling program (Waters *et al*. 2014). It is recognised, however, that model improvement is a continuous process and that there are many improvements to the modelling environment required to reflect new knowledge of landscape processes and the interpretations of the available data sets. A flexible modelling framework is essential to ensure these modifications and adaptations can be undertaken efficiently, from a modellers and a stakeholder end-user perspective. In addition, the information products that have been generated through the GBR catchment modelling program have fuelled end-user demand for further enhancements and development of plugins to meet improved functionality of the Source Catchments model. While sophisticated programming and design may create a modelling environment that appears capable of addressing a multitude of stakeholder interests, it is critical to manage these expectations and communicate the underlying assumptions and uncertainties within the model which are a simplification of reality.

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