CHAPTER 3. Description of the Models from the Integration Perspective

3.1 AGNPS Model

This section describes the AGNPS model in a more detailed way and from the perspective of the integration approach. The objective is to identify the variables that will be manipulated through the use of the interface. This means that only some of the equations will be presented and is by no means a full technical document for the model. When appropriate, references will be made to the manual and documentation of the AGNPS model (Young *et al.*, 1994) where the equations are defined.

The objective of the model is to compare the effects of various best management practices that could be incorporated into the management of watersheds. It is a distributed model that simulates agricultural watersheds for a single storm event assuming uniform precipitation patterns.

Watersheds modeled by AGNPS must be divided into homogenous square working areas called cells. Subdivision of main cells into smaller sub-cells, gives flexibility to account for the heterogeneity in the watershed. The hydrology is calculated by the SCS curve number approach and the USLE is used for predicting soil erosion. Erosion is predicted for five different particle sizes namely sand, silt, clay, small aggregates, and large aggregates.

The pollutant transport portion is subdivided into one part handling soluble pollutants and another part for sediment based pollutants. The methods used to predict nitrogen and phosphorus yields from the watershed and individual cells were developed by Frere *et al*. (1980); for pesticides the method described by Wauchope and Leonard (1980) is used. As in most nonpoint source pollution models, the equations are based on the CREAMS model described in Knisel, (1980).

The nitrogen and phosphorus calculations are performed using relationships between chemical concentration, sediment yield and runoff volume. For the pesticide component, a distinction is made between foliar and soil application to account for the different decay rates for each source of the same chemical. Pesticide runoff is partitioned between water and sediment using a linear form of the Freundlich isotherm.

Data needed for the model can be classified into two categories, watershed and cell data. Watershed data include information applying to the entire watershed such as watershed size, number of cells, and if running for a single event, the storm type, duration and intensity. Cell data includes information on the parameters based on soil type, land use, and management practices within the cell. The following sections will expand on the physical processes that the AGNPS model uses and will be described from the perspective of the proposed integration.

3.1.1 Hydrology

The purpose of this section is to identify the hydrology and hydraulic methods that the AGNPS model uses, together with the variables that are involved in the different processes. First, it is necessary to define the options available in the AGNPS model that affect the calculation of the hydrology and hydraulic related values. The options include (a) the choice of peak flow method, (b) the geomorphic calculation option and (c) the hydrograph shape generation option. The choice of peak flow method includes two different techniques for peak flow calculations called the *AGNPS* and the *TR55* options.

The *AGNPS* option uses the peak discharge equation based on the SCS curve number technique and limits the channel shape to triangular. The *TR55* option uses the SCS unit hydrograph generation theory and assumes a rectangular shaped channel (top width and bankfull depth). The *TR55* method is an extension of the basic curve number theory including rainfall amount and distribution through the use of a unit hydrograph.

The choice of peak flow method affects the peak flow calculations and the channel shape data requirements. As concluded in the verification section of the technical documentation of the model, the choice for the peak flow method should be based on the scale of the application. If the model is going to be used for watershed-scale applications, then the choice of the *TR55* option is recommended wherever one of the SCS rainfall distributions is reasonably assumed.

The geomorphology option provides a choice between having the model use the geomorphic calculations for channel dimensions or not. The hydraulic geometry predicted by geomorphic calculations is an approach that estimates the downstream trend of increasing channel widths, depths and lengths within well-defined geomorphic regions as a function of the drainage area.

If the geomorphic options and the *TR55* peak flow method are chosen, the channel widths, depths and lengths are calculated based upon functions of the drainage area. If the *AGNPS* peak flow method is selected, the geomorphic option is limited to the stream length, assuming a triangular shaped channel. This is the recommended option found in the model technical documentation. The non- geomorphic option requires cell-by-cell input of channel length, top widths and bankfull depths.

The options for the hydrograph shape generation, shape coefficient or percentage of total runoff prior to the peak, fix the method for calculating the triangular hydrograph. The composite hydrograph is partitioned into three equally spaced ascending limb increments and whatever number of partitions resulting on the recession limb for the time increment.

The algorithm for the hydrograph generation satisfies conservation of mass principles, using the runoff volume, peak flow and time to peak based on the amount of runoff under the ascending limb of the hydrograph. The pre-peak runoff fraction is the recommended option.

The following section presents the equations of the model to deal with the hydrology. The SCS curve number technique is a simplified method for estimating rainfall excess that does not require computing infiltration and surface storage separately. Both processes are included as one runoff watershed characteristic. The excess rain volume (runoff) depends on the amount of precipitation and the volume of total storage (retention). The runoff is predicted for each cell by the SCS equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{3.1}$$

where Q is the runoff volume, P is the total rainfall from the storm and S is the retention factor:

$$S = \frac{1000}{CN} - 10 \tag{3.2}$$

where CN is the curve number for the cell. These runoff curve numbers depend on the soil water content (moisture condition) and can be found as tabulated values for different land use descriptions. The CN value for each cell will be calculated, as a function of the landcover assuming an average moisture condition, with the values presented in the Lookup Table B4 in Appendix B.

The antecedent soil moisture condition (AMC) represents the watershed soil moisture content and the runoff curve numbers depend on the AMC as described by the SCS as follows:

AMC I - Dry soils but not to the wilting point.

AMC II - Average moisture condition. General case for annual floods.

AMC III - Nearly saturated if rainfall have occurred in the 5 days prior to the storm.

It is worth to note that the values stored in the database are for the average condition II. If a different soil moisture condition is present, the program internally modifies the curve number values according to the following relationships:

$$CN_I = 4.2*CN_{II} / (10 - 0.058*CN_{II}) \quad ; \quad CN_{III} = 23*CN_{II} / (10 + 0.128*CN_{II})$$

where CN_I is the curve number for moisture condition I, CN_{II} for condition II, and CN_{III} for condition III.

The SCS method uses the convolution of a triangular hydrograph to route excess rainfall; thus the peak time is the only parameter determining the shape of the hydrograph. The area under the unit hydrograph equals the unit volume of the rainfall excess. With the *AGNPS* hydrology option, the overland flow duration is calculated as the ratio between the slope length and the overland velocity. The slope length, L_s, is the length where the overland and rill erosion occurs, defined from the top of the slope to the point where the flow becomes concentrated.

The overland velocity V_r is:

$$V_r = 10^{\frac{1}{2}\log_{10}(S_l) - C_s} \tag{3.3}$$

where S_l is the average land slope for the cell and C_s is the surface condition constant based on the land use of the cell.

The average slope will be calculated automatically from digital elevation data for each cell. This will be explained with more detail in Chapter 4. The C_s value for each cell is calculated as function of the land use with the values presented in the Lookup Table B4 in Appendix B.

If the *TR55* option is selected there is no need to calculate the overland velocity. It is indirectly estimated resulting in the overland flow duration by adding the sheet and shallow concentrated flow times.

The equation to calculate the time of sheet flow, T_s, is:

$$T_s = \frac{0.007(n\,L_s)^{0.8}}{P^{0.5}(S_l\,/\,100)^{0.4}} \tag{3.4}$$

where n is the overland Manning's roughness coefficient and S_l is the average land slope for the element cell.

The Manning's coefficient for each cell will be calculated as a function of the land use with the values presented in the Lookup Table B4 in Appendix B. On the other hand, the time of concentrated flow is the ratio between the flow length, L_f, and the shallow concentrated flow velocity.

The flow length is calculated differently for primary and non-primary cells. Primary cells are the starting elements at the top of the watershed. Non-primary cells are elements receiving flow from other cells.

$$\textit{Non-primary cells:}\quad L_f = 1.061W - L_s \qquad \textit{Primary cells:}\quad L_f = 1.5\frac{W}{2} - L_s \tag{3.5}$$

where W is the cell width and the constant 1.061 and 1.5 factors are adjustments for the curving of the stream. The input required, considering the cell a square, is the area for a primary cell.

The cell width is then calculated as the square root of the area times a units conversion constant. The area for a basic cell will be calculated and stored when the grid is created. The triangular hydrograph is standard in the SCS version of the AGNPS. The time to peak at the top of the cell is used in calculating the hydrograph for the top of the cell.

Since the method only requires the duration for the storm rainfall flow in the cell, point source flows and volumes are not included in this calculation. The point sources are all considered to be downstream from the top hydrograph.

The time to peak at top of the cell hydrograph, t_{pt}, is calculated using the following equation:

$$t_{pt} = \frac{3600\, K_c\, Q_a\, A_a}{640\, q_a} \tag{3.6}$$

where the 3600 converts the time peak to seconds, K_c is the shape coefficient for the triangular part of the hydrograph, Q_a is the runoff volume above the cell and is accumulated in the routing portion of AGNPS

Since this is only for the cell flow, it simply uses the runoff volume from all the cells flowing into this cell. A_a is the drainage area above the current cell and q_a is the flow rate above. The flow rate below for all the cells flowing into the current cell is the flow rate from above. If the current cell is a primary cell, the value is zero.

Below the cell hydrograph, equation (3.6) is also used but with the values at the bottom of the cell (Q_b, A_b, q_b). The only difference is that the variables that go into this calculation include the amounts from the current cell together with any point source input into the cell. The peak flow rate q, for the current cell is calculated using the equation (Smith and Williams, 1980):

$$q = 200\, A^{0.7}\, S_c^{\;0.16}\, Q^{0.9A^{0.017}}\, L_w^{\;-0.19} \tag{3.7}$$

where A is the drainage area for the cell, S_c is the mainstream channel slope, Q is the runoff volume and L_w is the length-width ratio of the watershed. The flow rate of all the point sources above the current cell is then added to get the peak flow rate below the cell, q_b. The channel slope will be calculated with the average overland slope from the digital elevation model data.

Summarizing, the data detected from the equations that will be extracted automatically from digital files are for each cell: the SCS curve number, the surface condition constant, the overland Manning’s roughness coefficient, the topology of the grid (receiving cells and flow directions), the average overland slope and the mainstream channel slope.

3.1.2 Sediment Transport

The AGNPS model simulates the soil loss and sediment yield in a two-step process. For the soil erosion calculations it uses a modification of the USLE described by:

$$E_u = EI\, K\, LS\, f_{ss}\;\, f_{sh}\, C\, P \tag{3.8}$$

where E_u is the upland erosion, EI is the erosion index for the storm, K is the soil erodibility factor, LS is the slope length factor, f_{ss} and f_{sh} are the slope steepness and slope shape factors to account for the effects of steepness and shape of the slope, C is the vegetative cover factor and P is the control practice factor. The soil erodibility factor is a measure of potential erodibility of soil and is a function of soil texture. The K value for each cell will be calculated from digital soil type files with the values presented in the Lookup Table B2 in Appendix B.

The LS factor is a function of the overland runoff length and slope. It is a dimensionless factor that cover soil loss estimates for the effects of the field slope and is calculated with:

$$LS = \left[\frac{L_s}{72.6}\right]^d \tag{3.9}$$

where L_s is the slope length already defined in the hydrology section and d is a slope length exponent based upon the average land slope (0.3 for land slopes <4%, 0.4 for slopes between 4 and 5% and 0.5 for average land slopes >5%).

The average overland slope will be calculated automatically from digital elevation data for each cell. The slope steepness and shape factors are introduced to take into account the effects of steepness and shape of the average overland slope. The steepness factor is calculated internally in the model with a quadratic regression curve as a function of the land slope. The shape factor takes the value of 1 for uniform slope shape, 1.3 for convex shape and 0.88 for concave slope shape (Young *et al*., 1986).

The vegetative cover factor *C*, estimates the effect of ground cover conditions. It is a factor that accounts for the effect of vegetation and land management on erosion rates resulting from canopy protection, reduction of rainfall energy and protection of soil by plant coverage. The *C* value for each cell will be calculated, as function of the land use, with the values in the Lookup Table B4 in Appendix B.

The erosion control practice factor accounts for the effectiveness of soil conservation practices such as contouring, compacting, establishing sedimentation basins and other control structures. Because of the specificity of the *P* values, assignment requires input for each cell. Initially, in order to examine a worst case scenario, a default value of 1 will be assumed when extracting the data. Several values of P for various agricultural practices can be found in Wishmeier and Smith (1978) and in the AGNPS user's guide (Young *et al.*, 1994).

Once the sediment yield is estimated, it is then compared with the sediment transport capacity of the flow. The eroded sediment is then routed based on a steady-state continuity equation for sediment transport and deposition described by Foster *et al*. (1980). The model defines the sediment transport capacity for each of the five particle size classes: clay, silt, sand, small and large aggregates, and then computes deposition. The flow conditions for sediment transport are based on the calculated velocities at peak flow rates presented in the hydrology section.

Because the scope of the present section is only to describe the model from the integration perspective, no further details on the sediment equations will be included. A more detailed explanation of the process will be described in the water quality component development for the WATFLOOD model.

Finally, the data detected from the sediment equations that will be extracted automatically from digital files are for each cell: the soil erodibility factor and the vegetative cover factor. At the same time the slope shape factor and the erosion control practice factor will be defaulted to constant values as described during the data extraction.

3.1.3 Nutrients

The chemical component of the AGNPS model divides nutrient transport into two parts. The first deals with soluble nutrients that are transported by the runoff. The second part addresses nutrients that are transported by the sediment. This means that soluble and sediment-bound phases are calculated separately from available nutrient concentrations in the top 1 cm of the soil profile. From the point of view of the integration, and because similar equations will be used for the development of the water quality component for the WATFLOOD model, the presentation of the equations that drive the nutrient process is deferred to Section 3.3.2, and only the general process will be described here.

The AGNPS equations for nutrients are based on the rationale of the CREAMS model. The methods used to predict nitrogen and phosphorus yields (Frere *et al*., 1980) account for the effects of rainfall, fertilization and leaching. Rainfall is the driving force for the system and also contains nutrients. Nitrogen concentration occurring in precipitation varies around the 1 ppm range. This level is not agronomically significant for crops but could be for unfertilized and forested areas.

Other sources of nutrients are fertilizers. Normally nitrogen fertilizers are water soluble and phosphate fertilizers are moderately soluble. Consequently, water from the soil and light rains dissolves the granules from the fertilizer application. Only part of the rainfall leaves the field as runoff. The part of the rain that does not runoff fills the surface layer and leaches soluble nutrients into the soil. In the AGNPS model a leaching rate is calculated through the use of extraction coefficients for soil and runoff, with values assigned as defaults.

The input, for cells where fertilizer has been applied, include the level of fertilization and the availability factors for N and P. These refer to the percentage of fertilizer left in the surface of soil at the time of the storm and their values depends on the tillage practices within the field. Nutrient concentrations contributed by animal feedlots are treated as point sources.

These contributions are estimated within the model and routed along with the contributions from nonpoint sources, as well as the additions from springs, wastewater treatment plant discharges and other point sources. Inputs are accounted for by entering inflow rates and concentrations to the cells where the point sources are located. Sediment from stream bank and gully erosion is also treated as a point source input and is added to the overland sediment.

3.1.4 Pesticides

In this section the processes for pesticide fate and transport will be generally described and the pertinent input data will be outlined. The equations that drive the pesticide processes are presented in detail in the water quality component for WATFLOOD in Section 3.3.3.

In the pesticide component, foliar and soil applied pesticides are described separately so that different decay rates can be used for each source. Pesticide residing on foliage dissipates more rapidly than that from soil. Movement of pesticides from soil surface as a result of infiltrating water is estimated with different mobility parameters. Pesticide in runoff is partitioned between the solution and the sediment phase.

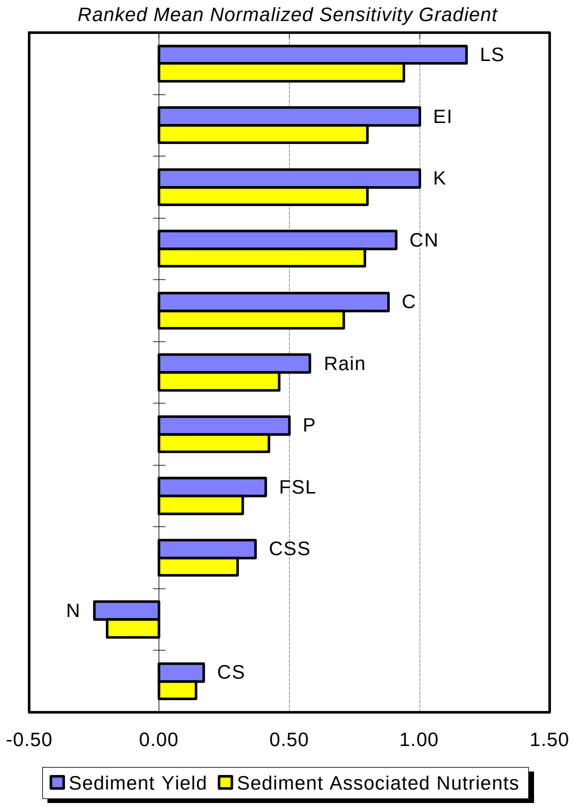
The primary source of pesticide available to enter the runoff stream is idealized as a surface layer of soil with a depth of 1 cm (Leonard and Wauchope, 1980). Washoff of pesticide applied to foliage is another source that may enter the runoff stream. In the AGNPS model, the type of application determines the required data for foliar washoff fraction and percent of canopy cover. For instance, if the pesticide is applied in a pre-plant stage then the canopy cover and subsequent foliar washoff fraction are not required. On the other hand, for a post-emergence application both values will be used in the calculations. Once in the surface, the pesticide dissipates primarily by degradation, infiltration and volatilization processes. Initial concentrations are computed as if they were uniformly incorporated into the top 1 cm depth.

Concentrations of incorporated pesticides are computed based on their incorporation depth and efficiency. A simple exponential dissipation rate is assumed for both soil and foliar residues throughout the model application period. Runoff potential of mobile pesticides is reduced as infiltrating water moves some of the pesticide below the soil surface. A linear adsorption isotherm is used to describe the distribution of pesticide between the solution and soil phases.

Finally the available pesticide is extracted by water flowing over the surface and by dispersion and mixing of the soil material by the flow. At the interface between the soil and the runoff, some mass of soil is effective in supplying pesticide to the runoff volume. Supporting information and parameter values for different kinds of pesticides are provided by the model and accessed through the use of an indexed database. Such a database is presented in Appendix D with the information for the 257 different types of pesticides that the AGNPS model delivers with its documentation and additional files. Summarizing, from the description and equations used in the AGNPS model, the variables and input requirements were defined.

A complete description of all the variables, their structure and naming conventions is presented in the next chapter. Appendix A contains a detailed description of all the variables that the AGNPS model uses. Some of the model parameters and values will be obtained automatically from digital files while others are assigned with default values or data from specific databases (*ie*. pesticides). In order to identify the variables involved in the extraction process and make the definition of the data suitable to be calculated automatically more robust, a preliminary sensitivity analysis was performed for the most common parameters in the model.

A detailed explanation of the method used to perform the sensitivity analysis, including the use of normalized sensitivity gradients to rank the most sensitive parameters to the model outcome, is presented in Chapter 6. The complete set of numbers for this analysis are compiled and presented in Table F1 of Appendix F. The resulting graph is presented in Figure 3.1, showing the ranked normalized sensitivity gradients for different parameters and the effects on the sediment yield and the sediment associated nutrients.



Variables:

LS	land slope
EI	storm energy-intensity
K	soil erodibility factor
CN	SCS curve number
C	cropping or cover factor
Rain	storm rainfall
P	practice factor
FSL	field slope length
CSS	channel side slope
N	Manning's roughness coefficient
CS	channel slope

Figure 3.1 Preliminary sensitivity analysis results for the AGNPS model.

The numbers for the present analysis were obtained from Young *et al*. (1986). It can be noted that the parameters for which the sediment related output is more sensitive to are: the land slope (*LS*), the energy intensity factor (*EI*), the soil erodibility factor (*K*), the SCS curve number (*CN*) and the cropping or cover factor (*C*).

All of these variables were selected to be extracted automatically from digital files and care was taken that they were estimated as accurate as it can be done from the resolution of the digital information. On the other hand, the outcome is much less sensitive to the practice factor (P) and the field slope length (FSL), which were selected to be assigned with default values.

3.2 WATFLOOD Model

A full description of the hydrologic model WATFLOOD can be found elsewhere (Kouwen *et al*.,1993 and Kouwen, 1999). As mentioned before, it is a flood forecasting system with a distributed hydrologic simulation model designed to work under the grouped response unit concept. It can use radar data, if available, for rainfall estimation. The model accounts for the dominant short duration rainfall-runoff processes including interception, evapotranspiration, surface storage, infiltration, interflow, snowmelt, and overland flow.

As each element response is based on land class area, the runoff is calculated in an element by adding the contributions from each land cover type and routing the results to the drainage system. It uses a storage routing technique to route the water through the channel system. The program includes a method (a pattern search optimization algorithm) to estimate the model parameters that cannot be previously assigned with standard values. The added water quality component calculates the transport of sediments, nutrients and pesticides based on the same concept of the grouped response unit.

3.2.1 Hydrology

The following is a brief description of the hydrologic section used in WATFLOOD in order to identify the requirements from the integration perspective. The equations have been extracted from the model documentation (Kouwen, 1997). Rainfall drives the model; interception is calculated with the exponential relationship presented by Linsley *et al*. (1949):

$$V = (S_i + C_p E_a t_R)(\overline{1} - e^{-kP}) \tag{3.10}$$

where V is the interception depth [mm], S_i the storage capacity [mm], C_p the ratio of vegetated surface area, E_a the evaporation rate [mm/hr], t_R the duration of the rainfall [hr], k a constant [mm^{-1}] and P the precipitation [mm].

The values for the storage capacity are set for each landuse class. The product of the cover area ratio and the evaporation rate is used as a single parameter. The surface storage is assumed to be reached exponentially (Linsley *et al.* 1949):

$$D_S = S_d \, (1 - e^{-kP_e}) \tag{3.11}$$

where D_s is the depression storage [mm], S_d is the surface retention value [mm] and P_e is the accumulated rainfall excess [mm]. The surface retention values are assigned depending on the type of landcover (ASCE, 1969). The infiltration process and the concept of surface detention, is represented by the formula (Philip, 1954):

$$\frac{dF}{dt} = K\left[1 + \left(\frac{(m - m_o)(Pot + D_1)}{F}\right)\right] \tag{3.12}$$

where F is the total depth of infiltrated water [mm], t is time [s], K is the saturated conductivity [mm/s], m is the average moisture content of the soil to the depth of the wetting front, m_o is the initial soil moisture content, Pot is the capillary potential at the wetting front [mm] and D_1 is the depth of water on the soil surface or detention storage [mm].

The values of the saturated conductivity are assigned through the optimization technique for each land class. Interflow is defined as a fraction of the initially infiltrated water or upper zone storage that is exfiltrated to nearby water courses. The simple storage-discharge relation is:

$$Q_{int} = REC * (WAC - RETN) * SLOPE \tag{3.13}$$

where Q_{int} is the interflow [m^3/s], *REC* is a coefficient representing the depletion fraction and estimated through optimization, *WAC* is water accumulation in the upper zone storage [mm] and *RETN* is the retained storage [mm]. Finally, when the infiltration capacity is exceeded and the depression storage has been satisfied, water is discharged to the drainage system based on uniform flow.

The Manning formula for overland flow as used in the model is:

$$Q_r = \frac{1}{R_3}(D_1 - D_S)^{5/3} S_l^{\ 1/2} A \tag{3.14}$$

where Q_r is the channel inflow [m^3/s], (D_1 - D_S) represents the runoff depth above ponding, R_3 is a combined roughness and channel-length parameter optimized for each land class, S_l is a average overland slope and A is the area of the GRU element [m^2]. The above equations are used separately for each land class in each computational element to calculate the total inflow to the river system.

The total runoff for each element is calculated by adding the surface runoff contributions from the various landcover classes to the base flow. The routing through the channel system is achieved using a storage-routing technique based on the continuity equation:

$$\frac{I_1 - I_2}{2} - \frac{O_1 - O_2}{2} = \frac{S_2 - S_1}{\Delta t} \tag{3.15}$$

where $I_{1,2}$ is the inflow to the reach [m^3/s] and consists of overland flow, interflow, base flow and channel flow from all contributing upstream basin elements, $O_{1,2}$ is the outflow from the reach [m^3/s], $S_{1,2}$ is the storage in the reach [m^3] and Δt is the time step of the routing [s]. The subscripts 1 and 2 indicate the beginning and end of the time step. Again, assuming uniform flow, the outflow is related to the storage through the Manning formula:

$$O = \frac{1}{R_2} A_x^{\ 4/3} S_o^{\ 1/2} \tag{3.16}$$

where O is the outflow [m^3/s], R_2 is the channel roughness parameter, A_x is the channel cross section area, geomorphic or actual if available, which is related to storage by dividing it by the channel length [m^2] and S_o is the channel slope.

Two aspects have been constantly mentioned in the above description, variables related to land cover classes and an optimization technique to assign some of the parameters values. The first deals with the input requirements for the model and the second refers to an automatic pattern search optimization for calibration purposes. Data requirements are divided in two sections: watershed and event data.

For the watershed input some topographical data are required for each cell, such as the stream bed elevation at half way through the element, the drainage direction, the fraction area of the cell within the watershed, the typical surface slope of the element and the number of channels crossing the element. All this data will be extracted automatically using digital elevation model files as explained in the next chapter.

3.2.2 Radar & Remote Sensing Data

WATFLOOD has been designed since its inception to take advantage of weather radar and satellite imagery. The fundamentals and equations used in the model in order to convert the radar reflectivity values into rainfall rates can be found in Kouwen (1988). In general terms consist of different processes to adjust the data for clutter, beam-blocking and attenuation, and compute rainfall rates with values of radar reflectivities using an exponential relationship.

Other processes are used to average the data hourly, calibrate the radar rainfall with raingauge data, fill missing data and distribute the rainfall at specified grid sizes. The scope of the present integration attempt will not deal with any modification or interface conversion of radar images and they are treated only as known input into the model. WATFLOOD is based on the group response unit approach. Runoff is calculated in a grid element by estimating the contributions from each land cover separately. This approach allows for larger element sizes as they are not limited to the hydrologically homogeneous assumption. Tao and Kouwen (1989) presented the advantage of using satellite derived land cover information for data input into WATFLOOD.

The input requirement is to transform land use maps into percentages of coverage for each landcover within the grid element. From the point of view of the integration approach, the source of data for automatically extracting the percentages of different land classes within a grid element is a digital land use map. This map is usually derived from Landsat imagery through the process of classification techniques upon spectral signatures. Once the image has being classified, vector polygons or raster data are created. This work is based on the vectorized information.

It has been found, at least for the personal computer environment and with the RAISON system, that searching techniques on the attributes and positioning on different geo-projections are better handled with the vector polygon data than with the raster values. The number of classes that the model can handle is not a restriction, but it is limited by the classification technique depending on the number of distinct spectral signatures that can be identified in the Landsat image. Provisions will be taken to make this class definition as transparent and robust as possible to include different sources of information. For example, some land classifications include a very detailed differentiation between land use classes, such as different crops types, while others are more general by grouping all crops as agricultural land.

As described in Kouwen *et al*. (1993), it is assumed that, unless there are major irregularities in the soil types, that is, completely heterogeneous soil content in the surface, the topographic and land cover effects far outweigh the effects of variations of soil. As this may be true for the hydrological response, when dealing with soil erosion, transport and deposition, the soil type will play a major role on the sediment component.

The variables that require soil data for the water quality component attached to the hydrologic model are described in Section 3.3. A similar extraction procedure from digital files, to account for the percentage of soil type within the study area, will be included to account for the sediment processes to be attached to WATFLOOD.

3.3 Water Quality Component for WATFLOOD

3.3.1 Sediment

A simple sediment yield model for single storm events (Hartley, 1987) was already coupled with the WATFLOOD model but had not yet been successfully implemented by the time this research was undertaken. A review of this model component revealed some units errors and coding omissions. As part of this research, the hydrology of the Hartley model was replaced by the values calculated with WATFLOOD. A brief description of the sediment component to be coupled with the model follows.

The sediment model is based on calculating the sediment transport capacity and the potential sediment supply, choosing whichever is less and routing it downstream. The sediment transport capacity is calculated with a simple shear stress relationship (Hartley, 1987):

$$c = A\left(\frac{t_d}{t_c}\right)^B \qquad (3.17)$$

where c is a volumetric sediment concentration, t_d is the dominant flow shear stress on the soil and t_c is the critical stress based on the shear Shields criteria (Simons and Senturk, 1976), A and B are constants with values of 0.00066 and 1.61 respectively. These values are empirical based on field data and taken directly from the original reference.

The shear stress for the runoff is derived from shear stress relationships on the soil surface and accounts for the part of the total flow shear stress absorbed by ground cover. The integration of the time average flow shear on the soil gives the dominant shear stress and is calculated with:

$$t_d = \frac{b}{b+1}\left(\frac{60}{K_f}\right) g\, H_L\, S_o \qquad (3.18)$$

where b is a constant discharge parameter with a value of 5/3, g is the water specific weight, H_L is average runoff depth, S_o is the average overland slope and K_f is an overland flow friction parameter. H_L corresponds to (D_1 - D_S) presented in the hydrology section of WATFLOOD.

The overland friction parameter is a function of the ground cover for each land class and is calculated with:

$$K_f = 60 + 3140\, GC^{1.65} \tag{3.19}$$

where GC is the ground cover factor and an estimate of the landcover density for different land uses. Values for GC can be found in Table B5 on Appendix B and are assigned automatically during the extraction process and stored as a parameter for the different land classes.

The critical shear stress is determined by:

$$t_c = (s - 1) g\ \Phi\, D_{50} \tag{3.20}$$

where D_{50} is the median size of the soil particles, s is the specific weight of the sediment and Φ is the Shields entrainment function depending on the Reynolds number, R^*, defined by:

$$R^* = \frac{\sqrt{t_d\, g}\ \ D_{50}}{n} \tag{3.21}$$

where n is the kinematic viscosity of water. The Shields relationship for shear stress is based on dimensional analysis and experimental observations. From the Shields diagram, a plot of the entrainment function against the Reynolds number, a linear relationship is obtained for $R^*<3$ from which Φ can be estimated. The equation is (Simons and Senturk, 1976):

$$\Phi = \frac{0.11}{R^*} + 0.021 \log_{10} R^* \tag{3.22}$$

To determine D_{50}, according to Foster *et al*. (1985), it is necessary to establish a distribution for particle size and specific gravity of detached sediment particles. A series of equations related to the primary particle define the size distributions of the matrix soil. The equations for size and numerical values of specific gravity are those suggested by Foster *et al*. (1980) for the CREAMS model. Figure 3.2 shows the size distribution using such equations, for a basic silt loam soil, as an example on how the particle median size is estimated. Table B2 on Appendix B presents the size distributions and specific weights based on the mentioned equations and adopted by Hartley in his sediment model.

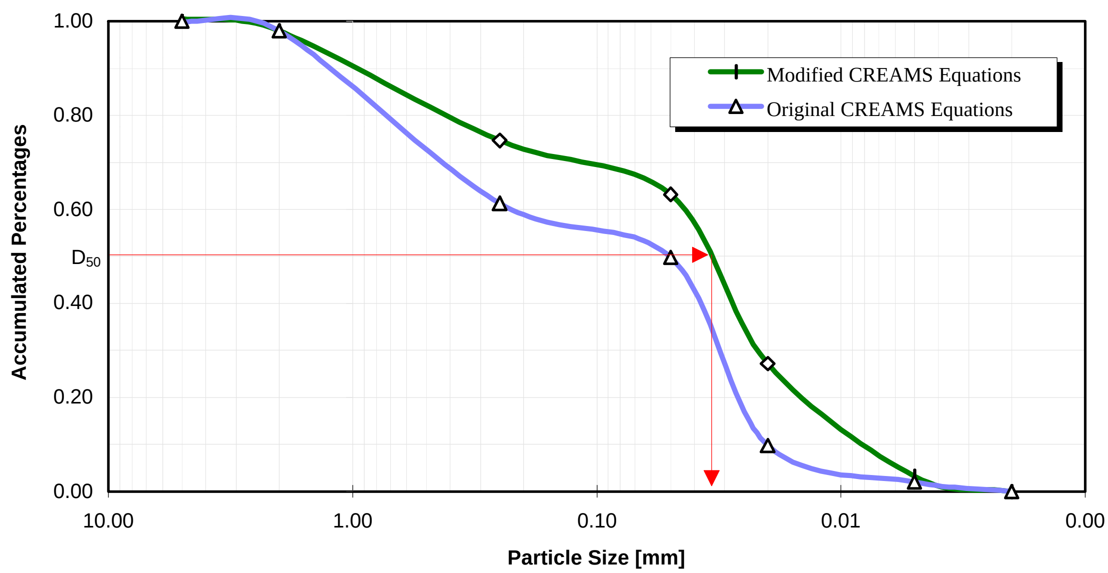


Figure 3.2 Particle size distribution for silt loam (after Foster *et al*., 1985)

Substituting the shear and critical stresses into equation (3.17) gives an average capacity of the flow to transport sediment for the whole surface over the runoff period. Finally, the sediment transport capacity in terms of mass per unit area is then calculated with:

$$Y_C = 2.65\, r \quad c\; r_f \tag{3.23}$$

where the 2.65 is the specific weight of the finer particles on the sediment (silt or clay), Y_C is the sediment transport capacity, r_f is the runoff amount provided by the hydrology section of WATFLOOD and r is the density of water.

To calculate the potential sediment supply due to rainfall and runoff, an empirical relationship for rainfall energy rate is calculated with:

$$E_{rf} = i\,(11.9 + 8.7\ \log_{10} i\,) \tag{3.24}$$

where E_{rf} is the rate of rainfall energy and i the rainfall intensity. In this case, the precipitation value used in WATFLOOD divided by the time increment will be used to convert it to rainfall intensity. The rate of soil detachment by rainfall is then calculated with:

$$G_{rf} = E_{rf}\ (1 - GC)\,CF\,D \tag{3.25}$$

where G_{rf} is the rate of soil detachment due to rainfall, CF is a canopy factor based on the percentage of canopy cover of the soil and D is a soil erodibility factor equivalent to the K factor from the USLE. The values for CF are assigned as parameters for the model depending on the landuse extraction and can be found in Table B5 on Appendix B. The values for soil erodibility are converted from the erodibility factor from the USLE, as described in Section 3.1.2, by a conversion factor during the extraction process.

Runoff also detaches and erodes sediment on the overland. The sediment supply due to surface runoff is calculated with:

$$E_{ro} = \left(\frac{60}{K_f}\right) g\ \frac{Q_L}{2}\, S_o \tag{3.26}$$

where E_{ro} is the rate of energy input to the soil by the flow and Q_L is a unit flow discharge passed from the hydrology section of WATFLOOD. The rate of soil detachment by runoff, G_{ro}, is analogous to that of the rainfall and estimated with:

$$G_{ro} = E_{ro}\ D \tag{3.27}$$

Taking into account both effects, rainfall and runoff detachment, the sediment yield based on the supply rate, Y_S, in terms of mass per unit area is:

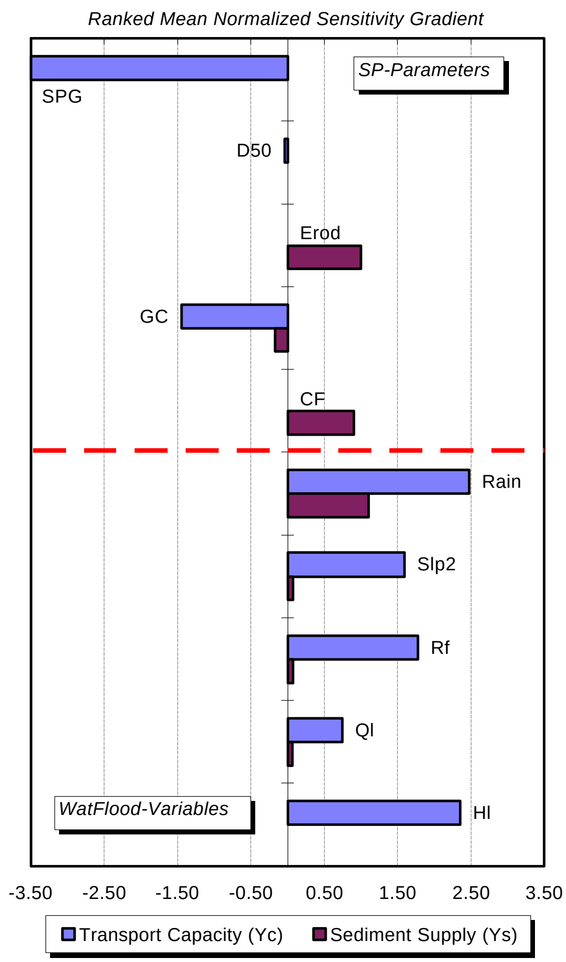
$$Y_S = (G_{rf} + G_{ro}) \Delta t \tag{3.28}$$

The minimum of Y_S and Y_C represents the sediment yield for the time increment for a single element and a specified land class that will be routed downstream based on a continuity equation for the cell.

The source FORTRAN code for the sediment subroutine was revised and some modifications made to correct for the units and omissions. It can be found in Appendix G. The listing is documented to identify variables and units to be used. In order to define how precisely the parameters and values assigned with the automatic extraction procedures must be, a preliminary sensitivity analysis was performed on the sediment model.

Figure 3.3 shows the results of the preliminary sensitivity analysis with the ranked normalized sensitivity gradients for different parameters, sediment model and WATFLOOD, and the effects on the sediment supply and transport capacity. A more detailed explanation of the methodology to perform sensitivity analysis and the use of normalized sensitivity gradients is presented in Chapter 6. The complete set of numbers are in Table F2 of the Appendix F.

The specific weight, once established does not change. It is therefore important to select the best possible value since the sediment transport capacity is highly sensitive to it. The median particle size changes with the soil type, but its impact on the sediment supply and transport is negligible. The sediment capacity is also quite sensitive to canopy and cover factors, so a good first estimation on these values is important. They will be extracted from landuse maps and assigned as parameters that can be optimized by the calibration procedure of the model.



Sediment Model Parameters:

SpG	Specific weight [-]
D_{50}	Median particle size [mm]
Erod	Soil erodibility, D [g/J]
GC	Ground cover [-]
CF	Cover factor [-]

WATFLOOD variables:

Rain	Precipitation intensity [mm/hr]
Slp2	Overland slope [-]
Rf	Runoff amount [mm]
Ql	Unit flow discharge [m^2/hr]
Hl	Runoff depth [mm]

Figure 3.3 Preliminary sensitivity analysis results for the sediment model/WATFLOOD.

3.3.2 Nutrients

The methods selected to simulate the nutrient processes in the water quality component for WATFLOOD are based on those used in AGNPS developed from the earlier CREAMS model. These algorithms are the most widely used and accepted. They were developed for CREAMS by several research teams attempting to create a model that would not require extensive calibration efforts (Frere *et al*.,1980). Young *et al*. (1986) modified the algorithms to use them at a watershed scale and created the AGNPS model. Further details can be found in the technical documentation on nutrient information from the AGNPS and CREAMS models.

The nutrient simulation is divided in two parts that handle the soluble nutrients in the runoff and in the sediments separately. For the soluble part, the general assumption is that the rate of change in concentration of soluble nutrients in the water, in the surface (top 1 cm) of soil, is proportional to the difference between existing concentrations and concentration in rainfall.

Nitrogen

The soluble nitrogen concentration in the runoff is calculated with (Young *et.al.*, 1986):

$$C_{RON} = \frac{(N_{AVS} - N_{AVR})}{F_{POR}}\left[e^{(-N_{DMV} I_{EFF})} - e^{(-N_{DMV} I_{EFF} - N_{RMV} R_{OFF})}\right] + \frac{N_{RNC}\ R_{OFF}}{P_{EFF}} \qquad (3.29)$$

where C_{RON} is the soluble nitrogen concentration in runoff [kg/ha], N_{AVS} is the available nitrogen content in the surface [kg/ha], N_{AVR} is the available nitrogen in rainfall [kg/ha], N_{DMV} is the rate for downward movement of nitrogen into the soil, N_{RMV} is the rate for nitrogen movement into the runoff, I_{EFF} is the effective or total infiltration [mm], R_{OFF} is the total runoff [mm], F_{POR} is a porosity factor, N_{RNC} is the nitrogen contribution due to rain [kg/ha], and P_{EFF} is the effective precipitation [mm]. The available nitrogen content in the surface is a result of combining the residual nitrogen in the surface with the amount from the fertilizer application:

$$N_{AVS} = [\,Sol_N + (N_{FER}\ N_{fa})\,]\,F_{POR} \qquad (3.30)$$

where Sol_N is the soluble nitrogen in the surface centimeter of the soil [kg/ha], N_{FER} is the nitrogen fertilizer application [kg/ha] given as a input data for the model, N_{fa} is the fraction of nitrogen availability for the fertilizer application also given as input data. The soluble nitrogen in the surface top of the soil is estimated by:

$$Sol_N = 0.10\ N_{CPW}\ Por \qquad (3.31)$$

where N_{CPW} is the nitrogen concentration in the pore water of the top centimeter of surface soil and is given as a default data value for nitrogen of 5 ppm, Por is the soil porosity.

The porosity and porosity factor are calculated with the bulk density, s, values for the soil as:

$$Por = 1 - (s \ / \ 2.65) \qquad ; \qquad F_{POR} = 0.00001 / Por \qquad (3.32\text{-}33)$$

The available nitrogen due to rainfall is:

$$N_{AVR} = N_{CRN} \ x 10^{-6} \qquad (3.34)$$

where N_{CRN} is the nitrogen concentration in the rainfall [ppm] and is given as input data. The movement rates are evaluated using:

$$N_{DMV} = \frac{N_{LEC}}{10\,Por} \quad ; \quad N_{RMV} = \frac{N_{REC}}{10\,Por} \qquad (3.35)$$

where N_{LEC} is the nitrogen leaching extraction coefficient with a default value of 0.25 and N_{REC} is the nitrogen runoff extraction coefficient with a default value of 0.05, both given as input data for the model. The 10 in the equation is the depth of soil interaction in millimeters, giving to the movement rates units of [mm^{-1}] that will cancel with the [mm] from infiltration and runoff in equation (3.29). In the AGNPS model the infiltration is calculated simply by subtracting the runoff from the amount of rainfall, while the runoff is calculated with the SCS curve number method. For this coupling, these values are taken directly from the hydrology section of WATFLOOD as:

$I_{EFF} = F$	total depth of infiltrated water [mm]
$R_{OFF} = H_L = (D_1\text{-}D_S)$	runoff depth [mm]

The WATFLOOD variables F, H_L and $(D_1\text{-}D_S)$ are defined in Section 3.2.1. For the nitrogen contribution due to rain, N_{RNC}, the following expression is used:

$$N_{RNC} = 0.01(N_{CRN})\,P \qquad (3.36)$$

where P is the storm precipitation [mm] and the 0.01 is a unit conversion factor.

The effective precipitation is related to the precipitation and soil porosity by:

$$P_{EFF} = P - (10\,Por) \tag{3.37}$$

The 10 in the equation is the top 1 cm in millimeters of soil interaction. The precipitation values will be taken directly from the radar files used by WATFLOOD as rainfall in a cell.

Phosphorus

The phosphorus calculations are similar to the nitrogen ones except that the effects of rainfall are omitted. This is due to the fact that very little soluble phosphorus is found in rainfall. The equation used to predict soluble phosphorus in the runoff is:

$$C_{ROP} = \frac{(P_{AVS} - P_{AVR})}{F_{POR}} \left[e^{(-P_{DMV} I_{EFF})} - e^{(-P_{DMV} I_{EFF} - P_{RMV} R_{OFF})} \right] + \frac{P_{AVR}\, P_{RMV}\, R_{OFF}}{F_{POR}} \tag{3.38}$$

where C_{ROP} is the soluble phosphorus concentration in runoff [kg/ha], P_{AVS} is the available phosphorus in the surface due to fertilizer application [kg/ha], P_{AVR} is the available phosphorus due to residual levels in the soil [kg/ha], P_{DMV} and P_{RMV} are the movement rates for leaching and runoff respectively. The rest of the terms are the same as in the nitrogen calculations:

$$P_{AVS} = [\, Sol_P + (P_{FER}\, P_{fa})\,]\, F_{POR} \tag{3.39}$$

where Sol_P is the soluble phosphorus in the surface centimeter of the soil [kg/ha], P_{FER} is the phosphorus fertilizer application [kg/ha] given as a input data for the model, P_{fa} is the fraction of the phosphorus availability for the fertilizer application also given as input data. The soluble phosphorus in the surface top of the soil is estimated by:

$$Sol_P = 0.10\, P_{CPW}\, Por \tag{3.40}$$

where P_{CPW} is the phosphorus concentration in the pore water of the top centimeter of surface soil and is given as a default data value for phosphorus of 2 ppm.

The available phosphorus due to initial soil residuals is solved using the equation:

$$P_{AVR} = Sol_P \; F_{POR} \tag{3.41}$$

The movement rates are evaluated using:

$$P_{DMV} = \frac{P_{LEC}}{10\,Por} \quad ; \quad P_{RMV} = \frac{P_{REC}}{10\,Por} \tag{3.42}$$

where P_{LEC} is the phosphorus leaching extraction coefficient with a default value of 0.25 and P_{REC} is the phosphorus runoff extraction coefficient with a default value of 0.025, both given as input data for the model. The rest of the terms are the same as in the nitrogen calculations.

The nutrient yields associated with the sediment are calculated using total sediment yields from each cell. Such values are obtained with the process described in the sediment section. The nitrogen yield in the sediment is calculated with the following equation:

$$N_{SED} = N_{SCN} \; Y_{SED} \; ER \tag{3.43}$$

where N_{SED} is the overland nitrogen transported by the sediment [kg/ha], N_{SCN} is the soil nitrogen concentration with a value of 0.001 g N/g soil, Y_{SED} is the total sediment yield [kg/ha], and ER is the nutrient enrichment ratio calculated with:

$$ER = a \, Y_{SED}{}^{b} \; T_f \tag{3.44}$$

where a and b are experimental constants with values of 7.4 and -0.20 respectively. T_f is a correction factor for soil texture and has a value of 0.85 for sand, 1.0 for silt, 1.15 for clay and 1.50 for peat. For the phosphorus yield in the sediment, the equation is:

$$P_{SED} = P_{SCN} \; Y_{SED} \; ER \tag{3.45}$$

where P_{SED} is the overland phosphorus transported by the sediment [kg/ha], P_{SCN} is the soil phosphorus concentration with a value of 0.0005 g P/g soil. The source FORTRAN code for the nutrient subroutines can be found in Appendix G.

3.3.3 Pesticides

As before, the methods used to simulate the pesticide processes in the water quality component are the same as the ones used in AGNPS. The pesticide model was developed by Leonard and Wauchope (1980) and adapted by Young *et.al*. (1986). The following information will describe how the soluble, sediment and percolated fractions of the pesticides are calculated. Further details can be found in the technical documentation for the AGNPS model.

Losses due to evaporation, application technique and other factors are taken into account by calculating the effective pesticide amount with:

$$P_{EFF} = P_{APR}\,(A_{EFF}\;/\,100) \tag{3.46}$$

where P_{EFF} is the effective pesticide amount [kg/ha], P_{ARP} is the pesticide application rate given as input data [kg/ha], and A_{EFF} is the application efficiency as the percent of pesticide that reaches the field and also given as input data. The amount of pesticide that ends up on the foliage of the plant immediately after application is:

$$P_{CAN} = P_{EFF}\;CC + P_{CAN_{res}} \tag{3.47}$$

where P_{CAN} is the pesticide on the canopy [kg/ha], CC is the canopy cover as the percent of ground area covered by foliage, P_{CANres} is the initial foliar residue before the application. The amount of pesticide in the soil is:

$$P_{SUR} = P_{EFF} - P_{CAN} + P_{SUR_{res}} \tag{3.48}$$

where P_{SUR} is the amount of pesticide that reaches the surface soil [kg/ha], P_{SURres} is the residual soil residue from previous applications [kg/ha]. To convert to concentrations, it is assumed that the interaction layer is the top centimeter of soil, then:

$$C_{P_{SUR}} = P_{SUR}\,(10\,/\,s\,) \tag{3.49}$$

where C_{PSUR} is the pesticide concentration available in the surface soil [ppm] and s is the specific weight of soil. This last value is extracted from the soil map and assigned for each cell during the data automatic extraction process. To take into account the effect of tillage, the concentration in the soil is affected by the incorporation depth and efficiency factors:

$$C_{P_{SUR\_T}} = C_{P_{SUR}} \left[\frac{In_{EFF} \ / \ 100}{In_{DEP} \ / \ 0.39} \right] \tag{3.50}$$

where C_{PSUR_T} is the concentration of available pesticide on the ground including the tillage effects [ppm], In_{EFF} is the incorporation efficiency in percent, and In_{DEP} is the incorporation depth [in]. The amount of pesticide remaining on the plant at the time of the rainfall event is:

$$P_{CAN\_F} = P_{CAN} \ e^{-0.693(t_a \, / \, F_{RHL})} \tag{3.51}$$

where P_{CAN_F} is the pesticide on plant at the time of the event [kg/ha], t_a is the time between the application and the storm [days], and F_{RHL} is the foliar residue half life of the pesticide [days]. This value is available for data input in the pesticide database. Similarly, the concentration of pesticide remaining in the soil at the time of the storm event is:

$$C_{P_{SUR\_F}} = C_{P_{SUR\_T}} \ e^{-0.693(t_a \, / S_{RHL})} \tag{3.52}$$

where C_{PSUR_F} is the pesticide concentration in the soil at the time of the event [ppm] and S_{RHL} is the soil residue half life also available in the pesticide database [days]. The potential amount of pesticide on the ground susceptible to enter the runoff, must include the foliar washoff:

$$C_{P_{WSH}} = P_{CAN\_F} \ \frac{F_{WF}}{100} \frac{10}{s} \tag{3.53}$$

where C_{PWSH} is the amount of pesticide washoff from the rainfall [ppm], F_{WF} is the foliar washoff fraction in percent. This value is also available in the pesticide database. The amount of pesticide on the ground, C_{PGRN} [ppm], is:

$$C_{P_{GRN}} = C_{P_{SUR\_F}} + C_{P_{WSH}} \tag{3.54}$$

To calculate the fraction of pesticide in the runoff, the following equation is used:

$$C_{P_{RFF}} = C_{P_{GRN}} \, e^{\left(-I_{EFF} \frac{0.1}{Por + K_{SW} \, s} \right)} \tag{3.55}$$

where C_{PRFF} is the amount of pesticide for runoff [ppm], I_{EFF} is the total depth of infiltrated water [mm], *Por* is the soil porosity as described in the nutrient section, K_{SW} is the soil-water partition coefficient calculated with:

$$K_{SW} = 0.0058 \, K_{OC} \, OM \tag{3.56}$$

where K_{OC} is the organic carbon sorption coefficient available in the pesticide database and *OM* is the soil organic matter percent. The amount of percolated pesticide is:

$$P_{PER} = (C_{P_{GRN}} - C_{P_{RFF}}) \frac{s}{10} \tag{3.57}$$

where P_{PER} is the amount of percolated pesticide [kg/ha]. The percent of percolated pesticide, PP_{PER}, can be estimated as a fraction of the application rate:

$$PP_{PER} = 100 \frac{P_{PER}}{P_{APR}} \tag{3.58}$$

The pesticide soluble concentration in the runoff, C_{PSOL} [ppm], is calculated with:

$$C_{P_{SOL}} = \frac{b \;\; C_{P_{RFF}}}{1 + b \;\; K_{SW}} \tag{3.59}$$

where b is a constant value of 0.5 if the solubility in water of the pesticide (database) is less than 1 ppm, 0.3 if between 1 and 3 ppm, and 0.1 for values greater than 3 ppm.

The amount of soluble pesticide is then calculated with:

$$P_{SOL} = C_{P_{SOL}} \frac{R_{OFF}}{100} \tag{3.60}$$

where P_{SOL} is the soluble pesticide amount [kg/ha], R_{OFF} is the runoff depth [mm]. The percent of soluble pesticide, PP_{SOL}, is then calculated as a fraction of the application rate as:

$$PP_{SOL} = 100 \frac{P_{SOL}}{P_{APR}} \tag{3.61}$$

Finally the amount of pesticide attached to the sediment is:

$$P_{SED} = P_{SOL}\, K_{SW}\, ER \tag{3.62}$$

where P_{SED} is the pesticide amount in the sediment [kg/ha] and ER is the enrichment ratio as described in the nutrient section. The percent of pesticide in the sediment, PP_{SED}, is calculated as a fraction of the application rate:

$$PP_{SED} = 100 \frac{P_{SED}}{P_{APR}} \tag{3.63}$$

3.3.4 Routing Processes

The routing of sediments, nutrients and pesticides are carried out using a mixing cell model based on the continuity equation. Deposition for sediments and the decay in the case of nutrients and pesticides will be estimated using fractions of the transported mass that can be calibrated with the optimization technique of WATFLOOD. Mixing cell models, like other transport models, are subject to numerical dispersion affected in part by cell size and the assumption of complete mixing. The mixing cell approach is used here as a first approximation for the transport module to create a complete system. If future research is devoted to the water quality component, more elaborate transport models can be easily incorporated into the routing process. In general terms, the process is summarized as:

(i) the amount of mass generated on each cell is calculated for each time step,

(ii) this mass is added from the cells flowing into the current cell to the amount generated within the current cell,

(iii) this amount is decayed (deposition for sediments) as it runs through the channel to get the amount remaining at the cell outlet.

The continuity equation for the sediments can be written as:

$$Sed_{OUT} = Sed_{ABOVE} + Sed_{WITHIN} - Sed_{DEP} \tag{3.64}$$

where the subscripts *OUT* refers to the sediment leaving the element, *ABOVE* stands for the sediment entering the cell from the elements above the current cell and *DEP* to the sediment amount being deposited in the cell. Using the sediment yield obtained from the sediment section and converting to concentration units, the equation takes the form:

$$Y_{SED\_OUT} = 1000\left[(1 - S_{DEP})(Y_{SED\_ABOVE} + Y_{SED\_WITHIN})\right] \tag{3.65}$$

where Y_{SED_OUT} is the sediment leaving the cell [ppm], S_{DEP} is a deposition fraction, Y_{SED_ABOVE} is the sum of all the sediment entering the cell [kg/ha] and Y_{SED_WITHIN} the sediment generated within the element. Similar equations are used for the soluble and sediment attached nutrients:

$$CC_{RON\_OUT} = \frac{100}{R_{OFF}}\left[(1 - N_{DEC})(C_{RON\_ABOVE} + C_{RON\_WITHIN})\right] \tag{3.66}$$

where CC_{RON_OUT} is the soluble nitrogen concentration in runoff leaving the cell [ppm], N_{DEC} is the nitrogen decay fraction and the rest of the terms are as described in the nutrient section.

$$CC_{ROP\_OUT} = \frac{100}{R_{OFF}}\left[(1 - P_{DEC})(C_{ROP\_ABOVE} + C_{ROP\_WITHIN})\right] \tag{3.67}$$

where CC_{ROP_OUT} is the soluble phosphorus concentration leaving the cell [ppm], P_{DEC} is the phosphorus decay fraction and the rest of the terms are as described in the nutrient section. For the sediment attached nutrients, the concentration terms are substituted by the N_{SED} and P_{SED} values and the same equations are used for the routing. Table 3.1 presents a list of the model parameters of the WATFLOOD water quality component summarized by category and showing the values, ranges and sources for each parameter.

Table 3.1 Model Parameters Summary of the WATFLOOD Water Quality Component

Parameter	Symbol	Value or Range	Comments
Physical Constants			
Gravity acceleration	g	9.806 m/s^2	Constant values in ASCII input data file
Kinematic viscosity	*n*	$1x10^{-6}$ m^2/s	
Density of water	ρ	$1x10^{6}$ g/m^3	
Experimental Constants			
Stress relationship coefficient	A	0.00066	Constant values in ASCII input data
Stress relationship exponent	B	1.61	Source Hartley, 1987
Landuse Coefficients			
Ground cover factor	GC	0 - 1	
Canopy factor	CF	0 - 1	Function of landuse (lookup table B5)
Soil Type Constants			
Median sediment diameter	d_{50}	0.015 - 0.61 (silt) - (clay)	Function of soil type (lookup table B2)
Particle specific weight	σ	1.84 - 2.45 (clay) - (sand)	Function of soil type (lookup table B2)
Soil Type Coefficients			
Soil erodibility factor	D	0.25 - 2.90 (sand) - (silt)	Function of soil type (lookup table B2)
Process Coefficients			
Nitrogen decay fraction	N_{DEC}	0 - 100%	
Phosphorus decay fraction	P_{DEC}	0 - 100%	Source: AGNPS manual
Sediment deposition fraction	S_{DEP}	0 - 100%	

3.4 Chapter Summary

This chapter described the models from the integration perspective, presenting the equations in order to identify the variables that will be calculated automatically from digital information with an extraction process. Some results of the preliminary sensitivity analysis, performed and described in Chapter 6, are presented in order to help in selecting which variables deserve more attention during the extraction process and which ones can be assigned with default values without impacting the simulation results. Finally the equations that will form the water quality component, for sediment, nutrient and pesticide transport, which will be coupled with the WATFLOOD hydrologic model, are presented together with the basic routing procedures. The algorithms and equations were coded in FORTRAN and the full source listings are included in Appendix G.