ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

# Application of the agricultural non-point source pollution model (AGNPS) to model surface water quality when data is scarce

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## Abstract
A catchment water quality management model which could be applied without parameter optimisation to ungauged catchments would be of great benefit to catchment managers to optimise surface runoff quality. The AGricultural Non-Point Source Pollution (AGNPS) model is a catchment scale water quality management model with measurable model parameters. As the model had a sound physical structure it was decided to check the applicability of the model to ungauged situations.

The paper explains the process in the estimation of the model parameters in ungauged situations and demonstrates the model's applicability by applying the model to a water supply catchment in Australia. The study revealed that the uncalibrated AGNPS model with estimated parameters can be used for catchment management provided some key parameters are estimated accurately.

## INTRODUCTION

All around the world drinking water is harvested from unprotected, multiple land-use catchments to meet the ever increasing demand. Multiple land-use catchments are exposed to higher levels of pollution, mainly from non-point sources (NPS). Pollutants in runoff can directly affect the extent of utilisation of the water supply sources. Controlling NPS pollution in multiple landuse catchments is costly and needs a spatially explicit method for targeting pollutant sources (Wolcott, 1988). Catchment management authorities have made considerable advances in tackling some of the pollution problems with the help of catchment management models. These models can locate critical landuse areas and evaluate the performance of water quality improvement measures developed as best management practices.

However the application of public domain models to water supply catchments is constrained by excessive data needs, complex calibration requirements and limited output of water quality parameters. A catchment model which could be applied without parameter optimisation and perhaps even to ungauged catchments would be of great benefit to water quality and catchment managers. This research paper is based on the results of a study that evaluated the applicability of the AGricultural Non-Point Source pollution (AGNPS) model (Young et al., 1995) to a water supply catchment in Australia. In this paper the strengths and constrains of the AGNPS model and the application of the AGNPS model to a mixed landuse catchment is discussed. Furthermore, the process followed in the estimation of model parameters in the application of the model to ungauged situations will also be described.

## THE AGNPS MODEL

The AGNPS model is a catchment scale distributed parameter water quality management model that simulates the surface runoff quality and quantity from rural catchments due to storm events. Version 5.0 of the AGNPS model (Young et at., 1995) was used in this study. The AGNPS model has a uniform orthogonal grid/cell structure. Version 5 of the AGNPS model allows cell sizes between 0.04 to 400 hectares. The AGNPS model cell segmentation scheme can divide primary cells up to 1/64 of its' size in three steps. This facility can be used to introduce higher resolution consideration of complex topographic and catchment characteristics.

The AGNPS model has 28 input parameters. Six of these are catchment scale data (Table 1) which is mainly the climatic information. The other 22 parameters (Table 2) detail physical characteristics of each cell. Pollutants are routed from cell to cell along drainage paths to the catchment outlet and if necessary flow and water quality at any cell can be examined. The AGNPS model calculates runoff volume, erosion, sediment yield, nutrient loss, chemical oxygen demand (COD) and pesticide washout from rural catchments. The nutrient transport is separated into sediment attached and soluble forms of nitrogen (N) and phosphorous (P). The outputs are available at cell and catchment outlets. As a result the AGNPS model can identify important pollution contributing areas. This is one of the key steps in NPS pollution control. The orthogonal grid structure used in the AGNPS model allows it to be linked to GIS databases enabling graphical identification of critical areas.

**Table 1. The AGNPS Model Catchment Scale Input Parameters.**

| | |
|---|---|
| Climatic | Rainfall volume, Rainfall distribution pattern, Rainfall duration, Storm energy intensity |
| Catchment Details | Number cells, Cell area, Hydrograph shape factor |
| Water Quality | Nitrogen content in rainwater |

**Table 2. The AGNPS Model Cell Based Input Parameters.**

| Parameter Type | Parameter Name |
|---|---|
| Location | Cell number, Cell division, Receiving cell number, Receiving cell division |
| Topographic | Cell slope, Cell aspect, Slope length, Shape factor |
| Soil Data | Soil texture |
| Cell Condition | SCS CN, Erodability Factor, Practice Factor, Cropping Management Factor, Surface Condition Constant, COD Factor, Overland Manning's Coefficient |
| Indicators | Fertiliser indicator, Pesticide indicator, Channel indicator, Point source indicator, Additional erosion source indicator, Impoundment indicator |

The AGNPS model estimates the runoff volume (Equation 1) using the SCS Curve Number method (McCuen, 1982) and peak flow using the SCS TR-55 method (McCuen, 1982).

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (1)$$

where, Q and P are surface runoff volume and rainfall volume in inches, $S = \frac{1000}{CN} - 10$ (retention parameter) and CN = SCS Curve Number

Upland erosion due to a storm event (Equation 2) is estimated using a modified form of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978). The model also allows inclusion of soil loss from other sources such as roads.

$$SL = (EI).\ K.\ (LS).\ C.\ P.(SSF) \qquad (2)$$

where, SL = Soil Loss (tons per acre), EI = Energy Intensity (tons per acre), K = Soil Erodability Factor, LS = Length Slope Factor, C = Cover Factor, P = Practice Factor, SSF = Slope Shape Factor

The EI in Equation 2 depends on climatic factors and is given by Equation 3.

$$EI = \Sigma \{[2.29 + 1.15 \log (Xi)]Di\}I \qquad (3)$$

where, Xi = rainfall intensity (cm/hr), Di = rainfall during the given time interval (cm), I = maximum 30 minute rainfall intensity (cm/hr), and EI = energy intensity value of the storm (tonnes/ha).

The peakflow and the energy intensity of the rainfall will be computed using the SCS rainfall distribution patterns. Transport of sediments in channels is based on the Einstein theory as described in Young et al., 1995. This algorithm allows for both channel erosion and deposition. The sediments are separated into five particle-sizes: clay, silt, small aggregates, large aggregates and sand. The chemical and pesticide transport Equations (4) and (5) are simulated by the algorithms developed by Knisel et al. (1980) and the algorithms in the Feedlot Evaluation model by Young et al. (1982).

$$Nut_{att} = (Nut_{sed})\ (Sed_{yield})\ E_R \qquad (4)$$

where, $Nut_{att}$ = Sediment-attached nutrient load (N or P), $Nut_{sed}$ = Sediment attached nutrient content in soil, $Sed_{yield}$ = Sediment Yield and $E_R$ = Enrichment ratio.

$$Nut_{sol} = (Nut_{sol})\ (Nut_{ext})\ Q \qquad (5)$$

where, $Nut_{sol}$ = Soluble nutrient load (N or P), $Nut_{sol}$ = Mean concentration of soluble N, P in the soil surface, $Nut_{ext}$ = Extraction coefficient of N, P into runoff and Q = Runoff volume

The major drawback of this model is that it does not simulate turbidity, colour, iron and manganese which are critical parameters in water supply catchments (Siriwardhena, 1999). The concentrations of above critical parameters were for this catchment with good accuracy by developing regression equations using surface runoff volume, suspended solids and total nitrogen concentration as independent parameters (Siriwardhena & Jayasuriya, 1999). These independent parameters could be simulated by the AGNPS model.

The AGNPS model has physically measurable parameters. Thus according to Perato and Shi, (1991) this model could be applied without calibration. The special features in the AGNPS model, such as the Resource Accounting Function, Graphics Facility and GIS capability provide enhanced capability for modelling catchment management scenarios.

## THE TARAGO CATCHMENT AND DATA

The Tarago catchment is a multiple land use water supply catchment located about 100 kilometers east of Melbourne, in Gippsland, Victoria, Australia (Figure 1). This 11,400 hectares catchment drains into the 37.5 gigalitre capacity Tarago reservoir. Water quality of the Tarago catchment is poor compared to other water supply catchments of Melbourne (Jayasuriya et al., 1994). Water abstraction from this reservoir has been temporarily suspended until catchment management initiatives put in place yields improved water quality. The flow of a large quantity of nutrients and sediments from the agricultural areas is considered as the major cause of the water quality problem. The west Tarago subcatchment is under forest cover and about 1.5% of forest land is clear felled each year. The East Tarago subcatchment is mainly agriculture land. Water quality data for this study were obtained during March 1993 to May 1995 using two automatic sampling machines which were located at the outlets of the west Tarago and east Tarago subcatchments. These Gammet samplers were triggered by the rising water levels linked to a preset stage, and collect 24 water samples during storm events at pre-determined intervals.

## APPLICABILITY OF THE AGNPS MODEL TO THE TARAGO CATCHMENT

The SCS CN method, SCS TR-55 method and USLE used in the AGNPS model are empirical methods based on data from the United States. The USLE is universally applicable as it is based on physical factors (Novotny and Chesters, 1981). Baker et al. (1995) reported that SCS CN method is applicable for all climatic conditions. The SCS TR-55 method is applicable worldwide wherever a SCS rainfall distribution pattern is applicable (Baker et al., 1995). The SCS rainfall distribution patterns were compared with the standard Australian rainfall distribution patterns (AR&R, 1987) for the Tarago catchment. As reported in Siriwadhena and Jayasuriya (1999) it was observed that the SCS Type 1A rainfall distribution pattern is similar to AR&R (1987) reported rainfall distribution patterns for the Tarago catchment. The maximum 30 minutes intensity occurs at the same distance in both rainfall distribution patterns. It was also found that the SCS Type IA distribution can estimate the Energy Intensity (EI) for the Tarago catchment area with a 99 % of coefficient of determination (Siriwardhena, 1999). The peakflow obtained from the daily streamflow hydrograph and computed peakflow from SCS-TR 55 method was also found to be close. Thus it was considered that the AGNPS model was applicable to the Tarago catchment area.

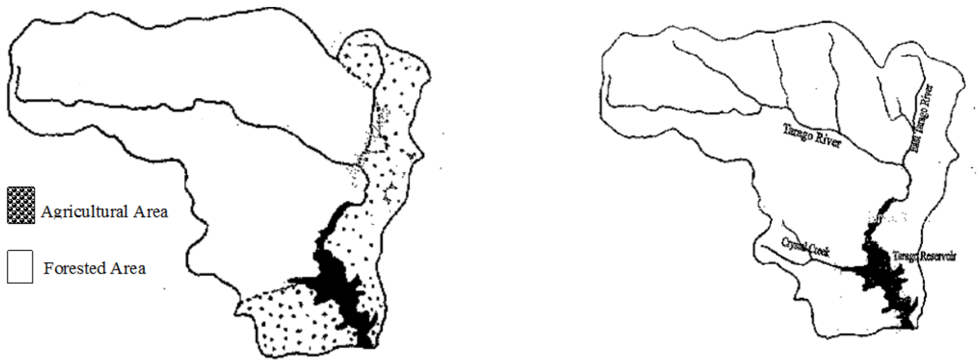


**Figure 1. Tarago Catchment Landuse and Drainage Maps.**

## ESTIMATION OF MODEL PARAMETERS

Whilst a smaller cell size will result in more homogeneous cells it can demand for input parameters not available at high spatial resolution. In this study the Tarago catchment was divided into 187 primary cells of 60.8 hectares each. The AGNPS model geomorphic equations provide convenient means to calculate the channel length, width, depth and channel slope. The channel length and width were computed using the in-built AGNPS model geomorphic equations. The coefficients employed in the geomorphic equations were estimated by calibrating the geomorphic equations to the Tarago catchment using the information from a sample of 40 cells. The channel slope was measured for each cell using the Tarago catchment GIS map.

The SCS Curve Number is the most important parameter in the AGNPS model as runoff volume and peakflow both depend on the CN value. Curve Number was estimated for each cell based on the landuse practice, soil type for catchment wetness given by Antecedent Moisture Condition (AMC) Class II (McCuen, 1982). The peakflow depends on runoff volume, rainfall distribution pattern and several other cell-based parameters. As mentioned earlier the SCS Type 1A rainfall distribution pattern was selected for peakflow computation in the Tarago catchment.

The topographic parameters in the USLE (Equation 2) slope, slope length and slope-shape were determined for each cell using the Tarago catchment's GIS map. Practice (P) and cropping management (C) factors were obtained from Novotny and Chesters (1981) for each landuse using the Tarago catchment landuse maps. Soil erodability factors were obtained as recommended by Stewart et al. (1975) using the Tarago catchment soil data given by Swan and Volum (1984).

The Hydrograph Shape Factor for composite hydrograph depends on the overall catchment slope. McCuen (1982) reported the hydrograph shape factor values for flat, moderate and hilly land slopes. Considering the Tarago as a hilly catchment the hydrograph shape factor was chosen as 600.

The Einstein theory is applied to obtained the amount of sediment transported. The channel roughness was determined based on Chow et al. (1964) on a cell by cell basis using channel information. The AGNPS model default values were assigned for most of the parameters that define the transport of sediment-attached and soluble nitrogen and phosphorus, as catchment data were not sufficient for their estimation. In the east Tarago subcatchment a part of the soluble nitrogen comes from fertiliser. The fertiliser application level was determined based on a survey of farming activities. However, the variation of fertiliser application level and the residual soluble nutrient content in the topsoil from storm to storm was not considered. The initial estimates of key model parameters are reported in Table 3.

Among the catchment data required by the AGNPS model, topographic data are the easiest to obtain with a good degree of reliability. They are slope, channel slope and slope length. GIS technology can significantly ease the estimation and improve the accuracy of all topographic parameters. According to Siriwardhena (1999) the parameters that were most difficult to estimate include those that involve subjective decisions such as the C factor in the soil loss equation and the parameters that change from storm to storm. Estimation of these parameters requires sound judgement based on experience of the modeller. The parameters that were obtained as weighted average were also found to be unreliable. In the Tarago study these parameters were selected for calibration. Soil parameters are the least available in literature. Considering the experience of the Tarago study, the estimation of soil parameters will be a major issue in any future AGNPS model application.

## APPLICATION OF THE AGNPS MODEL

The AGNPS model is amenable to uncalibrated or ungauged situations because it has physically measurable parameters. However, it was decided to first calibrate the model to check the applicability of the uncalibrated AGNPS model. The parameters that require calibration were identified (Siriwardhena, 1999). They were Curve Number, the soil erodability factors for sandy and clay soil and crop management factors for deforested and agricultural areas, soil nitrogen and phosphorous contents. In addition, the model parameters for soluble nitrogen transport were also calibrated (Siriwardhena and Jayasuriya, 1999). The calibrated parameter values are also reported in Table 3.

Table 4 reports the coefficient of determination and efficiency between the measured and simulated runoff volume, sediment and nutrient yields before and after calibration (Siriwardhena, 1999) from west and east subcatchments. They are of the same order as found in other studies by researchers such as Wu et al. (1993), Mitchell et al. (1993). Therefore the calibration of the AGNPS model to the Tarago catchment was considered satisfactory. The calibrated results for nutrients are not as good as for runoff volume and sediments due to spatial and temporal variation of the nutrient parameters. The east Tarago subcatchment will not be calibrated for sediment attached to phosphorus load. Soluble phosphorus data is not available for west and east Tarago subcatchments.

**Table 3. The AGNPS Model Parameters for Tarago Catchment Before and After Optimisation.**

| Parameter | Details | Before | After |
|---|---|---|---|
| Curve Number (CN) | *Forest<br>*Scrub Forest<br>*Deforested and Regrowing area<br>*Agricultural<br>*Pasture | 70<br>73<br>79<br>71<br>69 | 68<br>71<br>79<br>67<br>60 |
| Soil Erodability (K) | *Sandy Soil<br>*Clay Soil | 0.27<br>0.25 | 0.24<br>0.21 |
| Cropping Management (C) | Forest<br>Scrub Forest<br>*Deforested and Regrowing area<br>*Agricultural<br>Pasture | 0.001<br>0.004<br>0.04<br>0.05<br>0.003 | 0.001<br>0.004<br>0.036<br>0.045<br>0.003 |
| Nitrogen Content in Soil | *Sandy soil<br>*Clay soil | 0.001<br>0.001 | 0.0012<br>0.0022 |
| Phosphorus Content in Soil | *Sandy soil<br>Clay soil | 0.0005<br>0.0005 | 0.00005<br>- |
| Fertiliser Application | *Available N, P kg per hectare | 56 N, 22 P | 112 N, 44 P |
| Overland Manning's Coefficient (n) | Pasture: Permanent and good cover<br>Forest with sparse grass cover<br>Scrub forest: excellent grass cover<br>Agricultural : Bare soils after tilling<br>Growing period | 0.08<br>0.04<br>0.13<br>0.03<br>0.13 | 0.08<br>0.04<br>0.13<br>0.03<br>0.13 |
| Surface Condition Constant (SCC) | Pasture : Permanent and good cover<br>Woodlands : Scrub jungle areas<br>Forested : with heavy litter<br>Agricultural : Fallow<br>Raw Crop<br>Water and Submerged areas | 0.22<br>0.29<br>0.59<br>0.22<br>0.05<br>0.00 | 0.22<br>0.29<br>0.59<br>0.22<br>0.05<br>0.00 |
| Hydrograph Shape Factor | | 600 | 600 |

* parameters that were optimized

## EVALUATION OF THE UNCALIBRATED AGNPS MODEL

One of the main constraints in the application of water quality models to catchments is the large data and resource required for parameter calibration. Thus a model which can be applied to catchments without calibration is an advantage for management modeling particularly in ungauged simulations. The AGNPS model has physically measurable parameters and could be applied without calibration. The purpose of this evaluation is to assess the robustness of the AGNPS model used with uncalibrated parameters.

**Table 4. Coefficients of Determination ($R^2$) and Efficiency (E) between Measured and Simulated Model Outputs with Before and After AGNPS Model Calibration.**

| Output | West Tarago Subcatchment | | | | East Tarago Subcatchment | | | |
|---|---|---|---|---|---|---|---|---|
| | $R^2$ | | E | | $R^2$ | | E | |
| | Before | After | Before | After | Before | After | Before | After |
| Runoff | 0.82 | 0.82 | 0.45 | 0.62 | 0.66 | 0.81 | 0.21 | 0.53 |
| Sed. Yield | 0.27 | 0.28 | 0.23 | 0.25 | 0.72 | 0.70 | 0.65 | 0.70 |
| Sed N | 0.36 | 0.36 | 0.33 | 0.35 | 0.23 | 0.29 | -0.39 | 0.21 |
| Sed P | 0.21 | 0.21 | -195.0 | 0.14 | - | - | - | - |

In this study, 2 year 12 hour AR&R (1987) design storm event was used to simulate the water quality from the Tarago catchment. High sediment contributing areas were identified by running the model with uncalibrated and calibrated model parameters. Both Models identified the same main pollution contribution areas. They are predominantly the agricultural and deforested land with steep slopes near the catchment outlet or main channel.

Table 5 depicts the simulated runoff volume and water quality outputs from the west and east Tarago subcatchments, with the 2 Year 12 hour design storm event from the calibrated and uncalibrated (initial model parameters) AGNPS model. Siriwardhena (1999) investigated the sensitivity of the AGNPS model output to model parameters. It was observed that the runoff volume was very sensitive to the CN. Therefore, the concentration of water quality parameters in the surface runoff are also sensitive to CN. The runoff volumes are overestimated by the uncalibrated model in both subcatchments due to higher initial estimates of SCS CN. The estimated runoff volume in the east Tarago subcatchment has a higher percentage error mainly due to the poor estimate of initial CN for pasture (69) compared to the calibrated value of 60. This error was due to insufficient information being available to determine the ground cover in this type of landuse. As it is important to determine the CN accurately it is necessary to use reliable soil infiltration and ground cover data in the determination of CNs in ungauged catchments.

The sediment yield and suspended solids concentration both have percentage errors of less than 10% in the west Tarago subcatchment. However, in the east Tarago subcatchment the sediment yield is over-estimated by 40% in the uncalibrated AGNPS model. As both runoff volume and soil loss are over-estimated in east Tarago subcatchment the difference in total nitrogen between calibrated and uncalibrated models are as high as 50%. However, the percentage error for the suspended sediment concentrations between calibrated and uncalibrated models are low. In the west Tarago subcatchment this is due to close estimation of runoff volume and sediment yield by both models. In the east Tarago this is due to compensating effect of the overestimated runoff volume and sediment yield.

Sediment yield depends on both soil loss and sediment transport capacity in the channel system. Soil loss is directly proportional to the erosion factors defined in the USLE and an additional shape factor defined in the AGNPS model. The initial estimates of some of the K & C factors were unreliable. Determination of these two factors needs soil and ground cover data. Siriwardhena (1999) reported that above data was scarce and very difficult to determine accurately. However the above author reported that it is important that these data are determined with accurate field data in ungauged situations.

The AGNPS model was not calibrated to phosphorus in the east Tarago sub-catchment. The AGNPS model default parameter values that are used in the uncalibrated model gave very low estimates for soluble nutrient concentrations. It was shown that the AGNPS model default values for soluble nutrient transport parameters were poor for the Tarago catchment. Total nitrogen concentration also showed high percentage error in the east Tarago subcatchment due to the AGNPS model default values being used as soil nutrient parameters in the uncalibrated model. The optimised soil nitrogen content in west Tarago subcatchment soil is close to the default value given by the AGNPS model (Table 3). The percentage error is high for total iron concentration as the regression equations used to estimate this variable also include total nitrogen as a variable (Table 5). The percentage error for turbidity and colour are low as the estimated suspended solids concentrations by calibrated and uncalibrated models are close.

**Table 5. Percentage Difference Between Water Quality Parameters from Calibrated and Uncalibrated AGNPS Model.**

| Simulated Parameters | West Tarago | | | East Tarago | | |
|---|---|---|---|---|---|---|
| | Uncal | Calib | % Diff. | Uncal | Calib | % Diff. |
| Runoff (megaliters) | 625.2 | 546.5 | -14.5 | 93.4 | 65.1 | -43.4 |
| Sediment yield (1000kgs) | 93.7 | 89.8 | -4.3 | 75.3 | 53.8 | -40.0 |
| Suspended solids (mg/lit) | 149.8 | 145.7 | -2.8 | 714.8 | 710.3 | -0.6 |
| Sediment -N (kg) | 715 | 787 | 9.1 | 278 | 404 | 31.1 |
| Sediment - P (kg) | 358 | 36 | v.large | 139 | - | - |
| Soluble -N (mg/lit) | 0.0 | 0.20 | v.large | 0.20 | 0.80 | v.large |
| Total nitrogen (mg/lit) | 1.14 | 1.64 | 30.5 | 3.18 | 7.00 | 57.3 |
| Total phosphorus (mg/lit) | 0.57 | 0.06 | v.large | 1.49 | - | - |
| Turbidity (turbidity units) | 63 | 67 | 6 | 276 | 293 | 6 |
| Colour (hazen units) | 255 | 268 | 5 | 441 | 502 | 12 |
| Total Iron (mg/lit) | 1.68 | 2.24 | 25 | 42.86 | 32.30 | -33 |

The channel parameters including channel length and channel width are not sensitive to sediment yield when the entire catchment is considered (Siriwardhena, 1999). The other transport parameters, channel slope and roughness were measured on a cell by cell basis. They were assumed not to cause a systematic error in the sediment loads when total sub-catchments were considered. Sediment transport factors are important in the estimation of sediment from single cells. The most important are channel roughness, channel segment length and channel width. The accuracy of these parameters may affect the selection of critical sediment generating areas.

## CONCLUSIONS

Empirical equations in the AGNPS model are applicable to the Tarago catchment. The initial model parameters were successfully estimated using the Tarago catchment contour (GIS) map, landuse map, landuse reports, soil data and other research publications. In certain cases the AGNPS model default values had to be used. Based on the goodness-of-fit statistics obtained between measured and simulated runoff volume, sediment yield, sediment attached nutrient loads and soluble nitrogen concentration, the model was successfully calibrated. The study revealed that uncalibrated AGNPS model can be used for catchment management provided some key parameters can be estimated accurately. They are: SCS Curve Numbers for runoff estimation, erosion parameters for USLE and sediment attached nutrient content. The most important of the erosion parameters are: Soil Erodability Factor, Cropping Management Factor and Energy Intensity.

## Acknowledgement

Authors wish to acknowledge the Melbourne Water Corporation and the CRC for Catchment Hydrology in Australia for their support in this research project.

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