

*Review*

# Assessing Non-Point Source Pollution Models: a Review

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## Abstract

Although access to clean and potable water is a requirement for healthy living, the constant release of non-point source pollutants into water bodies has resulted in water quality degradation. In a bid to curb this situation, water quality models are used as a tool. This study reviews 10 non-point source models, namely: AGNPS, ANSWERS, CREAMS, SWRRB, HSPF, SWAT, EPD RIV1, DMA, CMBA, and MA, giving consideration to their nature, components, area of use, strengths, and limitations. Our review indicated that hydrological processes and mechanisms involved in the movement of non-point source pollutants have not been completely developed in these models. However, HSPF and EPD RIV1 models (which have in-stream process components) are limited due to limitations in their operations and computational difficulties. Further research would seek to develop a non-point source pollutant model that would not only adequately and effectively simulate non-point source pollutants in water bodies, but would also be easy to assess, user-friendly, and time-efficient.

**Keywords:** non-point source pollution, water quality, hydrological processes, water quality models, water quality degradation

## Introduction

Water is necessary for meeting agricultural, industrial, and domestic needs. Unfortunately, population growth, unplanned urbanization, and industrialization have resulted in increased pollutant loadings into water bodies that cause distortions to its ecosystem and are also detrimental to human health [1]. Pollutants that enter streams from identifiable sources are easily recognized and given due attention. However, a greater challenge comes from pollutants generated from unidentifiable sources considered non-point sources (NPS).

NPS pollutants originate through runoff from agricultural areas, informal settlements, and contaminated lands [2-4]. Due to their ubiquitous nature, they degrade the natural environment and constitute a health risk. NPS pollution is considered a leading threat to water quality and an unmanageable water pollution problem in many regions of the world [5-7].

## Non-Point Source Pollution

Non-point source pollutants discharge into water bodies through several outlets and in uncertain quantities [8]. They are not easily traced to a source but are linked to weather and geographic conditions within a catchment and maintain an active presence within the ecosystem due to the storage characteristics within the

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receiving basin [8-10]. NPS are characterised by varying spatial and temporal pollutant loading, and complex processes and mechanisms with arbitrary and irregular occurrence [11]. It is presumed more complicated for point source pollution due to its complexities in monitoring and control – especially during monsoon periods [12-14].

Runoff from various watersheds in monsoon season picks up pollutants that contaminate and alter the biological, physical and in some cases chemical properties of a water body [ 5, 15-17]. Discharge of non-point source pollutants into a water channel has a significant effect on water quality [18]. Water quality deterioration resulting from nonpoint source (NPS) pollution is being studied globally [19, 20]. Recent studies have established the impact of NPS pollutants in water environments. Lee et al. [21] observed that NPS contaminants constituted 69.3% of the total pollution loads discharged from 4 major watersheds in Korea in 2010. Hu and Huang [22] monitored NPS from an agricultural watershed in southern China. The results put the percentage of NPS pollution against total pollutant loads at more than 80% between 2008 and 2010.

An investigation into eutrophication of Dianchi Lake by Chen [23] revealed that total nitrogen (TN) and phosphorus (TP) generated by NPS pollution in the lake made up 4.5% and 26.7% of the total pollution load. In another study, Chen et al. [24] observed a similar trend of major contributions of TN and TP from NPS to the total pollution loading in the Jinjiang River, China. In the USA NPS pollutants made up 73% of the total chemical oxygen demand (TCOD), 89% of TN, and 83% of bacteria in rivers [25], while in South Africa according to Pegram and Bath [26], 85% of total contaminants in the Mgeni River basin are from NPS.

Further studies have been carried out on the effect of NPS pollutants on water quality in water bodies [14; 27-31]. Chasing storm events, identifying safe and representative sampling locations and catchments, and the delineation of runoff quality parameters proved a major challenge to assessing NPS pollutants by most researchers. This is largely due to the fact that the mechanisms and hydrological processes required in pollutant migration are not adequately catered for in currently available models [13]. However, these challenges were overcome by the use of remote sensing and GIS techniques in estimating the NPS inflow percentages in the water bodies.

The use of remote sensing and GIS is found to be effective in delineating basin areas that contribute NPS pollutants in water columns. Despite the use of this technique, however, most researchers recorded some margin of error. Considering that approximately 30-50% of the world's land surface is affected by NPS pollutants [32], accurate simulation and estimation of NPS is necessary to critically address NPS pollution.

## NPSP Modelling

Water quality models (WQM) were developed to determine the rate at which receiving bodies disperse pollutants and ascertain the occurrence of recovery through temporal responses. They were also developed to establish required flow augmentation for improved water quality [33-35]. However, the ever increasing pollution loading in water systems has led to continuous improvement and development of WQM [35].

These upgrades are necessary when considering NPS pollution due to the challenge in identifying its source and quantifying its loading [36]. Furthermore, according to Li et al. [37] and Liu et al. [38], continuous research on NPS pollution modeling is required as there is no universal model that could be used across regions with varying climatic, geographic, and anthropogenic backgrounds.

In studying NPS pollution, modeling has been widely used in attempts to simplify the complex natural processes of generation and transformation of NPS pollutants [39]. Watershed models that simulate hydraulic responses, and receiving water models that simulate water quality and hydrodynamic transport are required to estimate NPS pollutants [40]. The most frequently used watershed models are continuous simulation and storm event models. Continuous simulation models analyze long-term effects of hydrological changes while storm event models examine severe single-storm events.

Only a few models have both long-term continuous and storm event simulation capabilities. Most of them are based on simple empirical relations with robust algorithms, while others use physical-based equations whose numerical solutions are rigorous [41-42]. The simple models are sometimes unable to give the desired result, while the detailed models are inefficient and prohibitive in large watersheds. Therefore, finding an appropriate model for an application and for a certain watershed is quite a challenging task [41].

The use of any model is assessed through the determination of its capability to handle accurately its set out criteria [43]. Over time, extensive work has dealt with the contributing factors of NPS discharges from a watershed into the water body. However, the ultimate effect of the pollutant on the water body and its behavior within the water body is hardly considered.

## Review of NPSP Models

The complex processes that govern NPS pollutants make it difficult to assess and quantify its spatial and temporal extent. Physical and chemical cycles that control the amount of pollutant loading in water bodies are represented using physically based computer modeling.

Numerous models in the public domain have been used successfully in assessing and simulating NPS in watersheds. This review, however, would focus on

Table 1. Summary of NPS water quality models under review.

Model	Type	Major components	Strength	Limitations
AGNPS	Event-driven distributed model	Hydrology, chemical, and erosion/sediment transport	Simulates spatial distribution of catchment properties; gives immediate response compared with experiments; useful in understanding erosion processes	Requires exclusive and extensive data and much work and programming competence; it is unable to assess nutrient transformation and in-stream processes
ANSWERS	Distributed parameter, event-oriented model	Hydrology, evapotranspiration, infiltration, and overland sediment transport	Program codes are easy to modify and predicted results are comparable with observed data	Unable to simulate in-stream processes and simulate sub-processes like snowmelt or pesticides; requires elaborate and detailed input data preparations and is computationally intensive; output is sensitive to slight changes in input variables and this makes its validation challenging
SWAT	Continuous, semi-distributed, basin-scale model	Hydrology, climate, nutrients, sediment transport	Considers long-term impacts of rural and agricultural management practices, and conflux and sediment confluence; can be used for specialized processes such as bacteria transport	Requires large numbers of input files to run the model; unable to simulate daily changes of dissolved oxygen in water bodies and cannot accurately evaluate extreme daily flow occurrences, complex dynamic evolution of soil nitrogen and carbon, and simulation of runoff yield; database must be modified when used in different study areas
CREAMS	Field-scale lumped approach model	Hydrology, chemical and erosion/sediment transport	Forecasts single rainfall events, calculates runoff volume and storm loads; can be represented with simple mathematical terms	Limited simulation capability, incapable of simulating in-stream processes High level of competence is required by user It is easy to misapply and interpret model outputs
SWRRB	Long-term water and sediment yield model	Hydrology, climate and sediment transport	Capable of modelling large and complex watersheds	Incapable of simulating in-stream processes; input and output files are massive
HSPF	Long-term continuous simulation model	Hydrology, climate and sediment transport	Effectively evaluates the flow rate of runoff, sediment transport, and nutrient and pesticide concentrations; predicts results satisfactorily and is capable of simulating in-stream processes	Relies on many empirical relationships to represent physical processes and requires extensive calibrations and a high level of expertise; high data sets are required and it does not consider the spatial distribution of watersheds; complex
EPD-RIV 1	One-dimensional hydrodynamic model	Hydrodynamic and water quality	Simulates the impact of time-varying non-point source pollutants on water quality and in-stream processes	Data requirement is high and high level of expertise required
DMA	Mathematical model	Hydrology	Estimates NPS outflows in watersheds	Cannot delineate hydrological uniform areas when subdividing the watershed; does not consider NPS input as overland flow
CMBA	Mathematical model	Chemical mass balance	Estimates non-point loadings through upstream and downstream measurements in receiving water bodies	Is not reliable in accounting for all pollutants when time of travel between downstream and upstream is lengthy
MA	Mathematical model	Conservation of mass and reaction kinetics	Estimates inflow of NPS pollutants into a river reach during both rainy and non-rainy seasons; the approach assumes NPS input as overland flow	Is not reliable in accounting for all pollutants when time of travel between downstream and upstream is lengthy

agricultural non-point source (AGNPS), areal nonpoint source watershed environment response simulation (ANSWERS), and soil and water assessment tool (SWAT) models. Others include chemicals, runoff, and erosion from the agricultural management systems (CREAMS), simulator for water resources in rural basins (SWRRB), and hydrological simulation program FORTRAN (HSPF) models. The one-dimensional riverine hydrodynamic and water quality model (EPD-RIV1) will also be considered. The choice of the models under review was according to their wider use and availability.

### Agricultural Nonpoint Source Pollution Model

AGNPS is an event-driven and distributed parameter model developed by the United States Department of Agriculture (USDA) Agricultural Research Service. It simulates runoff and estimates sediment and nutrient loads from agricultural watersheds for single-storm events [44]. The water quality components of AGNPS are obtained by correlating nutrients and pesticides in runoff. The model calculates and estimates runoff and subsequent soil erosion using universal soil loss equation (USLE). Furthermore, it uses the unit hydrograph for the uniform rainfall and soil conservation service (SCS) runoff curve approach. AGNPS consists of three principal components [44]: hydrology for calculating peak flow rate and runoff volume, chemical transport for estimating chemicals such as nitrogen (N) and phosphorus (P), and erosion and sediment transport.

AGNPS is considered a very practical tool used in various watersheds to study the impacts of different land cover scenarios [45]. Land use parameters for specifying field processes and weather data required in AGNPS include cropland, pasture, rangeland, forest, urban areas, precipitation, temperature, and sky cover. AGNPS is suitable for interfacing with GIS to accelerate data input and interpret model results [46]. AGNPS is a useful tool in understanding erosion processes and locating areas that have a high potential for loss of nutrients within a watershed [13]. It simulates the spatial distribution of catchment properties using a square grid cells system and evaluates the surface runoff for individual grid cells. The estimated runoff is routed through individual grids within the catchment toward the drain outlet.

Different scenarios for minimizing nutrient and sediment discharge may be simulated, giving the user an advantage of immediate response compared with real-life experiments [39]. AGNPS is a useful tool for management decisions regarding watersheds [13]. The model is predominantly used in the United States. However, its effective use in other regions has been tested [13, 47-48]. AGNPS is not without its limitations.

Catchment scale models like AGNPS require exclusive and extensive data, as the simulation is based on the unit grid, which requires a large number of input

parameters. Technical documentation only exists for the input editor of AGNPS, where all the parameters are entered and edited. Moreover, adaptation of the model requires much work and programming competence [49]. The model is incapable of assessing nutrient transformation and in-stream processes and is only capable of simulating single events [40].

Due to the limitations observed in AGNPS as an event-based model, an annualized version AnnaAGNPS was developed to improve the simulation capability of AGNPS to evaluate the long-term effects of NPS pollutants in large watersheds [50].

### Areal Nonpoint Source Watershed Environment Response Simulation Model

ANSWERS is a distributed parameter and event-oriented model developed by the agricultural engineering department of Purdue University [51]. The primary use of ANSWERS is in planning and evaluating strategies for monitoring non-point source pollution from agricultural lands. The model predicts runoff, infiltration, evapotranspiration and sediment transport in agricultural watersheds.

In this model, the hydrological response to a storm event is the mechanism for the movement of pollutants in the watershed. The model requires the subdivision of watersheds into square grids and simulates the processes within the watersheds following rainfall events. The processes that include runoff, sedimentation, and erosion are evaluated and routed for individual cells [13]. Further, ANSWERS produces a number of output data that includes sediment yield hydrographs, runoff hydrographs, chemical movement masses, sediment loss, and deposition masses for the individual cells. Program codes are easy to modify using ANSWERS due to its modular program structure. However, its modeling capability of water quality constituents is limited to nitrogen and phosphorous, but the degradation of nitrogen and phosphorus in-stream is not considered.

ANSWERS is unable to simulate many subprocesses including snowmelt processes or pesticides. The model – like all distributed parameter models – requires elaborate and detailed input data preparations and is computationally intensive. Its output is sensitive to slight changes in input variables and this makes its validation challenging [52]. The erosion module of ANSWERS is empirical to a great extent.

### Soil and Water Assessment Tool Model

SWAT is a continuous, semi-distributed and basin-scale model developed for the agricultural research service (ARS) of the USDA [53]. It is physically based and operates on a daily time step. SWAT combines and expands the features of models like CREAMS [54] and SWRRB [55]. The model enables users to consider long-term impacts of rural and agricultural management practices. It considers the process of conflux and

sediment confluence and develops soil and water conservation modules when combined with GIS.

The major processes of SWAT include climate, soil type, sediment, nutrients, pesticides, vegetation growth, agriculture management, and surface and underground runoff. Additionally, its primary consideration is water, sediments, and chemical yields from agricultural lands in complex watersheds under differing soil types and management conditions. SWAT is used for more, including estimating streamflow and nutrient loading in various watersheds [56].

The model works by dividing the watershed into subunits known as hydrologic response units (HRUs) of similar soil types, land uses, and slopes [57]. SWAT has a high calculative efficiency and is effective for simulating big basins without much time and high investment involved. It is sensitive to changes in climate, plant cover, and management processes [58]. Though easy to use, an ArcGIS interface is required to facilitate simulation setup and modification due to large numbers of input files required to run the model. SWAT is only able to route one pesticide each time through the stream network. It is unable to simulate daily changes of dissolved oxygen in water bodies. [40, 59].

SWAT cannot accurately evaluate processes such as extreme daily flow occurrences, the complex dynamic evolution of soil nitrogen and carbon, and simulation of runoff yield [42, 56]. It is incapable of simulating single flood events, while its database must be modified when used in different study areas. Among several studies, MiSeon Lee et al. [60] used SWAT and QuickBird high-resolution satellite imagery to evaluate the reduction effect of non-point source pollution by applying best management processes (BMPs) in a select watershed. Poudel et al. [61] monitored the quality of surface water in Louisiana using SWAT. Xu et al. [28], using SWAT, estimated nonpoint source pollution loads in the Zhangweinan river basin.

In addition, SWAT was adopted along with the small-scale watershed extended method (SWEM) for the simulation of NPS in Three Gorges Reservoir Region [17;62-64]. Findings from these studies highlighted the strengths and flaws of the model. SWAT is the most widely used model when considering non-point source pollution and best management processes [37].

#### Chemicals, Runoff, and Erosion from Agricultural Management Systems Model

CREAMS is a field-scale lumped approach model developed by the USDA to assess agricultural management practices and pollution control [54]. The model calculates runoff volume, peak flow, infiltration, soil water content, percolation, and evapotranspiration on a daily basis. It determines storm load, average sediment concentrations, and dissolved chemicals in the runoff. The analysis is executed through interconnecting sub-models of hydrology, erosion, and chemistry [54]. The application of CREAMS varies from simple

to complex systems – especially in extreme cases of climate and management approaches [65]. In developing the model, some assumptions were made to simplify the complex systems and processes so that they are represented by simple mathematical terms. CREAMS employs SCS and USLE for continuous series and erosion simulation processes [54]. Furthermore, it has the ability to forecast single rainfall events that provide an average value for long-term rainfall. The simulated area in CREAMS is limited to a small field with the assumptions that the field has homogeneous soil, land use, and precipitation occurrences. The model has limited simulation capability for snow buildup, snowmelt, and subsequent runoff, and is limited in data management.

CREAMS cannot provide process information or be used for large-scale river basins. It is also incapable of simulating in-stream processes [66]. Users face certain restrictions if the model is run as 3 separate components. Because files generated by a component must first be recorded in order to pass the correct file to the next component, the user must be attentive to the numerous files that would be generated for specific situations and be aware of the assumptions and intrinsic limitations of the model to prevent misapplication or interpretation of the model outputs [54].

#### Simulator for Water Resources in Rural Basins Model

SWRRB was developed by modifying subroutines of CREAMS for the simulation of basin-scale processes in rural basins [55]. It is a long-term water and sediment yield simulator capable of predicting the effect of management decisions and assessing water quality in ungauged rural basins. The model consists of three components: hydrology, climate, and sedimentation. Furthermore, it considers both soluble pollutants and sediment-attached pollutants from surface runoff, percolation, evapotranspiration, return flow, transmission losses, reservoir storage, sedimentation, and crop growth [67].

Total nitrogen and phosphorus are evaluated using relationships between runoff volume, sediment yield, and chemical concentration. Surface runoff volume is measured using the SCS curve number, while return flow is evaluated in relation to soil water content and travel time of return flow.

SWRRB effectively models large and complex watersheds that are subdivided based on soil, land use, or management. It is, however, incapable of simulating in-stream processes [67]. And its input and output files are massive.

#### Hydrologic Simulation Program FORTRAN (HSPF)

Developed by the United States Environmental Protection Agency (USEPA), HSPF is a comprehensive

package that simulates watershed hydrology and water quality over land, in-stream, and in impoundments [68]. It is a broad watershed hydrology and water-quality model that allows for the integrated simulation of land and soil contaminant runoff processes. It simulates in-stream hydraulics, nutrients, and sediment chemical exchanges for a wide range of organic pollutants [40, 69]. HSPF effectively evaluates the flow rate of runoff, sediment transport, and nutrient and pesticide concentrations. It generates time series results for water quality and quantity within a watershed [70]. Furthermore, the model is used in assessing land-use change and flow diversions for point source and non-point source pollutant management processes [71].

Runoff capabilities in HSPF include simple relationships as empirical buildup, wash-off, and concentrations, and detailed soil process options. The in-stream nutrient processes include phosphorus and nitrogen reactions, and BOD, DO, pH, benthic algae, phyto, and zooplankton [70]. HSPF divides watersheds into homogeneous segments using the HRU concept. The model ignores the spatial variations within sub-watersheds, assumes overland flow to be uni-directional, and considers the receiving water system as completely mixed. Any time-step may be simulated from as little as a minute to upwards of several years. However, HSPF relies on many empirical relationships to represent physical processes requiring extensive calibrations and a high level of expertise.

HSPF does not consider the spatial distribution of watersheds, resulting in increased model complexity. The model also does not consider simulation time as it approaches a distributed model when smaller sub-watersheds are used. HSPF is limited to well-mixed rivers and reservoirs and one-dimensional flow [40].

### One-Dimensional Riverine Hydrodynamic and Water Quality Model

EPD-RIV1 is a one-dimensional model developed by Ohio State University for the USEPA as a modification of the CE-QUAL-RIV1 model [34]. The model employs the 2-point 4th-order Holly-Preissman scheme to solve mathematical formulations.

EPD-RIV1 consists of two components: hydrodynamic (RIV1H) and water quality (RIV1Q). RIV1H simulates the dynamics in water bodies to analyze prevailing dynamic conditions and waste load allocations within the water column. RIV1Q has the capacity to simulate water temperature, phosphorus species, nitrogen species, carbonaceous biological oxygen demand (CBOD), dissolved oxygen (DO), algae, manganese, iron, and coliform bacteria. Furthermore, it has the capacity to simulate the impact of time-varying non-point source pollutants on water quality and in-stream processes. However, the two components are not run simultaneously.

RIV1H is applied first, and the output is written in a file that is transferred and used for simulation in RIV1Q.

EPD-RIV1 evaluates longitudinal variants in hydraulic and water quality characteristics where lateral and vertical differences are small. Additionally, it predicts water surface elevations, flows, depths, velocities, and other hydraulic characteristics. The model uses differential equations to represent a change in values of variables, with one-day time step [34, 72].

In the application of EPD-RIV1, the assumption that the waterbody is one-dimensional is made. This assumption considers that velocities are suitably represented as average values over the cross-section. Furthermore, it assumes that mixing in the lateral and vertical cross-sections are adequate, thereby allowing for cross-sectional homogeneity. This assumption may not be absolutely true, since contaminants discharged into a waterway may not mix completely for some distance downstream. It is, therefore, inappropriate in areas where complete mixing has not taken place [72]. The hydrodynamic model solves the St. Venants equations as the governing flow equations and includes both point and non-point source inflows and outflows. The software has computer system shell, deliberator, preprocessor, post-processor, and pre-run. The required input data consists of initial conditions, geometric data, control and hydraulic parameters, and calibration data. However, data requirement is high [34, 72].

The governing equation is:

$$\frac{\partial \alpha}{\partial t} + \bar{u} \frac{\partial \alpha}{\partial x} = D \frac{\partial^2 \alpha}{\partial x^2} + \frac{q}{A} (\gamma - \alpha) - K_s \alpha + Sinks \quad (1)$$

...where  $\alpha$  = mass concentration ( $ML^{-3}$ ),  $t$  = time (T),  $\bar{u}$  = velocity ( $LT^{-1}$ ),  $x$  = longitudinal distance (L),  $D$  = dispersion coefficient ( $L^2T^{-1}$ ),  $A$  = cross sectional area ( $L^2$ ),  $q$  = lateral inflow rate ( $L^3T^{-1}L^{-1}$ ),  $\gamma$  = concentration of the runoff input to the channel by distributed flow  $K_s$  = biochemical uptake or decay rates (+) and growth rates (-) ( $T^{-1}$ ), and sinks = biochemical sources(+) and sinks(-).

### Other Attempts at Modelling NPS

Recently, however, attempts at modelling NPS have seen the emergence of mathematical models using several approaches.

### Distributed Modelling Approach

DMA is used in the estimation of NPS outflow from agricultural watersheds to a water column. It involves the collection of data from each field within a watershed by dividing it into small regular units. However, a major challenge is delineating hydrological uniform areas when subdividing the watershed [73]. The commonly used equation for agricultural watersheds is expressed as:

$$C_{out} = \frac{1}{100R_{off}} (1-k)(C_{in} + C_{np}) \quad (2)$$

...where  $C_{out}$  is the soluble concentration of the water quality constituent leaving the reach ( $ML^{-3}$ ),  $C_{in}$  is the soluble concentration of the water quality constituent entering the reach ( $ML^{-3}$ ),  $C_{np}$  is the soluble concentration of the NPS constituent generated within the river reach ( $ML^{-3}$ ),  $R_{off}$  is total runoff (mm), and  $k$  is the decay coefficient ( $T^{-1}$ ).

In the distributed modelling approach, the dissolvable concentration of NPS pollutants is combined with the reduction occurrences of the soluble concentration of water quality constituents at the inlet of the water column. This situation, however (according to Jha et al. [9] and Leon et al. [73]), is not consistent with actual field conditions. Rather, NPS pollutants enter the water column through the overland flow adjacent to it [9].

### Chemical Mass Balance Approach

CMBA is as represented in Eq. 3 [9, 74]. The equation estimates the magnitude of NPS as the difference between the sum of watershed discharge and point source discharges [75]. It has been previously used in indirect estimations of point and non-point loadings through upstream and downstream measurements in receiving water bodies.

$$Q_d C_d = Q_u C_u + \sum_{i=1}^n L_i \quad (3)$$

...where  $Q_d$  and  $Q_u$  are downstream and upstream discharge ( $L^3T^{-1}$ ),  $C_d$  and  $C_u$  are downstream and upstream concentrations ( $ML^{-3}$ ), and  $\sum_{i=1}^n L_i$  is the net outcome of individual loadings plus any losses or generation within the water body. If significant changes in contaminants occur upstream, the chemical mass balance equation might not be considered reliable in accounting for all pollutants – especially those that undergo significant changes except in conditions where the time of travel between downstream and upstream is small [74].

### Modified Approach

MA is based on the conservation of mass and reaction kinetics. The model estimates the inflow of NPS pollutants into a river reach during rainy and non-rainy seasons [9]. The approach assumes NPSs as uniformly distributed adjacent to the river reach [83]. The limitations observed in the distributed and chemical mass balance approach were tackled using the modified approach indicated as Eq. 4:

$$Q_d C_d = Q_u C_u e^{-kt} + Q_{np} C_{np} \quad (4)$$

...where  $Q_{np}$  is NPS discharge ( $L^3T^{-1}$ ), while  $k$  is the rate of attenuation ( $T^{-1}$ ) and  $t$  is travel time (T). This approach

was successfully used in estimating nitrate ( $NO_3$ ) and ortho-phosphate ( $o-PO_4$ ) loads due to NPS in the River Kali [9]. However, for long reaches the equation would require further modification, as in its present form, the distance between two sampling stations must be as short as possible.

### Conclusions

Ten non-point source pollution models were reviewed: AGNPS, ANSWERS, CREAMS, SWRRB, HSPF, SWAT, EPD RIV1, DMA, CMBA, and MA. The basic operation of each model was carefully highlighted with consideration given to their nature, components, area of use, strengths, and limitations. AGNPS and ANSWERS are single-event, distributed parameter models, while HSPF, CREAMS, and SWAT are long-term continuous simulation models. SWRRB (a modification of CREAMS) simulates basin scale processes. AGNPS, HSPF, CREAMS, and SWAT have three major components comprising chemical, hydrological, and sedimentation components.

AGNPS lacks the capacity to predict sediment, time-varying water, and chemical discharges critical in certain analyses due to its computationally intensive numerical structures. ANSWERS and SWRRB have hydrology and overland sediment as their main components, excluding chemical component and sediment simulation in stream channels. SWRRB, however, has a weather component. ANSWERS and HSPF use storage-based equations for flow routing while AGNPS, CREAMS, SWRRB, and SWAT use SCS runoff curve number to estimate peak flows and runoff volumes. Additionally HSPF and CREAMS require continuous precipitation data.

It is, however, observed that hydrological processes and mechanisms involved in the movement of pollutants have not been completely developed in these models. The limitations observed in DMA CMBA were addressed by the MA model. However, MA would require further modification in terms of the reach length to be considered, which is vital for non-point source modeling. In view of all models reviewed, both HSPF and EPD RIV1 have the capability of simulating in-stream processes. However, both HSPF and EPD-RIV1 have limitations that preclude their overall capability in effectively and easily evaluating non-point source pollutants in water bodies.

HSPF relies on a number of empirical relationships to distinguish physical processes. It lumps simulation processes for different land use types at watershed levels and transits to a distributed-type model when the watershed is small, resulting in an increase in simulation time and model complexity. HSPF requires extensive calibrations and a high level of expertise, plus a high data requirement.

EPD-RIV1 is a one-dimensional model comprised of two codes: hydrodynamic (RIV1H) and water quality

(RIVIQ), which do not run concurrently. RIVIH is applied first and stored before RIVIQ uses its output file to drive the transport of the water quality parameters. The assumption made in EPD-RIV1 on the homogeneity in the cross-section of a water column may not stand true, which makes the model inappropriate in areas where complete mixing has not occurred.

Considering these points, this study concludes that further research is required to develop a non-point source pollution model that would not only adequately and effectively simulate non-point source pollutants in water bodies, but would also be easy to assess, user-friendly, flexible to adopt different water quality parameters, and time-efficient.

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