International Journal of Scientific Research in Civil Engineering
© 2019 IJSRCE | Volume 3 | Issue 4 | ISSN : 2456-6667

A Review on Water Quality Models: QUAL, WASP, BASINS, SWAT and AGNPS

Najmussahar H Mulla[1] , Dr. B. M. Krishna[2], and Dr. B. Manoj Kumar[3]
[1]Ph.D Scholar, [2]Associate Professor, [3]Professor
Department of Environmental Engineering, Sri Jayachamrajendra College of Engineering, Mysuru, India
Corresponding Author Email: sahersabeer1413@gmail.com

ABSTRACT

Water is essential for life, human civilization, and to protect the nature and its resources. Any natural body of water may be viewed as a system composed of a number of complex interacting subsystems each having its own unique characteristics. The current population growth rate, human lifestyle significantly influences the physical, chemical and biological characteristics of water making it scarce. Scientific water resources management is the need of the day. The evaluation and analysis of point and non-point water pollution loads is a very important issue to be addressed presently. Models can be effective tools in assisting efficient ways for water resources development, treatment and use. Each water quality model has its own unique purpose and simulation characteristics and hence has to be reviewed thoroughly before use. The main goal of this paper is to address the recent developments in five well known water quality models: QUAL, WASP, BASINS, SWAT and AGNPS. The current focus is on improving the knowledge in the field of modeling for devising the new generation of models. All concerned water sector parties must make model usage compulsory for good governance and sustainable water resources management. The challenges of this path are inclusiveness, transparency, efficiency and productivity. Geospatial technologies have proven to be an effective enabler to meet these challenges. Integration of models with one another and Geographic Information System (GIS) and Remote Sensing (RS) is important to solve data related and simulation related problems.

Keywords: Nonpoint pollution; Water quality models; QUAL; WASP; BASINS; SWAT and AGNPS.

I. INTRODUCTION

Water is essential for life, human civilization, and to protect the nature and its resources. Any natural body of water may be viewed as a system composed of a number of complex interacting subsystems each having its own unique characteristics. The current population growth rate, human lifestyle significantly influences the physical, chemical and biological characteristics of water making it scarce. Degradation of these vital water resources can be measured as the loss of natural systems, their component species, and the amenities that they provide. The evaluation and analysis of water pollution from both technological and economic points of view is a very important issue in the ecology.[1-2]

Pollutant discharges from point sources are often continuous, with little variability over time. Often they can be monitored by events, such as heavy precipitation or major construction. Nonpoint inputs often derive from extensive areas of land and are transported overland, underground, or through the atmosphere to receiving waters. Consequently, nonpoint sources are difficult to measure and regulate.Sediments and nutrients are the most commonly recognized nonpoint pollutants, others include toxic contaminants (heavy metals and measuring discharge and chemical concentrations periodically at a single place. Point sources are relatively simple to measure and regulate, and can often be controlled by treatment at source. Nonpoint inputs can also be continuous, but are more often intermittent and linked to seasonal agricultural activity or irregular man-made chemicals such as pesticides and solvents), airborne inputs and pathogens (disease-causing organisms) from human or animal waste. [3]

Agriculture is the main cause of nonpoint-source pollution that affects streams and aquifers. The driving force of nonpoint source pollution is the rainfall-runoff process, which tends to be a complex non-linear, time-varying and spatially distributed process in agricultural watersheds. In agricultural watersheds, variable amounts of fertilizers and pesticides can be released to streams and aquifers through surface runoff and leaching, jeopardizing sources of drinking water. Modeling is a valuable tool in the analysis of the risk of contamination caused by nutrients and pesticides and in evaluating the effect of management practices in that process. [3-7]

II. METHODS AND MATERIAL

Models

A theoretical construct together with assignment of numerical values to model parameters incorporating some prior observations drawn from field and laboratory data, and relating external inputs or forcing functions to system variable responses.

A mathematical model is a quantitative formulation of physical, chemical and biological processes that simulate a system.

Importance of Mathematical Models:

- Simulation on models rather experiments on actual system.
- Best way to understand the physical behavior of the system.
- Economic way for measurements.
- Control on parameters.
- Allow us to predict the future nature which hasn't been seen so far.

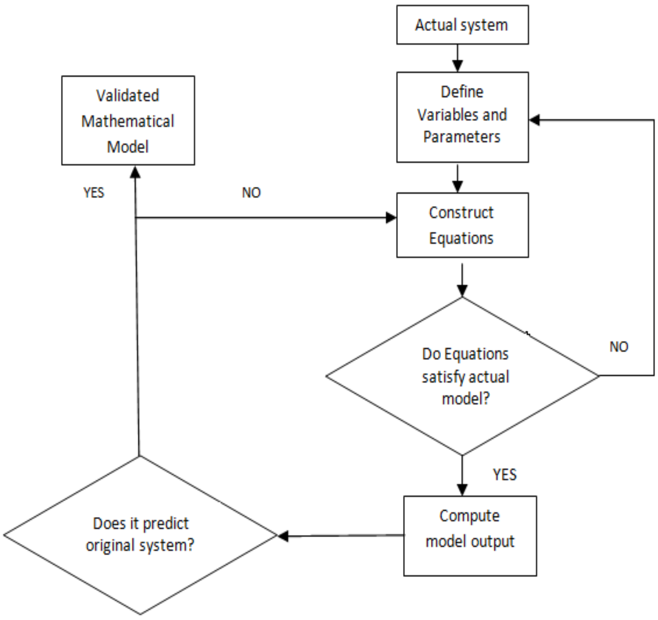

Figure 1.Process of mathematical modeling

Classification of Mathematical Models:

- **Linear and Non-linear Models**:

A function or an operator is called linear if it follows the principle of super- position. If all the functions and operators involved in the model are linear, then it is called a linear model otherwise a non-linear model.

- **Static and Dynamic Models:**

Static models account only for steady state or system in an equilibrium state and hence it is the time in-variant. Dynamic models deal with time-dependent changes in the state of system. They are typically represented by difference or differential equations.

- **Discrete Time and Continuous Time Models:**

Discrete time model treats object at countable time steps. Continuous time model deals for continuous time.

- **Deterministic and Stochastic Models:**

If every variable state involved in system can be uniquely determined by parameters in the model, it is termed as deterministic. If any one of the variable state shows random nature then it is called stochastic.

- **Autonomous and Non-autonomous Models:**

An autonomous model is one in which derivatives are not explicitly dependent on independent variable. When variable is time, the model is also referred as time-invariant model. A system in which derivatives are explicitly dependent on independent variable is called non-autonomous model. [4-7]

A Review of Water Quality Models

1. Stream Water Quality (QUAL) Models

The QUAL models are the most widely used computer models for simulating stream-water quality. QUAL-I was initially developed by F.D. Masch and Associates and the Texas Water Development Board in the 1970s. In 1972, QUAL-I was modified and extended to create QUAL-II. After extensive review and testing QUAL2E (Enhanced Stream Water Quality Model) was developed. In 2002, QUAL2K was developed after identifying limitations of QUAL2E, QUAL2EU. The major enhancement included the strengthening of computational structure and addition of new constituent interactions, such as algal BOD, denitrification, and DO change caused by plants [9]. Then, QUAL2Kw was developed by Chapra and Pelletier [9] by modifying QUAL2K. QUAL2Kw is one-dimensional, steady flow stream water quality model and thus its application is limited to steady state flow condition. It has many new elements [9] it includes DO interaction with fixed plants, conversion of algal death to CBOD and reduction of amount of CBOD due to denitrification. Additionally, it has autocalibration system. It is useful in data limited conditions and is freely available (http://www.ecy.wa.gov/). The model presently simulates the main stem of the river as depicted in **Figure 2**.

The latest version QUAL2Kw6 is a non-steady, non-uniform flow using kinematic wave flow routing. It does continuous simulation with time-varying boundary conditions for periods of up to one year with option to use repeating diel conditions similar to earlier version but with either steady or non-steady flows. It has optional transient storage zones (surface and hyporheic transient storage zones) [10].

The input data required is flow and concentrations for headwater, discharges and withdrawals; reach segment lengths, elevations, hydraulic geometry and weather data parameters.

The model can simulate temperature, pH, conductivity, inorganic suspended solids, DO, slowly reacting CBOD, fast-reacting CBOD, organic nitrogen, ammonia nitrogen, nitrate nitrogen, organic phosphorus, inorganic phosphorus, phytoplankton, detritus, pathogen, alkalinity, total inorganic carbon, bottom algae (periphyton) biomass, bottom algae (periphyton) nitrogen, bottom algae (periphyton) phosphorus. It can also simulate a generic pathogen as a function of temperature, light, and settling velocity. [10-11].

Most of the indicators are simulated as first order decays. DO, nitrate, and phosphate are represented in more detail. [12-13].

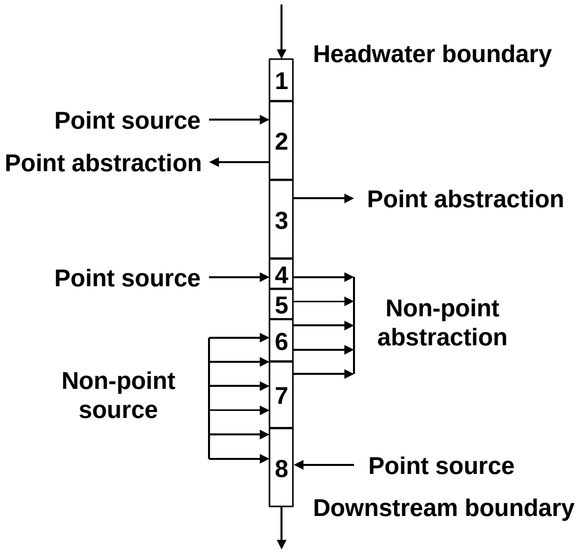

Figure 2.QUAL2K segmentation scheme

For auto-calibration, the model uses genetic algorithm (GA) to maximize the goodness of fit of the model results compared with measured data by adjusting a large number of parameters. The fitness is determined as the reciprocal of the weighted average of the normalized root mean squared error (RMSE) of the difference between the model predictions and the observed data for water quality constituents [9].

The strengths of the model are multiple loading and abstractions and can simulate both point and non-point pollution for 20 water quality parameters. It can also simulate water exchange between surface water column and hyporheic zone and sediment pore-water quality. It uses two forms of CBOD (slow and fast) and is capable of converting algal death to CBOD, macrophytes and detritus. The model can accommodate anoxia by reducing oxidation reactions to zero at low oxygen levels. Besides, denitrification is modeled as a first order reaction that becomes pronounced at low oxygen concentrations. Sediment–water fluxes of dissolved oxygen and nutrients are simulated internally rather than being prescribed. The model explicitly simulates attached bottom algae. Light extinction is calculated as a function of algae, detritus and inorganic solids. Alkalinity, total inorganic carbon and river pH are simulated. It has inbuilt automatic calibration system using genetic algorithm.[10-13]

The limitations are that the model simulates only the main stem of a river and does not simulate branches of the river system. It does not presently include an uncertainty component. [10-13].

Water Quality Analysis Simulation Program (WASP): The USEPA developed WASP model in 1983. It has been under continuous development since then with its latest enhanced version WASP 8, freely available at US EPA's website. It can run under Windows operating system and includes a graphical user interface for generating input files and visualizing the output files for easy evaluation of simulation results. The outputs of WASP can be transferred to programs used for Geographical Information System (GIS) and water quality statistics. It also has an interface to read the results generated by the Hydrological Simulation Program – FORTRAN (HSPF) [14-18].

WASP can be used to analyze a variety of water quality problems in such diverse water bodies as ponds, streams, lakes, reservoirs, rivers, estuaries, and coastal waters. It is a general dynamic mass balance framework for modeling contaminant fate and transport in surface waters. The model uses flexible compartment modeling approach and simulates spatial and temporal conservation of mass implementing a finite-difference equation for each compartment or segment. The model network comprises expanded control volume or segments as illustrated in Figure 3. It can be applied in one, two, or three dimensions with advective and dispersive transport between discrete segments. The WASP kinetic models are based on a set of transport and transformation equations. Advective transport is driven by water flow through a specified computational network as shown in Figure 3. Inflows bring boundary concentrations into the network, and internal flows advect most constituents along specified flow paths through the network and out the downstream boundaries. [18]

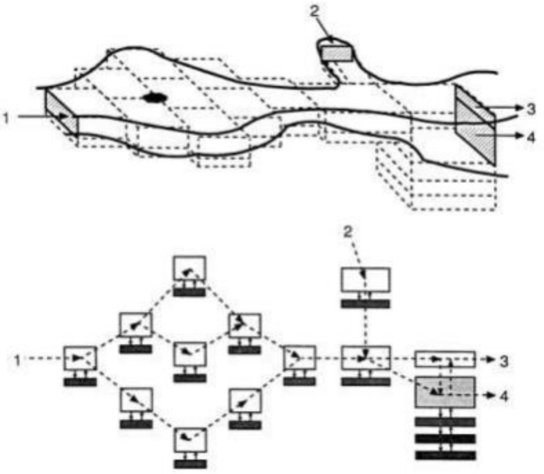

Figure 3. Model network with advective transport pathways

Advective transport is divided into six distinct fields viz., advective transport in the water column, in the sediment bed, transport of particulate pollutants by settling, resuspension and burial. The sixth transport field represents evaporation or precipitation from or to surface water segments. Flow routing, stream routing, kinematic wave, ponded weir, hydrodynamic linkage and dynamic wave are the flow options available. Beginning with version 8.0, the stream network includes kinematic flow, poned flow and dynamic flow (or backwater) segments. EUTRO, TOXI, MERCURY and HEAT are its submodels. The input data required are simulation and output control, model segmentation, advective and dispersive transport, boundary concentrations, point and diffuse source waste loads, initial concentrations and kinetic parameters, constants and time functions. The model simulates the variations in detrital and periphyton concentrations based upon the QUAL2 K algorithm [9]. The transport options for simulating hydrodynamics include internal stream transport algorithms and external linkage to Environmental Fluid Dynamics Code (EFDC) and the Hydrodynamic Program (DYNHYD)[17].

It can simulate DO, N (organic, ammonia, nitrite, nitrate), P (organic, inorganic), phytoplankton and periphyton (bottom algae C, N. P), particulate detritus (N, P, C), CBOD(fast, intermediate, slow), temperature, salinity, coliform bacteria, silica, cohesive sediments, noncohesive sedi-ment, sediment diagenesis, conservative tracer, pesticides, organic chemicals, mercury, heavy metals, and inorganic solids [17-20, 28].

2. Better Assessment Science Integrating point and Nonpoint Sources (BASINS):

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) was developed by the U.S. Environmental Protection Agency's (EPA's) Office of Water in 1996. It is a multipurpose environmental analysis system for use by regional, state, and local agencies in performing watershed- and water-quality-based studies. The latest enhanced version BASINS 4.1 is available at US EPA's website. The BASINS system combines five components: National environmental databases, watershed characterization tools, utilities, watershed and in-stream water quality models and analysis tools and postprocessors to perform watershed and water quality analyses [21]. **Figure 4** illustrates the system components of the model.

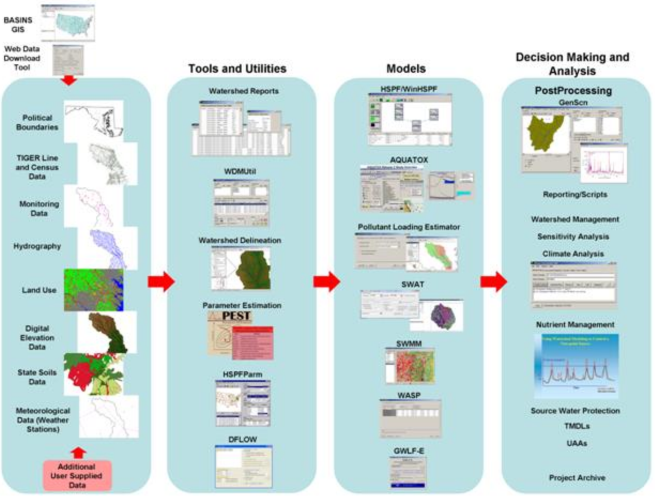

Figure 4.Graphical representation of system components of BASINS

Beginning from BASINS 4.0 the physiographic data, monitoring data, and associated assessment tools are integrated in a customized, non-proprietary and open-source GIS (MapWindow GIS). Arc GIS was used in earlier versions [21, 23].

National environmental databases: The BASINS system includes a tool, known as the BASINS Data Download tool, for downloading and extracting data from the EPA web server and several other federal agencies. The databases are compiled into compressed files according to geographic location, according to the 8-digit Hydrologic Unit Codes (HUCs) established for the United States by the USGS. The base cartographic data provides political and administrative boundaries, hydrologic features and drainage boundaries, and major road systems. Environmental background data provide spatially distributed information on soil characteristics, land uses, topography, and stream hydrography. It contains a national database of meteorological data that are essential to the successful application of BASINS assessment models. It also includes data related to direct pollutant loading from point source discharges. The estimated loadings are provided along with the location and type of facility. These data were extracted from the EPA PCS database. For each data type available for downloading, there is a unique Dynamic Link Library (DLL). This design makes the BASINS system easier and less expensive to maintain, since it eliminates having another copy of each dataset in the BASINS data holdings. In addition, updates to the data are available as soon as the agency producing the data makes the update available, making the most updated data available directly to the user [21-24].

The modeling tools available in BASINS 4.1 include the following:

Watershed Models:

WinHSPF is an interface to the Hydrological Simulation Program Fortran (HSPF), version 12.2. HSPF is a watershed scale model for estimating instream concentrations resulting from loadings from point and nonpoint sources [21-22].

SWAT is a physical based, watershed scale model that was developed to predict the impacts of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land uses and management conditions over long periods of time. SWAT2005 is the underlying model that is run from the BASINS MapWindow interface [21, 27].

SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators.

Instream / Water Quality Models:

AQUATOX is a simulation model for aquatic systems that predicts the fate of various pollutants, such as nutrients and organic chemicals, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. [21]

WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. [18, 21]

Loading models:

GWLF-E, an extension of the Generalized Watershed Loading Function (GWLF) model. GWLF-E is a 'mid-level' model that estimates monthly nutrient and sediment loads within a watershed [21].

PLOAD, a pollutant loading model. PLOAD estimates nonpoint sources of pollution on an annual average basis, for any user-specified pollutant, using either the export coefficient or simple method approach. BASINS also includes a plug-in for DFLOW 4.0 [21].

Analysis tools and postprocessors:

For postprocessing and analysis of time-series data, BASINS includes the program *GenScn* originally developed by the U.S. Geological Survey. GenScn stands for *Generation of Scenarios* and is included because of its excellent functionality for analyzing model simulation results including multiple model scenarios. One of the more recently added analysis tools in BASINS is known as the BASINS Climate Assessment Tool (CAT). BASINS model is designed around an extensible architecture that allows for the addition of new data types and new tools. This flexibility enables BASINS to continue evolving to meet the changing needs of the watershed management community [21].

3. Soil and Water Assessment Tool (SWAT):

SWAT a public-domain model, is a semi-distributed, continuous time, physically based basin scale model that operates on daily time step with up to monthly or annual output frequency [26-27]. The model was jointly developed by Jeff Arnold USDA Agricultural research service (ARS) and Texas A&M, AgriLife Research, to predict the effect of land management practices on water, sediment, agriculture and chemical yield in large complex ungauged basins having varying landuse, soil and management conditions over large period [25]. The model is available without any cost from http://www.brc.tamus.edu/swat. Models that contributed to the development of SWAT included the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model, and the Environmental Impact Policy Climate (EPIC) model, which was originally called the Erosion Productivity Impact Calculator, and is illustrated in the **Figure 5**. The current SWAT model is a direct descendant of the Simulator for Water Resources in Rural Basins (SWRRB) model. Since its creation in the early 1990s, it has undergone continued review and expansion of capabilities [26-27].

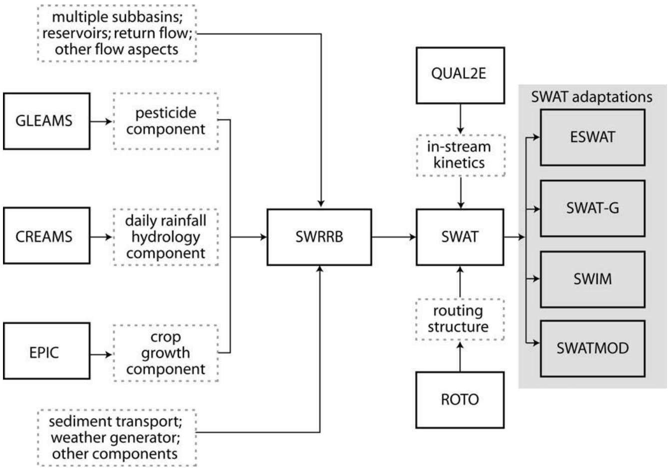

Figure 5.Schematic of SWAT developmental history, including selected SWAT adaptations

Key enhancements between the releases include: Multiple Hydrologic response units (HRUs), auto fertilization and auto irrigation were added. In-stream nutrient water quality equations from QUAL2E were added, metals, nutrient and pesticide routing expanded. Bacteria routine transport was added and in latter versions improved. Weather generator was improved and model was modified for use in Southern Hemisphere and tropical areas. Wet and dry deposition of nitrate and ammonium was improved. Modeling of on-site wastewater systems was included. SWAT has also undergone extensive validation with time. In SWAT a watershed is divided into sub basins, which are then further subdivided into Hydrologic Response Units (HRUs) on the basis of unique combinations of land use, soil and slope class. Input information required is climate, HRUs, ponds or wetlands, groundwater and the main channel or reach draining the sub basin. Climatic data can be input from measured records or generated using the weather generator (or any combination of the two). Hydrology and water quality computations are performed at the level of each HRU. They are summed to the sub basin level and routed through channels, ponds, wetlands or lakes to the watershed outlet. Hydrology in SWAT is based on water balance.

Overland flow runoff volume is computed using the Natural Resources Conservation Service (NRCS) curve number method. Curve numbers are a function of hydrologic soil group, vegetation, land use, cultivation practice and antecedent moisture conditions. SWAT accounts for sediment contributions from overland runoff through the Modified Universal Soil Loss Equation (MUSLE). In-stream kinetics and transformations of nutrients, algae, carbonaceous biological oxygen demand (CBOD) and dissolved oxygen (DO) are adapted from the Enhanced Stream Water Quality Model QUAL2E [25-28].

It does not simulate sub-daily events such and diurnal changes of DO in a water body, it is difficult to manage and modify if there are hundreds of hydrologic response units and during the spring and winter months, it has difficulties in modeling floodplain erosion and snowmelt erosion [27].

4. Agricultural Nonpoint Source (AGNPS) Model:

The AGNPS model was developed by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service (SCS). This event-based model was developed to analyze and provide estimates of runoff water quality from agricultural watersheds [29]. The development of a continuous version of the single event AGNPS watershed model [30] has been in progress, in one form or another, since the 1980s. This continuous version is Annualized Agricultural Non Point Source model (AnnAGNPS). The latest enhanced version AnnAGNPS v5.5 is available through the internet web address: **http://www.ars.usda.gov/Research/docs.htm?docid=5199** [29].

AnnAGNPS is the pollutant loading modeling module designed for risk and cost/benefit analyses. It is a batch process, continuous-simulation, surface-runoff, Pollutant Loading (PL) model in which watershed is homogeneously divided into cells to represent sheet and rill erosion, ephemeral gully erosion and the impact of conservation practices. All watershed characteristics and inputs are expressed at the cell level. The physical or chemical constituents are routed from their origin within the land area and are either deposited within the stream channel system or transported out of the watershed. Pollutant loadings (PLs) can then be identified at their source and tracked as they move through the watershed system as shown in **Figure 6.2**. **Figure 6.3** shows the input parameters for the model simulation. The basic modeling components are hydrology, sediment, nutrient, and pesticide transport. Runoff volume is estimated based on the SCS curve number method. A modified form of the Universal Soil Loss Equation (USLE) is used to estimate upland erosion. Output parameters are selected by the user [29-32].

Integration of other models with AnnAGNPS is done to simulate additional processes. These integrated models have been developed within the AGNPS suite of modules and is illustrated by **Figure 6.1**. The modules include: AnnAGNPS, Center for Computational Hydroscience and Engineering (CCHE1D) used to integrate the impact of upland loadings and channel characteristics, Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) to simulate bank and bed related processes, The Stream Network TEMPerature model (SNTEMP) to simulate water temperature, The Sediment Intrusion & Dissolved Oxygen (SIDO) a set of salmonid life-cycle models and an economic model that determines the net economic value of Pacific Northwest salmonids restored to either the commercial or recreational catch

model Databases include: TOpographic PArameteriZation program (TOPAZ) to generate cell and stream network information from a watershed Digital Elevation Model (DEM) and provide all of the topographic related information, The AGricultural watershed FLOWnet generation program (AGFLOW) is used to determine the topographic-related input parameters, The Generation of weather Elements for Multiple applications (GEM) program is used to generate the climate information, Complete Climate program is used to format data from GEM, a graphical input editor for developing database, a visual interface program to view the TOPAGNPS related GIS data and in addition to these there is a conversion program and a output processor [29].

All runoff and associated sediment, nutrient, and pesticide loads for a single daily event are routed to the watershed outlet before the next day simulation. There is no tracking of nutrients and pesticides attached to sediment deposited in stream reaches from one event to the next event. Point sources are limited to constant loading rates (water and nutrients) for entire simulation period [30-32].

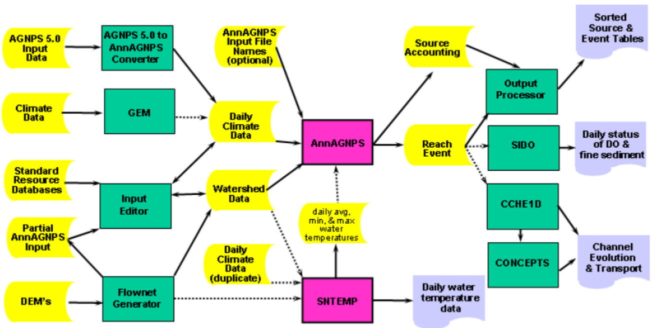

Figure 6.1. System components of AGNPS

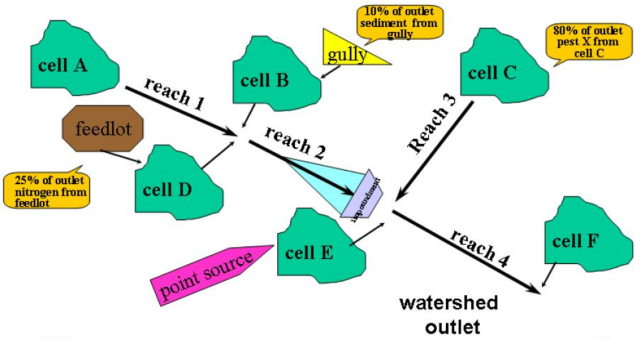

Figure 6.2. Major processes simulated by AGNPS with pollutant tracking techniques

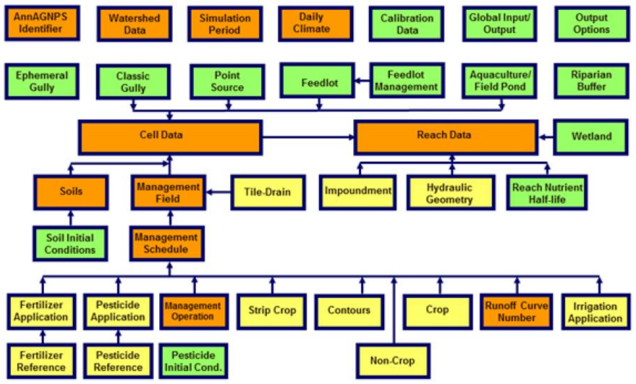

Figure 6.3. Data sections within annAGNPS (Orange color indicates data reqired)

III.CONCLUSION

Each water quality model has its own unique purpose and simulation characteristics and hence has to be reviewed thoroughly before use. All models focus on pollution discharge points in the river. In some situations the simulated results are generalized and do not lead to effective remediation measures. And hence standardization is very necessary. Large amount of data is required to run these models; this problem can be solved by integration of geographic information systems (GIS) and Remote Sensing (RS) with the models. All above mentioned models are flexible and robust. These can prove to be effective tools in maintaining natural balance with little modifications. Conferences and workshops should be held regularly throughout the world to identify and update regulatory models.

IV. REFERENCES

[1]. R. V. Thomann and J. A. Mueller, “Principles of Surface Water Quality Modeling and Control”. Harper and Row, Publishers, New York, (1987).

[2]. V. P. Singh, “Mathematical Modeling of Flow in Watersheds and Rivers,” Vol. II, Published by Water Resources Publications, (2001).

[3]. V. Novotny, et al., “Handbook of Nonpoint pollution Sourcess and Management,” published

by Van Nostrand Reinhold Company, New York, (1981).

[4]. J. L. Schnoor, "Environmental Modeling-Fate and transport of pollutants in Water, Air and Soil" published by John Wiley & Sons, Inc., New York, (1996).

[5]. S. C. Chapra, "Surface Water-Quality Modeling," published by Waveland Press, Inc., Illinois, (2008).

[6]. D. Sharma, and A. Kansal, "Assessment of river quality models: A review," Rev Environ Sci Biotechnol, 12, 285-311, (2013).

[7]. Q. Wang, S. Li, P. Jia, C. Qi, and F. Ding, "A review of surface water quality models," The Scientific World Journal, 2013, 1-7, (2013).

[8]. M. Benedini and G. Tsakiris, "Water Quality Modelling for Rivers and Streams", Water Science and Technology Library, 70, (2013).

[9]. G. Pelletier and S. Chapra, "QUAL2K: A modeling framework for simulating river and stream water quality (version 2.04). Documentation", (2005).

[10]. G. Pelletier and S. Chapra, "QUAL2Kw user manual (version 5.1)", (2008).

[11]. P. B. Kalburgi, et al., "Application of QUAL2K for water quality modeling of river Ghataprabha (India)," Journal of Environmental Science and Engineering, 4(12), 6-11, (2010).

[12]. P. R. Kannel, et al., "Application of automated QUAL2Kw for water quality modeling and management in the Bagmati River, Nepal," Ecological Modeling, 202, 503-517, (2007).

[13]. R. A. Camargo, et al., "Water quality prediction using the QUAL2Kw model in a small karstic watershed in Brazil," Acta Limnologica Brasiliensia, 22(4), 486-498, (2010).

[14]. Di Toro DM, J.J. Fitzpatrick, and R.V. Thomann, "Water Quality Analysis Simulation Program (WASP) and Model Verification Program (MVP) – Documentation". Contract No. 68-01-3872, Hydroscience Inc., Westwood, NY, for U.S. EPA, Duluth, MN, (1983).

[15]. Ambrose R.B., T.A. Wool, J.P. Connolly, and R.W. Schanz, "WASP4, A Hydrodynamic and Water Quality Model—Model Theory, User's Manual, and 31 Programmer's Guide". EPA/600/3-87-039, U.S. Environmental Protection Agency, Athens, GA, (1988).

[16]. Wool T.A., R.B. Ambrose, J.L. Martin, and E.A. Comer,"The Water Quality Analysis Simulation Program, WASP6; Part A: Model Documentation". U.S. Environmental Protection Agency, Center for Exposure Assessment Modeling, Athens, GA, (2001).

[17]. Ambrose, R. B., J. L. Martin, and T. A. Wool, "Wasp7 - Model Theory and User's Guide". U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-06/106 (NTIS PB2007-100139), (2006).

[18]. Ambrose, R. B., T. A. Wool, "Wasp8 - Model Theory and User's Guide". U.S. Environmental Protection Agency, Washington, DC, (2017).

[19]. Lai Y C, et al., "Evaluation of non-point source pollution and river water quality using a multimedia two-model system." Journal of Hydrology, 409 (3–4), 583–595, (2011).

[20]. Zhang M, Shen Y, Guo Y. "Development and application of a eutrophication water quality model for river networks." Journal of Hydrodynamics, 20(6), 719–726, (2008).

[21]. M. Wellman, et al., "BASINS user manual (version 4.1)", (2013).

[22]. Bicknell, B.R., et al., "Hydrological Simulation Program - Fortran (HSPF). User's Manual for Release 12.2. U.S. EPA National Exposure Research Laboratory", Athens, GA, in cooperation with U.S. Geological Survey, Water Resources Division, Reston, VA, (2005).

[23]. Evans, B.M., et al., "A comprehensive GIS-based modelling approach for predicting nutrient loads in watersheds". J. Spatial Hydrology 2(2), (2002).

[24]. Gala, S., G. Cothren, and A. Hannoura, "Modeling of Nonpoint Sources in the Tickfaw

River Watershed". ASABE International Conference 2006, ASABE Publication, (2006).

[25]. Arnold, J.G., et al., Large area hydrologic modeling and assessment part I: model development. J. American Water Resources Association 34(1), 73-89.

[26]. Arnold S L, Neitsch J. "Soil and water assessment tool theoretical documentation", (2009).

[27]. Arnold S L, Neitsch J. "Soil and water assessment tool theoretical documentation", (2012).

[28]. A. Ekdal, et al., "Application of WASP and SWAT models for a Mediterranean Coastal Lagoon with Limited Seawater Exchange," Journal of Coastal Research, 64(12), 1023-1027, (2011).

[29]. R. L. Bingner, et al., "AnnAGNPS Technical Processes Documentation", Version 5.5, (2018).

[30]. R. A. Young, et al., "AGNPS: A Nonpoint-Source Pollution Model for Evaluating Agricultural Watersheds," Journal of Soil and Water Conservation, 44(2), 168-173, (1989).

[31]. A. Sarangi, C. A. Cox, and C. A. Madramootoo, "Evaluation of the AnnAGNP model for prediction of runoff and sediment yields in St Lucia watersheds," Biosystems Engineering, 97, 241-256, (2007).

[32]. S. Das, et al. "Applicability of AnnAGNPS for Ontario conditions," Canadian Biosystems Engineering, 50, 1.1-1.11, 2008.

Cite this article as :