Nutrient Transport Model in CHAHNIMEH Manmade Reservoirs

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Abstract: - A Model for predicting nutrient transport to CHAHNIMEH reservoir is developed in this paper. Nitrogen and phosphorous have been simulated as the important parameters in evaluating water quality in the reservoir. Solar radiation and wind flow are considered in the model. Model uses mass balance equation to predict a one year period of changing concentrations. Results show the relative of different types of nitrogen to each other and similar behavior of phosphorous. Also results show the relative concentration of algal biomass with nitrogen and phosphorus changes in different times.
Key-Words:-Nutrient, CHAHNIMEH, Modeling, Reservoir, Transport, Water movement

1 Introduction

Today variety types of water wastes are produced in urban regions and industries. Entering this wastes to the streams and soils and groundwater cause their contamination. Beside they can transport to the reservoir of a dam by rivers. The most important constituent in this transfer are nitrogen and phosphorous. They can cause algal growth in reservoirs and reducing oxygen in lower layers and affecting reservoirs water quality.
Water quality control is an important problem in water resource management and surface and groundwater preservation. Furthermore is an important factor in this process. This costs includes water refinement, land use, agricultural works and etc. water quality control engineers consider all the environmental, ecological and economical aspects of any plan. These works needs a large volume of data and information of the investigation region. Because of these difficulties and costs, they prefer to develop water quality control models to predict constituent transport to reservoirs.

Water quality modeling

Water quality models are different. This is because of differences between reservoirs and the unique hydraulic and hydrologic properties of them. Many state and personal agencies involve water quality plans and each of them has their personal viewpoint and objectives. Thus there is not a general model for this work. In any region the model should be developed with the special characteristics of that region. A lot of researches have done in this field but most of them are based on experimental works.
M.A.Neves et al.(2007) worked on The Combined Effects of Salts and Calcium on Growth and Mineral Accumulation. Katsev

et al. (2006) studied on Factors controlling long-term phosphorus efflux from lake sediments. Komatsu et al.(2006) investigated in Modeling of P-dynamics and algal growth in a stratified reservoir—mechanisms of P-cycle in water and interaction between overlying water and sediment. Also Rukhovets et al. (2003) worked on Development of Lake Ladoga ecosystem models: modeling of the phytoplankton succession in the eutrophication process. In all of these studies the sources and sinks in the case study is differs to each other.

2 Nutrient cycles in water

Nutrient concentration gradient in lakes and reservoirs is an important factor in water quality control plans. Solar radiation penetrates in water and absorb with suspended particles. These particles create layers with different densities in the depth of the reservoir. Surface water in upper layer absorbs most of this radiation and is warmer. If there is not any velocity gradient in reservoir, less heat transfer occurs between layers. Wind is the second parameter that affects on transfer of heat and oxidation in the reservoirs. Therefore there are changes in nutrient concentration in reservoir in each time.

2.1 Nitrogen

Nitrogen is important in the formulation of plant and Nitrogen animal protein, Nitrogen similar to carbon, also has a gaseous form. Many species of blue-green algae can use or fix elemental or gaseous N2 as a nitrogen source. The most common forms of nitrogen in aquatic systems are ammonia (NH3-N), nitrite (N02-N), and nitrate (N03-N). All three forms are transported in water in a dissolved phase.
Ammonia results primarily from the decomposition of organic matter. Nitrite is primarily an intermediate compound in the oxidation or nitrification of ammonia to nitrate, while nitrate is the stable oxidation state of nitrogen and represents the other primary inorganic nitrogen form besides NH3 used by aquatic plants.

2.2 Phosphorus

Phosphorus is used by both plants and animals to form enzymes and vitamins and to store energy in organic matter. Phosphorus has received considerable attention as the nutrient controlling algal production and densities and associated water quality problems. The reasons for this emphasis are: phosphorus tends to lf. Limit plant growth more than the other major nutrients (see Table 1); phosphorus does not have a gaseous phase and ultimately originates from the weathering of rocks; removal of phosphorus from point sources can reduce the growth of aquatic plants; and the technology for removing phosphorus is more advanced and less expensive than nitrogen removal.
Phosphorus is a very reactive element; it reacts with many things such as iron and calcium and is readily sorbed on particulate matter such as clays, carbonates, and inorganic colloids. Since phosphorus exists in a particulate phase, sedimentation represents a continuous loss from the water column to the sediment.

Table1: Nutrient Demand: Supply ratios during nonproductive and productive seasons

	Demand: Supply (range)	
Element	Late Winter	Midsummer
Phosphorus	80000	800000
Nitrogen	30000	300000
Carbon	5000	6000
Iron, silicon	Generally low, but variable	
other elements	Less than 1,000	

3 Reservoir Characteristics and Process

Reservoir water quality is a response to the reservoir watershed, the regions climate, as well as geometry and internal characteristics and processes of the reservoir. Water quality is affected by the facilities. Macro and micro meteorological forces, inflows, internal processes, outflows and project operation are highly dynamic and can be dominant factors in determining the water quality in the reservoir. To understand why certain water quality conditions develop, one must understand the interaction of all dynamic phenomena influencing the reservoir and its associated waters.

3-1 Physical Characteristics and Processes

Morphometric variables that can influence hydrologic and limnologic characteristics of the reservoir include surface area, volume, mean depth, maximum depth, shoreline development ratio and fetch. Biological productivity, respiration, decomposition, and other processes influencing water quality are related directly or indirectly to reservoir morphometry. Morphometric characteristics themselves also are interrelated and provide insight in to existing or potential water quality conditions. Mean depth for example is completed as volume/surface area; shallow depth may indicate light penetration to the bottom, warmer water temperatures, higher organic decomposition rates and grater nutrient regeneration.

3-2 Longitudinal Gradients

Reservoirs can exhibit pronounced longitudinal and vertical physical, chemical and biological gradients. Long dendritic reservoirs with tributary inflows located a considerable distance from the outflow and unidirectional flow from headwater to dam, develop gradients in space and time. Although these gradients are continuous from headwater to dam, three characteristic zone result: a riverine zone, a zone of transition and a lacustrine zone.

3-3 Vertical Gradients

Attaining reservoir water quality objectives can be significantly affected by vertical stratification in the reservoir. This stratification typically occurs through the interaction of wind and solar isolation at the reservoir surface and creates density gradients that can influence reservoir water quality (Figure 1)

Stratification also can result from density inflows or high total dissolved solids (TDS) or suspended solids (SS) concentrations. Because of density stratification and its sensitivity to meteorological conditions and tributary inflows, proper hydraulic outlet design is imperative to ensure that reservoir and release water quality objectives can be met. Reservoir hydraulic outlet designs include the capability for bottom, surface and multilevel withdrawal.

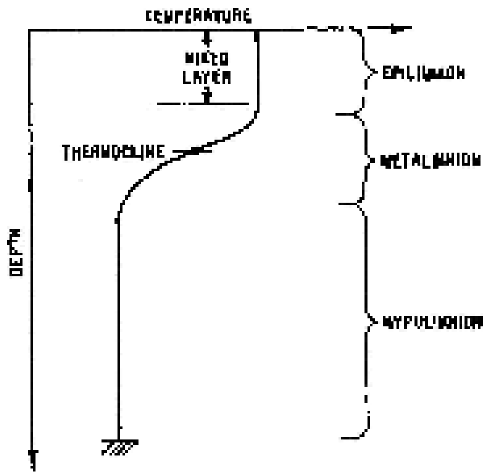

Figure 1: Vertical zonation resulting from thermal stratification

3-4 Other Stratifications

Density stratification due to a temperature gradient is the most common type of stratification, but other factors may also produce density differences that result in reservoir stratification. If density differences prevent mixing with the overlying water, the resulting condition is called a meromictic or incompletely mixed system. In meromictic reservoirs, the bottom waters are isolated by a monimolimnion, which is similar to the metalimnion. Density differences may be due to physical, chemical or biological factors.

4 Biological characteristics

Decomposition of organic matter in sediments or sedimenting organic matter can increase a salinity concentration which increases the density of the water and prevents mixing.

The microorganism associated with reservoirs may be categorized as pathogenic or nonpathogenic.

Pathogenic microorganisms including viruses are of concern from a human health standpoint in that they may limit recreational use.

Algae is influence Do and suspended solids concentrations, transparency, taste and odor, aesthetics and other factors that affect many reservoir uses and water quality objectives.

Total organic carbon (TOC) is composed of dissolved organic carbon (DOC) and particulate organic carbon (POC). Detritus represents that portion of POC that is nonliving. Nearly all the TOC of natural waters consist of DOC and detritus or dead POC. TOC is important in reservoirs for three reasons: decomposition, consumption and impact on fish. (Figure 2)

5 Water quality evaluations

Mass and energy balance equations are used to verify water quality evaluation equations. This balance considers growth, respiration, prey and … as sources and sinks. For a control element of discrete thickness Δz is:

$$\frac{\partial (V_j C_j)}{\partial t} = -Q_j C_j + Q_{j+1} C_{j+1} + \left(E_a \frac{\partial C}{\partial z}\right)_j - \left(E_a \frac{\partial C}{\partial z}\right)_{j+1} + C_j \frac{\partial V_j}{\partial t} \pm V_j \frac{dC}{dt} \qquad (1)$$

Where:

C_j : Concentration of any quality constituent that moves with the fluid

V_j: Volume of j th control element (L^3)

Q_j : Vertical flow rate ($L^3 T^{-1}$)

z : Depth (L)

E_a: Diffusion coefficient

Such equation is used for each parameter. Every parameter has its own sources and sinks.

For example dissolved oxygen move with water flow and produce with wind on surface water and photosynthesis and consume with chemical and biochemical oxidation and aquatic inspiration. For $j-1$ th, j th and $j+1$ th the mass balance equation for the constituents (Figure 3), and are:

$$\dot{C}_{j-1} = \alpha_{j-1,1} C_{j-2} - \alpha_{j-1,2} C_{j-1} + \alpha_{j-1,3} C_j + \beta_{j-1} \qquad (2)$$

$$\dot{C}_j = \alpha_{j,1} C_{j-1} - \alpha_{j,2} C_j + \alpha_{j,3} C_{j+1} + \beta_j \qquad (3)$$

$$\dot{C}_{j+1} = \alpha_{j+1,1} C_j - \alpha_{j+1,2} C_{j+1} + \alpha_{j+2,3} C_{j+2} + \beta_{j+1} \qquad (4)$$

Which when written in matrix form results in:

$$[I]\{\dot{C}\} = [A]\{C\} + \{R\} \quad (5)$$

Where
$[I]$: is an identity matrix
$[A]$: is a tridiagonal matrix of the coefficient
$[R]$: is a vector of all unknown parameters and external sources of C

Now this equation can solve using a numerical method.

6 Results

CHAHNIMEH reservoir near ZABOL city in southeast of IRAN has chosen for case study. The capacity of manmade reservoir is 340 MCM and its area is 47 Km^2 . Ammonia concentration in initial period of modeling is considered 0.366 mg/lit and nitrate concentration equal to 4.4 mg/lit .PH measurements in a daily experiment shows variations between 6 to 9 and average water temperature as 30^{oc} .This reservoir discharges with HIRMAND river coming through AFGHANISTAN (Figure 4). Because seasonal changes, in two months there is not any discharges. Agricultural and domestic demands of water have been considered in model formulation.

Results show that concentration of any parameter reduces when the discharge of river reduces. Ammonia can increase after two months but nitrate and nitrite have decreasing gradient. This shows nitrogen cycle in reservoir and changes of different types to each other (Figure 5, 6). Phosphorous concentration has a similar behavior. Because of agricultural activities near HIRMAND river the phosphorous concentration is 0.31 mg/lit in first month and is decreased frequently (Figure 7). In zero discharge months algae totally omitted from reservoir. Perhaps nitrogen decreasing in those periods is limitation nutrient for algal biomass. (Figure 8)

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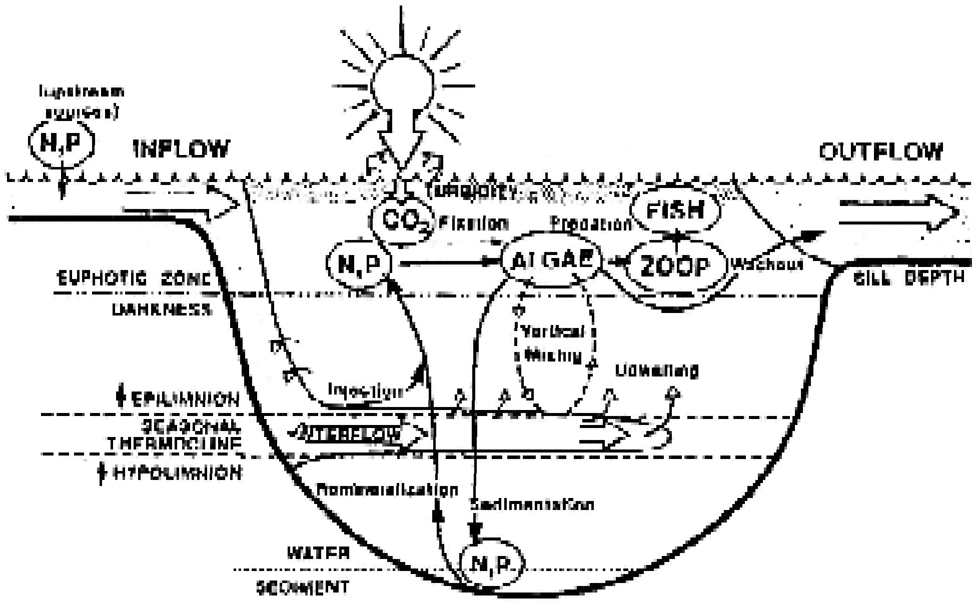

Figure 2: Generalized reservoir ecosystem

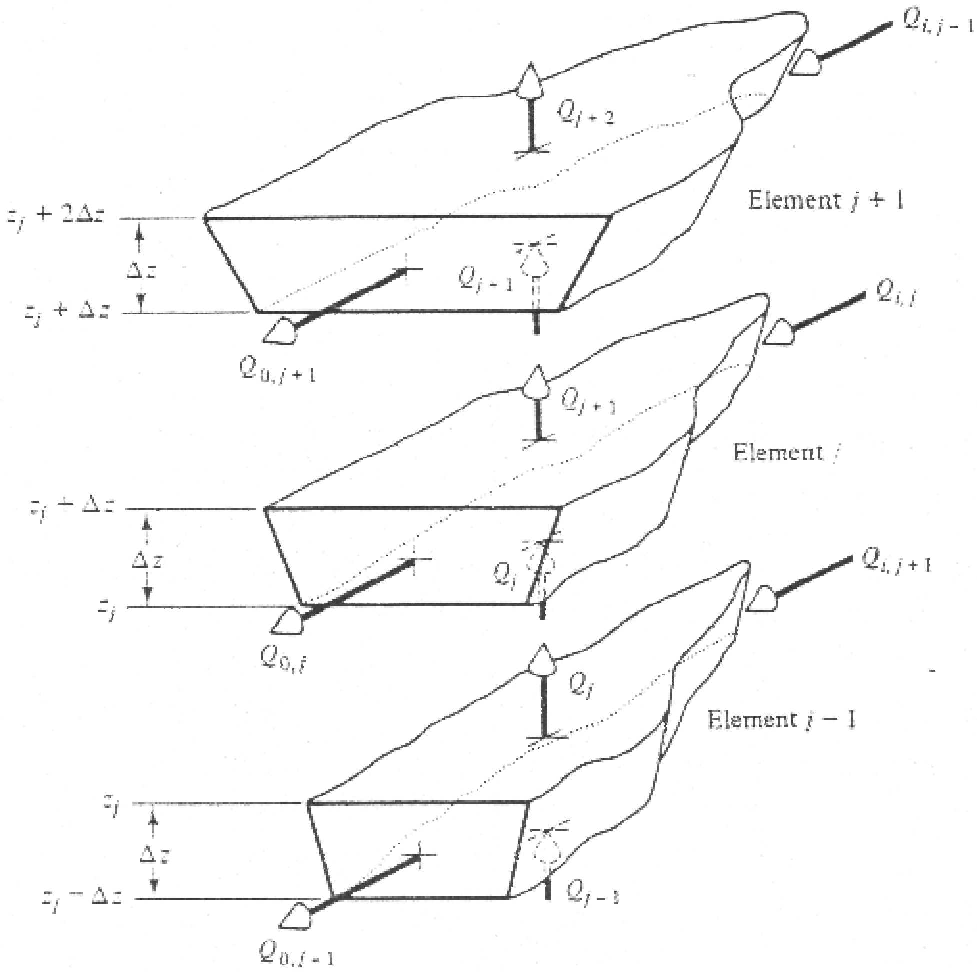

Figure 3: Water movement along three adjacent reservoir elements

Figure 4: CHAHNIMEH reservoirs position (southeast of IRAN)

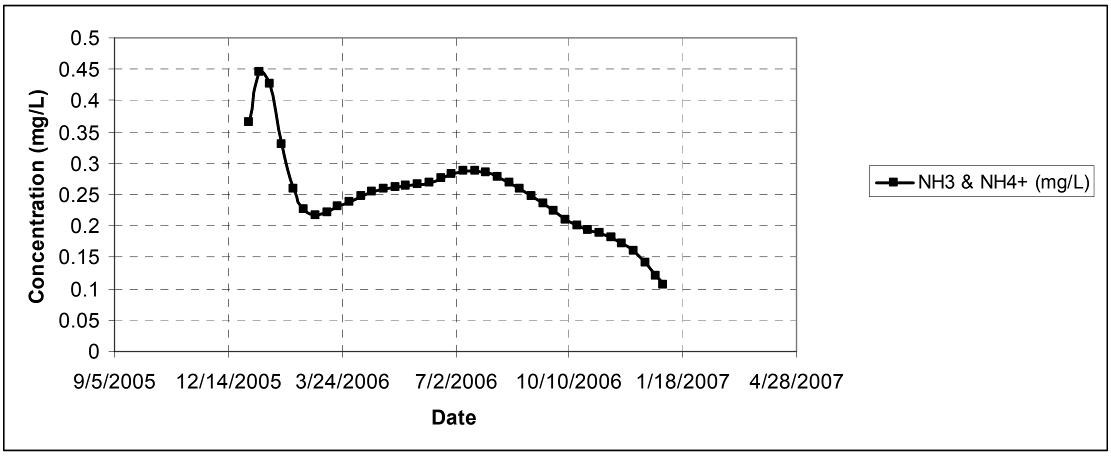

Figure 5: Concentration changes of Ammonia in the reservoir

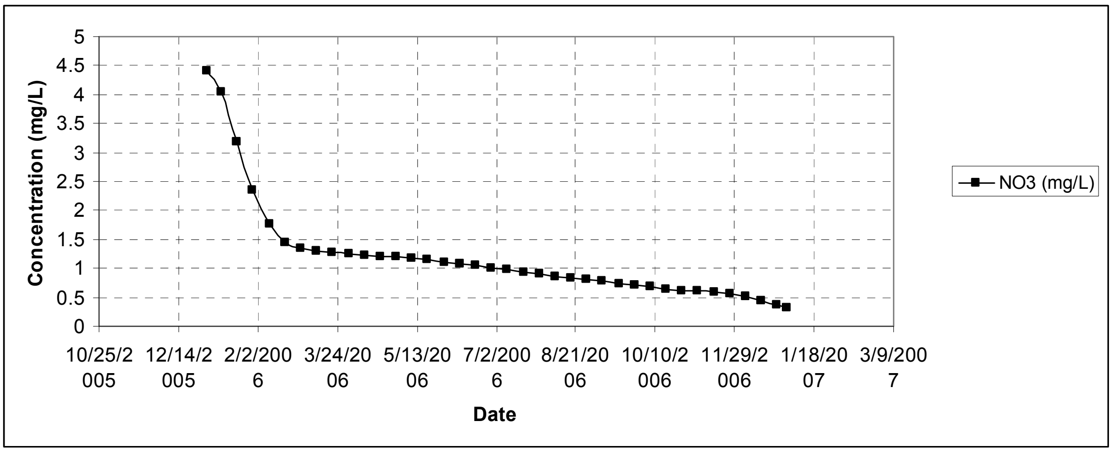

Figure 6: Concentration changes of Nitrite in the reservoir

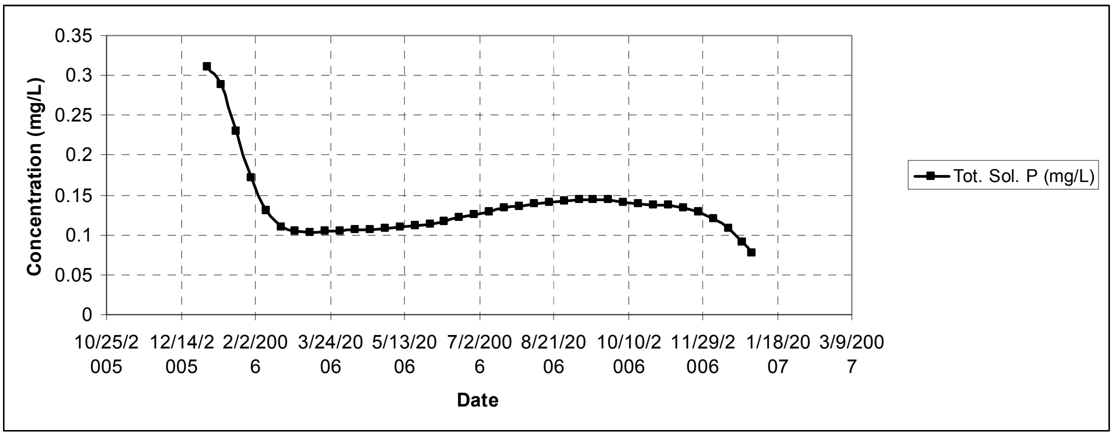

Figure 7: Concentration changes of Phosphorous in the reservoir

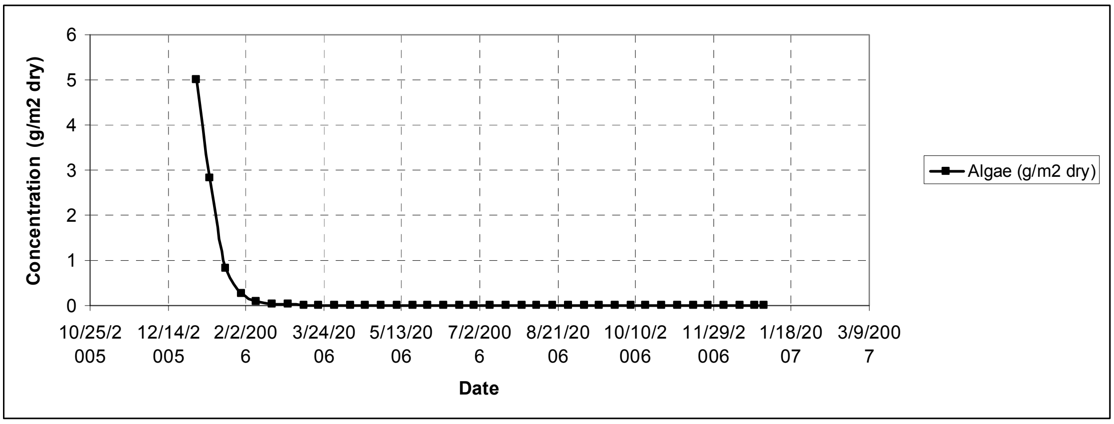

Figure 8: Concentration changes of Algae in the reservoir