MANAGEMENT OF AGRICULTURAL POLLUTION FROM RUNOFF: THE CASE OF LAKE VISTONIS

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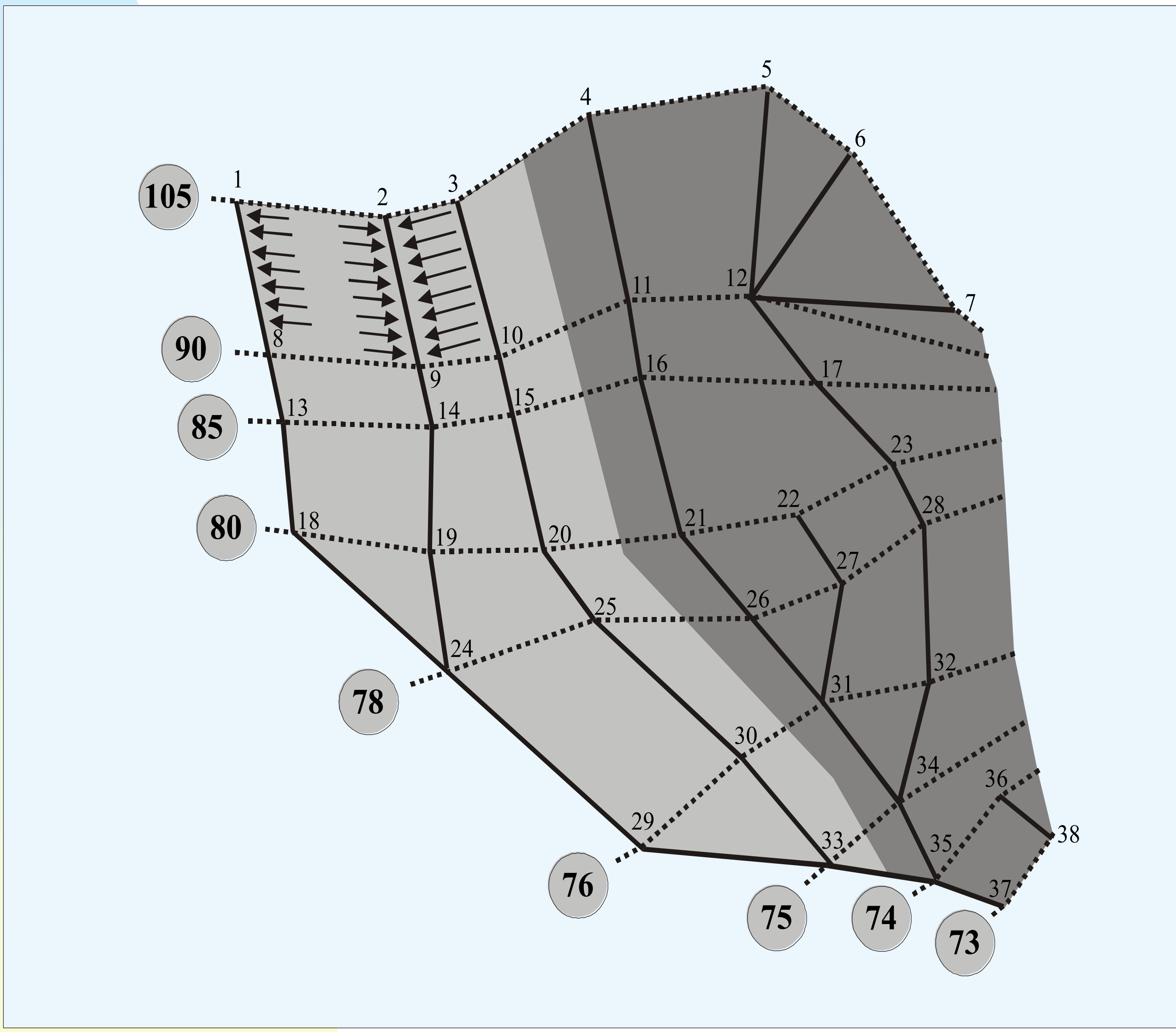
Basic objective of this work

- **is to present a simulation model for the precipitation – runoff process on agricultural areas and the transport of pollutants from their source to the outlet of the watershed**

Description of the hydrological model

- **It accepts as input the real morphology (map) of the hydrological basin using a digitizer interfaced to a computer**
- **The program divides automatically the hydrological basin into very small finite elements (small subbasins)**

Description of the hydrological model



Stream network

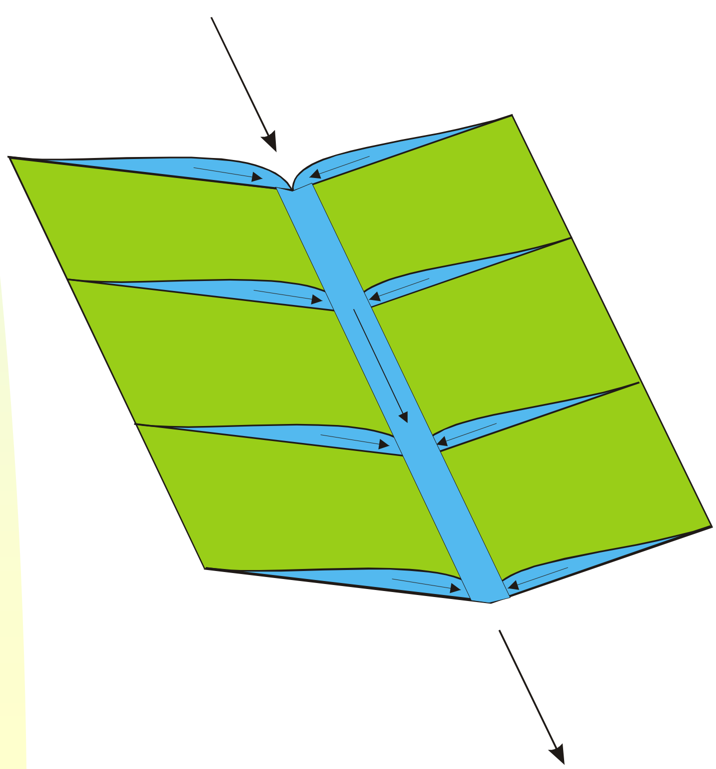
Contours

Overland flow

Contour’s level

Description of the hydrological model

The model substitutes each finite element with a V-shaped overland flow element of equivalent area, which consists of two equal orthogonal planes connected at one side of length L



Description of the hydrological model

- **The water initially travels over these surfaces as sheet flow. This (overland) flow is collecting by the corresponding collector channel. The collector channel has as lateral inflow the overland flow from the two orthogonal planes, uniformly distributed along the length L**
- **The model automatically generates and draws a dendritic channel system. So each channel carries both inflows from upstream channel as well as lateral flows supplied by the corresponding overland flow element.**
- **The model calculates a runoff hydrograph at any point of the hydrological basin**

The kinematic wave approximation has been chosen in our model to simulate both the thin sheet – flow (overland flow), which occurs on the overland flow elements and the stream flows too.

Continuity

$$\frac{\partial y}{\partial t} + \frac{\partial Q}{\partial x} = q_L + (i - f)$$

Momentum

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial y}{\partial x} = g(S_o - S_f) - q_L\frac{(u - v)}{y}$$

where

x = distance measured in downstream flow direction

y = mean depth

t = time

Q = discharge per unit width of channel

q_L = total lateral inflow per unit length of channel

i = rainfall intensity

f = infiltration rate

u = x-component of mean velocity

g = acceleration of gravity

S_o = average bottom slope

S_f = friction slope defined by the Manning equation

v = y-component of velocity for lateral inflow

- The basic assumptions made in the development of the basic differential equations of one-dimensional unsteady flow are:
  - the slope of the plane is small (less than 1:10)
  - streamlines are essentially straight,
  - the pressure distribution is approximately hydrostatic
  - resistance to flow may be described by empirical resistance equations such as the Manning equation
  - momentum carried to the fluid from lateral inflow is negligible

- **An order of magnitude analysis shows that inertia and pressure terms are not important in the momentum equation which is then reduced to the well known relation for steady, uniform flow in a "channel":**

  $S_0 = S_f$

  i.e. the bed slope is approximately equal to the friction slope. We calculate the volume flux Q at any point in the "channel" from Manning's formula

$$Q = \frac{1}{n} S_0^{1/2} R_h^{\,2/3} A = aA^{\,m}$$

- **Similarly the kinematic wave equations for channel flow routing are:**

$$\frac{\partial A_c}{\partial t} + \frac{\partial Q_c}{\partial x} = q_0$$

$$Q_c = a_c A_c^{\,m_c}$$

- **We use finite difference method for approximating the governing partial differential equations with simple difference equations for an array of stationary grid points located in the space - time (x-t) plane.**

Description of the agricultural pollution model

- **Rainfall and the associated runoff loosen, suspend and then transport the pollutants over the land surface to receiving water bodies**

- **In this research we describe the quality of storm runoff as a function of time, i.e. we predict the flow rate of a pollutant as a function of time.**

- **Phosphorous and persistent organochlorine insecticides are adsorbed on soil particles and have low solubility. They become pollutants in water because soil particles on which they are attached become suspended in water and are transported off the land by runoff into streams, ponds, and lakes or sea. Haith et al [11] suggested that since solid phase chemicals move with sediment, transport factors for sediment yield or sediment "delivery ratios" can be used directly. The sediment delivery ratio SDR, which is equal to the fraction of eroded soil that leaves the watershed in stream flow, is given by** $SDR = 0.47\ A^{-0.125}$

Description of the agricultural pollution model

- **The method of predicting sheet and rill erosion and the storm-event sediment yield from subbasins (without man made erosion control practice) is predicted by the equation (Williams [12]).**

- **SER = 11.8 (V Qp) $^{0.56}$ (K) (C) (LS) (SDR)**

- **where**
- **SER = sediment yield from the subbasin from an individual storm in tones**
- **V = storm runoff volume in m^3**
- **Qp = the peak runoff rate in m^3 /s**
- **K = soil erodibility factor based on soil properties (0.10)**
- **SDR= Sediment Delivery Ratio**
- **LS = slope length and gradient factor**
- **C = the crop management factor, reflecting the character and extent of ground cover (grass, brush, threes, etc.), (0.30)**

- **The topographic factor LS computed by the equation:**
- **LS = L $^{0.5}$ (0.00761+0.0053 S +0.00076 S^2)**
- **where L the length of the slope in m and S the grade of the slope expressed in percent.**

Description of the agricultural pollution model

- Suggested values for the crop management factor C for various types of ground cover are:
  - 1.0 for bare ground,
  - 0.01 for grass cover,
  - 0.6 for seed and fertilizer,
  - 0.3 for seed, fertilizer and straw mulch.

- The soil erodibility factor K depends on the soil properties and typically varies between 0 (no erosion) and 1 and can be determined experimentally. Typical values:
  - for a forest 0.3-0.4
  - for a park 0.2
  - for a commercial area 0.5
  - for agricultural area 0.1-0.3.

Description of the agricultural pollution model

- **Nutrient concentrations in sediment typically exceed those of the in situ soil, since the erosion and sediment transport processes selectively favor the small organic matter and clay particles which contain much of the soil's nutrients.**

- **In situ soil nutrient concentrations are multiplied by an enrichment ratio to estimate concentrations in the sediment. The enrichment ratios for N and P typically vary from one to four and are essentially unpredictable. Since most of the reported values are at the lower end, it is usually assumed that the concentration of N and P in sediment reaching a stream is approximately twice the concentration of the in situ soil.**

- **Since soil samples were not collected in the watershed, solid-phase nutrient concentrations in eroded soil were assumed as 3 g/kg and 1.2 g/kg for N and P respectively.**

Description of the agricultural pollution model

- **Concentrations of dissolved nutrients in runoff are related to the total nutrient content of the soil, fertilizer inputs, and the timing of runoff events.**

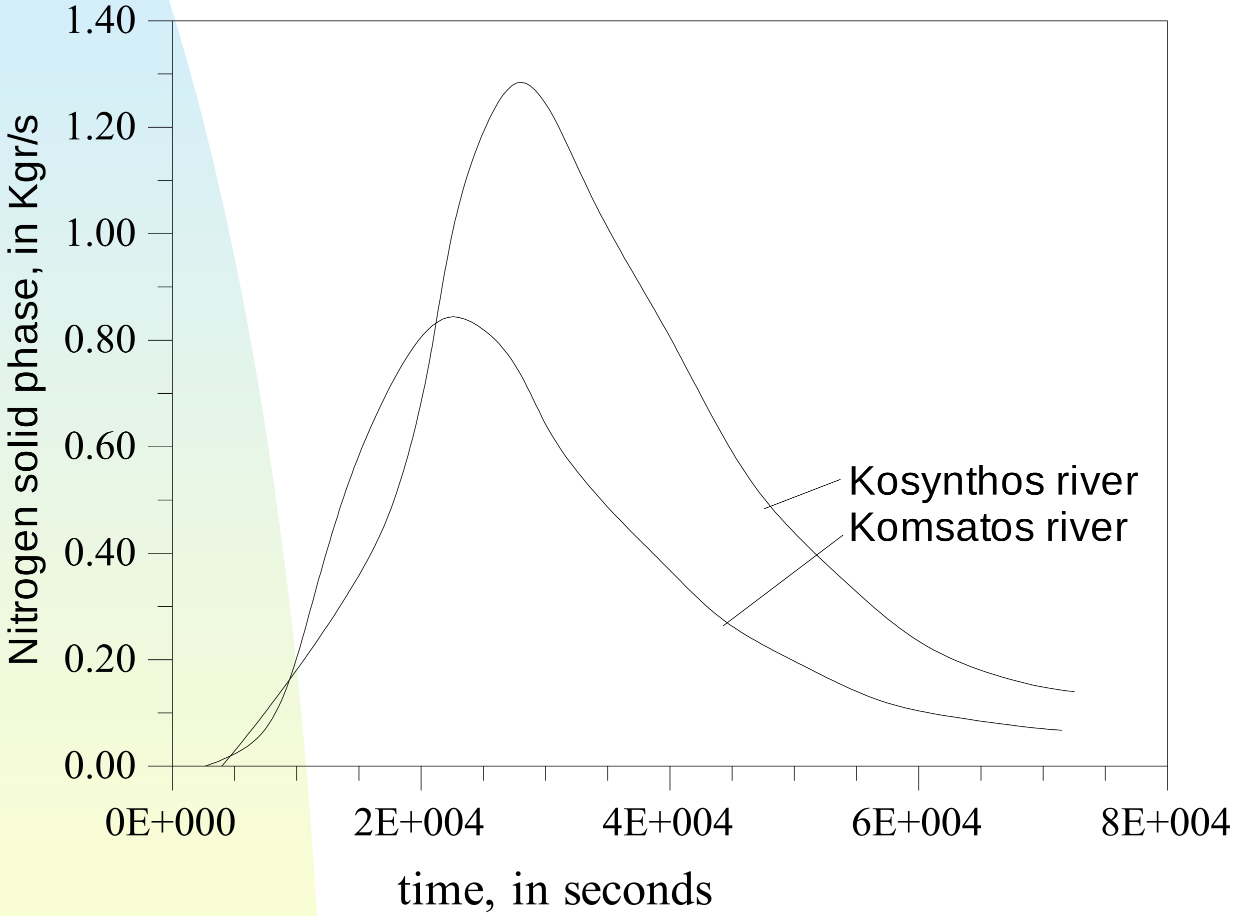
- **Provided that farmers fertilize at recommended or normal rates, it is reasonable to assume that available nutrients and thus dissolved nutrient concentrations in runoff similar are primarily functions of land use and of season, and that therefore estimates from experimental field runoff studies can be extrapolated Becher et al [13] results indicate that dissolved Nitrogen and phosphorous varies between 0.46 mg/l (October) to 11 mg/l (june) and 0.1 mg/l (November) to 0.38 mg/l (March) respectively. We used the values 2 mg/l and 0.25 mg/l for N and P respectively.**

Model application at Vistonis’s lake watershed

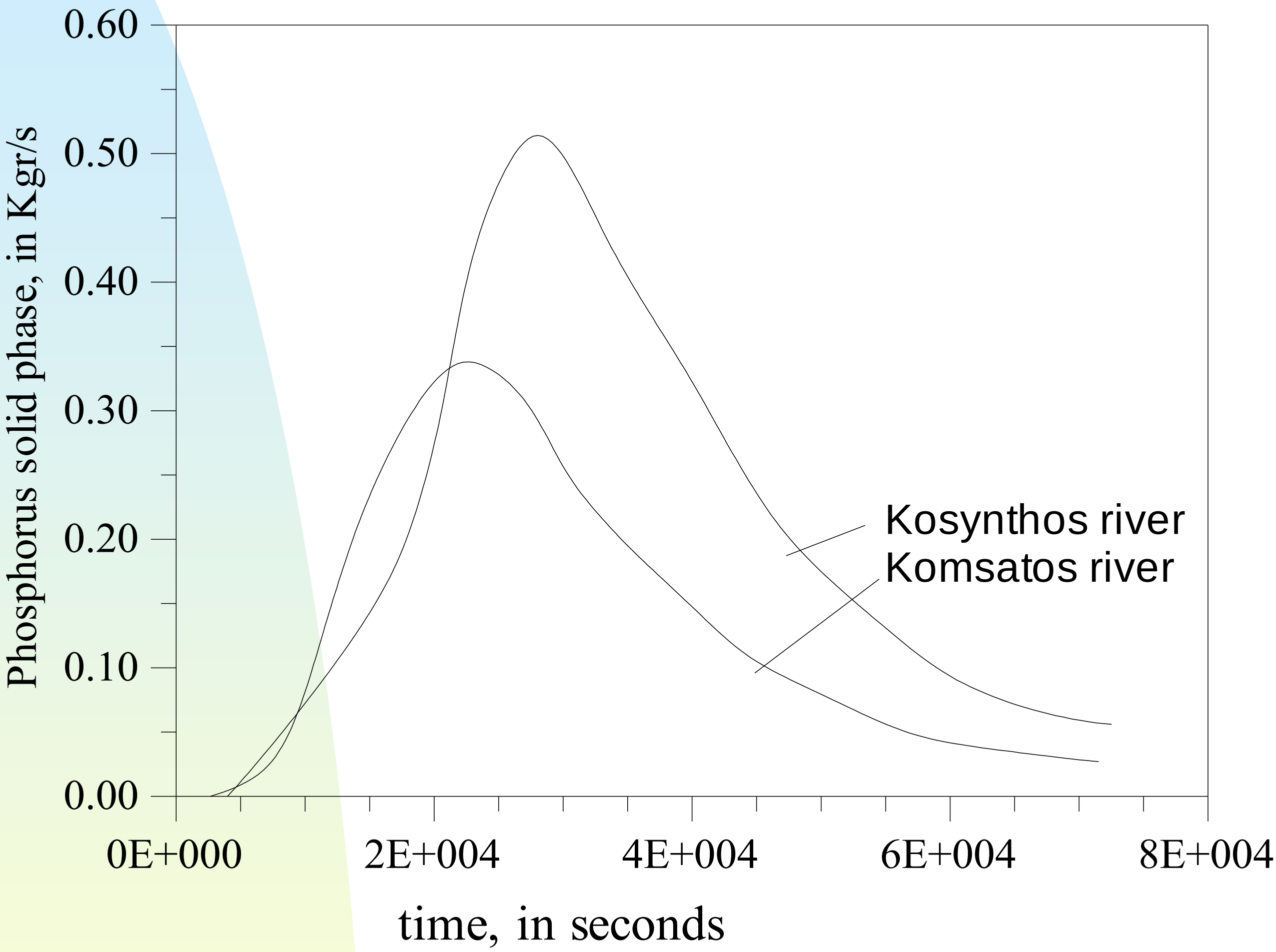
- **The hydrological basin of rivers Kosynthos and Komsatos in Northern Greece is modeled using this model.**
- **The basin is mainly an agricultural and forest and partially urban.**
- **Both rivers flow into the lake or lagoon Vistonis, which is connected to the Porto Lago bay in the Aegean Sea through a narrow outlet (40 m wide, 5.0 m deep).**
- **Vistonis lagoon has a surface of 45 km^2, a mean depth of 3.0 m and a catchment area of 1300 km^2.**
- **Both rivers carry into the lake fertilizer and pesticides residues of the intensively cultivated land surrounding the lake (400 km^2).**
- **Although the Vistonis estuary is very shallow, there is problem with the dissolved oxygen during the summer at the lower layers (below 2 m, associated with eutrophication).**

Model application at Vistonis's lake watershed

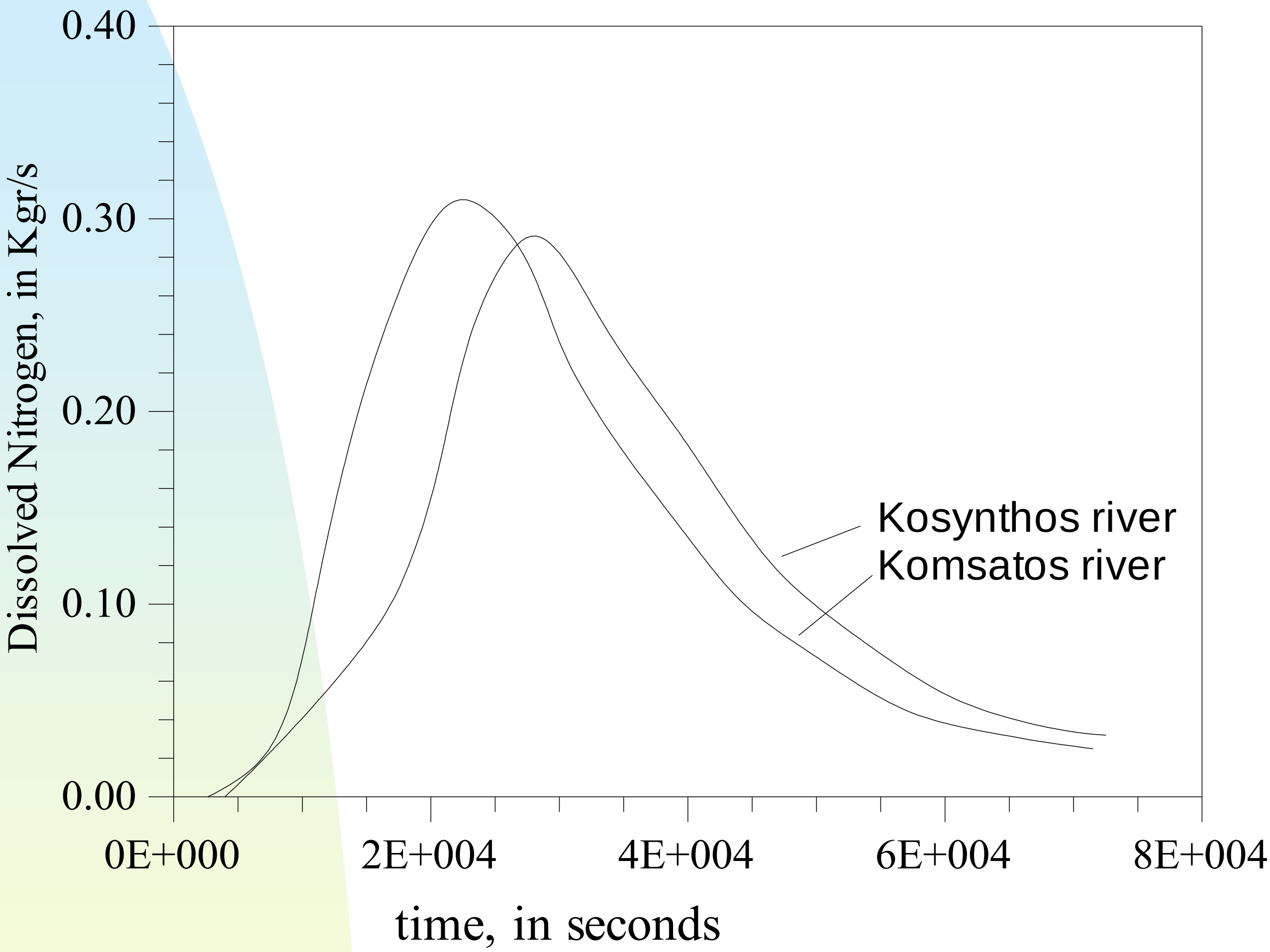
The model computes the hydrographs and the removal of pollutants causing by the overland flow, i.e. the flow rate of pollutants as a function of time at any place of the hydrologic basin, for individual (single) historical (or synthetic) events.



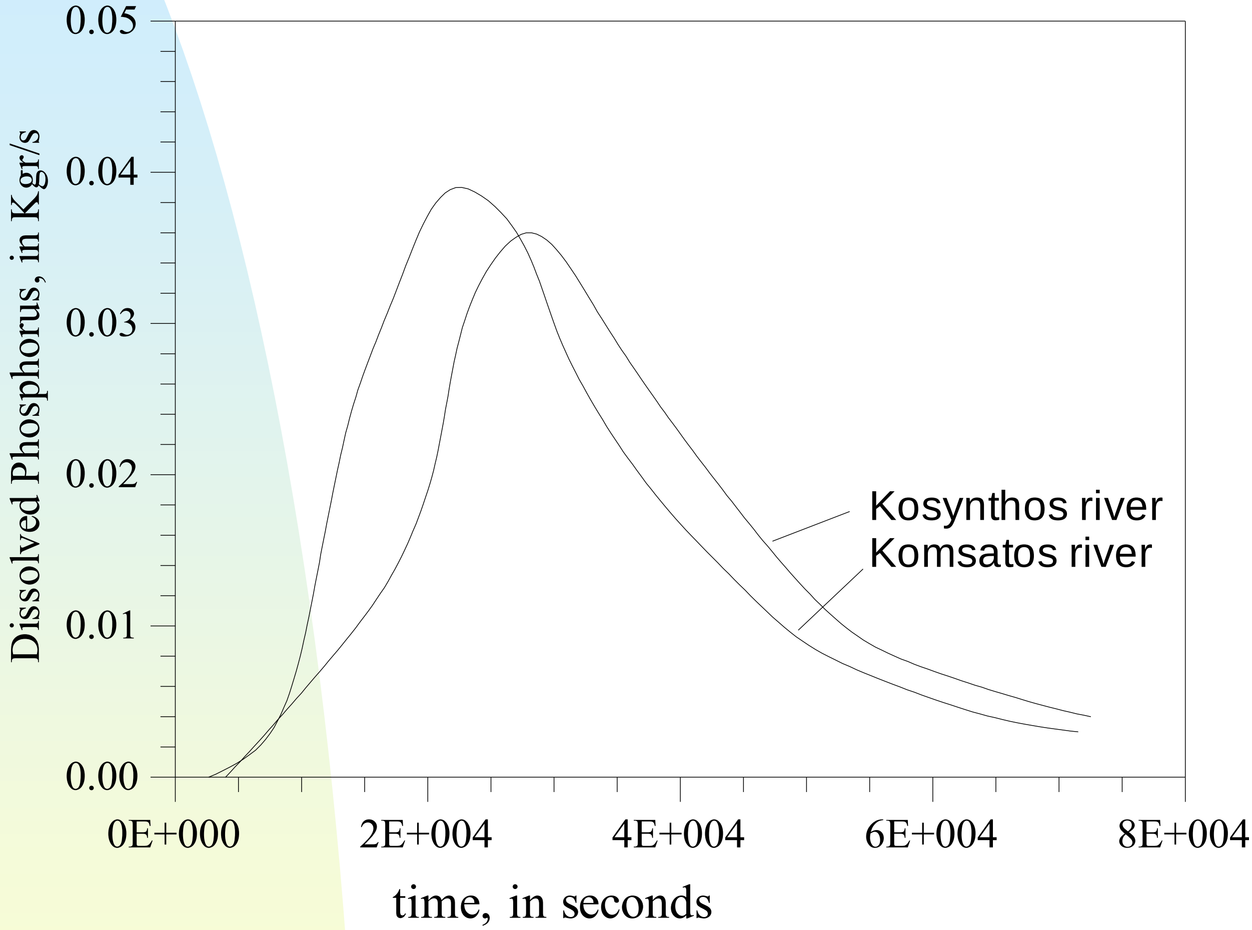
Model application at Vistonis's lake watershed



Model application at Vistonis's lake watershed



Model application at Vistonis's lake watershed



Model application at Vistonis's lake watershed

- **The used rainfall has a total duration of 2 hours, a mean intensity of 2.2 cm/hr and a frequency once per two years.**
- **The total dissolved nitrogen and phosphorus, which entered into the lake, was calculated 17 tones and 2.1 tones respectively. Dividing the above values with the total area of the lake we have a nitrogen level of 0.38 g m^{-2} and a phosphorus level of 0.048 g m^{-2} for a single rain.**
- **These values are significantly high. According to Vollenweider [15] permissible loading levels for total nitrogen and total phosphorus (biochemically active) are 1.0 g m^{-2} yr^{-1} and 0.07 g m^{-2} yr^{-1} respectively for a mean lake depth of 5.0 m.**
- **The dangerous loading level for total nitrogen and total phosphorus are 2.0 g m^{-2} yr^{-1} and 0.13 g m^{-2} yr^{-1} respectively.**
- **So only three similar rainfalls can accumulate total phosphorus loading greater than the dangerous loading level and only five rainfalls can accumulate total nitrogen loading greater than the dangerous.**

Model application at Vistonis’s lake watershed

- **The nutrient income on water body of lake Vistonis will cause eutrophication with the following effects:**
  - **species diversity decreases and the dominant biota change**
  - **plant and animal biomass increases**
  - **turbidity increases**
  - **rate of sedimentation increases shortening the life-span of the lake**
  - **anoxic conditions may develop.**

- **To minimize the eutrophication and the associated problems, the fertilizer of the intensively cultivated land surrounding the lake must be controlled.**

- **We propose the use of fertilizer in liquid form with application via fertigation in the sprinkler systems. Preplant application of nitrogen and careful water management (leaving capacity in the soil profile to hold some heavy rains) may get just as efficient nitrogen use.**

Conclusions

- **The mathematical – numerical model presented in this paper simulates the precipitation – runoff process and computes loads and concentrations of water quality.**
- **The advantages of the model are:**
  - **it accepts as input the real morphology of the agricultural watershed with a simple, quick and accurate way, using a digitizer interfaced to a computer,**
  - **it divides automatically the hydrological basin into small subbasins and generates automatically the dendritic channel system.**
- **Application of the model at Vistonis lake watershed shows high nitrogen and phosphorus loading levels.**
- **To avoid eutrophication we propose careful fertilizer application via fertigation in the sprinkler systems.**