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Water Quality Management by Means of Assimilative Capacity Considering Allowable Concentration and Affected Distance

S.A Hashemi Monfared [1*], M Dehghani Darmian [2], Bahareh Pirzadeh[3], Mehdi Azhdary Moghaddam[4]

1,3- Assistant Professor, Dept. of Civil Engineering, Faculty of Shahid Nikbakht Engineering, Univ. of Sistan and Baluchestan, Zahedan, Iran
2- M.Sc. Student, Dept. of Civil Engineering, Faculty of Shahid Nikbakht Engineering, Univ. of Sistan and Baluchestan, Zahedan, Iran
4- Associate Professor, Dept. of Civil Engineering, Faculty of Engineering, University of Sistan and Baluchestan, Zahedan, Iran

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ABSTRACT

Industrial and urban development, Population growth and settlement are common cause of increased pollution. Pollutants are in many instances discharged untreated to rivers due to lack of adequate treatment facilities and high treatment cost. This paper considers assimilative capacity as an important water quality index when the river point source pollution is controllable. The simulation of pollution transport in the river and calculation of assimilation capacity is based on the mathematical equations of pollution propagation with no turbulent flow. The proposed procedure for water quality protection is applied in a hypothetical case study and the obtained results are expressed. The results demonstrate that the river flow variation can modify the assimilation capacity up to 97%.

1. Introduction

Surface water and rivers are the most important human water resources. Unfortunately, sudden pollution entrance reduces the water quality of these resources and sometimes lead to huge damage to the environment. In these conditions, the high costs of water treatment needs to reach the minimum acceptable quality parameters of drinking water and other demands. Assimilation capacity is one of the cost-effective ways for controllable pollution treatment. Use of the assimilative capacity concept as an environmental threshold in various environmental management processes and techniques was generally founded on the concept of S theoretical message, providing an essential framework for the subsequent design of appropriate environmental standards and land- use regulations (Glasoe et al. 1990).

(Landner et al. 1994 and Tana et al. 1994) investigated that Mills using chlorine dioxide in their bleaching sequence are capable of producing effluents which, after realistic dilution in the receiving water, cause only very slight or no detrimental effects in the aquatic ecosystem. The main reason for this low impact probably is the efficient process control in modern mills, avoiding excessive dosage of chemicals, unstable production conditions and accidental spills (Landner. 1994). JoardarSouro (1998) developed an array of indicator measures through which the natural and man-made resources and assimilative capacities of urban areas with respect to water supply, sewerage, drainage and solid waste disposal can be assessed in quantitative and qualitative terms. (Smedt et al. 2005) investigated the solution enables to estimate the temporal and spatial evolution of the tracer

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[*] *Corresponding author's email: Hashemi@eng.usb.ac.ir*

concentration downstream of the injection point. The procedure was successfully applied to the Chilla´n River, Chile, where five tracer experiments were conducted. The observed concentration profiles vs. time at the different measuring locations are well reproduced by the model.

Some work was focused on finding the most convenient description of transport and transformation of dissolved and suspended substances by the advection –dispersion formulas, being one-dimensional description of sewage flow and various treatment of longitudinal dispersion coefficient was presented (Łagod et al. 2009). Chen et al. (2012) identified monitoring networks and water quality information as essential factors in the tolerable management of water resources and pollution control. Their monitoring and management method had been applied to optimize the water quality monitoring network on the Heilongjiang River in northeast China. De Andrade et al. (2013) proposed a river-pollution protection model using the simulated annealing (SA) algorithm and the enhanced stream water quality simulation model (QUAL2E). This approach was applied to determine the required oxygen concentration for biochemical activities in the Santa Maria da Vitoria River watershed of Brazil. The allocation of drinking and agricultural water of the Karaj dam in Iran was accomplished by using the CE-QUAL-W2 simulation model. An analytical solution of a model of contaminant transport in the advective zone of rivers was presented and evaluated (Schmalle and Rehmann. 2014).

This paper presents assimilative capacity as a practical remedial action to manage the quality of river water. To calculate the maximum assimilative capacity due to the different downstream water demands in different seasons of the year, water release from upstream reservoir to meet the water demands are assumed different. The purpose of this kind of simulation is that for any water release from the reservoir, the maximum assimilative capacity is determined.

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2. Materials and Methods

2.1. Simulation of Pollutant Transport in River

The mathematical equations of pollution propagation in a river with no turbulent flow and a specified velocity present the foundation for simulation methods of riverine transport. Eq. (1) indicates one -dimension differential advection-dispersion equation of pollution transport. (Van Genuchten and Alves 1982)

$$\frac{\partial c}{\partial t} = -u\frac{\partial c}{\partial x} + D\frac{\partial^2 c}{\partial x^2} - kc \qquad (1)$$

In which c= the pollutant concentration in time t and downstream distance x (mg/L); x = distance from point pollution source (m); t = time elapsed since pollution incidence in the river (s); D = diffusion coefficient (m^2/s); u = mean velocity of the river (m/s), and k = coefficient of pollution decay (1/s). In this equation the mean velocity of the river, the river cross -section and diffusion and decay coefficients are supposed constant, also it should be noted that the pollutant is point source and there is no input and output of pollution along the river.

Eq. (2) indicates the analytical solution of Eq. (1) when abrupt pollutant releases into river water.

$$c(x,t) = \frac{M}{A\sqrt{4\pi t D}} \exp\left(\frac{-(x-ut)^2}{4Dt} - kt\right) \qquad (2)$$

In which $c(x,t)$ = pollutant concentration at each distance and each time (mg/L); M = sudden pollutant mass at the discharge point (kg); A = area of the river cross -section (m^2).Other parameters are defined as before.

There are many experimental methods for calculating dispersion coefficient (Seo and Cheong 1998). In this paper Fischer method has been used to calculate the value of D (1975).

$$D = 0.011\frac{u^2 w^2}{hv} \qquad (3)$$

In which w = width of the river section (m); h= water depth (m); and v = shear velocity (m/s). v is calculated using bellow equation:

$$v = \sqrt{grs}$$

In which g = acceleration gravity (9.81 m/s2); R= hydraulic radius of the river calculated as A/P [A= area of the river cross-section (m^2); P = wet perimeter of the water flow (m)]; and s = hydraulic slope of the river (m/m).

2.2. Assimilation Capacity

A branch of the stressor-based monitoring approach is the concept of carrying capacity or assimilative capacity. The concept was formulated around the use of the freshwater and marine environments for the disposal of mainly organic wastes and associated effluents. In this context, Cairns (1977) had propounded that the assimilative capacity may be defined as the ability of an ecosystem to confront with certain concentrations of (organic) waste discharges, without suffering any significant deleterious biological effects. Several assumptions are inherent in the utilization of the assimilative capacity concept in water-quality management (Abbasi and S. A. Abbasi. 2012):

1) Each environment has a finite capacity to adapt

some wastes without unacceptable consequences.

2) Zones of initial mixing or zones of allowed adverse ecological impact may be required where significant ecological changes may occur.
3) Carrying capacity can actually be quantified and subsequently utilized through allocation and management at passable impact levels.
4) Unacceptable consequences can be measured and quantified.
5) The utilization of the assimilative capacity will not have an injurious effect on those biological processes that contribute significantly to that capacity.

Based on the expressed assumptions, the carrying capacity of rivers is different. Consideration of a river's self-purification capacity (assimilation capacity) for pollution treatment is an economic necessity leads to build optimum conventional treatment facilities and decrease costs.

If there are any reservoirs in the upstream of the pollution occurrence point and also the pollutant source is controllable, there are two scenarios for consideration carrying capacity of the river. To investigate these scenarios, it must take into account that: (1) the maximum assimilation capacity of the river occurs in low velocity of water flow, because according to the Eq. 2, the flow velocity must decrease to reduce the high pollutant concentration. So, by decreasing the water flow velocity, the assimilative capacity will increase and vice versa; and (2) there are some water demands in downstream of the rivers like: domestics, recreational, agricultural, industrial water demands. In this circumstance the water manager and decision maker should specify that which scenario is more important. Scenario A) reservoir release allocation to control the pollution or scenario B) water allocation to supply other objectives and downstream demands. Due to direct relation between the water release from upstream reservoir and water flow velocity, to satisfy the scenario A, the flow velocity must be decreased and to satisfy scenario B, the flow velocity should be increased. Thus, these two available scenarios have conflicting behavior. In this paper scenario B has been considered for calculation the assimilative capacity that for each water reservoir release to supply the downstream demands, the assimilative capacity is determined. The purpose of this paper is to transmit the unallowable pollutant concentration to permissible concentration by means of assimilation capacity.

2.3. Model Formulation

To determine the assimilation capacity, the pollutant source must be controllable. To calculate the maximum assimilation capacity, an optimization method was used to control the value of the dischargeable pollution mass by Farhadian et al (2014). They considered allowable concentration as a constraint and the nonlinear programming (NLP) method, which is a single-objective optimization approach.

There are two reasons to determine the assimilative capacity without optimization approach:

1) According to the NLP method, the optimum solution is determined by calculating the gradient at each point of the objective function space using mathematical differentiation which is a time-consuming process that can become insurmountable (Farhadian et al 2014).

2) Based on the nature of the assimilation capacity problem no optimization approach is necessary. Thus, with a simple simulation in MATLAB software the best assimilation capacity will be determined.

Therefore, in this study for determining the river assimilation capacity, MATLAB software has been used. To calculate the maximum assimilative capacity due to the different downstream water demands in different seasons of the year, water release from upstream reservoir to meet the water demands are assumed different. For each water flow velocity (due to direct relation with water reservoir release), each specified affected distance and each downstream allowable concentration constraint, the maximum assimilative capacity is calculated in the modeling process. The runtime of the applied MATLAB program is not high and the obtained answers are never insurmountable in compare with the calculation of assimilation capacity in former methods and investigation.

2.4. Case Study

A hypothetical river with a sudden pollution discharge is considered with the specified characteristics. The Schematic pollutant entrance into the river is shown in figure 1. Table 1 contains the assumed characteristics of the river. These values are hypothetical but they have been chosen in the range of the real values for these specifications. In Table 2, w = width; A = area; h = water depth; s = hydraulic slope; k = coefficient of pollution decay; = allowable concentration.

Table 1- Essential parameters in defining the assimilation capacity

Parameter	Value	Dimension
A	5	m^2
w	5	m
h	1	m
k	0.002	1/s
s	0.005	m/m
C_S	0.5,1	mg/l

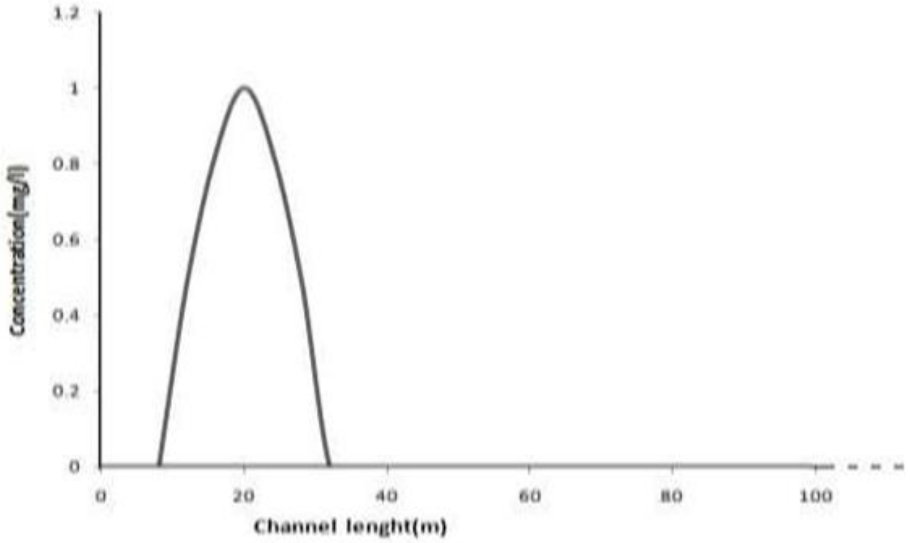

Figure 1. The initial point source pollution occurrence in the channel

In this paper the distance between water withdrawal and pollution occurrence point has been assumed equal to 200 meters and the water flow velocity has been considered in the range 0.07 – 1 m/s. Two scenarios have been assumed for C_s to determine the maximum assimilation capacity for each water flow discharge. It should be noted that due to the constant river area there is a direct relation between water flow velocity and water flow discharge Figure 2.

The simulation model which is explained in the Model Formulation section has been used to determine the maximum value of the assimilation capacity based on the input information.

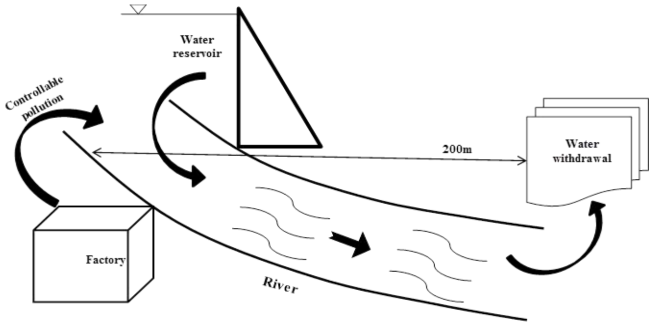

Figure 2. Schematic view of the case study

3. Result and discussion

In this section for the described case study the results for the assimilation capacity has been expressed.

Calculation of the Maximum Assimilation Capacity

To determine the maximum assimilative capacity, the water release from the upstream reservoir and the pollution entrance in the river are adjustable in this study. Thus, there would be the maximum a assimilative capacity for each amount of water release. Indeed, assimilative capacity is the maximum value of pollution mass that could be entered into the river such that the pollution concentration is less than the allowable limit after the water withdrawal location. It must be noted that in the constant water flow velocity and invariant allowable concentration constraint by increasing the location of water withdrawal from the pollution occurrence point the maximum dischargeable pollution mass increases.

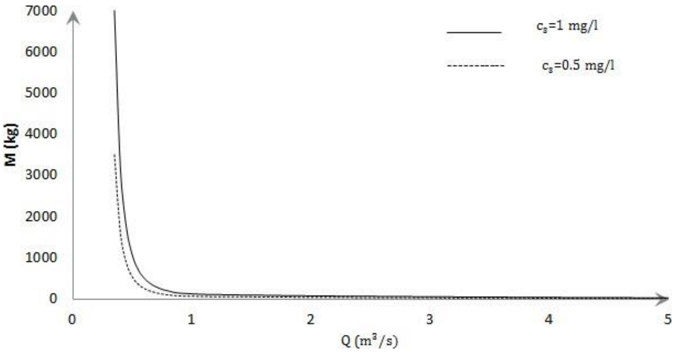

Figure.3. Maximum assimilation capacity corresponding to the several reservoir releases for the different values of the downstream allowable limit equal to 0.5 and 1 mg/l

Figure 3 shows maximum assimilation capacity of the hypothetical river which is represented in the case study due to the several reservoir releases for the both values of the allowable concentration equal to 0.5 and 1 mg/l using MATLAB software.

According to the Figure 3, two results could be concluded:

1)Increasing in the water flow velocity (due to direct relation with water discharge) causes decreasing in the assimilative capacity. Because by increasing water flow velocity the duration of pollution contact reduces and the time for pollution decay and dispersion is also decreases, thus it causes rapid pollution transmission from its happening point toward the downstream. So, the peaks of the pollutant chemo graphs increase in downstream position and the model is forced to reduce the pollution entrance to reach to the allowable limit. This concept is illustrated in figure 4.

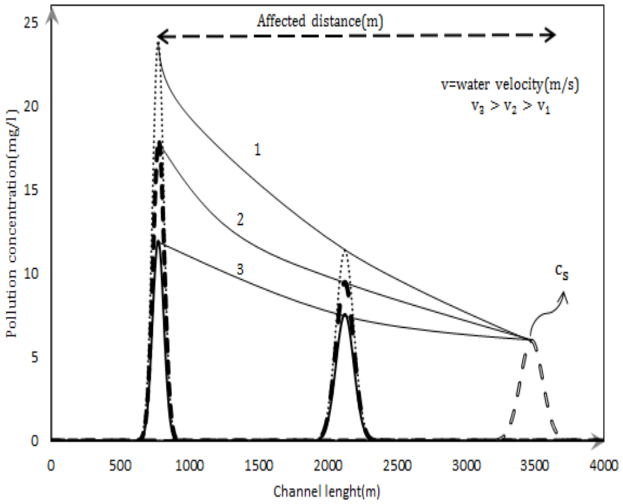

Figure 4. Relation between water flow velocity of river and its assimilative capacity

2) Increasing in the downstream allowable concentration (from 0.5 to 1) causes increasing in the maximum assimilative capacity by the same proportion. It means that in this case study for each water discharge and in a constant affected distance, maximum assimilative capacity increases at almost

twice the rate of the downstream allowable concentration.

4. Conclusion

This article determined a necessary characteristic (Assimilative capacity) for water quality management in the rivers when the river pollution is controllable. The simulation of pollution transport in the river and calculation of assimilation capacity was based on the mathematical equations of pollution propagation in a river with no turbulent flow. The proposed procedure was applied for water quality protection in a hypothetical case study and the obtained results were expressed.

The obtained results of using the propose ed simulation method in MATLAB demonstrated that the river velocity changes caused by the upstream reservoir release in the range 0.07 – 1 m/s can cause prominent and effective changes in the content of assimilative capacity. In the constant affected distance equal to 200 meters the variation in assimilation capacity changes from 100 to 3460 kg for downstream allowable concentration equal to 0.5 mg/L and is in the range of 200 to 6920 kg for the downstream allowable concentration equal to 1 mg/L. These values are vital and necessary to protect the river environment corresponding to the current and existing water quality conditions.

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