



Assessment of tools for protection of quality of water: Uncontrollable discharges of pollutants

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ABSTRACT

Selecting an appropriate crisis management plans during uncontrollable loading of pollution to water systems is crucial. In this research the quality of water resources against uncontrollable pollution is protected by use of suitable tools. Case study which was chosen in this investigation was a river-reservoir system. Analytical and numerical solutions of pollutant transport equation were considered as the simulation strategy to calculate the efficient tools to protect water quality. These practical instruments are dilution flow and a new tool called detention time which is proposed and simulated for the first time in this study. For uncontrollable pollution discharge which was approximately 130% of the river's assimilation capacity, as long as the duration of contact (T_c) was considered as a constraint, by releasing 30% of the base flow of the river from the upstream dilution reservoir, the unallowable pollution could be treated. Moreover, when the affected distance (X_c) was selected as a constraint, the required detention time that the rubber dam should detained the water to be treated was equal to 187% of the initial duration of contact.

1. Introduction

Contamination of surface water is one of the most controversial environmental issues. Pollution discharge is usually accidental and uncontrollable in the real world. This environmental hazard must be measured, simulated and calculated separately, so a suitable crisis management plan should be applied. Control of allowable concentration of the pollution for daily water demands needs special instruments for water treatment. Employing water refinery facilities is an inevitable resolution but establishing such equipment have notable expenses, so proposing applicable and replaceable solutions which are effective and also low in cost is crucial. Obviously a very cost-effective way to confront any disturbance is using the natural ability of a water system. This natural ability in the river is achieved by adjustment of water flow versus entered pollution (World Meteorological Organization Technical Report, 2013). Assimilative capacity and dilution flow are well-known instruments to protect water quality which employ regulation of water flow for treating polluted water. Assimilative capacity and dilution flow were used to manage controllable and uncontrollable pollution

entrance, respectively (Hashemi Monfared et al., 2017).

Regulation of water flow to minimize the hazards caused by sudden and unallowable entered pollution is a practical remedial action to manage pollution crisis, which is called dilution flow (Zhang et al., 2017). To determine the amount of dilution in the previous researches, a method was extended employing the equation of mass-balance for aluminum and considering sources of aluminum from surface water, groundwater and filter-backwash effluents. Hazards caused by water withdrawal, sedimentation and spill discharge from the reservoir were investigated. The method was used for 13 reservoirs and data on aluminum and dissolved organic carbon (DOC) concentrations in reservoirs and influent water were collected (Colman et al., 2016). Dilution flow was employed as a tool to protect the hypothetical case study when the pollution discharge into the river is accidental or uncontrolled (Ciolfan et al., 2018; DeSmet, 2014). Their simulation was based on the analytical method of pollution propagation (Farhadian et al., 2014; Skulovich and Ostfeld, 2017).

Precise solving of the pollution transport equations by different methods and models is the first step for accurate modeling of the

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behavior of pollution. It was proved that Symmetric Exponential Function (SEF) and Quick methods are appropriate to simulate the tools for water quality management with high accuracy (Hashemi Monfared and Dehghani Darmian, 2016; Ardestani et al., 2015). Pollution transport in the river was simulated using numerical methods and quality of that river water was managed (Falconer and Liu, 1988; Gao et al., 2015; Farhadian et al., 2016, 2018). Interaction between the finite-difference technique and the real GA optimizer to eliminate a heavy-metal pollutant plume from an aquifer was illustrated (Awad et al., 2011).

Compromising between desires and conflict targets in the state of abrupt pollutants discharge and selection of the appropriate strategy to analyze the reaction of water resource system is available by use of the system quality-quantity modeling and conflict-resolution methods. These methods are done employing the CE-QUAL-W2 model (Shokri et al., 2014) for loading of coliform pollution in the Karaj Dam, Iran (Haddad et al., 2013). Oscillation in quality of reservoir water was modeled and estimated upon entered biological load using CE-QUAL-W2. Some factors affected the pollutant behavior significantly, such as stored water volume in the reservoir and location of the entered contamination (Haddad et al., 2015).

Many researchers centralized their investigations on the identification of the pollution source in surface waters (Khorsandi et al., 2014). Information of the water quality and networks monitoring as necessary factors in tolerable of water resources management and pollution control were determined. Their management and evaluation approach had been used to optimize the monitoring of water quality network in the Heilongjiang River, northeast China (Chen et al., 2012). A method to optimize monitoring networks of water quality in river-reservoir systems to determine optimal sampling locations and discover the sudden pollution release [methyl tert-butyl ether (MTBE)] were developed considering two goals 1) minimizing the prediction error at the reservoir's outlet gate; and (2) minimizing the average time where MTBE is detected at sampling locations. A support vector regression (SVR) tool is coupled to non-dominated sorting genetic algorithm II (NSGAI) to optimize the sampling locations of water quality (Aboutalebi et al., 2016a). Transport of pollutants released into a water body was simulated by use of data-mining tools. Concentration of (MTBE) at various locations within a river-reservoir system was modeled by apply the (SVR) which is a data-mining tool (Aboutalebi et al., 2016b). Framework to Multi-objective optimization was proposed for determination of optimal load of pollutants into rivers considering three factors including: (1) the total cost of treatment, (2) the balance between the pollution dischargers and (3) the dissolved oxygen (DO) concentration in the water (Yandamuri et al., 2006). Complementing analytical chemistry approach to manage effluent or surface water was investigated by considering the importance of biomonitoring methods with special focus on zebrafish models (Li et al., 2018).

Data-driven models were considered to analyze indices of water quality (Mahmoudi et al., 2016; Karamouz et al., 2003; Solgi et al., 2017). Genetic programming (GP) as a data-driven model is an efficient instrument for identifying water quality parameters (Orouji et al., 2013).

Interaction between quality condition of soil and water were performed to achieve the best quality management tool according to the region's situation (Ali et al., 2017a; 2017b; 2018). A study investigated the pollution degree of toxic metals and rare earth elements in comparing sediment, soil and plant samples surrounding rivers in the African copperbelt area specified by the presence of numerous abandoned mines and industrial mining activities (Atibu et al., 2018). Evaluation of ecological hazards (Yang et al., 2017; Wang et al., 2018) and risk assessment of two coastal ecosystems in Iran including Hara Protected Area and the Azini Bay is accomplished using common pollution indices, by measuring daily concentration of Pb, Zn, Cu, Cd (Ghasemi et al., 2018) and similarly for Meiliang bay of Taihu lake in China (Rajeshkumar et al., 2018). Moreover, metal pollution indices and sediment specifications were evaluated (Sharifinia et al., 2018).

Suitable strategies to evaluate the health risk and uncertainties from trace organic chemicals in water environment were reviewed (Bieber et al., 2017).

One of the most important characteristics in the field of water resource management is considering of the opinions of stakeholders and fulfilling their requirements. Optimal operation of the reservoir systems is a challenging function in management of water resource; including stakeholders with several utilities which may sometimes are conflicting to each other (Fallah-Mehdipour et al., 2014).

Assimilative capacity of the river was proposed and calculated for managing controllable pollution discharge (Hashemi Monfared et al., 2017). In order to guarantee quality and safety of water and also improve consumer satisfaction, existence of an integrated quality management system against controllable and uncontrollable pollution entrance is essential. Therefore in this investigation, the management of uncontrollable loading of pollution which is greater than river's assimilation capacity has been discussed. For achieving this purpose based on the environmental conditions of the region and stakeholders requirements, two economical utilities for water quality management have been used; dilution flow and a new tool called detention time which is introduced and simulated in this study. These quality conservation tools rely on the adjustment of river-reservoir flow to tackle various amounts of pollution hazards and enhancing the quality of the water.

2. Materials and methods

2.1. Simulation of pollutant transport in a river

Equations of pollution propagation in a river with the specified velocity present the basis for simulation methods of riverine transport (Eq. (1)) demonstrates one-dimension differential advection-dispersion equation of pollution transport. (Van Genuchten and Alves, 1982; Ani et al., 2009; Schmalte and Rehmann, 2014; Singh et al., 2011; Veling, 2010; Monfared et al., 2014; Hashemi Monfared et al., 2016, 2017; Hashemi Monfared and Dehghani Darmian, 2016).

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

In which c = concentration (mg/L) of constituent; x = distance from source of pollution (m); t = time elapsed since incidence of pollution of the river (s); D = diffusion coefficient (m^2/s) and u = mean velocity of the river (m/s). In this equation, mean velocity, cross-section and diffusion coefficient of the river, are considered to be constant. There are two methods to solve Eq. (1) including:

- ❖ Analytical method
- ❖ Numerical method

2.2. Analytical method

The analytical solution of Eq. (1) when there is a sudden release of pollutant to the river water is given by Eq. (2) (Hashemi Monfared and Dehghani Darmian, 2016).

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

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

There are many experimental schemes for calculating dispersion coefficient (D) (Seo and Cheong, 1998). For instance, Fischer method to calculate D is presented by Eq. (3) (Fischer, 1975).

$$D = 0.011 \frac{u^2 w^2}{h \nu} \quad (3)$$

In which w = width of the river section (m); h = water depth (m); and ν = shear velocity (m/s). ν is calculated (Eq. (4)).

$$\nu = \sqrt{gR_s} \quad (4)$$

In which g = acceleration gravity (9.81 m/s^2); 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).

2.3. Numerical method

For solving Eq. (1) by use of numerical methods, it can be divided into two parts as below considering the superposition principle.

$$\begin{aligned} &\diamond \text{Advection term } \left(\frac{\partial c}{\partial t} = -u \frac{\partial c}{\partial x} \right) \\ &\diamond \text{Diffusion term } \left(\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \right) \end{aligned}$$

Advective transport according to the mean velocity of the river is being simulated considering the main term $\frac{\partial c}{\partial t} = -u \frac{\partial c}{\partial x}$ along the discrete distance. The distance and time intervals should be selected precisely for the convergence of solution in a specific geometry. A current number as $\beta = \frac{u \Delta t}{\Delta x}$ is applied to the discrete form of Eq. (1) and is limited from 0 to 1. Δt and Δx are the time and distance intervals respectively.

In numerical methods to solve advection term, a function should be determined on the cells of discrete area for transferring the concentration. The SEF method considers exponential function ($f(x) = ae^x + be^{-x} + d$) (see Fig. S1). The capability and sufficiency of SEF method to simulate pollution, has been prove. It was also demonstrated that SEF method is more accurate than other numerical approaches like Quick method (Hashemi Monfared and Dehghani Darmian, 2016). Therefore in this investigation, SEF approach is applied as a simulation strategy for determining necessary water quality management tools.

Also the crank-nickelson method could be applied to determine the diffusion term of the transport equation (Hashemi Monfared and Dehghani Darmian, 2016).

2.4. Pollution assessment indicators

Harmful effects of pollution in the river have been evaluated considering three factors in this research: (1) pollutant with a concentration greater than the allowable concentration constraint (c_s) along the river; (2) duration that such unallowable pollution is in contact with the riverine environment that is known as duration of contact (T_c) and (3) distance which unallowable pollution is in contact with the river, which is defined as the affected distance (X_c). These factors are related to each other (Eq. (2)) to: (1) reduce the duration of high pollutant concentration contact with the river water, the water flow velocity should be increased, so the pollutant has a shorter contact time with the river water; and (2) to minimize the affected distance and high pollutant concentration, the flow velocity must be decreased, such that it is long enough to enable pollutant decay. This will decrease concentrations of the pollutant and also the affected distance becomes minima (Fig. S2). These practical scenarios are selected depending on the situation of water quality in the riverine and the important desires of water stakeholders. Assumed indices for pollution assessment are crucial to develop the integrated quality management plan. This plan has specific schedules for treating and remediation of the river-reservoir system quality against different contamination inputs (controllable and uncontrollable) by use of three water quality management tools as follow:

$$\diamond \text{Assimilation capacity for controllable pollution entrance (discussed in Hashemi Monfared et al., 2017)}$$

$$\diamond \text{Dilution flow and Detention time for uncontrollable pollution entrance (discuss in this research)}$$

2.5. Dilution flow and detention time

Pollution that is discharged into a river could be incidental or intractable, such as the accidental release of chemical substances from industrial activities, where if the input concentration of the contamination is higher than the assimilative capacity, it must be reduced. Two tools are proposed in this study to decrement the unacceptable pollution concentration in the river depending on the condition of water quality in the riverine and the opinions of water managers and desires of stakeholders.

One of the simple and feasible remedial operations is to release a specific amount of water from upstream of the entered pollution point, which is called dilution flow. Therefore, the water flow is regulated to decrease the detrimental effects on the environment. This can only be achieved by manufacturing of the regulating structures.

Moreover, detention time is another practical remedial action which is introduced in this study to protect the water quality against environmental pollution. This can only be accomplished by designing of a controllable impermanent barrier in front of the water flow like a rubber dam.

2.6. Case study

In order to simulate the dilution flow and detention time, a river-reservoir system with an uncontrollable pollution discharge and specified river characteristics, the same as recent researches (Hashemi Monfared et al., 2017; Farhadian et al., 2014; Seifollahi-Aghmiuni et al., 2015; Fallah-Mehdipour, 2015) is considered which is demonstrated in Table S1. In this table, c^* = Sudden pollution entrance, Q^* = Base discharge of river, u^* = Base velocity of river, β^* = Initial current number corresponds to base velocity of river, Q = Capability of upstream reservoir flow, ΔQ , Δu , $\Delta \beta$ are discharge, velocity and current number intervals respectively. Also X_c is indicated as location's constraint and T_c is illustrated as time's constraint. Other parameters are defined previously.

Briefly, the main goals in this investigation are the conveyance (c^*) to (c_s) according to different regional conditions and water stakeholders opinions to decrease the environmental dangers in the specific T_c and X_c :

Case 1) $T_c = 200 \text{ s}$

Case 2) $X_c = 1000 \text{ m}$.

3. Results and discussion

Dilution flow has been used as a practical action to reduce the impact of pollution hazards when entered pollution to the river is uncontrollable (Farhadian et al., 2014; DeSmet, 2014; Elahe Fallah-Mehdipour, 2015; Seifollahi-Aghmiuni et al., 2015; Skulovich and Ostfeld, 2017; Hashemi Monfared et al., 2017; Ciolofan et al., 2018). Simulation process of dilution flow in these papers was done with complex optimization methods based on an analytical approach (Eq. (2)) which required a great deal of time. But in this paper, while the pollution discharge to the river is uncontrollable or accidental and the input concentration of pollutant is greater than the river's assimilative capacity, two instruments are proposed for decreasing the high concentration of pollution in the river depending on the opinions of water stakeholders. These conditions are as follow:

1) Transmission of the unallowable concentration of pollutant to permissible concentration at a specified period of time. This means that water stakeholders determine T_c as a constraint. This situation occurs for example when a special kind of aquatic lives in the river that

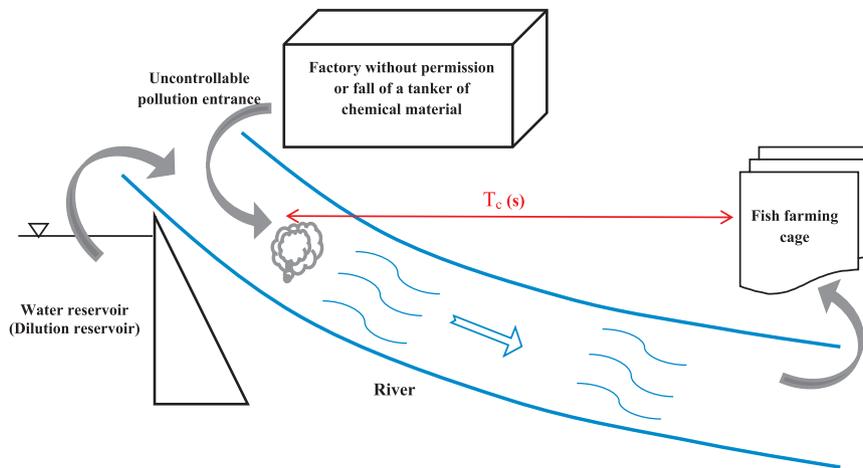


Fig. 1. Schematic view using dilution flow as a protection tool in a river-reservoir system.

cannot tolerate contaminated water over a certain amount of time (like fish in farming cages). Some research has been done in this regard recently. Effect of long contact time of fish and shellfish with heavy metal like arsenic contaminated water, is investigated (Copaja et al., 2017). Peoples are exposed to a lot of sources of arsenic (food, water, soil and air), but exposure via diet is the most important one which leads to increased cancer risk (Gao et al., 2018). Increasing the contact time between polluted water and the aquatic animals causes irreversible consequences on human health. Therefore to overcome these detrimental effects on the environment and eliminate the hazards, the unallowable pollutant concentration should be transferred to allowable at a specific time (T_c). Hence, when T_c is assumed constraint, dilution flow is the suggested tool for conservation of the water quality against environmental pollution.

Schematic view for determining the required flow to dilute the pollution in the river-reservoir system in a state of uncontrollable loading of pollution is demonstrated in Figs. 1 and 2. Target is transmission of the unallowable concentration of pollutant to c_s at T_c in Fig. 2, but in the state. 1 of this figure, this goal is not achieved with the base velocity and discharge of river (Q^* & u^*). After pollution transport, the downstream concentration of pollution is greater than c_s and so it is unacceptable. Due to this fact that the pollution mass is uncontrollable and inconvertible, dilution flow as a feasible remedial action is utilized to control the pollution hazards. Therefore, river flow (dilution flow plus base flow) is regulated to minimize the hazards to the

environment. This can only be attained by construction of regulating structures (Fig. 1, see the dilution reservoir).

After construction of the dilution reservoir, with releasing the precise volume of water, by increasing the discharge flow in the upstream point of the pollution loading, the contamination will be diluted and also the peak of the initial chemograph is decreased. This decrement of pollution will cause the downstream concentration being equal to c_s (Fig. 2; state. 2).

Releasing the dilution flow leads to increment in flow velocity of the river, so in a constant T_c , increasing the flow velocity causes an increase in the X_c (Fig. 2; comparison between state. 1 & state. 2).

2) Transferring the unallowable to permissible concentration of pollution at a specific distance, meaning that water stakeholders determine X_c as a constraint. This condition occurs when a water withdrawal location is provided with a specified water demand after a certain distance from uncontrollable loading of pollution. To satisfy this environmental necessity, the unacceptable concentration of pollution should be transmitted to allowable one within a specific distance X_c before reaching the location of water withdrawal. Therefore when X_c is specified as a constraint, detention time is the proposed instrument which is applied to protect the water quality against the environmental hazards.

Schematic view for determining the detention time in the river-reservoir system in a state of uncontrollable entrance of pollution is indicated in Figs. 3 and 4. Mentioned purpose according to Fig. 4 is the transmission of unallowable concentration of pollution to c_s at X_c , but initially in state 1 of this figure, this target does not attain with the (Q^* & u^*). In this situation as the pollution mass is uncontrollable, only the adjustment of river velocity must be employed to minimize the hazards to the environment. For accomplishing this goal, the velocity of water flow should be decreased, because by decreasing the flow velocity, the duration of pollution contact increases and the time for pollution decay and dispersion is also increased. It causes slow transmission of the pollution from its occurrence point toward the downstream. So peaks of the pollution chemographs decrease in downstream locations and are equal to c_s (Fig. 4, state. 2). This can only be attained with construction of controllable temporary obstacle in front of the water flow like a rubber dam (Fig. 3, see the rubber dam). After removing unacceptable concentration of the pollution, the air of rubber dam should be evacuated so that river flow continues.

Dilution flow could not be used as a tool for protection of the water quality when X_c is constant and assumed as a constraint, because by releasing the dilution flow, the affected distance changes and increases. So X_c constraint is violated.

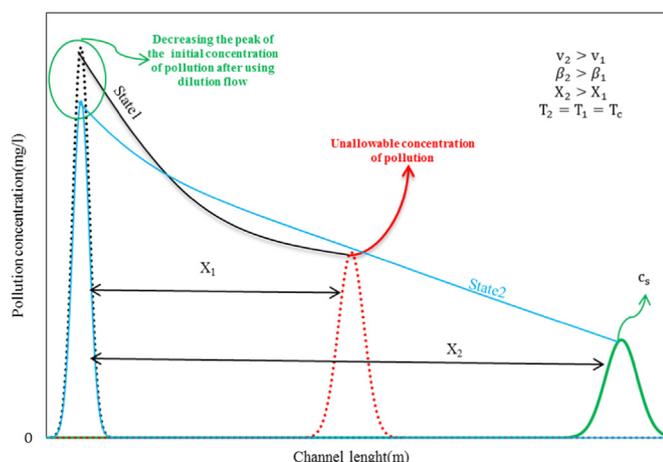


Fig. 2. Schematic view for determining dilution flow in a river-reservoir system.

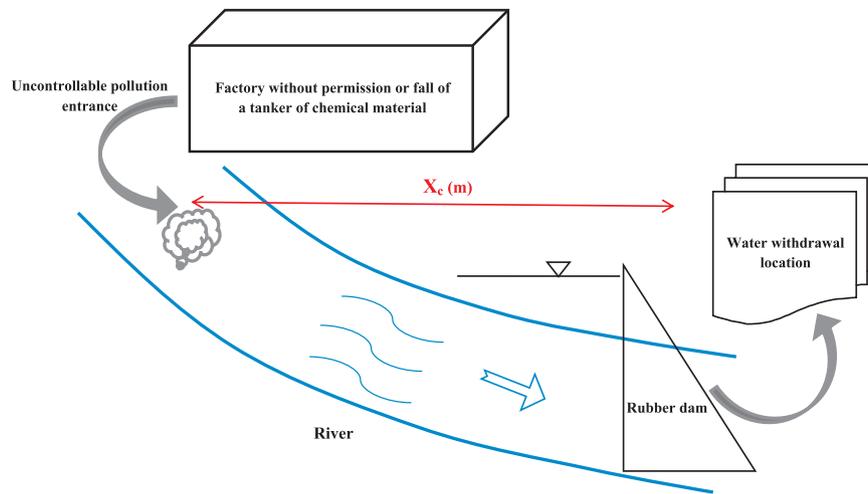


Fig. 3. Schematic view using detention time as the protection tool in a river-reservoir system.

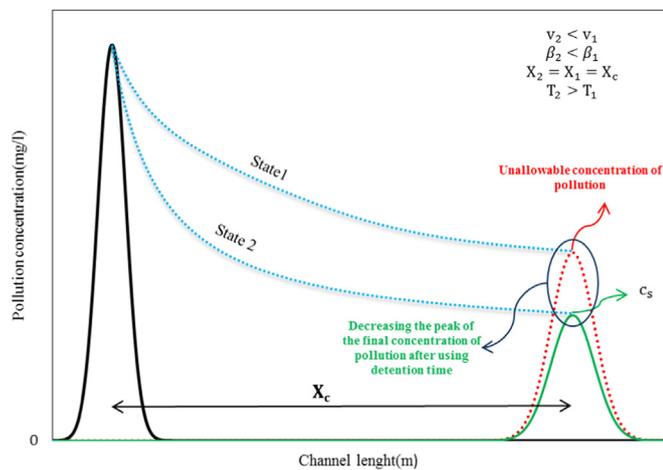


Fig. 4. Schematic view determining detention time in a river-reservoir system.

At last, due to constant X_c and by applying the detention time as a tool for conservation of the water quality, decreasing (V) causes increasing (T) (Fig. 4; comparison between state. 1 & state. 2).

Two parameters with approximately similar name but different concepts are discussed in this research (Figs. 1–4), including:

- ❖Duration of contact (T_c)
- ❖Detention time

The distinctions between these two parameters are as follow:

- 1) "**Duration of contact**" is a constraint like "Affected distance" while "**Detention time**" is an instrument to protect the water quality like "Dilution flow" and "Assimilative capacity".
- 2) "**Detention time**" is the proposed tool of this investigation to conserve the environment against the uncontrollable entrance of pollution when "Affected distance" is supposed constraint and attained by construction of the rubber dam; whereas, if the "**Duration of contact**" is assumed as constraint, "Dilution flow" is the suggested tool of this study to protect the environment against the uncontrollable discharge of pollution and achieved by making the regulating dam upstream of the loading of pollution.

Flowchart of modeling process to simulate simultaneously the "Dilution flow" and "Detention time" with SEF method is demonstrated (Fig. 5). According to this flowchart, after entrance of the

uncontrollable pollution to the river, values of the river's assimilation capacity which is simulated based on Eq. (2) (Hashemi Monfared et al., 2017) must be compared with the entered pollution. If the river's assimilation capacity is greater than the entered pollution, assimilation capacity should be employed as the tool to conserve water quality. Otherwise, if the river's assimilation capacity is lesser than the entered pollution, dilution flow and detention time must be considered as the effective tools to conserve the aquatic environment. Finally, the values of \bar{c}_d and \bar{c}_a (Hashemi Monfared et al., 2017) are calculated before and after using dilution flow and detention time in order to evaluation of the performance of these tools and compare the obtained results.

Right branch of Fig. 5 shows the steps to calculate the dilution flow whereas the left wing of this flowchart demonstrates the stages for determination of the detention time. In simulation process of dilution flow, in any iteration, the dilution reservoir releases the discharge interval ($\Delta Q = 0.01 \text{ m}^3 / \text{s}$) upstream of entrance point of the pollution (Fig. 1) and diluted the value of initial pollutant to the amount below: (Eq. (5))

$$\Delta c_i = \left[\frac{c^* Q^* \left(\frac{\Delta Q}{Q_i} \right)}{Q_{i+1}} \right] \quad (5)$$

This release of water flow continues in each iteration of simulation process until the concentration of pollution became equal to the c_s at the T_c constraint. Finally, the dilution flow is ultimate flow minus base flow of the river.

To calculate detention time, in each iteration of the simulation process, the water velocity of river is decreased with construction of the rubber dam (Fig. 3). Diminution of the water velocity continues until the concentration of pollution became equal to the c_s at the X_c defined constraint. Finally, the detention time is ultimate duration of contact (T_{final}) minus initial duration of contact (T_{initial}) of the pollution in the river.

Table 1 shows results from the simulation of the dilution flow and Table 2 is related to simulation results of the detention time.

Four results could be concluded from Table 1:

- 1) Required dilution flow to conserve the water quality for this case is $1.47 \text{ m}^3/\text{s}$.
- 2) Before using dilution flow, the amount of c^* was 5 mg/l and the concentration of pollution at downstream was equal to 0.525 mg/l . After employing dilution flow, c^* is decreased to 3.864 mg/l and the concentration of pollution at downstream is reached to 0.4 mg/l , which is allowable concentration of pollution (c_s).
- 3) Affected distance increased by 308 m after using dilution flow, while

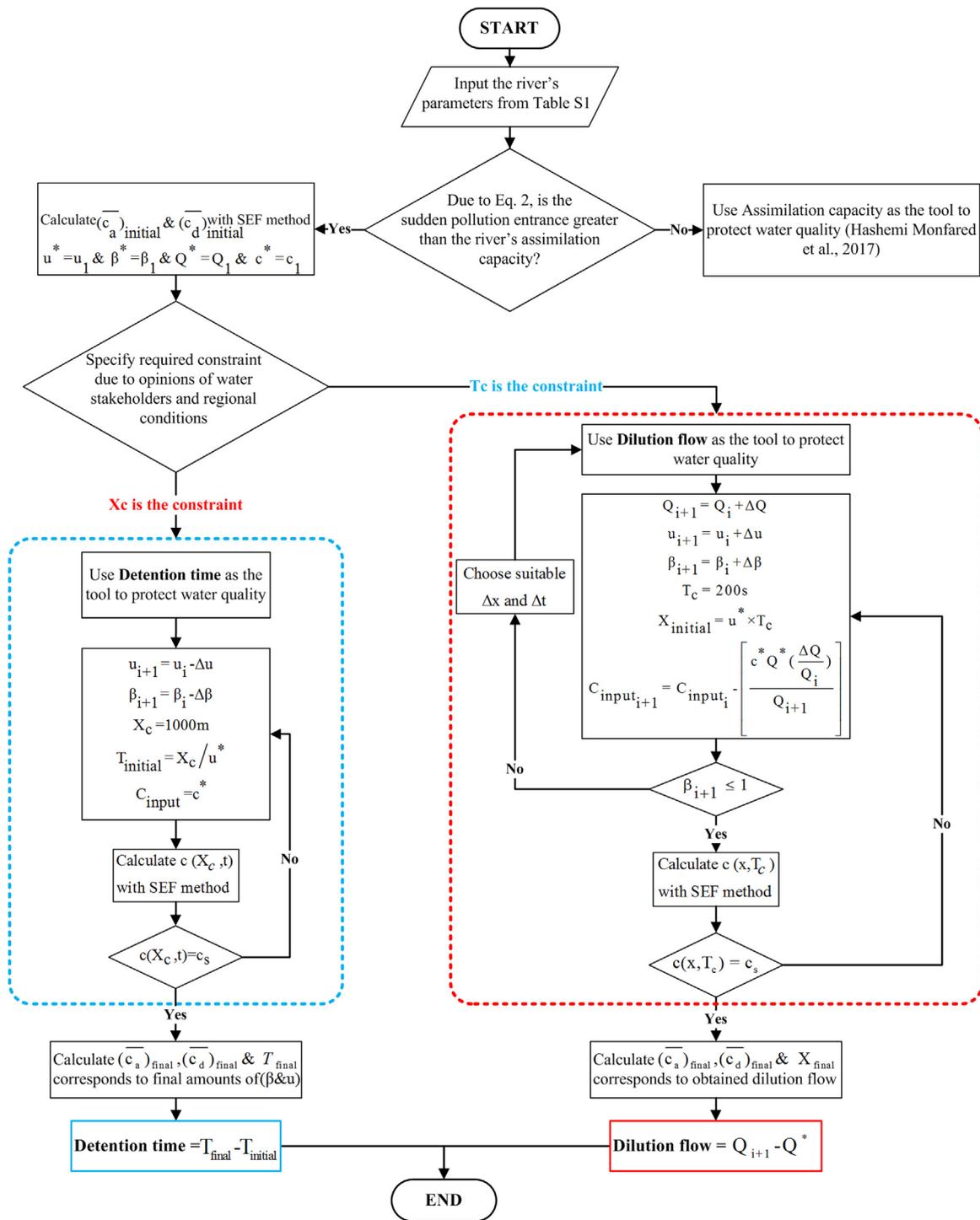


Fig. 5. Flowchart of simultaneous simulation of the "dilution flow" and "detention time" with SEF method.

T_c remained constant (see Fig. 2).

- 4) Values of \bar{c}_d and \bar{c}_a were 0.49 and 0.98 mg/l before applying dilution flow. They reduced to 0.37 and 0.75 mg/l, expressing 24% and 23% decreasing of these parameters after applying dilution flow.

Results for detention time could be explained based on Table 2:

- 1) Required detention time that the rubber dam should hold the water to treat the quality of river is 374.7 s for this case study.
- 2) Before using detention time, the amount of c^* and downstream concentration were 5 mg/l and 0.525 mg/l respectively. After

applying detention time and blowing air in the rubber dam, the concentration of pollution at downstream is reached to c_s .

- 3) Duration of contact increases from 200 to 574.7 s after using detention time, while X_c remained constant (see Fig. 4).
- 4) Variation of \bar{c}_d and \bar{c}_a ratify the treating behavior of detention time. Values of \bar{c}_d and \bar{c}_a before using detention time are 0.49 and 0.98 mg/l; after using detention time, these values are decreased equal to 18% and 16% respectively and reached to 0.40 mg/l for \bar{c}_d and 0.82 mg/l for \bar{c}_a .

Finally, the goal is to compare performance of the used instruments

Table 1

Values of quality parameters before and after using dilution flow with simulating by SEF method.

Parameter	Value before using dilution flow	Value after using dilution flow	Unit
Q	5	6.47	m ³ /s
β	0.375	0.485	–
Affected distance	1000	1308	m
T_c	200	200	s
Sudden entrance of pollution (c^*)	5	3.864	mg/l
Downstream concentration of pollution	0.525	0.4	mg/l
\bar{c}_a	0.98	0.75	mg/l
\bar{c}_d	0.49	0.37	mg/l

Table 2

Values of quality parameters before and after using detention time with simulating by SEF method.

Parameter	Value before using detention time	Value after using detention time	Unit
u	5	1.74	m/s
β	0.375	0.13	–
X_c	1000	1000	m
Duration of contact	200	574.7	s
Sudden entrance of pollution (c^*)	5	5	mg/l
Downstream concentration of pollution	0.525	0.4	mg/l
\bar{c}_a	0.98	0.82	mg/l
\bar{c}_d	0.49	0.40	mg/l

on water quality protection. Rate of changes in \bar{c}_d and \bar{c}_a are decreased 24% and 23% after using dilution flow and are reduced 18% and 16% after employing detention time (Tables 1, 2). These percentages indicate that reduction of \bar{c}_d and \bar{c}_a by use of dilution flow are 6% and 7% greater than detention time respectively. Therefore, efficiency of dilution flow for treating the quality of water is greater than detention time in the same initial situation.

4. Conclusion

Integrated quality management plan to control and conserve the quality of river-reservoir systems against uncontrollable entrance of pollution was proposed in this study. SEF method was selected to solve pollution transport equation for all modeling and simulation processes. Controllable discharge of pollution had been managed using assimilation capacity of river and also a novel simulation method invented to calculate that (Hashemi Monfared et al., 2017). In this research, suitable tools were presented and simulated to protect the water quality versus uncontrollable entrance of pollution which was greater than the river's assimilation capacity. In such conditions, based on the regional situation of water management and stakeholder's decisions, two economical and remedial tools were used to treat water: dilution flow and detention time which was simulated in this research as a new amendment tool. Before using dilution flow and detention time, amount of the initial entrance of pollution (c^*) and the downstream concentration were 5 mg/l and 0.525 mg/l respectively. Duration of contact ($T_c = 200$ s) and affected distance ($X_c = 1000$ m) were the corresponding values to the base flow of the river. Allowable concentration (c_s) in this case study is 0.4 mg/l. Since downstream concentration (0.525 mg/l) is greater than (c_s), two scenarios existed to tackle this problem: First, considering T_c as a constraint, by releasing dilution flow equal to 1.47 m³/s, c^* is diluted and reduced to 3.86 mg/l instantly and the downstream concentration reaches to c_s . Therefore, in this case study by releasing the dilution flow up to 30% of the base flow of river from

the upstream reservoir, the concentration of pollution could be treated in a constant T_c . Second, considering X_c as a constraint, by utilizing detention time equal to 374.7 s, downstream concentration reached to c_s . Thus, required detention time that the rubber dam should retain the water to treat the quality of river is 187% of the initial duration of contact in a constant X_c . Reduction of \bar{c}_d and \bar{c}_a by use of detention time are 6% and 7% lesser than dilution flow respectively. Hence, performance of dilution flow for treating the quality of water is better than detention time in the same initial situation. Suggested tools for quality management in this study, were practical and straightforward solutions to protect the water quality against suddenly discharged pollutants in river-reservoir systems.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.ecoenv.2018.05.087>.

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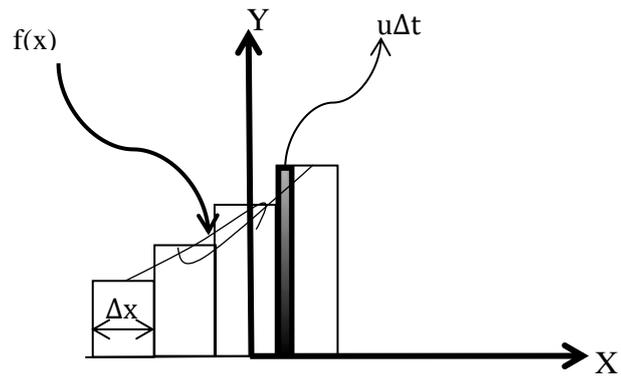


Fig. S1. Schematic transport of pollution in the discrete length of the channel.

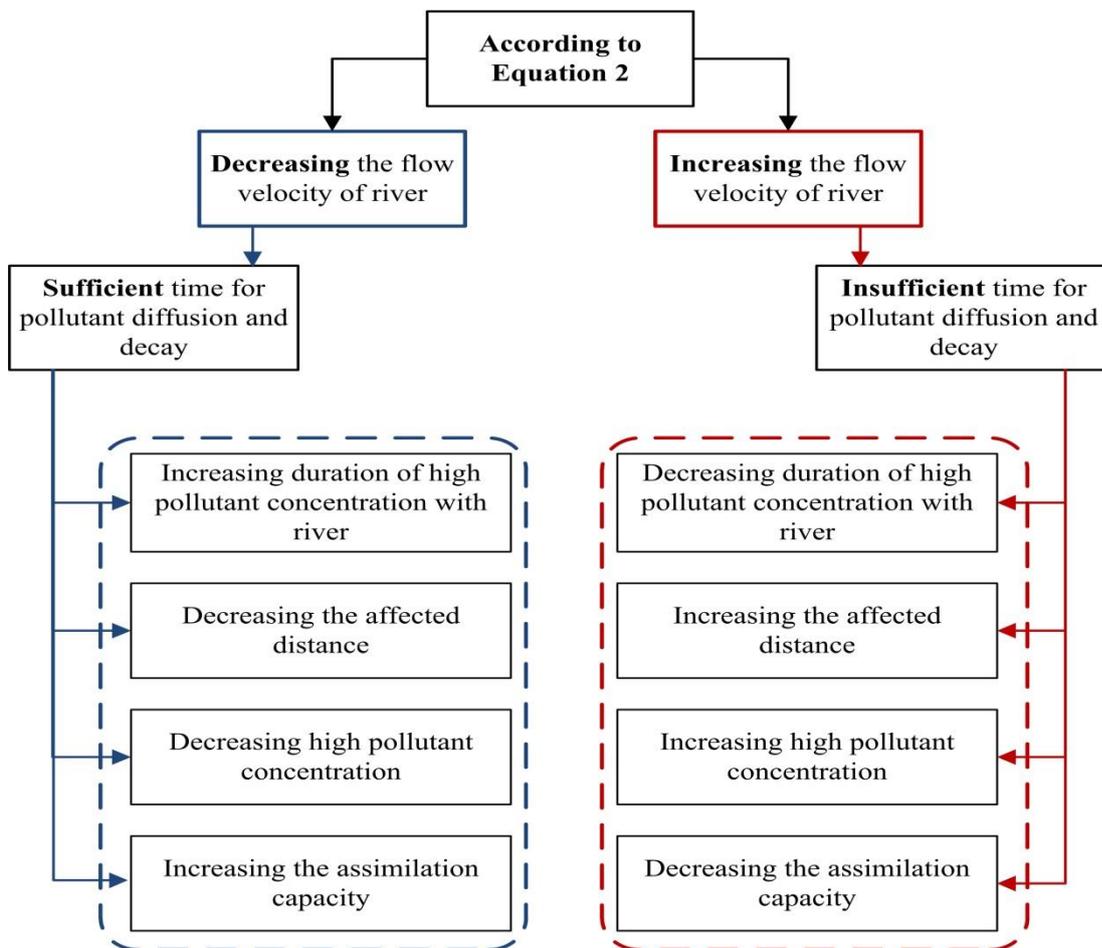


Fig. S2. Schematic relationships between water quality parameters.

Table S1. Essential parameters in defining the dilution flow and detention time with SEF method

Parameter	Value	Unit
A	1	m ²
w	5	m
h	0.2	m
s	0.005	m/m
Base discharge of river (Q [*])	5	m ³ /s
Base velocity of river (u [*])	5	m/s
Initial currant number (β [*])	0.375	-----
Capability of upstream reservoir flow (Q)	0.01-5	m ³ /s
ΔQ	0.01	m ³ /s
Δu	0.01	m/s
$\Delta \beta$	0.00075	-----
X _c	1000	m
T _c	200	s
Δx	4	m
Δt	0.3	s
c _s	0.4	mg/l
<i>Sudden entrance of pollution (c[*])</i>	5	mg/l