

## MULTIOBJECTIVE SIMULATION-OPTIMIZATION APPROACH IN POLLUTION SPILL RESPONSE MANAGEMENT MODEL IN RESERVOIRS

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### ABSTRACT

In this study, multi objective particle swarm optimization (MOPSO) technique is adopted to derive a Pollution Spill Response Management Model (PSRMM) in reservoir to characterize the existing trade-off. PSRMM consist of spatial system analyzing (SSA) model, 2D hydrodynamic and water quality simulation model (CE-QUAL-W2) linked to MOPSO to derive optimum strategy and/or emergency planning for Incident Commanders and/or decision makers during chemical pollution spill injection in reservoir. The simulation-optimization (SO) routine of PSRMM provides Pareto optimum reservoir operation strategy in selective scheme to minimize reservoir cleanup time, no. of water quality standard violation, and downstream worst water quality. The proposed methodology is applied in Ilam Reservoir in Iran, as a multipurpose hydraulic project providing water for drinking, irrigation, and flood control, during an accident spill of conservative hazardous material.

### 1 INTRODUCTION

Nowadays the safety and normal functionality of aquatic ecosystems and human health are threatened by chemical pollution spill events occurring in water bodies. Pesticides, fertilizers, municipal wastes, sewage, and mining are common source of accident pollutions. Contamination of river, estuary, lakes, artificial water bodies, or any water borne systems as a significant political, economical, and ecological natural source of any government poses major environmental risk. The most common types of pollution accident spills are collisions, technical failures, and fires/explosions (Rogowska and Namieśnik, 2010). Some examples of accident spill of pollution could be found in several places around the world.

On 1991, an accident spill of aqueous solution of the soil fumigant metam-sodium due to a car train derailed on the Cantara Curve near Mount Shasta, California led to the most ecologically damaging chemical spills in Sacramento River basin (Wang et al., 1997). An accident diesel fuel spill into a first order reach of the Cayuga Inlet, a tributary of Cayuga Lake near New York, USA had occurred in 1997. The accident spill

caused the chemical containment booms, slicks of the diesel fuel were floating on the surface of Cayuga Lake 16 Km downstream within 24 h (Lytle and Peckarsky (2001)). On April 25, 1998, a spill from a pyrite mine at the Los Frailes mine in southern Spain resulted in heavy metal-enriched tailings sludge and acidic mine water contaminated some 40 Km<sup>2</sup> of the Agrio and Guadamar river valley (Achterberg et al., 1999; Kraus and Wiegand, 2006).

During last decades, some artificial water constructions in Iran experienced sudden and unexpected hazardous pollution spills. The infrastructure such as Gheslagh Reservoir, Amirkabir Reservoir, and Zayandeh roud Reservoir as a source of drinking water in Iran cities had been contaminated due to technical failure and/or collision of hazardous material transportation systems. The recent events cleared the Iran infrastructure vulnerability to accident contaminations. Therefore, to protect of water resources designing pollution spill responses management models (PSRMM) are as one of efficient tools to provide emergency planning. The PSRMM enables the decision maker and/or incident commanders to analysis various scenarios immediately, assessment of 'what-if' scenarios, contaminant remediation, and emergency responses within real time periods. The integrated system calculates, locates, and maps the pollution from the introduction of contaminants to the reservoir outlet, enhance downstream water quality, and decrease the reservoir recovering (cleaning) time.

The process of fate and transport of pollutions in waterborne systems are described by different models and methodologies. In recent decades, numerous numerical hydrodynamic and water quality simulation models have been developed to assist the assessment of pollution transportation. To predict the aqueous concentrations of sparingly soluble compounds resulting from oil, fuel, or chemical spills onto rivers, a numerical simulation model has been developed by Hibbs et al. (1999). Imberger and Petterson (1981) developed a 1D hydrodynamic and water quality model to simulate temperature, salinity, and density in lakes and reservoirs. A one dimensional water quality simulation model to describe the fate and transport of temperature and 7 water quality parameters in rivers and/or reservoirs was developed by Willey et al. (1996). Cole and Wells (2008) developed 2D hydrodynamic and water quality simulation model to model basic eutrophication processes in rivers, reservoirs, estuary, and combination of water bodies.

Providing enhanced modeling tools to assist decision making process requires spill responses management systems. An Incident Command Tool for Drinking Water Protection (ICWater) has been developed by implementing a set of waterborne transport tools consist of RiverSpill, PipelineNet (Samuels and Bahadur, 2006). Concise summaries of current conditions and forecasts of future consequences of terrorist acts on public water supply safety have been provided by the integrated system of ICWater. GIS and simulation models are the main components of systems describe the fate and transport of pollutions in rivers and/or water distribution network system. An advanced modeling technology within a visual framework was developed by Camp et al. (2010) to improve decision-support process. The Spill Management Information System (SMIS 2.0) consisted of 3D hydrodynamic and chemical spill modeling system tool and geographic information systems (GIS) spatial environment. The predicted spill fate and transport as model responses was presented by GIS spatial environment.

Reservoirs as artificial constructions created to benefit a population regarding different objectives. Restriction these infrastructures due to any event cause worst

impacts with economic representations. Accident chemical spill restricted the reservoir availability during perceptible periods. In spite of advance research on spill response systems in rivers and/or water network systems, there are no study on developing a PSRMM to manage the responses in accident pollution injections in reservoirs. Therefore, a PSRMM has been developed by the authors to design the emergency planning in reservoirs. Similar to any accident pollution events in water bodies, reducing the unsuitable effect of pollution is the main aim of PSRMM in reservoir. Managing the pollution spill responses in reservoirs consist of prediction the fate and transport of pollution, minimization the reservoir clean up time, minimization the magnitude and frequency of water quality standard violation, and etc. Due to close relation of water quality and quantity in reservoirs, deriving optimum reservoir operational strategy would be an efficient solution to decrease the reservoir temporary suspecting time and/or immigration the magnitude and frequency of downstream water quality standard violation. To achieve these goals determining the optimum reservoir operation through selective withdraw framework would be as an efficient approach to control the downstream pollution and managing the reservoir cleanup time. During the several last decades, more studies have been accomplished to consider the advantage of the close relationships existing between quality and quantity variables with regard to effectively maximize the benefits for water utilization while simultaneously enhancing its quality (Loftis et al., 1985; Hayes et al., 1998; Chaves et al., 2003; Chaves and Kojiri, 2007; Kerachian and Karamouz, 2007; Shirangi et al., 2008). The researches have been implemented the jointly water quality and quantity issues for integrated water resources management.

In this research, a PSRMM consists of integrated Spatial System Analyzing (SSA) model, numerical, two-dimensional hydrodynamic and water quality model coupled with multi objective optimization algorithm would developed as an efficient tool for immediate scenario analysis, evaluation of 'what-if' scenarios, emergency responses, contaminant remediation, reservoir operation management within the short period after accident pollution spill. The coupled simulation-optimization (SO) approach controls supplying reliable and safe water through reducing the reservoir cleanup time, frequency of water quality standard violation, and decreasing the downstream worst water quality.

This research focuses on the controlling of reservoir releases that influence the fate and transport process of conservative pollution. Optimal strategies for release of water from stratified reservoir, given downstream water quality requirements and reservoir clean up time after accident pollution spill which are obtained using a linked simulation-optimization model. The reservoir operation policy determines the release from the reservoir in a given management period. The applied simulation model, CE-QUAL-W2 (Cole and Wells, 2008) is capable to incorporate various physicochemical processes. A Multi Objective Particle Swarm Optimization (MOPSO) technique is applied to generate Pareto optimal solutions to derive optimum operational strategy in selective scheme in Ilam Reservoir as a drinking source of Ilam city.

## **2 POLLUTION SPILL RESPONSE MANAGEMENT MODEL (PSRMM)**

The developed Pollution Spill Response Management Model (PSRMM) model in this research combines Spatial Systems Analyzing (SSA) model with two-dimensional

(2-D) surface water quality and hydrodynamic model, CE-QUAL-W2 Version 3.5, for surface water quality modeling and Multi Objective Particle Swarm Optimization (MOPSO) model for enhanced spill response support. The model input data, executions, and results representation have been implemented through programming in Intel Visual Fortran environment. The Spatial Systems Analyzing (SSA) model is programmed in Intel Visual Fortran environment to map the pollution spill location in spatial segmentation of hydrodynamic and water quality model. In this research, SSA model provides an interface between the PSRMM and its users, linking inputs, the real time data, outputs, and managing the temporal and spatial databases.

In simulation routine of PSRMM, the numerical simulation model (CE-QUAL-W2) is implemented into scenario analyzing, evaluation various scenarios, estimating the fate and transport of pollution in reservoir, track the pollution plume, and identifying the threat zones. This water quality model is linked to the MOPSO in SO routine of PSRMM to obtaining the optimal reservoir operation in selective withdraw framework to achieve the defined goals by decision makers and/or Incident Commanders. The various boundary conditions defined by MOPSO algorithm affect the transport process of pollutions in stratified reservoir. The natural process of thermal and vertical variation of pollution in the reservoir is modeled by CE-QUAL-W2 model. The coupled simulation-optimization model provides the optimum Pareto reservoir operational strategies in selective withdraw scheme.

## 2.1 Simulation Model

CE-QUAL-W2 model is a two dimensional laterally averaged hydrodynamic and water quality model supported by the U. S. Army Engineering Waterways Experiment Station. The temporal and spatial variation of water movement, temperature, and constituents are predicted by CE-QUAL-W2 model. Application of this model is based on minor lateral variation assumption. The model is applicable to lakes, rivers, and estuaries that do not exhibit significant lateral variability in water quality conditions. It allows application to multiple branches for geometrically complex waterbodies with variable grid spacing, time variable boundary conditions, and multiple inflows and outflows from point/nonpoint sources and precipitation (Steg, 2007; Cole and Wells, 2008). Advantages to choosing CE-QUAL-W2 model as simulation section of PSRMM includes addressing the concern contaminations, providing the output from upstream to downstream in the reservoir and at depth, providing adequate detail of analysis, and opportunity for advanced researchers to modify the code according the desired requests.

## 2.2 Optimization Model

A multi objective optimization problem has a number of objective functions which are to be minimized and/or maximized. The multi objective problem is defined as Eq. 1(Deb (2001)):

$$\begin{aligned}
 & \text{Maximize / Minimize} && f_m(x) && m = 1, 2, \dots, M \\
 & \text{Subject to :} \\
 & g_j(x) \geq 0 && j = 1, 2, \dots, j && (1) \\
 & h_k = 0 && k = 1, 2, \dots, K \\
 & x_i^L \leq x_i \leq x_i^M && i = 1, 2, \dots, n
 \end{aligned}$$

The optimization problem is to find the vector  $x^* = (x_1^*, x_2^*, \dots, x_n^*)$  which solves the above equations.

**Non-dominated Solutions:** Among a set of solutions  $P$ , the non dominated set of solution  $P'$  are those that are not dominated by any member of the set  $P$  (Deb, 2001).

**Global Pareto-optimal Set:** The non-dominated set of the entire feasible search space is the Global Pareto- optimal set (Deb, 2001).

### 2.2.1 Single Objective PSO

Particle swarm optimization (PSO) is a decade old concept in global optimization domain. Since PSO is based on population, it shares many similarities with evolutionary algorithm for solving real-world optimization problems. In PSO, the particle flies randomly in  $D$  dimension search space, the position and velocity of  $i$  th particle is represented as  $X_i = (x_{i,1}, x_{i,2}, x_{i,3}, \dots, x_{i,D})$  and  $V_i = (v_{i,1}, v_{i,2}, v_{i,3}, \dots, v_{i,D})$ , respectively. With increased iteration, the swarm will move towards the global best position (gbest) by keeping track of their personal best (pbest). In a  $D$  dimension search space the pbest of the  $i$  th particle is represented as  $pbest_i = (p_{i,1}, p_{i,2}, p_{i,3}, \dots, p_{i,D})$  and the gbest of the whole swarm is represented as  $gbest = (g_1, g_2, g_3, \dots, g_D)$ . The PSO algorithm updates the velocity and position of each particle by following Eqs. (2) and (3), respectively (Sabat et al. (2011)).

$$V_i(t) = W_{itera}^t \cdot V_i(t-1) + C_{1t} \times r_1(t) \times (P_{best(i)} - X_i(t)) + C_{2t} \times r_2(t) \times (g_{best(t)} - X_i(t)) \quad (2)$$

$$X_i(t) = X_i(t-1) + V_i(t) \quad (3)$$

where  $C_{1t}$  and  $C_{2t}$  are the learning factors that determines the relative influence of cognitive and social component, respectively (Eq. 4 and 5).  $r_1$  and  $r_2$  are real numbers chosen uniformly and at random in the range of [0,1]. The  $g_{best(t)}$  is the global best in  $t$  th iteration and  $P_{best(i)}$  is the personal best of  $i$  th particle in  $t$  th iteration.

To incorporate better compromise between the exploration and exploitation of the search space in PSO, time variant acceleration coefficients have been introduced as below.  $C_1$  has been allowed to decrease from its initial value of  $C_{1i}$  to  $C_{1f}$  while  $C_2$  has been increased from  $C_{2i}$  to  $C_{2f}$  using the following equations as below (Tripathi et al. 2007).

$$C_{1t} = (C_{1f} - C_{1i}) \frac{iter}{\max iter} + C_{1i} \quad (4)$$

$$C_{2t} = (C_{2f} - C_{2i}) \frac{iter}{\max iter} + C_{2i} \quad (5)$$

The presence of inertia weight balances between exploration and exploitation of the swarm. An inertia weight in the range of [1.2,0.9] was found to be a good choice, but the linearly decreasing inertia weight with increasing iterations also helps for faster convergence (Shi and Eberhart, 1998). The inertia weight is decreased linearly with increasing iterations using Eq. (6).

$$W_{inertia}^t = (W_1 - W_2) \times \frac{\max iter - iter}{\max iter} + W_2 \quad (6)$$

Where  $W_{inertia}^t$  is inertia weight at  $t$  th iteration,  $W_1$  and  $W_2$  are the maximum and minimum value of inertia weight, respectively.  $\max iter$  refers to maximum number of iterations. To allow the PSO algorithm to explore the search space to a greater extent, while obtaining better diversity, a mutation operator has been applied, that is based on the one introduced by Tripathi et al. (2007).

### 2.2.2 Multi Objective PSO

Multiple non-dominated solutions are sought in multi objective PSO (MOPSO). In multi objective approach, the *pbest* and *gbest* vectors are not unique and their defining is different from single objective optimization problems. Numerous researches on MOPSO extensions of the particle swarm have been proposed since several decades (Coello Coello and Lechuga, 2002; Parsopoulos & Vrahatis, 2002; Tripathi et al., 2007; Tsai et al., 2010). The applied multi objective technique in this study is based on the combination of proposed approach by Tripathi et al. (2007) and Tsai et al. (2010).

## 3 CASE STUDY

Ilam Lake has been formed behind Ilam Dam, an earth-fill project built by the Ilam Water Resources Management Company and completed in 2000. The reservoir is 65 meter deep and impounds 340 ha. of stored water at normal water level. It is used for flood control, downstream environmental regulation, and as a main source of municipal and agricultural water for the nearby population in Ilam city. Ilam reservoir as a dendrite reservoir consists of three main tributary, Golgol River, Chaviz River, and Ema River. Applying the CE-QUAL-W2 modeling framework require that a reservoir water body should be segmented into a number of completely mixed water cells. An iterative process has been implemented to determine the proper segmentation of the reservoir based on the bottom bathymetry. In this research, the reservoir is schematized to consist of three reservoir branches, which are one main reservoir water bodies around the water intake (Golgol branch) and two subsidiary (Ema and Chaviz branches). Then, each reservoir branch is segmented along longitudinal direction as well as water depth direction. The main water body is divided to consist of 10 longitudinal segments at the surface with the length 500 m. Each segment is then divided into 2 meter layers in the water column. Study Area of Ilam Reservoir and its main River Basin is presented in Figure 1.

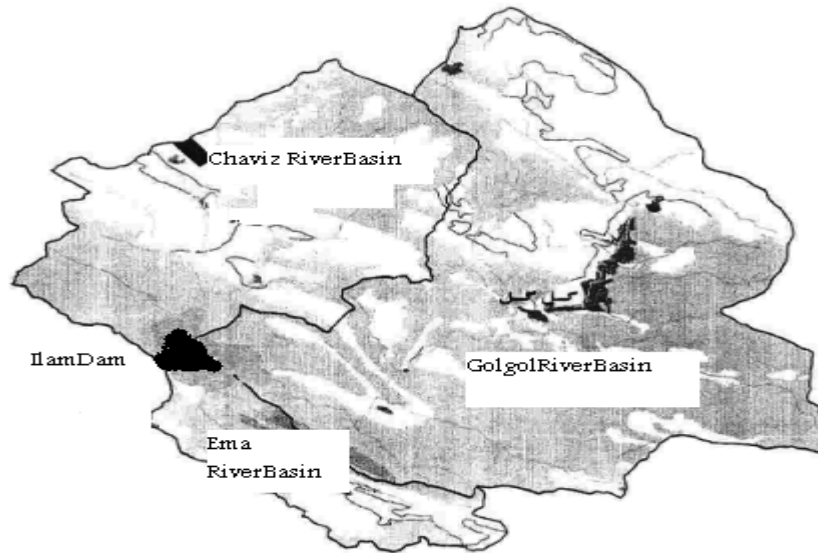


**Figure 1.** Study Area of Ilam Reservoir and its main River Basin

The comprehensive input data for CE-QUAL-W2 hydrodynamic modeling include reservoir topography, meteorological, inflow, temperature of stream information, and outflow. The hydrodynamic model of Ilam Reservoir has been calibrated with data in 2008. The model predicted water surface elevation (WSE) and thermal profiles show good match with daily WSE and monthly thermal profiles field data in 2008.

#### **4 MODEL APPLICATION**

To mitigate the unsuitable effect of sudden pollution spill in Ilam Reservoir, a drinking source of Ilam city, PSRMM has been applied to enhance the decision making process. Providing safe and reliable supply of water for costumers is a main mission of water resources authority in Iran. Recent accident pollution injection into reservoirs supplying drinking waters in Iran increased the concerns about reservoir availability restriction due to contamination. Therefore equipped emergency systems such as PSRMM could be effective tools in providing emergency planning at accident reservoir pollution and mitigating the inadvisable and/or adverse effects. Furthermore, the importance the health of thousand municipal and agricultural users of Ilam Dam signifies the pollution spill response management model application.

PSRMM developed a real-time data management and decision support system that seamlessly integrates real-time data sources, inflow and meteorological data, water quality simulation model, optimization algorithms tool to manage emergency pollution spill in reservoir. The presented results of developed PSRMM in this study relied on the hypothetical prediction of accurate real time forecasting system of inflow and meteorological data. To examine the model applicability, a simulation period of 31 days (Julian Day 400 to 431/ February to March in year) has been selected in this research. As an example of the capabilities of the proposed PSRMM, a hypothetical spill of 5000

kg of conservative chemical material released adjacent to the Golgol branch inflow as a main tributary of Ilam reservoir. The hypothetical truck collisions caused accidental pollutions spills over a period of 12 hours. The hypothetical water quality standard is assumed to be 0.2 mg/L.

With the aid of simulation routine of PSRMM, an immediate scenario analysis has been done to evaluate the temporarily suspended periods at the drinking water utilities (water quality standard; 0.2 mg/L). As a precautionary measure, operations at drinking water utilities along the Ilam Reservoir to be temporarily suspended over a period of more than 31 days.

During accident pollution spill in Ilam Reservoir, the SO routine of PSRMM derived the optimal reservoir operational strategy based on selective framework to minimize the reservoir cleanup time, no of water quality standard violation and worst released water quality concentration. The provided solutions aims to improve the environmental functionality during pollution spill injections with regard to two defined objectives. The SO routine of PSRMM is based on the linked CE-QUAL-W2 model and MOPSO algorithms. The various generated boundary conditions (different reservoir operational strategy in selective scheme) by MOPSO are defined the fate and transport process of contaminant in reservoirs which is evaluated by CE-QUAL-W2 model. The techniques of MOPSO algorithm guide the search direction to derive the Pareto optimal solutions. The defined objective functions in this study are conflict with each other. Decreasing the reservoir recovery time is conversely proportional with downstream worst water quality concentration.

The Defined objective function in this research is as below (Eq. 7)

$$\begin{aligned} \text{ObjectiveFunction}(1) = \\ \text{Min}(\alpha + \beta \cdot \frac{NSV}{S.P.} + \gamma \cdot \frac{NMWL}{S.P} + \lambda \cdot \frac{NMaxWL}{S.P}) R.R.T \end{aligned} \quad (7)$$

$$\text{ObjectiveFunction}(2) = \text{Min}(MaxC_{out})$$

where  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\lambda$  are weights assigned to the reservoir recovery time ( $R.R.T$ ), number of water quality standard violation ( $NSV$ ), the number of the minimum water surface level violation ( $NMWL$ ), and the number of the maximum water surface level violation ( $NMaxWL$ ).  $MaxC_{out}$  and  $S.P$  are the maximum quality concentration of released hazardous material and simulation period which is equal to 31 days in this study. The constraints such as minimum and maximum permissible reservoir volumes, and minimum and maximum allowable release rates, and no of water quality standard violation is considered in this research. The penalty approach is used to reformulate the constrained problem into an unconstrained problem. Ilam Dam has three outlets; the bottom outlet is used for sediment flushing and the middle outlet (outlet 1) and upper outlet (outlet 2) can be used for selective withdrawal scheme. Decision variables of the optimization model with the water quality objective are the release from the outlet 1 and outlet 2 in the pre-determined ranges. The decision variables of this evolutionary algorithm are number of outlet multiplied to simulation days ( $2 \times 31$ ). The presented result is obtained after testing and evaluating different parameter combinations.

The determined Pareto optimal solutions of SO routine of PSRMM in Ilam Reservoir control the released water quality concentration, increase the pollutant degradation and rate of hazardous material removal in Ilam Reservoir. The Linked

simulation-optimization model determines the optimal operational strategies in selective withdraw framework for real time operation. The Pareto optimal front of MOPSO\_CE-QUAL-W2 as a element of PSRMM has been represented in Figure 2.

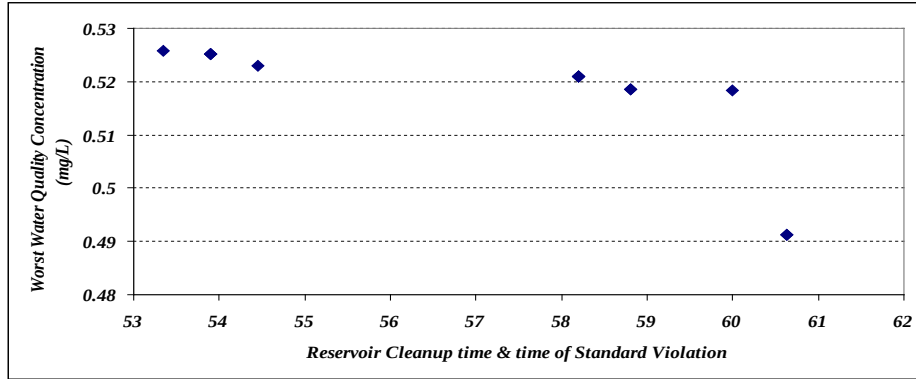


**Figure 2.** The Trade of between Worst Water Quality Concentration and Reservoir Cleanup & Standard Quality Violation Times

The detail of reservoir cleanup time, times of water quality standard violations, and worst downstream water quality obtained based on SO routine and simulation analysis routine of PSRMM are presented in Table I.

**Table I.** The Detailed Results of Pareto Optimal Solutions and Scenario Analysis Routine of PSRMM

|                                                  | Solution<br>(1) | Sol.<br>(2) | Sol.<br>(3) | Sol.<br>(4) | Sol.<br>(5) | Sol.<br>(6) | Sol.<br>(7) | Scenario<br>*1 | Scenario<br>*2 |
|--------------------------------------------------|-----------------|-------------|-------------|-------------|-------------|-------------|-------------|----------------|----------------|
| Reservoir<br>Cleanup<br>Times                    | 24              | 22          | 25          | 24          | 22          | 24          | 22          | 23             | 23             |
| No of Water<br>Quality<br>Standard<br>Violations | 18              | 19          | 18          | 21          | 20          | 19          | 18          | 18             | 20             |
| Worst Water<br>Quality<br>Concentration          | 0.521           | 0.52<br>52  | 0.49<br>13  | 0.52<br>59  | 0.51<br>83  | 0.52<br>09  | 0.52<br>58  | 0.5768         | 0.5519         |

The time series of released water quality concentrations during management period has been shown in Figure 3. Two Scenarios in PSRMM are defined based on inflow rate. In scenario 1; the daily release are equal to daily inflow which is withdrawn from middle outlet. In scenario 2, the daily releases are equal to daily inflow which is withdrawn from middle and upper outlet equally. As is clear, the worst released water quality of the derived optimum scenario by SO routine of PSRMM is lower compared with generated scenario by scenario analysis routine of PSRMM. The optimum scenario of SO routine, Pareto solution 3, is defined as reservoir operation strategy in selective framework which reservoir release in some days are zero. This strategy allows the

contaminant to be settled in lower layers and/or diffused within the reservoir to mitigate the withdrawn water quality concentration although the reservoir cleanup time would be longer compared with strategy (2). The time series withdrawn water from each Ilam Reservoir outlet according to the one of the Pareto optimal solution is presented in Figure 4.

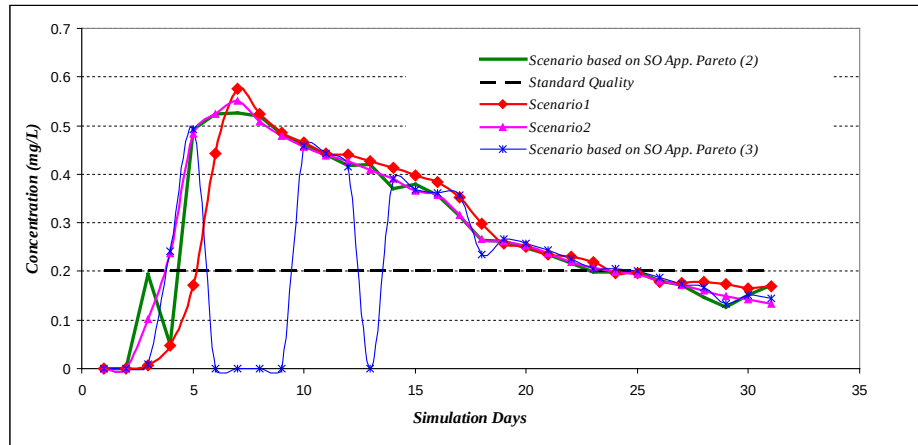


**Figure 3.** Time Series Released Downstream Water Quality Concentration

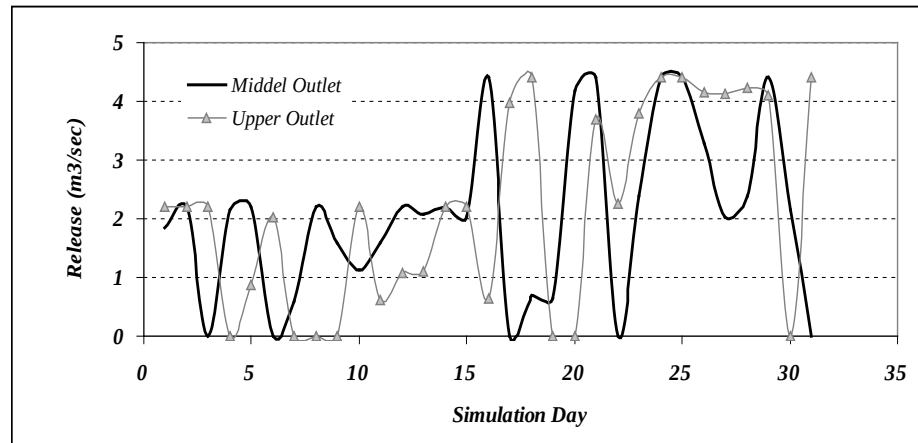


**Figure 4.** Time Series Withdrawn from Each Reservoir Outlet (One of the Pareto Solution)

## 5 CONCLUSION

In this research, PSRMM was proposed to assist in accident spill response efforts on Ilam Reservoir. The simulation analysis and SO routine are the main components of PSRMM. PSRMM included spatial system analyzing (SSA) model, a 2D hydrodynamic and water quality simulation model (CE-QUAL-W2) coupled with Multi Objective Particle Swarm Optimization (MOPSO) technique. An immediate scenario

analysis has been done to evaluate the temporarily suspended periods at the drinking water utilities (water quality standard; 0.2 mg/L) in Ilam Reservoir. Then SO routine of PSRMM controls the reservoir release concentration and reservoir cleanup time with providing Pareto optimum reservoir operational strategies in selective withdraw framework.

The linked CE-QUAL-W2 model, as a detailed description of systems responses to planning and design solutions, and MOPSO provided the Pareto optimum solutions which minimize the reservoir cleanup time, no of water quality standard violations, and downstream worst water quality. The meaningful management strategies, Pareto optimum solutions provided by MOPSO, affect the system responses to mitigate the adverse effects of pollution spill injections in Ilam Reservoir and/or degrade the contaminates in Ilam Reservoir as a drinking source of Ilam city.

The water quality simulation model (CE-QUAL-W2) provided propagation and identification of impact locations and response resources in proximity of the spill. The coupled simulation-optimization model as PSRMM component improving the response time and providing the mitigation strategy through optimal reservoir operation in selective withdraw scheme in the accident pollution spill events. Theoretical analysis and simulated results indicated that the SO routine in PSRMM is capable of reasonably predicting acute effects of chemical spills injection on downstream water quality concentrations and Ilam reservoir cleanup times.

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