EVALUATION OF RIVER WATER QUALITY MANAGEMENT LEVEL BASED ON COD-LOADS OPTIMALLY ALLOCATED TO POINT AND NONPOINT SOURCES

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A method is presented to evaluate the level of river water quality management using a multiobjective linear programming model, ε-RO model, and a Geographic Information System (GIS). The GIS can help delineate catchment boundaries influencing a diagnosed section of a polluted river, find outfalls of wastewater, and estimate discharge and COD (Chemical Oxygen Demand) load with a land use map and elevation data. COD concentration of discharged wastewater from NPS (nonpoint source) except forest is considered controllable in an optimal wasteload allocation, thus the polluted water is called CNPS (controllable NPS)-born wastewater. In contrast, since COD loading from forest is considered quite difficult to control, it is treated as uncontrollable. Wastewater discharges from PSs (point sources), CNPSs and forests are all given as known to the optimization model. The concentrations of COD and DO (Dissolved Oxygen) in the river, affected by lateral inflows and outflows, are supposed to be governed by one-dimensional steady-state transport equations. Since hydraulic condition and water quality environment in the river change uncertainly, stochastic approach is needed in mathematical programming of water quality management. Therefore a framework of robust optimization (RO) is adopted to control input parameters' influence on solutions under uncertainty using a scenario-based description of parameter realizations. In the context of managing river water quality in one year, each scenario is assumed to correspond to each month. By employing the ε-constraint method as one for generating noninferior solutions of a multiobjective optimization problem, the ε-RO model is formulated. Objectives defined in the ε-RO model are to maximize total allowable COD load (prime objective) and to keep river water quality close to the standard values. Main constraints considered in the model are: (1) COD and DO transport equations that are discretized by the finite element method at all scenarios; (2) Water quality standards at loading points and/or stream junctions in the river at all scenarios; (3) Water quality limitations at the downstream end; (4) Effluent limitation standards for wastewater from PSs at all scenarios; (5) Lower limit on expected total PS-born COD load; and (6) Upper and lower limits on the rate of optimal CNPS-born COD load to the current one at every subcatchment outlet.

The ε-RO model is applied to a downstream part of Yasu River (18.6km), Shiga Prefecture, Japan. COD loads originate from 74 PSs, clustered NPSs and clustered forests in each of the nine subcatchments which compose the whole catchment whose area is 89.6km^2. Flow analysis and calibration of the finite element model for COD and DO transport, which is embedded in the optimization model as equality constraints, in the river are conducted to identify two scenario components, i.e., deoxygenation coefficient and reaeration coefficient. The ε-RO model is solved by the simplex method subject to decision-makers' preferences supposed with parameter values of ε_2, ε_3, and ε_4 pertaining to objective criteria except the prime one and upper and lower limits on the rate of optimal CNPS-born COD load to the current one at every subcatchment outlet, r^{npl} and r^{npu}, respectively. Five noninferior solutions A through E and the current management policy are compared with each other (Table 1). Solutions A to D are produced by the model developed in this study, while Solution E is obtained from our earlier optimization model (Kawachi and Maeda, 2004a, 2004b) where loads from all the NPSs are assumed as uncontrollable. Note that Solution A allows the same amount of total PS-born COD load as Solution E, and moreover, the larger amount of total load from CNPS than both Solution E and current policy though better in-stream water quality is expected. Relatively small deviations of values of r^{npl} and r^{npu} from 1 in Solution C prohibit drastic change of CNPS-born COD load, which results in less gross load permitted (Table 1). In Solution C, however, deterioration of stream water quality is suppressed along the whole reach, satisfying water quality standard (2.3mg/L) at the downstream end (Table 1 and Fig. 1). Thus a decision-maker who prefers improving water quality in the river to increasing total allowable load can chose Solution C as the most favorable alternative of all. Fig. 2 illustrates optimal expected COD load and its concentration of wastewater allotted to PSs in Solution C. If the solution is employed as a policy for the management, 20 out of 74 PSs is required to improve quality of wastewater to observe the allowed level. It can be concluded that the model handling COD loading from NPS except forests and the same from PS as controllable could generate more strategic plans of load allocation than the model previously developed. The diagnostic results reveal that the optimal allocation exists which upgrades river water quality even if both PS- and NPS-born COD loads are increased.

Table 1. Characteristics of noninferior solutions and current policy

Solution	Mean COD concentration in river water (mg/L)	COD concentration at downstream end (mg/L)	Total PS-born COD load (g/s) [a]	Total CNPS-born COD load (g/s) [b]	Total controllable COD load (g/s) [a+b]
A	2.553	2.333	4.718	5.644	10.362
B	2.500	2.252	4.718	4.861	9.579
C	2.488	2.292	4.694	4.897	9.591
D	2.491	2.323	4.694	5.296	9.990
E	2.611	2.299	4.718	5.433	10.151
Current	2.662	2.357	4.694	5.433	10.127

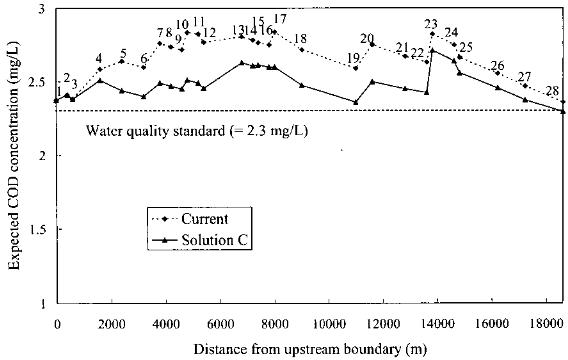

Fig. 1 Expected COD concentration profile in Solution C
(1-28 along line are node numbers.)

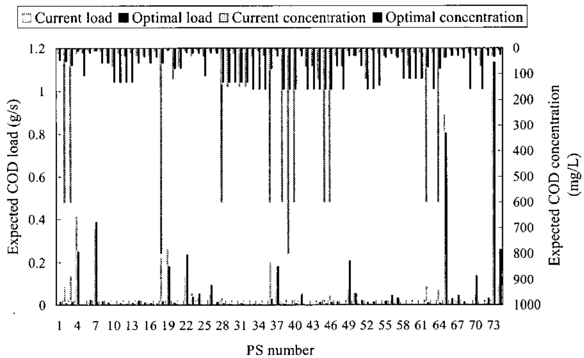

Fig. 2 Optimal PS-born COD loads and wastewater qualities in COD (Solution C)

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