

## **The establishment of water protection zones for water quality improvement in river basins**

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**Abstract** The results of practical experience in establishing a water protection zone (WZ) for water bodies (water courses and reservoirs) in Ukraine have been analysed and assessed, and corresponding databases for water environments, which take into account the real environmental conditions in riparian areas of river basins similar to those found in Ukraine, have been established. This has allowed the development, verification and validation of methodology, models and typical, practical functional schemes (with computerized support) for optimum creation, exploitation and regime control of WZs based on modern notions about areas of special environmental status of water bodies, and taking into account principles of regionalization, function planning and monitoring and the concept of system sustainability.

### **INTRODUCTION**

The freshwater contamination level and, as a result, the toxic, bacteriological and radioisotope characteristics of water bodies, including rivers and streams, and natural and artificial lakes, ponds, etc.) in the most of the river basins of Eastern Europe, including Ukraine, testify to an environmental situation in crisis and to the incapability of vital environmental systems for natural self-regulation. In such conditions, traditional environmental protection measures based on available technical and technological solutions may be limited, and a special place belongs to complex measures involving the step by step creation of a water protection zone (WZ). The latter may provide a relatively simple and effective option for improving the environmental state of water bodies, especially by preventing the occurrence of non-point pollution which is a problem on a large scale through surface and subsurface runoff from agricultural areas or land which is contaminated, primarily by radioactivity.

### **WZs — PROBLEMS, METHODOLOGIES AND SOLUTIONS**

#### **Basic positions**

Previous experience in the countries of the former Soviet Union (Samoylenko, 1989, 1993) has shown that the use of WZs to protect the natural resources of water bodies (water, land, biological, recreational and others) from problems such as exhaustion and pollution is complicated by:

- (a) the many different processes operating in water bodies and their coastal zones, and the considerable diversity in size and nature of water bodies,
- (b) insufficient correlation, completion and inspection of the organizational-technical solutions developed for WZs,
- (c) non-observance, even regarding the imperfect environmental protection law currently in force, of environmental (ecological) standards and requirements for WZs, which in regard of the area along the banks of a water body and the adjoining water table constitute a particularly sensitive environment.

The most blatant contravention of standards and requirements include:

- (i) soil ploughing up to the waterline or shore (bank) ledge,
- (ii) location of agricultural activity directly in the waterside zone and discharge of sewage into the water body,
- (iii) omission of simple biotechnical measures, such as bank forest shelter belts, etc.,
- (iv) herding of animals in the area close to the banks which causes deterioration in landscape stability through destruction and disturbance of the vegetation cover,
- (v) waterside dumping as a result of the fertilizer storage, uncivilized recreation and other negative environmental consequences of local economic and social activity.

The definition of such consequences, their correct assessment and the implementation of adequate actions for the removal of regional and local dangerous environmental impacts of point and, especially, non-point sources are difficult because of objective and subjective reasons, among which is the lack of recent methodology, including computerized support, for the establishment of WZs.

For this reason, the Ukrainian Environmental Centre (EC) "SIC WEMOW" has collated worldwide experience on the creation of areas with special environmental status and has used this information, in conjunction with the preliminary accomplishments of its own work (Samoylenko, 1989), to help in formulating the attributes of WZs and watersides, and in developing the basis and practical computerized procedures for their organization and regime management. On the basis of this procedure, a water protection zone is defined as the contact zone between the water mass and the shore (bank), where a special regime of land use and economic activity is established for environmental, and above all water and shore protection which ensures the necessary level of natural-technical and sanitary (i.e. environmental) conditions both in the WZ and the water body as a whole. The waterside is the part of the WZ with the most intensive development of environmentally unfavourable processes during water/shore interaction, where a severe regime, from restriction right up to total prohibition, of economic activity and land use is established.

The criteria for creating and distinguishing water protection zones and watersides in different physical geographical conditions of river basins can be determined with the help of existing models and schemes (Samoylenko, 1993) from the characteristics of undesirable (environmentally dangerous) geological-engineering, hydrogeological, hydrogeomorphological and other processes and agents. The components required for the establishment of optimum WZs (with corresponding software products), proposed by EC "SIC WEMOW" and based on the concepts of stochastic environmental hydrology (Samoylenko, 1993), include:

- (a) environmental regionalization (or substructuralization) of the WZ complex (Samoylenko, 1993)

- (b) WZ planning (including distinguishing of functional zones) with elaboration of typical WZ schemes (Samoylenko & Tavrov, 1996) for reconstruction of land and water courses in order to create a controllable environmental-technical shore system in the WZ (Samoylenko, 1993),
- (c) monitoring of environmental state and natural processes in the WZ during their exploitation (Samoylenko, 1996) for water quality management.

### WZ regionalization

The regionalization of water protection zones is supported by the representation of a WZ as a complicated dynamic environmental-technical system (denoted in this paper by *WZ*), which is defined by characteristics (non-normalized values) or parameters (normalized values) and consists of the representation of sign-sets for environmental variables by means of random functions. The most generalized level of modelling involves sets of characteristics and parameters, while at a more specific level, components and elements are used to reveal peculiarities in the temporal-spatial structure of ecosystems, and are based on computerized field databases which are updated from monitoring networks.

The most generalized level of modelling involves the following combinations:

$$(WZ_{ss}) \in [(HL);(HC);(HMD);(ET);(HB);(RE);(HG);(OS)] \quad (1)$$

$$(WZ_{ch}) \in [(HL)(w);(HC)(w)...(OS)(w)] \quad (2)$$

$$(WZ_{pr}) \in [F(HL)(w);F(HC)(w)...F(OS)(w)] \quad (3)$$

where  $WZ_{ss}$ ,  $WZ_{ch}$  and  $WZ_{pr}$  are the sign-sets, characteristics and parameters, respectively of the water protection zone ecosystem; *HL*, *HC*, *HMD*, *ET*, *HB*, *RE*, *HG* and *OS* are hydrological, hydrochemical, hydrogeomorphological, ecotoxicological, hydrobiological, radioecological, hydrogeological, and others sets, respectively; *w* is the value (quantity) of elementary experimental results for definite WZ temporal-spatial coordinates during field, laboratory or computerized WZ testing;  $F(HL)(w)$ , etc. are the normalized definite WZ ecosystem characteristics, i.e. the parameters of the WZ which have been normalized by the mean, or deviations from the mean, etc.

WZ dynamics, caused by human impacts, are simulated as an independent combination of random functions of WZ characteristics or parameters, i.e.:

$$D(WZ_{pr}) = [F(HL)(w,R,t);F(HC)(w,R,t)...F(OS)(w,R,t)] \quad (4)$$

where  $F(HL)(w,R,t)$  is a random function of a WZ sign-set; *R* is a spatial element to the random function in a specific system and is defined from geographical coordinates and a depth/height (*d/h*) definition as  $R \in [x,y,z,R_{dh}]$ , and *t* is continuous (real) time.

Diagnostics and prediction of WZ dynamics have been obtained and verified (Samoylenko, 1993) using *c.* 8000 initial temporal-spatial series of environmental information from >3000 water bodies. All the necessary WZ stochastic structure characteristics have been derived and verified at the specific level of representation from parameter elements in the sign-set of every ecosystem. This involved *c.* 50

main elements, and included, for example, concentrations of long-lived radionuclides, caesium-137 and strontium-90, in water ( $^{137}\text{Cs}/^{90}\text{Sr}$  dissolved,  $^{137}\text{Cs}$  suspended), and the near-shore zone and bottom sediments ( $^{137}\text{Cs}/^{90}\text{Sr}$  contamination density) for the radioecological set; changes in subsurface water levels, etc. for the hydrogeological set; heavy metals, chlororganic pesticides etc. for the ecotoxicological set; amplitude of surface watermarks, special probability watermarks, etc. for the hydrological set; organic and mineral contaminants, pH, oxygen, mineralization, etc. for the hydrochemical set; and wave/current parameters, shore/bank destruction, water turnover, etc. for the hydrogeomorphological set.

Normalization involved:

- (a) Joint or particular distribution functions for probability of exceedance (P) were derived for random functions of WZ parameter elements using a modified log-normal distribution scheme or modified gamma distribution stochastic law — such “ecostochastic” functions (e.g.  $P[F(ET)(w,R,t)]$ , etc.) allow the temporal-spatial probability of parameters to be calculated or solved as an opposite probability. The proved random function independence in other ecosystem sign-sets/levels makes it possible to estimate the synergetic effect of WZ environment pollution/disturbance agents.
- (b) Temporal-spatial correlation and spectrum density parameter functions allow parameter probability definition to be calculated for WZ diagnostics.

It should be noted that modelling options provide for complex probability four-dimensional environmental regionalization (or region distribution) as a way to distinguish the homogenous parts of a WZ, which is required for fixing ecological-economic costs in planning the natural resources utilization of WZs and water bodies.

In this study, the distribution of regions and zones, including length/depth/height parameters along the whole waterline, depends on the delimitation in space and time of environmental-technical compartments of different level in which the interaction processes between atmosphere, hydrosphere, lithosphere, biosphere and human impact on ecosystems are adequately understood. Compartments of different level (sub-ecosystems, sub-complexes, etc.) are defined as lower range regions in the principal WZ zone compartments of the shallow water subzone, waterside subzone, shore or bank subzone, and biological hyper-subecosystem. The WZ regionalization research procedure is based on the following quantity/quality criteria and model parameter integration and application:

- (a) landscape peculiarities of a WZ and its adjoining drainage basin; bed morphology and morphometry of the water body; hydrological and hydrogeomorphic regularities,
- (b) geological-geomorphologic and hydrogeological coastal zone peculiarities; hydro- and geochemical characteristics, including toxic and radioactive properties of coastal water and shore conditions; and the concentration of contamination compounds (organic, mineral, radioisotope, etc.) entering water bodies by surface and subsurface runoff,
- (c) WZ subecosystem self-regulation and self-purification abilities; sediment genesis types;
- (d) exploitation regime of the water body; area and causes of pollution entering a water body from the waterside; existing nature of environmental protection measures in a WZ and some other regularities.

Practical implementation of WZ regionalization is provided by formation and verification on the basis of a uniform property and the isotropy of representative random fields for WZ parameters both during different time series (month, season, etc.) and for different depths and heights. The principal division of water bodies during regionalization distinguishes streamflows and reservoirs. On the whole, the internal (water body) border of a WZ begins from the border of the surf zone in reservoirs or a calculated low watermark in the case of streamflows. The external (land) border of a WZ is varied and is marked by the furthest extent of environmentally dangerous processes and might include local basin borders, the line of predicted shore destruction, the computed extent of subsurface water, the borders of existing territories with environmental protection status, etc.

### **WZ planning and monitoring**

The aim of WZ planning is to define multipurpose functional regions/zones which have typical WZ schemes based on the regionalization results for WZs. The optimum WZ structure should be selected according to the environmental conditions required in the WZ.

Planning depends on:

- (a) ecological-economic criteria involving tariffs placed on the natural resources of a WZ, definitions of quantity and quality in connection with payment for resource utilization, and regulations (structure of recreation, limits, etc.),
- (b) development of techniques of WZ resources allocation under the priority of environmental protection and with the aim of establishing payments for resource utilization, and for the infringement of regulations,
- (c) selection of typical reconstruction schemes which secure the nature, functioning and interaction of the environment inside a WZ established for areas or subareas devoted to industry, rural or urban activity, transport, recreation, etc.; WZ reconstruction must be directed to the creation of controllable environmental-technical shore (bank) systems using constructive and technological solutions such as measures to prevent erosion, flooding and pollution, to protect shorelines and to ameliorate water quality; within these systems, the interaction between a water body and its coastal zone is mostly controlled and negative consequences of such interaction are sufficiently limited or excluded,
- (d) design and implementation of an adequate monitoring network of natural processes in the WZ as an information and simulation system for observation, estimation and prediction and database creation of environmental conditions in the WZ and water body in order to support environmental protection decisions and identify the impacts of water body contamination.

Monitoring, together with modelling, allows the definition of long- and short-term changes and sustainability for WZs. Sustainability is identified as a combination of direct stability and reliability with regard to the effects of synergetic environmental pollution agents and environmental risk assessment (cost/benefit) criteria. Direct stability relates to stability in the temporal development of WZ compartments and in observed ecological parameters, while reliability refers to the ability of the WZ to fulfill the positive social-economic, and particularly environmental protection, functions.

The sustainability level of a WZ ( $SL_{wz}$ ) can be defined as the superposition function of the following elements:

$$SL_{wz} = f(D_{wz}; R_{st}; R_{wz}; SR_{wz}; E_{wz}) \quad (5)$$

where  $D_{wz}$  is the WZ ecosystem dimension;  $R_{st}$  is the stability index of constructive and technological environmental protection solutions under WZ reconstruction;  $R_{wz}$  is the index of economic activity restriction;  $SR_{wz}$  is an index of WZ regulation (self-regulation) processes;  $E_{wz}$  is the index of WZ creation effectiveness, which is determined both by the extent of water protection achieved (limitation or elimination of pollution) and the level of rational WZ use, both land and water area, as a portion of the maximum possible level of exploitation without disturbing the environmental protection functions.

After formalization, the optimum WZ dimension, WZ parameters and the sustainability level can be computed by considering them as the random vector,  $Z$ , which is the function of two random arguments,  $X$  and  $Y$ . These arguments are formalized as systems involving the variation of WZ characteristics by random processes, and belong to two sign-sets of WZ environmental state:

- (a) signs of direct WZ environmental conditions (of WZ stability) ( $X$ ),
- (b) signs of WZ social-economic (and environmental protection) function fulfillment level (of WZ reliability) ( $Y$ ).

The joint distribution function of  $Z$  -  $G(Z)$  can be interpreted as:

$$G(Z) = P[Z > z] = P[f(X, Y) > z] \quad (6)$$

Setting by the required reliability of a WZ ecosystem, jointly with sustainability level, where  $G(Z)$  is equated with  $P_n$ , which is the required probability of exceedance, and solving the iteration test, allows the computational parameter probabilities of  $X$  and  $Y$  process systems, separately and together, to be estimated with regard to economic-environmental criteria.

## COMPUTER RESULTS

The general algorithmic scheme for computer modelling to establish water protection zones in river basins includes:

- (a) definition of WZ compartments, WZ ecosystem types and WZ parameters,
- (b) assessment of WZ formation, the ability of its compartments for self-regulation and self-purification, actual and potential social-economic functions of the ecosystem,
- (c) determination of the required social-economic functions for WZ compartments (including the ability for their fulfillment) and connection of these functions with the general WZ regime,
- (d) assessment of the restriction level for undesirable processes in the WZ (waterside) according to WZ functional planning,
- (e) definition of the main processes and agents which do not permit the WZ and its compartments to fulfill the required social-economic functions,
- (f) foundation of monitoring procedures and support for the sustainable functioning of the WZ,

- (g) determination of measures for WZ reconstruction, including steps for WZ compartment transformation into controllable shore (bank) systems,
  - (h) integral assessment of WZ (WZ ecosystem) environmental state (conditions) and the tendencies of this state to change under the protection measures implemented.
- The developed methodology, procedures and software products can be implemented for any river basin in a non-mountainous environment in order to improve the conditions in the water environment and to prevent the freshwater contamination.

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