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WATER QUALITY MANAGEMENT FOR PRESERVING FISH POPULATIONS WITHIN HYDRO-SYSTEM DANUBE-TISA-DANUBE, SERBIA

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Abstract: This paper focuses on the sustainable water quality management of the Hydro-system Danube-Tisa-Danube (HS DTD) which represents a canal network primarily constructed to provide drainage and water for irrigation, but also creates a habitat for aquatic organisms, including significant fish populations. Numerous sources of pollution both point and diffuse degrade the water quality over time, which results in eutrophication and occasional fish kills. Especially polluted is the canal reach Vrbas-Bezdan where mean annual values (period 2002-2011) for total ammonia, total phosphorus and dissolved oxygen are respectively: 6 $mgNH_4/L$, 1.3 mgP/L and 2.3 mgO_2/L. This paper presents a multidisciplinary approach towards the management of HS DTD's water quality by applying an integral methodology into the management process. The methodology used involves the Geographic Information System (GIS), water quality modeling and calculating maximum permissible daily loads of nutrients. Finally, the simulation outputs are presented on the GIS maps where the observed canal reach was colour coded based on water quality levels at various points along its length. The testing done on two cases of fish kills along reaches of Vrbas-Bezdan and Bečej-Bogojevo canal could be further used within the whole canal network for achieving good water quality and supporting the fish populations.

Key words: water quality, canal network, integral methodology, water pollution, fish populations

1. INTRODUCTION

The Hydro-system Danube-Tisa-Danube (HS DTD) represents a canal network primarily constructed to provide flood control, drainage and water for irrigation. Besides its hydro technical function, it is a wildlife habitat for various aquatic organisms and significant fish populations which are occasionally threatened by inappropriate water quality.

The water quality (WQ) of the HS DTD is moderate to good, but some reaches are extremely polluted (Hydrologic Yearbooks, 2002-2011; Džigurski et al., 2014). An example of extremely polluted canal reach is a part of the canal Vrbas-Bečej (Pantelić et al., 2012; Kolaković et al., 2014). The canal reach receives waste waters from point sources, e.g. food processing industries and municipal waste waters, and diffuse sources, such as agricultural runoff (Medbø et al., 2005). All these sources are contributing to pollution of nitrogen and phosphorus compounds (Grabić et al., 2011), which are problems studied and documented in the EU waters (EEA, 1999; European Commission, 2002) as well.

According to La & Cook (2011) occurrences of fish kills in aquatic ecosystems have been attributed to natural phenomena, as well as human modification and pollution of terrestrial and aquatic environments. Various pollutants and unfavorable environmental conditions represent stressors for fish populations it their tolerable limits are exceeded. Freshwater fish are susceptible to lack of oxygen, elevated concentrations of total ammonia and unionized ammonia concentrations (Camargo & Alonso, 2006). Whereas dissolved oxygen represents one of vital factors influencing fish behavior (Kramer, 1987) and survival (Pollock et al., 2007). The influence of ammonium on fish and other aquatic animals has been well studied by a number of authors (Camargo & Alonso, 2006; Tarazona et al., 1987) for about 40 years, since Emerson et al., (1975) formulated the relationship between the concentration of total ammonia, un-ionized ammonia, and pH and temperature levels. Upon scientific knowledge regulations establishing WQ standards for ammonia have been enacted and periodically revised (US EPA, 1999; US EPA, 2013; Environment Canada, 2001; CCME, 2010; Directive, 2006/44/EC). Nevertheless, the effect of ammonia on fish and other aquatic organisms is still an active field of research (Randall & Tsui, 2002; Constable et al., 2003; Zhang et al., 2012). Phosphorus is not directly affecting fish, but its excess leads to eutrophication process which could be harmful to fish. If nitrogen compounds are abundant, phosphorus tends to be the limiting factor for phytoplankton in fresh waters (WHO, 2002).

Complex nature of environmental problems requires integral approach for analyses. One of such aspects assumes linking GIS and WQ models and during past few decades many successful applications were achieved (Srinivasan & Arnold, 1994; Marsili-Libelli & Giusti, 2008). An advantage of the linkage can be seen in easier and more precise quantification of transport and transformation of pollutants along a watercourse. Besides, integral approach means considering important characteristics of a watercourse (e.g. hydraulics characteristics, especially flow rate and water regime, and WQ), data about polluters (e.g. details on number and distribution of polluters along a watercourse, dominating polluting substances) and spreading and transformation of pollutants. Finally, determining pollution load, which a watercourse could receive, and still to maintain satisfactory WQ (i.e. calculating Total Maximum Daily Load – TMDL) could be useful for water management (Piperski et al., 2010).

The aim of the research was to determine unfavorable conditions and possible scenarios for the fish populations along the 14.58 km reach of the Bečej-Bogojevo canal because of occurrence of serious pollution occasionally leading to fish kills. Therefore, an integral methodology has been used comprising of GIS, hydraulic and WQ modeling and calculating Total Maximum Daily Load (TMDL). Furthermore, the WQ model enables examining other possible scenarios arising from pollution within the canal, e.g. effects of exclusion of the biggest polluters and the degree of improvement of the canal WQ.

2. MATERIALS AND METHODS

2.1. Integral methodology

This methodology was designed with the purpose of offering a integral approach to WQ assessment. While the initial idea of the methodology has already been presented (Piperski et al., 2010), in this new research the methodology has been further elaborated and applied to the problem of protecting and preserving fish populations. It is comprised of three phases.

The first phase represents preparation and includes obtaining hydrometric and WQ data, and gathering the maps and data of the study area on both point and diffuse sources of pollution. This phase requires selecting WQ standards for the intended purpose of the research. There are a number of regulations governing WQ standards for total and unionized ammonia (US EPA, 2013; Environment Canada, 2001; CCME, 2010; Directive, 2006/44/EC), total phosphorus (Directive, 2006/44/EC; US EPA, 1986; CCME, 2004) and dissolved oxygen concentrations (Directive, 2006/44/EC). However, standards set by the EU Fish Directive (Directive, 2006/44/EC) are chosen. Besides standards, adequate simulation tools have been selected for hydraulic and WQ modeling, as well as an appropriate GIS tool. This preparatory phase also includes building a GIS database and an optional presentation of input data on maps.

The second phase is focused on modeling the input data. The output of the hydraulic modeling represents an input for the WQ model, which is not necessary in some cases since the WQ model also models the hydraulic properties of the watercourse. In this research, the HEC-RAS hydraulic model was applied in order to obtain more precise hydraulic outputs, which represent the input data for the QUAL2K WQ model. Important to note here is that other models could also be applied instead of QUAL2K, such as AQUATOX (Park et al., 2008). For this research QUAL2K has been chosen because it has already proved successful in modeling conditions characterizing canals in Vojvodina (Grabić et al., 2011; Piperski & Salvai, 2008). Moreover, its application for changes of nitrogen and phosphorus compounds has already been presented in the studies performed by Boyacioglu & Alpaslan (2008), who modeled the influence of nitrates, and Ennet et al., (2008), who modeled nitrates, total ammonia, total nitrogen, as well as inorganic and total phosphorus. Furthermore, it seems that AQUATOX has been designed to suit US EPA regulations, while QUAL2K does not have the possibility of assessing toxicity, thus allowing the user to choose standards that best fit to its specific application. In this case, it is application of standards established by the Water Framework Directive - WFD (Directive, 2000/60/EC) and the Fish Directive (Directive, 2006/44/EC).

Three data sets of hydrometric and WQ measurements were used for calibration and validation: measurements from 23 September, 2009 were used for calibration, and measurements conducted on 4 May and 13 August, 2010 for validation. Input data for QUAL2K for WQ modeling have included following parameters: temperature, dissolved oxygen, pH, conductivity, suspended solids, ammonium nitrogen, nitrate nitrogen, inorganic phosphorus and total phosphorus, as well as meteorological parameters: air temperature, due point temperature, wind speed and cloudiness. Inputs for HEC-RAS included data gathered by hydrometric measurements on two locations on the Becej-Bogojevo canal (14.58 km, and 4.47 km of the reach). Hydraulic modeling resulted in precise determination of its mean velocity and flow rate. The modeling procedure using QUAL2K as well as model calibration and validation is explained in detail in previous research (Grabić et al., 2011). In this research an integral methodology was applied dedicated to the management of WQ in order to support the fish populations. Figure 1 presents the flow chart of the integral methodology.

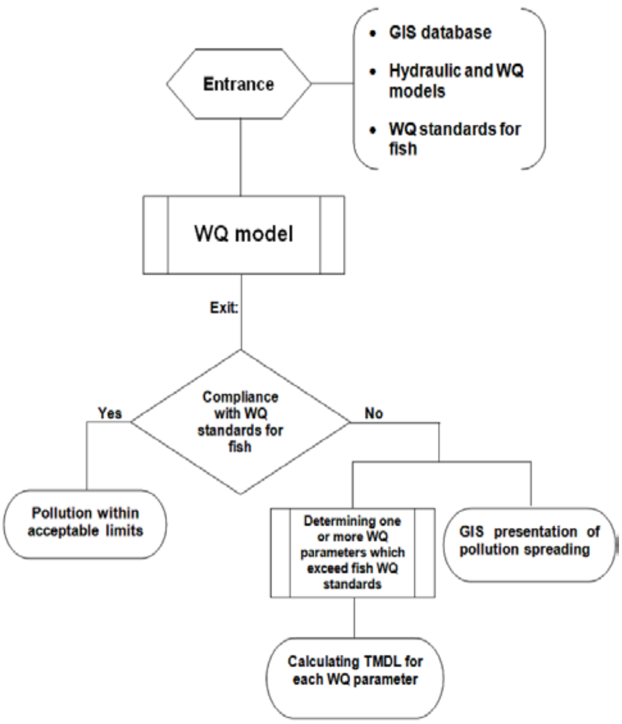

Figure 1. Methodology for integral management of WQ in order to support the fish populations

Within the methodology WQ model was used for simulating different scenarios for measured or imagined input data in order to determine if outputs are in compliance with WQ standards; in this case this means WQ standards for fish. The Total Maximum Daily Loads i.e. the load for each polluting substance that could enter the water body without harmful effects, i.e. the TMDL values (US EPA, 1999a), could be calculated upon simulation results. Finally, the WQ model outputs for each WQ parameter could be presented on GIS maps, showing how pollution spreads along the canal reach by coloring the reach in different colors corresponding to WQ classification according to the certain range of concentrations.

2.2. Study area

The whole HS DTD stretches across the Autonomous Province of Vojvodina situated in the north of Serbia. It consists of 960 km of canals, of which 600 km are navigable making it an important waterway in the region (Grabić et al., 2013). It connects the Danube with the Tisa River and serves as a buffer, providing water for irrigation when there is a shortage by draining and conducting excess water. The fishing areas of the HS DTD are colonized with 30 fish species from eight families (*Esocidae, Cyprinidae, Siluridae, Ictaluridae, Anguillidae, Centrarchidae, Percidae and Gobiidae*), with the prussian carp making up a large portion of the populations. The fish populations also includes some economically significant species, such as carp, pike, pikeperch, wels catfish, grass carp and silver carp (Maletin et al., 2005). The study area is located almost in the middle of the Province and includes reaches of two canals. The canal Vrbas-Bezdan is 80.9 km long and starts from the Danube River at the Bezdan lock and joins the Bečej-Bogojevo canal near the town of Vrbas. This intersection between the two canals is known as the Triangle. The Bečej-Bogojevo canal is 90 km long and stretches from the Danube River to the Tisa River, ending at the Becej lock. Both canals are regulated by locks. Within the study area there are two locks of importance for managing the flow rate of the canal reaches: the Vrbas lock that is situated on the Vrbas-Bezdan canal 6 km upstream from the Triangle, while Kucura is regulating the Bečej-Bogojevo canal and is 8 km upstream from the Triangle. A trapezoidal cross-section of the Bečej-Bogojevo canal and the hydrometric measurement conducted for the purpose of the research on three points (beginning, middle and end of the investigated reach) showed the following dimensions: 36 - 64 m water surface width; 1.8- 2.8 m average depth; 2.3 - 15.1 m^3/s flow rate, and 0.04 - 0.22 m/s average water velocity. The Vrbas-Bezdan canal flow rate is variable during the year, with small flow rates with an average value of 0.5 m^3/s during autumn – winter period and no-flow period which coincides with the growing season (Medbø et al., 2005). Moreover, the canal is heavily polluted with wastewaters originating from food processing industries, pig farms, municipal wastewater discharges, etc. (Medbø et al., 2005;

Pantelić et al., 2012). All these point sources either do not have wastewater treatment plants at all, or they operate insufficiently well. The reach between Vrbas and the Triangle is nowadays almost fully filled with the industrial sludge as it receives pollution from the whole area and in this research is considered as one point source of pollution. WQ of the Bečej-Bogojevo canal is along its entire length good to moderate quality (Hydrologic Yearbooks, 2002-2011) and it has been designated as a fishing area. Still, after the Triangle due to the inflow of the polluted water from the canal Vrbas-Bezdan, the eutrophic processes occur, causing poor aesthetic look, unpleasant odor and occasional fish kills.

This research was focused upon the reach of the Bečej-Bogojevo canal stretching from the Triangle and the confluence of the polluted water from the canal Vrbas-Bezdan and 14.58 km downstream in order to simulate the spreading and transformation of polluters (Fig. 2).

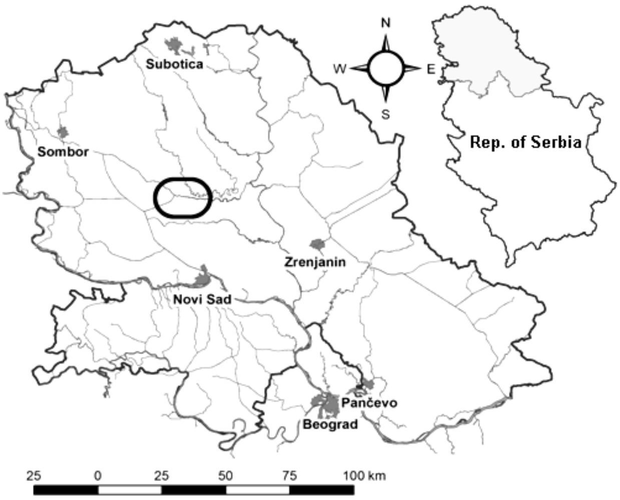

Figure 2. Map of the HS DTD in Vojvodina Province with marked investigated canal reaches

2.3. *Input data selection*

Due to the poor WQ management in the Bečej-Bogojevo canal, pollution related fish kills occur almost every year. Over the last few years these incidents were announced by the media, specifically in 2009 (16 April and 17 September), 2011 (14 May and 4 June) and in 2012 (21 August). There is no WQ data for these exact dates, and the only available data sets are the results of the systematic monthly monitoring of WQ conducted by the Hydrometeorological Service of Serbia which has been conducting monthly monitoring of WQ for a few decades until the end of 2011 on two points within the research area: Vrbas 1 (clean canal water before Vrbas lock) and Vrbas 2 (polluted canal water after the confluence of side drainage canals which are responsible for the majority of pollution in the Vrbas-Bezdan canal and Triangle). In order to simulate the WQ that might cause fish kills, available data sets indicating high total ammonia concentrations and were the closest to the fish kills events, were chosen. The data of flow rates for both canals were obtained from locks: from the Vrbas lock for the Vrbas-Bezdan canal, and the Kucura lock for the Bečej-Bogojevo canal for the exact dates when the fish kills were reported.

Hydrometeorological data on temperature, wind speed, humidity and cloudiness were obtained from the database of the same service for the meteorological station Novi Sad for the periods of day when WQ measurements took place. For the fish kills announced on 17 September, 2009, WQ data from 3 September, 2009 were chosen, while flow rates were taken from the 16 of the same month. The reason for this was that the Vrbas lock was completely closed for a few weeks and was only opened on the 16 with a flow rate of 0.7 m^3/s. In 2011, the fish kills occurred on several occasions from the middle of May to June and the closest available data sets with extremely high total ammonia concentrations were those from 13 July, which were taken for simulation.

3. RESULTS AND DISCUSSION

Hydrometeorological Service of Serbia has been conducting monthly monitoring of WQ at Vrbas 1 and Vrbas 2 for a few decades, but in this research only data from period 2002-2011 were analysed (Hydrologic Yearbooks, 2002-2011). According to Serbian regulation (Regulation 74/2011/RS), which is in compliance with the WFD, the canal network has been categorized as an artificial and heavily modified water body, thus allowing not so strict WQ standards. With respect to this, WQ at Vrbas 1 has been classified as good to moderate and Vrbas 2 has been of poor to bad quality.

Figure 3 illustrates changes in concentration of total ammonia, total phosphorus and dissolved oxygen for a period 2002-2011 at Vrbas 2, i.e. for polluted canal reach.

All parameters are indicating heavily polluted water. Mean annual value for total ammonia is 6 $mgNH_4/L$ (Fig. 3a), whereas according to the Fish Directive (Directive, 2006/44/EC) guide and mandatory values are respectively $\leq$ 0.2 $mgNH_4/L$ ($\leq$ 0.16 mgN/L) and $\leq$ 1 $mgNH_4/L$ (0.78 mgN/L). Concerning total phosphorus (Figure 3b) in cyprinid waters the Fish Directive requires not exceeding 0.13 mgP/L, which may be regarded as indicative, in order to reduce eutrophication. In the case of Vrbas 2 mean annual value is 1.3 mgP/L with one distinct peak in May with value 5 mgP/L. However, flow rate for that certain date was absent, according to the database accompanying study performed by Medbø et al., (2005), so even this elevated concentration of total P was not affecting much overall WQ after joining the two canals. Dissolved oxygen represents one of the most important parameters for supporting fish life. Concentrations of DO are not satisfying criteria of the Fish Directive either. Whereas, the Directive for cyprinid waters requires at least 5 mgO_2/L, mean value for the whole period is only 2.3 mgO_2/L (Figure 3c). Although, mean monthly concentrations are ranging from 4-6 mgO_2/L and are recorded for the January-March period. Similar analyses performed by Pantelić et al., (2012) and Kolaković et al., (2014) concluded that WQ in the Vrbas-Bezdan canal downstream from the Vrbas town has been relatively bad.

The concentration of dissolved oxygen from a polluting source for both dates of the reported fish kills were 0.0 mgO_2/L, while levels in the Bečej-Bogojevo canal were at 7.5 mgO_2/L (16 September 2009) and 9.7 mgO_2/L (13 July 2011). After joining the two canals and mixing the waters, the dissolved oxygen concentrations of the modeling outputs were brought up to an acceptable level ranging between 6.5 - 7.7 mgO_2/L, according to the requirements of the Fish Directive.

Modeling results for changes in the concentration of total ammonia, un-ionized ammonia and total phosphorus 16 September, 2009, and 13 July, 2011, respectively are shown on figures 4 and 5. Besides, on both Figures are given limit values as set by the Fish Directive. The simulation performed for 16 September, 2009, for both total ammonia and un-ionized ammonia concentrations are high, exceeding the set mandatory value, while the total phosphorus level is below the set guide value (Fig. 4, Simulation 1). For the simulation conducted with information gathered from 13 July, 2011, the total ammonia concentration is between the guide and mandatory values, but un-ionized ammonia significantly exceeds the mandatory value. Besides, the total phosphorus concentration exceeds the mandatory value, but only as a minor peak. In both cases it is obvious that nitrogen compounds which affect fish are in dangerous ranges, while total phosphorus concentrations are not critical (Fig. 5, Simulation 1). Furthermore, simulations were taken for the scenario when the two biggest polluters, i.e. the pig farm, Farmacoop, and the meat processing industry, Carnex, were excluded. According to the cadastre of polluters of the Public Water Management Company Vode Vojvodine, their contribution to the overall total nitrogen and total phosphorus pollution levels are 66.59% and 72.25% respectively. A share of total ammonia from these two sources of pollution is ranging from 70-100%, and in this case it is assumed to be 100%.

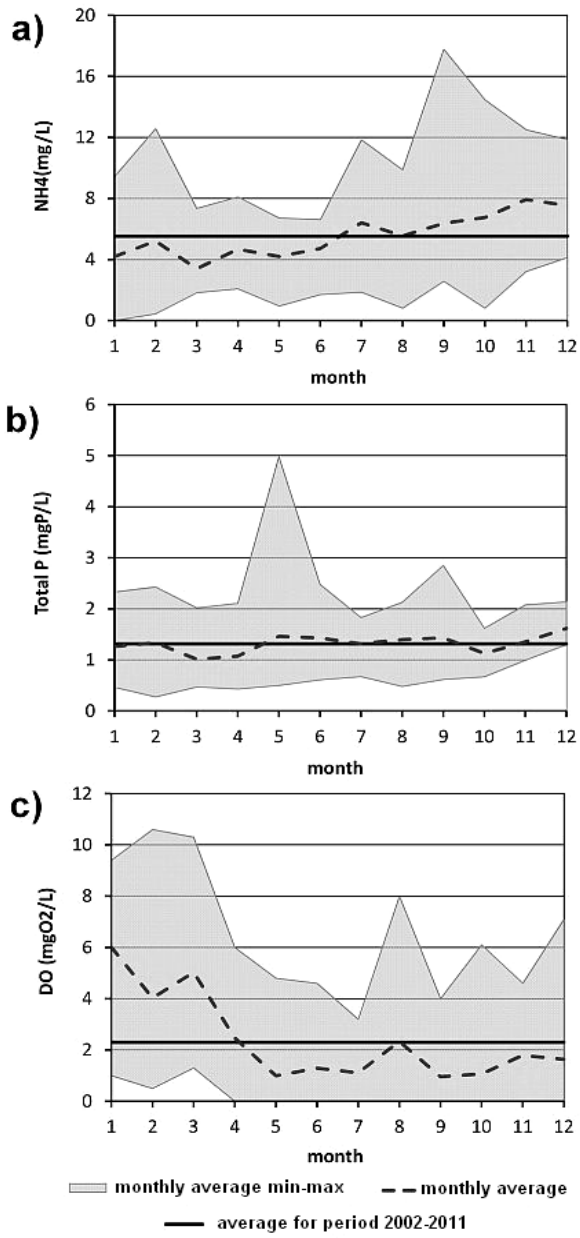

Figure 3. Water quality for Vrbas 2 for period 2002-2011

If both sources were excluded for the simulation for 16 September, 2009, both nitrogen compounds concentrations would be within the guide and mandatory values (Figs. 4a, 4b, Simulation 2), while the total phosphorus level would be far below the set guide value (Fig. 4c, Simulation 2). In the case of the simulation for 13 July, 2011, a significant decrease of the total ammonia level is shown and it reaches the mandatory value without passing it (Fig. 5a, Simulation 2), while un-ionized ammonia makes a minor peak above the mandatory value (Fig. 5b, Simulation 2).

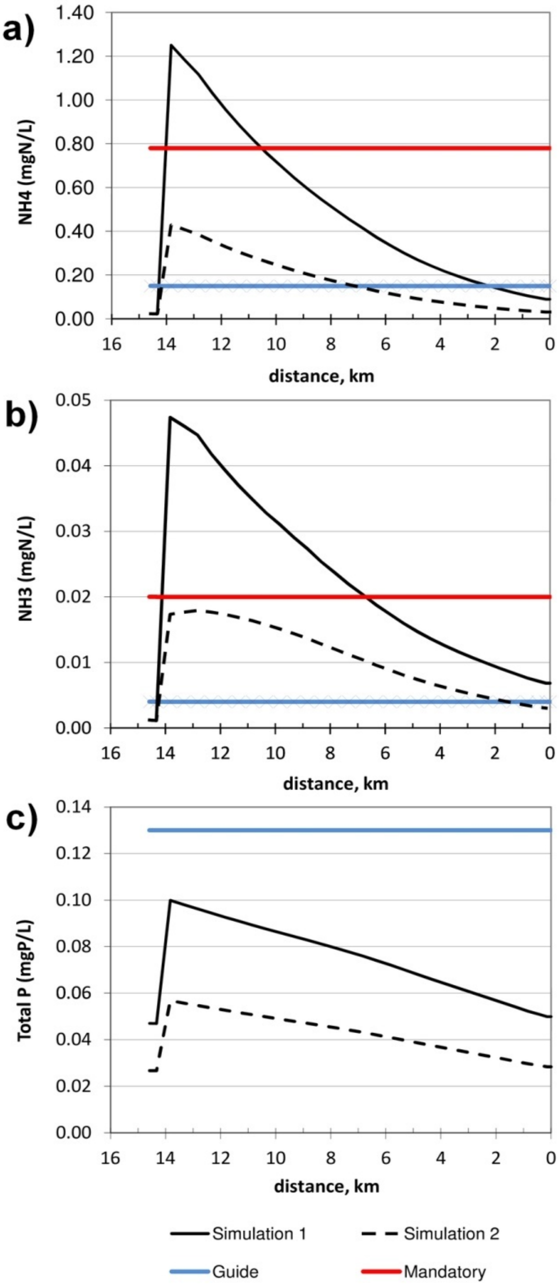

Figure 4. Simulations for input data for 16 Sept., 2009

The total phosphorus concentration dropped well below the guide value (Fig. 5c, Simulation 2). In general, the exclusion of the two biggest sources of pollution will significantly contribute to the improvement of the canal WQ within the investigated reach and will lessen the occurrences of pollution-related fish kills.

In order to determine the exact amount of pollution that might be present in the canal without affecting the wildlife, TMDL values are determined for both dates and for each WQ parameter in a manner similar to the one done by Boyacioglu & Alpaslan (2007 In references list is 2008). For 16 September, 2009, based on the simulation results, it was calculated that TMDL values are 898.6 kgN/day for the total ammonia, 22.5 kgN/day for un-ionized ammonia, and 102.8 kgP/day for the total phosphorus.

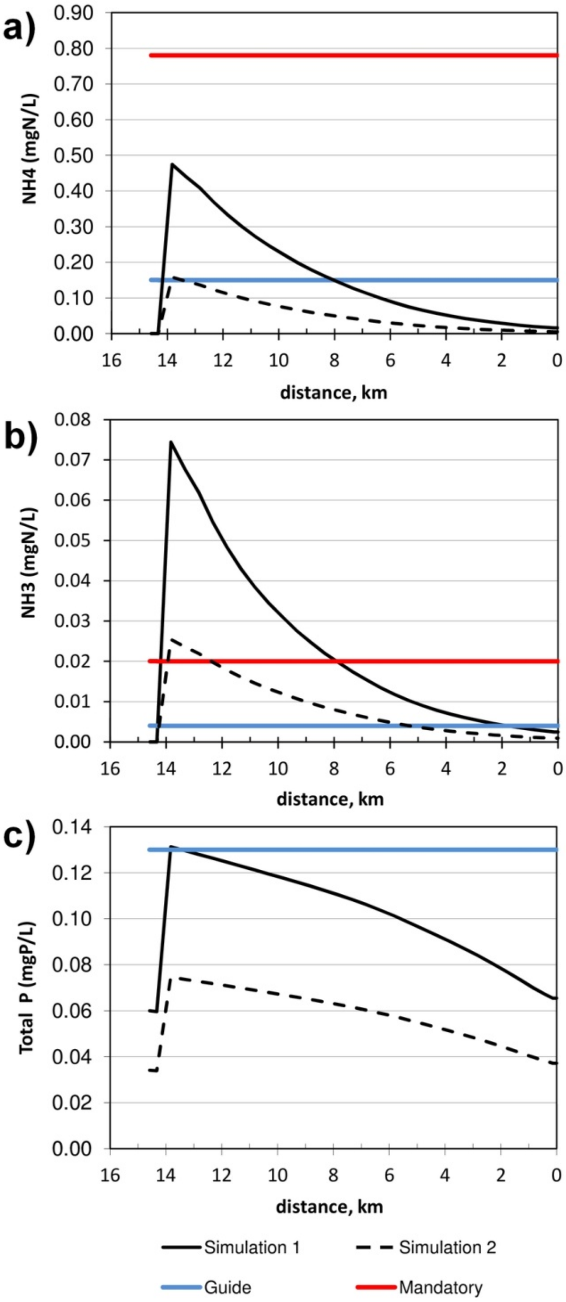

Figure 5. Simulations for input data for 13 July, 2011

However, determined TMDL values for simulations of the 13 July 2011, are 743.3 kgN/day for the total ammonia, 19.1 kgN/day for un-ionized ammonia and 71.1 kgP/day for the total phosphorus.

Permissible pollution loads have to be calculated daily because of changes in canal flow rates, changes in WQ of clean water (background loads), and the occasional occurrence of diffuse-source pollution (e.g. agricultural runoff after rain) and weather conditions. Finally, for the purpose of better visual observation of the changes in transport and transformation of each WQ parameter, the simulation outputs are presented on GIS maps in a way that for each WQ class a certain color was selected representing one WQ class of ecological potential set by the WFD. The limit values set for the ecological potential of total ammonia in artificial water bodies (Regulation, 74/2011/RS) are the following (all values are in mgN/L): < 0.16 (II class - good), 0.16 - 0.62 (III class - moderate), 0.6 – 0.78 (VI class – poor), and > 0.78 (V class - bad). Figure 6 gives an example of the GIS presentation of changes in the concentration of total ammonia along the investigated canal reach.

4. CONCLUSION

The methodology applied to the study area of the Bečej-Bogojevo canal could be used within the whole network of the HS DTD for the management and planning of good WQ sustainability and support of the fish populations. While it is difficult to continuously acquire input data (hydrological, meteorological, data on the pollution intake etc.) for the entire HS DTD because of large spatial and temporal variability, not to mention operating a non-line model for the operative management of WQ and regulation of polluters, it could be possible to establish this model for the most polluted reaches of the canal system. The results of these simulations for the tested reaches of the Bečej-Bogojevo canal have shown that the exclusion of waste water from the two biggest polluters would lead to a significant improvement of the canal water and would bring the concentrations of total ammonia, un-ionized ammonia and total phosphorus in line with the WQ standards posed by the Fish Directive. Besides nitrogen and phosphorus compounds and dissolved oxygen, other WQ parameters of importance for fish could be analyzed in a similar manner. The application of the methodology and designing of new facilities for waste water treatment, e.g. constructed wetlands (Josimov-Dunđerski et al., 2015) which would contribute to respecting the EU WQ standards and lead to improvement of the WQ in the whole HS DTD. This would be a great step towards wildlife preservation.

The problem that originates beyond the area of the HS DTD is cross border pollution (Gheju & Bogatu, 2006). However, the neighboring countries are the EU members and we believe that if they are determined to achieve the goal of improving the WQ as defined by the WFD that the problems will be overcome.

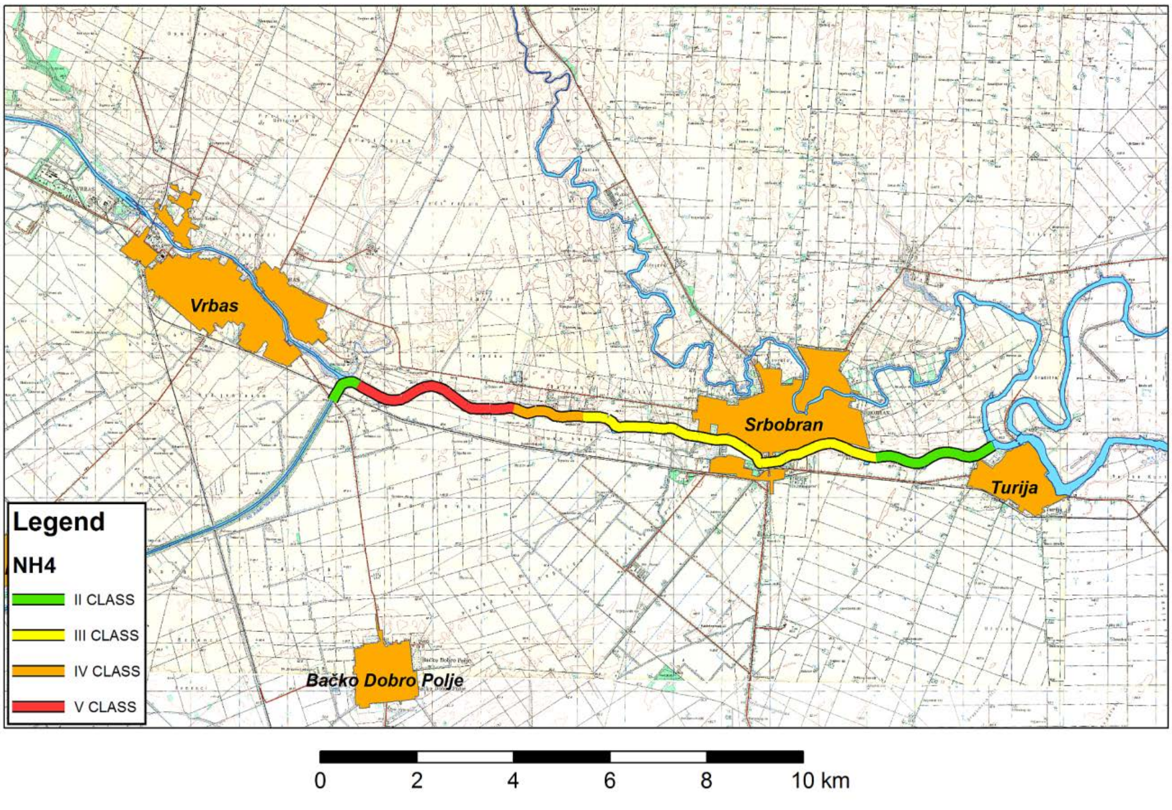

Figure 6. GIS presentation of simulation result for total ammonia concentration changes for 16 September, 2009 with respect to the WDF classification

REFERENCES

Boyacioglu H. & Alpaslan M.N., 2008. *Total maximum daily load (TMDL) based sustainable basin growth and management strategy***.** Environmental Monitoring and Assessment, 146 (1-3):411-421.

Camargo A. & Alonso A., 2006. *Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment.* Environment International, 32 (6):831-849.

Canadian Council of Ministers of the Environment - [CCME], 2004. *Canadian water quality guidelines for the protection of aquatic life: Phosphorus: Canadian Guidance Framework for the Management of Freshwater Systems.* In: Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. Excerpt from Publication No. 1299; ISBN 1-896997-34-1

Canadian Council of Ministers of the Environment - [CCME], 2010. *Canadian water quality guidelines for the protection of aquatic life: Ammonia. In: Canadian environmental quality guidelines.* Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. Excerpt from Publication No. 1299; ISBN 1-896997-34-1

Constable M., Charlton M., Jensen F., McDonald K., Craig G. & Taylor K.W., 2003. *An ecological risk assessment of ammonia in the aquatic environment.* Human and Ecological Risk Assessment, 9:527-548.

Directive, 2000/60/EC *of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy***.** Official Journal of the European Union –22.12.2000, L 327:1-73.

Directive, 2006/44/EC *of 6 September 2006, on the quality of fresh waters needing protection or improvement in order to support fish life.* Official Journal of the European Union - 25.9.2006, L 264:20- 31.

Džigurski D., Ljevnaić-Mašić B. & Nikolić L., 2014. *The effects of physical-chemical water parameters on the Nymphaeion alliance development in northwestern Serbia.* Acta Societatis Botanicorum Poloniae, 83 (2):103-111.

Emerson K., Russo R.C., Lund R.E. & Thurston R.V., 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. Journal of the Fisheries Research Board of Canada, 32:2379- 2383.

Ennet P., Pachel K., Viies V., Jürimägi L. & Elken R., 2008. *Estimating water quality in river basins using linked models and databases***.** Estonian Journal of Ecology, 57 (2):83-99.

Environment Canada, 2001. *Priority substances assessment report: Ammonia in the aquatic environment.* Minister of Public Works and Government Services Canada, Ottawa, ON, Canada.

European Commission, 2002. *Eutrophication and health***;** Office for Official Publications of the European Communities: Luxembourg.

European Environmental Agency - [EEA], 1999. *Nutrients in European Ecosystems.* Environmental Assessment Report No 4, European Environmental Agency, Copenhagen, Denmark.

Gheju M. & Bogatu C., 2006. *Preliminary ecological risk assessment to aquatic environment of Bega River due to presence of ammonia in treated sewage effluent.* Chem. Bull. Politehnica University Timisoara, 51(65), 1-2:67-70.

Grabić J., Bezdan A., Benka P. & Salvai A., 2011. *Spreading and transformation of nutrients in the reach of the Bečej-Bogojevo canal, Serbia.* Carpathian Journal of Earth and Environmental Sciences, 6 (1):277-284.

Grabić J., Bezdan A., Benka P., Salvai A. & Josimov-Dunđerski J. 2013. *Managing water quality of the HS DTD as a prerequisite for supporting fish fund.* Diversification in Inland Finfish Aquaculture II (DIFA II), September 24 – 26, 2013, Vodnany, Czech Republic, Book of abstracts, 94.

Hydrologic Yearbooks on Water Quality, 2002-2011. Republic Hydrometeorological Service of Serbia, Belgrade. (in Serbian)

Josimov-Dunđerski J., Savić R., Belić A., Salvai A. & Grabić J., 2015. *Sustainability of constructed wetland based on the characteristics in effluent***,** Agriculture Journals, Soil & Water Resources, 10:114-120.

Kolaković S., Vujović S., Kolaković S., Jeftenić G., Mašić B. & Ljubomir B., 2014. *Assessment of water quality of artificial water bodies in Vojvodina (Serbia) using factor and cluster analysis.* International Jubilee Conference: Science and Technic '65th anniversary Faculty of Hydraulic Engineering and 15th anniversary Hydraulic Engineering in German, Sofia, Bulgaria, November 6-7. 2014, University of Architecture, Civil Engineering and Geodesy Sofia, (on CD).

Kramer D. L. 1987. *Dissolved oxygen and fish behaviour.* Environmental Biology of Fishes, 18 (2):81-92.

La V.T. & Cooke S.J., 2011. *Advancing the science and practice of fish kill investigations***.** Reviews in Fisheries Science, 19 (1):21-33.

Maletin S., Ćirković M. & Jurakić Ž., 2005. *Conservation and improvement of diversity and production of fish fund in canals of Hydro-system Danube-Tisa-Danube***.** Contemporary Agriculture, 54 (1-2):119.

Marsili-Libelli S. & Giusti E., 2008. *Water quality modelling for small river basins***.** Environmental Modelling & Software, 23:451-463.

Medbø F., Ratnaweera H. & Øivind S., 2005. *Rehabilitation of the DTD-Canal in Vrbas, Assessment of environmental status, pollution sources, and abatement measures.* Norwegian Institute for Water Research – NIVA, Report No 5061-2005.

Pantelić M., Dolinaj D., Savić S., Stojanović V. & Nađ I., 2012. *Statistical analysis of water quality parameters of Veliki Bački canal (Vojvodina, Serbia) in the period 2000-2009.* Carpathian Journal of Earth and Environmental, 7 (2):255-264.

Park, A.R, Clough, S.J. V Wellman C.M. 2008. *AQUATOX: Modeling environmental fate and ecological effects in aquatic ecosystems.* Ecological Modelling**,** 213:1-15.

Piperski J., Benka P., Bezdan A. & Salvai A. 2010. *Methodology for water pollution assessment within agricultural area***.** Fourth International Conference BALWOIS, Ohrid - Repblic of Macedonia, Book of abstracts, 2:544.

Piperski, J. & Salvai, A., 2008. *Water Quality Models Application in Vojvodina's Canal Network, Serbia.* Third International Conference BALWOIS 2008, Ohrid, Republic of Macedonia, 27-31 May. 2008.

Pollock M S., Clarke L. M. J., & Dubé M.G., 2007. *The effects of hypoxia on fishes: from ecological relevance to physiological effects***.** Environmental Reviews, 15:1-14.

Randall, D.J. & Tsui, T.K.N., 2002. *Ammonia toxicity in fish***.** Marine Pollution Bulletin, 45:17-23.

Regulation, 74/2011/RS of 5th October 2011 on the parameters of the ecological and chemical status of surface waters and the parameters of the chemical and quantitative status of groundwater**,** R Serbia, Official Gazette No. 74/2011, (in Serbian).

Srinivasan, R. & Arnold, J.G., 1994. *Integration of a basin-scale water quality model with GIS***.** Water Resources Bulletin 30 (3):453-462.

Tarazona, J.V., Muńoz M.J., Ortiz, J.A., Nunéz, M.O. & Camargo, J.A., 1987. *Fish mortality due to acute ammonia exposure.* Aquaculture Research, 18:167-172.

United States Environmental Protection Agency - [US EPA], 1999. *Update of ambient water quality criteria for ammonia.* National Technical Information Service, Springfield, VA.

United States Environmental Protection Agency - [US EPA], 1999a. *Protocol for developing nutrient TMDL's***.** Office of Water (4503F), United States Environmental Protection Agency, Washington, DC.

United States Environmental Protection Agency - [US EPA], 2013. *Aquatic Life Ambient Water, Quality Criteria for Ammonia***,** *Freshwater 2013*. Washington, DC.

United States Environmental Protection Agency -[US EPA], 1986. *Quality criteria for water, (The Gold Book)***.** EPA-440/5-86-001, Office of Water Regulations and Standards. Washington DC.

World Health Organization - [WHO], 2002. *Eutrophication and health***,** Luxembourg: Office for Official Publications of the European Communities, p 14.

Zhang, L., Xiong, D.-M., Li, B., Zhao, Z.-G., Fang, W., Yang, K. & Fan, Q.-X., 2012**.** *Toxicity of ammonia and nitrite to yellow catfish (Pelteobagrus fulvidraco).* Journal of Applied Ichthyology, 28:82-86.

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