MODELING THE ECOLOGICAL STATUS OF VARNA BAY- APPLICATION OF SYSTEMS APPROACH FRAMEWORK

Eleonora RACHEVA, Snejana MONCHEVA,
Lyudmila KAMBURSKA*, Thomas HOPKINS**

ABSTRACT

The broad objective of the methodology applied in Varna bay experimental site is to identify the interactive linkages between the ecological, economical and social components of the system. The present paper aims at presenting how the ecological model (EXTEND software) of Varna bay captures the key features of the real system's response to the expanding tourism industry. Scenarios are employed to demonstrate the extent to which natural factors (rain/storm events) and the resorts' pressure influence the ecosystem health and stability. Given the increased frequency of heavy rain/storm events, complimentary to the up-grade of WWTP, improvement of SS could be a critical management option.

Key-words: *tourism, waste waters, water quality, Varna region, Black Sea.*

INTRODUCTION

Varna Bay ecosystem health has been facing multiple environmental pressures, resulted in significant environmental degradation. While anthropogenic eutrophication due to nutrient over-enrichment by the lake bay current has long been considered the major problem (1, 2, 3, 4, 5), the WWTPs loads associated to the tourism industry expansion and the altered demographic profile of the coastal region became a further threat during the last decade (6, 7, 8). The WFD as an imperative to reach a "good ecological quality" by 2015 calls for adequate management options. To this end, model studies provide valuable tool to offer scientifically informed policy advice. The available model expertise explores physical/biochemical modeling (MONERIS-LOICZ Model) to study the circulation/nutrients exchange through the Varna Channel (9, 10). A coupled hydro-physical-biological model has been developed to determine the thresholds of nutrients loads in Varna Bay coastal area in order to meet the WFD ecological quality targets (11). The substantial increase of the frequency and intensity of rain/storm events (12) in relation to Sewer System (SS) current state of operation and drainage facilities' capacity (8) emerged as environmental risk factor, as a source of nutrients, pollutants and Total Suspended Solids (TSS) into the coastal area, that has been paid less attention as a potential driver of ecological deterioration.

The study explore the System dynamics methodology (SD) and Systems Approach Framework (SAF) concept for modeling the ecological status of Varna Bay as a function of tourism industry pressure and the climatic projections.

METHODS

While SD models are commonly used to generate overall understanding of the system, SAF approach is applied here to identify the potential causes and provide achievable solutions to problems arisen from much in-depth study. The concept adopted for Varna Bay region is schematically presented on the Conceptual diagram (Fig. 1).

Assoc. Prof. Dr. Snejana Moncheva, Institute of Oceanology - BAS, Varna 9000, PO. BOX. 152, tel/fax: 00359 52 370485, e mail: snejanam@abv.bg
Eng. Eleonora Racheva, Institute of Oceanology - BAS, Varna 9000, PO. BOX. 152, tel/fax: 00359 52 370485, e mail: ainsteim@abv.bg
*L. Kamburska, PhD; EC DG-JRC, Ispra, Italy; e-mail: lyudmila.kamburska@jrc.it
**T. Hopkins, IAMS, CNR, Naples, Italy; e-mail: tom.hopkins@iams.cnr.it

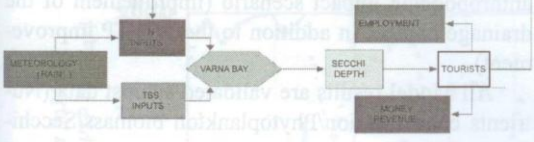

Fig. 1. Conceptual diagram of Varna Bay virtual system (VS), accounting for interactions between ecology (Secchi-depth), economy (Money Revenue) and society (Employment). Anthropogenic impact (tourism industry), Natural sources (TSS) and nutrient inputs from point (WWTP) and diffuse sources, are part of the "urban waste water metabolism" in the VS. Secchi-depth (proxy for the ecosystem health) is modelled as a linkage variable.

Numerical simulations are built through the use of EXTEND software. For the simulation of the ecological state data array from existing measurement programs was employed daily meteorological data, measurements from sampling stations in the Bay (bimonthly measurements of chemical and biological parameters - IO-BAS data), published data from various sources (WWTPs discharge volumes and capacity of treatment, normative values of freshwater/per capita usage). The necessary conversion of the input parameters into daily values was done to achieve the desired model resolution (daily time-step). Albeit nutrients are routine measurements, and large amounts of data exist, data collection is not with the adequate frequency and record gaps do exist in the different sources, accounting for some of the model approximations.

Virtual System (VS)

The Varna Bay ecosystem is modeled as a two layer system (Fig. 2). The approximations are that the two layers are mixed, but a salinity gradient persists because of the fresh water input to the surface layer. The fresh water balance is assumed to give a credible assessment of nutrient fluxes between Varna Lake and Varna Bay (13, 14, 15).

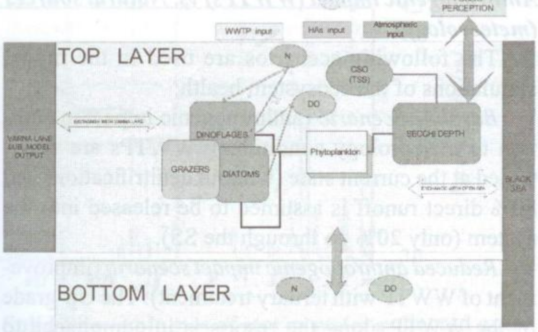

Fig. 2. The diagram presents the VS functionality with regards to the Impact and the causal set of environmental conditions (see explanations in the text).

Secchi-depth, assumed as a proxy of the ecosystem health, is modeled as a function of TSS (16, 17), the phytoplankton biomass, the latter controlled by nitrogen, available light, circulation, and zooplankton grazing (18) and the transformations processes in the ecosystem itself. Surface layer budget of the nitrogen sub-model is represented by different inputs: Lake input is calculated by the Varna Lake submodel; Atmospheric deposition and the land runoff of nitrogen are derived from precipitation data, drainage area and standard coefficients; Number of tourists (19), average water consumption/tourist/day (450 liters/day) (20) and the normative value of 0.0109 kg/m3/day nitrogen input/person/day are used to calculate WWTPs discharges and nutrient loads; Varna city WWTP input is included in the Varna lake, while the resorts WWTPs input is modeled separately in dependence to the wind direction and velocity. As a result of the predominant mass transport pattern (21), nutrients originating in the resorts (tourist pressure), are assumed to be introduced along with the coastal current flow.

In the TSS sub-model, Coastal Sewage Overflow (CSO) events reflect the amounts of TSS entering the system, proportional to the rain intensity and the respective concentrations of TSS in CSO waters (published data used). TSS contribution to water clarity reduction (16) is linked to meteorological driver (frequency and intensity of rain/storm events). It is assumed that at the present state of construction and operation of the SS the removal efficiency is 20%.

Anthropogenic impact (WWTPs) vs. Natural sources (meteorology)

The following scenarios are used in the model simulations of the ecosystem health:

Baseline Scenario (anthropogenic impact in addition to meteorology conditions): WWTPs are maintained at the current state (without denitrification) and 80% direct runoff is assumed to be released into the system (only 20% go through the SS).

Reduced anthropogenic impact scenario (improvement of WWTP with tertiary treatment): The Up-grade of the WWTP along the resorts is in compliance to EU DIRECTIVE 98/15/EO (75% denitrification of the outflow) aimed at analysis of the effect of reduced nutrients on phytoplankton biomass.

Reduced environmental impact - natural sources/meteorology scenario (improvement of the drainage and SS): explores the effect of reduced TSS inputs (by 20%-50%) over the water transparency.

Cumulative effect of reduced environmental and anthropogenic impact scenario (improvement of the drainage and SS in addition to the WWTP improvement)

All Model results are validated against data (Nutrients concentration/Phytoplankton biomass/Secchi-depth, CSO) for the test year 2001.

RESULTS

In a number of model runs, the main functional drivers of the model (Anthropogenic impact (WWTPs) and Natural sources (meteorology) were varied within realistic bounds to demonstrate the effect each has on the parameter water clarity/Secchi-depth.

Baseline Scenario. As evident from Fig.3 there is a good inverse correlation between the phytoplankton biomass and the Secchi-depth, while the trend line of phytoplankton biomass is very similar to the variability of the available nitrogen. Secchi-depth is maintained below the threshold value (3 m) for 130 days (June - October).

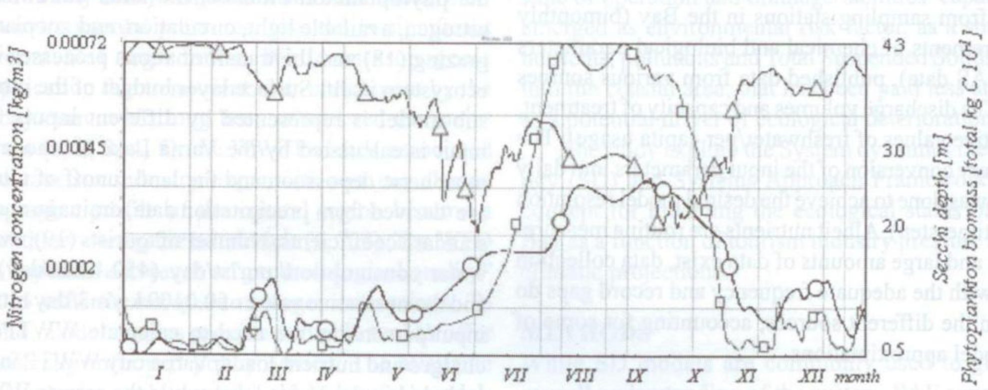

Fig. 3. Secchi-depth calculated [m] (-Δ-); Phytoplankton biomass [total kg C 10^{-1}] (-O-); Nitrogen concentration [kg/m^3] (-□-)
(Note: the Secchi-depth is the modelsimulation when both Phytoplankton and TSS are considered)

Reduced anthropogenic impact-improvement of WWTP with nutrients removal. The assumption is that the frequency and duration of the phytoplankton blooms in Varna Bay driven by the nutrients surplus from the resorts will drop significantly provided the resorts WWTPs outflow concentration is reduced by 75%. As depicted by the result the period with Secchi-depths bellow 3m in summer is substantially shortened (about 30 days). During June - October the improvement of water optical characteristics is by about 0.70 meters, up to 1 meter in July (during the high tourist season). In spite of such measures, nutrient concentrations are still high during spring and autumn, influenced by Varna Lake inflow (plot not shown here).

Reduced environmental impact- natural sources/meteorology (improvement of the drainage and SS). The model indicates that at the current percent of direct release (80 %), tripling elevation of WWTP capacity will have no effect on suspended matter removal (Fig. 4), suggesting that TSS contributing to water visibility reduction is mainly from non-point sources. The key variable is the percent of storm waters originating from watershed area directly released into the Bay, because of SS inefficiency. Running the model simulation with 20 % direct release only, results in a few occasions of insufficient capacity and the water transparency seems not to be directly influenced.

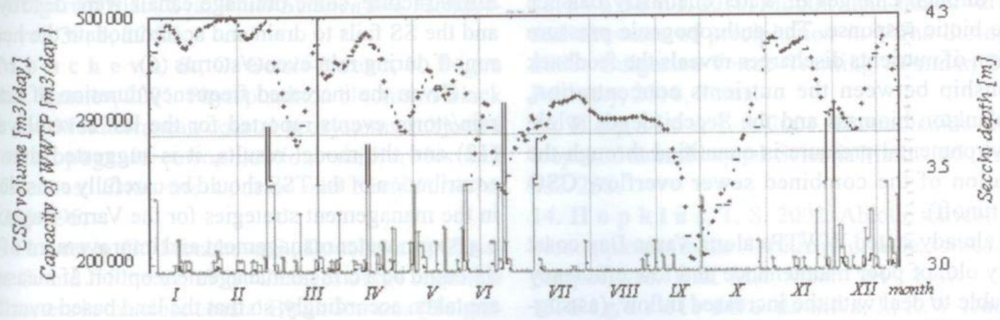

Fig. 4. Relationship CSO (TSS) - Secchi-depth: Solid line - volumes of storm water collected and treated (capacity of WWTP (m^3/day); (-•-) - volumes of storm water directly entering coastal water (CSO volume m^3/day); Symbols(+) - Secchi depth calculated [m] (note: the Secchi-depth is the model simulation when both Phytoplankton and CSO are considered)

Cumulative effect of reduced environmental and anthropogenic impact. As it is expected, the phytoplankton biomass does not drop at the same rate as the reduction of N during the summer (due to non-linearity of the processes), but reduction of nutrient loads substantially contribute to improvement of WQ- reducing phytoplankton stock and the attached to it Secchi-depth variability (Fig. 5). Reducing both the environmental and anthropogenic pressures result in targeted improvement of Secchi-depth values.

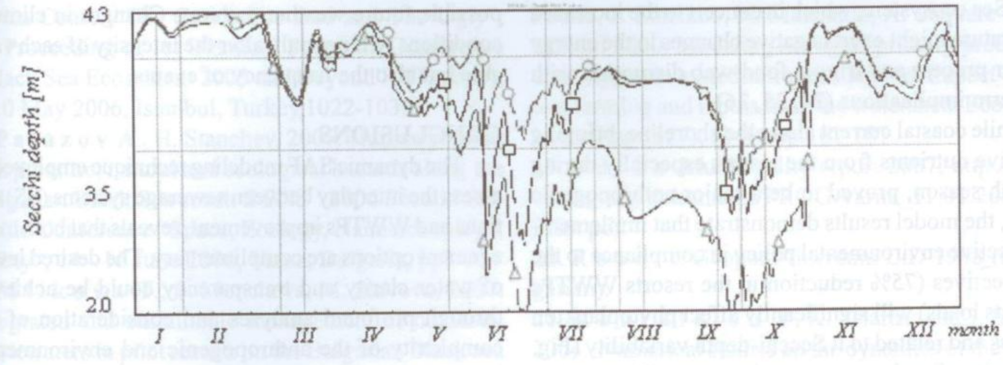

Fig. 5. Secchi-depth model output (m) for Varna Bay beach 2001: (-□-) with total denitrification performed, (-Δ-) - without denitrification performed, (-○-) Direct release of SS (20 %) in addition to total denitrification performed

DISCUSSION

Coastal ecosystems are subject to a variety of alterations resulting from a combination of human activities and natural processes (22). The SAF is adopted to provide a step-wise description of the causal chain between the anthropogenic drivers and environmental risk factors, and their impact to suggest adequate schemes for sustainable coastal zone management (23). Impacts occur at the end of the chain and take the form of loss of nature, resorts' attractiveness and diminished public welfare. The analysis in the present report is based on a top-down assessment. Starting with an evaluation of the potential importance of different environmental impacts, it investigates which pressures and how much they contribute to these impacts. In analyzing the causes, we look at the immediate emitters, and the feedback relationship to the quality of the marine environment, allowing for assessment of the environmental "cost" of the related activities and to suggest possible management options.

The ecological model of Varna bay captures the key features of the real system's behavior in relation to different scenarios for nutrients and TSS loads. The selected pressures change the state of the ecosystem quality through changes of water chemistry balance and the biotic response. The anthropogenic pressure reduction of nutrients discharges reveals the feedback relationship between the nutrients concentration, Phytoplankton biomass and the Secchi depth, while the environmental pressure is quantified through the calculation of the combined sewer overflow CSO (street runoff).

As already stated WWTPs along Varna Bay coast are very old, of poor maintenance and low efficiency (8), unable to deal with the increased inflow, (as suggested by the model results exceeding 3 times the capacity of the WWTP during the tourist season), leading to increased nutrient loads (Fig. 3). Resulted dramatic alteration in the phytoplankton community structure, natural succession, with extended and intensified periods of blooms, causing aesthetic problems (a decrease of the water transparency) and mass mortality of fish and benthic fauna have already been well documented (6, 8). What is of higher concern, the increased organic matter introduced to the system drives the shift of the microalgal assembly towards dominance of microflagellates and other mixo-heterothrophs, atypical for the Black Sea ecosystem, which in concert to the increased temperature might exert negative changes in the energy transfer process and trigger food-web disruption with long-term implications (24, 25, 26).

While coastal current along the shoreline, bringing excessive nutrients from the resorts especially during the high season, proved to be a major anthropogenic source, the model results demonstrate that implementing effective environmental policy in compliance to the EU directives (75% reduction in the resorts WWTPs nutrients loads) will significantly affect phytoplankton biomass and related to it Secchi-depth variability (Fig. 5). In spite of such a measure, there are still occasions during June and October when Secchi depth falls below the 3 m threshold.

Urbanization is inevitably associated with greatly increased runoff problems: runoff from impervious surfaces is more rapid than from land covered with vegetation; precipitation intensity and duration are major factors determining removal of runoff constituents during a storm (27); higher intensity rains wash more dissolved and suspended constituents from watershed surfaces (28). The crux of the problem lies in the fact that urban runoff, containing nutrients, TSS and other substances is simply routed to the nearest convenient watercourse and discharged without treatment (29). Experts compare the situation in Bulgaria with that of the Spanish coast in the 1960s. As a result of the overbuilt environment (30) and poorly planned city infrastructure, some drainage canals were destroyed, and the SS fails to drain and accommodate the heavy runoff during rain events/storms (6).

Given the increased frequency/duration of heavy rain/storm events reported for the last several years (12) and the model results, it is suggested that the contribution of the TSS should be carefully considered in the management strategies for the Varna Bay area, e.g. storm water management and improvement of the SS could be a critical management option. If measures are taken accordingly, so that the land based overflow is successfully decreased to the necessary levels (20% direct runoff only), the TSS concentrations can be significantly decreased, leading to further 0.40 m improvement of water transparency. Thus design and planning procedures firmly based on the fundamental processes governing the quantity and quality of urban runoff flows could result in one of the effective solutions to the problems facing planners and decision makers (31, 32). As demonstrated by the model in the case of Varna bay such measures should be complimentary to the WWTPs improvement/rebuilt. The model limitation here is that it is not meant to be a true representation of possible future weather patterns. Changes in climatic conditions will not only alter the intensity of each variable but also the frequency of events.

CONCLUSIONS

The dynamic SAF modeling technique employed to assess the interplay between sewerage systems (SS) options and WWTPs improvement, reveals that both management options are complimentary. The desired levels of water clarity and transparency could be achieved through profound analyses and consideration of the complexity of the anthropogenic and environmental impacts. The model outcome demonstrates that the SAF methodology proves to be an instrument, assisting the overall effectiveness of an integrated management and adequate policy framework targeted to long-term ecosystem sustainability by bringing together multiple sources of knowledge.

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