Chapter 10
Multi-Compartment Water Quality Assessment of Port Burgas and Burgas Bay

Svetla Miladinova, Dimitar Marinov, Venzislav Krastev and Jordan Marinski

Abstract The study employs the biogeochemical budget methodology of multi-compartment LOICZ model to the complex system of Burgas port and Burgas bay. Main model input data are turbidity and concentrations of phosphorous, nitrogen, and chlorophyll-a. Two distinct seasonal periods are considered in the study—low precipitation (September–November) and high precipitation (December–April). Internal nutrient fluxes are estimated and their dependence on nutrient load is discussed. The results show that system varies between autotrophy and heterotrophy during the year due to rainfall regimes, human activities in the basin, and the associated runoff and phosphorus loads or releases from sediments.

10.1 Introduction

Port Burgas, situated in the Burgas bay, is an important hub of the transborder Pan-European transport corridor 8. The existing terminals of the port Burgas are in process of reconstruction and even the new ones are expected to be built. However, the potential adverse effects of the port operation embrace a range of environmental issues like air and water pollution, contamination of sediments, loss of bottom biota, coast erosion, waste discharges, oil spillage, leaking of hazardous materials, etc. (Karagyozov et al. 2004; Peris-Mora et al. 2005). The effective management of such

---

S. Miladinova (✉)
Institute of Mechanics, Bulgarian Academy of Sciences, Sofia, Bulgaria
e-mail: svetla@imbm.bas.bg

D. Marinov · J. Marinski
National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences, Sofia, Bulgaria
e-mail: dimitar.marinov@meteo.bg

J. Marinski
e-mail: marinski@bas.bg

V. Krastev
Bulgarian Ports Infrastructure Company, Sofia, Bulgaria
e-mail: v.krastev@bgports.bg

C. Stylios et al. (eds.), *Sustainable Development of Sea-Corridors and Coastal Waters,*
DOI 10.1007/978-3-319-11385-2_10

systems among the others requires an improved scientific understanding of ecological responses to changes in nutrient inputs.

ECOPORT8 and TEN ECOPORT projects aim to better quality of Southeast European ports placing the prevention of pollution and preservation of natural resources in port areas and nearby coastal zones. Apart of the other measures, the mathematical modelling was identified as a reliable tool for recognition; the interplay of the main factors affecting seaport aquatic systems that could be used for better port ecological management.

A single-box application of LOICZ model (Gordon et al. 1996) for Burgas bay is presented in (Marinov et al. 2014). Although the main input sources and fluxes into/out of the port area were estimated, some open questions are still present. These include: To what extent the single-box model estimates the nutrient fluxes into/out the port area? What is the water quality into the different zones of the port Burgas? How nutrients and turbidity contribute to the overall ecosystem development?

To answer the above open questions a multi-compartment LOICZ model (LOICZ 2010) is developed in this study. The majority of input data, needed for model run, are provided by measurements performed in the aquatorium of the Burgas port and Burgas bay. A short model description and the details about the model set up, followed by a discussion of the obtained results, are presented in the next sections.

10.2 Study Area and Methods

Study area consists of "small" Burgas bay, including port Burgas, with a surface of 9.8×10^6 m^2 and mean depth 9 m. The water exchange with the coastal Lakes Mandra and Vaya (Fig. 10.1) is low and it is intensified in rainy conditions. The average annual precipitation is 590 mm while the evaporation is 675.9 mm. In terms of water balance, the small Burgas bay can be classified as weakly stratified positive estuary (Valle-Levinson 2010). Monitoring data are collected at four sampling stations close to the port terminals and one outside of the bay considered as a reference one in the model (Fig. 10.1; ECOPORT 8 project 2012; TEN ECOPORT project 2013). The monitoring involves surface water observations taken approximately three times per month, from the beginning of September 2011 till the end of April 2012.

Study area is divided into three compartments as shown in Fig. 10.1. The division allows computing the transport, net production rates, regional processes within the system (e.g., patterns of productivity and denitrification with regard to nutrient transports), and to isolate regions with high-abiotic activity. Such information could be used to assess how nutrient load reduction/amplification affects water quality, productivity, and net biogeochemical fluxes through particular areas.

Multi-compartment LOICZ model is applied assuming that the bay is well mixed vertically and at steady state. However, in the case study of the Burgas bay the salt budget cannot be accurately assessed as the salinity gradient is too small which could induce errors in the computed exchange rates (LOICZ 2010). Thus, instead of salinity budget our procedure involves suspended particulate matter (SPM).

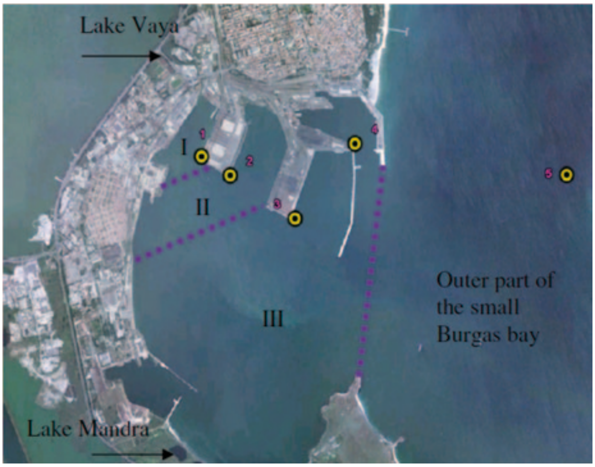

Fig. 10.1 Map of the study area, model compartments, adjacent coastal zone, and sampling points

The model calculations follow several steps: (1) budgets of conservative materials like water and SPM; (2) budgets of nonconservative materials such as dissolved inorganic carbon (*DIC*), nitrogen (*DIN*), and phosphorous (*DIP*); and (3) stoichiometric linkages. Two time periods are examined: with low (September 2011–November 2011) and with high (December 2011–April 2012) precipitation.

The water and SPM balances for the compartment $i+1$ in the multi-compartment scheme are described by the following relations:

$$Qr_{i+1} = Qr_i + Qf_{i+1} \tag{10.1}$$

$$0 = Qf_{i+1}Sf_{i+1} + Qr_{i+1}S_{i+1} - Qr_iS_i + E_{i,i+1}(S_i - S_{i+1}) + E_{i+1,i+2}(S_{i+2} - S_{i+1}) \tag{10.2}$$

where Qf_{i+1} is the freshwater input directly into the box, estimated as a difference between evaporation and freshwater inflows for each compartment; Sf_i is SPM in the freshwater input; S_i and S_{i+2} are the concentration of SPM in the landward and seaward boxes; $E_{i,i+1}$and $E_{i+1,i+2}$ are the diffusive exchanges with the landward box and with the seaward box, respectively. Equation 10.1 allows to calculate the residual flux Qr_i leaving each compartment, while Eq. 10.2 is used to find the flow across the compartment's boundary ($E_{i,i+1}$), used afterwards for the calculation of nonconservative compounds. In particular, the balances for the first box are:

$$Qr_1 = Qf_i \tag{10.3}$$

$$E_{0,1} = (Qf_1Sf_1 + Qr_1(S_1 + S_2)/2)/(S_2 - S_1) \tag{10.4}$$

The equations for nutrients are similar to those for SPM balance (Eqs. 10.2 and 10.4), where SPM is replaced with the water quality component (*DIN* or *DIP*) and also a net source/sink term (*ΔDIN* or *ΔDIP*) is added.

LOICZ model is designed to describe the role of ecosystem-level metabolism as a net source or sink of P, N, and especially C, so the interest is firstly to specify the difference between primary production and respiration. This difference is often called "net ecosystem metabolism" (NEM). Accepting the Redfield ratio as a representative, the model describes the organic metabolism as assimilation of forms of nitrogen (ammonium, nitrate, and nitrite) and phosphorous to support primary production (p). On the contrary, all nitrogen released during respiration (r) is immediately converted to ammonium, nitrate, and nitrite. The difference between these two biological process rates ($p-r$) is a measure of NEM. The nitrogen cycle is more complicated than the phosphorus and carbon cycles because of the side reactions of "denitrification" and "nitrogen fixation." These side reactions also consume or produce the measured forms of nitrogen.

10.3 Discussion

Water and SPM budgets are counted first in order to estimate the water exchange between different compartments. Principally, the studied system displays a net positive water balance since the total freshwater input from rivers/lakes and rain exceeds water loss by evaporation during both periods. Additionally, model results show that the water exchange with the seaward parts of the bay is the dominant renewal process for the each compartment. The average period of time that a specified unit of water spends in a particular reservoir is called the residence time. The steady-state residence time, tr_i, is given by the ratio of water volume of the compartment, V_i, and daily volumetric rate of water input/output, $(|Qr_i| + E_{i,i+1})$ (Pritchard 1969).

Water residence times for the both periods are given in Table 10.1. For comparisons, calculations based on the single-box model (Marinov et al. 2014) are also presented. During high season, the residence time of seaward compartment, $tr_3 = 25\,\text{days}$, is very close to the single-box residence time. The third compartment, that is largest one, represents to a greater extent the water renewal of the entire bay. Note that the residence time depends inversely on $E_{i,i+1}$, which is calculated in the case of single box using salt budget, while in the present study it is estimated on the base of SPM budget. The water renewal process in the landward and middle

Table 10.1 Volume and residence time for the three compartments (I, II, and III) and for the whole study area based on single-box model. (Marinov et al. 2014)

	Period	Box I	Box II	Box III	Single-box model
Volume $V_i \times 10^6\ \text{m}^3$	N.A.	4.5	20.2	63.6	88.2
Residence time tr_i day	High	1	8	25	23
	Low	8	28	26	32

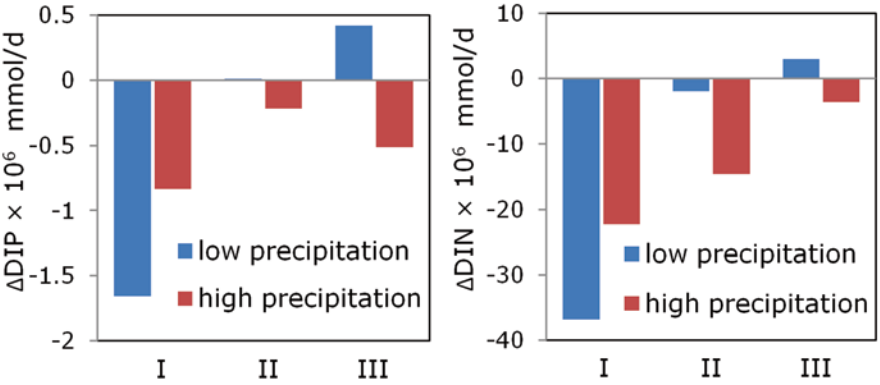

Fig. 10.2 Residuals of dissolved inorganic nitrogen (*ΔDIN*) and phosphorus (*ΔDIP*) in the three model compartments (I, II, and III) for both seasons in million mmol/d

compartments shows clear seasonal pattern. However, the seaward compartment is less susceptible to variation in precipitation than the other compartments.

The main input of nutrients in the study area is due to the industrial and domestic wastewaters. The treated wastewater enters the small Burgas bay through the discharges of Lake Vaya through a narrow connection. Another point source of nutrients is Lake Mandra connected with the seaward compartment (Fig. 10.1). Model input values of *DIN* and *DIP* in the runoff and precipitation are given in Marinov et al. (2014). The essential plant nutrients elements *C*, *N*, and *P* can be consumed and/or produced in the system, thus, in their budgets there will be residual elements (*ΔDIC*, *ΔDIN*, or *ΔDIP*) which are not balanced. The residual values are a measure of the net internal fluxes and should be interpreted as a function of the internal system dynamics.

The calculated *ΔDIN* and *ΔDIP* for the compartments during both seasons are presented in Fig. 10.2. Note that *ΔDIP* and *ΔDIN* are always negative in I and II meaning that there the ecosystem works as a sink of *DIP* and *DIN*. In contrast, III is a source in a low-precipitation season. In I the consumption of nutrients rises in low-precipitation season due to relatively long residence time, despite of lower runoff of nutrients. Obviously, the amount of nutrients is enough to keep high levels of primary production. The II experiences elevated *DIN* and *DIP* consumption in high-precipitation season even though water renewal period is 3.5 times shorter than in low-precipitation season. This compartment lacks a point source of nutrients and receives them from the landward or seaward compartment where the concentration of nutrients is lifted up during high-precipitation season. The seaward compartment is a producer/consumer of nutrients in low- or high-precipitation season. This result coincides with the findings of single-box model, although the residuals are greater in Marinov et al. (2014).

The model also involves the developing of stoichiometric linkages among non-conservative budgets. Assuming that plankton is likely to dominate the net metabolism with the Redfield *C*:*N*:*P* ratio 106:16:1, the LOICZ can evaluate NEM

Table 10.2 Stoichiometric calculations for II and III compartments and for the whole study area based on single-box model. (Marinov et al. 2014)

	Period	Box II	Box III	Single-box model
NEM (mmol/m^2d)	High	9.8	8.0	13.85
	Low	−0.36	−6.55	−4.03
Nfix.-Denitr. (mmol/m^2d)	High	−4.59	0.68	−0.55
	Low	−0.82	−0.56	32

and Nfix.-Denitr., which is estimated as a difference between calculated ΔDIN and expected $\Delta DIN=16\Delta DIP$.

LOICZ approach could not be successfully applied for small turbid systems like the first compartment of our study area. Thus, results for NEM and Nfix.-Denitr. are reported here only for II and III in Table 10.2 where the results of the single-box model (Marinov et al. 2014) are also presented. The estimated values of NEM are positive during high-precipitation period, demonstrating a net production of organic matter and an autotrophic state. Obviously, NEM in II is higher than that of III because II receives nutrient-rich water from Lake Vaya that spent only a day on average in I. In both compartments, NEM is lower than NEM of single box. The last is expected since the first compartment has been excluded from the NEM calculations. During winter-spring the small bay receives a huge amount of *DIN* from the point sources leading to production amplification. It appears that NEM is controlled more by the balance between inputs of *DIN* and total organic nitrogen. The estimated value of NEM is negative during low-precipitation period, showing a net mineralization of organic matter and a heterotrophic state. Moreover, negative NEM is an indicator that the system is likely a source of carbon dioxide and *DIP* release to the water column, probably from bottom sediments. The seaward compartment exhibits stronger respiration than the middle one though production prevails in II during growth season. Further model development is needed so that NEM estimation requires an accurate determination not only of the contribution of DIP fluxes, but also of the oxygen flux.

According to Swaney et al. (2011) the difference between nitrogen fixation and denitrification should be generally close to zero (with a dominance of denitrification). High-negative values of Nfix.-Denitr. (−4.6 mmol/m^2d) are estimated for II due to high-negative values of ΔDIN. Large inputs of *DIN* from the lakes lead to ΔDIN exceptionally negative in comparison with expecting ΔDIN indicating that an important sink of *DIN* is missing or some flux estimations are incorrect. In view of the fact that high-precipitation season includes period of algal growth phase, a significant role may be played by algae as a nitrogen storage. On the contrary, nitrogen fixation prevails for III in the same period, indicative of *DIN* source in this area.

In summary, the multi-compartment model shows that the denitrification overwhelms nitrogen fixation in low-precipitation period, while the single-box model shows that fixation prevails. Fixation is a source of *DIN*, while denitrification represents a sink of *DIN* and takes place in the water column under low-oxygen conditions, resulting from high rates of organic degradation that depletes oxygen content. Thus, we can conclude that estimations based on the multi-compartment model better represent the system pointing out that in the low-precipitation period the water quality of port area is low.

10.4 Conclusions

Multi-compartment LOICZ model computation of nutrient transport provides interpretive framework to examine possible causes and mechanisms underlying water quality, thus being useful tool for management related research. The results point out that even complex water quality patterns in variable coastal port areas can be better understood when detailed data are available for analysis.

Multi-compartment LOICZ model results for the small Burgas bay, including the aquatorium of port Burgas, allow concluding that the water renewal in landward and middle compartments is subject to clear seasonal pattern. In winter-spring period 1 day is required to replace the port water of the landward compartment by the fluxes of fresh or marine water (8 days for the middle zone), while it takes 8 days in summer-autumn (28 for the middle). The seaward compartment is not strongly influenced by the season change.

Port Burgas area receives a rich supply of nutrients from land-based sources leading to decrease in water quality, particularly in periods with high temperature and low precipitation. In high-precipitation season there is a clear relationship between nutrient loading from terrestrial sources and nitrogen metabolism. Phosphorous metabolism does not show such a relation since indicative phosphorous release from bottom sediments or load from another indeterminate source. One could suggest that nutrient loads to the system associated with terrestrial sources are the likely reason for the declining tendency in the water quality of this area, although the possibility still remains that other unidentified and uncontrolled factors can govern the system dynamic.

Acknowledgments This research was made possible thanks to a research grant provided by South East Europe Transnational Cooperation Programme within "Transnational enhancement of ECOPORT 8 network"—TEN ECOPORT project (SEE/D/0189/2.2/X).

References

ECOPORT 8 project (2012) Environmental management of transborder corridor ports. http://www.ecoport8.eu. Accessed 15 Oct 2013

Gordon DC Jr, Boudreau PRK, Mann H et al (1996) LOICZ biogeochemical modelling guidelines. In: LOICZ reports & studies No 5. http://www.ferrybox.eu. Accessed 15 Oct 2013

Karagyozov C, Karaivanova M, Ivanov V (2004) Review of oil and waste streams in the port of Bourgas. http://www.pse.ice.bas.bg. Accessed 15 Oct 2013

LOICZ (2010) LOICZ-biogeochemical modelling node. http://nest.su.se/mnode. Accessed 15 Oct 2013

Marinov D, Miladinova S, Marinski J (2014) Assessment of material fluxes in aquatorium of Burgas port (Bulgarian Black sea coast) by LOICZ biogeochemical model. In: Book of proceedings of 3rd IAHR Europe Congress, Porto, 14–16 April 2014, ISBN 978-989-96479-2-3

Peris-Mora E, Diez Orejas JM, Subirats A et al (2005) Development of a system of indicators for sustainable port management. Mar Pollut Bull 50(12):1649–1660

Pritchard DW (1969) Dispersion and flushing of pollutants in estuaries. ASCE J Hydraul Div 95(HY1):115–124

Project TEN ECOPORT (2013) Transnational enhancement of ECOPORT8 network. http://www.tenecoport.eu. Accessed 15 Nov 2013

Swaney DP, Smith SV, Wulff F (2011) The LOICZ biogeochemical modeling protocol and its application to estuarine ecosystems. In: Wolanski E and McLusky D (eds) Treatise on Estuarine and Coastal Science, Academic Press, Waltham, pp 135–159

Valle-Levinson A (2010) Definition and classification of estuaries. In: Valle-Levinson A (ed) Contemporary Issues in Estuarine Physics, Cambridge University Press, Cambridge, pp 1–11