QUALITATIVE-QUANTITATIVE ANALYSIS OF THE WATER FLOODING OF NATURE PARK "KOPACKI RIT"

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Abstract: This paper presents the analysis of relationships between relative water levels on Drava and Danube river and water level inside the Nature park "Kopacki rit" during the summer 2002. Due to high complexity of complete system under study, usual quantitative techniques couldn't be applied. Qualitative-quantitative analysis has set up some basic relationships and showed possibilities in dealing with complex water flooding systems. For the modelling procedure AI identification tool was used, based on circular qualitative-quantitative algebra.

keywords: process modelling, qualitative and qualitative reasoning, process identification, ecological system

1. INTRODUCTION

There are still a few places in Western and Central Europe that have not been completely changed through human manipulation and usage. One of them is Nature park "Kopacki rit" situated in Croatia, at the inlet of Drava river into Danube. The surface of the protected area is about 230 square kilometres. Nature park "Kopacki rit" represents a complex ecological system with 40 different habitats and more than 1600 animal and plant species. Due to almost completely preserve biodiversity, continuous monitoring and analysis are identified as necessarily steps in process preservation.
Due to high complexity of surface waters flow and undoubtedly high complexity of underground waters, it is impossible to establish a specific model that would suit the actual situation inside the Nature park "Kopacki rit". Conventional analysis techniques, such as differential equations, aren't suitable for such system investigation because of lack of parameters values and boundary conditions. On the other side qualitative reasoning aims to develop representation without precise information. If we possess quantitative information, it can be easily incorporated into qualitative mechanism, but even without it we can qualitatively analyse the system under study even if don't know a complete system structure. However, due to incomplete specification, qualitative reasoning may generate a set of possible behaviours that still require an expert's effort to interpret. Nature park "Kopacki rit" can be observed as a continuous-variable cyclic dynamic system with feedback loops and states, but very slow and inert. Process monitoring and interpretation don't have to be performed in real-time. The structure of complex ecosystem of the Nature park "Kopacki rit" was investigated in [Mihaljevic, 1999], and complete management strategy was proposed in [Jovic, et. al., 2001]. Those articles postulate that the basic force function for growth and disturbance in the Nature park "Kopacki rit" is flooding (i)regularity. Since the flooding (i)regularity in the park depends on Danube and Drava water levels, it was expected that these changes would affect water level inside the park. This analysis investigates mutual connection between high water levels of Danube and Drava river and water level inside Nature park "Kopacki rit", by means of the qualitative-quantitative mechanism.
In the next two sections we deal with quantitative information used for identification of high tide wave and define inflexion points. These phenomena are directly identified through water levels. In the fourth section a qualitative-quantitative modelling method is used for data analysis. Relevant qualitative-quantitative models are presented. We conclude with discussion.

2. HIGH TIDE WAVE IDENTIFICATION

Data necessary for the analysis were obtained from measurement points on Drava and Danube river and on Lake Sakadaš, measurement point inside the Nature park "Kopacki rit". Observed time period was between 10.08.2002. and 10.09.2002. Because the water level was measured each hour, there were 768 values obtained from each measurement point during these 32 days. Measurement points were: Batina and Vukovar at the Danube river; Osijek, Belisce and Donji Miholjac at the Drava river and Lake Sakadaš inside Kopacki rit. Relative position

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of all measurement points can be viewed in Fig.1. High tide wave input was at Batina and its influence on water levels on all other measurement points was observed during 32 days.

Figure 1: Relative position of all measurement points

Water levels at all observed measurement points can be viewed in Fig.3. Some key-spots should be noticed from Fig.3. Except from points were maximum water levels occurred, interesting are inflexion points, i.e. points at which water level become higher or lower than water level at other measurement point and at the same time water level is higher than 400 cm. Those spots are designated as ‘a’, ‘b’, ‘c’ on Fig.2. Also strong qualitative similarity between high tide shape between Batina, Kopacki rit, Vukovar and Osijek should be noticed.

From Fig.2. some general conclusion about water levels can be stated. There are time lags between maximum water level at Batina and all other measurement points. For example, maximum water level inside the Nature park “Kopacki rit” was reached about 25 hours after it reaches maximum value at Batina. Maximum water level at Vukovar was reached about 41 hours after it reaches maximum value at Batina. If we look again at Fig.2. connection between maximum water level at Batina and Vukovar is a natural consequence of river flow. But connection between maximum water level inside Nature park “Kopacki rit” and Batina should be further analysed. Also maximum water level at Belisce and Donji Miholjac can’t be directly connected with maximum water level and high tide wave at Batina.

3. INFLEXION POINTS

In the previous section it was stated that inflexion points are points at which water level become higher or lower than water level at other measurement point and at the same time water level is higher than 400 cm. The first inflexion point, designated as ‘a’ on Fig.2. is on the **ascending** wave front and describes situation in which water level inside Nature park “Kopacki rit” becomes higher than water level at Vukovar. Characteristic values for that point are presented in Table 1. It is obvious that water level inside the Nature park “Kopacki rit” increases much faster than the water level at Vukovar. Water level at Batina was higher than 500 cm and inside the park water level was higher than 400 cm.

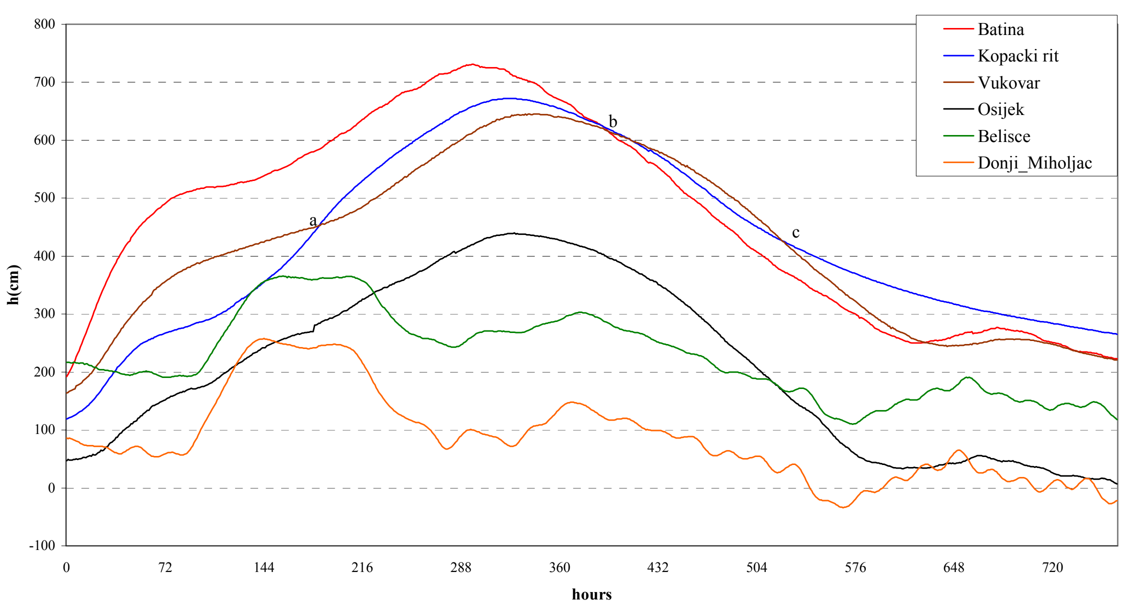

Figure 2: Water levels at measurement points

When Danube water level becomes higher than 400 cm at the entry of the park water from Danube starts to freely flow over into the park. Direct consequence is deceleration of water level increase at Vukovar. The park acts like a natural pool.

Table 1: Inflexion point: Kopacki rit-Vukovar

	Average water level (cm)	Average increase (cm)
Kopacki rit	438	2.66
Vukovar	449	0.87

The second inflexion point, designated as ‘b’ on Fig.2. is on the **descending** wave front after maximum water level was reached and describes actually three different situations. Characteristic values for each of these three situations are presented in Table 2, Table 3 and Table 4 respectively.

Table 2: Inflexion point: Batina-Kopacki rit

	Average water level (cm)	Average decrease (cm)
Batina	615	-1.71
Kopacki rit	619	-1.21

After maximum water level was reached at Batina, hide tide wave front is moving downstream toward Vukovar. After the hide tide wave front passes by the entry point for the park, draining of the park will start. Still, average decrease at Batina will be higher than average decrease inside the park, what will result in higher water level inside the park.
Table 3 represents situation in which relative water level at Vukovar becomes higher than relative water level at Batina.

Table 3: Inflexion point: Batina-Vukovar

	Average water level (cm)	Average decrease (cm)
Batina	615	-1.71
Vukovar	615	-0.94

Average decrease at Batina is higher than average decrease at Vukovar. Vukovar is downstream from the park, so draining of the park will affect water level at Vukovar.
Table 4 represents situation in which water level at Vukovar becomes higher than water level inside the park.

Table 4: Inflexion point: Vukovar-Kopacki rit

	Average water level (cm)	Average decrease (cm)
Kopacki rit	590	-1.46
Vukovar	592	-1.18

This situation is direct consequence of the park draining. Since the Danube water level at the park entry point is lower and lower, draining of the park is faster. It can be argument with average decrease, which is higher than for the inflexion point Batina-Kopacki rit (1.21<1.46).
The third inflexion point designated as ‘c’ on Fig.2. is also on **descending** wave front and describes situation in which water level inside Nature park “Kopacki rit” becomes higher than water level at Vukovar. Similar situation was identified on ascending wave front (inflexion point ‘a’). Characteristic values for that point are presented in Table 5.

Table 5: Inflexion point: Vukovar-Kopacki rit

	Average water level (cm)	Average decrease (cm)
Kopacki rit	435	-1.1
Vukovar	442	-2.1

Water level inside the park is very close to the value of 400 cm. When water level becomes lower than 400 cm, draining of the park almost stops. Entry point is higher than 400 cm, so there is no more direct water flowing out in Danube. High tide wave front passed Vukovar so average decrease at Vukovar is higher than average decrease inside the park. Result of that is higher water level inside the park than at Vukovar.
Analysis of the inflexion point was done with quantitative values, i.e. values of water levels. Though it seems very simple, it is far from trivial and it required an expert’s assessment. Certainly it provided good basis for qualitative analysing, by setting up some initial relationship between measurement points. Also it should be noticed that direct influence between Drava water level and water level inside the park wasn’t even taken into consideration.

4. IDENTIFICATION OF QUALITATIVE MODELS

Identification of the inflexion points has set up good basis for qualitative analysis. Expert’s assumption about mutual connection between Drava and Danube water levels and flooding (i)regularity inside the park was confirmed. It can be postulated that the park is uncontrollably flooded at extreme high and uncontrollably dried at low water levels of the Drava and Danube river and semi-controllably flooded at medium water levels. Qualitative models were generated using AI identification tool, similar to neural networks but exhibiting algebraic explicit forms of the solution, based on the circular quantitative to qualitative information conversion [Jovic, 1997; Jagnjic, 2001]. Some basic characteristic of the quantitative-qualitative algebra incorporated into AI identification tool called Medusa2000 will be presented here. Detailed overview can be found in [Jovic, 1997].

a) The primary data for the model are always taken from the set of quantitative sampled variables, i.e. discrete valued function or n-element vector.
b) Quantitative values can be mapped into the qualitative space, called qualitative data series, by the ranking procedure R{Vi}->{vi}
c) The qualitative distance between the two n-element qualitative vectors {vi} and {vj} is given as the sum of squared rank differences among the corresponding vectors points k.

$$d = \sum (\Delta_k)^2 \text{, where } \Delta_k = v_{ik} - v_{jk} \qquad (1)$$

d) The similarity between the two n-element qualitative vectors can be evaluated by using the qualitative correlation coefficient r, given by [Petz, 1985]:

$$r = \frac{\frac{n(n^2-1)}{6} - d - \sum A_1 - \sum A_2}{\sqrt{\left(\frac{n(n^2-1)}{6} - 2\sum A_1\right)\left(\frac{n(n^2-1)}{6} - 2\sum A_2\right)}} \qquad (2)$$

where d is the distance defined earlier, and A1 and A2 represent the effect of the same rank repetition for the two respective variables. If z denotes the number of a single rank repetition, the value Ai for the variable {vi} is given as:

$$A_i = \frac{z(z^2-1)}{12} \qquad (3)$$

The above features set the ground for the qualitative process modelling procedures based on the similarity calculus.
For the modelling purpose basic concept was proposed in the form of level dependent system behaviour, as presented in Fig.3.

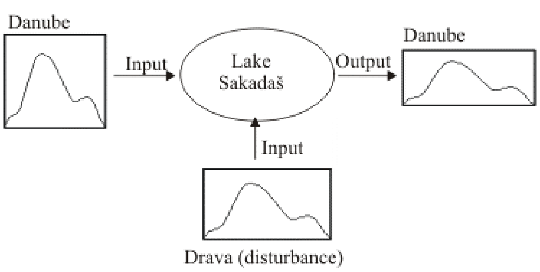

Figure 3: Basic concept

Previous quantitative analysis set up basic suppositions as follows:
1. All relative water levels are at the same altitude.
2. Time constant of ascending and descending waves are equal (for h>400 cm).
3. Model correlations depend on time lags/lead.
4. Drava influence can be neglected – thus process disturbance can't be expected (for h>>).

For the purpose of the modelling procedure, the basic set of the measurement values were divided into 32 sections, each with 24 measurement values. According to identified time lags and natural location of each measurement point, example of data necessary for the modelling procedure are presented in Table 6.

Kop0813 designates target function: water level inside the park during the 13.08.2002. All models that were generated for observed time period will not be presented here.

Table 6: Example of basic data set

	t0	t1	t2	…	t23
Bat0811	329	334	340		432
Bat0812	435	438	441		489
Bat0813	491	493	495		516
Os0811	62	65	64		111
Os0812	111	114	115		151
Os0813	152	154	155		172
Bel0811	204	204	204		195
Bel0812	195	197	197		191
Bel0813	191	191	191		197
DMih0811	72	72	72		69
DMih0812	70	71	72		58
DMih0813	59	60	61		86
Kop0813	267	268	269		285

Actually the whole situation that occurred during the observed time period was divided into three sections according to water level inside the park. First sections describes situation when water level inside the park was lower than 400 cm (the first 165 hours on ascending wave front and from 547 till 768 hours on descending wave front). The second section describes situation when water level inside the park was between 400 and 600 cm (from 166 till 254 hours on ascending wave front and from 414 till 546 hours on descending wave front). The third section describes situation when water level inside the park was higher than 600 cm (from 255 till 413 hours). For each section one general model was chosen. Target function for all models was water level inside the park. Those models are presented in Table 7.

Table 7: Qualitative-quantitative models

Hours	Water level (cm)	Model	Corr. coeff. r
0-165	less then 400	A	1
166-254	[400-600]	B	1
255-413	higher then 600	C	0.998
414-546	400-600	D	1
546-768	less then 400	E	0.81

A) Batina*Osijek-0.29 $\frac{Osijek}{Belišće}$

B) Batina*Osijek

C) Osijek+0.12 $\frac{Batina}{Belišće}$

D) Batina

E) $\frac{Osijek}{Belišće} + 0.2\frac{Donji\_Miholjac}{Osijek}$

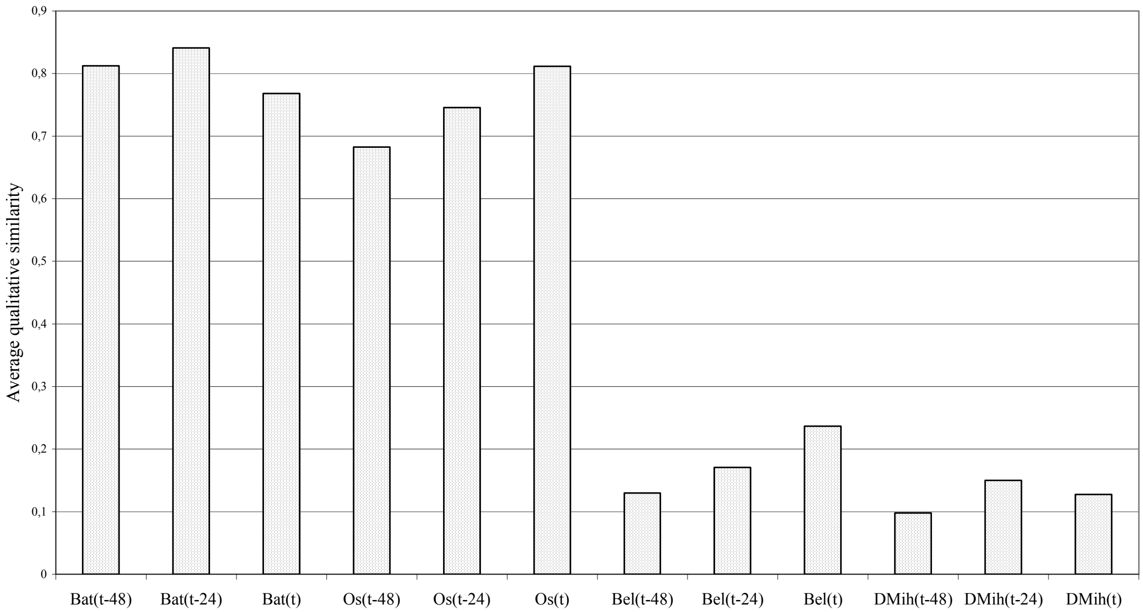

Figure 4: Qualitative similarity for Kopacki rit

All generated models shows high correlation coefficient with target function – water level inside the park. Also it should be noticed that the primary modelling variable in the case of ascending wave front is Batina. Model that is slightly different is model generated for descending wave front and water level below 400 cm. This model couldn't be explained and fully understood even by experts. Correlation coefficient was also rather low; only 0.81. But some expectations were confirmed. For medium water level (between 400-600 cm) on both ascending and descending wave front, similar model was generated. For the high water level, during the occurrence of maximum point, primary modelling variable is Osijek. It is explained with the fact that for the both maximum points, at Osijek and inside the park, approach to the maximum is much more smoother and uniform than for the Batina.
Additional explanations of generated models were confirmed with qualitative similarity calculus. Fig.4 shows average qualitative similarity between Kopacki rit and all other measurement points. From Fig.4. it can be seen that the biggest qualitative similarity is between Batina with 24-hour time lag, Batina with 48-hour time lag and Osijek without time lag.

5. DISCUSSION

In this paper analysis of mutual connection between water levels on Drava and Danube river and water level inside the Nature park "Kopacki rit" was investigated. Although some previous analysis showed high determinacy of that connection [Jovic and Mihaljevic, 1998], extreme high water levels during the summer 2002. year has offered new possibilities for exploration of new phenomenon. Such situations aren't usual so they demand to be analysed and investigated. Water levels on Drava and Danube measurement points were basic data set. The presence of the noise shouldn't be comment in detail. Because of that our investigation started very carefully, expressing only things that are actually natural consequences of water flow (identification of high tide wave). Identification of inflexion points helped us in setting up basic relationships between measurement points. Due to high complexity of the complete system, it wasn't possible to apply usual quantitative techniques for modelling procedures. Introduction of qualitative-quantitative modelling was right choice. Given models has confirmed experts expectation about mutual relationships.
During the modelling it was found out that one measurement point is obviously missing. It is measurement point at the inlet of Drava into Danube river. This point was identified as a major point for complete analysis. But, even without her some basic relationships were set up. How does complete flooding period affect biodiversity inside park should be investigated in a due time. Since we mentioned that complete system is very slow and inert, first data about those changes will be accessible in future. Our task is to continue with monitoring and preserving this earth paradise.

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