A Model for Intelligent Treatment of Floodwaters

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Abstract. This model reflects the situation of floodwaters of the river Danube in Upper Austria. The main idea is to use statistical data in this model, so that it will come very close to the real behavior of an inundating Danube in this area. Important input parameters are the water throughput at some crucial locations along the river and the amount of precipitation in the influencing region. This model shows how significant damages on areas nearby the river can be avoided after the installation of flood preventing constructions (e.g. flood polder). It will be adaptable for other territories by changing parameter values.

1 Introduction

In the years 2002 and 2013, during the period of summer, the nearby region of the river Danube was flooded. In Linz on June 4th, 2013 the maximum water level was at 9.3 meters, whereas the normal gauge height is about 3.5 m.

The two pictures below give an impression of this situation: Fig. 1.

The most important goal of this work is to be able to take efficient measures to minimize the damage of an inundating Danube that could go up to millions of Euros in particular when enterprises like *voestalpine* in Linz are affected. See also the documentation of the above mentioned floodwater: *Hochwasser Juni 2013, Donau, Ereignisdokumentation, Verbund AG* [3].

2 Brief Description of the Model

The most important input data are the values of the amount of the flowing water at the power stations. Some important parameters enable the computation of the amount of water of an inundated area depending on the actual water throughputs in that area. The output is a measure of the damage in a given situation.

With the help of this model I make suggestions for an intelligent control of the water power stations in such situations. Some more flood preventing actions like eliminating sediments in the river and their impact will be investigated.

Here is a map of the affected area: Fig. 2.

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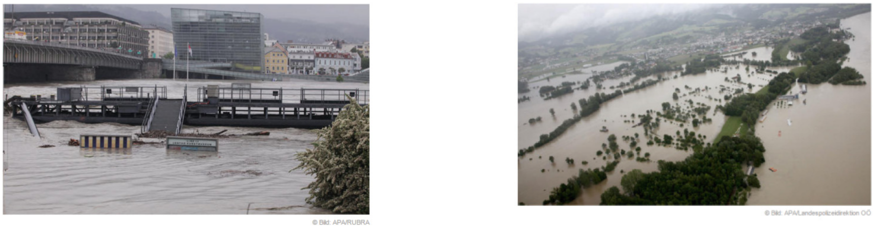

Fig. 1. Left: right riverbank, Ars Electronica Center and Nibelungen Bridge of Linz [1]. Right: deliberately flooded municipality area of Ottensheim [2].

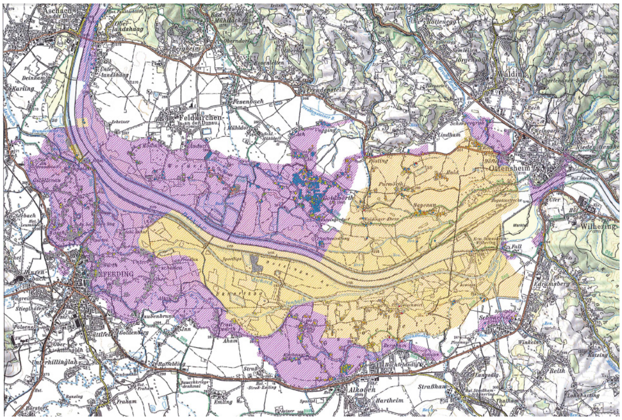

Fig. 2. The area of the Eferdinger Becken. The yellow depicted part was seriously affected, whereas the lila zone was less afflicted [5] (Colour figure online).

3 Mathematical Notation of the Model

This notation is made up of a DEVS (Discrete EVent System) and its functions. The most important one is the state transition function that transforms a given state s of the inundation model at some elapsed discrete time e to the next state s' that will be valid at the time **e + 1**. The time slot will be one hour. This system will start at time **e = 1** and stop after a given number **n** of hours. So we consider a certain interesting time interval within a few days.

Here is the DEVS formalism of the flooding model:

$$\mathrm{DEVS} = \langle X, Y, S, \boldsymbol{\delta}, \boldsymbol{\lambda} \rangle$$

with

X is the input set: a table (e, q) where e is a number between **1** and **n** and **q** is the amount of outflowing water in $\mathbf{m^3}$ at time **e**. This amount of water depends on the throughputs of water from the above power station and the one beneath after the saturation delay **d**.

Y is the output set: it represents the caused **damage** in **euros**.

S is the set of all possible states including the elapsed time: formed by a table (**e, s**) where s is the sum of already outflowed water at time **e**.

δ: S → S is the state transition function: it simply sums up the **q** values:

(**e', s'**): = (**e + 1, s + q**) for (**e, q**) of X and (**e, s**) of S.

For (**e** <= **d**) the value of **q** is **0**. For **e** = **1** the value of **s** starts with 0.

λ: S → Y is the output function: it takes the maximum value **s**, compares it with values in the damage table and takes the corresponding cost value from that table.

More details are stated in the next paragraph. The specific input table in this model mainly depends on the actual flowing water at the small village of Brandstatt (river km 2157). And this water flow depends on the operation mode and throughput of the power stations in Aschach and Ottensheim.

The difference $Q_{\text{Aschach}} - Q_{\text{Ottensheim}}$ (Q is measured in m^3 per second) is the approximate amount of outflowing water to the region called "Eferdinger Becken" which is about 50 km^2 large. About half of this region is severely affected. The input function table takes values on the basis of the real situation of **June 2013**. It reflects the observed amount of outflowed water and with the help of the damage table one can estimate the damage that adds up to about **100 million euros**.

4 The Computational Model

All the data and parameter values are stored in tables. The input table is generated by a PLSQL stored procedure. Here is a description of the most important parts:

4.1 The Tables and Their Values

There is a table that holds the data of the two power stations of interest. The next figure is a graphical representation of the input table during 27 h. At both power stations the peak of water throughput was reached about 20 h after the model starting time which is Monday 3rd of June 2013 at 5:15 am Fig. 3.

This diagram describes the outflowing water **q** in m^3 per hour at time e: Fig. 4.

The next figure shows the actual amount of outflowed water at the elapsed hour **e**: Fig. 5.

The following diagram shows that the overall damage is about **100 million euros** Fig. 6.

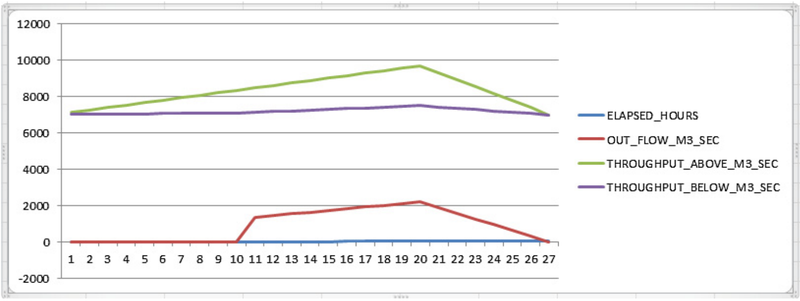

Fig. 3. The throughput data of Aschach and Ottensheim and the outflow.

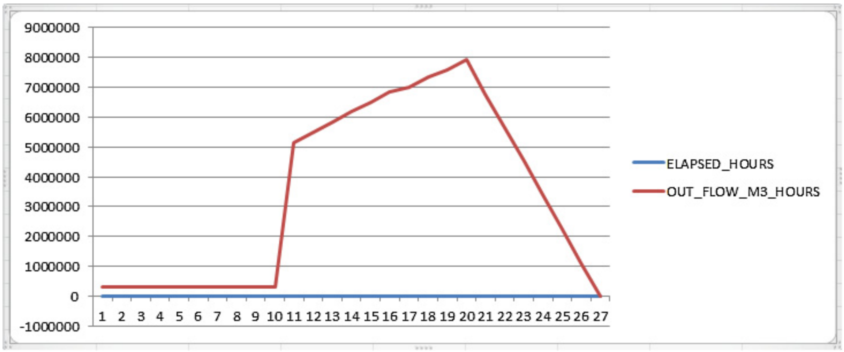

Fig. 4. The amount of outflowing water during 27 h in m^3 per hour.

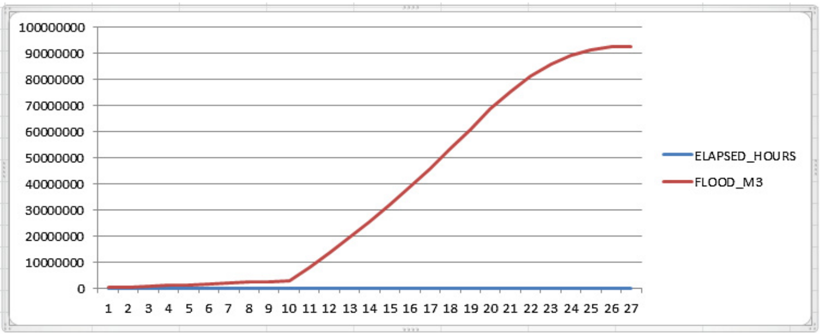

Fig. 5. The accumulated amount of outflowing water in m^3.

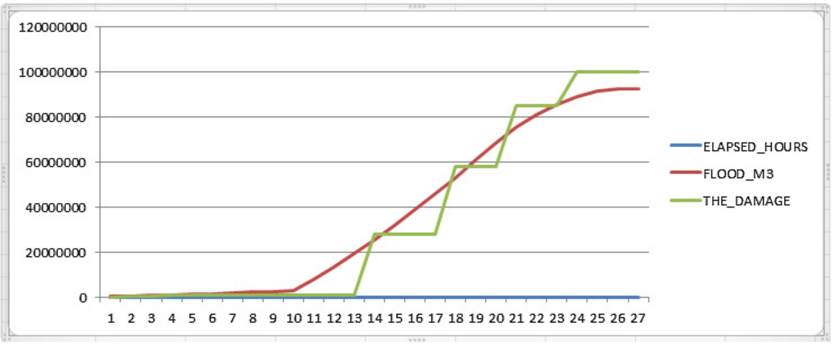

Fig. 6. The growth of the damage in euros relative to the increase of outflowing water.

4.2 The Parameters, Variables and Their Values

The following table lists the relevant characteristics with their names and values.

Characteristic	Variable names	Value
Name of the area	region_name	“Eferdinger Becken”
Size of this area	total_size	~50 000 000 m^2
Size of the most affected area (yellow)	size_yellow	~25 000 000 m^2
Size of the less affected area (lila)	size_lila	~25 000 000 m^2
Stowage space of power station Aschach	stowage_A	~114 000 000 m^3
Sediments increase during one year	sed_incr	~2 000 000 m^3
Size of future flood polder	polder_size	~12 500 000 m^2
Stowage space of future flood polder	stowage_P	~30 000 000 m^3
Peak water throughput KW Aschach	max_Q_A	~9 700 m^3/sec
Peak water throughput KW Ottensheim	max_Q_O	~7 500 m^3/sec
Maximum water outflow June 2013	max_out	~2 200 m^3/sec
Monitoring starting time	start_time	3rd June 2013, 5:15 am.
Time to fill stowage space KW Ottensheim	saturation_delay	10 h
Monitoring period from start time	duration	27 h
Tailback water amount	tailback_water	~5 000 000 m^3
Sum of water outflow + tailback water	sum_out	~92 500 000 m^3
Percentage of ground water	percent_gw	~50 %
Sum of water above ground	sum_over	~46 250 000 m^3
Average water hight in yellow area	avg_yellow	1,6 m
Average water hight in lila area	avg_lila	0,25 m

4.3 Dependencies Between the Variables

The following equations must be satisfied:

total_size = size_yellow + size_lila
max_out = max_Q_A - max_Q_O
sum_out = sum_over + sum_out * percent_gw/100
sum_over = size_yellow * avg_yellow + size_lila * avg_lila

4.4 The Definition of a Typical View Written in SQL

Here is one typical view, used to get the results above:

```
CREATE VIEW actual_damage  AS
SELECT elapsed_hours, flood_m3, MAX(extent_of_damage_euros) as the_damage
    FROM actual_flood, flooding_damage
    WHERE flooding_m3 <= flood_m3
    GROUP BY elapsed_hours, flood_m3
    ORDER BY elapsed_hours;
```

4.5 The Input Data Generator

For this purpose I wrote a PLSQL procedure to generate a plausible curve of throughputs at the power stations Aschach and Ottensheim. If available, this code can be replaced with statistical input data to store into the table “`flow_rates_m3_sec`”.

5 Case Studies

Now it is possible to consider some typical flood water situations. The first one describes an inundation of type “June 2013”, the second one assumes the elimination of sediments before this event and the third one includes a yet not existing flood polder of a plausible size.

5.1 The June 2013 Inundation

Taking the results of the model described above, this inundation caused an amount of outflowed water of approximately **92.5 million m^3** in this region and a damage that rounds up to **100 million euros**. It is a fact that the sediments above the power station of Aschach were constantly increasing and no flood preventing constructions were installed.

5.2 Same Inundation After Eliminating Sediments

Let us consider the constant elimination of the sediments. According to the above parameter of sediments increase, after 30 years about half of the stowage space of the power station Aschach was filled with **stones, gravel and sludge**. So it is not surprising that the company **Via Donau**, that manages the power stations, wanted to increase the water level upstream of (not only) this hydropower station. Because of the increase of the sediments the water amount in the stowage space decreases and therefore the performance of this power station also reduces to a certain extent.

After the elimination of the sediments we would have had **60 million m^3** more stowage space upstream this power station, and then the amount of outflowed water could obviously have been 60 million m^3 less which would have reduced the amount of the inundation to approximately **32.5 million m^3** in this region. So the damage could have been reduced from about **100 million** euros to only about **28 million** euros according to the damage table.

5.3 Same Inundation Having Flood Preventing Constructions

Additionally after the construction of a **flood polder** almost all the remaining **32.5 million m^3** of water can be hold in it and the flow off can be controlled so that the downriver areas are protected to that dimension. As a result, there is no need to deliberately flood the Eferdinger Becken and there will be **no damage at all**.

All the assumed parameter values are realistic and based on official documents and a discussion on this subject in a conference of the Landtag Oö held by Landesrat Rudolf Anschober [3, 4].

6 Recommendations

So far I have not mentioned the possibility of reducing the water amount in all stowage spaces before an obvious flooding event. This will also help a lot to minimize the devastating consequences of a natural catastrophe of this kind. The below stated recommendations are a summary of what I have learned by studying this subject.

6.1 Define Appropriate Rules of Operation

The reduction of the amount of water in all stowage spaces should begin more than 2 days before a critical rainy weather situation in the affecting areas. In such a situation rain probably will continue and therefore the flowing speed of the river is to accelerate to make sure that a maximum amount of water flows downstream, still without causing serious damage. A weather forecast with high quality prediction will facilitate decisions of this kind. These rules should operate in two modes:

(A) **pre-emptying** all stowage spaces upriver at least **54 h before** and

(B) **holding back as much water** as possible when the wave arrives.

Last time the prediction was based on a 24 h time window, but during 30 h it is possible to transport approximately **1 000 000 000 m^3 (one cubic kilometer)** of water downriver, so it is recommendable to extend this period to about 54 h.

6.2 Eliminate Sediments

The elimination of sediments along the whole river Danube in Bavaria and Austria and its tributary streams will contribute a lot to prevent floodwaters. There will be more space to temporarily store water and the throughput of water will be significantly higher as in the actual situation. There is one disadvantage, namely, during the period of pre-emptying the stowage spaces the power stations are almost out of service. In his speech on the 12th of June 2014, Landesrat Rudolf Anschober [4] made clear that flood prevention had a much higher priority than electricity generation.

6.3 Build Flood Polders

The existence of appropriate flood polders allows that a high amount of water can be stored temporarily and after a certain time it can be released without causing any damage. These constructions will make it possible to cope with extreme floodwaters caused by heavy precipitations.

6.4 Develop an App for Smart Phones

This "**Flood Warner**" application should alert the users and display important data such as water throughputs and water levels at all power stations and important places of residences. Moreover, it should also give a **prognosis** of the **expected maximum water level** and when it will be reached at a given user location.

7 Conclusion

Applying the above written recommendations will result in an intelligent treatment of floodwaters. I hope that in the near future we always will be able to say: "*We have been lucky, not even that heavy rainfall has caused any serious damage!*"

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