Development of synthetic velocity-depth damage curves using a Weighted Monte Carlo method and Logistic Regression analysis

Technical University of Crete

A.-E. K. Vozinaki[1], G. P. Karatzas[1], I. A. Sibetheros[2] and E. A. Varouchakis[1]

[1]School of Environmental Engineering, Technical University of Crete, Greece

[2]Department of Civil Engineering & Surveying and Geoinformatics Engineering, Technological Educational Institute of Athens, Greece

Contact e-mail: anthirini@gmail.com

EGU 2014

1. INTRODUCTION

✓ Methodology for flash flood loss estimation in agricultural and urban areas with limited or no flood damage data

✓ Synthetic development of damage curves ⇨ questionnaire-based survey among

- ○ practicing and research agronomists ⇨ rural loss data
- ○ building experts (civil engineers and architects) ⇨ urban loss data

Expert opinion ⇨ how damage to various crop/building types is related to a range of values of flood inundation parameters (i.e. floodwater depth (*h*) and velocity (*v*))

✓ The loss data compiled from the completed questionnaires ⇨ enhanced with synthetic data generated by a Weighted Monte Carlo method ⇨ processed via Logistic Regression techniques ⇨ logistic damage surfaces development for the agricultural and the urban sector

✓ WMCLR Python-based code ⇨ Weighted Monte Carlo method and Logistic Regression analysis combination. Every WMCLR code execution generates

- ○ Agricultural sector: Flood depth-flow velocity-damage surface for a specific crop and for every month of the year
- ○ Urban sector: Flood depth-flow velocity-damage surface for a specific building type

✓ Two Python techno-economic models ⇨ flood damage estimation in agricultural and urban sectors

2. MATERIALS AND METHODS

✓ Questionnaires

- ○ Agricultural sector: 4 crop types (Olive Trees, Fruit Trees, Tomatoes, Green Vegetables)
- ○ Urban sector: 3 residential building types (Concrete load bearing and brick masonry building, Stone building, Brick-cement brick building)

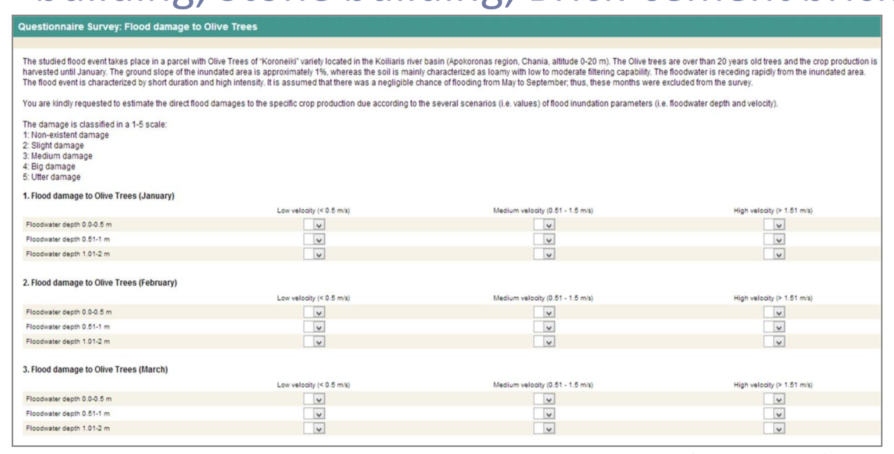

Figure 1: Online survey questionnaire for rural sector (Olive Trees)
https://www.surveymonkey.com/s/YQTWBYZ

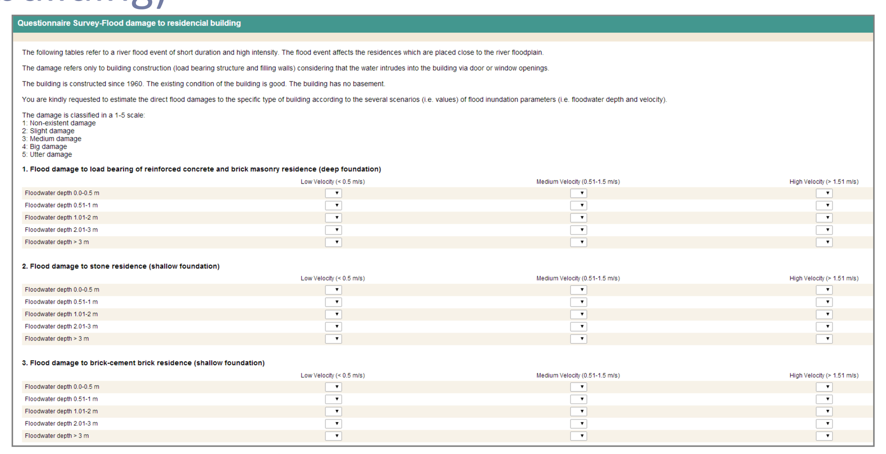

Figure 2: Online survey questionnaire for urban sector
https://www.surveymonkey.com/s/95PDK6H

Additional specifications depending on the crop:

- ○ Olive Trees: "Koroneiki" variety, over 20 years old, harvested until January
- ○ Fruit trees: "Merlin" variety, over 15 years old, harvested until March
- ○ Tomatoes and green vegetables grown on the same parcel alternately:
  - ▪ Early season tomatoes planted in April
  - ▪ Late season tomatoes harvested until October and November
  - ▪ Green vegetables grown from December to March

Flooding in April, October or November ⇨ affect only tomatoes

Flooding from December to March ⇨ affect only green vegetables

Additional specifications depending on the building:

- ✓ Residential buildings
  - ✓ Concrete load bearing and brick masonry residential building ⇨ deep foundation
  - ✓ Stone residential building ⇨ shallow foundation
- ✓ Storehouses
  - ✓ Brick-cement brick storehouse ⇨ shallow foundation
  - ✓ Stone storehouse ⇨ shallow foundation

✓Weighted Monte Carlo method

- ○ Weighted Monte Carlo (WMC) Python method ⇨ synthetic loss database enhancement using questionnaire data as feedback ⇨ *n* semi-random triplets (*h, v, d*) production
- ○ Random depth value, *h*, and random velocity value, *v*, within the range of values specified in the questionnaire ⇨ damage category $d \in \{1,2,3,4,5\}$ assigned to every random pair (*h, v*) according to the probability of occurrence computed from the questionnaires

✓ Logistic regression analysis method

- ○ Logistic regression: relationship of several independent variables to a dichotomous dependent variable ⇨ logistic function
- ○ Logistic regression (LR) Python code ⇨ logistic regression process simulation ⇨ logistic regression parameters estimation

✓ Synthetic damage surfaces

- ○ WMC & LR Python codes ⇨ Weighted Monte Carlo and Logistic Regression (WMCLR) Python model ⇨ synthetic damage surfaces development
- ○ WMCLR Python model execution
  - ▪ Agricultural sector ⇨ logistic depth-velocity-damage curve for every agricultural land use class and for every month of the year
  - ▪ Urban sector ⇨ logistic depth-velocity-damage curve for every type of building

✓ Flood loss estimation model

- ○ Flood loss estimation model in Python
  - ▪ Input: Land use shapefile (Fig. 4) MIKE FLOOD model output and
  - ▪ Grid model: same grid as MIKE FLOOD grid (5 m x 5 m grid cell)
  - ▪ Damage estimation for a given land use

• Rural sector

$$AD(k,m) = \sum_{i=1}^{n_i}\sum_{j=1}^{n_j} D_{ua}(i,j,k,m) \cdot TA(i,j,k)$$

$$D_{ua}(i,j,k,m) = C_{uw}(k) \cdot Y_{ua}(k) \cdot DC(i,j,k,m)$$

• Urban sector

$$UD = \sum_{k=1}^{w}\sum_{i=1}^{n_i}\sum_{j=1}^{n_j} EC_{res}(k) \cdot TA(i,j,k) \cdot DC_{st}(i,j,k)$$

AD(k,m) the agricultural damage (€), $D_{ua}(i,j,k,m)$ the agricultural damage per unit area (€·m^{-2}), n_i, n_j the grid rows and columns, respectively, *TA(i, j, k)* the total area of grid cell for crop/building type *k* (m^2). C_{uw} the estimated cost per unit weight of crop type *k* (€·kg^{-1}), Y_{ua} the normal year yield per unit area of crop type *k* (kg·m^{-2}) and and *DC(i,j,k,m)* the dimensionless damage value that corresponds to the logistic depth-velocity-damage surface for cell *(i,j)*, crop type *k* and month *m* (WMCLR code generated). *UD* the urban damage (€), *w* the total number of building types, $EC_{res}(k)$ the cost per unit area of building type *k* (€·m^{-2}), $DC_{st}(i, j, k)$ the dimensionless damage value that corresponds to the logistic depth-velocity-damage surface for cell *(i, j)*, building type *k* (WMCLR code generated)

3. CASE STUDY

✓ Study area: Koiliaris River basin, Chania Prefecture, Crete ⇨ 130 km^2 watershed area (Fig. 3)

✓ Flood event: February 11th-12th, 2003 ⇨ river segment extending 3.5 km from river outlet

Figure 3. Koiliaris River basin

Figure 4. Land use

4. RESULTS

✓ MIKE FLOOD

- ○ MIKE FLOOD = 1D-MIKE 11 + 2D-MIKE 21
- ○ Output parameters from inundation simulation ⇨ max floodwater depth and corresponding flow velocity in every 5 m × 5 m cell of the model grid (Fig. 5)
- ○ Model calibration using historical data reported by flood-affected residents (red dots, Fig. 5)

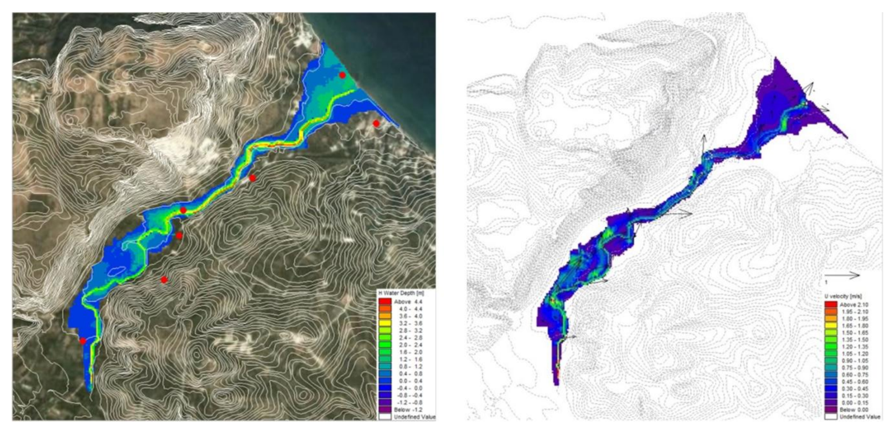

Figure 5. maximum floodwater depth (left) and corresponding flow velocity vectors (right), MIKE FLOOD model output

✓ Questionnaires

- ○ Rural sector (i.e. 22 Olive Trees, 21 Fruit Trees, 26 Tomatoes, 20 Green vegetables)
- ○ Urban sector (46 questionnaires for all building types)

✓ WMCLR Python model

- ○ Agricultural sector ⇨ 1800 damage triplets for every class of land use.
- ○ Urban sector ⇨ 5400 damage triplets for every residential building type

Damage transformation into a dichotomous variable

- ○ Damage value equal to 0 ⇨ damage categories 1-3 (zero to medium damage)
- ○ Damage value equal to 1 ⇨ damage categories 4-5 (big to complete damage)

Logistic function employed to describe the loss functions $DC = \frac{1}{1+\exp\left[-(a_0 + a_1 h + a_2 v)\right]}$

Logistic flood depth-flow velocity-damage surfaces

- ○ Agricultural sector: Olive (Fig. 6a) and Fruit Trees (Fig. 6b), Green Vegetables (Fig. 6c)
- ○ Urban sector: Concrete load bearing and brick masonry building (Fig. 7i), Stone building (Fig. 7ii), Brick-cement brick building (Fig. 7iii)

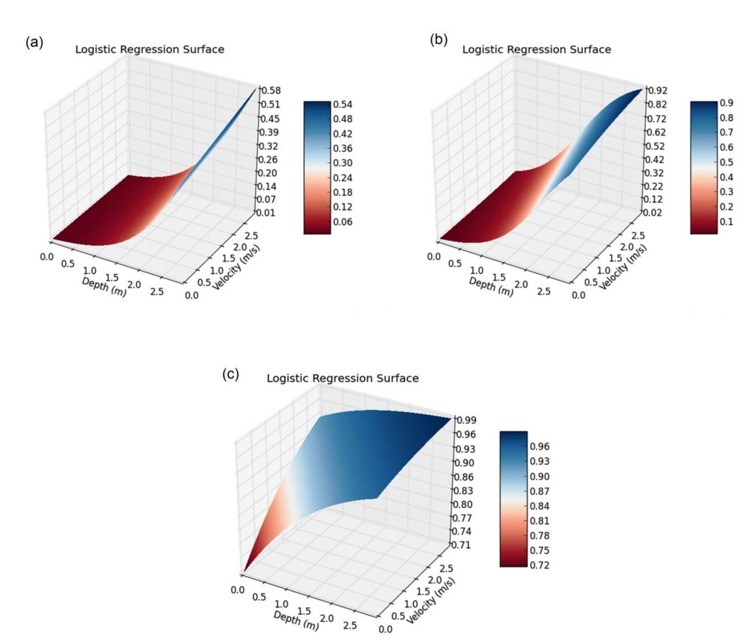

Figure 6. Logistic damage surfaces for the agricultural sector

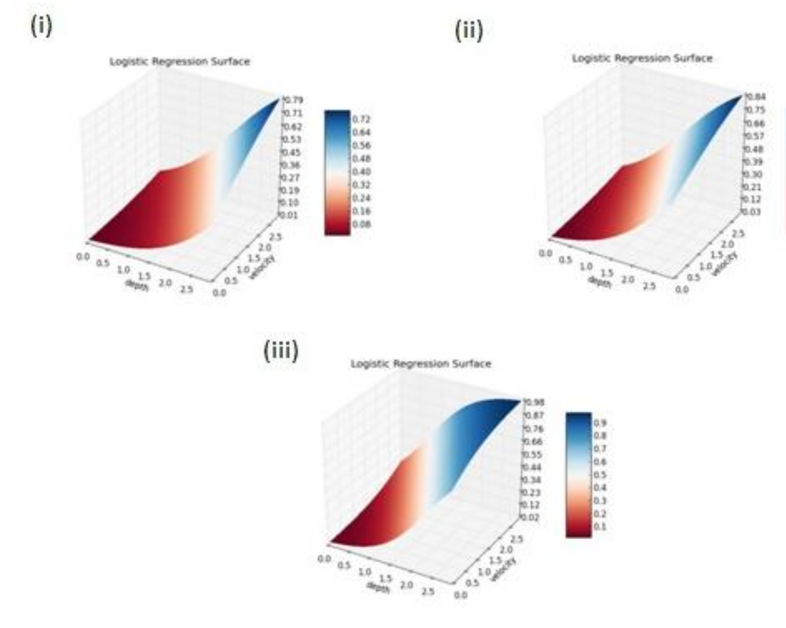

Figure 7. Logistic damage surfaces for the urban sector

✓ Flood loss estimation model

Table 1. Damage per agricultural land use class

Land use	Damage (€)	Inundated Area (ha)
Olive Trees	1,191.7	15.6
Fruit Trees	6,201.5	19.7
Complex cultivation patterns	42,398.4	13.8
Total damage	**49,791.6**	**49.1**

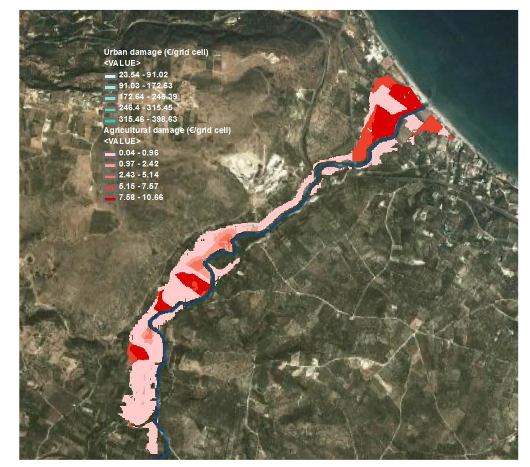

Figure 8. Agricultural and urban damage per grid cell

Table 2. Damage per residential building class

Residential use	Damage (€)	Inundated Area (m^2)
Residential building	12,375.0	1,475
Storehouse	681.8	225
Total damage	**13,056.8**	**1,700**

5. CONCLUSIONS

✓Flood loss estimation method ⇨ depiction of areas of both high flood risk and high flood damage risk in GIS

✓Study area ⇨ intensive agricultural activities ⇨ damage to complex cultivation patterns greater than damage to olive and fruit trees ⇨ avoid planting low-lying crops close to river

✓Downstream part of watershed ⇨ most prone to flooding ⇨ greater attention when designing risk assessment practices

✓Method utility ⇨ Compensation payment estimation to flood-afflicted farmers/residents

This research has been co-financed by the European Union (European Social Fund) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF)-Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund