

# Exercise 5a. Generating vulnerability curves

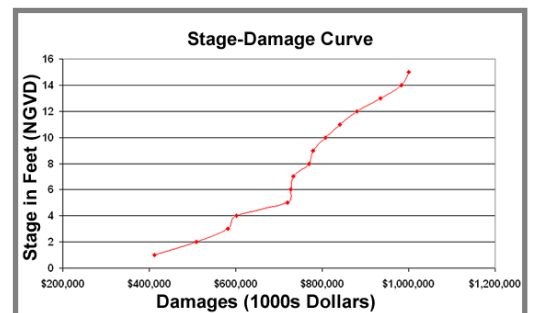
Expected time: 3 hours  
 Data: data from subdirectory: Riskcity\_exercises/exercise05a/data  
 Objectives: In this exercise we will learn how to perform flood damage assessment using depth-damage functions. We will extract from PGIS data the parameters to calculate the dept-damage functions.

## Input data

The data for this exercise consist of maps and tables related to: 1) Building types, 2) Flood depth, 3) Information related to the impact of flood on buildings from the PGIS survey.

Table/Maps	Column	Meaning
<b>Building_map_1998</b>	Landuse	Description of the building class
	Area	Area of the building footprint in m2
	Nr_floors	Numbers of floors
	Floorspace	Total area of the building (floorspace*number of storeys)
<b>Building_map_1997</b>		Building map showing the situation before the disaster in 1998.
<b>Flood_100y map</b>	Waterdepth (0.00 m)	Flood depth map calculated using outputs of HEC-RAS flood simulation model
<b>PGIS_Survey table</b>	Building type	Building types in the area
	Remember_flood_1998	Answers of interviews on flood height people remembered for the flood of 1998
	Nr_floors	Number of floors
	Flood_damage	Answers of interviews on flood damage to buildings that people remembered for the flood of 1998
<b>PGIS_Location map</b>		Point map showing the location of the surveys during the PGIS activities.

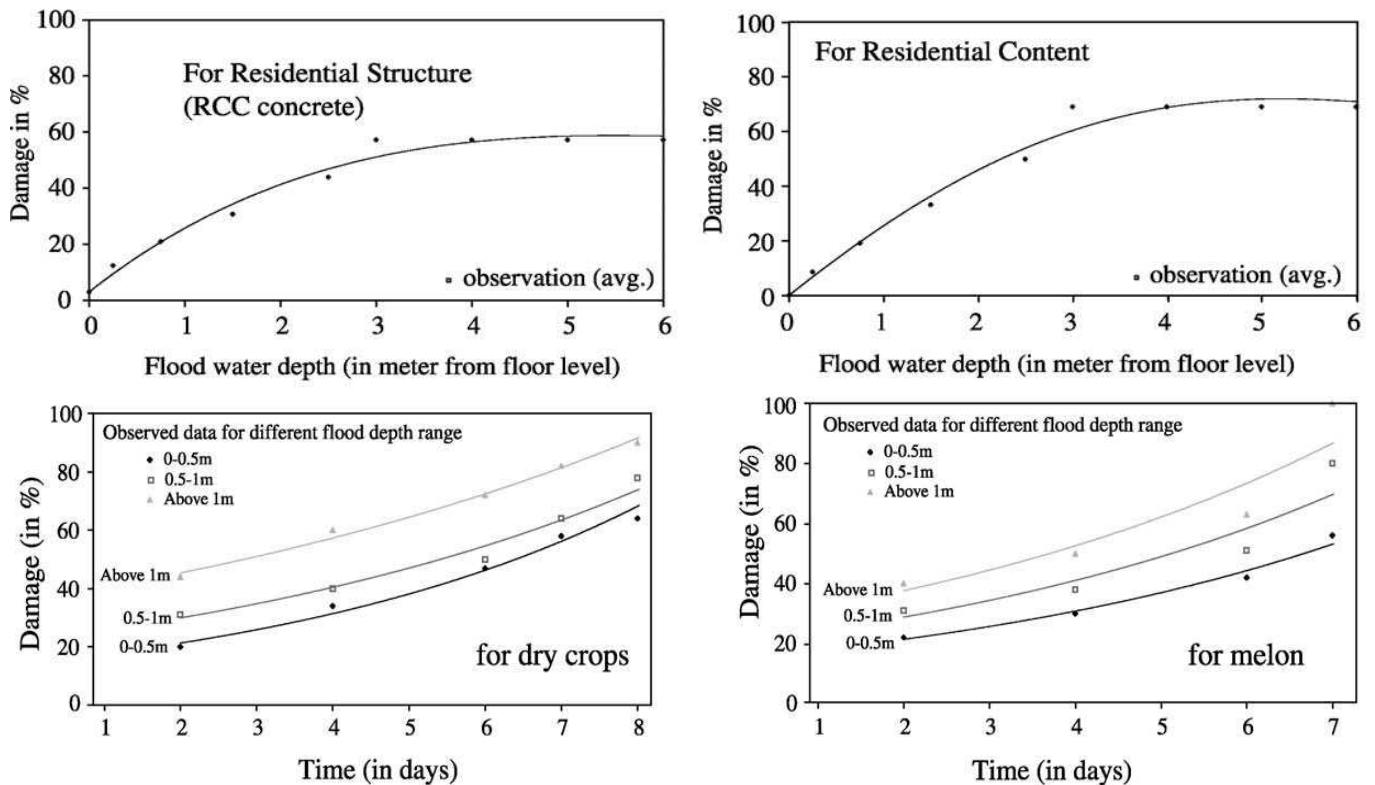
Flood damage assessment can be performed in a semi-quantitative way. It means that the damages have to be quantified per each category of asset according to the aggregation level chosen for the assessment. Stage-damage functions represent the most effective solution in relating flood parameters to damage in flood damage assessment models (Krzysztofowicz and Davis, 1983a; Krzysztofowicz and Davis, 1983b).



### Step A: Extract vulnerability parameters from PGIS survey.

In the following steps we will learn how to build depth-damage functions for different building types. Depth-damage functions are a particular type of stage-damage functions that relate the loss/damage to flood water depth. Stage-damage functions quantify, through mathematical equations, how the damage rate varies with the variation of flood parameter; therefore they are applied in semi-quantitative flood damage assessment. They express the vulnerability of each element at risk to a certain parameter when affected by a flood event. The elements at risk are grouped in classes according to the degree of aggregation at which we want to perform the risk assessment. Elements at risk can refer to building types (one storey wood buildings, single houses from bricks in mud, multiple storey reinforced concrete buildings, etc.) or they can be aggregated into residential, commercial, industrial and agricultural units. In figure X.X, two types of stage-damage functions are shown: the two graphs on top relate the damage expressed in percentage for residential concrete houses to water depth; the other two graphs represent the relation between the damage and the duration of flood for different types of crops (Dutta et al., 2003).

Stage-damage functions are mathematical functions that express the relation between the degree of the damage and flood parameters: figure below shows two types of stage-damage functions.



Stage-damage functions can be extracted following two strategies: the first consist of calculating the functions on the basis of historical flood damages data; the second is the calculation of functions from analysis based on: expert knowledge based estimations on assets classes, questionnaire surveys, and the aggregation of that information to assets units or landcover classes. In this case they are called synthetic stage damage functions. We will gather the information needed to build the functions from the surveys realized during PGIS activities. The data collected are stored in a table called **PGIS Survey**; the data are related to landslides and flood hazards, but we will use only the data related to the three historic floods occurred in 1993, 1998, 2008. The table shows 200 locations of interviews; each one related to one building; the IDs F001 to F100 regard the flood events; every record is an average of the answers and estimations of all the single families that live or were living during the disasters in that particular building. The questions regarded flood depth, caused damage, behavior of people, cars, and buildings in

relation to the strength of the flood. The answers are expressed by “codes” easily comprehensible for the population and meaningful for the further calculations.

☞ Open the table: **PGIS\_Survey** and check the columns content. Write below for each relevant column the type of domain (Class, Identifier, Boolean, Value):

- 1) Landuse: \_\_\_\_\_
- 2) Building\_type: \_\_\_\_\_
- 3) Nr\_floors \_\_\_\_\_
- 4) Remember\_flood\_1998: \_\_\_\_\_
- 5) Flood\_damage \_\_\_\_\_

☞ **Water\_heights**: the domain is related to flood depth, How can you identify intervals corresponding to the different levels? Write them below.

- 1) Ankle: from \_\_\_\_\_ to \_\_\_\_\_ meters.
- 2) Knee: from \_\_\_\_\_ to \_\_\_\_\_ meters.
- 3) Hip: from \_\_\_\_\_ to \_\_\_\_\_ meters.
- 4) Breast: from \_\_\_\_\_ to \_\_\_\_\_ meters.
- 5) Head: from \_\_\_\_\_ to \_\_\_\_\_ meters.
- 6) First floor flooded: from \_\_\_\_\_ to \_\_\_\_\_ meters.
- 7) Second floor flooded: from \_\_\_\_\_ to \_\_\_\_\_ meters.

The table is linked to the point map **PGIS\_Location** that represents the position of each interview in RiskCity. We first have to check the position of the interviews in relation to the flood extent; show the survey location together with the 100 years return period flood map.

☞ Open the following maps in this order:

- 1) **PGIS\_Location**: Check in the properties that the map is linked to the table **PGIS\_Survey**.
- 2) In the same viewer add the map **Flood\_100y** (assign transparency=50) Viewer > layers > add layer
- 3) Add the polygon map **Building\_map\_1998**
- 4) Add the polyline map **Building\_situation\_1997**

The buildings present in the 1997 map but not in the polygon map have been totally destroyed or irreparably damaged hence abandoned. Approximately how many buildings have been destroyed by the 1998 flood disaster? How can we extract this information?

We can now start to work at the extraction of the depth-damage functions. The damage data stored in the table are related to the major flood occurred in 1998, the depth-damage curves will be calculated on the basis of those data. First of all you need to copy the **PGIS\_Survey** table in Excel. Only the record related to floods are requested.

☞ You can do it in two ways:

- The best is to open the table in ILWIS, select and copy the information of the columns from records F001 to F100 and then paste them into an Excel sheet;
- or you can export the entire table by right-clicking on the table itself in the main window and by choosing *Export*; in this case you have to remember to choose the output format Delimited Text .TXT. Then in Excel you have to open it, and go through a number of steps.
- Once you have the table in Excel you need to delete the records and the columns that are not needed for this part of the exercise. Only keep the columns: **Building\_type**, **Nr\_floors**, **Remember\_flood\_1998** and **flood\_damage**.

The table should appear like the example in the following figure (before to delete the columns not needed).

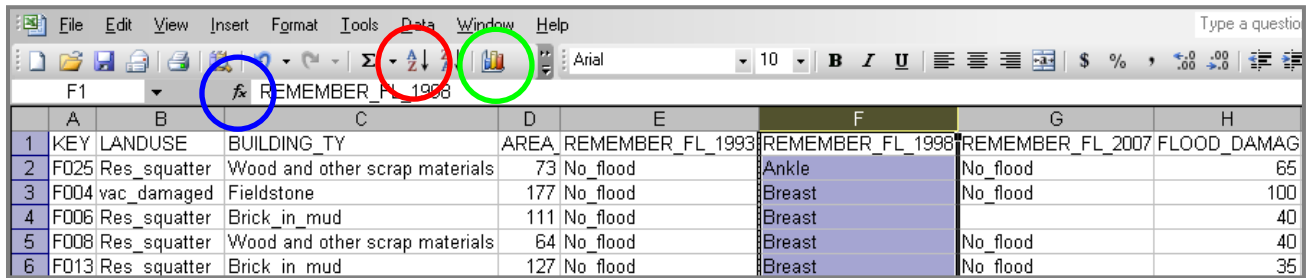


Table PGIS\_Survey exported in Excel.

### Step B: Calculate the stage damage function for all the buildings.

To calculate the depth-damage curves we use the records of the damages caused to the affected buildings; the data are stored in the table you just extracted in the column "Flood\_damage". This column shows the damage of the flood in 1998. We need to calculate the average of damage for each water-height interval.

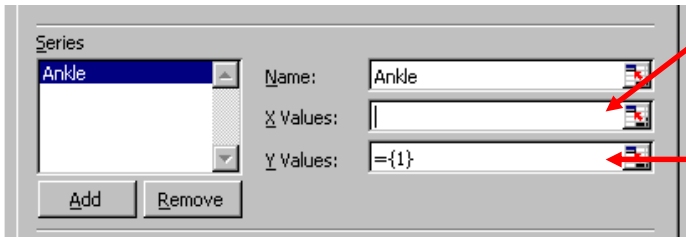
- Sort the records by water height related to the 1998 flood event in Excel: select the right column and click the button with the red circle in the upper figure
- Calculate the average of damage for each water height interval. Click the "Function" (blue circle) and chose "average".

Interval	Water height (m)	Centriod of the interval	Average Damage
Ankle	0 – 0.2	0.1	
Knee	0.2 – 0.5	0.35	
Hip	0.5 – 1.0	0.75	
Breast	1.0 – 1.5	1.25	
Head	1.5 – 2.5	2.0	
First floor fl	2.5 – 3.5	3.0	
Second floor fl	> 3.5	5	

Build in Excel a table with at least the last two columns; it will be used to show the results in an X/Y graphic. Add a row on top and a row at the bottom as shown here below. The first line represents the situation in which the buildings are not flooded; the last line represents the extreme situation with more than 7 meters of flood depth; we can assume that, when the flood depth is 7 meters or more, the average damage for all the building types is 90% (it has been previously calculated through other methods).

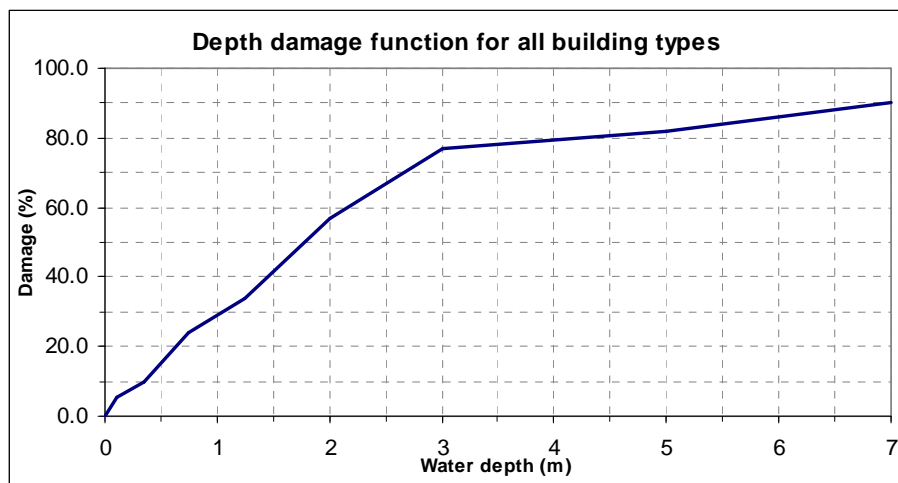
Interval	centroid	Av damage
No Flood	0	0%
Anke	0.1	—
Knee	0.35	—
Hip	0.75	—
Breast	1.25	—
Head	2	—
First floor flooded	3	—
Second floor floded (>3.5m)	5	—
7 or more meters	7	90

Now we have to build a graph in Excel using the values of the centroid of each interval as X value and the average of the damage as Y value. Open the "Graphics menu" in Excel by clicking the icon with the green circle in figure x.x. Chose "XY Scatter" and click next; then go to "series" tab; add a new series and fill the right side of the window as follows



1. Select the X Values and chose the cell where you stored the centroid of the interval "Ankle" and the cell above (blue cells in the table).
2. Select the Y Values and chose the cell where you stored the average of damages for that interval and the cell above (green cells in the table).

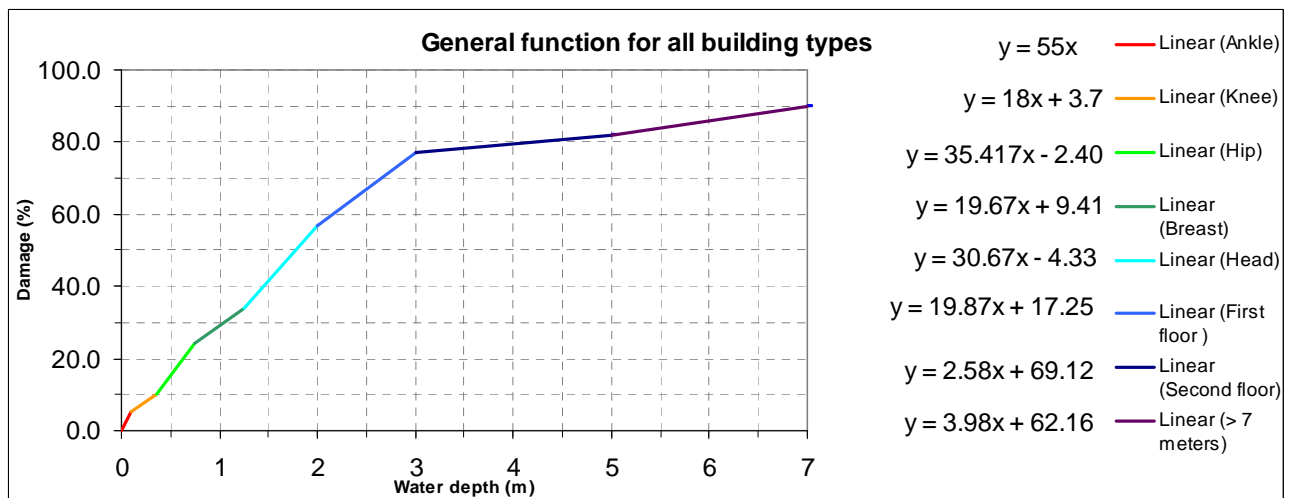
Follow the procedure for all the intervals (from "Ankle" to "7m or more") and display the graphic. If you don't see the line, right-click on each pair of points, chose "format data series", and, in "patterns" add the line. It should be similar to this figure.



Damage function for all the buildings.

The next step consists of fitting the trend line for each series. Right-click on each pair of points, and chose "add trend line". In the "Type menu" chose "linear function" and in the "Option menu" select "display equation on chart" (for the "Ankle" series select also "Set intercept = 0").

Follow the procedure for all the series and at the end you should have the trend lines for all the points and their equations like in the following figure



Depth - Damage function for all the buildings: equations of the trend lines.

This multiple functions model represents the variation of the damage rate for all the buildings (expressed in percentage) in relation to the flood depth. With the equations displayed in the graphic we can now write a command in ILWIS to calculate the damage for all the buildings affected by any flood.

 **Advanced task: application of the depth-damage function in ILWIS**

- Build a cross table between the **Building\_map\_1998** map and the **Flood\_100y** map, and call it **Building\_flooded**.
- Open the new table, go to Columns / Aggregation, chose the column: Flood\_100y, function: Average, group by: Building\_map\_1998, weight by: Area. Call the new column Water\_Height. What does it represent? Why did the operation calculate?
- Open the **Building\_map\_1998** table and join the new column from the **Building\_Flooded** table. Now we have for each building the water height related to the 1998 flood event.
- Apply the multiple functions we calculated in the previous part of the exercise to all the flooded buildings in RiskCity. You have to write an expression in the command line of the table Building\_map\_1998 that allows you to apply the equations; this could be an example. It has to be typed in a single line. Pay attention to the name of the maps!

**Damage\_Buildings:=IFF(Water\_Height<=0.1,Water\_Height\*55,  
IFF(Water\_Height<=0.35,Water\_Height\*18+3.7,  
IFF(Water\_Height<=0.75,Water\_Height\*35.42-2.40,  
IFF(Water\_Height<=1.25,Water\_Height\*19.67+9.41,  
IFF(Water\_Height<=2,Water\_Height\*30.67-4.33,  
IFF(Water\_Height<=3,Water\_Height\*19.87+17.15,  
IFF(Water\_Height<=5,Water\_Height\*2.58+69.12,Water\_Height\*3.98+62  
.16))))))**

- Check the column Damage\_Buildings, especially the highest values; are they correct according to the meaning of the column? What is the cause of the inaccuracies? How would you avoid them?
- Create an Attribute map from the map Building\_map\_1998 by choosing the column **Damage\_Buildings**; call the new map **Damage\_Buildings**.

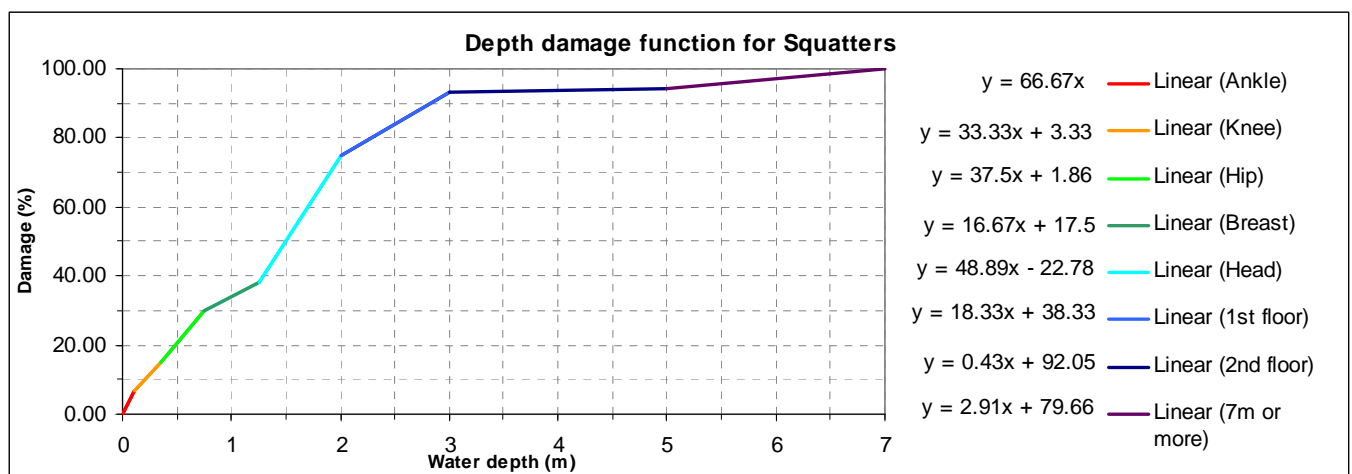
All the buildings are considered with the same characteristics and the different numbers of floors are not taken into account. A single storey squatter does not have the same damage rate of a 4 storey reinforced concrete building. In order to improve the procedure we should chose a smaller aggregation level. For instance we can start to calculate the depth-damage functions only for the Landuse Residential Squatters or at a more detailed level, for the different building types. The following instructions show briefly the procedure to calculate the functions for squatters, if you have time and you are interested in it, try to reach the task.

 **Advanced Task: Calculation of more detailed depth-damage functions.**

- Copy again the **PGIS\_Survey** table in Excel. Sort by ID and delete the records related to landslide damage. Now sort the records by Landuse and save only the "Res\_squatter" and "Vac\_damaged". Sort by landuse and delete the records related to "Fieldstone" and "Brick with mud"; due to the small number of records they can affect the calculation; therefore it's better not to take them into account.
- Sort by water height related to the 1998 flood and apply the procedure illustrated in the previous part of the exercise. For the class "7 meters or more" use as damage value 100. Compare the two graphics and comment them. Do they differ from each others? Why?

- Once you created the multiple function, write an expression following the one used for all the buildings as guideline.
- Extract the water height in the table **Building\_map\_1998** from the column Water\_height only for the squatters, and apply the ILWIS expression you created. Store the result in a column called **Damage\_Squatters**. Compare the two columns Damage\_buildings and Damage\_Squatters; what can you conclude?
- Create an attribute map from the map Building\_map\_1998 using the new column and call it **Damage\_Squatters**.

Here below, the graphic for the squatters is shown in order to facilitate the advanced task. The equations of the trend lines for each height interval are listed. If you don't want to calculate them by yourselves, use the ones shown in the graphic.



Depth – Damage function for 1 storey squatters: equations of the trend lines.

You can find the ILWIS expression in the Excel sheet called "Stage-Damage Curves" in the folder Result files.

We can add few comments to the exercise. We calculated the depth-damage functions without taking into consideration various parameters that could largely affect the results: for instance the number of floors. This generalization was dictated by the small amount of data available. The exercise wanted to introduce the use and the concepts of such methodology in calculating the damage in flood damage assessment. Once again it is essential to remember that such methodology can be applied to historic data related to flood damage and/or to data resulting from laboratory tests. In this case we opted to use as input the results of Participatory GIS activities because historical data were not available.

### References and further reading

- Dutta, D., Herath, S. and Musiake, K., 2003. A mathematical model for flood loss estimation. *Journal of Hydrology*, 277(1-2): 24-49.
- Krzysztofowicz, R. and Davis, D.R., 1983a. Category-Unit Loss Functions for Flood Forecast-Response System Evaluation. *WATER RESOURCES RESEARCH*, 19(6): 1476-1480.
- Krzysztofowicz, R. and Davis, D.R., 1983b. A Methodology for Evaluation of Flood Forecast-Response Systems 1. *WATER RESOURCES RESEARCH*, 19(6).