Session 3.C Task 3-B

Hazard analysis of cyclone flooding in Bangladesh

Part B Flood hazard analysis of the Banskhali area for different return period of the cyclone events

Expected time:	3 hours
Data:	Data file: **Riskcity exercises/exercise03C1/data**
Objectives:	After this exercise you will be able to: **-** display satellite images of the Baskhali study area; - display ground photographs of selected points; - display the available segment and point data layers; - interpolate the point elevation data to an elevation raster map; - understand and apply cyclone flood impact modeling for different return periods using ILWIS script language.

1. Introduction

During the years 1797 to 1991, Bangladesh was hit by 59 severe cyclones, of which 32 were accompanied by storm surges. Concerning 20 of these cyclones, information for the whole of Bangladesh is stored in the ILWIS table Landfall on Wind Speed, Wind Surge height, number of Casualties, Tidal Height during the event, etc.

Despite the fact that the Bangladesh Government issued warnings of the impending flooding, for the April 1991 cyclone, through its Cyclone Preparedness Program, and about 3 million people moved to safety, many inhabitants remained behind to protect their property.

During this disaster an estimated 138.000 people were killed and large numbers of houses, agricultural lands and infra-structural works were destroyed. Hundreds of schools were damaged and seven to eight thousand vessels were lost. Almost every bridge and culvert in the area was damaged and roads were washed out.

Within two days government air drops of food and medicine started, but they were hampered by continuing bad weather associated with the storm. Nearly two weeks had passed before massive international aid could react to the disaster and it was many months before the area returned to normal.

The Banskhali study area is situated in the East of Bangladesh, South of the city of Chittagong. Maps and attribute tables are given of the geomorphology, village population, the Union-districts, roads, embankments, cyclone shelters, and the elevation of the terrain with centimeter accuracy. Also available are Landsat Thematic Mapper and (scanned) SPOT panchromatic satellite images. For a general introduction you can make use of a geomorphological overview map of the whole coastal zone of Bangladesh as well as ten ground photographs of the Banskhali area.

In Part B of Task 3 you will first display the different data layers of the Banskhali area. Also field photographs from the ground can be displayed. Next you rasterize the segment and vector maps for further map calculation and also perform point interpolation to create the elevation map.. Finally flood hazard maps are created using ILWIS script for different return periods, as calculated by Khan (1995).

Some GIS files are derived from:

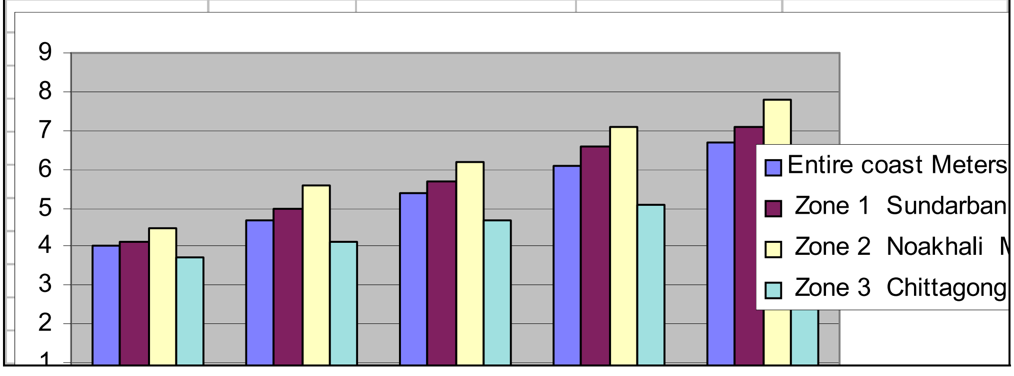
– Sirajur Rahman Khan (1995) - "Geomorphic Characterization of cyclone hazards along the coast of Bangladesh", ITC - MSc study.

- See also the table of contents.

Table 1:

Cyclone Surge Heights for different coastal tidal zones and different return periods

Return Period	**Entire coast**	**Zone 1 Sundarban**	**Zone 2 Noakhali**	**Zone 3 Chittagong**
Years	**Meters**	**Meters**	**Meters**	**Meters**
5	4	4.1	4.5	3.7
10	4.7	5	5.6	4.1
20	5.4	5.7	6.2	4.7
50	6.1	6.6	7.1	5.1
100	6.7	7.1	7.8	5.6



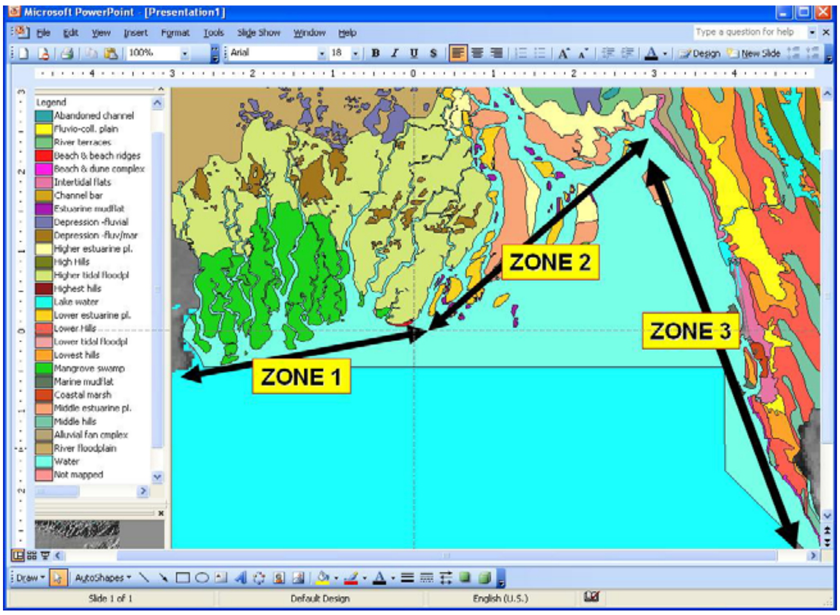


Figure 1

Three coastal zones of Bangladesh based on tidal amplitude. Zone 1: low; zone 2: medium & zone 3: high.

2. Exploring the input data

In the data catalog you see the icons of the available input data for this case study.

- In **Part A** of the exercise on cyclone flood hazard modeling you displayed already the data for the whole of Bangladesh.
- In **Part B** we are going to use also the data from the Banskhali area.

Name	Type	Meaning
Bdesh	Raster map	Hill-shading map made out of a low resolution DEM of the whole of Bangladesh
Bdgeom	Polygon map	Main Geomorphological Units of Bangladesh.
Landfall	Table	Information on Cyclone Events, Causalities, etc.
Landform	Polygon map	Landforms, including Rivers and Dikes.
Baskhali data for part 2 of the exercise:		
Shelter	Point map	Locations of Cyclone Shelters.
Roads	Segment map	Main- and Secondary- roads.
Village	Polygon map	Villages, including a table on Population.
Eleva	Point map	Point elevation in cm above mean sea level.
Waterlin	Segment map	Digitized coastline of the area.
Batm90b2->7	Raster map	Landsat-TM image 31-10-1990, bands 2, 3, 4, 5 and 7.
Baspotx	Raster map	SPOT panchromatic image, scanned from a paper print.
Photos 1-10	Raster photo	Scanned ground photographs of November 1994 taken by M. Damen.

3. Displaying satellite images of the Banskhali area

Of the Landsat Thematic-Mapper image of 31 October 1990 the bands 2 - 5 and 7 are given. The bands are geocoded and geometrically corrected.

The raster map **Batm90b453** to be made provides information on the terrain characteristics. From west to east you first have the sea (blue color). The beach has a light image tone; the wider zone in the south is a tidal flat. Clearly visible is a north-south running river with some tributaries. In the east you find the Chittagong hills consisting of soft sedimentary rocks; the eroded parts have a light image tone. Other image tone differences are caused by various types of land use, such as homestead gardens, rice fields and roads.

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- Make a color composite of Landsat Thematic Mapper bands 4, 5 & 3 for red, green and blue. Use for this: *Operations > Image processing > Color Composite*. Use the default values for this.
- Save the result as **batm90b453**
- Study the colors of the image, and zoom-in at selected sites.
- Close the map window when finished.

Now look at the SPOT panchromatic image with filename **Baspotx**. The image is from the 22nd of January 1994 and is scanned from a paper print and re-sampled to the original pixel resolution of 10 m.

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- Display the raster map **Baspotx**.
- Browse through the image. Study the image characteristics such as grey tone and pattern. Try to recognize the homestead gardens of the villages, the hills, the roads, and the lower parts in the terrain. Zoom-in, if necessary. Do you also see the embankment near the coastline?
- Look also at the map properties by selecting *File > Properties*. You now find information on the size of the map, the pixel size, and the domain: Image. Close the Properties dialog box.

4. Displaying ground photographs taken from point locations

Ten ground photographs taken by M. Damen in November 1994 can be displayed. The pictures are intended to give an impression of the terrain and the cyclone shelters; the points are not always at the exact location from which the photo have been taken.

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- Add as new data layer to the map **Baspotx** the point map **Photos**. Choose an appropriate symbol size and color.
- Select: *Layers > Double Click Action > Execute Action*, *OK.*
- Double-click a point to display a ground photograph. Repeat from other photographs
- Close the map window.

5. Display of the segment and point data layers

In this exercise the SPOT panchromatic image will be combined with other data layers, such as the landuse (map: **Village**), the geomorphology (map: **Landform**), the roads (map: **Roads)** and the point elevation data (map: **Eleva**).

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- Display the map **Baspotx**.
- Add as data layer the Polygon map **Village**. Select: Boundaries Only and boundary color green. Click: *OK* and you see the boundaries of the land use in green. These are digitized segments.
- Compare the map **Village** with your own visual interpretation.
- Look also at the map properties by selecting *File > Properties*. Information is displayed on the map size, the Identifier domain **Village** and the number of polygons. Note that also the table village is linked to the map

- Close the Properties dialog box.

All landuse data is stored in the table **Village**. You can display this data using the pixel information window.

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- Open from the ILWIS Main menu the Pixel Information window . Select: *Options > Always on Top.* Make sure that this window is displayed next to the SPOT image and that also the Catalog in the Main window is still visible.
- Drag-and-drop from the ILWIS Main window the polygon map **Village** into the Pixel Information window. Remark: You can also use: *File > Add Map…*
- Read the table information while browsing through the village areas.
- Add also the data layer **Landform** to the map window (polygon map with **red** boundary color).
- Drag-and-drop polygon map **Landform** into the Pixel Information window and "browse" again through the SPOT image.

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- Also drag-and-drop polygon map **Union** into the Pixel Information window. Union means local district; the total population is given.
- Finally add the polygon map **Union** (display only the boundaries in orange) and the segment map **Roads**.
- Change the layers **Union, Village, Landform** and **Roads** in the list in the Layer Management dialog box by clearing the checkbox for each of them. The maps are not shown anymore.

Finally, the elevation point information can be displayed as follows:

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- Add as new data layer to the map window the point map **Eleva**. In the Display Options window select: Attribute: **Eleva_cm**.
- Choose an appropriate symbol color and size. Click an elevation point to display the elevation. Remark: if you click in between the elevation points, not the elevation but the pixel value of the satellite map is being displayed!
- Drag-and-drop to the Pixel Information window the raster map **Eleva** This is the Digital Elevation Model of the area, created by interpolation of the individual elevation points (in point 7 of the exercise you can do this yourself).
- Right mouse-click the map **eleva** in the Pixel Information window and display the Properties dialog box; read the information. The domain is Value. Close the box.
- Browse through the images to know the information from the maps **Landform** and **Eleva**.
- Close the map windows and the Pixel Information window.

6. Rasterizing the maps

For the surge hazard modeling you need to perform several MapCalculations. For this you have to rasterize the maps first.

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- Rasterize the map **Landform** using the option Polygon to Raster in the Operations-list under Rasterize. Give the output raster map the same name. Use the Georeference : Baspotx.
- Repeat the same procedure for the polygon maps **Union** and **Village** using the same Georeference.
- Rasterize the segment maps **Waterlin** and **Roads.** Save the rastermap with the same name and use for all the maps the georeference **Baspotx.** Check the results.

7. Creation of the elevation map yourself by point interpolation

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- Select from the main menu: *Operations > Interpolation > Point, Interpolation > Moving Average*. Select from the point map **Eleva** the Column: **Eleva_cm**. (click for this selection the small box with the cross in front of the map icon **Eleva**).
  - o Use the georeference: **Baspotx**; and a value range: 0-1500 with a precision 1. Remark: the domain of the selected column is: Value
  - o Select Weight function: Inverse Distance; Weight Exponent: 1 and Limiting Distance: 700. The output map name is **Eleva**.
- Click*: Show*. Overwrite the already existing file **Eleva**.

8. Cyclone flood modelling - methodology

During this part of the exercise you will make a map of the floodwater depth during the April 1991 cyclone in the Chittagong/Banskhali area. For this two models will be used:

1. A surge model based on historical records of cyclone flooding in Bangladesh; and
2. The Digital Elevation Model (DEM) of the area (this is the map **eleva**).

The Surge Decay Coefficient (*SDC*)

Before starting the calculations for the Surge Model, you have to find out how the cyclone surge depth decreases inland. This is the so-called *Surge Decay Coefficient **(SDC)***, which will be different for each wave height at the coast. The ***SDC*** is a function of the friction caused by surface forms (morphology, embankments and elevated roads) and land cover (houses, rice fields, homestead gardens with trees, etc.).

The contribution to the friction of all the terrain elements to the ***SDC*** is not fully understood and is still under investigation. However, we know from historical records that in areas with low or no dikes along the coast the surge inundation depth will be more or less constant in the first strip along the coast. After this it will decrease until a certain distance inland.

The data from the total limit to inundation from the coastline for different Wave Heights have been taken from the Multi-purpose Cyclone Shelter project (MCSP, 1993) in Bangladesh. Some of these data for the whole coast of Bangladesh are presented in the Table 2 below.

Table 2: Relation Wave Height at coastline and Inundated area (Whole of Bangladesh)

Wave Height at Coastline (meters)	**Area with Constant Surge Depth** (distance from the coastline in meters)	**Total Inundated Area** (distance from coast in meters)
3.7	415	2000
4.1	520	2900
4.7	580	3900
5.1	670	4200
5.6	760	4400
6.0	880	4700
6.5	1000	5000

Various reports of the April 1991 cyclone event in the Chittagong/ Banskhali area indicate a Wave Height at the coastline of about 6.5 meter; the surge extended approximately 5000 m. inland.

The Wave Height included a tidal height during the time of landfall of + 1.7 meter. This means that the actual Wind Surge Height at the coastline in the Banskhali area was “only” 6.5m - 1.7m = 4.8m.

For the modeling we take a constant surge depth of 1000 meter starting at the coastline (see Table 1). Further inland the surge depth decreased with the ***SDC*** (see also Figure 2 on the next page).

The ***Surge Decay Coefficient*** **(*SDC*)** is calculated as follows:

$$SDC_{RP} = \frac{\text{Wave height at coastline - Avg. elevation of terrain at end of surge}}{\text{Width total inundated area - Width area with constant surge}}$$

Filling in the values from Table 2 in the above equation for a wave height at the coast of 6.5 meter, we find:

$$SDC_{\text{Surge 650cm in Chitt.}} = \frac{(650 - 267)\,cm}{(5000 - 1000)\,m} = 0.096\ cm/m$$

The SDC value will be used in the next part of the exercise on surge modeling

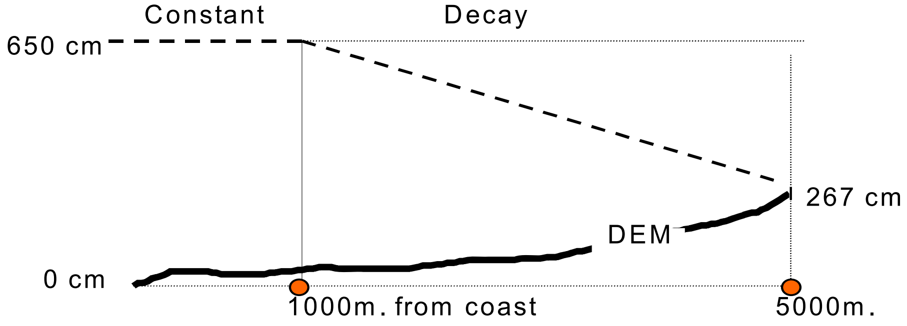

Figure 2: Cross section illustrating the surge decay inland of a Wave Height of 650 cm at the coastline

9. Cyclone surge modelling – Steps to be followed

The two steps for a surge modeling of a 650 cm. high Wave Height at the coastline are the following:

Step 1

Creation of a distance map starting at the coastline to at least 5000 m. inland. The coastline is given in the raster map **Waterlin**. First we remove the sea part. After this we save the result as the map **Codist**.

Step 2

Creation of several maps of the Surge Inundation depth for a wave height near the coast of 650 cm:

- One map from the coastline until 1000m inland, as if there is no decay and relief. To be saved as **In650a**.
- Another map from the decay starting at 1000 m. inland and giving linear decreasing values until 5000 m inland, to be saved as **Sdc650**.
- A map in which the values from the map **Sdc650** are subtracted from the map In650a. This map should be saved as **In650b**.
- Finally you subtract the values of the elevation map Eleva from the map **In650b**. This is the map **In650c**.
- To exclude the area at more than 5000m from the sea we remove all negative values. The final map is the cyclone flood hazard map and should be saved as **Haz650f**.

Step 1 – Creation of distance map starting at the coastline

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- Calculate a distance map using **Waterlin** as the starting map. Give precision 1.0. The output map is: **Distance.**
- Display the result and check the image values.
  The distance calculations are also performed in the direction of the sea. Exclude the sea with the formula:

  Codist:=iff(Landform="Sea",?,Distance)↵

Step 2 – Creation of a surge inundation map (650 cm surge)

Distance calculation: this operation assigns to each pixel the smallest distance in meters towards user-specified source pixels, for example distance to schools, to roads etc. The output is called a *distance map*. Input for a distance calculation is a *source map* and optionally a *weight map*. Check the ILWIS guide to read further explanation about the Distance calculation.

In this steps is explained how a surge inundation depth map for a surge height of 650 cm. can be made. According to Table 2 is the width of the inundated area for this surge height 5000 meters.

In part 10 of the exercise you will make maps for different surge heights "automatically" using an ILWIS script.

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- Type the following MapCalc formula in the command line to make the inundation map until 5000 m from the coast for a coastal wave height of 650 cm as if there were no decay and no relief:

  In650a:=iff(Codist<=5000,650,0)↵

  Save the map with domain Value and precision 1.0. Check the values.
- Make a map of the surge decay from 1000 until 5000 from the coast. Type the formula:

  Sdc650:=iff (codist>1000,0.096*(Codist-1000),0)↵

  The formula describes that for each meter distance from the coast (starting at 1000 m.) the map values will be reduced by the Surge Decay Coefficient (SDC). Save the map with domain Value and precision: 1.0. Check all the values.

- Subtract the pixel values of the **Sdc650** map from the pixel values of the **In650a** map. Save the resulting map as **In650b** with domain Value and check the pixel values.
- Subtract the elevation map from **In650b**. Save the map as **In650c** with domain Value and check the pixel values. As you will see, some pixels in the East have a negative value.
- Finally exclude the negative values in **In650c**, which make no sense for further calculations. The final hazard map is:

  Haz650f:=iff(in650c<=0,0,in650c)↵
- Display the map and check the pixel values. Close the map.

10. Cyclone surge modelling using ILWIS script

In this exercise you will make several hazard maps per return period. In the maps you include per return period, the extend of the flooded area and the flood depth per pixel (magnitude of the hazard).

The procedure is as follows:

a. For each recurrence interval the corresponding Surge Decay Coefficient has to be calculated using the data from Tables 1 and 2. Do not include the tidal influence in the calculations.

b. Flood Hazard maps per return period have to be made (inundation depth maps). This can be done relatively fast by using the ILWIS script option. With a script you make a sequenced list of ILWIS operations, equivalent to a batch file. In the script dialogue box, type your lines of calculations and operations. The parameters in a script must be written as %1, %2, %3, etc. The script can be run from the command line in the Main window of ILWIS.

c. Name the final hazard maps Haz***ret***y (***ret*** = return period).

a. Calculation of the Surge Decay Coefficient (Chittagong zone)

Example: Return period 5 years. Corresponding Wave Height at the coast: 370 cm.

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- Calculate SDC for all return periods using the SDC formula.
  First you have to fill in all data in the table below using the information from the tables 1 and 2.
- After this, you estimate the average elevation at the end of the flooded area::

  First make a map of the terrain elevations at the total flood distance from the coast using the maps **Codist** and **Eleva** (or DEM).
  Example MapCalc for the elevations at approx. 2000m from the coast (strip of 10m wide):

  elev370:=iff(inrange(codist,1995,2005),eleva,?)
- Next display the histogram of the map **elev370,** and read at the bottom of the histogram table the Average value (**Avg)**.
- Calculate the value of SDC using a pocket calculator and the existing function **SDC.** Write the result manually in Table 3.
- Repeat this for the other maps; fill in the table below.

Table 3: Table to be completed manually

Return period	**Wave height Chittagong** (cm)	**Area under const. Surge** (meters)	**Inundated Area** (meters)	**Avg. elev. at end of surge** (cm)	**SDC** (cm/m)
5 yr.	370	415	2000	274	0.061
10 yr.					
20 yr.					
50 yr.					

b. Flood hazard mapping per recurrence interval using ILWIS script

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- Open the script: **Surge.**
- Study the Script file (which is printed below). **Do <u>not</u> change it!** The Script file gives all the steps for the calculation of the surge inundation depth (as explained in section 3.5).
- Exit the script file.

Script file:

```
%1:=iff(Codist<=%2,%3,0)
%6:=iff(codist>%5,%4*(Codist-%5),0)
%7:=%1-%6
%8:=%7-Eleva
%9:=iff(%8<=0,0,%8)
```

Explanation :

% 1 : flood map as if there were no decay and relief (in<u>x</u>a.mpr) <u>x</u>:flood height

% 2 : the width of the inundated area

% 3 : the flood wave height at the coastline (surge plus tidal height)

% 4 : the value of the Surge Decay Coefficient (SDC)

% 5 : the width of the area with constant flood depth (strip near the coast)

% 6 : the map Sdc<u>x</u>.mpr (reduction by the SDC)

% 7 : the map In**<u>x</u>**b.mpr (**<u>x</u>**: Wind Surge height at the coastline)

% 8 : the map In**<u>x</u>**c.mpr (**<u>x</u>**: Wind Surge height at the coastline)

% 9 : the final hazard map Haz***<u>ret</u>***y.mpr (***<u>ret</u>***: return period of the Wind Surge)

Landform, Eleva, Codist: existing maps used for the calculations

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- Type in the command line of the main window the following for the 5 year return interval with a Wind Surge height along the coast of 370 cm (values from first row in the above table):

  Run Surge In370a 2000 370 0.061 415 Sdc370 In370b In370c Haz05y
- Meaning: run surge %1 %2 %3 %4 %5 %6 %7 %8 %9
- Press Enter and wait until the calculations have been finished. Now the maps **In370a-c, Sdc370** and final hazard map **Haz05y** are made.

For the flood hazard modeling for the different recurrence intervals we first have to make a table with all the data necessary to run the script files. For the Wave Heights at the coast we take the Storm Wave heights per return period (Table 3.1) <u>and do not take into account the unknown effects of tidal variations</u>.

Table 4: Table to be completed, containing input parameters for the script

	%	5 yr.	10 yr.	20 yr.	50 yr.
Wave height at coast (cm)	**<u>x</u> (cm)**	**370**			
Map: In<u>x</u>a	**% 1**	In**370**a			
Width of inundation (m)	**% 2**	**2000**			
Flood height at coast (cm)	**% 3**	**370**			
SDC	**% 4**	**0.061**			
Width of constant surge (r	**% 5**	**415**			
Map: Sdc<u>x</u>	**% 6**	Sdc**370**			
Map: In<u>x</u>b	**% 7**	In**370**b			
Map: In<u>x</u>c	**% 8**	In**370**c			
Map: Haz*<u>ret</u>*y	**% 9**	Haz***05***y	Haz***10***y	Haz***20***y	Haz***50***y

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- Create the formulae to be typed in the command line of the main window for return intervals of 10, 20 and 50 years:

  Flood hazard map with 10 year return interval - **Haz10y:**

  Run Surge ____ ____ ____ ____ ____ ____ ____ ____ ____
  %1 %2 %3 %4 %5 %6 %7 %8 %9

  Flood hazard map with 20 year return interval - **Haz20y:**

  Run Surge ____ ____ ____ ____ ____ ____ ____ ____ ____
  %1 %2 %3 %4 %5 %6 %7 %8 %9

  Flood hazard map with 50 year return interval - **Haz50y:**
- Run Surge ____ ____ ____ ____ ____ ____ ____ ____ ____
  %1 %2 %3 %4 %5 %6 %7 %8
  %9
- Type the first in the command line and press: *Enter*. Make sure that there is always one space in between the parameters.
- Repeat this for the other formulae.
- Check the hazard maps: **Haz05y, Haz10y, Haz20y** and **Haz50y.**

References

Only the references of the exercise are listed. At the end of the word file appendix.doc a much longer list is given.

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