LAND CONFERENCE 2011

Reducing Flood Impacts on Society: An Alternative Approach to GIS Modelling

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Presented by
Anesh Gopee
Sigma-Square Geo-Solutions

The devastating effects of floods & the need for effective mitigation/management strategies

Floods are responsible for:

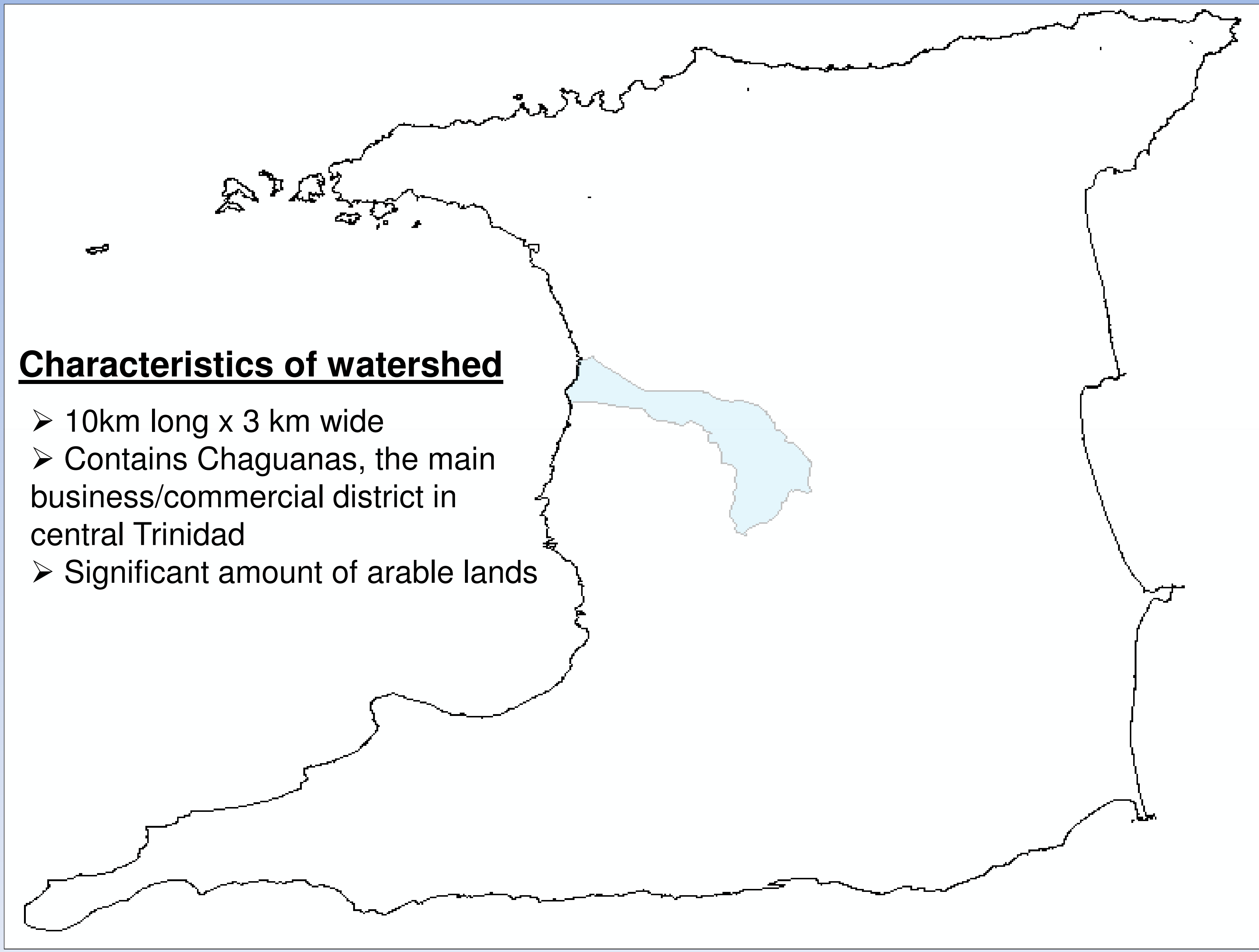
- ➢ **Damage to property/infrastructure**
  - **Economic/financial losses**
- ➢ **Injury/loss of life/emotional suffering**
- ➢ **Secondary disasters such as landslides, diseases**



The role of GIS in the development of flood mitigation/management strategies

- **GIS can be used to create a Flood Risk Map (FRM)**
  - **In simple terms, an FRM can be described as a map which shows the areas where the risk of flooding is relatively high**

Flood risk mapping for the Caparo watershed



Characteristics of watershed

- 10km long x 3 km wide
- Contains Chaguanas, the main business/commercial district in central Trinidad
- Significant amount of arable lands

Flood risk mapping for the Caparo watershed

- **Requires a determination of the main factors that influence flooding in the watershed**

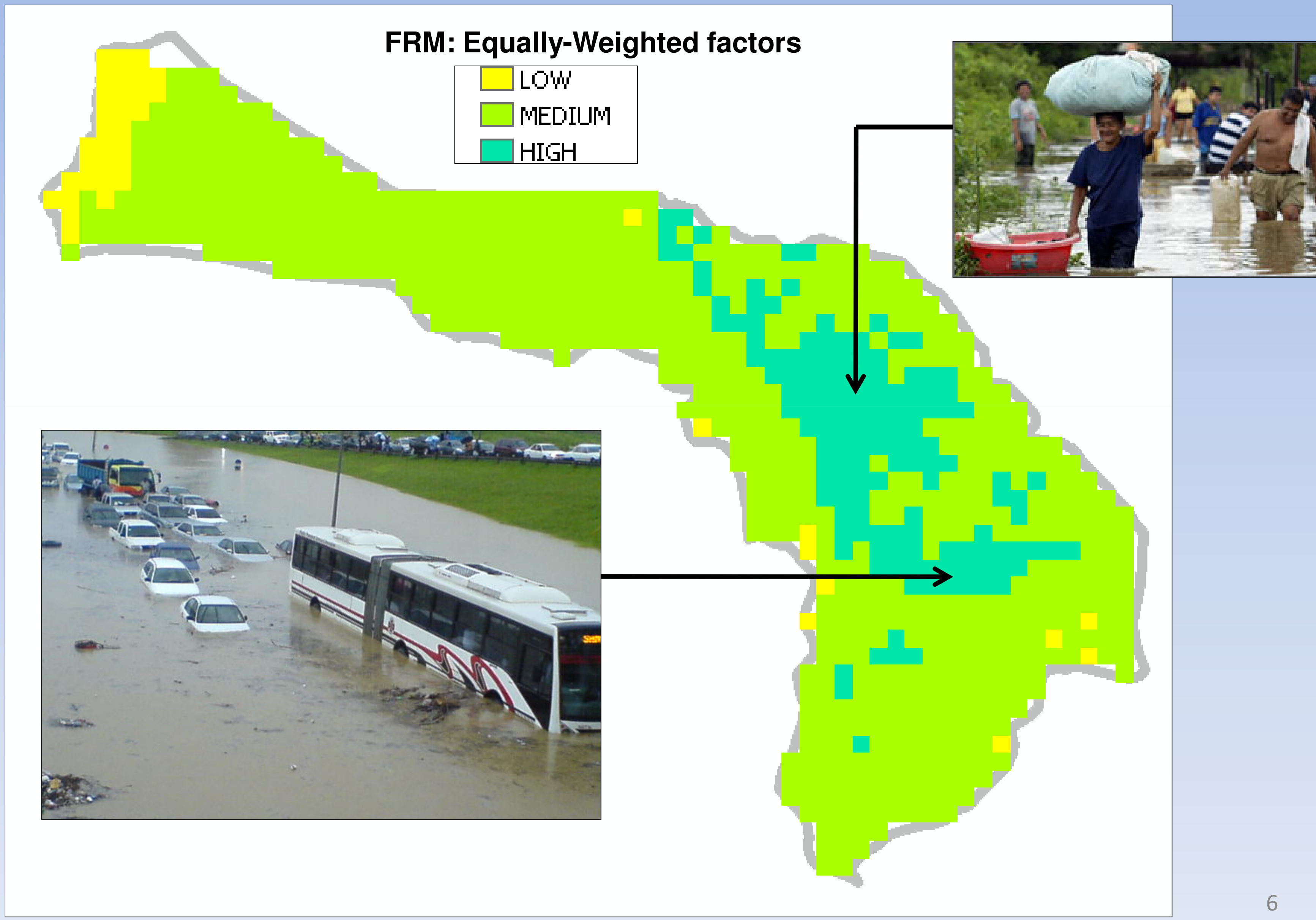
  For this preliminary study, the following factors were considered:

  - **Rainfall**
  - **Slope**
  - **Land Use**

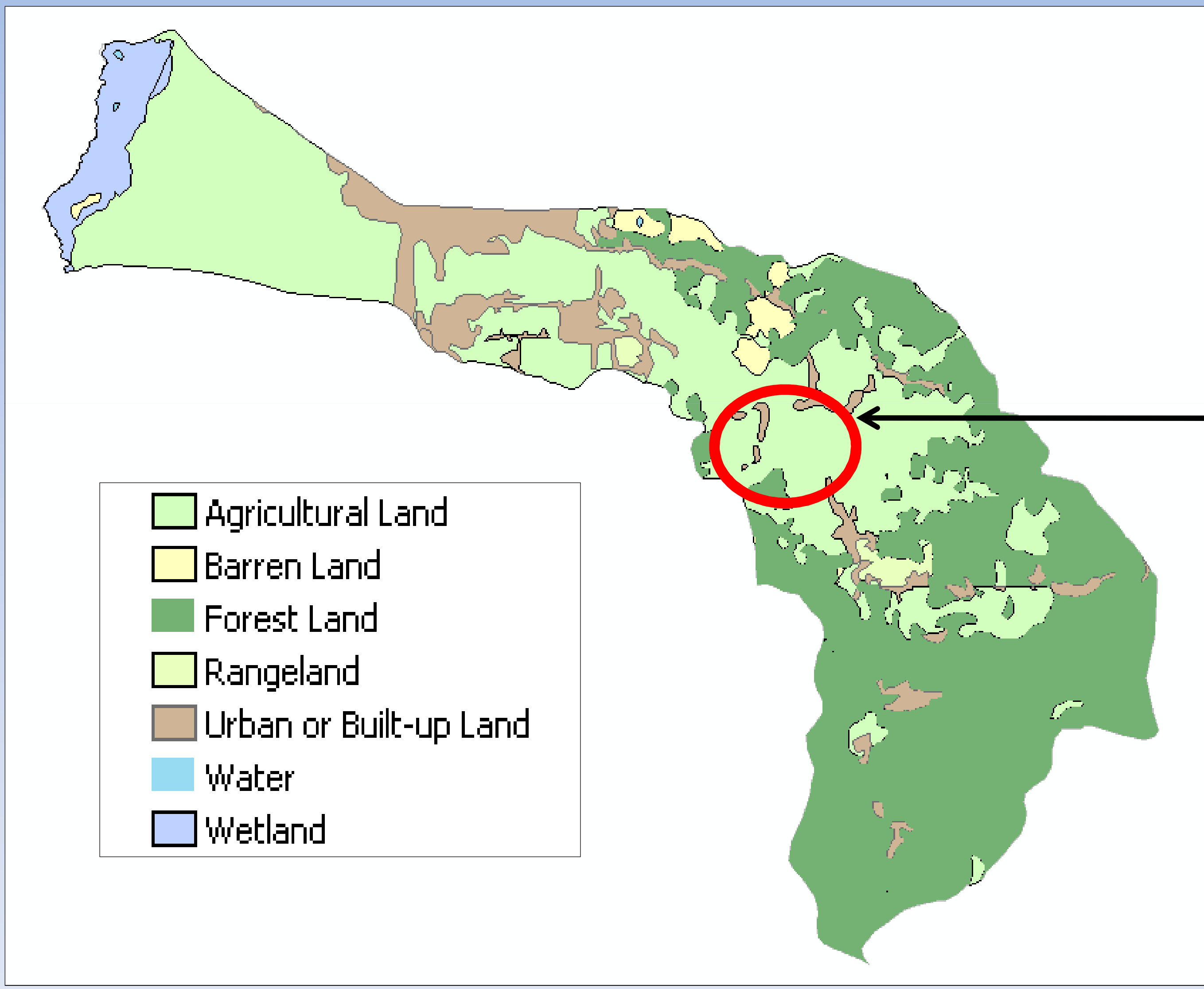
Spatial datasets that define each of these factors were acquired/generated for the Caparo watershed

- **Let's assume that the 3 factors were equally significant, in terms their influence on the occurrence of flooding in the Caparo watershed . In other words, the same weight is assigned to each factor, as part of the development of the FRM**
  - **Rainfall (weight = 33 1/3 %); Slope (weight = 33 1/3 %); Land use (weight = 33 1/3 %)**

Resultant FRM for the Caparo watershed:
Equal weighting of the factors that contribute to flooding



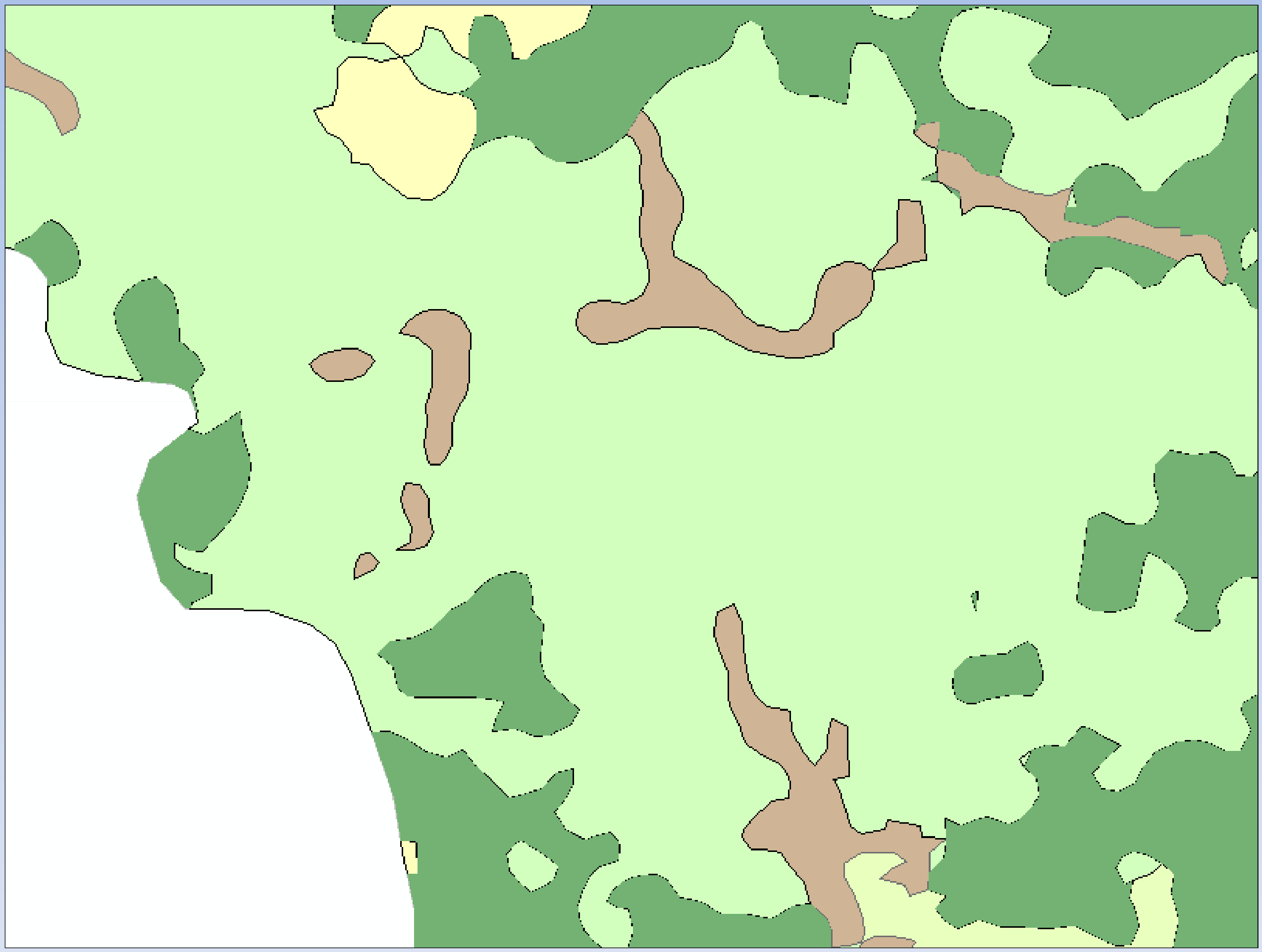
Demonstration of how the FRM can serve as a tool for forecasting/predicting the occurrence of floods



Let's analyse the various land cover/use types associated with the watershed

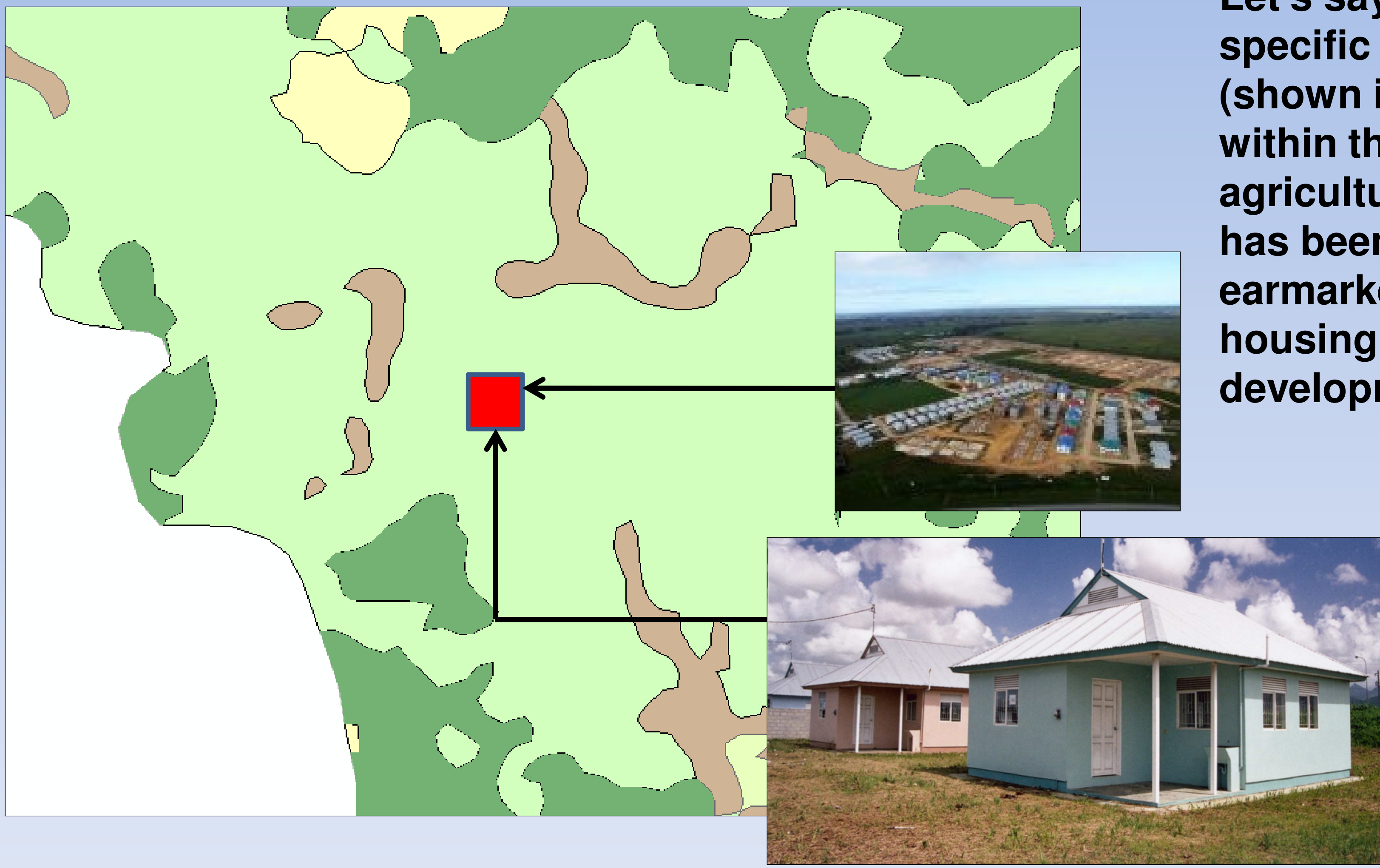
& let's consider this particular area within the watershed

Demonstration of how the FRM can serve as a tool for forecasting/predicting the occurrence of floods



As can be seen, this particular area is characterized mainly by the presence of <u>agricultural land</u>

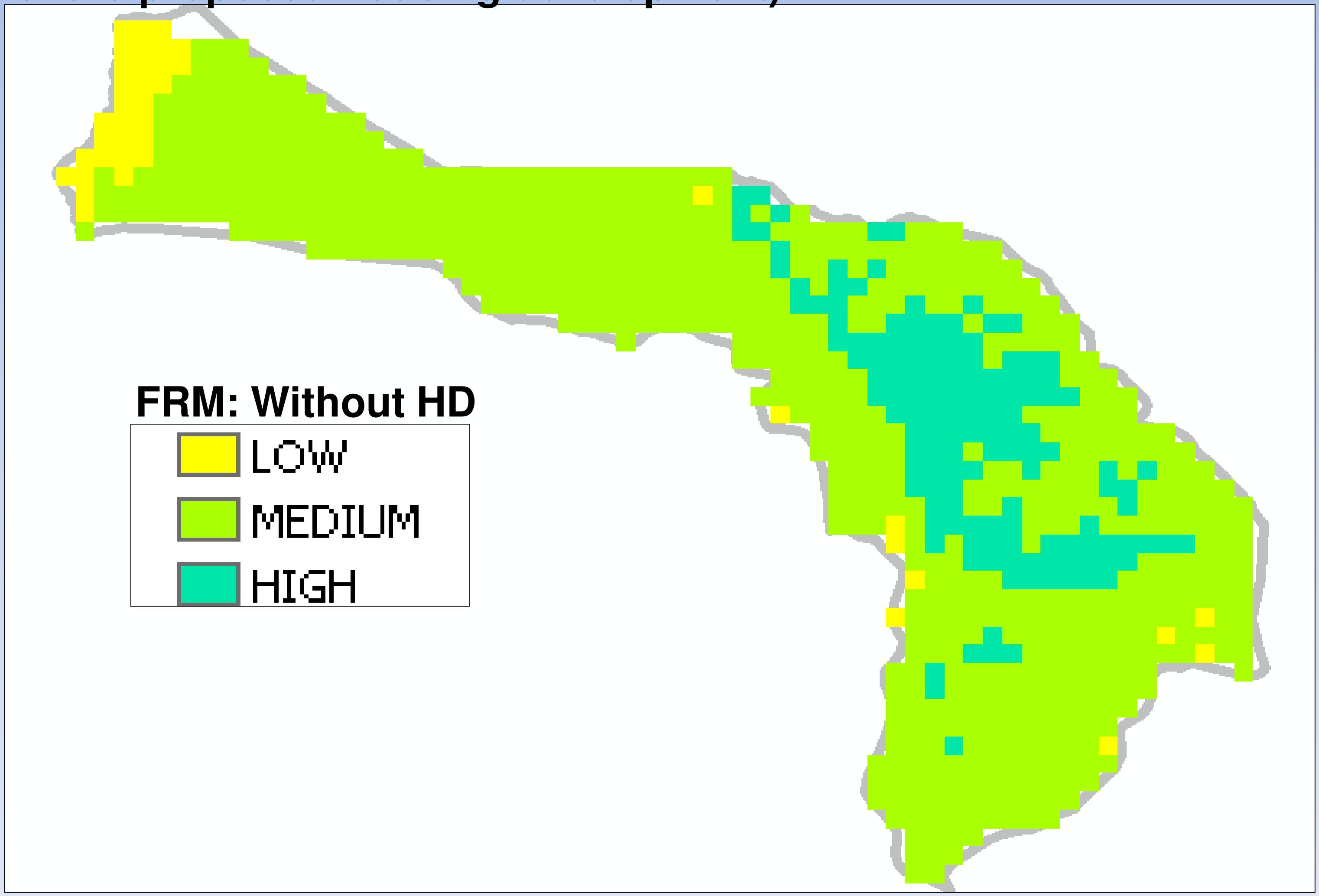
Demonstration of how the FRM can serve as a tool for forecasting/predicting the occurrence of floods



Let's say that a specific site (shown in red) within the agricultural land has been earmarked for a housing development

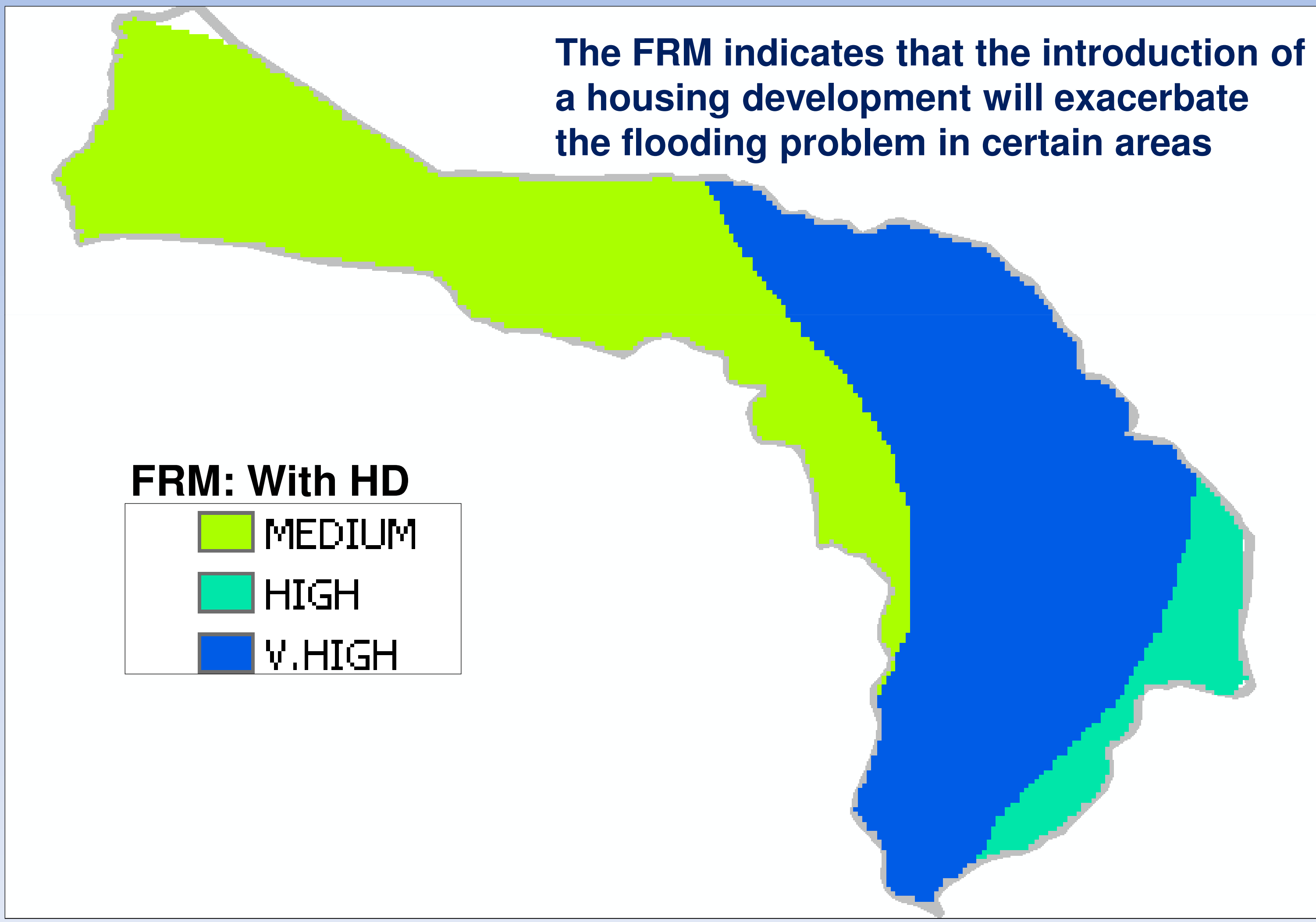
Demonstration of how the FRM can serve as a tool for forecasting/predicting the occurrence of floods

Recall that the FRM shown below was originally produced for the Caparo watershed, based on the existing land use (without considering the presence of the proposed housing development)



Demonstration of how the FRM can serve as a tool for forecasting/predicting the occurrence of floods

The FRM shown below is based on a modified (simulated) land cover/use dataset that reflects the proposed housing development



Benefits of the FRM

- **A useful tool for forecasting/predicting the occurrence of floods**
  - **The FRM is generated from a model that can be used to test various development scenarios, and to evaluate the likelihood/probability of the occurrence of floods, if certain development is attempted or undertaken**
  - **FRM could be used to assist the process of land use planning**
  - **FRM can be used to aid disaster management and preparedness**

How exactly do we weight the factors that contribute to the occurrence of floods???

How do we determine the relative influence of the different flood-causing agents?

- **The creation of an accurate FRM can become a challenging task since it requires a proper determination of the weights to be assigned to the individual factors that contribute to flooding in a particular area**

  Note that for different areas, the interplay of factors and their relative influence would vary!!!

- **Adoption of existing weighting strategies used by other countries/localities may not be sufficiently applicable in the local context**

- **Expert/local knowledge is required and used to guide the assignment of weights, however such knowledge may be limited in some cases**

Existing approach used to assign weights for FRM

STEP 1 — Adopt weights used in a previous model

STEP 2 — Modify weights according to expert/local knowledge

STEP 3 — Create FRM

STEP 4 — Collect data in the field at various sites across study area

STEP 5 — Use FRM to make predictions

Note:

- Field data collection (step 4) refers to a process of making and recording observations that pertain to the degree of flooding that takes place in different areas across the study area
- This data is used to crosscheck the results generated by the established FRM
- If the field data is consistent with the generated results, then the FRM could be suitably used as a predictive tool
- If the field data is not consistent, then the assigned weights are further modified until consistency is finally achieved

Proposed approach to assign weights for FRM

STEP 1 — Collect data in the field at various sites across study area

STEP 2 — Mathematically derive the unknown weights

STEP 3 — Modify weights according to expert/local knowledge

STEP 4 — Create FRM

STEP 5 — Use model to make predictions

Note:

- Field data collection is done at the start (step 1), in order to determine the degree of flooding that takes place in different areas across the study area
- This data is then used to mathematically determine the values of the weights that should be assigned to the individual factors
- In other words, the "real-world" situation is used to dictate the manner in which weights are assigned

Proposed approach: General concept

- **A mathematical approach is used, based on the principles of *least squares adjustment***
  - **Could be thought of as a "working backwards" approach**

$$OBS_1 = RF1 + SL1 + LU1$$

$$OBS_2 = RF2 + SL2 + LU2$$

$$OBS_3 = RF3 + SL3 + LU3$$

$$OBS_n = RFn + SLn + LUn$$

- **Each observation pertains to the degree of flooding at a particular site within the study area**
- **Each observation is considered to be the outcome of the combined values of the rainfall and slope factors as well as the land use associated with the site**

Proposed approach: General concept

➢ **A uniform set of weights are computed through least squares adjustment**

➢ **These weights serve to establish a relationship between the actual observations and the various factors that influence flooding**

$$OBS_1 = W_{RF}\,RF1 + W_{SL}\,SL1 + W_{LU}\,LU1$$

$$OBS_2 = W_{RF}\,RF2 + W_{SL}\,SL2 + W_{LU}\,LU2$$

$$OBS_3 = W_{RF}\,RF3 + W_{SL}\,SL3 + W_{LU}\,LU3$$

$$OBS_n = W_{RF}\,RFn + W_{SL}\,SLn + W_{LU}\,LUn$$

Proposed approach: Least squares processing

Number of observations = 10

Number of unknown weights (parameters) = 3

vector of flood observations, L (7 x 1)		Observed sites
	300	Ravine Sable
	100	Mid. Caparo
	300	Todd's Rd
	300	Mamoral
	400	Flanagin
	400	U. Brasso
	600	Lower Caparo
	0	Brickfield
	0	Chag. Proper
	0	Carlsen Field

A (design matrix) 10 x 3 n x m	RF	SL	LU	
	4	4	2	Ravine Sable
	4	4	3	Mid. Caparo
	2	4	3	Todd's Rd
	4	4	2	Mamoral
	4	4	2	Flanagin
	4	3	2	U. Brasso
	4	4	2	Lower Caparo
	1	4	3	Brickfield
	2	4	3	Chag. Proper
	2	4	3	Carlsen Field

At 3 x 10										
	4	4	2	4	4	4	4	1	2	2
	4	4	4	4	4	3	4	4	4	4
	2	3	3	2	2	2	2	3	3	3

Microsoft Excel is used to perform the matrix operations involved in the least squares adjustment process

Proposed approach: Least squares processing

At A	109	120	73
3 x 3	120	153	98
	73	98	65

	RF	SL	LU	
(At A)-1	0.122135	-0.23138	0.211676	RF
3 x 3	-0.23138	0.62894	-0.6884	SL
	0.211676	-0.6884	0.815544	LU

At L	9000
3 x 1	9200
	5200

(At A)-1 (At L)	71.27507		RF	71	0.18586	18.58639	19	RF
3 x 1	124.212		SL	124	0.32461	32.46073	32	SL
	-187.321		LU	187	0.48953	48.95288	49	LU
				382	1.00000		100	

The weights that were computed through least squares processing are given below:

W_{RF} = 19

W_{SL} = 32

W_{LU} = 49

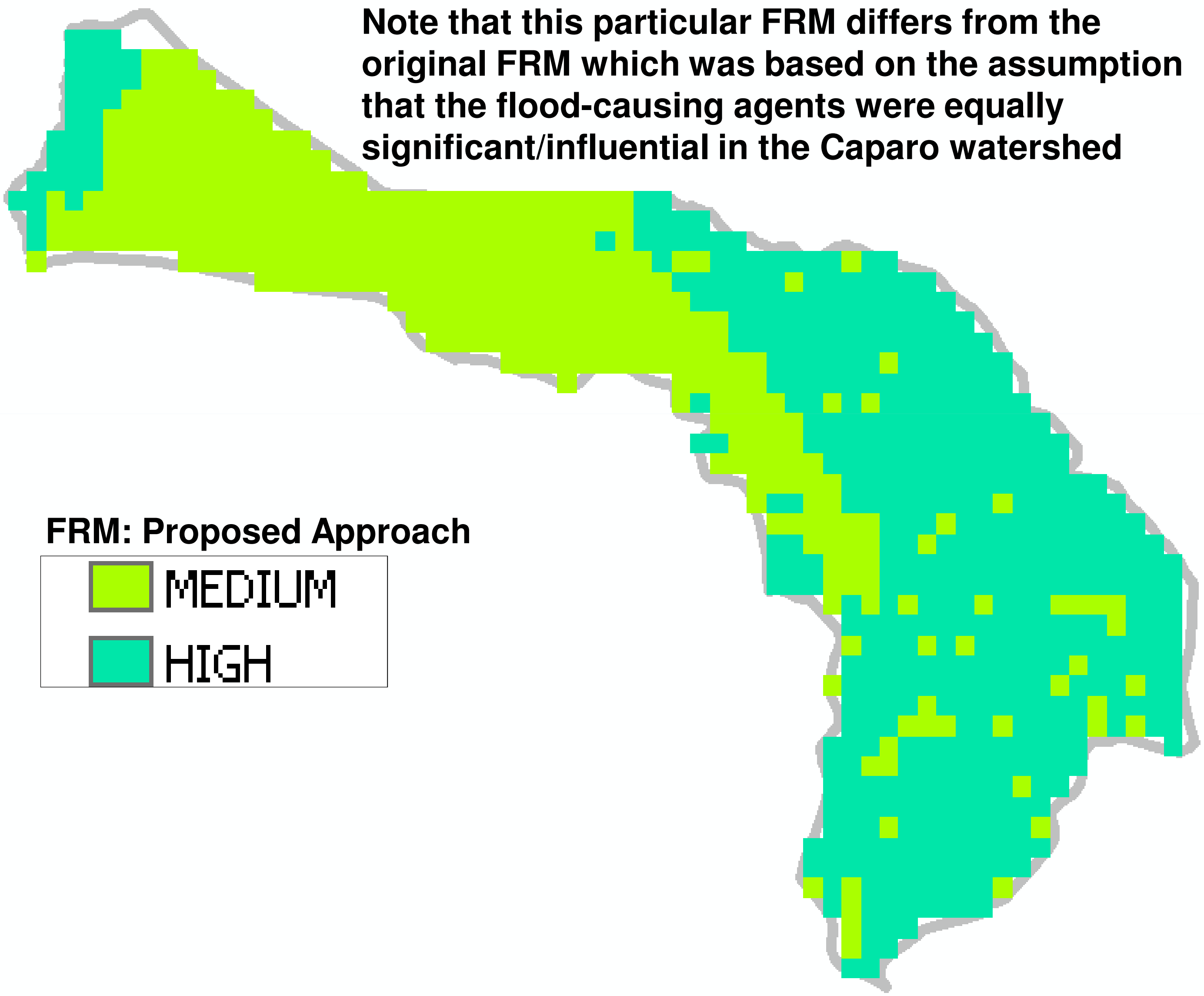
100

The proposed approach reveals that land use is the most influential determinant of flooding in the Caparo watershed

Note that this is not in agreement with the equal-weighting strategy that was initially used, where 33 1/3 % was assigned to each factor

Resultant FRM produced using proposed approach:
Differential weighting of factors that contribute to flooding

Note that this particular FRM differs from the original FRM which was based on the assumption that the flood-causing agents were equally significant/influential in the Caparo watershed



SUMMARY/CONCLUSIONS

- **GIS technology is a very useful tool that can be used for flood risk mapping, and the development of effective mitigation/management strategies**

- **This development of the mathematically-based weighting strategy which has been proposed in this study, can be described as "a work in progress". However, the promising results that have been yielded thus far, have indicated that this proposed strategy may have the potential to serve as a useful alternative to the existing approach currently employed for the establishment of weights during the GIS modelling process**

SUMMARY/CONCLUSIONS

- The advantage of the proposed strategy resides in the fact that it determines weights that are site-specific and are directly representative of the watershed that is being investigated. In other words, the construction of the underlying GIS model does not have to rely on the adoption of weights that have been determined and used by another country/locality where watershed conditions/characteristics may not be the same

- The results provided by the FRM should not be accepted as definitive proof that floods will or will not occur. Instead the FRM should be interpreted as a map which shows areas where the likelihood/probability of floods is high/low

- The process of using the proposed strategy to derive weights should always be supplemented and guided by expert/local knowledge

- The mathematical-based/site-specific weighting strategy (embodied by the proposed approach) can improve the accuracy of flood mapping, and in turn, reduce our level of vulnerability

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