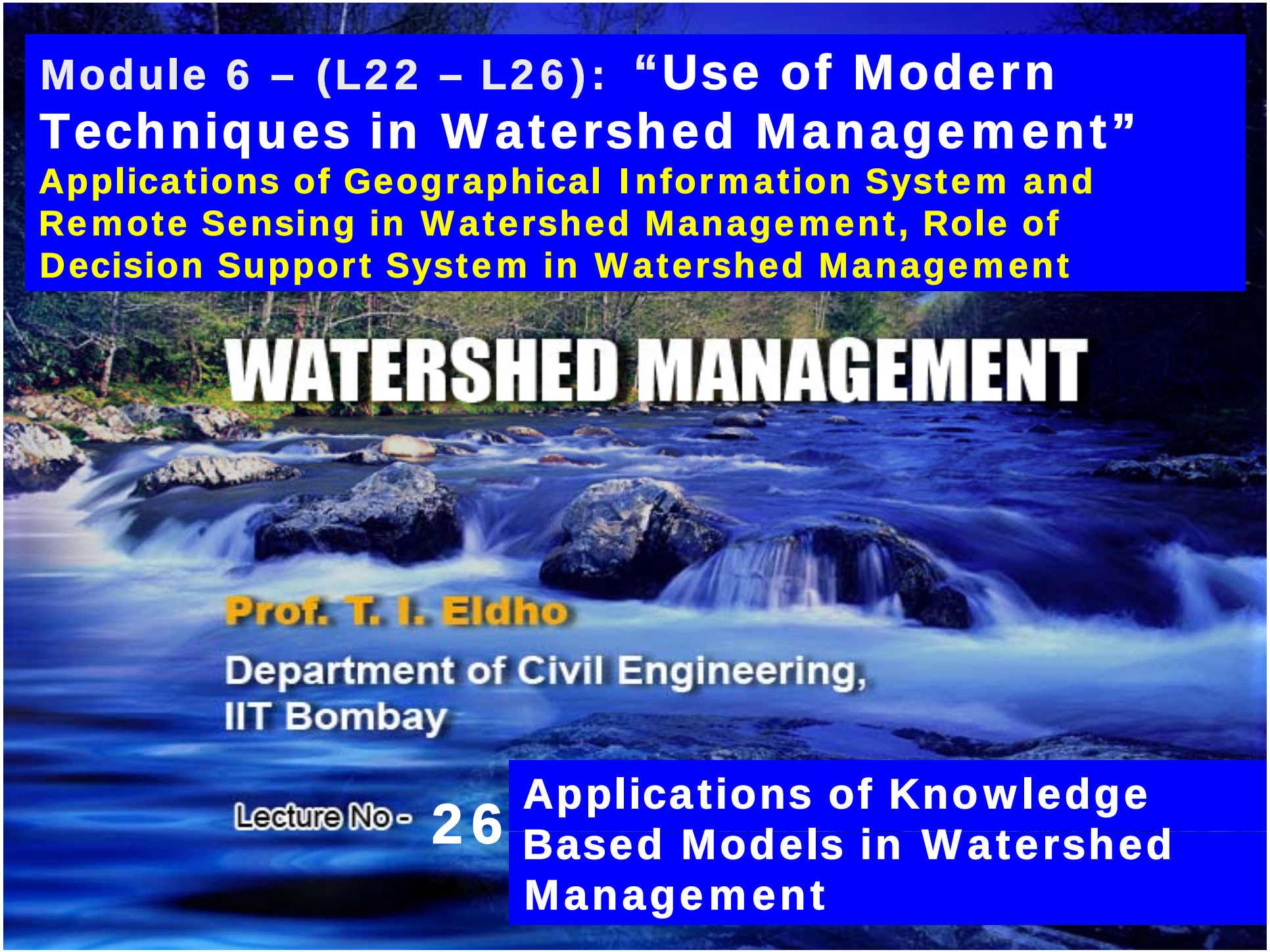
Module 6 – (L22 – L26): "Use of Modern Techniques in Watershed Management"

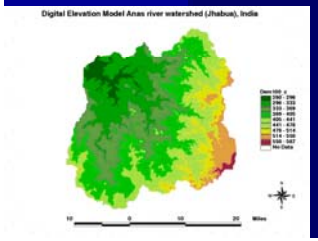
Applications of Geographical Information System and Remote Sensing in Watershed Management, Role of Decision Support System in Watershed Management



Applications of Knowledge Based Models in Watershed Management

L26– Applications of Knowledge Based Models in Watershed Management

- **Topics Covered**
- Knowledge based Modeling, Multi criteria decision analysis, Fuzzy Logic based modeling, Fuzzy systems, Applications of Knowledge based Systems in Watershed Management.
- Keywords: Knowledge based model; Multi criteria decision analysis; Fuzzy logic based modeling.



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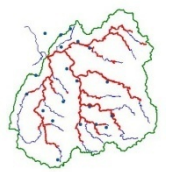
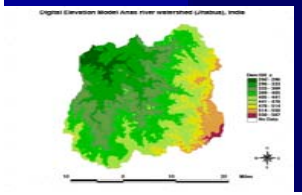


Knowledge Based Model (KBM)

- Knowledge-based systems are computer systems that are programmed to imitate the human problem-solving ability by means of artificial intelligence (AI) tools.
- Human reasoning using natural language can be reproduced in knowledge-based systems through AI tools.
- In KBM, knowledge can be: knowledge derived from basic analysis, experts' knowledge collected through surveys, & heuristic information from the field.
- Experts' knowledge and heuristic information related to the specific problems are generally stored in the form of a rule-base.

Knowledge Based Modeling

- A knowledge base is an organized body of knowledge that provides a formal logical specification for the interpretation of information
- In the knowledge-based modeling approach, watershed assessment is a multi-criteria evaluation in which knowledge of the experts is used to define the factors characterizing the watershed and the logic relations between the factors.
- The knowledge base encapsulates the assessment criteria and the relationships in an explicit form so that they can be easily examined, modified, or updated.



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Knowledge Based Systems

- The knowledge base contains knowledge & experience for the subject domain (domain knowledge) & specifies logical relations among topics of interest to an assessment.
- Inference engine performs knowledge-based approximate reasoning to draw conclusions about the state of the system.
- By integrating knowledge-based reasoning into a GIS environment provide decision support for watershed management.
- GIS application provides database management, spatial analysis, system interface, and map display.
- Assessment system allows user to evaluate knowledge base for a specific spatial database & view the results.

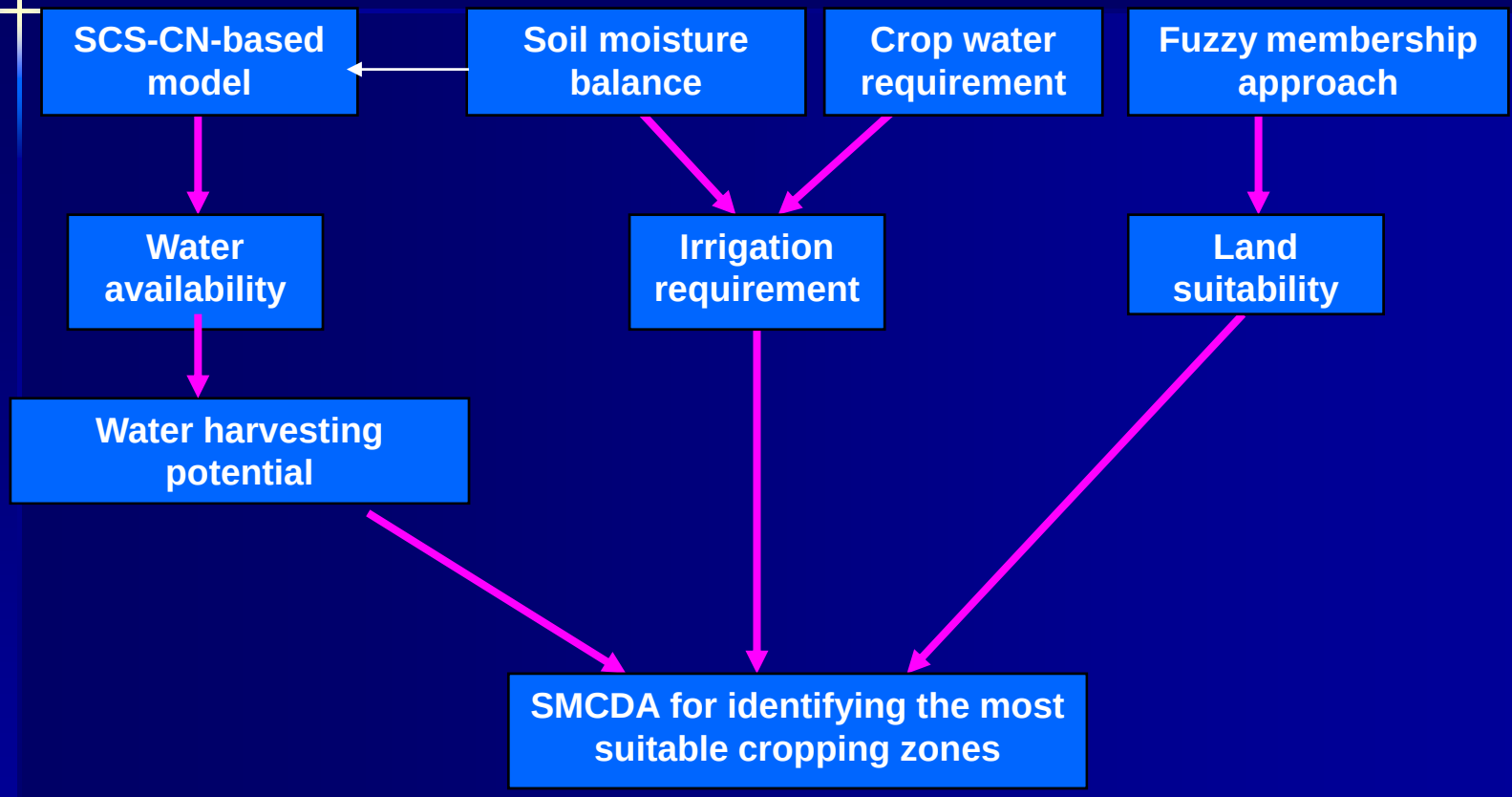
Knowledge Base Structure

- Knowledge base structure is a hierarchy of dependency networks. Each network evaluates a specific proposition about the state of watershed condition.
- Knowledge base structure is designed to address the issues concerned by the watershed managers and to reflect their opinions on the importance of each issue.
- At the top of the hierarchy is the network *watershed condition* for the proposition that the overall condition of the watershed is suitable for sustaining healthy populations of the native
- The *watershed condition* network depends on two lower level networks: *stream condition* and *upland condition*

Multi Criteria Decision Analysis (MCDA)

- Simulation Models of various hydrologic components of watershed - integrated with AI tools so as to make use of experts' knowledge & heuristic information in decision making process; used to help the end users to arrive at the best suitable decisions related to irrigation management.
- Irrigation assessment & management - multi-criteria decision analysis (MCDA) problems - use knowledge-based systems.
- MCDA - in which the land suitability criteria, water availability & irrigation requirement - various criteria to be evaluated- objective max. agricultural production.
- MCDA models -used in irrigation management to identify areas that can be irrigated, water release during different time period & best suitable cropping pattern for area

Typical Knowledge Based Systems for WM



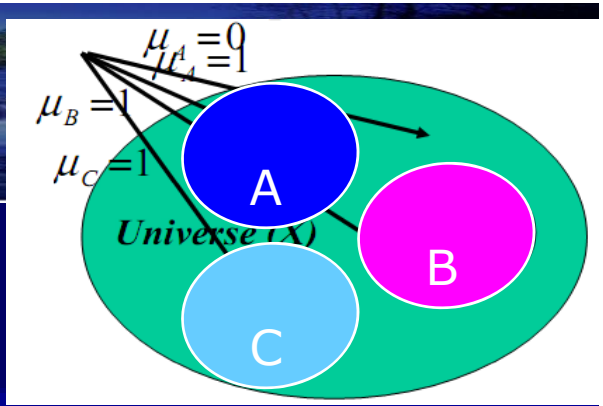
SMCDA – Spatio temporal Multi Criteria Decision Analysis

Ref: Reshmidevi (2008), PhD thesis, Dept. Civil, IIT Bombay

Fuzzy Logic Based System

- Lotfi Zadeh, first presented fuzzy logic in the mid-1960's, at the University of California at Berkeley,
- Zadeh developed fuzzy logic as a way of processing data
- later on he introduced idea of partial set membership
- Definition of fuzzy: "not clear, distinct, or precise"
- Definition of fuzzy logic
  - Fuzzy Logic (FL) is a multi-valued logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc.
- Fuzzy ≠ Probability
- Probability deals with uncertainty and likelihood
- Fuzzy logic deals with ambiguity and vagueness

Ref: L.A. Zadeh (1965) Fuzzy sets. Information and Control 8 (3) 338-353.



Why Fuzzy Logic?.

- Based on intuition and judgment
- No need for a mathematical model
- Provides a smooth transition between members and nonmembers
- Relatively simple, fast and adaptive
- Less sensitive to system fluctuations
- Because of the rule based operation,
- Can implement design objectives, difficult to express mathematically, in linguistic or descriptive rules
- Conventional or crisp sets are binary.
- An element either belongs to the set or doesn't. Example- -[True, False] OR [0, 1].

Ref: D. Dubois & H. Prade (1988) Fuzzy Sets and Systems. Academic Press, New York.

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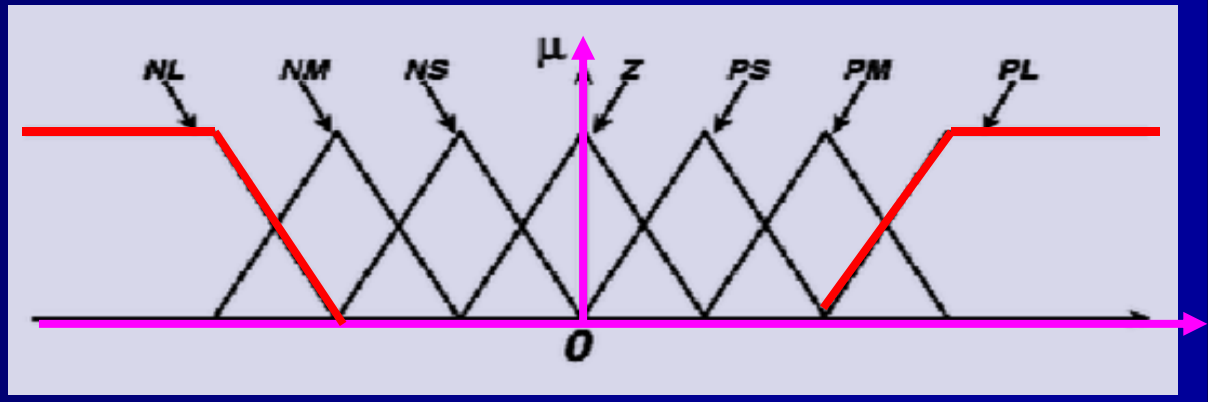
Fuzzy Sets

- Allow elements to be partially in a set
- Each element is given a degree of membership in a set
- A membership function is the relationship between the values of an element and its degree of membership in a set

(N = Negative, P = Positive, L =Large, M = Medium, S = Small)



Ref: D. Dubois & H. Prade (1988) Fuzzy Sets and Systems. Academic Press, New York.

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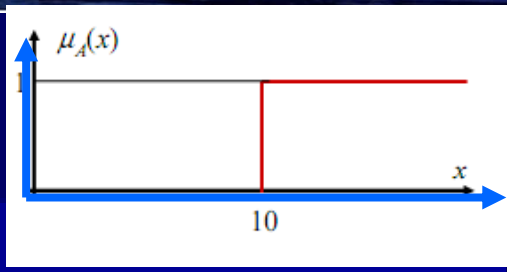
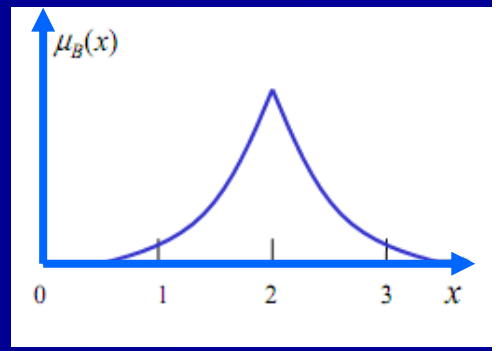
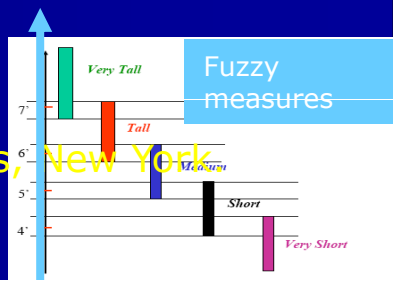
Membership Functions



- Crisp membership functions
- Crisp membership functions (μ) are either one or zero
- Example- Number greater than 10
- **A={x/x>10}.**
- Fuzzy membership functions
- Membership value of not only 0 or 1
- The degree of truth of a statement can range between 0 and 1
- Linguistic variables are used for fuzzy measures
- Examples of fuzzy measures include close, medium, heavy, light, big, small, smart, fast, slow, hot, cold, tall and short



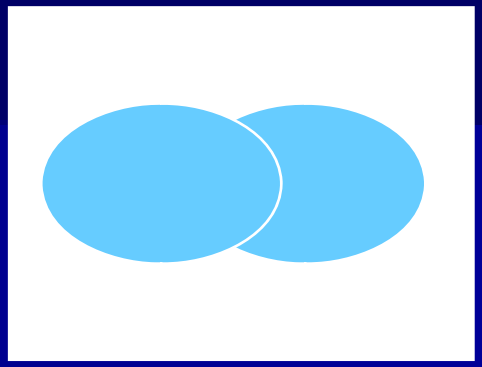


Ref: D. Dubois & H. Prade (1988) Fuzzy Sets and Systems. Academic Press, New York.

Fuzzy Logic Operations

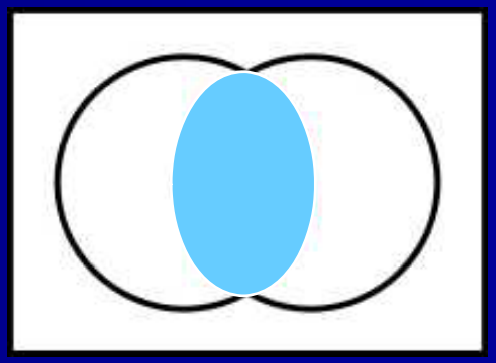
- Union

$$\mu_{A+B}(x) = \max\left[\mu_A(x), \mu_B(x)\right]$$

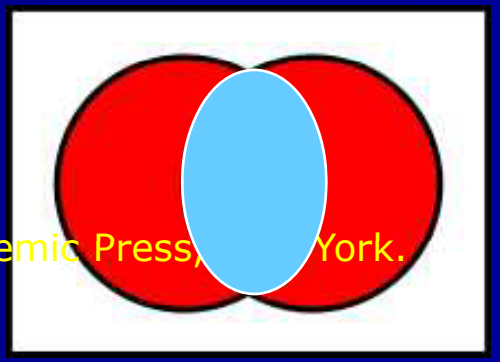


- Intersection

$$\mu_{A\cdot B}(x) = \min\left[\mu_A(x), \mu_B(x)\right]$$



- Complement
- the negation of the specified membership function



Ref: D. Dubois & H. Prade (1988) Fuzzy Sets and Systems. Academic Press, York.

Fuzzy Logic - Applications

- Fuzzy logic concepts can be applied in:
- Ride smoothness control
- Braking systems; High performance drives
- Air-conditioning systems; Digital image processing
- Washing machines
- Pattern recognition in remote sensing.
- Video game artificial intelligence
- Graphics controllers for automated police sketchers.
- Watershed related applications: Rainfall-runoff processes.
- Erosive soil measurement;hydro-ecological modeling over watershed; Flood forecasting; Water quality problems; Cropping & irrigation management

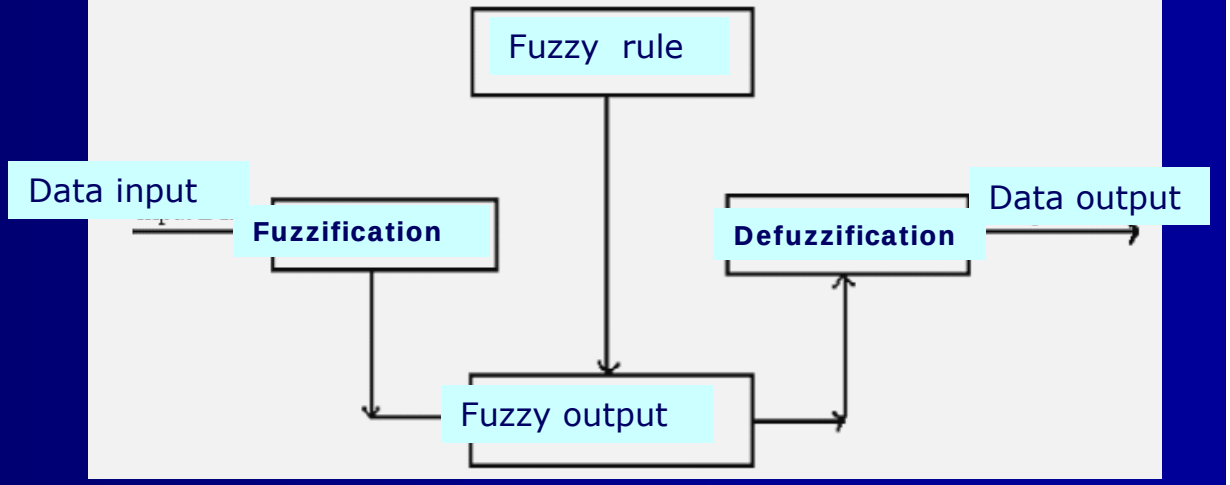
Fuzzy Logic – Advantages & Limitations

- **Advantages**
  - Allows the use of vague linguistic terms in the rules
  - No mathematical model
  - Rule based and descriptive type

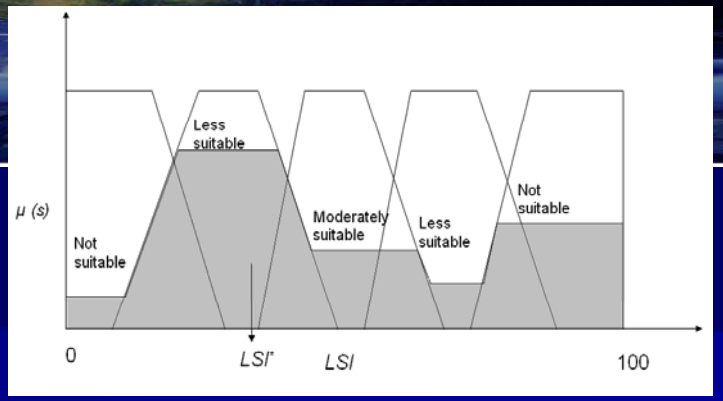
- **Limitations**
  - Difficult to estimate membership function
  - There are many ways of interpreting fuzzy rules
  - Combining the outputs of several fuzzy rules and defuzzifying the output

Fuzzy System – Basic Components

- Basic component
  - Input
  - Fuzzification
  - Fuzzy base rule
  - Defuzzification
  - Output



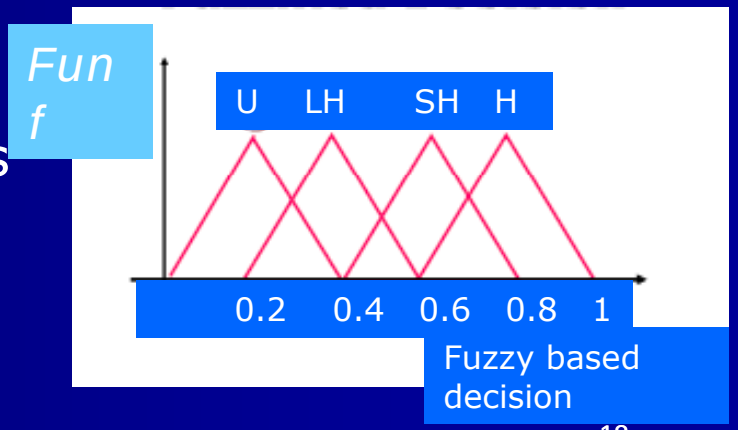
Fuzzification



- Fuzzifier converts a crisp input into a fuzzy variable
- It converts each piece of input data to degrees of membership
- The membership function is a graphical representation of the magnitude of participation
- Definition of the membership functions must
  - reflects the designer's knowledge
  - provides smooth transition between member and nonmembers of a fuzzy set
- Typical shapes of the membership function
  Gaussian; Trapezoidal; Triangular (commonly used)

Fuzzy Base Rule

- Include all possible fuzzy relations between inputs and outputs
- Rules are expressed in the IF-THEN format
- Rules reflect expert's decisions
- Rules are tabulated as fuzzy words
- Eg:– Healthy (H); Somewhat healthy (SH); Less Healthy (LH); Unhealthy (U)
- Rule Function: F ={H,SH,LH,U}
- Eg: IF height is tall and weight is medium THEN healthy (H)



Defuzzification

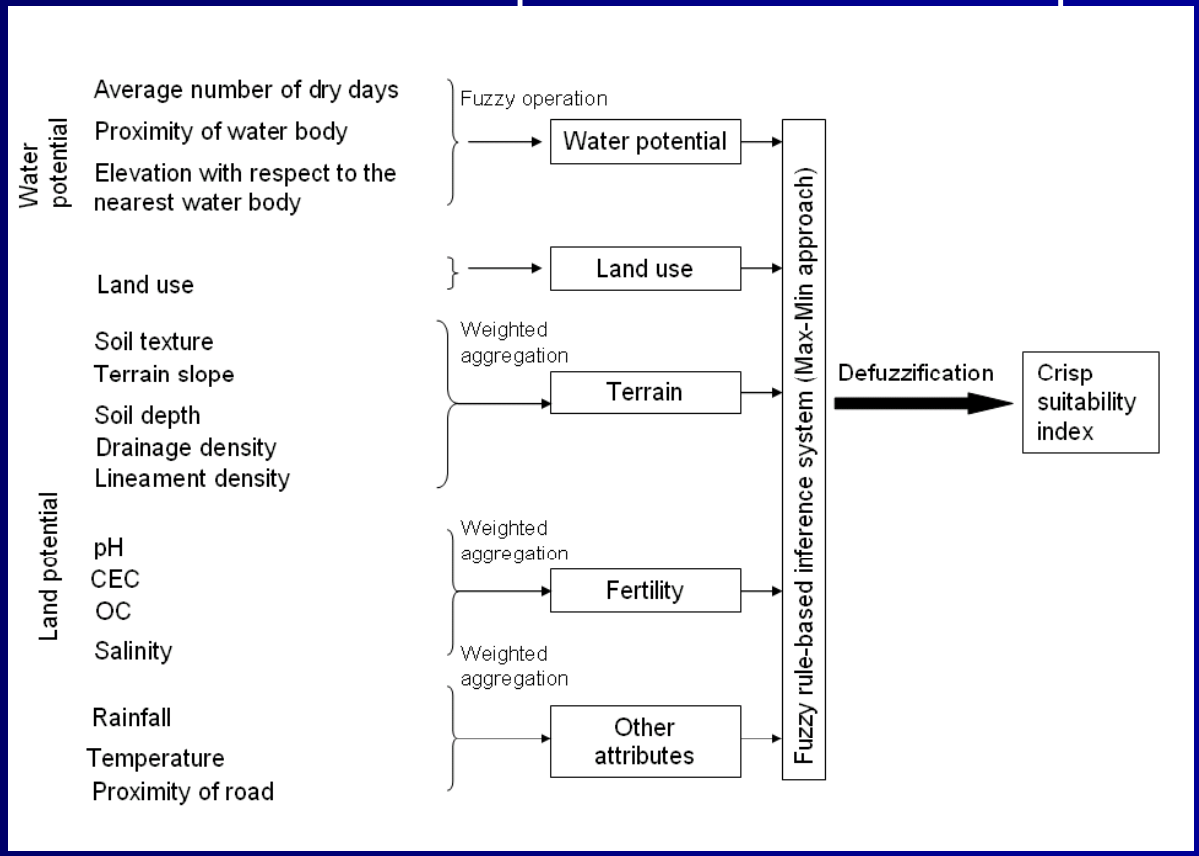
- Defuzzification converts the resulting fuzzy outputs from the fuzzy inference engine to a number
- Converting the output fuzzy variable into a unique number
- Defuzzification Methods
  - weighted average
  - maximum membership
  - average maximum membership
  - centre of gravity

Knowledge-Based Model Development

- **Reshmidevi (2008), "Knowledge-based Model for Supplementary Irrigation Assessment in Agricultural Watersheds" PhD thesis, Dept. Civil, IIT Bombay**
- Fuzzy rule-based inference system for land suitability evaluation
- SMCDA model for identifying the scope for supplementary irrigation
- Graphical user interface
- 5 Steps in the Model Development
  - Fuzzification of the attributes
  - Estimation of the intermediate land suitability index
  - Generation of the fuzzy rule base
  - Aggregation of the rules (Fuzzy output in terms of 5 suitability classes)
  - Defuzzification

Fuzzy Rule-Based Inference System

- Problem with large number of attributes
- Hierarchical classification is adopted
- Considered both land potential and water potential



Schematic representation of the fuzzy rule-based inference system

Fuzzification

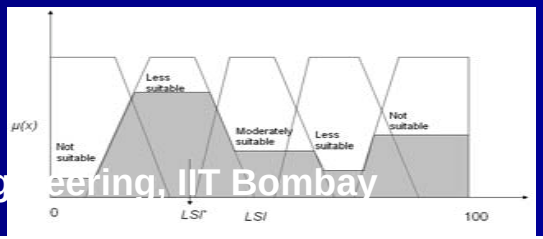
- Attribute values are mapped into [0,1]
- Two types of attributes: Thematic attributes for land potential → Unique membership value for each class; Continuously expressed attributes for land potential→ Semantic import membership function; Asymmetric left (AL), Asymmetric right (AR) or Optimal range (OR)
- **Intermediate Land Suitability Index**
- Weighted aggregation of the attribute membership values
- Attribute weights – Using Saaty's relative importance scale (Saaty, 1980)
- Relative importance is assumed based on literature, field observation and heuristic information
- Gives intermediate LSI in three suitability classes (Good, Moderate and Not-suitable) based on land & water potential

Fuzzy Rule Base and Aggregation of the Rules

- **Suitability criteria**
  - **Expressed in the form of IF..THEN rules**
  - **In terms of intermediate suitability indices**

IF LU is good AND water potential is good AND terrain is good
AND physico - chemical characteristics is Good AND other parameters are good
THEN the area is excellent
⋮
IF LU is good AND water potential is moderate AND terrain is moderate
AND physico - chemical characteristics is moderate AND other parameters are moderate
THEN the area is moderate
⋮
IF LU is not suitable AND water potential is not suitable AND terrain is suitable
AND physico - chemical characteristics is not suitable AND other parameters are not suitable
THEN the area is not suitable

- Generate fuzzy output in terms of 5 suitability classes (Excellent, Good, Moderate, less-suitable and Not-suitable)
- **Defuzzification:** Convert the fuzzy output into a single value (LSI^*)- Maximum centroid method



Generation of the Best Suitable Crop Map

- Relative importance & LSI*
- Three cases: Case 1- *LSI** of existing crop < another crop of higher priority; higher priority crop is selected

  Case 2- *LSI** of the existing crop < another crop of lesser priority

  Change in the cropping pattern if *less suitable* or *not suitable* for the existing crop

  Case 3- *LSI** is same for more than one potential crop

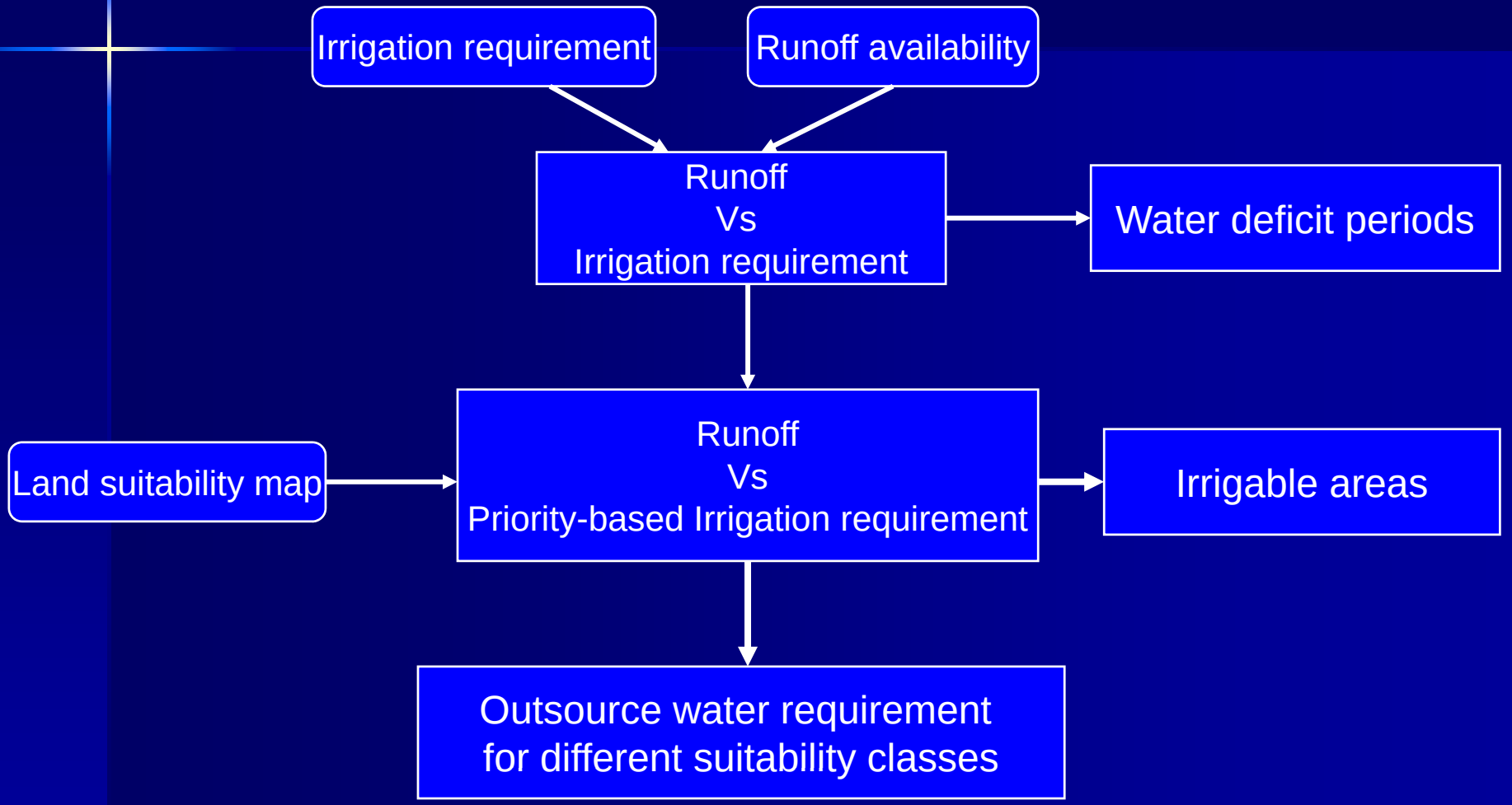
  - If *less suitable* or *not suitable* for the existing crop, and

  if relative importance of the existing crop < the other crop,

  – A change in the cropping pattern is proposed

  – Replaces the existing crop with the higher priority one

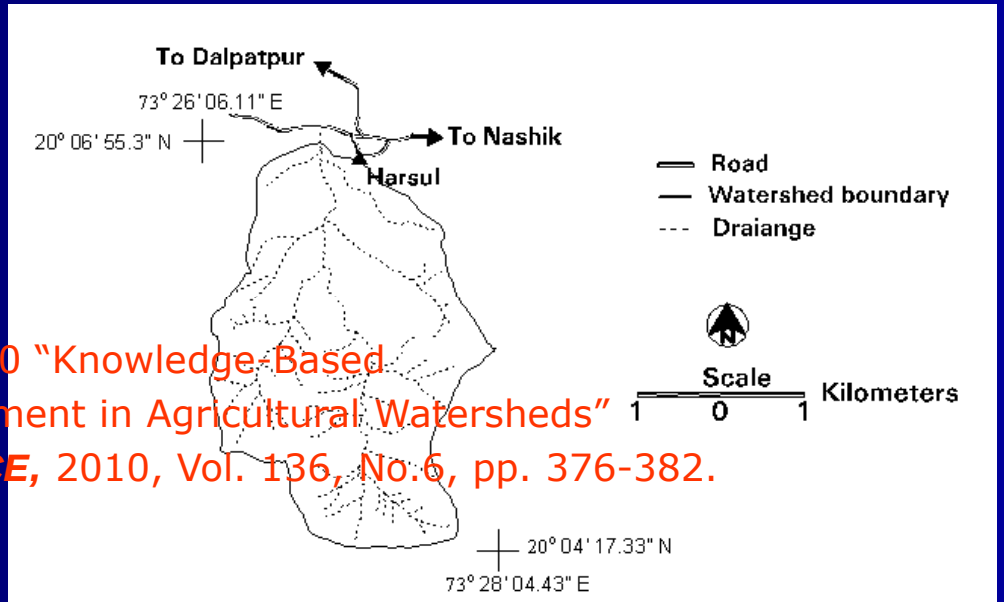
SMCDA Model for Irrigation Feasibility Analysis



Case Study: Harzul Watershed

Reshmidevi (2008), "Knowledge-based Model for Supplementary Irrigation Assessment in Agricultural Watersheds" PhD thesis, Dept. Civil, IIT Bombay

- Location- Nashik district, Maharashtra, India
  Tropical humid climate
- Area: 10.9 sq. km
- Principle crops: Paddy and finger millet



Reshmidevi, T.V., **Eldho T.I**., Jana, R., (2010 "Knowledge-Based Model for Supplementary Irrigation Assessment in Agricultural Watersheds" ***Journal of Irrigation and Drainage, ASCE,*** 2010, Vol. 136, No.6, pp. 376-382.

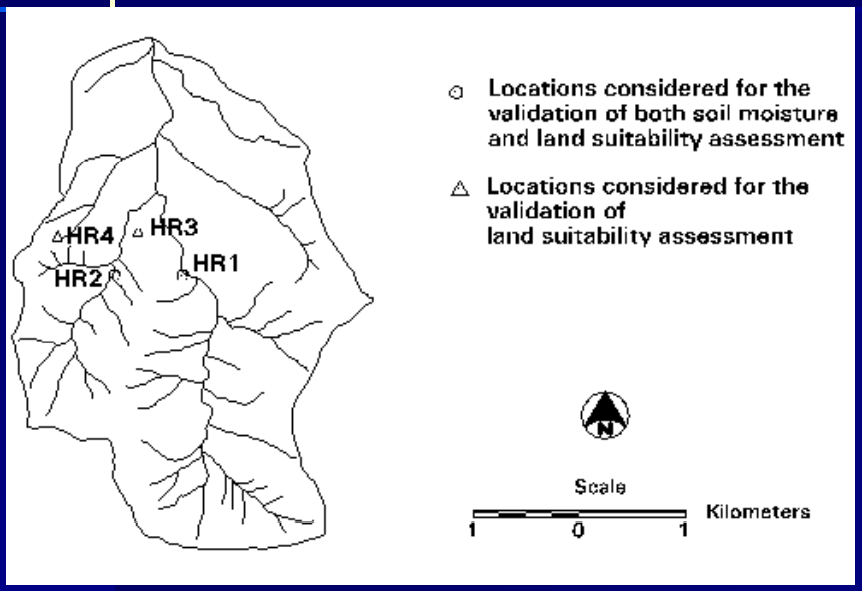
Generation of the Database

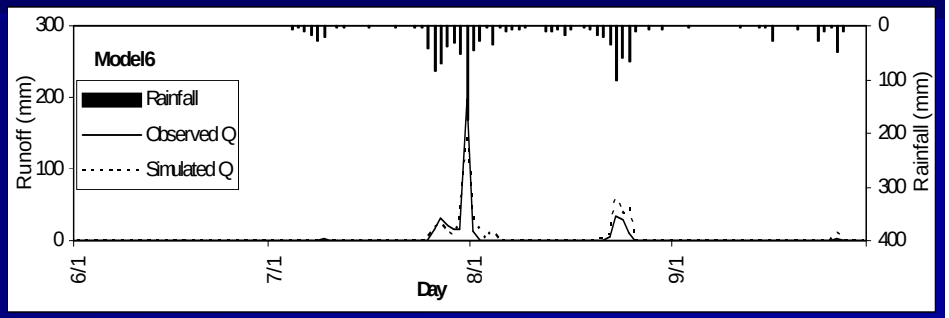
- **Heuristic information & field observation**
  - Attributes
  - Attribute suitability for different crops
  - Crop priority & agricultural practices
  - Land suitability criteria

- **Map layers**
  - Drainage map
  - Contour map
  - Soil map
  - pH map
  - Maps showing spatial variation in EC, Salinity etc.
  - Land use map
  - Drainage density map
  - Proximity to water body
  - Proximity to settlement

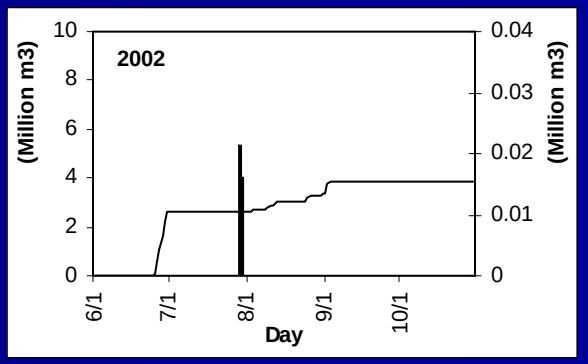
- **Hydro-meteorological data**
  - Rainfall
  - Stream flow
  - Temperature
  - Relative humidity
  - Sunshine duration
  - Wind speed

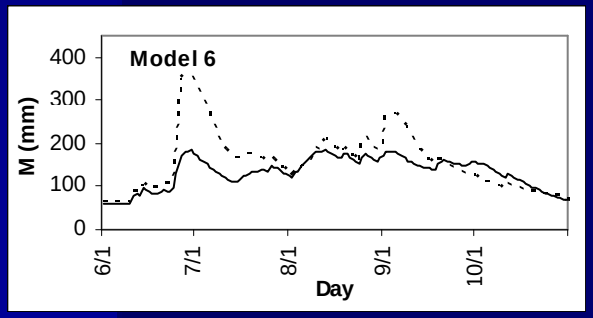
WATERSHED MANAGEMENT

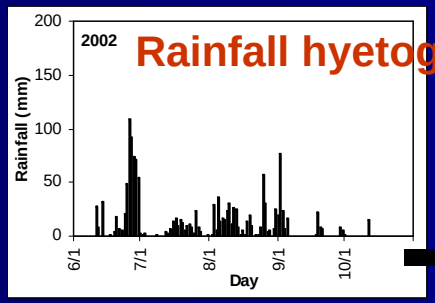




Year 1997 – SCS-CN- SMS- SCS-CN model incorporating Soil Moisture Simulation







Rainfall hyetograph

Irrigation requirement

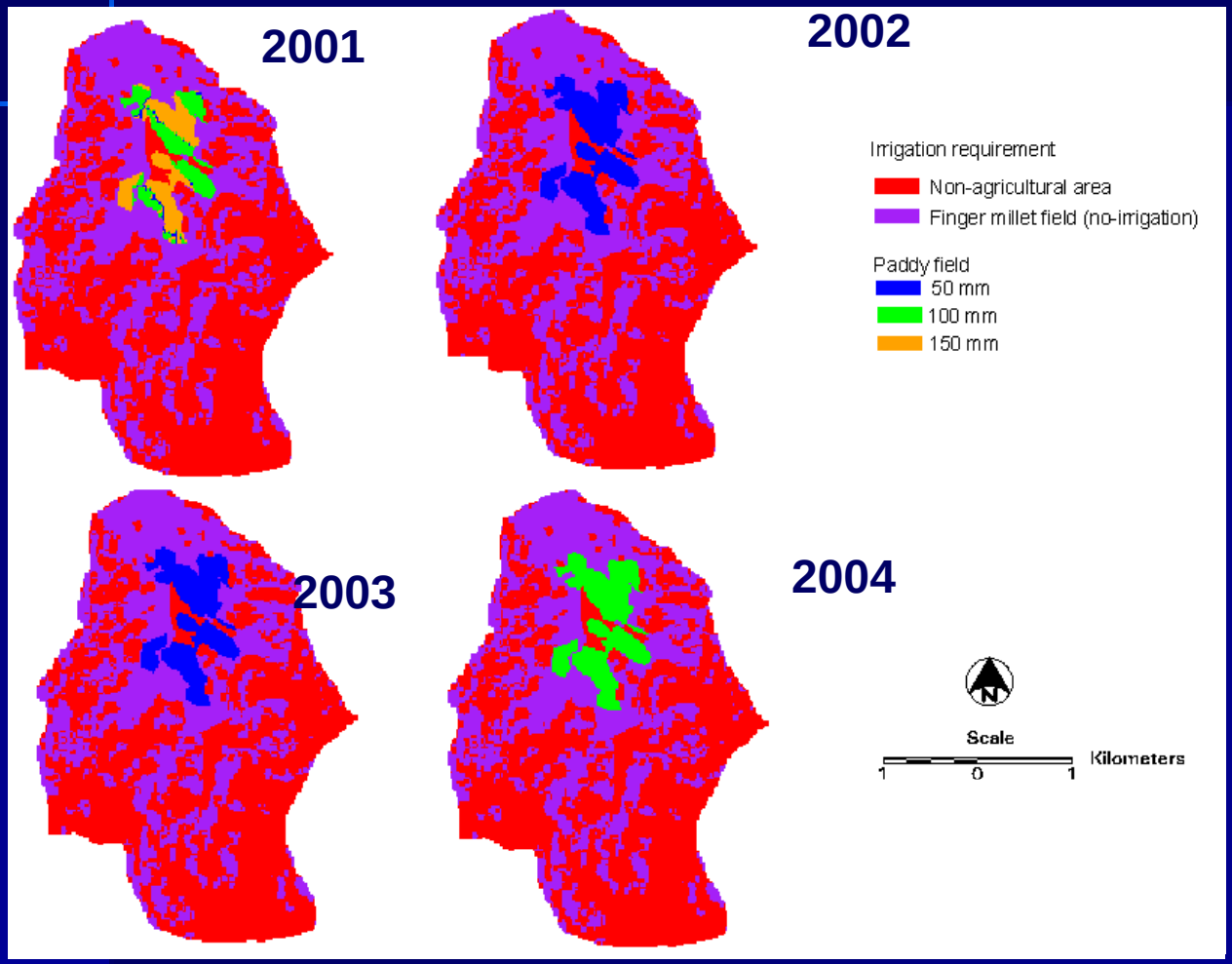
Accumulated runoff

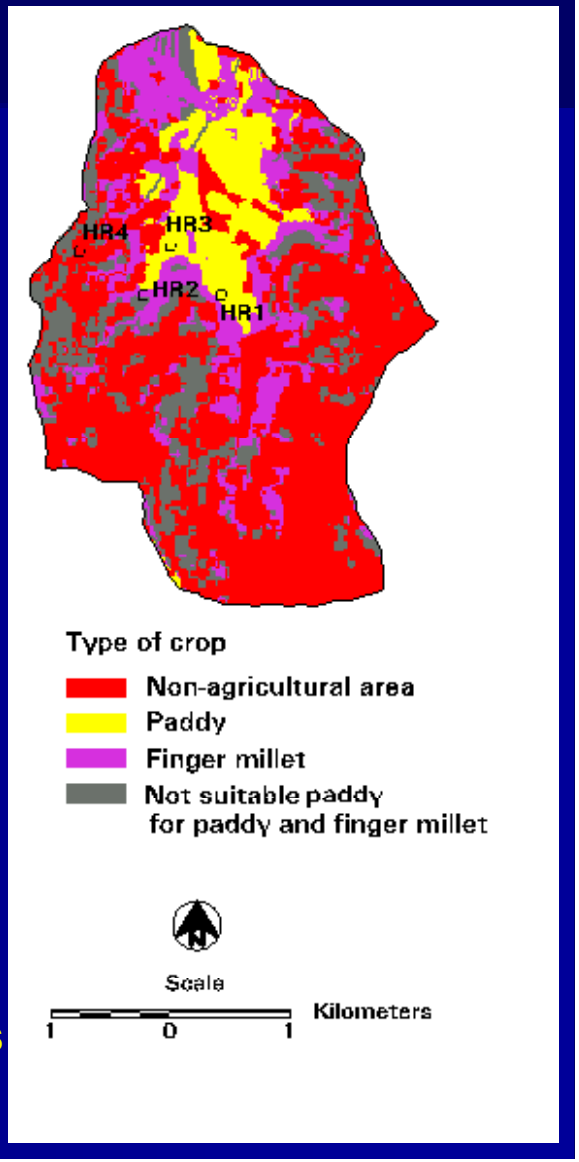
Year 2002, Dry year

Paddy field

Finger millet field

Irrigation requirement in the Harsul watershed

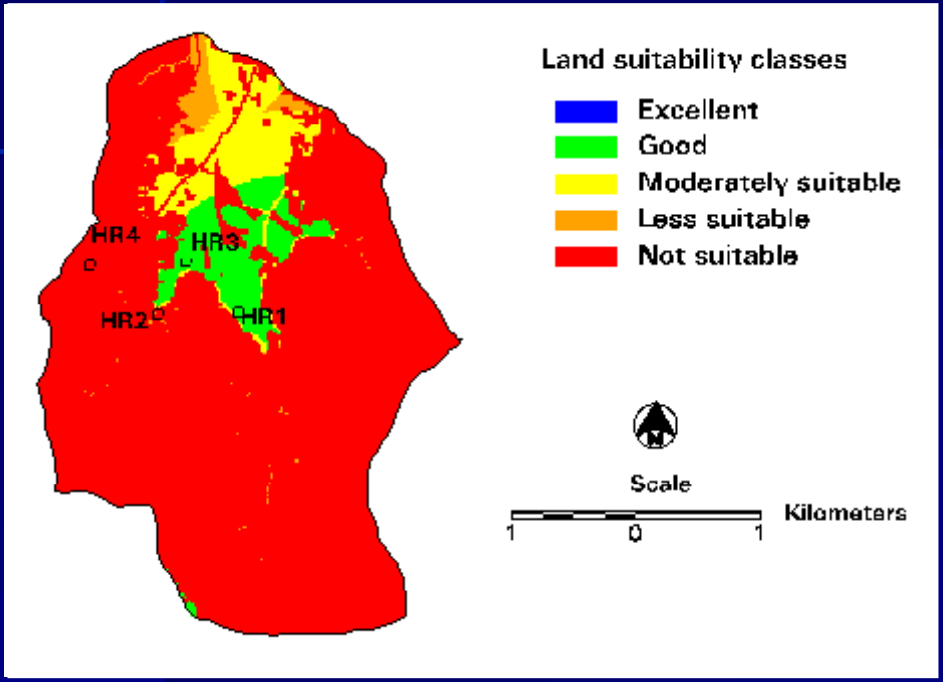




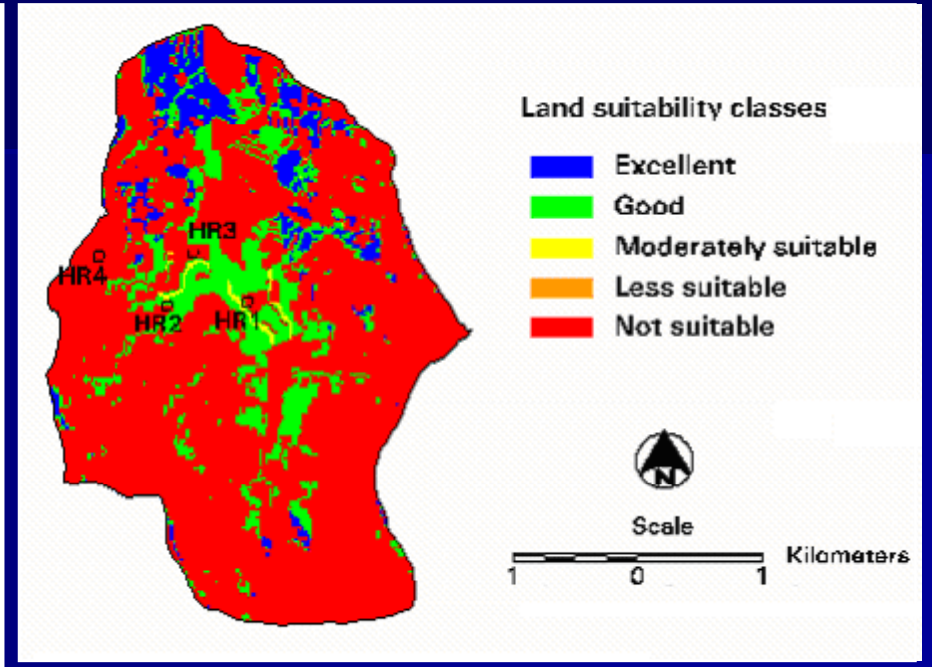
Best suitable cropping zones in Harsul watershed

Land Suitability for Crops in Harsul Watershed

Land suitability for paddy



Land suitability for finger millet



Land suitability for paddy

Suitability class	Range of LSI*	% Area
Not suitable	0 - 30	85
Less suitable	30 - 45	2
Moderately suitable	45 - 60	7
Good	60 - 80	6
Excellent	80 - 100	0

Land suitability for finger millet

Suitability class	Range of membership values	% Area
Not suitable	0 - 30	78
Less suitable	30 - 45	0
Moderately suitable	45 - 60	1
Good	60 - 80	15
Excellent	80 - 100	6

Knowledge Based Modeling–Concluding Remarks

- Many decision-making and problem-solving tasks are too easy to solve in the recent days using knowledge based system & Fuzzy Logic.
- Fuzzy logic provides an alternative way to represent linguistic and subjective attributes of the real world in computing
- It is able to be applied to control systems and other applications in order to improve the efficiency and simplicity of the design process
- Design objectives difficult to express mathematically can be incorporated in a fuzzy controller by linguistic rules.
- The knowledge-based model shows the irrigation requirement for the predicted rainfall- helps to choose / adopt appropriate crops & irrigation management plan

References

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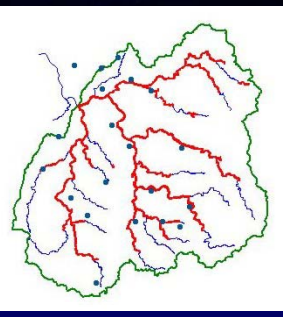
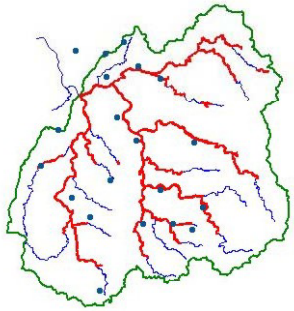


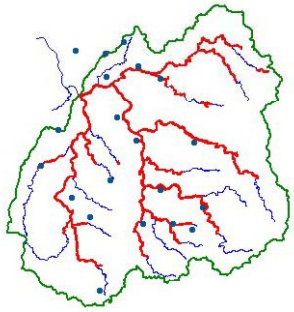
Tutorials - Question!.?.

- Critically study the applications of knowledge based systems for various water resources management problems. Study various case studies available in literature (details can be obtained from Internet).
- Study the role of knowledge based modeling in Integrated Water Resources Management.



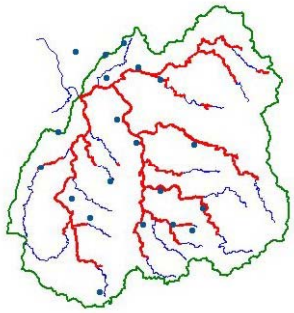
Self Evaluation - Questions!.

- Describe the features of typical knowledge based models.
- Illustrate the requirements of knowledge based systems.
- Describe typical knowledge based system for watershed management.
- Illustrate the fuzzy logic operators used in typical fuzzy logic.
- What are the important components of a fuzzy systems.



Assignment- Questions?.

- Describe the structure of a knowledge based system.
- What are the important features of Multi Criteria Decision Analysis (MCDA).
- Illustrate the features of fuzzy logic based systems.
- Describe applications, advantages & limitations of Fuzzy Logic?.
- Illustrate a typical Knowledge based model for watershed management.



Unsolved Problem!.

- Critically study a typical knowledge based model for the water and land management in a watershed.
- For your watershed area, study the scope of development of knowledge based model considering rainfall, various crops, land use, land suitability, water requirement etc.

THANK YOU

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