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Instituto de Ingeniería del  
Agua y Medio Ambiente

# *Simulation of operating rules and discretionary decisions using a fuzzy rule-based system integrated into a water resources management model*

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# CONTENT

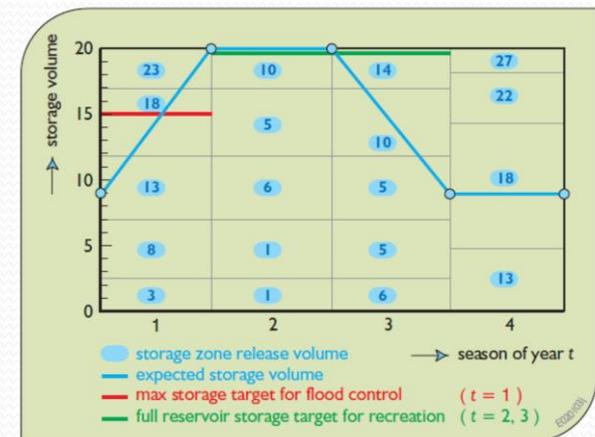
1. Introduction
2. Methods: Fuzzy management rules
3. Case study: Mijares River Basin (Jucar RBD)
4. Conclusions

Water resources systems are commonly operated with pre-defined **reservoir operating rules** based on:

- ❑ Historical water rights and priorities
- ❑ Relationship between available resources and conflicting demands
- ❑ Institutional agreements

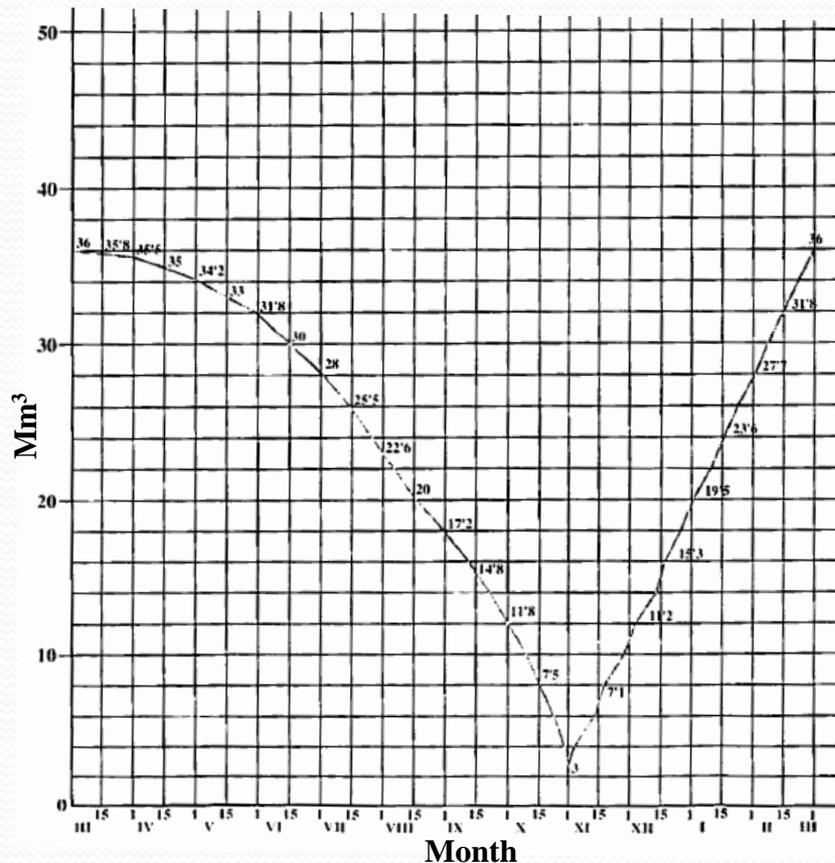
These operating rules are expressed as:

- ❑ Hedging rules
- ❑ Pack rules
- ❑ Zone-based rules
- ❑ etc.



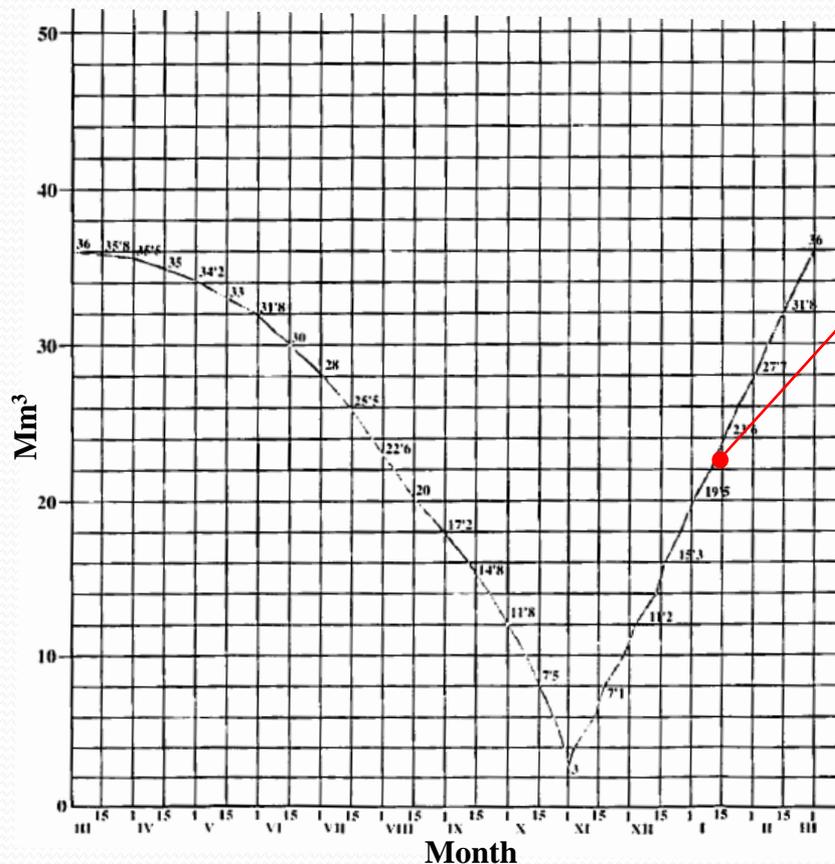
Source: Loucks and van Beek (2005)

**DISCRETIONAL DECISIONS** in historical management: release decisions taken to react to specific situations, deviating from the value expected from the reservoir operating rules



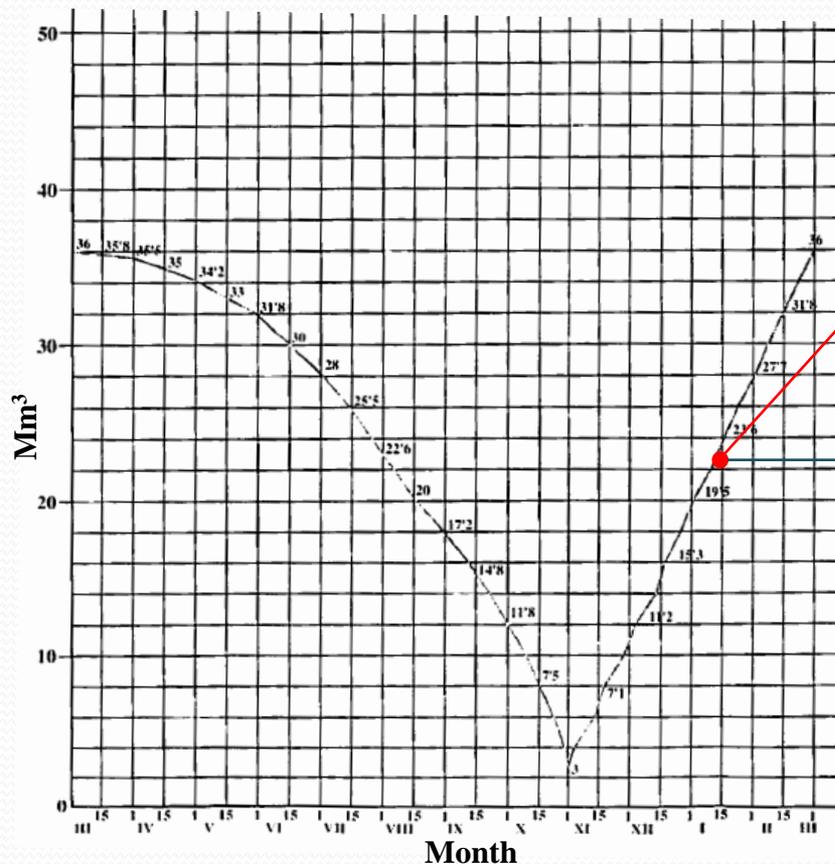
Source: SCRM (1973). Current Mijares operating rule

**DISCRETIONAL DECISIONS** in historical management: release decisions taken to react to specific situations, deviating from the value expected from the reservoir operating rules



- Storage just below the curve
- Good inflow expectation

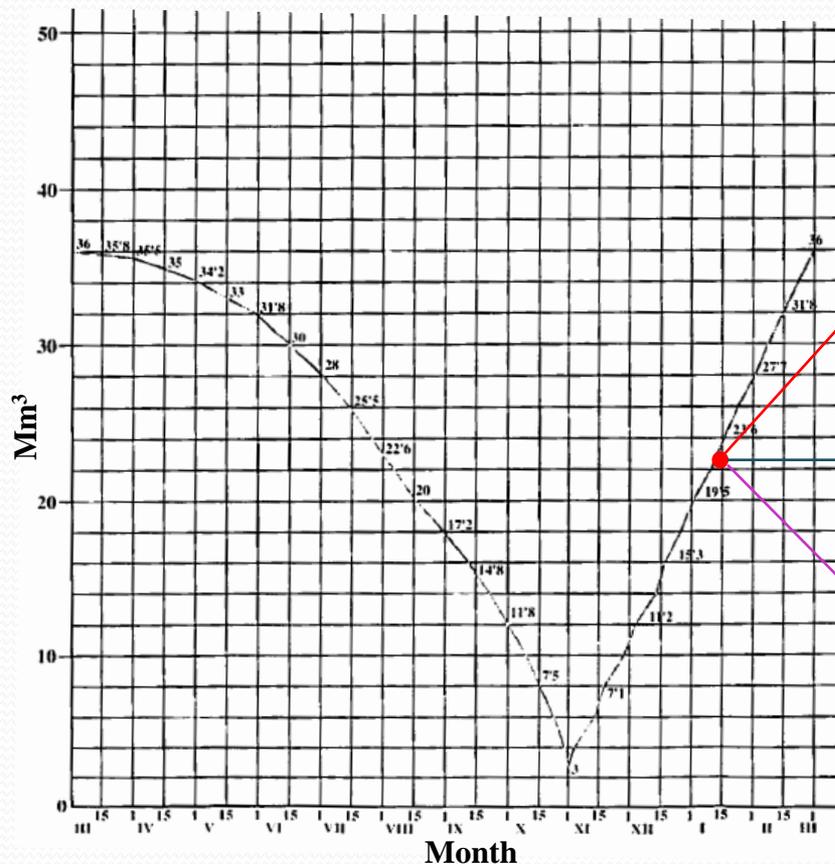
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**Operating rule:**  
no releases for supply

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- Storage just below the curve
- Good inflow expectation

**Operating rule:**  
no releases for supply

**Discretionary decision:**  
partial deliveries

**PROBLEM:** how to incorporate discretionary decisions in the simulation of future water management?

- ❑ Decisions made *ad hoc*
- ❑ Based on expert criteria / negotiation process

**GOAL:** to develop a model able to combine general operating rules and discretionary decisions under a single framework

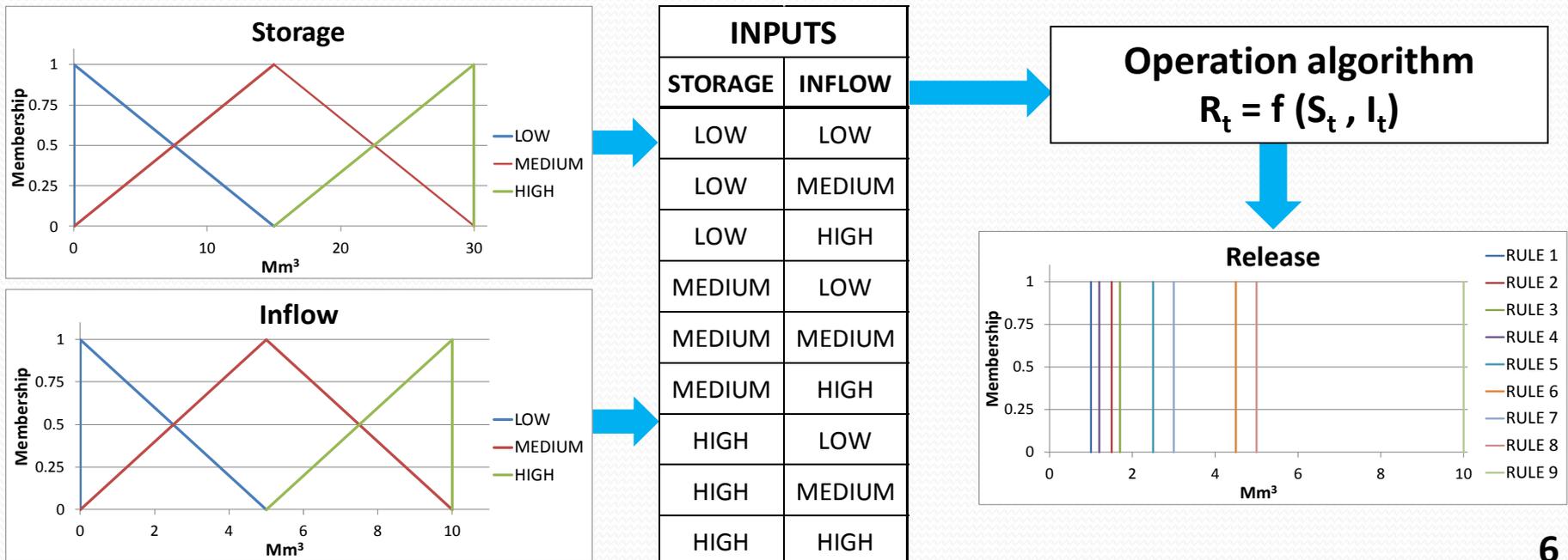
**APPROACH:** water resources system simulation model based on fuzzy rule-based (FRB) systems

# FUZZY MANAGEMENT RULES

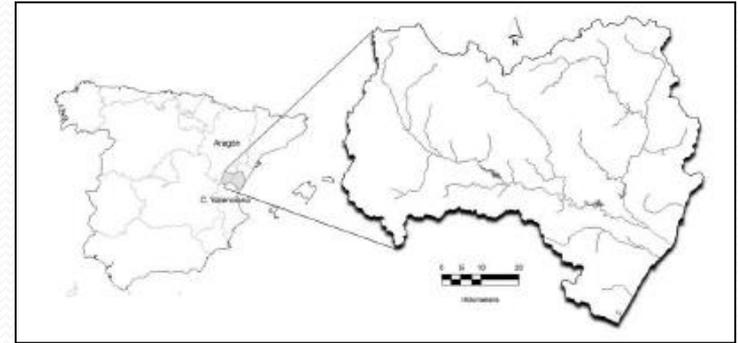
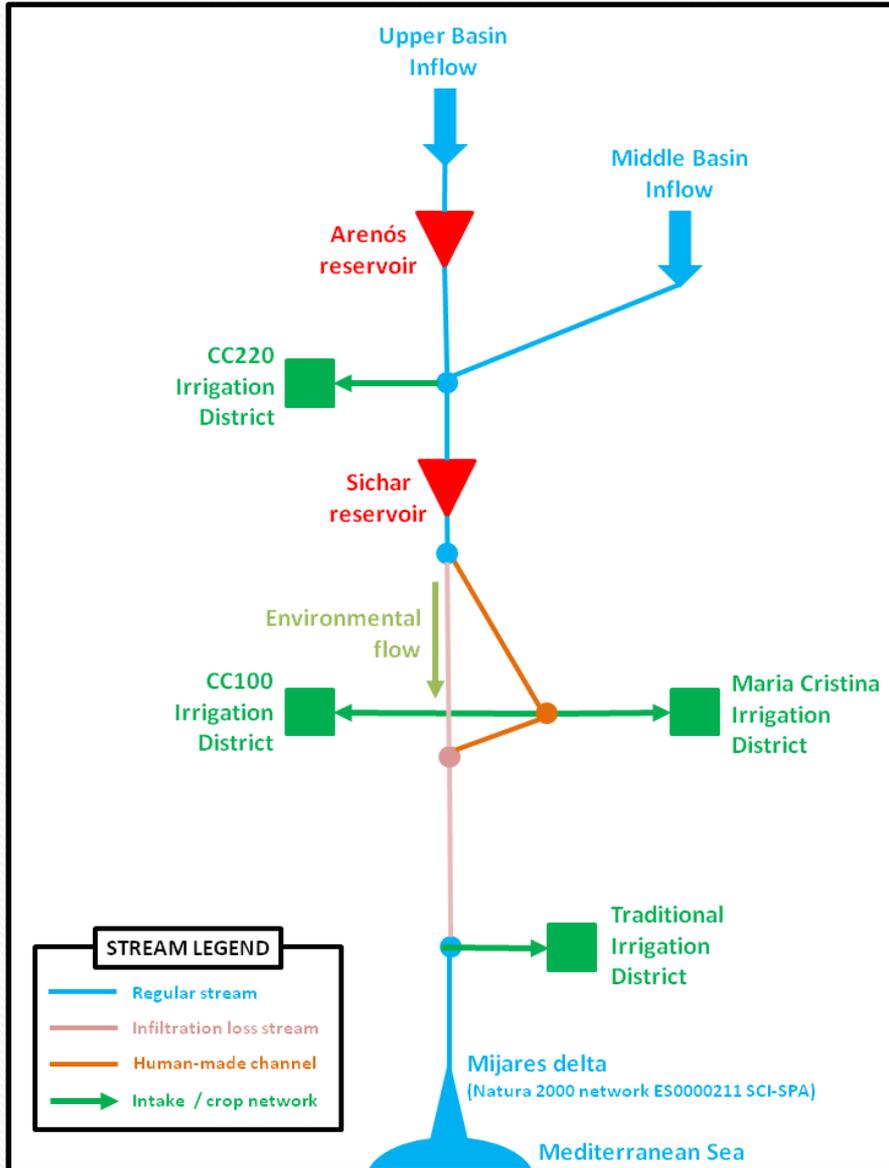
## Purpose

Basis: mathematical representation of system's operating rules to obtain a fuzzy rule-based system (FRB) reproducing its performance (e.g. Russell and Campbell, 1996; Panigrahi and Mujumdar, 2000)

Example of fuzzy rule-based system imitating pre-defined rules:



# CASE STUDY: MIJARES RIVER General view



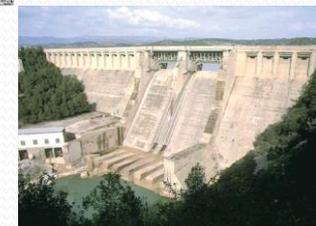
NAME	CAPACITY	START	MAIN USE	DEMAND
Arenós	93.00	1959	Agricultural	120.18
Sichar	49.00	1980	Agricultural	
<b>MEAN ANUAL INFLOW (1980-2009)</b>				<b>196.00</b>

Units in Mm<sup>3</sup>



**Arenós**

Source: CEDEX

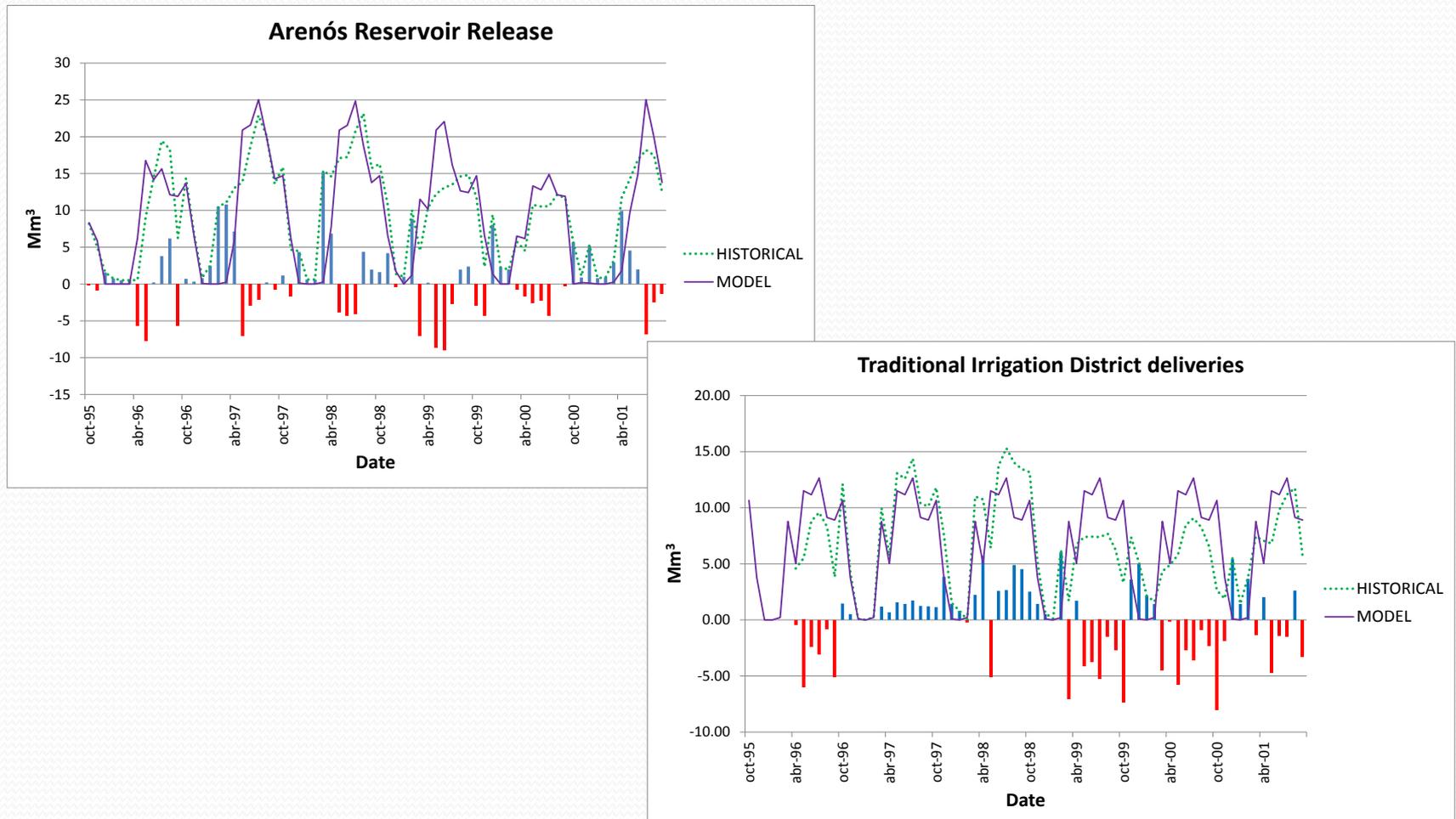


**Sichar**

# CASE STUDY: MIJARES RIVER

## Features

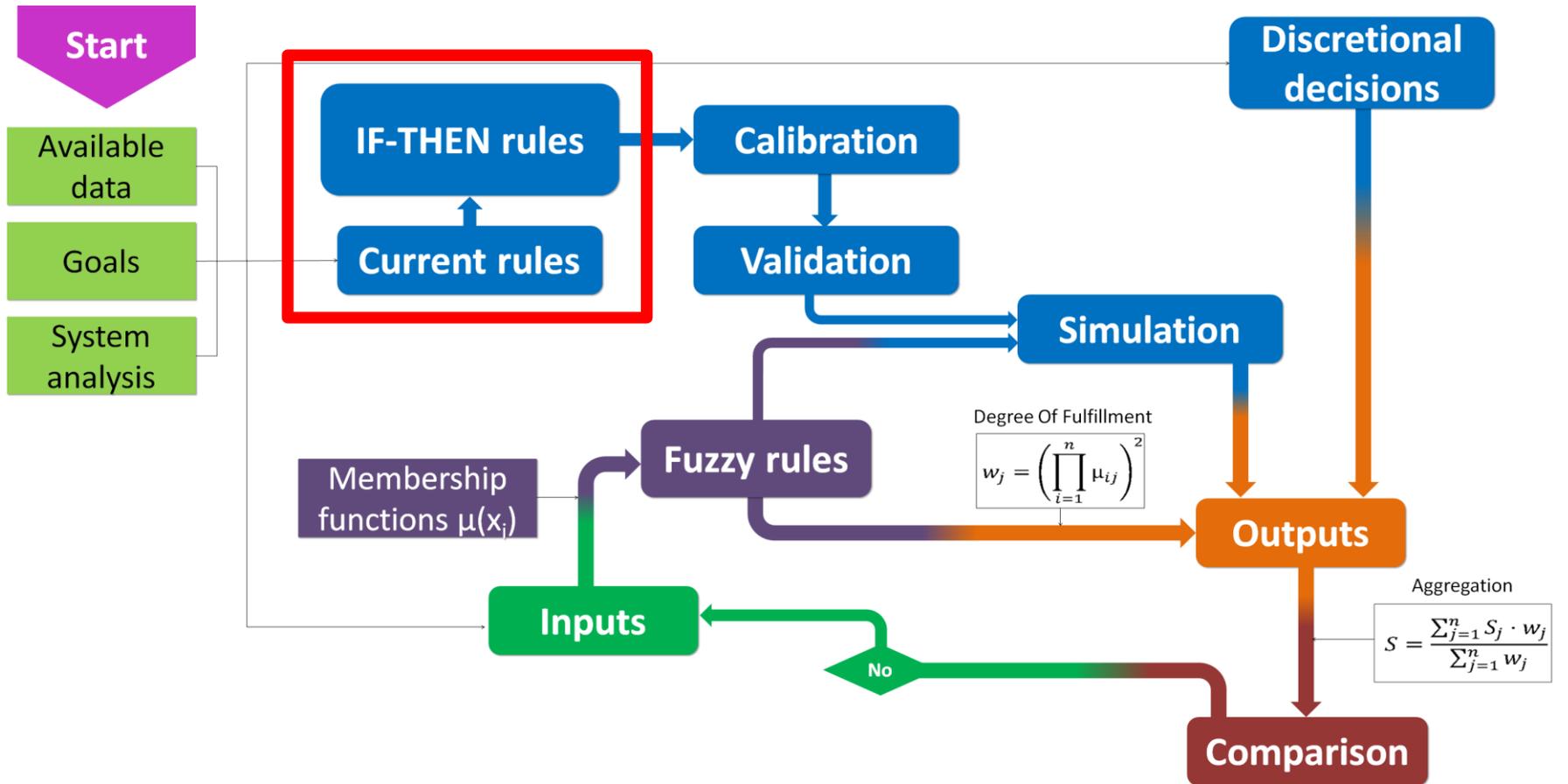
**PROBLEM:** historical releases do not always follow the existing operating rules (discretionary decisions)



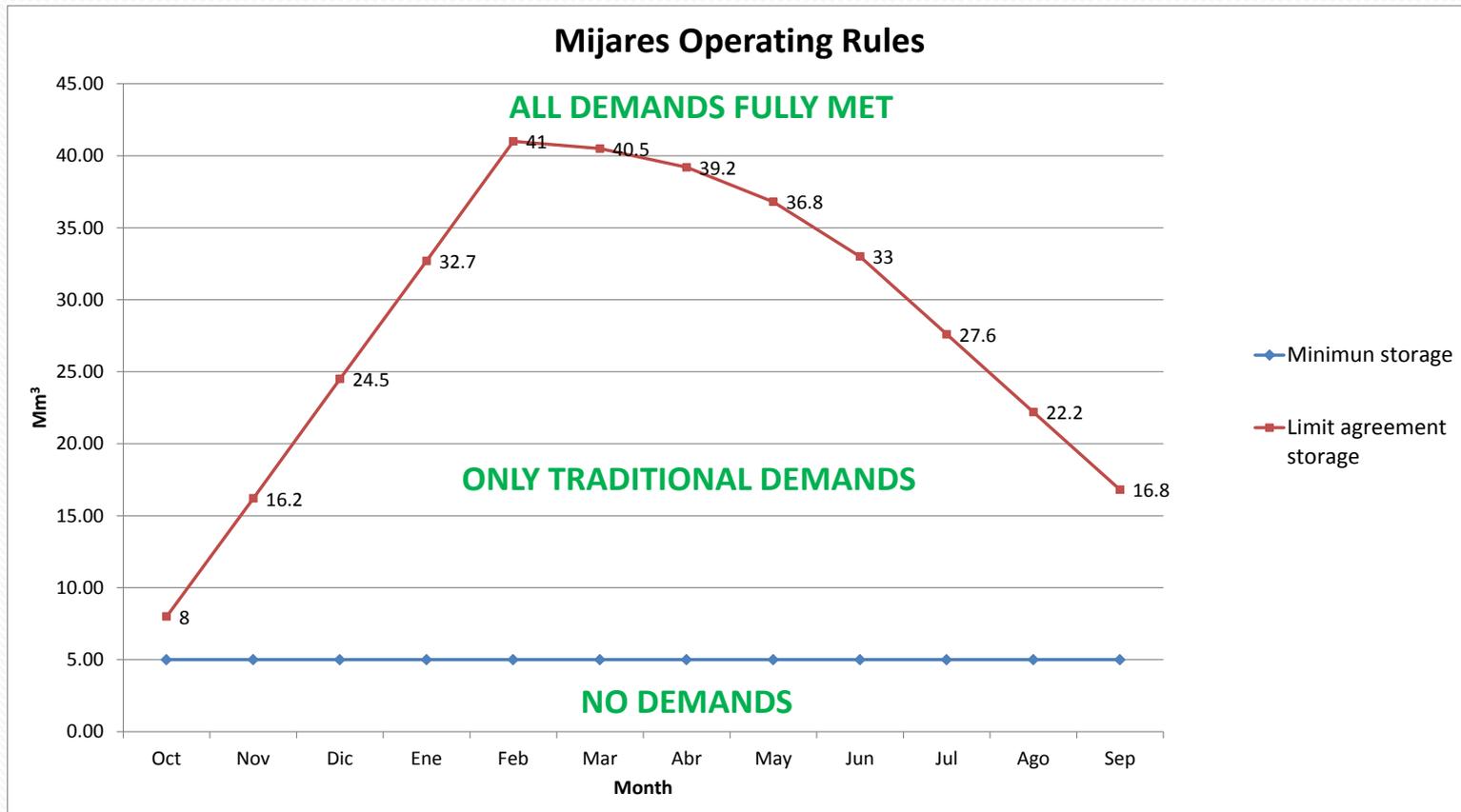


# CASE STUDY: MIJARES RIVER

## Current Policies



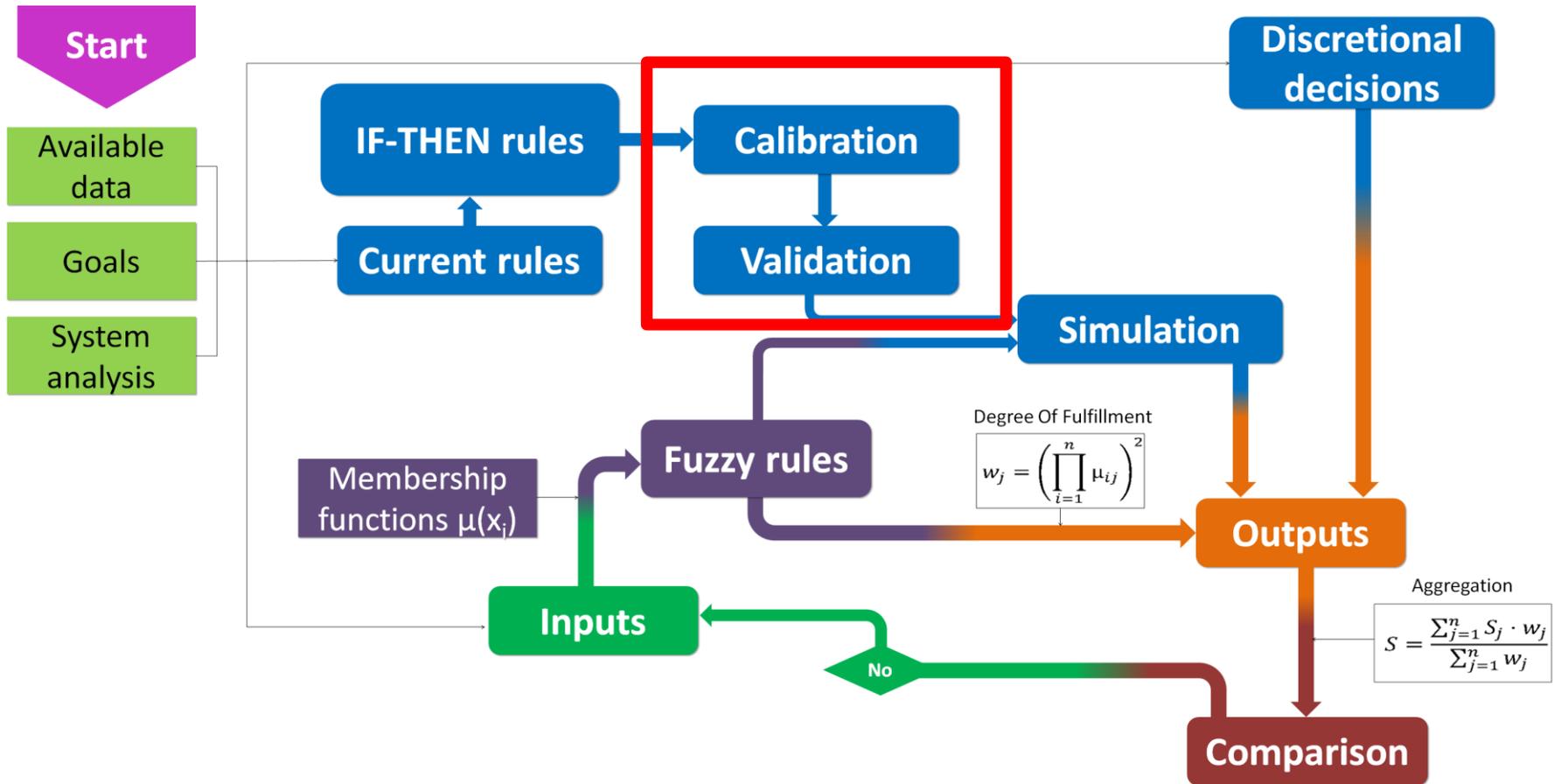
### Current operating rules: Zone-based rules



### Mathematical algorithm: IF-THEN sentences

# CASE STUDY: MIJARES RIVER

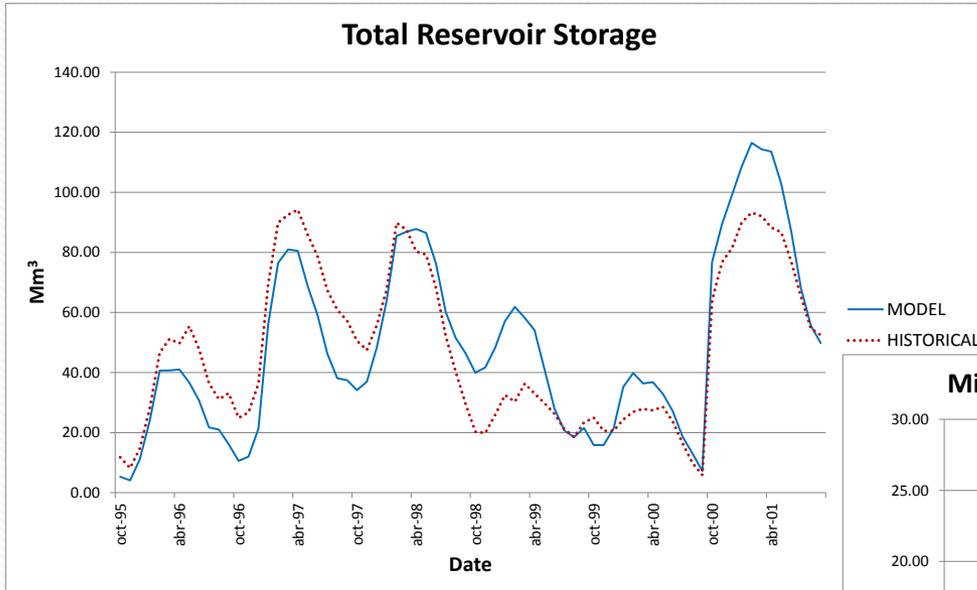
## Current Policies



# CASE STUDY: MIJARES RIVER

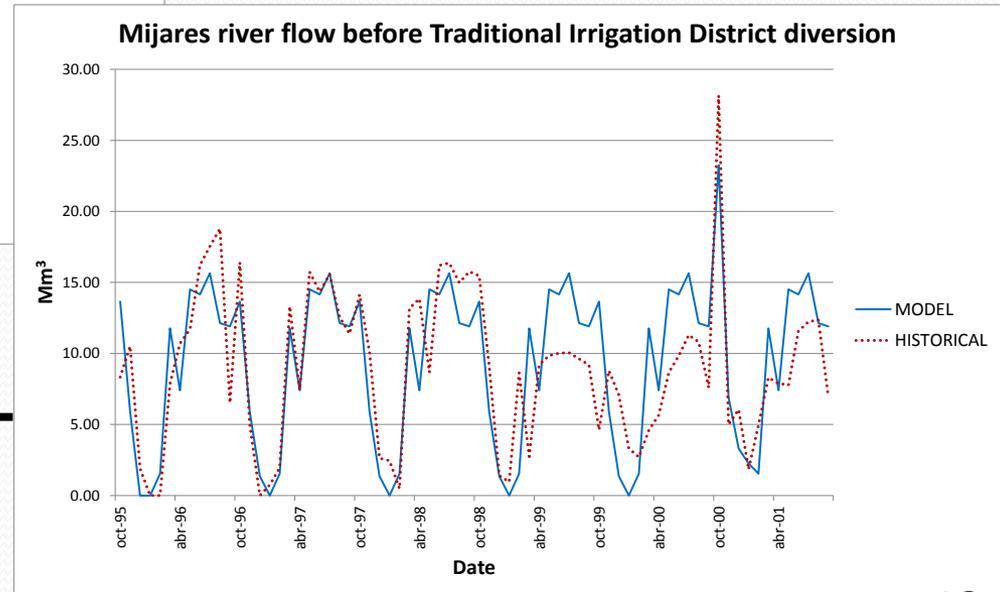
## Current Policies

Calibration and validation of algorithm using available historical monthly data



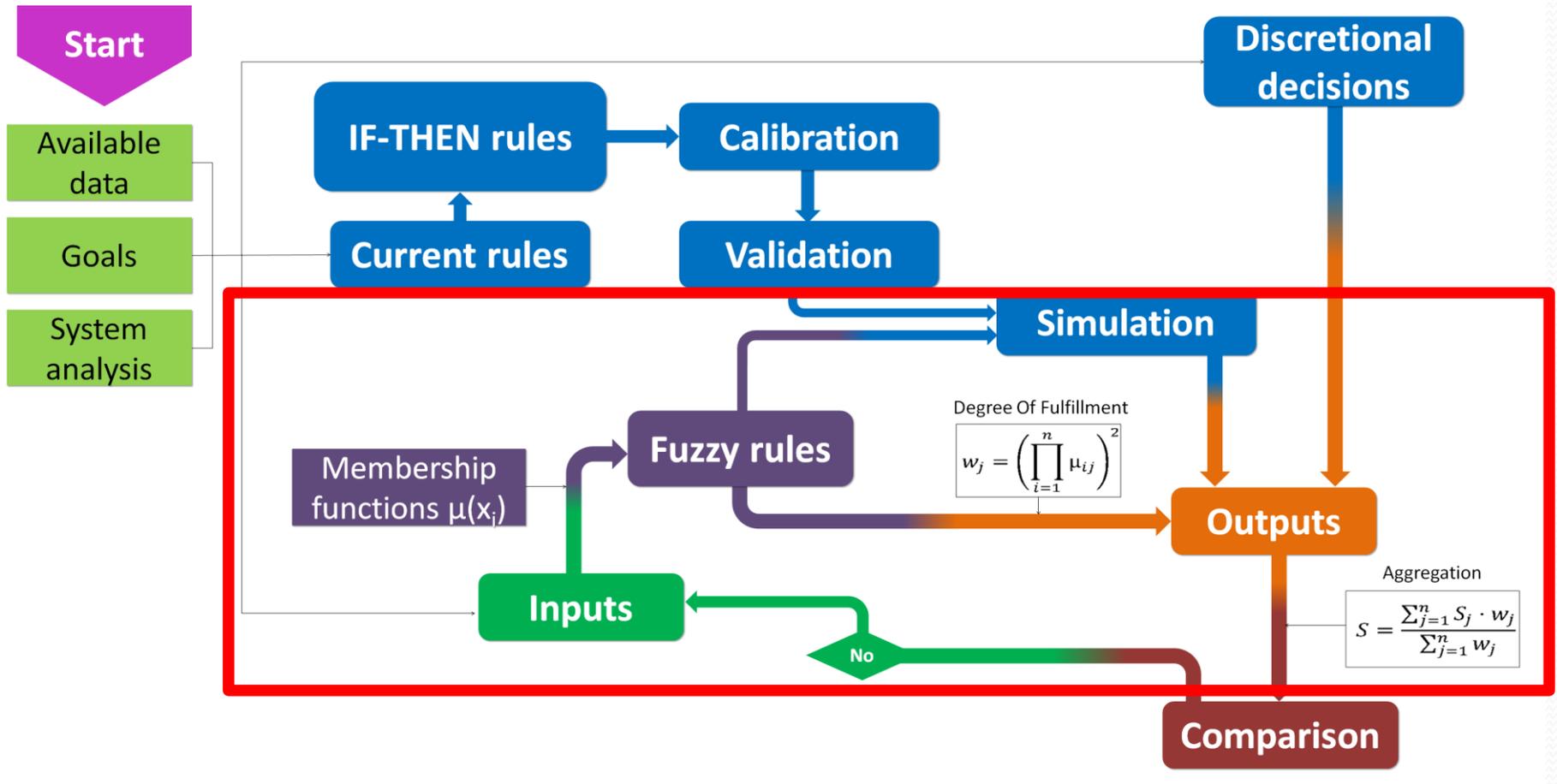
Correlation (R)	0.88
RMSE (Mm <sup>3</sup> )*	13.79
Nash-Sutcliffe	0.72

Correlation (R)	0.78
RMSE (Mm <sup>3</sup> )*	3.69
Nash-Sutcliffe	0.54



\* RMSE: Root Mean Squared Error

# CASE STUDY: MIJARES RIVER Fuzzy rules



# CASE STUDY: MIJARES RIVER Fuzzy rules

**FRB** features:

- ❑ **Inputs** (month and total reservoir storage) using triangular membership functions
- ❑ **Fuzzy rules** for all possible input combinations
- ❑ **Simulated Outputs** (deliveries) for each fuzzy rule
- ❑ **Modified Outputs** (discretionary decisions) based on historical decisions

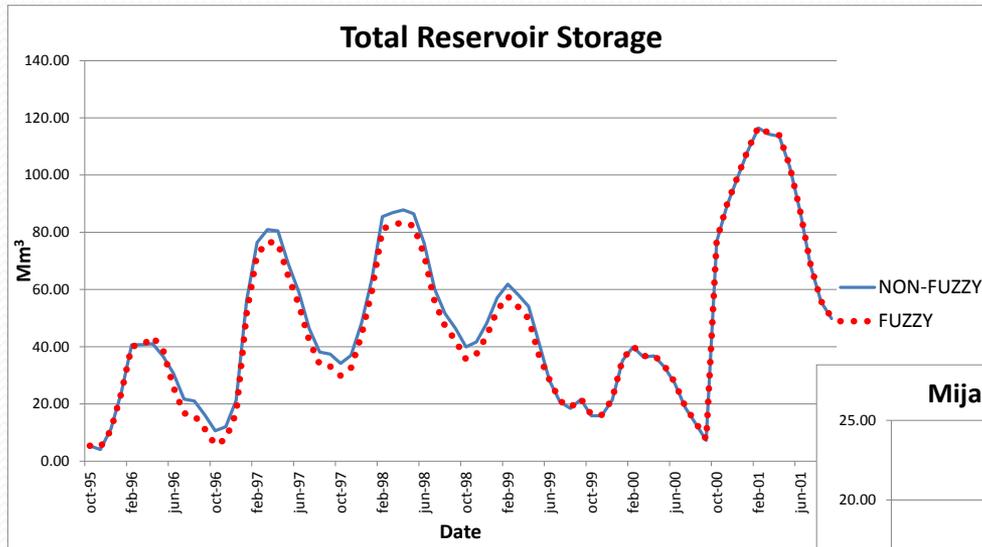
This FRB allows partial deliveries when storage close to the operating rule curves



# CASE STUDY: MIJARES RIVER

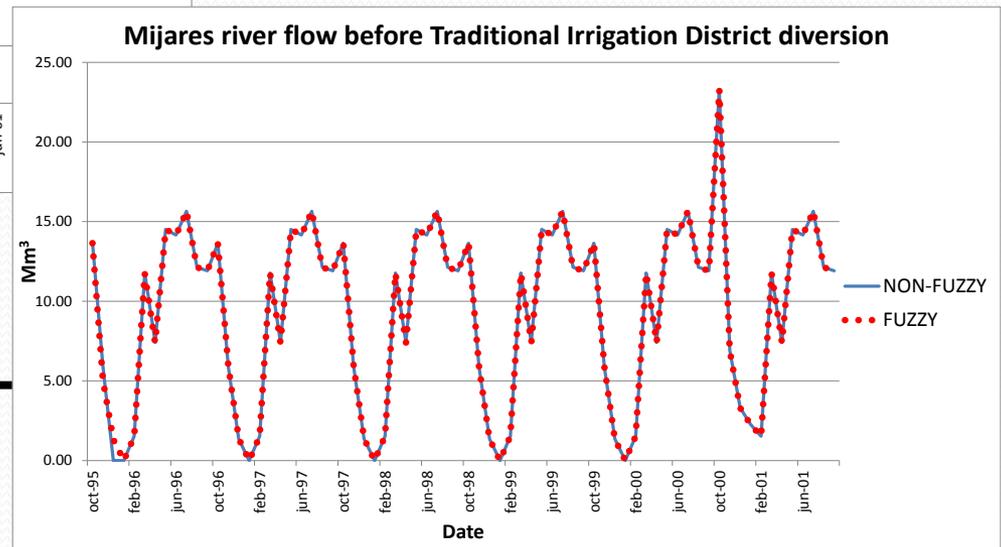
Classic Vs.  
Fuzzy

Comparison with the previously obtained operation rules algorithm (Storages & Flows)



Correlation (R)	1.00
RMSE (Mm <sup>3</sup> )*	3.14
Nash-Sutcliffe	0.99

Correlation (R)	1.00
RMSE (Mm <sup>3</sup> )*	0.18
Nash-Sutcliffe	1.00

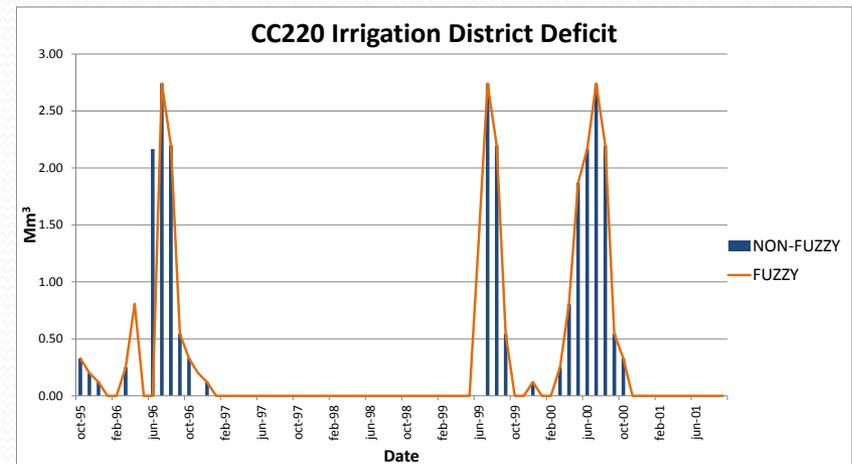
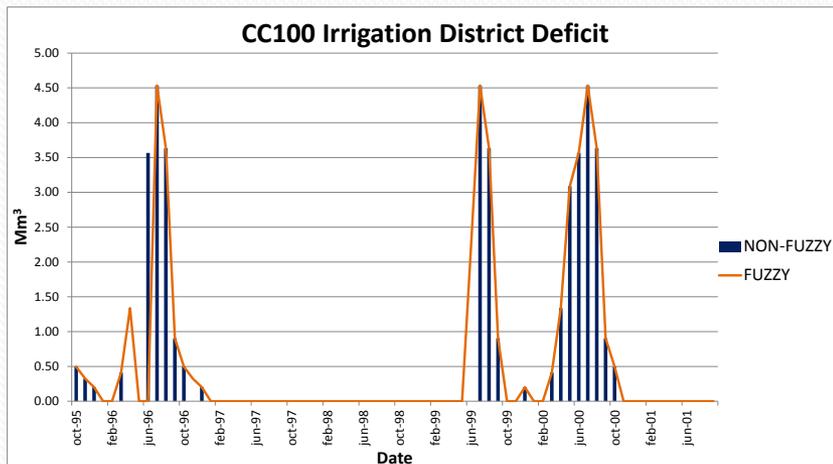
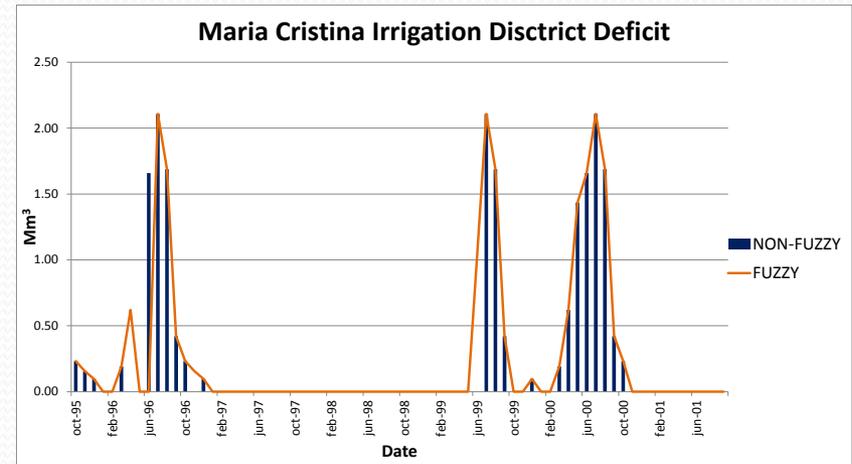
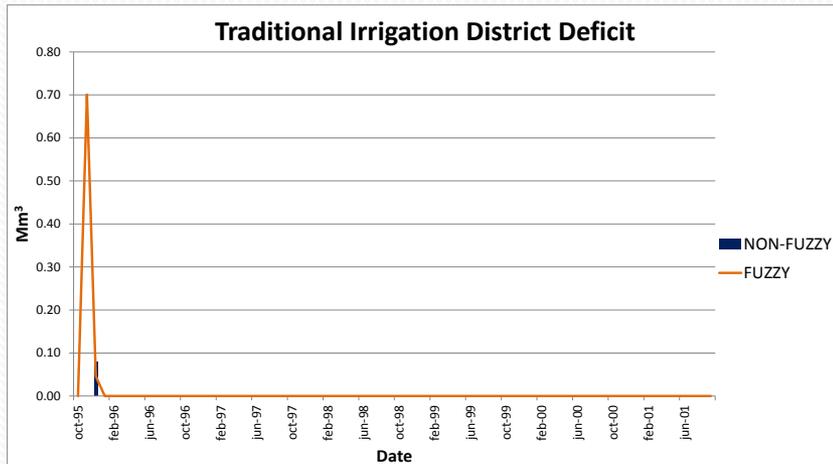


\* RMSE: Root Mean Squared Error

# CASE STUDY: MIJARES RIVER

## Classic Vs. Fuzzy

Comparison with the previously obtained operation rules algorithm (Demand deficits)

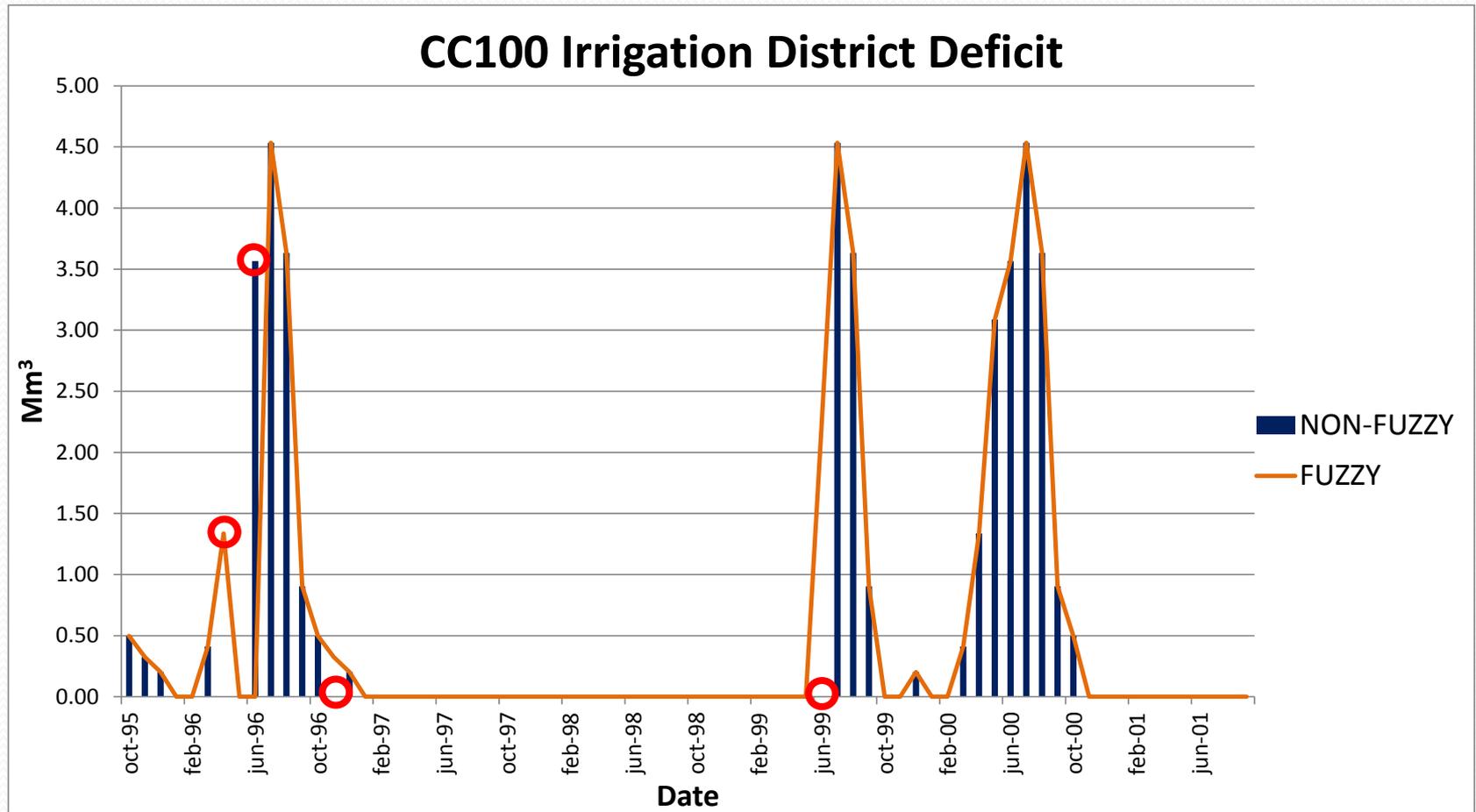


# CASE STUDY: MIJARES RIVER

Classic Vs.  
Fuzzy

Effect of discretionary decisions when specific situations occur

○ Time stage with discretionary decision

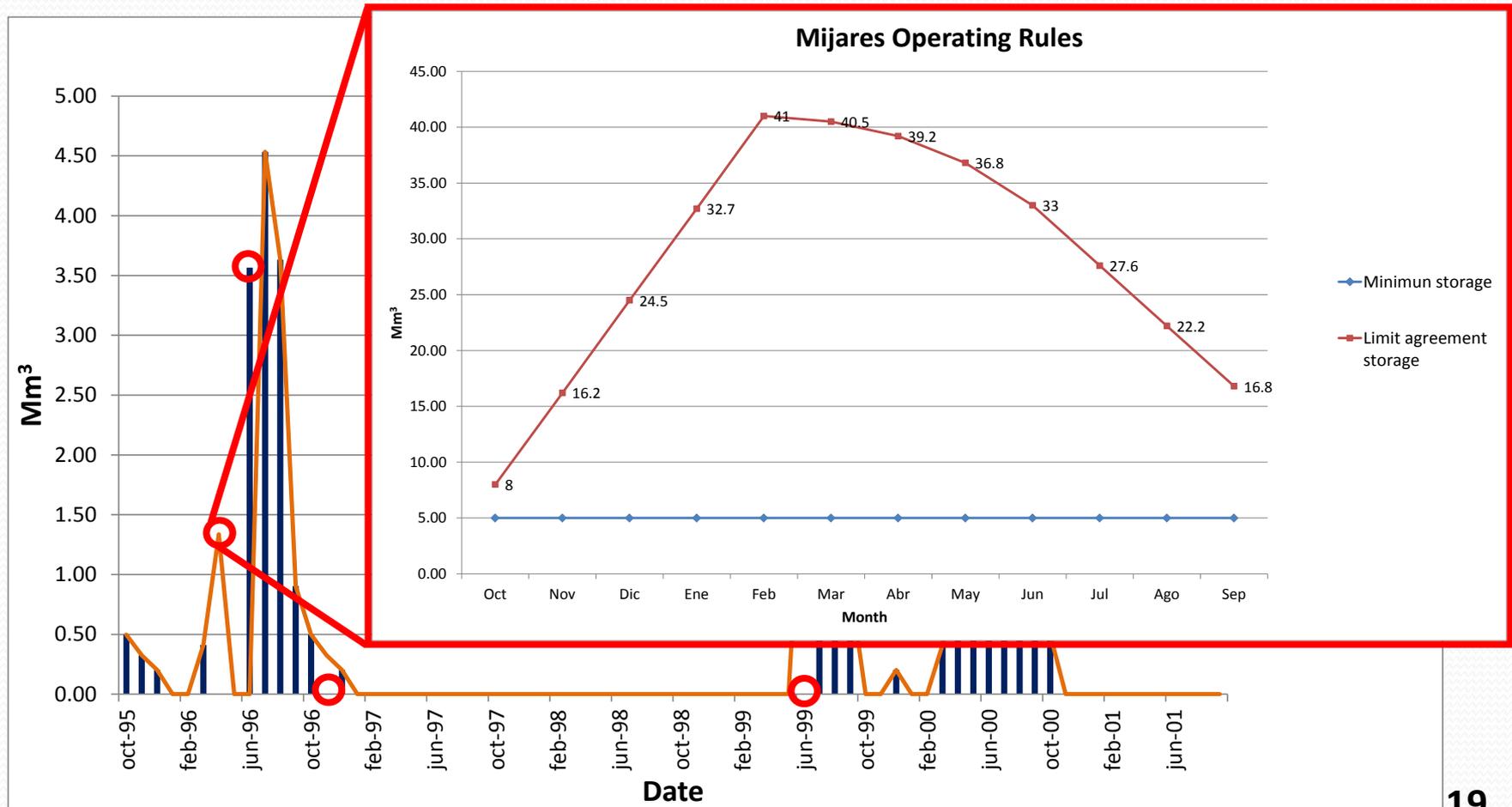


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Effect of discretionary decisions when specific situations occur

○ Time stage with discretionary decision

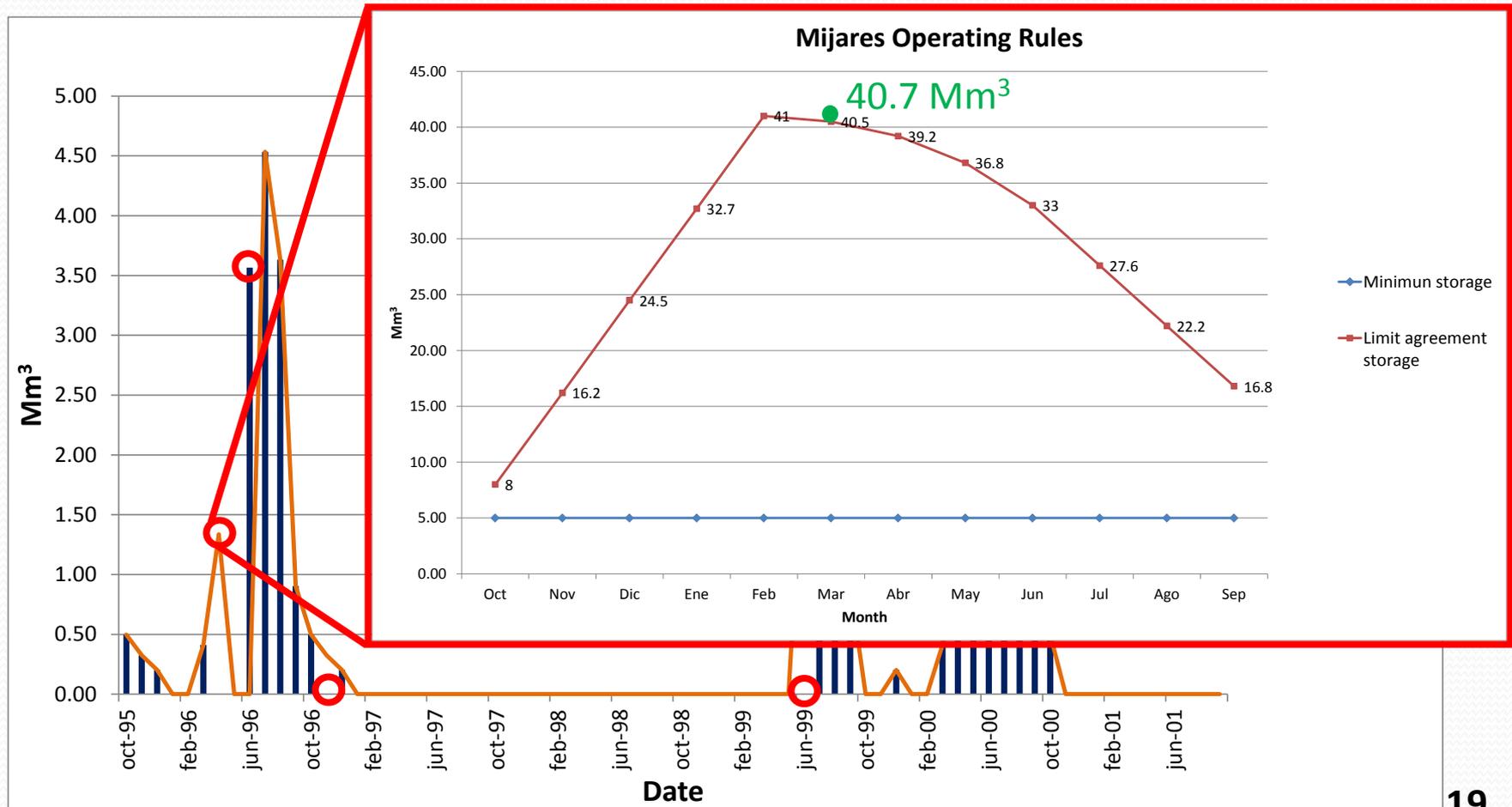


# CASE STUDY: MIJARES RIVER

Classic Vs.  
Fuzzy

Effect of discretional decisions when specific situations occur

○ Time stage with discretional decision



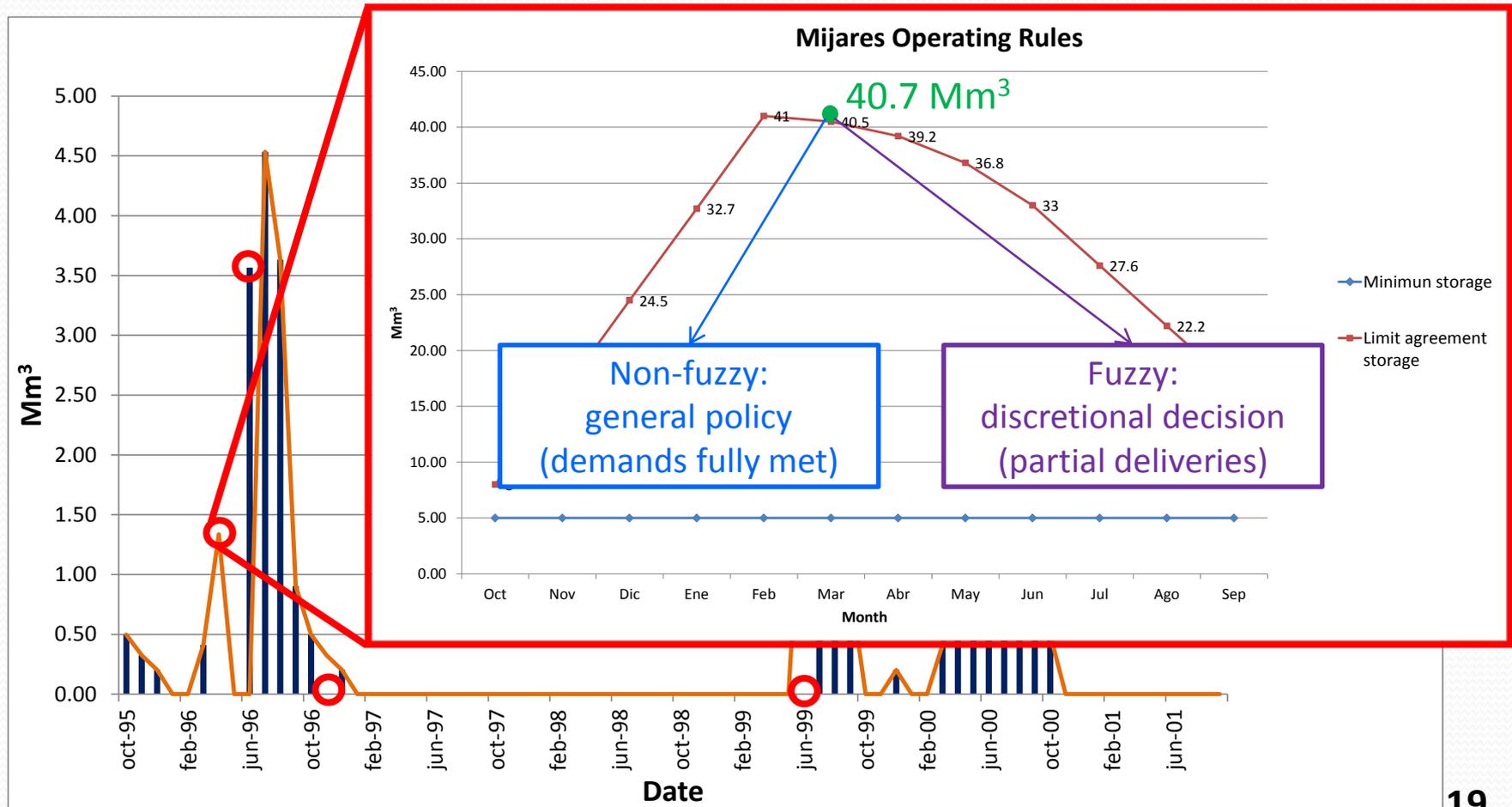


# CASE STUDY: MIJARES RIVER

Classic Vs.  
Fuzzy

Effect of discretionary decisions when specific situations occur

○ Time stage with discretionary decision



# CONCLUSIONS

- ❑ FRB systems **can be integrated in generalized DSS** in order to reproduce the actual operation of systems
- ❑ FRB systems **can reproduce discretionary decisions** within a **unique framework**
- ❑ Although FRB systems cannot reproduce each single historical discretionary decision, they allow to implement discretionary decisions to be applied under different special situations
- ❑ FRB systems are able to simulate the dynamics of the actual system operation, in which decisions are not “all or nothing”, what is important for the simulation of future scenarios



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**THANK YOU  
FOR YOUR ATTENTION**

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