Decision Support Systems for Water Management

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INTRODUCTION TO THE COURSE

Course objectives

- Overall objective:
  - to provide basic (and advanced) knowledge about the application of decision support systems for water management in Mediterranean environments.
- Specific objective:
  - To explain the structure, approach and purpose of decision support systems (DSS) in general and for water management and agricultural applications in particular;
  - To give a grounding about Geographical Information System (GIS), its structure, database development, format and management, and GIS/DSS applications and links in agriculture and water management
  - To expose about the use of new technologies (e.g. remote sensing – satellite and ground-based platforms) and modelling tools and their integration with DSS/GIS applications in agriculture and water management
  - To present and discuss the examples of DSS/GIS/modern technologies integration and applications in agriculture and water management and especially for risk assessment and alert/emergency management;
  - To start-up a dialogue and process of development of a DSS for early warning drought risk and irrigation management in Lebanon.

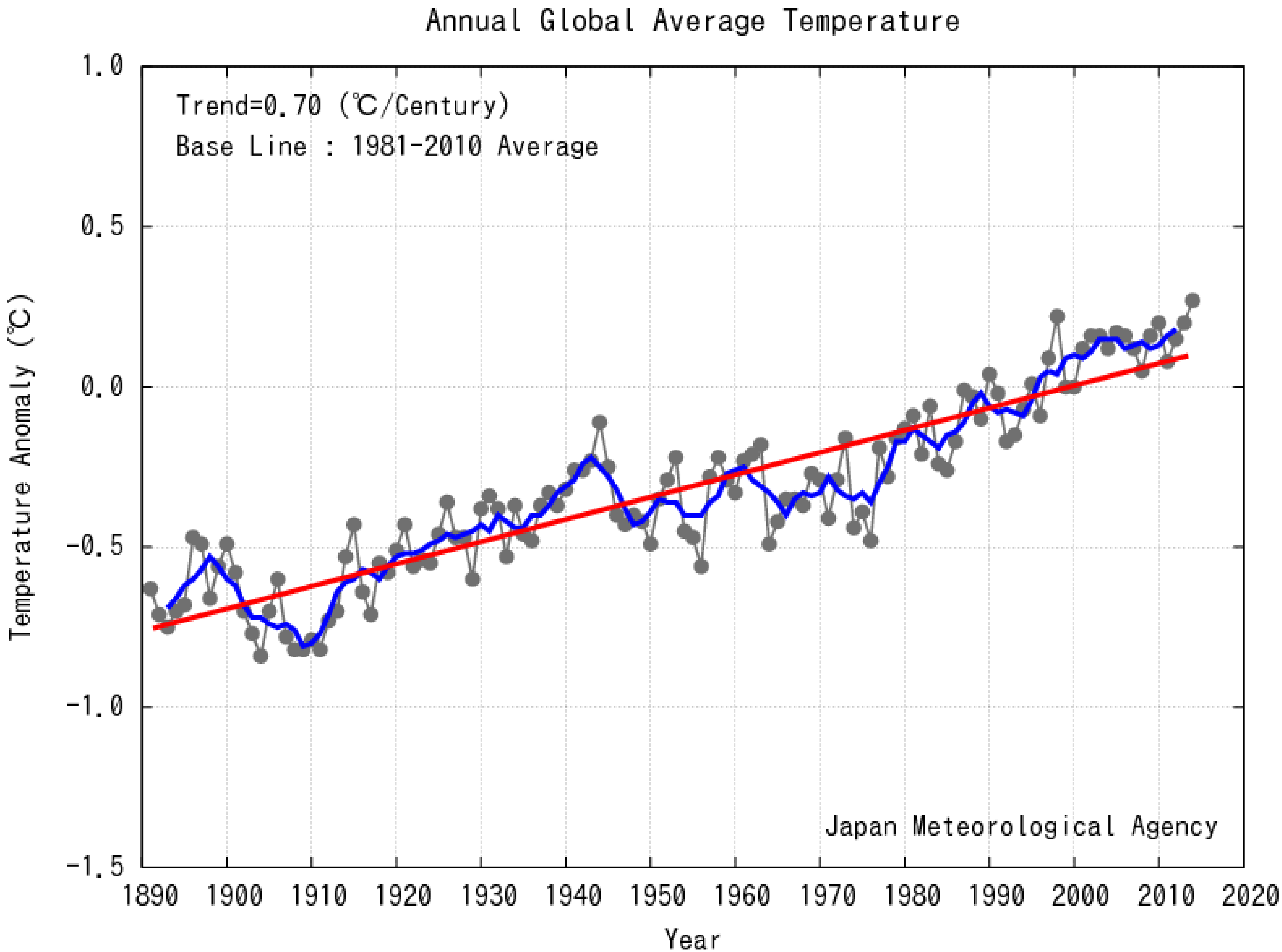
The contents of the course 1

- DSS definition, approach, scales of application, components (data and database management, models, software tools, query tool, etc.), optimization criteria, single/multi objective criteria definition, model attributes, objective functions, constraints, quantitative and qualitative risk assessment.
- GIS definition, components, benefits, limitations, sources of information, data models (vector, raster), applications in agriculture and precision farming, GPS/GIS integration, database development, operational functionalities, spatial queries, data classification, hydrological balance in GIS, GIS/DSS integration, decision making process, examples of application.
- Remote sensing applications with DSS/GIS interface, definition, platforms, principles, sensors, data acquisition and resolution (spatial, radiometric, spectral, temporal), satellite platforms, ground-based platforms, applications in agriculture and water management, commonly used vegetation indices (Normalized Difference Vegetation Index, Soil Adjusted Vegetation Index, Simple Ratio Vegetation Index, Water deficit Index, Enhanced Vegetation Index, Crop Water Stress Index, Vegetation Index Temperature Trapezoid, etc.), tools integration within a DSS.

The contents of the course 2

- Methodological approach for the development of a stakeholders driven DSS in agricultural water management. Socio-economic, soil, climatic, bio-physical, environmental and political issues, objective functions and concepts, from water use efficiency to water productivity and eco-efficiency, examples of application.
- DSS applications in agriculture, water management and risk assessment and alert management: Decision Support System for Agro-technology Transfer – DSSAT, Automated smart-based Decision Support System for sustainable water management in agriculture – BLULEAF, IRRISAT DSS for satellite-based irrigation management.(in Italy and Australia), CropIrri – irrigation DSS for optimal allocation of water resources (in China), etc.
- Interactive session on the development of a DSS for early warning drought risk and irrigation management in Lebanon. System components, data requirements and source, user type and interface, data flow and elaboration, awareness levels and thresholds, communication tools and procedures, etc.

CLIMATE CHANGE AND CLIMASOUTH PROJECT



Anomalies are deviation from baseline (1981-2010 Average).

The black thin line indicates surface temperature anomaly of each year.

The blue line indicates their 5-year running mean.

The red line indicates the long-term linear trend.

Source: Japanese Meteorological Agency (JMA), 2015

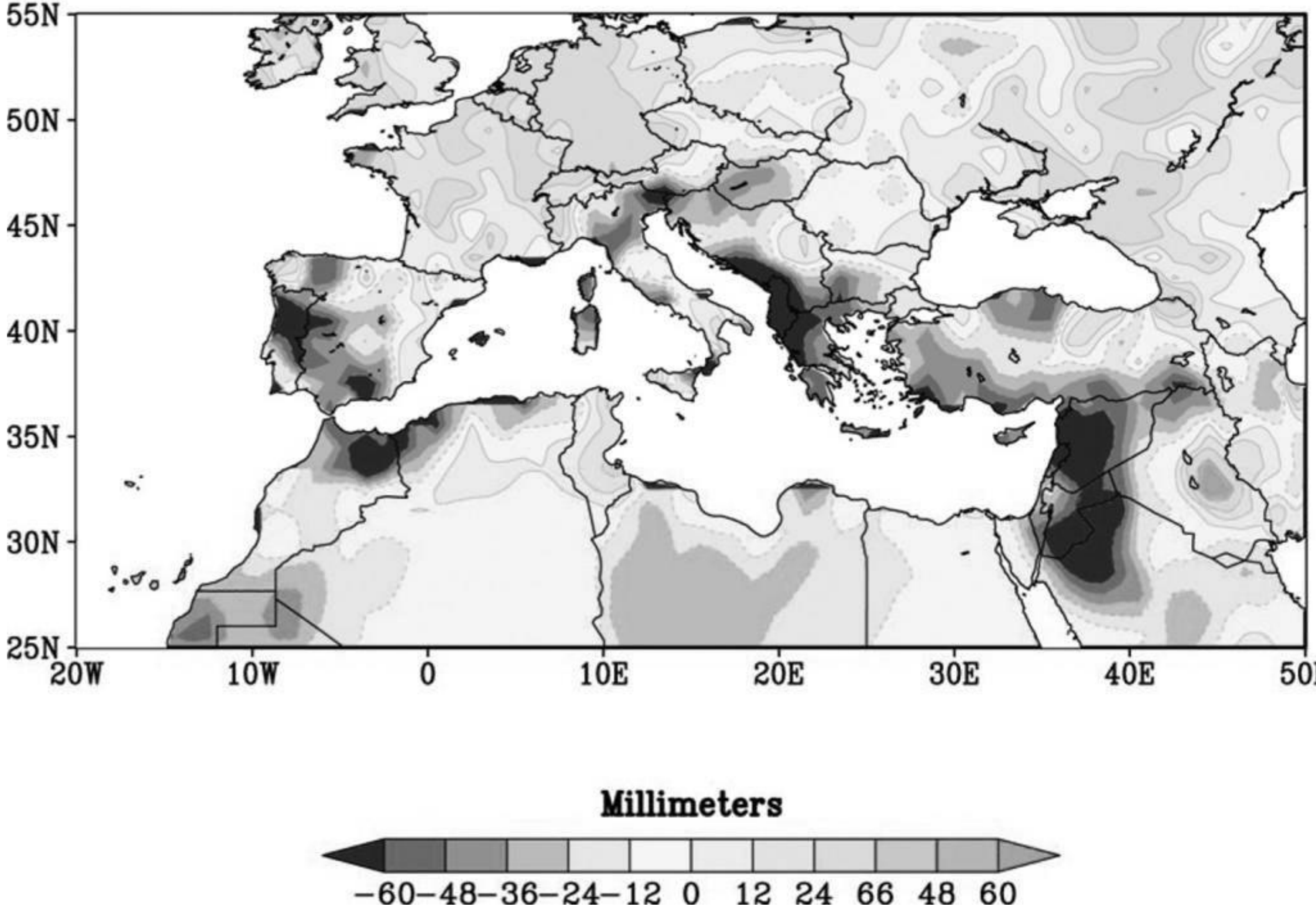


Figure 1. Greyscales highlight lands around the Mediterranean that experienced significantly drier winters during 1971–2010 than the comparison period of 1902–2010
Source: NOAA (2011).

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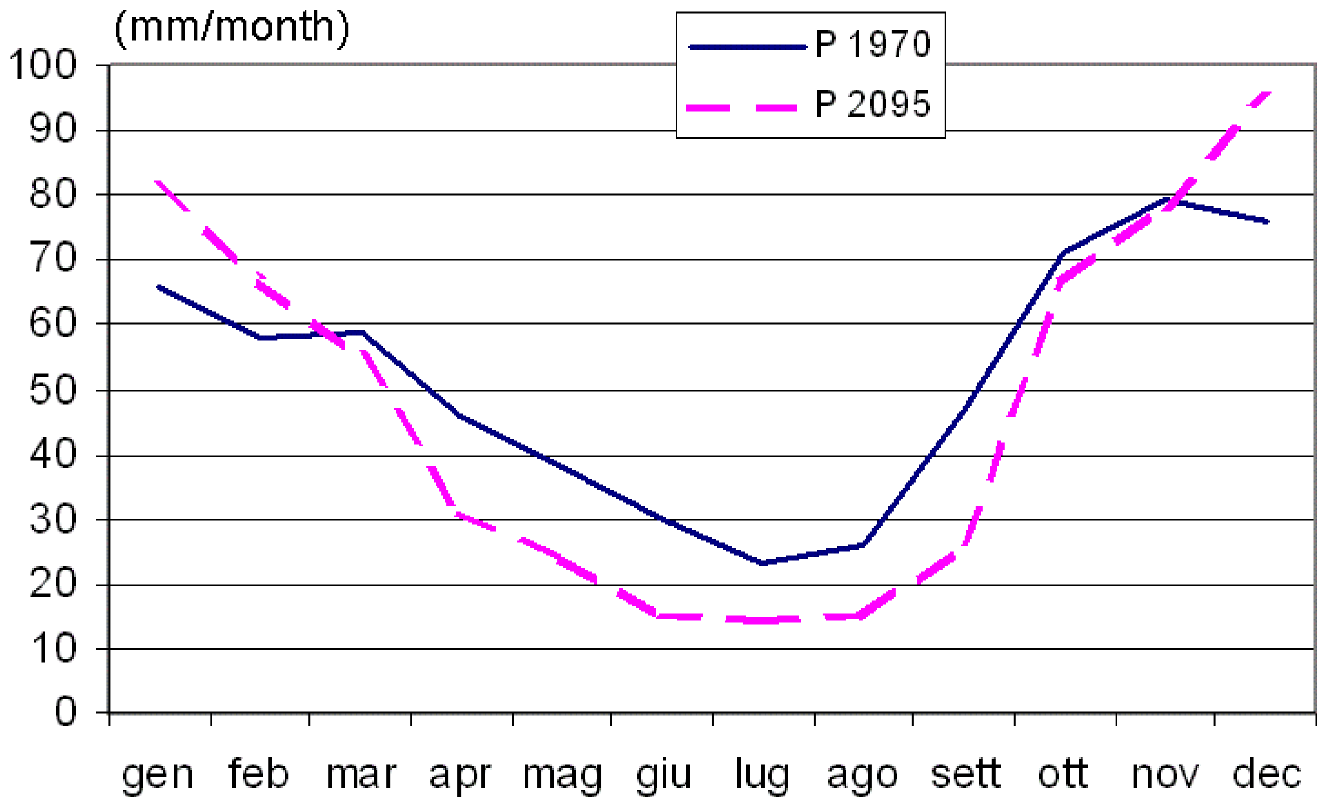
FACTS

FACTS

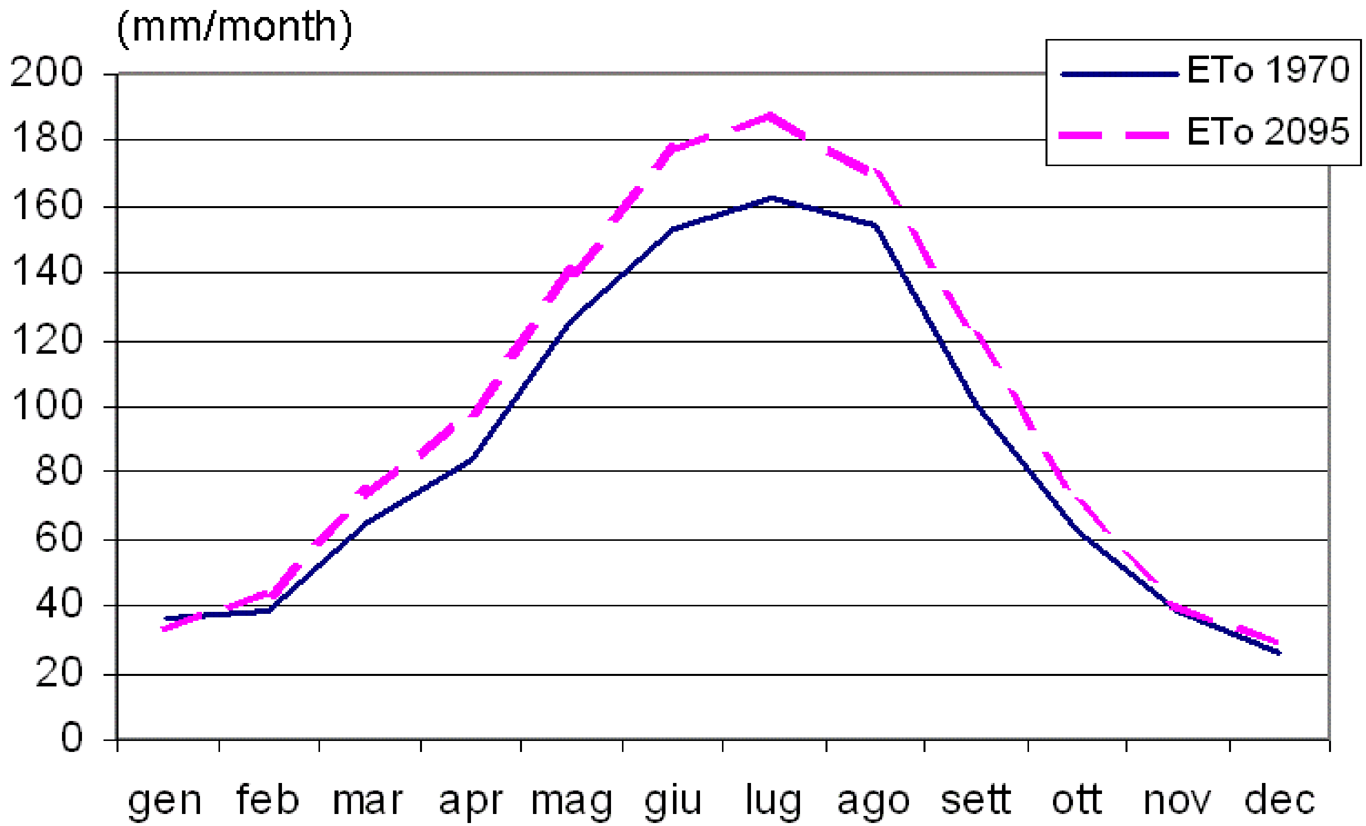
Todorovic and Steduto, 2002

Apulia Region (Southern Italy) - Average monthly precipitation measured in the period 1950-1990 and projected (HadCM3 - A2) for the period 2090-2100



Todorovic, 2007

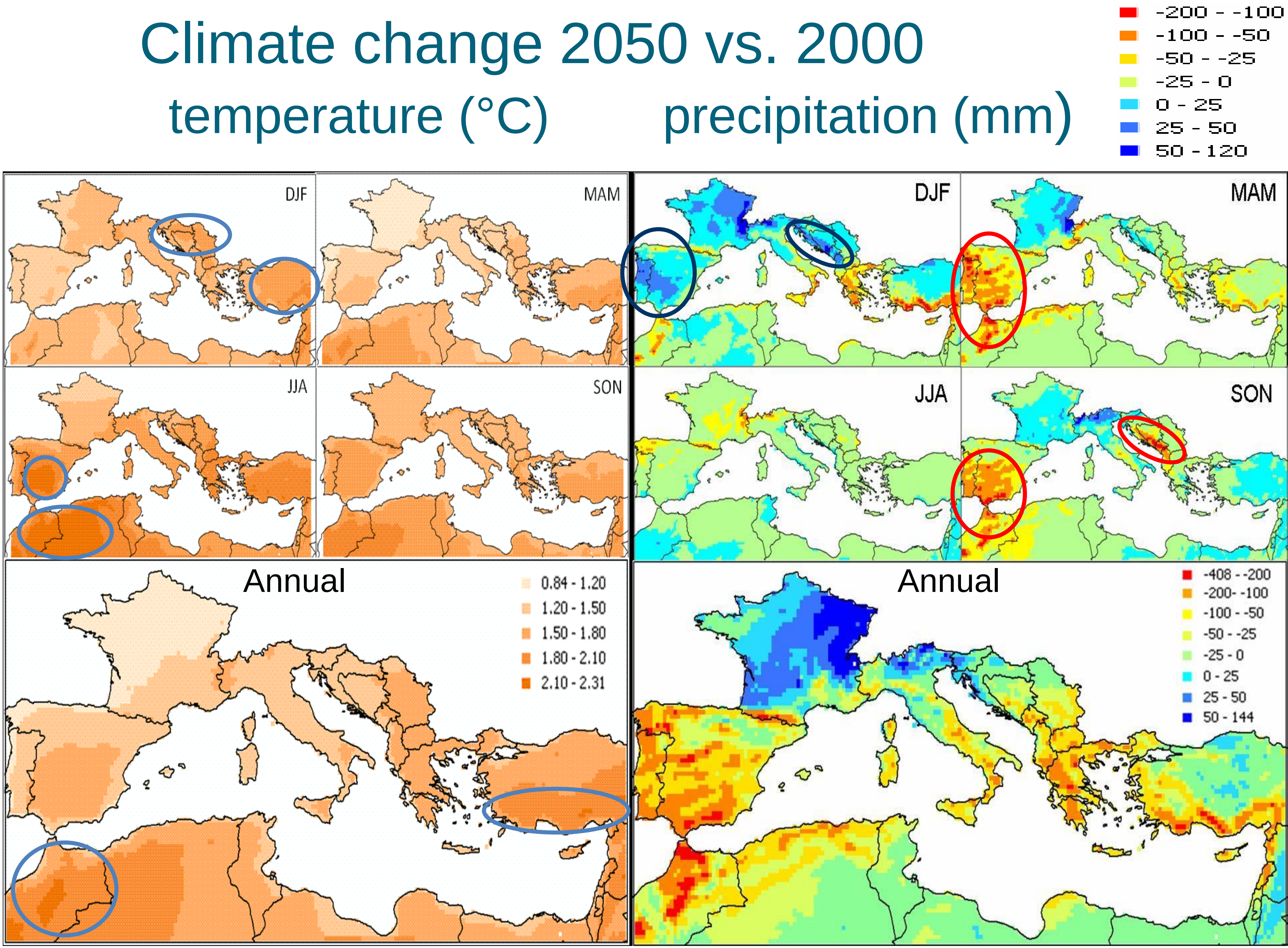
Apulia Region (Southern Italy) - Average monthly ETo measured in the period 1950-1990 and projected (HadCM3 - A2) for the period 2090-2100



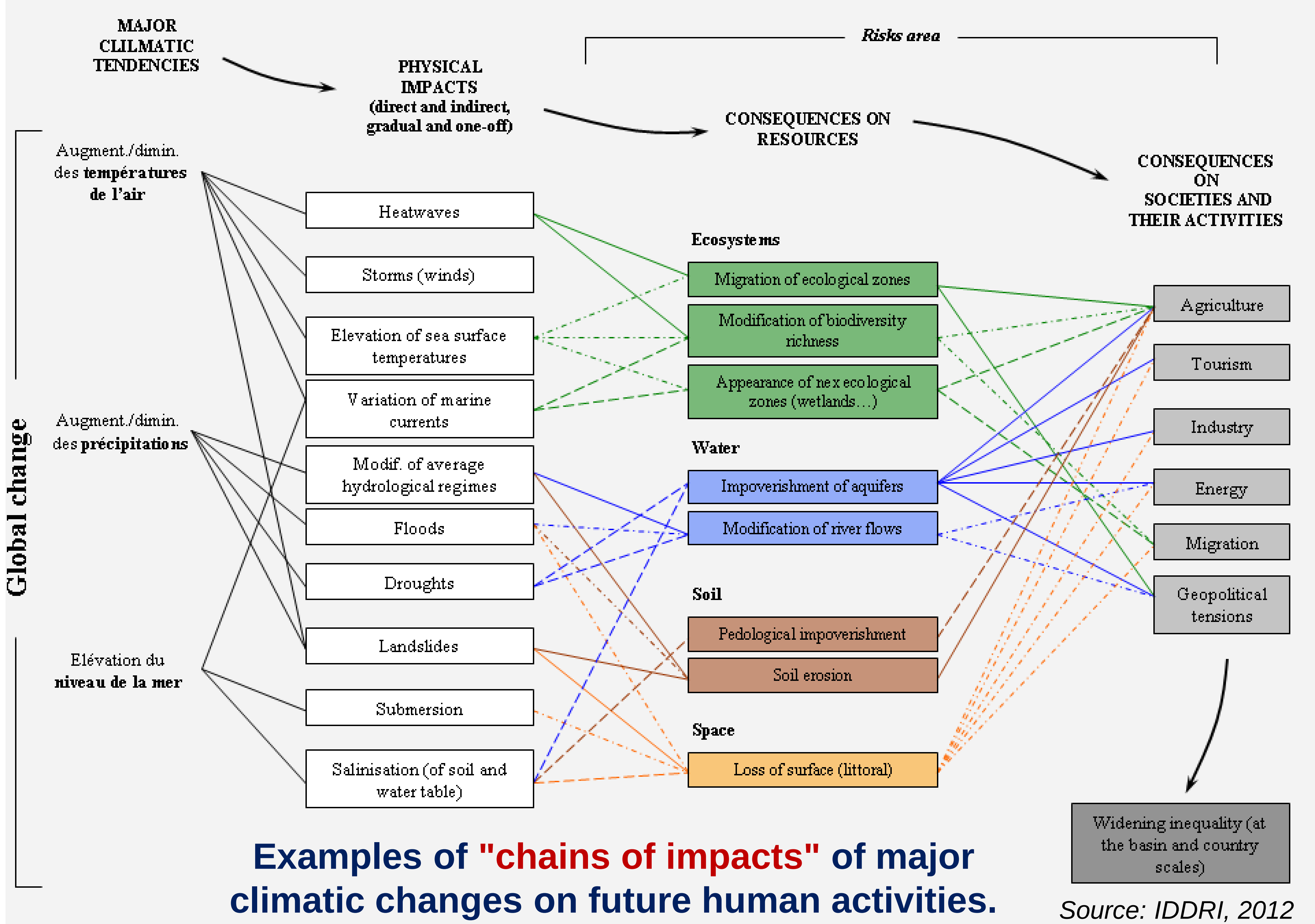
Todorovic, 2007

Climate change 2050 vs. 2000

temperature (°C) precipitation (mm)



Source: WASSERMed project (EC-FP7-ENV)



The use of different colours and lines for the arrows serves only to facilitate the appraisal of the links existing between the major climatic tendencies, physical impacts, consequences on natural resources and effects on societies. The same applies for the coloured boxes for the impacts and consequences..

ENPI CLIMA SOUTH
Euro South Mediterranean Initiative
Climate Resilient Societies
supported by Low Carbon Economies

Objective: Support the transition of 9 Mediterranean Countries towards low carbon development and climate resilience, by enhancing appropriate actions through capacity development, resource mobilization and proactive climate risk management.

- **Where**: Algeria, Lebanon, Morocco, Tunisia, Libya, Egypt, Palestine, Israel and Jordan

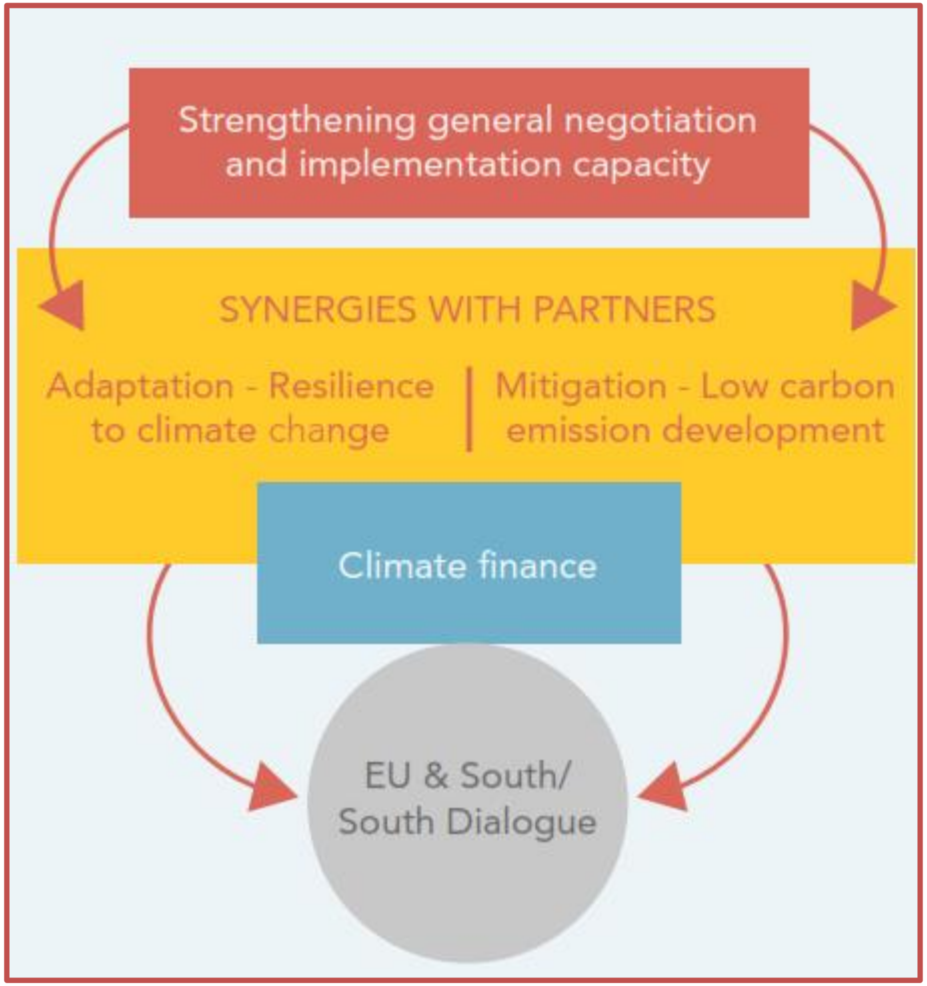
HOW ?

- ***Thematic workshops*** to address issues of regional character;
- ***National activities*** linked to the work programme & potential replication in the region.
- ***EU-South/South country dialogue*** website/platform

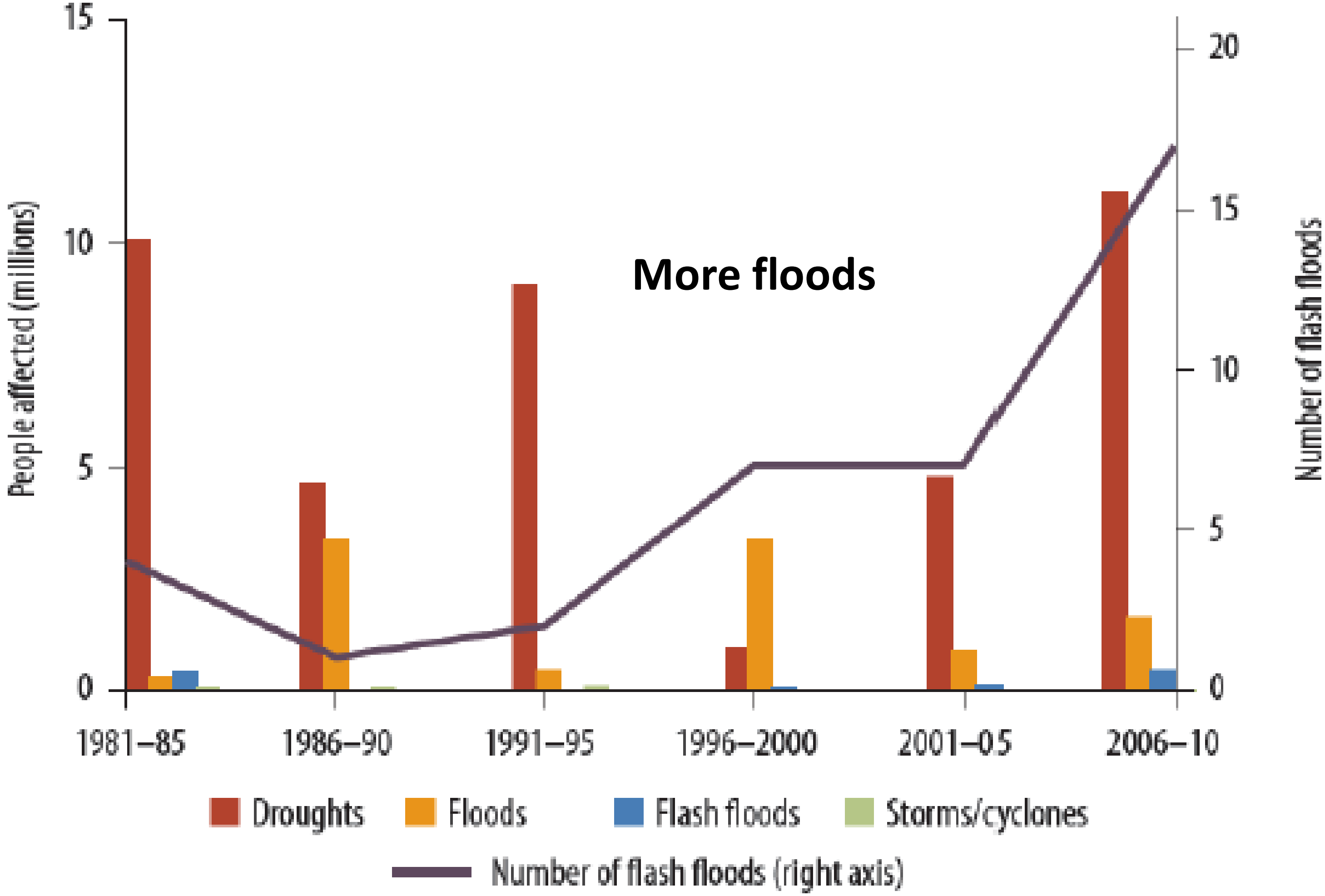
Project Consortium

ClimaSouth web site / KB platform ***http://www.climasouth.eu/***

Climate change is a risk multiplier with scarcer water resources, climate sensitive agriculture, limited natural resources associated to an increasing economic development and demographic growth along the coastal zones in particular.



Impact of climate-related disasters across the Arab Region



Source: "Adaptation to a changing climate in the Arab Countries« , World Bank, 2012

Climate change impacts

- **The IPCC projects (95% certainty):**
  - 2^{o} C increase by 2050
  - 4^{o} C increase by 2100
  - Changes in precipitation patterns
  - Stronger winds (more sand storms)
- Combined effects of temperature increase and precipitation variability will **increase the occurrence of droughts**
- **Maghreb**: Droughts have increased from 1 event every 10 years in early 20th century to 5-6 events every 10 years today
- **Global models predict sea levels rising from:**
  - 0.1 to 0.3 m by 2050
  - 0.1 to 0.9 m by 2100
- **1.0 meter sea level rise would affect:**
  - 3.2% of MENA's population
  - 1.5% of the regional GDP
  - 3.3% of wetlands
  - **Egypt:** A 1.0 m sea level rise in the Nile Delta would affect 10% of the population, and 13% of Egypt's agriculture

Acclimatization, adaptation and mitigation

- Acclimatization is essentially adaptation that occurs spontaneously through self-directed efforts.
- Adaptation to climate change involves deliberate adjustments in natural or human systems and behaviours to reduce the risks to people's lives and livelihoods.
- Mitigation of climate change involves actions to reduce greenhouse gas emissions and sequester or store carbon in the short term, and development choices that will lead to low emissions in the long term.

Mitigation versus Adaptation?

Synergy is the interaction of adaptation and mitigation measures so that their combined effect is greater than the sum of their effects if implemented separately.

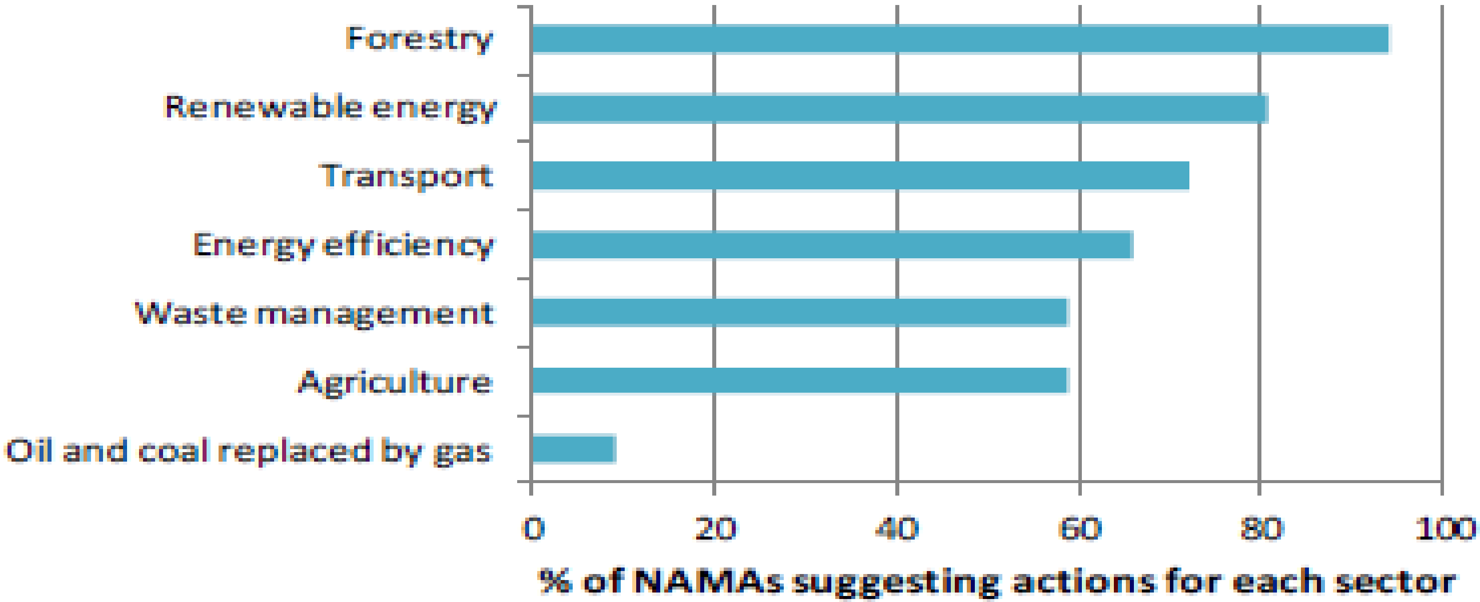
Synergies : Added value

Very often, clean energy is regarded as a «mitigation» activity, while water resources management is considered as an «adaptation measure». But :

Clean energy & **water resources** management together offer a good example of synergy and trade-offs between mitigation and adaptation measures which could be overlooked in a strict segregation among adaptation and mitigation stand alone actions => Win Win situation

Potential sectors for synergies

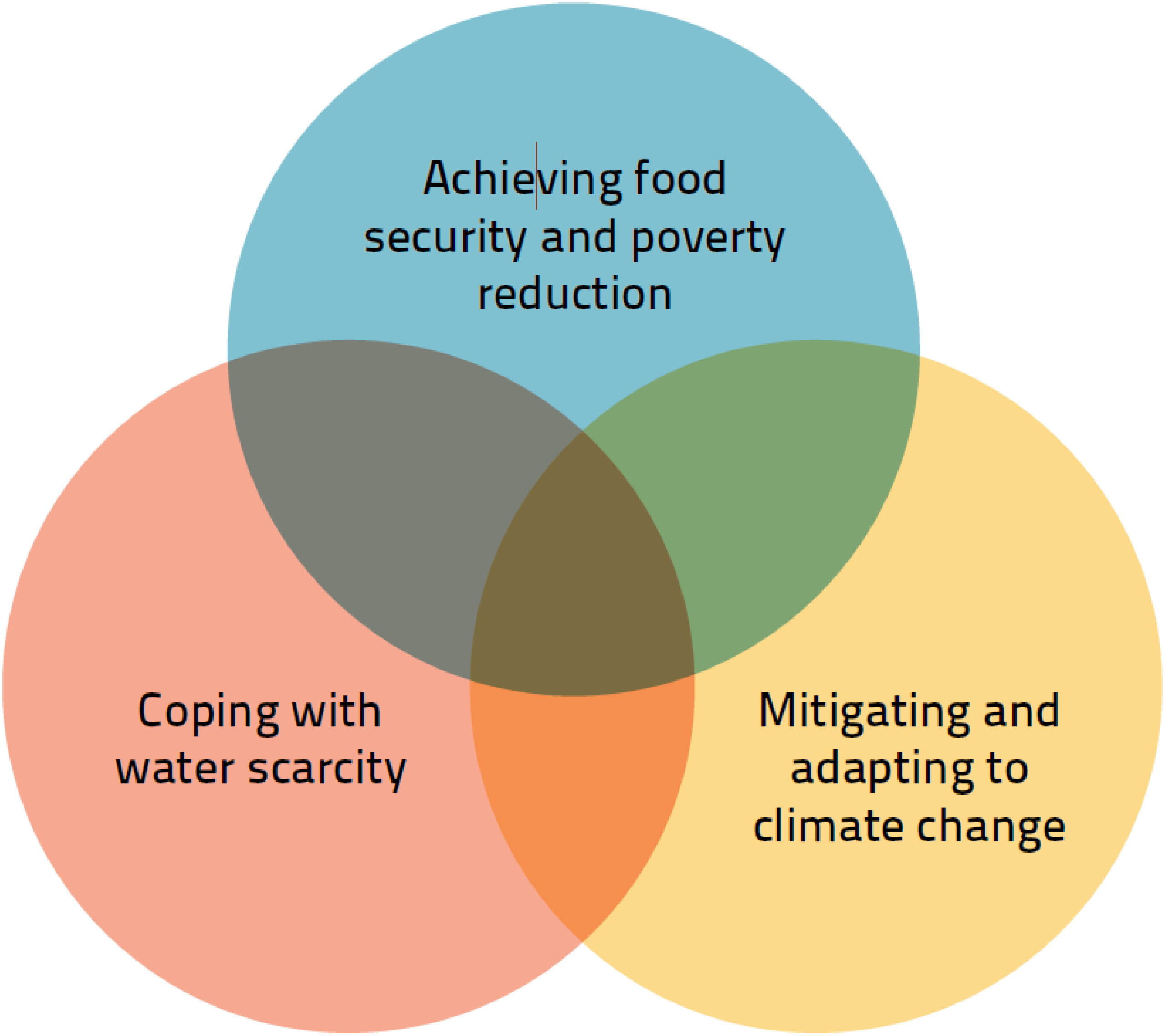
Review of NAMAs (Nationally Appropriate Mitigation Actions) priorities globally



Energy, agriculture and the water sector (including coastal management) provides relatively high potential for both mitigation and adaptation measures

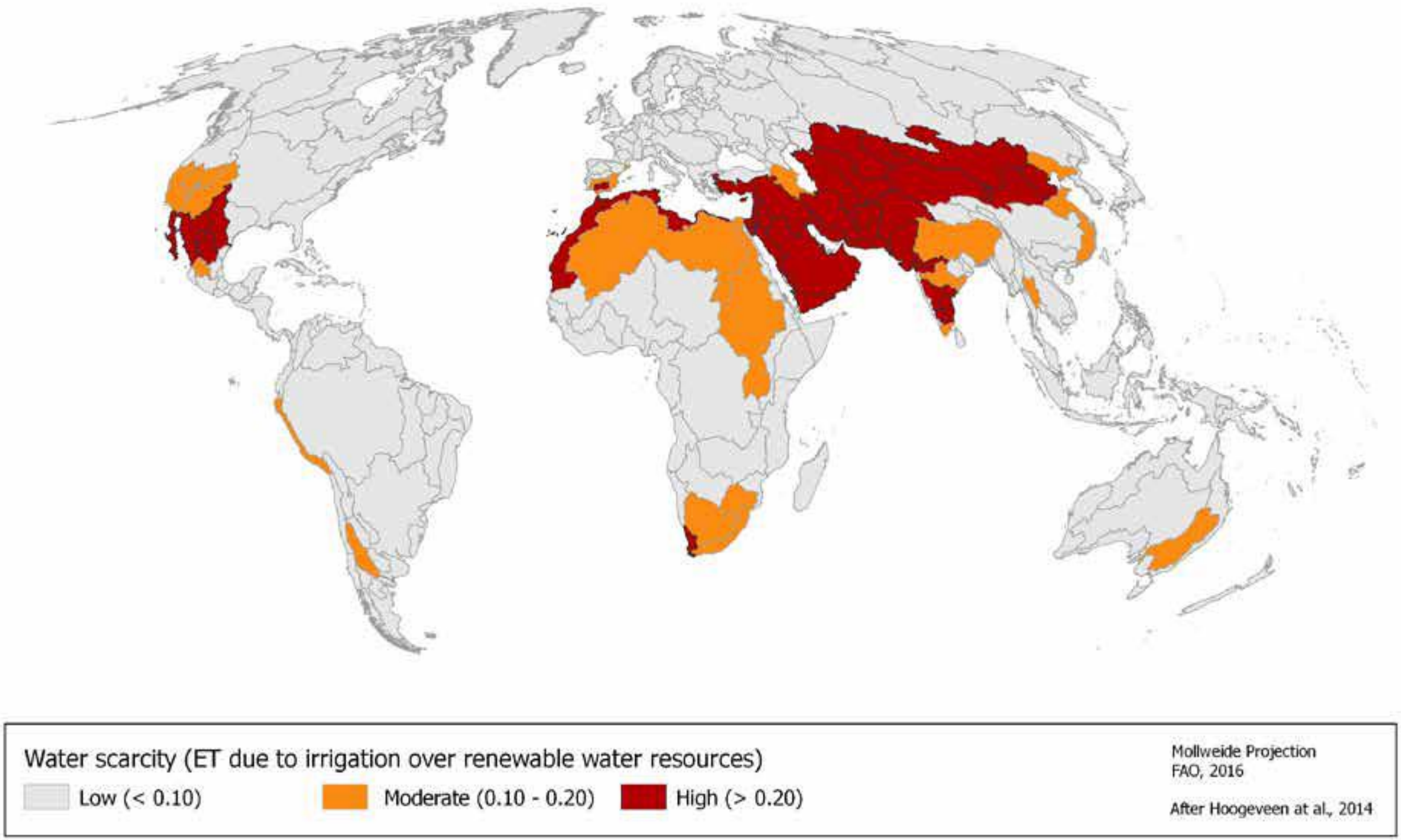
Source : Scoping study on financing adaptation-mitigation synergy activities, Nordic Council of Ministers, 2013.

THE FOCUS OF THE GLOBAL FRAMEWORK FOR ACTION IN A NUTSHELL



Source: FAO, 2016

GLOBAL MAP OF PHYSICAL WATER SCARCITY BY MAJOR RIVER BASIN



Source: Hoogeveen et al., 2014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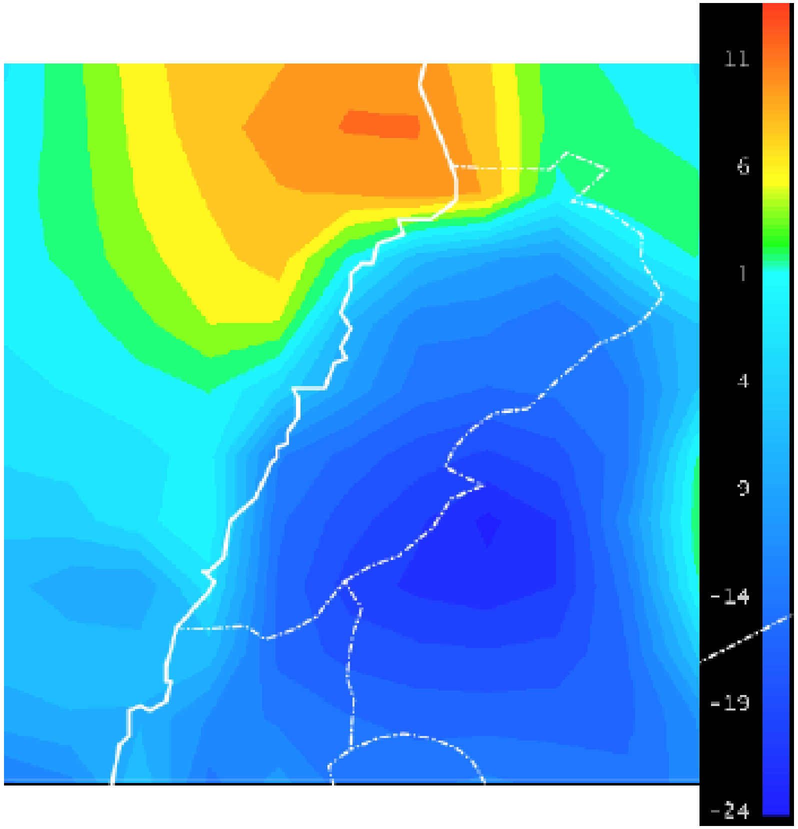
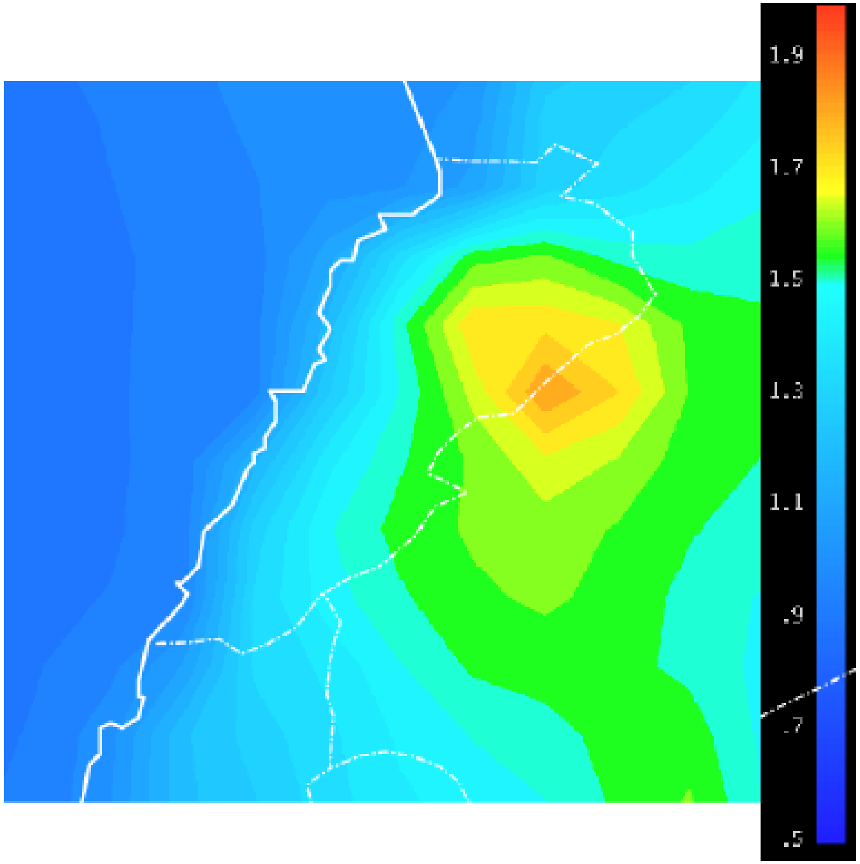
Mediterranean Sea
Lebanon
El Mina
Tripoli
Chekka
Batron
Jounieh
Joni
Beirut
Sidon
Jazzin
Tyre
Litani River
Israel
LEBANON MTS.
Bekaa Valley
Baalbeck
Zahl
ANTI-LEBANON MTS.
Syria
N
Damascus
20 mi
20 km
Syria
Syrian Desert
Golan Heights Israeli occupied
LEBANON
LOW / HILLS / MOUNTAINS

Expected change of precipitation (%) by 2045

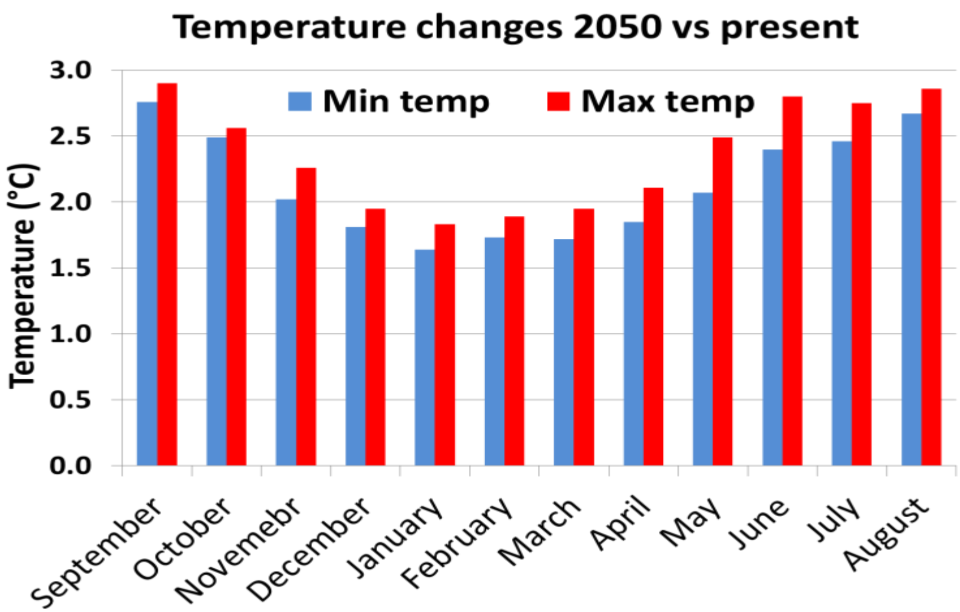


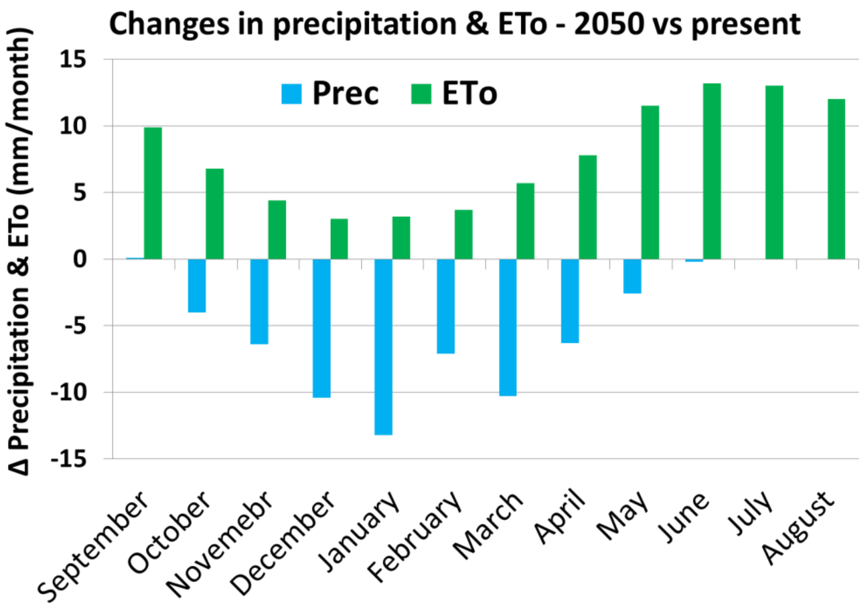
Expected change of Tmax (°C) by 2045



Source: Second National Communication to the UNFCCC (2011)

LEBANON, Bekaa Valley





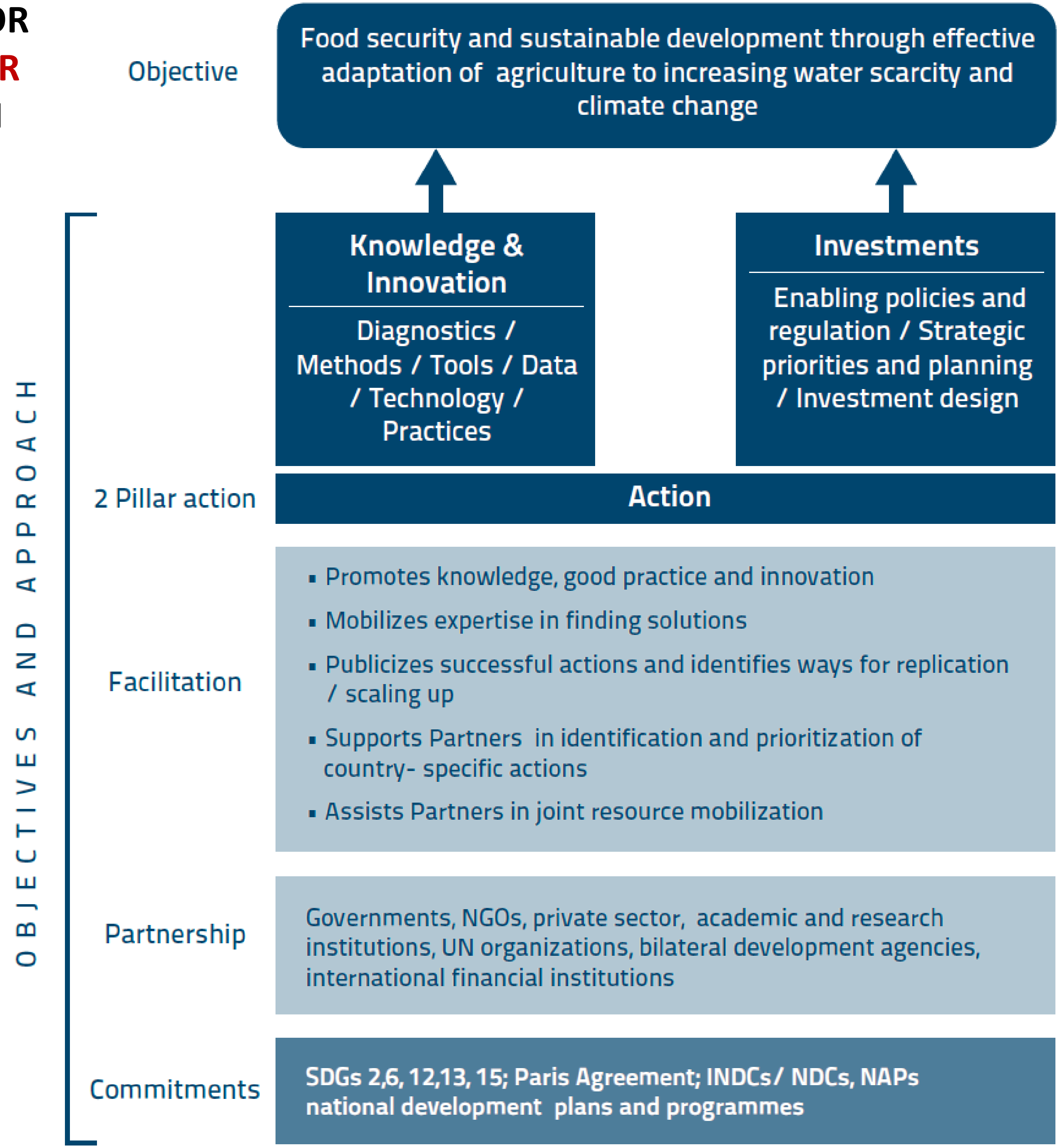
Climate variable	Baseline	2040-2060 RCP4.5	Changes vs. baseline	
			Difference	%
Precipitation (mm)	625	565	- 60	- 9.6
Mean Temperature (°C)	13.0	15.2	2.2	--
Minimum temperature (°C)	7.4	9.6	2.2	--
Maximum temperature (°C)	18.6	20.9	2.3	--
Thermal time accumulated December-June (°C d, or GDD)	2040	2460	420	20.5
Reference ET (mm)	1155	1249	94	8.1

Climate change analyses elaborated by CMCC

cmcc Euro-Mediterranean Center on Climate Change

Source: ACLIMAS project, Abi Saab, 2015

THE GLOBAL FRAMEWORK FOR ACTION TO COPE WITH WATER SCARCITY IN AGRICULTURE IN THE CONTEXT OF CLIMATE CHANGE



Source: FAO, 2016

What is HORIZON 2020?

Horizon 2020 is …
the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available over 7 years (2014 to 2020) – in addition to the private investment that this money will attract.

It promises more breakthroughs, discoveries and world-firsts by **taking great ideas from the lab to the market**.

… by coupling the research and innovation, THE GOAL is to remove barriers to innovation and makes it easier for the public and private sectors to work together in delivering innovation.

Source: http://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020

Geographical Information Systems

Crop growth models

Data …

Decision Support Systems

Remote Sensing

Sensors

Precision Agriculture

Satellite images

Smartphones

Unmanned Aerial Vehicles (UAV)

Drones

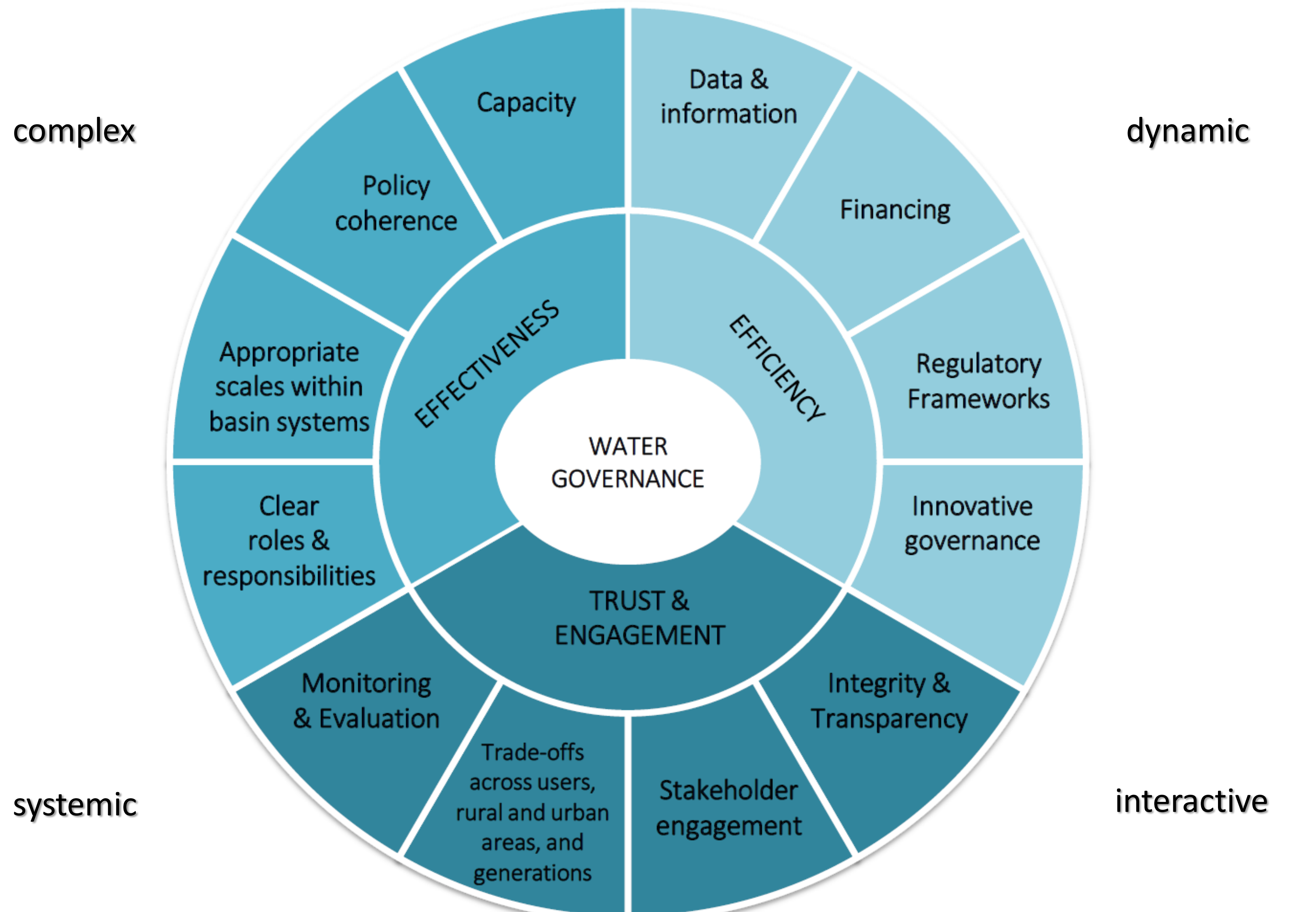
Cloud

Ground-based sensing

Data …

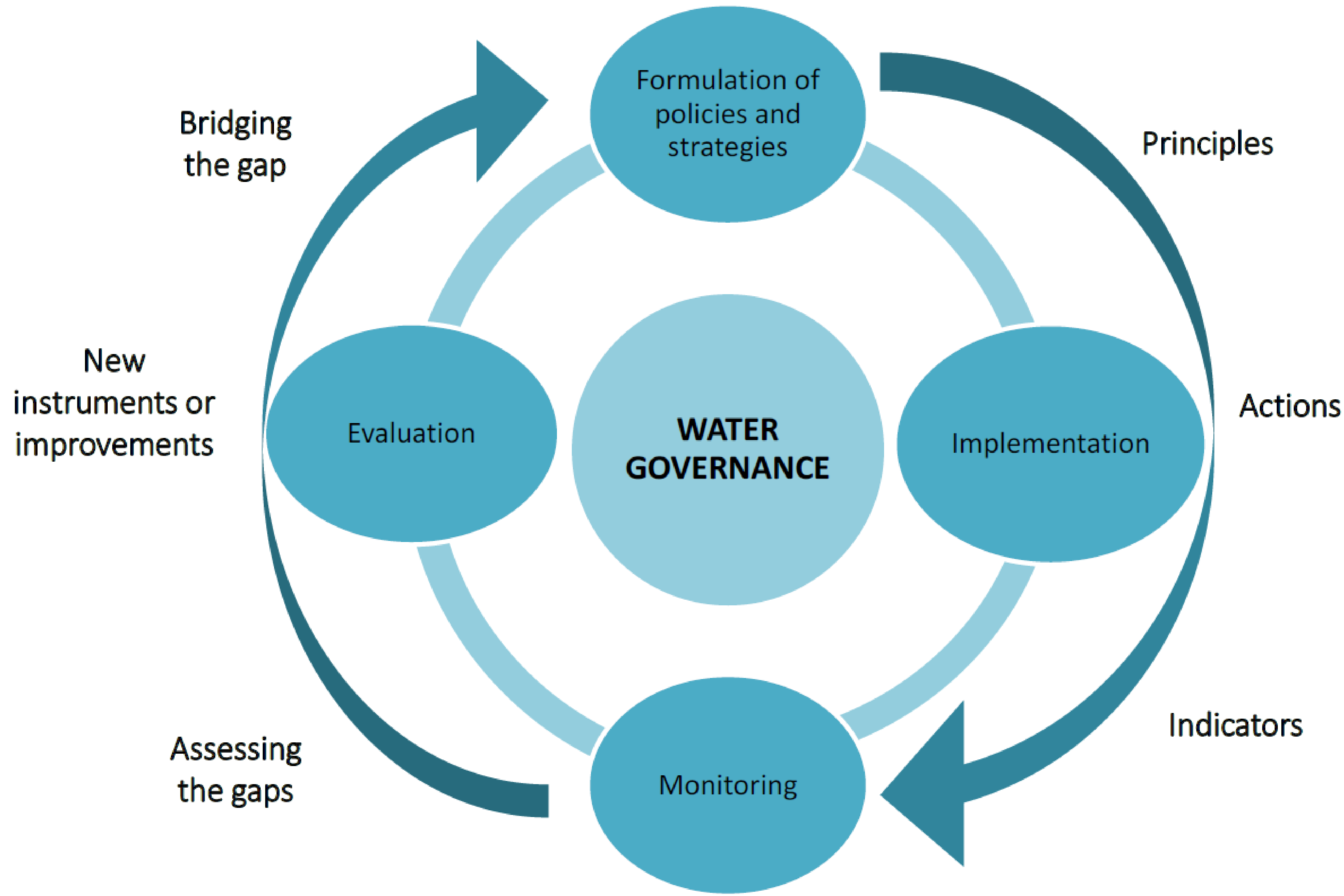
WATER MANAGEMENT, GOVERNANCE & DECISION SUPPORT SYSTEMS

Overview of OECD policies on water governance



Source: adapted from OECD, 2015

The Water Governance Cycle

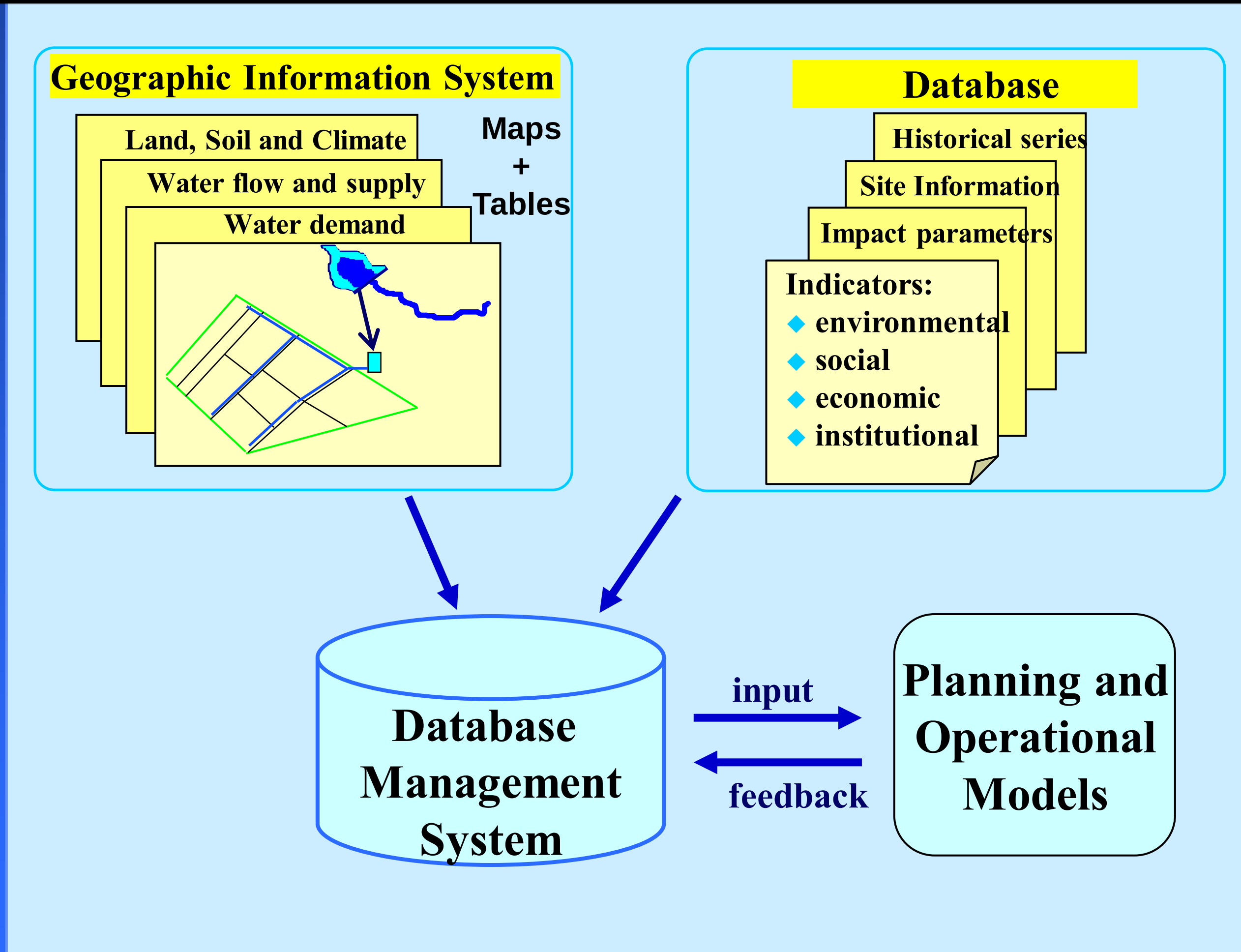


Source: OECD, 2015

DSS – definitions and approaches

- DSSs support the process of decision making.
- DSS is an interactive software-based system used to help decision-makers compile useful information from a combination of raw data, documents, and personal knowledge; to identify and solve problems; and to make an optimized decision.
- DSS can organize and process a large quantity of information, helping farmers to identify and concentrate on the most important information for each management decision.
- The DSS architecture consists of the database (or knowledge base), the model (i.e., the decision context and user criteria), and the user interface.
- End-users – decision makers are important in model development because they are capable of providing feedback concerning design issues, relevance, needs, and perceptions.

Principal components of a Decision Support System – an integrated approach in water resources management



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Source: Todorovic and Hamdy, 1998

DSS advantages and applications

- The main advantages of using a DSS include examination of multiple alternatives, better understanding of the processes, identification of unpredicted situations, enhanced communication, cost effectiveness, and better use of data and resources.
- Simple, single-issue decision support tools or models have several advantages over larger models including speed and cost of development, accessibility, ease of use, and transparency.
- Disadvantages of such simple tools include less comprehensive representation of processes, less flexibility, and reduced ability to include complex interactions (Freebairn *et al.*, 2002).
- The application DSS in agriculture and environment has been rapidly increased in the past decade, which allows rapid assessment of agricultural production systems around the world and decision-making at both farm and district levels, though constraints exist for successful adoption of this technology in agriculture.
- One of the important applications of DSS in agriculture is water management at both field and district levels.

DSS typical approaches

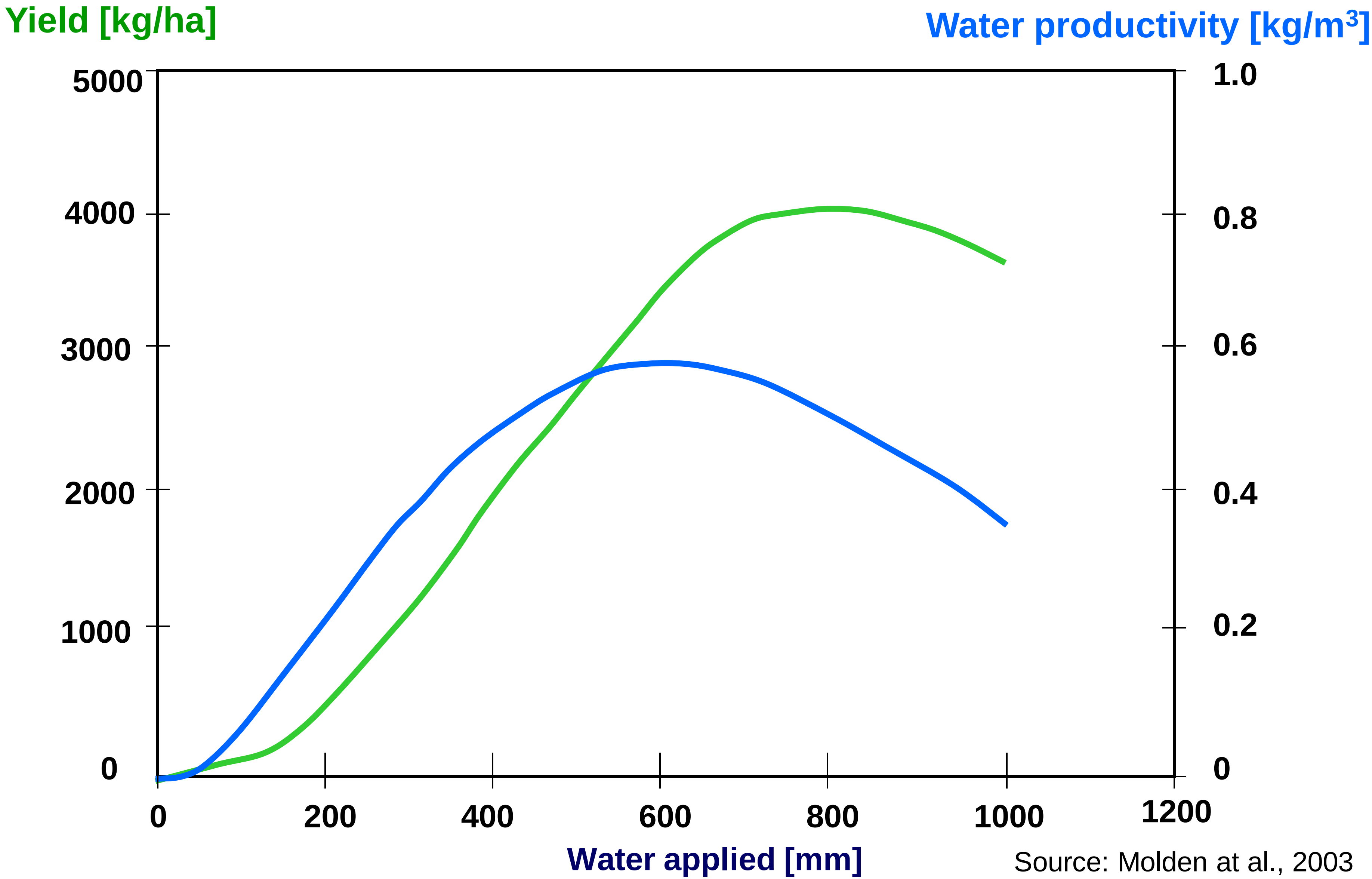
1. Model simulation: Some parameters values and decision variables need to be assumed and the results of simulated behaviors of the model are evaluated.
2. Single-objective optimization: A criterion and an objective function are defined and the solutions that are optimal with respect to this function are analyzed.
3. Multi-objective optimization: In environmental science, a good model based DSS should rely not on single but multi-objective optimization.
4. Goal programming: In interactive DSS where the decision-maker can change the preferences during the decision process, two classes of approach are useful in goal programming.
5. Reference point methodology: The idea of defining a goal in objective space and approximating to it is very attractive. The reference point approaches assume that the computerized DSS try to improve a given reference point, if this point is attainable.

Source: Rinaldi and He, 2014

Multi-criteria DSS

- The system is defined via mathematical simplification of the variables and relationships between them in order to understand the effect of any modifications of the initial conditions that characterize the system.
- Every system has variables that control the processes involved and that belong to the decision-making process as `decision variables'; e.g. the farmer can decide the crop distribution or the level of use of water and fertilizers.
- The crop plan selected will determine changes in certain attributes of the system.
- Attributes are relevant functions deduced from the decision variables, but as we have mentioned above, not all attributes are relevant to the decision makers. Fertilizer and water consumption may be the attributes of interest to policy makers but less relevant for the farmers.
- Attributes to which decision makers assign a desired direction of improvement are considered objective functions.
- Different types of objective functions can be considered: those relevant to the farmers' objectives but also those relevant to policy makers.

Maximizing YIELD vs. WATER PRODUCTIVITY

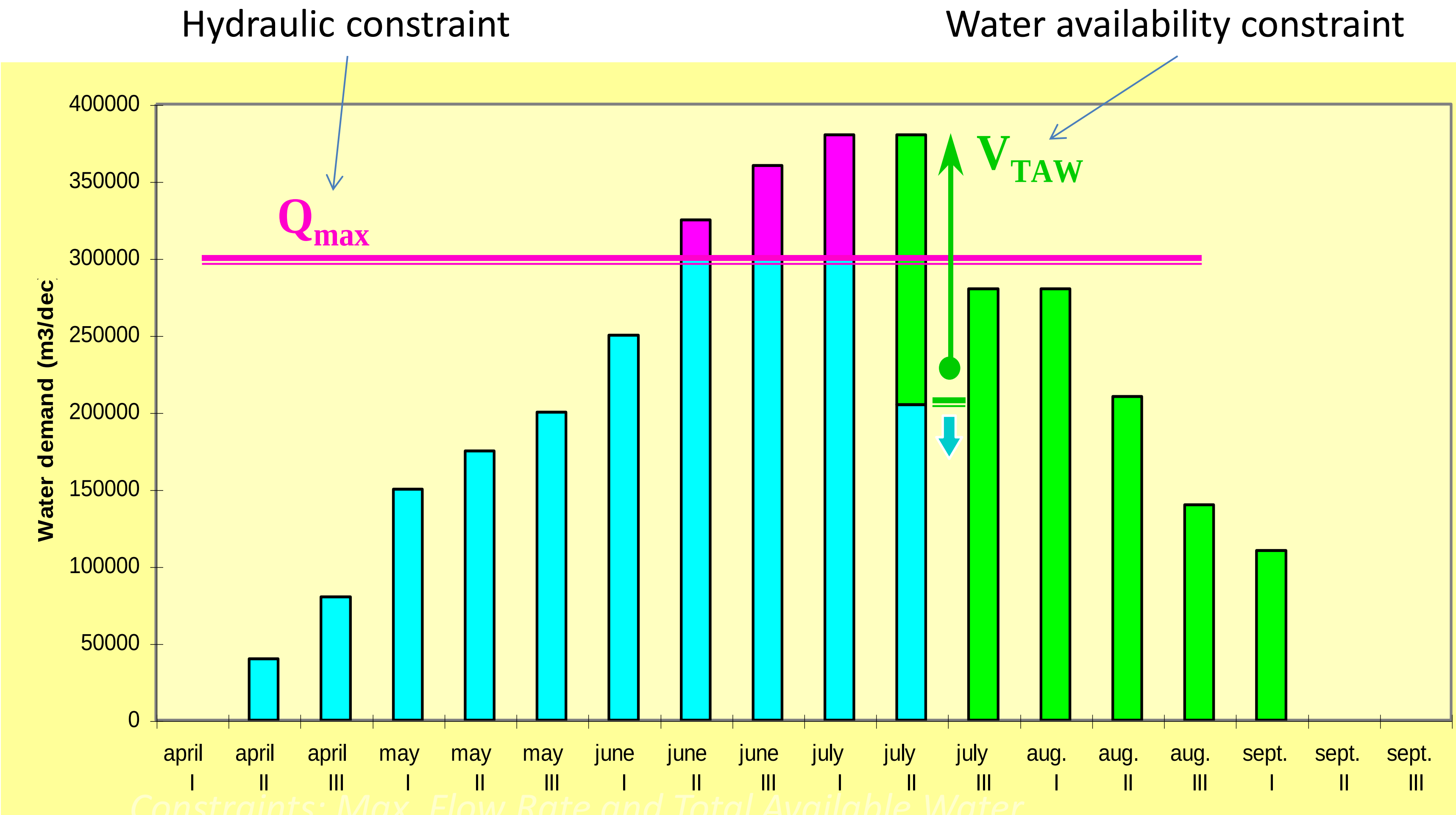


Source: Molden at al., 2003

Multi-criteria DSS 2

- Variables: each farmer has a set of variables Xi (crops) - these are the decision variables that can assume any value belonging to the feasible set.
- Objectives: belonging to the farmers' decision process:
  - Maximize profit – gross margin
  - Minimize water/fertilizer use
  - Minimize labour
- Constraints: network operational characteristics – hydraulic constraints, market constraints, strategic policy constraints, pedo-climatic constraints, etc.
- Attributes: water consumption, environmental impact, N balance in groundwater, etc..

Water Demand vs. Constraints in Global Assessment Strategy

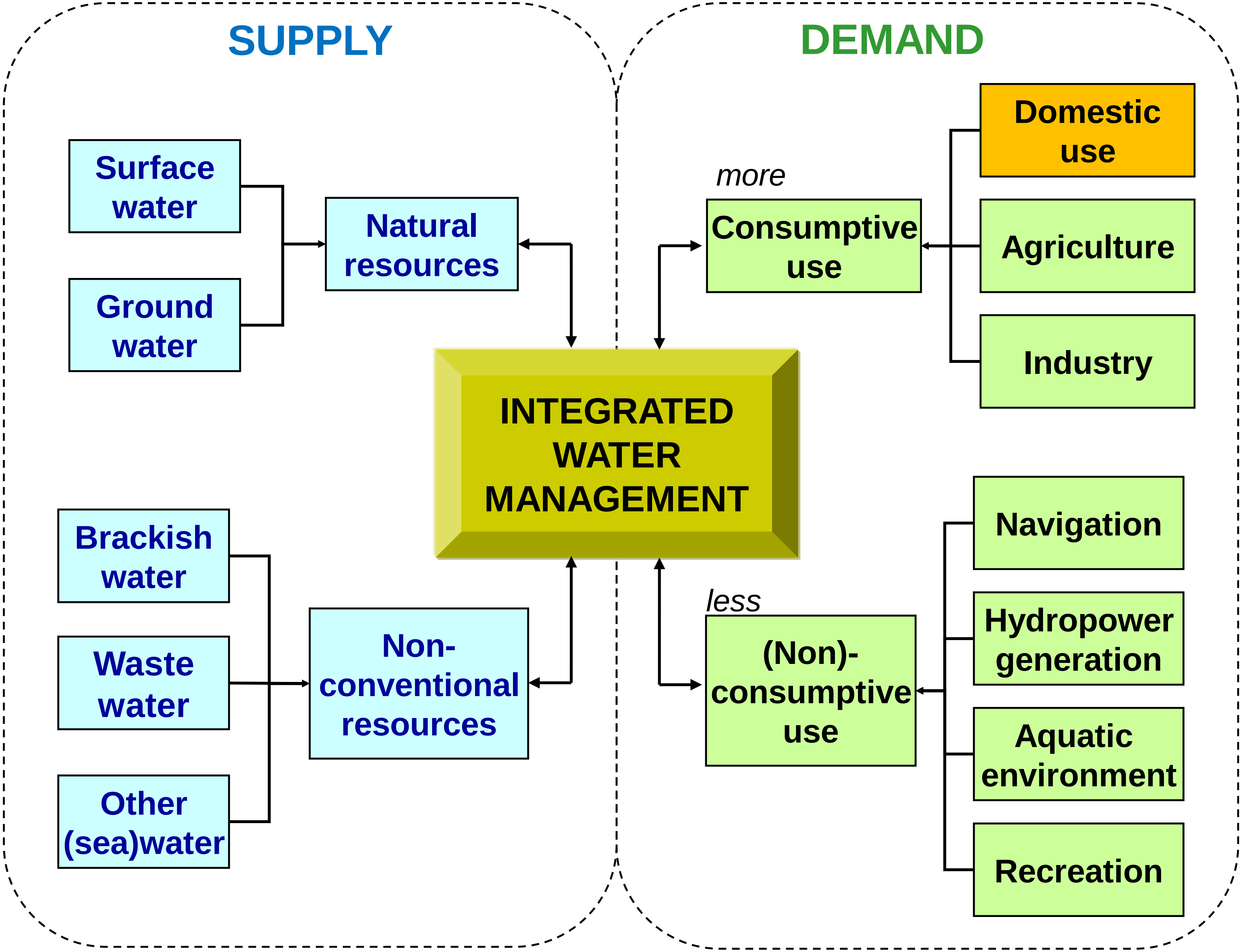


Source. Todorovic and Steduto, 2003

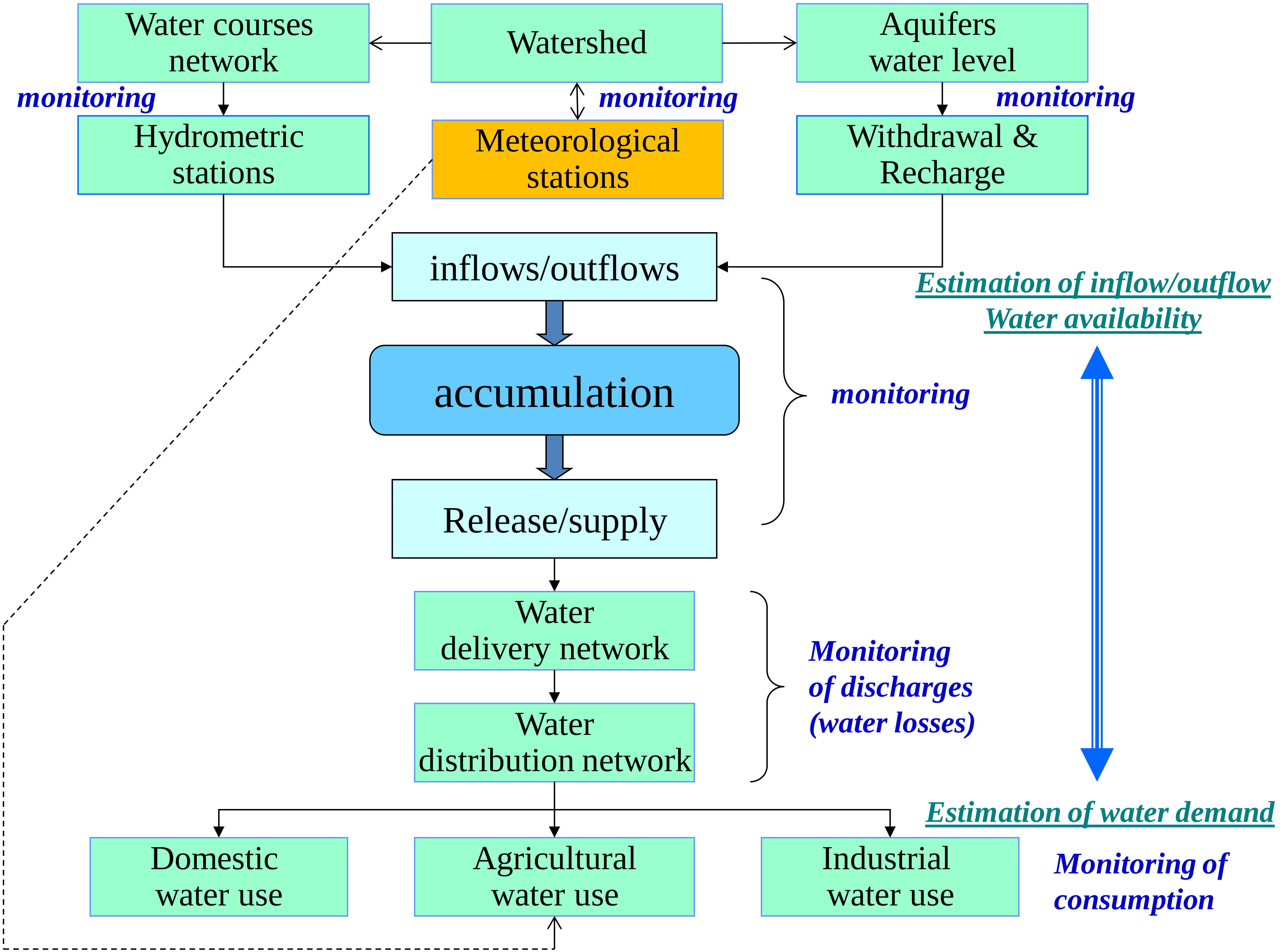
Criteria for designing a DSS for agricultural water management

- Data must be available for specifying processes;
- The biophysical representations must be dynamic, not static;
- Complexity and cost should be avoided;
- The user's (e.g. water managers, farmers, researchers, etc.) preferences and goals must be represented;
- They should have capacity for comparative analysis;
- They should have high relative accuracy, not necessarily absolute accuracy;
- Uncertainty should be represented;
- Models must be calibrated and validated to establish trust.

DSS FOR AGRICULTURAL WATER MANAGEMENT

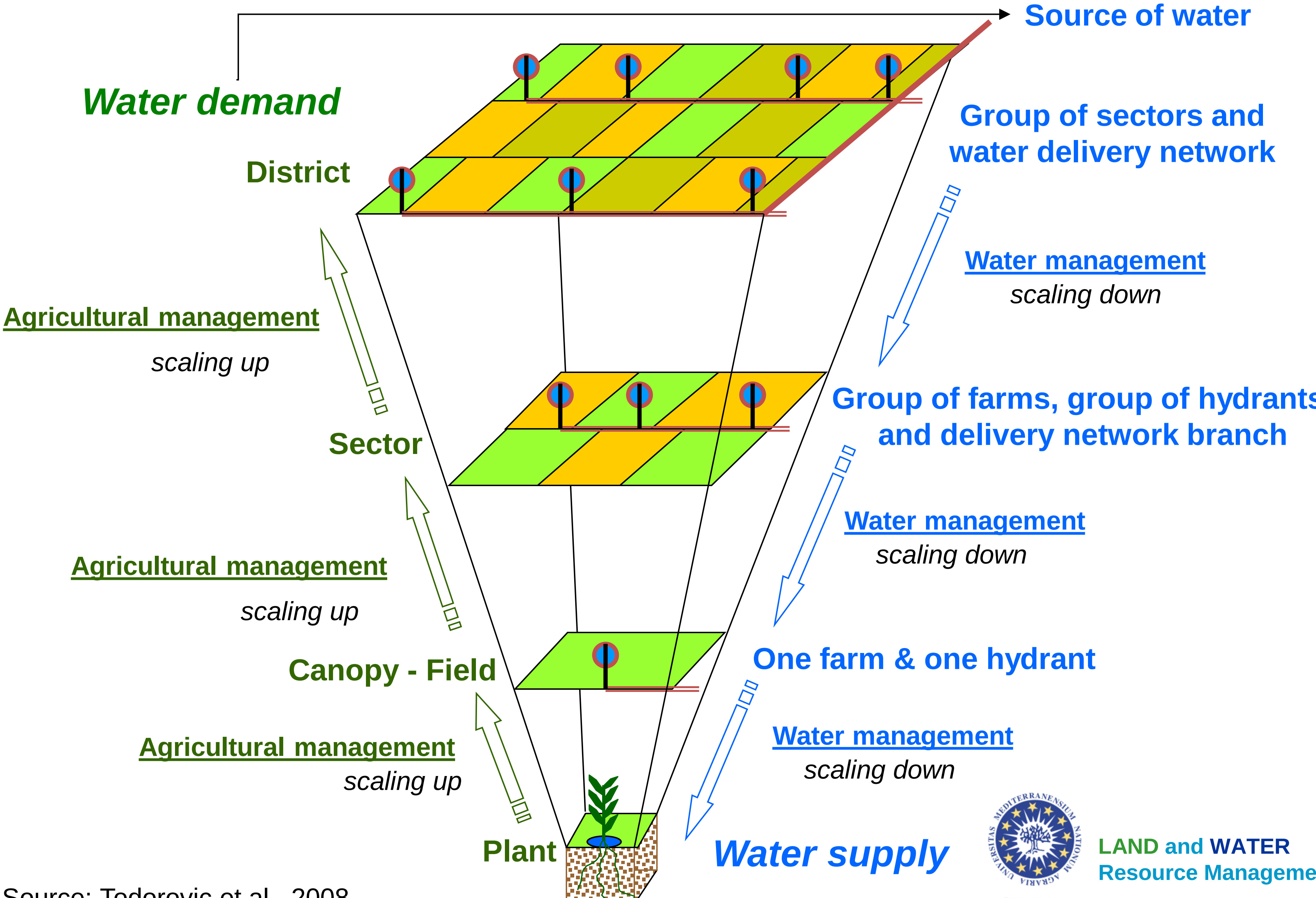


Source: adapted after Todorovic and Hamdy, 2001



Source: adapted after Todorovic, 2006

AGRONOMIC AND ENGINEERING ASPECTS OF WATER MANAGEMENT IN AGRICULTURE



Source: Todorovic et al., 2008

CIHEAM

LAND and WATER Resource Management

Water demand, supply, withdrawal & availability

$$WUE_{agriculture} = f(\text{Agronomic \& Engineering performance})$$

- **Water Demand, WD**

$$\text{WD} = \sum_{i=1}^{n} \left(\frac{ET_c - P_{eff}}{EFF_{app}} A\right)_i$$

- **Water Supply, WS**

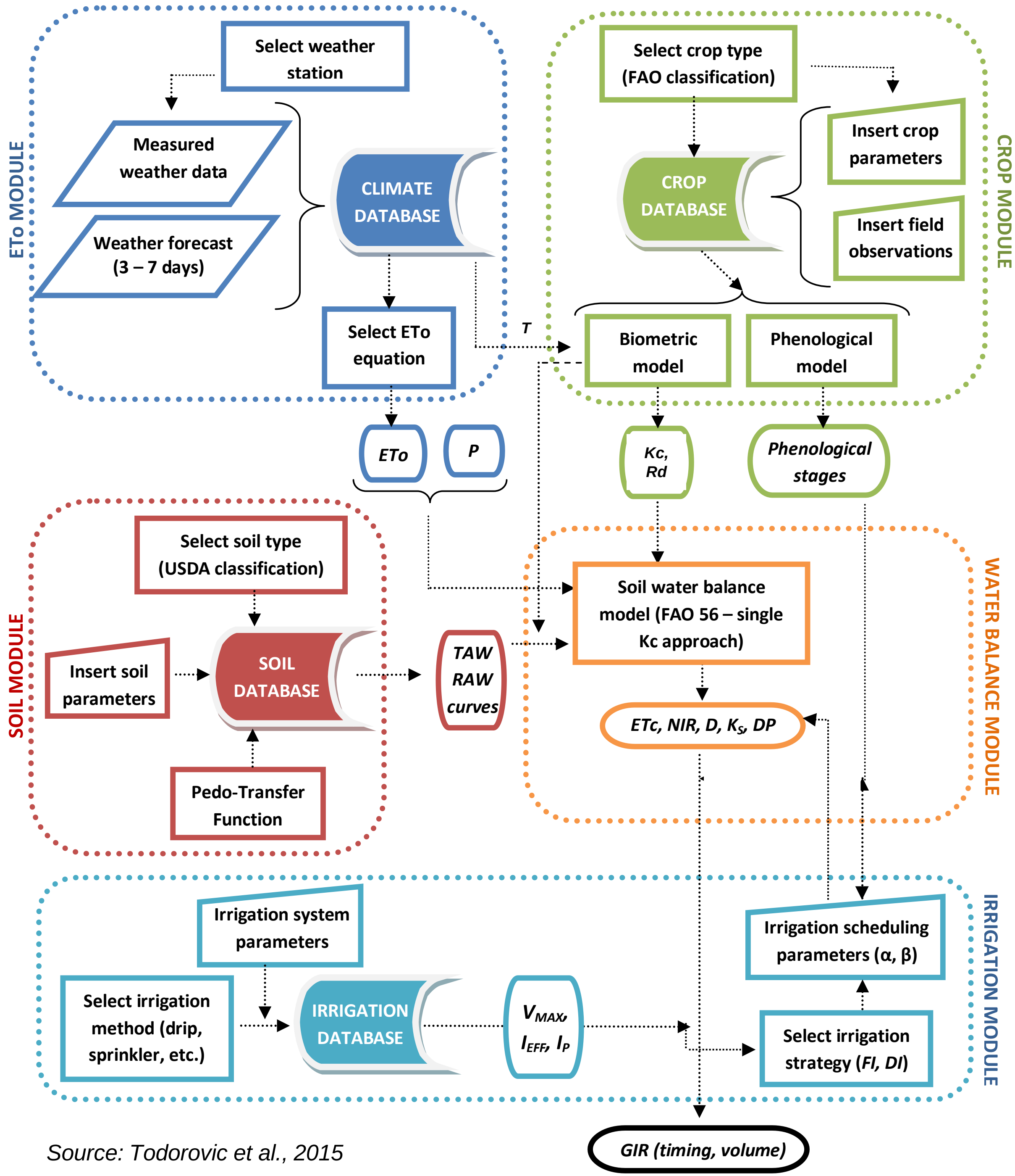
$$\text{WS} = \text{WD}$$

- **Water withdrawal, WW**

$$WW = \frac{WD}{\prod_{j=1}^{m} EFF_j} = \frac{\sum_{i=1}^{n}\left(\frac{ET_c - P_{eff}}{EFF_{app}} A\right)_i}{\prod_{j=1}^{m} EFF_j} = \frac{\textit{Agronomic demand}}{\textit{Engineering Efficiency}}$$

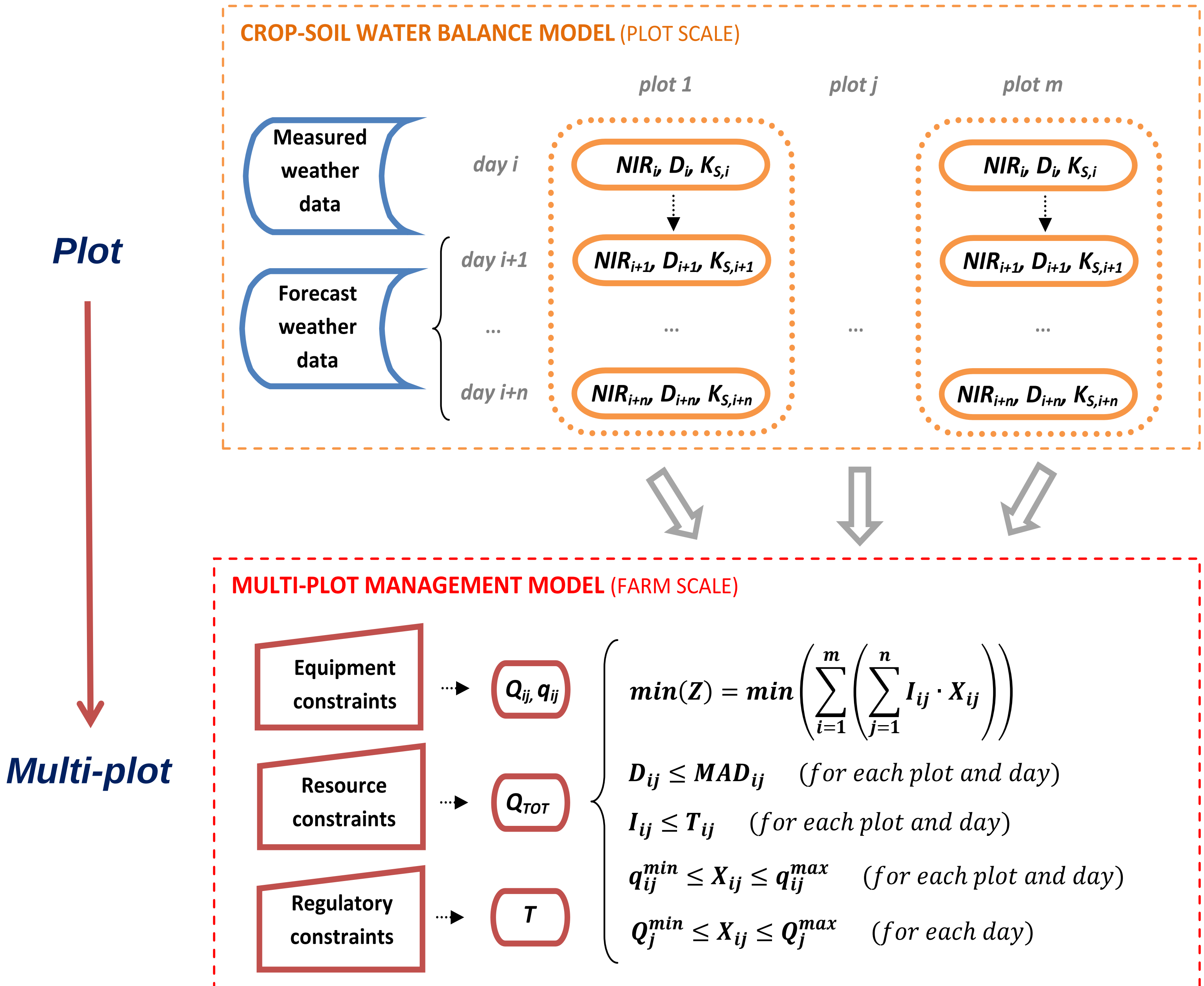
- **Water availability ⇩ when Demand ⇧**

MTIng, 2012

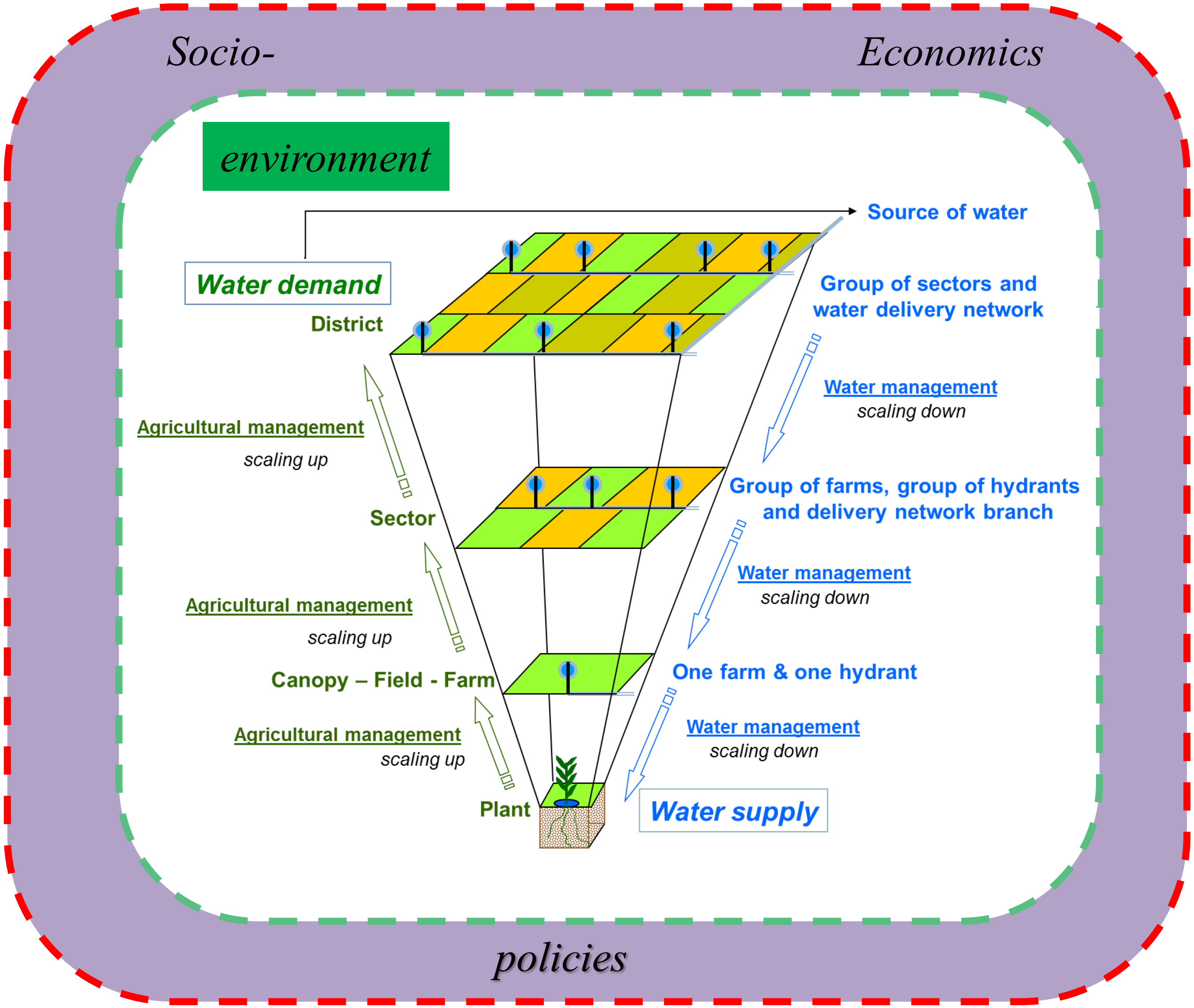


Source: Todorovic et al., 2015

Multi-plot dynamic water delivery optimizer



Agricultural Water Management:
Scaling-up … multilevel stakeholders approach



MTIng, 2015

FRAMEWORK FOR IMPROVING WATER PRODUCTIVITY IN AGRICULTURE

RAINFED AGRICULTURE IMPROVEMENT

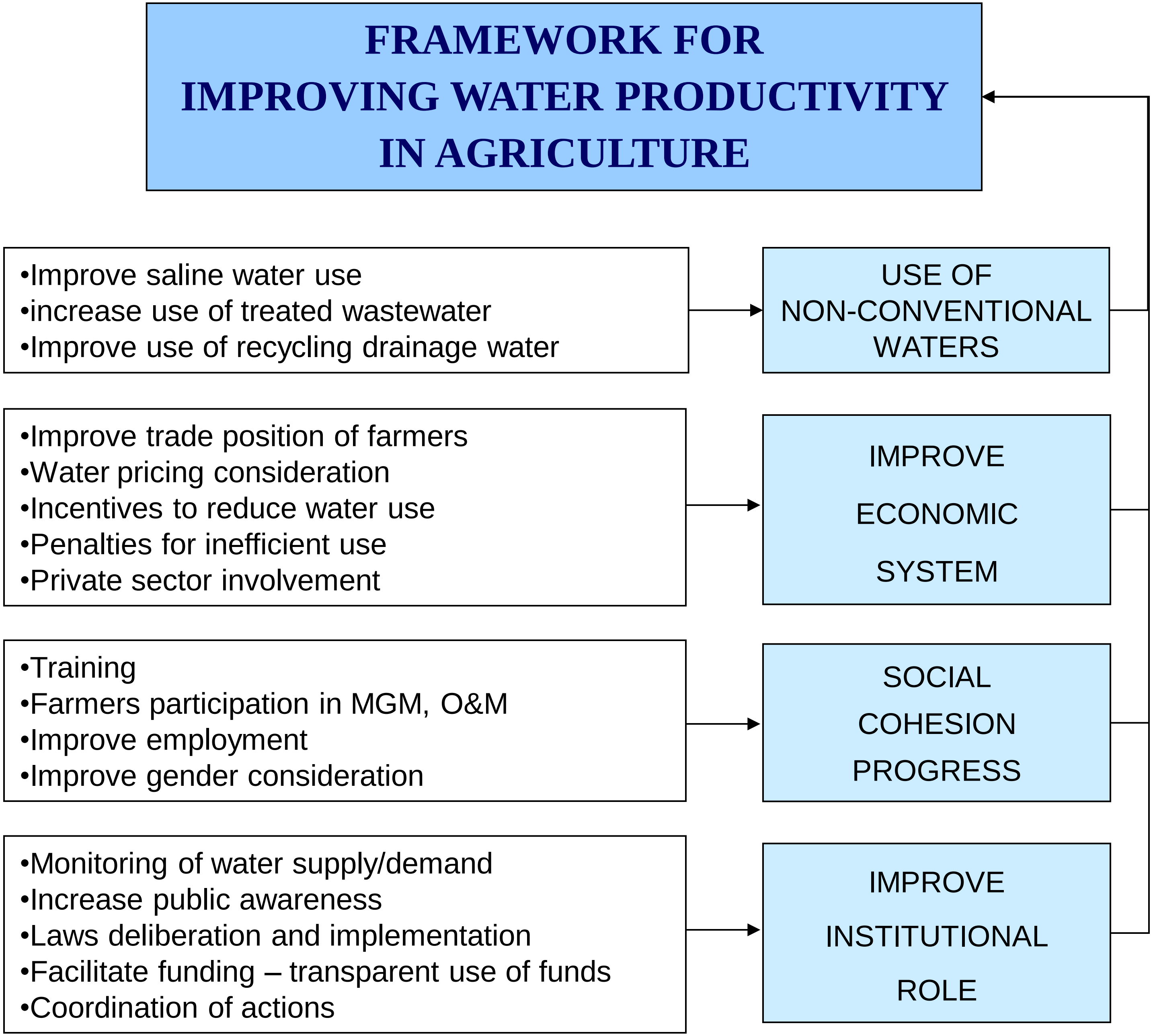
- Improve land management (zero till, etc..)
- Improve water harvesting
- Improve conventional breeding and genomics
- Improve cropping pattern selection

IMPROVE IRRIGATED AGRONOMIC PRACTICES

- Improve land management (terracing, tillage)
- Improve conventional breeding and genomics
- Improve cropping pattern selection
- Improve irrigation scheduling
- Improve deficit irrigation
- Use supplemental irrigation
- Use of new technologies (sensors, models)
- Use of greenhouses and mulching
- Improve N use, weeds control, etc.

IMPROVE ENGINEERING PRACTICES

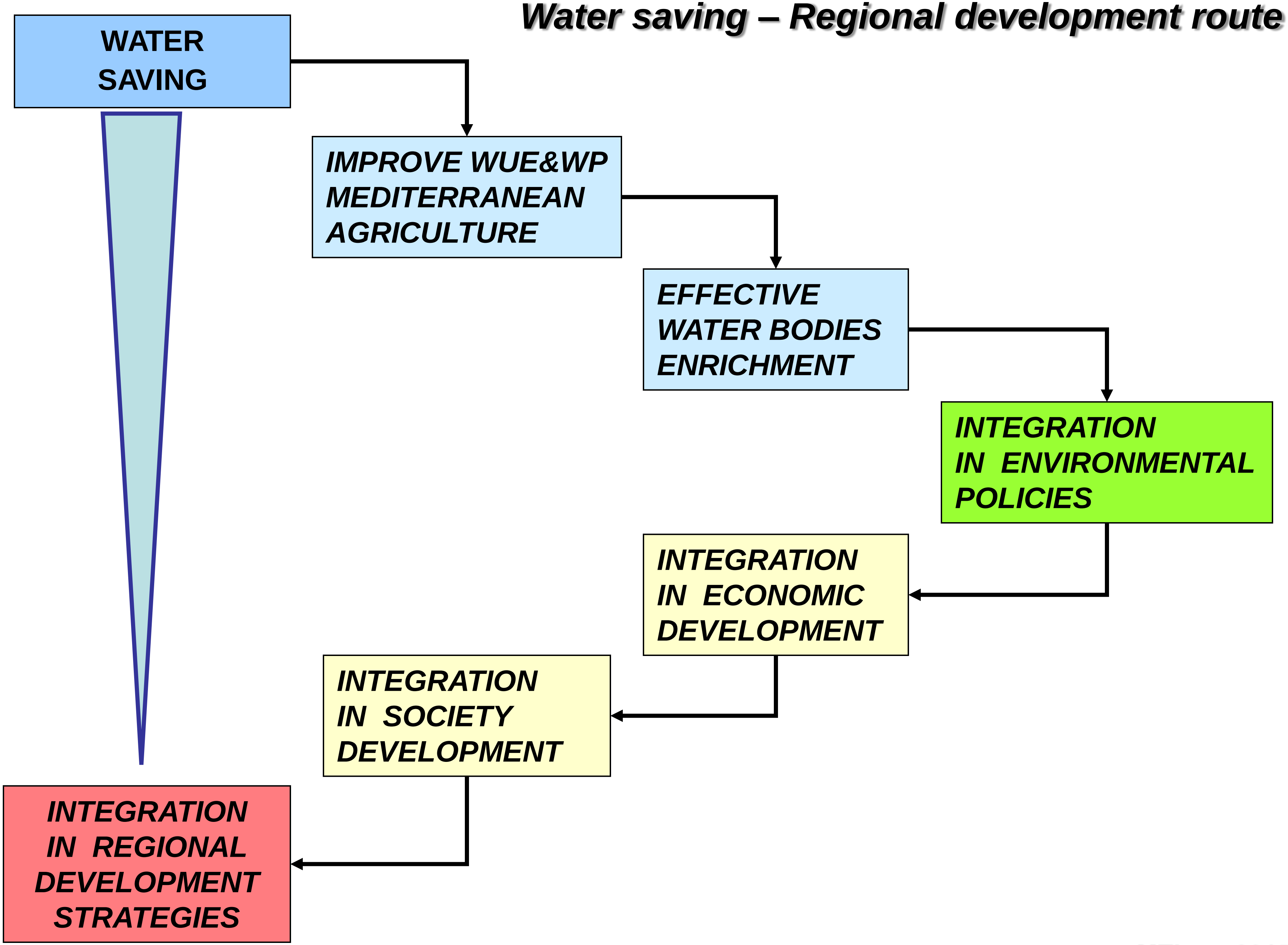
- Shift to pressurized network
- Shift to more efficient irrigation methods
- Improve design and distribution uniformity
- Use of land leveling and furrow diking
- Channel lining ?
- Use of new technologies and devices
- Improve operation and maintenance



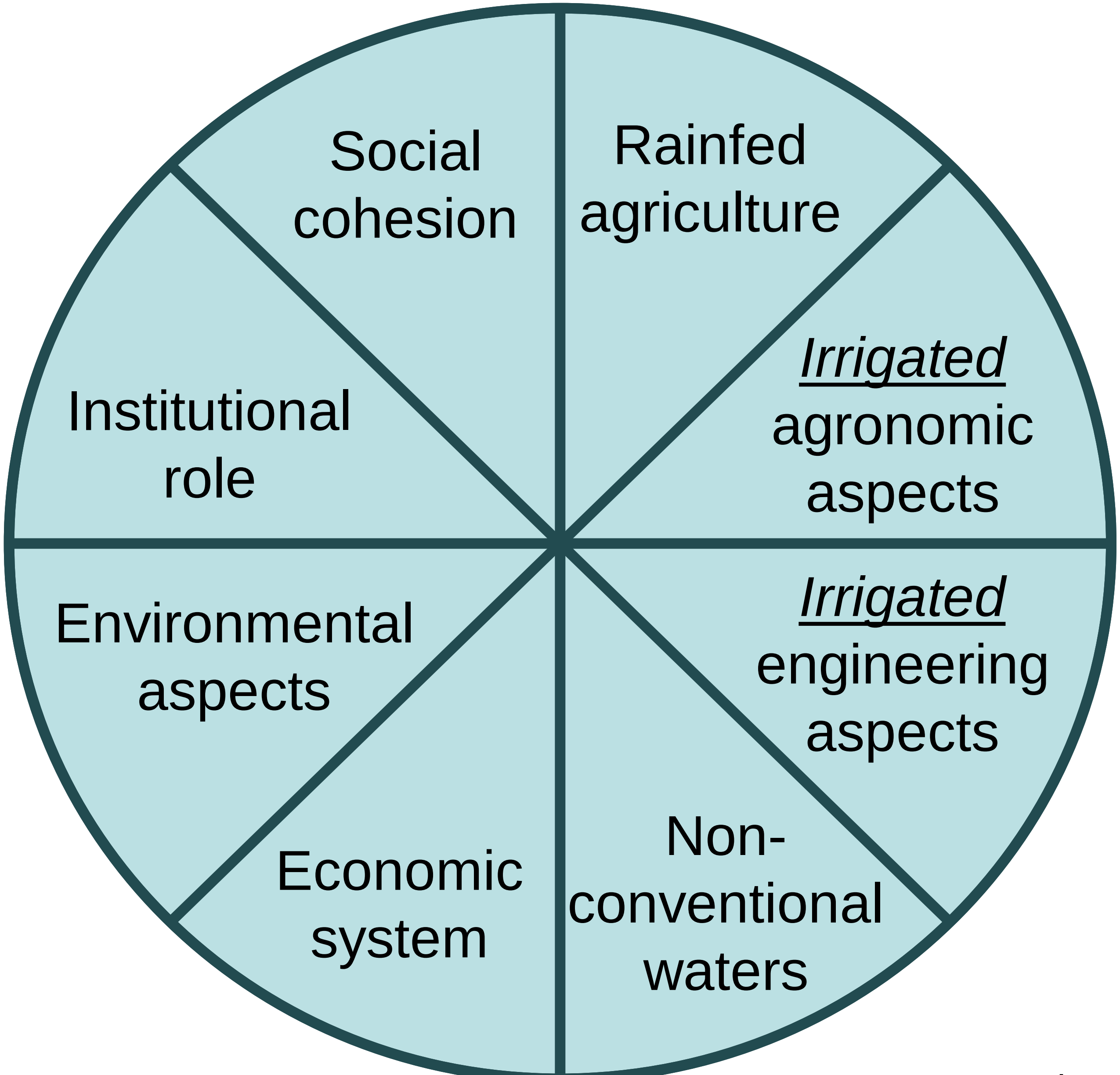
Consider cost of improvement and environmental issue

Source: Todorovic et al., 2016

Water saving – Regional development route

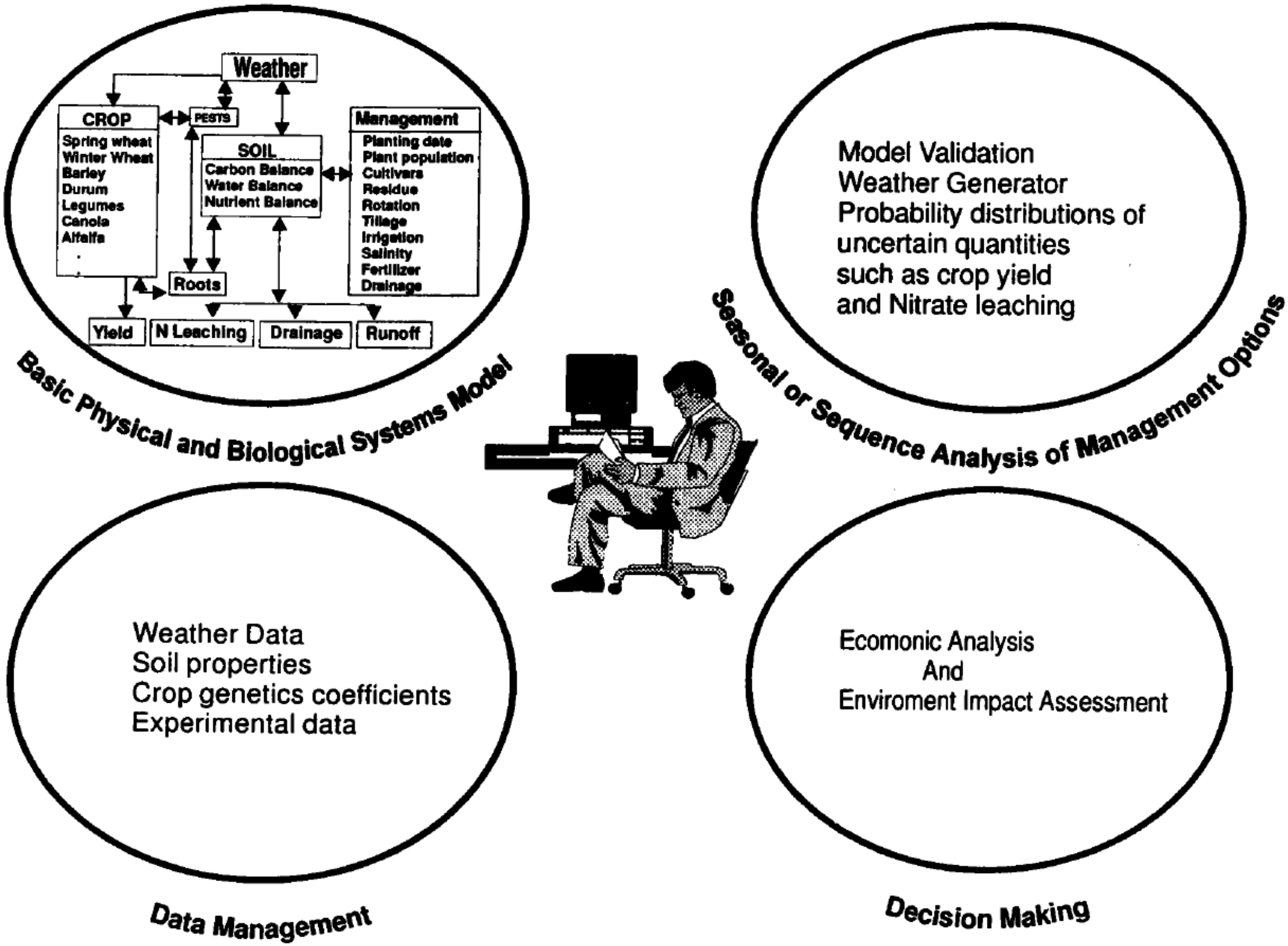


WATER PRODUCTIVITY TARGET



Source: Todorovic et al., 2016

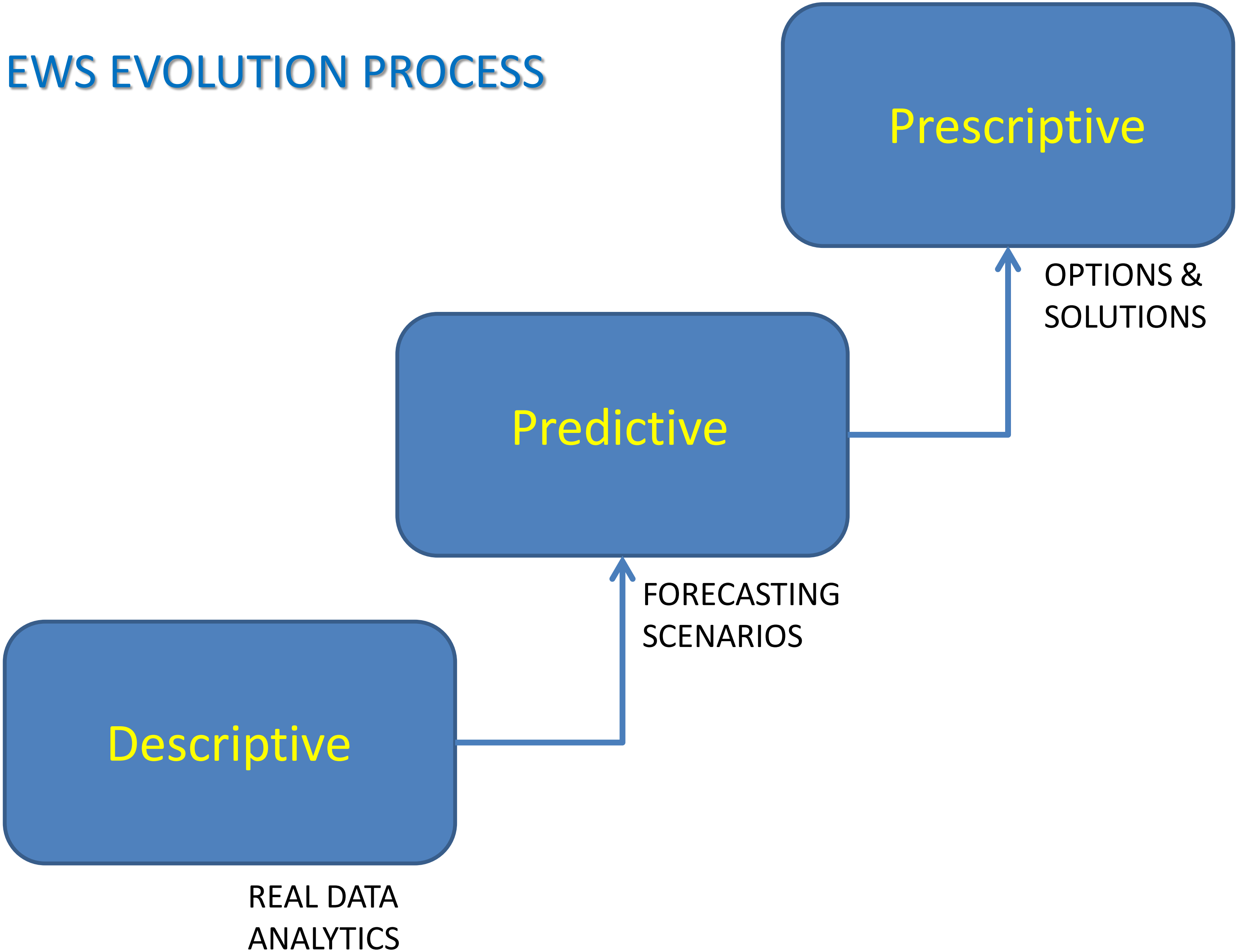
Structure of a field level agricultural decision system



Source: Jamme and Cutforth

EARLY WARNING SYSTEM FOR AWM

EWS EVOLUTION PROCESS



EWS Infrastructure

Agrometeorological observations

Network

- Rehabilitation
- Training

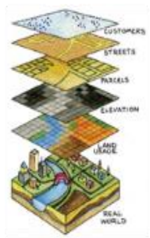
Database

- API download
- DBMS
- Users' interfaces
- QC
- Training

Weather forecasts

- Short
- Medium
- Long range
- Training

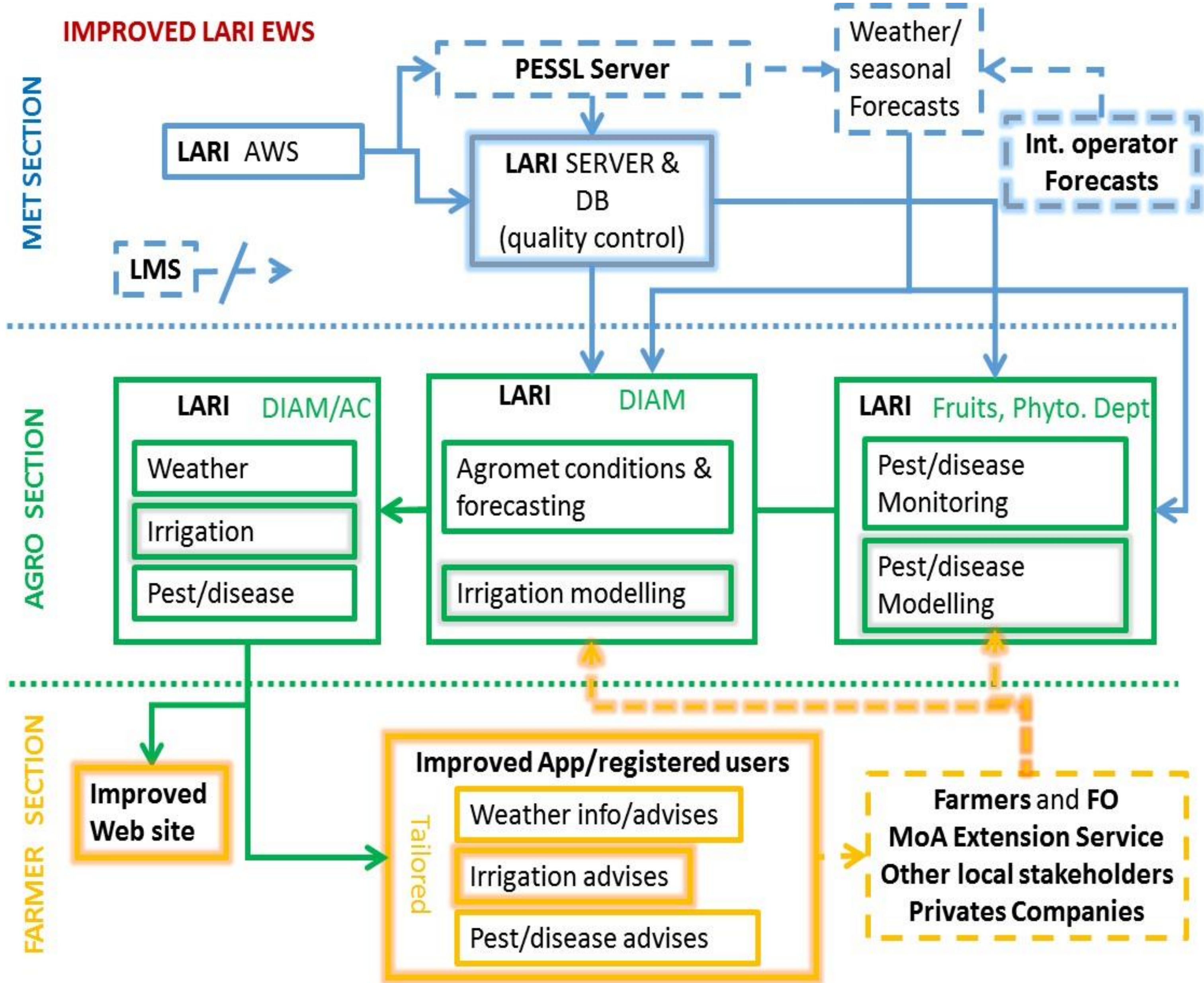
Agro-ecological zoning

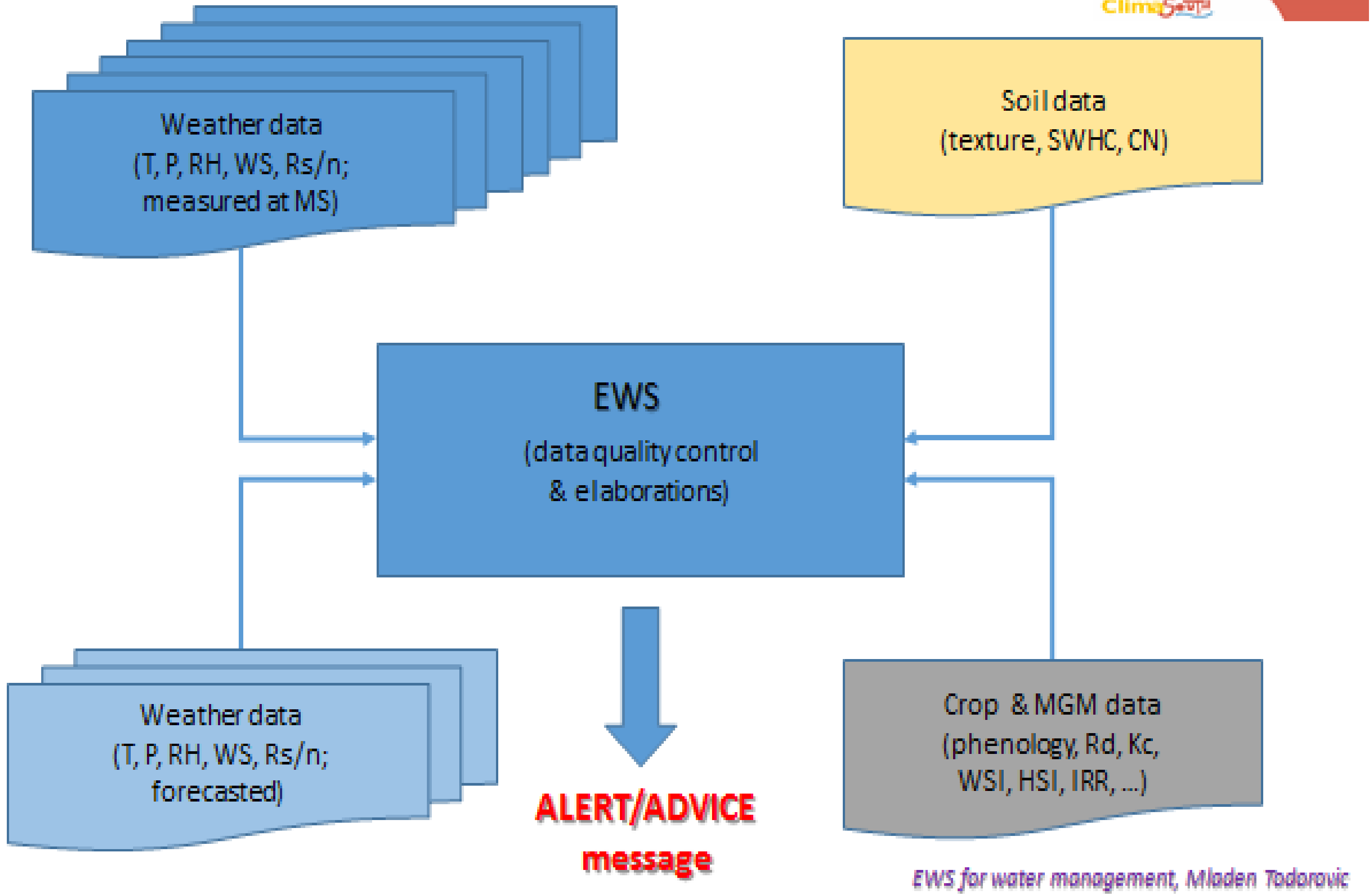


- Data collection
- Database
- Analysis
- Mapping

Communication and information

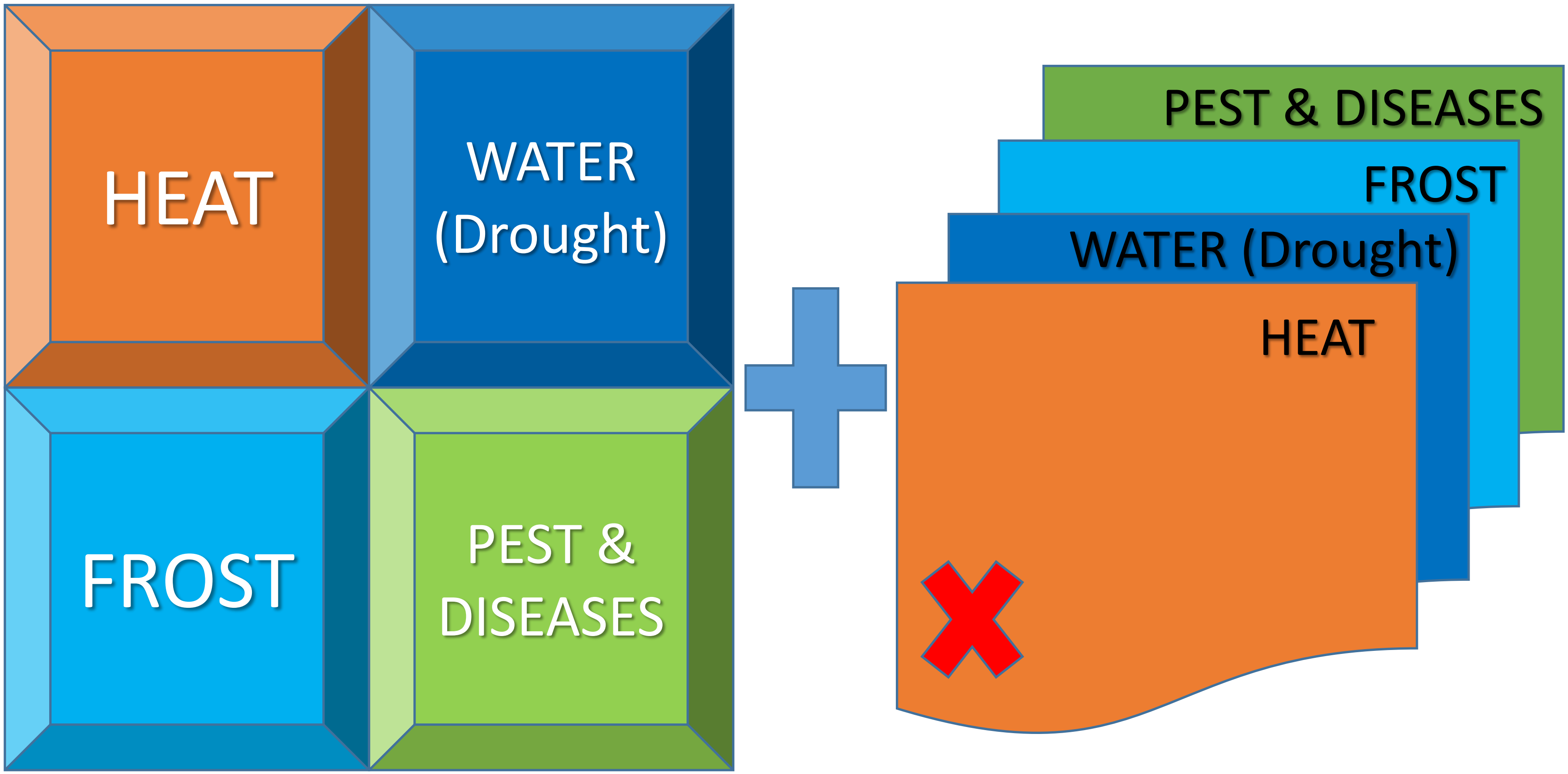
- SOP
- Improve web site
- Upgrade App
- Farmers
- Extension
- Public


IMPROVED LARI EWS
MET SECTION
PESSL Server
Weather/
seasonal
Forecasts
LARI AWS
LARI SERVER &
DB
(quality control)
Int. operator
Forecasts
LMS
AGRO SECTION
LARI DIAM/AC
Weather
Irrigation
Pest/disease
LARI DIAM
Agromet conditions &
forecasting
Irrigation modelling
LARI Fruits, Phyto. Dept
Pest/disease
Monitoring
Pest/disease
Modelling
FARMER SECTION
Improved
Web site
Improved App/registered users
Tailored
Weather info/advises
Irrigation advises
Pest/disease advises
Farmers and FO
MoA Extension Service
Other local stakeholders
Privates Companies

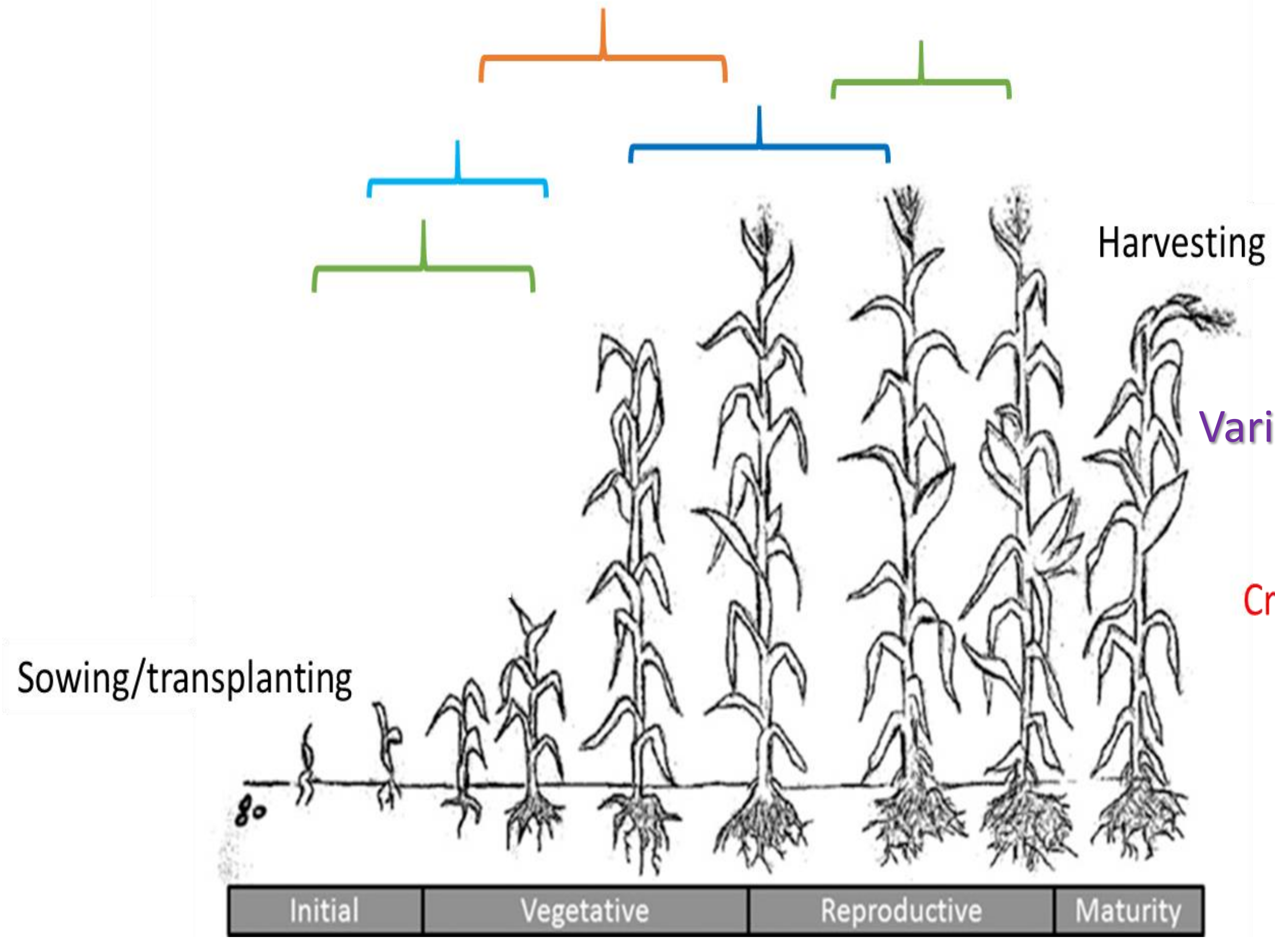


Weather data
(T, P, RH, WS, Rs/n;
measured at MS)
Soil data
(texture, SWHC, CN)
EWS
(data quality control
& elaborations)
Weather data
(T, P, RH, WS, Rs/n;
forecasted)
ALERT/ADVICE
message
Crop & MGM data
(phenology, Rd, Kc,
WSI, HSI, IRR, ...)
EWS for water management, Mladen Todorovic

Early Warning System for Agriculture



Crop development stages & Heat/Water/Frost/Pest/Disease Sensitivity periods



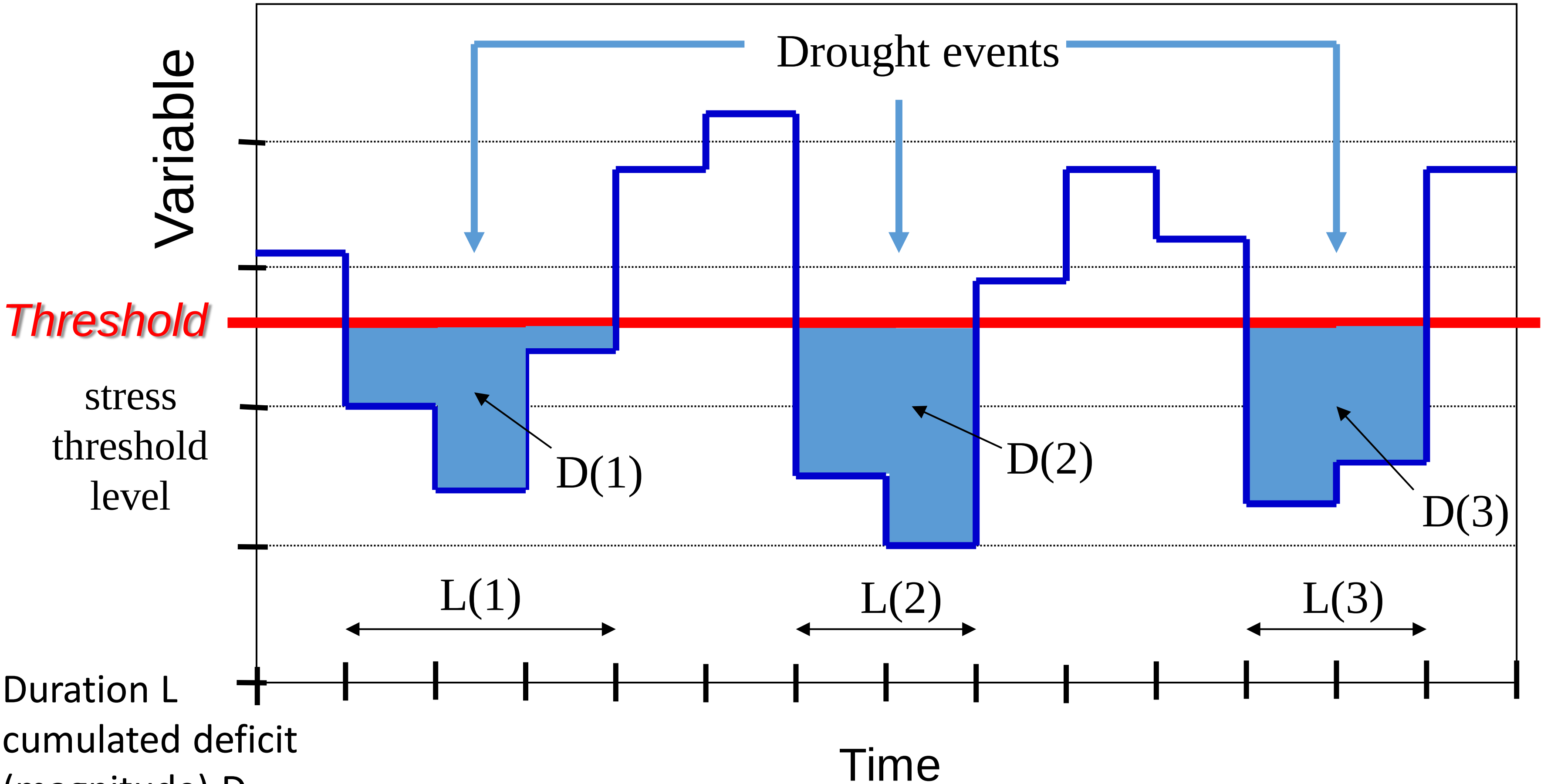
Variable, Dynamic, Overlapped

Crops, periods and duration?

Early Warning System for Agriculture: Basic concept of the stress risk assessment

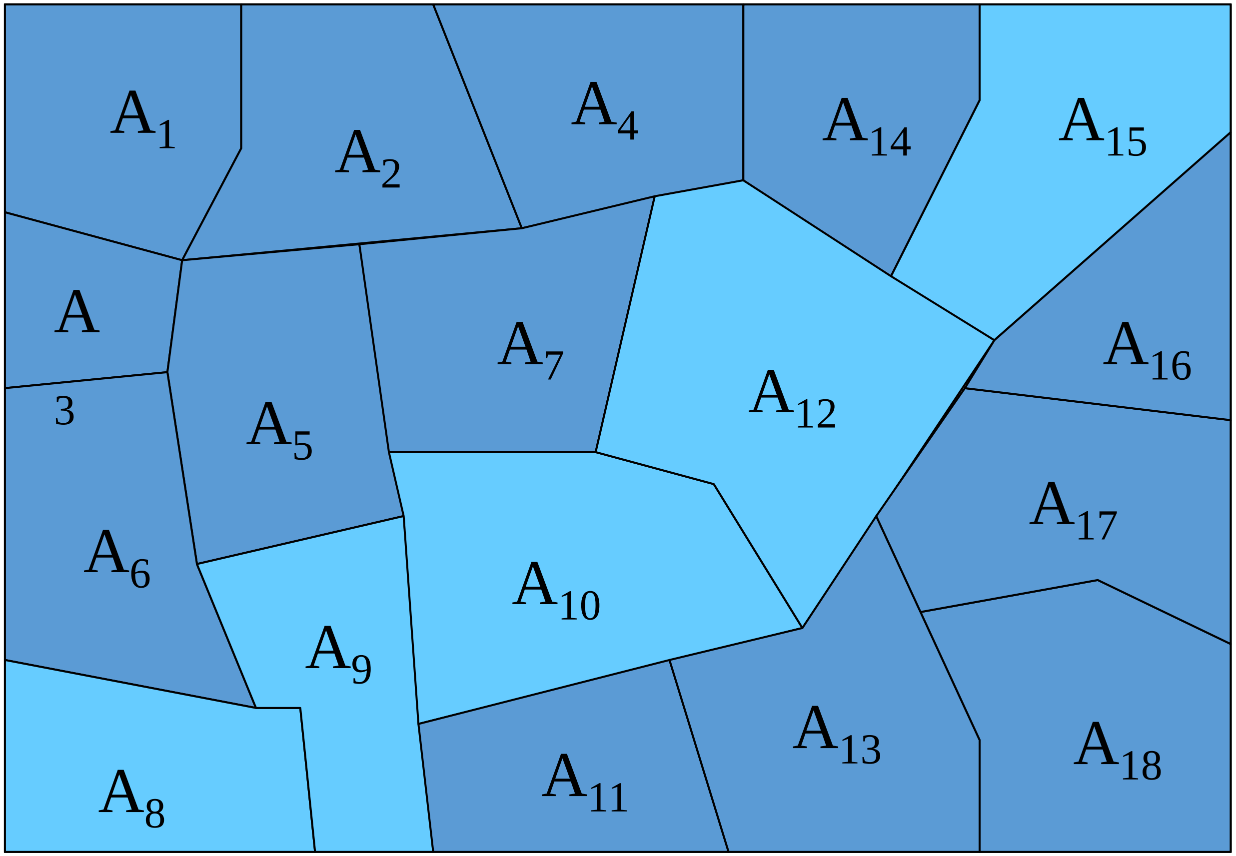
- Stress occurs when some weather (T, P) or system (root zone soil moisture content) parameter is above/below a predefined threshold during the stress sensitivity period.
- Stress risk thresholds differs among species and cultivars and in respect to the pedo-climatic and management conditions.
- Stress affects crop growth, development, biomass and yield.
- Yield-reduction function, the relative intensity of biomass/yield damage as a parameter under observation *rises above/decreases below* the stress thresholds.
- Maximum impact occurs when a parameter reaches an upper/lower critical limit.
- *In absolute terms, losses are potentially higher in more productive cropping systems*.
- The stress risk assessment includes several dimensions:
  - the duration and magnitude of stress,
  - the intensity of occurrence in relation to crop specific thresholds,
  - the frequency of occurrence of stress during sensitive periods,
  - the coinciding of different stresses – multi-stress, multiplicative effect
  - the expected impact (biomass/yield reduction of the affected crops).

Site Drought Identification - the Theory of runs



Duration L
cumulated deficit (magnitude) D
Intensity = D/L

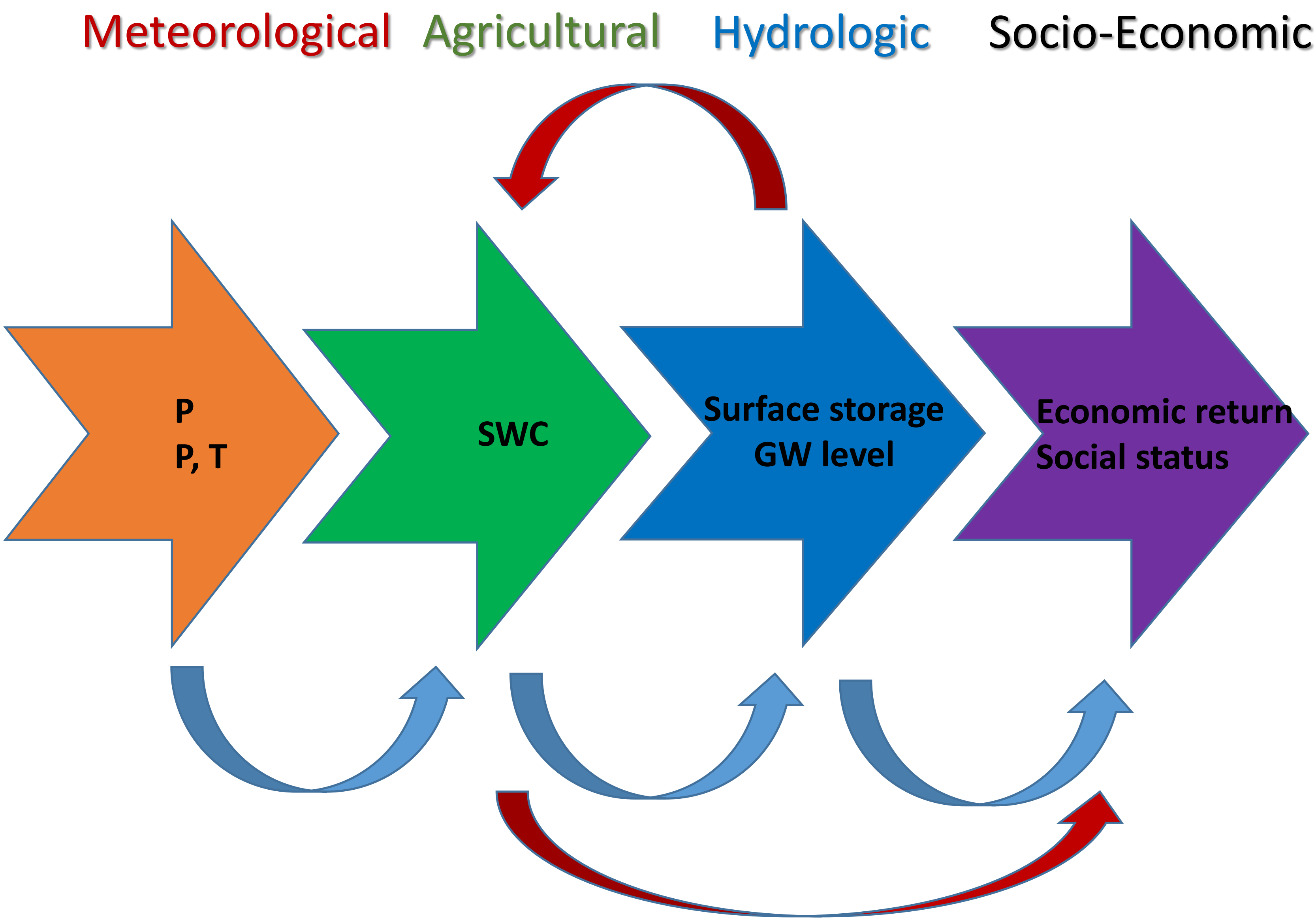
Regional Drought Identification



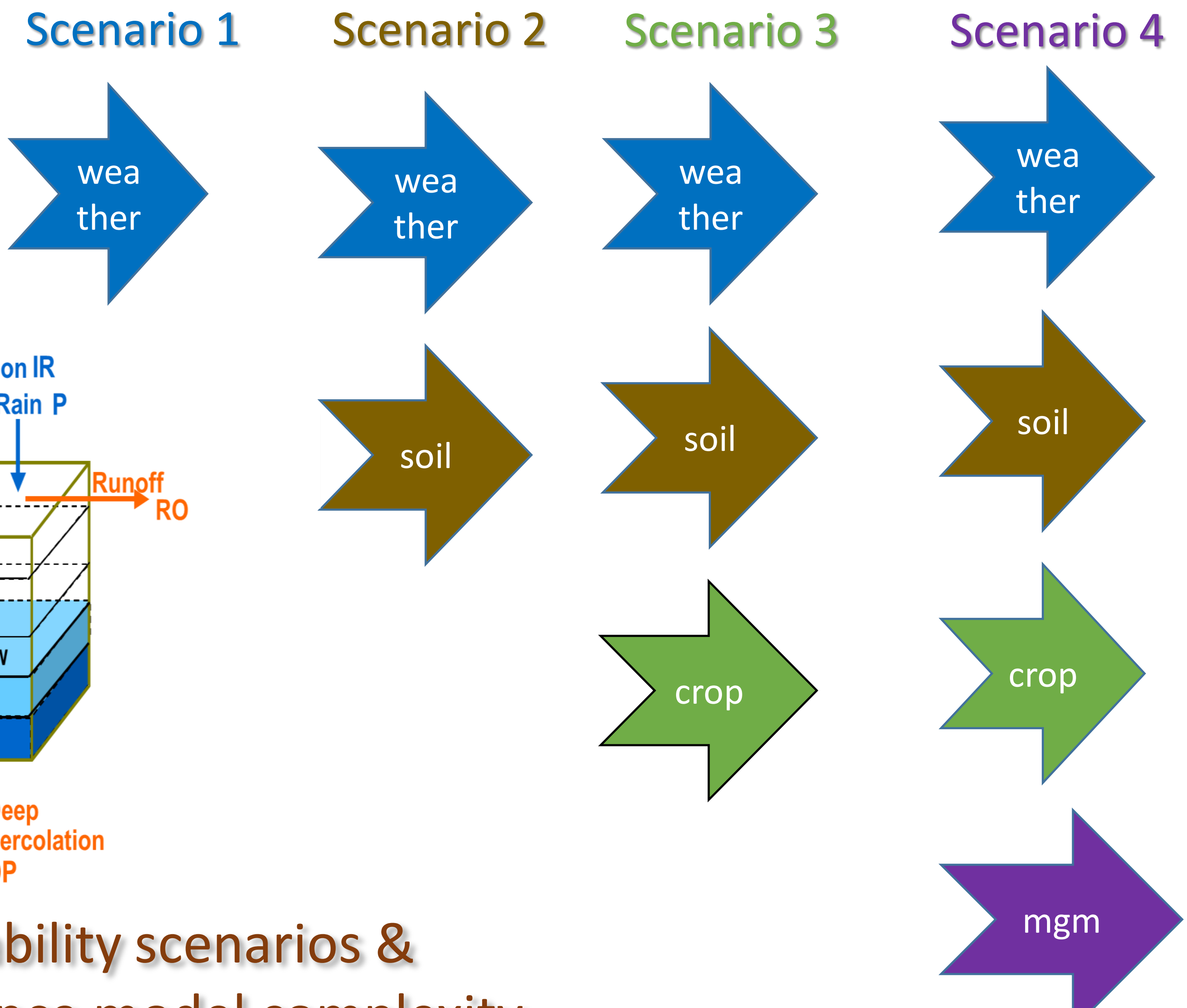
$$\Sigma A_j \geq A_C$$

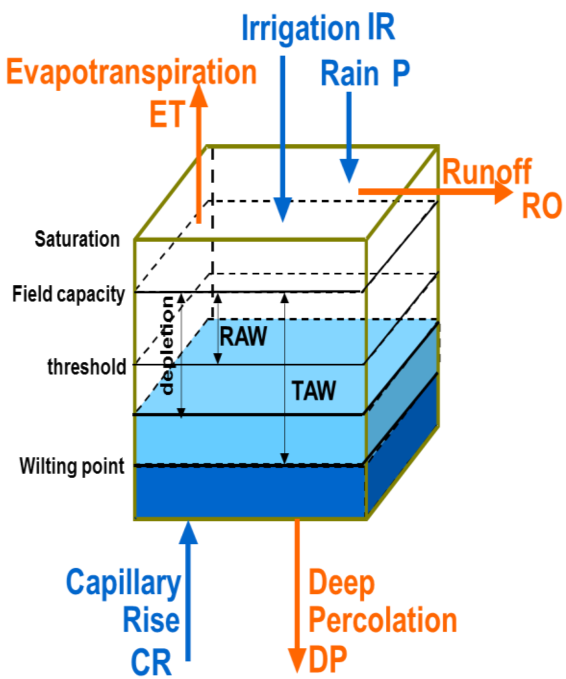
Regional drought - when the sum of the areas A_j affected by local drought reaches a selected threshold A_C (percentage of the total area under consideration)

Drought phases & evolution



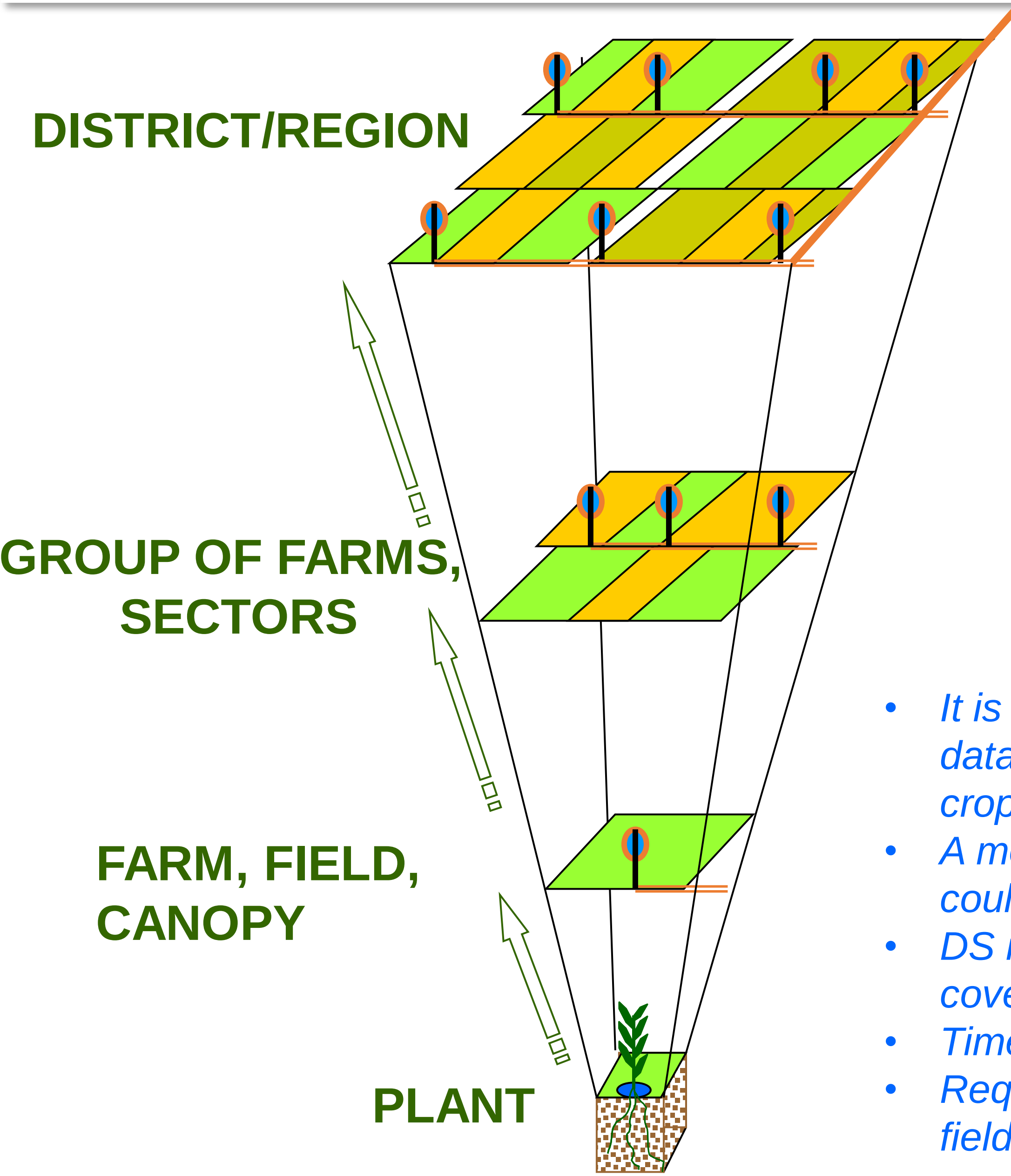
EWS for water management, Mladen Todorovic





Data availability scenarios & water balance model complexity

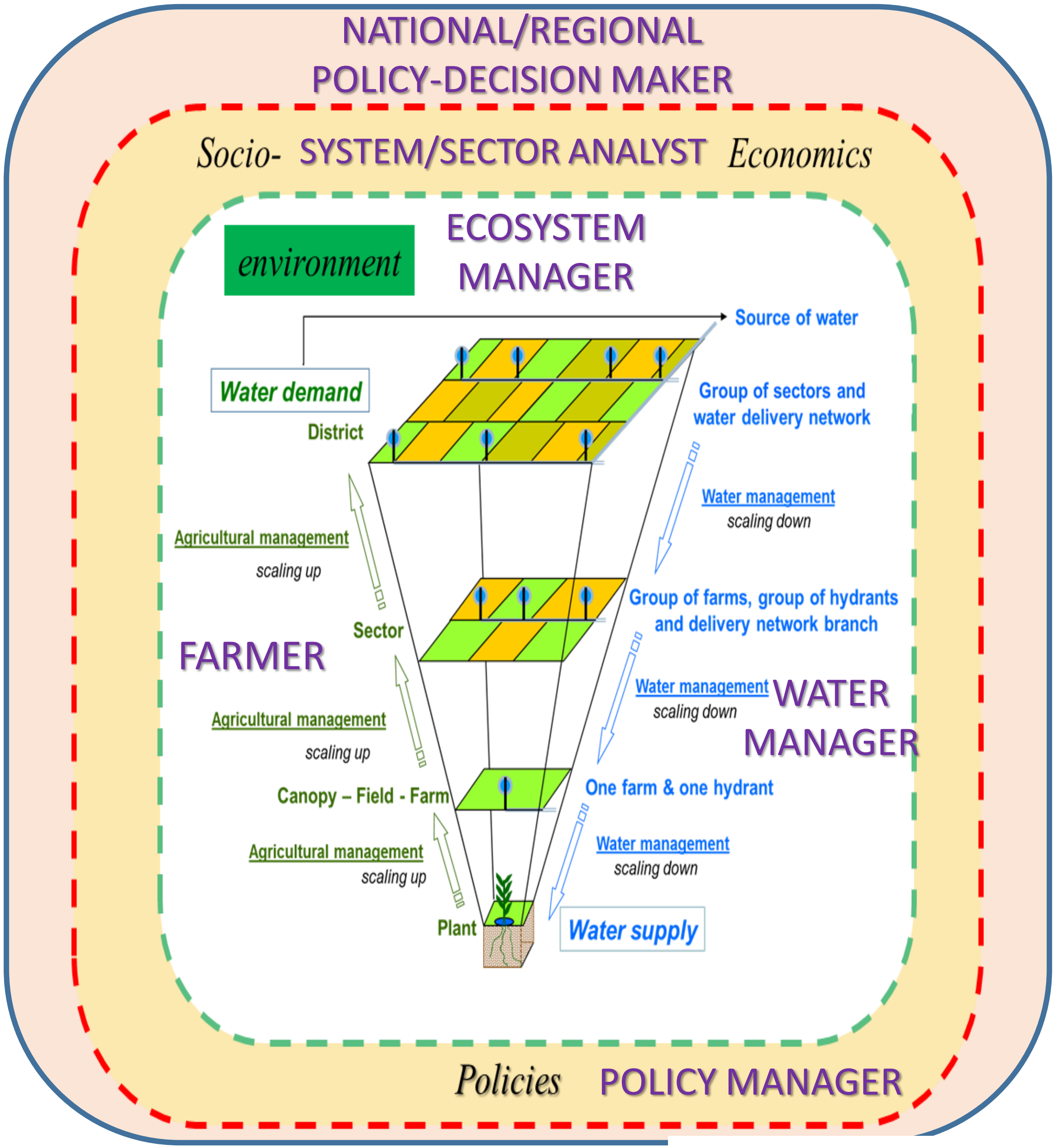
Data availability -> Approach & Application scale



- *Difficult to have timely, good quality and good resolution data*
- *Usually only weather data are available (and should be interpolated)*
- *A simple (basic) EWS approach should be adopted*
- *DS is rough (general) but covers large areas and could be useful for numerous stakeholders*
- *Easy to operate, maintain and understand*
- *Minimum maintenance requirements (staff support)*

- *It is possible to have timely and good quality data for some locations including weather, soil, crop and management practices*
- *A more complex, integrated EWS approach could be adopted*
- *DS is crop/site-specific and more accurate but covers small areas and is suitable to few users*
- *Time consuming setup and calibration*
- *Requires continuous monitoring/control (on-field staff support)*

Early Warning System for Agriculture: Multi-level stakeholders approach



Source: Todorovic, 2016

EWS key features

1. Modular, able to consider different type of risks and their interaction; and, therefore, flexible
2. Area (weather), soil, crop, management specific in agreement with data availability (to be assessed).
3. Focusing primarily on drought (water stress) risk
4. Based on different level of complexity (depends on data availability) and addressed to different type of users (farmers, water managers, extension service staff, policy/decision makers, etc.).
5. Dynamic, based on daily water balance generated in its simplest form from weather data and also from soil and crop/mgm data when available.
6. Include both site and region specific risk alert.
7. Include irrigation advice support (complexity depends on data availability)
8. Prone to consider different phases of drought (water) stress (meteorological, agricultural, hydrological)

EXAMPLES OF DSS FOR AWM ELSEWHERE

CropIrri – China (Zhang and Feng, 2010)

- designed for dryland crops (wheat, maize, and soybean) to provide a practical decision tool for irrigation management.
- Main functions:

  1. irrigation decision services to evaluate crop water requirements and to make pre-sowing and the real-time irrigation schedule based on the historical weather data and weather forecast information,

  2. to simulate daily change of soil moisture in the root zone,

  3. to evaluate a given irrigation schedule and to develop a better alternative irrigation schedule,

  4. to modify the planned results according to themeasured actual soil moisture content during crop growth period to enhance the forecasting accuracy,

  5. database management capability.
- combines environmental conditions, like climate and soil, with crop growth characteristics as a whole, and was established using soil water balance model, crop phenology model, root growth model, crop water production function, and irrigation decision-making model

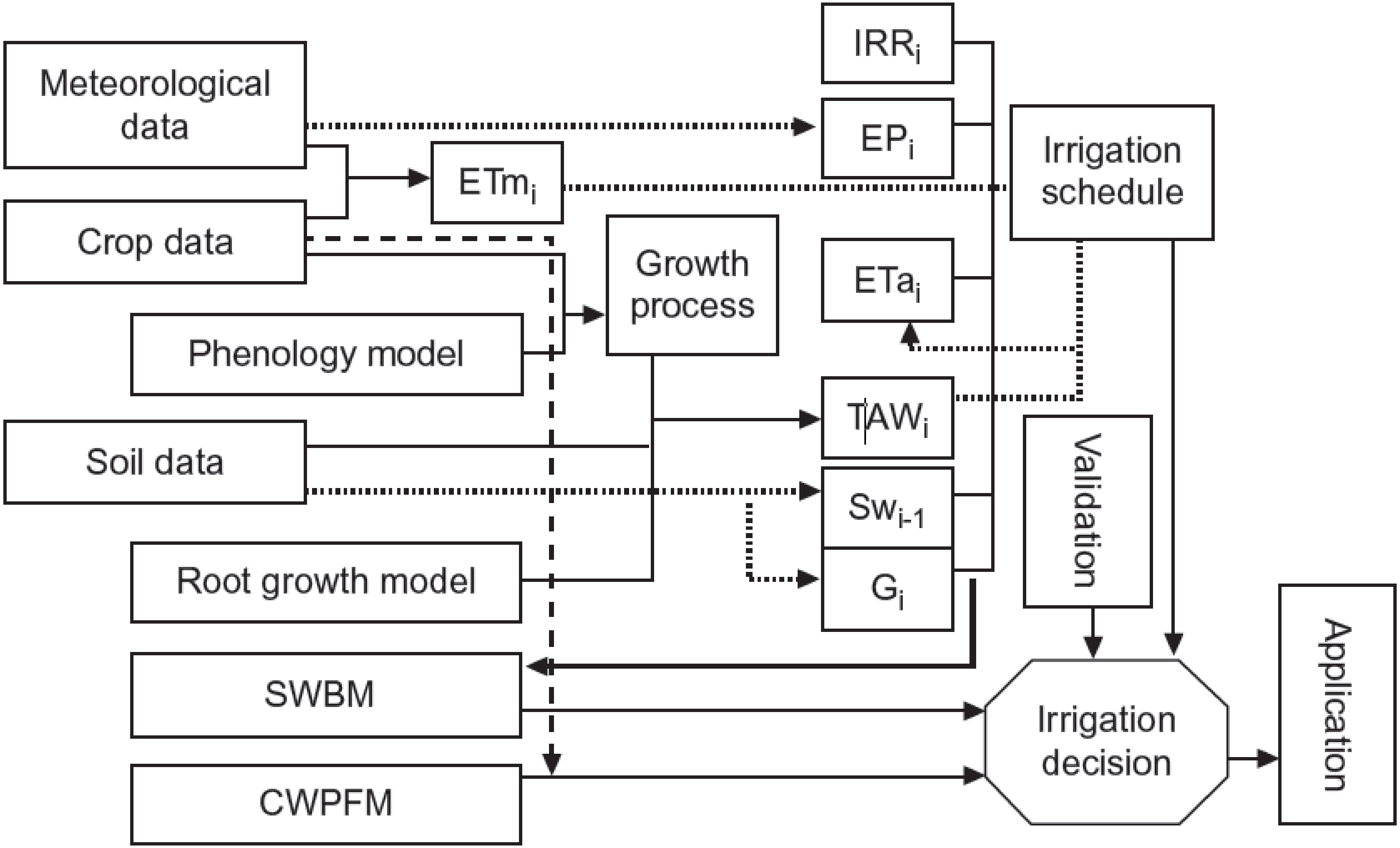


Figure 6.3 Irrigation flowchart of CropIrri (Zhang and Feng, 2010). The subscript "i" indicates a "i-th" day; SW_{i-1} is soil water depletion in the root zone at end of the previous day, i-1, ETa_i is actual crop evapotranspiration; ETm_i is maximum crop evapotranspiration; EP_i is effective precipitation; G_i is capillary rise from the groundwater table; IRR_i is net irrigation; TAW_i is total available soil water in the root zone.

CropIrri – irrigation management options

- Non-limiting: meets the need of CWR and obtains maximum crop production. By comparing the daily soil moisture deficit with readily available moisture in the soil profile, when soil moisture deficit approaches readily available moisture, irrigation is applied to avoid water stress. Soil water content is replaced to 80% of field capacity to avoid deep water losses.
- Water saving: the aim is to obtain highest yield with highest WUE. The critical period of water requirement is booting stage for wheat and flowering stage for soybean. The critical period of water requirement is from flowering stage to milk stage for maize. When the soil moisture content in the root zone is below the appropriate low-limited water content, irrigation schedule is made to irrigate to the appropriate upper-limited water content.
- Irrigation with experience: Irrigation is made by taking into account the farmer's experience. In order to ensure crop emergence, priority should be given to sowing irrigation and then to consider the importance of the crop water requirement to determine irrigation plan. Taking wheat as an example, if one irrigation is planned, it should be applied at the booting period. If two irrigations are needed, it should be applied at turning green stage and booting stage if wheat was irrigated at sowing and at winter stage and booting stage if wheat was not irrigated at sowing. Each irrigation amount should reach the SWC at 80% of field capacity.
- Advanced: for researchers and technicians. Users can customize the date and amount of irrigation for different purposes, such as periodic irrigation with certain amount of water, for example, irrigation with 50 mm of water or soil water content reaching to field capacity at soil moisture content decreasing to 60%of field capacity or irrigation with 100 mm at fixed interval of 30 days. This way we can understand the change of soil moisture content and crop water consumption. This could support and assist scientific research in crop water relation.

HydroLOGIC

- designed in Australia, mainly to evaluate the consequences of several irrigation strategies and to explore options to optimize yield and WUE at a field level in cotton (Richards et al., 2008).
- This information maybe subsequently used to assess economic and environmental consequences resulting from differences in irrigation production practice.
- OZCOT cotton crop simulation model (Hearn, 1994) is embedded within the HydroLOGIC system – this model is used to predict daily crop growth and water use.
- Predictions of yield and water use are based on potential growth determined by OZCOT, historical climate records, and the alternative irrigation management scenarios for the rest of the season.
- HydroLOGIC is also designed to balance calibrated soil moisture monitoring systems.
- The HydroLOGIC interface can be divided into five main components

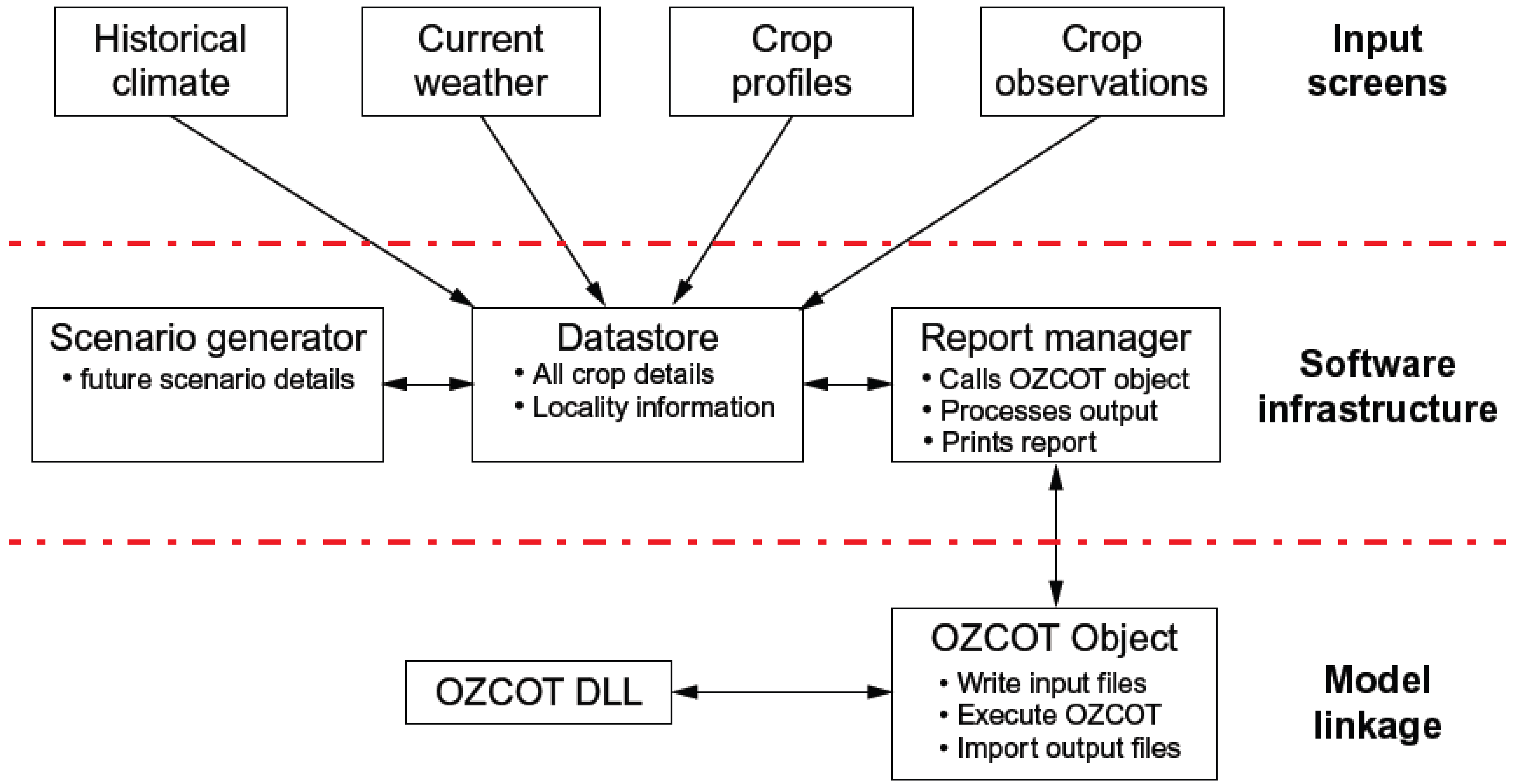
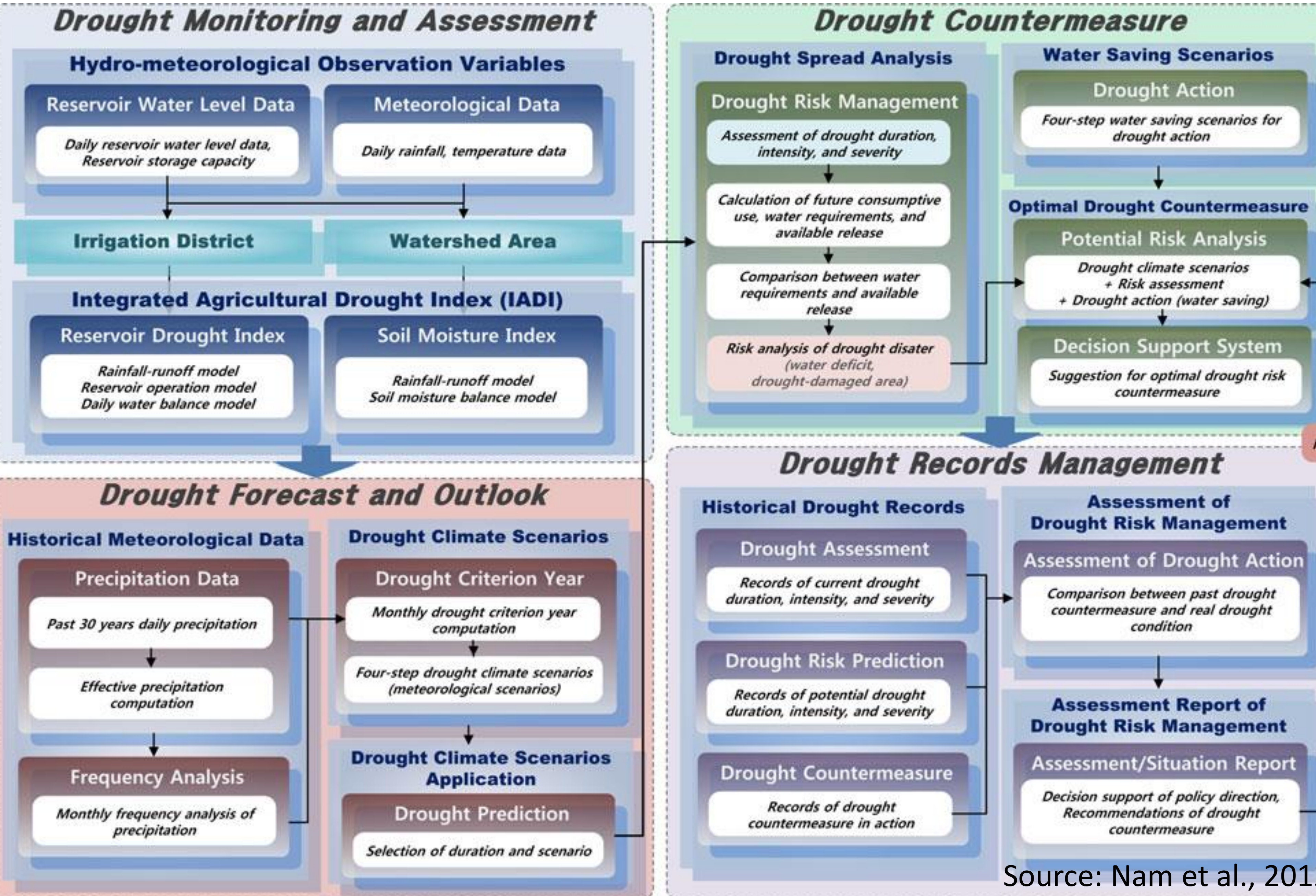


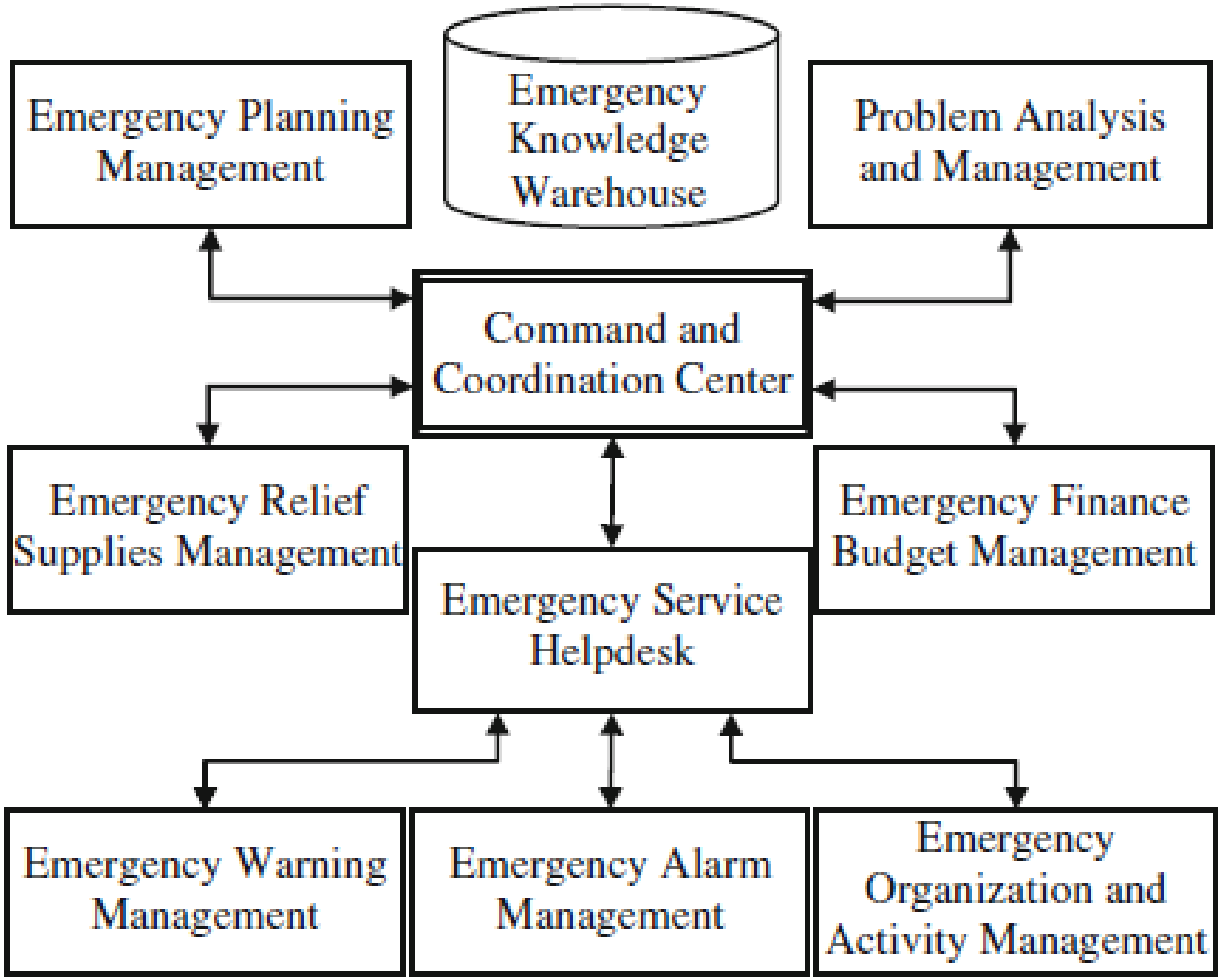
Figure 6.4 HydroLOGIC scheme (Richards et al., 2008).

Decision support system process for agricultural drought management using risk assessment



Source: Nam et al., 201

Emergency Response DSS



Source: Shan et al., 2012

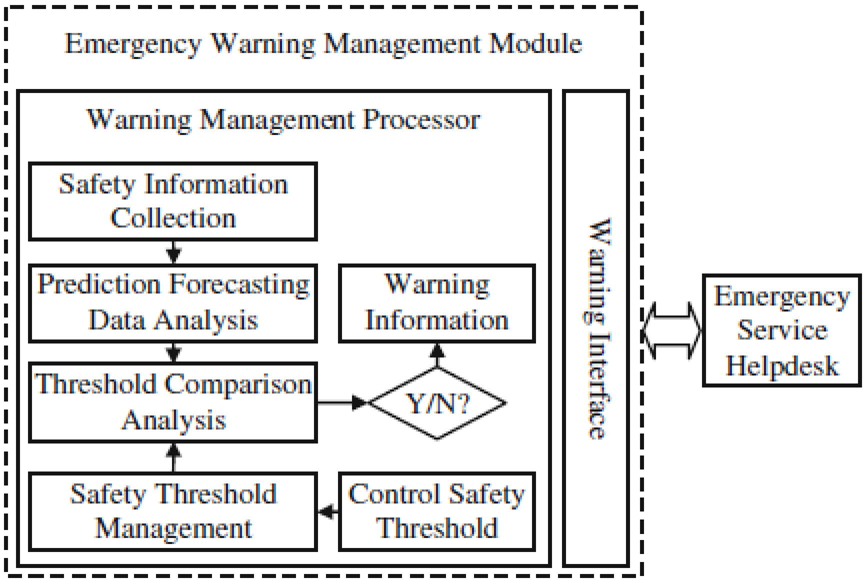


Fig. 9 Architecture of the Emergency Warning Management Module

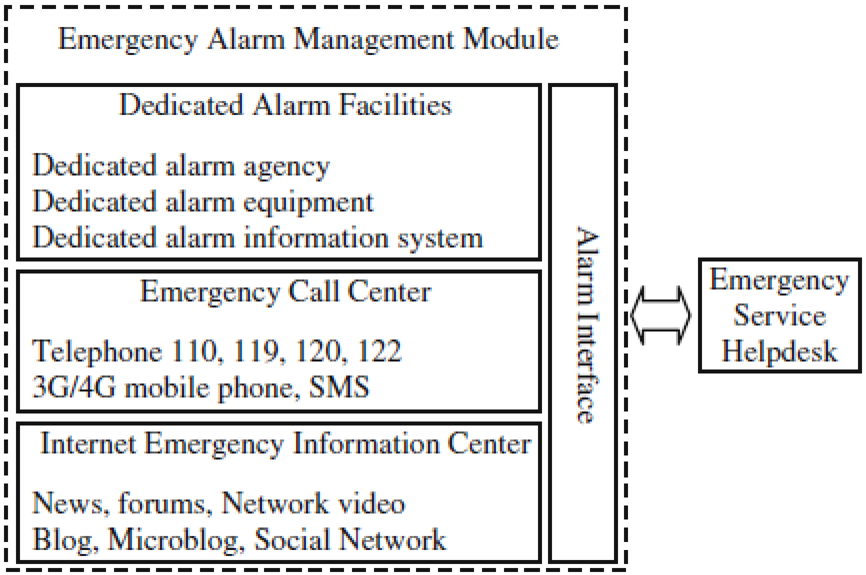


Fig. 10 Architecture of the Emergency Alarm Management Module

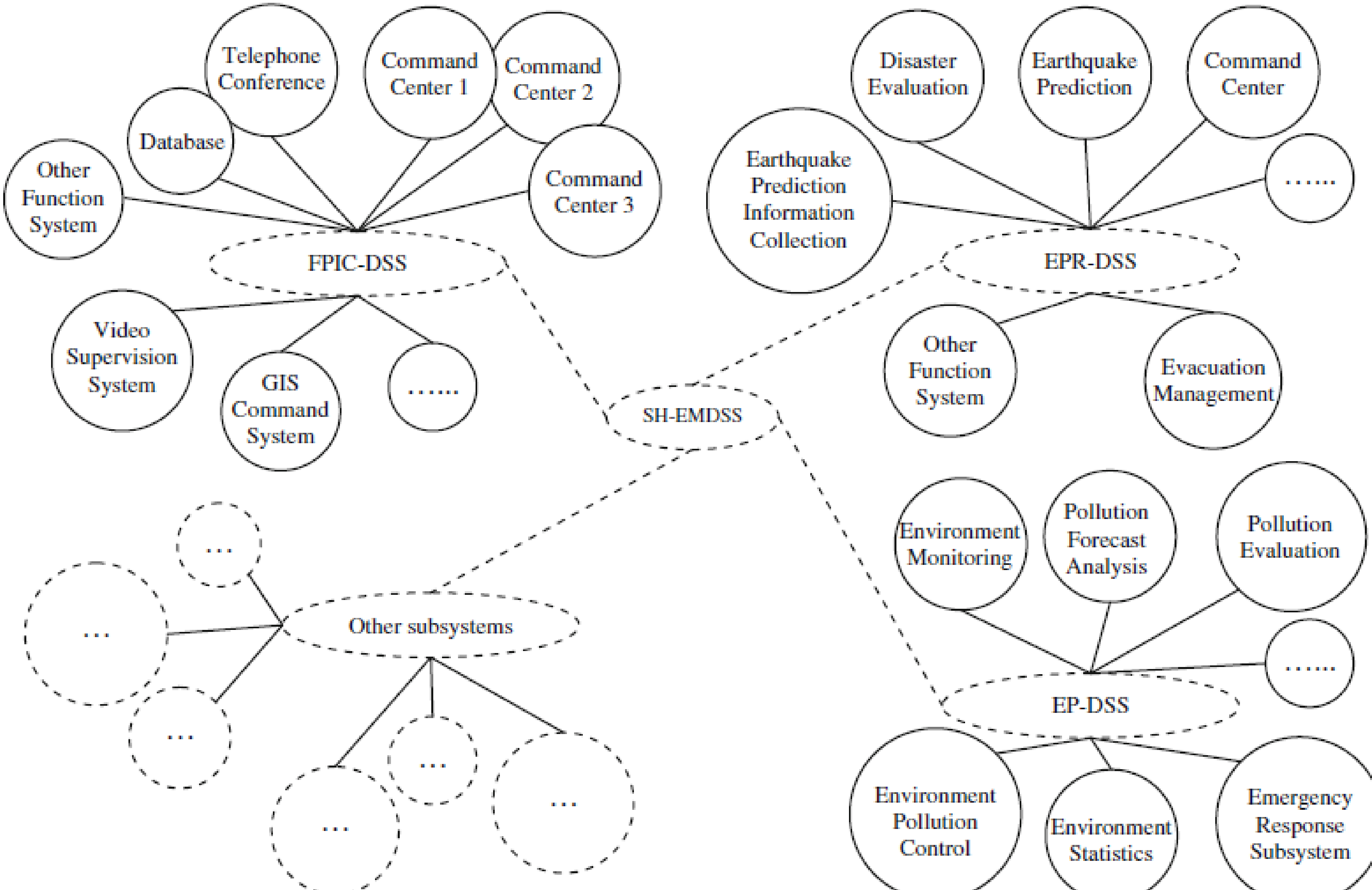


Fig. 12 The SH-EMDSS framework