Assessment of Irrigation Sustainability in Tha Chin Basin, Thailand and Development of a Framework for Water Management in the Basin and under Climate Change

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Outline

- Objectives of the Study
- Background of the Study Area
- Analyses
- Results
- Conclusions

Objectives of the study

1. To identify/select major factors affecting irrigation systems in Tha Chin Basin based on primary and secondary data.

2. To develop an irrigation sustainability index (ISI) based on key indicators using Principal Component Analysis (PCA).

3. To assess the sustainability of two irrigation projects in Tha Chin Basin based on ISI.

4. To Adopt DPSIR framework to improve irrigation management in the basin, and recommend climate change adaptation measures.

Background of Study Area

According to NESDP, Tha Chin Basin is considered as one of the critical basins in the central Thai region with respect to its water resources and condition of existing irrigation infrastructures. Two irrigation projects located in Tha Chin Basin, namely Kamphaengsaen (KPP) and Phophraya (PPP) O&M projects are selected for evaluation based on their location and crops.

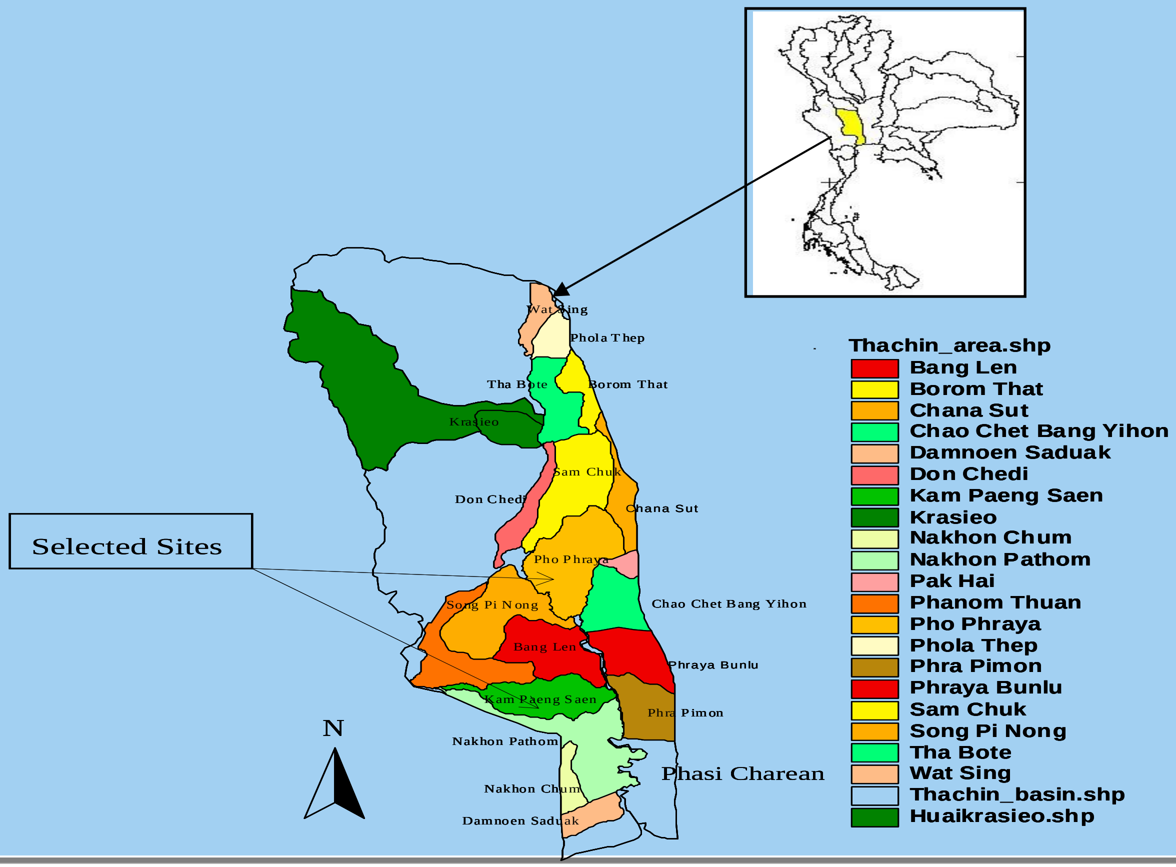


Fig 1 Operation and Maintenance projects in Tha Chin Basin

Table 1 Site Description of KPP and PPP

Features	KPP	PPP
Project implementation	First irrigation project as part of development of Mae Klong basin (1975)	First irrigation project as part of development of Suphanburi river basin (1921)
Land area	50,560 ha	66,550 ha
Irrigated area	40,448 ha	59,200 ha
Population	225,904	191,781
Soil type	Mostly clay	Clay
Average rainfall	1,255 mm	1,290 mm
No. of canals	29	17
No. of zones	27	11 (Section 1)
Ave area per zone	1,873 ha/zone	1,455 ha/zone
Water sources	Mae Klong Dam	Chao Praya Dam
Sample size for survey	1,396	462

Questionnaire survey

Sample size is estimated using the equation:

$$n = \frac{N}{1 + N.e^2} \qquad (1)$$

$$e = \left(\frac{\frac{N}{n} - 1}{N} \right)^{1/2} \qquad (2)$$

Where

n = number of household samples

N= total number of household

e = precision level

Site description (cont) - KPP

The total land area covers 50,560 ha and irrigated area is 40,448 ha. Rice, sugarcane and farm crops (maize, finger root, asparagus) comprise 43 %, 32% and 17% of the area, respectively, while the remaining 8% include fruit trees, fish pond and shrimp farm

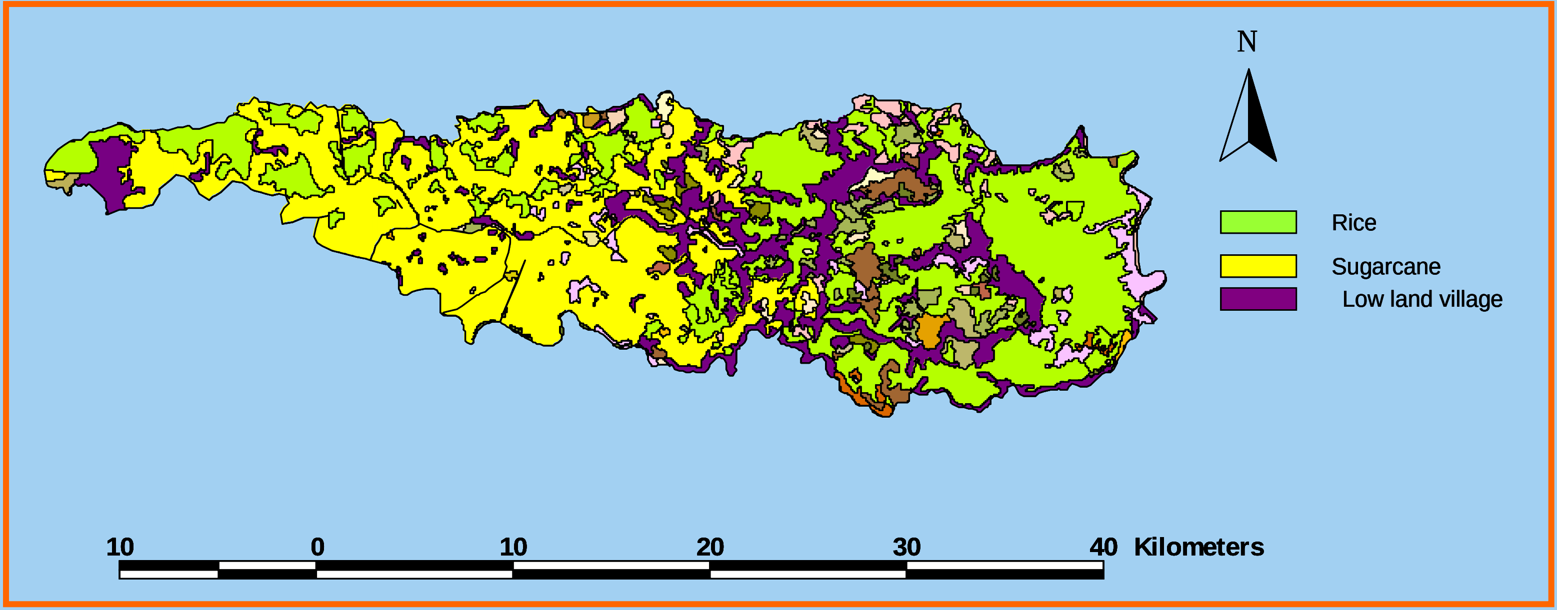


Fig 2 Land Use in KPP

Cropping Pattern

The main crops are rice, sugarcane, baby corn, asparagus. Rice is cultivated twice a year.

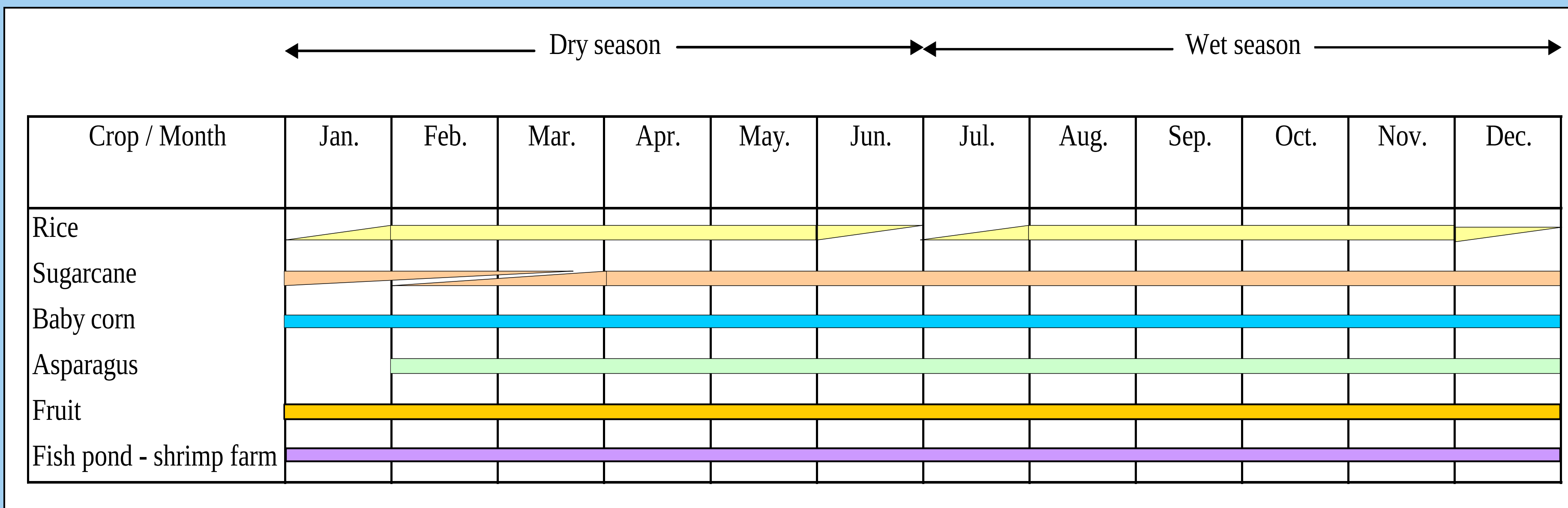


Fig 3 Crop Calendar of KPP

Site description (cont) - PPP

The total land area covers 66,550 ha and irrigated area is 59,200 ha. Rice covers 90 % of the area and the remaining 10% consists of fruit trees, fish pond, shrimp farm and farm crops.

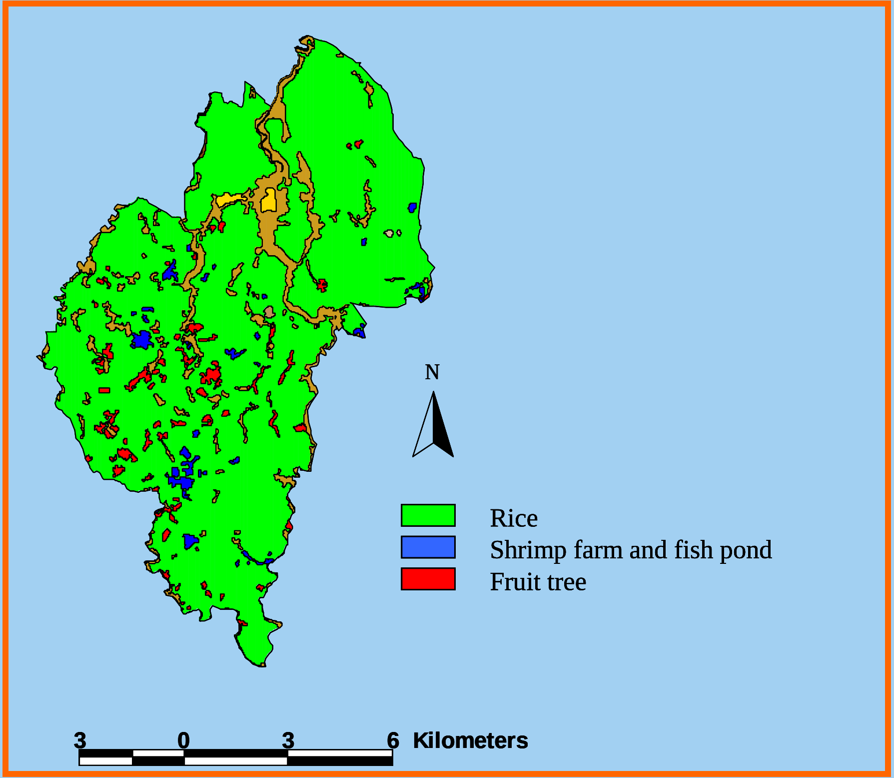


Fig 4 Land use in PPP

Cropping Pattern

The main crops are rice, earth almond, sweet potato. Rice is cultivated more than twice a year

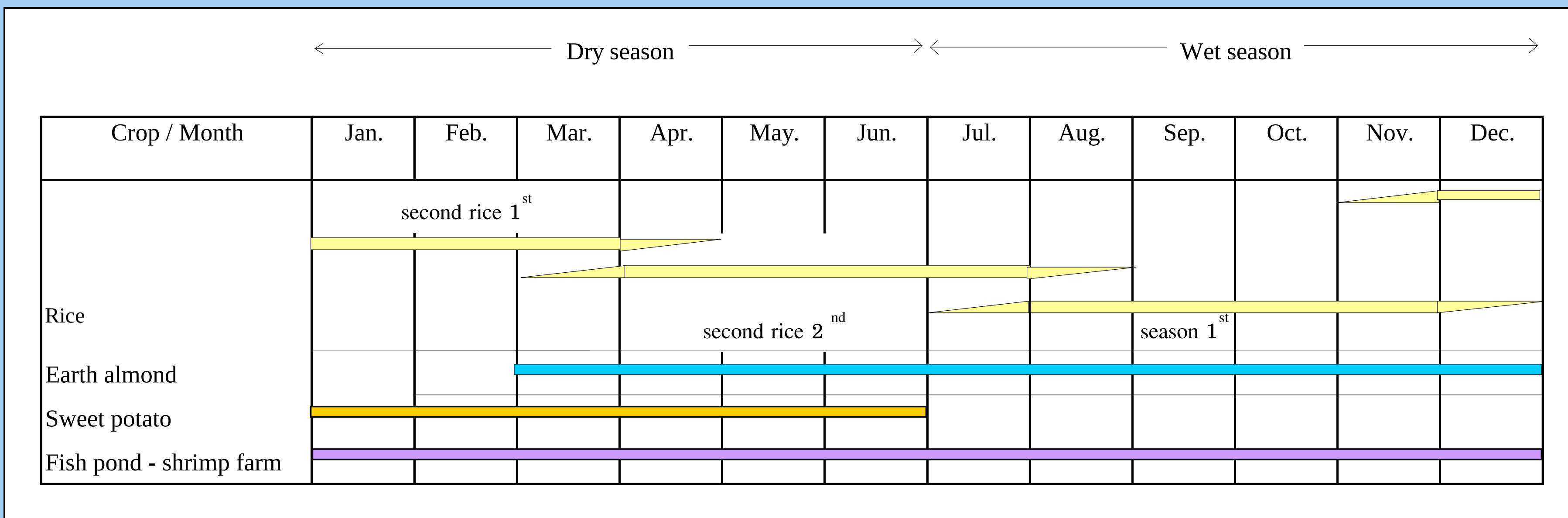


Fig 5 Crop Calendar of PPP

Evaluation of Key Indicators using Principal Component Analysis (PCA)

Determination of key indicators

1) Select a set of physical, socio-economic, institutional and environmental indicators for the study area.

2) Find out principal components (PCs) which best represent the indicator using PCA.

PCA Approach

1) T-test – check for data distribution

2) Assessment of the suitability of data
   - Sample size (KMO≥0.5)
   - Strength of relationship among the variables

3) Factor extraction
   - Eigenvalue ≥ 1.4

Table 2 Selected indicators in the study area

Categories	Indicators
Physical	Soil property (soil fertility)
	Flow ratio
	Field application ratio
	Flooding frequency
Socio-economic	Crop yield
	Farm income
	Net farm income
	Awareness on irrigation water use
	Water user conflict occurrence
Environmental	Soil property (EC, pH)
	Irrigation water quality (EC, pH)
	Perception of drained water quality
	Perception of soil quality
	Type of crop residue treatment
Institutional	Satisfaction on adequacy of water distribution
	Matching of farm operations with RID water delivery
	Satisfaction on reliability of continuous flow
	Satisfaction on institutional organization
	Willingness to pay

Table 3 Indicators Used for PCA in KPP and PPP

Indicators
Flow ratio
Field application ratio
Flooding frequency
Crop yield
Farm income
Net farm income
Awareness on irrigation water use
Water user conflict occurrence
Soil property
Irrigation water quality (pH)
Perception of drained water quality
Perception of soil quality
Willingness to pay
Satisfaction on adequacy of water distribution
Matching of farm operations with RID water delivery
Satisfaction on reliability of continuous flow
Satisfaction on institutional organization
Type of crop residue treatment (only in KPP)

Table 4 Output from PCA for KPP

Indicators	Principal Components (PCs)				Communalities
	1	2	3	4	
Flow ratio		0.258	-0.219	0.823	0.79
Field application ratio		-0.173		<u>0.888</u>	0.83
Farm income	0.980				0.97
Net farm income	<u>0.985</u>				0.97
Awareness on irrigation water use		<u>0.793</u>	-0.111		0.65
Perception of drained water quality		0.719		-0.112	0.53
Perception of soil quality		0.735	0.164	0.108	0.58
Satisfaction on adequacy of water distribution	-0.145	0.182	0.627		0.45
Matching of farm operations with RID water delivery			<u>0.837</u>	0.122	0.73
Satisfaction on reliability of continuous flow			0.793	-0.190	0.67

Note: Loading values less than 0.10 are ignored (absolute values)

: Factor loadings which are underlined are considered highly weighted (key factor)

Table 5 Output from PCA for PPP

Indicators	Principal Components (PCs)				Communalities
	1	2	3	4	
Flow ratio			-0.163	<u>0.928</u>	0.89
Field application ratio	0.148			0.918	0.87
Crop yield	-0.119		0.677	0.151	0.50
Farm income			0.862	-0.273	0.82
Net farm income	-0.110		<u>0.873</u>	-0.174	0.80
Water user conflict occurrence	-0.659		0.196		0.47
Perception of drained water quality	<u>0.834</u>				0.71
Perception of soil quality	0.826				0.71
Satisfaction on adequacy of water distribution	-0.235	<u>0.718</u>		0.362	0.70
Matching of farm operations with RID water delivery	0.453	0.667			0.66
Satisfaction on reliability of continuous flow		0.687	-0.148		0.50
Satisfaction on institutional organization		0.798		-0.161	0.66

Note: Loading values less than 0.10 are ignored (absolute values)

: Factor loadings which are underlined are considered highly weighted (key factor)

Table 6 Key Indicators for KPP and PPP

Categories	Key Indicators	
	KPP	PPP
Physical	1. Field application ratio	1. Flow ratio
Socio-economic	2. Net farm income 3. Awareness on irrigation water use	2. Net farm income
Environmental	-	3. Perception of drained water quality
Institutional	4. Matching of farm operations with RID water delivery	4. Farmers' satisfaction on adequacy of water distribution

Developing an Irrigation Sustainability Index (ISI)

ISI is developed based on the equation:

$$ISI = \sum_{i=1}^{n} W_i * Y(X_i) \qquad (3)$$

where

W = PC weighting factor

y = the score of the retained variable (key indicator)

= (z - s) / (1.1t – s)

z= value of key indicator (0 to 1), s = lowest possible value of indicator (i.e. s = 0), and

t = highest possible value of indicator

X = Key indicators

ISI equation was developed using all indicators that are retained within all components with Eigenvalue ≥ 1.4.

Table 7 Principal Components (PCs) for KPP

PCs	Eigenvalue	% of Variance	% of Cumulative variance	Weight*	MDS- Indicators	Symbol
1	1.990	19.898	19.898	0.277	Net farm income	X_1
2	1.824	18.239	38.137	0.254	Awareness on irrigation water use	X_2
3	1.817	18.165	56.302	0.253	Matching of farmer operations with RID water delivery	X_3
4	1.551	15.512	71.814	0.216	Field application ratio	X_4

The general equation for estimating ISI for each zone in KPP:

$$ISI = 0.277Y_{(X1)} + 0.254Y_{(X2)} + 0.253Y_{(X3)} + 0.216Y_{(X4)} \quad \text{....... (4)}$$

Y = the score of the retained variable (key indicator): the greater means higher contribution
= (z - s) / (1.1t - s)
X1 = Net farm income
X2 = Awareness on irrigation water use
X3 = Matching of farm operations with RID water delivery
X4 = Field application ratio

ISI equation was developed using all indicators that are retained within all components with Eigenvalue ≥ 1.4.

Table 8 Principal Components (PCs) for PPP

PCs	Eigenvalue	% of Variance	% of Cumulative variance	Weight*	MDS- Indicators	Symbol
1	2.148	17.901	17.901	0.259	Perception on drained water quality	X_1
2	2.089	17.412	35.312	0.252	Farmers' satisfaction on adequacy of water distribution	X_2
3	2.064	17.200	52.513	0.248	Net farm income	X_3
4	2.006	16.713	69.225	0.241	Flow ratio	X_4

The general equation for estimating ISI for each zone in PPP:

$$ISI = 0.259Y_{(X1)} + 0.252Y_{(X2)} + 0.248Y_{(X3)} + 0.241Y_{(X4)} \quad \text{......(5)}$$

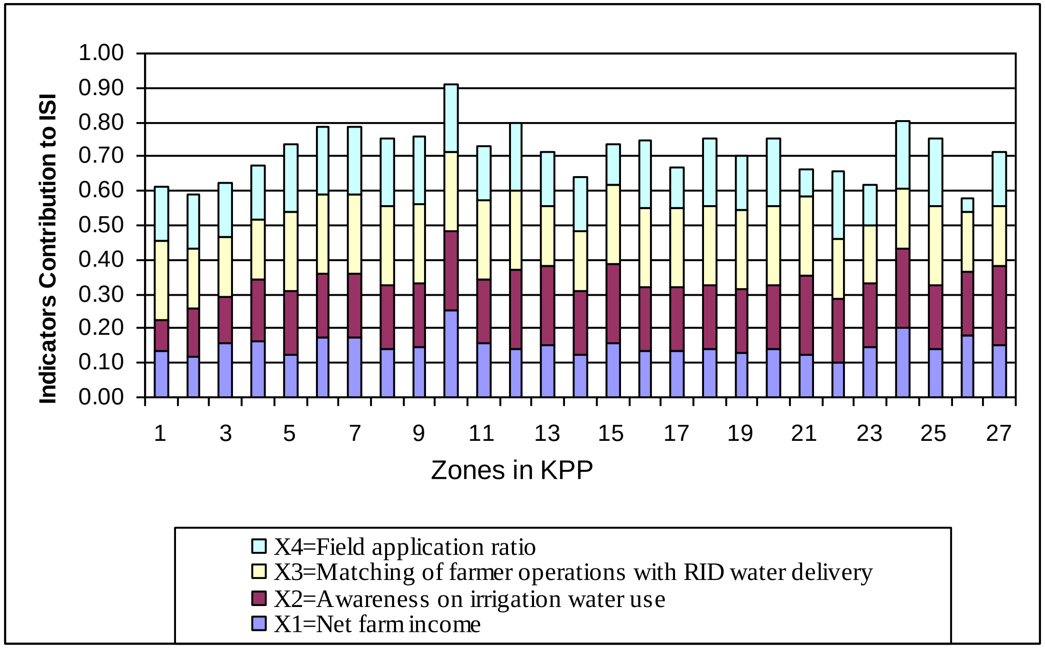
Y = the score of the retained variable (key indicator): the greater means higher contribution
= (z - s) / (1.1t- s)
X1 = Perception on drained water quality
X2 = Farmers' satisfaction on adequacy of water distribution
X3 = Net farm income
X4 = Flow ratio

Irrigation Sustainability Map

- GIS maps are used to show the sustainability levels of each zone in the study area based on ISI.

- Sustainability level of each zone are indicated in the map according to five classes (very low, low, medium, high, and very high)

Fig 6 Contribution of indicators to ISI for each zone in KPP



Classification Score	Index Interval	Sustainability
<0.570	1	Very low
0.571-0.645	2	Low
0.646-720	3	Medium
0.721-0.795	4	High
>0.796	5	Very High

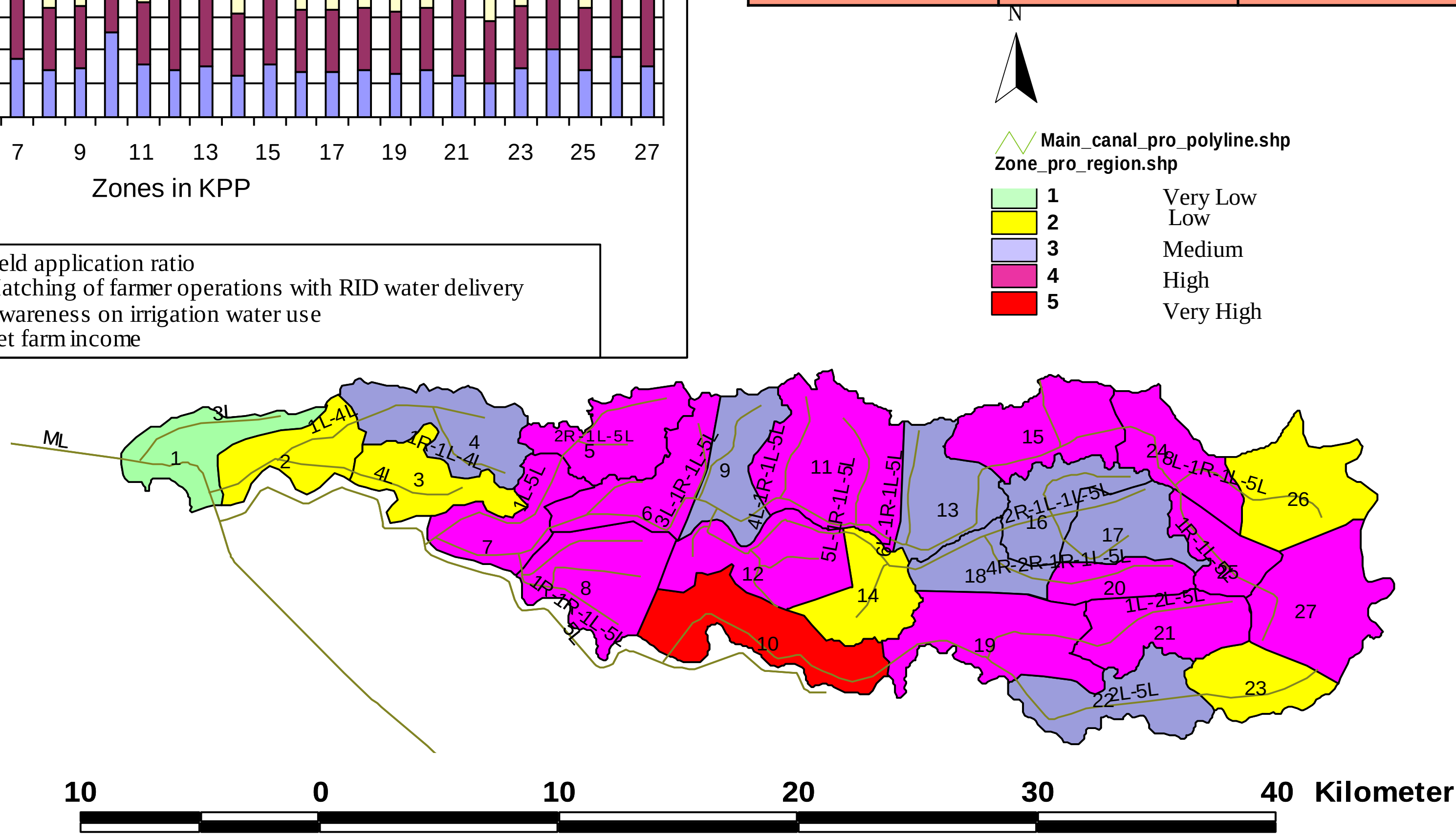


Fig 7 Irrigation sustainability levels for different zones in KPP

Classification Score	Index Interval	Sustainability
<0.688	1	Very low
0.689-0.731	2	Low
0.732-0.774	3	Medium
0.775-0.817	4	High
>0.818	5	Very High

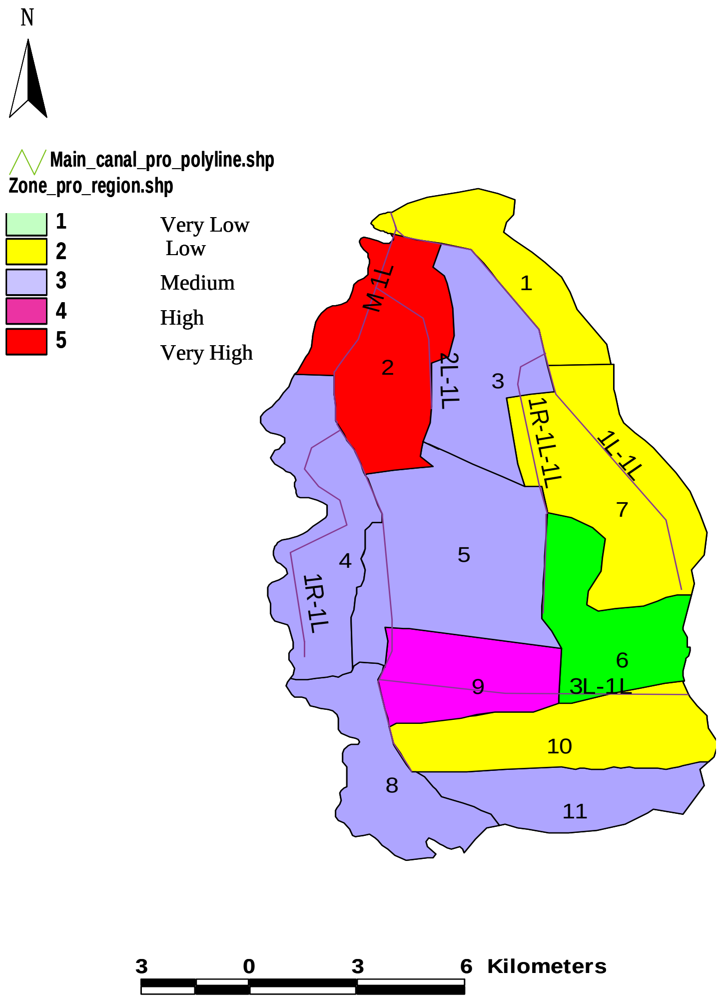


Fig 8 **Contribution of indicators to ISI for each zone in PPP**

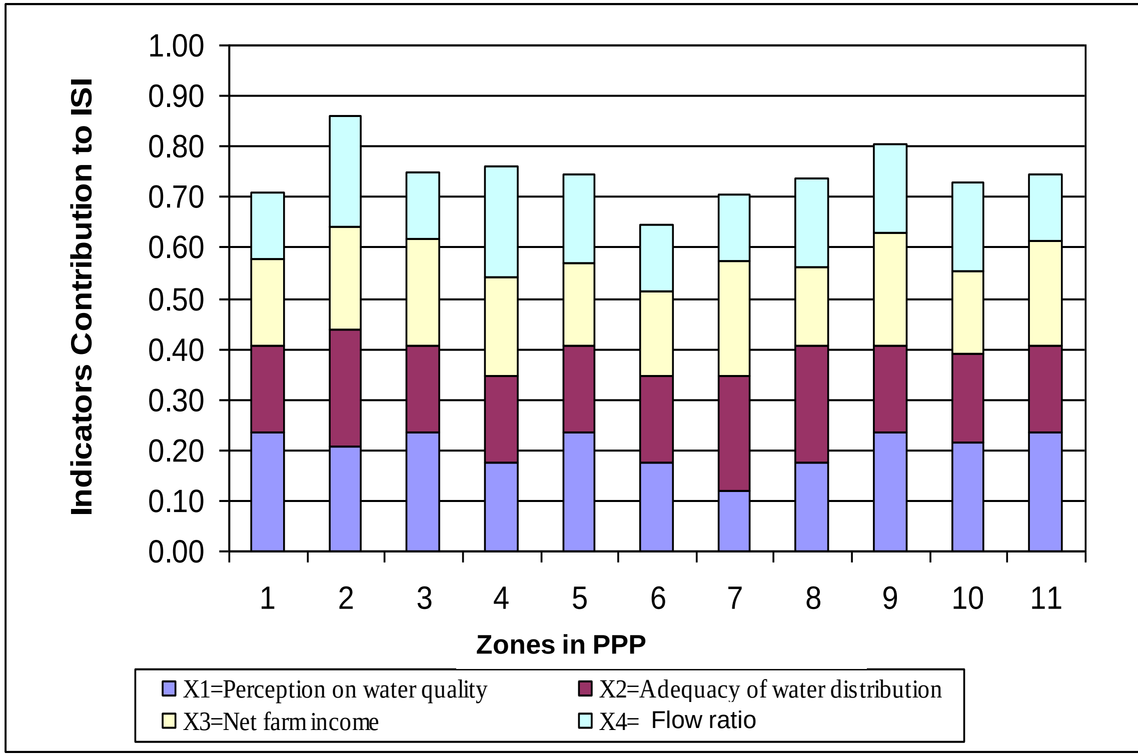


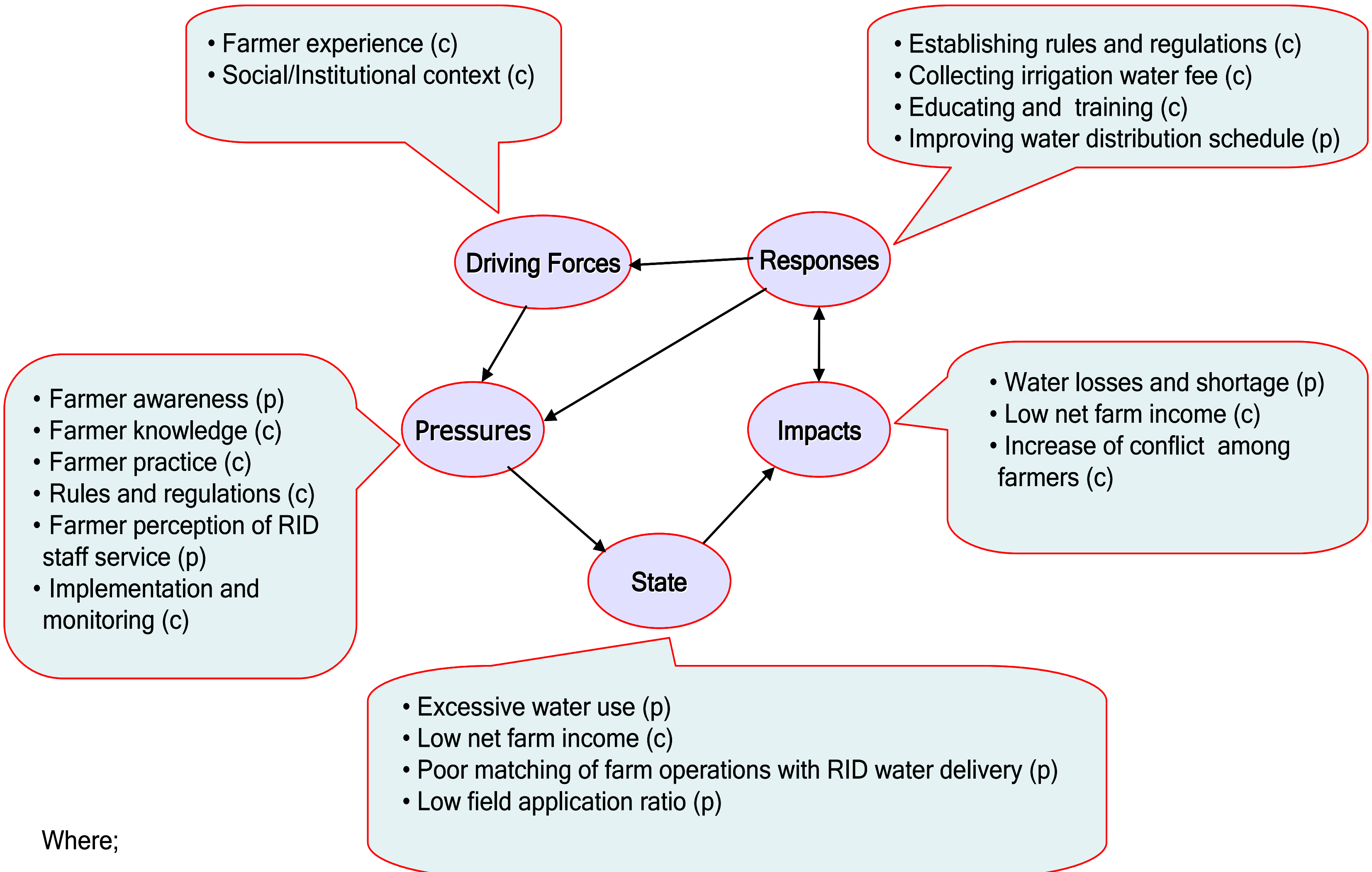
Fig 9 **Irrigation sustainability levels for different zones in PPP**

Management Strategies for Improving Irrigation Sustainability

Driving force-Pressure-State-Impact-Response (DPSIR) framework (EEA, 1999) is used as an analytical framework to help understand the cause-effect relationships among key indicators and relate with measures to enhance sustainability.

- **The *Driving forces* (D) are the underlying physical and anthropogenic factors affecting the sustainability of the irrigation system.**
- **The *Pressures* are outcome of the driving forces influencing the current situation. It also represents the specific translations of drivers into the study site.**
- **The *State* (S) assesses the current status of problems.**
- **The *Impact* (I) refers to the effects of the problems identified.**
- **The *Responses* (R) relates to the management options/strategies to address problems or their causes.**

Fig. 10 A Modified DPSIR Framework for KPP

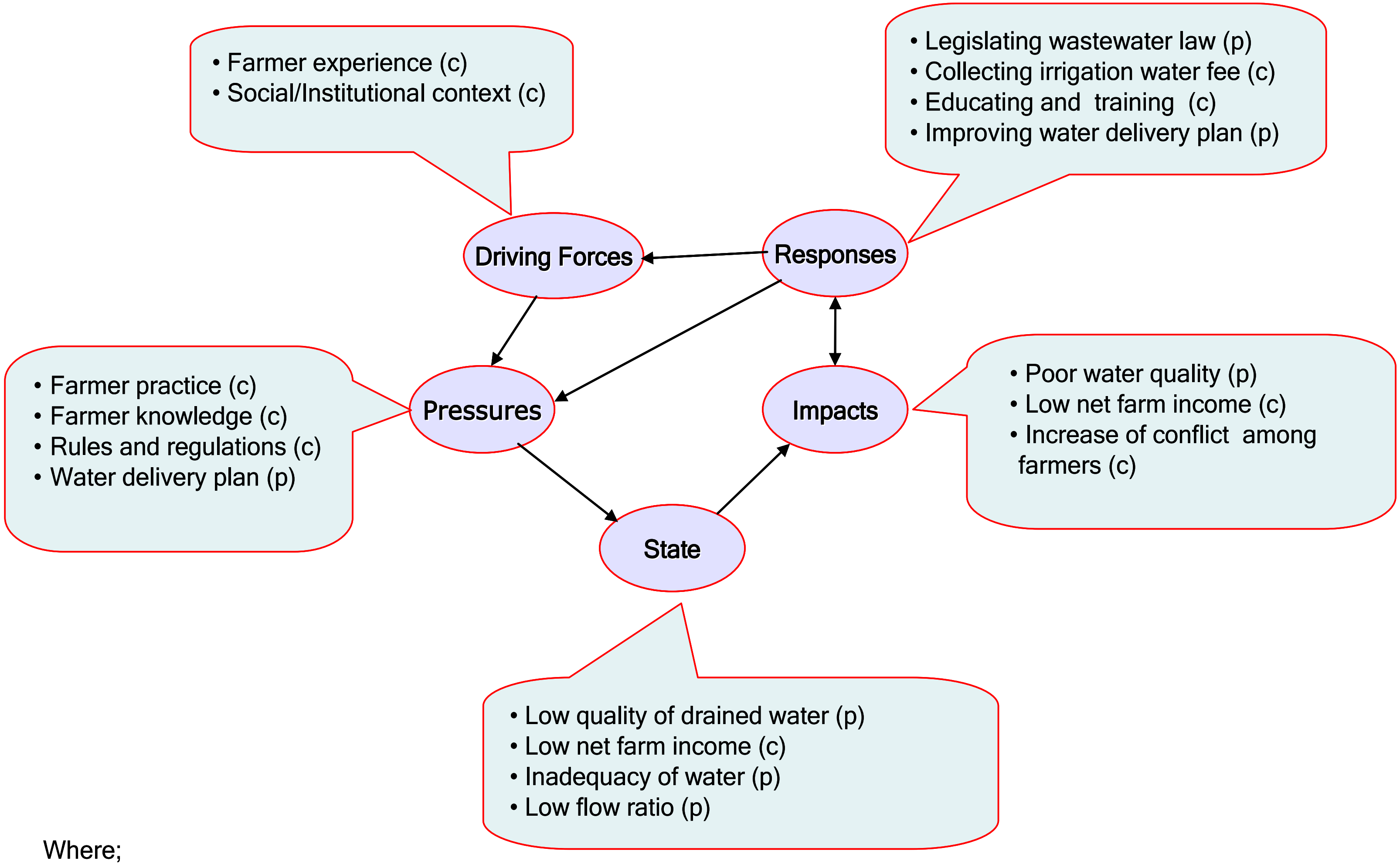


Where;

P= Project specific

C= Common to both projects

Fig. 11 A Modified DPSIR Framework for PPP

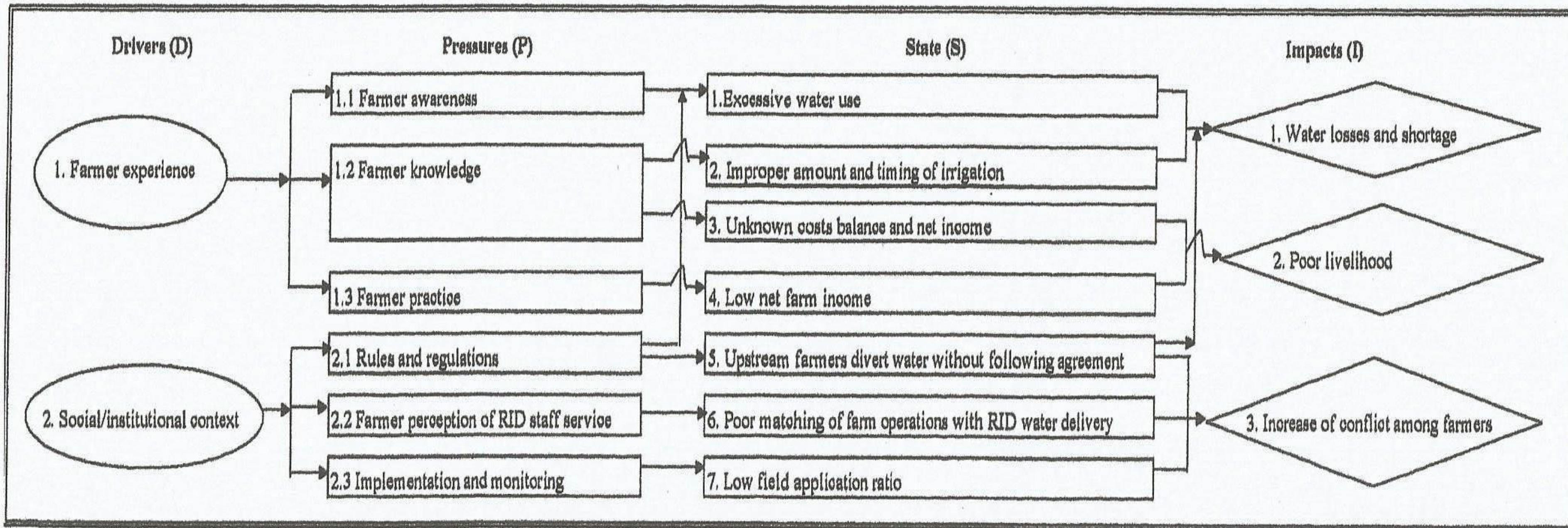


Where;

P= Project specific

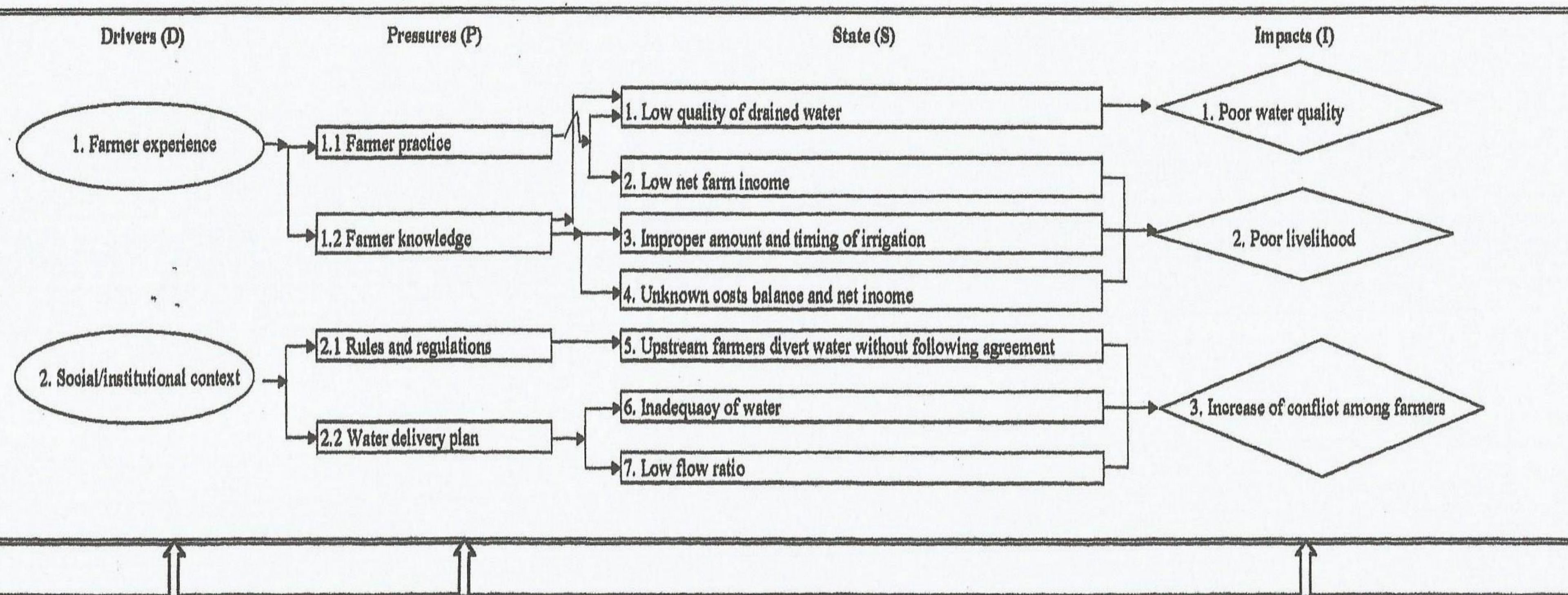
C= Common to both projects

Fig 12 A Cause and Effect Matrix for Irrigation Management in KPP



(R) Responses; Policy and management options for (D),(P) and (I)	Level of response
1) Establishment and strengthening of water user groups (1 D), (2 D), (1.1 P), (2.1 P), (1 I), (3 I) 2) Provision of support services and promotion of mutual assistance (1 D), (1.3 P), (2 I) 3) Establishing rules and regulations on water use (2 D), (1.1 P), (2.1 P), (1 I), (3 I)	On farm level
1) Enhance awareness and attitude of farmers on water use efficiency (1 D), (1.1 P), (1.2 P), (1.3 P), (1 I), (3 I) 2) Education and training of farmers (1 D), (1.1 P), (1.2 P), (1.3 P), (1 I), (3 I) 3) Teaching economic or financial management (1 D), (1.2 P), (1.3 P), (2 I) 4) Encouraging farmers to change farming practices (2 D), (2.2 P), (3 I) 5) Improving of water distribution schedule (2 D), (2.2 P), (2.3 P), (3 I) 6) Training RID staffs (2 D), (2.3 P), (3 I) 7) Calibration or check the functions of structure (2 D), (2.3 P), (3 I)	Project level
1) Collecting irrigation water fee (1 D), (1.1 P), (1 I), (3 I) 2) Encouraging farmer participation in irrigation management (1 D), (2 I), (1.1 P), (1 I), (3 I) 3) Provision of external support for rehabilitation (1 D), (2 D), (1.2 P), (2.3 P), (1 I), (2 I), (3 I)	RID level

Fig. 13 A Cause and Effect Matrix for Irrigation Management in PPP



(R) Responses; Policy and management options for (D),(P) and (I)		Level of response
1) Establishment and strengthening of water user groups (2 D), (2.1 P), (3 I) 2) Provision of support services and promotion of mutual assistance (1 D), (1.1 P), (2 I)	3) Establishing rules and regulations on water use (2 D), (2.1 P), (3 I)	On farm level
1) Promotion of organic fertilizer (1 D), (1.1 P), (1 I), (2 I) 2) Monitoring drainage water quality (1 I) 3) Educating and training farmers (1 D), (1.1 P), (1.2 P), (1 I), (2 I), (3 I) 4) Teaching economic or financial management (1 D), (1.1 P), (1.2 P), (2 I)	5) Training RID staffs (2 D), (2.2 P), (3 I) 6) Improving irrigation water delivery plan (2 D), (2.2 P), (3 I) 7) Improving flow measurement (3 I)	Project level
1) Legislating agricultural wastewater law or act (1.1 P), (1 I) 2) Collecting irrigation water fee (1D), (3 I)	3) Provision of external support for rehabilitation (1 D), (2 D), (1.2 P), (1 I), (2 I), (3 I)	RID level

Summary on DPSIR and matrix for KPP

- ***(D) Farmer experience*.**
- ***(P) Farmer practices;*** **Farmers apply excessive fertilizer, weedicide and pesticide which increases production cost and affects net farm income.**
- ***(S) Low net farm income*; The net farm income in zone 1 is low despite its high crop yield and selling price. This is due to the high production cost. In zone 2, the net farm income is low despite high crop yield and is attributed to low selling price of crop and its high production cost.**
- ***(I) Poor livelihood*; The low net farm income causes low quality of life for the farmers.**
- ***(R)* Provision of support services and promotion of mutual assistance.**

(Cont.)

- ***(D) Social/institutional factors***
- ***(P) Implementation and monitoring of water delivery;*** **Zonemen do not collect information on crops cultivated and they estimate crop water requirement by themselves; they do not compare the measured discharge to water delivery plan. .**
- ***(S) Low field application ratio;*** **The field application ratios are low because the applied water is less than water requirement. The actual planted areas are more than the RID planned areas and the official cropping calendar does not correspond to the real agricultural activities of farmers. Hence, the estimated amount of irrigation water did not match with the actual withdrawal.**
- ***(I) Increase of conflict among farmers;*** **Conflict among farmers occur because the applied water is less than water required and the upstream farmers divert irrigation water to their plots without regard to downstream users.**
- ***(R)*** **Training and cooperation between RID staff and farmer to improve schedule of water delivery.**
- ***(R) C*****heck functionality of structures and provide appropriate equipment and technology to monitor and control water delivery efficiently.**

Summary on DPSIR and matrix for PPP

- *(D)Farmer experience*
- *(P) Farmer practice;* **Farmers apply excessive fertilizer, weedicide and pesticide for rice which can be cultivated five times in two years. This causes poor drained water quality.**
- *(P) Farmer knowledge;* **This refers to the skill of farmers in farming and knowledge on the proper use of agricultural chemicals. Farmers experience low water quality due to lack of awareness on water contamination due to fertilizer and pesticide use.**
- *(S) Low quality of drained water;* **The drained water may be contaminated with chemical residues. There are two locations in PPP which show low values of DO. Farmers are not aware of guidelines and rules for wastewater use in agriculture.**
- *(I) Poor water quality;* **After farmers divert water to their plots for growing crops, they drain excess water from their fields to the drainage system which is contaminated with chemical residues. This causes problems on water quality.**
- *(R)* **Promotion of organic farming and control excessive use of chemical farm inputs to preserve water quality.**
- *(R)* **Monitoring drainage water quality and effluent discharges from pollutiant sources.**
- *(R)* **Legislation of agricultural wastewater act to control wastewater use for agriculture.**

Conclusions

1) Key factors affecting irrigation system varied from one project to another and from zone to zone within a project

2) Based on ISI, the zones of each project showed different sustainability levels. Six of twenty seven zones and four of eleven zones have poor sustainability in KPP and PPP, respectively.

3) Results imply that there is a need to improve many zones in the two projects to make them more sustainable.

4) Some recommendations are provided to address irrigation sustainability issues in some zones in KPP and PPP (i.e. linking ISI with DPSIR framework)

5) The methodology adopted and results obtained can provide valuable information in the formulation of policies or management options for improving sustainability of irrigation systems

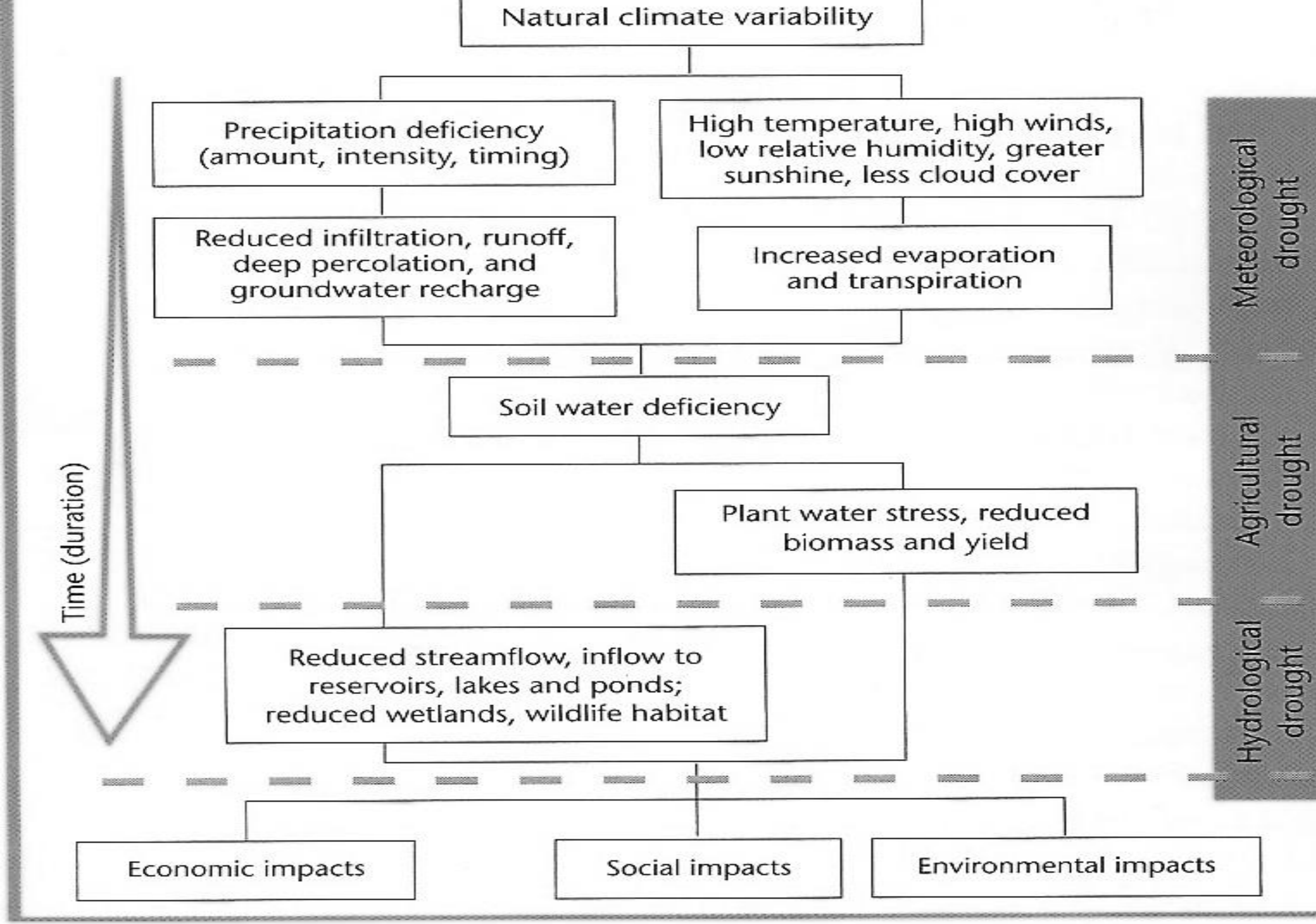
Climate Change and potential impacts on Agriculture

- **Climate change (CC): Any long-term significant change in the "average weather" that a given region experiences. Average weather may include average temperature, precipitation and wind patterns. These changes can be caused by dynamic processes on Earth, external forces like sunlight intensity, and more recently by human activities**

- **IPCC (2007) indicated that there has been an increase in extreme events since 1970; Precipitation decreased in the Tropics, while it increased in northern Hemisphere**
- **An increase or decrease in rainfall due to CC will cause a number of water related problems:**

  More intense and frequent rainfall - can cause localized or regional flooding, erosion and sedimentation

  More severe and extended period of meteorological, hydrological and agricultural drought - can cause water scarcity for all sectors; less productivity of agricultural lands, conflicts among water users, water quality issues such as Non point source pollution of water resources from agrochemicals and salinization.



Impacts of drought Water and Disasters (WMO, 2004)

Adaptation measures to address impacts of climate change on the study basin

- **Some problems identified in selected zones in Tha Chin Basin include low flow ratio, poor water quality , and water shortage**
- **These can worsen in the future due to global warming. In addition to the management options identified in DPSIR framework, some measures that can be adopted include:**

Crop variety – select varieties resistant to water stress and tolerant to salinity

Cropping pattern – the cropping calendar in Fig. 3 and 5 should be adjusted according to rainfall patterns (e.g. SPI, or trend analysis of rainfall)

Tillage practices – minimum tillage with mulch farming to improve soil moisture storage

Input of chemicals – regulate use and adopt fertigation (use of water quality models for assessment and management of NPS pollution)

Irrigation delivery – demand management (Deficit irrigation)

Among the many problems challenging the sustainable development and management of water resources, FAO identified five key issues that need to be addressed:

1) **Scarce water resources management** – many countries are faced with chronic water shortages and will be aggravated because of increasing population, water demand and climate change.
2) **Water quality management** – improper water management and agricultural practices have resulted in the contamination of surface/ground water systems by nitrates, pesticides and animal wastes. This can be aggravated by extreme events under climate change.
3) **Waterlogging and salinity** – at global level, it is estimated that about 20 to 30 million ha of the 250 million irrigated lands have become unproductive because of waterlogging and salinity.
4) Small scale water programs – inadequate support to local communities and low priority given to small scale programs seriously limit the productivity of small farmers.
5) Water use efficiency – around 60% of water diverted for irrigation is not made available to crops due to losses

Climate Change Adaptation

- **Some initiatives and measures to reduce vulnerability and increase resilience of natural resources (e.g. land and water) and living things to climate change include:**

Scarce Water Resource Management

Water quality management

Water logging and salinity control

Other adaptation measures

Scarce Water Resource Management

FAO has emphasized that many countries are faced with chronic water shortages and will be aggravated because of increasing population, water demand and climate change.

Adaptation measures for drought impacts reduction

- **Demand management (e.g. Deficit irrigation)**
- **Supply management (e.g. Water harvesting, Conjunctive use of water, Mulching)**
- **Engineering approaches (check dams, microcatchment, etc)**

Demand Management for Water Conservation in Irrigated Agriculture

Objective	Technology
Reduce Water Delivery	• **Increase irrigation efficiency and water application uniformity (e.g. Deficit irrigation).** • **Irrigation scheduling and control based on monitoring the soil, plants, and/or the microclimate.** • **Reduce evaporation from water and soil surfaces**
Reduce Evapotranspiration	• **Limit irrigation by applying less water than maximum ET demand (e.g. Deficit irrigation)** • **Limit irrigated cropland acreages by converting irrigated cropland in water-short areas to dryland farming.** •**Crop selection and modification for drought-resistant strain that can withstand dry periods.** • **Decision-making models and systems for irrigation scheduling and crop simulation using expert system**

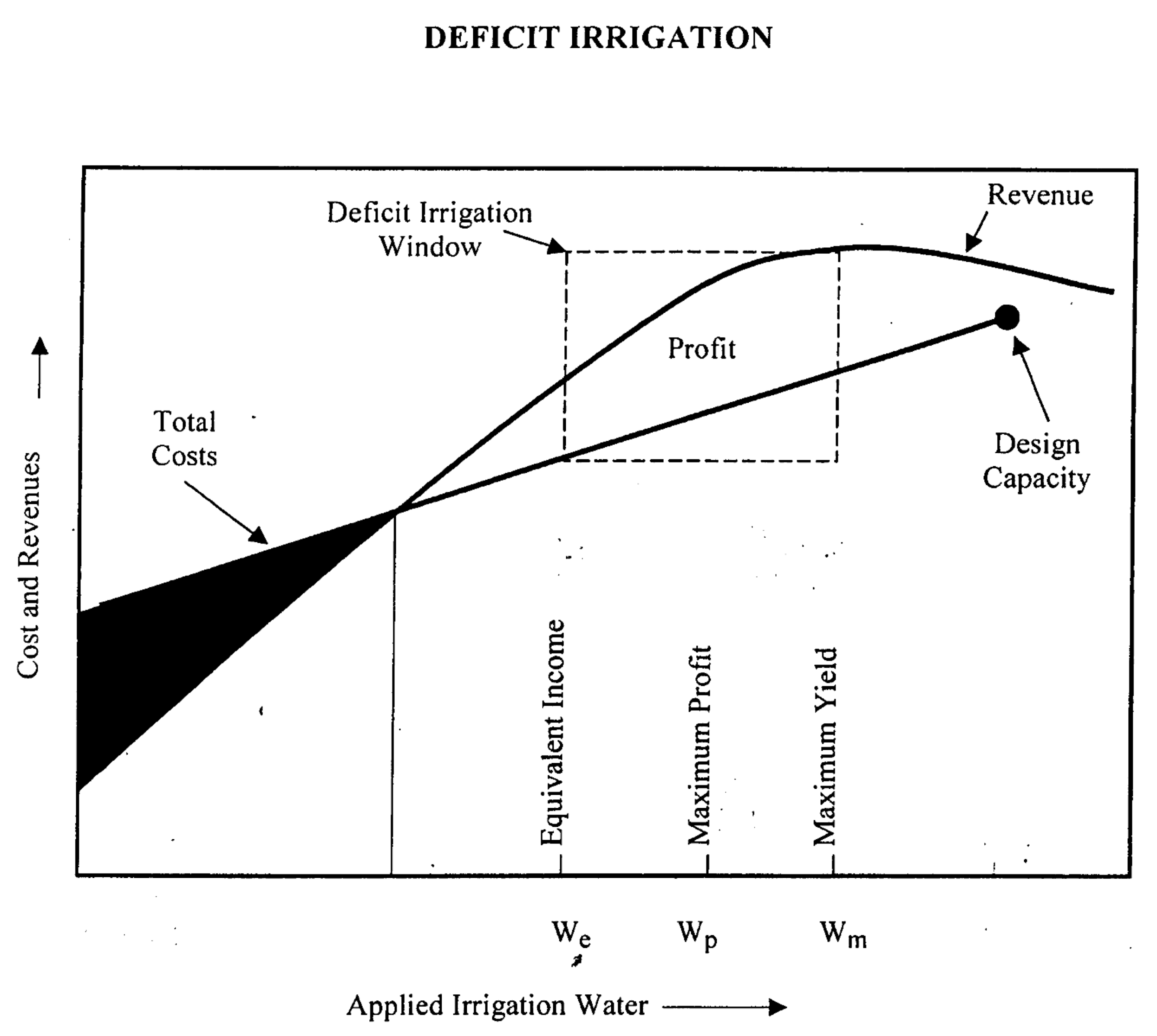


Fig Revenue and Cost as a function of applied water (adapted from English et al., 1990)

Generalized Water-Yield Relationships

- **Dorrenbos and Kassam (1979) analyzed the available information on crop yield (Y) response to water and empirically derived response factors, K_i. The yield as affected by water deficits can be estimated by:**

$$1-\frac{Y}{Y_M}=K_i\left(1-\frac{AET}{PET}\right)_i$$

- ***Y = expected yield, Ym = max possible yield, K_i*** **= sensitivity indices for water stress of crops, and AET and PET are actual and potential evapotranspiration respectively in specified physiological growth stages (*i*)**

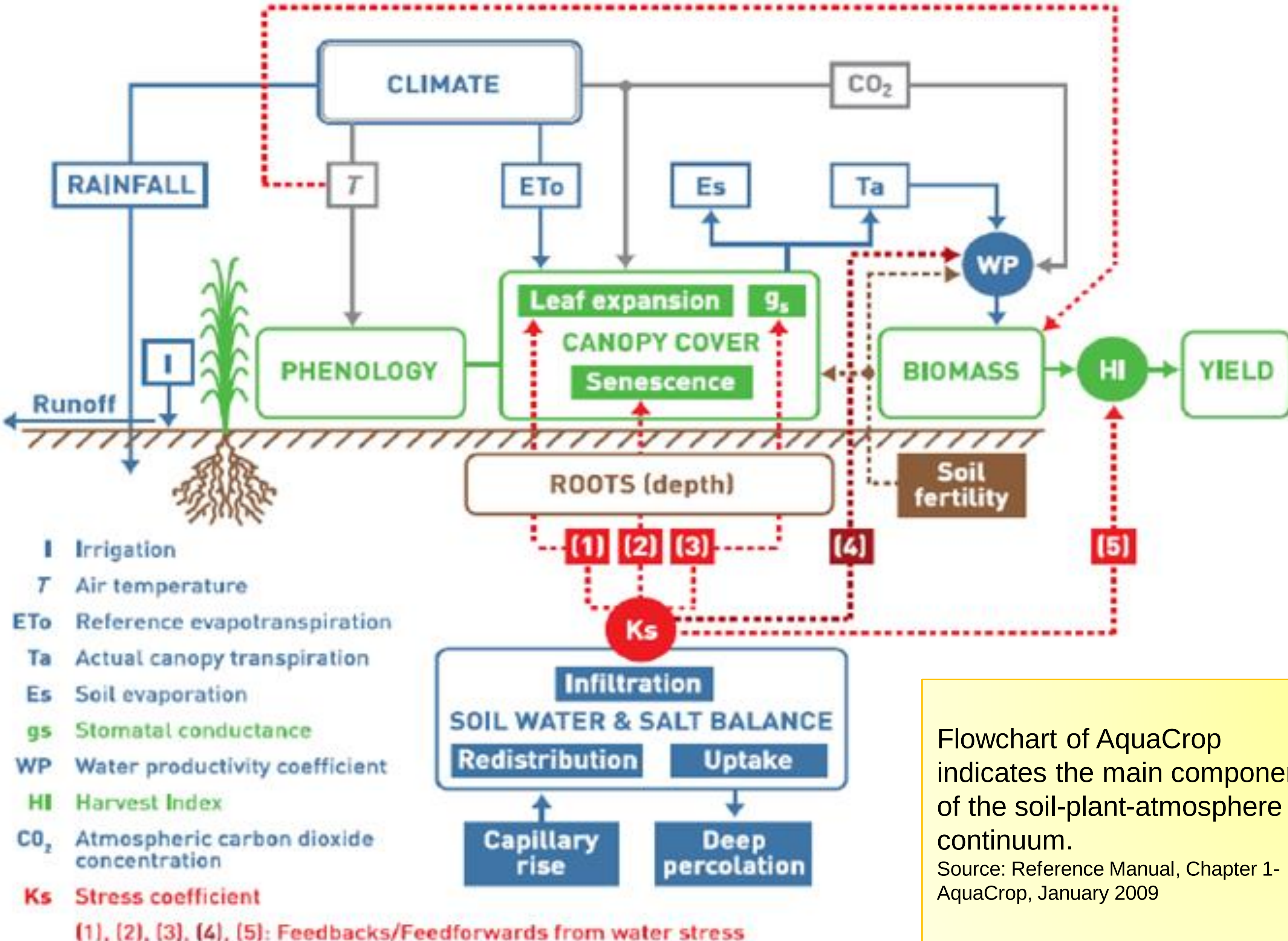
- If a water deficit occurs in the first (vegetative) growth period alone, the resulting yield Y_1 will be

$$f_1 = \frac{Y_1}{Y_M} = 1 - K_1\left(1 - \frac{AET}{PET}\right)_1$$

where the suffix 1 refers to the first growth stage.

- Same equations holds true for other growth stages (*i=2, 3, 4*) with K_2, K_3, K_4 etc.

- AQUACROP model developed by FAO (Raes, 2009) can simulate yield response to water of most field crops and has been used by many researchers (Trang, 2012; Nontikansak, 2011; and Chenda, 2009) to assess effect of climate change (water deficits) on yield.



Flowchart of AquaCrop indicates the main components of the soil-plant-atmosphere continuum.
Source: Reference Manual, Chapter 1- AquaCrop, January 2009

Supply Management for Water Conservation in Irrigated Agriculture

Objective	Technology
Increase storage of runoff water	•<u>Small reservoirs</u> to catch and retain flood water for release during droughts • Groundwater recharge by conveying or confining surplus runoff to recharge areas
Increase water yield	• <u>Water harvesting</u> by constructing an impermeable surface to reduce infiltration and store runoff • Vegetative management by manipulating vegetative cover to decrease runoff for improved groundwater recharge
Capture and retain precipitation	• <u>Soil moisture management</u> by cultural and mechanical practices to decrease runoff and evaporation, thereby increasing soil moisture storage (e.g. Mulching) • Increase crop rooting depth by breaking up hardpans and selecting crop species and cultivars that root more deeply to expand soil moisture extraction.
Add to available water supply	• Inter- and intra-basin transfers. • Re use of wastewater effluents for irrigation, using moderately saline drainage water and conjunctive use of water

Water Harvesting and Management in the Cultivated Uplands of Dhading Watershed, Nepal

Clemente, R., Rashid, I., and Wahid, S.M.
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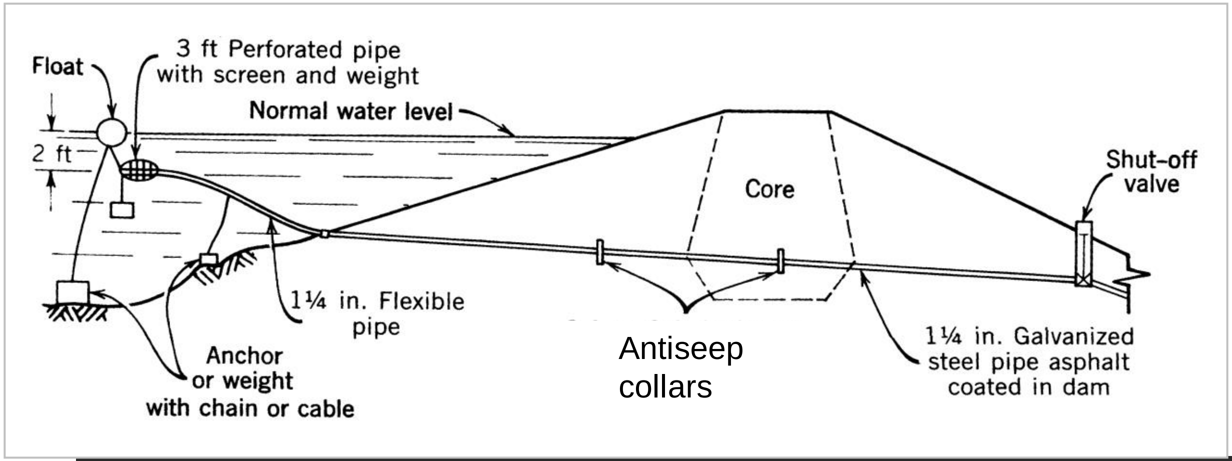
Pond for Irrigation and Livestock drinking

Float being fixed

Float mechanism for water distribution

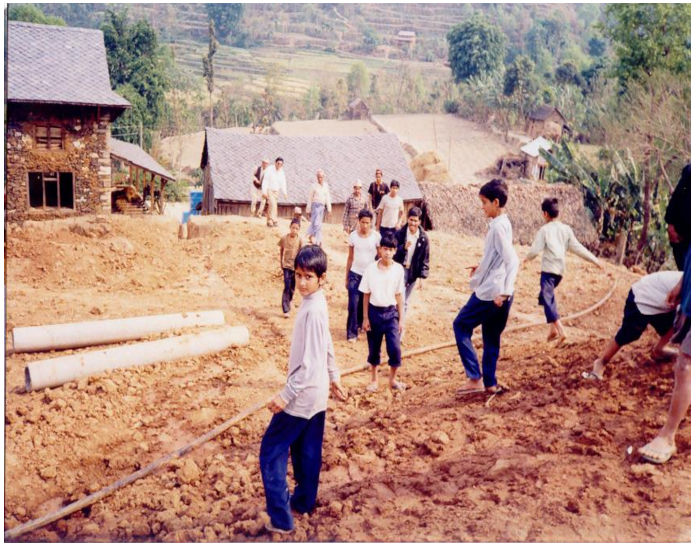


Water distribution

- **Time to irrigate**

$$t = (10*A*D) / (Ea * Q * 3600)$$

t = time to irrigate (hr),
A = area of each farm to be irrigated (ha)
D = depth of irrigation (mm) estimated from CROPWAT
Ea = irrigation efficiency (fraction)
Q = pipe discharge (m^3/sec)



Farm units are located below the plateau

Mulching

Process of spreading mulches from plant residues (leaves, stalks, crowns, roots, straws, woodchips and sawdusts) and synthetic materials (plastic sheets, aluminum foil, kraft paper and newspaper) over the ground between crop rows or around tree trunks

Advantages:

- Reduces the impact of rainfall on bare soils
- Reduces soil erosion
- Improves soil moisture retention
- Allows buildup of organic materials and enhances soil fertility
- Suppresses growth of weed by blocking out sunlight
- Serves as insulator that keeps soil cool under intense sunlight and during cold weather

Mulch farming

Supply management: Conjunctive Use of Water Resources

This water management concept refers to the coordinated and harmonious development and use of water resources from different sources such as surface and ground water systems. The specific objectives of conjunctive use of water include:

a) **Increase the dependability of existing water supplies,**

b) **Mitigate the shortages in canal supplies due to seasonal variation in stream flow**

c) **Alleviate the problems of high water table and soil salinity**

d) **Facilitate the use of saline ground water**

These objectives can be achieved through appropriate systems of conjunctive use of surface water with ground water and/or rainfall which include the following approaches:

a) **Augmentation of canal water by pumping ground water thru deep tube wells**

b) **Direct application of groundwater in rotation with canal water**

c) **Mixing of saline water pumped through tube wells along the water courses of the canals**

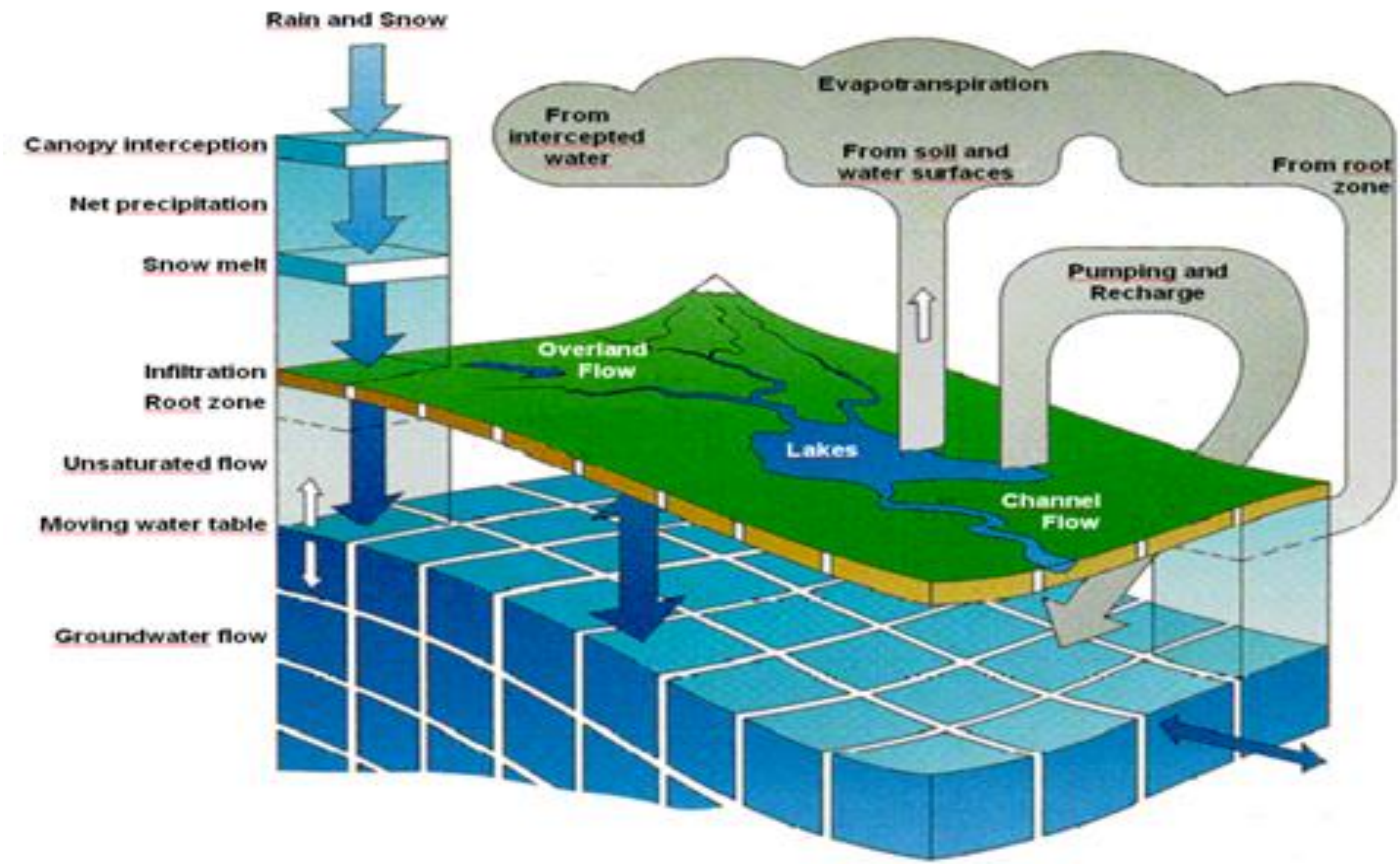
d) **Storage of surplus rainwater in farm ponds and its conjunctive use with canal or ground water**

e) **Artificial recharge of ground water from supplies (canal/irrigation) and rainfall/runoff, etc**

f) **Reuse of drainage waters in rotation with surface water**

The choice of management scheme is however, site specific. To adopt an appropriate conjunctive use of surface and ground water resources needs an investigation of available resources (e.g. use of models like MIKE SHE) and the possible consequences of development (e.g. water quality, water logging, water table recession, etc.).

Conjunctive use of surface and ground water
MIKE SHE (DHI, 1998)

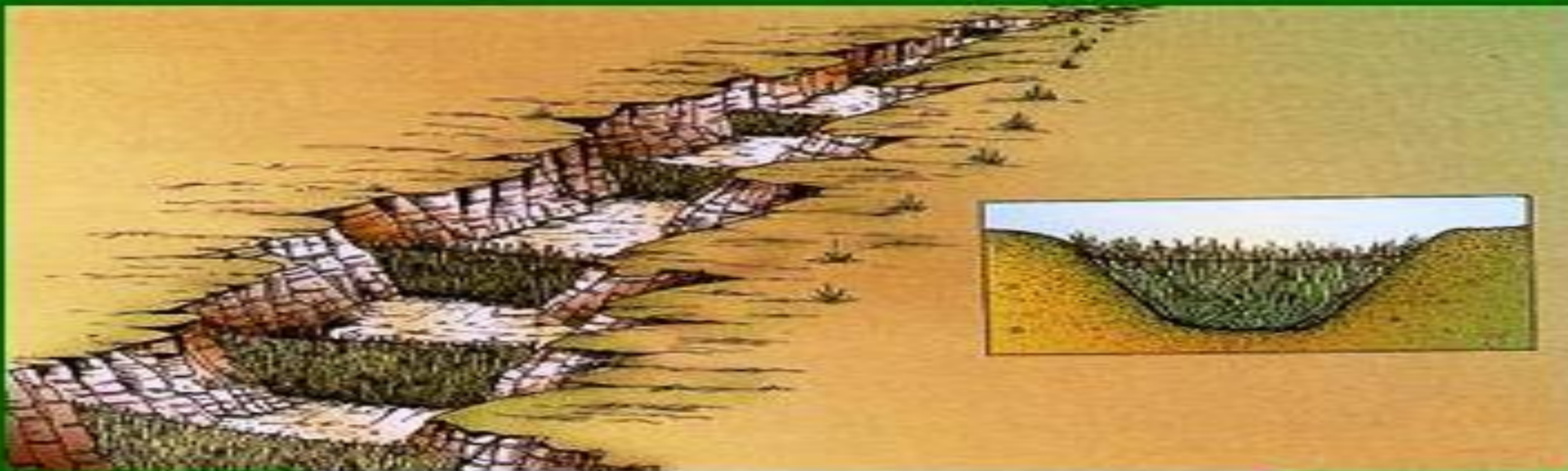


MIKE SHE (Integrated Catchment Modeling)

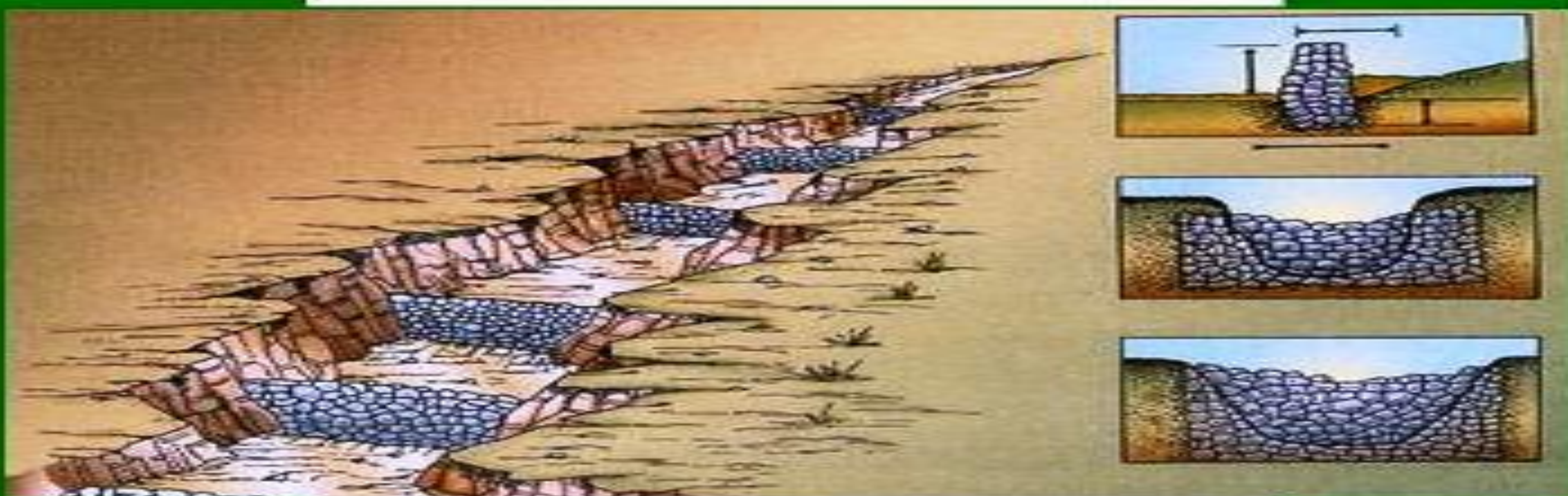
MIKE SHE has been used for the analysis, planning and management of a wide range of water resources problems such as:

- **River basin management and planning**
- **Water supply design, management and optimization**
- **Irrigation and drainage**
- **Soil and water management**
- **Conjunctive use of groundwater and surface water**
- **Groundwater management**
- **Contamination from waste disposal**
- **Floodplain studies**
- **Impact of land use and climate change, etc.**

Engineering measures: Check dams

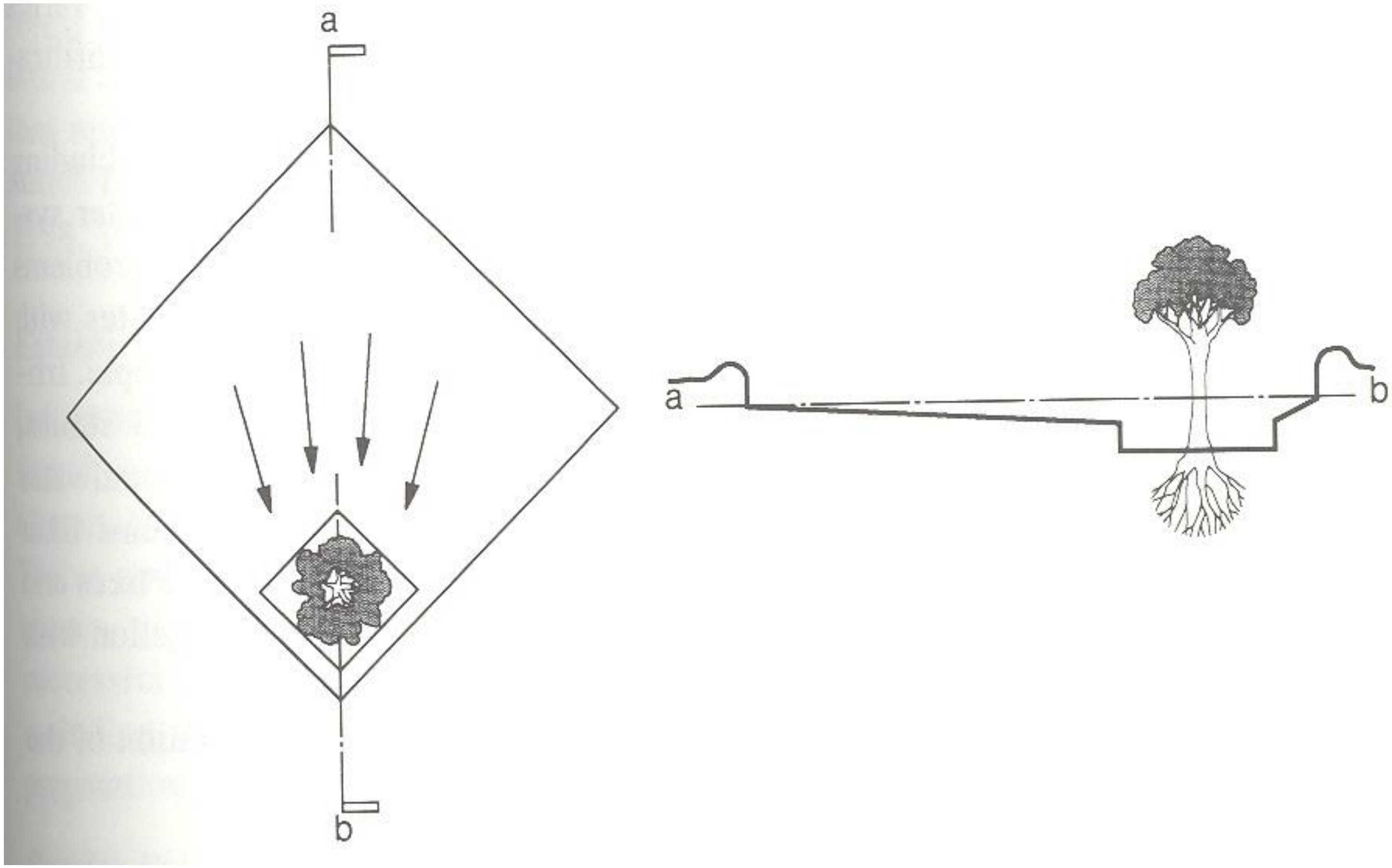


Check dams made out of brush wood.



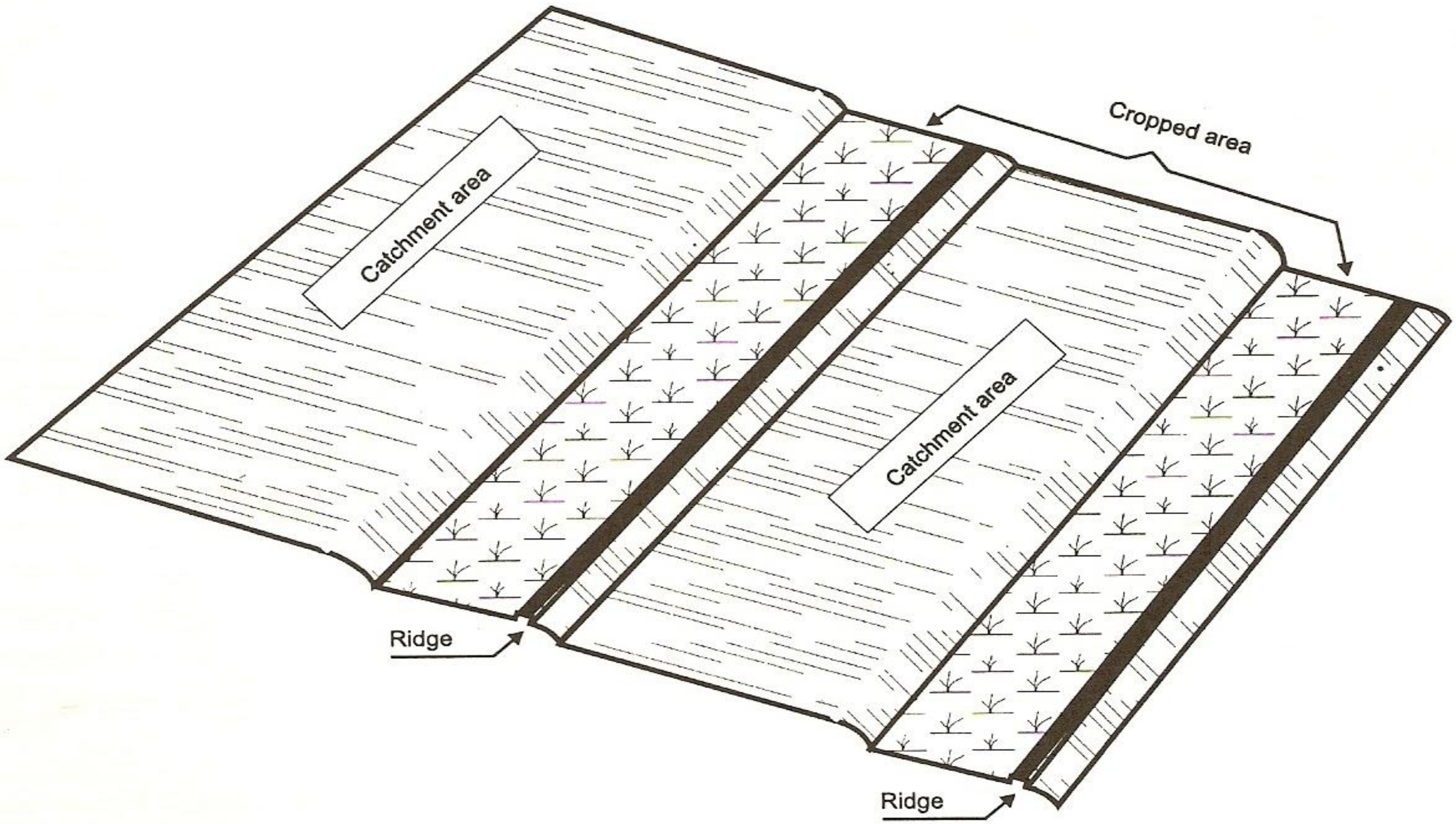
Check dams made out of loose rock.

Engineering approaches: Micro-catchment



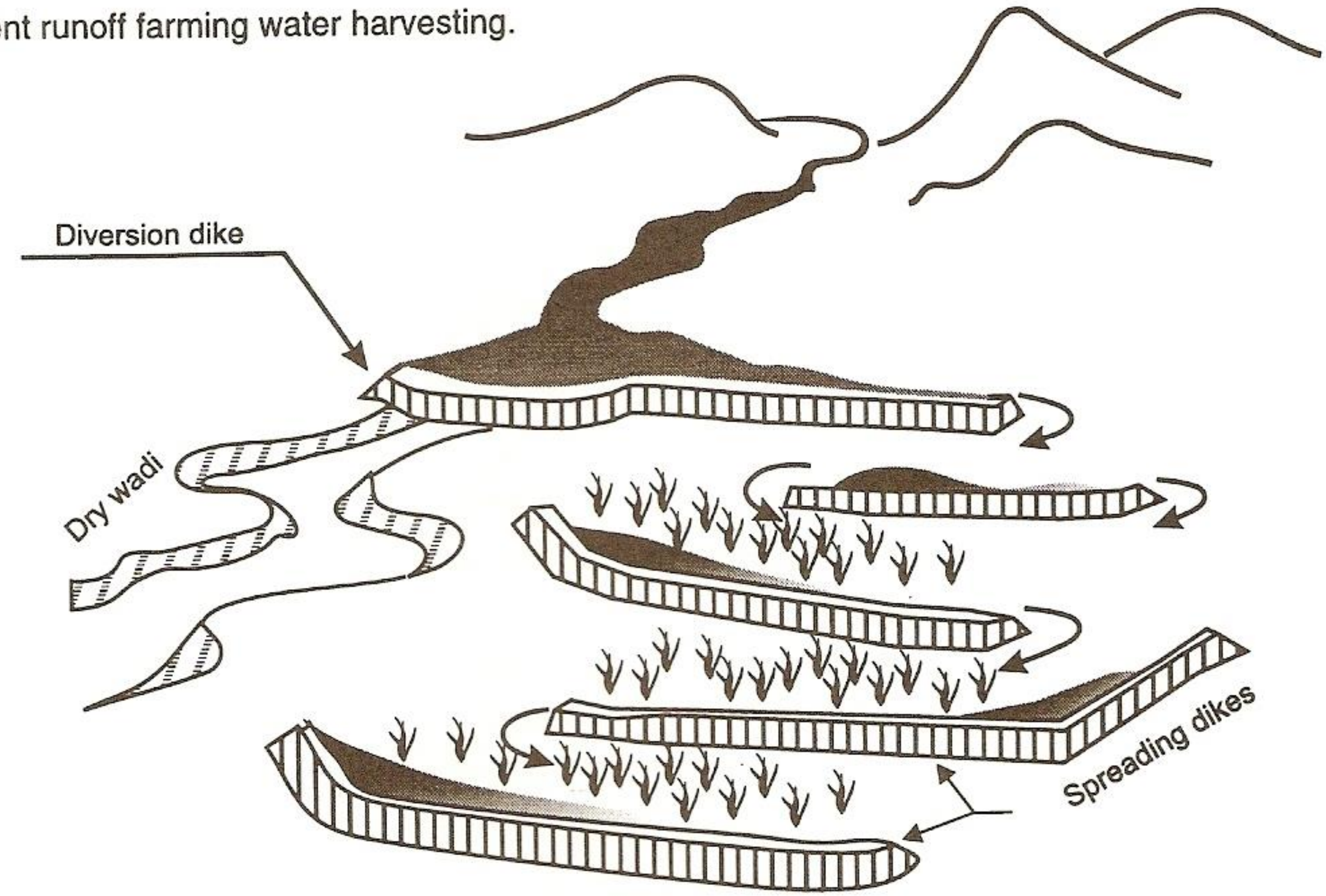
Engineering approaches: Mini-catchment

Mini-catchment (strip) runoff farming water harvesting.



Engineering approaches: Macro-catchment

FIGURE 4.
Macro-catchment runoff farming water harvesting.



Water Quality Management

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FAO has also reported that improper water management and agricultural practices have resulted in the contamination of surface/ground water systems by non point source (NPS) pollutants such as nitrates, pesticides and animal wastes. This water quality issues can be aggravated by extreme events under climate change

Effects of NPS pollution on water quality

It

Pollutant Category	Form of Pollution	Primary	Secondary	Tertiary
Nutrients (phosphorus and nitrogen)	Total Nitrogen Nitrate Ammonia Total phosphorous Soluble phosphorous	Accelerated growth of algae and aquatic plants Eurrophication of Slow-turnover water bodes Interference with potable and recreational uses	Decrease in oxygen Color changes Increased concentrations of N03 and NH4	Death of fish in surface water bodies Reduction in recreational benefits Higher degree of treatment required for potable use Toxic effects of nitrate on infants
Sediments	Suspended solids	Blockage of channels, canals, and reservoirs Obstruction of outlets and filters Interference with recreational uses Increase in treatment costs	Reduction of light penetration Color changes	Negative effects on fish reproduction zone Adsorption/desorprion phenomena of toxic substances
Salinity	Dissolved salts	Damage to fish community and vegetation Corrosion Of Pumps and turbines Conspicuous increase in treatment costs for potable use		Reduction of germinative capacity from downstream use Reduction in growth of some plant species
Herbicides, pesticides (insecticides, fungicides, nematodicides)	Organochlorine and organophosphorus pesticides Carbarnate Triazine	Toxicity for fish and aquatic plants Heavy treatment for potable uses	Sublethal effects Synergistic effects	Biomagnification in the food chain Long-term mutagenesis
Animal wastes (nitrogen, phosphorus, oxidizable substances, pathogens	Biological oxygen demand (BOD) Chemical oxygen deamand Coliforms and streptococcus	Analogous to nutrients Reduction in fish populations Increase in level of t reatment for potable use	Smell Color	Anaerobic transformations with methane, amine, and sulfide production

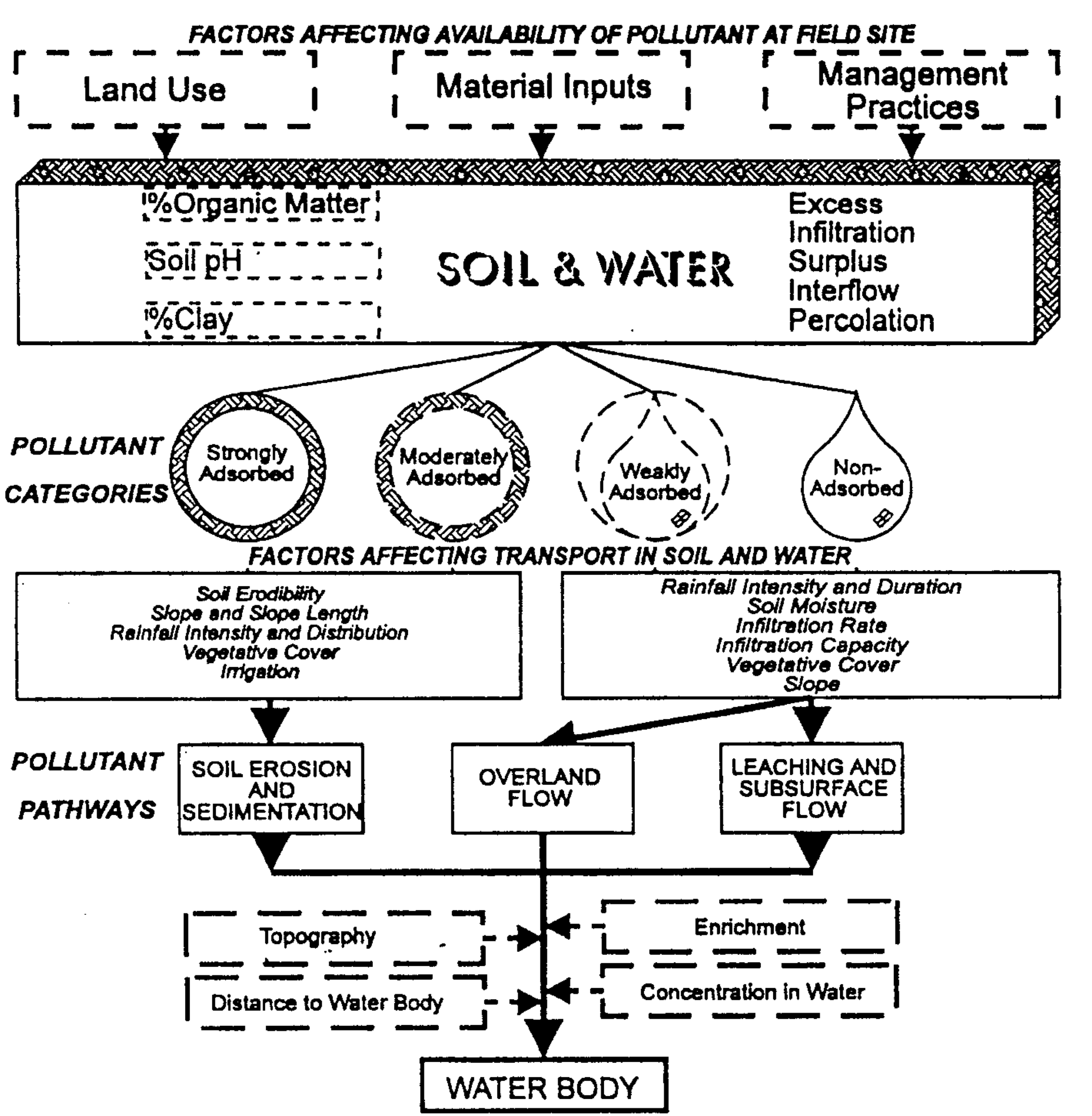
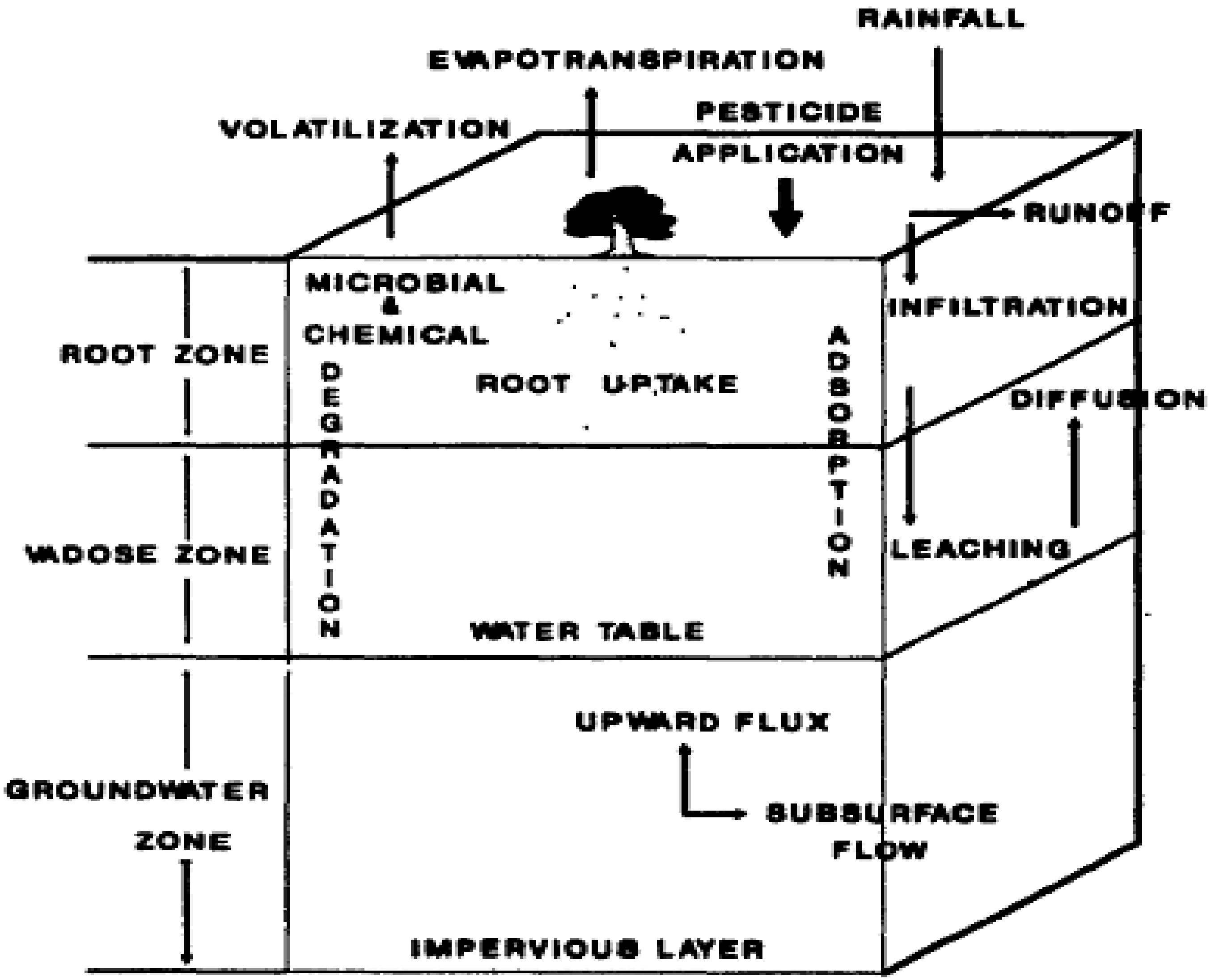


Figure:
Factors that affect the process of pollutant transfer from agricultural nonpoint sources to receiving water bodies.

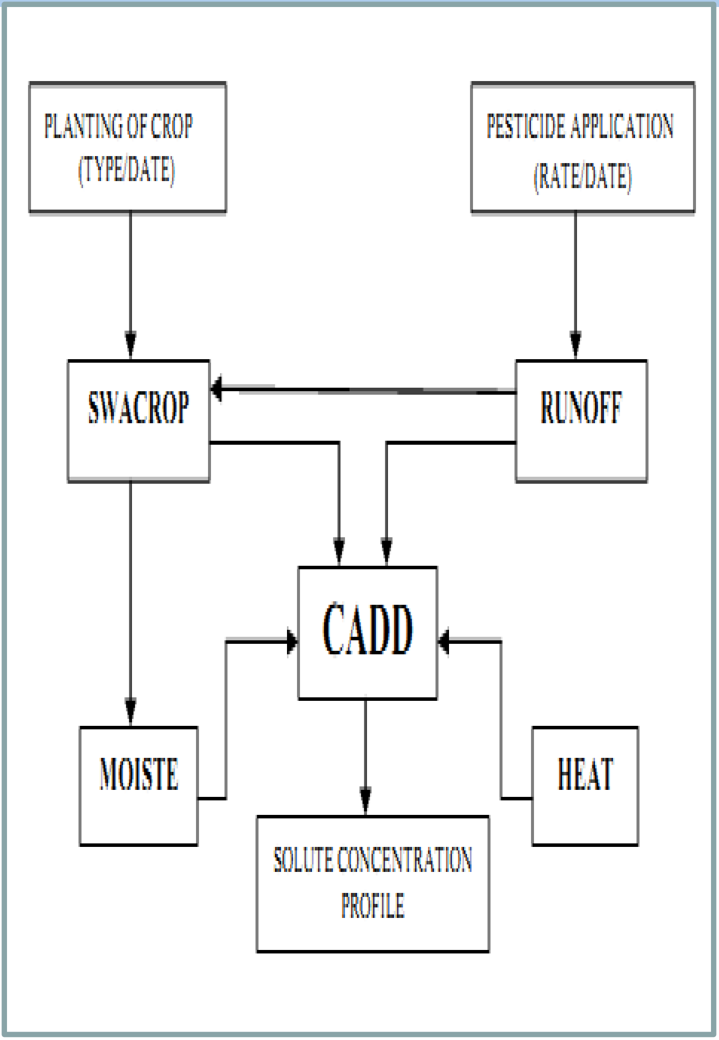
Water transport and Chemical loss pathways
(PESTFADE, Clemente, (1991)



Pesticide Fate and Dynamics in the Environment (PESTFADE) Model

- **The model consists of 4 modules: RUNOFF, SWACROP, HEAT and CADD.**
- **RUNOFF module simulates runoff/erosion and chemical partitioning in runoff/sediment**
- **SWACROP evaluates unsaturated water flow to obtain the moisture distribution in homogeneous or layered soils**
- **HEAT FLOW module analyzes the temperature distribution in the soil profile to evaluate microbial degradation.**
- **CADD is the main module which uses inputs from previous modules outputs plus its own specific inputs and simulates solute transport over depth and time.**
- **The final output is chemical concentration in solution along the soil profile, for each day, from application until the end of the simulation.**

- **Model has been tested/applied in Canada, Thailand, and Philippines (Clemente (1991) Clemente et al (1993,1998, 2002), Kaluli et al (1997), Shrestha (2001), Clemente (2007/2008) and Shrestha (2013)**



A simplified diagram of PESTFADE structure and operation (Clemente, 1991)

The need for computer modeling in water quality assessment and management

- **The complex and expensive nature of actual field monitoring encourages the use of comprehensive mathematical models for assessing the fate and transport of contaminants through various pathways and under different climatological, geological, watershed and management scenarios.**

- **Also, the simulation of soil-crop-water-chemical interactions can provide a very useful guide as to what Best Management Practices (BMPs) can be adopted to minimize pollution of natural resources (e.g. surface and ground water) by Non-point sources (e.g. pesticide/fertilizer residues, sediments, salts, heavy metals, etc).**

- **In effect, computer simulation models, once fully calibrated/validated under various field scenarios, can be used as an alternative and innovative tool for assessing and managing environmental impacts associated with agro-chemical use, soil erosion and other agro-industrial development activities.**

Water logging and salinity control

FAO indicated that at global level, it is estimated that about 20 to 30 million ha of the 250 million irrigated lands have become unproductive because of waterlogging and salinity. This phenomenon can also be aggravated by extreme events under climate change.

Some measures to address water logging and salinity include design of surface drains to remove excess water or leach salts via subsurface drainage.

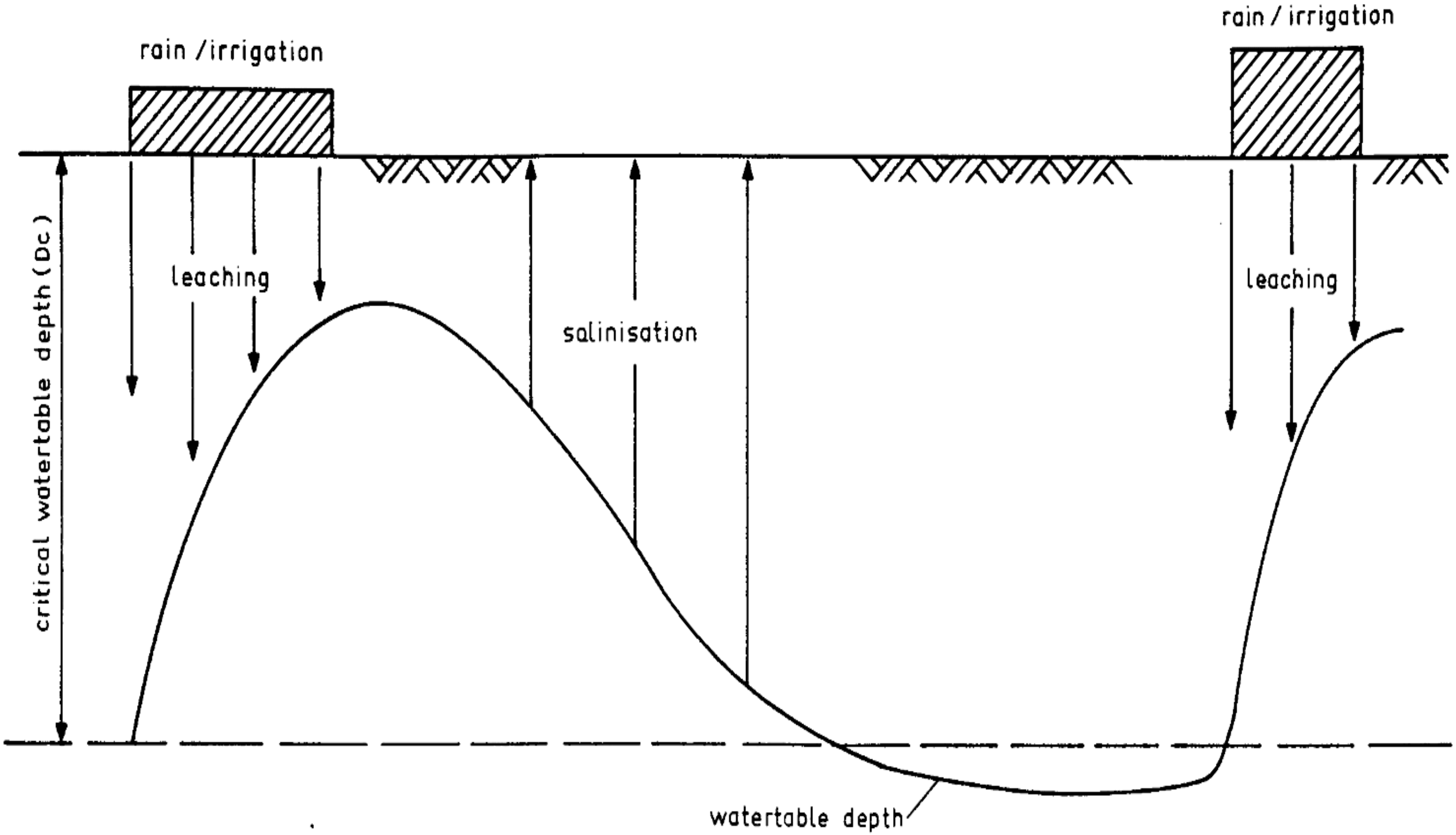


Figure: Cyclic movement of salts due to watertable fluctuation

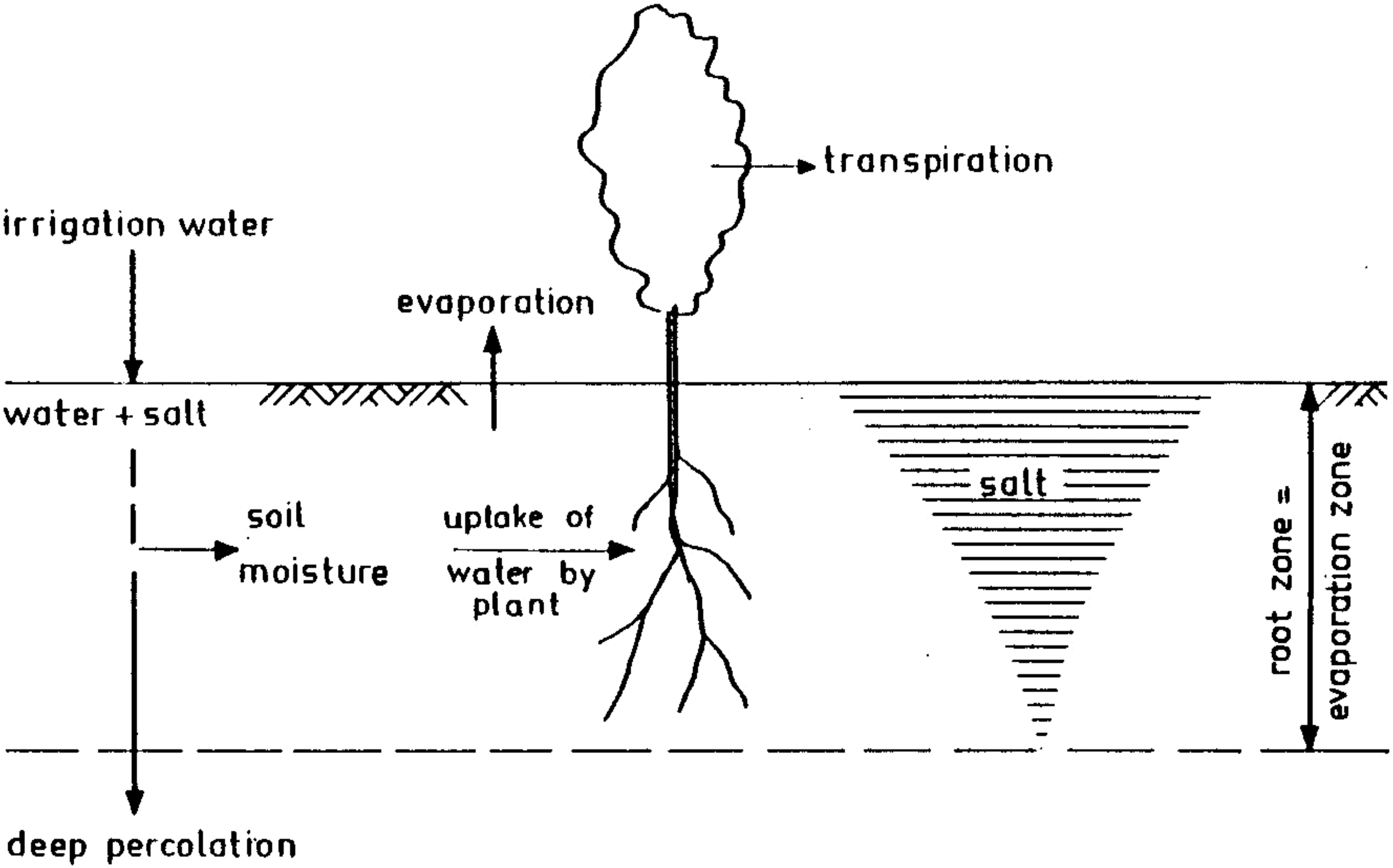


Figure: Direct salinization by irrigation

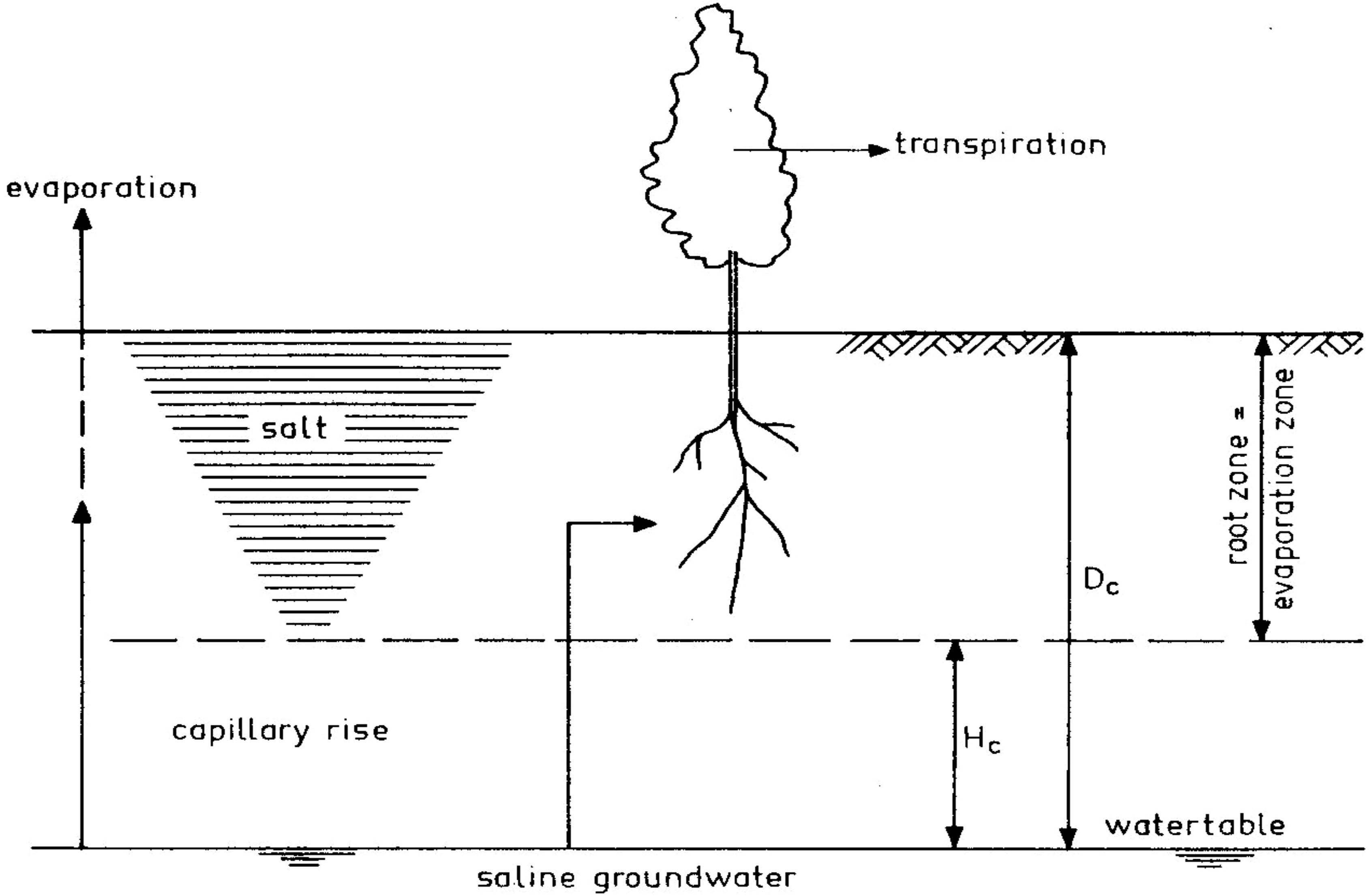
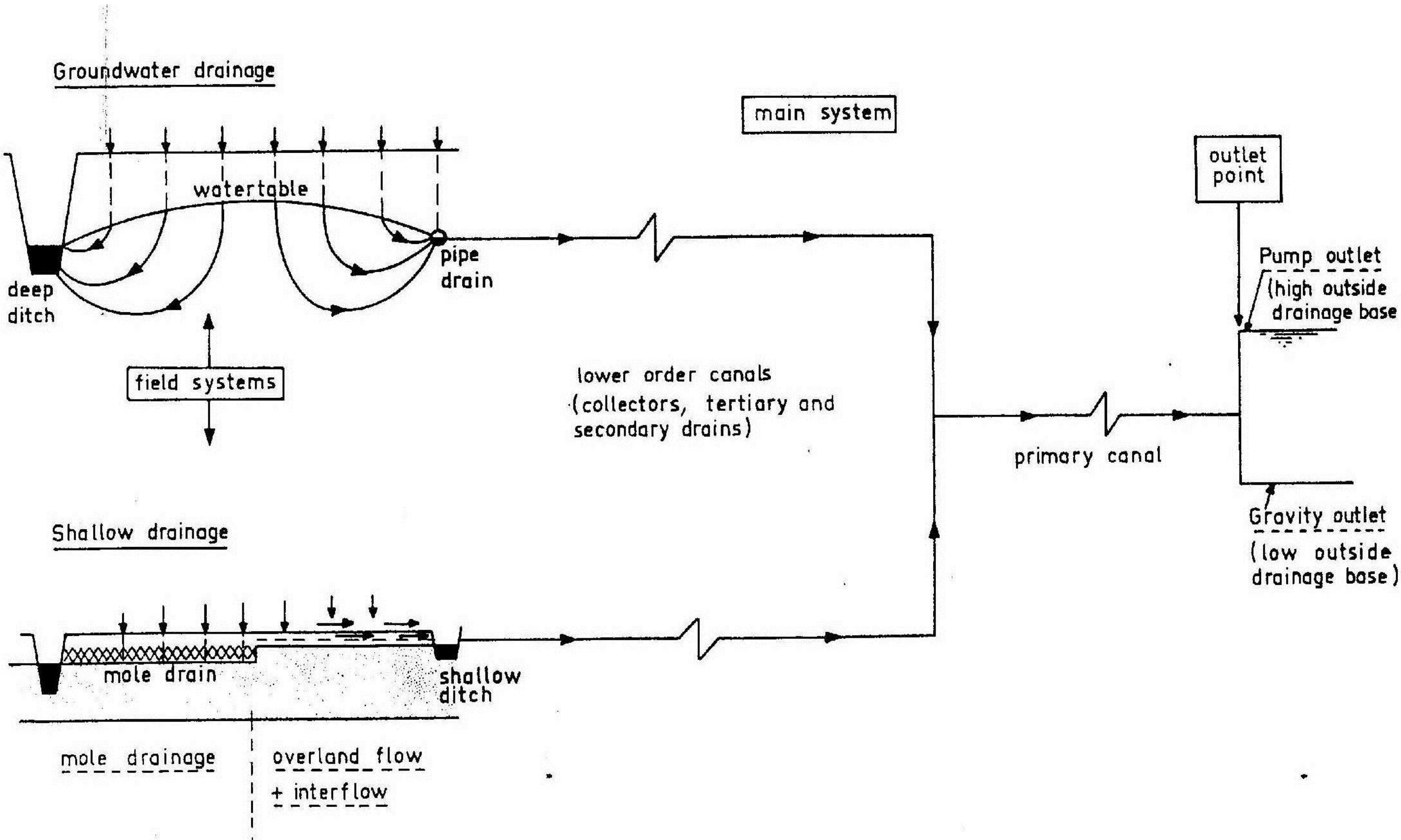


Figure: Capillary salinization

A typical agricultural drainage system has the following main components (see figure 2.3).



Other climate change adaptation measures

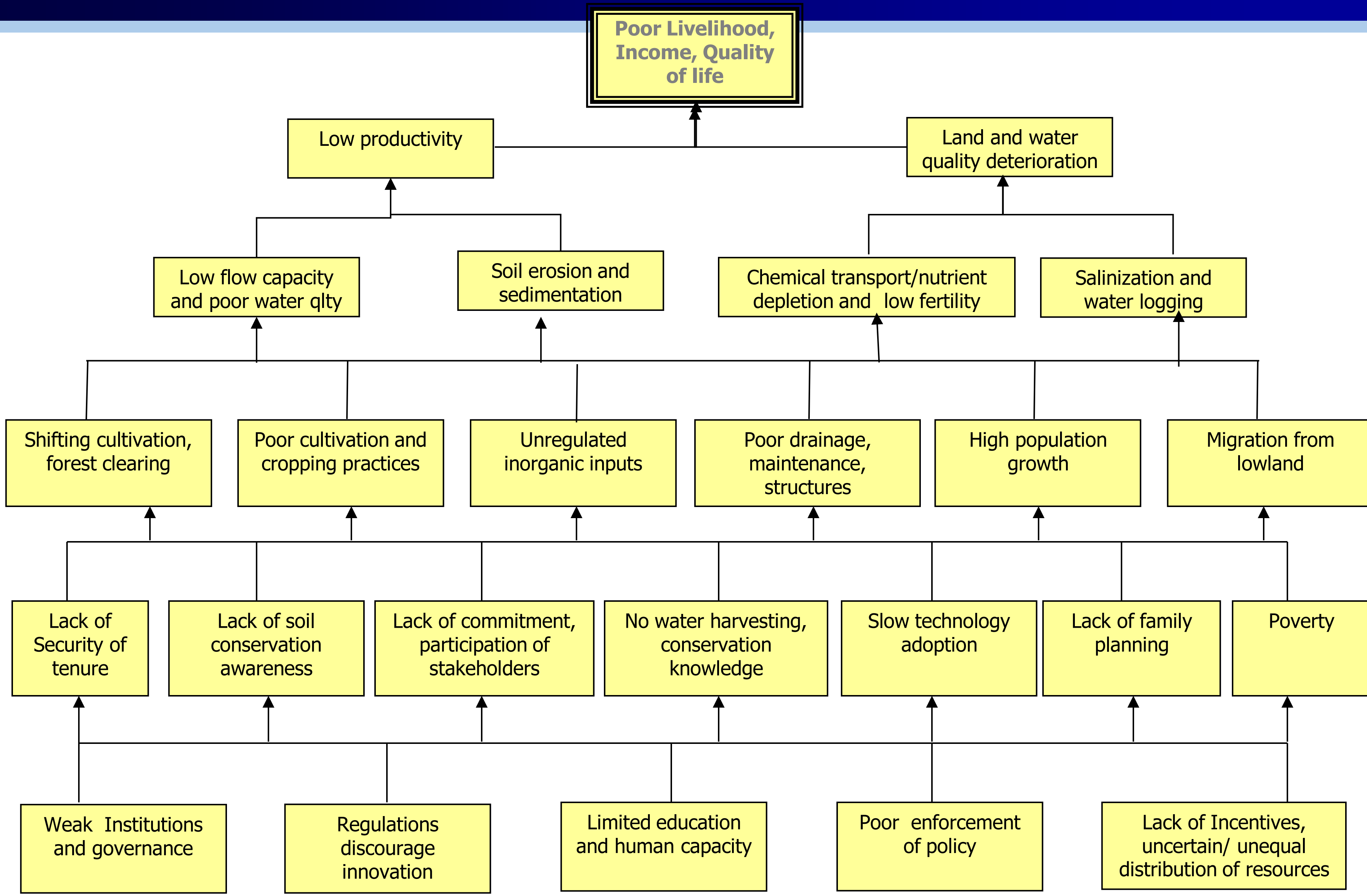
Crop diversification and cultivation of crops which are tolerant to salinity and waterlogged conditions

Enhance adaptive capacity of people to cope with flooding or drought through training/awareness programs

Land use planning to establish better cropping patterns in conjunction with Climate change

Integrated and participatory approach to land and water management

Integrated and Participatory approach to sustainable management of land and water degradation



Thank you.

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