Technological and management innovations in irrigation water management and their impact on agricultural production

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PREAMBLE

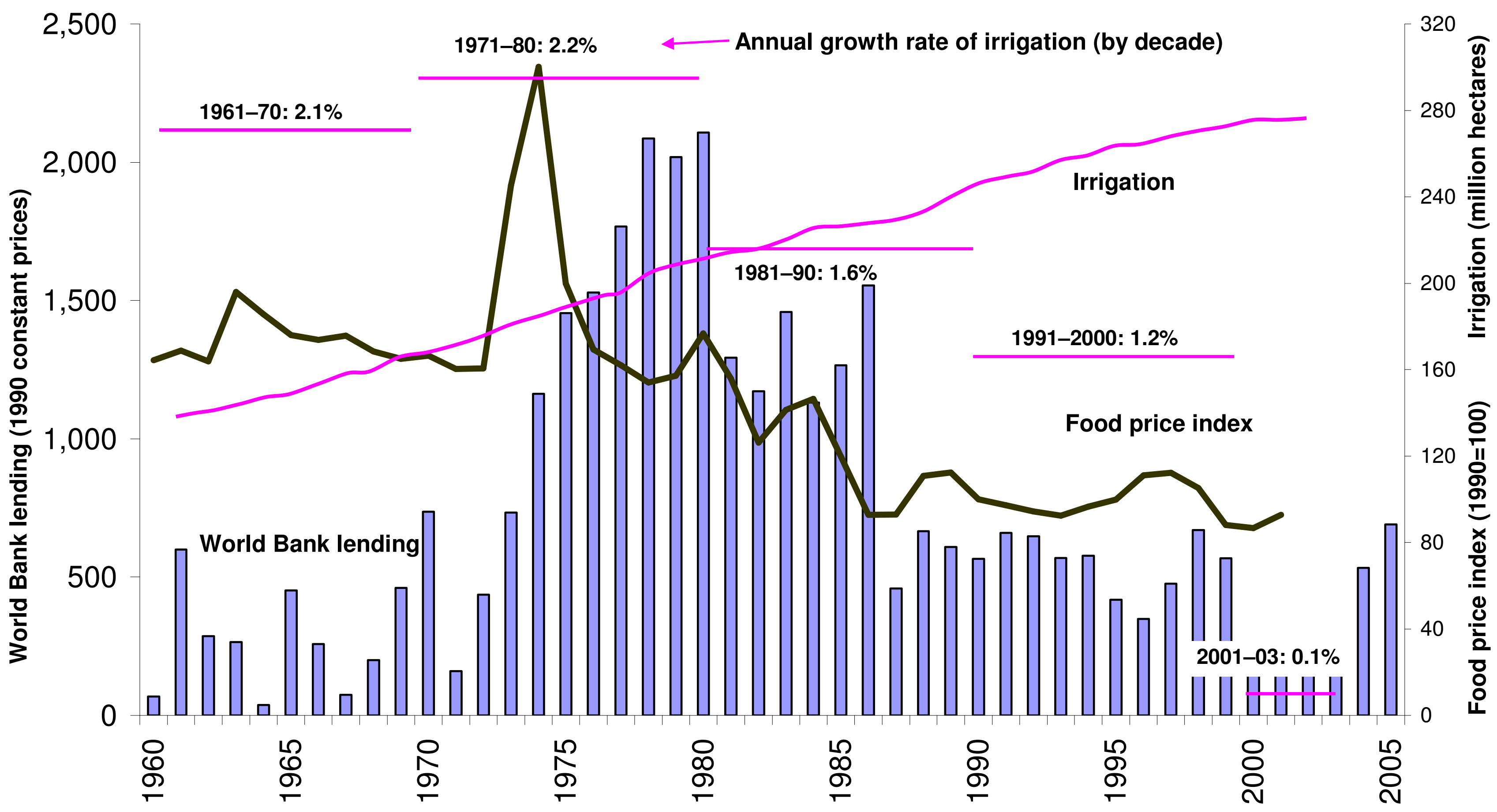
Irrigation expansion 1950-2000

- Irrigation key element of Green Revolution "tripod": water, fertilizers, seeds:
  - Need for rapid food production increase
  - Massive investments in irrigation (particularly in Asia)
  - Investment peak in late 1970s
  - Focus on large scale, public, surface irrigation schemes

Table 3. Typology of irrigation benefits and costs.

Type	Benefits	Cost
Type 1	Direct benefit from employment generation	Direct cost of displacement of the poor households and potential for land encroachment
Type 2	Direct benefit from increase in crop productivity	Direct cost of land degradation through salinity and over-use of chemical fertilisers
Type 3	Localised indirect benefits from productivity induced employment, wages, income and consumption	Localised indirect cost of unemployment through land degradation, mechanisation and other labour saving technologies
Type 4	Other localised benefits from multiple usage of water, groundwater recharge and private investment in irrigated agriculture	Other localised costs of public health risks, loss of biodiversity and water pollution
Type 5	Broader level multiplier benefits from linkages with non-agricultural sectors	Broader level costs of abstraction of river waters leading to degeneration of river health and consequent impact on livelihoods of poor communities dependent upon river health.

Investments in irrigation



Evolution of public irrigation

	1960s to 1980s	1990s to present
Goals: drivers	Food security	Livelihood, income
Resources: land, water, and labor	Abundant	Increased scarcity
Hydraulic development stages	Construction, utilization	Utilization, allocation
Dominant expertise	Hydraulic engineering, agronomy	Multidisciplinary, sociology, economics
Irrigation governance	Public	Mixed
Irrigation technology	Surface	Conjunctive use, pressurized
System management	Supply-driven	Farmer-led
Crops	Fixed, cereals and cotton	Diversified
Cropping intensity	1–1.5	1.5–2.5
Value of water	Low	Increasing
Concern for environment	Low	Increasing

Source: Adapted from Barker and Molle 2004.

Main driving forces for AWU

- Demography
  - Population growth (although slowing down)
  - Urbanisation and changes in diet preferences
- Economic growth
  - Trade and globalisation
    - accelerated pressure on water
- Increasing concern for environmental sustainability
  - Competition for water (incl. other sectors)
  - Pollution (see agriculture in MA)
- Climate change
- Bioenergy ?
- Poverty alleviation, bridging rural-urban gap …

Future investments in irrigation

- Irrigation growth rate will be slower than in the past: 0,6% p.a. against 1.6% in the past
- Irrigation still important in the world food system, with 45 percent of total food production in 2030
- Irrigation will increasingly serve a market-oriented agriculture
- Increased competition for water
- Increased need for transparency in management
- Increased reliability and flexibility of the service of water

Plan

- Raising water productivity
- Technology and management together
- Management innovations
- Evaluation of performance of irrigation systems in Asia
- Technology development
- Some recommendations
- Future pathways

A general introduction

Raising water productivity

KEY PRINCIPLES FOR IMPROVING WATER PRODUCTIVITY

The key principles for improving water productivity at field, farm and basin level, apply regardless of whether the crop is grown under rainfed or irrigated conditions:

(i) increase the marketable yield of the crop for each unit of water transpired by it

(ii) reduce all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomatal transpiration

(iii) increase the effective use of rainfall, stored water, and water of marginal quality

- (ii) and (iii) should be considered parts of basin-wide integrated water resource management (IWRM) for water productivity improvement.
- IWRM recognizes the essential role of institutions and policies in ensuring that upstream interventions are not made at the expense of downstream water users.

- These three principles apply at all scales. However, options and practices associated with these principles require different approaches and technologies at different spatial scales.

ENHANCING WATER PRODUCTIVITY AT PLANT LEVEL

- Plant-level options rely mainly on germplasm improvements, e.g. improving seedling vigour, increasing rooting depth, increasing the harvest index (the marketable part of the plant as part of its total biomass), and enhancing photosynthetic efficiency.
- The most significant improvements in yield stability have usually resulted from breeding programmes to develop an appropriate growing cycle such that the duration of the vegetative and reproductive periods are well matched with the expected water supply or with the absence of crop hazards.

- The modern rice varieties have about a threefold increase in water productivity compared with traditional varieties.

- Progress in extending these achievements to other crops has been considerable and will probably accelerate following the recent identification of the underlying genes.
- Genetic engineering, if properly integrated in breeding programmes and applied in a safe manner, can further contribute to the development of drought tolerant varieties and to increasing the water use efficiency.

RAISING WATER PRODUCTIVITY AT FIELD LEVEL

Improved practices at field level relate to changes in crop, soil and water management:

- selecting appropriate crops and cultivars;
- planting methods (e.g. on raised beds); minimum tillage;
- timely irrigation to synchronize water application with the most sensitive growing periods;
- Nutrient management;
- drip irrigation;
- improved drainage for water table control.

- The significance of soil improvement in enhancing water productivity is often ignored.
- Integrated crop and resource management practices, such as improved nutrient management, can increase water productivity by raising the yield proportionally more than it increases evapotranspiration.
- Integrated weed and integrated pest management have also contributed effectively to yield increases.

- irrigation provides a powerful management tool against the vagaries of rainfall. Irrigation also makes it economically attractive to grow high-yielding crops and to apply the adequate plant nutrition and pest control required in order to obtain the full potential of modern varieties.

deficit irrigation

- One of the field-level methods for increasing water productivity, where deliberately less water is applied than that required to meet the full crop water demand.
- The prescribed water deficit should result in a small yield reduction that is less than the concomitant reduction in transpiration. Therefore, it causes a gain in water productivity per unit of water transpired.
- For deficit irrigation to be successful, farmers need to know the deficit that can be allowed at each of the growth stages and the level of water stress that already exists in the rootzone.

… service needs

- Most importantly, they need to have control over the timing and amount of irrigations. Deficit irrigation carries considerable risk for the farmers where water supplies are uncertain.
- Where water availability falls below a certain level, the value of the crop can fall to zero, either because the crop dies or because the product is of such low quality as to be unmarketable.
- When water is scarce, farmers could reduce the irrigation as appropriate to maximize returns to water if they have control over the timing and amount of irrigations.

- This degree of flexibility is usually the case with sprinkler and drip irrigation, and also with pumped groundwater if the farmer owns the pump.
- A totally flexible delivery system for surface irrigation in large irrigation systems is expensive because of the required overcapacity in the conveyance system.
- The trade-off between reduced yield and higher water productivity needs to be quantified in economic terms before recommending deficit irrigation (and other water-saving irrigations in rice production).

The case of rice

- The often cited low water productivity per unit of water supply in rice cultivation derives from considering as losses the percolation resulting from the standing water layer on the field surface. However, this water is often recycled, and rice water productivity generally compares well with that of a dry cereal.
- Nevertheless, water-saving irrigation techniques such as saturated soil culture and alternate wetting and drying can reduce the unproductive water outflows drastically and increase water productivity while maintaining yields.
- This requires also reliable and flexible irrigation service

Supplementary irrigation and water harvesting

- Water-related problems in rainfed agriculture are often related to large spatial and temporal rainfall variability rather than low cumulative volumes of rainfall.
- The overall result of rainfall unpredictability is a high risk for meteorological droughts and intraseasonal dry spells.
- Bridging crop water deficits during dry spells through supplementary irrigation stabilizes production and increases both production and water productivity dramatically if water is applied at the moisture-sensitive stages of plant growth.
- Water harvesting for agriculture involves a storage reservoir, while in runoff farming the collected runoff is applied directly to the cultivated area. Either way, the investmentsare relatively small.

ACCOUNTING FOR WATER PRODUCTIVITY AT SYSTEM AND BASIN LEVEL

At the larger scale, the effect of agriculture on other water users, human health and the environment becomes at least as important as production issues.

Options for improving water productivity at the agro-ecological or river-basin level are found in:

- better land-use planning;
- better use of medium-term weather forecasts;
- Improved irrigation scheduling to account for rainfall variability;
- conjunctive management of various sources of water, including water of poorer quality where appropriate.

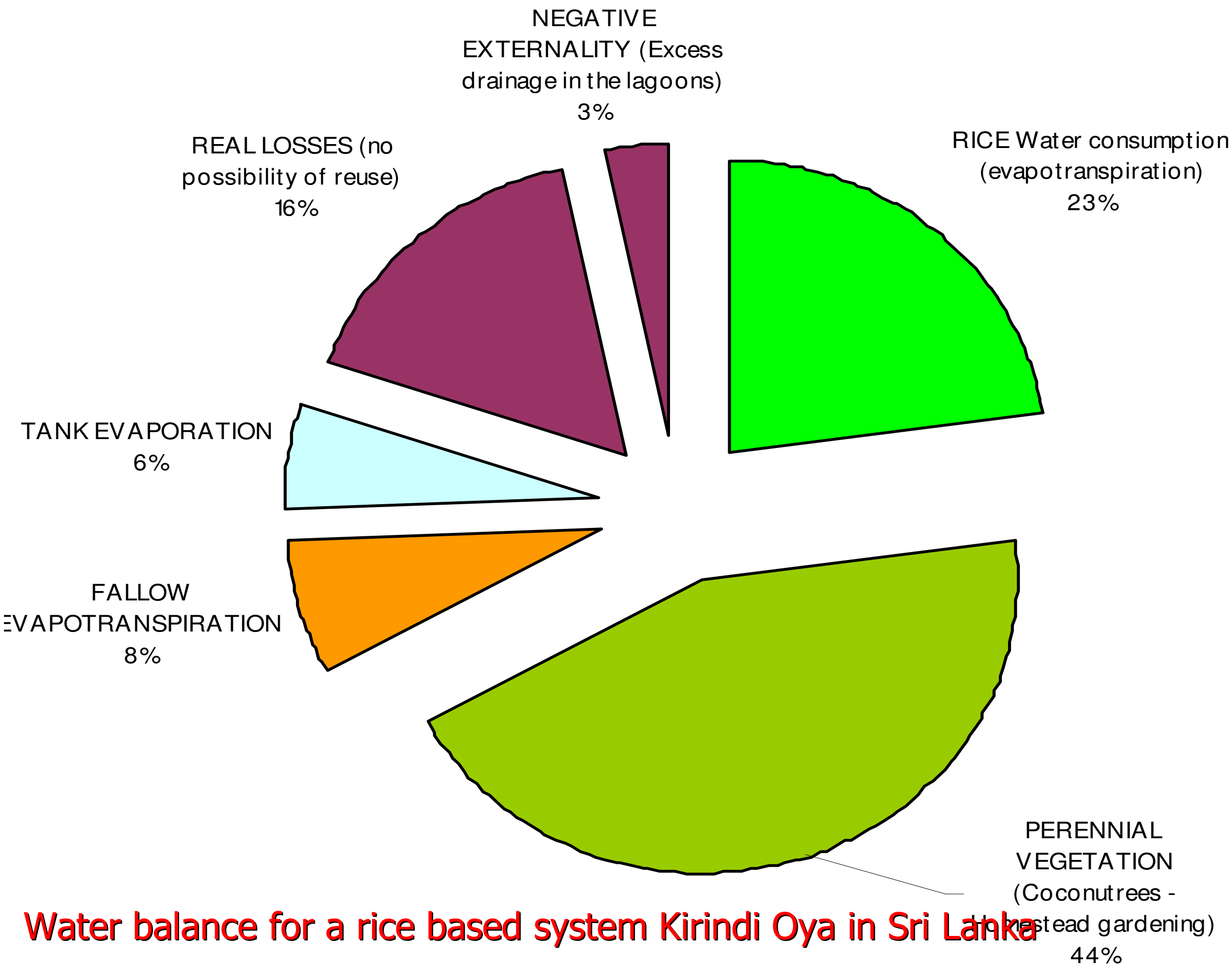
Multi-scale … and service requirements

- Therefore, integrating germplasm improvement and resource management is crucial in the enhancement of water productivity at the field scale and above.
- Gains in water productivity are possible by providing more reliable and flexible irrigation supplies, e.g. through precision technology and the introduction of on-demand delivery of irrigation supplies.
- However, an increase in water productivity may or may not result in greater economic or social benefits. The social benefits represent the benefits to society resulting from the water-productivity enhancing interventions.

Some caution is needed

- Water in the rural areas of developing countries has many uses. Thus, water is both a public and a social good, a fact that complicates value calculations.
- These many uses of water include: the production of timber, firewood and fibre; and raising fish and livestock. Non-agricultural uses of water include domestic (drinking and bathing) and environmental uses.

- Not all measures to increase water productivity are appropriate in all circumstances.
- It is essential to consider the various uses of water in agriculture before measures are introduced that would increase water productivity at the expense of other benefits from the same source of water, especially those benefits that accrue to the local poor and landless people.



Water balance for a rice based system Kirindi Oya in Sri Lanka

Arguably, the largest gains in water productivity in value per unit of water are achieved by diversification and by using water for many productive purposes—such as fisheries, livestock, home gardens, and other small enterprises. This may require changes in irrigation design to incorporate small dams, fisheries, and flood protection.

THE SALINITY AND DRAINAGE QUESTION

- Much of the environmental impact of irrigated agriculture is linked to the management of water and salt balances of irrigated lands. This includes both minimizing the amount of water required to remove salt from the root-zone, and minimizing the land area required to store the salt temporarily or permanently.
- Good management has proved difficult. Although human-induced salinity problems can develop swiftly, solutions can be time consuming and expensive.
- Various improvements in irrigation and agronomic practices can be introduced depending on the type of salinity and on the cause of the accumulation of salts to harmful levels in the root zone.
- Experience in locations, where negative long-term effects from irrigating with saline or sodium-rich waters have been observed, indicates that more permanent interventions in the water and salt balance are generally required.

The challenge of managing the conjunctive use of groundwater and canal water successfully

- In some areas, over-abstraction of groundwater is evidenced by the rapid dropping of water-table levels.
- In other areas where the groundwater is too saline for agricultural production, the water table rises as a consequence of over-irrigation and seepage from irrigation canals.
- Much agricultural land has gone out of production as capillary rise from shallow water tables has ruined soils and poisoned crops.

- Reversing this process is difficult and expensive. In India, the extent of the waterlogged areas is estimated at 6 million ha.
- It is estimated that salinization alone causes 2-3 million ha/year of potentially productive agricultural land to be taken out of production.
- How much of this land is reclaimed (to various degrees) and then cultivated again is unknown.

- Pollution of groundwater by salts and residues of agrochemicals is also a common occurrence.
- Where slightly saline groundwater is used for irrigation, the repeated cycles of water application to the fields, seepage of the excess water and pumping it up again from the top of the aquifer increases the salt load of the groundwater.
- If the vertical permeability of the aquifer is restricted, only limited mixing of seepage water takes place and the top of the aquifer from which the water is pumped becomes increasingly saline.
- This process has been documented for several irrigation systems in Punjab, Pakistan, where conjunctive irrigation with canal water and groundwater takes place.

CONCLUSION

- System-level improvements in irrigation and drainage infrastructure and in the institutional and policy arrangements for managing these systems will enhance water productivity and hence food security.
- However, the greatest benefits are expected from integrated crop and resource management. These will accrue when the three components of plant breeding, agronomic improvements, and changes in the operation and management of irrigation facilities work together so that the potential benefits of new crops and varieties are fully realized.
- There are few successful examples of this three-way collaboration. Its realization amounts to reinventing agricultural water management.

7 key messages

- **1. Accepting the fact that there is no single solution for maintaining food security when water is scarce.**
- **2. Finding the best options for specific conditions.**
- **3. Realizing that the link between irrigated agriculture and rural development is not always straightforward**
- **4. Adopting natural resource based policies and institutions**
- **5. Facilitating and supporting actively the development of improved varieties**
- **6. Supporting actively the application of seasonal climate predictions**
- **7. Investing in irrigation modernization**

Plan

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IPTRID defines its mission as:

"To improve the uptake of research, exchange of technology and management innovations by means of capacity development in the irrigation and drainage systems and sectors of developing countries to reduce poverty, enhance food security and improve livelihoods, while conserving the environment".

A recent expert consultation felt that a formulation such as:

"To facilitate the application of scientific knowledge to practical purposes in the irrigation and drainage sector of developing countries to contribute in reducing poverty, enhance food security and improve livelihood while conserving the environment"

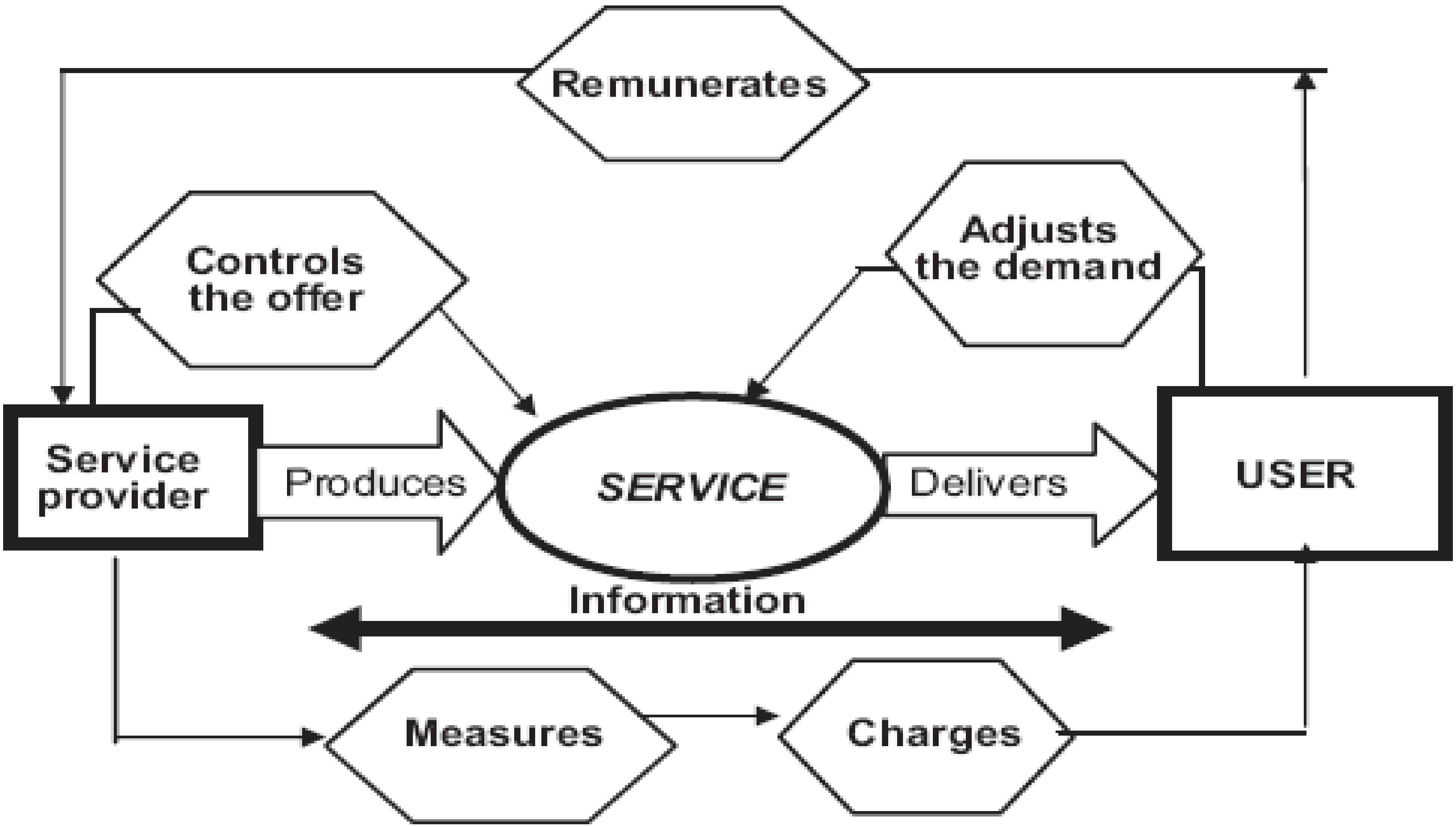
- Many professionals argue convincingly that technological innovation by itself would rarely improve the performance of irrigation.
- Many also argue that institutional reforms and management innovation alone would not turn irrigation around.
- There is a wide consensus that a combination of the three plus economic incentives would make a difference.
- On the other hand, the focus of irrigation reforms in the past years has been very much on the institutional side. Technological issues have been neglected.

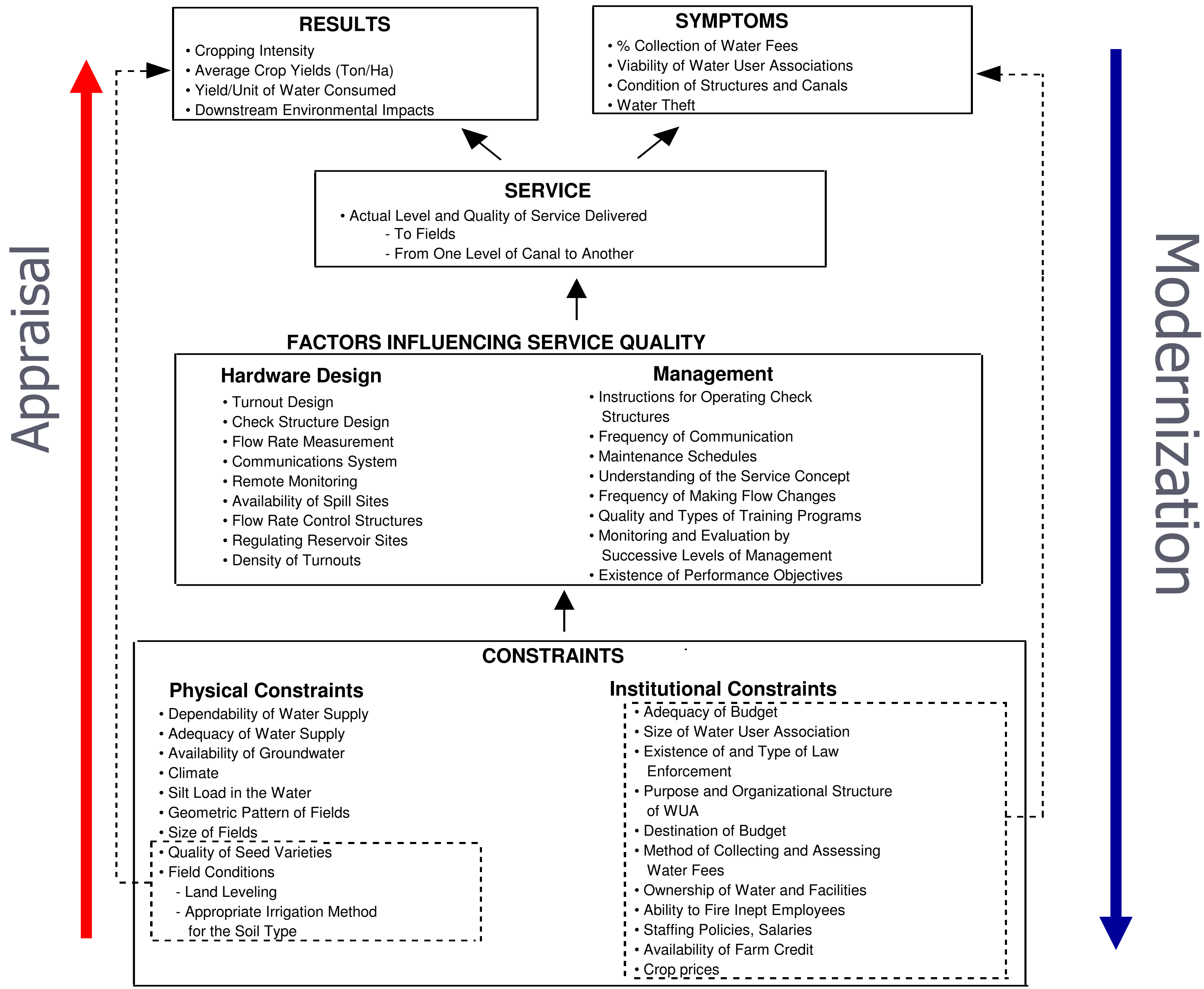
FAO's viewpoint

The concept of modernization and service orientation:

- A process of technical and managerial upgrading (as opposed to mere rehabilitation) with the objective of improve resource utilization (labour, water, economics, environment) and water delivery service to farms service to farms
- The transition from supply-driven to service-oriented management

FIGURE 3
The service-oriented management approach





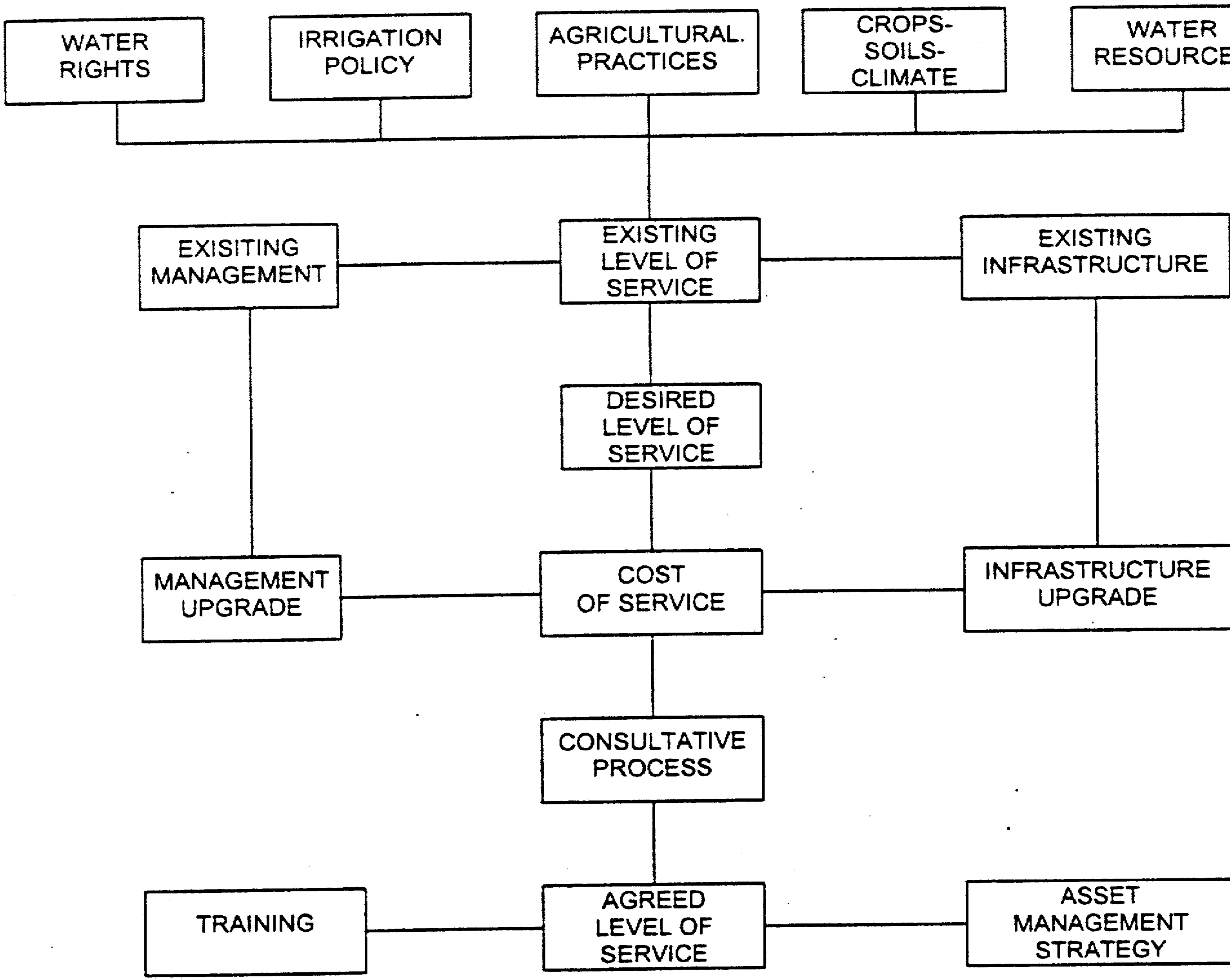
Appraisal
Modernization
RESULTS
• Cropping Intensity
• Average Crop Yields (Ton/Ha)
• Yield/Unit of Water Consumed
• Downstream Environmental Impacts
SYMPTOMS
• % Collection of Water Fees
• Viability of Water User Associations
• Condition of Structures and Canals
• Water Theft
SERVICE
• Actual Level and Quality of Service Delivered
- To Fields
- From One Level of Canal to Another
FACTORS INFLUENCING SERVICE QUALITY
Hardware Design
• Turnout Design
• Check Structure Design
• Flow Rate Measurement
• Communications System
• Remote Monitoring
• Availability of Spill Sites
• Flow Rate Control Structures
• Regulating Reservoir Sites
• Density of Turnouts
Management
• Instructions for Operating Check Structures
• Frequency of Communication
• Maintenance Schedules
• Understanding of the Service Concept
• Frequency of Making Flow Changes
• Quality and Types of Training Programs
• Monitoring and Evaluation by Successive Levels of Management
• Existence of Performance Objectives
CONSTRAINTS
Physical Constraints
• Dependability of Water Supply
• Adequacy of Water Supply
• Availability of Groundwater
• Climate
• Silt Load in the Water
• Geometric Pattern of Fields
• Size of Fields
• Quality of Seed Varieties
• Field Conditions
- Land Leveling
- Appropriate Irrigation Method for the Soil Type
Institutional Constraints
• Adequacy of Budget
• Size of Water User Association
• Existence of and Type of Law Enforcement
• Purpose and Organizational Structure of WUA
• Destination of Budget
• Method of Collecting and Assessing Water Fees
• Ownership of Water and Facilities
• Ability to Fire Inept Employees
• Staffing Policies, Salaries
• Availability of Farm Credit
• Crop prices

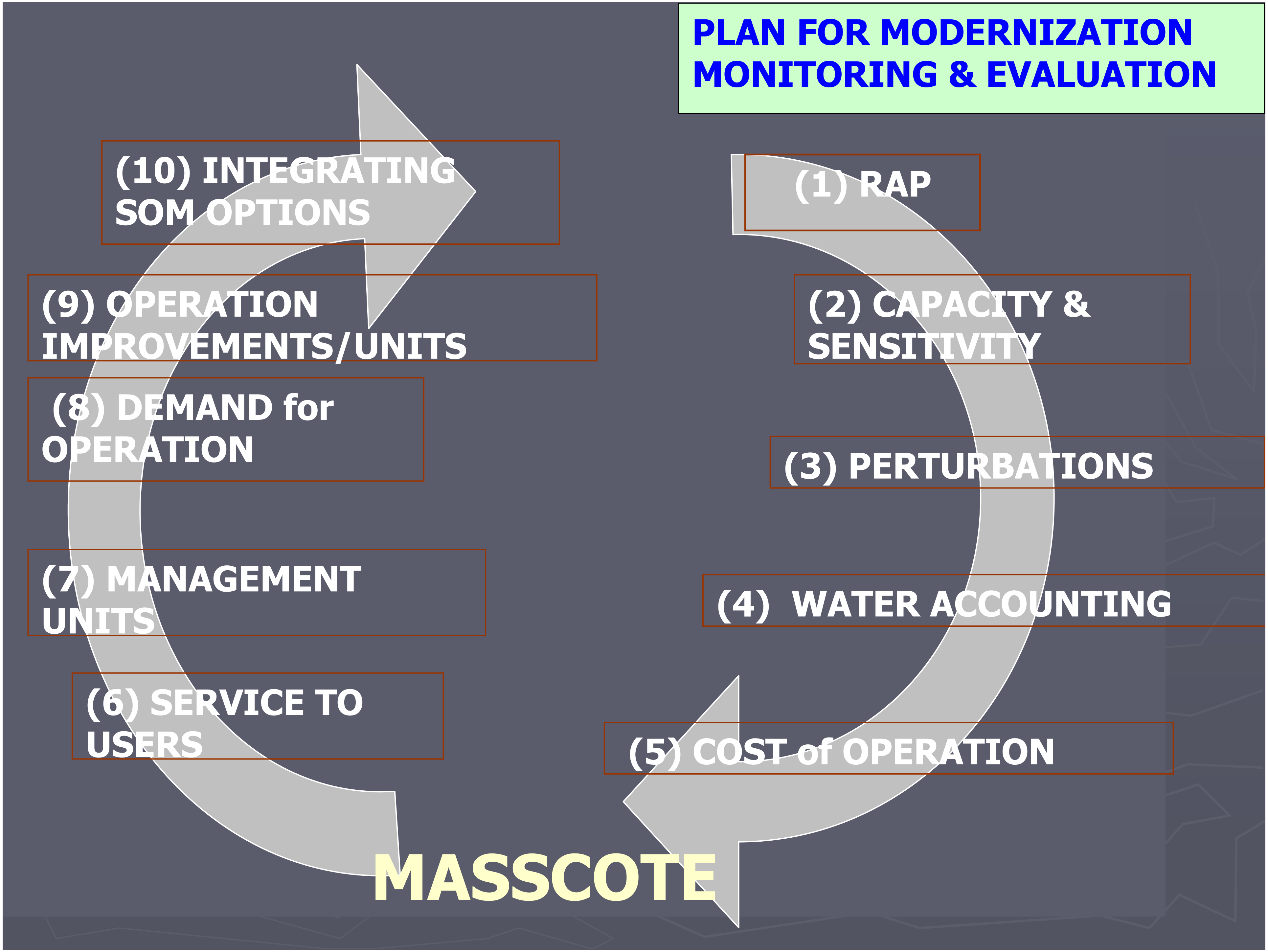
Each level of management delivers service to the next lower level

Bulk water supply to the system

- Primary delivery/conveyance
  - Levels of canals/management
    - Down to the farm

A powerful idea for management innovations and re-engineering: Unbundling service delivery


WATER RIGHTS
IRRIGATION POLICY
AGRICULTURAL. PRACTICES
CROPS-SOILS-CLIMATE
WATER RESOURCES
EXISITING MANAGEMENT
EXISTING LEVEL OF SERVICE
EXISTING INFRASTRUCTURE
DESIRED LEVEL OF SERVICE
MANAGEMENT UPGRADE
COST OF SERVICE
INFRASTRUCTURE UPGRADE
CONSULTATIVE PROCESS
TRAINING
AGREED LEVEL OF SERVICE
ASSET MANAGEMENT STRATEGY


PLAN FOR MODERNIZATION
MONITORING & EVALUATION
(1) RAP
(2) CAPACITY & SENSITIVITY
(3) PERTURBATIONS
(4) WATER ACCOUNTING
(5) COST of OPERATION
(6) SERVICE TO USERS
(7) MANAGEMENT UNITS
(8) DEMAND for OPERATION
(9) OPERATION IMPROVEMENTS/UNITS
(10) INTEGRATING SOM OPTIONS
MASSCOTE

Plan

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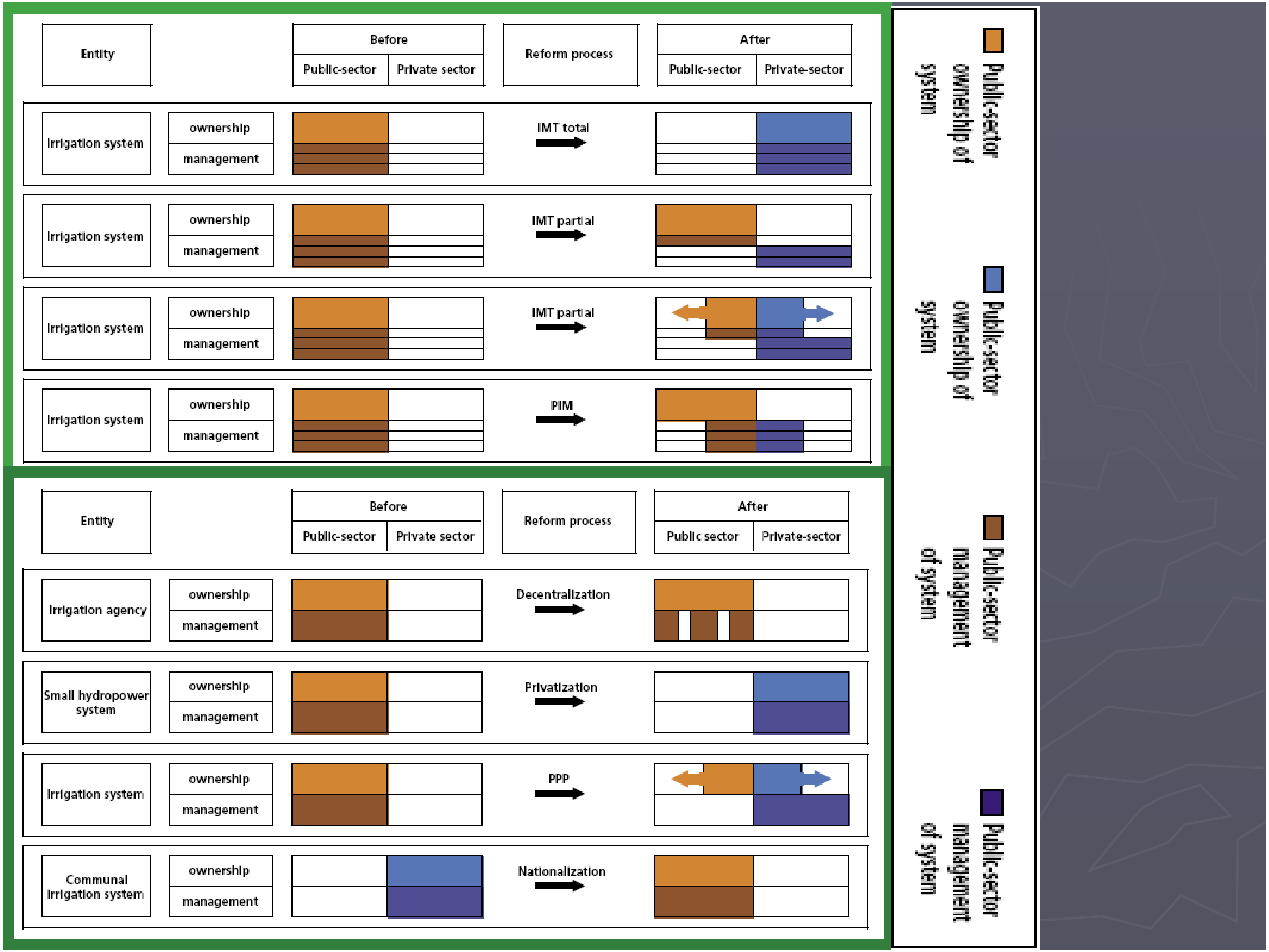


Entity
Before
Public-sector
Private sector
Reform process
After
Public-sector
Private-sector
Irrigation system
ownership
management
IMT total
Irrigation system
ownership
management
IMT partial
Irrigation system
ownership
management
IMT partial
Irrigation system
ownership
management
PIM
Entity
Before
Public-sector
Private sector
Reform process
After
Public sector
Private-sector
Irrigation agency
ownership
management
Decentralization
Small hydropower system
ownership
management
Privatization
Irrigation system
ownership
management
PPP
Communal irrigation system
ownership
management
Nationalization
Public-sector ownership of system
Public-sector ownership of system
Public-sector management of system
Public-sector management of system

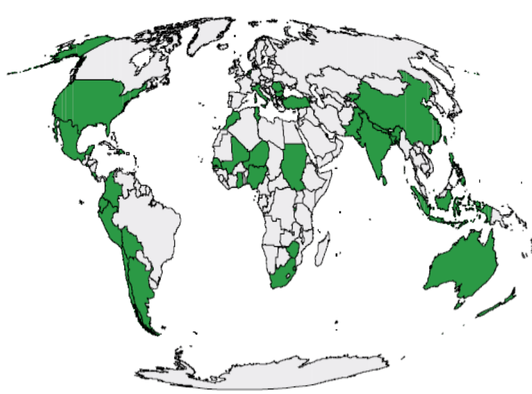
Roles of government irrigation sector agencies relative to WUAs and water users

Roles	Asia (11)	Latin America (7)	Africa (3)	Europe (3)	Worldwide (24)
Make policy, laws, strategy, plans about WUAs	11	7	3	3	24
Establish WUAs & approve WUA statutes	11	7	3	3	24
Regulate, supervise & inspect WUAs	11	6	3	3	23
Provide technical assistance & training	10	3	3	3	19
Construction & rehabilitation	10	2	2	2	16
Manage main system/large systems	9	3	2	1	15
Help settle disputes	7	4	2	0	13
Grant water allocations & concessions	5	6	1	1	13
Conduct technical & management audits	6	3	1	1	11
Arrange maintenance contracts with WUAs	4	0	0	1	5
Approve WUA O&M plans & budgets	1	2	1	0	4
Set water service charges	3	0	0	0	3

Factors motivating adoption of IMT

Factors	Number of countries where factor is:	
	Most important	Second most important
Shortage of government funds to allocate to irrigation O&M	24	6
Poor maintenance of irrigation systems	5	13
Government not able to collect enough fees from water users	4	11
Part of general liberalization policies of government	3	0
Poor operation of irrigation systems	2	2
Farmers requested to take over management of schemes	2	4
Donors and international agencies	2	0
Political transition in former Soviet Union countries	2	0
Pressure from central department (such as planning or finance)	0	3

FIGURE 2
Map of countries represented in the study



Entity providing water delivery and canal maintenance after IMT

Entity delivering water	Water delivery			Canal maintenance		
	Field level	Distributary level	Main system level	Field level	Distributary level	Main system level
Farmers coordinated by WUA	17	5	4	14	8	3
Staff of WUA	16	14	9	15	10	6
Farmers not coordinated by WUA	5	0	0	3	1	0
Staff of government agency	3	11	14	2	10	14
Staff of private-sector contractor	0	1	2	2	3	1
Staff of public utility or state-owned enterprise	0	3	2	0	3	4
Staff of company owned or contracted by WUA	1	1	0	2	2	1
Total cases reported	42	35	31	38	37	29

TABLE 3
Authority transferred

Function devolved	Number of countries where authority is:			
	Fully devolved	Partially devolved	Not devolved	Total
Operations	31	12	0	43
Maintenance	30	13	0	43
Finance O&M	21	19	1	41
Can apply sanctions & resolve disputes	20	20	0	40
Can develop cooperative business	17	9	9	35
Finance rehabilitation & modernization	10	18	9	37

Legal rights of WUAs

Legal rights of WUAs	Number of countries
Have bank accounts & make contracts	18
Can fine members	17
Water right or water-use right	15
Can own property	11
WUA canals have rights of way	7
Can cut off water supply to users	6

Type of organization taking over management after transfer

Type of organization	Number of country profiles	Examples
Water users association	39	Widespread
Irrigation district	5	United States of America, China
Mutual company	3	United States of America, Spain
Local government	3	Turkey
Public utilities	2	France
Joint government / farmer committee	1	Sri Lanka, Philippines
Limited responsibility entity	1	Mexico

Legal rights of and responsibilities granted to WUAs, 24 countries

Legal rights and responsibilities granted to WUAs	Number of countries
WUA pays for O&M	24
WUA has legal status	23
WUA has water use right	15
WUA established voluntarily	14

Purposes of WUAs as specified by law

Purposes of WUAs as specified by law	Number of countries
Irrigation	24
Drainage	19
Groundwater	7
Agribusiness	6
Manage watershed	5
Construct or extend system	4

Rights and responsibilities of WUA members

Rights and responsibilities of WUA members	Number of countries
Pay O&M fees	23
Voting rights	23
Membership is voluntary	13
Water rights held by members	7
Must give land for irrigation & drainage infrastructure	6
Members can obtain compensation for damages	3

Problems and issues in implementing IMT

Problems & issues in implementing IMT	Asia (21)	Latin America (7)	Africa (9)	Eastern Europe (3)	United States of America, Australia, New Zealand (3)	Worldwide (43)
Resistance to IMT by agency	16	5	7	2	1	31
Inadequate training of WUA	18	2	4	1	0	25
Difficult for govt. to finance IMT	12	0	3	0	0	15
Irrigation systems heavily deteriorated	6	2	4	1	1	14
Weak capacity to train WUA	11	0	2	0	0	13
Weak legal framework for IMT	9	2	2	0	0	13
Inadequate farmer payment for O&M	7	0	4	2	0	13
Weak techn. & mngt. capacity of WUA	10	1	1	0	0	12
Inadequate training for govt. staff	11	0	0	0	0	11
Agency reform & staff disposition	5	3	1	0	1	10
Farmers resist IMT	4	4	1	0	1	10
No clear/single IMT policy or programme	5	3	1	0	0	9
Resistance to IMT by local government	8	0	0	0	1	9
Democratic elections of WUA officers difficult to achieve	7	0	1	0	0	8
Conflicts between farmers/villages	4	1	3	0	0	8
Politicians resist IMT	6	0	1	0	0	7
Inadequate support services	3	0	3	0	0	6
WUA cannot apply sanctions	3	0	2	0	0	5
Farmers lack access to credit	2	0	3	0	0	5

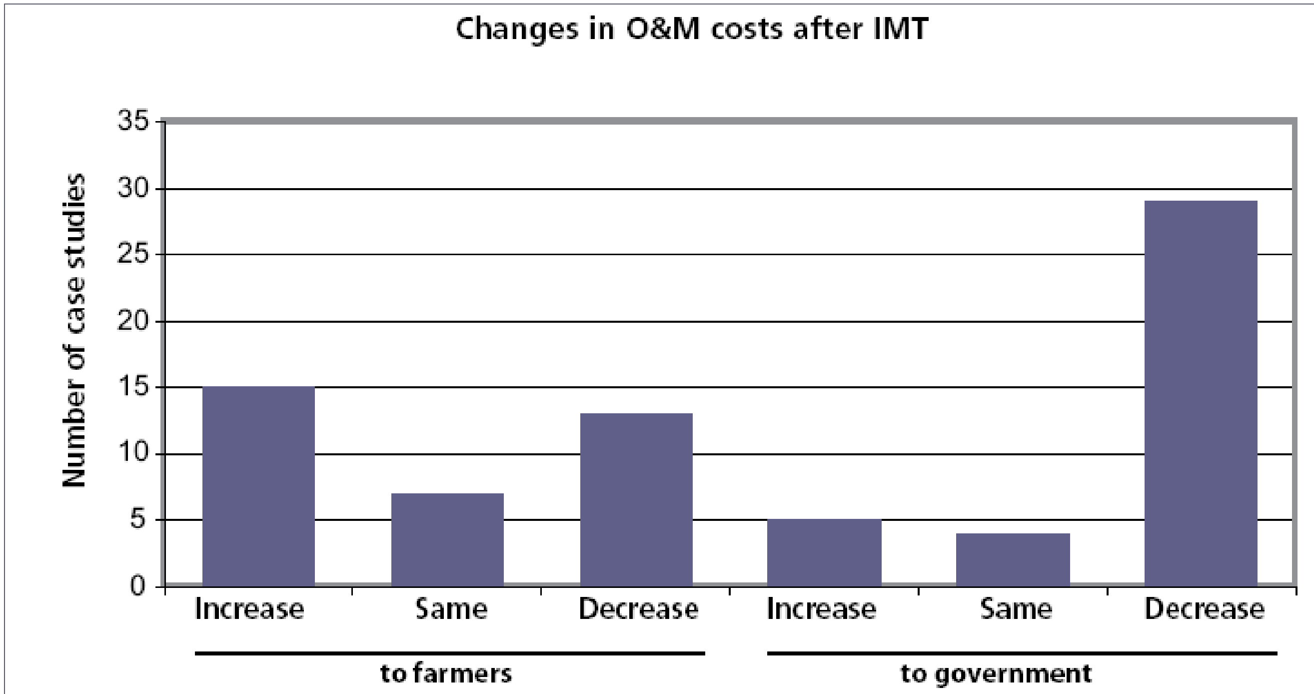
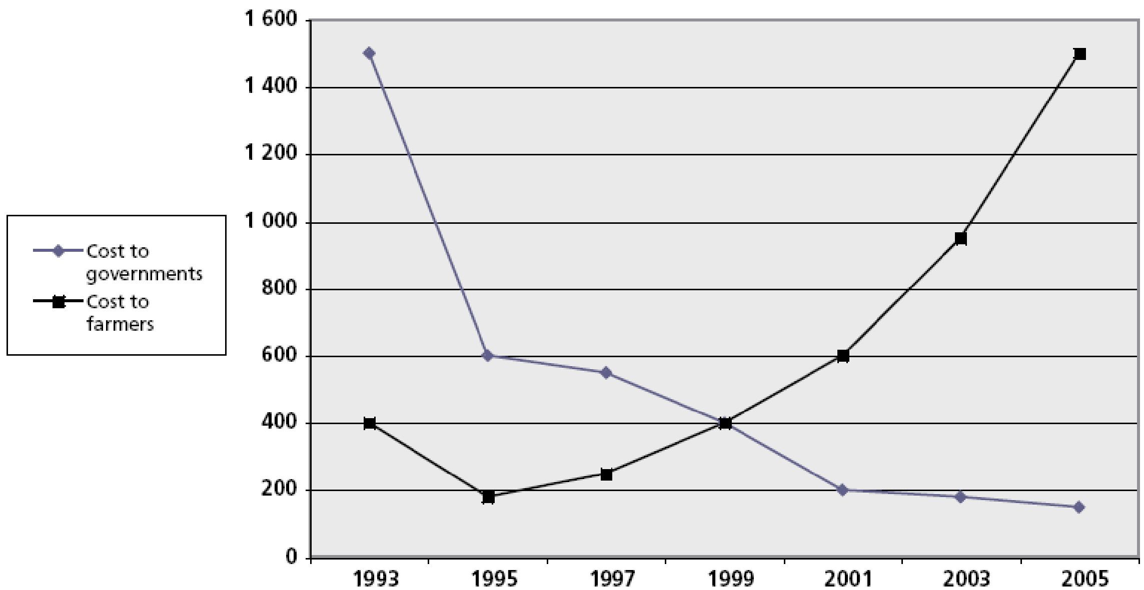
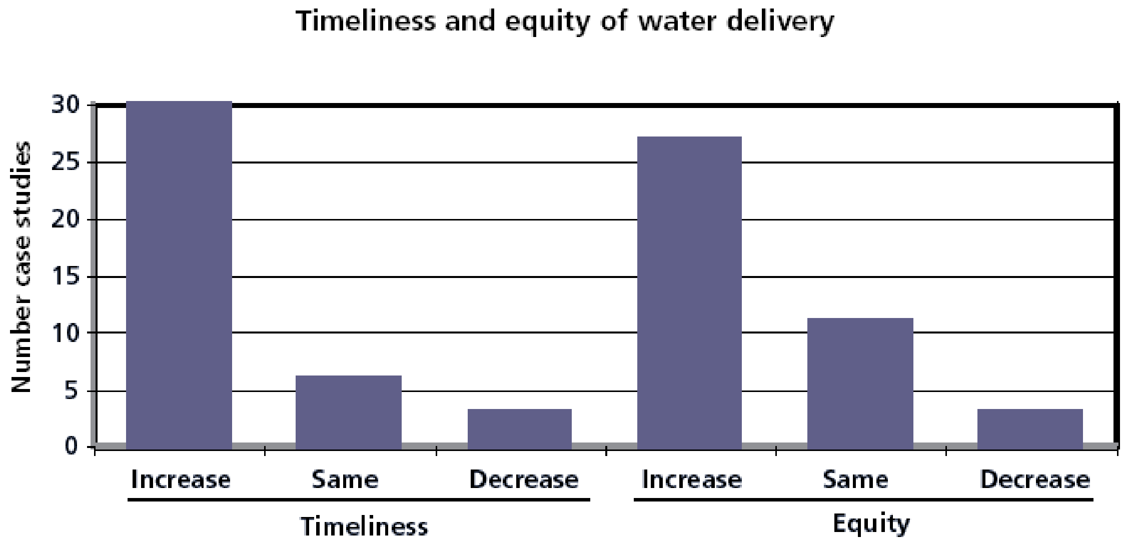


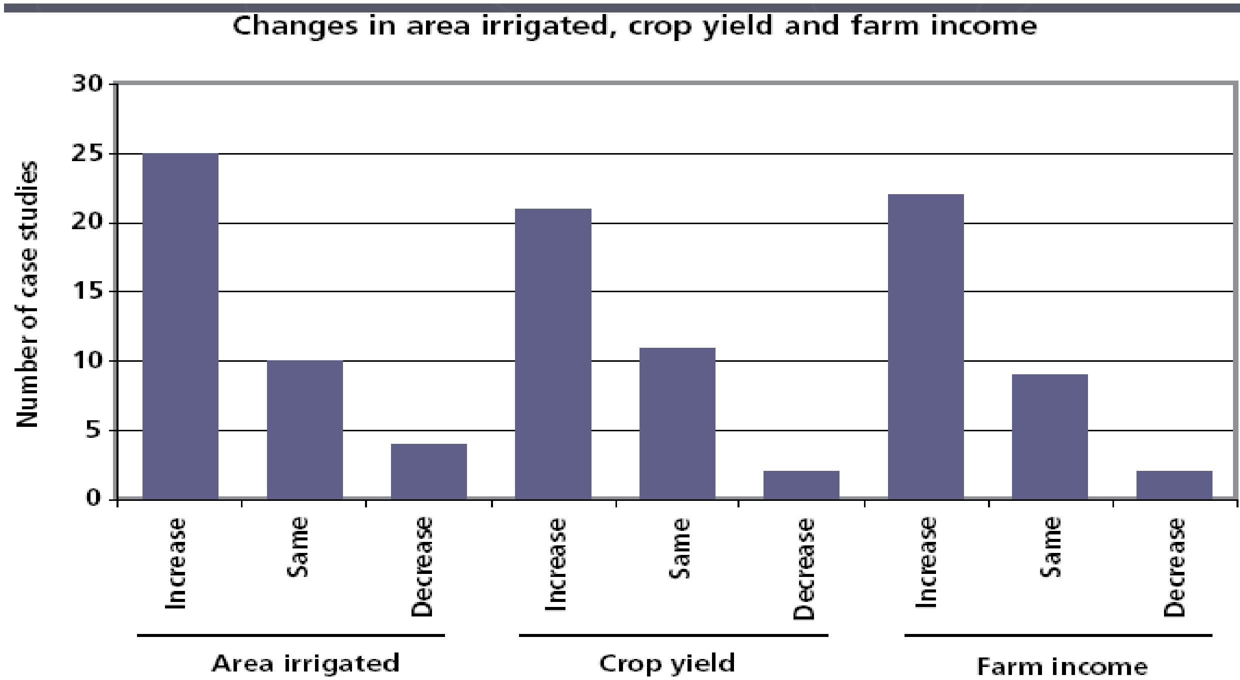
FIGURE 8
Evolution of O&M costs for government and farmers in Ecuador, in 2003 US$



- not that good for agricultural production
- unless you do improve sustainability
- Drive to improve yields and/or incomes cash crops

Some results and some questions





- Flexibility?
- Effect of rehabilitation?
- Land productivity?
- Water productivity?
- Case studies?
- Questionnaires?
  - Andhra Pradesh
  - China

- **Monitoring of investments and results and benchmarking !!!**

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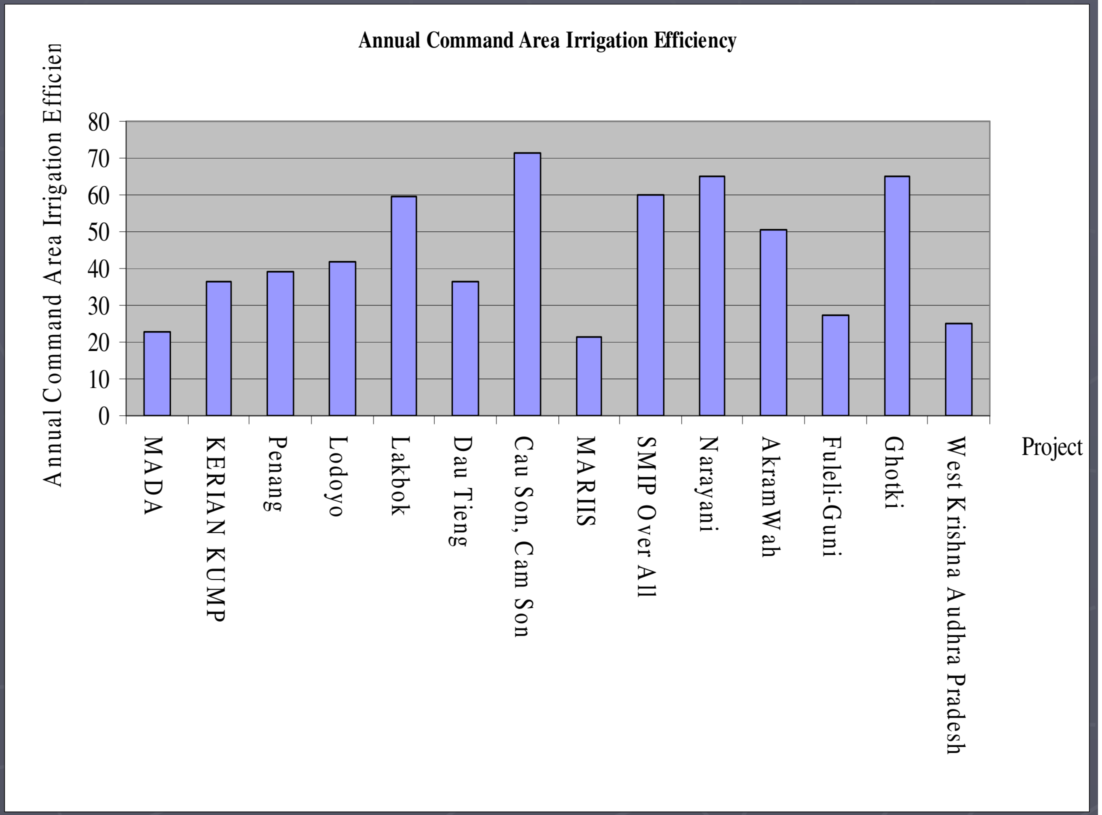
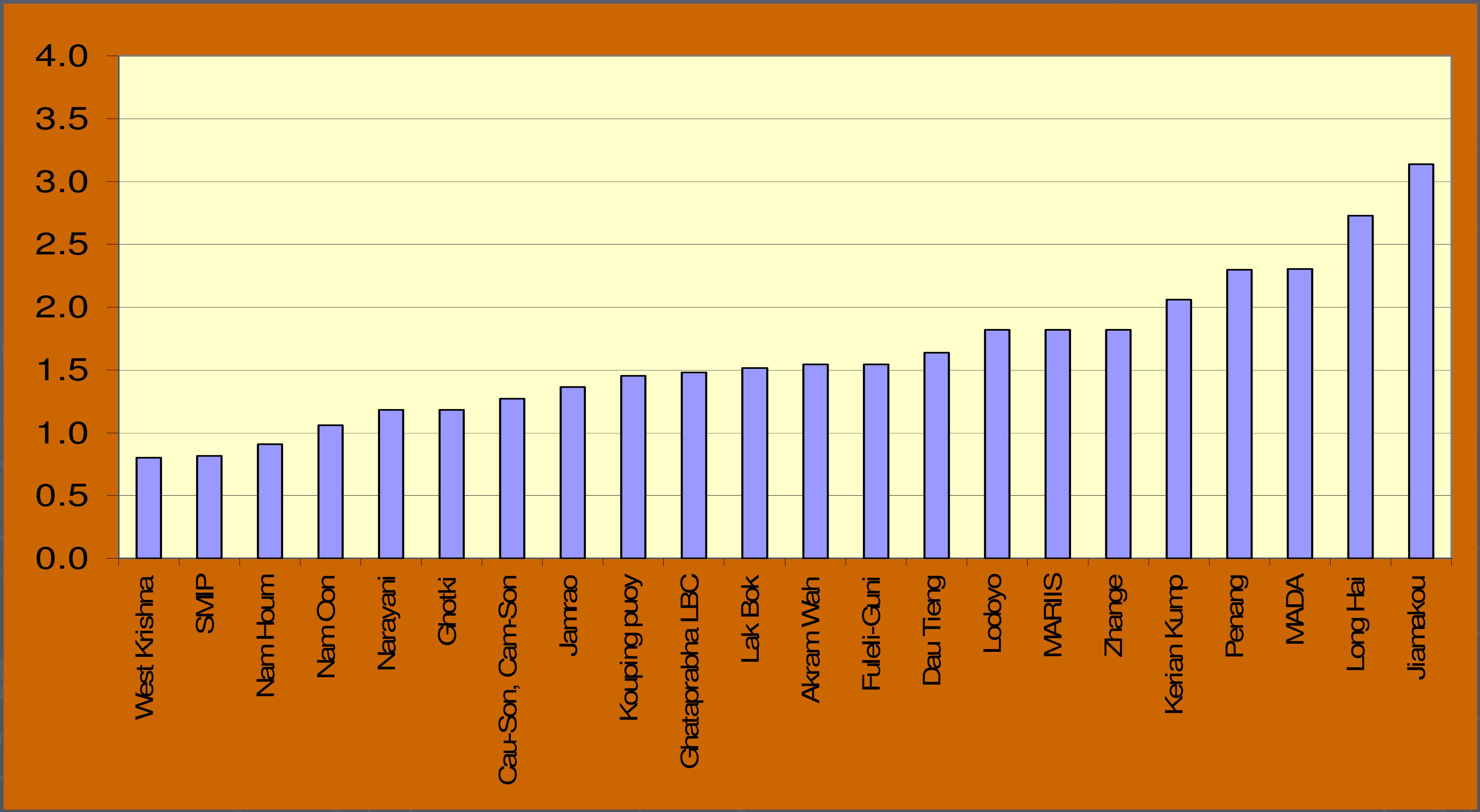
Summary findings from an evaluation of systems in Asia

- Sources, uses and destination of water

- efficiencies are frequently estimated with such wide confidence intervals that it is often impossible to define or evaluate related improvement objectives



Actual service delivery to the farm



- Farmers are not inactive and take measures to address poor or inadequate service delivery
- In systems where pumping by and paid by farmers is ubiquitous, pumping costs can be very high compared with overall capital & O&M spending on the surface system and surface delivery water fees.
- Farmer investment and spending considerably improves overall system performance.
- Very little happens at WUA levels …

In most systems:

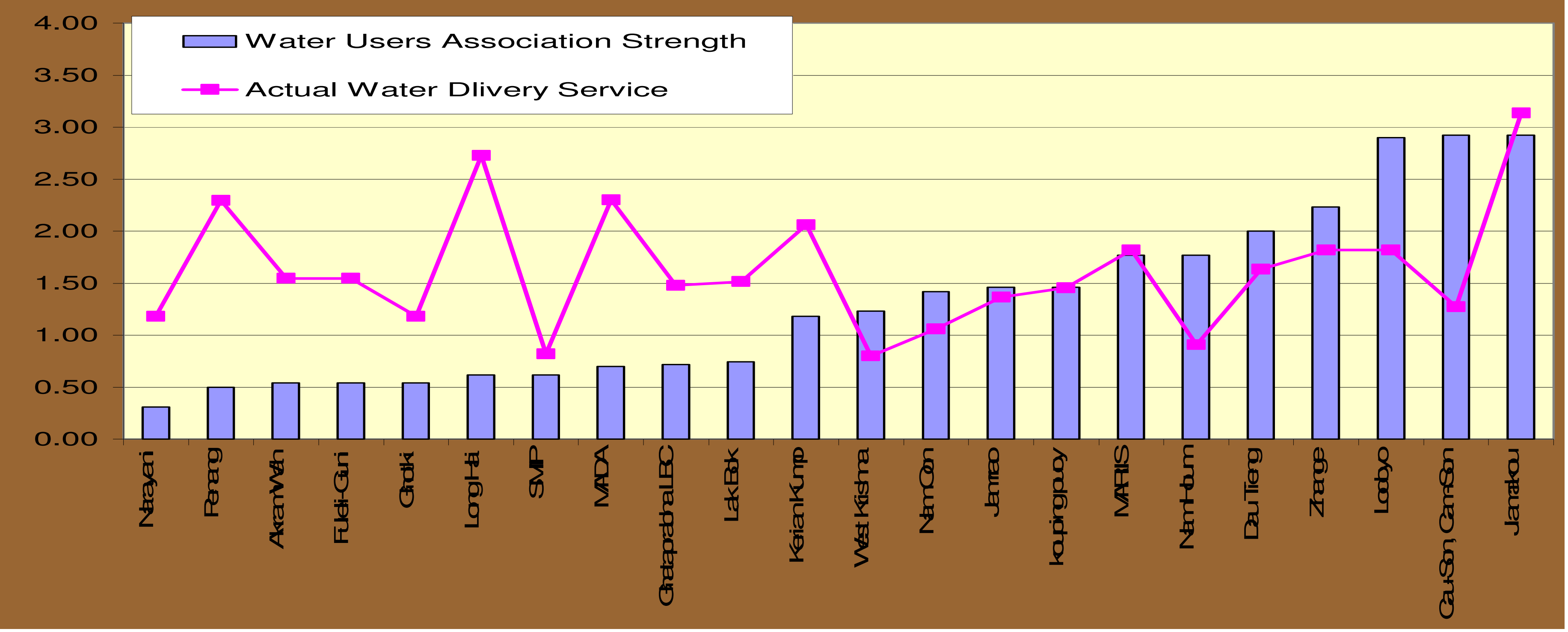
- high level of chaos (difference between stated policies and results, and actual policies and results)
- high level of anarchy (subversion of policies)

- Recent investments following standards or classical strategies have poor results in terms of performance, control and service.
- Many of the problems can be traced to design, layout, operation, service delivery, lack of flexibility, poor training esp. in hydraulics.
- Standard improvement projects, including their PIM component, usually fail to address these issues
- Reform maintains operational details that cause problems and chaos.

Financing

- O&M remains a big problem
- Focusing only on O&M of assets that are designed to deliver poor service and performance will not solve the problem

- WUAs in most systems are weak and have little to say in the way system is managed, even when they have been there for long time.
- WUA strength does not influence water delivery service to farms: no correlation between WUA strength and service to farms ratings.



- A blueprint or standardized institutional reform package, with little adaptation to local circumstances and goals, and with essentially the same poor results.
- Participation of WUAs has not led to management objectives and policies that reflect the reality of water management in the systems:
  - where farmers need to pump from canals or groundwater or recycle drainage water
  - actual cropping patterns, schedules and even crops in some cases are not reflected in official cropping patterns and scheduling.

- Excessive reliance in:
  - policy reform,
  - institutional reform,
  - improved control technology,
  - improved management,
  - economic incentives and instruments or
  - on-farm water management

  as measures which would **single-handedly** deliver improved performance or service.
- When considered in isolation, these measures may be inconsistent (eg volumetric water pricing and proportional water division)
- A complex and articulated mix of changes is in fact required.

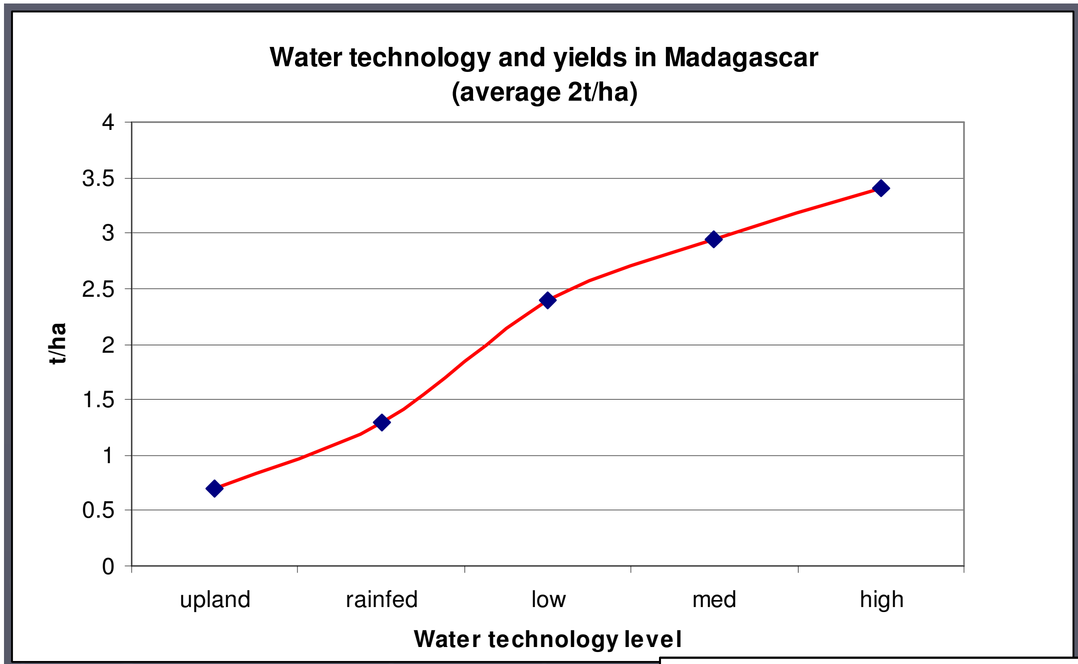
Some conclusions

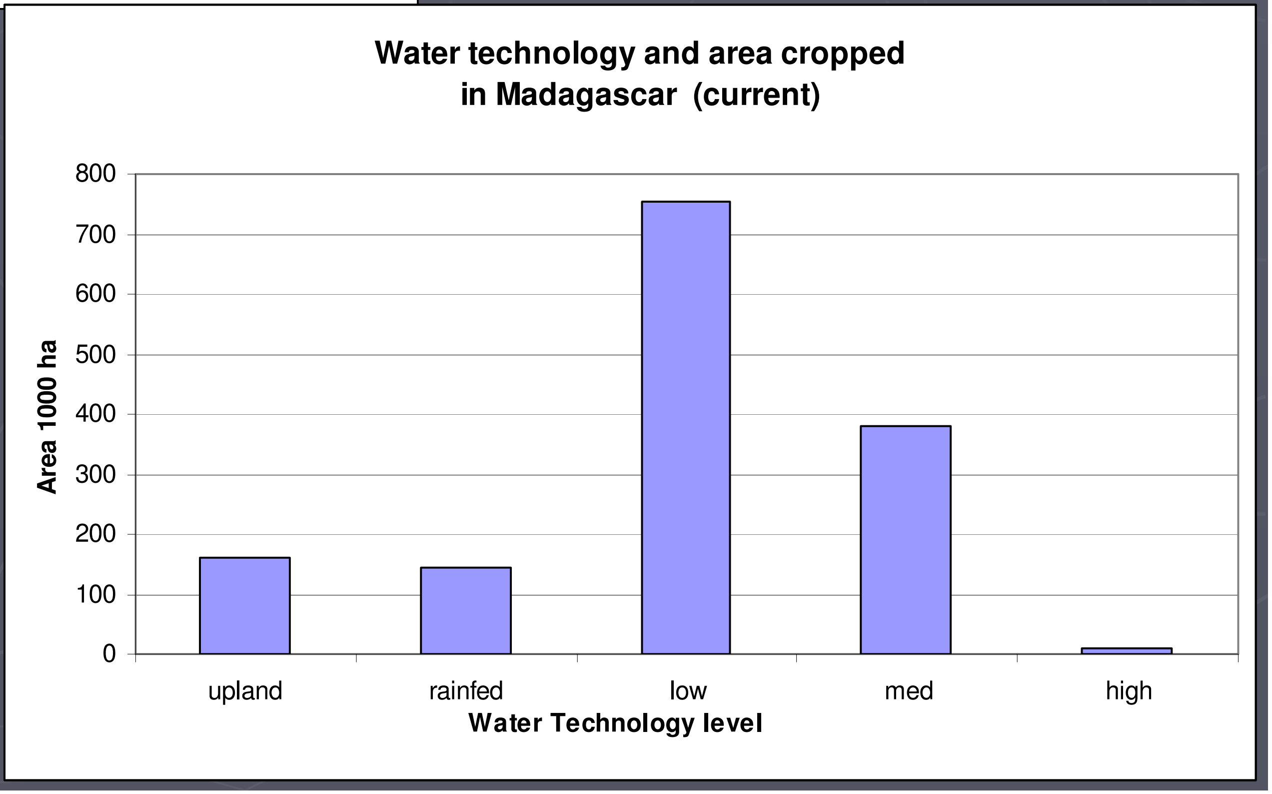
- Responsiveness of management to service requirements and a basic agreement between managers and users on how water is managed in the system for what objective is still largely lacking.
  - This includes taking into account the multiple uses and roles of water in the irrigation systems.

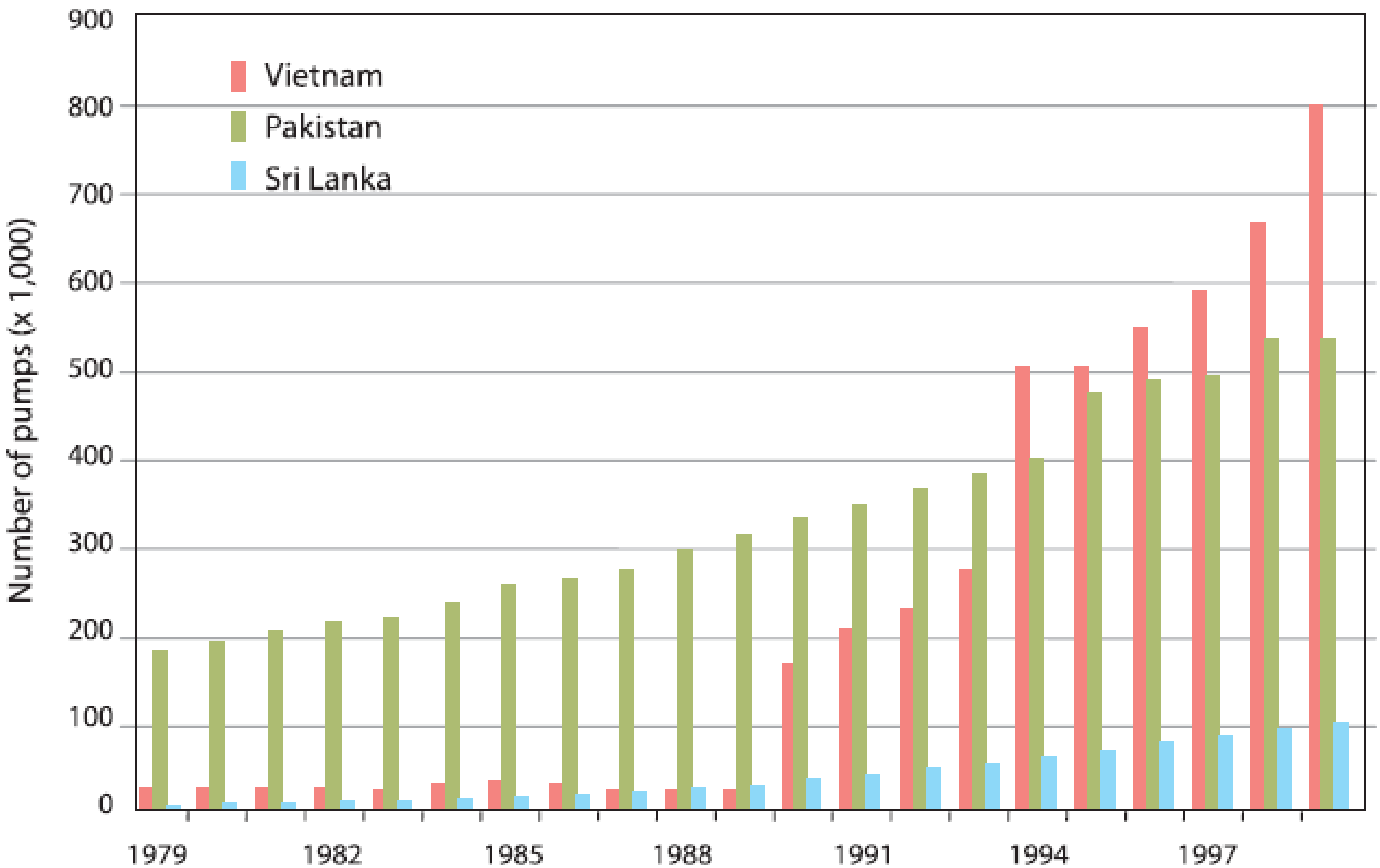
- The reforms take a long time to deploy but:
  - seem to address to a large extent yesterday’s problems (lack of funding for operation and maintenance and establishing basic equity)
  - largely fail to achieve those objectives
  - if and when they eventually achieve then, they will be insufficient to meet the new requirements of farmers.

Plan

- Technology and management together
- Management innovations
- Evaluation of performance of irrigation systems in Asia
- Technology development
- Some recommendations
- Future pathways


Water technology and yields in Madagascar
(average 2t/ha)
4
3.5
3
2.5
2
1.5
1
0.5
0
t/ha
upland
rainfed
low
med
high
Water technology level


Water technology and area cropped
in Madagascar (current)
800
700
600
500
400
300
200
100
0
Area 1000 ha
upland
rainfed
low
med
high
Water Technology level


Vietnam
Pakistan
Sri Lanka
Number of pumps (x 1,000)
900
800
700
600
500
400
300
200
100
0
1979
1982
1985
1988
1991
1994
1997

Groundwater
Surface sources
Percent
80
70
60
50
40
30
20
10
0
1965
1978
1984
1995

Water application

Table 1: Classification of Irrigation Systems

Irrigation Group	Irrigation System	
Flood	Furrow Border Basin	
Non-mechanized sprinkler	Dragline Portable Permanent	Hop-along Big gun Floppy
Mechanized sprinkler	Side-roll Travelling gun Boom	Centre pivot Linear ravelling boom
Micro	Drip Micro jet Micro sprinkler	

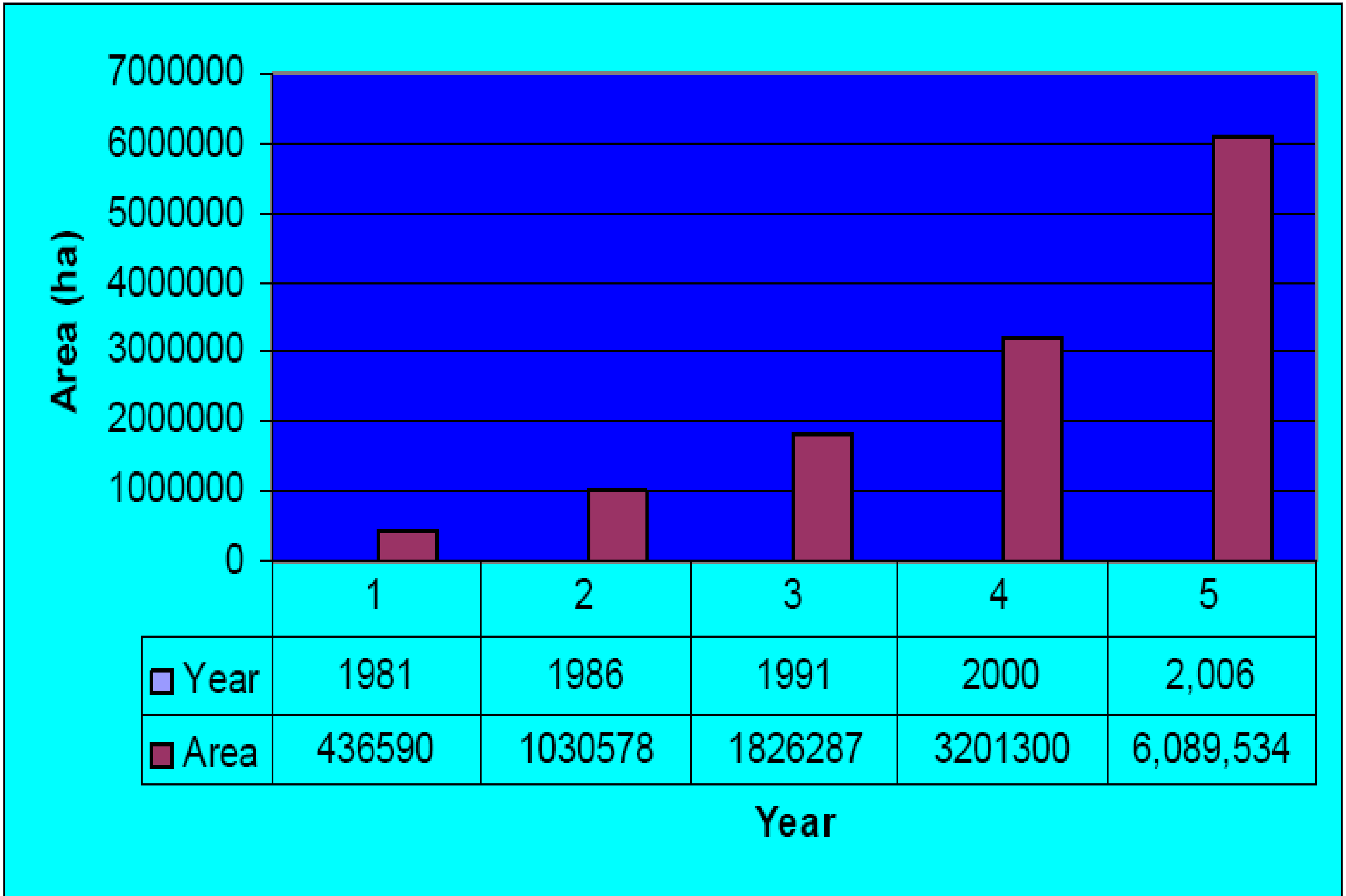
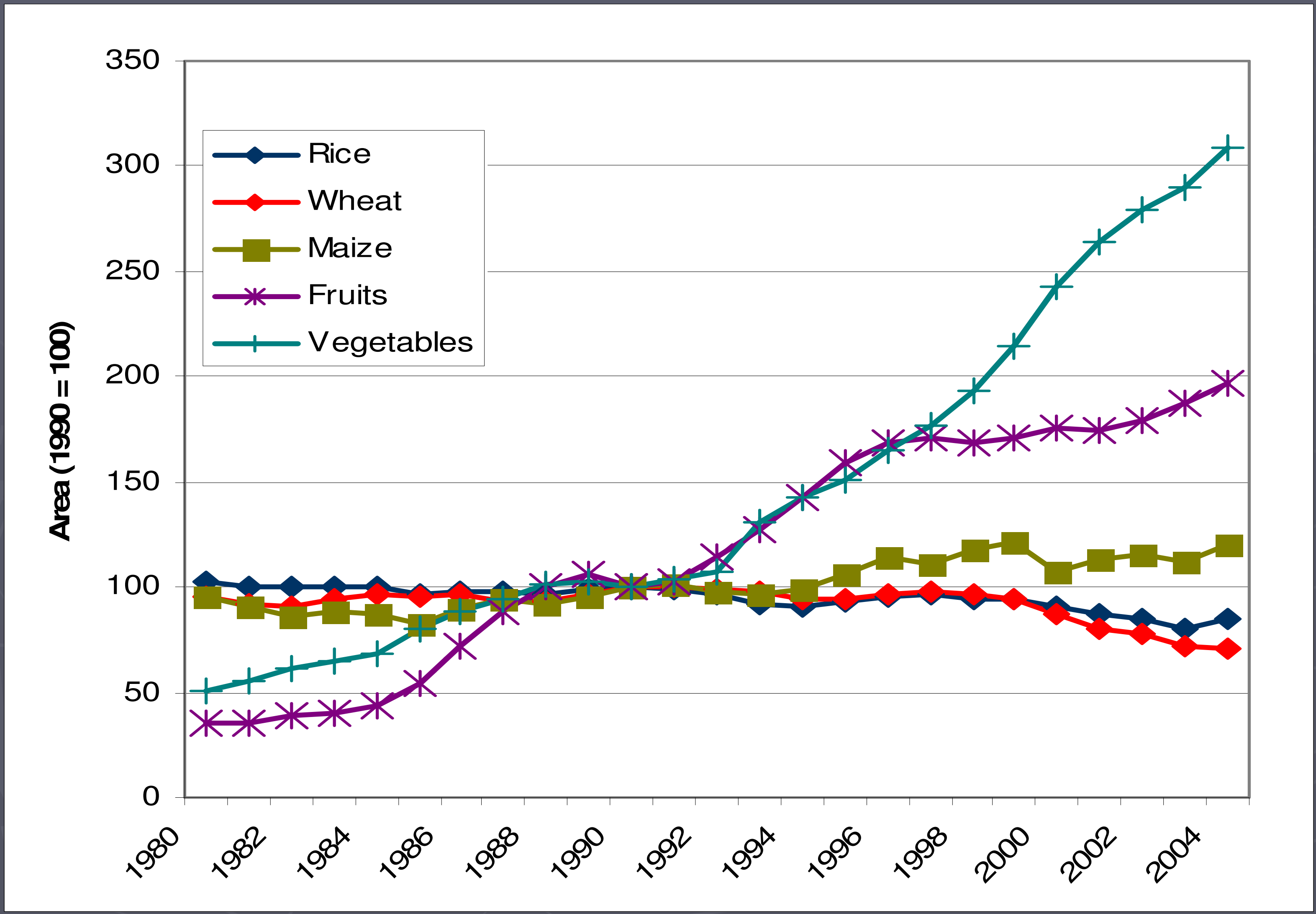


Fig. 7: Area under micro-irrigation in the world

Change in cropping patterns in China



Pipes and hoses!

- Rigid:
  - Metallic
  - Cement
  - PVC, etc.
- Flexible:
  - Pipes and hoses

LOW COST MICRO IRRIGATION TECHNOLOGIES FOR THE POOR

FINAL REPORT

October 2003

Main findings

- In the right context and with adequate investment in establishing supply and demand, the market-oriented approach appears to offer benefits in terms of potential for efficiency of crop production and water use.
- Small unit AMIT kits do not offer much incentive in terms of livelihood impact to resource-poor farmers, albeit they can provide some assistance with regard to food security through production of vegetables for the household.
- The larger customised and pressurised systems, more akin to conventional drip technology, do offer greater benefits and are more attractive to farmers who can make the required investment
- These people are usually not in the poorest wealth categories but the technology nonetheless offers them substantial benefits.
- The technology is attractive in the Indian context because it places a low cost product in the market place that competes directly with the price of other ‘commercial’ hardware after state or national price subsidies have been claimed.

- AMIT makes drip irrigation available to the many thousands of farmers who cannot satisfy the requirements of the subsidy system. It may prove difficult to transfer such a context to many African states.
- The market-oriented approach itself can offer advantages in getting technology to poorer farmers, in a specific enabling environment.
- The approach certainly overcomes the constraints of state and federal subsidy systems that exist in India. However, it is not 100% reliant upon market forces and should not be considered as such.
- NGOs play an essential role in increasing access to the poor but their subsidising of the ‘market approach’ must be recognised.

Intermediate conclusion

- The increased availability and adoption on a large scale of these technologies calls for a management response
- Development of atomistic irrigation, large ignored by formal management systems
- Some traditional systems seem to be able to adapt and evolve (e.g. montane systems in northern Thailand)

TO LINE OR NOT TO LINE?
THE DEBATE

- Since seepage recharges the groundwater, overall water saving could be marginal
- *Cost of pumping*
- *Deterioration of water quality*
- *Waterlogging and salinization of adjacent lands*
- Farmers use groundwater more efficiently

THE PROBLEM OF CANAL LINING

- Canal lining is a very expensive element in canal construction. Cost of lining typically represents about 40 percent of total cost.
- Before making such a large investment, there must be a clear idea of the benefits to be obtained
- Seepage losses typically represent 10 to 40 percent of diverted water
- The reduction of seepage losses is often assumed to be constant for the expected life of the lining to have a chance of achieving a favorable economic return

THE TECHNICAL CASE FOR CANAL LINING IS NOT STRAIGHTFORWARD

- There is now strong evidence that hard surface linings deteriorate within a few years until seepage losses return to that for an unlined canal

INDIA: PUNJAB
brick lined canals

- Sunam branch (four-month old)
  0.06 m/day
- Mudki distributary (15 km, 5-year old)
  0.29 m/day
- Mukstar distributary (6-year old)
  0.49 m/day
- Watercourses (24): seepage losses from channel older than 4 years are comparable to losses from unlined channels

INDIA: PERIYAR VAIGA

	seepage losses lined/unlined %
Main canal	29.7
distributary canal	
large	44.4
medium	66.6
small	75.0

CONCLUSIONS ON EFFECTIVENESS OF CANAL LINING

- Linings that have imperfections are shown to result in a small reduction of seepage losses
- Before embarking on a costly lining program, it is important to use realistic values for seepage reductions, life of lining and maintenance costs
- High standards of construction is essential

Geomembranes and geotextiles



Plan

- Technology and management together
- Management innovations
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- Some recommendations
- Future pathways

Towards new recommendations

- The challenge of atomistic irrigation

Table 9. Socio-technical context of surface irrigation in different eras

	Pre-Colonial (Adaptive Irrigation)	Colonial (Constructive Imperialism)	Post-Colonial (Atomistic Irrigation)
Unit of irrigation organization	Irrigation Community	Centrally managed irrigation system	Individual farmer
Nature of the state	Strong local authority; state and people lived off the land; forced labor; maximizing land revenue chief motive for irrigation investments	Strong local authority; land taxes key source of state income; forced labor; maximizing land revenue and export to home-markets chief motive for irrigation investments; state used irrigation for exportable crops	Weak state and weaker local authority; land taxes insignificant; poverty reduction, food security and donor funding key motive for irrigation investments; forced labor impossible; electoral politics interfere with orderly management
Nature of Agrarian society	No private property in land. Subsistence farming, high taxes and poor access to capital and market key constraints to growth; escape from farming difficult; most command area farmers grow rice.	No property rights in land. Subsistence farming and high taxes; access to capital and market key constraints to growth; escape from farming difficult; tenurial insecurity; most command area farmers grow uniform crops, majorly rice.	Ownership or secure land use rights for farmers; subsistence plus high value crops for markets; growing opportunities for off-farm livelihoods; intensive diversification of land use; command areas witness a wide variety of crops grown, with different irrigation scheduling requirements
Demographics	abundant land going abegging for cultivation; irrigable land used by feudal lords to attract tenants	abundant land going abegging for cultivation; irrigable land used by feudal lords to attract tenants	Population explosion after 1950 and slow pace of industrialization promoted ghettoization of agriculture in South and South-east Asia and China.
State of irrigation technology	Lifting of water as well as its transport highly labor intensive and costly;	Lifting of water as well as its transport highly labor intensive and costly;	Small mechanical pumps, cheap boring rigs, and low cost rubber/PVC pipes drastically reduce cost and difficulty of lifting and transporting water from surface and groundwater.

- If we are to unlock the value hidden in South Asia's surface irrigation systems, they must morph in ways they can support and sustain the rising groundswell of atomistic irrigation;
- and by doing that secure the resources and cooperation they need from farmers to counter anarchy, atrophy and noise.
- If they themselves cannot become demand-driven, they should try integrating with a demand driven atomistic irrigation economy.
- This is already happening in many systems but by default; but much hidden value can be unlocked if this happens by deliberate design. This requires a paradigm shift in irrigation thinking and planning.

- The situation in South Asia suggests that instead of institutional reforms, surface irrigation systems here themselves need to morph to fit in today's socio-technical context.
- For millennia, irrigation systems were 'supply-driven'. They offered a certain volume of water at certain times with certain dependability; and farmers had no option but to adapt their farming systems to these; they adapted because doing so was better than rainfed farming.
- Atomistic irrigation—offering water-on-demand year-round--has turned south Asian irrigation increasingly 'demand-driven', giving a whole new meaning to the term 'irrigation management'.
- With the option of 'exit' available, farmers in command areas are now reluctant to exercise 'voice' through PIM/IMT, refusing to give their loyalty to an irrigation regime that cannot provide them irrigation on-demand year- round.

Towards new recommendations

- Combining service-oriented modernization approach with (social) farmer management of atomistic irrigation with strategies inspired from social management of groundwater in Andhra Pradesh?
- Unbundling irrigation to develop these options

CONCLUSIONS FROM HCMC 2005 WORKSHOP FINDINGS AND RECOMMENDATIONS

- modernization to increase flexibility, in river basin management context, delivering service needed by farmers, taking into account multiple functions, is more required than ever.
- Unless management adapts, the discrepancy between stated and actual management will widen: chaos will increase, etc.

- new layers of complexity have been added to our understanding of irrigation and need to be managed.
- Technology needs to be embedded in management
- Design manuals need to be revised
- Management needs to be professionalized (managers and WUAs).
- Focus on operational management.

- present institutional reform models need to be evaluated and overhauled to respond to new demands and characteristics of farmers.
- Capacity building of managers, intermediate service providers consulting firms, and various components of civil society will need to be substantially boosted.
- Tools such as benchmarking and rapid appraisal procedure for investment and management

new recommendations

From:

- generation of both positive and negative externalities by accident
- development of autonomous farmers’ responses by neglect

To:

- explicit management of multiple roles
- recognition of farmers’ service and other objectives, of their contributions to overall efficiency and productivity (e.g. By pumping)
- search for the most practical, economical options on where, how and at which levels (main system, intermediate distribution, farmers, conjunctive use, etc.) to locate improvements for service delivery.

Plan

- Technology and management together
- Management innovations
- Technology development
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- Future pathways

AWP: past gains

- water needs for food per capita halved between 1961 and 2001 from about 6 m3/d to less than 3 m3/d (Renault, 2003)
- In order to produce the equivalent of the domestic water supply, a gain of 10 percent in agricultural water productivity would be required, which is a matter of years.
- Therefore, it can be argued that investing in agriculture and in agricultural water is the best avenue for freeing water for other purposes.

Future agricultural gains

(i)compensation for the reduction of agricultural production areas as a result of urban encroachment, soil degradation, and the depletion of water resource availability or access (groundwater)

(ii) increased water access for the rural poor and vulnerable groups

(iii) generation of wealthier farming systems

(iv) freezing water for other uses including the environment.

Typology of irrigation and investment priorities

	Agricultural based economies	**Economies in transition**	**Industrial economies**
Large-scale public irrigation schemes in dry areas			
Capital investment	Small and large dams, gravity irrigation development, drainage development, on-farm groundwater development		Upgrading irrigation and drainage infrastructure
Management innovations	Increased reliability in system operation, improved flexibility of water services	Restructuring, improved accountability and transparency, improved system control and operation, enhanced flexibility of water service, enhancing multifunctionality	
Technology	Energy efficient pumping, interim and on-farm storage, drainage, communication	Measuring devices, SCADA, communication, controlled drainage	Automation, pressurized irrigation systems, water quality monitoring, controlled drainage
Large-scale public irrigation schemes in humid areas			
Capital investment	Small and large dams, gravity irrigation development, drainage development, on-farm groundwater development		Upgrading irrigation and drainage infrastructure
Management innovations	Increased reliability in system operation	Restructuring, improved system control and operation, enhanced flexibility of water service, managing soil water level	
Technology	Land levelling, shallow wells, conjunctive water use	Interim and on-farm storage, SCADA, communication, controlled drainage	Automation, SCADA, controlled drainage

	Agricultural based economies	Economies in transition	Industrial economies
Small to medium scale community managed schemes			
Capital investment	Runoff river, weirs, diversion, local storage and small dams	Local storage, small dams, improved water distribution, infrastructure	Not applicable
Management innovations	Conflict management, on-farm water management; multiple use systems (MUS)		n.a.
Technology	Small-scale micro-irrigation systems, tanks, energy efficient small-scale pump technology	Mechanized agriculture, deep tubewell drilling, pressurized irrigation systems	n.a.
Commercial privately managed schemes			
Capital investment	Diversion dams, deep tubewells	Runoff recycling, automation of water supply	Automation
Management innovations	Farm reservoirs. Irrigation scheduling, soil moisture monitoring and management of soil water level		
Technology	Overhead irrigation, sprinkler, micro-irrigation	Precision farming, pivots, lateral moves, micro-irrigation, fertigation, controlled drainage, energy efficient pumping	
Farm-scale individually managed schemes for local markets			
Capital investment	Shallow well drilling, canals, local storage		
Management innovations	Waste water reuse, management of soil water level		
Technology	Low-cost, robust irrigation technology	Mechanized groundwater use	Water measurement and control, automation, low pressure irrig.

Thank you

www.fao.org/nr/water

www.watercontrol.org

www.spmwater-asiapacific.net

1. Accepting the fact that there is no single solution for maintaining food security when water is scarce.

- All sources of water (rainwater, canal water, groundwater and wastewater) are important.
- They can all be developed under the right set of conditions, and additional storage capacity and recharge of groundwater resources form part of the long-term solution.

2. Finding the best options for specific conditions.

- Good and poor-quality land can be used for the production of food crops and other commodities
- The best combination of land, crop and water is site-specific
- Do not ignore the inherent productivity of natural ecosystems.

3. Realizing that the link between irrigated agriculture and rural development is not always straightforward

rural development may be better served by investments in sectors other than irrigation.

4. Adopting natural resource based policies and institutions

That encourage the integration of crop and resource management in order to identify the best location-specific options.

5. Facilitating and supporting actively the development of improved varieties

as part of the solution for future food security.

6. Supporting actively the application of seasonal climate predictions

in order to create the best combination of crop and resource management for the anticipated climate conditions.

7. Investing in irrigation modernization

as an ongoing process, while recognizing each system's specific comparative advantages. The aim of modernization should be to make the water delivery system and its management flexible enough to take full advantage of new technologies and crop varieties.

- REVISITING ASSUMPTIONS
- Rejecting the assumption of homogeneity
- Rejecting the assumption that "simple is beautiful"
- Reversing the approach – an upward service-oriented approach
- Promoting a cost-effective service
- Questioning the concept of equity
- Introducing the reliability concept
- Broadening the concept of flexibility
- Repositioning water management at basin level

Towards new recommendations

At a regional workshop on

the future of large rice-based irrigation systems in Southeast Asia

Ho Chi Minh City, 2005

- main focus: improvement of performance of existing assets.
- new systems may be still developed: predominantly agrarian economies, types of systems with comparative advantages
- their planning and appraisal process should be reformed to adhere to improved water governance, comparing other options to achieve the same objectives.

- Evolution scenarii, objectives and strategies will vary greatly according to the types and socio-economic environment of the systems.
- Non-rice drivers will play a very important role in their evolution.

3 critical questions for large rice-based irrigation systems evolution: the next 25 years

- How will agriculture, water resources management and society evolve in SE Asia?
- What changes are required in irrigation service provision by the large rice-based irrigation systems and what new roles will they play?
- How will on-going and expected reforms and investment programmes measure up against the projected needs of the region?

Financing and multiple roles

- Modernization should aim to secure reliable, equitable and predictable water supply and be responsive to individual needs of farmers where possible. Trust farmers to respond to such a water supply, e.g., through conjunctive water use.

- Water-delivery systems need to be flexible (technically, institutionally) to deliver water to multiple uses (agriculture, environment, city, industry, energy generation), from entire river basins down to (within) large irrigation systems.

Financing and multiple roles

- Financing (capital and O&M) needs to progressively move from subsidies to market-based incentives, and public-private cost-sharing mechanisms, as economies evolve (Early -> Transition -> Post-agriculture).

- "Early economies" should anticipate for, "transition economies" should plan for, and "post-agriculture economies" should harmonize (social, cultural, institutional, and policy) water management for different ecosystem services within irrigation area and catchment.

Management and Institutions

- Invest in professionalization of irrigation management through the establishment of continuous in-service training focused on operational management:
  - Training of today's graduates who are tomorrow's managers
  - **Training at all professional levels within irrigation systems across all relevant disciplines.**
  - Overseas secondment of irrigation managers within the region and in higher-income countries.
  - **Practical trainings for farmer organisations / WUAs / Federations.**

Management and Institutions

- operationalise and mandate assessment and performance measures to continually upgrade and compare the effectiveness of service provision and the management of negative externalities, such as environmental impacts:
  - RAP
  - Benchmarking
  - Introduction of service related performance for irrigation service provider staff.
  - Public accountability – balance sheets
  - Improve and sustain monitoring, data collection and processing and management for improved service provision.

Management and Institutions

- Existing PIM approaches should be diagnosed, and successful approaches and their contexts identified and replicated.

- **key focus of initiatives to implement PIM and IMT on:**
  - **Minimizing the transaction costs relative to actual benefits of participation**
  - **Incentivizing participation and compliance of the irrigation service providers:**
    - **Self-financing arrangements**
  - **Functional WUAs and federations, with clear rights, responsibilities and programs of action in management and local investment.**
  - **For them to be effective, the service delivery of WUAs and Federations must be improved and support is required to realize this.**

Design and Operation

- **Revise national design standards and operation manuals** to take advantage of new knowledge in the irrigation sector and state-of-the-art technologies.
- Replicable pilot projects to demonstrate modern technologies; learn from practical experience for a relative small cost.
- Consider use of new donor lending instruments – e.g., adjustable program loan (APL) (longer time periods are needed to design and implement modernization programs; typical 5 year loans are too short).
- Massive and structured capacity building
- Centers of excellence
- RAPs before any new investment for a diagnosis of the system, developing proper water management strategies, and benchmarking.

Top 10 Irrigation Technologies (ICID)

1. Farmer controlled water supply, or total channel control or downstream control of canals;
2. Emitter delivery systems for precision irrigation and for undulating terrain, not just through drip systems but also through centre pivots, and with sweeps programmed to serve typical farm blocks.
3. Wetting front indicator;
4. Drain controllers, for their capability to improve control of soil moisture and stimulate sub-irrigation.
5. Wetting-drying rice, in its widespread application in China.
6. No-till (NT) or minimum tillage technologies already used to conserve erodible soils and nutrients, and save fuel, but which can also conserve water in irrigated as well as rainfed production.
7. Fresh-saline irrigation, where saline and brackish water is used for part of the growing period without much loss of yield or detriment to the soil structure.
8. Salt and drought tolerant food crops, perhaps used in conjunction with 7, or independently, especially where irrigation is ephemeral or only supplementary.
9. Remote sensing coupled with the Internet and mobile communications to help the farmer with everything from establishing land tenure to operational forecasting.
10. Drainage, an "old" technology thatcan improve and sustain production in rather more parts of the world than irrigation on its own.

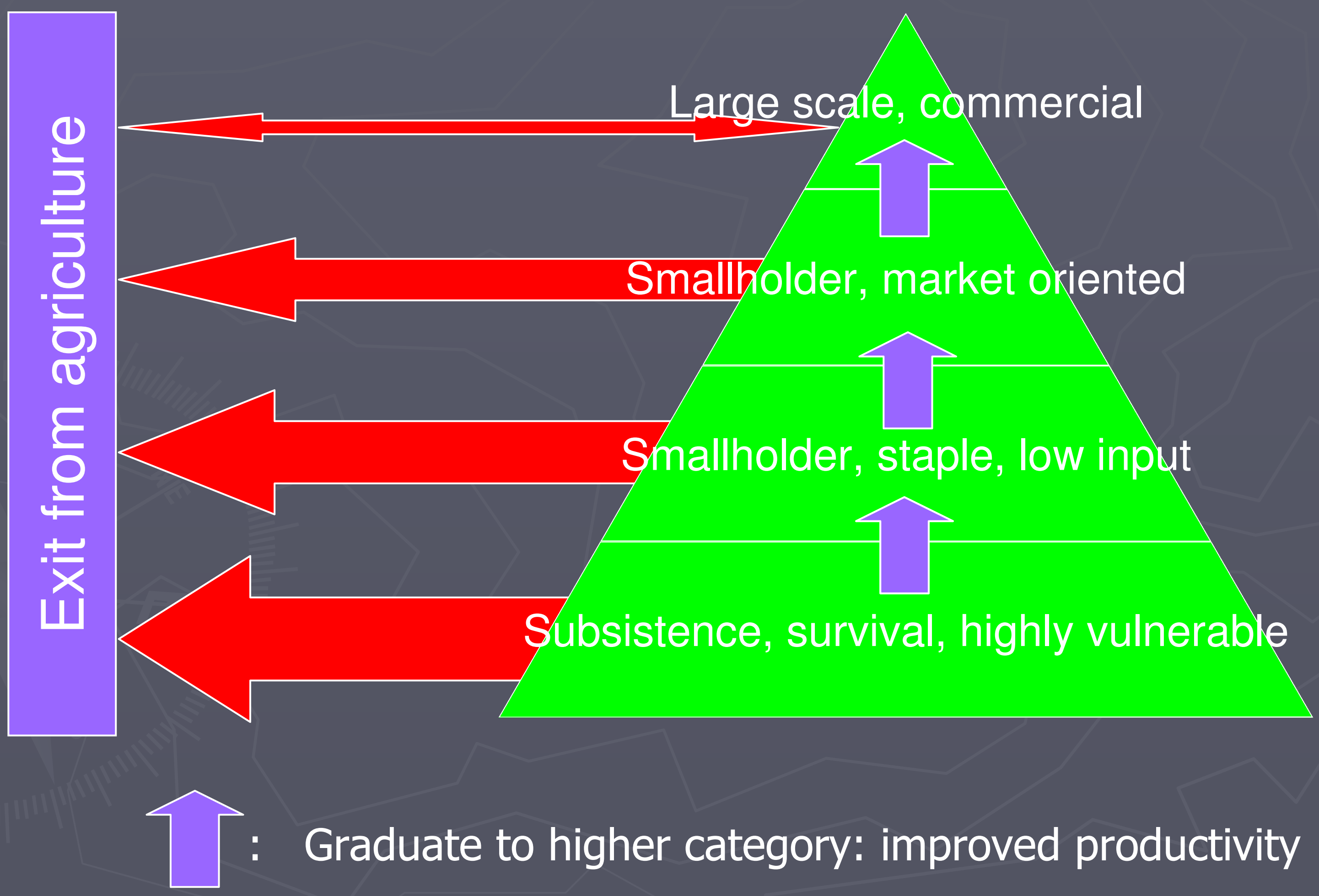
Proposed priorities for IPTRID

- Technologies and management innovations for improving the performance of large scale systems;
- Technologies and management innovations for utilizing the potential of small scale systems.
- Technologies and management innovations for moisture control (drainage).
- Technologies and management innovations for the utilization of marginal water.

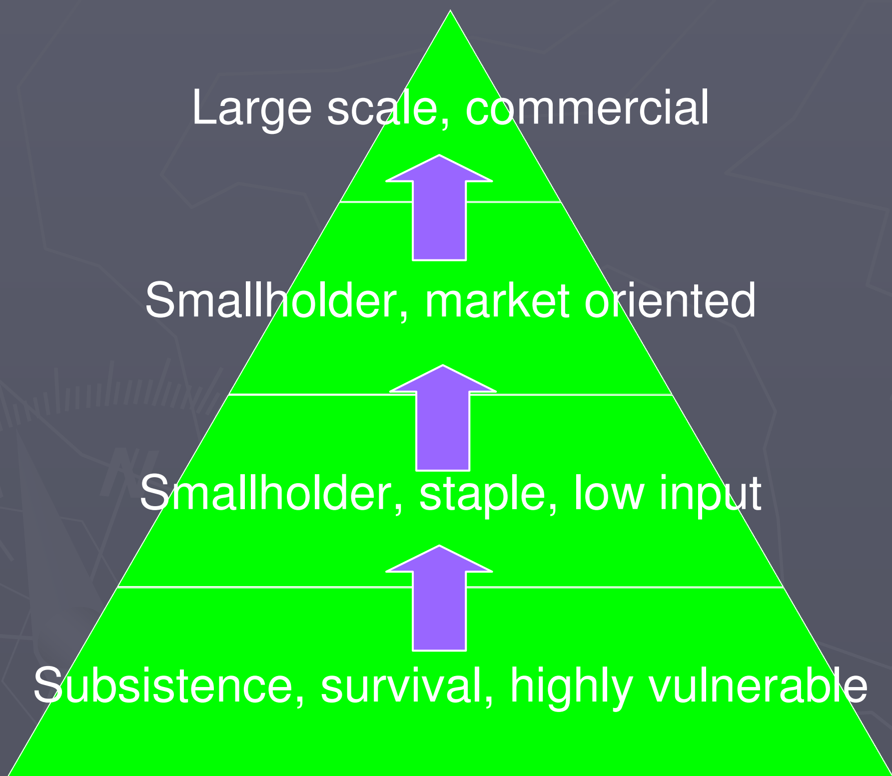
	North Africa /Near East/ Mediterranean	Central Asia	South Asia	South-East Asia	West Africa /Madagascar	East / South Africa	Central America	Andean
Performance LS arid	x	xx			x	(x)	xx	x
Performance LS humid			x	x	(x)		(x)	
Potential SC Schemes	(x)	(x)	x	x	xx	xx	x	xx
Marginal Water	x	xx	(x)	(x)	x	x	x	
Drainage Environment	(x)	xx	x	xx	(x)	(x)	xx	(x)

xx very important x important (x) less important

Adapting agricultural strategies

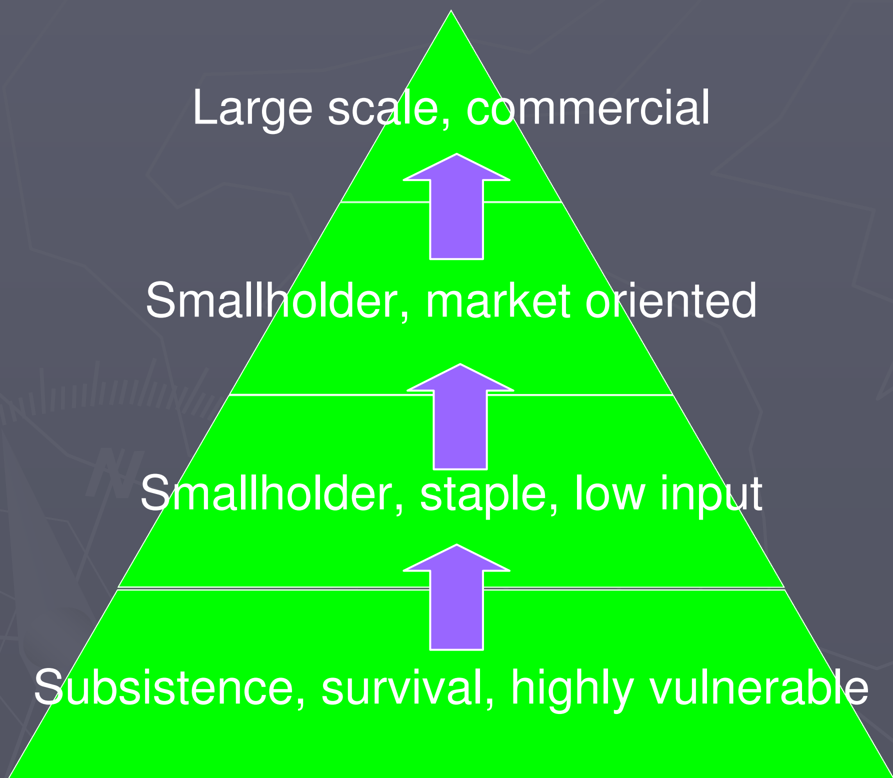


Role of farmers in irrigation



Export-oriented production, rural employment, investment in and maintenance of infrastructure
Cost-sharing on irrigation investment, O+M, WUA
O&M of water infrastructures, WUA
Operation of water control systems

Options for public intervention



Improve political, fiscal and legal environment, large scale infrastructure investments, supervision
Cost-sharing on irrigation investment, improve market access, land tenure, credit
Irrigation investment, improve market access, land tenure, support to WUA, targeted subsidies
Social programmes, vulnerability reduction (water harvesting, watershed management, etc.), highly subsidised

The questions on the resource that need to be answered

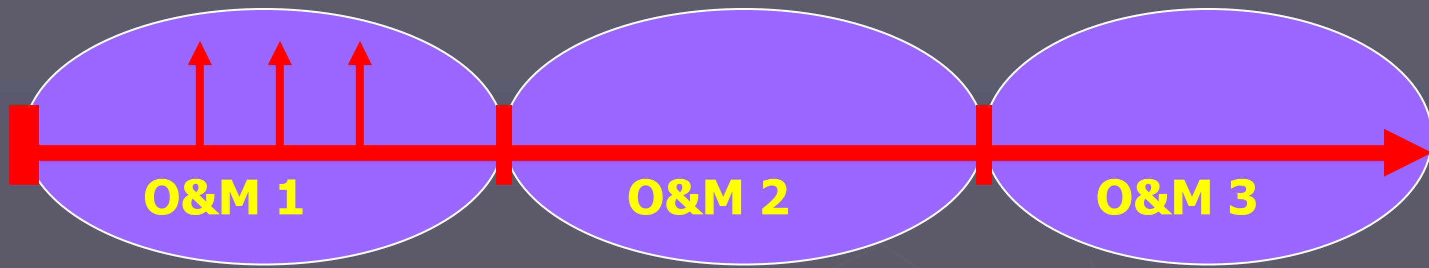
–> **How much additional storage capacity** in dams and reservoirs is required?

–> **How can nations and regions** ensure the sustainable use of pumped groundwater that is critical to agricultural production?

–> **How can additional sources of water,** such as municipal and industrial wastewater, be best used in irrigated agriculture without adverse effects on human and ecological health?

- Water depletion occurs when water evaporates from moist soil, from puddles between rows and before crop establishment.
- All cultural and agronomic practices that reduce these losses, such as different row spacings and the application of mulches, improve water productivity.
- The irrigation method also affects these evaporative losses.
- Drip irrigation causes much less soil wetting than sprinkler irrigation.

National and Sub-national stage	Type 1: Reservoir gravity	Type 2: Off-river gravity	Type 3: Off-river pump	Type 4: Conjunctive	Type 5: Integrated management deltas
Post-agriculture	0	-	+	+	-
	Optimizing multiple use economically justified; limited number of sites available for new systems	Reduce. Merge or neglect due to low reliability Convert to type 3 or 4 Convert to different crops/land use	Increasing energy costs Crop diversification Rice phases out economically justified; limited number of sites available for new systems	Highly flexible Farmers decide Market rules (export possibilities) (manymers use pumps)	urnanizationOptimizing multiple use (environment, drainage isuues, per-urban agriculture, urbanization) ; more crop diversification
Agricultural Export	not economically justified by agriuclutre alone but may expand;	0	0/-	+	Expand short term then decline due to urbanization, sea level rise, salinity?
	Anticipate on multiple uses	Improve, modernize (endless) Inherent limitations of supply	Likely reduction due to energy costs (for paddy)	Highly flexible Farmers decide Market rules (export possibilities) (several farmers use pumps)	Optimize multiple use Expensive drainage (environment, drainage isuues, per-urban agriculture, urbanization)
Agriculture focus	0	+	+	+	Expand short term then decline due to urbanization, sea level rise, salinity?
	Too expensive for rice but plan for future or multi-purpose structure	low costs Comparative advantage (compared with oither options)	Affordable investment Subsidized O&M	Highly flexible Farmers decide Market rules (export possibilities) (some rich farmers use pumps)	Developing paddy systems Not yet urbanization



Reform maintains operational details that cause problems and chaos.

Solutions are software AND hardware

Reform maintains operational details that cause problems and chaos.

Decentralization:

- Shifting from public managers fighting each other to WUAs or local gvts fighting each other hardly is an improvement
- Designing and operating for decentralization or institutional reform? Unbundling

Findings: PIM and WUAs

- Jiamakou irrigation system in China: ranks high on water delivery service to the farm, water delivery service to WUAs, strength of WUAs, and incentives to management staff and operators.

- WUAs in almost all the irrigation systems have negligible budgets with most members contributing in kind.

- Irrigation service fee collection rate are often high in the systems with strong WUAs. Even in those cases, overall financial requirements for O&M are often not covered, and WUAs do not have the capacity to invest in system improvements.