DRAINAGE EXPERIENCES IN ARID AND SEMI-ARID REGIONS

EXPÉRIENCES DE DRAINAGE DANS RÉGIONS ARIDES ET SEMI-ARIDES DES

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ABSTRACT

The state of development of drainage in arid and semi-arid countries is lagging far behind the development of irrigation. This leaves the worlds' irrigated agriculture at high risk of losing productive lands to waterlogging and salinization. As development of new irrigation projects will not likely happen any more as in the sixties and seventies, drainage of existing irrigated lands can contribute to food security both by increasing the productivity and avoiding any further decline in the yield due rising water tables and/or salinity. Serious development of irrigated agriculture on a sustainable basis needs to address the drainage needs within a sound policy, institutional, technical, economic and social framework.

RESUME ET CONCLUSIONS

L'état du développement du drainage dans les pays arides et semi-arides est peu avancé en comparaison avec celui de l'irrigation. De ce fait, l'agriculture mondiale irriguée risque de perdre une grande quantitée de terres productives pour cause de l'engorgement des sols et la salinisation. Comme le développement de nouveaux projets d'irrigation ne se produira probablement plus au même rythme que durant les années 1960 et 1970, le drainage des terres irriguées pourrait contribuer à la sécurité alimentaire en augmentant la productivité des sols et en évitant une reduction du rendement des cultures dû à l'engorgement et la salinité des sols. Le développement sérieux de l'agriculture irriguée sur une base soutenable doit donc satisfaire les besoins du drainage dans un cadre politique, institutionnel, technique, économique et social bien défini.

Une stratégie et un cadre politique bien défini pour le drainage devraient être en place pour satisfaire les besoins de l'agriculture irriguée et devrait être intégré avec le développement de nouveaux projets d'irrigation. Ceci dit, a part quelques exceptions, peu de pays au monde ayant une large superficie irriguée ont un programme pour le développement du drainage. Une gamme de technologies du drainage sont disponibles et alors le choix des solutions, du point de vue technique et économique, dépend plutôt de la capacité d'identifier les problémes et les solutions. Les avantages directs et indirects devraient être pris en considération dans la planification et l'évaluation de nouveaux projets de drainage. La satisfaction des besoins de drainage est confronté au manque de données suffisantes aux niveaux nationaux et internationaux. Les efforts en cours pour

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établir une base de données pour les besoins globaux de drainage devrait être complété par une base de données nationales, sur le drainage.

Le développement du drainage dépendra, du moins aux étapes initiales, d’un soutien gouvernemental important. Le rôle du gouvernement augmente lors qu’il s’agit de pays pauvres avec un cadre foncier de petites propriétes. Encourager la participation des usagers est toujours souhaitable mais, dans ce cas, les gouvernements devraient demeurer pro-actifs pour s'assurer que le développement du drainage a bien lieu et que les réseaux de drainage sont bien entretenus. Dans les pays où les capacités manquent pour permettre le développement de drainage à grande échelle, une capacité professionnelle devrait être établie et des activités pilotes favorisées. Des organizations avec la responsabilité explicite pour le drainage devraient être créees avec le mandat clair et une capacité légale et administrative de mise en application de la politique nationale du drainage. L'évaluation de l'impact du drainage sur l'environnement devrait faire partie du processus de conception des projets et les mesures de réduction d ímpact devraient être mises en place simultanément avec les réseaux de drainage.

1.INTRODUCTION

Arid and semi-arid regions are characterized by a climate with no or insufficient rainfall to sustain agricultural production. These regions are mostly inhabited by developing countries with dense population. The Middle East, Pakistan, North-West and South India, Northern China, and Central Asia are among those regions dominated by harsh aridity. Irrigation with surface or ground water is inevitable for growing crops in the arid and semi-arid zones. According to FAO-database (FAO-STAT), the world irrigated land in 1997, was about 267 million ha, of which 70 % is located in Asia. Irrigation has helped raising the agricultural productivity of the world. Although, irrigated agriculture represents only 17 % of the cropland, it accounts for producing about 40 % of the world’s food and 60 % of the world's grain production.

With the expected increase of food consumption due to growth of world population and rise in the standard of living, the required increase of cereal demand is estimated at 37 % between 2000 and 2025. Assuming that the role of irrigated agriculture will remain the same during the next 25 years, then it should provide 60 % of this additional demands. Future growth of irrigated areas is not expected to exceed its present low rate of 1 % due to the fact that most of the easy to develop irrigated lands have already been brought under irrigation (Schultz, 1998 and Shady, 1999). Consequently, implementing new large scale irrigation projects, although very important, will not likely to occur. Then the greater potential in realizing food security will remain with increasing the productivity of the already existing crop land.

Increase in yield can be achieved through different inputs such as fertilizers, pest control, mechanized farming and better seed varieties and good management. Improved drainage is another major input for increasing crop productivity. The role of drainage in food security could be significant and deserves serious consideration specially when augmented with other benefits which involves, the so important but difficult to quantify, social and environmental improvements. In this paper, experiences with drainage of irrigated lands in arid and semi-arid regions will be highlighted. A complete coverage of the existing world's experience with drainage in arid and semi arid region during the past half century is rather difficult to be covered in one paper. The discussion will be limited to some cases and examples from the arid and semi-arid regions in countries with major drainage programs or countries with significant irrigated areas with drainage problems.

2. PRESENT STATE AND FUTURE NEEDS

2.1 Historical Development

Some structural drainage improvements can be traced back to the Egyptian, Greek and Roman civilizations. About 400 B.C., Egyptians and Greeks drained land using a system of surface ditches to drain some areas. The Romans first used open drains to remove ponded surface water, then they soon used closed drains to remove surplus water from the soil. They exported their drainage knowledge to colonies in North Africa and Asia. Modern drainage in the arid and semi-arid regions started during the eighteenth century in the Mid-West of the United States and extended to the arid west by the beginning of the twentieth century(USDA, 1987). A similar, effort was made by the Former Soviet Union in Central Asia. By the end of the eighteenth century perennial irrigation practices brought to the Nile Delta resulted into signs of deterioration caused by a rising water table. Number of main drains were excavated before the turn of the century in an attempt to control waterlogging and salinity (Amer and de Ridder, 1990). The Dutch, inspired by their great and long experience in drainage of the deltas and polders of the Netherlands, adapted and transferred their knowledge to arid and semi-arid regions in Egypt, Pakistan and India during the second half of this century.

2.2 Current Drainage Status

Poor irrigation water management combined with inadequate drainage infrastructure renders irrigated areas at risk of becoming waterlogged and gradual build-up of salt concentrations leading to soil degradation. Data on drainage conditions of the world are scarce and scattered. The Drainage Working Group (DWG) of ICID is going through the challenging and difficult job of building a data base (Serrano, 1999). Some estimates however, suggest that over 50 % of the world's irrigated land has developed drainage problems, and about 25 million ha have become unproductive as a result of these problems. This area is expected to increase as long as low efficiency irrigation is practiced and continued on soils with insufficient natural drainability without providing adequate drainage. The current annual rate of land loss due to waterlogging and salinity is about 0.5 million ha per year (Smedema, 2000) Although far from being final and accurate, the drainage status in some countries, as described in the DWG data base, is given in table 1.

Table 1. Drainage problem areas in some irrigation countries (Area x1000 ha)

(Superficies présentant des problémes de drainage dans quelques pays dírrigation.)

Country	Irrigated Area	Drainage Problem Areas	
		Water Logging	Salinity
China	51,819	5,000	7,500
Egypt	3,150	600	1,000
India	57,000	2,460	3,300
Iran	7,265	NA	2,180
Mexico	6,500	1,300	464
Morocco	1,251	NA	500
Pakistan	17,580	1,743	2,366
Sudan	1,950	NA	390
Turkey	4,200	NA	1,519
USA	21,400	NA	4,280

Source: Global drainage needs dat a base, under development by ICID Drainage Group;(NA= not available)

The efforts made so far is not enough just to cope with the damage already occurred, without mentioning the need to prevent a potential increase of waterlogging and salinization to new areas. In the USA, drainage improvements has almost stopped in the arid West and slowed down in the Mid-West, mainly driven by environmental concerns and partly encouraged by national surplus agricultural production and low economic return to justify the investment. The assessment made by Smedema and Ochs (1998), shows that out of the agricultural land in the developing countries, only 7 % are provided with some form of drainage. This is not necessarily the adequate and sufficient type of regular drainage. With the exception of the ongoing intensive subsurface drainage program in Egypt and Pakistan and at smaller scale in Iran, Mexico and Turkey, the once existing programs in other countries such as Central Asia, China, North Africa, Iraq, Peru have Largely been discontinued.

Investments in improving drainage conditions in developing countries of the arid and semi-arid zones seems to be very modest. The World Bank portfolio during the past 25 years included 218 projects with drainage and related work such as water quality and downstream flood control, often combined with irrigation, agricultural development and other type of work. Although US$ 38 billion were allocated to these projects, only about US$ 8.5 billion (22 %) was for drainage and related work. The Bank was involved in financing these projects together with other multi-lateral and bi-lateral donors. The share of the arid and semi-arid regions was approximately US$ 4,600 million allocated to 16 countries (Table. 2). About 94 % of the allocation for the arid and semi-arid regions was for projects in only seven countries which are, China, Egypt, India, Iran, Mexico, Pakistan, and Turkey. Egypt and Pakistan stand alone for 57 % of the investment in drainage. This means that the average annual investment in the arid and semi-arid zones during the last quarter of this century was about US$ 190 million per year. Although drainage projects exist in other countries, they represent a minor addition. There are more new drainage projects in the pipeline, mainly in Egypt and Central Asia. The current rate of developing subsurface drainage systems is approximately 100,000 ha per year (Smedema,2000). It is rather difficult now to draw an estimate for the development rate of main open drains and field ditches at present.

Table 2: The World Bank's drainage portfolio for arid regions(1975-1999)

(Le portefeuille des projets de drainage de la Banque Mondiale dans les régions arides.)

Country	Cost, million US$	Country	Cost, million US$
Albania	9.00	Kazakhstan	50.00
Algeria	50.00	Kyrgyz	24.00
Afghanistan	15.00	Mexico	512.00
Azerbaijan	1.20	Morocco	30.00
China	272.00	Pakistan	1,476.00
Egypt	1,150.00	Peru	70.00
Iran	160.00	Tunisia	20.00
India*	116.00	Turkey	644.00

* Not including the projects in Monsoon areas with long dry seasons at an estimated cost of US$ 289

2.3 Future Drainage Needs

In the context of future development, drainage should be regarded as a multifunction instrument for food security, sustainability and rural development. Many developing countries, specially those who invested in large scale irrigation projects during the past 25 years, realize the need for drainage to maintain and improve the productivity of their crop lands. Smedema (2000) estimated that future drainage needs during the next 25-years, by about 10-15 million ha including 2-3 million ha of subsurface drainage. The corresponding annual rate will be 400-600 million ha. This will not be sufficient to recover the area already suffering serious deterioration. It may barely cope with the current rate at which additional areas are going out of production. However, the achievement of this goal seems rather realistic in the light of the limited capacity of the existing institutions, competition on funding, and the absence of public and political support.

The future needs are not limited to the physical construction of new drainage systems or rehabilitation of existing ones but should be extended to address the institutional, environmental and social aspects connected with drainage development. Effective O&M programs should be in place with the maximum possible participation of farmers preferably since the early stages of developing the systems. The environmental impacts of drainage systems resulting from drying coastal lakes in the lower deltas or disposing saline drainage water in rivers gave drainage the bad reputation that offsets the environmental benefits of combating waterlogging and salinity and shadowed the other economic and rural benefits. Cost effective and proven technologies should be adopted. Research and pilot areas are the vehicles to test and introduce new technologies and practices.

3. EXPERIENCE AND LEARNED LESSONS

3.1 The Policy Context

Drainage development has been considered in most cases on a single project basis. With few exceptions, countries do not usually have a strategy with a definite policy framework for developing drainage at the national scale. They may have one for irrigation but often it does not address the drainage development needs at equal priority footings. As a result of this situation, some countries went a long way for developing irrigation without even having a provision for surface or subsurface drainage. In many cases drainage has been deferred to a later stage until it turned to be too late or too expensive to implement drainage system. Many farmers and even governments think that they should not invest in drainage until they exhaust all other alternatives for increasing the crop yield. Of course, one can argue that this is neither economic nor sustainable solution. Experience shows that the rate of watertable rise in several large scale irrigation projects has exceeded all expectation (FAO, 1990) and waterlogging and salinity spread over the project area.

A country strategy for drainage improvement should foresee the “without” risk, define the direct and indirect benefits of drainage and target the mitigation of any adverse effects during the post-project phase. The drainage strategy should take into account the state and trends of irrigation development, hydrological conditions, physical and soil characteristics land use, and the economical and social goals. Drainage development requires also a legal framework defining the rights and obligations of all parties.

3.2 Drainage benefits.

The principal benefits of drainage are economic, environmental and public health. Some of the benefits accrue to a wide range of beneficiaries, while others can be attributed or accrued directly to identified beneficiaries. The first category of benefits deals with the rural welfare, the sustainability of natural resources and the impact on the national economy. Indirect benefits are often overlooked and hence the advantages gained from drainage by the entire rural community, and the national trade and economy are not appreciated. The second category are the direct farmer's benefits from drainage. They are related to the yield increase due to removing the excess moisture and salts from the root zone, prevention of further deterioration in productivity and providing a more favorable environment for other agricultural inputs to reach their potential benefits. In addition, improved drainage allows the diversification and intensification of crops. As a typical example, crop intensity in the drained lands of Egypt is currently between 200 – 240 % . The estimated increase in yield of 13 different crops due to improved drainage ranges between 10 % and 20 % (World Bank, 1991). This was augmented by the prevention of 10 % decline in yield of all crops during the following 20 years (Figure 1)

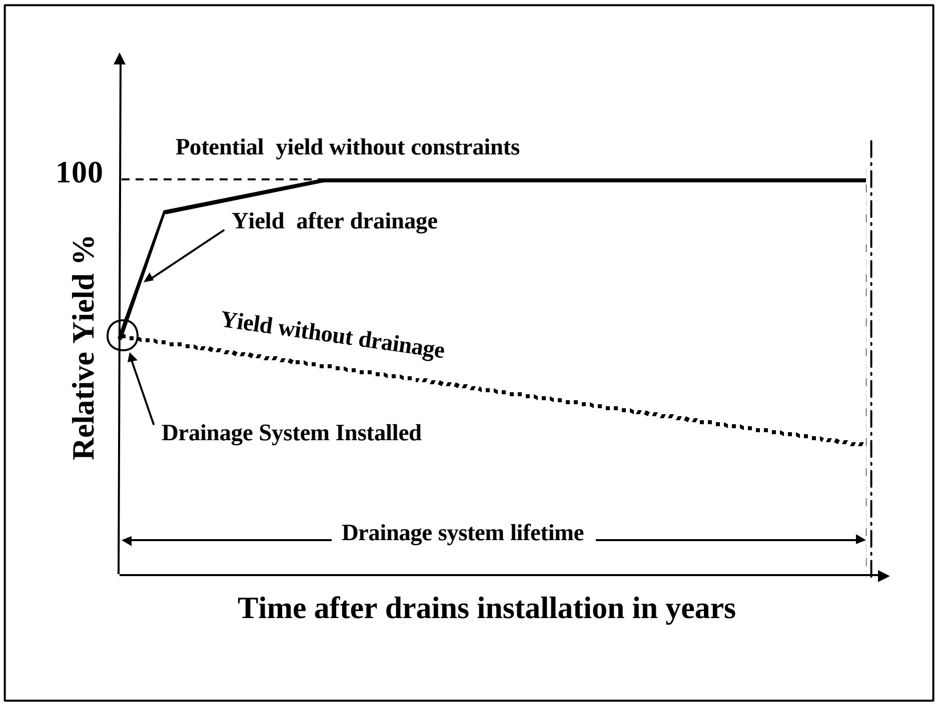

Figure 1. Trends of crop yield with and without drainage and net yield increase (Evaluation des rendements agricoles avec et sans drainage)

3.3 Drainage Practices

Open drains seem to be the most popular practices in all countries. Out of 218 World Bank’s supported projects with drainage component during the past 24 years, 201 projects (92 %) involved construction of new open drains or remodeling existing drains. Open drains could be either main drains for collecting and evacuating the drainage effluent from the field systems to the final receiving water bodies, or field ditches commonly known as surface drains mainly to drain surface runoff. Open drains have limited effect on controlling waterlogging and salinity due to factors of depth and intensity. The density of open main drains is seldom more than 4-5 m per ha. Field ditches are often of limited depth and can not be spaced close enough, otherwise they could hamper the agricultural operations particularly when mechanized farming is used. About 1.35 million ha predominantly for rice growing in the Lower Indus Plains in Pakistan are provided with surface drainage. In Egypt, shallow surface drainage is provided to newly reclaimed land in the coastal zone of the Nile delta within a package of practices including gypsum application and deep plowing for reclaiming the saline-sodic soils, till they are ripe enough to implement more expensive type of field drainage systems.

Subsurface drainage is commonly practiced either through implementing vertical drains (tube-wells) or horizontal subsurface drains (buried pipes). The choice between, open drains, tube-wells, and pipe drains is governed by several factors. The main objective is often to select the most cost-effective system and this in turn depends on the initial cost of construction, the crop type and intensity, the ground water characteristics, the cost of O&M, the technical capacity to carry out the structural work and the market prices and economic return.

Pumped tube-wells are extensively used in the irrigated land of Pakistan , Northern India and Northern China. They are often used in areas with extensive fresh groundwater aquifers mainly for irrigation. Pumped water could be used beneficially for irrigation or to supplement the surface irrigation supplies without posing any disposal problems. In Pakistan, a total number of 12717 tube-wells are installed in fresh groundwater area of about 4.4 million ha (NESPAK-Mott MacDonald, 1993 and World Bank, 1997). Another 2726 tube-wells, including 376 scavenger tube-wells were installed in area of about 1.5 million ha with saline groundwater aquifers. Tube-well drainage is more beneficial to water table control rather than for salinity control. To have more grip on salinity control, there is clear shift in Pakistan towards subsurface pipe drains.

At present, pipe drainage is implemented in about 2.8 million ha in the developing countries. The majority of this area (2.0 million ha) is in Egypt. The field subsurface drainage system of Egypt discharge freely by gravity in open main drains in which the water level is maintained by pumping stations which lift water into the Nile or to the northern lakes and the Mediterranean Sea. In contrast, the subsurface drainage system in Pakistan is mostly discharging into sumps and water is lifted by small pumps into irrigation canals. In both countries the subsurface pipe drainage system consists of field drains (laterals) and collectors. In some countries as in the South of Spain, laterals discharge into open collector drains.

The depth of the pipe drains is significantly different from one country to the other. Deep subsurface drains installed at an average depth of 2.0-2.5 m are often used in the arid zones of the USA, Central Asia, Iraq and Pakistan. Two factors are usually justifying this choice. The first is the drain's depth-spacing relationship and the second is the critical depth concept to control salinity during the fallow period. Shallow drain depth of 1.25 m has been successfully used in Egypt to control waterlogging and salinity. The later choice seems more relevant in areas with high crop intensity. While the density of drains should be less for deeper drains, implying cheaper systems, the cost of pumping could be more expensive at the long run. With more intensive cropping, the concept of critical depth has lost ground, as the net deep percolation becomes sufficient to remove the salts accumulated during the dry season of the year. Even, with single crop agriculture, a heavy pre-irrigation at the beginning of the year can take care of the salt accumulated during the fallow season. From, a water management point of view shallow subsurface drains may be regarded as more effective in water saving and improved water quality.

3.4 Drainage Institutions

The main objective of an institution in the drainage sector is to improve the drainage conditions in the agricultural land. Institutions responsibilities extend from policy and decision making to ensuring good quality of the physical systems implementation and their performance. The management results of an institution determine its effectiveness in performing its tasks (Shultz,1990). The importance of institutions with central responsibility for drainage is overlooked in many countries. The responsibility is often distributed among several government departments belonging to different ministries without real coordination or shared vision and integrated plans. Such departments usually have other responsibilities such as agriculture, rural development, water resources management, environment, etc and they end with other priorities or shortage of funds to make them defer drainage needs until there is urgent situations. This leads to treating drainage problems on ad-hoc basis.

Few countries only have developed institutions with capacity to address the drainage needs on sound and sustainable basis. It is no coincidence that two well established institutions stand behind the two largest current drainage programs in the world. The Egyptian Public Authority for Drainage Projects (EPADP) in Egypt and the Water and Power Development Authority (WAPDA) in Pakistan are two models of institutions with central responsibilities towards promoting land drainage. They may be different in their scope and organizational structure, but similar in being accountable for implementing national policies directed towards combating waterlogging and salinity in their countries. Their accomplishments over the past half century are remarkable.

Institutions, however are living objects involving law, policy and administration functions and they have to continuously adapt themselves to the changes in political economy and social life. The major thrust of institutional reforms within the water sector in general, is to enhance the functional capabilities, operational strength, and institutional readiness to handle the challenges, at present and in the future (Saleth and Dinar, 1999). Recent institutional reforms require redefinition of roles and functions, decentralization of roles and responsibilities, streamlining, transferring management responsibility for those functions which should be managed by other entities and capacity building including public participation, financial management and information systems. It is healthy to notice that both EPADP and WAPDA are undergoing this type of institutional reforms (World Bank, 1991 and 1997). The donors' community is encouraging the borrowers to adopt institutional reform policies to ensure the effectiveness of their development plans.

3.5 Cost recovery: Principles and Practices

The principles of cost sharing or cost recovery remains with the desire of achieving the objectives of economic efficiency, income distribution, and public savings. The economic efficiency objective requires that the beneficiaries be charged a price for the service they receive. The income distribution (poverty alleviation) objective targets the ability of different categories of beneficiaries to pay the charges. The public saving objective allows the public sector to capture part of the increased net benefits for funding future investments. Cost recovery or cost sharing covers the cost of investment and operation and maintenance (O&M) costs. Beneficiaries should be responsible for drainage investments that benefits them directly. This is why government or the wider community usually finance most of the investment of the main drainage systems (off-farm), while on-farm drainage investments is recovered from or shared with the direct beneficiaries.

The policies of cost recovery/cost sharing however differs from one country to the other according to the national economic and social objectives (World Bank/ ICID, 1998). The National Drainage Program in Pakistan has set a policy that farmers should share the cost of investment by paying about 10 % up-front and assume the responsibility for a sustainable proportion of O&M costs. In Egypt, the full investment cost of the subsurface drainage system is recovered over 20 years after the construction of the system without interest and allowing 5 years grace period. Farmers pay also about 35 % of the O&M through the land taxes. Legislation in Turkey , provides for recovery of capital and O&M costs fore large-scale irrigation investments, however similar legislation on cost recovery was lacking for on-farm small-scale irrigation and drainage development works. Agreement was reached with the World Bank to permit cost recovery and payment should be related to farmers' ability to pay, and allow a 5-year grace period. In Iran, the law provides for the recovery of O&M costs, however there are shortfalls in this process. Under the World Bank (1993) Irrigation Improvement Project the government was committed to the full recovery of O&M costs within three years of the completion of project investment.

3.6 User Participation

Conventional type of projects which are driven by central government decisions, often fall short of providing the intended benefits to the community. Usually, they offer little or no incentives for the community to support or participate in a project that they did not request and that may not serve there goals. Prompted by the increasing dissatisfaction, governments and donors took a greater interest in promoting community participation in development programs. This alternative strategy promise more sustainable impact due to the high level of beneficiary involvement in project planning, design and implementation. The participatory approach took off in the irrigation sector since the 1970s and scored some successes in several countries. It involves establishment of Water User Associations (WUA) with legal status and financial independency to contribute to capital costs and take over the management responsibility of the water courses and become accountable for O&M. Evaluation of the impact of the management transfer to WUAs has shown that some risk still exists and more time and information are required to fully evaluate the impact of the participatory approach (Vermillon, 1997).

Unlike irrigation, the participatory approach in drainage has not shaped or developed to the same level. In irrigation districts with open or tube-well drainage systems transfer of drainage to WUAs was often integrated with irrigation and O&M of drainage within the district became the responsibility of the same WUA. The situation is somewhat different with subsurface drainage. In areas where a blanket of subsurface drain was implemented by the government, as the case of Egypt, the boundaries of a drainage system do not often coincide with the boundaries of the irrigation system under the jurisdiction of a WUA. This implies that the transfer of the irrigation and drainage systems involves different groups of users within the same area generating legal and administrative complications. Another different feature that makes drainage different from irrigation is that operation requirements of gravity drainage system is negligible. As noted above, the delayed benefits of drainage calls government to remain in the lead of implementing new drainage systems without ignoring the importance of users participation especially in O&M.

The history and diversity of drainage in Pakistan has prompted different initiatives for user participation. Among those was the social mobilization strategy developed for the Second SCARP Transition Project in the mid 1990s, which sought to establish Farmer Organizations (FOs) throughout the project area with the capacity to install, operate and maintain community tube-wells (CTWs). In spite of variety of obstacles, the ongoing NDP Project is supporting the expansion of the transfer program for the fresh water tube-wells and the farmer participation in development and management of community tube-wells. At the on-farm drainage side, NDP assists Drainage Beneficiary Groups (DBGs) to install surface and pipe drainage systems on pilot basis in an area of 20,000 to 30,000 ha. The project would provide technical assistance including preparation of detailed designs and establishment of DBGs, and funds to supplement beneficiaries' contribution to construct the systems, while DBGs operate and maintain installed facilities after contractors' maintenance period expires.

By 1998, O&M of irrigation and drainage in almost 1.5 million ha was transferred to private sector in Turkey and appears to be sustainable. In Egypt, farmer groups are informally organized at the pipe collector drain (100-300 ha) level to carry out the simple maintenance work of the subsurface systems. They express interest in participation but their technical capacity is far less than handling the more complex maintenance work. Although couple of thousands of these Collector User Groups (CUGs) already exist they lack the legal ground for their existence. More evaluation of the current worlds' practices is required and further innovation should be sought for promoting user participation and the private sector in drainage development and operation and maintenance.

3.7 Environmental and heath considerations

Drainage has the direct positive environmental benefits of eliminating/controlling waterlogging and salinity. It also reduces the risk of waterborne diseases. However, drainage of the lower deltas and coastal zones dries up lands which are habitats for wild and aquatic life. Drainage water is also considered as carrier of several pollutants, including soluble salts, nutrients, and residual toxic agricultural chemicals (herbicides and pesticides). Moreover, in the absence of the proper facilities and regulations, agricultural open drains receives substantial amount of untreated domestic and industrial water. Under such circumstances, the disposal of drainage water becomes a real problem for the final receiving bodies and downstream users. These environmental problems are not the same or of similar extent in each case, but they are site specific and depend on the prevailing conditions in each country or even each project. The question is neither whether these issues should be addressed; nor, in most cases, which issues should be addressed. Rather, the question is, how can water quality and other environmental impacts be quantified in such a way that they can be objectively considered in the design and operation of drainage projects?.

There are number of cases in which the disposal of drainage water from irrigated lands turned to be a serious problem or at least imposing great concern. In the United States, the West side of San Joaquin Valley has serious drainage and salt management problems. The disposed drainage water from 200,000 ha of agriculture land to Kesterson National Wildlife Refuge contains high levels of selenium and other trace metals, such as boron. These elements which are leached into the drainage water from the valley, injure fish and wild life and could potentially affect human health. Although continued operation of the drainage system appears unacceptable, shutting down the system appear equally untenable. The estimated loss for California economy was estimated as US$ 1.5 billion per year, if the polluted drainage water is not controlled (USDA, 1987). The final decision was to close drains in all spots where concentrations of selenium and other trace elements are high.

In Pakistan, about 9 million tons of salts are discharged annually with drainage water into the Indus River causing water quality and environmental problems. The Amu Darya River in Uzbekistan, receives an average of 6.5 billion m^3 per year of drainage water causing an increase of the downstream river water to 1.0 gram/litre during normal flows and up to 2.0 gram/litre during the low flow season. The same thing happens in many rivers around the world. In such cases, the public health of the people who depend on the river water for drinking is at risk and the agricultural production in the downstream is depressed. When drainage water is disposed into evaporation ponds it may seriously pollute the underlying ground water aquifers.

A conventional approach is to understand or assess the potential environmental impacts of the various alternatives for accomplishing the objectives of the drainage project. Then the environmental impacts of the alternative designs are assessed to determine if they are acceptable from the environmental point of view. When possible the "environmental costs" of the alternatives may be assessed and used in selecting the final design. Another approach is to consider the maintenance of given water quality or environmental standards as one of the project objectives. The environmental impacts are thus considered at each stage and in each component of the design. If enough alternatives are considered in the conventional approach, the two approaches tend to merge and could result in the same final design (Skaggs, 1999).

3.8 Research and Technology

It is good to notice the progress made over the past few decades in agricultural land drainage research in general and in arid and semi arid zones in particular. Concepts and theories about water table management for waterlogging and salinity and leaching of salt affected soils are well developed. Knowledge about causes, governing factors, and solutions are now much better. Modeling techniques now allow us to handle more complex situations and multi-objectives designs. Applied research on drainage materials and machinery helped so much in improving the quality and performance of drainage systems. Remote sensing and geographical information systems are now increasingly used in surveying and mapping problem areas.

Many research institutions and universities are engaged in research related to waterlogging and salinity control. In the developing countries, the Drainage Research Institute (DRI) in Egypt, the Central Soil Salinity Research Institute (CSSRI) at Karnal, India and the International Waterlogging and Salinity Research Institute (IWASRI), Pakistan are now three strong research establishments for solving drainage and drainage related problems in there respective countries. The International Program on technology and research on Irrigation and Drainage (IPTRID) is promoting research and networking in developing countries. Its waterlogging and salinity network sponsored by ILRI has been successful in bringing researchers from different countries together to share knowledge and exchange experience.

CONCLUSIONS

Sustainable development of irrigated agriculture in arid and semi-arid regions needs more attention to the drainage needs to control the twin menace of waterlogging and salinity. Except in few countries, there is no well shaped and regular programs for drainage development even in some of the worlds' major irrigation countries. A definite strategy and well defined policy framework for drainage should be in place to address the needs of the existing irrigated agriculture and to go side by side and integrated with developing new irrigation projects. Technologically, alternative structural solutions are available and the technical and cost effective choice depend on the awareness and capacity to identify the causes and solutions. Both direct and indirect benefits should be taken into account in planning and appraising new drainage projects. Addressing drainage needs is confronted by the lack of sufficient data at the national and international levels. The ongoing effort for building data base for the global drainage needs should be supported and supplemented by national drainage data basis.

Drainage development, at least in the initial stages, needs strong government support. The government role increases in poor countries with small land ownership. Participatory development is always desirable but governments should remain pro-active in assuming that the needed/desired drainage development takes place and that the drainage systems remain well maintained. In countries which are not ripe for large scale drainage development as in Africa, a core professional capacity should be established and pilot activities should be promoted. Institutions with explicit drainage responsibility should be established with clear mandate and legal and administrative capacity to implement the national drainage policy. Environmental impact assessment of drainage has to be a part of the design process and the mitigation measures should be implemented simultaneously with the drainage scheme.

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