Review of the Potential for Controlled Drainage Around the World

(KAR Project R7133)

C L Abbott
P Lawrence
G R Pearce
S Abdel-Gawad

Report OD 146
July 2002

DFID Department For International Development

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Contract - Research *continued*

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Summary

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Introduction

Controlled drainage has the potential to improve water use efficiency, maintain crop yields in periods of water stress, and ensure that land drainage systems work to the maximum benefit of farmers. The report examines the basic requirements and benefits of controlled drainage, and reviews which areas of the World are most appropriate for application of the technique. The report identifies arid, humid, and tropical areas where irrigation and drainage are widely practiced, and where controlled drainage has the potential to be beneficial to farmer groups. Particular attention is paid to countries that are predicted as suffering from water shortage over the next 25 years, and where controlled drainage could improve water use efficiency.

Controlled Drainage Benefits

Whilst the principle benefit of controlled drainage in irrigated agricultural areas is improved water use efficiency, there are others, including:

- Improvements in crop yield.
- Controlling soil water through-flow rates to ensure that nitrate and phosphate levels are maintained, and that soil fertility is not degraded in high irrigation or high rainfall areas.
- Reduced nitrate and phosphate losses to downstream water bodies, reducing eutrophication and ecological damage.
- Conservation of wetlands and water–sensitive regions.

It is particularly beneficial in areas where farmers experience periodic water shortages, which limit crop production or where water application costs are high. In terms of the basin water balance, the benefits are greatest where rice forms a significant part of the crop rotation, and also in areas where reused water is of poor quality.

Requirements for Application

Controlled drainage is applicable in relatively flat areas where surface irrigation is widely practised and artificial drainage has been provided (or is planned). The following set of controlled drainage pre-conditions has been developed. These are considered as pre-requisites for locations where controlled drainage is being contemplated:

- Relatively flat agricultural areas.
- Surface irrigation is the main method of water application.
- Artificial drainage systems comprising a network of open drains and/or horizontal sub-surface piped systems with suitable access points (such as manholes) is in place or planned.
- There is farmer incentive for controlled drainage, such as in regions where water supply is sporadic or unreliable, or areas where water is pumped from canals to fields.
- Crop consolidation along drainage lines is feasible. (This implies large landholdings, or areas where groups of farmers are able and willing to collaborate over crop rotations.)
- Farmer organisations willing to take on the organisational tasks associated with controlled drainage exist or can be formed.

Countries Where Controlled Drainage is Potentially Most Applicable

In the review it was only possible to take a broad look at countries of the World where controlled drainage may offer benefits. Countries in Europe and North America where controlled drainage is already applied were not included. The analysis was based on identification of countries, or for large countries such as China and India, regions within countries, with significant irrigation and drainage infrastructure, and having current or projected pressures on limited water resources.

The identified countries were:

North Africa: Algeria, Egypt

Middle East: Israel, Syria, Iraq, Bahrain

Central Asia: India (Punjab, Haryana, Rajastan), Pakistan, Northern China, Uzbekistan, Tajikistan, Turkmenistan

These countries are identified as the ones where controlled drainage will be most applicable, and offer greatest benefit. The report includes a more detailed assessment of the potential application of controlled drainage in Egypt and India.

Potential Application in Egypt

Egypt is one of the countries where controlled drainage is most applicable, and offers significant benefits to the farmer and the wider community. The vast majority of the agricultural land is irrigated (most of it by traditional surface methods) and over 90% is served by artificial drainage systems. The extensive drainage network comprises open drains and horizontal sub-surface pipes, with many suitable access points for operation of controlled drainage. There are certainly areas where the incentives for controlled drainage will be attractive to farmers – this includes areas where sporadic water shortages impact crop production, and rice areas where savings in water application translate to considerable savings in energy and manpower costs. Farmer groups also appear to be sufficiently developed to facilitate management of controlled drainage across farming areas.

Agricultural production in Egypt relies on irrigation, with very little rainfall contribution. Controlled drainage management would thus be driven by irrigation applications. Simple controlled drainage devices have been tested, and farmer operation would be based on use of weirs to reduce drainage flows following irrigation, or application of flow blocking devices in rice growing areas.

In the Nile Delta farmers have already tested controlled drainage under rice in a number of areas. The water savings were in the order of 40%. The main attraction to the farmers was the resultant saving in irrigation application times. As the water requirements for rice are much higher than those for dry-foot crops, the potential savings in water application from controlled drainage are also higher. Areas with rice included in the rotation will thus benefit most from controlled drainage.

Controlled drainage under other crops also offers benefits, which will increase as water resources across Egypt are put under increasing pressure. Farmer groups are sufficiently developed within the Nile Delta to facilitate the collaboration required for controlled drainage management across cropped areas, and the necessary support would be provided by a strong farmer extension service.

Potential Application in India

Experimental work to date in India has indicated that controlled drainage can offer significant benefit to farmers in terms of improved crop yields, through relatively simple operation. An operational practice based on unconstrained drainage in the rainy season, and controlled drainage in the dry and irrigated seasons would be simple for farmers to understand and manage.

Although the review identified the potential for controlled drainage the scope for uptake is limited at the moment due to the lack of centralised effort to solve widespread problems of water-logging and salinity by installation of sub-surface drainage. One technical constraint to widespread drainage provision is safe disposal of drainage effluent. The adoption of controlled drainage could help with this problem, as the volumes of drainage water requiring disposal are reduced.

Summary *continued*

Artificial drainage will become more widespread as the water management and salinity problems escalate in the future, placing increasing demand on effective solutions, particularly across North West India. As the extent of drained land increases, so too does the scope for controlled drainage to form part of an integrated approach to irrigation and drainage management. Introduction of the technique at an early stage will increase the chances of success, as will support at the government level in the form of incentives and technical support from extension services. There is also a key role for Water Users' Associations (WUAs) which should be supported throughout the process.

The states of Punjab, Haryana and Rajasthan in North West India were highlighted as initial target areas for controlled drainage in India for two main reasons:

- Water management and salinity problems mean that these states have sufficient irrigation and drainage infrastructure in place.

- These states are particularly short of water.

Glossary / List of Abbreviations

ARC	Agrarian Reform Co-operative
CUG	Collector Users' Group
DAS	Drainage Advisory Services
DRI	Drainage Research Institute
DRP 2	Drainage Research Project 2
EPADP	Egyptian Public Authority for Drainage Projects
Feddan	Egyptian unit of land (1 hectare = 2.36 feddan)
IAS	Irrigation Advisory Services
LE	Egyptian Pound
Mesqa	Tertiary irrigation canal/unit
MoA	Ministry of Agriculture
MPWWR	Ministry of Public Works and Water Resources
WB	Water Board
RAJAD	Rajasthan Agricultural Drainage Research Project
HOPP	Haryana Operational Pilot Project
CSSRI	Central Soil Salinity Research Institute
AKRSP	Agha Khan Rural Support Programme
WALMIs	Water and Land Management Institutes
CWC	Central Water Commission
INCID	Indian National Committee on Irrigation and Drainage
ICAR	Indian Council of Agricultural Research
WUA	Water Users' Association

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1. INTRODUCTION

1.1 The Project

This report is an output from the DFID KAR (Knowledge and Research) Contract R7133 – Integrated irrigation and drainage to save water. The project was carried out by HR Wallingford, working in collaboration with the Drainage Research Institute of the National Water Research Centre, Egypt.

The research aimed to develop integrated irrigation and drainage management strategies incorporating controlled drainage, to save water, and protect soil and water resources in semi-arid regions. At the farm level the introduction of controlled drainage has the potential to improve the livelihoods of farmers by reducing water application costs and maintaining agricultural production in water short years. The project outputs are:

- A predictive tool to assess water saving, crop production, soil salinity and drain water quality under controlled drainage.
- Practical guidelines for designing and assessing the benefits of integrated irrigation and drainage incorporating controlled drainage.
- Guidelines for uptake and dissemination of controlled drainage strategies.
- Report on the potential for controlled drainage around the World.

The project was carried out in two stages. In the first stage a literature review and an investigation of the potential and constraints to the introduction of controlled drainage in the Nile Delta in Egypt, and the initial development of software tools to predict the impacts of controlled drainage were completed. The results of these activities are presented in the phase 1 report, OD/TN96.

Activities in the second stage of the project included a field study of controlled drainage in Egypt, development and refinement of the predictive tools, and development of practical guidelines for the controlled drainage technique. The field results and verification of the CDWaSim Simulation Model used to predict the impacts of controlled drainage are reported in OD/TN102. Guidelines and an uptake and dissemination plan are to be presented in forthcoming reports.

This document is the final output in the list above, a review of the potential for application of controlled drainage around the World. The analysis identifies countries where controlled drainage appears to be an attractive option now, or in the foreseeable future. This is followed by a description of the potential for controlled drainage in India and Egypt, countries where application has been assessed in more detail.

1.2 Controlled Drainage

Agricultural land drainage systems are usually over designed to cope with worst-case situations in terms of crop rooting depths and drainage requirements, as well as the expected loss of performance as systems age. For many crops and for much of the time this results in more water being removed from the soil profile and passed to drains than is necessary to control water-logging or the build up of salinity in the soil profile. Farmers frequently over-irrigate to compensate for rapid removal of water by drainage systems.

Controlled drainage is a method of integrating irrigation and drainage management. It involves reduction of drainage flows to maximise the crop utilisation of water provided by irrigation (or rainfall), whilst preventing water-logging and the accumulation of salinity in the soil profile. It thus enables irrigation applications to be reduced. The water that is "saved" is available for use without the substantial decrease in water quality that would have occurred if it had been passed through the drainage system before reuse.

Whilst the principle benefit is improved water use efficiency in irrigated agriculture areas, there are others, including:

- Improvements in crop yield.

- Controlling soil water through-flow rates to ensure that nitrate and phosphate levels are maintained, and that soil fertility is not degraded in high irrigation or high rainfall areas.

- By reducing drainage flows it can help control nitrate and phosphate losses to downstream water bodies, reducing eutrophication and ecological damage.

- Conservation of wetlands and water–sensitive regions.

1.3 Water Use Efficiency and Water Saving

The link between improved water use efficiency at farm level and water saving at basin level is not always clear. A water saving at field level does not always translate to a water saving at basin level, especially if water is recycled or reused once it has passed through the drainage system, or if groundwater recharge is a significant component of the basin water balance. It is thus important to assess the impacts of an increase in water use efficiency due to controlled drainage at the field level, on the water balance of the basin.

In areas where significant volumes of agricultural drainage water flow out of the basin, or to sinks, then any increase in field water use efficiency directly benefits the basin in terms of water saving. It is also important to consider water quality as well as quantity. In areas where drainage water is reused for agriculture, or other purposes, it is common for a reduction in quality to reduce the productivity of the reused water. Drainage water is inherently of poorer quality, and thus lower productivity (for agriculture and other uses). For this reason, water savings at field level resulting in reduced drainage flows nearly always result in water savings (in terms of productivity) at basin level.

1.4 Requirements for Controlled Drainage

The following set of controlled drainage pre-conditions has been developed. These are considered as pre-requisites for locations where controlled drainage is being contemplated:

- Relatively flat agricultural areas.
- Surface irrigation is the main method of water application.
- Artificial drainage systems comprising a network of open drains or horizontal sub-surface piped systems with suitable access points (such as manholes) in place or planned.
- There is an incentive for introducing controlled drainage, such as regions where water supply is sporadic or unreliable, or areas where water is pumped from canals to fields.
- Crop consolidation along drainage lines is feasible. (This implies large landholdings, or areas where groups of farmers are able and willing to collaborate over crop rotations.)
- Farmer organisations willing to take on the organisational tasks associated with controlled drainage exist or can be formed.

2. POTENTIAL FOR APPLICATION OF CONTROLLED DRAINAGE AROUND THE WORLD

In this chapter countries or regions are identified where controlled drainage may offer significant benefits, either now or in the foreseeable future. It focuses on areas with substantial irrigation and drainage infrastructure installed (or planned), and where periodic water shortages affect crop production.

2.1 Major River Basins in Arid and Semi-Arid zones

An initial assessment of regions where controlled drainage may offer benefits can be developed by identifying regions with low rainfall and areas suitable for large scale irrigated production. These conditions are found in the plains of many major river systems. These large river basins provide wide expanses of flat fertile soils, with favourable growing climates and abundant water supplies. They have thus become centres of irrigated food production. Populations reliant on irrigation have flourished, but various problems have developed. These include localised water-logging and soil salinisation, requiring the installation of drainage, and inefficient use of water, resulting in water shortages.

Major rivers systems in Africa and Asia located in regions where the mean annual rainfall is less than 500 mm are shown in figure 1.

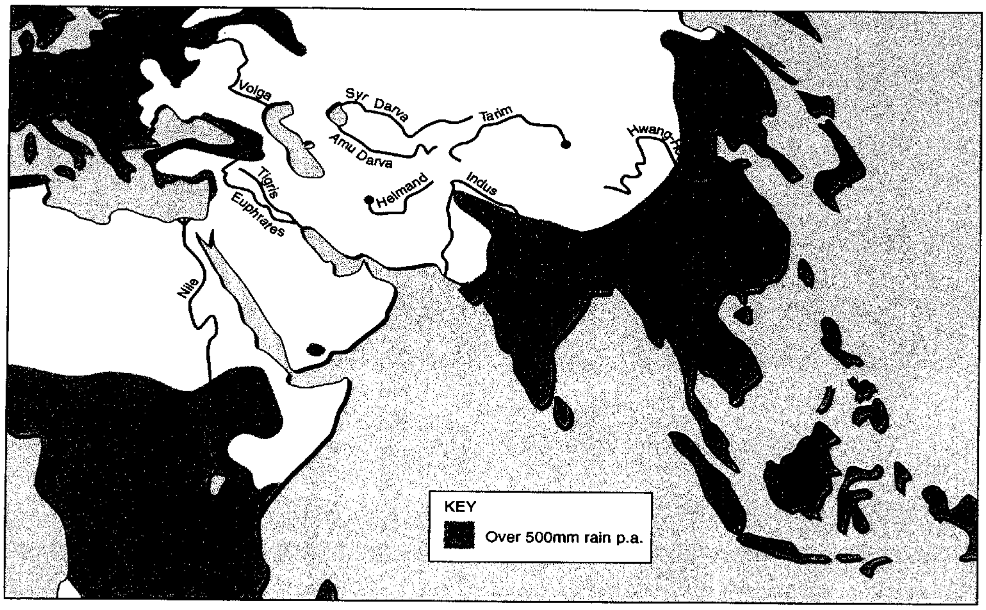

Figure 1 Low rainfall areas in 5 major river basins of Africa and Asia

More specific information can be obtained by considering countries where water is scarce, and that also have a significant irrigation and drainage infrastructure.

2.2 Areas of Predicted Future Water Scarcity

The International Water Management Institute have attempted to identify countries where water for agriculture is scarce using a relative water scarcity index (IWMI 2001), and have also projected future water shortages, for the year 2025 (Seckler et al, 2000). These are indicated in figure 2, from IWMI 2001.

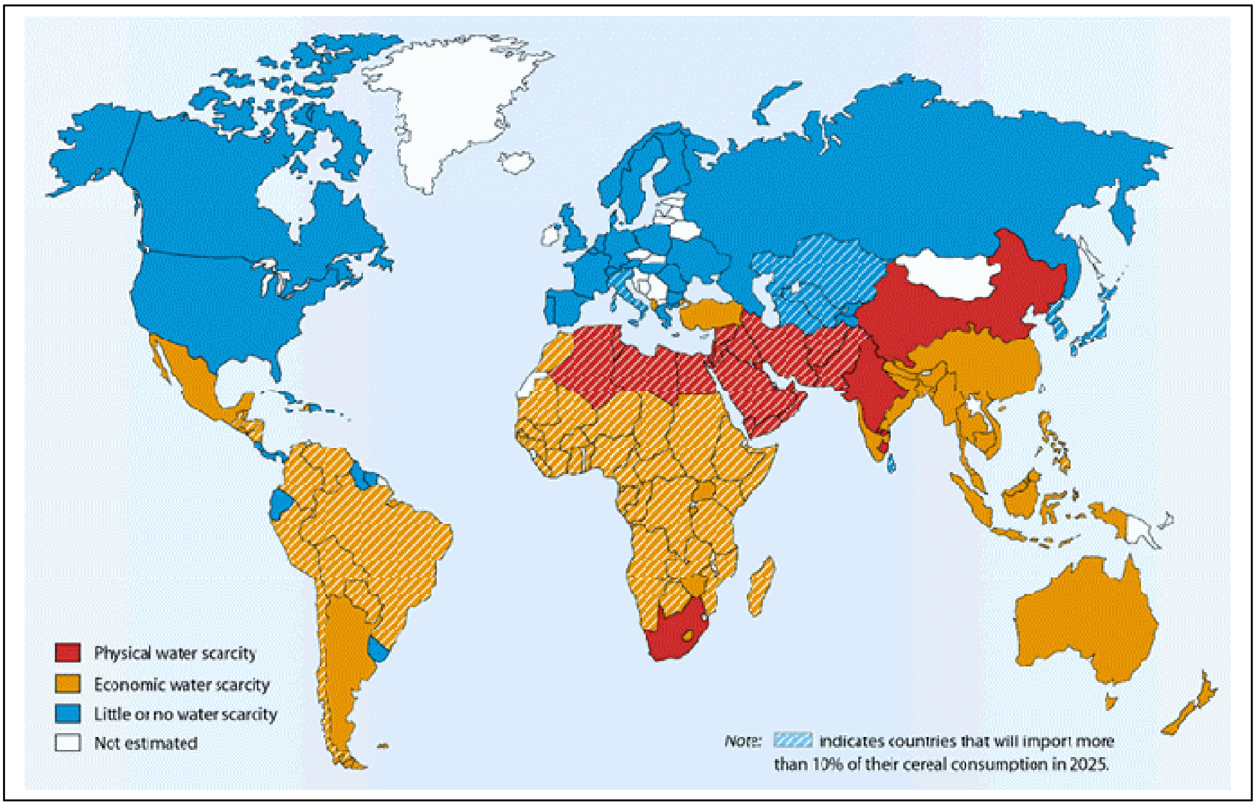

Figure 2 Water Scarcity predicted for the countries of the World in 2025 (IWMI, 2001)

The figure indicates that the water short counties, where there will be increasing pressures for more efficient use of irrigation water are, from west to east:

Algeria, Libya, Egypt, Israel, Palestine Territory, Jordan, Syria, Iraq, Saudi Arabia, Yemen, Oman, Gulf States, Iran, Pakistan, and Afghanistan, India (Punjab, Haryana and Rajasthan), and Northern China, South Africa.

These countries (with the exception of South Africa) are located in the regions with annual rainfall < 500 mm (as indicated in figure 1). Very large physical water shortages are not predicted to occur in South or Latin America, nor in Australia.

2.3 Distribution of Irrigated Agriculture

FAOSTAT figures (FAO, 2001) on the relative extent of irrigation around the World, show that significant irrigation occurs broadly in the same band of water short countries across North Africa, the Middle East and South Asia (see figure 3).

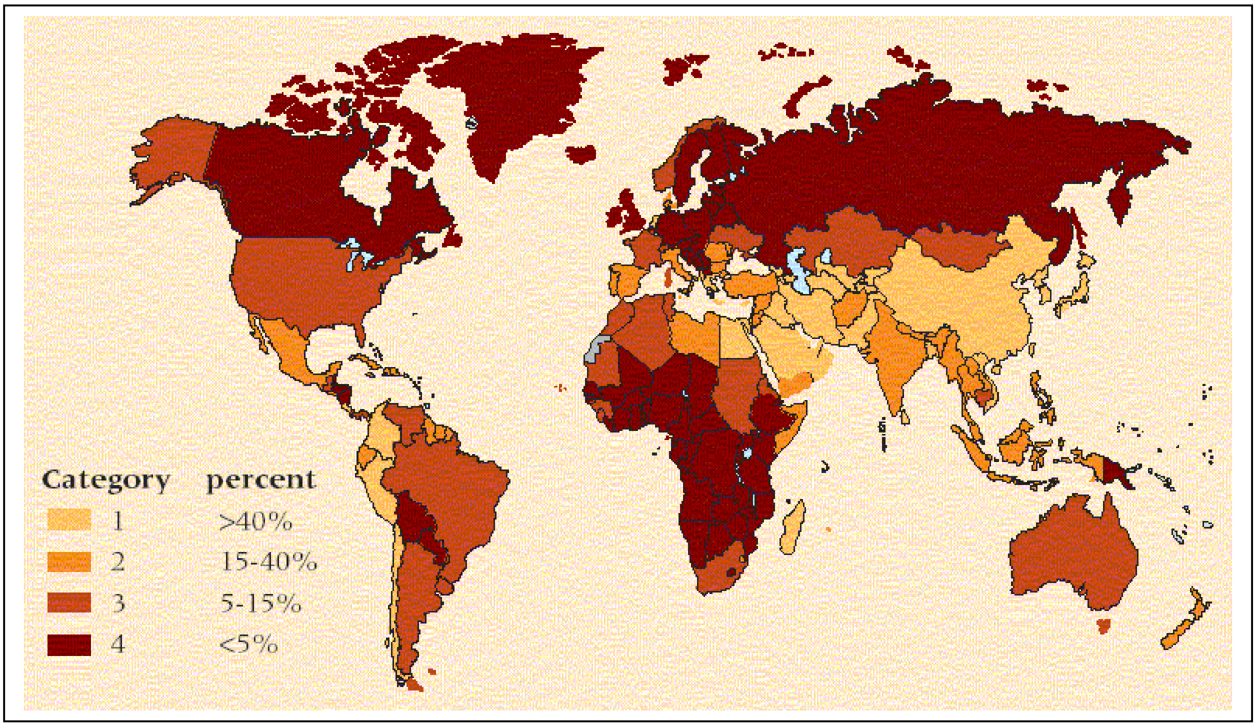

Figure 3 Distribution of significant irrigation countries around the World (FAO, 2001)

Countries with largest investment in irrigation, (ratio of irrigated area to total cropped area > 40%), are in the Middle East (including Egypt), and the band of Central Asia located to the North of India. The countries that have the greatest investment in irrigation (as defined by the ratio of irrigated area to total cropped area) are:

Egypt, Iraq, Saudi Arabia, Oman, Gulf States, Iran, Pakistan, and China.

Libya, Israel, Palestine Territory, Jordan, Syria, Yemen and Afghanistan, India (Punjab, Haryana and Rajasthan) fall in the next, 15-40%, band of irrigated: cultivated land area ratio.

This very largely comprises the same countries identified as having principal water shortage.

The top band of irrigating countries also includes some countries or regions of larger countries where water is more available, namely the West Coast of South America, Peru, Colombia and Chile, parts of China including its neighbours Korea and Japan, and the Central Asian States of Uzbekistan, Kyrghyzstan, Turkmenistan, and Tajikistan, and the Malagasy Republic off the East coast of Africa.

2.4 Distribution of Drainage around the World

In order to implement controlled drainage, it is necessary to have artificial drainage installed.
Data that help identify where significant drainage investment has taken place, or even is likely to take place in the future, are difficult to acquire. Some information about drainage area and type of drains, is held by the FAO's AQUAWEB database, but this is still in the development stage. However, an initiative by the Drainage Working Group of ICID has started to collate information on the drained areas of different countries. The following analysis is based on the preliminary information that has been acquired and which has kindly been made available (Zimmer et al, 2002) prior to their own publication of this information.

The ICID Working Group Paper combines countries into continental blocks and compares the extent of drainage investment. Figure 4 shows that North America and Western Europe have the highest proportion of drained area compared to their total cropped area. There has been research into controlled drainage in these two regions, and it has been adopted in areas of USA, Canada and Holland. As well as water conservation benefits, impacts have included increased crop yields and reduced transport of agrochemical pollutants to receiving water courses.

The figure shows that countries in Oceania and Africa have made relatively little investment in land drainage.

The countries that have made significant investment in drainage, and for which there would appear to be scope for considerably more investment are Asia, MENA (Middle East and North Africa) and Eastern Europe.

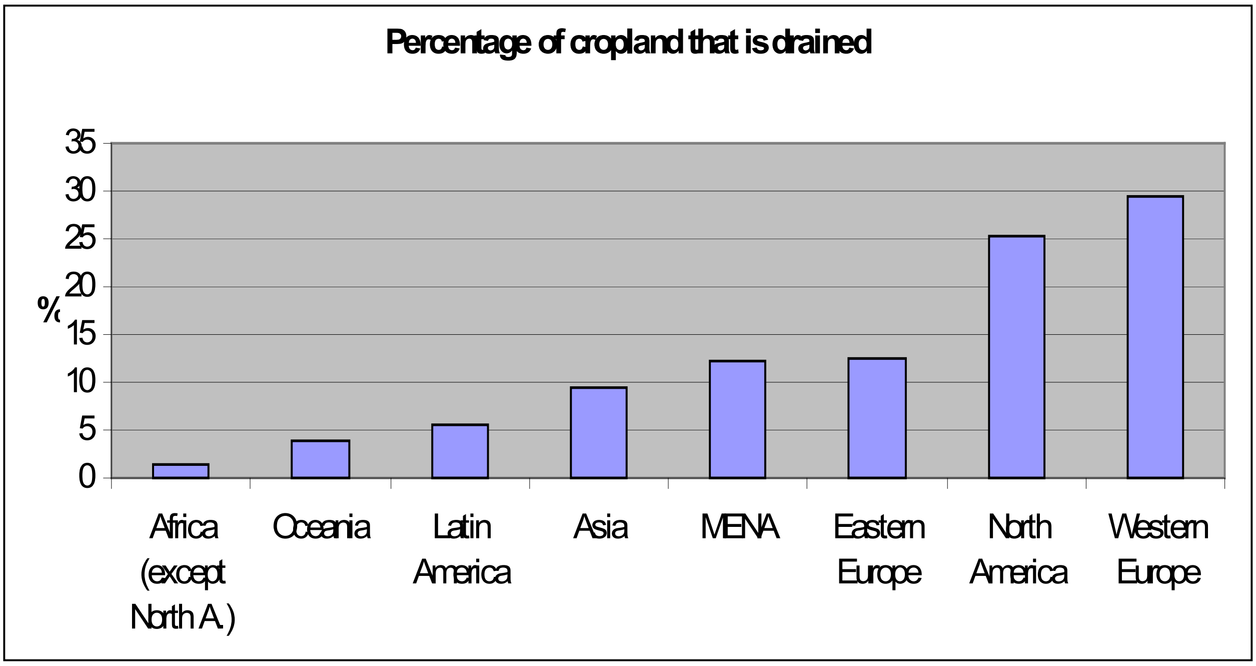

Figure 4 ICID figures on relative investment in drainage in different continents (Zimmer et al, 2002)

2.5 Countries with Significant Irrigation and Drainage Infrastructure and Projected Water Shortage

The next piece of analysis undertaken in this review is to combine the drainage distribution and irrigation distribution information, so as to identify those countries that have a relatively high proportion of land drainage installed compared to their irrigated area, together with current or projected water shortages. The table in appendix A details the information for a range of countries around the World.

The ratios of drained: irrigated area have been used to separate countries into four classes linked to climate, as shown in table 1.

Table 1 Climatic classes and D/I ratio (drained area: irrigated area)

D/I > 1000%	Drained area greatly exceeds irrigated area, mainly drainage countries of temperate/ humid climates.
D/I >100%	Countries where the drained area is larger than the irrigated area (still predominantly the western drainage countries).
D/I > 10%	**Countries where the drained area is less than the irrigated area , (but there is a significant area installed). These are the countries where controlled drainage would be of greatest interest and widest application.**
D/I < 1%	Countries where the drainage sector is very small compared to irrigation. Interest in controlled drainage would thus be low.

The data in table 1 can be used to develop a list of arid and semi-arid countries, where there is significant drainage experience and a large irrigation sector and therefore where the interest in applying and succeeding with controlled drainage is likely to be highest. These countries are:

Mexico, Brazil
Senegal, Mauritania, Algeria, Tunisia, Uganda, Ethiopia
Greece, Albania, Romania
Egypt, Turkey, Israel, Cyprus, Iraq, Bahrain, Syria
Uzbekistan, Turkmenistan, Tajikistan, Kyrgyzstan, China, Pakistan, India
Australia

The location of these countries is shown in Figure 5.

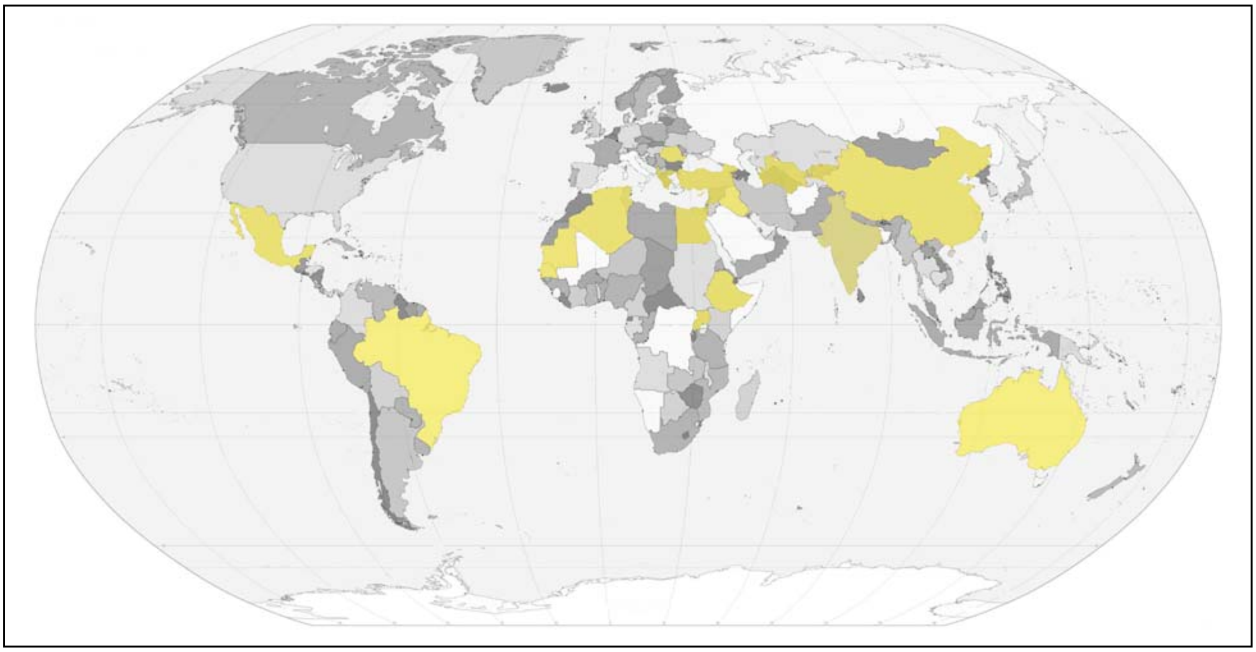

Figure 5 Countries with widespread irrigation, and significant drainage (D/I >10%)

Countries from this group that were identified as being particularly threatened by water scarcity over the next 25 years are:

Algeria, Egypt, Israel, Syria, Iraq, Bahrain
India (Punjab, Haryana, Rajastan), Pakistan, Northern China, Uzbekistan, Tajikistan, Turkmenistan

These countries are thus the ones where controlled drainage may be most applicable, and offer greatest benefit, and where promotion of controlled drainage concepts should be initially focussed. The potential for application of the technique in two of the major countries in the above list, Egypt and parts of India, is explored in the following chapters.

3. THE POTENTIAL FOR APPLICATION OF CONTROLLED DRAINAGE IN EGYPT

3.1 Introduction

A map of Egypt is shown in figure 6.

Figure 6 Map of Egypt

There is considerable potential for the application of controlled drainage in Egypt for three key reasons:

- There is an extensive irrigation and drainage infrastructure in the Nile Valley and Delta,
- Water resources are fully allocated and scarcities will become more severe over the next twenty to thirty years, and,
- Controlled drainage has already been tried in some (rice) growing areas.

3.2 Water Saving and Drainwater reuse

Egypt's existence depends on the Nile, the principle source of water for agricultural, industrial and domestic use. The agricultural sector is the largest water consumer, using about 85% of surface water resources. A network of 30,000 km of irrigation canals and 17,500 km of drainage channels serves around 3.3 million ha of irrigated land. Drainage, consisting of open and sub-surface drains, is used to control rising watertables and soil salinity problems. About 90% of the irrigated area is currently drained.

All crop production is irrigated, the main crops being maize, cotton and rice in the summer, and wheat, berseem and vegetables in the winter. Following recent reforms farmers are now free to grow any crop they choose (except rice). Rice production helps to reclaim lands affected by salinity, but requires a large amount of irrigation water. Thus there are controls on the locations where rice may be grown, and on the total area of production, but these are not strictly enforced at present.

The 1959 treaty with Sudan fixed Egypt's share of Nile water at 55.5 billion m^3/yr. To alleviate pressure on existing agricultural lands the Government has initiated several strategic expansion programmes, that in total will provide more than 0.7 million ha of new irrigated land. Additional demands for water for agriculture and other uses will result in irrigators facing significant reductions in supply as the pressures on water increase.

An ongoing Irrigation Improvement Project (IIP) is introducing quite radical technical and operational changes to farmers' irrigation practices. The project aims at increasing efficient use of irrigation water by minimising water losses and spillage to the drainage system and other measures. It is estimated that 5 bcm/yr fresh irrigation water might be saved, (Abdel-Aziz, 1995), however drainage water will decrease in quantity and increase in salinity as a result of this approach.

The IIP approach is based on replacing the traditional rotation system with an on-demand continuous flow system controlled by automatic gates. Canals are lined to reduce seepage losses, and on-farm irrigation practices are being improved**.** The new water control arrangements move farmers' control further up the system, but at the same time introduce a need for co-ordination of demand by groups at the distributary level. There is now discussion about co-ordinating the functioning of irrigation and drainage groups in so-called meska 'federations'.

At present 4.5 bcm per year of drain water is made available in the Nile Delta for reuse through the MPWWR's official drainage reuse programme, and reuse will be increased as part of the expansion programme. Unofficial reuse, where farmers individually lift water from drains for immediate reuse, is a very significant additional component of re-use within the Delta. It is difficult to estimate the exact extent of this practice, but it has been estimated (Drainage Task Force Committee, 1997) at about 2.8 bcm/yr.

Although drain water reuse increases overall water use efficiencies, it is better to save water earlier in the cycle, due to increasing water quality problems when water is reused. Controlled drainage offers one means of achieving this.

3.3 Controlled Drainage in Rice Areas

In Egypt rice is grown along with dry-foot crops, creating field water management conflicts. These are greatest in areas with sub-surface drains, where the drainage systems are designed for the most water-sensitive crops. Rice is not sensitive to water-logging, and most of the growing cycle does not need drainage. The farmers' solution to this problem is to block drains serving rice fields to maintain standing water in the fields. Whilst this improves the situation for rice, problems arise when dry-foot crops are grown upstream of the blocked section. The straw and mud used to block drains results in blockage of the downstream drains and an increased maintenance burden.

For these reasons the Drainage Research Institute (DRI) carried out a research programme on controlled drainage in rice areas, and a modified drainage system was developed in the early 1980's.

In the modified system, drainage water flows from the laterals into sub-collectors, subsequently into the collector, and finally into an open drain. Sub-collectors join the collector at access manholes, where it is possible to block the sub-collectors. Drainage control is achieved by use of flap gates to block the outflow from sub-collectors. Operational requirements are minimal; closing the drain at the beginning of the rice season, and opening towards harvesting time. The impact of blocking the drainage flows in this way is restricted to the area served by each sub-collector, which is generally not more than 20 ha. Crop consolidation is much easier to accomplish at the level of the sub-collector than at the level of the collector due to the smaller land areas involved. With the chances for effective co-operation between farmers enhanced due to the smaller numbers involved, the potential for conflict is greatly reduced.

The Egyptian Public Authority for Drainage Projects (EPADP) implemented sub-surface drainage systems based on the modified layout over an area of around 8500 ha. Crop consolidation could be accomplished relatively easily as the Government, through the agricultural co-operatives, fixed the cropping patterns. Now farmers have a free choice with regard to cropping patterns, complicating any effort to arrive at crop consolidation. Also the modified system is more expensive to construct, and as farmers are charged for the construction costs, there is obvious reluctance to raise the costs of implementation.

DRI continued testing controlled drainage in rice areas, notably as part of the Drainage Research Project 2 (DRP 2). Farmers participated in the experiments through Collector User Groups, and in an area covered by the IIP, through a Water Users Association. The principle conclusions from this work were:

- In an area outside the IIP, applying controlled drainage saved about 43% of the irrigation water for the rice fields compared with conventional drainage operation.
- In an area improved under IIP, applying controlled drainage saved about 42% of the irrigation water for the rice fields compared with conventional drainage operation.
- Whereas in general, water savings due to controlled drainage in rice areas would be around 40%, the combination of irrigation improvement under the IIP <u>and</u> controlled drainage together would lead to water savings in rice areas in the order of 50%.
- The costs to farmers of pumping water were reduced by similar amounts.
- The main attraction to the farmers was that less time was needed for irrigation under controlled drainage; farmers were less motivated by savings in water or pumping costs.

Based on the DRI findings, the Advisory Panel on Land Drainage recommended "that EPADP considers introduction of the modified drainage system in rice growing areas as water can be saved at no or very little cost" (Advisory Panel Project, 1998).

EPADP is currently (2001) contemplating the possibility of constructing controlled drainage systems in areas with more than 30% rice in the cropping pattern, where farmers are willing to participate, and potential conflicts between rice and non-rice farmers can be resolved. At present the possibility of using controlled drainage under non-rice crops has not been taken into account in these deliberations. This could offer benefits to all farmers in a controlled drainage area, not just those growing rice, and could make the introduction of controlled drainage a more attractive option.

3.4 Controlled Drainage of Dry-Foot Crops

There are some important differences between controlled drainage for rice and dry-foot crops. For rice, where the objective is to keep the watertable as close to the soil surface as possible, a drain-blocking device, or a weir set at a high level during the crop season, can be used. For dry-foot crops the watertable must be kept below a level at which water-logging in the root zone would affect crop production. Although an "on/off" blocking device can be used, control is best achieved with a weir, with the weir depth set at a safe level. If controlled drainage is practised under rice and dry-foot crops in the same area, adjustable weirs satisfy the requirements in both cases.

As the water requirements for rice are much higher than those for dry-foot crops, the potential savings in water application from controlled drainage are also higher. Areas with rice included in the rotation will benefit most from controlled drainage.

DRI and HR Wallingford carried out field trials of controlled drainage for maize and wheat in 1999 and 2000 at an experimental site in the western Nile Delta. A simple controlled drainage weir device was developed that could be produced locally at a reasonable cost, and used by farmers to set a maximum watertable depth for each crop. Drainage flows were significantly reduced under controlled drainage of both crops (maize and wheat), giving considerable scope for savings in irrigation water application. This work is reported in detail in HR Wallingford Report OD/TN102.

A drainage simulation model (developed by HR Wallingford and Cranfield University) was developed to simulate controlled drainage (CDWaSim), and can be used to assess the impacts on the soil water and salt balance, watertable depths, drainage flows and crop response to different controlled drainage strategies. (The CDWaSim model and its field verification are presented in HR Report OD/TN102.)

The model has been used to simulate a wide range of controlled drainage strategies for different crop rotations, soil types etc. Typical results from simulations of one crop rotation using good quality irrigation water (ECw = 0.7dS/m) on a medium texture soil are shown below:

Table 2 Controlled drainage predicted water savings using the CDWaSim model

2 year crop rotation	Conventional irrigation application (mm)	Recommended controlled drainage weir depth (m)	Potential water saving (mm)	Potential water saving (% of total rotation water use)
Cotton	1265	0.8	640	18.4
Wheat	728	0.8	512	14.7
Maize	1098	0.6	686	19.7
Short Berseem	392	1.1	293	8.4
Total Rotation Water Use	3483			

In general the simulations show that typical water savings for dry-foot crops could range from 8 to 20% of the total rotation water use. This constitutes a significant water saving.

3.5 Uptake of Controlled Drainage in Egypt

The main benefit to the wider community from controlled drainage is water saving. However individual farmers will not necessarily see this as a benefit. In areas where water deliveries are short, or unreliable, increased security against crop damage or failure, or the possibility of a shift in cropping pattern towards more water demanding or higher income crops, are likely to be key attractions. Generally water short areas are found at the tail ends of canals, and in the northern-most part of the Nile Delta. Although water shortage is currently not a widespread feature of irrigated agriculture in Egypt, it is expected to increase rapidly in the future.

In areas where water is plentiful other benefits such as reduced pumping costs, reduced labour requirements for irrigation, and savings in fertiliser costs must be large enough to ensure farmer interest.

Small, poor farmers put a high premium on security and risk avoidance. Their strategy is clearly exemplified by the high degree of land fragmentation, valued by the farmers because of the lower risks of crop failure, and the wide variety of crops grown even on single plots. Small farmers normally prefer to plant a mixture of commercial, subsistence, and fodder crops.

Whilst farmers are not averse to modernisation of agriculture, any proposed change in practice will also be assessed in terms of risk. The benefits must thus be clear.

Possible (perceived) risks of controlled drainage include:

- *crop damage*
  If proper care is not taken with controlled drainage (particularly of dry-foot crops), crop damage from root water-logging or the build up of salinity can result. Farmers may need practical demonstration or other guarantees before adopting the new technology. A serious extension effort will thus be required.

- *water rights*
  Farmers can be expected to be reluctant to give up existing water rights. Instead, they may prefer to over-irrigate and subsequently drain the surplus water, instead of decreasing their water abstraction without sufficient guarantee that water will be available if needed in the future.

- *social conflicts*
  Joint decision making is an important feature of controlled drainage, as farmers need to co-operate on identical (or similar) cropping patterns in the area served by the sub-collector to be controlled. This implies that farmers will have to give up part of their traditional strategy aiming at security and risk aversion. Strong farmer user groups equipped to resolve potential conflicts will be essential.

These issues and the mechanisms for overcoming them are discussed in more detail in a forthcoming report.

4. THE POTENTIAL FOR APPLICATION OF CONTROLLED DRAINAGE IN INDIA

4.1 Introduction

The continuing growth in India's population means that food production must increase and, in particular, that the productivity per unit of water and land must be improved. Although the irrigated area has increased rapidly since Independence, agricultural productivity per unit of land is low in comparison with many other parts of Asia. Amongst other problems, considerable areas of agricultural land are affected by water-logging and, salinity, and to a lesser extent, alkalinity. The states of Punjab, Haryana and Rajasthan are particularly short of water.

4.2 Extent of Irrigation and Drainage

In 1990 the total water use in India was estimated at 500km^3 of which 92% was for irrigation (FAO, 1999). The irrigated land area is estimated at 59 million ha, or 32% of the total cultivable area (FAO, 2001). Drainage has been installed on about 10% of the total irrigated area. (Zimmer et al, 2002). Some 2.5 million ha of irrigated land are estimated to be affected by water-logging, 3.1 million ha are affected by salinity and 0.24 million ha by alkalinity. Measures to counter water-logging and salinity are being taken by constructing drains, and by encouraging the combined use of surface water and groundwater. Salinity principally affects North West India with over a million hectares in Uttar Pradesh, nearly 1 million ha in Gujarat, 0.5 million ha in Punjab, 0.2 million ha in Haryana and a smaller area in Rajasthan. A significant area in Tamil Nadu in the south is also affected. (Thatte et al, 2000).

4.3 The Drainage Need

Many large irrigation schemes are subject to a high watertable due to over-supply of water at the head ends of the canal networks, and yet they simultaneously suffer from water shortage at the tail ends. Farmers at the tail may respond by pumping from ground water to irrigate their crops, and control the rise in the watertable. Without informed management of the wells, there is a major risk that the soil becomes progressively salinised because groundwater quality over much of arid/semi-arid North West India is poor. Sub-surface drainage, discharging to canals or drains avoids the risk and provides the opportunity to retain and use groundwater of improved quality.

There is unanimity amongst drainage experts in India that sub-surface drainage should be extended to cope with the widespread problems of water-logging and salinity. Initial target areas for expansion would be in North West India (Gujarat, Haryana, Punjab, Uttar Pradesh, Rajasthan). Unfortunately the costs are a deterrent to state governments and farmers alike, and alternative solutions such as canal lining, improved water management and bio-drainage are proposed. Incentive schemes to promote drainage, similar to earlier incentives to add gypsum in alkaline areas, have been mooted, but are not established.

Traditionally, when irrigation schemes have been constructed in India, drainage works are postponed to reduce initial expenditure, and despite the increasing scale of the environmental problems, that is still generally the case. Experience of reclamation and drainage has come with the construction of projects like RAJAD (Rajasthan), HOPP (Haryana) and pilot projects in a number of states throughout India undertaken by CSSRI, Karnal, and other organisations.

Despite concern at national level, there is no national policy for dealing with the problems. Individual states set their own agendas. Because of the perceived cost of implementing sub-surface drainage, other measures like canal lining, water management, vertical drainage, and bio-drainage tend to be considered in preference to horizontal sub-surface drainage. At present three states, Maharashtra, Rajasthan and Haryana have submitted status reports on drainage problems in irrigation commands to the Central Water Commission, but it is believed that no plans have yet been drawn up by the states for implementation.

Based on experience in the Netherlands, Egypt and Pakistan, Croon (1997) identified a set of pre-conditions for the widespread uptake of improved drainage technologies. Principle conclusions were that:

- National governments need to play an initiating role.
- Financial support is needed over a sustained period.
- Projects and financing need to be set in a legal framework.
- Long-term, large volume, well-financed programmes are a pre-requisite for effective development of a drainage tradition and industry.

At present these conditions remain to be established in India. Previous initiatives by national government to promote, for example, the reclamation of alkali soils have been successful. Amongst other factors, governments need to be able to convince treasuries of the case for support. At present, strong advocacy of the developmental benefits of supporting drainage is lacking. With increasing pressure on available land and water supplies, the case for government to play an initiating role will be strengthened.

4.4 The Scope for Controlled Drainage in India

Although some states in India currently have significant artificial drainage provision, there is a growing need to extend the drained area, and implement improved irrigation and drainage management to control water-logging and salinity problems. As the drained land area increases, so too does the scope for integrated irrigation and drainage management involving controlled drainage. Controlled drainage could certainly offer benefits, particularly to improve water distribution and management in command areas which suffer water-logging, salinity and periodic water shortage. The states most likely to introduce controlled drainage and derive the largest potential benefits in the foreseeable future are Punjab, Haryana and Rajasthan. This is because:

- These states already have some drainage provision, which will increase in the coming years, and,

- These states are particularly short of water.

These states (in North West India) are highlighted in figure 7.

Figure 7 Map of India with Punjab, Haryana and Rajasthan highlighted

India's climate, consisting of a wet season, a winter season, and a dry season, means that rainfall makes a significant contribution to crop water requirements, and has to be included in design of controlled drainage management strategies. For example, in central Haryana, the watertable can rise to the ground surface in the rainy season, and then decrease steadily to a level below the root zone by the time of the hot season.

Some preliminary work has been carried out on the operational requirements for controlled drainage in India. Pilot studies in Haryana (Rao et al, 1992) have indicated that suitable controlled drainage management involves keeping the drains open in the rainy season to flush out salts, and closing them later in the year (in the dry and irrigated seasons) to hold moisture in the soil profile. At this time the crops can benefit from capillary rise from the shallow watertables, and as the evapotranspirative needs of the crop are lower, the risk of reintroducing salinity in the root zone is low. Significant reduction in soil salinity, leading to substantial increase in yields from dry season (rabi) crops, was obtained in pilot trials. Such an operational strategy helps in saving scarce irrigation water, whilst maintaining the salt balance at a favourable level, leading to potential increases in crop yield.

The success of the technique in India depends on identifying a suitable outfall for poor quality drainage effluent, which represents a real problem in parts of North West India. Controlled drainage should help with drainage water disposal, as it reduces drainage volumes. In the case of the trials, the effluent was discharged to irrigation canals when they were flowing close to capacity, so that the quality of the canal water was only marginally effected. When the scale of drainage operation is increased, informed management of the canal system would be essential to ensure an acceptable mixing ratio was maintained.

Controlled drainage is also being piloted in the Chambal command area of the RAJAD project. After about 10 years of canal irrigation, 161,000 ha of the 229,000 ha under irrigation showed evidence of water-logging, and 25,000 ha were severely affected by salinity. The affected area is increasing at about 1% per annum. From 1992-95 experimental test sites were established on 2100 ha of land to assess the effectiveness of sub-surface drainage for salinity control and to develop the design criteria for the project. Based on the design criteria developed, more than 15,000 ha of sub-surface drainage has been installed. A slightly costlier drainage system was adopted in some areas of the Chambal Command to provide the option for farmers to control the drainage flow from the laterals. Indications are that the cost of provision for controlling drainage is about 10% more than the standard drainage layout (RAJAD, 1995).

Whilst there is clear evidence that controlled drainage can provide significant benefits in India, it has only been tested at the pilot scale.

4.5 Constraints to Implementation in India

One of the main barriers to adoption of controlled drainage in India is the limited area of land that is currently drained. The technique is certainly appropriate in the states of North West India, and will become more so as the land area under artificial drainage increases.

Achthoven and Lohan (1998) looked at the reasons why drainage installation has lagged behind in India. Their analysis applies equally well to uptake of controlled drainage methods:

- It is vital for governments to play an initiating role, in widespread implementation of sub-surface drainage. Despite concern in India at national level, there is currently no national policy promoting drainage development.

- Drainage as a solution to salinity and water-logging problems must be considered effective by all stake-holders concerned, especially if the costs are to be shared by all. The current situation in India is that despite clear, demonstrated benefits of drainage, farmers generally are not sufficiently organised to co-operate effectively in established Drainage Societies. Knowing this and the extra costs involved, state planners tend to focus on other solutions, like bio-drainage and canal lining.

- The severity of the problems and the effectiveness of the solution must be part of the political agenda. The Eighth five-year plan recognises the threat to agricultural productivity, referring to it as a “national menace” in need of a phased programme, involving amongst other measures, sub-surface drainage. A Committee on Wastelands development has recommended the creation of a department of Land Resources, because of the failure of fragmented sectoral approaches. Large-scale financing for drainage is not available, although national government will contribute 50% to Command Area Development (CAD) projects identified by states.

- A legal framework must support the projects and the financing methods. Projects undertaken to date have tended to be donor-funded or smallscale government-funded pilot projects.

- Experience in Egypt has shown that the initial training of national authorities in planning, supervision and design contributes to the development of local know-how, which could eventually be privatised. Expertise in India does now exist at national level and in a few states. However, it is thinly spread and subject to dispersal as staff are posted away.

- Long-term, large volume, well-financed programmes are a pre-requisite for effective development of a drainage tradition and industry. Large volumes are required to make the programmes cost-effective, and to ensure that the initial investments can be written off. At present, there is no indication of a concerted programme of drainage.

- Mechanisms are needed to make it possible for local private firms to finance the initial investment in machinery and, if necessary, to import foreign technology.

The above constraints to sub-surface drainage are clearly also constraints on controlled drainage techniques. There are still only small areas of the country under formal drainage schemes, reflecting the fact that drainage has yet to receive priority at state level. In part, this reflects a lack of drainage expertise, in part a belief amongst engineers that drainage is expensive, and in part, a strong reluctance on the part of farmers to take out loans, even on soft terms, for drainage installation.

4.6 Social and Institutional Aspects

Co-operative management of the drainage system by farmers is essential to the success of controlled drainage. Although efforts to establish well-functioning water user groups have been made throughout India, there are only a limited number of places where real success has been achieved. It is generally acknowledged that farmers in Maharashtra are particularly progressive, tending to seek innovative methods in agriculture. At present, according to ICID, problems of salinity and water-logging in the state are relatively limited.

In view of current official thinking in Maharashtra and the limited scale of the problems, a state such as Gujarat, where there has already been some experience with sub-surface drainage, would be a better location for promoting controlled drainage. The Agha Khan Rural Support programme, and other NGOs, working with farmers, have a long-established presence in the state. Such continuing support to water user groups will be necessary to promote innovations like controlled drainage and convince farmers of the need to consolidate cropping patterns. Continuing institutional support will also be necessary. Many Pilot schemes have fallen into disuse when state governments have withdrawn support for operation and maintenance, despite the fact that farmers recognised a clear benefit to drainage in terms of better yields.

There are well-established, highly skilled and experienced researchers in India who are fully aware of the issues. Research on drainage is carried out by the Central Soil Salinity Research Institute (CSSRI), Karnal, by Indian Council of Agricultural Research (ICAR) through the All India Co-ordinated Research Project (AICRP), various State Agricultural Universities, Water and Land Management Institutes (WALMIs) and some State Irrigation Departments. The Ministry of Water Resources sponsors and co-ordinates drainage related activity through the Central Water Commission (CWC) and the Indian National Committee on Irrigation and Drainage (INCID). These institutions would need to be involved in development of controlled drainage techniques for Indian conditions, and in subsequent monitoring of performance in the field.

The Canadian and Dutch governments have both supported the drainage sector, although it is believed that no active implementation of sub-surface drainage is currently contemplated. Until, and unless, national and state governments establish policies and introduce incentives for new techniques such as controlled drainage, necessary support to farmers could be sought from long-established developmental NGOs like the Agha Khan Rural Support Programme (AKRSP) who are working to strengthen water user societies, particularly in Gujarat. Technical direction and guidance would depend upon a body such as CSSRI, probably with training support from a WALMI (Water and Land Management Institute).

5. CONCLUSIONS

Countries Where Controlled Drainage is Potentially Most Applicable

The areas of the World where controlled drainage is likely to be applicable and offer greatest benefit are:

North Africa: Algeria, **Egypt**

Middle East: Israel, Syria, Iraq, Bahrain

Central Asia: **India (Punjab, Haryana, Rajastan)**, Pakistan, Northern China, Uzbekistan, Tajikistan, Turkmenistan

Potential Application in Egypt

A more detailed assessment of the potential for controlled drainage in Egypt indicated that this is one of the countries where controlled drainage is most applicable, and potentially offers significant benefits to the farmer and the wider community. There are areas where the incentives for controlled drainage will be attractive to farmers – this includes areas where sporadic water shortages impact crop production, and rice areas where savings in water application translate to considerable savings in energy and manpower costs. Farmer groups also appear to be sufficiently developed to facilitate management of controlled drainage across farms.

In the Nile Delta farmers have already tested controlled drainage under rice in a number of areas. The water savings were in the order of 40%. The main attraction to the farmers was the resultant saving in irrigation application times. As the water requirements for rice are much higher than those for dry-foot crops, the potential savings in water application from controlled drainage are also higher. Areas with rice included in the rotation will thus benefit most from controlled drainage.

Controlled drainage under other crops also offers benefits, which will increase as water resources across Egypt are put under increasing pressure. Farmer groups are sufficiently developed within the Nile Delta to facilitate the collaboration required for controlled drainage management across cropped areas, and the necessary support would be provided by a strong farmer extension service.

Potential Application in India

Although there is potential for controlled drainage in India, the scope is currently limited due to the lack of a centralised effort to solve widespread problems of water-logging and salinity by installation of sub-surface drainage. It is anticipated that this situation will change, as the water management and salinity problems escalate in the future, placing increasing demand on effective solutions. As the extent of drained land increases, so does the scope for controlled drainage to form part of an integrated approach to irrigation and drainage management. Introduction of the technique at an early stage will increase the chances of success, as will support at the government level in the form of incentives and technical support from extension services. There is also a key role for water user associations (WUAs) which should be supported throughout the process.

Safe disposal of drainage effluent is a key technical constraint to widespread drainage provision, but the adoption of controlled drainage could help with this problem, as the volumes of drainage water requiring disposal are reduced.

Experimental work to date in India has indicated that the technique can offer significant benefit to farmers in terms of improved crop yields, through relatively simple operation. An operational practice based on unconstrained drainage in the rainy season, and controlled drainage in the dry and irrigated seasons would be simple for farmers to understand and manage.

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Appendix A

Extent of Irrigation and Drainage around the World

Appendix A Extent of Irrigation and Drainage around the World

The table below combines information on extent of irrigation distribution and drainage installation for a range of countries. It can be used to identify those countries that have a relatively high proportion of land drainage installed compared to their irrigated area. The information for each country was processed to show an indicative percentage representing the ratio of "drained area : irrigated area".

The table also identifies the predominant climate type in each location.

Table A1 Extent of Irrigation and Drainage around the World (from Zimmer et al 2002)

Country	On-farm drained area 1000 ha	Irrigated area 1000 ha	Drained area : Irrigated area %	General climate type
Africa				
Senegal	45	71	**63**	**A**
Uganda	3	9	**33**	**A**
Mauritania	13	49	**26**	**A**
Ethiopia	29	190	**15**	**A**
Côte d'Ivoire	3	73	**4**	**A**
Nigeria	4	233	**2**	**A**
Kenya	1	67	**1**	**A**
Sudan	0	1950	**0**	**A**
Asia				
Japan	3660	2659	**138**	**M**
Korea, Rep.	1153	1159	**99**	**M**
Philippines	1470	1550	**95**	**H**
Uzbekistan	2821	4281	**66**	**A**
Turkmenistan	1026	1800	**57**	**A**
Tajikistan	329	719	**46**	**A**
Bangladesh	1501	3985	**38**	**H**
China	20000	53740	**37**	**HAM**
Pakistan	6000	17950	**33**	**A**
Viet Nam	1000	3000	**33**	**H**
Malaysia	53	365	**15**	**H**
Kyrgyzstan	149	1072	**14**	**A**
Myanmar	193	1841	**10**	**H**
India	5800	59000	**10**	**HA**
Nepal	82	1135	**7**	**A**
Indonesia	272	4815	**6**	**H**
Kazakhstan	123	2350	**5**	**A**
Sri Lanka	33	662	**5**	**H**
Thailand	155	4750	**3**	**H**
Iran, Islamic Rep of	40	7562	**1**	**A**
Eastern Europe				
Lithuania	2620	7	**37429**	**M**
Croatia	762	3	**25400**	**M**
Poland	4205	100	**4205**	**M**
Slovenia	72	2	**3600**	**M**
Czech Republic	405	24	**1688**	**M**
Hungary	2320	210	**1105**	**MA**
Russian Federation	7399	4600	**161**	**MA**
Albania	145	340	**43**	**MA**
Romania	300	2673	**11**	**MA**
Bulgaria	74	800	**9**	**MA**
Latin America				
Suriname	51	51	**100**	**H**
Guyana	150	150	**100**	**H**
Mexico	5203	6500	**80**	**A**
Honduras	62	78	**79**	**H**
Venezuela, Boliv Rep	289	575	**50**	**H**
Brazil	1280	2900	**44**	**HAM**

Drained / irrigated areas %	
Group 1	>10 times
Group 2	> 100%
Group 3	> 10%
Group 4	< 10%

	Climate
H	**humid / tropical**
A	**arid / semi-arid**
M	**moderate/temperate**

Table A1 Extent of Irrigation and Drainage around the World (from Zimmer et al 2002) (continued)

Uruguay	78	180	**43**	**M**
Cuba	327	870	**38**	**M**
Costa Rica	38	108	**35**	**M**
Colombia	234	850	**28**	**M**
El Salvador	8	40	**20**	**M**
Bolivia	20	130	**15**	**M**
Paraguay	10	67	**15**	**M**
Dominican Republic	30	269	**11**	**M**
Argentina	117	1561	**8**	**M**
Peru	85	1195	**7**	**M**
Ecuador	52	865	**6**	**M**
Guatemala	1	130	**1**	**M**
Chile	15	1800	**1**	**M**
Middle East and North Africa				
Egypt	3000	3300	**91**	**A**
Turkey	3143	4500	**70**	**A**
Israel	100	199	**50**	**A**
Cyprus	20	40	**50**	**A**
Iraq	1540	3525	**44**	**A**
Bahrain	1	5	**26**	**A**
Syrian Arab Republic	273	1186	**23**	**A**
Tunisia	80	380	**21**	**A**
Algeria	56	560	**10**	**A**
Morocco	120	1305	**9**	**A**
Lebanon	10	120	**8**	**A**
Jordan	4	75	**5**	**A**
Saudi Arabia	44	1620	**3**	**A**
Kuwait	0	7	**0**	**A**
North America				
Canada	1665	720	231	M
USA	47500	22400	212	M
Oceania				
Australia		2251	**87**	**A**
Western Europe				
Austria	195	4	4875	M
United Kingdom	4650	108	4306	M
Finland	2120	64	3313	M
Germany	4900	485	1010	M
Ireland Rep.	1150			M
Sweden	1100	115	957	M
Netherlands	3000	565	531	M
Switzerland	121	25	484	M
Denmark	1440	447	322	M
Belgium-Luxembourg	70	40	175	M
France	2500	2100	119	M
Greece	469	1441	**33**	**A**
Spain	300	3640	**8**	**A**
Italy	60	2698	**2**	**MA**
Portugal	8	650	**1**	**MA**