# Agricultural Land Drainage: a wider application through caution and restraint.

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## 1. A critical introduction

In the last decade, the profession of agricultural land drainage has lost some credibility, whether justified or not, and especially in the industrialized countries, the number of drainage professionals is declining. The fact is that many drainage projects, though certainly not all, were too expensive, had not enough positive effects, or had too many negative side-effects. Yet there are many parts of the world that could benefit from agricultural land drainage projects, but their prospects are reduced in the wake of the weakened reputation.

This lecture calls for the application of cautious and restrained criteria for agricultural land drainage - criteria that can lead to effective drainage systems at reduced costs and with diminished environmental hazards, and that can be applied to many areas that are still in need of drainage.

## 2. What is (land) drainage?

Literally, the word ‘drainage’ means the removal of a liquid. For us at ILRI, the liquid is water, but in the medical world it may be a body liquid. Figuratively, also non-liquid substances can be drained, for example: drained of energy, brain drain (this is not a drain for brains as may be used in a hospital but it is draining away people with brains). For a surgeon, however a brain drain does not mean an opening to remove brains, but a tool to remove liquid from the brains.

In subsurface hydrology, the word drainage is often used to just indicate a flow: the groundwater drains, or seeps, through the aquifer. Taking the word “drainage’ literally, the removal of water from a river for irrigation would be called drainage, but instead one uses the words diversion, take-off, intake, etcetera.

When we limit ourselves to land drainage (which is of course not the removal of land but the draining of water from the land) the term has still ,many different meanings. The only thing we are sure about is that the concept of land drainage excludes the drainage of water from cities, highways, or airports through sewage systems or superficial channels.

When you ask the question: “What is land drainage?”, a geographer will probably refer to the pattern of natural watercourses in a hilly or mountainous area, whereas a pedologist thinks rather of the permeability of the soil (a poorly drained soil is t them a soil with a slow hydraulic conductivity). The geographer and the pedologist, however, have both in mind the concept of some form of natural drainage. The civil engineer, on the other hand, usually thinks in this context of artificial, man-made drainage systems, which are implemented when the natural is deficient for the proposed land use.

Two drainage projects in Peru, the San Lorenzo Drainage Project (*Chanduví*, 1973) and the Anta Pampa Drainage Project (*van Immerzeel and Oosterbaan* 1990), are engineering projects aimed at the enlargement, straightening, embanking, and/or cleaning of natural watercourses to prevent the flooding of adjacent land. This shows that in Peru the word drainage is sometimes interpreted by engineers as the (re)construction of natural waterways rather than as the removal of water. The perception of drainage as flood control ( the prevention of water to enter the land) is found in many parts of Latin America.

In Canada (*Found et al*. 1976), the term land drainage is clearly associated with the reclamation of marsh lands for agricultural or urban development. Therefore, the Canadian perception of what is land drainage is closely associated with the word “impoldering” as introduced by the Dutch. This “impoldering” has a wider meaning than land drainage alone, because it involves both flood protection (i.e. the construction and maintenance of embankments or dikes) and the removal of rain water through a system of channels and pumps inside the “polder”. In fact, the purpose of land drainage is then not in the first place the removal of water, which is a nuisance, but rather obtaining dry land.

When you ask a Dutch farmer or a Dutch drainage engineer the question “What is land drainage”, there is a good chance that he will answer: “It is the installation of drain pipes in the soil”. Also, to many a person involved in drainage for salinity control in the irrigated lands of (semi) arid regions, a drainage project means the installation of a drainage system consisting of drain pipes/ditches or even tube-wells. Nowadays, therefore, it very often happens that the word drainage refers more to the means by which drainage is accomplished than to its literal meaning.

The different notions I have given, can lead to a confusion when international experts are discussing the subject of drainage, especially if they come from different disciplines. In addition, the different interpretations make it difficult to give an unambiguous definition od what “drainage”, “land drainage” or “agricultural land drainage” is.

In the last decades, environmentalists opposing the reclamation of wetlands for agriculture or urban development, have cast a shadow over the drainage engineer’s profession, like mine. It is therefore necessary to define more clearly the concepts of land drainage and to indicate the purpose and when it is useful or damaging. There is still enormous scope for modest forms of land drainage, but we need to be more precise about what we wish to accomplish and how we assess the effects.

## 3. The quick removal of excess water: a good definition?

An example of ambiguous definition of land drainage is: “the removal of excess water from the land as fast as possible” (e.g. *Roe and Ayres* 1954, sections 1.2 and 4.1). Such drainage is intended to make the land suitable for a specific purpose, e.g. some form of agriculture. The quick removal is the regarded by hydrologists or environmentalist as a threat to lower lying lands because of the increased risk of their inundation from rivers that due to the quick removal experience higher peak discharge than before the drainage activity. They also see it as a factor of drought risk, because the quick removal of water prevents its storage, which would otherwise be beneficial during dry spells. They further see it as a factor of environmental threat because of the spread of pollutants carried with the drainage water (Hoffman 1990).

The term “excess water” as used here, is usually not well defined, but on the basis of hydrological considerations, rather than on agricultural or other land use requirements, its value is often taken drastically high (*Raadsma and Schulze* 1974, *van Dort and Bos* 1974, *van de Goor* 1974). This leads to excessively costly drainage systems and environmental problems.

In fact, agricultural land drainage ought not to aim at the quick removal of large quantities of water. Instead, the drainage should be cautious and restrained, aiming at flows that are as gentle as possible, and at quantities that are as small as possible.

In this respect we also need to make a distinction between surface and subsurface drainage. Subsurface drainage is practised when the natural drainage to the underground is insufficient to prevent water-logging and excessively high water-tables. After a subsurface drainage system has been installed, the average level of the water-table will be lowered, and at the same time some discharge of water will occur through the system (figure 1). Because the water-table has been lowered, the soil above it will become drier than before. This creates a facility for the temporary storage of water during periods of occasional exceptionally high recharge. This storage facility acts as a buffer, so that the exceptionally high recharge is transformed into a relatively slow discharge (e.g. *Rycroft* 1990, figure 2). Without the artificial drainage system, this buffer would not be present, and the runoff would have been faster.

Thus the system has achieved a reduction of the intensity of the peak runoff: the water is not removed quickly, but relatively slowly over a longer period of time. When, in addition, the drainage system is installed at a fairly shallow depth, it will not function continuously and its total discharge will be relatively low and water is saved for periods with little recharge. In drainage systems from which water has to be pumped, the same effect is obtained if the pumping is done with restraint.

With surface drainage systems in agricultural lands, a similar effect can be obtained, though to a lesser degree. Surface drainage systems are used when the drainage problems occur mainly on top of the soil. If the land surface is shaped so that the water can move down slope slowly but steadily, the surface is no longer waterlogged and the infiltration capacity of the soil increases. Thus, during a period of intensive rainfall, a larger part of the rain can be stored in the soil with a surface drainage system than without. This leads to a reduction in total surface runoff and possible to an attenuation of runoff intensity. Nevertheless, the attenuating effect of a surface drainage system is not as clear as that of a subsurface drainage system, because the water flows faster over the surface than before and this may offset the advantage scored with the increased buffer capacity. It is therefore wise to avoid drastic land-shaping operations for surface drainage.

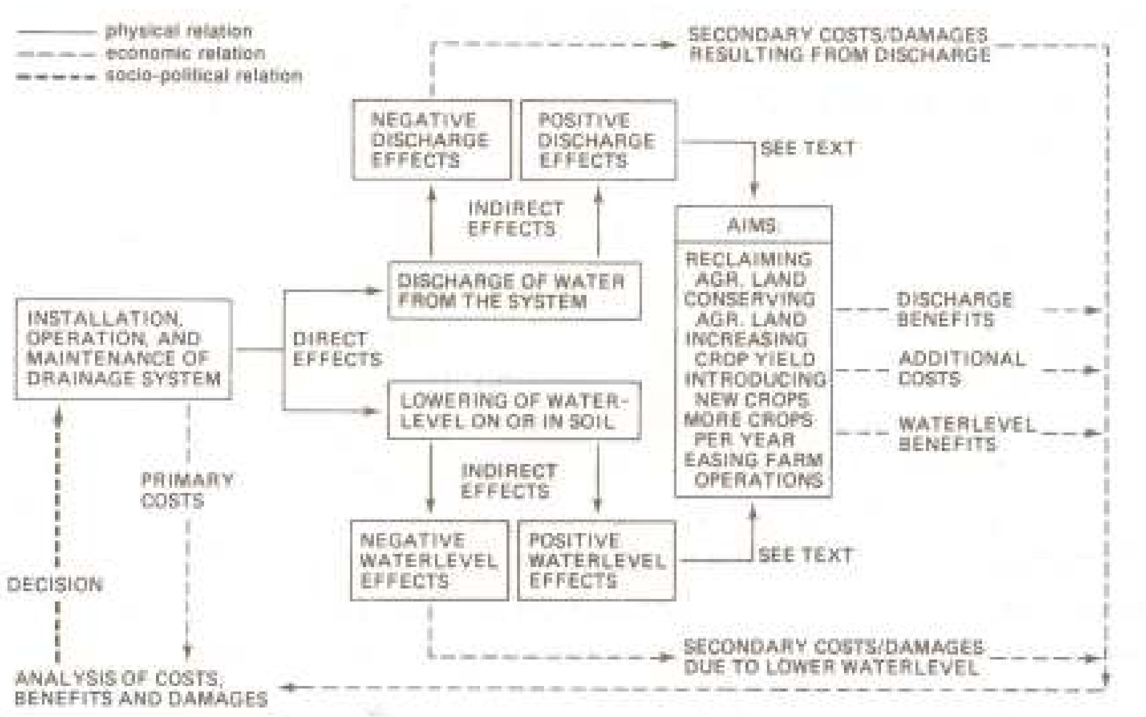


Figure 1. Diagram of the effects of drainage on agriculture and the economic/environmental evaluation.

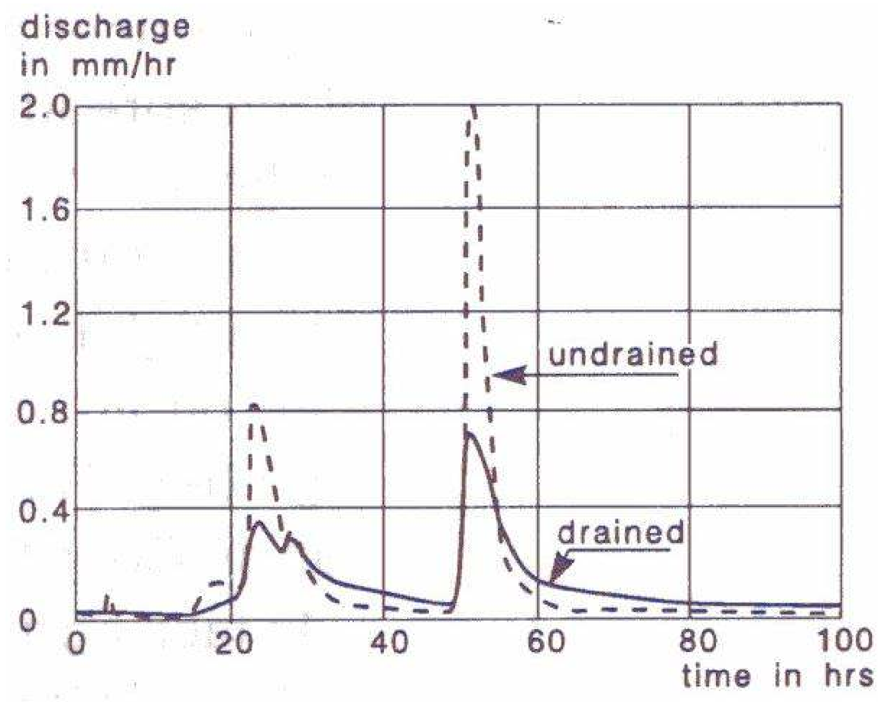


Figure 2. Illustration of reduced peak flows by agricultural land drainage systems. (*Arrowsmith et al*. 1989 as cited by *Rycroft* 1990)

With respect to the speed and quantity of flow, one can say that the drainage of agricultural lands differs from drainage for flood control or the drainage of urban areas and roads. The aim of such systems is indeed fast flow velocities, lest distressing inundations may occur. On the other hand, it also differs from erosion control, which rather aims at retaining and conserving the water than letting it runoff at all. So, agricultural land drainage needs a specific definition, quite different from those of the other cases.
For agricultural purposes, land drainage would be better served with a definition relating to a modest degree of water-table or water-level control than with a definition relating to the removal of water. The amount of water that then needs to be drained results from the required degree of water-table control and is no longer an independent "quick removal of excess water". Such a definition is supported by the fact that the drainage flow occurs mainly by the force of gravity, so that the water is not actively removed, but it moves by itself. Further, the degree of water-table control is usually better related to the purposes of agricultural land drainage (e.g. improved crop production) than the discharge as such. Also, the definition avoids the use of the unfortunate expression "excess water", that is difficult to quantify.

When developing the proposed definition, we should consider the fact that in some instances the flow of water through the drainage system can remove dissolved substances like salts, acids, or alkalis. The removal of these substances can be part of the aims of land drainage, e.g. soil salinity control. If this is so, the removal must be done with the utmost care and as slowly and gradually as possible. Drainage systems designed fir this purpose should be "checked" systems by which the drainage flow can be halted at any desired time. Here we see a second illustration of what is meant by the words "caution" and "restraint" in the title of this lecture.

After all, we would not like to drain the soil so intensively that valuable and beneficial substances, like nutritive minerals and fertilizers are removed at undue speed, thereby impoverishing the soil, or that harmful substances are rapidly spilled into the environment

## 4. Defining drainage systems

We have seen that the definition of (land) drainage fluctuates between the concepts of "the (natural) flow of water from the land", "the removal ( and even the quick removal) of excess water (and even excess salts) from the land", "flood control or flood protection", "impoldering", to the concept of "installing a drainage system" and from there to "water-table or water-level control", with a possible extension to "salinity, acidity, or alkalinity control". A generally acceptable definition of land drainage is therefore difficult to give. Instead, I prefer here to give a definition of the systems that can be used for agricultural land drainage. This is:

> 'Agricultural land drainage systems are systems by which the flow of water from the land is made easier so that the agriculture can benefit from the effects of the subsequently reduced degree of water-logging and/or the subsequently reduced presence of soluble toxic substances."

This definition is ample enough to permit the distinction of several different kinds of drainage systems (figure 3) and several desired effects (figure 4). Details about the different kinds of systems and effect are given by *Oosterbaan* (1991).

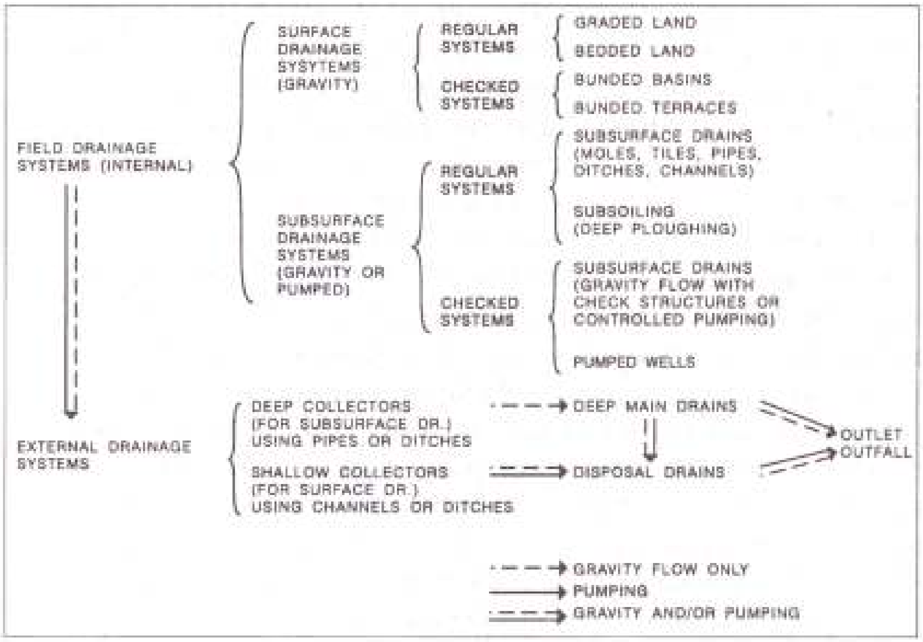


Figure 3. A classification of types of agricultural drainage systems.

## 5. Defining drainage criteria

When designing drainage systems or evaluating their performance, one needs certain drainage criteria which serve to arrive at optimal drainage systems, and to have a yardstick to judge their functioning (figure 4).

An optimal drainage system is a system that materializes the maximum possible benefits at minimum possible cost and with minim possible (environmental) damage. The maximum possible benefits will have to be related to the agricultural drainage criteria (ADC), whereas the minimum possible costs have to be related to the technical drainage criteria (TDC). Similarly, the environmental drainage criteria (EDC) have to be related to the minimum possible environmental damage.

The ADC can also be called “effectiveness criteria”, whereas the TDC can also be called “efficiency criteria”, but they are sometimes referred to as “cost-effectiveness criteria”. All three types of criteria need to be connected to the sustainability of the systems.

Limiting ourselves to the ADC, we can define them as follows:

> “Agricultural drainage criteria are criteria defining the just permissible water-levels on or in the soils to which the original water-levels are to be reduced so that the maximum possible, yet sustainable, agricultural benefits are attained”.

The drainage criteria will be different from region to region, from crop to crop, from land-use type to land-use type, and from period of time to period of time. Their role in the optimisation, design, and evaluation of agricultural drainage systems is illustrated in figure 5.

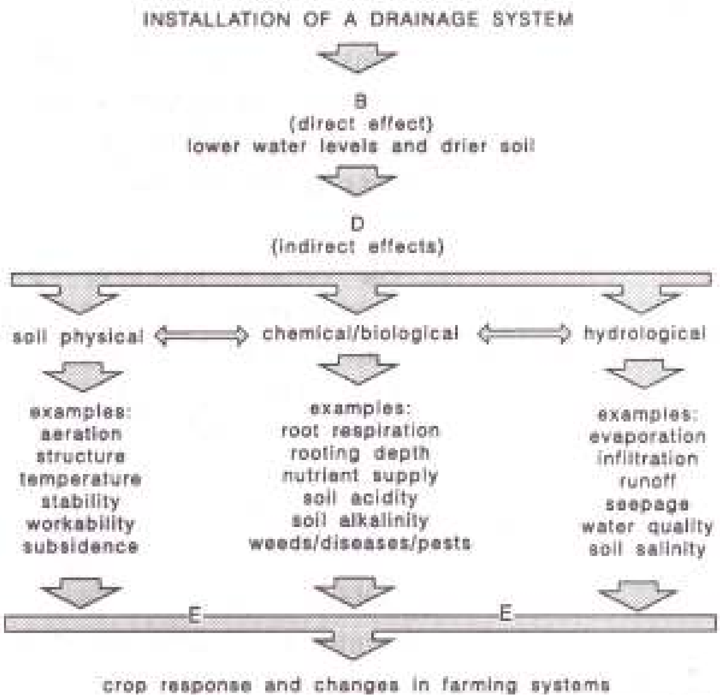


Figure 4. Diagram of the soil physical, chemical /biological and hydrological effects of agricultural land drainage systems.

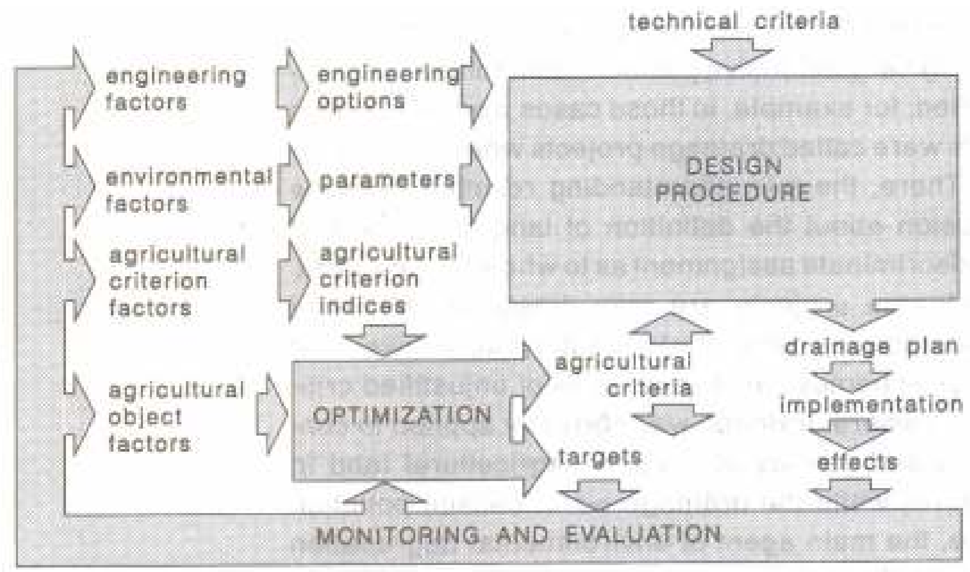


Figure 5. The role of agricultural drainage criteria in the optimisation, design, and evaluation of drainage systems.

On purpose, the definition of drainage criteria does not include the removal of water (or drainage discharge), nor the removal of dissolved substances (e.g. salts) . The reason for their omission is that the drainage discharge is entirely determined by the hydrological conditions (including the irrigation) prevailing in the area, together with the chosen water-level. In other words, there is no extra degree of freedom involved in determining the discharge; it is only a logical consequence which, nevertheless, requires much effort for its proper assessment.

## 6. Bias towards technical criteria

In many designs of drainage systems in the past, much emphasis was given to the technical drainage criteria (TDC), whereas the agricultural and environmental criteria (ADC and EDC) were relatively neglected. This frequently led to the aggressive, of the subsidized, implementation of drainage systems that were giving unsatisfactory agricultural responses and/or environmental damage, or the responses and damage were not even monitored.

Highly indicative for the lopsided attention to the technical/hydraulic aspects of the systems is the formulation of drainage criteria in terms of design discharge, speed of removal of water, water carrying capacity of the system, "drainage coefficient", drainable surplus, "drainage module", etcetera.

In some European and North American countries, the prestige and credibility of drainage engineers is declining and also their numbers are dwindling, like in The Netherlands. The drainage profession is now forced to occupy a strategically defensive position. Sometimes, the criticism is not justified, for example in those case where certain adverse projects were called drainage projects whereas actually they were not. There, the misunderstanding resulted from the babylonic confusion about the definition of land drainage and there was an indiscriminate assignment as to who was the culprit. Examples of adverse projects are over-drastic flood-control schemes or "impolderings" which unfortunately were given the name of drainage schemes. Other examples of unjustified criticism can be found where drainage was correctly applied to control water-logging and soil salinity of irrigated agricultural land in (semi)arid regions, while the drainage water caused pollution elsewhere. Here, the main agent of environmental degradation was the indiscriminate introduction of irrigation. Other forms of much criticised environmental pollution through drainage waters may have their source in the excessive application of fertilizers and/or biocides to the cropped lands, for which drainage as such bears no responsibility.

Yet, there are many instances where the introduction of drainage measures has had disappointing results. A partial explanation lies in the fact that drainage projects with embarked upon with considerable over-optimism, whereby grossly over-estimated yield predictions played their role. The opportunity for such over-enthusiastic predictions was created by drainage experiments in the laboratory, in pots and lysimeters, and in scientific experimental fields whereby external influences were carefully fenced off. The optimism was maintained by the absence of any monitoring programs in the executed projects (*Found et al.* 1976), or by suppression of the disappointing results thereof, or else the program referred mainly to the hydraulic aspects, covering the agricultural and environmental aspects to a much lesser extent. In addition, many drainage projects were implemented as an element of more encompassing (subsidized) agricultural development projects aimed at the utmost intensification and productivity of the farms. This aggressive strategy was introduced in the belief that conservability and sustainability were automatically guaranteed.

Also, especially in developing countries, many drainage projects were initiated on soft, but repayable loans from internationally operating development banks. Such loans could only be acquired when the internal rate of return of the investments was satisfactory. Internal rates of return can only be high if the investments yield quick results and high increases in production. The applied accounting (or rather discounting) method has a relatively short time horizon, beyond which the result of the project (either the positive or the negative ones) vanish. It is well documented that such procedures are conducive to both unrealistically high production estimates and irresponsibly low estimates of the costs of operation and maintenance. Further, many projects in developing countries were designed on the basis of application of high-tech materials and equipments that were not commensurate with the local handling abilities.

When projects fail to bring about the expected increases, and yet the bank loan plus interest rate has to be repaid, governments will have to adjust their budgets. This is often done at the expense of social sectors, like schooling and health care, which is not favourable at all for the nation's development.

Much of what has been said before also holds for irrigation projects (*Oosterbaan* 1989).

## 7. Cautious and restrained drainage

It would be a pity if the chances of applying potentially successful drainage undertakings are diminishing because of a poor reputation instigated by one or more of the above misconceptions. To avoid the disappointments, and to stop the reputation decline , a more cautious, modest, and defensive approach to the art and science of land drainage is required. Hereby it should be realized that drainage projects can accomplish considerable achievements in conserving agricultural lands, in improving marginal agricultural lands, and in mitigating effects of other land and water development projects., Hence land drainage should often be regarded as a preservative measure rather than as a dramatic production booster. The definition of the agricultural drainage criteria (ADC) given before cam play a key role in such an approach.

I shall now give some examples of such ADC in different geographical and environmental settings.

**Example 1. Surface drainage for sugarcane cultivation in the coastal lowlands of Guyana.**

Naraine (1990) was able to establish a critical value of the seasonal Number of days with a High Water-level in the open collector drains (NHW, above 90 cm below soil surface), by relating it to the production of sugarcane. The critical NHW value was found to be 7 days, below which the production was not affected, but above which the production showed a declining trend (figure 6).

On this basis, Naraine could determine which estates had excessive, good, and deficient drainage systems and he could recommend remedial measures where required.

This example shows a good use of the water-level (instead of the discharge flow) as a criterion for land drainage. Once this criterion is well established, the corresponding discharge can be determined by the standard hydrological procedures. The criterion is cautious and restrained in the sense that drainage measures were proposed only in a few necessary instances, while excessive drainage in some other instances was clearly earmarked.

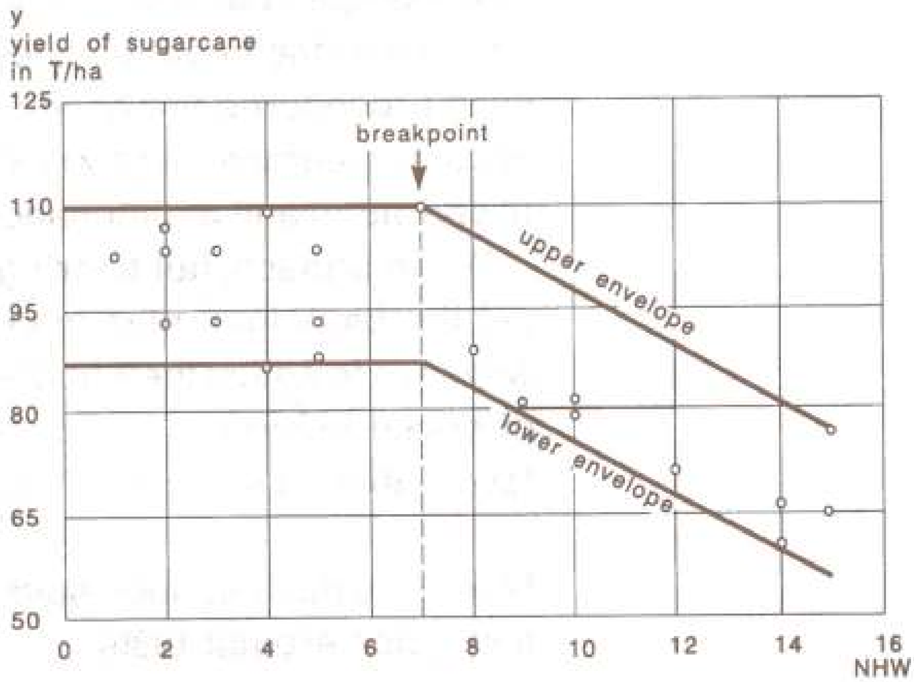


Figure 6. The yield of sugarcane versus the seasonal number of days (NHW) with a water-level in the open collector drains above a level of 90 cm below soil surface (*Naraine* 1990).

**Example 2. Subsurface drainage for water-logging and salinity control in the Nile Delta, Egypt**

On the basis of data collected in the Mashtul Pilot Area in the Nile Delta, *Oosterbaan and Abu Senna* (1990), using a hydro-salinity model, found that a modestly deep water-table (about 0.8 m as a seasonal average) is sufficient to control the soil salinity at a safe level (table 1).

More intensive drainage (i.e. by imposing deeper water-levels) would have the negative side-effects that drainage losses would be higher and irrigation efficiencies would be lower.

It has been shown (*Safwat Abdel-Dayem and Ritzema 1990*) that the seasonal average depth of 0.8 m is amply sufficient for good crop production (figure 7), even a depth of 0.5 m does not harm the yields.

Employing the 0.8 m depth as a drainage criterion, one can avoid the design of excessively intensive drainage systems. In this sense the criterion is cautious and restrained. Also the technical criteria (e.g. the optimal drain depth) can be modest (1.0 to 1.2 m).

Figure 8 shows that the level of the water-table is jot influenced by a deeper drainage system, because of the soil's decreasing hydraulic conductivity with depth.

Further, much irrigation water was saved by introducing gates into the drainage system: these gates can be closed when rice is grown in submerged fields (*Qorani et al*. 1990, table 2). Such checked (restricted) and restrained drainage systems successfully prevent excessive drainage, without negatively affecting the crop production (table 3). They merit further study to assess their applicability to areas under crops other than rice.

Table 1. The simulated effects of different values of NDR (natural drainage to the aquifer in mm/year) on several water and salt balance factors, obtained with SaltMod under the drainage conditions pertaining in the Mashtul Pilot Area prior to the installation of the new drainage system in 1980.81 (*Oosterbaan and Abu Senna* 1990)

| NDR | $SCR_{eq}$ | IR | $E_i$ | $S_i$ | DWT | DRT | CAP |
|---|---|---|---|---|---|---|---|
| | Summer season | | | | | | |
| 0 | 9.3 | 250 | 100 | 76 | 0.49 | 40 | 86 |
| 70 | 7.8 | 280 | 100 | 75 | 0.51 | 23 | 54 |
| 140 | 4.5 | 310 | 100 | 74 | 0.52 | 20 | 20 |
| 210 | 3.1 | 480 | 92 | 97 | 0.50 | 25 | 0 |
| 280 | 2.4 | 530 | 85 | 100 | 0.53 | 18 | 0 |
| | Winter season | | | | | | |
| 0 | 9.7 | 330 | 99 | 75 | 0.51 | 32 | 32 |
| 70 | 7.8 | 450 | 94 | 97 | 0.56 | 16 | 0 |
| 140 | 4.4 | 500 | 88 | 100 | 0.57 | 13 | 0 |
| 210 | 3.1 | 500 | 85 | 96 | 0.95 | 0 | 0 |
| 280 | 2.4 | 500 | 80 | 91 | 1.46 | 0 | 0 |

$SCR_{eq}$ = Equilibrium salt concentration of the soil moisture at field saturation expressed in electric conductivity (dS/m)
Note: $SCR_{eq} = 2\,EC_e$
IR = Amount of irrigation water applied to the crops other than rice in mm/season
$E_i$ = Field irrigation efficiency for crops other than rice in %
$S_i$ = Field irrigation sufficiency for crops other than rice in %
DWT = Average depth of the watertable in m
DRT = Amount of subsurface drainage water in mm/season
CAP = Amount of capillary rise in mm/season

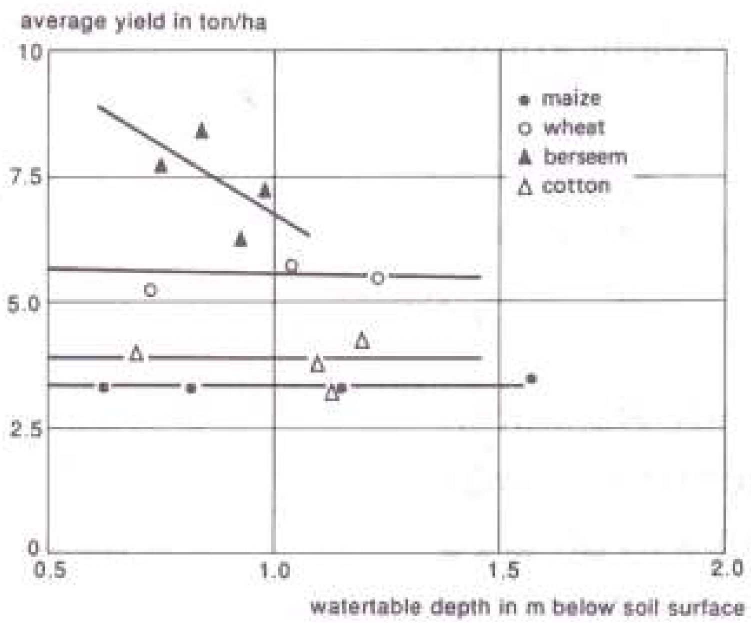


Figure 7. Yield of crops versus seasonal average depth of the water-table (ADW) in the Nile Delta, Egypt. (*Safwat Abdel Dayem* and *Ritzema* 1990)

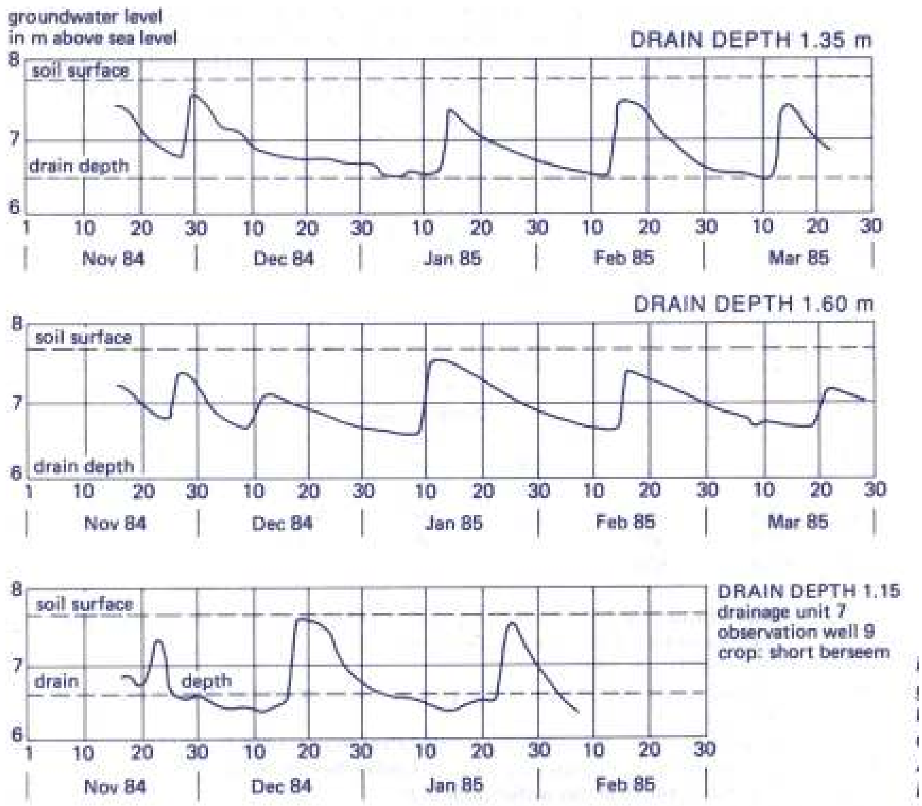


Figure 8. Hydrographs of the water-table at two different drain depths
(*Safwat Abdel Dayem and Ritzema* 1990)

Table 2. Average rate of irrigation application during main growing season in mm/day with restricted (checked) and unrestricted drainage systems, Nile Delta, Egypt (*Qorani et al*. 1990)

| Station | Drainage treatment | | Difference | |
|---|---|---|---|---|
| | Unrestricted | Restricted | Absolute | Percentage |
| King Osman | 21.8 | 13.5 | 8.3 | 38 |
| Sakha | 11.8 | 5.2 | 6.6 | 56 |
| Zankalon | 15.7 | 7.0 | 8.7 | 55 |

Table 3. Average grain yield of rice in ton/feddan (1 feddan = 0.4 ha) with restricted (checked) and unrestricted drainage systems, Nile Delta, Egypt (*Qorani et al.* 1990)

| Station | *) | Drainage treatment | | Difference | | N |
|---|---|---|---|---|---|---|
| | | Restricted | Unrestricted | Absolute | % | |
| King Osman | Ya | 2.20 | 2.10 | + 0.10 | + 5 | 10 |
| | SD | 0.15 | 0.11 | 0.19 | | |
| Sakha | Ya | 3.39 | 3.00 | + 0.39 | +12 | 10 |
| | SD | 0.17 | 0.13 | 0.21 | | |
| Zankalon | Ya | 1.84 | 2.16 | - 0.32 | -17 | 15 |
| | SD | 0.10 | 0.17 | 0.20 | | |

*) Ya = average yield
SD = standard deviation with N = number of observations

**Example 3. Subsurface drainage for water-logging and salinity control in northwest India**

In the Sampla Pilot area of the Central Soil Salinity Research Institute, Karnal, Haryana, a subsurface drainage system was laid out manually to reclaim seriously salinized soils in an area with upward seppage of salty groundwater (*Rao et al.* 1990). The system ends in a sump from which the water can be pumped into an open drain. The salty drainage water, however, is discharged only during the rainy season (monsoon period , June-September), when the rivers and canals carry a large amount of fresh water, so that the mixing of the water will do no harm. Almost all the river water (Yamuna river, a tributary of the Ganges) in that period reaches the sea (Bay of Bengal). In the dry season, when irrigation water is scarce, the salty drainage water is successfully used for irrigation. There is no danger of undue salinization of the soil when once in two or 3 years the monsoon gives sufficient rainfall to leach the soils and to evacuate the accumulated salinity.

At present, studies are underway to see how far the dry season crops can benefit directly from the upward seepage of groundwater and the subsequent capillary flow, so that pumping in the dry season is not even required.

This example illustrates that with only occasional, restrained operation of the drainage system, whereby the water-table is permitted to be as shallow as possible, a cautious drainage strategy cab be developed and savings can be made on irrigation water, operational costs and the environment.

**Example 4. Subsurface drainage for the improvement of acid-sulphate and muck (peat) soils in southwest India.**

I a poder area, 1 to 2 m below the mean seas level, in the Kerala state of India, a subsurface drainage system was installed in farmers' fields to improve acid-sulphate and muck (peat) soils . Traditionally only surface drainage is practised for this purpose. Rainfall is high (about 3000 mm/year) and there is plent of fresh water in the ring canals so that the area is maintained almost permanently under water to yield two rice crops a year, with duck rearing in between.

It was found that lowering the water-table in the month of December (a dry month) was effective in raising the crop yield from 1.5 ton/ha to about 2.5 ton/ha. The temporary lowering of the water-table permitted the acids and related toxic elements to be washed down to a deeper depth with the next flooding of the field. The lowering of the water-table in December may also have contributed to a better aeration of the soil, with a subsequent improvement of the quality of the organic matter.

A similar phenomenon is possibly occurring in the, by tradition, restrictively drained areas of Pulau Petak, south Kalimantan, Indonesia (*Oosterbaan* 1990).

In both cases, noticeable benefits are being obtained with cautious, restrained drainage, whereby negative environmental effects are minimized.

It is now under study whether it is beneficial to permit subsurface drainage to continue functioning during all the growing seasons or whether checked drainage, permitting subsurface drainage only during the dry season, deserves preference.

**Example 5. Subsurface drainage in winter for wheat production in England**

In a pilot area near Drayton, England, the summer production of winter wheat (i.e. wheat sown in the previous autumn) was measured in different fields and related to the measured average depth of the water-table in winter, because in summer there is no problem of water-logging due to higher evaporation.

The relation showed that the production only decreased when the average depth of the water-table in winter was less than about 0.5 m. If the water-table is deeper, the production was not affected (*Oosterbaan* 1991, figure 9). This indicates that it is beneficial to install a drainage system only when the average water-table is less than 0.5 m deep during winter. In other cases it is not advisable.

A suitable agricultural drainage criterion (ADC) for the design of systems in the so identified problem areas would be: the minimum permissible average water-table depth during winter is 0.5 m below the soil surface. Using this ADC, one assures that no unnecessary drainage measures are introduced, whereas the necessary measures are not over-designed: drainage measures are taken cautiously, not aggressively.

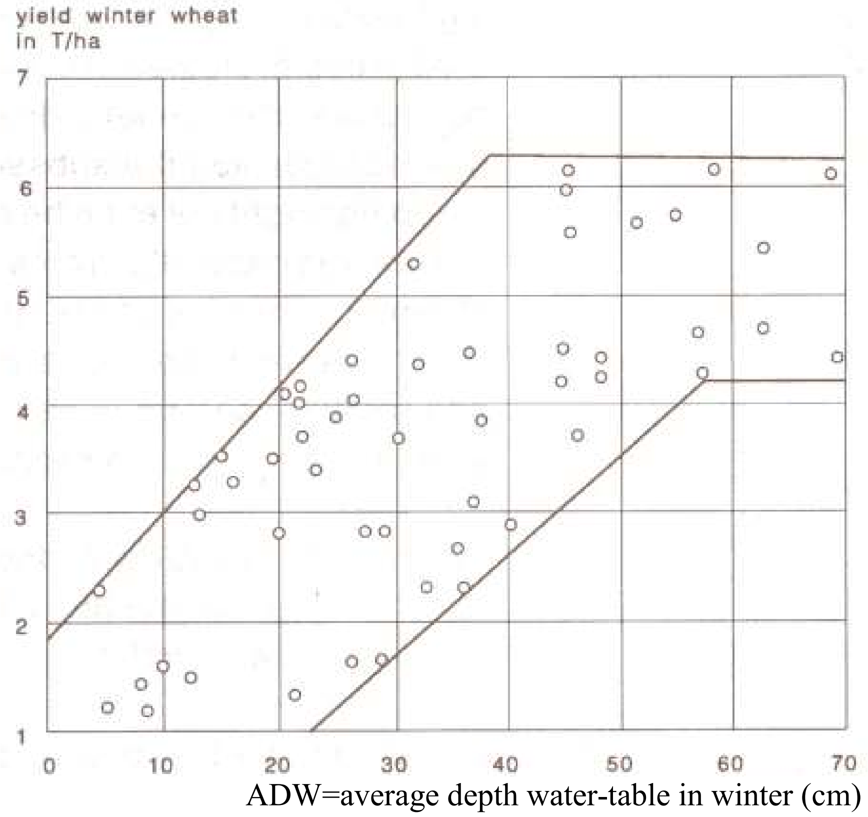


Figure 9. Yield of winter wheat versus average depth of the water table during winter, 1975 to 1980, Drayton, England (data from Field Drainage Experimental Unit, Ministry of Agriculture, UK)

## 8. Conclusion

From the previous thoughts and examples it can be concluded that modest, cautious and restrained drainage projects can be successful, provided that proper criteria are developed. These criteria can be instrumental in avoiding unnecessarily excessive drainage, as has often happened. The same criteria provide a good yardstick to measure the effectiveness of the project after its execution.

In the long run, the cautious and restrained approach may be able to restore confidence in the drainage profession. Further, it may lead to relatively cheap and simple drainage projects that can, at least partly, be implemented, operated and maintained by the farming communities themselves. Finally it may lead to the wider application of drainage systems than hitherto, especially in developing countries.

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