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CONTROLLED DRAINAGE FOR INTEGRATED WATER MANAGEMENT[1]

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ABSTRACT

Controlled drainage is an essential component of Integrated Water Resource Management (IWRM) and Water Demand Management (WDM). Controlled drainage can play an important role to save water and nutrients and to improve and optimise downstream water availability and quality. Examples of controlled drainage practices in the Netherlands, USA, Egypt and brief references to work in other countries are given. Shifts in priorities of different aspects of water management take place. These shifts in paradigms to "do not drain unless absolutely necessary", controlled drainage, and "give room to flood waters" (controlled flooding) are described. In the Netherlands, the new water management tool Waternood emphasises the relation between land functions and water management and aims at managing conflicting objectives. The impact of agricultural water management on nature and the use of Best Management Principles (BMP) to control downstream impacts are described. In the USA, sub-irrigation is also a component of BMP and controlled drainage. The options, advantages and constraints of controlled drainage are given, while on-going activities in the field are presented.

Keywords: Controlled Drainage, Best Management Principles, BMP, Integrated Water Management, Water Exploitation Index, WEI, EU Water Framework Directive. European Environmental Agency, EEA.

1 INTRODUCTION

Controlled drainage has been practiced for many years, but may not always have been referred to as "controlled drainage". It is the principle of restricting free flow from drains, such that they only discharge when it is necessary, based on pre-determined water management criteria. In temperate climates drainage is primarily a function of rainfall, while in arid and semi-arid climates drainage is a function of irrigation and (monsoon) rainfall. Controlled drainage applies to both surface and subsurface drainage. On a larger scale (river basins) flood control is also an essential aspect of drainage. In dry years we often wish we had not drained so efficiently. Recently also the water requirements of nature, both in quantity and quality have become focus of attention. UNESCO and FAO are much concerned about a looming water crisis. Is there one or not? This and the role of drainage for Integrated Water Resources Management will be described in this paper.

1.1 Agricultural production and drainage

Good water management in the broadest sense is critical for the global food production. A well-designed drainage system is often a necessary component of the overall water management system, which enhances agricultural production and leads to reduction of negative environmental impacts. Drainage systems are applied in 15% of the world agricultural lands. Forty percent (40%) of the world food production is achieved in irrigated areas and in about a quarter of these areas man-made drainage has been installed. Irrigated crop production needs to increase by more than 80% by 2030 to meet future demand of food in developing countries (Fresco 2002). This cannot be met by an increase of 80% in the water supply, and hence other methodologies such as (genetic) improvements of crops, and more efficient water use (more crop per drop), will have to be developed. Sixty percent (60%) of the food production takes place in rain fed areas. In order to supply the increasing world population, increase of food production needs to be achieved primarily on the existing agricultural lands. Currently agriculture takes a share of about 70-80% of global freshwater use. Due to increased pressure on the (scarce) water resources, other potential users will critically consider this large share of water used by the agricultural sector. It is estimated that only 12% more water can be made available by 2030 (Fresco 2002). New and innovative water management tools offer considerable scope for the

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reduction of water use in agriculture. Integrated water management as mentioned in the Fourth National Policy Document on Water Management of the Netherlands[4], as well as, in numerous other international water policy documents, is aimed at balancing human, agricultural, environmental and industrial needs, and has, therefore, a wide scope of applicability in the world.

Controlled drainage or sub irrigation through sub-surface drains has been advocated for many years in North America. Yet, design criteria or guidelines are scant. The ASA Agricultural Drainage Monograph, devotes various chapters to water table management and controlled drainage, but limits the descriptions to general considerations. Although the text gives a very thorough description of the topic, emphasis is on computer modelling and few practical experiences are reported. Most other literature also assumes sizeable farms, sizeable drainage and irrigation systems, and seems to ignore the needs of small farmers in developing countries and the potential role of water user groups in the planning, design and management of controlled drainage. Anticipated or actual water shortages in irrigated areas, or regions with a rainfall deficit, can be a major incentive for farmers and policy makers/executives to apply or stimulate controlled drainage. Unfortunately most existing drainage and irrigation systems are not designed for integrated management of irrigation and drainage waters. Drainage systems should be designed and built with additional water table control options built-in. This should already be planned during design stages of the irrigation or the drainage system. Practical drainage operation guidelines for small farmers in developing countries are required.

1.2 Water Scarcity, Water Savings, and Water Exploitation Index

Integrated Water Resources Management (IWRM) is a process that promotes the coordinated development and management of water, land and related resources, to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Drainage is a vital link in water management to secure adequate food production for the anticipated growth in world population.

In Europe and the Netherlands the concept of Water Demand Management (WDM) is often used, referring to managing the water demands for agriculture, industry, urban areas, households and tourism. Water demand management generally refers to initiatives aiming at satisfying existing needs for water with fewer resources (more efficient water use). The European Environmental Agency defines water demand management as the implementation of policies or measures, which serve to control or influence the amount of water used (EEA 2001). Water demand management seeks the right balance between the demand- and supply-side options (EEA 1999).

Although drinking water is a ready to use product and may be costly to produce if extensive treatment is required, leakage reduction is not always economically viable (EEA 2001). Guidelines for the state of water losses/efficiencies are shown in Table 1. Typical domestic use in Europe based on the UK, Finland, Switzerland (EEA 2001) and the Netherlands (Brouwer 2000) is shown in
Figure 1. Water use for human consumption is surprisingly low. Research and development in the urban water use appliances has led to substantial reduction of water use by washing machines in Europe (Figure 2). Similar achievements with toilet flushing systems are reported. Efficiencies in agricultural water use (Figure 3) show that there may be ample scope for improvement of water use efficiency in the agricultural settings. It is expected that a major portion of the increase in water use will occur in urban areas (Figure 4).

Table 1 Benchmarks for drinking water distribution efficiency.

Type of network	Bad (%)	Insufficient (%)	Average (%)	Good (%)
Urban	< 60	60 – 75	75 – 85	> 85
Intermediate	< 55	55 – 70	70 – 80	> 80
Rural	< 50	50 – 65	65 – 75	> 75

[4] 4e nota Waterhuishouding.

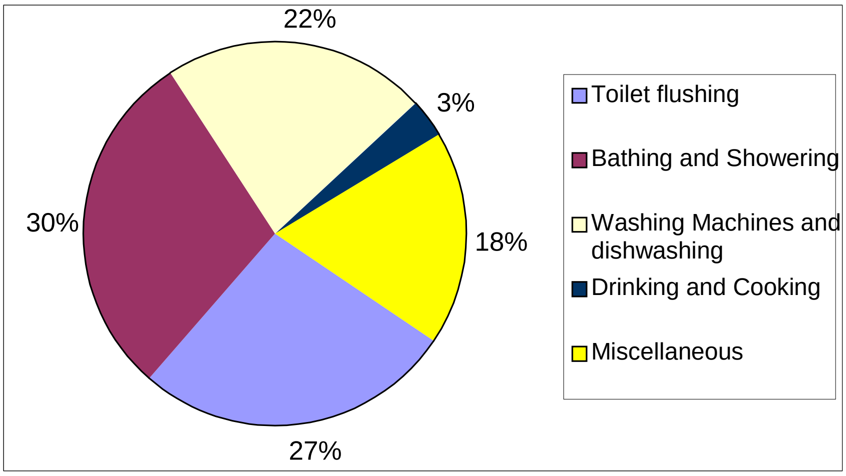

Figure 1 Average household water use in Europe.

A major development in IWRM and WDM is the awareness that the environment is not just another water user, which needs to be given its fair share. Much more, ecologically sound water systems are now considered essential for the survival of the very resource: without them there will soon be not enough water to satisfy the demands of all users. Within the agricultural context, there is another aspect that needs to be considered: the sustainability of the land resource. Drainage plays an essential role in reducing and managing waterlogging and salinity, thereby avoiding the degradation of the production potential of the land resource. Controlling drainage and thereby controlling water quality and quantity is essential for sound environmental management and crop production. Recently drainage has become an integral part of Best Management Practices (BMP), which aims at minimizing agricultural inputs to control environmental impact beyond the point of application and yet achieving optimal crop production.

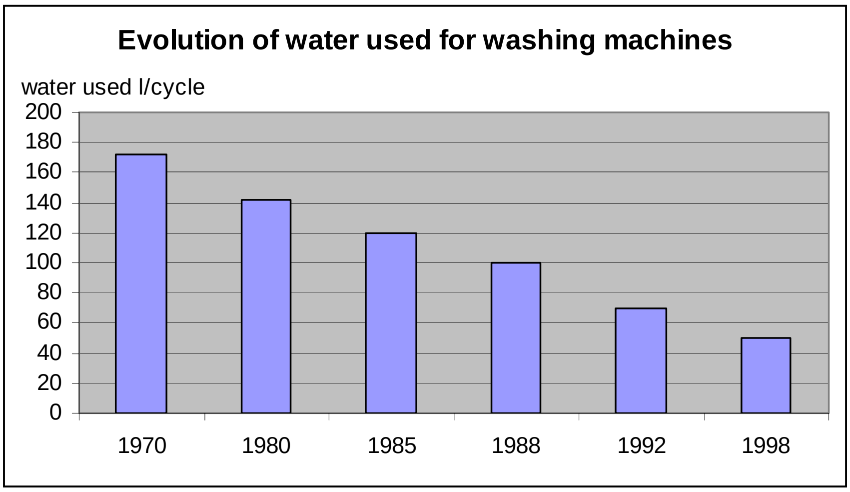

Figure 2 Evolution of water savings with washing machines (EEA 2001).

In addition, the pressure on water systems is continuously increasing and the allocation of the scarce resource becomes more and more subject to priorities that need to be balanced. Often, more interests than (traditionally) agriculture put a claim on the water. Water management has thus become more politicised and more comprehensive, including water quality, groundwater and, sometimes, soil moisture.

Progress is being made in improving the quality and quantity of Europe 's water resources, particularly in the European Union. Much of this improvement has been made through measures aimed at reducing the pressures on Europe 's water from households and industry, often introduced through European policy initiatives. However, many of Europe 's groundwater bodies, rivers, lakes, estuaries, and coastal and marine waters are still significantly impacted by human activities. For example,

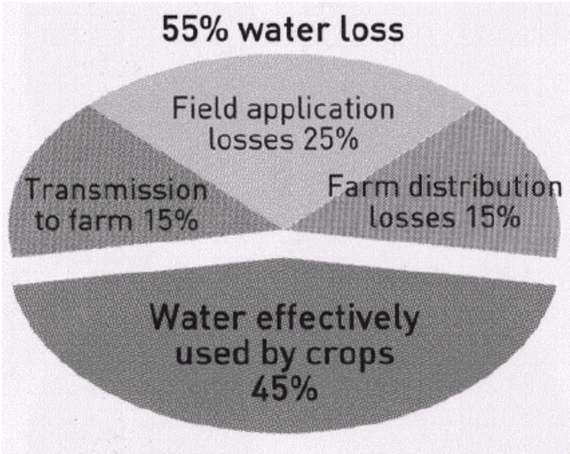

Figure 3 *Average (global) efficiencies of agricultural water distribution (Source UNESCO website)*

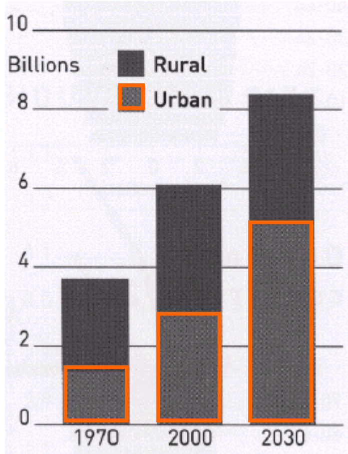

Figure 4 *Competition for water: rural and urban uses predicted (Source: UNESCO website).*

pollutant concentrations remain above, and water levels below, natural or sustainable levels. In many parts of Europe this leads to a degradation of aquatic ecosystems and dependent terrestrial ecosystems such as wetlands, and to drinking and bathing water that sometimes does not comply with human health standards.

The EU water framework directive represents a major advance in European policy with the concepts of ecological status and water management at the river basin level being included in a legislative framework for the first time. Ecological status must include an assessment of the biological communities, habitat and hydrological characteristics of water bodies as well as the traditional physic-chemical determinants. For the first time, measures will have to be targeted at maintaining sustainable water levels and flows and at maintaining and restoring riparian habitats. To quantify the needs of water for all the EEA (2003) uses the Water Exploitation Index (WEI). The WEI in a country is the average annual total abstraction of freshwater divided by the long-term average fresh water resources. It gives an indication of how the total water demand puts pressure on the water resource. The WEI identifies those countries that have high demand in relation to their resources and therefore are prone to suffer problems of water stress. It should be underlined that it is an indicator of the average water stress in a country and thus can hide considerable regional differences within a country.

A total of 20 countries (50 %of Europe 's population) can be considered as non-stressed (Figure 5), mainly situated in central and northern Europe. Nine countries can be considered as having low water stress (32 %of Europe 's population). These include Romania, Belgium, Denmark and southern countries (Greece, Turkey and Portugal). Finally, there are four countries (Cyprus, Malta, Italy and Spain), which are considered to be water stressed (18 %of population in the study region). Water stressed countries can face the problem of groundwater over-abstractions and resulting water table depletion and salt-water intrusion in coastal aquifers.

A major new component in the water balance identified by EEA (2003) is the use of water for energy cooling. This water is extracted temporarily from the system and returned at a higher temperature for use downstream. During exceptionally warm seasons, e.g. the summer of 2003, power plants have difficulties in maintaining the temperature of the disposal water below the maximum temperatures prescribed by EU Directives. Not enough cooling water was available and energy production had to be reduced in order to not affect aquatic life in the already much warmer surface waters.

2 WATER TABLE CONTROL IN THE NETHERLANDS

For hundreds of years the Dutch Water Boards, Provinces and Municipalities were principally responsible for flood control, drainage and creating liveable conditions in the country. It was only in the past two decades that water quality became an important issue in water management. The deteriorating surface water quality was imposing a threat not only to public health but also to wildlife habitats. Since the late nineteen sixties, the problem of surface water pollution was systematically dealt with. Besides Water Boards, now also Sewage Water Treatments Boards were established that were principally responsible for the purification of water. This meant that quantitative and qualitative water management were addressed by different organisations.

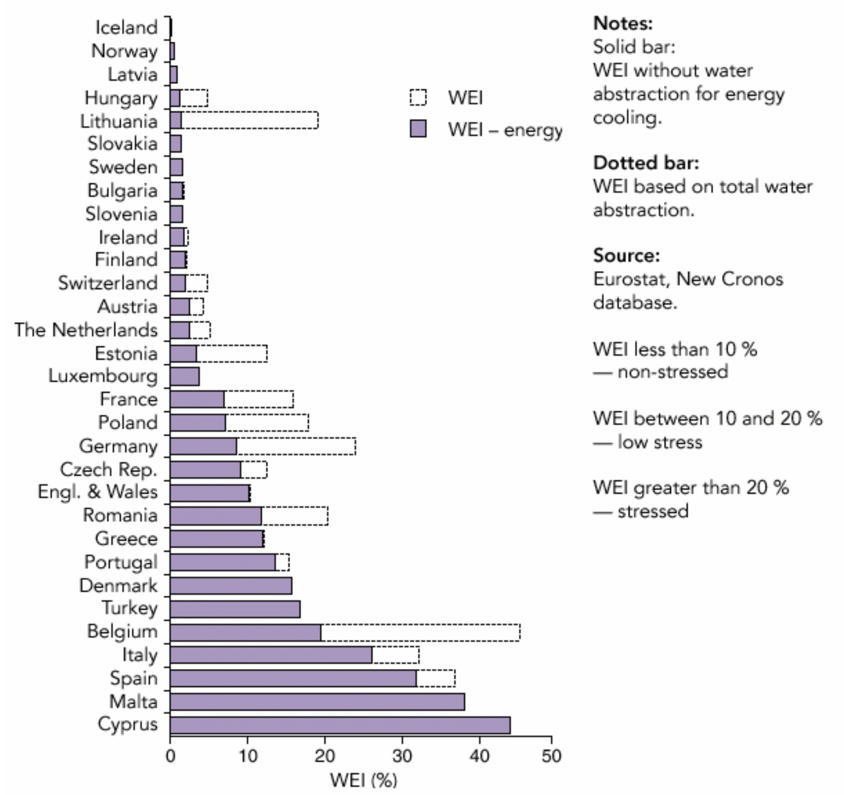

Figure 5 Water exploitation index (WEI) across Europe (EEA 2003).

In the mid-nineteen eighties, there was a growing awareness that public (water) safety and optimal living conditions could not be viewed in isolation from that of healthy and sustainable water systems and that an integrated approach in water management would be more effective, which would then also include other relevant areas of policy.

An additional factor that started becoming an important consideration was the drying out of topographically higher (light textured) soils, primarily affecting natural areas. The area affected by this drying out was approximately 5000 km^2 or about 1/8th of the Netherlands. Although the rivers entering the Netherlands have ample fresh water supplies and there is no shortage of drainage water (generally), importing water in natural habitats proved to be not appropriate due to differences in the chemical composition of the water. The most valuable ecosystems depend on clean (nutrient free) water from (deep) ground water systems, while surface water is often nutrient rich. Hence water needed to be conserved and managed in the area itself. For this purpose controlled drainage amongst and other measures were introduced.

Another trend emerging was to not separate surface water and ground water in water management, and to also consider functionality of the area (nature reserve, industrial, urban, etc). This is described as the area function in the Netherlands. Water Boards were primarily responsible for surface waters and they now also have to deal with ground water, both quantity and quality. The water system became an important concept in regional planning. The water system is the starting point for operational water management.

In 1998, the Dutch national Union of Water Boards, together with the Government Service for Land and Water Management (DLG) decided to develop and apply a common methodology for the design of water management infrastructure and measures to implement regional water management. This methodology is referred to as “Waternood” (see Box 1). Waternood is not so much concerned about design criteria or specific safety features but considers the most appropriate water regime during the year in an area as function of its land use and soil. Regimes are determined for appropriate water management units.

Box 1 Some Dutch expressions and translations

Name	Dutch description	English Translation
WaterNood	WAtersysteemgericht NOrmeren, Ontwerpen en Dimensioneren.	Water system oriented designing and standardisation of water management systems
GGOR	Gewenst Grond- en Oppervlaktewater Regime	Desired *(or target)* Ground- and Surface water Regime (DGSR)
OGOR	Optimaal Grond- en Oppervlaktewater Regime	Optimal Ground- and Surface water Regime (OGSR)
AGOR	Actueel Grond- en Oppervlaktewater Regime	Actual Ground- and Surface water Regime (AGSR)
VGOR	Verwacht Grond- en Oppervlaktewater Regime	Expected Ground- and Surface water Regime (EGSR)

2.1 Optimum and target ground- and surface water regime

Waternood aims at identifying the various area functions and soil types within a water management unit. For each combination (of area function and soil), the optimum hydrological regime is determined. This regime is referred to as “Optimum Ground- and Surface Water Regime”. Given the usual spatial variability of area functions and soils, the optimum ground- and surface water regime will vary within each water management unit.

This optimum ground- and surface water regime will, generally, not concur with the actual ground- and surface water regime. By means of an appraisal procedure (Figure 6), the desired or target ground- and surface water regime is determined.

Drainage systems are, generally, one of the most determining factors in terms of water table control and impacts on the groundwater regime. In the past, (rural) drainage systems were principally aimed at the optimum groundwater regime (soil moisture conditions) for agriculture. The target (ground) water regimes are, however, the result of a much broader appraisal of area functions. The management of existing drainage systems should, therefore, be adapted accordingly, and remodelling of drainage infrastructure may be required. Being such a determining factor for the water regime, existing and future drainage systems should be (re)designed as “controlled drainage systems”, which can serve as effective tools to establish and maintain target ground- and surface water regimes and allow for active intervention in water management.

2.2 Implementation of water management tool

The methodology, aimed at determining, establishing and sustaining target ground- and surface water regimes, does not only require other concepts of thinking on water management, but also more knowledge of the respective areas, geo-historical information and knowledge of the evaluation methods. For these reasons, a research programme has been implemented to provide the tools to determine the target ground- and surface water regime for a given area and to assist in the development and management of the water systems. The research programme will be concluded in 2002. Box 2 presents the various research topics. The result of the individual research activities will be disseminated as guidelines and computer applications. The research results will be integrated into the Waternood "tool", which includes a computer application running in a GIS environment.

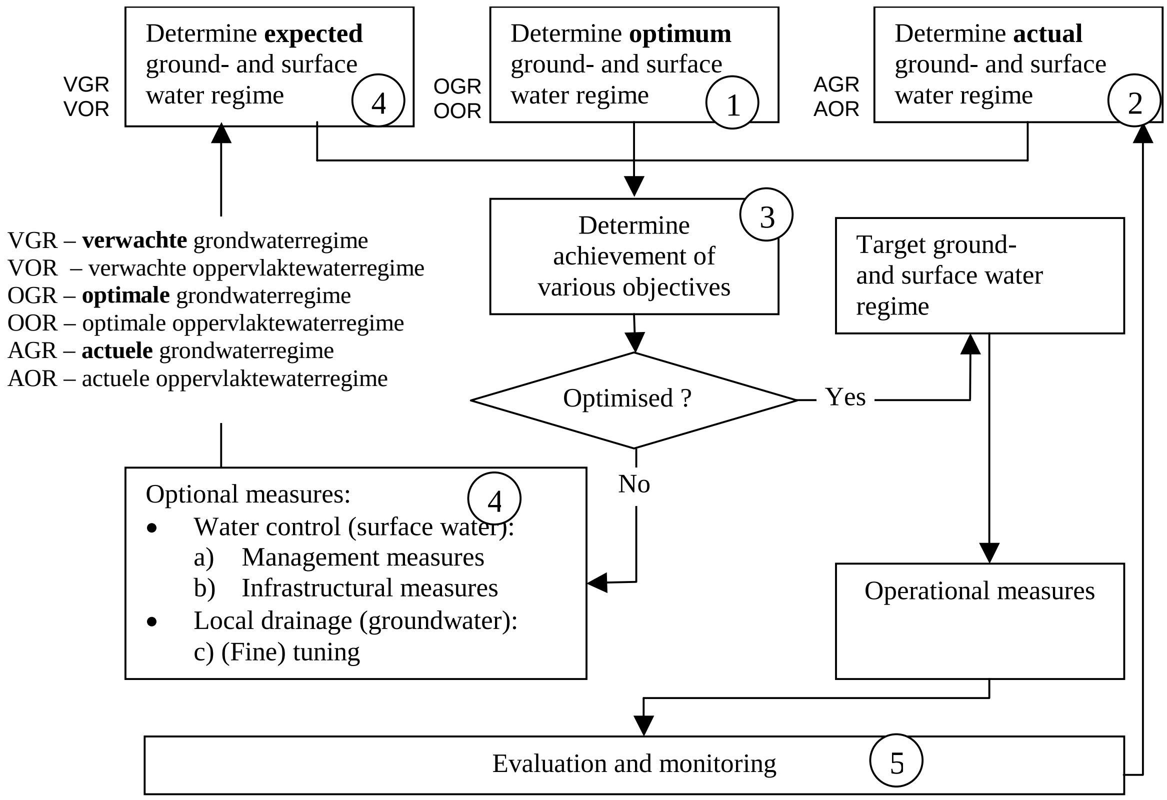

Figure 6 Waternood process

To judge whether a system has been optimised according the process depicted in Figure 6 the following criteria are used for each unit (Prak 2002, Figure 7):

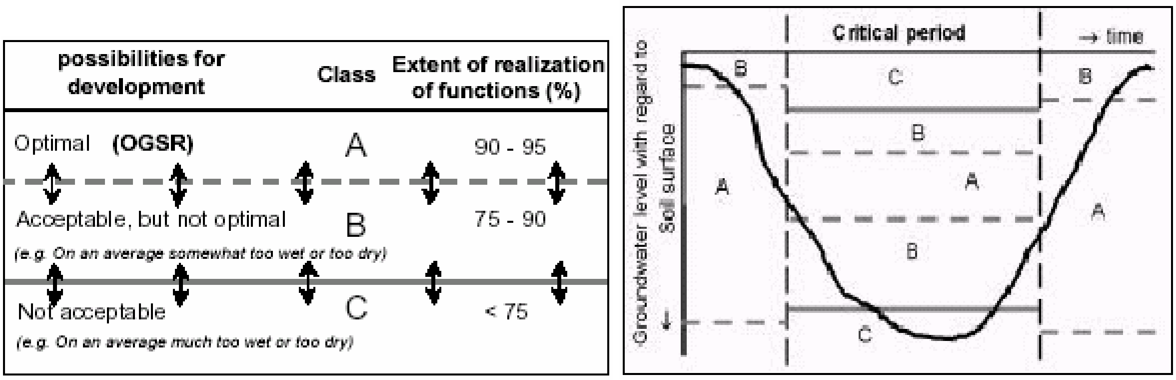

Figure 7 Classes and example of realisation of classes (Prak 2002).

A Optimal sustainable functionality in 90 – 95% of the area
B Acceptable but not optimal in 75 – 90% of the area (e.g. on average somewhat too wet or too dry);
C Not acceptable (and therefore not sustainable) situation in less than 75% of the area.

The objectives are to balance agricultural, nature and flood control needs and balance the expected damage (weighing of different damage functions). Note that in this process no mention is made of the water level because some need it dry, others wet. Yet, the water level in time and space determines in which class the area will fall as far as compliance with the objective functions of the area (Figure 7).

In time the water table may fluctuate as shown in Figure 7 but the optimal water level may not be the same in each period. Figure 7 shows typically a present state, where optimal ground water regimes have been determined, the actual ground (and surface) water is know, and where through appropriate measures the optimal ground water regime needs to be achieved as closely as possible. Hence, in the same area, the class allocation can differ. Details of this elaborate assessment system are not yet published, but are expected towards the end of 2002.

Box 2 Research topics of Waternood

Research activities for water management tool Waternood:

- Waternood toolkit
- Relation Ground- and Surface Water (Drainage Resistances)
- OGOR terrestrial nature and function appraisal
- HELP-tool agriculture (quantification of yield reductions)
- Water quality
- Aquatic ecology
- Communication
- Maintenance strategies
- Example book Waternood
- Monitoring networks
- Extremes
- Precipitation characteristics

2.3 Drainage

As drainage determines to a large extent the groundwater conditions, special attention should be paid to the proper quantification of the relationship between drainage systems and the groundwater regime.

One of the topics of the research programme is the relation between groundwater and surface water. This relationship is described with the concept of drainage resistance, assuming linear relationships between groundwater levels and surface water discharge. This concept does not make a distinction between natural and man-made drainage and also does not provide (direct) design guidelines. However, links with design aspects of main watercourses (geometry) have also been investigated.

The research programme assists in the quantification of the drainage resistances of existing systems, for various conditions, and impacts of future scenarios. Additional investigations are required to establish the relationship between a future “target” drainage resistance and the actual design of a (controlled) drainage system, which would incorporate the layout, drain depth, spacing, diameter or perimeter, structures, etc. In the case that (some of) the above-described water management practises be followed in countries or areas where new drainage systems are to be implemented, this is a possible research topic for Alterra-ILRI.

Methods to quantify surface water discharges as a function of the groundwater levels are based on existing data (principally a statistical analysis) or area information. For this purpose a GIS environment is used. The methodology developed allows for the calculation of drainage resistances for various groundwater depth intervals (classes, see Figure 7). Also lumped values can be calculated (for a certain “homogeneous sub-area"). This results in the spatially variable characterisation of drainage systems. Once the drainage resistances have been quantified, various water management scenarios can be evaluated.

2.4 The role of controlled drainage

Controlled drainage is, often, an important water management tool for existing water systems. Design and operational parameters of controlled drainage refer both to infrastructure as well as to operational practises. For example, decisions must be made on the locations, sizes and type(s) of weirs, the weir levels and weir operation (incorporating seasonal target levels, response policies to rainfall events, dry periods, pollution loads, etc.). Discharge control infrastructure (such as drain outlets) and its operation should also be taken into account. Thereupon an assessment must be made of the intended measures, in terms of the expected ground- and surface water regime.

The assessment should address groundwater levels and soil water contents (both a function of time and space), as well as quality aspects such as the composition of the ground- and surface water, the discharge of nutrients, salts and pesticides from the land, etc. With the terrestrial nature and function appraisal, the agricultural yield reductions and information from the aquatic ecology, it should be assessed whether the expected ground- and surface water regime represents the optimum for the distinctive area functions. Should this not be the case, modified measures should be evaluated, etc, until the required ground- and surface water regime is established.

2.5 Area functions and required water management

The optimum ground- and surface water regime for agricultural area functions is, generally, much better known than for nature or specific ecological functions. The research programme, therefore, also includes the requirements in terms of the hydrological regime for (terrestrial) nature.

Although the research is aimed at The Netherlands, the methodology may also be applied in other countries. It is also noted, that in various countries, for example South Africa, valuable information on water quality requirements of aquatic ecosystems has already been investigated and is applied in operational water management (DWAF 1996).

2.6 Appraisal of area functions

The target ground- and surface water regime must be determined from the optimum ground- and surface water regimes with respect to each area function. In conflicting situations, a balancing of interests is required. As the required water regimes for the distinctive area functions are often conflicting (for example agriculture and wetlands), a scientifically robust assessment and optimisation method should be used. Such a methodology, in which the various requirements are appraised and balanced, is currently being developed.

2.7 Determination of adverse impacts on agriculture

As the target ground- and surface water regime for any area function may deviate from the optimum hydrological regime, the negative impacts should be quantified (Figure 6). This will allow for the allocation of any indemnities to affected parties. In The Netherlands, existing relationships between crop growth reductions and excessive or deficient soil water conditions are being (re)evaluated and incorporated in a GIS environment. The relationship between the crop yield and water regime are usually described by (Van Bakel and Huygen, 2001):

1. the yield versus groundwater depth relationships;
2. the HELP-method;
3. the SOW method;
4. the Regime curve method;
5. the Water table versus time method; and,
6. deterministic methods.

The first method was developed in the nineteen fifties, but can still be used. Limitations are that trafficability and other operational aspects were not included. The method evaluates both wet and dry conditions.

The HELP-method uses soil types and groundwater depth classes. For 70 soil types the yield reductions due to excessive and deficient soil water conditions can be assessed for grass and other cropland[5]. The method is currently adapted and incorporated in the Waternood tool. As groundwater depth classes refer to an average situation, no information can be obtained on yield reductions in specific (or extreme) years or the period in the year in which the reduction occurs. In addition, the assessment of damage due to wet conditions is often tentative.

The SOW-method uses the concepts "Sum of Excessive Water" and "Sum of Deficient Water". This method compares the actual groundwater tables with the critical groundwater tables for excessive and deficient soil water conditions. The groundwater regime should, therefore, be known, as well as relations between SOW and actual damage (yield reductions). The SOW-method allows for the evaluation of individual years and periods within a year. A disadvantage is that critical groundwater depths and damage coefficients are only known for a few soil types. In the USA an approached based on the original SOW of the Netherlands is used and referred to as SEW_{30} (Sum of Excess Water, Skaggs and van Schilfgaarde, 1999). The 30 denotes the target water table depth below the surface and can be any depth.

[5] In the Netherlands it is customary to distinguish grassland or pastures as a separate main crop in many technical statistical and economic analyses. All other crops are then taken together under cropland (“bouwland” in Dutch).

The regime curve method calculates the average groundwater tables (regime) during the year. The method requires at least 8 measurements per monitoring date (hence at least 8 years of monitoring). Reliability intervals of the groundwater regime are then calculated. For various periods during the year, critical groundwater tables for excessive and deficient soil water conditions can be defined. The method allows for the assessment of the probability of damage.

The "Water table versus time" and deterministic methods are under development not yet operational in The Netherlands.

The data acquired in The Netherlands is, most probably, not applicable abroad, given the specific climatic condition, soil characteristics and groundwater monitoring/evaluation practises. The developed methodologies of assessment may, however, be used and applied. In principle, similar relationships of adverse impacts should be determined for other area functions, but these data is much scarcer.

Methods for relating crop response to excess soil water.
Agronomy Monograph No 38 (Skaggs and van Schilfgaarde 1999):

- Stress Day Index Approach
- Stress Day Factor (incl. SOW and SEW)
- Crop Susceptibility Factor

ILRI Publication 16 (Ritzema 1994):

- Depth of WT at harvest time
- Average seasonal WT depth with rainfall excess
- Average WT depth during irrigation season
- SEW_{xx}, SOW_{xx}

FAO I&D Paper no 33 (Doorenbos et al. 1979

- ET_{max}/ET_{act}, and yield response factor

2.8 Monitoring

Integrated water management requires effective monitoring, in order to investigate and characterise the hydrological systems, to collect data necessary for the daily operations and to evaluate plans and measures. Guidelines to set up monitoring systems for water management have been developed in The Netherlands and can, most probably, be applied abroad (possibly with some minor adaptations).
The monitoring system should prescribe the parameters to be monitored (qualitative and quantitative), locations, frequencies and data processing. In the case of controlled drainage systems specific performance monitoring may also need to be included.

3 WATER TABLE CONTROL AND BEST MANAGEMENT PRACTICES IN THE USA

The prime reasons for water table management from a drainage perspective is the removal of excess water to permit farming on poorly drained soils. This includes improving trafficability during certain times of the growing season (especially planting and harvesting time). Salinity control is another typical drainage objective. In irrigated areas, the amount of irrigation is of paramount importance for control of salinity in the root zone. This is slightly different in coastal zones, where salinity is caused by seepage/intrusion of seawater.

An extension of controlled drainage is the use of the drainage system for sub-irrigation. This was first reported in 1956 when experiences with sub-irrigation in California, Idaho, Utah and Colorado were described (Skaggs, 1999). The drainage system water level is controlled by a weir or gate. Water may be pumped into the drainage system through the manholes or in the open drain beyond the subsurface outlet. The weir that controls the water level is usually in the open drain. Early experiences with sub-irrigation are on the lighter textured soils. It was found that sub-irrigation requires only 5 – 25% of the energy required by sprinkler irrigation. Actual water savings have not been reported, as they vary widely based on the sophistication of local water management practices. Skaggs (1999) gives a thorough review of the state of the art of sub-irrigation in the US, while Fouss et al. (1999a&b) also describe the design and operational features and facilities required for water table management. Controlled drainage and sub-irrigation are seen as integrated water table management in the USA. Approximately 10% of cropland in the USA that has potential for controlled drainage is actually provided with a water table management system.

Controlled drainage is also applied at watershed scale, and this involves allowing drainage from the upper reaches of the watershed to supply the lower part of the watershed (Parsons et al. 1991 in Skaggs 1999). It has, in many cases, greater potential than it does on a field scale (Evans et al. 1992).

In areas where deep drainage outlets have been constructed to provide drainage to the lowest elevations in the watershed, excessive drainage (or over drainage) of the higher elevation areas is typically the result. Over drainage frequently occurs in soils with higher permeability and low water holding capacity. In the Netherlands the drying out of forest and nature areas in the topographically higher portions of the Netherlands is also a typical example of this.

Another interesting development of controlled drainage, which applies both to field level and watershed level is the reuse of drainage water in a serial fashion. This practice is relatively advanced in the USA (FAO 1996) and Australia (Christen 2001) and was recently further discussed under the topic Bio-Drainage at the 8th International Drainage Workshop in New Delhi, India (ICID 2000).

Controlled drainage has been applied to conserve water and increase crop yield. It is also effective in reducing losses of plant nutrients and other pollutants to surface waters. It is currently promoted for the latter, in nutrient sensitive coastal areas. It is essential in the prevention of blue-green algae blooms in the USA (Evans et al. 1996) and Australia in the Murray Darling basin (MDBC 1995). Historically it is also used to control subsidence in peat (organic) soils, such as the Everglades in Florida, Western Johor in Malaysia, Indonesia and the Netherlands. Controlled drainage allows management of deficit and excessive soil water stress, and allows tillage and other field operations. Besides all the advantage some disadvantages need to be considered as well. These potentially are: deterioration of soil structure around pipe drains due to long submergence; biological clogging, ochre formation in iron laden waters, and sloughing of ditch banks.

Controlled drainage is considered one of the components of Best Management Practices (BMP) in the USA (Evans et al. 1996). Turning point in many of the measures that stimulate BMP is the 1985 Food Security Act that imposes considerable restrictions on land development and drainage. This Act seemed to have had similar effects on surface water quality as the 1970 Pollution of Surface Water Act (de Jong 2001) in the Netherlands had, which stimulated a major clean up of the water quality of surface waters. BMPs as promoted by the 1985 Act typically benefit the environment only. Controlled drainage was proven to benefit both agriculture and the environment. Since Controlled drainage, as part of Water Table Management was designated as a BMP it qualified for state and federal support, and in July 1989, more than 2 500 control structures have been installed in North Caroline alone (Evans et al. 1996). For BMP in Australia see Christen and Ayers (2001).

4 CONTROLLED DRAINAGE IN EGYPT

Water scarcity will become a major concern in the first half of the 21st century in Egypt. Already during the early eighties the Drainage Research Institute (DRI) in El Kanater, Egypt, introduced modified drainage for rice areas in the Nile Delta (Box 3). This meant that sections of the drainage system (3 – 20 ha) could be closed during the rice season. Water savings of up to 50% were possible depending on local conditions. Farmers saved considerable time irrigating (at least one irrigation less of a total of 4 –5 per rice growing season). Direct pumping costs were reduced by as much as 43% of total seasonal pumping costs (DRP/DRI 2001). The farmers recovered investment in control structures in the subsurface drainage system in one to two seasons. The approach requires crop consolidation in the sub-catchments of the drainage system, adjustments in the traditional drainage design (more sub-collectors), willingness of farmers to consolidate, and passing on of the savings to the farmers by water user associations. In 1995 DRI re-introduced modified drainage as controlled drainage, through traditional field trials, new Participatory Rural Appraisal techniques, and by advertising the opportunities with all stakeholders. Controlled drainage is not only important to reduce water use during the rice-growing season, but will become an essential water management tool during water scarce situations for all crops.

Box 3 From modified drainage to controlled drainage in Egypt.

•1977-1979	Experiments with water management in rice fields
•1980-1988	Testing of the modified drainage concept in experimental fields and pilot areas Nashart, Roda and Mashtul
•1992	Crop liberalisation
•Since 1992	Encouraging of farmers involvement in on-farm water management.
•1996	Controlled drainage study using Collector User Groups
•1997	Controlled drainage study using Water User Associations
•1998	Controlled drainage study using key-persons (influential people in the village
•October 1998	Land tenure liberalisation
•April 1999	Workshop was held to present the results of controlled drainage.
•2000	Multi-disciplinary team to apply the controlled drainage on a large scale
•2001	Final report DRP and DRP2 with guidelines for controlled drainage (DRP/DRI 2001)

The principle of the system is shown in Figure 8. By providing subsurface sub-collectors and connecting these via manholes, and fitting the outlets in the manhole with simple locally produced gates, it is possible to drain the field with a non-rice crop and stopping discharge from the field with rice. The method requires more drainpipes, and it was calculated that the construction costs of a system with additional sub-collectors, manholes etc. would cost 16 - 25% more per hectare. Although this is a substantial increase, it actually only increased the cost component of the farmers seasonal budget by 5 – 10%. No detailed calculations of cost recovery of a system constructed completely as a controlled drainage system have been made yet, but the costs of installing gates in existing systems was recovered in one to two seasons. For primarily maintenance reasons, and reducing risk of area affected when a collector fails, the present Egyptian subsurface drainage systems has sub-collectors in about 16% of the area which can be used for the system described before. Except for the experimental areas of DRI none are equipped with gates. The typical area served by sub-collectors is between 10 and 40 feddans (approx. 4 – 17 ha).

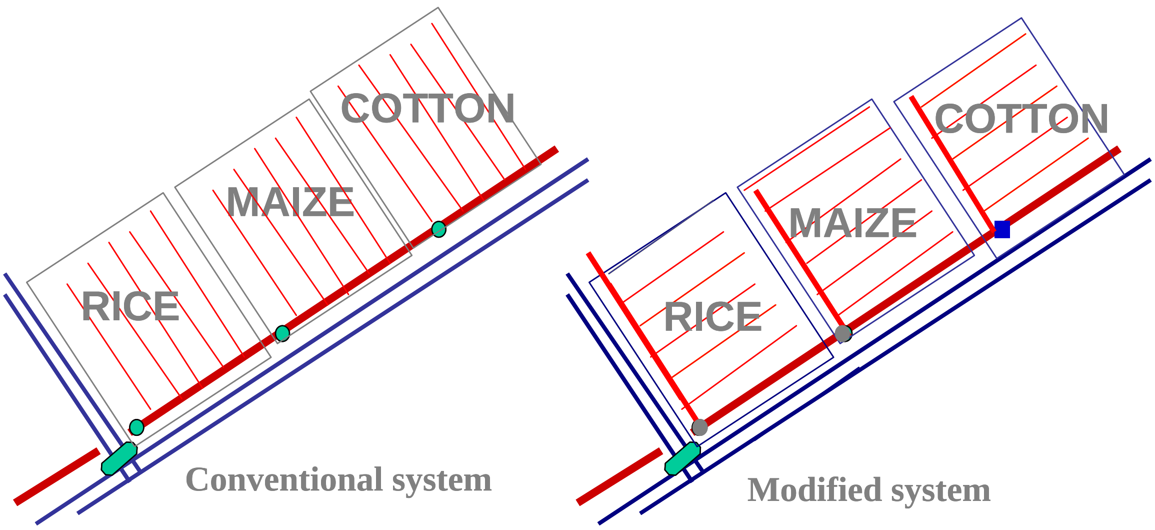

Figure 8 The principle of modified drainage system design (DRP/DRI 2001).

5 CONTROLLED DRAINAGE

Controlled drainage is a best management practice, which can only be achieved by appropriate planning, design and operation of the water conveyance systems and appurtenant structures. The management component is: drain only when there is a direct (and immediate) benefit, otherwise store the water. This applies both to surface drainage (rivers, canals, main drains, field drains) and subsurface systems (tubewells, subsurface perforated plastic pipes, vertical wick drains). The objectives of controlled drainage are:

1. Achieving optimum production conditions (water table and salinity (leaching) control, trafficability) at minimum costs (irrigation, input of fertilisers);
2. Obtaining optimum water quality and quantity downstream (control of transport of salts and other solutes, such as nitrogen and phosphorus by drainage water).

Human activities that cause in-balances in the natural water resources are:

1. Damming of rivers and streams
2. Discharge of municipal, industrial waste directly into rivers, streams, estuaries
3. Urban and rural development resulting in more intense storm water runoff that may carry nutrients, suspended solids, etc.
4. Artificial drainage to promote agriculture and forestry
5. Introduction of nutrients from agricultural fertilisation, from live-stock and domestic waste
6. Alteration or conversion of wetlands to other uses such as agriculture, rural and urban development, recreation, and tourism.

In the previous sections the role and practice of controlled drainage in Integrated Water Resources Management has been sketched using experiences from the Netherlands, North America, Egypt and Australia. This does not mean that there are no experiences elsewhere with controlled drainage. On the contrary, the literature describes cases in Sweden, Pakistan, etc. As these cannot all be described here, they will receive attention in a more elaborate report of research carried out by ILRI (see www.ilri.nl/research). Nevertheless, some preliminary guidelines can be gleaned from the foregoing.

5.1 Layout

Controlled drainage requires an entirely different layout of water management than traditional systems. The design engineer should consider reuse and disposal of drainage water in a manner that is convenient and attractive to farmers and other users. Administrative, hydrological and physical boundaries should all be considered. It is not necessary that water be disposed off in the lowest part of the area, even though there were compelling technical and economical reasons to do so in the past. New, mostly environmental considerations have put additional value to clean water and therefore more expensive designs have to be considered (e.g. the modified drainage system for rice in Egypt).

5.2 Design and management

Irrigation and drainage should be considered in an integrated way, with major attention to water quality. Downstream users, either agricultural, industrial, domestic or ecological, require certain water qualities, which with forethought of planners and designers can be achieved by managing the water in a more appropriate way. Serial biological reuse is one of the options open to designers. For this, appropriate new control structures in the drainage system are necessary, and many are already available, both for surface systems and subsurface systems (Fouss et al. 1999a&b). Sub-irrigation has been a common practice for quite some time in the USA and in the Netherlands many of the surface drains and structures can work in either drainage or water supply mode.

A balance needs to be achieved by draining adequately to allow aeration of crops and to obtain good trafficability in the field when required, and at the same time using the soil as a water storage reservoir to the maximum extent possible. The latter is to prevent drying out of topographically high areas (typical for humid areas with rainfall deficit during part of the season) and to keep as much as possible water at location for possible contribution to the crop water requirement (typical for irrigated areas in the arid and semi-arid regions). In the case of flower bulb production this control requires accuracy of centimetres, for grassland in the Netherlands tens of centimetres, while for other crops, and other conditions (climate and elevation differences) less accuracy is required. In all cases a balance between function of the area and water table regimes needs to be achieved and new developments in the Netherlands with the Waternood programme perhaps point the way for other regions as well. The same balances and principles of water quantity and quality apply to wetlands, peat lands and nature reservations (protectorates; think of the Ramsar Convention sites).

Flood protection is critical, but room for water, such as the water policies in the Netherlands prescribe, requires different approaches to design. Whereas in the past design of flood plains was a given, with the intent to give room for water, most of these have been lost due to (illegal) construction of houses and industries. Value of property has increased many folds in the last decades (Schultz 2001), and economic balances and financial considerations have resulted in other priorities and policies. In the Netherlands this has lead to the situation that calamity polders are being considered (rather than using flood plains appropriately). Calamity polders are areas (polders) with relatively low property value and thus minimal economic loss during short periods of controlled flooding. In the USA similar experiences with loss of flood plains have also resulted in serious flooding problems during the last decade. Loss of flood plains is not the only reasons for the flooding, but it is significant.

5.3 Monitoring and Evaluation

Better monitoring and evaluation of the actual water management situation is pre-requisite for the intended sustainable integrated water resources management. Many automated measurement systems are available and are being developed for just this purpose. GIS is applied for example in the flood prediction system POLDEVAC (van der Meulen 2002). Yet systems do not have to be sophisticated to be able to manage the ground water level as is shown in Australia, where farmers have developed a simple but effective water monitoring tool. Flow measurement in subsurface drainage systems takes some more original thinking but many new systems have and are being developed (Fouss et al. 1999b).

6 CONCLUDING REMARKS

Controlled drainage is an important component in Integrated Water Resources Management and Best Management Practices. The traditional role of drainage is still important, but additional objectives need to be considered in the planning, design and management process, as a distinct change in the paradigm of drainage has taken place: from (free) draining and keeping your feet dry (prevention of flooding) to preservation, storage, and multiple reuse of drainage water.

Drainage systems should not be designed anymore without considerable thought to controlling the drainage, both in quantity and quality. Existing drainage systems should be modified to become water management control systems. If appropriately designed, farmers themselves can exercise this control. There is a major role for policy makers and governments (through Water Boards for instance) to also stimulate control at watershed level.

Controlled drainage has the following benefits: it reduces water need at field level, it helps storing water in the soil profile, and it reduces solute loads on downstream surface waters. The application of controlled drainage can lead to an increase of areas with deteriorated soil structure around drain pipes, with biological and chemical clogged subsurface drains (under certain conditions), and to additional stretches sloughing of canal/ditch banks due to rapid changes in water level in open drains. These problems however also experienced with traditional drainage systems.

An aspect that is, generally, not mentioned in literature is the potential health hazard. Whereas, the first three effects are highly localised, and can be effectively dealt with locally, the effect on health, requires more investigation. In the past, drainage of wet areas contributed to the control of water-borne diseases, such as malaria and bilharzia (through the elimination of mosquito and bilharzia breeding grounds). The creation of wetlands and acceptance of higher water tables may lead to wet spots again, that encourage propagation of less desirable organism.

Controlled drainage can improve downstream water quality and quantity. It also may result that less irrigation water is needed, hence less diversion at the head of branch irrigation canals and more (fresh) water in the primary distribution system. With less irrigation water, also smaller amounts of solutes are leached from the fields, resulting in a decrease of the load of solutes to downstream areas. As a result, more water of better quality is available for downstream users. Serial reuse systems can also contribute to the increased availability of fresh water. However, still little is known on the management of the "end products" such as extremely poor quality water, marginal agricultural products (halophytes, Eucalyptus wood, etc.), and possibly contaminated salts.

Another aspect, advocated in different settings before, is that local control of drainage concentrates pollution at the source, and, the polluter pays!

And so we have a new paradigm for drainage design and an additional paradigm for IWRM: controlled drainage; do not drain unless absolutely necessary and give room to flood waters allowing nature to take it fair share of (good quality) water and space.

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