WATER QUALITY MANAGEMENT FOR SUSTAINABLE IRRIGATED AGRICULTURE

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ABSTRACT

Water quality management is a critical element in the maintenance of sustainable irrigated agriculture systems in the Mediterranean Region as well as throughout the World. The management of water quality requires thorough attention to all aspects of the water regimen from the water source until disposal. Many aspects such as water quality assessment, water source protection, irrigation water management, salinity management, water table management, management and disposal of drainage water, as well as the monitoring and evaluation system require consideration and controls to protect the water quality for an irrigated area and for downstream users.
Water quality control within the scheme requires good field and scheme level management, proper agronomic practices to control salinity and pollution, sound salinity management practices to permit reuse of water when appropriate and water table control where conditions permit. The management and disposal of drainage water that is to leave a scheme, should involve consideration of using saline drain water for salt tolerant plants, biological and chemical treatments, constructed wetlands, stabilization ponds, evaporation ponds, dilution of disposed drain water and final discharges that consider downstream users.

RÉSUMÉ

La gestion de la qualité de l'eau est un élément essentiel pour réaliser des systèmes d'agriculture irriguée durable dans la Région Méditerranéenne et dans le monde. Elle nécessite la prise en compte de tous les aspects du régime hydrique depuis la source hydrique jusqu'à l'exutoire. L'évaluation de la qualité de l'eau, la protection de la source, la gestion de l'eau d'irrigation, de la salinité et de la nappe, la gestion et l'évacuation des eaux de drainage, ainsi que le système de monitorage et d'évaluation sont tous des aspects à prendre en compte afin de protéger la qualité de l'eau apportée à un périmètre irrigué et aux utilisateurs de l'aval.
Le contrôle de la qualité de l'eau à l'intérieur du périmètre doit compter tout d'abord sur une bonne gestion au niveau de la parcelle et du périmètre, de bonnes pratiques agronomiques pour le contrôle de la salinité et de la pollution, des pratiques de gestion valables en conditions de salinité pour permettre la réutilisation de l'eau et le contrôle de la nappe si les conditions le permettent. La gestion et l'évacuation des eaux de drainage du périmètre devraient tenir compte de la possibilité d'utiliser l'eau salée des drains pour irriguer des cultures tolérantes à la salinité, pour les traitements biologiques et chimiques, pour les terres humides, les étangs de stabilisation, les bassins d'évaporations, ainsi que pour la dilution des eaux drainées et des décharges finales qui concernent les utilisateurs à l'aval.

WATER QUALITY ASSESSMENTS

Water quality assessments should be carried out prior to project implementation as a baseline study and at intervals after an irrigated area has been developed. Timing of follow-up water quality assessments largely depends on the seriousness of water quality problems in or adjacent to the irrigated area. Often the original water quality assessment can be carried out as a part of the environmental assessment that is required in most countries and by most financing organizations prior to project approvals. Water quality assessments for irrigation supply should include details on salinity, sodicity, ionic balances, boron and trace elements. Additional water quality details related to environmental and health conditions should also be carried out.

Salinity

According to ASCE (1990), "salinity of an irrigated water is defined as the total sum of dissolved inorganic ions and molecules". The major components of salinity are the cations Ca, Mg, and Na, and the anions Cl, SO4 and HCO3. Some other ions such as K and NO3 and constituents like boron are often considered minor and not normally used in assessing the salinity component for irrigation water quality. Salinity is usually measured by determining the electrical conductivity (EC) of water or soil-water solutions in the case of land evaluations. Evaluations by Rhoades (1984) indicate that high frequency irrigation increases the utility of water of any given EC when compared to conventional irrigation systems. This is true for a number of leaching fractions tested. FAO (1985) in their "Water Quality for Agriculture" paper provides guidance on restrictions for use of water to irrigate and are noted in **table 1**.

Sodicity

Too much sodium can have a negative impact on crop production by reducing infiltration of water at the soil surface. Infiltration reductions are related to the surface soil crusting, soil dispersion and migration of clay into the soil pore space as well as the swelling of expandable clays. Infiltration restrictions are easily predicted by using FAO (1985) guidelines outlined in "Water Quality for Agriculture" which indicates an evaluation of electrical conductivity of the water (ECw) measured in deciSiemens per meter (dS/m) or the equivalent millimhos per centimeter (mmho/cm) and the sodium adsorption ratio (SAR) provide an idea on risks for agricultural production as noted in **table 2**.

Ionic balances and boron

Plants normally tolerate wide variations in concentra-

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Table 1 ***Salinity as related to degree of restriction for irrigation use.***

Factors	Units	None	Slight to Moderate	Severe
ECw* (or)	dS/m	< 0.7	0.7 - 3.0	> 3.0
TDS**	mg/l	< 450	450 - 2,00	> 2,000

* ECw (electrical conductivity of the water) in deciSiemens/meter or the equivalent millimhos/centimeter (mmho/cm).
** TDS (total dissolved solids) in milligrams/liter (mg/l).

Loading rates for the above maximum concentrations in kg/ha-yr can be calculated from the relationship that 1mg/l in the water gives 10 kg/ha-yr when water is used at a rate of 10,000 cubic meters / ha-yr.

Table 2 ***Infiltration as related to degree of restriction for irrigation use.***

Factors	None	Slight to Moderate	Severe
SAR = 0 - 3 and ECw =	> 0.7	0.7 - 0.2	< 0.2
SAR = 3 - 6 and ECw =	> 1.2	1.2 - 0.3	< 0.3
SAR = 6 - 12 and ECw =	> 1.9	1.9 - 0.5	< 0.5
SAR = 12 - 20 and ECw =	> 2.9	2.9 - 1.3	< 1.3
SAR = 20 - 40 and ECw =	> 5.0	5.0 - 2.9	< 2.9

tions of major cations an anions. Suitability as related to specific ion toxicity is indicated in FAO (1985) Irrigation and Drainage Paper 29 for surface irrigation and sprinkler irrigation are indicated in **table 3**.

Boron can be toxic to plants but is also essential for plant growth. Toxicity for most plants take place in the ranges indicated in **table 2** which comes from the FAO paper 29 noted above. Factors that impact on water quality sometimes relate to the boron interaction between the irrigation water supply and the soils boron.

Table 3 ***Ion toxicity as related to degree of restriction for use.***

Ion and irrigation type	Units	None	Slight to Moderate	Severe
Sodium				
— surface irrigation	SAR	< 3	3 - 9	> 9
— sprinkler irrigation	me/l	< 3	> 3	
Chloride				
— surface irrigation	me/l	< 4	4 - 10	> 10
— sprinkler irrigation	me/l	< 3	> 3	
Boron	mg/l	< 0.7	0.7 - 3.0	> 3.0

mg/l = milligram per liter (very close to parts per million - ppm).
me/l = milliequivalent per liter (mg/l divided by equivalent weight = me/l.

Careful analysis is necessary to evaluate the potentials for impacting crop production.

Trace elements

Trace elements can occur in the irrigation water supply as well as in soil-water solutions. Engineering Practice No. 71 of the ASCE (1990) includes a table listing 15 trace elements and the recommended concentrations for long-term protection of plants and animals. **Table 4** provides these details.

Water source protection

Water quality considerations cannot ignore the source of water. Irrigation sustainability can also be ruined by degradation of water quality upstream from the scheme or project area. Thus, water resource planning and management for the entire water basin is critical to the sustainability of many irrigation schemes. The World Bank policy paper on "Water Resources Management" (WB 1993) outlines the importance of a systematic analytical framework for managing water resources. Water quality control is a significant part of this reasoning. Some of the critical water source measures include:

— protecting the catchment areas from erosion and deforestation above storage reservoirs and scheme supply streams,

— controlling pollution from urban and village areas that discharge wastewater to the streams supplying water to irrigated areas,

— controlling discharges from upstream users that may degrade water supplies such as industry and large animal feeding areas, and

— control of discharge from upstream irrigation schemes to minimize water quality degradation.

Water quality control within the scheme

Water quality within irrigated areas can be greatly influenced by the practices and activities of the farmers and the overall system operators.

Good irrigation water management should be practiced at scheme level as well as field level to control water quality.

Agronomic considerations and the cultural practices used with agricultural chemical applications require attmntion to resultant water quality.

Salinity management issues should address proper leaching requirements and within scheme reuse of drainage water.

Water table management systems should also receive more consideration for water control and water quality control where applicable.

Table 4 ***Recommended maximum concentrations of 15 trace elements in irrigation waters for long-term protection of plants and animals.***

Trace Elements	Recommended Max. Concentration (mg/l)	Comments
Arsenic	0.10	— This guideline will protect sensitive crops grown on sandy soils. Higher concentrations can be tolerated by some crops for short periods when grown in fine-textured soils.
Beryllium	0.10	— Toxicity's to plants have been reported at concentrations as low as 0.5 mg/l in nutrient solutions and at levels in the soil greater than 4% of the cation-exchange capacity.
Cadmium	0.01	— Concentrations = to or < than 0.01 mg/l will require 50 years or more to exceed the recommended maximum Cd loa ding rate. Removal in crops & leaching will partially compensate and may allow use of the water indefinitely.
Chromium	0.10	— Toxicity in nutrient solutions has been observed at a concentration of 0.50 mg/l & in soil cultures at a rate of 120 kg/ha. Toxicity depends on the form of Cr existing in the water & soil & on soil reactions.
Cobalt	0.05	— A concentration of 0.01 mg/l is near the toxic threshold for many plants grown in nutrient solution. Toxicity varies depending on the crop type & soil chemistry.
Copper	0.20	— Concentrations of 0.1 mg/l to 1.0 mg/l in nutrient solutions have been found to be toxic to plants, but soil reac tions usually precipitate or adsorb Cu so that soluble Cu does not readily accumulate.
Fluoride	1.0	— This concentration is designed to protect crops grown in acid soils. Neutral & alkaline soils usually inactivate F, so higher concentrations can be tolerated.
Lead	5.0	— Plants are relatively tolerant to Pb, & soils effectively sorb or precipitate it. Toxicity to animals typically is caused not by Pb absorption from soils, but by aerial deposition of lead on foliage of pasture and forage plants.
Lithium	2.5	— Most crops are tolerant to Li up to 5.0 mg/l in nutrient (citrus = 0.075) solutions. Citrus is very sensitive to Li. Lithium is a highly mobile cation & will leach from soils over an extended period of time.
Manganese	0.20	— Some crops show Mn toxicity's at a fraction of a mg/l in nutrient solution, but typical soil pH & oxidation-reduction potentials control Mn in the soil solution so that the Mn concentration of irrigation water is relatively unimportant.
Molybdenum	0.10	— This concentration is below phytoxic level but is recommended to protect animals from molybdosis because of excess Mo in forages.
Nickel	0.20	— Many plants show toxicity at Ni concentrations of 0.5 mg/l to 1.0 mg/l. Toxicity of Ni decreases with increases in pH, so acid soils are the most sensitive.
Selenium	0.02	— This guideline will protect livestock from selenosis because of Se in forage. Selenium absorption by plants is greatly inhibited by S04 so these guideline can be increased for gypsiferous soils and waters.
Vanadium	0.10	— Toxicity in some plants has been recorded at V concentrations above 0.5 mg/l.
Zinc	0.50	— A number of plants show Zn toxicity at concentration of 1 mg/l in nutrient solutions, but soils have a large capacity to precipitate this element. This guideline is designed to provide protection for acid sandy soils. Neutral and alkaline soils can accept much larger concentrations without developing toxicity's.

Irrigation water management

Irrigation water management means the proper control of water being distributed to minimize losses that could cause degradation of water quantity and quality as well as the proper application of water on fields as the crop needs dictate. Thus, seepage from distribution systems is controlled, irrigation water is applied in a timely manner and over irrigation is avoided.
Scheme wide considerations. Good irrigation water management involves control of seepage from reservoirs and canals as these water wastes can create problems with high water tables adjacent to the works and on low lands in and near the schemes. High water tables in arid and semi-arid climatic zones will move excessive saline water to root zones and water tables thus causing water quality problems.
– *Field considerations.* Irrigation water management within farm fields requires careful timing of water application to be certain the crop water requirements are met but not exceeded. Excessive water applications not only waste water but provide the flows to move agricultural chemicals or other elements that under some conditions become toxic, from the crop or crop root zone where they can be used by the plants to groundwater aquifers or high water table areas where they are usually considered pollutants.

Agronomic practices

Agronomic practices in irrigated areas can also impact water quality. Pest control for example can greatly reduce the opportunity for water quality degradation when integrated pest management systems are used. Agricultural chemicals that are properly used should be applied as needed by the plants to minimize the chances for leaching from rain storms or over irrigation. Planting and harvesting techniques should also consider the potential for water quality degradation. Field erosion can also transport pollutants such as sediment and phosphorous to surface waters and thus needs to be controlled.

Salinity management issues

Salinity management issues relate to the same water application conditions noted above. Water seepage at any facility or from an irrigated field within the system moves through the soil mass causing leaching of salts and other pollutants or elements that often collect at a point which is normally not desired by farmers or managers of the system. Salinity management also requires careful consideration of leaching fractions so excessive irrigation water is not applied to move salts not only out of the root zone but well beyond the field soil profile thus mobilizing excess salts and other pollutants needlessly. Within a scheme full consideration should be given to the reuse of drainage water if water balance and water quality determinations do not require discharges of a predetermined quantity and quality to downstream users.

Leaching requirements. According to ASCE (1990), "the amount of leaching needed to maintain a viable irrigated agriculture depends on the salt content of the irrigation water, soil, and ground water; the salt tolerance of the crop; the climate; and the soil and water management". ASCE goes on to state that "the only economical way to control soil salinity is to ensure a net downward flow of water through the root zone to a suitable disposal site. If leaching is inadequate, harmful amounts of salt can accumulate within a few cropping seasons". This same source goes on to discuss formulas for determining proper leaching and details for proper control of salinity in the crop root zone. Water quality functions within the scheme and throughout the region can be directly impacted by not controlling the leaching excesses or over irrigating.

Within scheme reuse of drain water. Water is a precious commodity, and drain water can often be reused within the scheme area for productive purposes. Depending on the extent of degradation by the initial irrigation, reuse of less sensitive crops, trees or grasses is often possible. Downstream rights to water quantity and quality must be considered in planning these in-scheme reuse systems to assure that legal considerations are met. Sometimes environmental values can be improved by reusing the drainage water do develop wetlands or windbreaks. Wetlands will be discussed later but can even provide the benefit of reducing some of the pollutants as the drain water passes through a series of these vegetative filter areas to the point of discharge back to the outlet for the scheme or project. Windbreaks often are needed adjacent to irrigated areas to provide control from desertification in arid climatic zones.

Water table management

Water table management involves controlling the drainage water levels to provide a subirrigation from the capillary rise. In some cases, full subirrigation can be introduced by adding water to the drainage system in dry periods to maintain a watmrtable that will provide the crop water requirements. The practice is not thoroughly evaluated for arid and semi-arid regions where complications due to the control of salinity make management difficult and risks of salinization high. Some of the Mediterranean Region should be quite adaptable to good water table management systems. The system is particularly adaptable to flat humid lands where drain outlets can be modified to control the depth of water in a drain. Madramootoo (1996) indicated this practice has enormous potential for reducing nitrate pollution in subsurface drainage effluent in flat, humid regions. An elevated water table enhances denitrification, thereby reducing nitrate concentrations in the drain discharge (Gilliam and Skaggs, 1986). In the humid region of eastern Canada, Kaluli and Madramootoo (1995) showed that by keeping the water table at 50 to 75 cm from the soil surface, nitrate losses can be reduced by 58 percent, compared to a free outlet, conventional drainage under intensively cropped grain corn.

Management and disposal of drainage water

Water quality from irrigated areas varies significantly in accordance with the crops grown, the efficiency of the irrigation and drainage systems, the pollutants introduced by urban and village populations, the quality of water discharged from industries within the scheme area, and the reuse that is made of waters within the system. Often it is beneficial to reuse the drain water that is to be discharged for environmental improvement or mitigation. It is sometimes possible to also use the project effluent for growing salt tolerant vegetation that has an economic value. Biological and chemical treatments may be required under some conditions to protect downstream interests. Wetland developments, stabilization ponds and evaporation ponds are also used under some conditions. In line with the rights of downstream users, it may even be necessary to provide dilution of the system wastewater to meet requirements agreed upon in treaties or protocols. The easiest disposal is direct discharge to the ultimate disposal point of most river systems, the sea.

Using saline drainage water

Saline drainage water can often be used to enhance or mitigate environmental values downstream from or adjacent to irrigation areas. These saline discharges can also be used in many cases to grow salt tolerant plants. Water quality, particularly the salinity content of the discharged waters, play a big part in the applicability of these practices. The acceptable parameters are so variable that field pilot installations are normally required to test the proposals that seem the most viable.

Environmental uses. Environment values are a key concern for irrigation project management and drainage water can provide help in minimizing these problems. Saline drainage water must be treated as a resource and used to enhance or mitigate environmental values under many situations. In desert environments windbreaks are critical to the protection of irrigated agricultural systems. The planned development of windbreaks using very salt tolerant trees has been used in China's

Tarim River Basin for many years. It is also possible to develop or improve wetland areas near projects with the drainage water. Constructed wetlands and natural wetlands can even be managed to improve the water quality to some degree.

Using saline water for growing salt tolerant plants. The production of salt tolerant vegetation using drainage water is practical for many locations. In these systems the drain water is continually reused to irrigate salt tolerant crops, trees, and halophytes. The final effluent is disposed of in a solar evaporator so downstream water quality is not degraded. Madramootoo (1996) reported that in California for one pilot project, the final drainage volume was reduced by about one-tenth, and its salt and selenium concentrations increased 10 and 2 fold, respectively. For a cropland are of 1,000 ha, the area of salt tolerant trees is 20 ha, and the halophytes cover 8 ha, and the area of the solar evaporator is 4 ha. Materials in the solar evaporator may have a marketable value and the production of crops, trees and grass for biomass certainly has some value.

Biological and chemical treatments

Advances in recent years in the biological and chemical treatment of drainage water have been made. FAO and ICID (1997) have prepared a document that is being printed titled, "Management Guidelines for Agricultural Drainage and Water Quality". A chapter within this document deals with drainage water treatment and discusses the selection of a treatment process and provides a brief discussion about the multitude of treatment methods and processes.

Constructed wetlands, stabilization ponds and evaporation ponds

Constructed wetlands can also be used to improve water quality from disposal drains. Ochs et al. (1996) notes that flow through wetlands have promise for providing improved discharges from irrigation projects by constructing them in series with varying types of vegetation. Filtration potential for sediments help control those pollutants that attach to soil particles and vegetative uptake by plants help remove some pollutants that move with the water flow. Treatment of drain effluents in stabilization ponds is commonly used for domestic wastewater management. FAO and ICID (1997) provides guidance for these systems as well as evaporation ponds. Applicability of each type of system requires careful study. Water quality can be improved with stabilization ponds, but evaporation ponds concentrate salts and other elements and dangers of developing toxic levels of elements such as selenium must be carefully evaluated.

Dilution

Dilution of the drainage water from an irrigated area is sometimes necessary to meet downstream water quality standards or treaties. This requires valuable water that could be used for irrigation or another beneficial use in the irrigated area and provides an extra incentive to minimize degradation of the water quality within the irrigation scheme.

Discharge

The ultimate disposal is normally to the sea and discharge of the poorer quality water can also degrade estuary ecosystems. Care must be take in selecting discharge points to minimize environmental problems from drain discharges. It is important to monitor the water quality from these discharges to watch for significant changes in the drainage effluent that could lead to environmental problems. If changes are noted, steps should be taken to alleviate the problem condition that has developed in the irrigation area or other contributing watershed.

Monitoring and evaluation

Water quality control is critical to the success of any irrigation project. The quality of water is a dynamic value with many components and requires careful monitoring and evaluation to manage the system for water quality protection.

Monitoring must be systematic, continuous and include measurements related to the water source, within the scheme and the outlet.

Irrigated areas should support river basin management systems that they are a part of.

The integrated monitoring of all organizations concerned with water quality in a basin should be the goal of all irrigation scheme management authorities. ●

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