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WATER QUALITY MANAGEMENT AND CONTROL OF WATER POLUTION

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WATER QUALITY MANAGEMENT AND CONTROL OF WATER POLUTION

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SUMMARY REPORT

The Expert Group emphasized that water is a key resource for all economic sectors which increasingly must compete for this scarce commodity. Therefore, every effort must be taken to mobilize personnel, facilities, financial resources and the application of new practices and technologies to facilitate the efficient and effective use of all types of water (freshwater, brackish, saline, wastewater) in agriculture. An integrated and comprehensive approach is essential for water allocation and management both for water quantity and quality.

Use of wastewater in agriculture has substantial benefits in the Region. However, substantial change in practices are required to safeguard public health and the health of agricultural workers, to ensure efficient water use, and to control salinity and off-site water pollution.

Protection of water quality is a multi-jurisdictional issue, however national water programmes suffer from lack of policy focus for water quality. Modernization of water quality policies and programmes are required to prevent institutional and policy failure, and to ensure effective delivery of data programmes that have benefit to agriculture and other sectors of the economy.

CONCLUSIONS

For beneficial use of **wastewater** in agriculture, the following were identified as the principal issues:

- **The need to exploit the potential of treated wastewater and excreta as valuable resources:** Current practices vary within in the Region, however wastewater use rarely complies with the required health and environmental safeguards. Environmentally sound use of wastewater and excreta could lead to enhanced food and feed production, conservation and enhancement of water resources, reduction in use of agro-chemicals, and in improved health and environmental benefits.
- **Salinity:** This is a serious problem which affects yield and may cause deterioration of surface and groundwater quality with adverse and potentially irreversible effects on soil and the environment.
- **Low water use efficiency:** This is one of the main factors that reduces water productivity and increases the potential for environmental pollution in agricultural areas.

For control of **water pollution** from agriculture, and for use of polluted water in agriculture, the following were identified as the principal issues:

- **Policy failure**: Water quality management is first and foremost a problem of policy which in many countries fails to recognize the national significance of water quality, the cost of degraded water to the national economy and to the agricultural sector, and the loss of environmental benefits from water pollution. A modern policy response to water quality management is essential but is lacking in most national water resource policies.

- **Institutional and legal reform:** These are key elements in water quality management and include a better definition of roles and responsibilities of institutions, and a cooperative framework for water quality management. It also includes a legislative response to efficient and enforceable regulations to ensure data quality, the regulation of effluents, and the definition of achievable and realistic water quality standards and objectives.
- **Data programmes:** are a key element in development of modern water management policies, in planning and management, and in decision-making on water quality remediation investments. However, data programmes in most countries are inefficient and often provide little information of value to the policy maker or to the regulator. For agriculture, water quality data programmes rarely take into account the specific needs of agricultural agencies for information required to develop and evaluate farm management practices that will improve off-site impacts on water quality.
- **Management practices:** These are a key element to achieving improved off-site and grroundwater quality from agricultural activities. Greater accountability is required of the private sector in its role in agro-industries and agricultural production.
- **Capacity building:** National governments often adopt an uncritical approach to donor programmes that often focus more on what the donor perceives to be needed rather than on what the country may actually need. Consequently, there are many examples of unsustainable technologies that are introduced into national programmes that fail when the donor withdraws. There must be a more focused effort to transfer technologies (hard and soft) that are sustainable in the environment of the receiving country. Concern was also expressed over the use of foreign experts who often leave little improvement in local capacity, and in the use of tied aid that focuses on the support of the donor's private sector rather than necessarily on what is actually needed in the receiving country. At national levels, much greater use could be made of local expertise however this is often frustrated by competition amongst national agencies for donor support. Use of modern information technology tools, such a decision support systems that bring knowledge and expertise into the hands of decision-makers, can be very efficient and effective.

RECOMMENDATIONS

The following recommendations were made for implementation by local, national, regional and international organizations:

Wastewater use in agriculture

Public policy

- It is recommended that the guidelines developed by WHO/FAO/UNEP for use of wastewater in agriculture be promoted as a basis for preparing national guidelines, regulations, and codes of practice. Governments should consider providing incentives to industry to treat effluents to the minimum level that is recommended for use by the agricultural sector.

Health aspects

- Protecting public health and the environment are the main concerns associated with wastewater use. The health and environmental risks should be within acceptable levels. A minimum treatment is required to achieve acceptable purified wastewater that is safe for designated uses. Raw wastewater is not recommended for any irrigation purpose.

- There are apparently no controls in the countries of the Region over the crops grown which are irrigated with wastewater. It is recommended that vegetable crops, normally eaten raw, should not be irrigated with inadequately treated wastewater. Wastewater may be primarily used in agro-forestry, orchards, cereal and industrial crops. To prevent workers from wastewater exposure, they should use footwear and gloves and utilize appropriate methods of irrigation and sludge application. Farmers need to be more awareness of these facts.

Environmental aspects

- Wastewater irrigation can enrich the soil with organic matter and nutrients (N, P, K) and increase its water holding capacity and it may increase crop production. However, urban and industrial wastewater may also contain toxic chemicals like heavy metals. Long term uncontrolled use of wastewater may lead to a build-up of soil salinity, accumulation of toxic chemicals and reduction of soil permeability, and pollution of surface and groundwater. General guidelines on irrigation water quality (FAO) should be applied to avoid immediate, short and long term detrimental effects on the environment. Monitoring of ground and surface water resources close to the wastewater area should be carried out regularly to provide an early warning of pollution status and risks.
- Promoting use of wastewater in agriculture as an alternative to discharge to surface waters will decrease potential for eutrophication of surface waters.
- In order to control pollution of water bodies due to disposal of saline drainage, efforts should be made to minimize drainage surplus by resorting to methods for increasing water-use efficiency.
- Treatment procedures for waste purification which are cost effective and environmentally friendly should be promoted.

Legal and institutional aspects

- Develop, amend, and/or adopt legislation which will enable the appropriate use of treated wastewater and excreta. Compliance with the legislation needs to be enforced. National action plans should be prepared to include, among others, institutional framework, inter/intra sectoral co-ordination, human resource development and technology options.

Socio-cultural aspects and human resources development

- The socio-cultural aspects of wastewater reuse should be examined before planning local wastewater systems; Women should be actively involved in all phases.
- Public awareness at local, national and regional levels should be promoted through increased dissemination of information through public media as well as at workshops, seminars and exchange of visits.

Research and development, technology transfer

- Gaps in knowledge and information should be identified and research proposals prepared for submission to national and international agencies for support. Adequate funding is essential.

Health, agricultural, environmental, and ecological implications, and various issues related to operation, maintenance, and management need to be studied in-depth in order to develop regional strategies and country-specific norms.

- A regional network for this sector should be established to promote information and experience regarding relevant research and technologies, and to promote exchange and co-operation among the countries of the region and with UN organizations.

Control of water pollution

Public policy

- Modern water policy formulation must explicitly include water quality concerns. Policy reform for water quality management should include clear objectives and an action plan for implementation.

Institutional issues

- Institutional and legal reform is required to bring institutional efficiency and modern legal and enforceable regulations into the management of water quality. Important elements include new and enforceable approaches to effluent control, the legalization of national data standards, and the evaluation of new or alternative institutional arrangements that make better use of public-private sector partnerships.

Programme reform

- Water quality programmes, including monitoring and data programmes, need to be modernized both to take into account new technical developments in efficient water quality monitoring and assessment, and also to increase efficiency and effectiveness in these programmes so that they respond to real data needs by data users and by decision-makers.

Management practices

- Management practices can be greatly improved to increase efficiencies in water use, to reduce use of agrochemicals, and to reduce of off-site impacts on surface and groundwater quality.

Capacity building

- Capacity building is essential, but needs to be more carefully considered both by donors and recipients to ensure that there are real gains in capacity and the new tools and techniques are sustainable within the socio-economic fabric of the receiving country.

These recommendations are amplified in much greater detail in the general report of the Expert Meeting.

FOLLOW-UP RECOMMENDED

The following are recommendations for follow-up to United Nations specialized agencies, other multi-lateral agencies, donors, and to national governments, in the field of wastewater reuse and for control of water pollution:

1. Promote and assist in the modernization of policies, regulations, laws and programmes in water quality management and wastewater reuse, and to encourage governments' commitment to this objective. This should include transparency of government policies and programmes and accessibility to data.
2. Capacity building needs to focus more on developing local expertise and on sustainable practices so that foreign "experts" increasingly become facilitators rather than "doers". Conduct training courses, seminars and workshops at local, national and regional levels in different countries. Assessment of training needs and existing training facilities should be made. Existing curricula in the field of agriculture, aquaculture and forestry, health, engineering and water resources management should be strengthened and modified to include issues related to control of water pollution and to wastewater use. For the in-service workers and managers, continuing education and non-formal short term training modular courses should be instituted.
3. United Nations organizations should facilitate transfer of appropriate and cost effective technologies and to help with their adaptation under local conditions. This should include programmes that allow countries to share experiences, lessons learned, and which promote technical cooperation amongst developing countries,.
4. United Nations agencies need to more carefully coordinate and rationalize their collection of data on water quantity and quality, water use and reuse, and related issues in the Region and globally, and to ensure accessibility to these data sets.
5. Carry out a selection of case studies in representative countries of the region in order to elaborate the benefits, dis-benefits and best management practices that can be applied to the region in wastewater reuse and management, and for control of water pollution.

Keynote papers

Water quality management in Asia and the Pacific

Abstract

In its recent examination of global water scarcity the United Nations system identified water quality as one of the key concerns in Asia in the next century. This concern is based on the fact that water quality degradation is so severe in many Asian countries that it is placing serious constraints on economic growth; it continues to be a serious problem for human health; it is causing widespread ecosystem collapse; and has serious negative impacts on marine systems. The problem of future management of water quality in Asia is a complex one, and requires re-examination of a number of key issue areas - including technical, institutional, legal, and governance issues. In this paper we examine some of the key areas where progress needs to be made, and what can be realistically be expected.

In its recent examination of global water scarcity the United Nations system (1997) identified water quality as one of the key concerns in Asia in the next century. This concern is based on the fact that water quality degradation is so severe in many Asian countries that it is placing serious constraints on economic growth. In most Asian nations the most visible evidence is of serious human health problems associated with discharge of pathogens into drinking water sources, and the widespread eutrophication of lakes, rivers and reservoirs with associated algal blooms and fish kills that results from point and non-point source discharges of nutrients. In Asia the impact of agriculture on eutrophication is widely known but poorly quantified. The United Nations also noted that the problem of aquatic contamination that is associated with many rapidly industrial nations, is poorly known because of the lack of reliable data. There is also widespread evidence of the destruction of aquatic ecosystems due to the combination of water supply policies and of uncontrolled discharge of human and industrial wastes. Further, the scientific literature makes it quite clear that waste discharges are having widespread destructive influences in near-shore and off-shore marine environments in Asia. This includes coral reef destruction and the contamination of marine life with implications for human health as well as for dysfunctional behaviour of marine species.

Groundwater quality management in many Asian countries is as serious as surface water quality management. As noted in the GEMS review of groundwater in Asia-Pacific (UNEP, 1996) the destruction, especially of shallow riverine and coastal aquifers, through over-pumping and pollution is greatly adding to the water crisis now experienced by many Asian nations.

The issue of water quality management in many Asian countries has become very critical, especially in countries such as China, India and Pakistan where large parts of these countries

Edwin D. Ongley
Senior Advisor, United Nation's GEMS/Water Programme
Ontario, Canada

suffer serious water deficits. Degraded water quality that cannot be used for industrial, human or agricultural use represents a net loss of water resources. Even countries such as Thailand are now experiencing water deficits in important industrial areas through lack of integrated water resource planning. The linkage of water with food security also has major implications for water quality management. Most Asian countries are not able to further develop new and inexpensive sources of water, and the cost of remediating degraded water is increasingly competitive with the current cost of developing new water resources. The construction of new dams is now largely focused on managing floods and the containment and distribution of flood waters, and is not focused on the development of new water resources. However, many new reservoirs are suffering from eutrophication as well as sedimentation which places limits on their use for long-term water supply purposes.

The problem of future management of water quality in Asia is a complex one, and requires re-examination of a number of key issue areas - including technical, institutional, legal, and governance issues. This paper examines some of the key areas where progress needs to be made, and what can be realistically expected.

CURRENT STATUS

The current status of water quantity and quality and related management issues in the Asia-Pacific Region are documented in a variety of publications, including an extensive series of monographs by ESCAP (e.g. 1994, 1995, 1997). Although now dated, the United Nations 1995 State of the Environment in Asia and the Pacific is also useful. The UNESCO publication (Takeuchi, 1995, 1997) on Asian rivers is also useful.

Some current examples of the current status of water quality in Asia and the Pacific region will demonstrate both the severity of the problem and the often uncritical attitude that is brought to the expectation of solving the water quality problem.

In China, water quality is a major concern (Table 1) with some 27% of that country's surface waters exceeding the worst class of water (>Grade 5). For agricultural purposes, the percentage of surface water that is not fit for irrigation is estimated at approximately 13%. This means that 13% of the total surface water in China is not fit for any human purpose – and this in a country

TABLE 1
Percentage of river in each water quality class in China (1998 data)

River/Lake	Grade 1*	Grade 2	Grade 3	Grade 4	Grade 5	>Grade 5
Rivers						
Songhua	0	0	4	67	21	8
Liao	4.5	2.3	4.5	22.7	4.5	61.4
Hai	5	19	4	10	9	53
Yellow	0	24	5	47	12	12
Huai	0	11	17	19	6	48
Yangtze	4	67	4	11	10	4
Pearl	29	36	7	22	2	4
Average	**6.1**	**22.7**	**6.5**	**28.4**	**9.2**	**27.2**
Lakes						
Chaohu					X	
Tai				X	X	
Dianchi					X	

Source: Weng, J. 1999. Water Quality and Irrigation in China. [This meeting]
* Grade 1 is best quality; Grade 5 is worst quality.

that has an estimated annual water deficit of 35 thousand million m^3. Recently reported (WWEG, 1999) is the observation that half of China's population consumes water that fails to meet minimum quality standards. It is estimated that deaths from liver and gastric cancers account for 40% rate of all deaths from malignant neoplasms (compare with India at 11%). Infectious diseases are also rising in China, rather than falling as one might expect with improved health care and a rising standard of living.

In the recent Stockholm Water Symposium of 1999, the World Water Council presented the results of its Visioning exercise – an attempt to define a vision for action to deal with the global water crisis and which will be presented to a meeting of Ministers in the Netherlands in year 2000. The vision is being developed by regional experts. However, the presentations on water quality almost universally demonstrated a profound naivete about the reality of resolving the water quality problem. Generally, there seemed to be the expectation that by 2025 (the target year) that water quality would be restored to some reasonable level, both for human and ecosystemic purposes. Informed professionals however made the following anecdotal observations as examples of the reality of coping with degraded water quality:

- A World Bank study of the 1980s was cited as indicating that a doubling of the Thai economy would increase water pollution by a factor of x10.
- A similar study for India was cited for the period 1975-1995, based on a very conservative American model, indicated that a doubling of the economy would increase water pollution by at least a factor of x4.
- To achieve effective pollution control in India, the country would have spend some US$ 40 thousand million annually on pollution control which is vastly more than is spent in the entire water sector.
- Japan spent some 25% of the value of industrial output on pollution control. Can India or other developing countries afford it – Obviously NO.

Additionally, the United Nations (1997) cites a UNIDO report that indicates that water pollution in rapidly industrializing countries of Asia and the Pacific, under a scenario of no change to water quality management policies, will result in further pollution by a factor of up to x18. Clearly, this is not sustainable. However, the complexity of pollution issues, and the severity and spread of seriously impacted water quality is increasing at a rate that exceeds the technical, institutional and economic means of most developing countries in Asia.

From a policy perspective, governments typically have no comprehensive policy for water quality management except for highly generalized statements about water quality improvement, and a set of (usually) unenforceable discharge regulations. Water quality management is usually devolved to the local level for that is where the impact of water quality degradation is most felt. However, as noted below, this is not an especially effective approach and leads to miscalculation of the benefits of pollution control and generally excludes any consideration of comprehensive approaches to water quality management.

Integrated Water Resources Management (IWRM) is the current mantra of water resource professionals and of multilateral technical agencies such as FAO, yet few developing countries have seriously addressed the institutional or legal frameworks required to carry out IWRM. On the other hand, even getting consensus amongst the stakeholders for water quantity management in large multi-jurisdictional river basins, let alone all the other aspects of IWRM, is a major step forward in many countries and represents significant progress.

The trend towards remediating water quality problems offers an interesting insight into the larger concept of IWRM. Remediation decisions, as noted above, are usually left to local levels of government. However, the data and skills required to make informed judgements about the likely results relative to the cost of alternative remediation options is generally absent. As an example, the very contaminated Huaihe river in China lacks the database with which to make comprehensive remediation decisions and has necessitated a very expensive program of data collection by a foreign company to enable the identification of a set of remediation options. As noted below, there are now alternatives methodologies that can be used to make judgements about remediation alternatives in the absence of reliable data, however the skills required to carry out alternative decision-making analyses are lacking.

The status of water quality data programmes in developing countries in Asia and the Pacific is a serious issue especially as these should form (but do not!) the basis for a national action programme on water quality management. Usually the selection of water quality parameters is out-of-date, methodologies are often very old, the data are often not quality controlled or quality assured and may be very unreliable, the data are not easily available to users and are neither evaluated nor converted into data products that can be used for decision-making. As a consequence, much of Asia and the Pacific can be categorized as "data poor" and a major challenge is to find alternative ways of decision-making in data-poor environments.

With this background, it is interesting to note that multilateral lending agencies and ODA assistance programmes are anticipating growing needs for financial resources for water quality remediation. The question now is – how to most effectively address these various shortfalls in policy and technical application so that future planning for water quality management, as well as remediation decisions, are most cost-effective.

Programme modernization

Programme modernization (Ongley, 1998) describes a series of steps that can be taken to implement a more useful transition - from policy to technical programmes to management decisions. Other aspects of the modernization process are summarized by Ongley in ESCAP (1997).

Policy reform

Policy reform, especially as it applies to agricultural management of water, has been extensively reviewed by FAO (e.g. 1995). In the Asia and Pacific Region the work of the Asian Development Bank is also relevant (Arriens, 1996). As noted above, most national policies on water management have little to say about water quality. Generally, water quality is dealt with in "motherhood" terms combined with legal and administrative arrangements for defining (a) water quality objectives/criteria, and (b) end-of-pipe effluent regulations that are often unenforceable in many countries. A process of policy reform should consider the following elements for surface and groundwater management:

- A consultative process for defining the policy elements and for reviewing implementation of the policy elements,
- Requirement for review of water quality at national and regional levels, identifying data weakness, hot-spots, and key water quality concerns having major social, public health and economic implications,

- A process for identifying and prioritizing specific goals that are achievable and sustainable, including the integration of water quality within the larger IWRM concept,
- Identification of areas of legal reform including establishment of data standards (see below),
- Identification of core areas of capacity that are lacking relative to national needs for decision-making, and a realistic approach to filling these capacity gaps.
- Specific targets of implementation.

Legal reform

Legal reform relative to water quality management is a key element. The most important areas that need to be addressed tend to be the following:

Creation of national data standards: A significant problem in many (if not most) developing countries is the lack of standards for data quality. The consequence is that laboratories too often produce data that are often internally as well as externally inconsistent or unreliable. There is no ability to create a national database from which a national perspective on water quality concerns and priorities can be developed. National data standards can be achieved in a variety of ways, however these generally involve some mechanism for national quality assurance of data and a quality control regime for government, university and private sector laboratories that produce data for government programmes. This approach, especially in more advanced countries, should include consideration of "performance-based" analytical methods rather than legislated methods. The latter is administratively easier but it generally results in methods being brought to the lowest common denominator and penalizes laboratories that wish to adopt newer and more cost-effective analytical technologies.

Creation of a national process of data analysis and review: This is a form of national reporting and needs legal status so to ensure that the process is appropriate dealt with by those institutions having primary responsibility. The importance of this lies in the fact that few countries have a reliable and comprehensive overview of the outstanding water quality issues at national and regional levels, and at a level of detail at which decisions on priorities can be made relative to other social, public health and economic priorities.

In this context the Transboundary Basin Analysis process of the multinational Danube River Basin is instructive (DPCU, 1999). The main objective of the TBA is to provide the technical basis for development of a Pollution Reduction Programme for the protection of the river basin. This approach can also be used within large single-country river basins. The analysis includes:

- detection, characterization, comparison, and evaluation of pollution sources, water quality and pollution loads throughout the basin, including evaluation of data quality;
- identification and characterization of areas and issues that are sensitive to pollutant concentrations or loads;
- evaluation of the effects of pollutant concentrations and loads on sensitive areas and issues, including national effects as well as transboundary effects;
- discovery and evaluation of immediate causes of pollution;
- identification and evaluation of root causes of water quality problem situations;

- identification of alternative (structural[1] and non-structural) interventions to reduce pollution and eliminate water quality problems, based on all of the mentioned considerations;
- development of criteria for basin-wide evaluation of possible interventions to reduce pollution;
- preliminary ranking of possible interventions;
- determination of stakeholders and evaluation of constraints to interventions."

The DPCU notes that "The overall purpose of the Transboundary Analysis Report is to show the clear relationship between the sources of water pollution and environmental effects. Particular attention is given to the identification of Hot Spots and their transboundary implication not only in relation to ecosystems, but also in relation to economic and social development. Based on these results, policies for pollution reduction, prevention of environmental degradation and protection of resources and ecosystems should be implemented….."

In Asia, UNEP has carried out a diagnostic study of the Mekong River Basin (MRCS, 1996). This study, which deals with all development sectors, is an example of a comprehensive analysis of status and trends, and of policy, legal, institutional and technical actions that are necessary to achieve sustainable development within the basin. This is being followed by a detailed water management programme that is now being pursued through the Global Environment Facility.

Effluent Regulation: Most Asian countries have legal standards for effluent discharges to surface waters. The need for reform involves three elements:

(i) <u>Parameters</u>: Knowledge of environmental protection has progressed to the point where there are now alternative approaches to end-of-pipe measurements that can be much more cost effective. Examples include the evaluation for toxicity impacts where use of simple, field-portable, toxicity assays can replace parameters that measure for toxic impact.

(ii) <u>Use of Screening Criteria</u>: "Screening" parameters are used as part of a two-step approach to effluent regulation. Screening is the process where, using low-cost measurement techniques, an effluent can be judged on a pass/fail scale without carrying out more expensive physico-chemical or biological measurements. When the effluent fails the screening level test, then a larger set of physico-chemical determinations is required. This approach can be used to lower the cost both for government and for the private sector. More importantly in developing countries, this approach is more sustainable due to its lower cost.

(iii) <u>Waste Load Allocation</u>: Large countries, such as China, are finding that national standards for effluent regulation, even when industry is adequately regulated, are insensitive to the number of effluents being discharged to a water course with the result that surface waters are becoming worse rather than better. There is a need, therefore, to move to a waste load allocation approach that looks at permissible load to the river rather than end-of-pipe criteria that are insensitive to the site conditions of any particular river. This is a technical issue but which can only be implemented by a change in national law.

An additional consideration is the legal requirements for discharges to groundwaters.

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[1] "Structural": capital works projects leading to improved infrastructure such as waste treatment systems, sewer construction, etc.. "Non-structural": Examples include development and enforcement of standards; waste treatment operator training; institutional development; etc..

Water Quality Objectives/Standards: Although this is a technical subject, the use of water quality objectives or standards is often a legal process for defining legal objectives for surface waters and for wastewater reuse. These standards are generally based on risk assessment for human health purposes. However, many countries tend to adopt western water quality objectives/standards that are inappropriate to the level of development and economic state of the adopting country. A more rational approach to the use of risk assessment in wastewater reuse in agriculture is provided by Shuval *et al*. (1996).

Institutional reform

Institutional reform is a complex issue for which there are no simple answers. However, for water quality management there are certain key principles that can guide institutional reform.

Water quality monitoring as a service function: As noted by Ongley (1994, 1998), water quality data programs tend to be data-driven and not client-driven. This has a number of serious consequences, including inefficiency, lack of relevancy (out-of-date), and lack of accountability. Data programmes are intended to provide information of relevance to decision-makers, however few data programmes, including those in many developed countries, are optimized for client needs. This arises generally from an institutional structure in which data-gatherers are quite separate from data-users. The interaction between data-gatherers and data-users should be handled as a client relationship so that the data-gatherer know exactly what is needed by the client(s), and the client understands the limitations and costs of the data-gathering process. This process also builds a constituency for water quality programmes that is necessary to defend these programmes from arbitrary cutting by politicians.

In agriculture (Ongley, 1996), there is rarely interaction between agricultural managers and water quality managers with the result that the database that is needed to assess agricultural impacts on water quality is almost never available. This has particularly serious consequences for developing water quality remediation programmes in developing countries.

Technical Efficiency: In several studies of technical efficiency in water quality programmes by this writer in Asia and Latin America, efficiency was measured against a standard that could be achieved by modern environmental laboratories. This analysis considered only laboratory and field programmes and found that in these examples programme efficiency was only some 10% of potential efficiency. The cause lay in poor technical judgement, inadequate laboratory technique, and poor management of human, facility and financial resources. Efficiency also suffers in many countries because of the overlapping and often redundant mandates of a variety of agencies that operate in the water quality sector.

Capacity Issues: Capacity development is a major topic area, however three issues that are key to developing countries in the water quality sector are:

- Managerial reform: The need to reform management processes, including the promotion of young and often foreign-trained professional staff. China is a good example of a recent change in management technique whereby older senior managers are obliged to step down in favour of younger colleagues.
- Training: Training is often poorly focused and tends to reflect what donors want to provide rather than what the agency really needs. Follow-up is often lacking.
- Sustainability: There is a tendency for national agencies and donors to implement advanced technical capabilities that are not sustainable in the local environment.

New Institutional Models: Government-operated programmes, worldwide, tend to be very inefficient. Therefore, the traditional focus on government-operated programmes is giving way in some countries to the recognition that greater efficiency can be obtained through innovative new arrangements involving such aspects as outsourcing of analytical needs (with appropriate QA control), use of public-private sector partnerships, fee-for-service and income generation models. These latter models require that government agencies adopt a much more business-like approach to revenue and expenses, including delegation of accountability to programme managers for decisions on costing, pricing, retention of earnings, reinvestment, etc..

Technical reform

Technical reform is the area that tends to attract the most attention and investment. Unfortunately, however, technical reform tends to focus on the most obvious (such as facility modernization) and not on the more fundamental technical issues that can reduce facility expenditures by exploring new ways of carrying out the business of water quality management. Here we identify several key areas of technical reform that are key to making meaningful progress in developing Asian countries.

Data Programmes and Networks: In rapidly industrializing countries water quality data should form the basis for making meaningful judgements on water quality priorities, on investment priorities for remediation, and for determining allocation strategies amongst competing economic sectors. However, almost all countries attempt to do this with fixed-site networks using parameters that are often of little use in making these decisions.

One good example of inadequate parameterization is the use in many countries of COD (Chemical Oxygen Demand) as the principal measure of industrial pollution. COD is a useful indicator parameter, however, it is a measure of the combined influence of many types of industrial pollutants having different types of sources, different bio-geochemical pathways in the aquatic system, different toxicological implications, and different impacts depending on whether one is interested in simple water chemistry, or in aquatic life and/or human health. COD is a very poor parameter, therefore, for determining remediation options.

In most countries the fixed-site network is commonly used both for generic descriptive information about surface and ground quality and for management of effluents. In Mexico (Ongley & Barrios, 1997) it was found that the fixed site network could provide adequate descriptive information for public information purposes and to meet international boundary waters treaty needs, but it was not effective nor cost-efficient for effluent regulation. By developing a two-prong approach to network development the cost savings were more than 60% over the original estimates of a single large fixed-site network, and with large gains in efficiency and in the ability to manage effluent impacts.

Technical Innovation: In the past decade there has been a revolution in monitoring technologies. Much of this follows from a better understanding of aquatic and environmental processes and how to more effectively monitor and measure these. In many western countries there is move away from conventional and expensive laboratory measurement, especially for trace organic chemicals and heavy metals, towards inexpensive screening parameters and toxicologically-based “screening” techniques. Screening techniques permit a quick and inexpensive determination of presence/absence of a chemical, or of an “effect” (as measured by some set of toxicological criteria). If the analysis is above some pre-defined limit, then the sample is identified for further analysis; if the result is less that the limit, then the sample is not analysed further. Screening tests can now be applied to effluent measurement, especially as many of these tests are now miniaturized and available as field kits.

Other technical innovation involves a better use of in-stream characterization of organic pollution using biological indices. Recent work in Korea (Chung *et al*. 1998) demonstrates how a bio-index protocol can identify broad patterns of organic pollution.

Data Management and Data Products: An essential component in the modernization of water quality programmes is the ability to effectively deploy data and to create data products that are informative and useful to decision-makers. This involves three key areas: data transmission, data manipulation, and data products. Regrettably, national agencies and donors tend to focus on the mechanics such as the implementation of advanced GIS systems that are often not sustainable, and ignore the most important questions such as the cost of data acquisition and the types of data products that are effective. New technologies using the World Wide Web and e-mail are revolutionizing data transmission which now makes distributed data systems highly effective.

Remediation: In many Asian countries water scarcity is now so profound and water quality so impaired, that the only long-term solution is for massive investment in remediation of water quality. We are now seeing this trend emerging in countries such as China which, like most Asian countries, does not have easily accessible and inexpensive new sources of water to develop. Remediation is a complex issue that involves policy and institutional issues, however here we look only at the technical components.

Because of the lack of a national policy for remediation priorities, the problem of water quality is largely left to local governments. This creates a profound institutional dilemma insofar as remediation in most aquatic systems requires a basin-scale and an integrated approach if the response is to be effective and cost-efficient. For example, a typical river system is highly polluted from a combination of municipal, industrial and agricultural sources. What then is to be the most effective approach? Most national and local agencies do not have the data to judge the relative importance of these types of sources, and do not have the expertise to anticipate with some certainty what the consequence of any particular remediation intervention is likely to be. The result too often is a short-term and usually expensive decision to focus on one sector in which large amounts of money are spent without any ability to accurately predict the outcome. Examples are common from inland waters of some Asian countries where sector decisions had little or no impact on water quality. Of special importance to agriculture are remediation decisions involving eutrophication as it is well known that expenditures on eutrophication control are often unsuccessful especially for lakes in Asia. It becomes very important, therefore, to determine the relative balance of contribution of nutrient loadings from different economic sectors, including the loading that is stored in bottom sediments ("internal" load) and which is historical, in order to assign costs and benefits appropriately.

The problem of lack of knowledge and experience in Asia with complex remediation problems is also worthy of note. These problems are usually contracted out to foreign companies who may (or may not) solve the problem but, more importantly, almost never leave any new capacity at the local level to deal with similar problems in the future. The need to develop local capacity is critical if remediation is to be cost-effectively dealt with by local agencies. Fortunately, there is now new computer-based technology available using "knowledge-based" techniques that permits local experts to access knowledge that is relevant to the issue. These knowledge-bases are generally packaged as decision support systems (DSSs) that focus on specific problems. Another advantage of these new systems is that, through the analysis of uncertainty, they can assist in identifying realistic objectives and can guide the user towards those types of solutions that make practical and economic sense in the local environment (Ongley & Booty, 1999).

For the purpose of agricultural planning and its impact on water quality FAO has developed several types of decision support systems (Ongley *et al*. 1998). These systems are designed to permit planners to make simplifying decisions on land, water and crop management characteristics that allow a first estimate of water quality impacts without having to collect site data. Following from these estimates the planner can then decide if more data are necessary, or if adjustments at the planning stage will produce a less damaging environmental condition. DSS systems offer great potential in data-poor environments by focusing on judgements that can be derived from "domain" (what is known in a subject area) knowledge and supplemented by any useful data and knowledge that are available about the local situation.

References

Arriens, L.W., Bird, J., Berkoff, J., & Mosley, P., (Eds.), 1996. *Towards Effective Water Policy in the Asian and Pacific Region*. Asian Development Bank, Manila. (in three volumes)

Chung, P-R., Cho, K-S., Jung, Y., Shen, Y., Gu, M., & Feng, W., 1998. *Biological evaluation of running waters in Korea, with special reference to bioassessment using the PFU system*. Manuscript accepted by Hydrobiologia. (in press).

ESCAP, 1994. *Guidelines on Monitoring Methodologies for Water, Air and Toxic Chemicals/Hazardous Wastes*. Economic and Social Commission for Asia and the Pacific (ESCAP), United Nations, New York.

ESCAP, 1995. *Integrated Water Resources Management in Asia and the Pacific*. Water Resources Series No. 75. Economic and Social Commission for Asia and the Pacific (ESCAP), United Nations, New York.

ESCAP, 1997. *Guidelines on Water and Sustainable Development: Principles and Policy Options*. Water Resource Series No. 77. Economic and Social Commission for Asia and the Pacific (ESCAP), United Nations, New York.

DPCU, 1999. Transboundary Basin Analysis as summarized in Danube Watch, Issue 2/99, Danube Programme Coordination Unit (DCPU), Vienna, Austria.

FAO, 1995. *Reforming Water Resources Policy*. FAO Irrigation and Drainage Paper 52. FAO, Rome.

MRCS, 1996. *Mekong River Basin Diagnostic Study*. UNEP-sponsored study carried out by the Mekong River Commission Secretariat. MRCS, Bangkok, Thailand.

Ongley, E.D., 1994. Global Water Pollution: Challenges and Opportunities. In: *Integrated Measures to Overcome Barriers to Minimize Harmful Fluxes from Land to Water*, Proceedings of the Stockholm Water Symposium, Stockholm, Sweden. Aug.10-14, 1993, 23-30.

Ongley, E.D., 1996. *Control of Water Pollution from Agriculture*. FAO Irrigation and Drainage Paper 55. FAO, Rome.

Ongley, E.D., 1998. Modernization of water quality programmes in developing countries: issues of relevancy and cost efficiency. *Water Quality International*, Sept/Oct-1998, 37-42.

Ongley, E.D. and E. Barrios Ordoñez, 1997. Redesign and modernization of the Mexican water quality monitoring network. *Water International* **22**:3, 187-194.

Ongley, E.D. Dorner, S., Swayne, D., Pal, C., and A. Kandiah, 1998. *A case-matching decision-support system to predict agricultural impacts on water quality*. In: "International Workshop on Management of Water Quality and Control of Pollution in Latin America", FAO, Arica, Chile. (in press).

Ongley, E.D., and Booty, W.G, 1999. Pollution remediation planning in developing countries: conventional modelling versus knowledge-based prediction. *Water International,* 24/1, pp.31-38.

Shuval, H., Lampert, Y., and Fattal, B., 1996. Development of a risk assessment approach for evaluating wastewater reuse standards for agriculture. *Water Science and Technology*.

Takeuchi, K., Jayawardena, A.W. and Takahasi Y. (eds.). 1995 & 1997. Catalogue of Rivers for Southeast Asia and the Pacific. Volumes 1 and 2. UNESCO-IHP Publication, UNESCO Regional Office, Jakarta, Indonesia.

UNEP, 1996. *Characterisation and Assessment of Groundwater Quality Concerns in Asia-Pacific Region.* Environmental Assessment Report, Prepared by the British Geological Survey. UNEP/DEIA/AR.96 1.

United Nations, 1997. *Comprehensive Assessment of the Freshwater Resources of the World*. World Meteorological Organization, Geneva, Switzerland.

WWEE, 1999. "*Half of China's population consumes contaminated water*". Reported in *World Water and Environment Engineering,* June 1999, citing a report of the World Resources Institute, Washington D.C.

Integrated system of phytodepuration (ISP) applied to agro-industrial wastewaters: two case examples

Abstract

The Integrated System of Phytodepuration (ISP) is a patented biotechnology based on the combination of phytodepuration in pluriculture and conventional depuration (sewage treatment) technology. This biotechnology bases its efficiency on the energetic balance of the biological systems that intervene on bio-dynamics present in the natural waters of river and lakes. ISP is different from other conventional phytodepurative systems, and two case examples are presented to show typical ISP applications.

General description

The Integrated System of Phytodepuration (ISP) is a patented biotechnology based on the combination of phytodepuration in pluriculture and conventional depuration (sewage treatment) technology. This biotechnology bases its efficiency on the energetic balance of the biological systems that intervene on bio-dynamics present in the natural waters of river and lakes. ISP is different from other conventional phytodepurative systems because is based on two fundamental principles:

- The decomposition of organic substances into inorganic compounds (nutrients) that is achieved through biological processes of aerobic micro-organisms (bacteria)
- The ability of rooted plants in hydroponics cultivation and of phytoplankton to absorb and transform inorganic nutrients through plant and micro-algae growth.

The operative characteristics of the process allow a simplification of the system's planning and management. The resulting costs are reduced in comparison with conventional technologies of depuration.

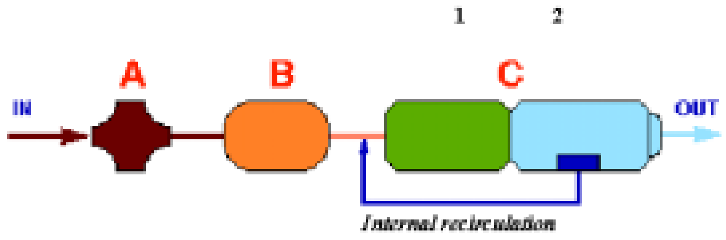
The ISP treatment plant has three operative stages as shown in the Figure 1.

Stage A: screening of all the sewage in-flow to remove non-biodegradable solids
Stage B: biological treatment with conventional oxidation systems
Stage C: basin of phytodepuration divided into two functional sections: the first with rooted plants and the second with phytoplankton (micro-algae).

At the end of the process, the effluent discharged is completely depurated of all organic and inorganic compounds that cause pollution, and can be used in agriculture, industrial use, etc. ISP guarantees the total absence of noxious odours.

Maurizio Giannotti
Wastewater Consultant, Viterbo, Italy

FIGURE 1
General flow chart



Beginning in 1986 several applications of the "Integrated System of Phytodepuration" were financed in Italy for more than USD 10 million. They were designed and dimensioned to treat sewage coming from cities, industries, agro-industries, etc.

Stage A - Conventional physical treatment

The physical treatment is the same normally used in each depuration plant to separate the liquid phase from non-biodegradable raw materials that are collected into tanks and then drained for discharge.

Physical treatments normally used are: grilling; sand catching and / or screening systems; and primary decantation, etc. The standards that determine the choice and dimensioning of physical pre-treatment are the same as those used in conventional depuration systems.

Stage B - Biological treatment

The function of Stage B is to partially treat the influent wastewater by eliminating: aggressiveness, acidity characteristics; and oxygen deficiency. The standards that determine the choice and dimensioning of biological treatments are the same as those used in conventional depuration systems.

Stage C - Phytodepurative tank

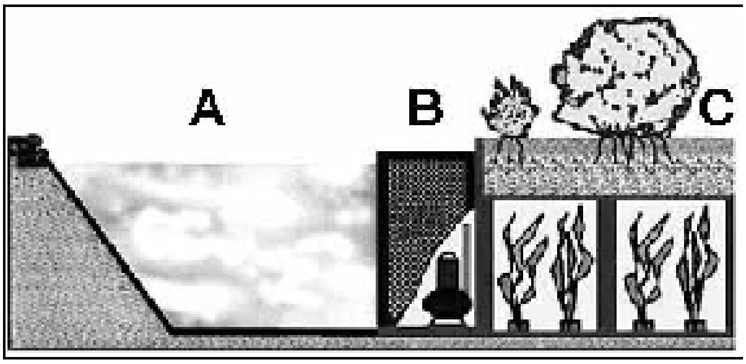
Stage C is an artificial structure divided in two different and separated sections:

1. **Section with rooted plants:** This section is a modification of the hydroponics plant growth system where plants are grown directly on an inert substratum to which a flow of wastewater is continuously applied. It consists of a tank in reinforced concrete divided into parallel channels. On top, they are covered with an iron grille that supports a stratum of gravel where rooted plants have been planted in hydroponics cultivation. Plant top-growth provides nutrient uptake.
2. **Free light section – lagoon:** This consists of an artificial lagoon with fish, where the growth of unicellular algae with their photosynthetic capabilities: oxygenate water again, and transform nutrients into biomass.

Wastewater is a valuable substrate for the production of useful biomass. The presence of fish regulates the growth of algae biomass and prevents insect larvae such as mosquitoes, etc.

Internal recirculation: A pump system, inside the lagoon, provides for internal re-circulation of water to obtain a constant phytodepurative efficiency and to ensure functional integration between rooted plants and phytoplankton.

FIGURE 2
Phytodepurative section



A - Pond with fish
B - Re-circulation pump
C - Rooted plants section

All the ISP (Stages A+B+C) are dimensioned and calibrated for:

- Space requirements
- Climatic conditions
- Biological adaptation of vegetable species
- Use of native species that are found in the same area is recommended.

ISP main advantages

Recovery of pre-existent depuration structures. This system can reuse and integrate conventional treatment plants that are out of order or not working properly or efficiently.

- The building of ISP treatment plants is cheap and easy, and is suitable for local organisation.
- Effluent has the qualities of an unpolluted river and can be used in agriculture, etc.
- Total absence of unpleasant smells or colours of the basin water and of troublesome insects.
- Possibility of embodying the system in public contracts on water treatment and land management.
- Contributes to reclamation of coasts, rivers or lakes which receive the treated effluent.
- Modest cost for the construction and maintenance of the system.
- No need of foreign technicians.
- Produced biomass can be re-used “as is”, or after preliminary transformation.
- ISP works well with water of polluted rivers and lakes; or with saline and brackish waters.
- ISP does not produce biological sludge.

Functional comparison

The table below shows a functional comparison between ISP and conventional treatment technologies. The following examples show typical ISP applications.

DAIRY SEWAGE TREATMENT: PESCI’S DAIRY

Pesci’s dairy is a private industry built in 1995 in the province of Viterbo, Central Italy. It is a covered area of 2 000 m^2, and uses the most modern technologies for the production of fresh

ISP	CONVENTIONAL TECHNOLOGIES
System Structure	
Pre-treatments Primary biological stage Phytoabsorbing basin	Pre-treatments Primary biological stage Secondary biological stage Denitrification and dephosphatizing system
Depurative efficiency	
Unchanged	Changeable, according to the organic load and flow
Effluent quality guarantee	
Effluent discharged by the ISP is not affected by variations in load or flow.	Effluent quality is not guaranteed if machinery installed does not function properly.
Energy expenditure	
Lower electrical energy consumption: up to 80% less in comparison with other technologies	High energy expense due to greater number of machines required in the different depurative stages
Maintenance and management	
Low management is required: two visits per week	Need of diligent, continuous, daily maintenance
Management costs	
No expenditure for chemical products such as flocculants and/or disinfectants	Use of chemical products of different kinds with consequent tarring system problems and high costs
Sludge production	
No biological sludge production	Sludge Production and draining problems

and seasoned cheese. The dairy can process 20 tons of cows' and sheep's milk per day, producing from 3 to 4 tons of cheese a day.

Main features of the sewage to be treated	
Total flow	50 m^3/d
Average flow	1.5 m^3/h
Max flow	4 m^3/h
pH	6.0 – 6.5
Total load	75 kg/d in COD
Specific load	1,500 ppm in COD
Inhabitants equivalent	**750 to 800**

All sewage produced is piped to a depuration plant arranged outside the covered dairy area and built following the ISP.

The ISP application consists of the three stages illustrated in Figure 1.

Stage A: consists of an Imhoff tank that collects the dairy sewage. Its volume is 5 m^3 and it is equipped with a barrel pump. During the primary decantation, solid materials fall at the bottom of the tank. The liquid part is pumped to Stage B for biological treatment.

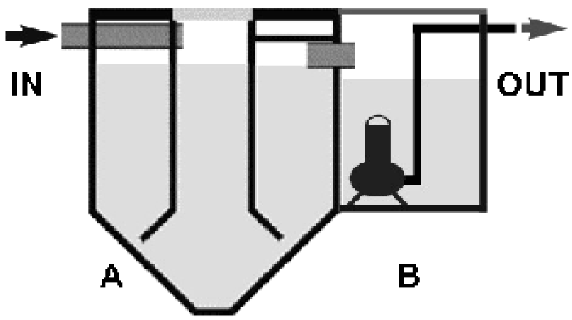
Stage B: Considering the space available, the biological pre-treatment chosen is a compact solution with the same yield and depurative efficiency as the conventional depuration systems, but without unsightly and noisy external structures. The biological technology used is the Submerged Oxygenated Percolating System (SOPS); it consists of an oxidation tank (parallelepiped-shaped 22 m. long, 4 m. wide, 2 m. deep, 80 m^3 total volume), divided into two parallel channels by an intermediate wall. Special plastic strips are laid out at the bottom of the channels to support the adhesive biological film (Figure 4).

The oxidation tank is equipped with two submerged oxygenators that supply the needed oxygen for the digestion of the organic substance and circulate the water continuously. From Stage B, water passes to Stage C through an overflow pipe.

Stage C: the phytodepurative basin is pie shaped, in the form of an arc of a circle, with a total volume of 500 m^3, area of 420 m^2 and depth of 1.2 m (Figure 5).

In the basin one can distinguish between: (i) Section 1 basin with evergreen rooted plants and (ii) Section 2 pond with fish and phytoplankton activity

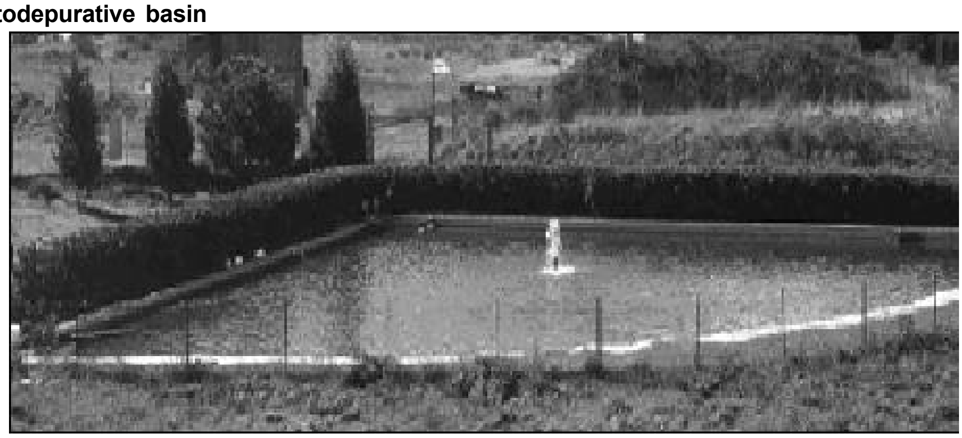
FIGURE 3
Imhoff tank and feed pump



A - Imhoff tank
B - Feed pump to the biological stage

FIGURE 4
Submerged oxygenated percolating system

FIGURE 5
Phytodepurative basin



Section 1 - basin with rooted plants: This consists of a tank of reinforced concrete divided into two parallel channels; on top is an iron covering that supports a stratum of gravel, 40 cm thick, where 400 rooted plants have been planted in hydroponics cultivation. Vegetable species used are *Pittosforum* sp., *Laurus comunis* and *Laurus nobilis*.

Section 2 - Pond with fish: This is a small aerobic lagoon where phytoplankton activity is fostered. Microalgae absorb nutrients (N and P) and produce oxygen through photosynthesis. It also reduces pathogenic bacteria with the result that the effluent has a low concentration of bacteria, without using chlorination of conventional systems. The purified effluent flows to the final well and is piped underground for sub-irrigation.

Fish: Fish prevent both eutrophic phenomenon and the proliferation of troublesome insects (mosquitoes, flies, etc.). Several species of fish live in the pond: (i) herbivorous species, feeding on microalgae and organic sediments and (ii) predatory species, feeding on larvae and insects.

FIGURE 6
ISP Stage C: Pond with rooted plants

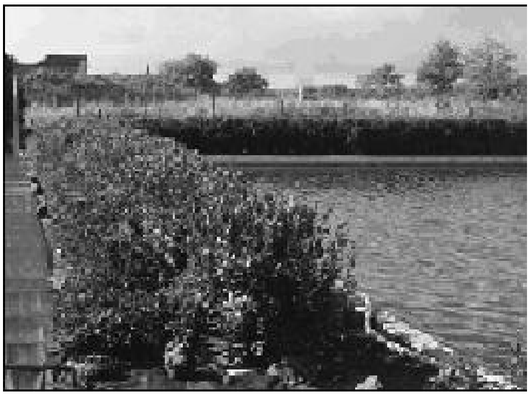
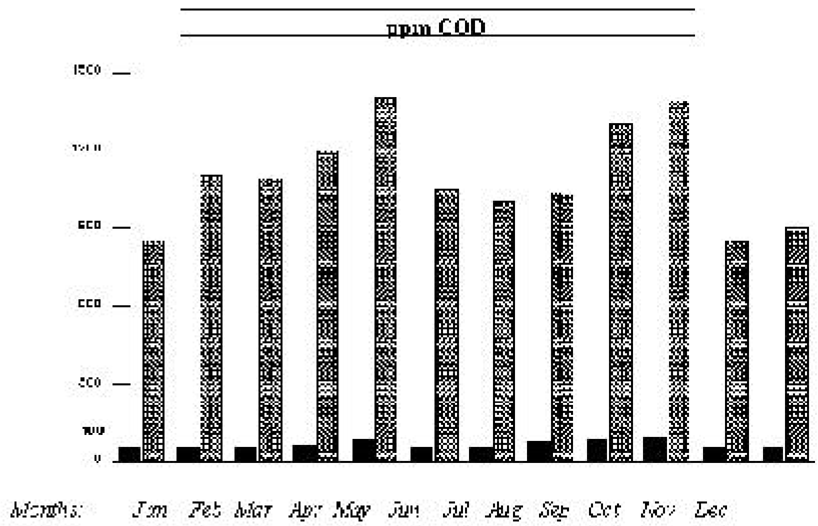


FIGURE 7
ISP Stage C: Pond with fish

FIGURE 8
Pesci's Dairy: ISP COD reduction in 1997



Internal water re-circulation: A pump system installed in the pond allows continuous water circulation at the head of the phyto-absorbing basin allowing oxygen distribution that is essential for successful growth of the rooted plants. Internal re-circulation feeds also the fountain situated in the middle of the pond. Apart from aesthetics the fountain mixes water homogeneously, thus avoiding stagnation.

Power required: The operation of the ISP plant needs only **6 kWh** of electrical power.

Conclusion: Operating since 1995, the ISP has always discharged an effluent with chemical and microbiological characteristics within legal limits. This allows Pesci's Dairy to work in a sustainable way without fear of sanctions due to its own discharges.

Vinegar Sewage Treatment: Monari's Vinegar Company

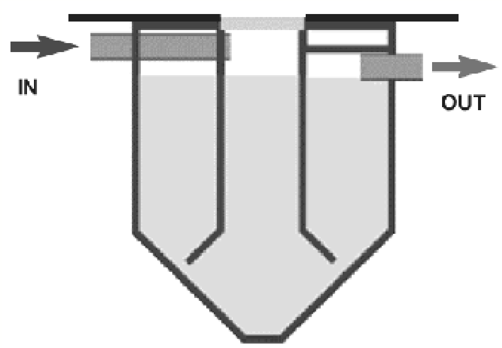
Monari's vinegar company is a private industry built in 1912 in Province of Modena in northern Italy. It has a covered area of 15,000 m^2 and uses the most modern technologies for the production of vinegar. Sewage produced is piped to a depuration plant located on its property and built according to the ISP. The ISP application has the same three stages as noted in Figure 1 including:

Stage A: Imhoff Tank, to remove solids
Stage B: biological oxidation with submerged oxygenated percolation system
Stage C: phytodepurative basin with rooted plants section and lagoon

Main features of the sewage to be treated	
Total flow	20 m^3/d
Average flow (10 hours)	2 m^3/h
Maximum flow	4 m^3/h
pH	4.0 – 4.5
Total organic load	140 kg/d in COD
Specific load	7,000 ppm in COD
Inhabitants equivalent	**1,200**

Stage A: consists of an 8 m^3 Imhoff tank that collects all sewage. During the primary decantation solid materials fall to the bottom of the tank. From Stage A, water passes to the oxidation system through an overflow pipe.

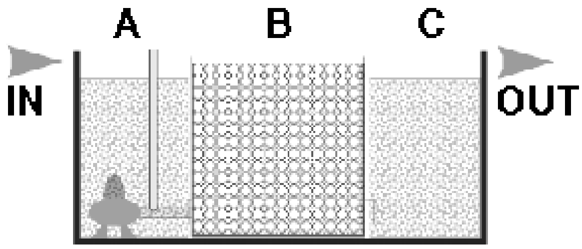
Figure 9
Imhoff tank



Stage B: The oxidation stage is a high-load biological treatment based on the SOPS. Total tank volume is 12 m^3. The oxidation tank is equipped with one submerged oxygenator that supplies oxygen for the digestion of organic substances and circulates the water continuously. The bowers injector (Venturi system) makes it possible to recirculate and oxygenate the liquor at the same time. When the liquor goes through the filling bodies, it reaches the adhesive biological film that "captures and digests" the existing organic substance. In this stage the organic load (COD) is reduced from 7 000 to 1 000 ppm. Water acidity (pH) decreased from 4.0 – 4.5 up to 6.5 – 7.0. The outlet effluent passes to the stage C through an overflow pipe.

Stage C is a fan-shaped phytodepurative basin, 1.5m deep, with a total volume of 900 m^3 (Figure 11). In the basin can be distinguished: (i) Section 1 basin with evergreen rooted plants and (ii) Section 2 pond with fishes and phytoplankton activity.

FIGURE 10
Submerged oxygenated percolating system



A - Blending chamber with submerged oxygenator
B - Distributing chamber
C - Filling bodies chamber

Section 1 - basin with rooted plants: consists of a tank of reinforced concrete divided into three parallel channels covered on top by an iron grille that supports the stratum of gravel where 1,000 rooted plants have been planted in hydroponics cultivation. Vegetable species used are *Pittosforum* sp., *Laurus comunis* and *Laurus nobilis*.

Section 2 - Pond with fish: is an aerobic lagoon where phytoplankton activity is fostered. Microalgae absorb nutrients (nitrates and phosphates) producing oxygen through photosynthesis; microalgae activity cuts down pathogenic bacteria. The final effluent has a low concentration of bacteria, without using chlorination of conventional systems.

FIGURE 11
Fan-shaped phytodepurative basin

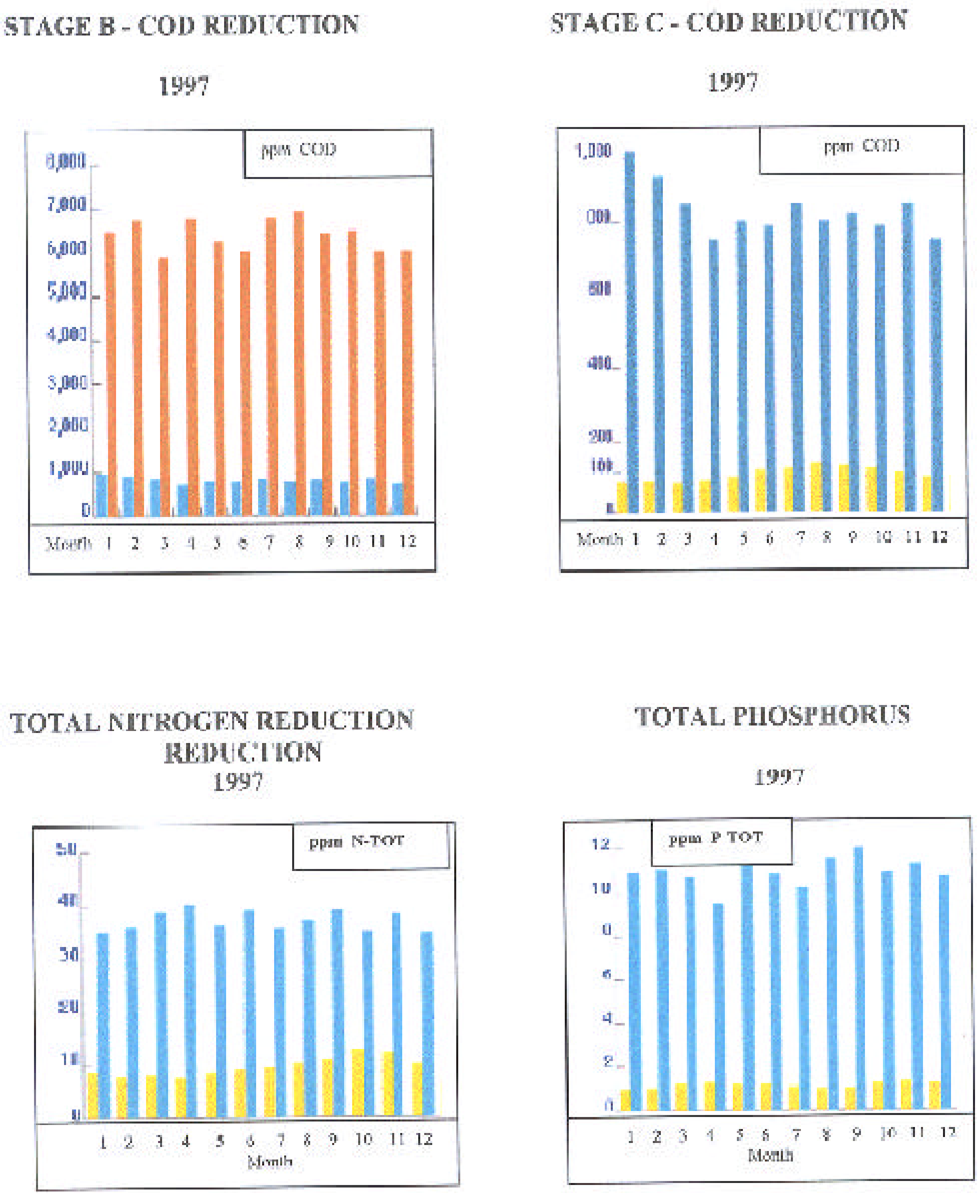
Fish. Fish presence prevents eutrophic phenomenon and proliferation of troublesome insects (mosquitoes, flies, etc.). Several species live in the pond: (i) herbivorous species, feeding on microalgae and organic sediments and (ii) predatory species, feeding on larvae and insects.

Internal water recirculation: A pump system installed in the pond allows continuous water circulation at the head of the phytoabsorbing basin. Internal recirculation also feeds two waterworks; the first is a fountain in the middle of the pond, the second is in a lateral position on the rooted plant section wall. The waterworks function is to mix water homogeneously to avoid stagnation. Internal recirculation allows oxygen distribution that is necessary for the rooted plants. Treated effluent flows to the final well and from there it is piped into a little river.

Power required. The ISP plant, once built, needs only **8 kWh** of electrical power

Conclusion: Since 1995 the ISP plant has always discharged an effluent with chemical and microbiological characteristics within legal limits. This has allowed the Monari Co to work in a sustainable way without fear of sanctions due to its own discharges.

Figure 12
Comparison of : Inlet / outlet loads of COD in the Stages: B and C; Inlet/ outlet loads of N-TOT and P-TOT in Stage C



Use of treated wastewater for irrigation: agronomic aspects, and environmental and health impacts

Abstract

In most countries of the world, due to the rapid development of urban and rural domestic water supplies, conventional water resources have been seriously depleted and wastewater reclamation and use in irrigation has gained an increasing role in the planning and development of additional water supplies. However, protecting public health and the environment are the main concerns. Wastewaters are unique in composition and their acceptability to replace more conventional or other non-conventional water sources for irrigation is highly dependent on whether the health risks and environmental impacts are within acceptable levels. This paper presents the benefits and problems associated with wastewaters and provides information on present use practices and future prospective uses of treated wastewaters for irrigating agricultural crops, including vegetables and flowers, within acceptable levels of risk.

Land and water development in most countries was slow until the 1950s. Thereafter, rapid development started and most of the countries introduced national development plans, which accorded the agricultural sector, and particularly irrigation development, top priority. This rapid development of irrigated agriculture has meant that easily accessible water resources, such as rivers and shallow ground water of good quality, are almost entirely committed. The resulting scarcity of water has caused great concern. Thus, it became urgent to give serious thought to policies geared to economical management of this precious and costly commodity. Account must be made of the variable and limited supply, as well as to incessantly growing demand, in order to better respond to present-day needs without detriment to future generations. To the scarcity factor must be added that of fragility. Water quality is increasingly endangered by pollution (fertilizers, pesticides, heavy metals, outflow of wastewater from the cities), and water often loses its natural ability to purify itself to an adequate extent in the face of such pollution. In order to avoid serious hazard to people's health and to safeguard the environment, it is becoming more and more urgent to resort to high-cost procedures for the treatment of water. In this respect, most countries are devising ways to optimize available water supplies and to promote the use of non-conventional water resources with particular emphasis on wastewater reclamation and use in irrigation.

Use of wastewater in irrigation, without planning, has been practiced in many countries for centuries. It has been recognized that wastewater could be a valuable way to cope with the scarcity of water resources, if its use is based on sound planning taking into consideration the

I. Papadopoulos
Agricultural Research Institute, Nicosia, Cyprus

risks associated with the use of this water for irrigation. Planned wastewater use may also present to the countries of these regions an opportunity for pollution abatement when it replaces effluent discharge to sensitive surface waters. This could be of particular importance for the countries of Southeast Asia.

In 1989, WHO published the "*Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture"*. In the same year, UNEP and WHO, jointly published the "*Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture*", with emphasis on environmental and public health protection. In 1991 UNEP and FAO, jointly published the *"Environmental guidelines for wastewater reuse in the Mediterranean region"*. These were followed by an FAO publication on *"Wastewater Treatment and Use in Agriculture"* in 1992. These guidelines have been supporting many developing countries to implement or upgrade environmentally sound and safe wastewater use systems adapted to their own technical, socio-economic and cultural conditions. The FAO Regional Office in Cairo in 1995 prepared a publication on *"Wastewater management and environmental protection in the Near East Region"* intended to help the countries of the region. The FAO Regional Office in Cairo is now preparing a new practical manual aimed at recommending solutions associated with wastewater reuse.

The Scientific Group, which produced the WHO Guidelines, recommended that research into several areas of wastewater use should be continued and intensified. Among the priority items was the development of new wastewater treatment technologies which could provide treated effluent quality compatible with the WHO guidelines. The need to complement the available health protection information was also stressed, particularly with respect to the effects of viruses and of chemical compounds present in mixed domestic/industrial wastewater used in many developing countries for irrigation of crops. The Group also recommended that WHO should, in association with other UN agencies working in the sector, take the necessary steps to disseminate its findings to assist Member States in planning and implementing schemes for wastewater use and in developing appropriate legislation, institutions and training programs to enable them ensure that health is protected when such schemes are implemented. The objective is to respond to these issues and to produce a package of technical recommendations concerning treatment, reuse, health and environmental impacts.

Quality considerations

Chemical and physicochemical quality characteristics and considerations

The physical properties and the chemical and microbiological constituents of wastewater are important parameters in the design and operation of collection, treatment and use of the treated effluent (Asano *et al*., 1984). The magnitude of the problem of sewage effluent and its acceptability for use, therefore, can be assessed properly if its quantity and quality are viewed as integral part of an overall policy that includes water, land use, agricultural production, human health and environmental protection.

The constituents and the composition of wastewaters vary widely and depend on the composition of the municipal water supply, nature of the wastes added during use, and the degree of treatment the wastewater is receiving (Asano *et al*, 1984). In an integrated approach to treatment and use of the treated wastewater for irrigation, the assurance of treatment reliability and avoidance of often and regular monitoring are highly desirable. In recent guidelines (Ayers, 1977; FAO, 1985; Kandiah 1987; Westcot and Ayers, 1984; Pescod, 1992; FAO/RNEA, 1993), four problem categories, namely salinity, infiltration, toxicity and miscellaneous problems, are used for evaluating conventional sources of irrigation water. Irrigation water may be classified into one of three categories, namely - no restriction, slight to moderate restriction and severe restriction for use.

Biological quality criteria

The health problems associated with the use of raw or partially treated wastewater are well-documented (Feachem *et al*., 1980; Mara and Cairncross, 1987; 1989). Water reuse guidelines are principally directed at public health protection and are generally based on the control of pathogenic organisms. Several countries in arid and semi-arid regions have developed criteria and/or guidelines intended to ensure that the use of wastewater does not present unreasonably health risk.

In the 1960s, a microbiological approach to health risks was dominant, concentrating on potential risks and not actual risks, and strict guidelines were set where wastewater was to be used to irrigate crops eaten raw. In California (State of California, Department of Health Services, 1978), this was set at the minimum bacterial (indicator) concentration detectable by routine monitoring (<2.2 coliform/100 ml), and was meant to indicate that the wastewater was pathogen free.

In 1989, a WHO Scientific Group formulated new guidelines for wastewater use in agriculture and aquaculture (WHO, 1989). They are based on preliminary recommendations from Engelberg in 1985 (IRCWD, 1985). The main consideration was given to the fact that in many developing countries the actual health risks associated with human waste use, are associated with helminthic diseases and that the safe use of wastewater in agriculture or aquaculture will, therefore, require a high degree of helminth removal.

IRRIGATION WITH WASTEWATER

Irrigation with municipal wastewater is a well-established practice in many countries in the Near East, North Africa, Mediterranean European countries, North and South America. In these countries, often 70 to 90% of applied water is used for agricultural and landscape irrigation. Thus, as the demand for water increases, irrigation with reclaimed wastewater became an important component of the total water resources planning and development.

However, reuse of reclaimed wastewaters may adversely affect public health and the environment. Of particular concern is the degree of purification, but the selection of the most appropriate methods of irrigation and the water use efficiency by which wastewater is applied at the farmers level are also important. The lower the water use efficiency, the higher is the possibility of contaminating soil and ground water. In this respect, selection of the irrigation method and scheduling of irrigation are important components in the overall system for efficient and safe use of the reclaimed wastewaters on environmentally sound bases. Most counties, even though practicing irrigation with modern irrigation systems, are still suffering from very low water use efficiency. This creates severe environmental problems. In some countries water use efficiency at the farmer level is less than 35%.

Strategy to protect human health and environment

The success of using treated wastewater for crop production depends greatly on adopting appropriate strategies aimed at optimizing crop yields and quality, maintaining soil productivity, and safeguarding public health and the environment. Several alternatives are available and a combination of these alternatives may offer an optimum solution for a given set of conditions. The user should have prior information on wastewater supply and its quality to formulate and adopt an on-farm management strategy.

In the past particular attention has been given to waste treatment as the only feasible and fully effective measure for the reduction of health risks. However, in most countries, full treatment of wastes is not feasible or even desirable, due mainly to economic constraints. It is, therefore, necessary to consider ways for the protection of human health and environment by means other than waste treatment, especially where economic constraints are felt (Mara and Cairncross, 1987; Hespanhol, 1990). To achieve this and to protect environment and human health, four groups of measures are available (Blumenthal *et al*., 1989):

- waste treatment;
- restriction of the crops grown;
- choice of methods of application of the treated effluent to the crops; and
- control of human exposure to the waste, and hygiene.

While full treatment prevents excreted pathogens from reaching the field, crop restriction and human exposure control act later in the pathway, preventing excreted pathogens from reaching the persons concerned, namely the crop consumers and the agricultural workers. An integrated approach to planning wastewater reuse schemes will allow an optimum combination of agrotechnical measures to be selected, depending on the local socio-cultural, institutional and economic conditions.

Crop restriction is a strategy to provide protection to the consuming public (Hespanhol, 1990). However, it does not provide protection to farm workers and their families who remain at high risk since they are still exposed to pathogens in the waste on the soil and on the crop. Adopting crop restriction as a means of health and environment protection in reuse projects requires a strong institutional framework and a capacity to monitor and enforce compliance regulations. Farmers must be advised why such crop restriction is necessary and be assisted in developing a cropping pattern, which fully utilizes the constant production of a certain quality treated wastewater. Crop restriction includes high risk if strong control and legal authorization are absent. In certain countries the notion of purifying wastewater for unrestricted use is gaining popularity. With restricted use the main problem is monitoring and control.

Regulatory considerations

To protect public health and environment, and without unnecessarily discouraging wastewater reclamation and reuse, many accepted regulations include water quality guidelines as well as requirements for treatment process, sampling and monitoring, treatment plant operations, and treatment process reliability. The management of the reclaimed water once it leaves the wastewater treatment facility is also an important facet of the overall wastewater reclamation and reuse operation. Generally, in order to minimize health risks and aesthetic problems, tight controls are also imposed on the delivery and use of reclaimed water.

Most of the guidelines and regulations adopted in developed countries were intended to control and protect the quality of the water bodies to which reclaimed water is discharged. In most of these countries, rarely has been considered the reuse aspect as an integral component of the overall treatment system. Because of this, the quality parameters considered as important in these guidelines are BOD_5, SS and faecal coliforms.

The first official criteria for wastewater treatment and reuse are probably those developed and adopted in California. These criteria, although extremely stringent to a level that is prohibitive for reclaimed water reuse for irrigation in most of the countries, have been adopted in a number of countries throughout the world as a base for formulating their national criteria and guidelines.

In 1992, the US Environmental Protection Agency revised and updated their own guidelines. The primary purpose of these guidelines is to provide information about how to develop effective wastewater reuse programs. They are intended for U.S. utilities and regulatory agencies that are seeking to establish standards or regulations for the reclamation and reuse of wastewater. They provide useful albeit general information for developing countries.

France has recently adopted the WHO guidelines. Some other European countries are also oriented toward accepting the same guidelines. In some countries more strict guidelines were adopted with the aim of dealing with specific local conditions. These guidelines are followed by a code of practice to ensure the best possible application of the wastewater in irrigation.

Agronomic and environmental studies

The value of treated wastewater as a source of nutrients is illustrated in Tables 1, 2 and 3. The yield results indicate the superiority of treated wastewater and the possibility of producing high yields without additional N fertilizers. Similar results have been obtained with phosphorus and potassium fertilizers (Papadopoulos and Stylianou, 1987, 1988a, 1988b, 1991). The yield results indicate also that with wastewater, in most cases, good yield could be obtained with no additional N. In this case yield might not be the highest but with no additional N, pollution problems are minimized. It is therefore, imperative that recommendations to the farmers concerning fertilization should be different for wastewater and fresh water. This is especially critical in situations with shallow groundwater which is easily polluted by nitrate-N.

TABLE 1
Yield of fresh sudax as influenced by water and N level

Water	N-Treatment ($g N/m^3$)	Yield (kg/plot)	
		1995	1996
Farm water	Nil	80.2 c	67.5 d
	30	106.7 b	102.8 c
	60	118.2 b	111.5 b
	90	125.3 a	118.2 a
Mean		107.6 B	100.0 B
Wastewater	Nil	127.1 a	119.1 a
	30	126.9 a	122.8 a
	60	127.9 a	124.2 a
	90	128.5 a	125.7 a
Mean		127.6 A	123.0 A

New directions for wastewater reuse

Wastewater use in irrigation has been accepted in many countries. However, it is used mostly for irrigating fodder and industrial crops. The question, therefore, is whether we should restrict irrigation with treated wastewater to fodder and industrial crops or to extend its use to more promising and profitable crops including vegetables and flowers. Actually, this should be one of the ultimate goals of wastewater since profitable reuse creates the

TABLE 2
Yield of fresh corn as influenced by water and N level

Water	N-Treatment ($g N/m^3$)	Yield (kg/plot)	
		1995	1996
Farm water	Nil	83.9 d	86.6 d
	30	114.9 c	113.6 c
	60	111.9 c	128.4 b
	90	135.6 b	129.2 b
Mean		111.6 B	114.5 B
Wastewater	Nil	129.8 b	136.0 b
	30	137.4 b	136.2 b
	60	145.1 a	146.0 a
	90	149.0 a	147.2 a
Mean		140.3 A	141.3 A

TABLE 3
Yield of eggplant per plot of 41 plants as influenced by water and N level

Water	N-Treatment (g N/m^3)	Yield			
		Yield kg/plot		Number of fruits/plot	
		1995	1996	1995	1996
Farm water	Nil	160.3 e	129.6 e	644 d	696 d
	30	184.8 d	145.8 d	754 c	836 c
	60	207.4 c	197.8 c	838 b	956 b
	90	206.1 c	198.0 c	871 b	974 b
Mean		189.6 B	167.8 B	777 B	865 B
Wastewater	Nil	227.3 b	221.6 b	942 a	1120 a
	30	251.1 a	230.6 a	999 a	1156 a
	60	237.0 b	223.0 b	964 a	1112 a
	90	234.1 b	235.7 a	991 a	1226 a
		237.4 A	227.7	974 A	1154 A

appropriate conditions for sustainability. More emphasis should be particularly focused on flowers. The reason is that even though the microbiological quality of the wastewater could be within acceptable risk to irrigate vegetables, the **psychological** factor is always present. Moreover, there is always the fear of **biomagnifigation** (accumulation of chemicals in edible parts at high concentrations) of heavy metals and nitrates which may adversely affect human health. With flowers these reservations are overcome.

References

Asano, T. 1987. Irrigation with reclaimed municipal wastewater. GeoJournal 15:273-282

Asano, T., Smith, R.G. and G. Tchobanoglous, G. 1984. Municipal wastewater: Treatment and reclaimed water characteristics. In: G.S. Pettygrove and T. Asano (eds). Irrigation with reclaimed municipal wastewater. California State Resources Control Board.

Ayers, R.S. 1977. Quality water for irrigation. J. Irrig. Drain. Div., ASCE. 135-154.

Blumenthal, U.J., Strauss, M., Mara, D.D. and S. Cairncross, C. 1989. Generalized model of the effect of different control measures in reducing health risks from waste reuse. Wat. Sci. Tech., 21:567-577.

EPA. 1992. Guidelines for water reuse. WASH Technical Report No.81. pp 252.

FAO. 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29.

FAO/RNEA. 1992. "Wastewater management and environmental protection in the Near East Region

FAO/RNEA. 1993. Monitoring wastewater for irrigation. Tech. Bul. No. 7, p18.

Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. 1980. Appropriate technology for water supply and sanitation. Vol. 3: Health aspects of excreta and sludge management -The World Bank, Washington, D.C.

Hespanhol, I. 1990. Guidelines and integrated measures for public health protection and agricultural reuse systems. J. Water SRT-Aqua Vol 39, No 4:237-249.

IRCWD. 1985. Health aspects of nightsoil and sludge use in agriculture and aquaculture: The Engelberg Report, IRCWD News 23:Duebendorf, Switzerland.

Kandiah, A. 1987. Reuse of sewage effluent in agriculture. Some new dimensions. Treatment and Use of Wastewater, Split, Yugoslavia.

Mara, D. and Cairncross, S. 1987. Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture measure for public health protection. United Nations Environment Programme/World Health Organization, Geneva.

Mara, D. and Cairncross, S. 1989. Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture: Measure for public health protection. United Nations Environment Programme/World Health Organization, Geneva.

Papadopoulos, I. and Stylianou, Y. 1987. Secondary treated urban effluent as a source of N for trickle-irrigated cotton, sunflower and sudax. In Proceedings of 4th International CIEC Symposium, Braunscheweig, 11-14 May, 1987.

Papadopoulos, I. and Stylianou, Y. 1988a. Trickle irrigation of cotton with sewage treated effluent. J. Environ. Qual., 17:574-580.

Papadopoulos, I. and Stylianou, Y. 1988b. Treated effluent as a source of N for trickle irrigated sudax. Plant and Soil, 110:145-148.

Papadopoulos, I. and Stylianou, Y. 1991. Trickle irrigation of sunflower with municipal wastewater. Agric. Water Manag., 19:67-75.

Pescod, M.B. 1992. Wastewater treatment and use in agricultural. Irrigation and Drainage paper 47, FAO, Rome, Italy.

State of California. 1978. "Wastewater Reclamation Criteria". Calif. Code of Regulat., Title 22, Div. 4, Health Depart. Berkeley, California.

UNEP. 1991/92. Environmental data report. Third Edition, Basil Blackwell, Oxford.

UNEP/FAO. 1991. Environmental guidelines for municipal wastewater reuse in the Mediterranean region. pp. 127. Split.

Westcot, D.W. and Ayers, R.S. 1984. Irrigation water quality criteria. In G.S. Pettygrove and T. Asano (eds). Irrigation with reclaimed municipal wastewater. California State Resources Control Board. Sacramento, CA.

WHO. 1989. Health guidelines for the use of wastewater in agriculture and aquaculture. Report of a Scientific Group. Technical Report No. 778.

Organic sewage treatments with reference to urban sewage

Abstract

Organic wastewater is a mixture of different organic compounds that can be classified according to their physical-chemical characteristics. The different treatment processes are chosen according to the characteristics of the wastes. Normally the biological treatments used for the urban wastewater are divided into three functional stages: conventional pre-treatment, biological treatment, and final settling.

Main characteristics of organic wastewater

Organic wastewater is a mixture of different organic compounds (carbohydrates, fats, proteins etc) that are to be quantified as relative concentrations by specific physical, chemical and biochemical analysis. The polluting compounds, which are present in the urban and industrial wastes, can be classified according to their physical-chemical characteristics.

Urban wastewater

Urban sewage is an organic mixture that is rather constant in the world notwithstanding the different foods styles and ways of living of different peoples. It is known that the difference among different wastes is not in the type of compounds that are present but in their concentration inside the wastewater. This concentration is a function of the individual average consumption of water per day and may vary from 100 to 500 litres per inhabitant per day. This allowed, and continues to allow, the transfer of the technological expertise from one to another region of the world. Table 1 shows the main components of the urban waste.

The different treatment processes are chosen according to the characteristics of the wastes and taking into consideration the individual consumption of water per day.

General description of main wastewater treatment methods

Normally the biological treatments used for the urban wastewater are divided in three functional stages, how showed in the general flow sheet. The three functional stages of an organic wastewater treatment plant are: A - conventional pre-treatment; B - biological treatment; C - final settling.

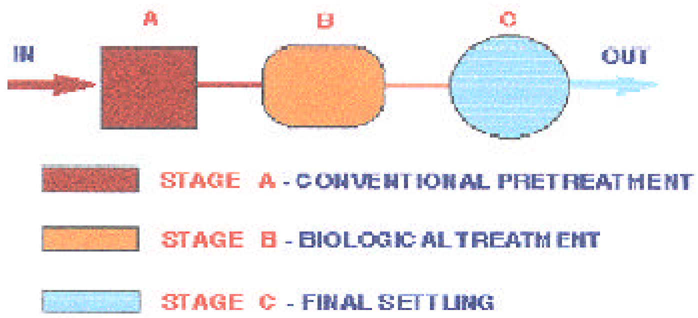
Below is a general description of the standard technologies used in each stage for the treatment of the urban wastewater.

Maurizio Giannotti
Wastewater Consultant, Viterbo, Italy

TABLE 1
Main characteristics of urban wastewater

Composition	Concentration (mg/l)		
Compounds	**A - Strong**	**B - Average**	**C - Weak**
Total solids	1,200	700	350
Total dissolved solids	850	500	250
Inert dissolved solids	525	300	145
Volatile dissolved solids	325	200	105
Total suspended solids	350	200	100
Inert suspended solids	75	50	30
Volatile suspended solids	275	150	70
Settling solids (ml/l)	20	10	5
BOD5	300	200	100
COD	1,000	500	250
Ammonia Nitrogen	50	25	12
Nitrites	0	0	0
Nitrates	0	0	0
Total Phosphorus(P)	20	10	6
Inorganic Phosphorus	15	7	4
Chlorides	100	50	30
Alkaline (CaCO3)	200	100	50
Fats	150	100	50

FIGURE 1
Wastewater treatment plant flow sheet



Stage A: primary treatment

The conventional pre-treatment is normally used in each depuration plant to separate the liquid phase from non-biodegradable raw materials that are collected into tanks and then drained for discharge.

Physical pre-treatment involves:

- Primary decantation
- Grilling and fine screening systems.

The standard methods that determine the choice and dimensioning of physical pre-treatment take into consideration the following factors:

- Type of sewage to treat
- Concentration and typology of gross materials (sand, plastic residues, etc.)

- "Refining" level to reach
- Number of inhabitants served.

In the case of civil sewage, the choice of pre-treatment is conditioned from the number of inhabitants and the characteristics of the town interested.

For Small Villages : Primary decantation tank - Imhoff : An Imhoff tank is normally chosen for small and medium plants as the physical stage for primary decantation and sewage clarification, in place of screening and other primary treatments. Imhoff tank efficiency depends on type and quantity of sedimentable and solid gross materials existing in the wastewater to treat.

For Medium And Big Towns: Grilling and fine screening systems: Fine screening is recommended in case of medium or big communities when the quantity of gross solids or sedimentable to be eliminated needs to be discharge for an average of 48-72 hours. The use of special machinery, capable of separating, accumulating and storing gross materials into solid waste tanks, is required. The more common solutions offered by current market consist of two possible applications:

i) External rotary fine screening
ii) Conveyor worm with integrated compactor.

Primary Decantation Tank - Imhoff

Fitting an Imhoff tank into small plants, subject to regular cleaning, is a successful choice for the following reasons:

- Plant is sufficiently protected from solid residues that can be grilled and sedimented.
- Reduction of the cost of daily management
- No unpleasant smells.
- Programmed cleaning eliminates the external, daily deposit accumulation, typical of conventional screening and grilling technologies; in this manner drawbacks caused by gross materials stored into tanks are completely removed. ***This is extremely important when building plants near to built-up areas.***

Rotary fine screening

An inlet wastewater well complete with gross grilling and fine screening is required and consists of the following structures and machinery:

- Wastewater inlet and accumulation well
- Gross grilling for keeping non-degradable solids (cross section 2 cm).
- Sewage water pump feeding the fine screening
- Rotary fine screening provided with sieve, section 2 x 5 mm, as shown in the picture.

The inlet well shape must be suitable for containing gross grilling and pump that feeds the screening step; grille and pump must be accessible for cleaning and servicing. The grill can be fixed or provided with a mobile system for cleaning and kept solids collection. The gross grilling step is important in order to avoid obstruction and/or system failure.

Conveyor worm with integrated compactor

A conveyor worm with integrated compactor is a new method of separating solids existing in effluents; this system has been conceived for mechanical depuration of effluents coming from industries and networks of urban sewers. The advantages of this grilling system are the very high capacity of separating, a continual functioning and a minimum servicing. It consists of a grill immersed in wastewater and of a variable pitch conveyor worm; the last one carries the material collected, compacts it and discharge it into solids waste thank, as the following diagram shows.

Conveyor worm systems have the following advantages:

- Improvement in the depuration plant performance,
- No liquor in non-degradable solid substances;
- Compact screening, partially dehydrated and ready for drainage
- Considerable reduction of wastewater disposal costs
- No noxious odours: the whole process is implemented under special covering canvas.

Stage B: biological treatment

The term "biological treatment" means a treatment that causes the organic matter present inside the waste water to be digested by a population of micro-organisms (bacteria, etc.).

Biological oxygenation system

The biological oxygenation sump represents the 80 - 85 % of biological stages in the urban treatment plants. The living bio-mass, instead of remaining dispersed, tends to agglomerate in a flock form that is called active sludge. These bacteria are aerobic and their optimal life conditions are reached by oxygenating the waste inside a sump (called oxygenation sump or biological oxygenation sump). In this sump the oxygen is dispersed into the waste water by means of special devices like turbine, impellers, bowers injectors which produce an intensive mixing of the liquid mass with the oxygen reaching an uniform dispersion of the oxidizing agent. The active sludge biological treatment can reach very high yield, greater than 90 % of digestion of organic pollutants.

Percolation system

The percolation system uses the same concepts of the active-sludge biological treatment plant. The difference is that the bacteria are not allowed to float freely inside the liquid mass but they are kept stuck onto an inert support (stones, plastic material etc) forming a uniform film called Biological Film which fills all the free spaces available on to the inert material. The typical percolation device has a cylindrical structure some meters high. Inside this cylinder there is packing made with pebbles. The wastewater, previously clarified, is sprayed on the top surfaces of pebbles by rotating arms made with holed pipes. The rotation is caused by the trust of the out-coming water through the holes. The flow of the waste through the packing of pebbles is by gravity from one stone to the other; the packed bed is never full of water and its free spaces allow the air to penetrate. There are no mechanical devices because the oxygenation rate is guaranteed by the natural convection of the air. The air can flow through openings made on the bottom part of the percolation device. The biological environment so created favours the adsorption and digestion of the organic pollutants by the biological film.

The treated wastewater comes out from the bottom together with the parts of the biological film that are detached from time to time from the pebbles. Channels send the outflow to a settler where the sludge is separated from the treated wastewater. A percolation unit includes a primary settling plant for taking off the coarse material incoming with the waste and a secondary settler to separate the organic sludge from the water. Percolation biological treatment can reach efficiency from 75 to 85 % in the removal of pollutants.

Submerged oxygenated percolation system

A new biological pre-treatment is a compact solution with the same yield and depurative efficiency as the conventional depuration systems, but without unsightly and noisy external structures; this solution is called: Submerged Oxygenated Percolation System (SOPS). The Submerged Oxygenated Percolation System is the natural evolution of percolation and activated sludge systems and consists of a tank filled with special plastic filling bodies in which an oxygenation and blending system (bowers injector) has been fitted.

The SOPS tank is divided into three sections:

A - blending chamber with the submerged oxygenator
B - distributing chamber
C - filling bodies chamber

Main features:

- The same advantages of epurative efficiency as an analogous activated sludge system or others, but without unsightly and noisy external structures.
- Smaller volume, so permitting a cost reduction of C. A. tanks.
- Machinery and power consumption costs reduction.
- Environmental advantage: no external structures; the plant is underground and “hidden”.
- Slight noise, no aerosol risk
- The SOPS can reach efficiency from 90 to 95 % in the removal of pollutants.

Stage C: final settling

Final settling is one of the most important stages of wastewater treatment. To accomplish the separation process by settling, gravity is used to separate solids that have a greater specific gravity than water. The settling process is done inside sumps that have a particular shape to facilitate the separation of solids particles from water and their concentration in the bottom of the sump. In order that a solid particle can precipitate in the bottom of the sump some conditions have to be fulfilled:

- Enough retention time inside the sump
- The settling velocity of the particle has to be lower (sic) than the ascent velocity of the liquid.

Normally a settler is of funnel shape with vertical walls in the upper part and conical walls in the bottom to concentrate the solids at a point; the slope of the conical bottom is variable from 15 to 60 degrees. The inlet slurry (solid-liquid mixture) is guided inside the sump towards the bottom part with a proper baffle; the sludge solid particles settle downward. The heavy phase settled in the bottom is discharged with suitable piping. Clarified water moves towards the upper part and is discharged by means of channels in the top. Now, the final effluent is ready to be discharged into the environment.

A case-matching decision-support system to predict agricultural impacts on water quality

ABSTRACT

Future development of sustainable agriculture in a water-scarce world requires that the off-site impacts on water quality be estimated at the time an agricultural project is proposed. This will ensure that any degradation of water quality due to agriculture can be anticipated and factored into basin-wide, integrated water resource planning. The methodologies for estimating sediment, nutrient and pesticide runoff, such as modelling, are extremely limited in developing countries because of the absence of data, the expense of collecting reliable data, and the absence of relevant reference studies for model development and calibration. An alternative approach using a decision-support system (DSS) is demonstrated which uses examples (cases) where water quality has been measured in earlier agricultural programmes. These cases are used to estimate the water quality outputs of proposed agricultural projects that have physical and agronomic characteristics that are similar to "cases" held in the case library. The demonstration used here is for dryland farming insofar as the intent is only to demonstrate proof of concept of this approach. In the future, development of the DSS would likely focus on irrigation.

The global problem of water scarcity (United Nations, 1997) will inevitably have a major impact on national plans for water allocation in many developing countries. The implications for agriculture are particularly ominous, especially as less and less water will be available for agriculture as more and more is allocated to municipal and industrial uses (Ongley and Kandiah, 1997). Additionally, the fact that water pollution adds to water scarcity by reducing the beneficial uses of water has additional implications for agriculture.

Cost-effective management of water quality increasingly requires an integrated approach to pollution control at the river basin (or sub-basin level for very large river systems). This ensures that the correct balance between point and non-point sources is achieved in regards to planning and investment. For agriculture, which is the largest non-point source contributor of nutrients and of some forms of contaminants (pesticides), there will be an increasing need to minimize off-site pollution caused by agricultural practices. This is especially evident in developed degradation (Table 1). In most developing countries, the role of agriculture in water pollution

Edwin D. Ongley, Emeritus Scientist, Environment Canada, Ontario, Canada
Sarah Dorner, David Swayne and Chris Pal, Department of Computing and Information Science, University of Guelph, Guelph, Ontario, Canada
Arumugam Kandiah, FAO, Rome, Italy

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TABLE 1
Leading sources of water quality impairment in the United States (US-EPA, 1994)

Rank	Rivers	Lakes	Estuaries
1	Agriculture	Agriculture	Municipal point source
2	Municipal point sources	Urban runoff/Storm sewers	Urban runoff/Storm sewers
3	Urban runoff/Storm	Hydrological/Habitat modification	Agriculture
4	Resource extraction	Municipal point source	Industrial point sources
5	Industrial point sources	On-site wastewater	Resource extraction

is less well documented, however experience indicates that agriculture is also a major contributor countries where agriculture has been identified as a major contributor to environmental to water quality degradation.

It is not surprising, therefore, that water quality issues have come to the forefront of debate and decision making in sustainable agricultural development and food security (Ongley, 1996, Ongley & Kandiah, 1997). Projections of agricultural production required over the next several decades to meet food security requirements indicates that national and international agricultural agencies will focus on agricultural expansion (especially of irrigated agriculture), increase in productivity, and use and reclamation of salinized and degraded soils of existing or abandoned irrigated areas. Therefore, the future potential for increased water quality degradation from agriculture is substantial.

The importance of water quality management in agriculture stems from two inter-linked perspectives – (1) that sustainable crop production requires a certain minimum water quality standard and (2) that agricultural activities do not cause deterioration of water quality which impacts on the subsequent use of water for other purposes. This paper, which reflects work carried out for FAO in the field of decision support systems (DSS) refers to the second perspective and focuses on off-site water quality impacts of agricultural activities.

Alternative approaches to preduction

Agencies such as FAO are often involved in assisting or promoting agricultural projects in developing countries. Increasingly there is requirement to evaluate off-site impacts at the project proposal stage, and to be able to assess alternative management options in order to achieve an appropriate balance between conservation, economic costs, and water quality objectives. Various techniques (often called “screening” tools) are used to evaluate the *potential* for off-site water quality impacts at the pre-feasibility or feasibility stage of project development. At a screening level, one is general interested in gross estimation of pollutant impacts relative to crop and management practices that are proposed for the particular project in question.

Guidelines

One approach commonly used by agricultural organizations is the production of guidelines. Published guidelines represent cumulative knowledge in fields such as wastewater use in agriculture, optimizing water use in irrigation, and scoping probable impacts of agricultural projects on water quality, to name but three examples. However, guidelines are seriously limited by:

- space and cost limitation of printed guidelines.
- cost of frequent updating and printing of guidelines.
- inability to incorporate the complexity of real-world situations into printed guidelines.
- difficulty in circulating printed guidelines to potential users.

Most importantly, while guidelines can outline a methodology, they can not exert any direct real-time control on either the evaluation process or the outcome.

Modelling

Another method of prediction is the use of modelling wherein site data are collected or estimated and models are run. A variety of models for agricultural sediment, nutrient and pesticide runoff are tabulated in Ongley (1996). However, although there are much data on off-site (or downstream) water quality that are associated with agriculture in developed countries, hard data are rare in developing countries where the development scenarios for food security are likely to be implemented, and where the ability to collect the sophisticated data needed for modelling is limited. There are also problems of model reliability due to absence of reference studies or other means of verification of predicted impacts. Although models are used within decision-support systems (see below) their use is seriously limited for the reasons noted here. This suggests that some other methodology may be more practical and cost-effective, especially at the prefeasibility or feasibility stage of project evaluation.

Decision-support system

Decision-support systems (DSS) typically use some form of knowledge base that is built into computer software, that guides the user in making an informed decision on some (environmental) issue. In the case of agriculture, project evaluation and prediction of off-site water quality impacts may be done by local or foreign experts. Increasingly, however, for reasons of cost or lack of availability of sufficient specialists, it is necessary to transfer the ability to carry out these tasks to individuals who may not have the appropriate range of skills. This requires some form of DSS technology that will guide the non-specialist and impose a high degree of consistency to the evaluation process.

Rather than use a modelling approach that we have rejected for reasons noted above, we have used an alternative approach - one that is consistent with how agricultural experts approach such problems. This alternative approach uses a "knowledge-centred" approach rather than a "data-centred" approach (e.g. as in modelling). In this "knowledge-centred" approach past experience in off-site impacts on water quality ("cases") is used as a guide as to how proposed future agricultural projects with similar characteristics may behave in regards to off-site water quality impacts. This makes use of new developments in the field of Information Technology (IT) that resolves the problem of putting reliable information and decision criteria into the hands of non-experts, and also exerts control over the evaluation process. Moreover, the incorporation of knowledge bases (as opposed to databases) into PC-based decision-support software designed around such problems can bring a wealth of experience into the hands of non-expert users in an easy-to-use manner.

Using experience from other agricultural projects together with available site information, the DSS makes it possible to forecast the range of probable off-site water quality conditions for the existing physical conditions and the anticipated crop and crop management choices. This makes it possible to "game" with alternative crop and management options in order to develop an appropriate balance between economic output, implementing and operating costs, and off-site pollutant loadings.

CASE-MATCHING DECISION-SUPPORT SYSTEM

The objective was to develop a simple, interactive, and computer-based DSS for water quality management in agriculture that would enable the "stakeholders" to make their own decisions.

Decision-making would be based on experiences and knowledge from a variety of sources such as: (1) “hard copy” guidelines and other publications produced by FAO and other institutions, (2) scientific literature, (3) experts’ individual experience, and (4) experiences and data recorded from previous agricultural projects of FAO, the World Bank and other professional and financial institutions. Such systems “package” the knowledge base and present it to the user through user-friendly expert systems. The objective, therefore, was to develop a comprehensive, computer based and interactive Decision Support System (DSS) for water quality management in agriculture which would enable stakeholders to make their own decisions to protect water quality while achieving optimum agricultural production on a sustainable basis.

The DSS prototype described here, **AgriScreen** (**Agri**cultural Project **Screen**ing - Table 2), is currently designed only to demonstrate proof of concept. It is intended to demonstrate a screening-level capability to predict the probable range of off-site pollutants from proposed new agricultural projects. The conventional approach of building a DSS around modelled relationships amongst site, crop and agricultural practices, was rejected as inaccurate for reasons noted above, too expensive for most typical projects at the feasibility stage, and therefore not especially useful nor reliable for screening purposes.

We recognize that the greatest use for a DSS in developing countries is likely for irrigation agriculture. However, the knowledge base necessary to develop a demonstration of the case matching approach for irrigation was difficult to access with the limited budget available. Therefore, for the purpose of demonstrating proof of concept we have used dryland farming with cases drawn from the North American agricultural literature because of the wealth of published “cases”.

TABLE 2
Components of the *AgriScreen* DSS

CASE LIBRARY	SCREENING LEVEL	PLANNING LEVEL (not included in prototype)
“Knowledge base” based on real cases of combinations of climate, soil, landscape, crop, management, etc. Requires Case Librarian.	**Inputs:** Input field characteristics per template. Where site data are unknown can access electronic information sources such as world soil, climate maps or databases.	Runs AGNPS or other models, prompting re data needs, output reliability, etc.
	Actions: Attempts to match field situation with one or more cases in the case library. Allows interrogation of cases for pertinent metadata. Forecasts ranges of water quality conditions that are expected from the proposed project.	
	Outputs: High/Medium/Low values for: -Erosion and sediment output. -Nutrients - N,P (K) - (Pesticides) - (Salinity) ( ) not included in prototype Measures of reliability given.	

The input is based upon standard physical and agronomic information that are used in the Universal Soil Loss Equation insofar as the USLE is the basis of many standard models such as the AGNPS model and, therefore, is the framework for much published information.

The methodology adopted is the "case matching" approach wherein a "case library" captures water quality outputs that have been observed and/or published in the primary or grey literature for a selection of crop, management, soil, landscape and climatic variables. We recognize that the published cases included in the prototype will not include terrain and crop types in many developing countries. However, the intent is only to demonstrate the concept. For full application, the case library is designed to be expanded for other geographic conditions through the addition of case histories based on the experience of agricultural professionals in developing countries.

For any proposed agricultural project the planner fills a template with available physical, climatic and agronomic information. The DSS predicts the probable range of pollutant outputs by matching the input information against the case library, the uncertainty associated with cases used for the prediction, and makes available pertinent metadata so that the user can evaluate the adequacy of the prediction for his particular situation. This approach can also be used at a more detailed planning level (Table 2) where the screening component advises which types of parameters are most likely to be a problem under different conditions of agricultural practice. Any subsequent investigation can then focus only on the problem component(s).

Case library

For the purpose of demonstrating the concept, case data for the prototype were collected for 137 watersheds located primarily in the temperate region of the United States and Canada. Cases that had an area in which wastewater from human activity would skew the results, were omitted. Watersheds ranged in size from less than 1 km^2 to 100 km^2. Factors describing climate, topography, crop type, soil type and supporting practices were determined for each watershed. Where the information was not known, it was left as "unknown" (?) in the database.

The input template for the case matching and range prediction techniques is based on factors included in the Universal Soil Loss Equation (USLE). The present template reflects the type of information that is currently in the case library for the purposes of the prototype. Therefore, some of the factors such as crop type and supporting practices are very limited. It will be necessary to devise either a classification method for these factors or another means of dealing with the large number of crop types and practices that would ordinarily be included in a full DSS system. In the future, it may be possible to include other data that are available, for example, percent tile drainage or chemical properties of the soil. The matching and prediction system are currently integrated and operational. However, future development of the system would require a much larger and more complete case library to obtain better matching estimates and range predictions for new cases.

An advantage of this type of Decision Support System is the ability to include pictorial and descriptive information rather than only numerical data. For example, pictures that describe land classes or land management practices can be presented to the user who then can pick the photograph of the situation that most closely reflects his case. From these selections, the system automatically fills the appropriate information into the template.

Input characteristics

Area: The area is expressed in km^2. It is assumed that the sediment and nutrient yields occur at the outlet of the watershed.

Climate type: The climatic classification chosen for the prototype is from the FAO world soil resources publication (FAO 1993). This climatic classification is not sufficient for distinguishing between all climatic regimes but provided a simple method for the purpose of the prototype. Most of the present cases fell within a single climatic class. The annual rainfall is the parameter that further defines the climatic factor. The menu bar displays only the climate types that are present in the case library. In the future, where climate type is not known by the user, the user could "click" onto the FAO map to locate the project and the system would automatically determine the climate type and add the appropriate information to the input template.

Annual rainfall: The annual rainfall was chosen since it has been used as an estimator of erosivity when the data are not available for the R-factor of the USLE. Since most of the cases were in the United States and Canada, there are R values available for all of the cases. However, this would not be the case in developing countries. Where rainfall data are not available to the user, the climate type could be used to create an estimate using a set of expert rules.

Soil type: For the prototype the soil classification is based on texture, as the majority of the cases were already classified in this manner. The USLE K-factor is also based on texture, but also includes permeability, organic matter and soil structure in its value. Eventually, it could be useful to move towards the FAO classification as one could then make use of resources such as the digital Soil Map of the World (FAO 1996).

Topography: The topographical classification is based on FAO's SOTER database classification (FAO 1995). It would be possible to use more precise information such as dominant slope value at a later time. Most of the cases were classified as level, which is why further classification would be helpful to distinguish rolling hills from level land. It would be useful in future to offer the user a series of photographs from which the user would make a choice of topographic type which would automatically input the appropriate information into the input template.

Percentage crop, forest and pasture: Many of the cases selected had this information and thus we made use of it. The % pasture is closely correlated to the number of animal units, which is a factor not considered. An classification algorithm could consider these other factors, if desired.

Dominant crop type: Currently, the list of crop types reflects only those crops that are in the case library.

Supporting practices: These are agricultural management practices. Only those practices that are included in the case library are included. Agricultural practices are different in various parts of the world and the template would have to reflect this for future applications of the DSS.

Fertilizer added: The fertilizer added is expressed in tonnes/ km^2/yr and is broken down into P and N added as well as manure P and N added.

Implementation of the graphical user interface

The implementation of the graphical user interface (GUI) was constructed using a scripting language, tcl/tk (pronounced tickle tee-kay). This particular scripting language is portable, therefore a program developed in tcl can be run on various operating systems including UNIX, Windows95™ as well as older versions of Windows™. This is an important consideration since not everyone will be running the latest version of Windows™. Another advantage of using tcl is that it is currently freely available for download from the Internet. If this system were to be developed further, other programming languages such as Visual Basic and Java could be used depending on which is the most appropriate for the potential users.

The case matching methodology

Cases in the case library are examined and a decision tree is constructed. The user enters his case into the template and the case (or leaf) in the decision tree that best represents the input space of the user's case is located. A list of matching cases is obtained in this manner and they are ranked according to a distance calculation (or distance metric). This provides the user with a relative idea of how close his case is to the matched case.

Quinlan's C5.0 tree induction algorithm was used to generate the tree used in this study. C5.0 is a tree induction algorithm that builds a tree based on tests of the factors given for each case. These tests correspond to splits of the tree and are determined based on maximizing the information relevant to classifying the cases. C5.0 is a commercial version of the C4.5 tree induction algorithm developed by Quinlan (1993). Other similar tree induction algorithms such as Breiman *et al.*'s Classification and Regression Tree (CART) algorithm could be used with equal effectiveness. Another advantage of this type of matching technique is that the tree could be modified by an expert.

C5.0 can handle unavailable data as well as continuous values. Additionally, like common classification algorithms, C5.0 can use descriptive information representing broad categorical variables to describe a system that is useful for prediction and classification in data-poor environments in contrast to traditional water quality models that demand very specific numerical data for the same variables.

Case Matching is accomplished by partitioning the input variables into a decision tree. The decision tree is a compact summary of the data that is contained in the case library. The decision tree can be envisioned as statements describing the various situations, such as: "if <area is between A and B km^2> and climate type is <type C> and topography is <type D> then the most similar case will be close to cases <E or F>." Each attribute is ranked and partitioned based on a measured information gain to create the decision tree. The gain is a function of the information contained within the case attributes and the probability distribution for the case ranges or individual cases. Each node of the decision tree uses the attribute with the greatest information gain among attributes not yet considered in the path from the root to the leaf.

The user enters his case into the spaces provided in the GUI. The program takes the list of the user's attribute values and follows the partitioning of the decision tree to determine which case the user's case most closely resembles. A list of cases from the case library is obtained from this procedure.

Once a list of matching cases is obtained from the case matching procedure, it is useful to know how different the user's case is from the matched cases. A distance function based on a Euclidean distance measurement for each of the variables calculates the distance between the user's case and each case returned from the case matching process. The distance function is a normalized and weighted Euclidian distance measurement. It is similar to a probability in that it ranges from 0 to 1 and that a matched case that returns a distance metric of 0.96 is likely to have a high probability of matching the case. Since the true probability is not known, the distance metric provides an estimate of how close the user's case is to the matched case, based on the measured attributes included in the study. It is like saying the user's case is 96% similar to the matched case based on the measured attributes versus saying there is a 96% probability that it is the same case. The weights were estimated from the decision tree that was created and are based on the relative importance of the factors.

The results displayed enable each case to be ranked in order of similarity and the resulting distance metric is displayed with each matched case to provide the user with an idea of how similar his case is to the matched case. The user may also browse through the displayed cases with the metadata and decide which case may be the most similar considering all factors, thus adding another dimension to the case matching.

Sometimes, in the case library itself, part of the case attributes (input data) are not known. Although this does not prevent the system from creating a decision tree, full data would help create a more accurate tree. The system will run with missing data and it will provide an answer giving an estimate of the match quality based on the distance metric. Unknown values can also be used as input, however, they add an element of uncertainty that is particularly apparent in the case matching mode. It may happen that a case that is identical to a case in the case library containing unknown information may not come up with the exact matched case that includes the same missing information. The misclassification results because the algorithm uses the most likely attribute value when dealing with missing information.. More advanced techniques assigning probabilities over the possible values of the missing variable could address this problem.

The C5.0 classification algorithm was also used to determine an estimated *output range* for sediment and nutrient yields. The decision tree for the case matching and for range prediction are slightly different. For case matching, a tree is constructed in terms of the attributes that make each case most distinct from the others in the library. For range prediction, a decision tree is created based on the attributes that are the most relevant or contain the most information for the prediction that the result will lie within a given range (i.e. sediment yield).

Although AgriScreen predicts the range of sediment yield, caution should be used in classifying results that are continuous such as sediment yield into discrete categories such as high, medium and low because it is likely that a case with a result that falls close to an upper or lower bound will be misclassified. Other more advanced techniques may be used to overcome these problems in the future. Examples of these techniques include Bayesian networks (Heckerman 1995)

At this time, the relative importance of the factors for predicting water pollution from agriculture is only roughly approximated, but with a larger case library the relative importance of the various factors and interactions between the factors could be more accurately assessed. The most important parameter for this application is *area*. The case library is biased because the area is always available for each case. Cases for which the area was not defined were omitted from the case library as this was already understood to be a key factor. Also, most of the cases were in similar geographical areas with similar climate and topography. Therefore, the factor that was the most important for distinguishing one case from another was area, which had the highest level of variation among the factors. In a more global and complete study, the relative importance of the factors would likely change.

Although the classification algorithm is functional, its accuracy is presently limited by its case library size. Furthermore, the case library itself contains a fair amount of missing data. Future developments could also include common pesticides and a larger and more complete case library.

Outputs

The classification algorithm provides two types of outputs. One is "Case Matching" wherein the DSS matches the input characteristics of the user's project with other cases held in the case library that have similar characteristics. The matching cases are ranked according to a distance metric. The principal use of "Case Matching" is to allow the user to examine those cases from which estimates of off-site impacts (sediment, nutrient outputs) will be generated for the proposed project. It is quite possible that matching cases may include characteristics that are quite inappropriate for the project at hand (for example, the wrong climate type). In the future, the DSS would contain the ability for the user to remove such cases from the selected matching cases.

The DSS provides an estimate (Range Prediction) of sediment and chemical outputs from agricultural runoff (in tonnes km^{-2}) from the proposed project. The estimates are based upon the case library and are assigned to a classification of "high", "medium" and "low" ranges. For project screening purposes, it was felt that it was only necessary to know whether the probable water quality outputs would likely by high, medium or low. Also, we recognize that the ability to reliably predict exact values of sediment or chemical outputs, at the screening level, is impossible. With a larger case library, statistical techniques for confidence interval estimation could be used. In "Range Prediction" mode, the user can game with alternative crop and land management practices to establish whether gross changes in sediment and nutrient runoff are likely to occur using alternative crops or practices.

Conclusions

Future development of sustainable agriculture in a water-scarce world requires that the off-site impacts on water quality be estimated at the time an agricultural project is proposed. This will ensure that any degradation of water quality due to agriculture can be anticipated and factored into basin-wide, integrated water resource planning. The methodologies for estimating sediment, nutrient and pesticide runoff, such as modelling, are extremely limited in developing countries because of the absence of data, the expense of collecting reliable data, and the absence of relevant reference studies for model development and calibration.

An alternative approach using a decision-support system (DSS) is demonstrated which uses examples (cases) where water quality has been measured in earlier agricultural programmes. These cases are used to estimate the water quality outputs of proposed agricultural projects that have physical and agronomic characteristics that are similar to "cases" held in the case library. Because the intent is only to demonstrate proof of concept of this approach the demonstration used here is for dryland farming for which data were easily accessible. In the future, development of the DSS would likely focus on irrigation.

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References

Breiman, L., Friedman, J.H., Olshen, R.A., Stone, C.J., 1984. Classification and Regression Trees. Wadsworth, Belmont, CA.

FAO. 1993. World Soil Resources. An explanatory note on the FAO World Soil Resources Map at the 1:25 000 000 scale. *World Soil Resources Reports 66 Rev. 1*. FAO, Rome.

FAO. 1995. Global and National Soils and Terrain Digital Databases (SOTER). ProceduresManual. *World Soil Resources Reports 74 Rev.1*. FAO, Rome.

FAO. 1996. *Digital Soil Map of the World and Derived Soil Properties*. FAO, Rome.

Heckerman, D. 1995. Bayesian networks for knowledge representation and learning. In: Advances in Knowledge Discovery and Data Mining, eds. U.M. Fayyad, G. Piatetsky-Shapiro, P. Smyth, and R.S. Uthurasamy. MIT Press.

Ongley, E.D. 1996. *Control of Water Pollution from Agriculture*. FAO Irrigation and Drainage Paper No. 55. FAO, Rome.

Ongley, E.D. and Kandiah, A. 1997. "Managing Water Pollution from Agriculture in a Water-Scarce Future", In *With Rivers to the Sea*, Proceedings of the Seventh Stockholm Water Symposium, Sweden, Stockholm International Water Institute (SIWI), Report #2, 1997, pp. 309-316.

Ongley, E.D. and Kandiah, A. 1997. Agriculture and water quality: new approaches to old problems. In Kandiah, A, and Hamdy, A. (Eds.) *Control of Agricultural Water Pollution*. Special Session of the International Conference "Water Management, Salinity and Pollution Control: Towards Sustainable Irrigation in the Mediterranean Region", 22-26 Sept., 1997. Istituto Agronomico Mediterraneo, Valenzano (Bari), Italy, pp. 1-22.

Quinlan, J.R. 1993. C4.5: Programs for Machine Learning. Morgan Kaufmann Publishers, San Mateo, California. 107 p.

United Nations. 1997. *Comprehensive Assessment of the Freshwater Resources of the World. Report of the Secretary General,* Commission on Sustainable Development, 5th Session, 7-25 April 1997. Document E/CN.17/1997/9.

United States-EPA. (1994). *National Water Quality Inventory*. 1992 Report to Congress. EPA-841-R-94-001, Office of Water, Environmental Protection Agency, Washington, D.C.

[1] This paper was formerly presented at the FAO "International Workshop on Management of Water Quality and Control of Pollution in Latin America", Arica, Chile, 1998.

Country papers

Crop production in the southern saline belt of Bangladesh

ABSTRACT

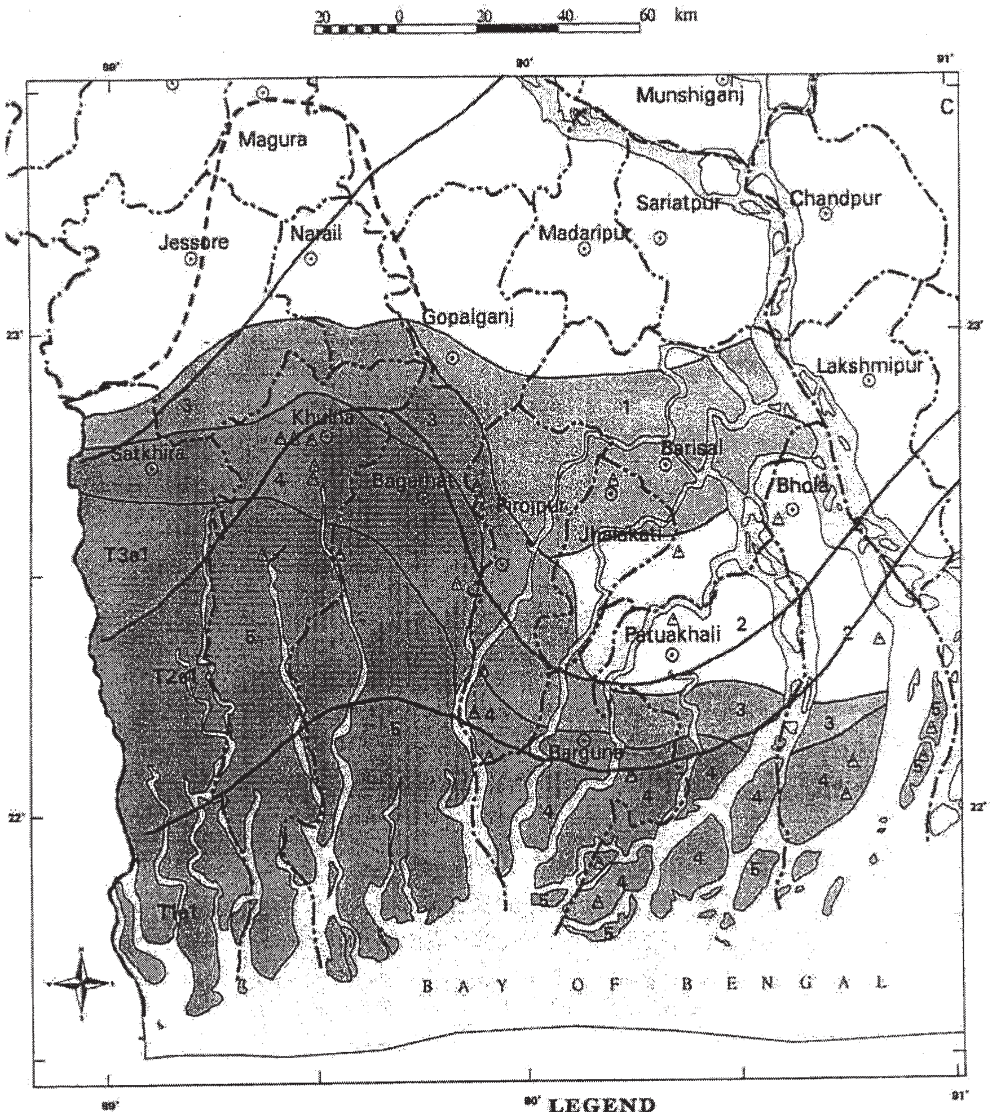
In Bangladesh, over 30% of the net cultivatable area lies in the coastal belt comprising about *2.85* million hectares. About 1 million hectare is affected by varying degrees of salinity. Most of this saline area is along the south and southwestern part of the country. Because of salinity a peculiar environmental and hydrological situation exists in the region which restricts normal crop production throughout the year. Intensity of cropping in this area is about 133% (BBS, 1992) which is the lowest of the country. Unfavourable soil and land characteristics, tidal inundation during April to November resulting in intrusion of saline water in the cropland, capillary rise of saline groundwater during the dry season usually from January to April, scarcity of irrigation water, high variation in annual rainfall, perennial water logging due to inadequate drainage systems etc. are problems to be dealt with for intensification and diversification of crop cultivation in the area. Collaborative approaches are being made by research bodies and the Department of Agricultural Extension (DAE) to develop technological interventions for enhancing crop production in the southern saline-belt of the country. This paper highlights the salinity situation and Government efforts and achievements made in increasing agricultural production in the southern part of Bangladesh.

Bangladesh, a country of 120 million people, is striving to achieve self sufficiency in food production. To achieve this, Government policy is to utilize all available resources including intensive use of the Net Cropped Area (NCA) of the country for increasing agricultural production. Of the 9.03 million hectares of NCA of the country, the coastal and offshore (sic) area is about 2.85 million hectares. The southern part of the country comprised of Barisal, Jhalakati, Pirojpur, Bhola, Patuakhali, Barguna and parts of Khulna districts constitute more than 30% of the coastal ecosystem. Out of about 1 million hectares of cultivable land of the coastal area, about 0.38 million hectares represent the polder zone. Land within and outside the polder zone is affected by varying degrees of salinity. Factors contributing to salinity are, inundation of land by saline water or brackish tidal water during wet season, and vertical rise of saline ground water during the dry season (November -May). Other factors are variations in annul rainfall, prolonged water logging due to inadequate drainage system and crop production practices.

Transplant Aman crop grown during the wet season (July, December) still dominates the area as a monocrop. Due to salinity problem, vast lands remain fallow during the dry season. Medium high lands which constitute the major part of the area, are potentially suitable for a wide range of crops through technological intervention.

M. Abu Bakar
Deputy Director, Field Service Wing, Dept. of Agricultural Extension, Dhaka, Bangladesh

FIGURE 1
Soil salinity map (March-May): Khulna - Barisal Division 1997-1998, SOil Resource Development Institute



LEGEND

Conventional signs

- International boundary
- Division boundary
- District boundary
- Upper limit of soil salinity boundary
- Wide river
- District Head Quarters
- Mapping Unit
- River Water Salinity Monitoring Sites
- Thermal zone

Mapping Unit	Area (ha.)	Soil Salinity (dS/m)
1	2,60,000	<2.0
2	2,90,000	2.0- 4.0
3	3,10,000	4.0-8.0
4	6,20,000	8.0-12.0
5	8,60,000	>12.0

Location and extent

The southwestern part of the coastal saline area lies approximately between 21°48¢ N and 23°20¢ N latitude, and 88°55¢ E and 91°0¢E longitude. Including the Sundarbans, it occupies about 24,400 km^2 (Figure 1).

Climate and hydrology

Total annual rainfall ranges from 1682 mm to 2823 mm and is mostly received during the later part of the summer (Rahman *et at* 1999). The most significant hydrological feature is that about 70% of this area is subjected to shallow flooding of up to 90 cm for different durations. As a result, soil and water salinity are the major limitations of growing crops in the saline ecosystem (Karim *et at* 1990).

Assessment of saline area

The Soil Resource Development Institute (SRDI), a research organization of the Government of Bangladesh, have been monitoring soil and water salinity since 1990. Based on peak salinity data recorded during March - May period and salinity data generated by semi -detailed soil survey, a soil salinity map with thermal boundary has been prepared. According to degrees of salinity five mapping units are identified (Figure 1). Total area and saline area for each mapping unit is shown in Table 1.

TABLE 1
Total area and saline affected areas under each mapping unit.

Mapping Unit	Salinity Class*	Total area (ha.)	Salinity affected area (ha.)	Name of the District
1.	Non Saline (<2 ds/m)	260,000	2,600	North of Barisal, Jhalakati, Pirojpur & south of Gopalaganj
2.	Very Slightly Saline (2-4 ds/m)	290,000	145,000	North part of Bhoal, Patuakhali, Barguna & Southern part of Barisal & Jhalakati
3	Slightly Saline (4-8 dslm)	310,000	186,000	Southern part of Bhoal, Jhalakati & Pirojpur, Middle part of Patuakhali, Northern part of Barguna, Bagerhat, Khulna & Satkhira
4.	Moderately Saline (8-12 ds/m)	620,000	496, 000	Southern part of Bhola, Patuakhali, Barguna, Pirojpur, Bagerhat, Khulna & Satkhira
5.	Strongly Saline (>12 ds/m)	860,000	817,000** (included Sunderbans)	Southern part of Bhola, Patuakbali, Barguna, Bagerhat, Khulna & Satkhira.
Total:	2,340,000	11,646,000		

Source: Soil Salinity Monitoring Report (1990-97) & Thana Nirdeshika (1985-97), SRDI.
* FAO Irrigation and Drainage pepar no. 29,Rev- 1,1985.
** 507,5 000 ha. Sunderbans reserve (Land Use Map of Bangladesh, 1996, SRDI).

Types of salinity

Studies to determine Electrical Conductivity of soil (ECe) and water (ECw) confirm 4 types of salinity in the area (IQBAL *et al* 1993). These are.

a) Soil Salinity
b) Shallow Groundwater Salinity
c) Deep Groundwater Salinity
d) River Water Salinity

a) Soil Salinity: Top soil (0-15cm) salinity at different sites of the area show wide range of ECe, varying from 2-4ds/m to as high as 16 ds/m recorded during December to May. The peak salinity is observed during March-May. The subsoil (15-30cm) salinity is always less them the topsoil salinity. The subsoil salinity is somewhat nonsaline in most areas and is moderate (2-8 ds/m in some areas. The salinity of substratum (30-60 cm) is variable ranging from <2.0 ds/m to 6-7 ds/m.

b) Shallow Groundwater Salinity: Shallow Groundwater salinity is within 3 meters from the surface during the dry season. During March - April it shoots up to 20-25 ds/m in some places. This implies that continuous irrigation with shallow groundwater may raise the salinity to the root zone of field crops and, therefore, irrigation is not advisable.

c) Deep Groundwater Salinity: Electrical Conductivity of deep ground water (275-300 metre depth) are around 0.8 ds/m to 1.25 ds/m at different areas *(CCRP* 1991). Deep ground water is also not suitable for continuous irrigation.

d) River Water Salinity: The southern coastal area is criss-crossed by numerous distributary rivers and canals of two large rivers - the Meghna and the Ganges. Monthly variations in river water salinity (IQBAL *et al* 1993) are shown in Table 2. It appears from Table 2 that river water salinity is within <1 .Ods/m to 3.Ods/m with the occasional rise beyond 3.O ds/m during March-

TABLE 2
Monthly variations in river water salinity

River/Station	Salinity level ECw ds/m		
	<0.75	0.75-3.0	>3.0
1. Tetulia River			
a . Kalia	throughout the year	-	-
b. Dasnuna	June-March	April-May	-
c. Rangopaldi	June - Jan.	Feb. - March	April - May
2. Lohalia River			
a. Patuakhali	May - Feb.	March- April	-
b. Jainkat	June - Feb.	March - May	-
c. Galachipa	Jun - Feb.	March - May	-
3. Paira River			
a. Labukbali(Pandab R)	May - March	April	-
b. Pairkunja	May - Feb.	March-April	-
c. Gulishakbali	Jun-Feb.	March-May	-
d. Amtali	Jun-Feb.	March	April-May
e. Taltali	July-Aug.	Sept.-Jun	Feb.-Jun
4. Bishkhali			
a. Baman	throughout the year	-	-
b. Barguna	May-December	June-March	April
c. Patharghata	June-November	Dec.-June	Feb-May
5. Shakaria Khla	Jun-Feb.	March	April-May
6. Andcnnenil River	Sept.	October	Nov. -August

Source: River Water Salinity Maps prepared by the Surface Water Modelling Centre, Dhaka.

April. This suggests that there is enormous scope of utilizing river water for surface water irrigation during the dry season.

Agro-ecological diversities

The greater Barisal and Patuakhali, lying in the southern saline belt, are dominated by medium highland constituting 88% of the total land area (Table 3) and are suitable for growing a wide variety of crops.

TABLE 3
Distribution of land types by districts (hectares)

District	Total cultivable area	Highland	Medium highland	Medium lowland	Lowland
Barisal	180 916	17 127	133 072	26 146	4 571
Jbalakati	61 273	859	59 923	419	-
Pirojpur	111 045	3 263	98 065	5 552	4 165
Bhola	170 259	420	149 655	20 184	-
Patuakhali	205 893	2 188	190 392	13 313	-
Other	124 414	-	124 100	314	-
Total	853 800	23 857	755 207	65 928	8 736

Source: SRDI, RSS Report, Barisal District, 1968.

Soils range from loam to clay loam *(SRDI* 1968). There are wide variations in Kharif (April-November) and Rabi (December-February) growing periods. The Kharif growing period ranges from 240 to 300 days. In general, the area has a relatively shorter winter, about 30-40 days shorter than other parts of the country. The Rabi growing period is about 50-70 days on the north and 30-40 days in the south within the area *(FAO* 1988).

The extent and intensity of soil salinity is dependent on the distribution of monsoon rainfalls intrusion of saline water towards the main land and upstream discharge during dry season. It is observed that during March soil and river water salinity crosses tolerance limits of most field crops.

Technological interventions

Varietal interventions

Transplant Aman is the main crop grown in the coastal area during the Kharif season. In higher elevations some farmers grow broadcast Aus followed by Transplant Aman. Traditional Aman varieties have photoperiod sensitivities with low yield/ha. The use of modern varieties (MVs) is still limited although there is wide potential to increase the MVs area up to 30% (Quazi 1989). Problems in expanding MVs, apart from salinity tolerance from variety to variety, include the reduced height of MV seedlings that barely exceed the depth of stagnant water at the optimum time of transplanting and which have a weak tolerance to tidal submergence. Field trials, together with farmers' practice with the popular MVs, have shown that, BRi 1, Binashail and BR 23 are promising (Table 4).

TABLE 4
Yield (t/ha) of potential MVs

Varity	Patuakhali		Burguna	
	Yield	Days Maturity	Yield	Days Maturity
Br-11	3.21	148	2.43	142
Br-23	2.64	167	1.98	152
Binasail	2.68	148	2.85	131
Pajam	2.82	140	1.57	131
Rajashail	1.91	126	1.66	114

Source : Research report BARI, 1990-91

BRRI plant breeders have developed a few salt tolerant lines having prospects of withstanding soil salinity to some extent. Out of three promising lines tested against a salt tolerant local variety (Pokkali) and a salt susceptible variety (MV 48), the line BR 1 840-2B-4-1-3 appears to be a very potential T.Aman variety for the coastal area.

After the harvest of T.Aman, lands remain mainly in fallow during the dry or Rabi season for about 4-6 months. The reasons are excess soil salinities and lack of adequate amounts of irrigation water. To evaluate suitable dryland crops, BARI conducted studies in the saline areas of selected districts (Hannan 1991). Wheat, maize, potato, sunflower, linseed and groundnut performed quite well in low saline environment. Wheat and groundnut are now expanding as dry land crops in many location-specific coastal areas. What is needed for exploration and expansion of dry land crops is a combination of technology, extension services, and government policy decisions to allow the utilization of surface water irrigation by low lift pumps (LLP). The government's decision to withdraw from rental systems of LLPs drastically reduced surface water irrigation facilities during 1981-1988.

Management interventions

Mulching of the soil surface**:** Soil surface coverage by mulching with material such as rice straw and other organic wastes after harvest of Aman rice, causes more favourable salt distribution and facilitates yield increase of dryland crops (Bandopadhya and Sen 1977). BARI conducted similar studies under 'low' or 'no' tillage and reported promising results for wheat, potato, maize and cowpea.

Irrigation with brackish water: The prospect of using brackish river water for irrigation seems to be promising. In an experiment it was observed that wheat, barley and millet can be grown successfully with brackish river water having electrical conductivity of 5 ds/m (Sattar *et a.l* 1990).

Rainwater harvesting by levee management: Drought is an occasional occurrence for T.Aman crops when monsoon rainfall is inadequate and irrigation facilities are scarce. Harvesting of rainwater is a potential option for farmers to cope with a drought situation. Farm levee management through proper construction and maintenance can help farmers to store rain water in the field. Works done over years suggest such intervention may be very helpful to farmers in the coastal area.

Rainwater harvesting by mini-ponds: Research and field trials show that rainwater stored in a ditch of 2m depth of *4-5%* area of the field, is enough to provide supplementary irrigation to a rice crop when it is affected by moisture stress. Such efforts may increase T.Aman yield by 50% in a drought situation (Islam 1988).

Improved cultural practices**:** Improved agricultural practices such as: closer spacing with less number of seedlings per hill for rice cultivation; ridge-furrow technique in Rabi season to overcome soil salinity problems; rapid and deep tillage after harvest of T.Aman to avoid hardening of soils and to break capillary rise of saline groundwater, are also recommended (Karim *et al* 1990).

Polder establishment: Polder establishment by the Bangladesh Water Development Board in 0.38 million hectares to protect from tidal saline water intrusion has changed the hydrological scenario of the region. However, because of poor management, occasional damage is caused by floods, siltation and drainage congestion within the polder area, and improper management of the sluice gates, and crop cultivation is only profitable in about 0.08 million hectares of the polder area.

Conclusions

The coastal saline belt in the southern part of Bangladesh has substantial potential for increasing crop production. Research, participatory extension, polder management and, above all, judicious decisions for surface water utilization for irrigation, may change the scenario of the southern saline belt in the coming years. Fortunately, progress is being made.

References

Bandopadhya, A.K.and Sen, H.S. 1977. Introduction of a second rice crop and mulching as reclamatory management practices for saline soils of monocropped areas of south 24 Parganas, West Bengal. *Indian Soc. Soil Sci.* 25:326-330

BBS. 1992. Bangladesh Bureau of Statistics, 1992.

CCRP. 1991. Report of the Committee on the Project Comprehensive Crop Rehabilitation Programme (CCRP) in southern district, Ministry of Agriculture, Dhaka.

FAO. 1988. Land Resources Appraisal of Bangladesh for Agriculture Development. Report No 2. Agro-ecological region of Bangladesh. Rome. pp. 275-293

Hannan, M.A. 1991. Management of salt affected soils of Bangladesh. Paper presented at a BARC Workshop Dhaka, Bangladesh Oct 26-27, 1991.

Islam, M.J. and Haq, K.A. 1988. Rain Water Harvesting for stabilizing T.Aman production. *Proc.of the BRR! Workshop* 1988. 180-196.

Iqbal, A., Jalaluddin and Shoaib. 1993. Evaluation of Soil and Water Salinity for Cropping in the Coastal Region of Bangladesh. *Journal of NOAMI* 10(1). June 1993

Karim, Z., Hussain, S.G. and Ahmed, M. 1990. Salinity Problems and Crop Intensification in the Coastal Region of Bangladesh. BARC, Dhaka.

Quazi, S.T.H. 1989. Prospects and problems of Aman rice cultivation in coastal areas- a Workshop Paper for DAE-BRRI Annual Workshop *4-5* April, 1989,Dhaka

Rahman, M., Islam,S., Awal, A,. Panaullah, G.M., Aich, C.A., Islam, N. and Wahiduzzaman. 1999. Salinity Constraints in the Southern Salt Affected Region in Bangladesh - a Committee Report for the Ministry of Agriculture, Dhaka.

Sattar, M.A. Aich, C.A. and Poddar, S.P. 1990. Integrated Research on the exploration of the production potentials of coastal saline soils of Bangladesh- a paper presentd at a BARC Workshop, Dhaka, 10-28 Sept. 1990.

Water quality and irrigation in China

Abstract

China's water environment in general, and agricultural production in particular, faces three serious and long term problems: serious water pollution, water resource shortage, and flooding. The gap between water supply and requirement in Chinese agriculture is now estimated to be some 30 billion m^3 annually. Some 10 million ha. of farmland are polluted by wastes from industries and urban cities and by agricultural application of chemical substances with loss of 10 billion kg of production per year at a cost of more than 12 billion Yuan (RMB). Water quality of the seven major rivers and of three large lakes in China ranges from good to very poor, with 27% exceeding (worse than) Grade V. (highly polluted) This has serious impacts for agricultural use of surface water and exacerbates the problem of water scarcity in China. Examples are provided for several case studies of soil, ground water and surface water pollution impacts from irrigated agriculture, and of the impact on agriculture of use of municipal sewage for irrigation purposes. A number of water management strategies are proposed for future use in China.

China's water environment in general, and agricultural production in particular, faces three serious and long term problems: serious water pollution, water resource shortage, and flooding. Of these three, pollution and water shortage are the more serious problems in Northern China.

A gap between water supply and requirement in Chinese agriculture is now estimated to be some 30 billion m^3 annually. The cultivated area suffering from drought is about 13-20 million ha. nation-wide. The existing irrigated area is 48.7 million ha. It is proposed to increase the irrigated area to 53 million ha by the end of this century, while the annual water shortage is predicted to be 60-70 billions m^3 even without the establishment of new irrigation facilities (Anon, 1994).

Altogether there are some 10 million ha. of farmland polluted by wastes from industries and urban cities and by agricultural application of chemical substances, and causing a decrease in grain production of 10 billion Kg per year at a cost of more than 12 billion yuan (RMB) (Anon, 1994) in lost agricultural production. Although the amount of wastewater discharged has been somewhat reduced in recent years the pollution level in water bodies was still high. In the vast rural areas, there was an increase in pollution caused by the inappropriate use of chemical fertilizers and pesticides. Urban and industrial centres discharge high loadings of pathogens, suspended solids, nutrients and organic and inorganic contaminants. Countless rural enterprises are also responsible for substantial and often uncontrollable discharges of industrial wastewater. The major pollution parameters are ammonia nitrogen, permanganate index [COD_{KMnO4}], and volatile phenols. Industrial pollution is monitored as COD_{cr}.

Weng Jianhua
Water Quality Research Center, China Institute of Water Resources and Hydropower Research, Ministry of Water Resources, Beijing, China

Due to abnormal climate and ecological destruction over many years, very serious flooding takes place regularly in central and northern China. Yet, there is a water deficit in some arid and semi-arid regions of northwest China and on the North China Plain. The policy for managing this situation is to build more flood retention facilities on such rivers as the Yellow River in order to better use flood waters for beneficial use.

To this time, there are insufficient data to evaluate monitoring and assessment for quality of irrigation water in countrywide scale. In this paper, therefore, the quality of irrigation-source water is examined, together with a discussion of standards of water quality related with agricultural irrigation. The current status of water quality of the irrigation water are explored for selected cases and some strategies are discussed.

GUIDELINES FOR IRRIGATION WATER QUALITY

Standardization of irrigation water quality criteria has been given much importance in China. The National Guideline, "Standard for Irrigation Water Quality" (GB5084-85) was published at 1985, and was modified to (GB5084-92) in 1992 (Gov. China, 1992), as shown in Table 1.

There are also other national guidelines such as the "Environmental quality standard for Surface Water (GB3838-88)" (SEPA, 1988), instituted by the State Environmental Protection Agency, and "Quality Standards for Surface Water Resources (SL 63-94)" (Min. Water Resources, 1994) instituted by the Ministry of Water Resources. Water quality in those standards is divided into five grades - Grade 1 to Grade V representing a range from excellent to highly polluted.

All water falling into Grade V is suitable for irrigation according to the "Standard for Irrigation Water Quality". Because the standards for BOD5, CODcr, SS, LAS, TP, F, CN, petroleum, phenols, and so on, are more than (worse than) Grade V for irrigation purposes, some water that falls into the >V category is also suitable for agricultural irrigation.

TABLE 1
Standards for irrigation water quality (GB5084-92) (mg/l)

No.	Parameter	Paddy field	Arid land	Vegetable
1	BOD5 ≤	80	150	80
2	CODcr ≤	200	300	150
3	SS ≤	150	200	100
4	LAS * ≤	5	8	5
5	N ≤	12	30	30
6	T-P ≤	5	10	10
7	Temperature, °C ≤	35		
8	pH ≤	5.5 ~8.5		
9	Total-salt ≤	1000(non-saline-alkali area), 2000(saline-alkali area)		
10	CL^- ≤	250		
11	S^{2-} ≤	1		
12	T-Hg ≤	0.001		
13	T-Cd ≤	0.005		
14	T-As ≤	0.05	0.1	0.01
15	Cr^{6+} ≤	0.1		
16	T-Pb ≤	0.1		
17	T-Cu ≤	1		
18	T-Zn ≤	2		
19	T-Se ≤	0.02		
20	F^- ≤	2.0(High F- area) 3.0(normal area)		
21	CN^- ≤	0.5		
22	Petroleum ≤	5	10	1
23	Phenols ≤	1		
24	Benzene ≤	2.5		
25	Tri-cloro-aldehyde ≤	1	0.5	0.5
26	Allyl aldehyde ≤	0.5		
27	B ≤	1-3		
28	Coliform ≤	10000		
29	Roundworm ≤	2		

* Anionic Surface Activated Agent (surfactant)

USAGE FOR AGRICULTURAL WATER

The usage of agricultural water in China is rapidly increasing (Houng Xiujiao, 1998), as shown in Table 2.

The data from Table 2 indicate the following trends:

TABLE 2
Trends in agricultural use of water resources in China

Year	1949	1957	1969	1980	1993
Total use (billion m^3)	103.1	204.8	274.4	443.7	525.0
Agricultural use (billion m^3)	100.1	193.8	254.5	391.2	385.0
Irrigation area (million ha)	15.9	25.0	32.0	48.0	49.7
Ratio of agricultural use (%)	97	95	93	88	73
Water amount (m^3/ha)	6285	7785	7950	8145	7770

- The trend of proportion of usage of agricultural water in total water use is decreasing, from 97% in 1949 down to 73% in 1993. Although use of agricultural water has increased by a factor of x3.8, total use has increased by more than x5. This has serious implications for future water allocation policy in China, especially in regards to food security concerns.
- Average usage of agricultural water per hectare is between 7500-8250 m^3. Although masked in the table, the shift in crop types and intensification of agricultural production over the years implies a significant improvement in water use efficiency.

Current status of irrigation water quality

Monitoring specifically for agricultural water quality standards in China is not carried out. However, monitoring for water quality of inland water is performed regularly by various components of the Ministry of Water Resources and by environmental monitoring center at different levels of the State Environmental Protection Agency (SEPA). Using the Grade V ("Environmental quality standard for surface water (GB3838-88)" (SEPA, 1988) class of water quality as an estimate of the minimum acceptable standard for irrigation water, the national monitoring data can be used to evaluate irrigation potential of surface water from various parts of China.

There are seven large river systems and some major lakes in China that are extensively used for agricultural irrigation. These are, from north to south: Songhua River, Liaohe River, Haihe River, Yellow River, Huaihe River, Yangtze River, and Pearl River, and the lakes: Taihu, Chaohu Lake and Dianchi . These comprise the major water systems in China Their current water quality status is shown as follows, according to the newest statistics in 1998 (Gov. China, 1999).

TABLE 3
Percentage of river in each water quality class (1998 data)

River/Lake	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	>Grade 5
Rivers						
Songhua	0	0	4	67	21	8
Liao	4.5	2.3	4.5	22.7	4.5	61.4
Hai	5	19	4	10	9	53
Yellow	0	24	5	47	12	12
Huai	0	11	17	19	6	48
Yangtze	4	67	4	11	10	4
Pearl	29	36	7	22	2	4
Average	6.1	22.7	6.5	28.4	9.2	27.2
Lakes						
Chaohu					X	
Tai				X	X	
Dianchi					X	

The monitoring results of water quality in these basins showed that, on average, 35% of river sections are Grade III or better of the Environmental Quality Standards for Surface Water, of which 6.1%of the sections met Grade I; 22.7% met Grade II, and 6.5% met Grade III. 28.4%were Grade IV, 9.2% Grade V, and 27.2% were lower than Grade V. Compared with the situation in 1997, the water quality in the Yangtze River, the Huaihe River and the Pearl River has improved to some extent. But there was no change in the water quality of the Yellow River, the Haihe River and the Songhuajiang River, and the water quality in the Liaohe River was even worse. Among the seven large river systems of China, the Liaohe River was most polluted, followed by the Haihe River, the Huaihe River, the Yellow River, the Songhuajiang River, the Pearl River and the Yangtze River. Pollution in large freshwater lakes and urban lakes was intermediate-level, though the pollution in Chaohu Lake, Dianchi Lake and Taihu Lake remains as serious as before.

Major rivers

Songhuajiang River: The pollution in the Songhuajiang River was relatively serious. There were only 4% of the monitored sections that met the Grade III standard. Of the remaining sections, 67% were Grade IV, 21% Grade V and 8% worse than Grade V. There were no sections that met Grade I or II standards. The major pollutants were volatile phenols and petroleum.

Liaohe River: The Liaohe River was very seriously polluted, with most monitored sections being Grade V standard or worse. Only 11.3% of the monitored sections met Grade III or better, of which 4.5% met Grade I, 2.3% met Grade II, and 4.5% met Grade III. In addition, there were 22.7% that met Grade IV, 4.5% that met Grade V, and 61.4% were worse than Grade V standard. The major pollutants were ammonia nitrogen, permanganate index, and volatile phenols.

Haihe River: Except for water diverted from the Luanhe River, most of the water in the Haihe River was polluted to some degree. The water quality in 28% of monitored sections was Grade III or better, including 5 % at Grade I standards, 19% at Grade II and 4% at Grade III. In addition, 10% met Grade IV, 9% met Grade V, and 53%was worse than the Grade V standard. The major pollution indices were petroleum, permanganate index, volatile phenols, and ammonia nitrogen.

Yellow River: In 1998, 29% of the monitored river sections was Grade III standard or better, of which 24% met Grade II standards, and 5% met Grade III standards. Forty-seven percent is Grade IV, with 12% of Grade V and 12% worse than Grade V. Suspended substances and volatile phenols were the major pollution parameters.

Huaihe River: Water quality is generally bad. The water quality in 28% of the monitored sections was Grade III standards or better, including 11% at Grade II and 17% at Grade III. In addition, 19% met Grade IV, 6% met Grade V, and 48% was worse than Grade V. Permanganate index and dissolved oxygen were major pollution indices.

Yangtze River: In this large river the pollution loadings are greatly diluted. Therefore, water quality in the main stream was basically good. The percent of monitored sections meeting Grades I – III standards are 4%, 67% and 4%, respectively. Eleven percent met Grade IV and 10% Grade V standards. Four percent are worse than Grade V. The major pollution indices were suspended substances, permanganate index, and ammonia nitrogen.

Pearl River: The water quality was fairly good. Of the monitored section, 72% met Grade III standards or better, of which 29% were Grade I, 36% were Grade II, 7% of Grade III standard.

In addition, 22% of the sections met Grade IV, 2% met Grade V, and 4% was lower than Grade V. The major pollution indicators included oil, suspended substances and ammonia nitrogen.

Major lakes

Taihu Lake: The major controlled parameter, permanganate index, basically met Grade II standards, but the pollution caused by nitrogen and phosphorous was relatively serious. In parts of the lake, such as Wulihu and Meilianghu, eutrophication was significant. The entire Taihu Lake was in a moderate state of entrophication. The water quality in Taihu Lake was between Grade IV and Grade V due to nitrogen and phosphorous pollution. The rivers around the lake that run through Wuxi City, Yixing City and Xishan City were seriously polluted and exceeded Grade V standards. The rivers running through Wujiang City, Suzhou City and the surrounding areas of Zhejiang Province met Grade II-V standards. The water in the areas bordering Taihu Lake was heavily polluted.

Dianchi Lake: Dianchi Lake in the southwest of China was polluted heavily by nitrogen and phosphorous, causing serious eutrophication. The water quality was Grade V or worse. The major pollutants were nitrogen, phosphorous, permanganate index, and BOD5.

Chaohu Lake: Pollution by nitrogen and phosphorous was significant, with serious eutrophication effects. The water quality in the entire lake exceeded Grade V. For nitrogen and phosphorous, the percentage of monitored sites that exceeded surface water standards for these two nutrients were 100% and 50% respectively.

Those monitoring results were assessed using the “Environmental quality standard for Surface Water (GB3838-88)”. Although the water quality of Grade V of “Environmental quality standard for Surface Water” approximates the minimum acceptable standard for irrigation water, some parameters such as BOD5, CODcr, SS, LAS, TP, F-, CN-, petroleum, phenols, and so on, are less restrictive for irrigation purposes. Also, certain of the water quality parameters that are deleterious for surface waters (such as BOD5, N and P), can be beneficial for agriculture. Consequently, while the overall percentage of surface water that exceeds (worse than) Grade V is 27%, the percent that is unsuitable for agricultural use is less. Nevertheless, this still represents an enormous amount of water that remains unsuitable for irrigation agriculture and which causes loss of production and loss of soil resources through salinization, soil contamination, etc.. In general, however, all these facts indicate that the quality of irrigation source (surface) water in China continues to be a serious problem and requires attention. Notably, however, the pollution of surface waters and its economic consequences both for agriculture and other sectors of the economy is recognized by the government and there is increasing emphasis and investment into pollution control.

Some case studies

Effects of sewage irrigation on the agro-environment

Shi-jia-zhuang City, located at Hebei province in northern China, has a very serious water shortage. The city discharges 270 million m^3 of untreated sewage per year to the Xiaohe River. This sewage has been using for irrigation since 1957. Monitoring for water quality and for impacts on agriculture by sewage irrigation has been performed continuously for 5 years. These impacts include effects on crops, soil and ground water in Shi-jia-zhuang sewage irrigation areas (Sun Zhiqiang, *et al*., 1998).

TABLE 4
Monitoring results of water quality of Xiaohe River

Item	pH	SS	COD	BOD_5	CN^-	As	Hg	Cr^{6+}	Cd	Pb	Petroleum	Cl^-	S^{2-}
Range	7.06- 7/53	130- 210	144- 331	133- 155	0.004- 0.056	0.007- 0.180	0.00002- 0.00015	0002- 0.027	0.002	0.005- 0.026	5.98- 8.50	114- 157	0.29- 6.92
Irrigation standard	5.50 8.50	<200	<300	<150	<0.5	<0.1	<0.001	<0.1	<0.005	<0.1	<10	<250	<1.0

The sewage in Shi-jia-zhuang is polluted moderately by organic matter, seriously by sulphide, and lightly by heavy metal, as shown at Table 4.

Groundwater that is 100 to 200m distant from the sewage channel is also polluted. In the past 40 years, the heavy metals content in seeds of wheat and corn planted in the sewage-irrigated land remain lower than those of the National Foods - Heavy Metals standard. Metals in surface soil are all lower than the second degree standard of the National Soil Environmental Assessment Standard. The study also shows that soil organic matter and total nitrogen can be improved by reasonable use of sewage irrigation.

Evaluation of environmental quality in three production bases of green food vegetables

This Shanghai suburb, a suburb county of southern China, is a production base for typical green food vegetables. Irrigation water is taken from surface water. In order to determine and evaluate the environmental quality condition of these three bases of production (Zhou Gendi, *et al*. 1998), samples of soil, irrigation water and atmosphere were taken for analysis from the following 3 vegetable production bases: Qianwei Village in Chongming County, Shanghai "Wusi" Farm and Meiqiao Horticultural Farm of Qingpu County. Water quality of farmland irrigation water is shown in Table 5. The results showed that the contents of various related pollutants in the above-mentioned soil, irrigation water and atmosphere samples were all better than the standards concerned and the comprehensive pollution indexes were all less than 1.0. The environmental quality grades were 1~2, respectively. The reason for higher concentration of chloride at one of the sites (Chongming Island) is caused by extracting Yangtze river water at a point where it is mixing with marine water. All these locations met the environmental quality requisite for the production of green food vegetables.

TABLE 5
Analyses of farmland irrigation water

Vegetable base	pH	Hg	Cd	Pb	As	Cr	F	CN^-	Cl^-
Chongming Island	8.31-8.60	0.00002-ND	0.0007-0.0013	0.011-0.024	0.002-0.008	0.015-0.026		0.02	775.3-5150.7
Wusi Farm	7.85-8.39	ND-0.0008	0.0004-0.0022	0.008-0.035	0.007-0.027	0.040-0.049	0.046-0.078	ND	700.9-2458.5
Meiqiao Farm	6.62-6.78	ND-0.0008	0.0003-0.0009	0.024-0.047	ND-0.006	0.011-0.024	0.046-0.050	ND-0.001	65.3-73.8

Strategies and measures

Management of agriculture in China is part of the larger issue of sustainable environmental management in China in the 21st Century. For sustainable environmental management, it is urgent to establish an ecologically-based system of development for rural areas which will promote sustainability of land and water resources. Five actions are recommended:

a. Develop a rational and integrated monitoring and inventory system for the main croplands, water resources, forestry, grassland, and biological resources. This would for the basis for a conservation and resource utilization strategy.

b. Resource accounting needs to be strengthened and included in the national systems of economic planning, operations and accounting.
c. Optimize resource management as vehicle for achieving specific and sustainable agricultural goals.
d. Strengthen the comprehensive control of water and soil erosion to establish various forms of forestry protection systems.
e. A more effective planning system for the rational location of township and village industries with strengthened construction of infrastructure for prevention of pollution from these dispersed economic activities.

Specifically in the agricultural and water resource sectors, a much greater integration of water and land management must be achieved in China. Several recommendations are:

a. Long-term planning of water supply and demand for each province, city and basin should be established on the basis of planned socio-economic development.
b. Legislation for development and utilization of groundwater resources should be strengthened. In particular, measures for source protection of groundwater resources should be determined to strictly prohibit groundwater pollution from industrial waste water, solid waste and harmful and poisonous materials.
c. Strengthened water pollution control and management measures, including a waste load allocation approach to effluent management.
d. A more integrated national approach for the rational development and optimal allocation of water resources, including development of policies towards basin-scale remediation of badly polluted surface water systems.
e. Enhanced international and regional cooperation with a particular focus on new and more cost-effective approaches for water quality management, planning and remediation.
f. Adoption of a truly multi-sectoral, integrated approach to water resource management (IWRM) in which management systems use river basins as planning units. This should be the basis for regional and national decision-making for water resource management.
g. Water quality monitoring for agricultural water needs to be enhanced and integrated into other national programs of surface water quality monitoring.

References

Anon a, 1994. Sustainable development in China, Ocean Publishing House.

Gov. China, 1992. Standards for Irrigation Water Quality, GB 5084-92

Gov. China, 1999. Report on the state of Environment in China, 1998.

Houng Xiujiao, 1998. China rural water and hydropower. 11, pp7-9

Min. Water Res., 1994. Quality Standards for Surface Water Resources, SL 63-94, Ministry of Water Resources.

SEPA, 1988. Environmental Quality Standard for Surface Water, GB 3838-88. State Environmental Protection Administration.

Sun Zhiqiang, *et al*., 1998. Effects of sewage irrigation on agro-environment, Eco- Agriculture Research, Vol.6 (4) 68-71.

Zhou Gendi, *et al*. 1998. Determination and evaluation of environmental quality conditions in three production bases of green-food vegetables, ACTA Agricultural Shanghai 13 (3): 37-40.

Agriculture and water quality in India towards sustainable management

Abstract

To provide food security for its ever increasing population from the available cultivated land, India must increase its crop productivity by bringing larger areas under irrigation and by adopting yield increasing technological innovations which involve intensive use of agro-chemicals. The desired level of extension in irrigated area is however likely to be constrained by the availability of fresh water. The irrigation sector may have to rely on polluted/ partially treated water to meet its requirements. Similarly intensive application of agro-chemicals may have adverse environmental effects on surface and ground water. Recognizing the intense agricultural-water quality linkages, this paper evaluates the likely impacts on the basis of available empirical evidence, though the absence of a consistent and comprehensive data base has often made it difficult to establish a direct link between the two. The paper also attempts an identification of the alternative agricultural practices and discusses the possible changes in the prevailing policy environment that could help minimize the adverse environmental impacts relating to agriculture - water quality interactions and encourage adoption of sustainable agricultural practices.

The problem

The agriculture sector in India, which currently accounts for about 80 percent of the total utilizable water resources of the country, faces major challenges in the coming years. By the year 2025 the total population of the country is estimated to increase by between 38 to 46 percent from the current level of about 950 million to between 1313 and 1392 million (Natrajan:1993, United Nations :1994, Visaria and Visaria: 1996). To meet the food requirements of this estimated population, the country will need an estimated 322 to 365 million tonnes of food grains (NCIWRDP:1998). The cultivated area of the country has already reached its plateau of 143 million hectares while the area under food grains has stabilized at around 124 million hectares. With no new major technological breakthrough likely in the near future, the only option of increasing agricultural production is to use the available cultivated land more intensively and adopt cultural practices which help raise crop productivity. While intensive cultivation of available land will require conversion of currently rainfed areas to irrigated ones by making irrigation water available to such areas, adoption of yield increasing technological innovations will require more intensive application of agro- chemicals namely chemical fertilizers and pesticides (Malik and Kashyap:1999).

This suggested path of increasing food/ agricultural production is however beset with serious problems on at least two major counts. The first problem relates to the likely constraints on the availability of required quantity of desirable quality of irrigation water. It has been estimated

R.P.S. Malik
Agricultural Economics Research Centre, University of Delhi, Delhi, India

that for meeting the projected demand for food and other agricultural commodities, the gross irrigated area under food grains and non-food crops will need to increase from the current level of 71 million hectares to between 118 and 140 million hectares by the year 2025. As a result the demand for irrigation water is likely to increase from the current level of about 428 Bm^3 to between 731 and 867 Bm^3 in 2025 (Malik and Kashyap:1999). The utilizable water resources of the country have been estimated at 1086 Bm^3 which will leave only between 219 to 355 Bm^3 water for meeting the demand of other water-using sectors. With increasing population and rapid industrialization, the demand for water from other sectors is also likely to increase substantially which will intensify further the inter-sector water allocation problems. Agriculture, being the single largest user of water, will be under greater pressure to release part of the water for use by other sectors. To meet the likely shortfall in the availability of required quantity of good quality water for irrigation, the agriculture sector may have to increasingly rely on poor quality/polluted water. The use of such polluted water for crop production may however cause adverse impact on soils, crop quality, environmental quality and health of the people in areas receiving such waters.

The second problem relates to the process of achieving enhanced crop yields. Since a more intensive use of agro-chemicals, specially inorganic fertilizers and synthetic pesticides, is the most plausible mode for realizing increased crop yields and thereby in ensuring continued food security for the teeming millions, there seems no escape from continued reliance on these chemicals. The intensive use of these chemicals however may cause serious environmental impacts specially on soil and water quality.

Given such intense agricultural- water quality linkages, it would be desirable to ascertain the likely impact that use of polluted water (partially treated/untreated) may have on agriculture - soil health, crop quality, crop yields etc, on quality of environment and more importantly on public health. It will similarly be desirable to ascertain the likely impact that intensive use of chemicals in agriculture may have on water quality. The paper attempts an evaluation of these likely impacts on the basis of available empirical evidence, though the absence of a consistent and comprehensive data base has often made it difficult to establish a direct link between the two. In view of the growing public awareness about environmental impacts and the increasing emphasis on adoption of sustainable agricultural practices, the paper attempts an identification of the alternative agricultural practices and discusses the possible changes in prevailing policy environment that could help minimize the adverse environmental impacts relating to agriculture - water quality interactions and encourage adoption of sustainable agricultural practices.

Water pollution scenario in India: an overview

The pollution of water resources – both surface and ground- is a major environmental concern in India. Pollution of water resources is caused by a variety of substances originating from many different activities: while many of them originate from man's use of water the others are related to the introduction of undesirable constituents into water bodies, directly or indirectly. In India the major sources of water pollution are: untreated municipal sewage due to unplanned urban development without adequate attention to waste disposal; rapid industrialization without provision of proper treatment of effluents and disposal of wastes; intensive agricultural practices increasingly based on use of agro-chemicals coupled with over irrigation; and overexploitation of groundwater causing intrusion of saline water in fresh water.

The facilities to treat waste water are woefully inadequate. For example, in class I cities only 5 % of the total waste water is collected, of which only 25% is treated. More than half of the cities have no sewerage (Govt. of India: 1999). The magnitude of damage caused by such activities to India's water resources can be judged from the fact that about 70 percent of rivers and streams in India contain polluted water (Anonymous : 1997). Table 1 gives an overview of the most polluted stretches of rivers in India and the quality problem of water therein while Table 2 gives a synopsis of the groundwater problem areas of India classified according to the nature of the pollutant. The water quality monitoring results indicate that organic and bacterial pollution continue to be pre-dominant sources of pollution in India's aquatic resources.

In a country where almost 90 percent of the villagers use pond water for bathing and washing utensils and clothes, and more than 50 percent use the same water for cooking, the health

TABLE 1
Polluted river stretches in India

River	Polluted Stretch	Desired	Existing Class	Critical Parameters	Possible Sources
Sabarmati	Immediate upstream of Ahemdabad	B	E	Dissolved oxygen, BOD, coliforms	Domestic and industrial waste from Ahemdabad
	Sabarmati Ashram to Vautha	D	E	Dissolved oxygen, BOD, coliforms	Domestic and industrial waste from Ahemdabad
Subernarekha	Hatia Dam to Baharagora	C	Partly D and partly E	Dissolved oxygen, BOD, Coliforms	Domestic and industrial waste from Ranchi and Jamshedpur
Godavari	Downstream of Nasik to Nanded	C	Partly D and partly E	BOD	Waste from sugar, distillery and food processing industry
	City Limit to Nasik and Nanded	B	Partly D and partly E	BOD	Waste from sugar, distillery and food processing industry
Krishna	Karad to Sangli	C	Partly D and partly E	BOD	Waste from sugar and distillery industry
Indus (tributaries, Sutlej)	Downstream of Ludhiana to Harike	C	Partly D and partly E	Dissolved oxygen, BOD	Industrial waste from hoseries, tanneries, electroplating and engineering
	Downstream of Nangal to Anandpur	C	E	Ammonia	Wastes of fertilizer, chlor alkali,and paper mills from Nangal
Ganga (Tributaries) Yamuna	Delhi to Confluence with Chambal	C	Partly D and Partly E	Dissolved oxygen, BOD, coliforms	Domestic and Industrial waste from Delhi, Mathura nad Agra
	In the city limits of Delhi, Mathura	B	Partly D and partly E	Dissolved oxygen, BOD, coliforms	Domestic and Industrial waste from Delhi, Mathura and Agra
Hindon	Saharanpur to Confluence with Yamuna	D	E	Dissolved oxygen, BOD, coliforms	Industrial and domestic waste from Saharanpur and Ghaziabad
Chambal	Downstream of Nagda and downstream of Kota	C	Partly D and partly E	BOD, dissolved oxygen	Domestic and industrial waste from Nagda and Kota
Damodar	Downstream of Dhanbad to Haldia	C	Partly D and partly E	BOD, toxic	Industrial waste from Dhanbad, Durgapur, Asansol,Haldia, and Burnpur
Gomti	Lucknow to confluence with Ganga	C	Partly D and partly E	Dissolved oxygen, BOD, coliforms	Industrial waste from distilleries and domestic waste from Lucknow
Kali	Downstream of Modinagar to confluence with Ganga	C	Partly D and partly E	BOD, Coliforms	Industrial and domestic waste from Modinagar

Quality Classification of Water: A: Drinking water Source without conventional treatment but after disinfection, B: Outdoor bathing, C: Drinking water source with conventional treatment followed by disinfection, D:Propogation of wildlife, fisheries, E: Irrigation, industrial cooling and controlled waste disposal
Source : MoEF(1993)

TABLE 2
Status of groundwater pollution in India

Sl	Pollutant	State	Places of Occurrence (Districts)
1.	Salinity (Inland)	Maharashtra	Amravati, Akola
		Bihar	Behusarai
		Haryana	Karnal
		Rajasthan	Barmer, Jaisalmer, Bharatpur, Jaipur, Nagaur, Jalore, Sirohi
		U.P.	Mathura
2.	Salinity (Coastal)	Andhra Pradesh	Vishakhapatnam
		Orissa	Puri, Cuttack, Balasore
		West Bengal	Haldai and 24 –Parganas
		Gujarat	Junagarh, Kachch, Varahi, Banskantha, Surat
3.	Fluoride	Kerala	Palghat
		Andhra Pradesh	Krishna, Anantpur, Nellor, Chittoor, Cuddapah, Guntur, Nalgonda
		Gujarat	Banskantha, Kachch, Amreli
		Haryana	Hissar, Kaithal, Gurgaon
		Orissa	Bolangir, Bijapur, Bhubneshwar and Kalahandi
		Punjab	Amritsar, Bhatinda, Faridkot, Ludhiana, Sangrur
		Rajasthan	Nagaur, Pali, Sirohi, Ajmer, Bikaner
		Tamil Nadu	Chengalpett, Madurai
		U.P.	Unnao, Agra, Aligarh, Mathura, Gizibad, Meerut, Rae Bareli
4.	Sulphide	Orissa	Balasore, Cuttack, Puri
5.	Iron	U.P.	Mirzapur
		Assam	Darrang, Jorhat, Kamrup
		Orissa	Bhubhaneshwar
		Bihar	E.Champaran, Muzaffarpur, gaya, Manger, Deoghar, Madubani
		Rajasthan	Bikaner, Alwar,Bharatpur
		Tripura	Dharamnagar, Kailasanar, Ambasa, Arnarpur, Agaratala
		West Bengal	Midnapur, Howrah, Hoogly, Bankura
6.	Mangan Ese	Orissa	Bhubhaneshwar, Athgaon
		U.P.	Muradabad, Basti, Rampur, Unnao
7.	Arsenic	West Bengal	Malda, Murshidabad, Nadia, 24-Parganas
8.	Nitrate	Bihar	Patna, E.Champaran, Palamu, Gaya, Nalanda, Nawada, Banka
		Andhra Pradesh	Vishakhapatnam, E.Godavari, Krishna, Prakasam, Nellure, Chittoor, Anantpur, Cuddapah, Kurnool, Khaman, Nalgonda
		Delhi	Nariana, Shahadra (blocks)
		Haryana	Ambala, Sonepat, Jind, Gurgaon, Faridabad, Hissar
		Himachal Pra	Kullu, Solan, Una
		Karnataka	Bidar, Gulbarga, Bijapur
		Madhya Pradesh	Sehore, Bhopal (west and central part of state)
		Maharashtra	Jalna, Beed nanded, Latur, Osmanabad, Solapur, Satara, Sangli, Kolhapur
		Punjab	Patiala, Faridkot, Firozpur, Sangrur, Bhatinda
		Rajasthan	Jaipur, Churu, Ganganagar, Bikaner, Jalore, Barmer, Bunda, Swaimadhopur
		Tamil Nadu	Coimbatore, Periyar, Salem
		West Bengal	Uttar Dinajpur, Malda, Birbhum, Murshidabad, Nadia, Bankura, Purulia
9.	Chloride	Karnatka	Dharwar, Belgaum
		Madhya Pradesh	Bhind, Shagapur Sehore
		Maharashtra	Solapur, Satara, Amravati, Akola, Buldana
		Rajasthan	Barmer, Jaisalmer, Jodhpur, Jalore
		West Bengal	Contai, Digha, Haldia
10.	Zinc	Andhra Pradesh	Hyderabad, Osmania University Campus
		Delhi	R.K.Puram
		Rajasthan	Udaipur
11.	Chromium	Punjab	Ludhiana

Source; Bhu-Jal News(1997)

implications are obvious (AIIHPH: 1993). Further, although polluted groundwater has generally been a localized problem, and not as widespread as for surface water, the potential impacts of groundwater contamination on human health are perceived to be still greater as more than 80 percent of rural domestic water supply and 50 percent of urban and industrial water supply comes from groundwater sources[1]. The health costs associated with impure water are staggering. It is estimated that approximately 30.5 million Disability Adjusted Life Years (DALYs) are lost each year in India due to poor quality water, sanitation and hygiene. For children the situation is particularly serious: 0.5 to 1.5 million children under the age of five die annually from diarrhea alone (World Bank: 1998).

While the impact of domestic and industrial sources of water pollution, often referred to as point sources, have been widely recognized and some efforts at controlling them have been underway for some time, the impact of agriculture, which is perceived as the single largest non-point sources of pollution, on water quality has evinced greater public concern only in the recent past.

Impact of agro-chemicals on water quality

Agro-chemicals have played, and will continue to play, a major role in increasing food production in India. The consumption of these chemicals has increased very rapidly in the recent past. During the three decade period 1965-66 to 1996-97, the consumption of chemical fertilizers has increased from a mere 785 thousand tonnes to more than 14,300 tonnes (FAI:1998). In terms of usage per land unit area, the consumption of fertilizers per hectare of cultivated land at an all-India average has increased from about 6 kg in 1965-66 to more than 98 kg in 1996-97. There are, however, wide inter-regional variations in per hectare fertilizer consumption in the country. In States like Punjab, Haryana, Tamilnadu and Andhra Pradesh the per hectare fertilizer consumption is much higher than the all-India average. For example the per cultivated hectare fertilizer consumption in Punjab during 1996-97 was about 300 kg.

The intensive crop production systems in India also rely heavily on chemical pest control. Between 1965-66 and 1996-97, farm use of pesticides in Indian agriculture has increased almost five times- from about 14.5 thousand tonnes to more than 72 thousand tonnes (Puri and Verma: 1999). In terms of per hectare use, the all-India average consumption of pesticides has increased from about 107 gm to 507 gm per cultivated hectare. Concurrent with the increased intensity of pesticide usage there has also been a compositional change in use of pesticides. Thus while the proportionate share of insecticides in the total use of pesticides has declined, that of fungicides and herbicides has increased over the years. Modern herbicides in general are short lived but tend to have fairly high water solubility and low soil water partition coefficients that make them susceptible to groundwater leaching. There has also been a shift in nature of pesticides usage from persistent, chlorinated hydrocarbon insecticides, such as DDT, to compounds such as the organophosphates that are less persistent but have acute toxicity. A number of pesticides that are classified by WHO as highly hazardous and are either banned or highly controlled in Western countries continue to be commonly used in Indian agriculture. Three crops - cotton, rice and wheat account for more than 73 percent of the total pesticides used in Indian agriculture.

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1 A 1994 survey of groundwater quality at 138 sampling locations in 22 industrialized zones indicated that water was unfit for drinking due to high bacterial and heavy metal pollution (Government of India:1999).

Fertilizer leaching in groundwater

The all-India average consumption ratio of N, P, K nutrients in India during 1996-97 was 10.0:2.9:1.0 (FAI:1998). Of the three nutrients, it is the fertilizer N which is most amenable to leaching. The leaching of fertilizers into groundwater is influenced by a number of factors such as soil characteristics, level of fertilizer use, the timings of fertilizer application, depth to water table, irrigation practices, nature of crops cultivated etc.. In India, documentation on the incidence of groundwater contamination in general and from use of agricultural chemicals in particular, is very limited. Some of the earlier attempts made to link fertilizer use with nitrate pollution in groundwater in India have been made amongst others by Singh (1975), Singh and Sekhon (1976), Kakar (1985), Handa (1987) and Singh et.al.(1987). The general conclusion from these studies has been that fertilizers are polluting groundwater.

We also attempted to ascertain the impact of fertilizers on groundwater pollution. Since, *a priori*, the possibility of such an association to hold is more likely in the regions where fertilizers are being used intensively, we attempted to ascertain the possible relationship between the two in the agriculturally most advanced region of the country viz. the North-West States of Punjab and Haryana.

TABLE 3
Nitrate concentration in groundwater: 1995

State/Nitrate Concentration (mg/l)	Number of Samples	Average Nitrate Level
Punjab		
0-45	328 (69.8)	14.50
46-100	71 (15.1)	66.49
>100	71 (15.1)	238.97
Total	470 (100.0)	56.26
Haryana		
0-45	222 (63.1)	15.41
46-100	62 (17.6)	68.58
>100	68 (19.3)	283.65
Total	352 (100.0)	85.59
N-W India		
0-45	550 (66.9)	14.86
46-100	133 (16.2)	67.46
>100	139 (16.9)	260.82
Total	822 (100.0)	64.97

Note: Figures in parentheses denote percentages

The Punjab and Haryana State Groundwater Boards, as part of their program on monitoring of groundwater resources, collect data on depth to water table and a few of the groundwater quality parameters including that on nitrate levels, from a number of shallow wells spread throughout the region. While the data on depth to water table is collected both during pre and post monsoon period, the data on water quality is collected only for the pre monsoon period (during the month of May). The number of observation wells in Punjab is 460 (including 72 pizeometers) while that in Haryana is 534 (including 164 pizeometers).

The results of analysis of the nitrate content of water samples in the two States are presented in Table 3. The Indian Standards Institution (ISI) has specified the desired nitrate limit for drinking water to be below 45 mg/l. The results obtained indicate that more than 33 percent of the water samples in North-West Indian states of Punjab and Haryana had nitrate level above the desired limit for drinking water standards. In fact in about 17 percent of the samples the nitrate levels exceeded 100 mg/l.

Sources of nitrate

Given that there are no major geological deposits in the study area and major water polluting industries are only a few and that too in the small and medium sector only, the major source of nitrate concentration in groundwater could either be sewage and animal wastes and/or agricultural chemicals — principally N fertilizers. The study area is densely populated with population density of around 400 persons/km^2. The area is predominantly rural. Raw or inadequately treated sewage is either discharged into irrigation channels or quite often discharged into pits or depressions from where the pollutants could percolate down into the groundwater. The region also has a high density of cattle population, the density of cattle population being around 200 animals/km^2.

To assess the nature of relationship between observed nitrate level in groundwater and the possible sources of nutrient leaching, micro level information on associated variables viz. level of fertilizer use, livestock density, population density, crop cover, depth to water table, irrigation practices, soil conditions etc is needed. However information on these parameters is not available. As such, attempting to estimate the nature of statistical relationship between these parameters is beset with problems.

A close scrutiny of the available data however reveals that there is no discernible pattern of distribution of nitrates in ground waters of Punjab and Haryana. At some places where high nitrate levels in groundwater have been detected there is a sharp decrease in nitrate concentration a short distance away and vice versa. Such sudden changes of nitrate levels in groundwater would indicate that there is no regular pattern of nitrate distribution and pollution is localized. This pattern of nitrate distribution together with other circumstantial evidence available would however lead one to conclude that in shallow water tables of the study region, sewage disposal along with leaching of fertilizers are contributing to the nitrate pollution of the groundwater- the extent of contribution of each source is however difficult to evaluate.

PESTICIDE LOSSESTHROUGH LEACHING AND RUNOFF

A bulk of the pesticides applied for plant protection reach soil either through direct application or indirectly as fall out from foliar sprays. Rainfall immediately after the foliar spray dislodge the residue from the plant and deposit in the soil. Plant debris from pesticide treated crop and use of FYM and compost contaminated with pesticides are the potential sources of pesticide found in the soil. Rivers/ canals which flow through the agricultural fields are easily contaminated with pesticide residues present in the soil under the influence of rain and irrigation water by the processes of surface run-off, sediment transport and movement of groundwater from aquifer to river. The groundwater flows to river when its water table is higher than the river water level.

In India, while a lot of research work has been done on the incidence of pesticide residues in crops, buffalo milk, mother's milk etc, the evidence on contamination of water from agricultural pesticides is scanty. It is however generally acclaimed that agricultural fields treated with pesticides act as the main source of non- point pollution of river systems and other water bodies. The available evidence also indicates that contamination of water from pesticides involves only a few compounds. These compounds have relatively high water solubility, have a low affinity for soil and are relatively persistent (long living).

Data on pesticide residues in surface water bodies is collected as part of the river water monitoring system by the Central Pollution Control Board (CPCB) through a network of "hot spot" monitoring stations set up on all the major river basins spread throughout the country. A majority of the monitoring stations are however located either near the urban agglomerates or industrial zones. Analysis of the pesticide residue data conducted on Ganga river indicate levels of various pesticide chemicals (HCH, DDT, endosulfan, malathion etc.) which exceed international quality standards. On the basis of such an analysis it is however difficult to ascribe the resultant pesticide residues detected in these water samples to agricultural pesticides alone.

To study the contribution of agricultural application of pesticides on the quality of ground and river water, a systematic study was recently commissioned by the Ganga Project Directorate

(Agnihotri: n.d). Under this study, agricultural fields covering an area of 6 km^2 were selected on the banks of River Ganges where intensive agriculture is being practiced and farmers are using pesticides routinely for crop protection. The area consists of several small fragmented holdings growing a variety of crops –maize, potato, wheat, tobacco, vegetables etc. About 25 different pesticides are being used in the area depending on the crop, type of pest and availability of pesticides. Most of the farmers in the area are illiterate and not even aware of the type of pesticides they are using. They use whatever material is available to them through cooperatives, plant protection department or recommended by agrochemical merchants.

Pesticide leaching in groundwater

During the percolation of water in soil, a part of the pesticides is adsorbed on soil particles in different layers of the soil profile. However, not all the pesticides that move along with water reach the ground water. In ground water, pesticides in water are in equilibrium with that adsorbed on soil particles of the aquifer. When water recedes either due to movement to the river or on account of utilization for irrigation, industry or domestic use, a part of the pesticides remains in soil in adsorbed form. When the water moves in the aquifer either from river or percolation from the surface, a part of this soil-adsorbed pesticide can be released or desorbed in to the water. Thus the amount of pesticide present in groundwater is a net result of adsorption-desorption processes. In the present study HCH, DDT, aldrin, endosulfan and organophosphates were apparently added to the soil at the rate of 300, 620, 46, 378, and 594 gms/ha. Of this, the net amount of pesticide added to the groundwater from soil was calculated to be 0.229 gm of HCH, 0.158 gm of DDT, 0.112 gm of aldrin, 0.223 gm of endosulfan and 0.078 gm of organophosphates. (Table 4). Thus of the 1938 gm pesticides added per hectare, 0.600g leached to groundwater.

Pesticides lost in river water

The transportation of pesticides from agricultural fields to the Ganges river water was calculated on the basis of losses that occurred through surface run-off and sedimentary transport from soil and movement of groundwater from aquifer to the river. The amount of pesticides moving into the river depends on their concentration in the soil and rainfall. Table 5 gives the amount of pesticides lost through different processes from agricultural fields to Ganga River. It is interesting to observe that the loss of pesticides by sedimentary transport was much higher than surface run-off. The loss of HCH and DDT was four times higher through sedimentary transport than surface run-off. Similarly the loss of endosulfan and organophosphorous insecticides was 26 and 46 times more by sedimentary transport than by surface run-off. It seems that pesticides that are relatively more soluble in water have a tendency to be adsorbed on soil particles and these are readily lost by sedimentary transport. The loss of pesticides from ground water to river was calculated on the basis of movement of water from aquifer to river and vice-versa.

TABLE 4
Pesticides leached into groundwater or adsorbed on soil from water

Pesticide	Pesticide leached into the aquifer (g/ha)	Pesticides adsorbed on the soil (g/ha)	Net amount of pesticide added to groundwater from soil (g/ha)
HCH	0.807	0.578	0.229
DDT	1.426	1.268	0.158
Aldrin	0.550	0.438	0.112
Endosulfan	0.388	0.165	0.223
Organophosphates	0.690	0.612	0.078
Total	3.661	3.061	0.600

Source: Agnihotri(n.d.)

TABLE 5
Contribution of agricultural application of pesticides to the quality of river water

Pesticide	Surface run-off (g/ha)	Sedimentary transport (g/ha)	Pesticide movement (g/ha)		Net amount of pesticide moving to river (g/ha)
			Aquifer to river	River to aquifer	
HCH	0.240	0.406	0.151	0.089	0.708
DDT	0.149	0.556	0.218	0.241	0.682
Aldrin	0.068	0.091	0.077	0.036	0.200
Endosulfan	0.014	0.363	0.024	0.027	0.374
Organophosphates	0.019	0.867	0.071	0.031	0.926
Grand Total	0.490	2.283	0.541	0.424	2.890

Source: Agnihotri (n.d.)

Thus in the case of DDT and endosulfan there was net movement of these pesticides from river to groundwater while in the case of other three, there was movement from ground water to the river.

Thus the residues of HCH, DDT, aldrin, endosulfan and organophosphates added to the soil contributed as much as 0.708 g/ha HCH, 0.682 g/ha DDT, 0.200 g/ha aldrin, 0.374 g/ha endosulfan and 0.926 g/ha organophosphate insecticides to the river. Thus in all, out of total of 1938 g/ha pesticides added, 2.890 g/ha was transported to the river.

The evidence presented above on the fate of applied chemicals on the agricultural fields do suggest that at least a part of the applied chemicals do get lost either through leaching and/or through surface run-off and pollute the groundwater and surface water bodies.

Impact of using polluted water on agriculture

As mentioned above, to meet the demand for water of ever-growing population and rapid industrialization, increasingly larger quantities of fresh water are likely to be diverted to these sectors. The waste water generated by municipal sewage and industrial effluents is also likely to increase correspondingly. To minimize the impact of these effluents on further deterioration of the already polluted water bodies, strict environmental regulations are being enforced. Minimum National Standards (MINAS) for effluent discharge are being formulated for different industries. Polluting industries are now increasingly required to install effluent treatment plants either individually or as joint/ common treatment plants. Similarly municipal bodies are now more than earlier required to at least partially treat the sewage before discharging it to water bodies. Although these efforts have so far met with a limited success, it is expected that these efforts will gradually succeed in containing the increasing pollution of water bodies. The agricultural sector, to meet its demand for irrigation water, may have to increasingly rely on this polluted /partially treated waste water for irrigation.

Use of treated wastewater for irrigation

Use of wastewater for irrigation of agricultural crops is not new in India. There are a larger number of instances where wastewater, directly from industries or from canals where municipal sewage is regularly dumped, has been regularly used for years for irrigation purposes. However little systematic effort has gone in to ascertaining the wider implications of using such waste water for irrigation.

The River Ganges is the holiest and most important river and flows through a distance of more than 2000 km after descending to plains from Rishikesh. The Ganges basin is facing environmental problems of unprecedented magnitude due to degradation of river water quality as a result of disposal of industrial effluents, municipal sewage, solid wastes, agricultural run-off, bathing of animals, dumping of half burnt dead bodies etc. As part of the efforts to cleanse the polluted rivers in the country, the Government of India in 1986 initiated a massive programme – the Ganga Action Plan (GAP) - to cleanse River Ganges. As part of GAP, 35 Sewage Treatment Plants (STPs) with a combined treatment capacity to partly treat household and industrial waste water volume of 919.82 million litres per day have been constructed at different points along the course of the river. Partly treated water from STPs is made available to the farmers for irrigation in the adjoining villages of the GAP project. Since conventional STPs reduce mainly the organic load these are not very effective in reducing the levels of metals, pesticides etc, except that a larger fraction of these toxicants is retained with the sludge generated by STPs, the remainder is discharge with the treated waste water effluent.

To analyse the implications of using treated/untreated waste water (metals and pesticides) discharged by STPs on agriculture, public health and environmental quality of the areas receiving the treated waste water from the STPs, a systematic study was undertaken (Metroeconomica *et.al*:1997). The study focussed on two areas – one near Kanpur where treated waste water from Jajuman STP plant was mixed up with untreated waste water for irrigation, and the second near Varanasi where unmixed treated waste water was used for irrigation. Concurrent with these areas receiving treated/partially treated waste water (exposed areas) for irrigation, adjoining areas which used fresh water for irrigation (unexposed areas) were also selected in order to compare the impacts.

Impact on agriculture

Use of treated waste water and sludge containing elevated levels of persistent toxicants such as metals and to some extent pesticides can lead, in long run, to built up of higher concentration in soils as a result of accumulation. The higher metal levels in soil may cause negative impacts on crops, inhibiting the growth in one or other way. However one of the most important factors is the pH of the soils. Alkaline pH of the soil usually restricts the mobilization of the metal in the soil matrix and consequently, the metal uptake by the crops can be controlled thereby reducing the risk of metal toxicity.

An analysis of the soils irrigated with waste water indicated that the mean level of Cd and Cr were above their critical levels in the Kanpur region while the mean level of Cd, Ni, and Pb were above their respective tolerable limits for agricultural crops in the Varanasi STP region. However the disposed waste water in both the areas had mean pH value of about 8 and the mean pH value for the agricultural soils irrigated with waste water was found to be more than 8. Therefore even though the level of a few metals were above their critical limits, their mobilization and plant uptake might be restricted by their alkaline pH. Therefore, as yet there seems no adverse impact of metals and pesticides on agricultural crops in these areas.

A questionnaire survey of individual farmers was conducted in all the four exposed and unexposed areas to ascertain information from the farmers on agricultural crop production trends during the last few years. In the exposed areas near Kanpur STP, almost 90 percent of the farmers reported that the crop yield had declined over the past few years due to some root disease infestation causing plant death or weakness leading to small grain size. However in Varanasi STP area an enhancement in crop yields was reported by about 65 percent of the farmers. The reason for reduced productivity near Kanpur may not however necessarily be due to the use of toxic waste water. However the enhanced yield in Varanasi STP area is more likely due to availability of waste water having a higher nutrient/fertilizer (N,P,K,Org C etc) value.

Impact on environmental quality

The impact of treated waste water toxicants on the environmental quality of the disposal areas was assessed in terms of the differences in toxic levels in different media samples viz. water, soil, crops, vegetation, food grains and biological samples obtained from exposed and unexposed areas. An analysis of the collected samples shows elevated levels in all the environmental compartments in the exposed areas. These toxicants therefore have definite adverse impacts on the environmental quality of the disposal areas.

Impact on health

The impact of the waste water toxicants on human health in the areas receiving waste water was assessed through a standard questionnaire based on the exposed and unexposed population groups. Three different approaches – neurobehavioral analysis, environmental exposure risk analysis and biomonitoring of the metals and pesticides levels in the human blood and urine samples - were used to assess the health impact. The results of all the three approaches indicate a considerable risk and impact of heavy metals and pesticides on human health in the exposed areas receiving the waste water from STPs.

Towards sustainable management of agricultural-water interactions

An appraisal of some of the evidence on the fate of applied agro-chemicals, used intensively to realize higher crop yields, vis-à-vis their effect on water bodies does suggest that applied chemicals- in particular fertilizer-N and pesticides, do pollute the water bodies. While the observed level of nitrates in water samples may not be ascribed fully to the use of N fertilizer alone, the available evidence nevertheless does indicate that fertilizer- N indeed leaches to the groundwater. Similarly while the available evidence on the effects of using partially treated waste water for crop irrigation does not provide any conclusive evidence of using such water on crop yields, it does provide conclusive evidence of harmful effect on the quality of the environment and on human health. Given the harmful effects of using both - the treated waste water and intensive use of agro-chemicals- sustainable agricultural production systems will require consideration/ incorporation of principles that prevent or minimize contamination of surface and groundwater. While a number of alternative management practices have the potential to decrease agricultural water pollution, these however have yet to be developed into functioning systems that are acceptable to the farmers or are economically viable. The following are some of the available options that could help better manage agriculture-water interrelationships.

To reduce the potential for water contamination from use of pesticides, source control appears to be the only effective means. Source control includes restricting the use of more mobile compounds in areas of high groundwater vulnerability; using integrated pest management (IPM) or alternative pest control measures instead of prescription pesticide application wherever possible. Source control also includes the use of good housekeeping measures such as proper rinsing of spray tanks and disposing of containers. Of these the first and last are likely to be more effective in the short run. Although intensive efforts are underway to encourage farmers to adopt IPM practices, the farmers have yet to adopt these to any large extent as these strategies are highly pest and crop specific. Initial results on switching over to IPM practices indicate that such practices do result in reduced used of pesticides without any adverse effects on crop yields.

Farmers in the intensive agriculture areas, such as those in the North-West India, have a tendency to apply fertilizers at levels somewhat more than that recommended by the scientists or that required by the crop (Malik: 1988). In addition the use of different fertilizer nutrients is highly imbalanced – farmers use N far in excess of the other two nutrients. Use of fertilizer doses far in excess of the requirement by the crop and relatively more reliance on use of N fertilizer, leaves a large part of fertilizer N unutilized by the crop thereby enhancing N loss through leaching. While part of the differences in actual and recommended doses of fertilizer could partly be due to differences in perceptions of farmers and the scientists about the recommended doses, a large part of the overuse and imbalance in fertilizer use could be attributed to the subsidies on fertilizers and the relative prices of different fertilizer nutrients. Reforms in fertilizer pricing could encourage a more judicious and more balanced use of fertilizers leading to reduced loss and environmental impact.

Given the harmful environmental and health effects of using partially treated water for crop irrigation, widespread use of such water, possibly without further treatment, may not be desirable. To partially meet the additional irrigation water requirements, the efficiency of use of available water for irrigation will need to be increased so that a given quantity of available water can be used to irrigate larger areas. More efficient use of available water through, amongst others, curbing over-irrigation of crops will not only save water but also help in minimizing the loss of applied agricultural chemicals from fields through leaching and run-off. Reforms in pricing of irrigation water and rationalization of electricity prices for irrigation pumping will go a long way in improving water use efficiency.

Although partial information on non-point sources of water pollution is occasionally available, no agency in India seems to have a systematic program for monitoring potential non-point sources of pollution. Special monitoring needs to be implemented to systematically monitor agricultural pollution. It is also simultaneously important to define standard procedures for data collection and its analysis. Inventories and studies of the main sources of pollution are also essential. The resulting information will reveal which pollutants are encroaching and thus how to better target pollution control activities. In addition to data on pollution, data on dynamics of hydrological systems are also required. In general, pollution and water quality monitoring should address management information needs.

References

Agnihotri, N.P. n.d. Contribution of Agricultural Application of Pesticides on Quality of Ground and River Water. Report prepared for the Ganga Project Directorate. Division of Agricultural Chemicals, Indian Agricultural Research Institute, New Delhi.

AIIHPH. 1993. as quoted in World Bank 1998 op cit.

Bhu-Jal News. 1997. Ground water pollution and Quality Hazards Scenario in India. Bhu-Jal News, Vol 12, Nos 3&4, December 1997.

FAI. 1998. Fertilizer Statistics 1997-98. Fertilizer Association of India, New Delhi.

Government of India.1999. Economic Survey. Planning Commission, New Delhi.

Handa. B.K. 1987. Nitrate Content of Ground water in India. Fertilizer News, June 1987. Fertilizer Association of India, New Delhi.

Kakar, Y.P. 1985. Nitrate Pollution of ground water in Haryana. in "Seminar on water quality and its management" Central Board of Irrigation and Power, New Delhi, December 1985.

Malik, R.P.S. 1988. Regionwise Cropwise Fertilizer consumption in Punjab. Agricultural Economics Research Centre, University of Delhi, Delhi (mimeo).

Malik, R.P.S. and S.P. Kashyap. 1999. Water for Food and Livelihood Security: A 2025 Vision for India. Paper prepared for India Water Vision 2025, India Water Partnership (mimeo).

Metroeconomica, IEG, ITRC, AIIHPH, University of Patna, CICFRI and Ecotech Services. 1997. A Cost-Benefit Analysis of the Ganga Action Plan. Report prepared for Ministry of Environment and Forest, Government of India and Department for Internal Development, Government of United Kingdom (mimeo).

MoEF. 1993.National Environment Programme, Ministry of Environment and Forests, New Delhi.

NCIWRDP. 1998. Water Resources Development Plan of India: Policy and Issues, Ministry of Water Resources, New Delhi.

Natrajan, K.S. 1993. Population projections for India. Paper presented at the 17th Conference of the Indian Association for Study of Population, Annamalai University, Tamilnadu.

Puri S.N. and P.V. Verma. 1999. Pesticide Database Information System. National Centre for Integrated Pest Management, New Delhi.

Singh, Bijay. 1975. Are fertilizers polluting groundwater? *Everyday Science* 20(2).

Singh, Bijay and G.S. Sekhon. 1976. Nitrate Pollution of groundwater from nitrogen fertilizers and animal wastes in the Punjab. *Indian Agriculture and Environment* 3.

Singh, I.P, B. Singh,and H.S. Bal. 1987. Indiscriminate fertilizer use vis-à-vis groundwater pollution in Central Punjab. *Indian Journal of Agricultural Economics* 42(3).

United Nations. 1995. World Population Prospects - The 1994 Revision. United Nations, New York.

Visaria, L .and P. Visaria. 1996. Prospective population growth and policy options for India. The Population Council, New York.

World Bank.1998. India: Water Resources Management Sector Review, World Bank, Rural Development Unit, South Asia Region. Washington D.C.

Bioremedial effectiveness of a herb bed treatment system for wastewater quality improvement

Abstract

The bioremedial effectiveness of Herb Bed Treatment System (HBTS) with Bulrush (*Scirpus litoralis* Schrad), Water morning glory (*Ipomoea aquatica* Forsk), and Garden cormous herb (*Typhonium javanicum* Miq) through a small-scaled field trial and laboratory simulation were studied. The water used for both the field experiment and laboratory simulation was taken from the heavily polluted water of the Sunter-Kemayoran river basin, in a densely populated area in Jakarta. The effectiveness of the herb filters was measured against the parameters of water quality (physical, chemical, and biological), for standard D classification (wastewater), and of B classification (raw drinking water). For physical parameters, the filters showed that the effectiveness was either positive or negative, while for organic chemical parameters most of them showed a positive effectiveness except for *Typhonium javanicum* which showed a negative relationship with organic parameters. Against the inorganic chemical parameters, half had positive effectiveness, while for the other half the effect was negative. Against the microbiological paramaters, the filters showed that the effectiveness was all positive. Among the three plants, the bulrush (*Scirpus litoralis* Schrad) was superior compared to the other two plants.

Background

The pollution of rivers, lakes, and other water bodies in the surrounding area of big cities and densely populated area, and the global concern over fresh water scarcity, are serious problems for the environment and which have negative impacts on public health. The problem is that appropriate small scale wastewater technology management is not yet known by communities.

In Indonesia, especially in big cities, most of the river pollution comes from many small sources of pollutants, i.e. from households, markets, restaurants, hotels, hospitals, industries, etc. In the urban area, detergent, fat, excreta and other compounds flow to sewers and then onwards to rivers. In the lower areas, and at river mouths, the rate of flow is reduced and the river is often connected with stagnant water bodies and ponds. In such locations grow several macrophytes or aquatic weeds, e.g. *Typha spp*. (*purun*), *Cyperus spp*. and *Scirpus spp*.(*mendong*), *Eichornia crassipes* (*eceng-gondok*), *Salvinia spp.* (*kiambang*), and *Ipomoea aquatica* (*kangkung*). Some of those macrophytes are edible, and some are used as raw materials on a

S.Hardjoamidjojo and M.S.Saeni
Bogor Agricultural University, Bogor , Indonesia

small scale for home industries such as the fabrication of hats, bags, and other hand-made ornaments.

Although more attention to environment improvement issues focuses on gardening and tree plantings as a counter to physical development (housing, hotels, hospitals, etc.), one can make use of these unused aquatic plants. A biofilter of Herb Bed Treatment System (HBTS) having a bioremedial effect was developed using Bulrush (*Scirpus litoralis* Schrad), Water morning glory (*Ipomoea aquatica* Forsk), and Garden cormous herb (*Typhonium javanicum* Miq). The HBTS system is adapted to the aquatic environment and could protect the above mentioned water bodies from pollution. The three Herb Bed Treatment Systems were named HBTS-Bulrush, HBTS-Glory, and HBTS-Cormous, respectively.

Objectives and use of the study

The objectives of the study are to:

- measure the effectiveness of Bulrush (Scirpus *litoralis* Schrad), Water morning glory (*Ipomoea aquatica* Forsk), and Garden cormous herb (*Typhonium javanicum* Miq) of the Herb Bed Treatment System (HBTS), in terms of the physical, chemical, and biological parameters, against the water pollutants of Sunter river, Jakarta;
- assess whether this bioremedial technology is effective in improving polluted water to the point where the water can be reused;
- to determine if this affordable, simple wastewater treatment process can be used by a community as an integral measure for esthetics as well as for environment improvement;
- to determine if this bioremedial technology can be integrated with agricultural technology to produce a healthy food with less risk of diseases caused by pollution;

The physicochemical and microbiological parameters were assessed according to the water quality standard D classification (Wastewater), and B classification (raw drinking water).

Methodology

Bulrush (*Scirpus litoralis* Schrad), Water morning glory (*Ipomoea aquatica* Forsk), and Garden cormous herb (*Typhonium javanicum* Miq) were the plants used for the experiments as the filter plants. The reason for using those three plants are:

- from earlier experiments, these three plants have more advantages compared with others;
- the plants are easy to find and easy to grow so that community use is facilitated.

The experiments with these three plants were conducted in the Field Experiment Unit as well as the Laboratory Experimental Unit, but with less rooting biomass (about one third).

The Field Experimental Unit consisted of a wooden box containing a sand bed covered with plastic sheet with the dimension of 100 cm x 55 cm (surface area) and depth of 50 cm. The box was filled with different particle density layers (from bottom to top) as follows: pumicestone (5 cm), palmfiber (5 cm), fine sand (25 cm), palmfiber (5 cm), and coarse sand (10 cm). A water sampling apparatus was attached to the box. The plants to be grown were placed in the box, and were named HBTS-Bulrush, HBTS-glory, HBTS-cormous, and HBTS-sand (for control).

To differentiate between the bioremedial effects of root absorption and microbes associated with the rhizosphere, a small-scaled laboratory experiment was conducted as follows. Eight glass wall boxes with the dimensions of 25 cm x 50 cm surface area, and 30 cm depth were prepared, and provided with a drain valve. The boxes were filled with sterile sand to a height of 25 cm. The sand in four of those eight boxes were again sterilized, and three of the four boxes were planted with sterilized Bulrush, Water morning glory, and Garden cormous herb plants. One sterilized box was used as control (no plant). The other four boxes were used as follows. Three boxes were planted with Bulrush, Water morning glory, and Garden cormous herb plants, and filled with polluted water directly taken from Sunter river in Jakarta. One box was used as control (no plant). The parameters observed and will be discussed were: color, biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, coliform, and *Escherichia coli*.

Water quality tests were conducted in the Laboratory of The Environment Assessment Office in Jakarta. Water samples were taken using 500 cc. sterile plastic bottles after three days (Retention 3), 10 days (Retention 10), and 20 days (Retention 20) after the first filling time in the first month (Month-I); then every month three days of retention time for four months (Month-II, Month-III, Month-IV, and Month-V). Data analyses for these Laboratory Experiments as well as for the Field Experiments were conducted using a randomized block design with two factors (Sand and Plants), four treatments and four replicates.

Results and discussion

Colour : Water color usually arises from degradation of organic matter and the presence of inorganic matter. The color before, and the average after being filtered, are presented in Tables 1 and 2. Note that The same letter in the column means no significant difference; a different letter means significantly different. The ability of each filter to reduce polluted water color (in effectivity percentage) is shown in Table 3.

TABLE 1
Colour levels: Month 1 - Retention 3 days, 10 days, and 20 days for each filtering result (Quality Standard B = 100), in pt. co.

HBTS	Sunter River	Reservoir	Retention		
			3 days	10 days	20 days
Glory	255	52	59 a	40.25 a	21.25 a
Cormous	255	52	47.5 ab	93 a	19.25 a
Sand	255	52	50.25 a	37.5 ab	12 a
Duncan Test			P = 0.0428	P = 0.0603	P = 0.2161

Remarks: The same letter in the column means no significant difference; a different letter means significantly different.

TABLE 2
Colour level: Initial Stage - Month I, II, III, IV, and V, Retention 3 days for each Filtering result (Quality standard B = 100), in pt.co.

Result	Month				
	I	II	III	IV	V
Initial stage	255.00	29.00	125.00	153.00	366.00
HBTS-Bulrush	24.250 b	1.250 a	5.250 b	48.750 a	27.000 a
HBTS-Sand	59.000 a	1.250 a	7.000 b	54.000 a	24.750 a
HBTS-Cormous	47.500 ab	3.250 a	6.500 b	23.250 a	20.750 a
HBTS-Glory	50.250 a	5.500 a	23.750 a	32.250 a	19.250 a
Duncan Test	P = 0.0428	P = 0.5936	P = 0.0496	P = 0.2772	P = 0.6053

TABLE 3
Effectiveness of each filter for colour (in percentage)

HBTS	Month I			Month II	Month III	Month IV	Month V
	Ret. 3	Ret.10	Ret.20	Ret.3 days	Ret.3 days	Ret.3 days	Ret.3 days
Bulrush	90.49 a	90.98 b	98.039 a	95.69 a	95.8 a	68.14 a	92.623 a
Sand	76.863 b	84.216 b	91.667 a	95.69 a	94.4 a	64.71 a	93.238 a
Cormous	81.373 ab	82.843 b	92.451 a	88.79 a	94.8 a	84.8 a	94.331 a
Glory	80.294 b	85.294 ab	95.294 a	81.03 a	81 b	78.92 a	94.74 a
Duncan Test	P=0.0428	P=0.0603	P=0.2161	P=0.5936	P=0.0496	P=0.2772	P=0.6053

The colour level of Month I, Retention 3 days to Month V are less than the quality standard B; the lowest level is shown in HBTS-Bulrush.

The rooting system of bulrush is more fibrous, and more solid. and stronger than of the water morning glory or garden cormous herb. If some of the bulrush root dies or is cut, the roots remain strong, and are rot resistant. In contrast, water morning glory and garden cormous herb easily rot and contribute to organic matter in the water. This is why bulrush has greater ability to reduce colour.

From Table 3, the effectiveness of each filter in reducing colour (in %) are as follows: HBTS-Bulrush = 88.55; HBTS-Sand = 84.98; HBTS-Cormous = 88.82; and HBTS-Glory = 83.20. It was suspected that this was because Water Morning Glory breaks easily during removal and transplanting, and increases the organic load to the water. The result is an increase in initial load and decrease in effectiveness.

Biological Oxygen Demand: Table 4 presents the BOD content at Initial Stage, in the Reservoir, Retention 3, Retention 10, and Retention 20, for each filter (Quality Standard B and D). BOD values before filtering, and the average after filtering are shown in the Table 5. Although the lowest BOD value for each filter is within or below Quality Standard B, the BOD value for Month III, Retention 3, is in the range of Quality Standard B, and the rest are below Quality Standard D. The differences between filters related to the different plants are understandable,

TABLE 4
The BOD value at initial stage, in the Reservoir, Retention 3, Retention 10, and Retention 20, for each filter (Quality Standard B = 10, D = 20), in mg/l

HBTS	Sunter River	Reservoir	Month I, Retention		
			3 days	10 days	20 days
Sand	90.48	48.88	19.28 a	11.68 a	4.62 a
Glory	90.48	48.88	17.2 ab	12.18 a	12.05 a
Bulrush	90.48	48.88	12.48 b	12.86 a	10.82 a
Cormous	90.48	48.88	12.61 b	10.82 a	5.43 a
Duncan Test			P = 0.0815	P = 0.2974	P = 0.2811

TABLE 5
The BOD value at initial stage, Month I, II, III, IV, and V Retention 3 , for each filter (Quality Standard B = 10, D = 20), in mg/l

Result	Month I	Month II	Month III	Month IV	Month V
Initial stage	48.880	54.67	65.000	66.500	49.920
HBTS-Bulrush	12.480 b	8.850 c	23.28 c	16.153 a	17.900 a
HBTS-Sand	19.280 a	11.360 bc	7.100 ab	10.290 b	16.230 a
HBTS-Cormous	12.610 b	15.943 ab	3.798 bc	6.175 c	15.693 a
HBTS-Glory	17.200 ab	20.090 a	10.270 a	11.565 d	9.295 b
Duncan Test	P = 0.0815	P = 0.0214	P = 0.0061	P = 0.0006	P = 0.0152

TABLE 6
Effectiveness of each filter on BOD content (in percentage)

HBTS	Month I			Ret.3, Month II	Ret.3, Month III	Ret.3, Month IV	Ret.3, Month V
	Ret. 3	Ret.10	Ret.20				
Bulrush	74.468 a	73.691 a	77.752 a	83.81	96.419 a	75.711 c	68.565 b
Sand	60.546 a	76.089 a	90.441 a	79.22	89.077 bc	84.526 b	64.063 b
Cormous	74.202 b	77.854 a	73.660 a	70.84	94.158 ab	90.714 a	67.488 b
Glory	64.812 ab	72.509 a	75.348 a	63.25	84.2 c	82.609 b	81.38 a
Duncan Test	P=0.0815	P=0.2974	P=0.2811	P=0.0214	P=0.0061	P=0.0006	P=0.0152

but the differences related to time are assumed to be caused by the microbiological development differences in each rhyzosphere related to nitrate content as an electron acceptor in the disintegration of organic matter.

The ability of each filter in reducing BOD (in effectivity percentage) is shown in Table 6.

Because of the high nitrate content, the filtered oxygen content in the water increased in three days, with the result a sharp drop in the BOD value. Besides the work of microbes, the increase in the oxygen content in the water can also because of the flow of oxygen from plant leaves to the stem, to the roots and exit from the roots to the water by the difference in concentration.

The HBTS-Sand with no plants seems to be the less effective HBTS since there is no such combination. The drop of BOD value is solely by micro-organism work. Although all of the materials have been sterilized, the work of the microbes in the filtered water in three days shows a relatively effective work. The average effectivity of each filter to BOD (in percentage) are as follows: HBTS-Bulrush = 79.80%; HBTS-Sand = 75.49%; HBTS-Cormous = 79.48%, and HBTS-Glory = 75.25%. The high effectivity of HBTS-Bulrush was probably caused by the more solid rooting system of bulrush, thus more oxygen are flowing into the water resulting in less BOD.

Chemical Oxygen Demand: Chemical oxygen demand (COD) shows the amount of chemical compounds that can be chemically oxydized, and usually more compared to the biologically oxydized. That is why, COD value is usually higher than BOD value. The COD value before, and the average after being filtered are shown in Tables 7 and 8.

The ability of each filter in reducing the COD (in effectivity percentage) are shown in the Table 9.

The reduced COD value by HBTS-Sand and HBTS-Bulrush are still above the water Quality Standard D, while the COD at Retention 3, Month I is below the water Quality Standard D, and Month III is even below the water Quality Standard B. Those large differences stated that there

TABLE 7
COD value, at Initial Stage, in the Reservoir, Ret. 3, Ret. 10, Ret. 20 for Month I, for each filter (Quality Standard B = 20, D = 30), in mg/l

HBTS	**Sunter river**	Reservoir	**Ret. 3 days**	**Ret. 10 days**	**Ret. 20 days**
Sand	128.32	129.4	76.85 ab	64.16 a	52.5 a
Glory	128.32	129.4	88.99 a	64.16 a	57.75 a
Bulrush	128.32	129.4	36.4 b	64.16 a	49.64 a
Cormous	128.32	129.4	56.63 ab	56.14 a	60.9 a
Duncan Test			P = 0.1223	P = 0.9514	P = 0.2378

TABLE 8
COD value, at Initial Stage, Month I, II, III, IV, and V, Retention 3 for each filter (Quality Standard B = 20, D = 30), in mg.l

Result	Month I	Month II	Month III	Month IV	Month V
Initial Stage	129.40	143.86	71.00	180.00	180.00
HBTS-Bulrush	36.41 b	52.70 ab	39.13 a	40.00 ab	50.00 a
HBTS-Sand	76.86 ab	43.30 b	39.28 a	28.75 b	46.25 a
HBTS-Cormous	56.63 ab	43.40 b	35.70 a	36.25 ab	51.25 a
HBTS-Glory	88.99 a	62.00 a	32.15 a	46.25 a	46.25 a
Duncan Test	P = 0.1223	P = 0.1010	P = 0.7202	P = 0.042	P = 0.2608

TABLE 9
Effectiveness of each filter to COD (in percentage)

HBTS	Month I			Ret.3, Month II	Ret.3, Month III	Ret.3, Month IV	Ret.3, Month V
	Ret. 3	Ret.10	Ret.20				
Bulrush	71.88 a	50.43 a	61.65 a	63.37 ab	54.75 a	77.778 b	72.222 a
Sand	40.63 ab	50.43 a	59.441 a	69.90 a	44.68 a	84.028 b	74.306 a
Cormous	56.25 ab	56.63 a	52.951 a	69.83 a	49.72 a	79.861 a	71.528 a
Glory	31.25 a	50.43 a	55.385 a	56.90 b	54.72 a	74.306 b	
Duncan Test	P=0.1223	P=0.9514	P=0.2378	P=0.1010	P=0.7202	P=0.0420	P=0.2608

are many chemical compounds still un-oxydized by microbial activity as well as the oxygen produced by the plants. This condition is common, since it is usual that COD value is higher than BOD value.

The average effectivity of each filter to COD values are as follows: HBTS-Bulrush = 68.00%; HBTS-Sand = 62.71%; HBTS-Cormous = 65.44%, and HBTS-Glory = 54.29%. The high effectivity of HBTS-Bulrush was probably caused by the more solid rooting system of bulrush, thus more oxygen is flowing into the water; and it is usual that COD value is higher than BOD value so that the effectivity in general will be lower.

pH

The pH measures the concentration of hydrogen ion in the water, characterizing the balance of acid and bases. The free mineral acid and carbonate acid raise the acidity, while carbonate, hydroxide, and bi-carbonate raise the bases. The uptake of anion will decrease at high pH (bases condition), while the uptake of cation will decrease at low pH (acid condition). The level of pH will affect the availability of nutrient, and toxicity of the micro-organism, which in turn will affect the type and the formation of the water environment. Since pH is determined by interaction of many nutrients in the water, pH is unstable, thus the pH determination has to be done instantly after water sample is taken.

The pH at initial stage, the average after being filtered, Month-I Retention 3, 10, and 20 are relatively stable, and is in the quality Standard for drinking water (Table 10). The same condition occurred in the later months (Month-II, III, IV, and V, Table 11). The instability of pH will affect the bacterial performance, decreasing the bioremedial effect. The bacteria will be in optimum performance at pH 7.0-7.4.

The ability of the filters in stabilizing pH are presented in Table 12.

The effectivity of each filter to pH are as follows: HBTS-Bulrush = 3.62; HBTS-Sand = 6.52; HBTS-Cormous = 6.22; and HBTS-Glory = 7.42. The lowest effectivity shows the most stable pH; the smaller the effectivity, the smaller the changes, which means the pH is more stable. It was suspected that this was caused by the stability of the rhyzosphere ecosystem in balancing the acid and bases conditions.

TABLE 10
pH at Month-I, Retention 3,10,20 for each filter (Quality Std. B = 6.5–8.5)

HBTS	**Sunter river**	**Reservoir**	**Month-I**					
			Ret.3		**Ret.10**		**Ret.20**	
Bulrush	6.8	7.3	7.35	a	6.9	a	7.03	a
Sand	6.8	7.3	7.05	a	7.1	ab	7.03	a
Cormous	6.8	7.3	7.00	b	6.9	b	6.98	a
Glory	6.8	7.3	6.83	b	7.33	a	7.13	a
Duncan Test			P = 0.0256		P = 0.0928		P = 0.7845	

TABLE 11
pH at Initial Stage, Month I, II, III, IV, and V Retention 3 for each Filter (Quality Std. B = 6.5-8.5; D = 6-8.5)

Result	**Month I**		**Month II**		**Month III**		**Month IV**		**Month V**	
Initial Stage	7.300		8.600		7.100		7.300		7.400	
HBTS-Bulrush	7.350	a	7.150	a	7.375	a	7.075	a	7.175	ab
HBTS-Sand	7.050	ab	6.875	a	7.175	a	6.825	b	7.125	ab
HBTS-Cormous	7.000	b	6.925	a	7.000	a	7.050	a	6.900	b
HBTS-Glory	6.830	b	6.850	a	7.100	a	7.025	ab	7.125	ab
Duncan Test	P = 0.0256		P = 0.2226		P = 0.3463		P = 0.0805		P = 0.1438	

TABLE 12
Coliform content, at Initial Stage, in Reservoir, Ret. 3, Ret.10,and Ret.20, Month I for each Filter (Quality Standard B = 1000 MPN/100 cc)

HBTS	Sunter river	Reservoir	Month I					
			Ret. 3 days		Ret.10 days		Ret.20 days	
Sand	> 2,400	> 2,400	36	b	13	a	1	a
Glory	> 2,400	> 2,400	244	c	105	b	29	a
Bulrush	> 2,400	> 2,400	8	a	8	a	2	a
Cormous	> 2,400	> 2,400	318	c	5	a	9	a
Duncan Test			P = 0.05		P = 0.05		P = 0.05	

Coliform

Coliform is a bacterium used as an indicator of environment quality related to its high ecological resiliency, and is found in most places with poor environment sanitation. If coliform grows easily, then any other bacteria or germs can grow easily as well. The ability of the filters to reduce coliform is sufficiently effective as it dropped drastically to less than Water Quality Standard B after only 3 days retention (Table 12).

The ability of the filters to reduce coliform, stated in effectivity percentage are shown in Table 13. All filters are relatively effective in reducing the coliform content, and there is no significant difference amount the filters. To see the differences among treatment, it is better to see the coliform content in Table 12.

TABLE 13
Effectiveness of the filters to Coliform (in percentage)

HBTS	Month I					
	Ret. 3 days		Ret.10 days		Ret.20 days	
Bulrush	99.67	a	99.67	a	99.93	a
Sand	98.51	a	99.46	a	99.95	a
Cormous	86.74	a	99.80	a	99.61	a
Glory	89.93	a	95.62	a	98.81	a
Duncan Test	P = 0.05		P = 0.05		P = 0.05	

The effectivity of the filters in reducing the coliform are as follows: HBTS-Bulrush = 99.67; HBTS-Sand = 98.51; HBTS-Cormous = 86.74; and HBTS-Glory = 89.93. All of the filters are effective in reducing the coliform, and there are no differences among treatment.

Escherichia coli

The *Escherichia coli* is a bacterium that used to be called bacteria, since its existence is in human and animal faeces. Under normal condition these bacteria caused no disease, but if the number is abundant these bacteria will be pathogenic. Since its existence is tied with the human or animal waste, these bacteria are used as an indicator of environmental pollution by man or animals.

The effectiveness of the filters in reducing *Escherichia coli* is presented in Table 14.

TABLE 14
Number of E.coli at Initial Stage, in Reservoir, the average at Ret.3, Ret.10, and Ret.20 for each filter (Quality Std.B = 2.000 MPN/100cc)

HBTS	Sunter river	Reservoir	Retention 3		Retention 10		Retention 20	
		Month I						
Sand	> 2.400	> 2.400	34	a	13	a	1	a
Glory	> 2.400	> 2.400	62	a	61	b	12	a
Bulrush	> 2.400	> 2.400	7	a	8	a	2	a
Cormous	> 2.400	> 2.400	52	a	3	a	9	a
Duncan Test			P = 0.05		P = 0.05		P = 0.05	

This means that its existence will have a disease risk, so its existence is unwanted in the environment. The ability of the filters to reduce the *E.coli* is fairly effective, to far below Water Quality Standard B for drinking water.

TABLE 15
Effectiveness of each filter to *E.coli* (in %)

HBTS	Retention 3 days	Retention 10 days	Retention 20 days
	Month I		
Bulrush	99.72 a	99.67 a	99.93 a
Sand	98.58 a	99.45 a	99.95 a
Cormous	97.84 a	99.88 a	99.61 a
Glory	97.42 a	97.46 a	99.49 a
Duncan Test 0.05	= 0.05	P = 0.05	P =

The effectivity of the filters in reducing the *E.coli* are about the same with no significant difference, which means that the plant component in the HBTS has no direct role in reducing the coli bacteria (Table 15). It was suspected that the physical components such as the palm fiber, sand, and gravel have a greater role in reducing the number of *E.coli*.

There is an increase in effectivity from Retention 3 to the longer retention times which shows that the microbial ecosystem in the rhizosphere as well as among the physical components, are beginning to settle down. In any case, the role of the microbial ecosystem is much smaller than the roles of the physical components in the filters. This more visible in the laboratory experiment.

The average effectivity of each filter (in %) to *E.coli* are as follows: HBTS-Bulrush = 99.72; HBTS-Sand = 98.58; HBTS-Cormous = 97.84; and HBTS-Glory = 97.42. This indicates that the filters have been working normally because coliform and *E.coli* are not different in size, so that the effectivity is relatively equal.

Conclusions and recommendations

Conclusions

1. Through the Herb Bed Treatment System (HBTS), *Scirpus litoralis*, *Ipomoea aqutica*, and *Typhonium javanicum* aquatic plants have shown their ability to reduce the disintegrated organic pollutant and pathogen content of Sunter River water.
2. There are variations in the effectivity of each plant, as follows: the most effective is HBTS-Bulrush (49.62-99.72%), followed by HBTS-Sand (30.81-98.58%), BHTS-Cormous (37.39-97.84%), and HBTS-Glory (32.73-97.42%).
3. The effectivity of the HBTS is influenced by the growth of the plants and the microbes; the effectivity is increased according to the rooting biomass and the ability of the microbes ecosystem in the rhizosphere.
4. The effectivity of the HBTS' to microbes (coliform and *E.coli*) as water quality indicators is relatively high (86.74-99.72%)
5. In all, the HBTS using the three aquatic plants can improve the water quality from below D to above D Water Quality Standard; some parameters are in the B Standard.
6. If the retention days used are longer (more than 10 days), and the HBTS are applied for long term (more than five months), the HBTS effectivity can become negative.

Recommendations

1. Research into the improvement of rhyzosphere ecological systems involving microbial innoculation into the rhyzosphere adjusted to the initial condition of pollution characteristic is needed.
2. The HBTS should be equipped with a channel that can trap the mud.

References

Bowling, D.J.F. 1976. Uptake of Ions by Roots. John Wiley & Sons, Inc. New York.

Box, G.E.P., W.G.Hunter and J.S.Hunter. 1978. Statistics for Experimenters: An Introduction to Design, Data Analyses and Model Building. John Wiley & Sons, Inc. New York.

Brink, R.H. 1981. Biodegradation of Organic Chemicals in the Environment, in Environmental Health Chemistry. Ann Arbor Science Publisher, Inc Collingwood.

Burgoon, P.S., T.A.DeBusk, K.R.Reddy and B.Koopman. 1991. Vegetated Submerged Beds with Artificial Substrates.. I: BOD Removal. J.of Environmental Engineering. Vol.117 no.4.

Cooper, P.F., D.A.Hobson and S.Jones. 1990. Sewage Treatment by Reed Bed System. J. IWEM.

Finlayson, C.M. and A.J.Chick. 1983. Testing the Potential of Aquatic Plants to Treat Abattoir Effluent. Water Res. Vol. 17 no.4. pp.415-422.

King, R.B., G.M.Long and J.K.Sheldon. 1992. Practical Environmental Bioremediation. Lewis Publisher. London.

Low, K.S. and C.K.Lee. 1981. Copper, Zinc and Chromium Uptake by *Ipomoea aquatica* Forsk. Fertanika 4(1), pp.16-20.

Seregeg, I.G., M.S.Saeni and S.Hardjoamidjojo. 1995. The Effectivity of Biofilter of Three Aquatic Plants in Waste Water Quality Improvement (in *Indonesian*). Paper presented at the Joint Seminar JICA-IPB. Bogor.

Shimp, J.F., J.C. Tracy, L.C. Davis, E. Lee, W.Huang and L.E. Erickson. 1993. Beneficial Effects of Plants in the Remediation of Soil and Groundwater Contaminated with Organic Materials. Critical Reviews in Environmental Science and Technology. 23: 1, 41-77.

The impact of agriculture on water quality and the methodology for its improvement in Japan

ABSTRACT

Based on a Japanese case study, the paper covers the following points, with emphasis on the eutrophication issue: the characteristics of water resources and irrigation; the present state of water quality; the agricultural damage caused by water pollution: the impact of agriculture on water quality; and possible countermeasures to protect water quality.

With 430 thousand million m^3 of water potentially available annually in Japan, only half of these water resources can be controlled and the requirements for agricultural activities alone amount to 58 thousand million m^3 per year or more than sixty percent of the total water use. The protection of water quality is basically enacted under the Basic Environment Law and water quality standards are set under the Water Pollution Control Law. Not much improvement in water quality has been achieved in rural areas despite the various actions taken, but there has been a decrease in the water pollution caused by agricultural activities. Recently, urban wastewater has become a main source of pollution of the water resources.

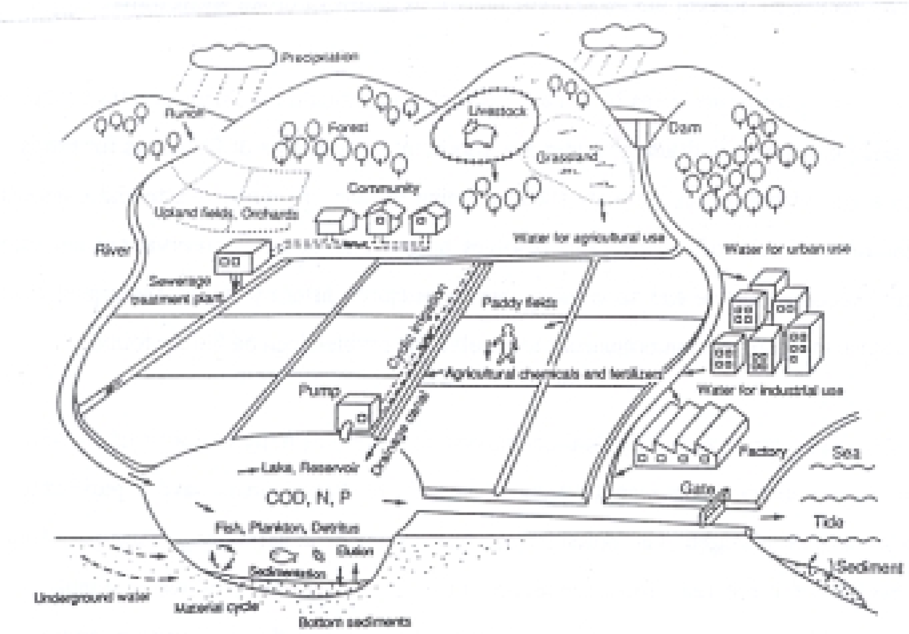
The water quality problems linked to agriculture are linked to the fertilizing practices in use and any improvement will require a series of measures adapted to each different region. Paddy farming remains an important activity and through proper water resources management at the watershed level a series of measures can be taken to combine optimum food production with the achievement of water quality protection and conservation objectives.

It is often stated that the problem of insufficient supply of food accompanied by both a population increase and environmental deterioration on a global scale will become more serious by the middle of 21st century. It is also pointed out the sustainable development approach offers a particular challenge in the area of freshwater resources (Chitale, 1997). The conservation of farmland and the improvement of irrigation performance are essential steps to increase the food production under the current situation where the development of new water resources is becoming difficult. To keep good water quality is a prerequisite for sustainable water use.

The environmental problems associated with agricultural activities are caused by an excessive utilization of fertilizers and agricultural chemicals, the loss of topsoil and the generation of greenhouse gases. While the impact of agricultural drainage is widely recognized (Madramootoo *et al.*, 1997), in contrast paddy fields in Asia monsoon regions have been described as having positive environmental effects such as flood mitigation (Yuyama *et al.*, 1996), conservation of

Yoshito Yuyama
JICA Expert, Royal Irrigation Department
Bangkok, Thailand

Figure 1
Flow of pollutants in a watershed



water resources and soil as well as water quality improvement (Tabuchi *et al.*, 1985 and Yuyama *et al.*, 1998a), improvement of amenity and so on.

Pollutants are generated, partially removed on site and discharged into a water body, where they alter water quality through physical and bio-chemical reactions. Figure 1 shows the flow of pollutant.

This paper is based on a Japanese case study and will address the following points, with emphasis on the eutrophication problem: (1i the characteristics of water resources and irrigation, (ii) the present state of water quality, (iii) the agricultural damage by water pollution, (iv) the impact of agriculture on water quality, and (v) possible countermeasures to protect water quality.

Characteristics of water resources and irrigation

The average annual rainfall and evaporation in Japan total 1,800 mm and 800 mm, respectively. The water resources potentially available can be calculated, that is the rainfall minus evapo-transpiration, to amount to 430 thousand million m^3 in a normal year and 300 thousand million m^3 in a drought year. Only the half these water resources can be controlled and the other half ends up as direct discharge into the sea during the rainy season and typhoon periods.

The total annual water consumption is about 91 thousand million m^3. Paddy fields occupy 2 720 000 ha; upland fields, 1 220 000 ha; orchards 390 000 ha; and pasture land, 660 000 ha. As for the livestock population, there are 4.83 million head of cattle, 9.90 million pigs and 310 million chickens. The annual amount of water required for agricultural activities is about 58 thousand million m^3, representing more than 60 percent of the total water use in Japan. The water quantity used for agriculture is broken down as follows: about 96 percent were used for the irrigation of 1 970 000 ha of cultivated paddy field in 1996, with the remainder used for the irrigation for upland field (3 percent) and for livestock-related requirements (1 percent). The standard paddy field consumes 2 000 mm of water during one season. In paddy filed areas the irrigation increases the amount of water discharged. For example, in an area where 30 percent is used for of paddy fields, discharges could be increased by 50 percent. In large river basins, irrigation water is used four to five times when the river is the source of that water.

Paddy farming is strongly connected with the rural social system. Without cooperation among farmers, proper water management including flood protection would not be carried out. The setting up of Land Improvement Districts (LID) to regroup farmers for their irrigation needs has been playing an important role in this regard. The total number of LIDs is about 7,000 and for 80 percent of these the area covered is less than 500 ha and exceeds 2,000 ha for about 4 percent of them.

Among some 124 000 irrigation intake facilities, 85 percent of these depend on rivers as the source of water; 13 percent, on reservoirs and irrigation ponds; and 2 percent, on groundwater. As for the size of these facilities, 92 percent draw water at less than 0.3 m^3/s, 6 percent at a rate of 0.3 to 1.0 m^3/s, and 2 percent, at more than 1.0 m^3/s. Irrigation water for paddy fields is supplied over the period from mid-April to September to coincide with the transplanting season.

Paddy fields and water resources were developed just like the construction of a spiral staircase (Okamoto *et al*., 1990). Drought periods do occur from time to time (Miyamoto *et al*., 1996) and they have provided the stimulus for the development of adequate water resources. The access to water resources in a given area was controlled by those in charge of their development. Therefore, the priorities for water use have been set up historically by farmer and irrigation associations. In a serious drought period, some adjustment and accommodation of water use are usually carried out.

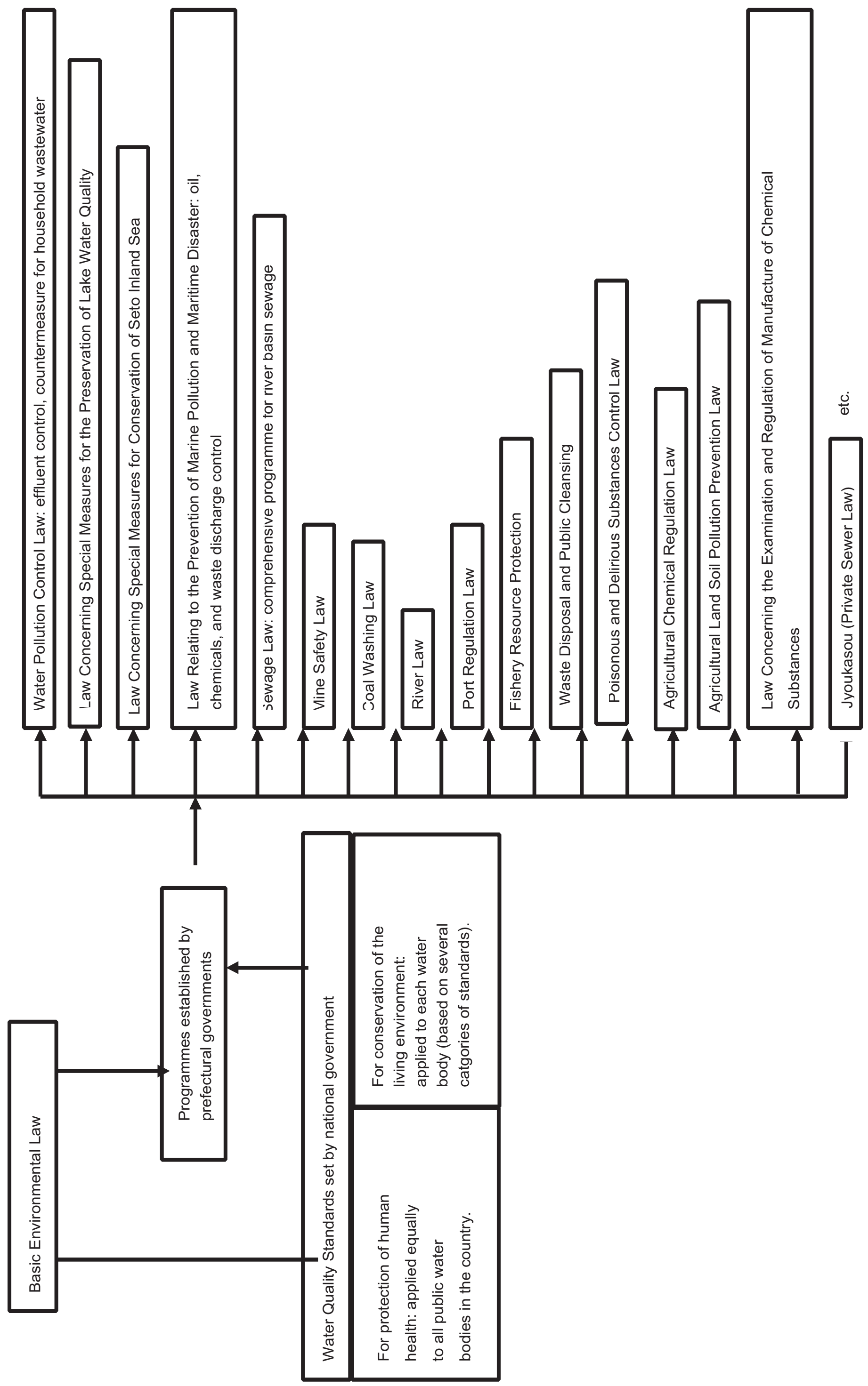
Legal system of water quality management

The legal system within which water quality management is carried out in Japan is shown in Figure 2. The Basic Law for Environmental Pollution Control was enacted in November 1993 to improve the Basic Environment Law. The Water Pollution Control Law was enacted to achieve and maintain environmental quality standards and thereby to prevent pollution and damage. The environmental quality standards addressing water pollution are divided into two sets: one covering the protection of human health and the other covering the conservation of the living environment. The latter is adapted for individual rivers, lakes, and coastal areas. Water bodies are classified on the basis of their water usage. Effluent standards were also established to achieve environmental quality standards.

Present status of water quality in public water bodies

In 1996, almost all the parameters pertaining to those environmental quality standards related to the protection of human health were measured at levels below the maximum limits set for public water bodies. However, the arsenic level was above the maximum limit at 26 of the 4 929 stations sampled. A total of 0.7 percent of the 5 513 samples failed to meet the standards. These results represented a great improvement over the status prevailing 25 years ago (Environmental Agency, 1998). In terms of groundwater quality, 78 wells or 1.9 percent of the 4 194 wells sampled failed to meet the standards, with the measured arsenic and tetra-

FIGURE 2
Legal system for water quality management



chloroethylene levels not meeting the standards in 1.6 percent (43/2 648) and 0.5 percent (18/3 864) of the wells, respectively.

An examination of the 1996 data for BOD and COD levels revealed that they were in compliance with environmental quality standards for 81.8 percent of the 586 samples of coastal area water, for 42.0 percent of the 131 samples of water from lakes and reservoirs, and for 73.6 percent of the 2 514 samples of water from rivers. Although considerable improvement was evident in case of the case of water in rivers and coastal areas, it was not as notable for lakes and reservoirs.

Steps are being taken in the case of 10 lakes which have been designated for action by the Law Concerning Special Measures for the Preservation of Lake Water Quality. A certain amount of improvement has been noted. However, the water quality of these lakes still falls short of environmental quality standards. In the rivers, lakes and reservoirs of areas where urbanization is progressing rapidly, the development of adequate sewage systems has not kept pace with the population increase.

Problems of water pollution at non specific points occur where pollutants are washed out by rain and other mechanisms from broad built-up urban areas, land development sites, farmland, etc.. Water pollution is also caused by the discharge of nutrients into water bodies where they accumulate at the bottom.

Figure 3 shows the relationship between the hydraulic retention time (HRT) and COD levels in major lakes. Figure 4 shows the relationship between total nitrogen (T-N) and total phosphorus (T-P) concentrations in the same lakes. Generally, land use patterns have a great impact on the water quality observed in a watershed as does the hydraulic retention time in the case of lakes and ponds.

FIGURE 3
Relationship between HRT and COD

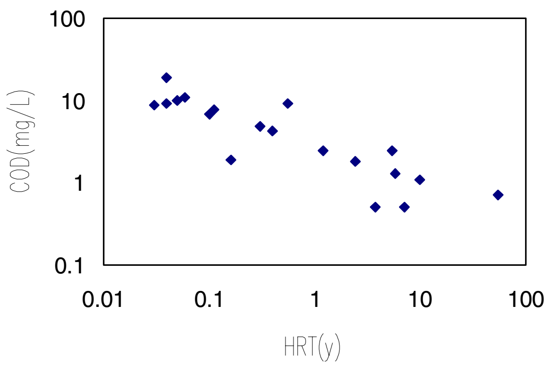
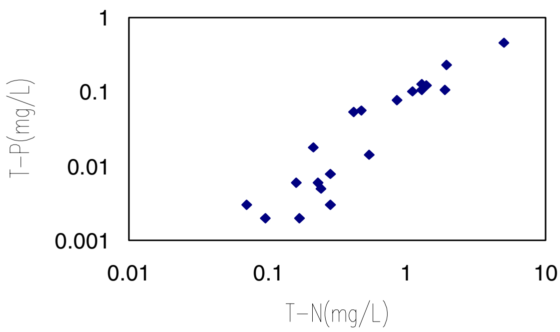


FIGURE 4
Relationship between T-N and T-P



Present status of water quality in rural areas

Table 1 shows the water quality standards set for the water used in the irrigation of paddy fields. Water quality data measured by the Ministry of Agriculture, Forestry and Fisheries (MAFF) measured in irrigation canals, irrigation ponds, dams for irrigation purposes, and in groundwater for irrigation. Some of these data have been assembled in Figures 5 and 6 and in Table 2.

The average values of water quality parameters measured at 2,296 points in irrigation canals between 1991 and 1993 were as follows: pH,7.4; EC, 156 mS/cm; COD, 4.1 mg/L; and T -N, 1.3 mg/L. While the T-N values exceeded the value set under the applicable water quality standard, for 38 percent of the sampling points the values for all the other parameters met the standard. Achievement of the water quality standard was observed in 82 percent and 54 percent of the values obtained for the COD and T-N parameters, respectively; for 8 percent of the T-N values, the level exceeded 3.0 mg/L. In Figure 5, the data cover rural areas that were classified as mountainous, middle, plain, or urbanized.

TABLE 1
Water quality standards for water used in the irrigation of paddy fields (MAFF, 1970)

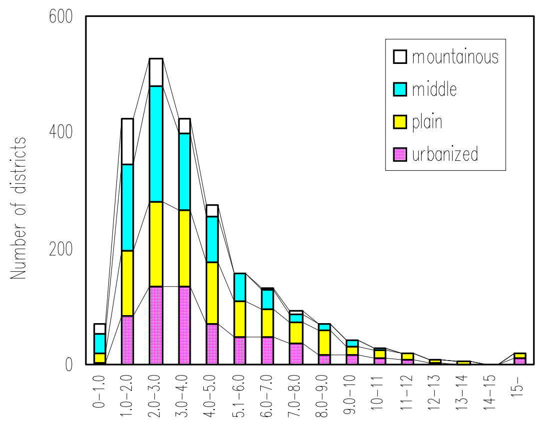
Item	Standard values
pH	6.0-7.5
COD	6 mg/L or less
SS	100 mg/L or less
DO	5 mg/L or more
T-N	1 mg/L or less
EC	300 µS/cm or less
As	0.05 mg/L or less
Zn	0.5 mg/L or less
Cu	0.02 mg/L or less

The average values for water quality parameters measured at 896 points in irrigation ponds between 1991 and 1993 were: pH, 7.7; EC, 153 mS/cm; COD, 8.7 mg/L; T-N, 1.5 mg/L; and T-P, 0.11 mg/L. The investigation included irrigation ponds occupying more than 5 ha in both urbanized and plain agricultural areas. The average COD concentration observed in ponds was about twice larger than that of irrigation canals located in the same areas, with the COD standard met in about 40 percent of the points sampled.

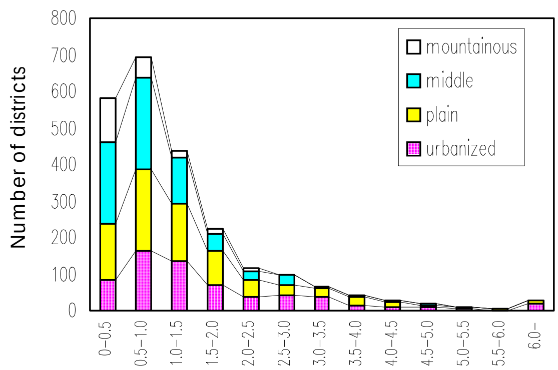
Water quality parameters in dams created for irrigation purposes were measured at 55 locations between 1983 and 1992 and the following average values were obtained: pH,7.5; EC, mS/cm; DO, 9.4 mg/L; COD, 3.7 mg/L; T-N, 0.51 mg/L; and T-P, 0.026 mg/L. All those values met the values set under the applicable water quality standard. Water was relatively clean, but some dams had water pollution problem caused by factors such as the inflow of wastewater from rural settlements and/or livestock complexes as well as by internal nutrient production caused by excessive algal growth.

In normal years, the volume of groundwater used for irrigation amounts to 6.4 percent of the total volume of water used for that purpose. The average values of water quality parameters measured in the period 1987 to 1991 at 297 wells used as a source of irrigation water were as follows: pH, 6.7; EC, 341mS/cm; COD, 1.96 mg/L; T-N, 5.48 mg/L; NH_4-N, 0.26 mg/L; and NO_3- N, 4.83 mg/L. The drinking water quality standard for nitrogen is less than 10 mg/L of NO_3-N. At 15 percent of the sampling points, the value for T-N exceeded 10 mg/L. High concentration

FIGURE 5
Water quality in irrigation canals (MAFF, 1994)

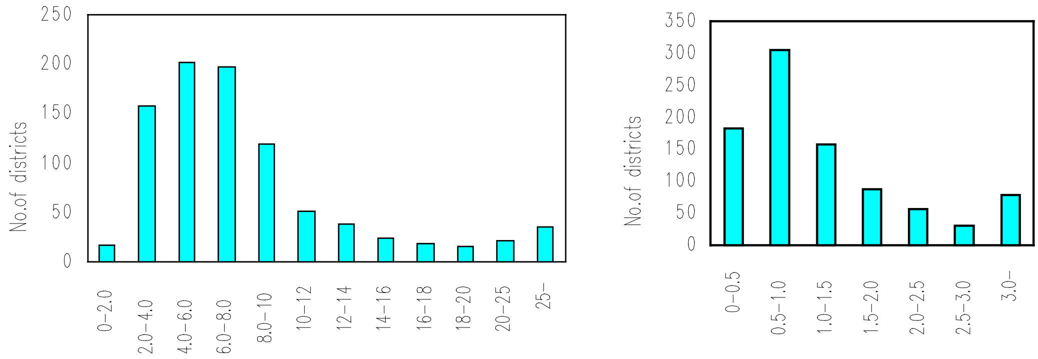


(a) COD (mg/L)



(b) T-N (mg/L)

Figure 6
Water quality in irrigation ponds (MAFF, 1995)



(a) COD (mg/L)

(b) T-N (mg/L)

of NO_3-N was observed in the water of wells located in the a watershed area that comprises upland fields, orchards, greenhouses and livestock complexes. At some sampling points, values exceeding 80 mg/L of NO_3-N were observed.

TABLE 2
Water quality at dams created for irrigation purposes (MAFF, 1993)

	pH	EC µS/cm	DO mg/L	COD mg/L	T-N mg/L	T-P mg/L
Maximum	8.8	199	12.3	9.8	1.60	0.160
Minimum	6.4	7	3.0	0.7	0.10	0.004
Average	7.5	89	9.4	3.7	0.51	0.026

Agricultural damage by water pollution

The main water quality problems linked to agriculture are as follows: acid mine drainage, low temperature, high salinity, muddiness, and excess nutrient such as nitrogen and phosphorus. Water pollution can have a negative impact on agricultural activities in various ways: decrease of crop yield and quality, deterioration of agricultural facilities and adverse effects for farmers and other rural residents. Figure 7 shows the evolution over the period 1958 to 1995 of the damage to farmland due to pollution contributed by irrigation water. An analysis of the data for 1995 revealed that:

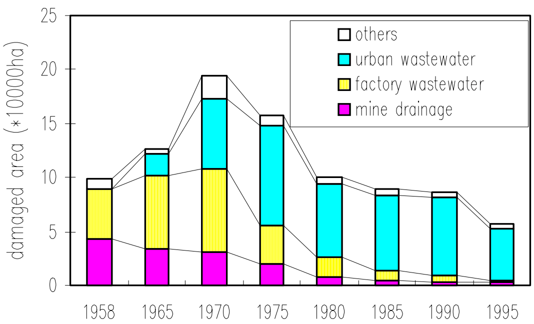
a) approximately 870 districts with more than 5 ha farmland area were adversely affected;

b) the damaged farmland area totalled about 57 400 ha or 2.1 percent of the total paddy field area;

c) for 85 percent of the total damaged area, polluted urban water was the cause of the damage;

d) measures such as water pollution control the carrying out of a rural sewage project contributed to

Figure 7
Farmland area damaged by water pollution (MAFF)



eliminate the damage in 34 109 ha over a five year period, but new damage occurred in 12 197 ha.

IMPACT OF AGRICULTURE ON WATER QUALITY

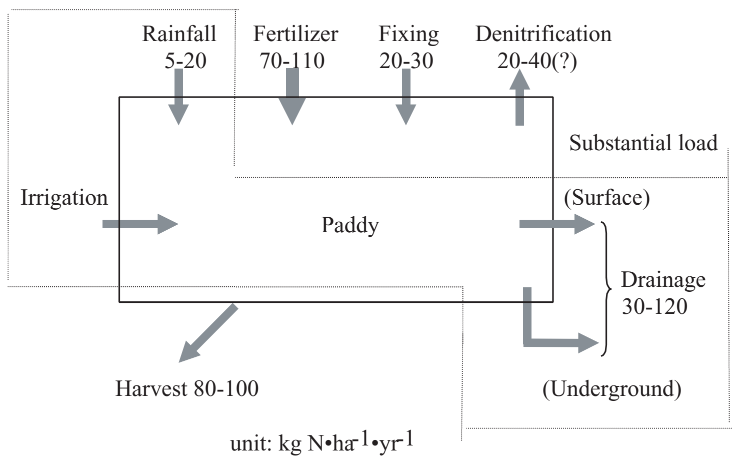
Water pollution has a negative impact both in terms of water use and ecosystems. The drainage from farmland itself is one source of water of pollution. In paddy fields, nutrients to the soil are contributed by rainfall, irrigation water and fertilizers. Figure 8 shows the nitrogen balance in a typical paddy field. The substantial load, that is "runoff load minus irrigation and rainfall load" can vary within a range of -20 to +20 kg $N \cdot ha^{-1} \cdot yr^{-1}$ depending on factors such as the soil type, the amount of water consumption, the quantity of fertilizer applied and the quality of the irrigation water. Generally, a paddy field receiving irrigation water containing more than 1.5-2.0 mg/L of T-N functions as a purification area in that serves as a buffer for the nitrogen content. The investigation promoting energy conservation during not only the rice-planting season, but also during other periods, namely plowing and irrigation before transplanting, non-irrigation and heavy rainfall, will clarify this buffer mechanism more accurately.

The drainage water from upland fields, orchards, tea fields and lotus fields contains a higher concentration of nutrients than from paddy fields as larger quantities of fertilizers are used in these areas. As well, livestock raising supplies important nutrient loads to surrounding water bodies. Those activities are a source of pollution downstream for both surface water and groundwater resources. When considering the impact of agriculture on water quality, the rapid increase of the nitrate concentration in groundwater must be regarded as a very serious problem and the impact of agricultural pesticides and herbicides on water quality cannot be ignored.

COUNTERMEASURES FOR WATER QUALITY CONSERVATION

In rural areas houses, farmland and livestock are the usual sources of water pollution and appropriate technology specific to each region has to be put in place for their control. In order

FIGURE 8
Nitrogen balance in a typical paddy field



to maintain water quality, it is essential and most effective to counter these pollution sources with on site measures as to treat and/or reuse receiving waters is very demanding in terms of technology and is more expensive. An integrated set of countermeasure is necessary to achieve the primary purpose of water quality conservation. Recently, countermeasures focused on the effluent load from farmland have been reported in the literature (Takeda, 1997a) and progress continues to be made on controlling point source pollution. A possible set of countermeasures has been developed by this author (Yuyama *et al*.,1998a) and includes five steps as described below.

(1) Restraint of the pollution load from farmland

Common countermeasures applicable to both paddy field and upland field activities are focused on minimizing the effluent pollutant load through appropriate fertilizing. It is important to ensure a good diffusion of the fertilizers applied to the soil for gradual effectiveness, to cultivate good farm soil including the return of organic matter to the soil and to develop a low-input type of farming.

Paddy fields can be either a pollutant source or a pollutant absorbent source. The following countermeasures have been developed and some of them are practically used:

a) Inserting the fertilizer into the deeper part of the soil next to a transplanting paddy with a machine capable of transplanting and fertilizing simultaneously.
b) Leveling the paddy field before transplanting under shallow water depth.
c) Containment of the drainage just after leveling until the floating soil starts to settle.
d) Setting up the location of the outflow structure at a higher level.
e) Establishment of two-step underground pipe and/or settling facility.
f) Adoption of direct seeding without tillage.
g) Water saving with a device for automatic supply control.
h) Closing the levee of the paddy field during the non-irrigation period.
i) Introducing a more gentle slope in the design of the drain facing the paddy field.
j) Designing a levee with a larger width.
k) Setting up an impermeable sheet on the slope of the drain.

The specific amount of fertilizer used in upland fields and orchards is usually larger than that in paddy fields. Countermeasures for this aspect include basically a utilization of fertilizers based on a knowledge of the absorption properties of the crop and the establishment of a crop rotation system to permit low-input farming.

During periods of heavy rainfall, the following countermeasures can be taken effectively against soil erosion and the release of organic matter and nutrients in surface runoff water:

a) Mulching, that is covering the bare farmland with straw of paddy, branches of tree and so on.
b) Making the slope of the field more gentle.
c) Making the length of the field shorter.
d) Setting up a small pond or ditch inside the farmland to collect muddy drainage water.
e) Installing a settling pond and /or permeable pond outside the farmland.

(2) Restraint of the pollution load by water management at the regional level

Water management at the regional level can contribute to preserving water quality. Water recycling in areas of various sizes is effective (Kaneki, 1997 and Takeda *et al*., 1997b), even though it might be motivated by the need to solve water shortage problems. In some areas, recycling is performed despite its cost in order to mitigate the runoff load to public water bodies.

In areas where paddy fields are located downstream of upland field and/or livestock raising activities on tableland, they can receive drainage water enriched with high nitrogen concentration. Not only does this situation contribute toward the effective use of water resources but it can have also a beneficial role in the control of nitrate pollution in groundwater due to a denitrification process taking place in paddy soil. However, caution is indicated when the ammonium nitrogen concentration in drainage water exceeds 3.0 mg/L, as excess ammonium nitrogen might cause a decrease of productivity in paddy fields.

Several kinds of countermeasures aimed at preserving water quality in a given area can be carried out as necessary, for instance separating irrigation and drainage canals, providing for the dilution of the drainage water, changing the sources of irrigation water and relocating the intake facility, and releasing the wastewater outside of the area.

(3) Water purification in fallow paddy fields

About 25 percent of Japan's paddy fields are under fallow conditions, because of the significant restrictions currently covering the production of rice. Rather to keep these fields idle, it is preferable to continue using them for their water purification role considering the merits of this practice, namely a long retention time can be ensured, the energy consumption is negligible, and removal of nitrogen and phosphorus is possible. In order that production in paddy fields can be restored later on, an excessive accumulation of harmful substances and nutrients in the soil must be avoided.

(4) Water purification in canals, lakes, dams, ponds and groundwater

Water purification in water bodies such as canals, rivers, ponds, and lakes constitutes an important objective and it deserves urgent attention. Examples of countermeasure in practical use are described below.

Water purification in canals and rivers can be achieved by using submerged contact filters whose biofilm can increase the natural purification process. One method is to submerge these filters directly into canals and rivers (direct process). The other is to channel the water to an outside area for treatment and then return it to the river or canal (by-pass process). The utilization of plants is also effective when the total system include the removal and recycling of plants.

In lakes and dams, water purification measures that can be carried out include: the control of algae multiplication by using an aeration and/or circulation device; the removal of nutrient by systems such as reed plain and floating artificial wetland; the removal of algae; and the dredging of bottom sediments for mitigating the release of nutrients. The countermeasures in irrigation ponds have just started. Some attempts to circulate water through nearby fallow paddy field and to dredge bottom sediments were tried.

Nitrate pollution in groundwater is a serious problem and a drastic countermeasure has yet to be developed. This is a situation where bioremediation technology might hold some promise in the future. At the moment, the best practical approach to counter this situation is to decrease the amount of fertilizer used.

(5) Wastewater Treatment

Many wastewater treatment processes have been developed (Yuyama, Y. *et al*., 1997a). Wastewater from settlements and waste from livestock raising complexes should be treated and reused, with appropriate technology used in each region. Keeping in mind the accumulated scientific knowledge accumulated in this area, it is desirable to select a single one and/or a combination among the approaches available, namely zero-emission, advanced treatment, normal treatment, and natural purification process.

Case study

(1) Creek Network Area Located along the Lower Reaches of the Chikugo River

Recently, the water quality of the creek located along the lower reaches of the Chikugo River (Yuyama *et al*., 1998b and 1999) has undergone remarkable deterioration. The conservation of water quality is needed to keep good sanitary condition and a comfortable living environment as well as to make sustainable farming possible. A study to evaluate some water quality improvement measures was carried out.

The study area is bounded by the Ariake Sea and the Yabe, Okinohata and Shiotsuka Rivers. The measures set up in this area to counter flood, drought and water quality deterioration conditions have to be discussed at the same time. As of 1996, about 60 percent of a total of 3,140 ha of land were used as low-lying paddy fields. The testing of the Chikugo Barrage as a new source of water was started in 1997. Observations made during the irrigation period and the non-irrigation period are discussed separately, because different types of farming, water use and temperature occur during these periods.

At the time of the study, the water quality characteristics observed in the main creek during the irrigation period were as follows: COD, 6.16 mg/L; T-N, 2.37 mg/L; and T-P, 0.230 mg/L. With a view to create a desirable rural area environment, tentative goals for water quality improvement were set as follows: COD, less than 6.0 mg/L; T-N, less than 2.0 mg/L; and T-P, less than 0.2 mg/L.

A flow diagram analysis technique was used to create a diagnostic of the current water quality situation. The study led to the observations enumerated below.

a) The load from household discharges accounted for 30-60 percent of the total discharge load generated within the watershed of the creek.
b) The source of the water supply for irrigation was an important factor affecting the water quality of the creek.
c) The significant discharge load from paddy fields was estimated to have the following characteristics: COD, 50-400 $kg \cdot ha^{-1} \cdot yr^{-1}$; T-N, 0-40 $kg \cdot ha^{-1} \cdot yr^{-1}$; and T-P, 0.3-10 $kg \cdot ha^{-1} \cdot yr^{-1}$.
d) The specific variation rate for the parameters observed in the creek was estimated to be 100 to 400, -150 to -30 and 2 to 60 $mg \cdot m^{-2} \cdot d^{-1}$ for COD, T-N and T-P, respectively.

The following measures for preserving water quality were under consideration: the promotion of farming with low discharge load; wastewater treatment; direct purification; inflow of water from the Chikugo Barrage to the creek; the unification of laver (sic) factories; and the dredging of bottom sediments in the creek. Among these measures, the first four were evaluated and their observed effects during the irrigation period were as described below.

a) Realistic measures taken at the farm level led to a decrease of the COD concentration by 0.33 mg/L, but significant improvement for the T-N and T-P parameters proved to be difficult.
b) The initiation of wastewater treatment projects covering all the study area led to a decrease of the concentration of the COD, T-N and T-P parameters, by 0.84 mg/L, 0.13 mg/L and 0.029 mg/L respectively, where an advanced treatment process was applied. In cases where a conventional treatment process was used, its low removal capacity was reflected in an increases of the T- N concentration.
c) Some forty direct canal purification facilities were installed and such action led to pollutant removal with a 22-24 percent efficacy factor and a decrease of the COD, T-N and T-P concentrations by 0.29 mg/L, 0.10 mg/L and 0.01 mg/L, respectively.
d) The inflow of water from the newly developed Chikugo Barrage at the rate of 1.18 m^3/s contributed to a decrease of COD, T-N and T-P concentrations of by 0.34 mg/L, 0.11 mg/L and 0.015 mg/L, respectively.

The effects observed during the non-irrigation period showed basically a similar trend as that noted during the irrigation period. The positive effects of wastewater treatment with an advanced process and of direct canal purification were more significant during the non-irrigation period than those during the irrigation period.

The goal of achieving adequate water quality is not an easy one to pursue and an objective evaluation of the results obtained can be helpful to planners and decision-makers who are responsible for water quality conservation. It is necessary that the measures taken be integrated to the maximum extent possible.

(2) Kojima Lake Project

Kojima Lake was constructed artificially by closing the Kojima Bay in 1956. The purpose of the project was to eliminate drought and salt damage for 5,100 ha of coastal farmland area, to improve the internal drainage for lowland, and to create a safe dike.

The relevant characteristics of Kojima Lake are: 532 km^2 of catchment area, 1,880 ha of lake area, a total volume of 26 MCM (million cubic metres), an effective storage volume of 18 MCM, a controlled water level (above sea level) varying between +0.8 m (non-irrigation period) and +0.5 m (irrigation period); a mean water depth of 24 m and a hydraulic retention time (HRT) of 0.05 year.

Since its creation, the water quality of Kojima Lake has been deteriorating due to significant urbanization in the watershed. The water quality parameters observed during the study were: COD, 10-12 mg/L; T-N, 1.35~1.8 mg/L; and T-P. 0.18~0.24 mg/L. This situation is the cause of social tensions. Improvements of the water quality will require cutbacks of both the inflow load from hinterland areas and the sources of pollution within the lake itself. The latter type of pollution is mainly due to releases from bottom sediments.

Based on the background information mentioned above, the new project to improve water quality of Kojima Lake was started from 1992 and covered an area made up of 4,480 ha of paddy fields and 20 ha of upland fields. The water quality targets set under this project were as follows, corresponding to the standard set for the irrigation water used paddy fields: COD, less than 6.0 mg/L and T-N, less than 1.0 mg/L. An outline of the actions to be taken as part of this project during the period 1992~2003 is provided below (Oda, 1997 and Terao, 1998):

a) Dredging of bottom sediment: 2,000 thousand m^3.
b) Dredging of gut (water route): 300 thousand m^3.
c) Covering with sand: 500 thousand m^3 (depth = 50 cm).
d) Filling up deep area.
e) Developing land with dehydrated sludge.

DISCUSSIONS AND CONCLUSIONS

There has not been too much water quality improvement in rural areas even though various types of countermeasures are being carried out. In fact, the situation is currently worsening in some areas. In many districts, it is difficult to ensure that irrigation water has a T-N concentration lower than 1.0 mg/L as set under the standard. While the damages to agricultural caused by water pollution have been decreased, the inflow of urban wastewater is becoming the main source of the damages.

It is a responsibility to ensure that agricultural activities do not contribute to the pollution of water bodies. Recommendable and acceptable countermeasures differ between regions and between countries. In order to be able to resolve unexpected problems, a consensus must be reached in advance on the need to share cost and carry out feasibility studies. The annual cost to remove 1 kg of COD, T-N, T-P is about 1-80 thousand yen 5-200 thousand yen and 0.4-30 thousand yen, respectively (1.0 US$=115-125 yen). The instauration of flood protection measures can be a source of conflict in rural areas. To improve the motivation of farmers, priority should be given to countermeasure that can save labor and costs.

Water quality analysis (Yuyama, 1995b, 1998c) is needed to diagnose the present condition and to estimate the effect of countermeasures so as projects can be assigned the right priority and designed correctly. In many cases, an integrated set countermeasures is indicated as there is no single drastic countermeasure to resolve the problem.

The basic unit in the management of water resources at the regional level is the watershed (Yuyama *et al*., 1995a). Given that excessive levels of nitrogen and phosphorus in water cause eutrophication, control measures should be focused on input sources of these nutrients. It is necessary to complete as much as possible a nutrient material balance for regions, taking into account the recycling of organic waste and compost. Situations with negative impact downstream and on groundwater must be avoided. Caution should be exercised about the reuse of water with carries a certain, albeit little, risk. Nitrogen is one of the most important constituents of fertilizers for crops. With stricter control of fertilizer and adequate water management practices in place, the standard value set for T-N could be raised up to 3-5 mg/L.

The combined use of surface water and groundwater resources should be examined more quantitatively. Even though the water supply from groundwater is helpful to cope with water requirements in a drought year, the negative impact of the practice and the difficulties with aquifer recovery have to be discussed in advance. For example, the groundwater level fell by about 18 m and the rate of subsidence accelerated to as high as 16 cm/year in the Shiroishi district of the Saga Plain, due to a water shortage that caused a great demand for groundwater in 1994 (Hachiya *et al*., 1996). The aquifer recovery cost being estimated to be higher than the cost of public compensation to farmers, irrigation to paddy fields was partially suspended during that crop season.

Water resources management at the regional level should also consider the aquatic organisms as resources. Paddy irrigation systems influences have an impact on fish habitat (Hata, 1998) and adequate protection should be given careful attention in any project. The construction of habitat streams and artificial wetland is worthy of discussion. The use of new technologies to upgrade the production of biomass is also desirable. In areas within or near rural settlements, both the construction and the management of the required facilities can be incorporated in the groundwork activities.

To achieve sustainable agricultural production, the circulative use of nutrients for crops is needed (Yuyama *et al*., 1997b) and purely exploitative agriculture should be denied. To ensure the conservation of water and soil which constitute resource base for agriculture, forest conservation in the watershed and to decrease energy consumption for agricultural production are important goals to pursue. Also, the treatment of livestock waste should be given more attention. In the future, land use regulations to conserve farmland might be needed and successfully justified in terms of the carrying capacity concept.

It is very clear that the increasing importation of food and livestock feed contributes additional amounts of nitrogen and phosphorus into the environment, thus leading to water pollution. Any progress realized toward food self-sufficiency can assist in the conservation of water quality and the effective use of regional resources. Even in the presence of a global competitive market, a system to ensure a self-sufficient supply of basic food commodities should be established in each region or country. In this point, economical rationalism should be reconsidered. The leftovers have to be refrained.

Agriculture in Asian monsoon regions could be carried out on far smaller farmland than is the case in countries such as the USA or Australia. Possible reasons for this situation are the abundant rainfall and sunshine, both factors that enable high plant productivity. The social system in place in rural areas is also a contributing factor. The capital-intensive, highly mechanized agriculture model may not suit every developing region and intensive polyculture systems, as exemplified by rice cultivation, may be better (Francesca, B., 1994).

Paddy fields have a water purification capacity, particularly for the nitrogen content and this can be managed. Now is a good opportunity to review paddy farming in this area with due consideration of various sustainability aspects. Good management of paddy fields is essential for not only food production but also in terms of water quality, ecosystem and watershed conservation and protection.

Although paddy farming is strongly connected with the rural social system in Japan, the interactions between the farming and rural communities is changing. Recent statistics on the Japanese agriculture have revealed overwhelming majority of part-time farmers and an increasing number of aged farmers. Economically independent sustainable agriculture has to be pursued as a goal and at the same time, a wholesome and holistic approach to watershed management has to be discussed among all stakeholders.

References

Chitale M. A.: Water and Food Security, Commonwealth Water Forum, Seventh ICID Drainage Workshop, Penang, 16p. 1997

Environmental Agency: Environmental White Paper (Year Book), 1998(in Japanese)

Francesca, B.: Agriculture for Developing Nations, *Scientific American*, 271(1), pp.18-25, 1994

Hachiya, Y., Kitajima, J. and Jinno, K.: Land Subsidence in Saga Plain due to Water Shortage in 1994, *Jour. of Ground Water Hydrology*, 38(3), pp.181-191, 1996(in Japanese)

Hata, K.: Influence of the paddy Irrigation System on Fishes Habitation in Japan, *Jour. of JSIDRE*, 66(2), pp.15-20, 1998 (in Japanese)

Kaneki, R.: Material Circulation System and Its Reconstruction, Regional Environmental Management Engineering, JSIDRE, pp.65-96, 1997(in Japanese)

Madramootoo, C. A., Johnston, W. R. and Willardson, L. S. eds.: Management of Agricultural Drainage Water Quality, Water Reports, 13, ICID&FAO,1997

Miyamoto, K. and Horikawa, N.: Study on Water Management of Large-scale Irrigation Project against the Drought in 1994, *Bull. Natl. Res. Inst. Agric. Eng. Japan*, 35,pp. 1-38,1996(in Japanese with English Summary).

Oda, T.: The Work of Dredging of Muddly Sediments, Water Removal and Filling-up Reclamation in Lake Kojima, *Jour. of JSIDRE*, 65, pp.501-506, 1997 (in Japanese)

Okamoto, M. and Satoh, M.: Some Characteristics of Irrigation for Paddy in Japan from the Viewpoint of Hydrology and Water Resources Engineering, *Jour. of Japan Soc. Hydrol. & Water Resour.*, 3(1), pp.1-6, 1990(in Japanese with English summary).

Tabuchi, T. et al.: Discharge of Nitrogen and Phosphorus from Watershed, Tokyo University Press, 1985(in Japanese)

Takeda, I: Nonpoint Source Pollutants in Agricultural Lands, *Jour. of Japan Society on Water Environment*, 20(12), pp.12-16, 1997a (in Japanese)

Takeda, I. et al.: Non-point pollutant Reduction in a Paddy-Field Watershed using a Circular Irrigation System, *Water Research*, 31(11), pp. 2685-2692,1997b

Terao, M.: Water quality improvement and bottom sludge treatment in Kojima lake, *Report of Research Division on Material and Construction*, JSIDRE,36, pp.1-15, 1998 (in Japanese)

Yuyama, Y. et al.: Development of Water Resources in Kasumigaura-Lake for Sustainable Use of Watershed and Agriculture, *Proc. of International Lake Conference Kasumigaura '95*, Tsukuba & Tsuchiura, pp.1796-1799, 1995a (in Japanese with English summary)

Yuyama, Y. et al.: Models for Analyzing Water Quality Environment, *JARQ*, 29, pp.231- 239, 1995b

Yuyama, Y., Yoshino, H., Kitamura, Y.: Impact of Paddy Fields on Mitigation of Flood Damage, *Proc. of 6th ICID Drainage Workshop*, Slovenia, pp.272-280, 1996

Yuyama, Y., Hata, K.: Wastewater Treatment in Rural Area of Japan, *Proc. of International Symposium "Rural Environment Improvement"*, Seoul, pp.55-87, 1997a

Yuyama, Y., Shiratani, E.: Dynamics and Effective Use of Soluble Material in Farmland, *Research Journal of Food and Agriculture*, 20(10), pp.19-24, AFFTIS, 1997b (in Japanese)

Yuyama, Y., Hata, K., Chan, A.S., Chiang, T.T.: Water Quality Conservation in Paddy Fields Area, *Proc. of Young Professional Forum of ICID*, Bali, Vol.2-C, 8p.,1998a

Yuyama, Y., Ono, K. and Kobayashi, H.: Water Quality Conservation in Low-lying Paddy Fields Area with Creek Network faced to Ariake Bay, *Proc. of International Symposium on Lowland Technology*, Saga, pp.411-418, 1998b

Yuyama, Y.: Models of Water Quality Analysis, Science for Clean Water, JSIDRE, pp.127-152, 1998c (in Japanese).

Yuyama, Y., Miyamoto, K., Ono, K.: Influence of Drought on Paddy Farming and Water Quality, *Trans. of 17th International Congress on Irrigation and Drainage*, Vol.-1B, pp.193-202, ICID, Granada, 1999

Status of agricultural water quality in Korea

ABSTRACT

Following the heavy industrialization and urbanization in Korea during the last several decades, water pollution by several sources of contaminants is becoming one of the major environmental concerns because these natural resources may directly impact on human health. The objectives of this paper are to discuss the current status of water resources in terms of quantity and quality and to report on monitoring results of a case study addressing surface and groundwater quality in a Korean agricultural area during the period 1995 to 1998.

In Korea, water quality standards were met only with a 32 percent success rate in 1998. To improve this situation, government has taken several management actions to preserve water quality such as by installing monitoring networks nationwide, designating water conservation zones, setting a stricter standard for wastewater effluents, and enforcing several environmental conservation laws, etc. In 2011, the total water consumption is expected to reach $36,673 \times 10^6$ m^3/yr, about 22 percent more than in 1994, while the supply of irrigation water is anticipated to increase only by 1.8 percent during the same period. The Government plans to meet the increasing water demands include the construction of dams or reservoirs.

Major pollution sources influencing the quality of irrigation water are wastewater from industries and livestock, sewage and acid mine drainage (AMD). This pollution problem continues to grow as both the human and livestock populations keep on increasing over the years. In 1997, the Environmental Agriculture Law was enacted to enforce the Best Management Practices (BMP) approach in an effort to maintain agricultural sustainability and to conserve soil and water quality.

Modelling studies of the nitrogen mass balance in the agricultural ecosystem indicated that more than 50 percent of the applied nitrogen fertilizers flow into water bodies, pointing to the need for appropriate measures to control this pollution load. With concentrations of COD, nitrate-N and ammonium-N observed in streams of the agricultural watershed at levels exceeding values set under the water quality standard, this constitutes an evidence of the impact of agricultural activities on water quality. Groundwater quality is also showing signs of continuing degradation, with observed concentrations of salts and nitrate-N at levels higher than those set under the water quality standard. Based on the values measured for parameters such as electrical conductivity and concentrations of nitrate-N and ammonium-N, irrigation water was classified into five categories in terms of quality.

Surveys have shown that more than 95 percent of the population in rural areas thought that the agricultural environment was contaminated and that water pollution was the most serious problem faced by the agricultural community. This suggests that the importance of water management is acknowledged and that more effective and appropriate policies focused on water quality conservation are required.

Jong-Sik Lee
National Institute of Agricultural Science & Technology, RDA, Suwon , Korea
Jae-E. Yang
Division of Biological Environment, Kangwon National University, Chunchon , Korea

Korea is one of the few countries that can count on ample clean freshwater resources. However, with rapid industrialization and urbanization since the 1960s, many water resources have become polluted. This development has led to the deterioration of water quality and, as a result, government has made various efforts to conserve water quality. For instance, monitoring networks have been established nationwide, riverside areas have been designated as conservation zones where industrial or agricultural activities cannot be located, and stricter standards for wastewater effluent have been setting. Various laws contain water pollution control measures, namely the Basic Environmental Policy Law, the Water Quality Conservation Law, the Mining Safety Law, and the Waste Management Law.

Water consumption has increased sharply in Korea during the last decade, mainly due to population growth, economic development, and improvement of living standard. With this trend continuing, water shortage problem can be expected in the future. Thus, the water management policy has been primarily focused increasing the supply to meet an ever-increasing water demand. To cope with the water shortage problem, various management options are carried out in Korea, such as the construction of dams and the instauration of measures to conserve water resources in terms of quantity and quality.

Agricultural activities have been known for some time to contaminate the water resources. While we agree in principle with this statement, it is unknown or difficult to determine the extent of water pollution that can be attributed to agriculture. Recently, there has been some progress in Korea with efforts to preserve the quality of water resources. In 1997, the Environmental Agriculture Law was enacted with an objective of conserving soil and water quality in agricultural areas, with the adoption of a Best Management Practices (BMP) approach toward decreasing adverse environmental impacts and sustaining agricultural production.

Poor water resources management can cause the depletion of surface and groundwater resources due to their overexploitation and pollution of these resources can seriously decrease the proportion that is of suitable quality for utilization. As a consequence, we have to continue to develop programmes not only to sustain the availability of water resources but also to maintain and manage the quality. This paper discusses the status of water quality in Korea and the effects of agricultural activities on water quality.

Water quality status and management

Water resource management

Table 1 shows the supply and demand of water resources in Korea. In 1994, the total amounts of water resources available were equivalent to about $32{,}000\times10^6$ m^3/yr. Government plans are to increase these resources to about $40{,}000\times10^6$ m^3/yr by 2011, by constructing dams and reservoirs or by using alternative management options. The total water consumption in Korea will reach $36{,}673\times10^6$ m^3/yr by 2011, or about 22 percent more than in 1994. Thus, water resource management plan is essential in Korea to cope with the water shortage problems expecting in the future. However, amounts of irrigation water will be increased only by 1.8 percent from 1994 to 2011. It is relatively lower rate increase as compared to other water use. By 2011, reserve ratio of water source will be increased from 7.7 percent to 8.5 percent, and ratio of dam water to total water supply will be 50 percent, as compare to 39 percent in 1994.

Surface water quality

The Korea Ministry of Environment divides the water quality standards for river and lake into five grades (I to V). Table 2 shows the quality standards used set for river water, namely pH,

TABLE 1
Supply and demand of water resources in Korea (10^6 m^3/yr)

	1994	2001	2006	2011
Total amount of the water supply	32 463	35 064	38 747	39 802
· River	17 221	17 093	16 997	16 953
· Groundwater	2 571	2 709	2 808	2 907
· Dam	12 671	14 562	14 802	14 802
· Planned future exploitation of new water sources	-	700	4 140	5 140
Total amount of water demand	30 144	33 662	35 014	36 673
· Public water	6 209	7 435	8 073	8 706
· Industrial water	2 582	3 873	4 074	4 544
· Irrigation water	14 877	15 027	15 226	15 150
· Maintenance	6 476	7 327	7 641	8 273
Reserves	+2 319	+1 402	+3 733	+3 129

Source: (Ministry of Environment, 1998)

TABLE 2
Water quality standards for river water in Korea

Grade	Major Usage*	Water Quality Standards				
		pH	BOD (mg/L)	SS (mg/L)	DO (mg/L)	MNP† (per100mL)
I	Drinking water level 1	6.5-8.5	<1	<25	>7.5	<50
II	Drinking water level 2	6.5-8.5	<3	<25	>5	<1,000
III	Drinking water level 3 Industrial use level 1	6.5-8.5	<6	<25	>5	<5,000
IV	Industrial use level 2 Irrigation water	6.0-8.5	<8	<100	>2	-
V	Industrial use level 3	6.0-8.5	<10	No solid wastes floating	>2	-

* *Drinking water level 1: use as drinking water after the primary treatment.*
Drinking water level 2: use as drinking water after the secondary treatment.
Drinking water level 3: use as drinking water after the tertiary treatment.
Industrial use level 1: use as industrial water after the primary treatment.
Industrial use level 2: use as industrial water after the chemical treatment.
Industrial use level 3: use as industrial water after the special treatment.
†*Most Probable Number test for Coliforms*

Biochemical Oxygen Demand (BOD), Suspended Solid (SS), Dissolved Oxygen (DO) and the Most Probable Number (MPN) test for coliforms. The nationwide river water system is divided into 195 sections, with each section encompassing five major rivers. The purpose of this classification is to facilitate the management of water quality within a river and the assessment of whether water quality goals are achieved.

Table 3 provides data on the status of water quality in rivers compared to the applicable standards. The overall percentage of rivers with water meeting the standards is only 32 percent, with the 55 percent and 38 percent as the two highest rates observed in the Kum and Han river systems, respectively. In the other river systems, the rates were below the national average. These results demonstrate that a more adequate management is needed to conserve water quality in Korea.

Irrigation water quality

Table 4 provides the results of a survey conducted at 500 sites to assess whether the water quality was suitable for irrigation use. Guidelines were recently proposed by the Rural

TABLE 3
Current status of river water quality (Kwak, 1999)

Major river water systems	Total sections	Water Quality Grade					Achievement Ratio (%)*
		I	II	III	IV	V	
Total	195 (62)†	121 (33)	49 (16)	9 (4)	8 (6)	8 (3)	32
Han river	52 (20)	30 (11)	11 (4)	3 (3)	2 (1)	6 (1)	38
Nakdong river	40 (10)	32 (8)	6 (1)	1 (0)	-	1 (1)	25
Kum river	38 (21)	20 (6)	12 (9)	1 (1)	5 (5)	-	55
Yongsan river	12 (2)	5 (0)	5 (2)	1 (0)	1 (0)	-	17
Sumjin river	6 (0)	6 (0)	-	-	-	-	0
Others	47 (9)	28 (8)	15 (0)	3 (0)	-	1 (1)	19

† Numbers in parentheses indicate the number of sections where the water quality standards have been met.
* The achievement ratio is the number of sites meeting the standards over the total number sites.

TABLE 4
Number of sites meeting the guidelines for agricultural water use (Rural Development Corporation, 1997)

Parameters	Reservoir (253)*	Water pumping station (111)*	Irrigation bank (136)*	Total (500)*	Ratio† (%)
pH	32	4	13	49	9.8
EC	3	10	5	18	3.6
SS	62	7	9	78	15.6
COD	117	78	75	270	54.0
T-N	87	87	88	262	52.4
T-P	79	87	96	262	52.4
Cl	7	19	8	34	6.8

* Number of sites monitored for each category
† (Number of sites×100)/(total number of sites)

TABLE 5
Influence of pollution sources on irrigation water quality (Rural Development Administration, 1991)

Pollution source	pH	EC	NH_4-N	$COD_{Cr.}$	SO_4^{2-}	Cd	Cu	Pb
		(dS/m)	---------------------------- (mg/L) -----------------------					
Reference*	7.4	0.12	0.7	10.1	5.8	0.003	0.004	0.016
Industrial complexes	7.4	0.55	9.9	52.4	67.4	0.005	0.029	0.023
Sewage	7.4	0.33	6.2	35.2	20.9	0.004	0.009	0.016
Mine waste	3.1	0.84	0.3	13.8	346.8	0.004	0.074	0.009
Livestock waste	7.4	0.39	21.0	63.3	-	0.011	0.036	0.059

* Reference corresponds to irrigation water sampled from sites not affected by pollution sources

Development Corporation (1997). While at about 50 percent of the sites the water quality guidelines for COD, T-N, and T-P were met, those for pH, EC, SS, and Cl were met at less than than 20 percent of the sites. Among the water quality parameters measured, electrical conductivity (EC) was the one with the lowest (3.6 percent) compliance ratio, indicating an excessive salt content in the water at most of the monitoring sites regardless of their category. Judging from the values observed for the COD, T-N and T-P parameters and their above 70 percent compliance rate, the water quality at pumping stations was relatively better than at sites of the other categories. These results indicate that the water resources might be unsuitable for irrigation use due to contamination or that the irrigation water quality guidelines in Korea might be too strict.

Pollution sources for water quality

The data shown in Table 5 provide a comparison of the values of selected water quality parameters that have been measured at irrigation water supply sites affected by different pollution sources. Where possible pollution sources could affect the quality of irrigation water, higher levels of electrical conductivity (EC), NH_4-N, COD, and heavy metals were observed as compared to the control or reference site. The acid mine drainage (AMD) at the abandoned mining sites was strongly acidic and contained high levels of sulfate and Cu, indicating that this source of water might not be suitable for irrigation use. Wastewater from industrial complexes and livestock farms contributed a high levels of NH_4-N, COD, Cu and Pb into the receiving water bodies. These results demonstrate a need for the proper control of possible pollution sources to prevent the deterioration of the water quality in receiving waters.

The yearly changes in the size of the population and in the amount of sewage produced are shown in Table 6. As can be seen by the trend in the data reported, the daily amounts of sewage produced per person as well as the quantities of industrial wastewater produced and discharged increased linearly with population.

The population in Korea has increased steadily over the period 1988 to 1994, to reach $46{,}249 \times 10^3$ in 1994. As well, the total amount of sewage produced increased form $10{,}190 \times 10^3$ m^3/day in 1988 to $15{,}976 \times 10^3$ m^3/day in 1994. The improvement in the living standard recorded during the same period was accompanied by an increase in the amount of sewage produced, from 243 to 345 L/person·day.

TABLE 6
Yearly changes of population, and amounts of sewage and industrial wastewater in Korea (Ministry of Environment, 1998)

Division	1988	1990	1992	1994
Population	41 975	43 520	44 178	46 249
Amount of sewage (10^3 m^3/day)	10 190	12 323	13 416	15 976
Amount of sewage (L/person·day)	243	283	303	345
Division	1994	1995	1996	1997
Amount of Industrial wastewater produced (10^3 m^3/day)	7 259	8 741	8 926	4 874*
Amount of industrial wastewater discharged (10^3 m^3/day)	2 316	2 375	2 511	2 618

* Until 1996, recycling cooling water in the iron-making industry was considered as wastewater, but from 1997 only the discharged cooling water was considered as wastewater

TABLE 7
Yearly changes in number of major livestock and livestock raising households (Ministry of Agriculture and Forestry, 1998)

Year	No. of livestock ($\times 10^3$)			No. of livestock farming house ($\times 10^3$)			Amount of wastewater (10^3 m^3/day)
	Beef cattle	Pig	Poultry	Beef cattle	Pig	Poultry	
1992	2 019	5 463	73 324	585	99	188	154.0
1993	2 260	5 928	72 945	570	70	192	169.6
1994	2 393	5 955	80 569	540	54	189	174.5
1995	2 594	6 461	85 800	519	46	203	168.2
1996	2 844	6 515	82 829	513	33	187	197.0
1997	2 735	7 096	88 251	465	27	162	206.4

TABLE 8
Yearly changes of chemical fertilizer consumption in Korea (10^3M/T) (Ministry of Agriculture & Forestry, 1998)

Fertilizers	1990	1995	1996	1997
Nitrogen	562.3	471.6	455.9	446.1
Phosphorus	256.2	223.2	208.5	198.8
Potassium	285.5	259.4	243.5	237.4
Total	1,104.0	954.2	907.9	882.3

Table 7 shows the data to follow the changes in the number of major livestock animals and in the number of households involved with livestock raising. While there has been a steady decrease over the years in the number of such households, the number of major livestock heads has been increasing, namely for beef cattle, pig and poultry by passing from 2 019×10^3, 5 463×10^3, and73 324×10^3 in 1992 to 2 735×10^3, 7 096×10^3, and 88 251×10^3 in 1997, respectively. These results point to livestock farming in Korea becoming an activity carried out on a larger scaled and as an industry. Accordingly, the amount of livestock wastewater discharged has been increasing over the years, reaching as high as 206.4×10^3 m^3/day in 1997. Most of the wastewater was discharged into streams, thus causing serious water pollution problems on account of its high content of organic matter and nutrients. This situation signals the need for special measures to prevent the contamination of water resources.

The yearly changes in the consumption of fertilizers in Korea are shown in Table 8. Fertilizers are essential for food and fiber production, but when applied in excessive quantities on fields, especially those that are sources of nitrogen and phosphorus, they contaminate receiving water bodies and can cause their eutrophication. As an effort to avoid this problem, the Korean government promulgated the Environmental Agriculture Law in 1997, a legislation focused on sustainable agricultural production. Under the terms of this law, farmers are urged to adopt the Best Management Practices (BMP), reduce the applications of chemical fertilizer and substitute organic by-product fertilizers to chemical fertilizers. Accordingly, as shown in Table 8, the chemical fertilizer consumption has been decreasing gradually over the years, passing from 1,104×10^3 metric tons (M/T) in 1990 to 882×10^3 M/T in 1997.

TABLE 9
Pesticide residue in the water samples collected from the major rivers (µg/L) (Jung *et al.*, 1997)

Pesticides	Han	Geum	Mangyung	Youngsan	Nagdong	Somjin
Diazinone	tr	0.08	0.40	0.12	0.06	tr
Dichlorpyrifos	0.025	0.105	0.063	0.074	0.044	0.023
Chlorpyrifos	tr	tr	tr	tr	tr	tr
Iprobenfos	0.30	0.50	0.83	0.73	0.56	0.10
Procymidone	0.08	tr	0.10	0.18	0.04	tr

Table 9 provides data on residual concentrations of selected pesticides in the major rivers of Korea. Pesticides are an important tool in agriculture and they contribute undoubtedly to food and fiber production. However, some of the pesticides have an adverse effect on the environment due to their persistence. Possible pathways for the entry of pesticides into aquatic environments are through leaching and run-off from fields where they are used. Korea is among the countries where the amount of pesticide applied per unit area of the arable land is the highest in the world. Thus, the government has tried to adopt the concepts of biological control and integrated pest management (IPM) since 1980s. Even with these efforts, the amount of pesticide applied for disease and pest control has been increasing been increased steadily over the years.

Since the 1970s, the use of pesticides leaving important residues, such as organochlorine insecticides, for example DDT, has been prohibited. As a result, organochlorine insecticides are not detected in aquatic ecosystems these days (Table 9). As for organophosphorus insecticides, residual concentrations are very low. In Korea, resources dedicated to research on the effects of pesticide on water quality and the monitoring of pesticide residues in aquatic ecosystems are not as important as those for similar activities focused on other contaminants.

Farmers' consciousness of water quality

Table 10 summarizes the results of a questionnaire aimed at determining the farmer's consciousness of water pollution in agricultural areas. The national survey was administered 1 287 farmers in 51 sites across the country. More than 95 percent of the farmers felt that the environments was contaminated in agricultural areas, with 10 percent of these regarding this pollution as serious. Korean farmers considered water contamination to be the most serious pollution problem. In the opinion of farmers, the contaminants responsible for the pollution in agricultural areas were as follows in order decreasing importance: garbage, livestock animal waste, municipal sewage, agricultural sewage, pesticides, industrial wastewater and fertilizers.

Separately from the survey described above, a report from the Korea Ministry of Environment (1998) revealed that the amounts of wastewater discharged from pollution sources were in the

TABLE 10
Farmer's consciousness on pollution of agricultural environment in Korea (Shim, 1994)

Category	Result of questionnaire
Status of pollution	Contamination (86.2%) > Serious contamination (9.6%) > Unpolluted (4.2%)
Environmental component seriously contaminated	Water (54.4%) > Air (20.6%) > Others (19.9%) > Soil (5.1%)
Sources of contaminant of agricultural water	Garbage (33.5%) > Livestock animal waste (17.8%) > Municipal sewage (13.4%) > Agricultural sewage (13.3%) > Pesticide (11.3%) > Industrial wastewater (10.0%) > Fertilizer (0.7%)

following decreasing order: wastewater, industrial wastewater and livestock wastewater. The pollution load, however, resulting from the industrial and livestock wastewater even in small quantity could be much higher than that from the domestic wastewater, possibly due to a higher content of organic and inorganic contaminants. In Korea, about 70 percent of the industrial wastewater are known to be treated prior to their release into receiving waters. This percentage is lower, however, in the case of domestic and livestock wastewater.

Considering the common views shared by farmers on the level of importance to be given to water resources management in agricultural areas, there is a need to set and promote within the agricultural community more effective and appropriate management policies on water quality conservation.

Mass balance of nitrogen cycle in agriculture in Korea

The diagram shown in Figure 1 provides the data applicable to the mass balance of the nitrogen cycle for the agricultural sector in Korea (Lee and Jung, 1993). The total amount of nitrogen input to the agricultural sector was estimated at 652×10^3 M/T, of which 61 percent was contributed by chemical fertilizers. The amount of nitrogen used for domestic food supply was only 171×10^3 M/T with an environmental load equivalent to 481×10^3 M/T. The data show that the fertilizer applications constitute the major input source for the nitrogen environmental load and that the nitrogen losses were estimated at 132×10^3 M/T through denitrification, 36×10^3M/T through release into surface water and 6×10^3M/T through leaching into groundwater. Other pollution sources are regarded as responsible for the rest of the environmental load (307×10^3M/T), an amount equivalent to 58 percent of the total nitrogen input artificially (chemical fertilizer + imported feeds). If these amounts of nitrogen will not be purified and mixed with all the water resources (662×10^9 M/T), then a pollution load of 5 mg/L can be expected as a result and such a concentration is high enough to cause the eutrophication in the aquatic environment.

Case study on agricultural water quality in Korea

Status of agricultural water quality

Water quality monitoring is one of the most important prerequisites for proper water resources management. The largest portion of water use in Korea is associated with agricultural activities. As part of the case study presented below, surface and groundwater quality in agricultural areas in Korea was monitored. Surface water samples were collected monthly from May to October at agricultural vulnerable areas and groundwater samples, used for irrigation of plastic film hothouse cultivation areas, were taken twice (dry and rainy season) per each monitoring year.

The electric conductivity (EC) and the pH of the samples were measured using the appropriate meters, respectively, and their concentrations of K, Na, Ca, and Mg were determined by ICP (inductively coupled plasma emission spectrometry). Their concentrations of NH_4-N, NO_3-N, SO_4^{2-}, and Cl^-, were determined by spectrophotometry.

Table 11 shows the yearly changes in the monitoring data gathered during the case study for irrigation water in agricultural vulnerable areas. Agricultural vulnerable areas are those regions where the irrigation water is likely to be contaminated by sewage water, livestock wastewater, and industrial wastewater, etc. The data provided in Table 11 point to an improvement in water quality during the period 1995 to 1997. Chemical oxygen demand (COD), which is indicator of

FIGURE 1
Mass balance of nitrogen cycle and pollution load from an agricultural sector in Korea (10^3 M/T) (Lee and Jung, 1993)

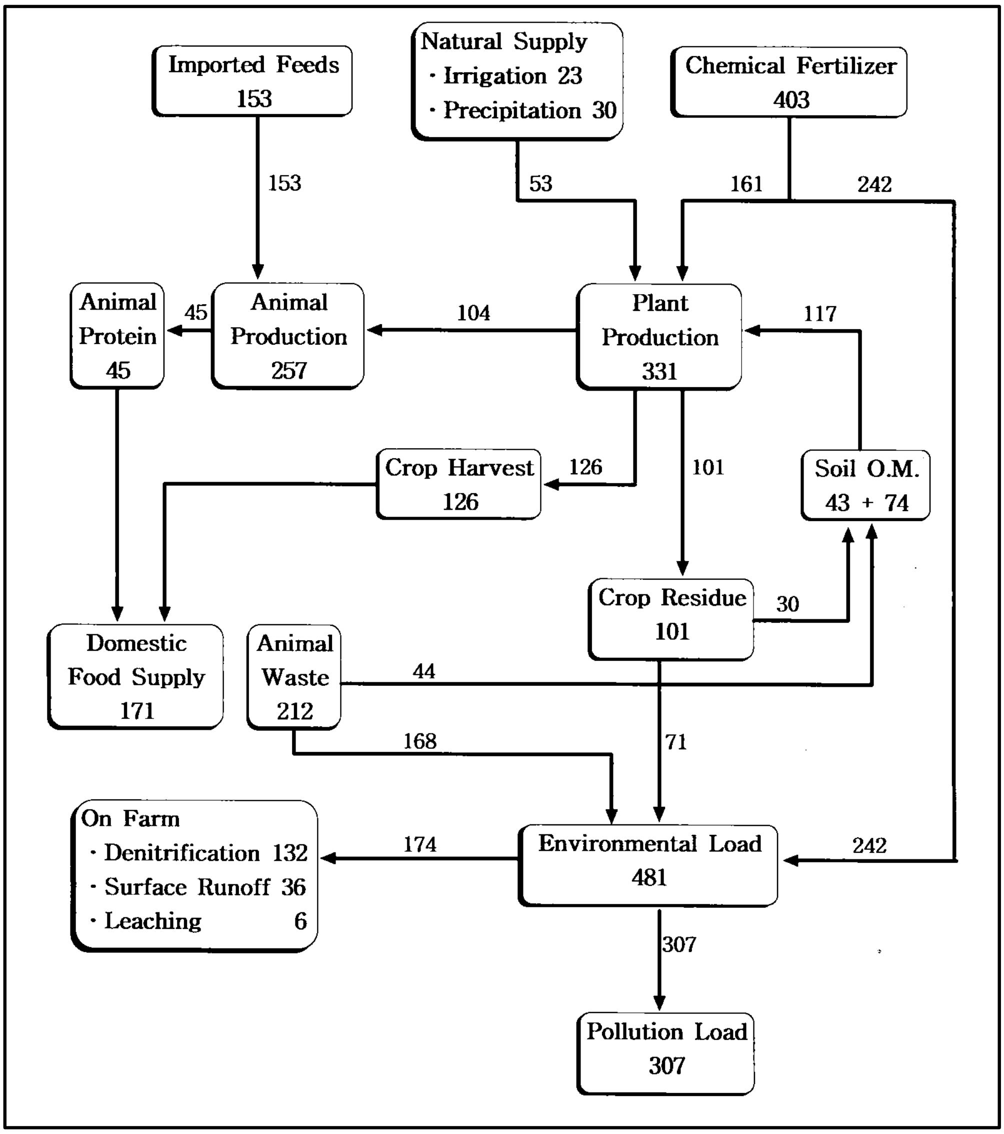


TABLE 11
Yearly changes of water quality at agricultural vulnerable areas

Year	EC	$COD_{Cr.}$	NH_4-N	NO_3-N	SO_4^{2-}	Cl^-
	(dS/m)	----------------------------		(mg/L)	----------------------------	
1995	0.35	22.9	3.14	1.73	44.8	51.6
1997	0.24	13.7	2.45	2.00	34.1	29.3

water contamination by organic matter, was decreased from 22.9 mg/L in 1995 to 13.7 mg/L in 1997. While there was a slight increase of the NO_3-N concentration over the same period, but the values for NH_4-N, EC, sulfate, and chloride decreased. This general improvement of water quality might be the results of good management, such as monitoring water resource, management of wastewater, and reducing the fertilizer consumption, etc.

Water quality of the agricultural watershed

Table 12 shows the monthly changes of water quality in 1997 in a specific agricultural watershed, in which the Kyoungan stream is the main water body. Major environmental components in this watershed are forestry, paddy and upland soils, and residential areas. Agricultural activities, particularly small scale livestock raising, are commonly practiced in this area. The Kyoungan stream is one of three main tributaries which flow into Paldang Lake. This stream has a total length of 49.5 km, with an average slope of 1/720, and the total drainage area is 589 km. The stream is likely to be contaminated by sewage water and livestock wastewater. About twenty-five million people and many industries in the Seoul Metropolitan rely heavily on the water resources of Paldang Lake for drinking water and industrial uses.

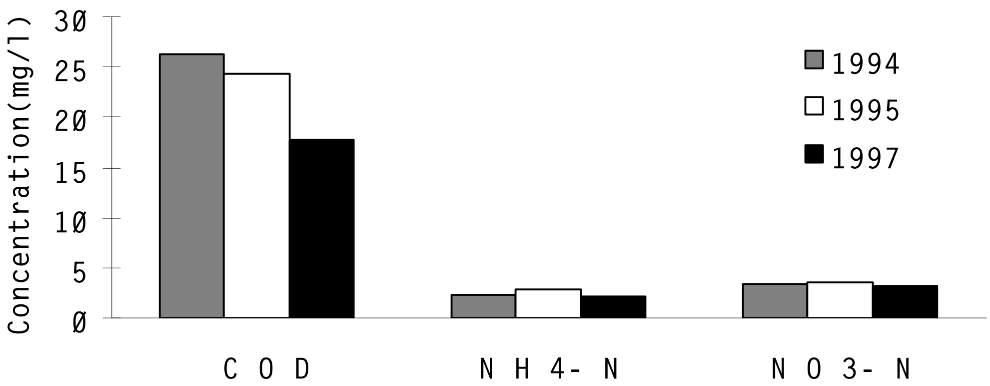
The water quality observed in July and August was better than in any other months, possibly due to the dilution by the rainwater. The amount of rain during these months, which are in the core of monsoon season, represents half of the annual precipitation. The water quality parameters observed in the Kyoungan stream during the drought season was considered to be very poor. Judging from the COD concentration, one of the key parameters to judge the water quality in river water against the standard, the water in this stream can be used only for industrial and agricultural purposes (Table 2).

Figure 2 represents the results of water quality monitoring along the Kyoungan stream in 1994, 1995 and 1997. While the chemical oxygen demand (COD_{Cr}) show a gradual decline over the period, it was still high enough to prevent the use of the stream as a source of drinking water, based on the Korea water quality standard for river water (Table 2). The COD value should be lower than 6 mg/L in a source of water if it is to be considered suitable for drinking water after a proper treatment. The NH_4-N and NO_3-N concentrations showed no significant changes over the same period.

TABLE 12
Monthly changes of water quality of Kyoungan stream in 1997 (Lee *et al.*, 1998)

Month	EC	$COD_{Cr.}$	NH_4-N	NO_3-N	Cl^-	SO_4^{2-}
	(dS/m)	---------- (mg/L) ----------				
Mar.	0.267	10.7	5.02	3.11	33.0	31.2
Apr.	0.280	38.4	2.83	2.79	33.4	33.0
May	0.210	34.5	1.15	4.02	17.8	22.7
Jun.	0.485	27.2	1.94	3.28	49.6	37.2
Jul.	0.191	15.2	0.74	2.77	18.0	1.5
Aug.	0.299	8.1	1.23	3.53	32.9	2.7
Sep.	0.493	11.3	6.26	2.10	59.3	5.0

FIGURE 2
Yearly changes of water quality along the Kyoungan stream (Lee *et al.*, 1998)



Groundwater quality in a plastic film hothouse

Cultivation in a plastic film hothouse has become one of the major agricultural production systems in Korea, mostly for vegetable and horticultural crops and with urban populations as the main clients for that production. The controlled environment provided by this cultivation environment makes it possible to plan several harvests of vegetables in a year. Since the ambient temperature inside the hothouse is higher than outside, a higher rate of evapotranspiration is observed. This intensive cultivation approach requires high input of fertilizers and pesticides, resulting in the accumulation of high concentrations of soluble salts in the surface soils. Hard pan in the subsurface soil is formed in some areas due to the compaction by the heavy machinery, causing the increase in soil bulk density. Along with these phenomena, higher rates of organic fertilizer application inhibit the water movement in the soil profiles.

The irrigation in plastic film hothouses in Korea depends mostly on shallow groundwater resources. Contamination of groundwater with mobile ions such as nitrate is often reported, exceeding the drinking water standard of 10 mg/L. Table 13 summarizes the monitoring results of groundwater quality during the period 1996 to 1998 in areas where plastic film hothouse cultivation is carried out, with measurements done at 165 and 195 sites in 1996 and 1998, respectively.

As the number of cultivation years increased at a given site, the data reported in Table 13 show a deterioration of the quality in groundwater. Both the values of the electrical conductivity and the concentrations of soluble salts increased in the water samples analyzed. The increase in the level of NO_3-N from 10.8 to 14.2 mg/L during the two year period is particularly noteworthy. In many places, groundwater is also used as drinking water. It is well known that high levels of NO_3-N can lead to the eutrophication of the water as well as be harmful to human and animal health.

TABLE 13
Yearly changes of groundwater quality in areas of plastic film hothouse cultivation

Year	EC	NO_3-N	SO_4^{2-}	Cl^-
	(dS/m)	-------- (mg/L) --------		
1996	0.34	10.8	32.4	36.1
1998	0.36	14.2	35.3	37.8

Under government regulations, the water quality standards for the concentration of NO_3-N in drinking water and agricultural water have been set as 10 and 20 mg/L, respectively. According the groundwater surveyed during this study was not of a quality suitable for drinking. When groundwater is used for irrigation purposes, special control measures should apply to ensure that just the adequate level of nitrogen is available for crop growth, for instance by controlling the amount of irrigation water and nitrogen fertilizer applied.

Criteria of water quality

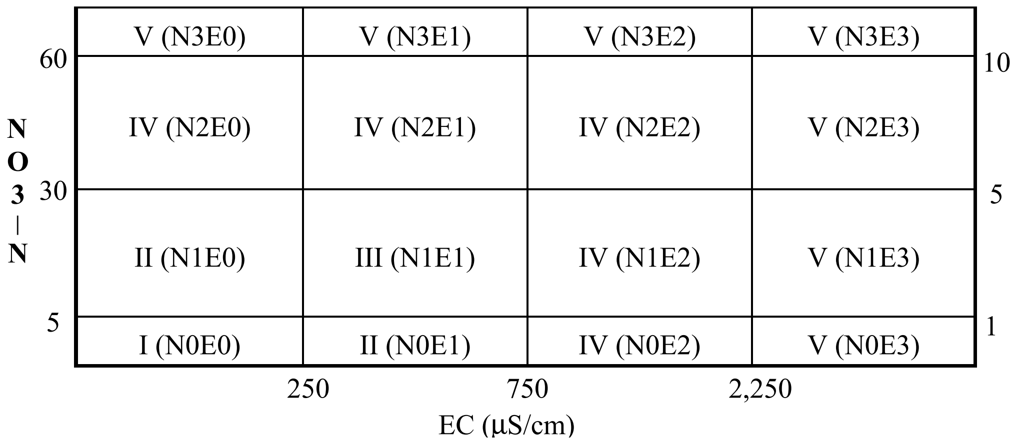
The electrical conductivity (EC) and nitrogen (N) level are important parameters for assessing the quality of irrigation water. As shown in Figure 3, the quality of irrigation water quality can be been classified into 5 categories on the basis of the values measured for NO_3-N, NH_4-N, and EC (Jung *et al.*, 1997). Irrigation water in category I (N0E0) shows no detrimental effects on crop cultivation due to low values of EC and N. In category II (N0E1 or N1E0) irrigation management such as flooding and drainage with general fertilization is needed. In category III (N1E1) fertilizer application and irrigation must be managed to ensure a reduction in the nitrogen level. In the case of category IV , salt accumulation and crop injury due to an excessive nitrogen level are possible adverse effects when irrigation water is applied continuously. Finally in category V, the water cannot be used as irrigation water due to the higher salt and nitrogen concentrations.

The quality of the groundwater surveyed in the areas where plastic film hothouse cultivation is practiced falls in the category III(N1E1), thus indicating that proper management of irrigation and N fertilizer applications is necessary. However, the monitoring data for samples of surface water obtained as part of the case study show the quality to fall in the category I or II.

References

Jung Yeong-Sang, Jae-E Yang, and Bok-Young Kim, 1997. Current Status of Agricultural Water Quality, Diffuse Pollution Problems and Improvement in Korea. The Korean Society of Environmental Agriculture. P.65-94.

Figure 3
Classification of irrigation water quality based on NO_3-N, NH_4-N **and electrical conductivity** (Jung *et al.*, 1997)



Korea Ministry of Agriculture & Forestry, 1998. Statistical Yearbook of Agriculture & Forestry, Kwachon, Korea.

Korea Ministry of Environment, 1998. Environment Statistics Yearbook. Kwachon, Korea.

Korea Rural Development Administration, 1991. Studies on Protection of Agricultural Environment from Pollution. Suwon, Korea.

Kwak K.H. 1999. Water Management Policy toward 21 Century in Korea. International Symposium on Development of Water Quality Renovation System. p.5-17.

Lee and Jung 1993. Sustainable Management in Crop Production and Farmland. International Symposium : Sustainable Agriculture & Environmental Conservation. P.31-55.

Lee J.S., G.B. Jung, J.H. Kim, and B.Y. Kim. 1998. Irrigation Water Quality of the Kyoungan Stream. Korean Journal of Environmental Agriculture. 17(2):136-139.

Rural Development Corporation, 1997. Study on System Improvement for Establishment of Agricultural Water Standards. p.17. Suwon, Korea.

Shim J.H. 1994. Status of Agricultural Water Quality and Management in Korea. International Symposium of Agricultural Water Quality Management Techniques. p.13-39.

Water quality management in Lao PDR

Abstract

In general, the water quality in the Lao PDR is considered to be good. However, water quality and related environmental issues exceed current national capacity to deal knowledgeably with them, and long-term professional assistance is required for supervision of the water quality monitoring programme, for technical assistance for laboratories, and for providing basic interpretation, technical support and professional advice to national officials.

Country overview

The population of the Lao PDR is about 4.8 million with an annual increase of almost 03%. More than 90% of the population relies on farming which depends on the Laos climate. The whole country is subject to the monsoon which imposes a rainy season from May to September, and a dry season from October to April. Annual rainfall varies from 1300mm to 3000 mm depending on exposure to the southwest monsoon.

The important aspect of Lao demography is the unequal geographical distribution of the population. This is related to the availability of good agricultural land, and to access and other communication channels. In addition to geographical factors, there are other historical reasons for the small population density.

According to the 1990 World Development Report of the World Bank, Lao PDR was rated in 1988 as the tenth poorest country in the world with a per caput GNP of US$180. A more recent estimate by UNICEF (1992) is US$216. That agency also notes the major disparities in income between urban and rural areas. The manufacturing sector accounts for only about 09% of GNP. The national economy is highly dependent upon agriculture (mainly rice production and some livestock) and forestry, with a combined share of over 50% of GDP and about 75% of the labour force. In the past the low population density has not encouraged high productivity in agriculture or new employment opportunities, however this situation is now changing rapidly.

Agriculture is the main sector of the economy and some food crops such as rice, peanuts and soy beans are produced in surplus during favourable years. Most are, however, consumed domestically and only small surpluses find local market outlets. Local cash crops of cotton, tobacco and tea are produced by subsistence farmers in addition to their traditional food crops. Major cash crops are coffee, cardamom and sesame. The development of these crops will depend on higher commodity and farm-gate prices, better trade policies, the improvement of transportation, and agricultural extension programmes.

Fishing is a common activity in all lowland areas and in many locations provides an important source of protein. Some fish are raised in ponds and paddy fields. The construction of new

Keobang A. Keola
Deputy Chief of Cabinet, STEA, Vientiane, Lao PDR

hydropower reservoirs offers new opportunities for fish production in the Lao PDR. This, however, depends on careful management of the combined river/reservoir environment and of water quality, as well as on development of appropriate methods for fish farming, and new skills in local communities.

Forestry is of great importance to the country's economy. It is estimated that the total wood volume of all types of forest is about 12000 million m^3. At present, timber and forest products are estimated to provide about 40% of export earnings.

The Lao PDR possesses the greatest hydroelectric potential of all countries in the lower Mekong River basin. This potential is estimated at up to 13 000 MW. This compares with 2 500 MW for Vietnam and 350 MW for Thailand. At present, electricity is principally generated by the Nam Ngum barrage in Vientiane Province, with 100MW capacity, and up to 80% of the output is sold to Thailand, contributing 28% of the value of all exports.

National policy environment related to water quality

Protection of environmental resources is highlighted in the Constitution of the Lao PDR. Natural resources to be protected include those on land and in the water. As water is used by all, the overall responsibility for maintaining water quantity and quality is at the national level. However, without standards or legal and technical management tools, it is very difficult for national and sectoral institutions to carry out their duties towards water quality protection.

The Science, Technology and Environmental Organization (STENO) has the responsibility for coordinating national environmental strategies between line ministries who, respectively, have responsibility for their jurisdictions. STENO also has the responsibility for establishing national water quality standards for different uses and for effluent criteria from industries, etc. As yet, STENO has no direct influence over, nor access to, legal and scientific data to help it implement its policy mandate. Nevertheless, even though the institutional capacity of the government that is required to attain its water quality management objectives is weak, the foundation for integration of economic development goals with targets for environmental control are now in place. The Ministry for Industry and Handicraft (MIH), among others, has already designed a set of standards for industrial emissions control. Because legislation will demand that maximum allowable pollution targets be set for specific discharges, an established laboratory within STENO will enable the linkage of scientific data with the legislative process so that these targets can be monitored and maintained.

Domestic water supply

Urban water supply throughout the country is presently under the responsibility of Nam Papa Lao, a state-owned service provider under the jurisdiction of the Ministry of Communication, Transport, Post and Construction (MCTPC). Water in other cities is the responsibility of provincial Nam Papas. The Department of Housing and Urban Planning (DHUP) of MCTPC regulates urban water supply. At present, about 56% of the urban population has access to piped water supply. If coverage includes people within reach of supplies, but not directly connected, the percentage of coverage is around 70%. In addition, many older properties have access to groundwater through dug wells that are now used only for non-potable supplies, however there is no information on the extent of these supplies. The main sources of water are rivers. Springs and groundwater are also used in some towns and districts. On-going water supply projects will supply an additional 24 towns by the year 2000. These projects will enable

TABLE 1
Water supply and sanitation in Lao PDR.

Water Supply and Sanitation	Urban	Rural
Population served by public piped water supply to house	56% (increasing)	small
Population served by public piped water supply	70% (increasing)	63% (increasing)
Population served by piped/covered sewage	0	0
Population served by septic system	Not known	Not known

TABLE 2
Water use and access to safe water in Lao PDR.

Use	Percentage
Agriculture	82% (increasing)
Industrial	10% (increasing)
Domestic/ Municipal	08% (increasing)

	Safe Water	Sanitation
Rural	63% (increasing)	32% (increasing)
Urban	56% (increasing)	37% (increasing)

a significant increase in urban water supply coverage. In 1997 the Asian Development Bank provided technical assistance to the Government to prepare a project for developing piped water supply and improving sanitation in about 30 more small towns. The population of these 30 towns was estimated at about 172 000 at the end of 1997.

Rural water supply is under the responsibility of Nam Saat within the National Institute of Hygiene and Epidemiology of the Ministry of Health. The main sources for rural water supply are springs and groundwater as many streams in remote areas have a torrential regime and quickly dry up after the rainy season. Overall service coverage in 1996 was believed to average only some 57% for rural water supply. Coverage remains even lower in the remote, ethnic minority-populated provinces. In the most critical areas such as remote rural communities in the Savannakhet Plain, villagers may have to travel up to one or two kilometers to get two buckets of water which is often of poor quality. Statistics on water supply and sewage are provided in Table 1.

Uses of water

Because water is viewed as an expendable commodity in Lao PDR, little effort has been directed towards resource conservation. To date, only a small fraction of the surface water has been used while the groundwater remains practically unused except for water supply in rural areas and some small towns.

Although groundwater is a significant source for some urban and most rural water supplies, there has been no large-scale investigation of groundwater resources. Use of either ground or surface water for town supply is not likely to affect other users because of the small volume, but reduced water quality or quantity at the source will affect the town supply. Groundwater is, and will probably remain, the main source of potential rural and small town water supply, especially in lowland areas located far from surface water sources such as the southern and western part of Champassak Province, and the hinterlands of the Sebang Fai, Sebang Hieng and Sedone valley.

In recent years, increasing population pressure and development changes have reduced fish numbers. Over-fishing, combined with environmental degradation from human activities has resulted in a gradual decrease in natural fish stocks. The construction of dams has had serious impacts on downstream fishing because of poor water quality released from the reservoirs, obstruction to fish migration, change in habitat, and other associated changes in the river downstream.

TABLE 3
Water and ecosystem characteristics in Lao PDR

Condition adversely affected by human activities	**Impact**			
	Severe	**Moderate**	**Slight**	**No Impact**
Length of rivers with natural flow regimes that are affected	10% Increasing	20% Increasing	70% Decreasing	0%
Area of wetlands with natural flow regimes and/or water quality are affected	0%	20% Increasing	80% Decreasing	0%
Length of rivers with affected water quality	0%	20% Increasing	70% Decreasing	10% Stable
Length of principle rivers where aquatic systems are affected.	0%	20% Increasing	80% Decreasing	0%
Length of minor rivers and streams where aquatic ecosystems are affected	0%	0%	80% Decreasing	20% Decreasing
Surface area of principal lakes where aquatic ecosystems are affected	0%	0%	Negligible	Close to 100%
Surface area of principle lakes where water quality is affected	0%	0%	Negligible	Close to 100%
Area of upper catchments affected by human-induced soil degradation and/or erosion	10% Increasing	40% Increasing	50% Decreasing	0%
Area of irrigated areas affected by salinization	0%	0%	0%	100% Stable
Area of country affected by desertification	0%	0%	0%	100% Stable

WATER QUALITY MANAGEMENT

The overall situation for water and ecosystem conditions is outlined in Table 3.

The water quality monitoring network has been developed within the framework of the Mekong River Commission's basin-wide monitoring program. The Ministry of Agriculture and Forestry (MAF), the Department of Irrigation's tudy and Design of Irrigation Centre, are involved in operational activities of monitoring and developing analytical measurement techniques for basic chemical parameters together with the elaboration of procedures for data treatment. This network derives from a mix of objectives and technically feasible methods and for which the primary objective has been to enable data collection and related database activities. General water quality objectives and criteria are missing which makes it difficult to derive meaningful evaluations for use by decision-makers. The current network has, therefore, limited value for some of the management judgements that are needed for sustainable and cost-effective development of water resources of the country as a whole.

As part of the above activities related to water quality management in Lao PDR, a pollution monitoring program for the Vientiane Integrated Urban Development Project (VIUDP), is also being carried out by STENO. This infrastructure improvement program, starting in 1995 and financed through the Asian Development Bank, will cover a ten year period and has drainage, sanitation and solid waste management components.

There are five water testing laboratories in Vientiane: the MRC laboratory for Mekong water characteristics; two laboratories at the Ministry of Public Health – one at the Drug Quality Control Centre for drinking water and one at the Institute of Hygiene and Epidemiology for pesticide analysis; the Vientiane Water Supply (Nam Papa) laboratory for key chemical parameters only; and the STENO laboratory for domestic waste water. The Ministry of Industry and Handicrafts has no laboratory and uses portable field kits but which can not be used for biological testing.

Within the MRC Agreement on Cooperation for Sustainable Development of the Mekong River Basin and, in particular, on problems of water quality, the Sub-Committee on Rules for water quality was set up to assist the MRC Joint Committee in formulating rules for water quality. These rules are to specify water quality standards, criteria, guidelines and measures to protect the environment, and to establish methodologies and procedures to avoid, minimize and mitigate harmful effects that might result from the use of the water of the Mekong. This Sub-Committee has agreed on the outline of a broad Phase I framework that would: support the existing water quality monitoring network; identify a legal framework to meet urgent needs for water quality and pollution control in the Mekong countries; develop integrated water quality and pollution control standards, criteria and guidelines; and to strengthen human and institutional capacity.

Summary of analysis of development issues in Lao PDR

Table 4 summarizes the poten-tial impact on water quality of land use and development issues on a country-wide basis (Lyngby *et al*. 1997).

The impacts are divided into present and future scenarios. Based on this assessment it is considered that on a national basis the development issues posing the greatest risk for water quality at present and into the future are: (1) fertilizer and pesticide use in agriculture; (2) deforestation causing increased erosion and siltation problems; (3) industrial development, and (4) urban/rural development. Some of these, at present, cause little local impact but have the future potential of impacting on water quality to the extent that there could be restrictions on water use in certain areas.

TABLE 4
Development issues and water quality

LAO PDR	Present	Future
Land Use Issues		
Salinization / salinity intrusion	1	1
Deforestation / Erosion / Siltation	3	2
Development Issues		
Aquaculture	0	2
Industrial Development	0	2
Hydropower	1	1
Solid Waste Disposal	0	1
Mining	2	2
Agriculture: Fertilizer , Pesticides	1	2
Oil and Gas: exploration, exploitation	0	1
Ports and Navigation	0	1
Urban/Rural development	0	2
Pulp and Paper Mills	0	1

Scale of water quality problem: 0 = No problem; 1 = potential; 2 = Moderate; 3 = significant

Additional issues that merit attention, not included in Table 4, are: modification of flow regimes, drainage of wetlands, change in ambient water quality from upstream causes, changes in aquatic ecosystems, increase in surface water area from hydropower reservoirs, human modification of upper parts of catchments, urbanization including rural to urban migration, and mining impacts including use of mercury at local scales for recovery of alluvial gold.

Conclusions

In general, and based on the United Nations GEMS monitoring standards, the water quality of rivers within the Lao PDR and the Mekong is considered to be good. The level of oxygen is high and nutrient concentrations low. Sediment loads in the tributaries vary considerably, from

41 to 345 tonnes/km^2 /yr. Industrial and urban wastewater discharges also meet the standards adopted by neighbouring countries except in a few cases of discharges from garment factories.

Groundwater is emerging as a large and generally untapped resource. Assistance will be required to enable exploitation in a sustainable manner. Activities now ongoing in the southern provinces is a good beginning, however extensive groundwater investigation and hydro-geological mapping is necessary, and should lead to a master plan for groundwater exploitation. Local capacity for appropriate well construction and development is also required.

There is also an urgent need to develop and implement a program of national data standards that will provide reliable data for national policy development, water resources planning and development, decisions on investments, and on regulation and remediation. Water quality and related environmental issues exceed current national capacity to deal knowledgeably with them. Long-term professional assistance is required for supervision of the water quality monitoring program, for technical assistance for laboratories, and for providing basic interpretation, technical support and professional advice to national officials.

References

Lyngby, J.E., Ongley, E.D. and Wilander, A. 1997. *Water Quality Monitoring Network Project Review and Modernization.* Final Report to the Mekong River Commission, Bangkok, Thailand. December.

Water pollution by agriculture, agro-industry and mining In Malaysia

Abstract

Agriculture plays an important role in the economic development of Malaysia even though industrialization has progressed at a fast pace over the last two decades. Various types of agro-chemicals are being widely used to safeguard and increase the yield of the crops. This has resulted in the residues of these chemicals flowing into the natural waterways together with runoff and discharge. However these chemicals are largely undetected as the annual water-quality report on rivers does not record the presence of these chemicals. Land clearing for agriculture purposes, especially on steep slopes, has resulted in increased sedimentation in the river systems. Tin mining operations, which were active until the mid-80's, has been the main cause of sedimentation of the rivers resulting in the deterioration of water quality and frequent flooding. Activities linked to agriculture such as rubber and palm oil processing are generally under control and the pollution of rivers due to the discharge of untreated effluents from the processing factories are rare except for some isolated cases.

Malaysia lies between latitudes 1degree and 7 degrees north and longitudes 100° and 120° east, comprising Peninsula Malaysia, which is south of Thailand, and the two states of Sabah and Sarawak on the Island of Borneo. The country covers a land area of 329 758 km^2 with a population of approximately 20 million (1996). Malaysia lies completely in the equatorial zone. The weather is governed by the regime of northeast monsoon, which blows from October till March, and southwest monsoon blowing from May to September. The average annual rainfall ranges between 2 000 and 2 500 mm. The northeast monsoon, which blows from the South China Sea, brings heavy rainfall to the East Coast of Peninsula Malaysia and the states of Sabah and Sarawak, while the north-western part of Peninsula Malaysia experiences dry spell especially during the months of December and February. In contrast, Malaysia experiences a drier period during the southwest monsoon, especially the East Coast of Peninsula Malaysia.

The climatic conditions observed in Malaysia make the country an ideal place for agriculture. However, due to rapid industrialization over the past two decades, the GDP share attributed to the agricultural sector had declined from 18.7% in 1990 to 13.5 % in 1995. Nevertheless, as a result of the economic crisis that started in July 1997 and the introduction of the National Agricultural Policy (NAP), a greater emphasis has been given to increase food and agricultural production in order to reduce the importation of food items. As such, agriculture still remains an important activity in terms of its contribution towards the economic development of the country. Consequently, it is predicted that agro-chemicals will become more widely used with possible adverse effects to the natural environment, especially in terms of the water quality of the water resources, and ultimately to human health.

YONG Tan Choo

Trans-Perak/Tumboh Blok, Integrated Agricultural Development Project, Malaysia

Besides agricultural activities, the other possible contributors to water pollution are industries related to agriculture such as the processing of palm oil and rubber, tin-mining activity and land clearing for agricultural purposes. However, the main contributors towards pollution in Malaysian rivers are other industrial effluents and domestic sewerage. Out of 116 rivers and distributaries where 892 sampling stations are monitored by the Department of Environment (DOE), 10% of the rivers fall in the very polluted category based on measured values of the Biochemical Oxygen Demand Index, 30% based on values of the Ammoniacal Nitrogen Index and 56% based on values of the Suspended Solid Index.

Water pollution by agriculture

Paddy cultivation

The ideal climatic conditions make paddy cultivation possible throughout the year and double-cropping in areas with adequate water supply. The total paddy area in Malaysia is estimated to be 598 480 hectares of which 379 470 hectares are located in Peninsula Malaysia and the balance in the states of Sabah and Sarawak in East Malaysia. In Peninsula Malaysia, 76% of the paddy area are provided with irrigation facilities while only 15% of the paddy area in East Malaysia are irrigated. The irrigated areas have been classified into major granary areas consisting of 8 schemes with a combined area of 212 500 hectares, 74 secondary granary areas with a total area of 28 440 hectares and 172 minor granaries which are scattered throughout the countries.

Before the introduction of double-cropping, organic fertilizers such as bat guano were widely used by the farmers. As the adoption of modern high yielding rice varieties requires increased fertilizer usage, the farmers were encouraged to apply inorganic fertilizers. Very often some progressive farmers apply more fertilizers in order to increase yield. Most farmers use nitrogenous fertilizers, namely urea as well as urea–based mixtures. As a direct seeding method is widely practiced among the farmers, the plant density is much higher than when the traditional replanting method is used and this results in higher application of fertilizers. When the direct seeding method is used weed control is more difficult. Also a dry direct seeding method results in noxious weed infestation. Herbicides are widely used to control weed infestation so that yield loss is minimized.

The change of cropping intensity from single to double cropping could result in an increased availability of hosts for pest insects and diseases for the rice plants. The change in the cultivation method from transplanting to direct seeding could have led to a modification of field habitats and changes in microclimate which in turn would affect the occurrence of rice pests. For instance the increase in the proportion of direct-seeded fields results in an increase in the proportion of fields infested by weeds, a situation favoring the outbreak of the ear-attacking bug. Various types of insecticides and other agro-chemicals are used to control this problem.

As the water from the paddy fields gets discharged into the drainage system without any treatment, residues of the agro-chemicals applied will definitely pollute the drains as well as the receiving waters. This problem will become more acute if the application of these agro-chemicals is not controlled. However, samples of water taken from strategic locations have been tested and the quality of the water has been found to be consistently good except for some isolated cases with pollution of little impact. But the long term impact on water quality due to the widespread application of these chemicals should not be underestimated. In order to ensure that water quality remains consistently good, Integrated Weed Management (IWM) and

Integrated Pest Management (IPM) are being developed by the department of Agriculture as approaches to minimize the application of agro-chemicals. These programs involve a biological control using selective biological agents that control weeds, insects and pests without affecting the growth of paddy plants. As well they promote an effective application of pesticides, insecticides and herbicides as a mitigating measure to reduce possible adverse effects of using these agro-chemical in rice production. The features of some of these programs are enumerated below.

- The release of barn owls (*Tyto alba)*, which are the natural enemy of rats, by establishing nests around the paddy field as a step to control the rat population and reduce the destruction of paddy crops. Results obtained in IADP Trans-Perak show that the area destroyed by rats had been reduced from 8% in 1988, prior to the release of barn owls, to less than 1% in 1998.
- The rearing of catfish and Muskovi ducks is a measure to control a number of pests and weeds. This program is still at the pilot stage and more data are being collected to assess its effectiveness before management action is taken.
- The installation of ultra-violet lamps to trap black bugs during moonlit nights has significantly reduced the application of chemicals to control this pest as the chemical approach is only used when the out-break is beyond control by this means alone.
- Proper water level management to ensure adequate depth of flooding in the fields at the right time will control the growth of weeds and enhance the effectiveness of any herbicide applications.
- An adequate surveillance and forecasting of pests and diseases is an effective means to counter these problems as control measures can be taken before any out-break occurs.

Even though the quality of drainage water from the paddy fields is generally good, it is inevitable that agro-chemicals will continue to be used especially if there is an outbreak of pest and diseases. Therefore, a comprehensive monitoring system is necessary to check the quality of drainage water and to assess the effectiveness of management actions put in place, such as controlling the use of agro-chemicals by farmers. As part of a project entitled "Study On Modernization Of irrigation Water Management in Granary Areas Of Peninsula Malaysia" and carried out in 1997-98 by the Japan International Cooperation Agency (JICA), it was recommended that permanent monitoring stations be established at major drains and rivers and at pumping stations for the recycling of irrigation water. It was also recommended that water sampling be carried out at least twice a month at each sampling station to obtain representative data for each month. The frequency of the sampling could be adjusted subsequently according to the adequacy of the results and the timing of sampling would be during the agro-chemical application period.

Upland crops cultivation

The conversion of forests for cultivation of upland crops such as vegetables and flowers leads to an increased rate of soil erosion in the watershed area due to the land clearing process involved. For instance, in Cameron Highlands, a region which is in the watershed of some of main rivers in Peninsula Malaysia, the clearing of forests on steep slopes for cultivation of vegetables and flowers has led to widespread soil erosion on the unprotected land surface and resulted in the sedimentation of rivers and a reservoir used for hydroelectric power generation. The sediments were carried further downstream of the river and silted up at a diversion headwork set up for irrigation purposes. As the sediments are also transported into the canal systems, they have to be removed from these canals regularly.

Various types of agro-chemicals are also widely used in the cultivation of upland crops. Monitoring data have shown that some stretches of rivers flowing from the Cameron Highlands are contaminated, with levels of some chemical residues exceeding the acceptable limits set by the European Union. However, as the water reaches further downstream the water quality remains reasonably good after proper treatment for irrigation purposes as well as for domestic and industrial consumption.

Even though the water quality remains reasonably good in spite of sedimentation and excessive application of agro-chemicals in the upstream portion of the rivers, this situation is not expected to continue in the future and mitigation measures must be taken to not only prevent further deterioration of the water quality but also to improve it. To achieve this goal, the clearing of forests for agriculture must be strictly regulated and prohibited on steep slopes. Anti-erosion measures such as the cultivation of cover crops on the cleared surface and the provision of proper drainage systems with silt retention ponds must be taken. With regards to agro-chemicals, only those characterized by low toxicity, low dosage and pest-specificity are to be allowed and the use of those with high potential for leaching through the soil must be restricted or prohibited. The amount of chemical residues allowed to enter any water body has to be controlled by law as such control does not exist at the moment. The Department of Environment is currently reviewing its approach to water quality monitoring of rivers and considering additions to the list of pollutants to be monitored. However, the most effective way to prevent water from being polluted by chemicals is to overcome chemical dependency and promote organic farming. It is a sad fact that this approach is only practiced by a small number of farmers who are environmentally conscious. Therefore various steps have to be taken to reduce the dependency on agro-chemicals and to promote more sustainable and safer methods of food production. In this context, consideration should be given to the following recommendations:

- the government should set up an effective mechanism to control the sale of pesticides, with the long-term view of phasing them out;
- the government should strictly enforce the law that regulates the highly toxic pesticides;
- the Pesticides Board should ban all highly toxic pesticides and control the use of the other pesticides;
- those pesticides banned or severely restricted overseas should be banned or severely restricted as well in Malaysia;
- farmers should be encouraged and guided (and even given incentives) to turn to pesticide-free farming in order to phase out the usage of pesticides;
- subsidies and loans to organic farmers would encourage crop growers to adopt organic farming practices.

Tree crop cultivation

There are more than 5 million hectares of tree crop plantations in Malaysia, mainly comprising rubber and palm oil trees. With the revised National Agricultural Policy's emphasis on increasing food production, more land will be opened up for palm oil cultivation. Any clearing and opening up of new land for agriculture will definitely cause erosion on the land surface and results in sedimentation of the waterways and deterioration of water quality. Soil erosion will also occur when replanting of the tree crops takes place as the land surface will be left barren for a long time after the existing old trees have been cleared. The problem will become more acute on hilly terrain and. To overcome this situation, the barren soil surface must be planted with cover crops. Proper terracing on hilly areas and the construction of proper catch drains leading to silt retention ponds need to be carried out. Water discharging from these retention ponds will carry minimum amounts of silt and thus minimizing the sedimentation and pollution of the receiving waters.

As is the case with the upland crop cultivation, agro-chemicals are widely used in tree crop cultivation. While multinationals in the plantation sector who are conscious about their public image and are carrying out audits to comply with the Pesticide Act, other smaller plantations and small holders may practice widespread misuse of pesticides. Pesticides residues may be flushed away and become diluted during the wet season, a situation that does not happen when there is a low flow during the dry season. Even though most of the pollution in rivers is due mainly to industrial effluents, sewerage and household wastes, agro-chemicals do also contribute even though their residues escape detection under the existing monitoring systems. In order to safeguard the water quality, as the water supply becomes more and more scarce due to an increasing demand, mitigation measures must be applied through both enforcement and education so that the agriculture sector will be reformed and the dependency on agro-chemicals minimized.

WATER POLLUTION BY AGRO-INDUSTRIES

The major agro-industries in Malaysia are those linked with the processing of palm oil and rubber. The palm oil mill generates tremendous amounts of solid biomass consisting of fiber, shell and empty fruit bunch as well as liquid waste which is known as palm oil mill effluent (POME). The fiber and shell waste is used as fuel to generate steam and electricity for the palm oil and palm kernel extraction process in the palm oil mill. POME is treated by biological processes to meet the discharge standard set by the Department of Environment. In the 70's the negative environmental impact of POME had become an issue of much concern to the government and the public. Accordingly, the government acted responsibly by enacting the Environment Quality Act in 1974 and the Environment Quality (Prescribed Premises) (Crude Palm oil) Order 1977 to regulate the discharge of POME. Since then it has been mandatory for all palm oil mills to treat their POME on site to an acceptable level before discharge into receiving waters. A concerted and intensive research and development program had been initiated by the public and private sectors to find a cost-effective solution to minimize the environmental impact associated with the palm oil industry. Research has found that POME contains a very high level of plant nutrients and can be beneficially used as a source of fertilizer. POME recycling through land application will not only eliminate the negative environment impact on the water quality of receiving waters but also reduce fertilizer costs. Land application of POME can be viable only when mills and plantations are located nearby and allow an outlet for the voluminous quantities of POME. For those mills which are far away from plantations, alternative waste recycling or minimization methods must be found. One such method is a zero-waste technology achieved through the application of an evaporation technology which is generally applied to remove water from aqueous solution in a broad range of applications. The water is evaporated, recovered and reused as boiler feed water or process water. This approach would offset or minimize the intake of water from rivers or other sources. The solid concentrate resulting from the evaporation process retains all the nutrients contained in the POME and can be used as fertilizer or animal feed.

Considering the public awareness of the importance of environment conservation, it is envisaged that the discharge standards for the POME will become more and more stringent so that ultimately the contribution of the palm oil industry to water pollution will be eliminated.

Similarly, the rubber processing mills had been the source of pollution to rivers prior to the enactment of the Environment Quality Act in 1974. As the untreated discharge contained chemicals and rubber latex, this produced a pungent smell and contributed to the pollution of receiving waters. However, since the enforcement of legislation, steps have been taken by the mills to minimize pollution by constructing a series of retention ponds to trap the leftover latex that has been washed during processing operations. As an added benefit, the salvaged latex can be used as rubber scrap which has economic value.

Although water pollution due to palm oil and rubber processing is under control, there are still isolated cases of pollution reported and the relevant agencies have to take punitive actions against the culprits.

Water pollution by tin mining

The tin mining activity in Malaysia is a localized one that is confined mainly in the alluvial plains of some valleys and some hilly areas. This activity had been undertaken since the 18th century and remained important until the mid 1980's. Due their nature tin mining operations have been a major source of pollution in rivers, namely through important sediment load discharges in some major rivers. The heavy sediment load in the rivers adjacent to the tin mines is often due to the indiscriminate and illegal discharge of mine effluents that exceeds the permissible limits set under the Mining Rules 1934. With the stricter control introduced under the Mining Rules 1934 and the decline of activity in the tin mining sector the problem of sediment in the rivers is diminishing. However, the former land where mining activities have been carried is left unattended as well as in barren and semi-arid conditions, thus easily exposed to surface erosion and a source of sediment in the rivers. The embankments of the former mining ponds become weak and easily breached as a result of the overtopping of the water retained behind these embankments. As a result, large loads of sediments will be washed into the rivers nearby, the rivers will be badly silted up and large amount of money will be spent to improve these conditions.

With research and studies, the mined-out lands are being put into sustainable and productive use and the problem of sedimentation of rivers can be gradually overcome. The activities include converting the mined-out lands into agricultural lands for planting cash crops; filling up of ponds and building of housing and industrial parks on them; and converting the ponds into recreational parks or as flood and sediment retention ponds.

Conclusions

The problem of water pollution from agriculture can be overcome by having concerted efforts from both the public and private sectors towards reducing the usage of agro-chemicals. Land clearing activities should follow strictly the applicable rules and regulations so that the sedimentation and the deterioration of water quality in the rivers can be minimized or eliminated. The discharge of effluents from agro-based industries should be strictly regulated to prevent the contamination of the water in the nearby rivers.

Agriculture's influence on water quality: case study of Pakistan

Abstract

This paper describes the importance of the impact of agriculture on natural resources, especially on land and water, in the Indus Basin Irrigation System. In this largest contiguous system in the world, 73 percent of the total available water is used for agriculture development. The resulting water-logging and land salinization problems are discussed along with the drainage measures being implemented since 1960 on an area-specific basis under Salinity Control and Reclamation Projects (SCARPs). Experiences of the disposal of drainage effluent and the impact on this practice on the receiving water bodies are described. The overall situation of salt inflow and its distribution within the basin and further mobilization of salts resulting from SCARP's operations are also described. Overall salt balance issues in the basin are highlighted for consideration as part of planning means for ensuring proper water quality management.

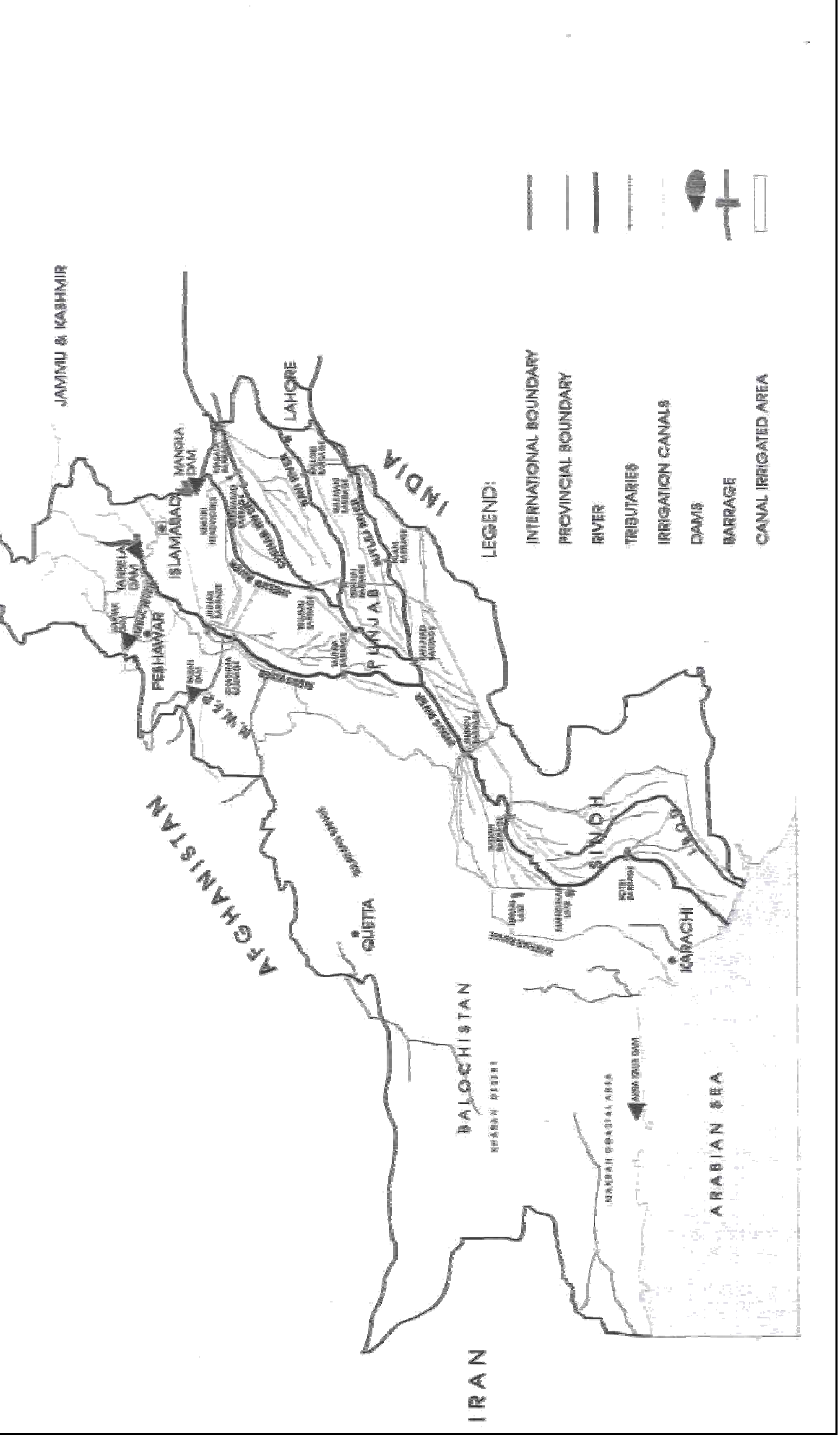
The recent development of the much needed sectoral approach to drainage problems is discussed in the context of the 'Drainage Sector Environmental Assessment Study' which finally culminated in the National Drainage Programme (NDP), under implementation since January 1998. The paper describes the mid-term and long term strategies being adopted under the NDP for the safe disposal of drainage effluent as well as for the mitigation of adverse impacts and the enhancement of positive ones. The legal and institutional frameworks are also discussed.

Agriculture is the main stay of Pakistan's economy and contributes nearly 26 per cent to the Gross Domestic Product (GDP). The Indus River Basin is the focus of the major agricultural activities in Pakistan. The Basin is drained by five rivers, namely, the Ravi, Sutlej, Chenab, Jhelum and the mighty Indus (Figure 1). After the Indus, the Chenab is the second longest river of Pakistan. The Jhelum river joins it from the right, just upstream of the Trimmu Barrage, while the Ravi falls into it from the left, downstream of Trimmu. The Sutlej joins the Chenab from the left upstream of the Panjnad barrage. After collecting waters of three rivers, the Chenab falls into the Indus 85 km upstream of the Guddu barrage and the combined waters of the five rivers travel downstream of the Guddu Barrage for about 745 km before flowing into the Arabian sea. The part of the Indus Basin upstream of Guddu is called the Upper Indus Region while that downstream is called the Lower Indus Region.

Under the Indus Basin Treaty of 1960, the head waters of the two eastern rivers, i.e., Ravi and Sutlej, were allocated to India while the three western rivers, i.e., Chenab, Jhelum and Indus were allocated exclusively to Pakistan. As a consequence of this treaty, an extensive

Bashir Ahmad and Shabaz A. Kazi
National Engineering Service Pakistan (Pvt) Ltd., Lahore, Paistan

FIGURE 1
Indus basin river system



system of storage reservoirs, barrages and inter-river link canals had to be constructed for transferring water from the western rivers to the command areas of the two eastern rivers.

Today the Indus Basin Irrigation System (IBIS) of Pakistan is one of the largest contiguous irrigation system of the world, with two large storage reservoirs, i. e., Tarbela and Mangla, 17 barrages, 8 inter-river link canals and 43 canal commands serving 14 Mha of cultivable commanded area (out of a 16.85 Mha gross commanded area), through an extensive network of main canals, branches, distributaries and minors, measuring over 64,000 km. Nearly 75 percent of the 171.20 km^3 average annual basin inflow is diverted into the canal network for agricultural production, a water resources utilization which is far in excess that encountered in any other country of the Asia and the Pacific region (Ahmad *et al*., 1998). In addition nearly 49 km^3 are pumped annually from an aquifer of about 59 km^3 capacity, in order to augment the supply of irrigation water. In such a large irrigation system with a very high water resource utilization percentage, agriculture has obviously a great influence on the water quality of rivers and other water bodies.

The pollution of rivers and other water bodies resulting from agricultural activities relates mainly to an increase in salinity resulting from the disposal of agriculture drainage effluents into the water bodies, to the leaching of agro-chemical (pesticides, insecticides and fertilizers) residues into groundwater as well as their contamination of surface water, and to the disposal of agro-industry effluents into the water bodies.

The main agro-industries in Pakistan are mostly located within certain industrial sectors along with other types of industries. Because the wastes from all types of industries are discharged jointly into the existing surface drains or natural waterways leading to the rivers, it has not been possible so far to estimate separately the contribution of agro-industries to the water pollution observed.

The monitoring of the impact of agro-chemical residues has been done only sporadically in Pakistan. A comprehensive country-wide study is not yet available, although there is an urgent need to address the issue because the use of agro-chemicals has increased many folds during the past 20 years. Under the Pakistan Drainage Sector Environmental Assessment (NESPAK and MMI, 1993), a study was carried out on a limited scale in a cotton-growing area where the use of agro-chemicals is most intensive. This study indicated the presence of pesticide and fertilizer residues in groundwater and soils as well as in the surface drains.

As Pakistan has been continuously combating with the double menace of water-logging and salinity over the last 40 years, vast experience has been gained on the control measures as well as on the provision of agriculture drainage facilities, the disposal of drainage effluent and the effect of effluent disposal on the receiving water bodies. This paper mainly presents the findings on these aspects.

Key issues

General

Extensive irrigation for more than a century had caused high water table conditions in nearly 38% of the area Upper Indus Region by the late 1950's rendering 7% of the lands severely saline and 22% moderately saline. In the Lower Indus Region, the high water table occurred in 37% of the area, with severe surface salinity in 32.5 % of the area and moderate salinity in another 56%.

Under the Salinity Control and Reclamation Projects (SCARP's) initiated in 1960, the strategy of obtaining drainage as a by-product of tubewell irrigation from fresh groundwater (FGW) areas was adopted, which was to be followed by pumping out and disposing of saline effluent from saline groundwater (SGW) areas through surface drains into existing water bodies, evaporation ponds and the Arabian Sea.

Under the SCARP's, surface and sub-surface drainage facilities had been completed in a 5.85 Mha area (2.95 Mha in FGW areas and 2.90 Mha in SGW areas) by 1992 and work on another 2.2 Mha area was continuing. At this stage, it was felt that more attention needed to be given to the impact of drainage operations on human health and on natural resources and that, instead of area-specific projects, a sectoral approach to drainage was required. It was in this perspective that the Pakistan Drainage Sector Environmental Assessment Study (NESPAK and MMI, 1993) was carried out in 1993 with assistance from the World Bank. The study ultimately culminated in the National Drainage Program (NDP), currently under implementation since January 1998. The impact of agriculture on water quality is one of the major concerns of the NDP and the safe disposal of the agricultural drainage effluent is a pre-requisite for eligibility to financing under the NDP.

Presently, under the SCARP's, 10.3 km^3 of effluent are being re-used in FGW areas, 2.4 km^3 are being recycled after mixing with surface water (46% through canals, 54% through rivers) and 0.31 km^3 is being drained into existing lakes. Plans also include the disposal of another 0.61 km^3 into evaporation ponds and 1.12 km^3 into the Arabian Sea through the Left Bank Outfall Drain (LBOD) which drains about a 728,800 ha area on the left bank of the Indus in the Lower Indus Region. The envisaged long term solution is the northward extension and enlargement of the LBOD for taking all the drainage effluent from the southern part of Upper Indus Region to the sea as well, provided the technical and economic feasibility of the solution can be demonstrated.

Salt balance issues

Besides the solution to the immediate problem of the removal of excess soil moisture from the root zone and its safe disposal, the long term issues of salt balance at the basin level also need to be addressed for understanding the impact of agriculture on water quality and for finding the ultimate solution.

<u>Salt Inflow and Distribution:</u> It has been estimated that the rivers and their tributaries bring about 33 Mt of salts into the basin annually of which 24 Mt remain within the basin, namely 13.6 Mt in the Upper Indus Region (mainly in Punjab) and 10.4 Mt in the Lower Indus Region (Sindh and Balochistan). In Punjab, nearly 75% of the incoming salt end up into the FGW zone, whereas nearly the same amount in Sindh goes to SGW zones.

<u>Mobilization of Salts by Tubewell Drainage</u>: In Punjab and Sindh, 24.7 Mt and 3.5 Mt of salts are being mobilized respectively every year by drainage in FGW zones. The annual application of these salts along with those brought in by canal water in FGW areas, has risen over the years from 1.58 to 4.90 t/ha in Punjab and from 2.32 to 4.32 t/ha in Sindh. Partial retention in the soil is causing salt accumulation in FGW areas.

In SGW areas, drainage water is drained out of the area. The salt balance in these areas is therefore improving and the water table needs to be kept sufficiently lower to stop upward movement of salts to the soil.

Effect on FGW Quality: In a study carried out by the Environment Department of the World Bank (Ahmed *et al*., 1991), salt build-up in FGW and SGW areas was predicted with only a nominal rate of salinity increase. Accordingly, it was concluded that by disposing of about 10 percent of drainage effluent from FGW areas, the FGW quality could be managed properly.

Although the long-term prediction of salt balance is difficult, a preliminary study indicated the tendency of the system towards a balance, suggesting that the situation may not be equally detrimental at all places. However, the Pakistan Drainage Sector Environmental Assessment Study recommends soil salinity surveys every ten years to monitor the situation and to provide remedial measures.

Drainage effluent disposal issues

The disposal of drainage effluent, particularly the saline one, is an issue of critical importance in Pakistan. The various options available for the disposal of agricultural effluent include disposal into rivers, sea, lakes and evaporation ponds, and mixing with irrigation water. The major disposal of agricultural effluent is being done into the Indus River and its tributaries and into the Arabian Sea. Although few monitoring programmes exist as part of some projects, no regular water quality monitoring of agricultural effluent is being carried out in Pakistan. A monitoring programme in the Lower Indus Right Bank Irrigation and Drainage Project in Sindh is being carried out to check the quality of the effluent and the environmentally safe disposal of the influent into the Indus River. A potential negative environmental impact has been identified for the storage of drainage water from deep saline aquifers into evaporation ponds, as in the project SCARP-VI, and such disposal may be considered only as a temporary solution. Drainage effluent with low salinity may be disposed of into lakes or evaporation ponds and can also be mixed with irrigation water for recycling but close monitoring of water quality in such cases is very important.

Effect of drainage disposal on water quality

Current disposal arrangements, their effect on the system and related problems are described briefly in the following sections.

Effluent disposal from Upper Indus Region

The Upper Indus Region comprises the North West Frontier Province (NWFP) and the Punjab Province. The NWFP terrain is generally sub-mountainous, with good land drainage and the drainage effluent issue is one that applies only to a limited agricultural area. In the Punjab plains, however, due to the gradually flattening topography, drainage problems increase as one proceeds southwards. The effects of agricultural drainage on water quality in the two provinces are discussed in the following sections.

Effluent Disposal from NWFP: The Indus river provides the drainage outlet for irrigated areas of the North West Frontier Province, either directly or through its tributary the Kabul river. Groundwater in all the projects considered is usable and therefore can be mostly re-used. The input of drainage effluent into the river comes from the Mardan and Swabi tile drainage projects and the river water quality has not been found to be adversely affected. Drainage facilities have also been provided in the Chashma Right Bank command area. A sub-surface drainage system has been provided to intercept seepage water mainly from the surface irrigation and from the Paharpur and Chashma Right Bank Canals. As for the quality of groundwater, it is considered

TABLE 1
Disposal of saline effluent in the Punjab area

Projects Status	Total Quantity (km^3)	Destination of Disposal (km^3)		
		Canals	River	Ponds
Completed	1.88	0.48	0.79	0.61
On-going/new	1.75	0.26	0.73	0.76
Total	3.63	0.74	1.52	1.37

mostly suitable for irrigation purposes judging from the parameters measured in samples collected during a study in 1995 (Gazette of Pakistan Extra, 1997), namely total dissolved solids (TDS) ranging from 232 to 1240 ppm and sodium adsorption ratios (SAR) ranging from 0.6 to 7. Therefore any disposal into the river does not affect its quality.

Effluent Disposal from Punjab: Except for the areas on the right bank of the Indus in NWFP, as mentioned above, the drainage outlet for the Upper Indus Region is only through Panjnad. Due to extensive irrigation use in Punjab, effluent disposal into rivers from drainage projects is mainly recycled within the existing areas irrigated by canals.

The total saline effluent from the entire irrigated area of Punjab in need of sub-surface drainage is estimated as 3.63 km^3 and Table 1 shows the distribution of this volume among the various disposal routes.

Effect of Drainage Disposal on River Water Quality: As the western rivers have to share their waters with the eastern rivers through the link canals in Punjab, water availability in rivers is at a bare minimum for meeting the command area requirement, especially in low flow season. The drainage effluent from agricultural sources discharging into the rivers gets mixed with the river flow and the mixed flow is again diverted to the downstream irrigation systems. Thus the drainage effluent is also being fully recycled into the system and during the low flow period, there is virtually no flow below Panjnad, the most downstream barrage of the province. Worst hit are the eastern rivers which do not have their own water and as such their assimilative capacity is quite limited.

Regular water quality monitoring is not being carried out at all barrage sites on the rivers of Pakistan. Under the Drainage Sector Environmental Assessment, a study was carried out to estimate the effect of saline drainage disposals from various projects on water quality of the rivers at various barrages in the Upper Indus Region, taking a salinity value of 160 ppm as the freshwater bench mark. The results on the water quality at selected barrages are presented in Table 2 in terms of salinity values.

The data Table 2 provide the evidence of a progressive deterioration of water quality in rivers as one proceeds downstream, with the maximum salinity values observed at the confluence of the Chenab and Ravi rivers. There is a slight improvement in water quality further downstream at Panjnad, partly because of self-purification along the river length and partly because of some additional inflow from the Sutlej river. The salinity value of the Indus river at Guddu, however, is in the range of the freshwater benchmark in spite of a considerable saline contribution from Panjnad and the situation is mainly due to mixing with the substantial flow of the Indus itself.

The deteriorating water quality situation in Punjab calls for urgent safeguard measures for preventing further degradation, lest the river water quality falls below the international standards for irrigation and drinking water uses.

Effect of Drainage Disposal into Ponds: Under the project SCARP-VI in the Panjnad-Abbasia canal command in southern Punjab, the drainage water is being disposed of into a pond area covering 13,360 ha of low lying interconnected interdunal flat valleys, surrounded by sand dunes. The valley floors include those with highly sodic clays which do not support any vegetation and have low permeability; those having loamy soils support shrub vegetation and have moderate permeability.

Current plans are to ultimately drain nearly 0.61 km^3 of saline (21 000 ppm) effluent per year into these ponds. Over a 2-year period of operations, the saline effluent has reportedly spread over an area of 4 455 ha, with an average depth of 1.5 to 2.5 m. The rapid rise of the water table adversely affected with salinity nearly 800 ha area of adjoining irrigated areas. The use of evaporation ponds for drainage effluent disposal is very recent and its environmental impact needs to be monitored carefully. The observed or anticipated adverse effects of this practice are:

- waterlogging and salinization of adjoining irrigated areas;
- the temporary nature of the arrangement, as the storage capacity is expected to become depleted due the deposition of salts and wind-blown sand;
- the hazards of salt-dust spray from the pond areas to the adjoining irrigated areas during the dry and windy season;
- the elimination of the natural vegetation in valleys and dependent fauna from the pond area after submergence.

TABLE 2
Salinity values at selected barrages in Upper Indus Region, 1985-86 (ppm)

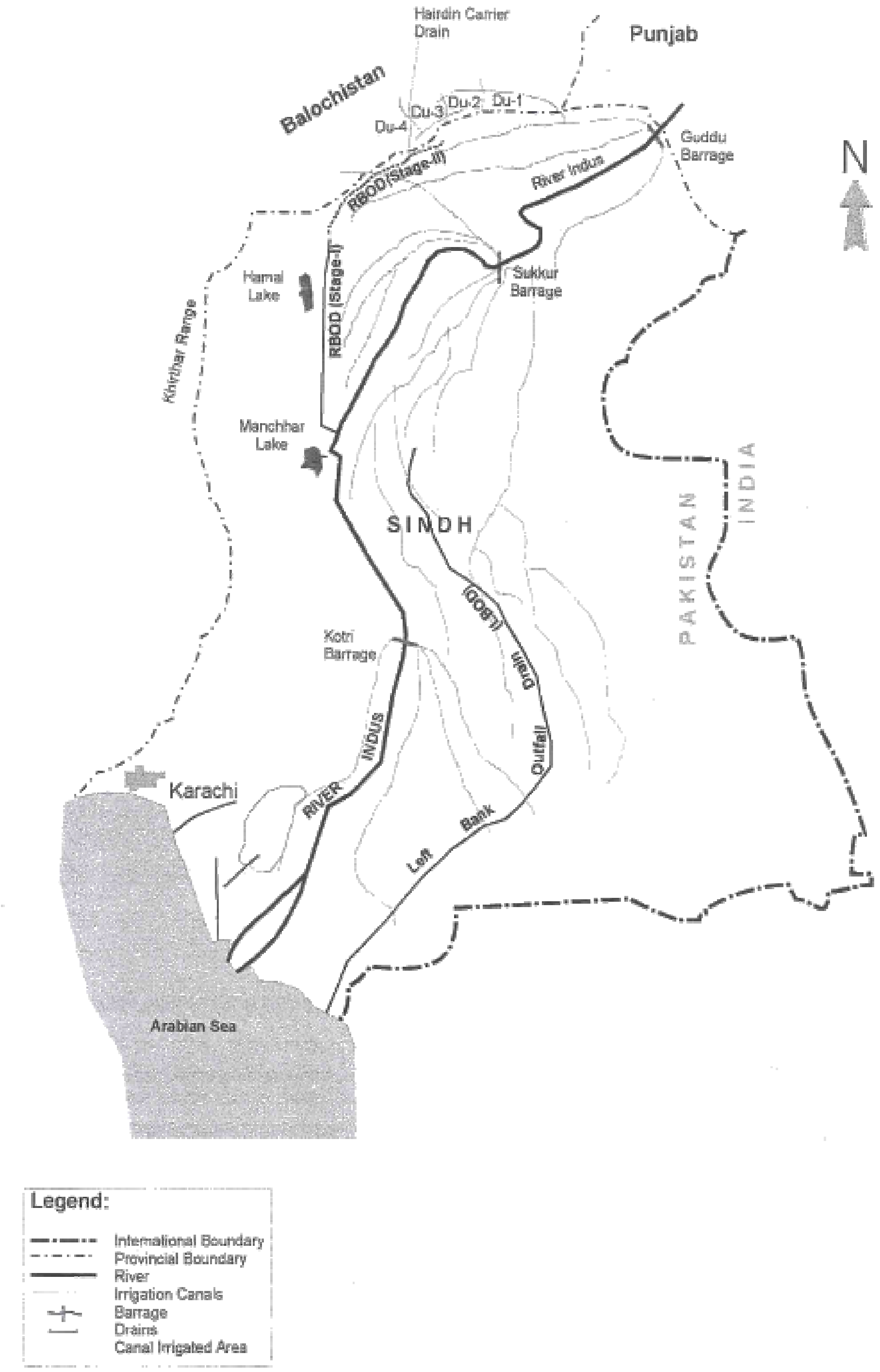
Period	Chenab at Trimmu	Ravi at Sidhnai	Confluence Chenab & Ravi	Chenab at Panjnad	Indus at Guddu
April	437	551	815	805	187
	434	508	813	746	183
	435	538	835	762	184
May	455	535	821	879	175
	505	613	904	602	171
	511	552	906	681	170
June	425	438	805	476	166
	394	415	777	386	164
	396	434	699	377	164
July	393	431	777	526	164
	245	283	261	377	172
	203	192	208	209	185
August	203	187	207	209	176
	217	183	219	214	181
	284	226	288	273	177
Sep	385	351	449	314	171
	392	391	576	335	167
	390	401	610	364	165
Oct	388	409	623	325	165
	397	301	391	404	180
	435	430	721	374	167
Nov	417	456	527	407	168
	417	492	529	478	169
	383	432	459	591	170
Dec	410	469	487	395	170
	430	516	516	453	170
	400	476	430	845	171
Jan	386	354	427	424	230
	390	242	385	511	267
	423	226	367	445	229
Feb	441	566	498	467	182
	413	436	461	509	167
	432	501	490	772	167
March	495	128	605	603	169
	388	316	414	1074	169
	333	229	317	685	167

Source: Pakistan Drainage Sector Environmental Assessment, National Drainage Programme, Main Report, Vol. I (1993).

Some of the positive impacts of evaporation ponds are:

- the creation of a new wetland for fish and other waterfowls;
- a humidity increase in the area which may favor the establishment of new fauna and flora;
- the stabilization of sand dunes

FIGURE 2
Lower Indus region



In addition to the SCARP-VI area, evaporation ponds are also planned for disposal of agricultural drainage effluent from the SCARP-VIII area, which covers the command of the Fordwah and Eastern Sadiqia canals in southern Punjab and where similar effects may occur.

As already mentioned, evaporation ponds are being planned only as temporary disposal arrangements. The long term plan is to extend the existing LBOD upwards to accommodate saline effluents from the SCARP-VI and SCARP-VIII areas for ultimate disposal into the Arabian sea. The implementation of this approach, however, is still subject to a demonstration of its economic viability.

Effluent Disposal from Lower Indus Region

The Lower Indus Region comprises the following three major drainage sub-basins as shown in Figure 2, namely: the Left Bank commands of the Guddu and Sukkur Barrages; the Right Bank commands of the Guddu & Sukkur Barrages; and the Kotri Command.

Out of the three areas, the Left Bank command area is already being drained into the Arabian sea through the Left Bank Outfall Drain (LBOD), which carries nearly 1.2 km^3 of drainage effluent annually with a salinity of around 20,000 ppm. The Kotri command is also draining directly into the sea. The drainage effluent from the Right Bank command area, however, is being partially re-cycled into the irrigation system while some areas are being drained into the Manchhar and Hamal Lakes, two freshwater lakes of immense environmental importance.

Effect of Drainage into Natural Lakes: A water quality monitoring programme is being carried out under the on-going Lower Indus Right Bank Irrigation and Drainage Project (LIRBP) Stage-I to obtain the baseline data for the drains, the lakes and the Indus river. Presently 0.124 km^3 of agriculture drainage effluent from the Larkana-Shikarpur drainage unit is being discharged into Hamal lake. Through a statistical analysis of the salinity data observed over the period 1994-98, a median salinity value of 2,104 ppm has been determined for Hamal lake.

From the North Dadu drainage unit, 0.174 km^3 of drainage discharge is going into Manchhar lake through the Main Nara Valley Drain, which was originally meant to be a natural water way connecting the two freshwater lakes. Through a statistical analysis of the salinity data observed over the period 1994-98, a median salinity value of 1,600 ppm has been determined for Manchhar lake. Although the agriculture drainage effluent emanating from the rice cultivation area is not highly saline, continuous disposal over the years has caused considerable degradation of the water quality in the two lakes, thus endangering the natural ecosystems. The degradation problem becomes more important during relatively dry years when there is little flow from the hill torrents feeding the lakes.

Future Disposal Plans: According to the Right Bank Master Plan (Mott MacDonald International Limited *et al*., 1991), the agriculture drainage effluent from a number of drainage units in the Right Bank command of the Guddu and Sukkur Barrages is proposed for re-cycling by disposal into the canal system while that from the remaining units will be discharged into the Indus river through the Right Bank Outfall Drain (RBOD). Drainage development in the area has been proposed in four stages going almost up to end of 14th Five Year Plan of Pakistan, i.e., up to the year 2028. Details on the drainage area covered in the various stages and the planned disposal are provided in Table 3.

The effluent ending up into the RBOD consists mostly of the excess irrigation water drained from the rice fields. The rice irrigation practices in the area are to fill the soil profile up to the water table and then to periodically replace this water. As such, the salinity of this effluent cannot be very high. Generally, during the first month or so, the effluent is slightly more saline as it carries the salts built up in the soils during the preceding “Rabi” season through evaporation. Subsequently, the effluent is less saline.

In the first stage of the RBOD project, which is already under implementation, the existing MNVD is being extended northwards to the point where it can take the discharge from the Larkana-Shikarpur drainage unit (Figure 2). On the southern side, it is being diverted from Manchhar lake towards the Indus river through a 65 m^3/sec capacity outfall drain called the Indus Link. In its next stage, the drain will be extended further upwards to accommodate the discharge from the Hairdin drain in Balochistan. Under the current design, the ultimate discharge of the RBOD at the fourth stage is estimated to be about 200 m^3/sec.

TABLE 3
Overview of future drainage development

Stage	**Cumulative Area Drained** (ha)	**Area to be drained into** (ha)	
		Indus River	**Canals**
I	866 061	367 919	498 142
II	1 123 225	593 341	529 884
III	1 357 921	828 037	529 884
IV	1 817 318	1 287 434*	529 884

* 62 760 ha from Pat Extension to go into evaporation pond.

<u>Effects of Effluent Disposal on Indus River</u>: Under the Right Bank Master Plan, an evaluation of the effect of Right Bank Outfall drain (RBOD) discharges on the water quality of the Indus river has led to the conclusion that the mixed water salinity of the river will not exceed 581 ppm for 1 in 10 years low flow at Kotri and not beyond 746 ppm for 1 in 25 years low flow for all the four project stages. The evaluation data have been summarized in Table 4.

Regular monitoring of the river salinity was recommended and the possibility of taking 28 to 56 m^3/s across the Indus River to LBOD through a siphon for ultimate disposal into the sea was also suggested if the monitoring results showed the salinity to be exceeding safe limits.

In view of the concerns of the Provincial Government and the people of Sindh, the Federal Government authorized a study to be carried out by an International Panel of Experts (POE) in 1996 (Bishay *et al*., 1996) to assess for all the four stages of the project the impact of the disposal of drainage effluent on the water quality of the Indus River at Kotri, the most downstream barrage on the Indus. By using the water quality data collected from twenty sites in the project area over two years under the on-going monitoring programme, the salinity of the mixed water

TABLE 4
Impact of the Right Bank Outfall drain (RBOD) discharges on the water quality of the Indus River at Kotri

	Salinity (ppm)											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1:25 Year low flow at Kotri												
Existing	269	284	332	350	341	279	230	217	228	246	270	283
Stage-I RBOD	287	284	332	369	372	317	263	249	285	366	278	382
Stage-II RBOD	289	284	332	371	389	345	289	272	329	460	374	395
Stage-III RBOD	289	284	332	371	391	350	299	286	352	497	407	395
Stage-IV RBOD (Total Flow)	303	284	332	371	519	354	330	350	450	746	585	415
28 m^3/s to LBOD	286	284	332	350	341	302	298	334	420	598	270	283
56 m^3/s to LBOD	286	284	332	350	341	279	265	318	289	417	270	283
1:10 Year low flow at Kotri												
Existing	296	272	316	335	320	260	217	208	218	231	253	268
Stage-I RBOD	270	272	316	342	339	294	233	233	263	309	258	355
Stage-II RBOD	271	272	316	342	348	320	246	251	299	374	316	367
Stage-III RBOD	272	272	316	342	350	323	251	262	318	401	336	367
Stage-IV RBOD (Total Flow)	284	272	316	342	426	327	267	312	399	581	452	385
28 m^3/s to LBOD	269	272	316	335	320	280	251	300	374	470	253	268
56 m^3/s to LBOD	269	272	316	335	320	260	234	287	348	343	253	268

Source: Right Bank Master Plan (RBMP) Pakistan

TABLE 5
Salinity of the mixed water at Kotri

Month		Salinity (ppm)			
		Stage I	Stage I +II	Stage I+II+III	Stage I+II+III+IV
1	January	282	288	294	307
2	February	314	326	326	346
3	March	294	307	314	326
4	April	262	269	269	275
5	May	256	269	275	301
6	June	166	173	173	173
7	July	166	173	173	179
8	August	230	237	237	237
9	September	256	256	262	288
10	October	435	493	518	589
11	November	422	474	493	563
12	December	358	397	416	480

was calculated by the POE for various stages of the project throughout the year. At the fourth stage of the project, a maximum salinity of 589 ppm was predicted to occur in October as shown in Table 5.

According to the conclusions of the studies available so far, the discharge of agriculture drainage effluent from the Right Bank commands of the Guddu and Sukkur Barrages into the Indus river is not expected to have any adverse environmental effect. Nevertheless, regular monitoring of water quality at 20 critical points in the system is continuing to ensure that the water quality of the river does not suffer with the disposal of RBOD water into it.

Effluent disposal from Balochistan

The Pat Feeder canal command has been divided into four drainage units (Du-1, -2, -3 and -4) in the Right Bank Master Plan (RBMP) for drainage purposes (Figure 2). Du-1 represents the present Hairdin project which drains into a pond from where the effluent is pumped into the Kirther canal. It has been proposed that the RBOD in stage-II (2008) be extended to provide an outlet for drainage units 1 to 3, whereas unit 4 is to drain into an evaporation pond to be created for this purpose.

The Pat Feeder canal project is in progress and delaying its drainage until an extension of the RBOD is not desirable. Besides the drainage of Du-2 and -3 into the RBOD against the natural slope may be difficult. The alternative available is to construct the Carrier drain-2 along the right bank of the Kirther canal and dispose of it into the main Nara river channel. The ultimate destination of part of this effluent is expected to be the Hamal lake and through it to the RBOD.

Hamal lake currently receives the effluent from the Mirokhan and Shadadkot drains of the Larkana Shikarpur Project, an effluent whose salinity varies from 1000 to 4000 ppm. But these drains are to be connected to the RBOD under the on-going LIRB project - Stage I. The salinity of the effluent from the Pat Feeder drainage units is expected to be less than 3000 ppm, as it would only be the drainage from the rice cultivation areas. In addition, the effluent is likely to be diluted on its way by water from numerous natural streams and it is not expected to harm the water quality of the Hamal lake.

SAFEGUARDS AGAINST WATER QUALITY DEGRADATION UNDER NDP

As discussed in the preceding sections, there is ample evidence of the need for an effective and efficient drainage system to sustain environmentally-sound irrigated agriculture. This need has provided the impetus for the National Drainage Programme which is currently under implementation and provides a sectoral approach to the issues of irrigation and drainage. The Programme has the following four components: sector planning and research; institutional reforms; drainage investment components; and programme coordination and supervision.

The programme sub-components which are specifically related to improvement of water quality in rivers cover the following topics:

- national water policy;
- national surface drainage system;
- Balochistan effluent disposal;
- wetlands management plan;
- flood protection and drainage of the Peshawar Valley;
- exploitation and regulation of groundwater;
- institutionalized environmental monitoring of land and water conditions;
- protection of drainage water from pollution by municipal effluent;
- reduction of drainable surplus by biological control.

The programme includes the formulation of a National Water Policy and it also specifies the preparation of Environmental Impact Assessment (EIA) reports as a pre-requisite for the implementation of any proposed water resources project. Wetlands management is also one of the important aspects of the NDP. Under the NDP, it is proposed to drain the riverine areas, lakes and flood plains after preparing full EIAs and in accordance with Pakistan's Environmental Protection Laws.

The programme specifies that only those schemes or projects which meet the NDP selection criteria would be implemented. One of the most important features of the criteria is that an Initial Environmental Scoping (IES), and/or Environmental Impact Assessment (EIA) as necessary, has to be carried out before the implementation of any project, thus ensuring the environmentally safe disposal of drainage effluents. The criteria also require that a project should have a net positive environmental impact on rural areas. In particular case, a project should not be located in an area where an excessive irrigation water supply has caused water-logging, unless a plan has been prepared demonstrating that measures would be taken to reduce the excess supply. Hence, the excess drainage effluent would be reduced and the projects would have lesser impact on the water quality of the receiving waters and the quality of the land would also improve. It is also planned under the NDP that only those projects which have a safe outfall facility would be implemented. Also, only those projects in which the highly sodic soil portion does not cover more than 15 percent of the area would be implemented under the NDP. Again, this approach is meant to prevent excessive degradation of the water quality of the receiving waters. As well projects involving the draining of wetlands would not be allowed. The NDP is spread over eight years and is expected to gradually bring about an improvement in the water quality by controlling the agricultural sources of pollution.

Institutional, legal and social frameworks

Institutional Framework

Water quality management of rivers in Pakistan is undertaken in the context of water resources and environmental management, as both aspects have bearings on the water quality of the rivers. The institutional arrangements for these two aspects are described in the following paragraphs.

Water Resources Management: The overall responsibility for establishing policies and plans regarding water resources management lies with the Ministry of Water and Power (MoWP) at the federal level. The Water and Power Development Authority (WAPDA) serves within the ministry as the executive agency and the custodian of national water resources, in accordance with the provisions of the WAPDA Act (1958).

After completing the development projects, WAPDA hands them over to the Provincial Irrigation Departments (PID's) for operation and maintenance. However WAPDA remains responsible for the operation and maintenance of two major storage reservoirs at Tarbela and Mangla and for releasing water from them for irrigation and power generation. Recently the PID's have been converted into the Provincial Irrigation and Drainage Authorities (PIDA's) through the Provincial Irrigation and Drainage Authority Act (1997), which requires them to operate and maintain the irrigation and drainage systems and flood protection works in the provinces through the formation of Area Water Boards (AWBs) around canal commands.

In the new framework, WAPDA and the PIDA's would prepare EIA's for the projects proposed as part of the NDP. The EIA's would be submitted by provincial NDP cells for approval by the respective Environmental Protection Agency (EPA). Provincial EPA's, in collaboration with the WAPDA's Environmental Cell and Provincial NDP cells, would arrange for public consultations in coordination with EPA's, Non-Governmental Organizations and other relevant organizations. Environmental Management Committees (EMC's) would be established for those projects requiring mitigating measures.

Environmental Management: Pakistan became conscious of environmental concerns in the early 1970's. The 1973 Constitution of Pakistan defined the federal and concurrent legislative lists in which the terms "Environmental Pollution and Ecology" was included for the first time. It was following the UN Conference on Human Environment in Stockholm that the Government of Pakistan, realising the seriousness of the emerging problems of environmental degradation, established in 1974 the Environment and Urban Affairs Division (EUAD) within the Ministry of Housing and Works. The Division was given the responsibility for the formulation of a national environmental policy and for the administration of national environmental impact assessment procedures, which it mainly undertakes through a limited review of federal projects.

In 1983, the Pakistan Environmental Protection Ordinance was promulgated, followed by the creation at the federal level of the Pakistan Environmental Protection Council (PEPC) consisting of the President, various federal and provincial ministers and selected environmental experts. The Pakistan Environment Protection Agency (PEPA) was also established in the same year. Among the provinces, Punjab was the first one to establish its EPA in 1987, followed by the other three provinces. One main activity of these EPA's is to create public awareness through printed and electronic media, holding meetings, lectures and seminars, and distributing literature. Other responsibilities include collecting industrial effluent data, sampling and analysis of waste streams, issuing No Objection Certificates (NOC) for industrial discharge, and training of the staff for the successful implementation of the Environmental Protection Ordinance.

In 1988, a Minister of State for Environment was appointed and since then the EUAD is reporting to him. The National Conservation Strategy (NCS) was prepared by the EUAD in 1992, in collaboration with the International Union for Conservation of Nature (IUCN), which provided a detailed analysis of environmental problems and a broad strategy for tackling them. In keeping with the policy guidelines and the action plans developed under the NCS, the National Environmental Quality Standards (NEQS) were formulated and officially notified in 1993 to be made effective from July 1, 1994 for the new industrial units and from July 1, 1996 for the existing ones. Since the NCS programme also covers water resources management and, by extension, water quality of rivers, it includes the protection of watersheds, supporting forestry and plantations, restoring rangelands and maintaining soils in crop lands. The eigth five-year plan currently being implemented incorporates most of these aspects in various projects. As part of the implementation of the NCS, The Ravi and Kabul rivers have been the subject of studies on pollution and monitoring surveys carried out in 1997 (OPCV-NESPAK, 1997).

In 1995, the Punjab EPA was given the status of an independent 'Department' and it is now called the Punjab Environmental Protection Department (PEPD). Similar to the council at the federal level, the Environmental Protection Council, Punjab (EPCP) was created in 1996 and given the responsibility for policy formulation, integration of environmental considerations into provincial development plans, and coordination with other agencies, groups or persons to ensure the enforcement of the Environmental Protection Act. The implementation of this approach in the other three provinces is being contemplated.

Legal framework

The legal framework available for the protection of water quality in Pakistan is quite new. The Constitution of the Islamic Republic of Pakistan (1973) provides concurrent legislative power to the Federation and the Provinces in the areas of environmental pollution and ecology.

The cornerstone of environmental legislation is the new Pakistan Environmental Protection Act (1997) which has superseded the Pakistan Environmental Protection Ordinance promulgated in 1983. Although this law is the main federal environmental legislation, other laws also deal with environmental issues.

The new Act delegates powers to the concerned federal and provincial agencies to take action against environmental pollution throughout the country and it provides the legal framework to cover air, water, soil, marine and noise pollution, waste disposal and the handling of hazardous substances, and the conservation of biodiversity. The Provincial Environmental Protection Agencies/Department have been given enhanced statutory status.

The National Environmental Quality Standards (NEQS) have also been drafted and are enforced since 1997 as part of the Pakistan Environmental Protection Act (1997). Discharges or emissions in excess of the NEQS or other standards established by the Pakistan Environmental Protection Agency where ambient conditions so require, have been prohibited. The Federal Government has been empowered to levy a pollution charge on anyone not complying with the NEQS. A two-stage environmental screening process has been introduced for proposed projects involving the filing of either an Initial Environmental Examination or, for projects likely to cause an adverse environmental effect, a comprehensive Environmental Impact Assessment.

Social framework

The social framework for environmental protection currently places the Pakistani people at the cognition stage, where they are becoming familiarized with the concept of environment and its protection, through the vigorous media campaigns launched by the government from time to time. Further endeavors for community organization and mobilization through the fostering of public advocacy groups and environmental NGO's and Community Based Organizations (CBO's) would steer the path towards bringing about attitudinal and behavioral changes amongst the communities. Once the common people feel responsible for the protection of their environment, at the individual and the community level, the social framework could be considered adequate.

The role of NGO's and CBO's in the irrigation and drainage sector would be expanded during the implementation of the NDP. For new projects, provincial EPA's, in collaboration with WAPDA's Environmental Cell and provincial NDP Cells, would arrange public consultation meetings in coordination with NGO's and other relevant organization to ensure the environmental viability of a project.

Under the new institutional arrangement and as a result of the establishment of PIDA's, public participation has gained support through the proposed creation of Farmers' Organizations (FO's). The Farmers' Organizations would comprise local inhabitants and they would make sure that IES or EIA's, as required, are conducted. It is also proposed in the NDP that the concerned PIDA, AWB or FO would establish Community Advisory Committees (CAC's) on various issues which require the local knowledge, advisory input and active participation of NGO's, farmers' associations, local community leaders and other stakeholders to help them manage land acquisition, environmental and other issues.

A large number of local environmental NGO's, with support from Provincial EPA's/EPD, are active in various cities, small towns and villages in all provinces of Pakistan and some of them have the support of important international NGO's such as the IUCN and the WWF. An important task for these groups is to develop programmes for raising the public awareness about the significance of environmental protection and pollution abatement through adoption of good environmental practices. In addition, the support of the community can be achieved by creating public awareness and mobilizing the community into stronger public advocacy.

The Punjab EPD initiated a community based Public Education and Awareness Project in 1991. The project had several components, including the publication and distribution of pamphlets, posters, stickers, etc., arranging workshops and seminars through public consultation practices, exposure in the media for environmental issues through radio and TV talk-shows, print-media advertising, etc., and deliberations with media, industry, NGO's, educational and public organizations, and the general public.

The capability for designing and implementing a community organization or mobilization programme also needs to be developed in the current setup. Progress in this area requires urgently the involvement of personnel with an academic social sciences background, in addition to the people already employed in public sector with technical expertise in areas such as engineering or other sciences,.

The educational institutions and NGO's, with the assistance of EPA's/EPD, have managed to establish a number of environmental clubs in educational institutions and they have also developed reference books on environmental education for teachers as part of efforts to change the curriculum in the current educational syllabus. Various NGO's along with EPA's/EPD have also conducted, through different media under externally funded aid, a number of programmes pertaining to public awareness about the environment.

Various NGO's and CBO's have also kept alive the issue of disposal of agricultural effluent of the right bank of the lower Indus basin and have managed to investigate the impact of the effluent on the Indus River and other water bodies. Under their pressure, the proponents of the drainage project have carried out various studies, with the collaboration of local and foreign experts, to determine the impact of drainage effluent on receiving waters and decide on the best available option.

CONCLUSIONS

The need for an effective and efficient drainage system to sustain environmentally-sound irrigated agriculture has been greatly felt in last few years. A sectoral approach to the issues of irrigation and drainage was missing in the planning and development of water resources projects. These factors led to emergence of the NDP, which is being implemented now.

A National Water policy is also non-existent in Pakistan and it is planned that its formulation will take place under the NDP. Environmental Impact Assessments of planned water resources projects will also be carried out under NDP as the programme specifies that only those schemes or projects meeting the NDP selection criteria would be implemented. This would ensure the environmentally-safe disposal of the effluent. Besides, implementation under the NDP would be restricted to projects in which highly sodic soils do not cover more than 15 percent of the affected area. All these measures are meant to prevent an excessive degradation of water quality in the receiving water bodies.

The enactment of the Environmental Protection Act (1997) is also the cornerstone of environmental legislation in Pakistan. NEQS have been promulgated under this Act and they empower the Federal and Provincial Governments to levy a pollution charge on anyone not complying with these standards.

The role of NGO's and CBO's in the irrigation and drainage sector needs to be expanded. Through the institutional reforms being carried out under the NDP, AWB's and FO's are being established and it is envisaged that local communities and stakeholders will be involved in addressing the issues such as land acquisition, resettlement and environmental issues.

References

Bashir Ahmad and Javaid Afzal, 1998. *Status of Water Quality Problem in Pakistan*. ESCAP, United Nations, New York.

Bishay, B. G., Hoffman, G.J and Willardson, L.S. 1996. *The Effects of Agricultural Drainage Discharge on the Quality of the River Indus*, International Panel of Experts.

Gazette of Pakistan Extra (Dec. 6, 1997), "Pakistan Environmental Protection Act".

Masood Ahmed *et al*., 1991. *Environmental considerations in Irrigation Planning*; A case study of Indus Basin (IBRD paper 166); Environment Department, World Bank.

Mott MacDonald International Limited and Hunting Technical Services Limited, 1991. *Lower Indus Region, Right Bank Master Plan*.

NESPAK, HARZA & ACE, 1995. *Chashma Command Area Development Project (CRBC) Stage-I - Project Completion Report (Drainage Component*).

NESPAK & MMI, 1993. *Pakistan Drainage Sector Environmental Assessment-National Drainage Programme.*

OPCV-NESPAK , 1997. *Implementation of the National Conservation Strategy.*

Modelling non-point source pollution of surface and groundwater systems in selected agricultural watersheds in the Philippines

ABSTRACT

This paper describes a numerical pesticide transport model in terms of its components and applications. The model is called PESTFADE which consists of Runoff/Erosion, Water Flow, Heat Flow and the Convection-Adsorption-Diffusion-Degradation sub-models. The Soil Conservation Service (SCS) equation for estimating runoff and the Universal Soil Loss Equation (USLE) for calculating soil erosion were modified so the model can evaluate chemical partitioning in runoff and sediments. The model was applied in several watersheds in the Philippines under different land use scenarios. These include a grassland and pineapple plantation at the Siniloan watershed in Laguna, lowland rice farming systems in Nueva Ecija, a vegetable farm draining into the Laguna Lake, a fully vegetated forest draining into the Angat Reservoir in Bulacan and a deforested watershed in Mt. Banahaw, Quezon. Also, a pesticide spill scenario in the Bulacan watershed was simulated using actual soil and climatic data. Results of the simulation indicated a total soil loss of 75.5 and 322.6 tons/ha/yr from the grassland and pineapple plantations, respectively. For the Angat Reservoir, Laguna Lake watershed, and Mt Banahaw, soil loss rates of 46.9, 119.0 and 120.3, tons/ha/yr were obtained respectively. The relatively high soil erosion rates for the pineapple, Mt Banahaw and vegetable areas were attributed to watershed characteristics (e.g., slope, soil hydrologic conditions, etc.) and farming practices which enhance runoff rates. For lowland rice and forested areas, leaching of chemical to groundwater was more prevalent especially in the lowland rice due to the saturated conditions of the soil profile, and is of concern. Various field scenarios were simulated to develop Best Management Practices (BMPs) that will minimize the environmental risks associated with erosion and agrochemical applications.

The advent of modern farming practices (e.g. agricultural chemical applications) in the late 1970s is now causing much public concern because of the resulting environmental problems such as the pollution of surface water and groundwater resources. For instance, the herbicide Atrazine, one of the most commonly used pesticides in corn production, has been found in Canadian rivers, streams, wells and tile drain discharge in concentrations of up to 170 mg/L (Junk *et al*., 1980, Gold and Loudon, 1982). It has also been reported that 2/3 of the river basins in the United States have been contaminated by various agricultural pollutants such as sediments, pesticide residues, excess nutrient loadings, etc. (US-EPA, 1978). Similar problems are encountered now also in developing countries like the Philippines where major lakes and

R.S. Clemente and E. Wilson
Environmental Science Program, University of the Philippines, Diliman, Queson City, Philippines

reservoirs are reported to be affected by levels of chemical residues, sediments and heavy metals. For instance in the Lake Laguna region, intensified farming activity and the proliferation of factories/industries and residential sub-divisions are factors linked to the observed water quality deterioration. Specifically, the pollution and siltation of Laguna Lake as a result of runoff and soil erosion of surrounding forest landscapes and agricultural watersheds is now a major socio-ecological concern because aquatic life is seriously affected and so much livelihood depends on the Lake. Similar concerns are expressed for the La Mesa Reservoir and other water resources across the country where toxic wastes (e.g. heavy metals from industries, domestic wastes from urban/rural communities and pesticide residues from rice farming systems) are threatening the quality of these resources for safe use.

The maximum admissible concentration (MAC) of a chemical in drinking water varies from place to place, depending on an assessment of its human toxicity. For instance, the US Environmental Protection Agency (US-EPA) has set the MAC value for Atrazine at of 3 mg/L, while values of 2 and 0.1 mg/L have been set by the World Health Organization (WHO) and the European Community Commission (EC), respectively (Malcolm and Burn, 1991). In their investigations, Gold and Loudon (1982) have found that these values are frequently exceeded in agricultural watersheds, especially when it rains soon after chemical application.

Government agencies and research institutions are now looking for new technologies or alternative methodologies that can assess non-point source (NPS) pollution of our ecosystems and how to alleviate the problem. One approach that is considered more cost effective and less time consuming compared to actual field studies is the use of mathematical models.

Computer simulation modelling is now recognized as an alternative tool for research and development in the area of land and water resources. The complex and expensive nature of field experiments encourages the use of comprehensive mathematical models for assessing water and solute transport through various pathways and under different climatological, geological and management scenarios. Also, the simulation of soil-plant-water-chemical interactions can provide a very useful guide as to what best management practices (BMPs) can be adopted to minimize pollution from non-point sources (e.g., pesticide/fertilizer residues, sediments, salts, heavy metals, etc.).

Methodology

In this study, a state-of-the-art water and solute transport computer model was applied for the non-point source pollution evaluation and remediation of watersheds that are potentially vulnerable to pollutants such as pesticides, nutrients, sediments, etc.

Model description

This provides a brief description of the model in terms of its components, structure and the simulation scheme. PESTFADE (Pesticide Fate and Dynamics in the Environment) is a one-dimensional mathematical model which was developed, tested and applied in Canada (Clemente, 1991; Clemente *et al*., 1993; Clemente *et al*., 1997; Clemente *et al*., 1998a) and also applied in the Philippines (Clemente *et al*., 1998b). The model is designed to simulate the surface/subsurface transport of water and solutes under various hydrogeological conditions. PESTFADE consists of the following four major programs:

1. Runoff sub-model - this evaluates runoff and soil loss as well as the loss of chemical at the soil surface through runoff and soil erosion.

2. Unsaturated Water Flow sub-model using SWACROP - this evaluates moisture content and flux distribution along the soil profile using the Richards equation as affected by different upper and bottom boundary conditions and water table management systems.
3. Heat Flow sub-model - this analyses soil temperature distribution as affected by moisture content, soil thermal conductivity and other soil factors.
4. Solute Transport sub-model - this evaluates the processes such as mass flow, dispersion, chemical/microbial degradation, adsorption/desorption and volatilization.

The incorporation of new sorption/degradation kinetics and macropore flow in PESTFADE is some of its advantages over other existing models.

The Runoff sub-model is based on the US Soil Conservation Service (SCS) (Mockus, 1975) method of calculating runoff depth as a function of rainfall, Curve Number and antecedent moisture and soil hydrologic conditions. The calculation of soil erosion is based on the Universal Soil Loss Equation (USLE) (Williams, 1975) which is a function of watershed soil and topographic characteristics. The SCS and USLE approaches were modified to incorporate the dissipation of chemical through runoff and erosion. A detailed description of the other components of PESTFADE has been published in the literature (Clemente, 1991; Clemente *et al*., 1993; Clemente and Prasher, 1993).

Application of the model to various study areas in the Philippines

Siniloan Watershed

The Siniloan watershed in the Province of Laguna is bordered by a vast rangeland in the northeast, by Real, Quezon and by Laguna Lake in the southwest. The watershed covers around 8,000 hectares of undulating and sloping topography. The climate is characterized as having distinct rain from June to September. Because of the varying land use, soil cover and vegetation, it was decided to subdivide the watershed into sub-areas for simulation purposes. This approach allows an evaluation of the mechanisms occurring in smaller portions of the watershed which represent specific slope, cropping patterns, and agricultural practices. Accordingly, a grassland area and a pineapple plantation area were selected.

The grassland area covers 11.43 hectares with an average slope of 25%. The soil is characterized as clayey with a bulk density at the soil surface of 0.74 g/cm^3 . Because of the steep slope and low infiltration characteristics of the area, it was categorized as a potentially high runoff site and was assigned a Curve Number (CN) value of 89. The other factors that were measured or estimated from the site consist of available moisture, soil erosion parameters such as erodibility, length-slope, cropping and contouring factors. A 10-month rainfall record for 1995 (from January 1 to October 31) was available for a nearby site (Tanay, Rizal). Since there was no chemical application at the site, only the runoff and erosion rates were calculated in this sub-area of the watershed.

Using the same rainfall data and other general soil properties (e.g. moisture retention curves, sorption coefficient, etc.) the model was also applied to another sub-area of the watershed used a pineapple plantation and treated with the herbicide Diuron at the rate of 6.4 kg/ha. This sub-area occupies around 51 ha with an average slope of 25%. The soil is characterized as clay loam with a bulk density at the soil surface of 0.95 g/cm^3. Since pineapple is an annual crop, the model was run for one year from the planting date in June 1, 1994 up to May 31, 1995.

TABLE 1
Description of the sub-areas of the Siniloan Watershed

Land Use	Area (ha)	Soil Texture	Conservation Practice	Chemical Application	Simulation Period (days)
Grassland	11.43	Clay (0.74)#	CN = 89*	NA	302
Pineapple	51.30	Clay (0.95)	CN = 91	Diuron (6.4 kg/ha)	365
Mt. Banahaw	264.30	Clay Loam (1.14)	CN = 87	NA	365
Angat Dam	7813.00	Clay (1.4)	CN = 80	NA	365
Lowland rice	8.00	Clay Loam (1.2)	CN = 60	Carbofuran (17 kg/ha)	90
Vegetable	6488.00	Clay Loam (1.2)	CN = 80	Diuron	90

\# Values inside the parenthesis represent the Bulk Density of the soil (g/cm3).

* CN stands for Curve Number which is a critical parameter in the Soil conservation Service (SCS) method for estimating runoff. The higher the CN value, the greater the potential for runoff since it reflects low infiltration, minimal conservation practice and minimal conservation practice and poor hydrologic condition.

TABLE 2
Basic Input Parameters Used in the Simulations

Parameter	Land Use					
	Pineapple	**Grassland**	**Lowland Rice**	**Vegetable**	**Forest**	**Bare**
Chemical applied	Diuron	None	Carbofuran	Diuron	None	None
Application rate	6.4 kg/ha	None	17.0	6.4	NA	NA
Rate constant	0.002 per day	0.017	0.0140	0.002	NA	NA
Sorption Coefficient	3.2 cm^3/g	3.20	0.88	3.2	3.2	3.20
Bulk Density	0.95g/cm^3	0.740	1.22	1.2	1.4	1.14
Available moisture	0.22 cm^3/cm^3	0.130	0.2	0.17	0.2	0.17
Drainage area	51.3 ha	11.40	8.0	6488.0	7813.0	254.3
Erodibility factor	0.14 tons/ha	0.12	0.15	0.22	0.20	0.20
Length-slope factor	11.3	8.94	1.0	16.1	6.19	42.1
Curve Number	91.0	89.0	60.0	80.0	80.0	87.0
Others*						

* Other input data consists of time series climatological data such as daily rainfall, air temperature and pan evaporation taken from a gauging station near the study site as well as soil/hydrologic and crop properties such as moisture retention curves and crop characteristics/coefficients derived from the literature.

Lowland rice farming systems in Nueva Ecija

The study area is within the nearly flat recent alluvial plain in San Antonio, Nueva Ecija. The rice plantation covers around 8 hectares and the soil is characterized as Quingua clay loam with a bulk density of 1.22 g/cm^3. It has been reported also that the soil is acidic and has a low organic matter content (LREP, 1987). The cropping period used for the study was from January 21 to May 20 1997, but since the insecticide Carbofuran was applied once on February 20, 1997 the simulation was started on that date.

Vegetable farm near Laguna Lake

The Laguna Lake area is surrounded by municipal and agricultural regions of the Laguna Province. In addition to precipitation as a source of water, the province can rely on 10 national irrigation systems as well as on seven major rivers and tributaries which all end up to the Laguna Lake. Although a number of land management units (e.g., vegetable, coconut, and sugarcane) exist in the lacustrine plain, lower footslope and tuffaceous plain areas surrounding the Lake, only the sub-area used for vegetable crops will be presented in this paper. This sub-area measures around 6,488 ha and is characterized as having a clay loam soil with land slopes ranging from 3 to 8%. A one-year rainfall record for 1994 (from January to December) for a nearby site (Tanay, Rizal) was used as input to the Runoff sub-model.

Watershed draining into the Angat Reservoir, Bulacan

The Angat reservoir is the source of raw surface water supply of Metro Manila and is located in the Province of Bulacan. The watershed draining into the reservoir measures around 7 813 ha and is characterized as having a moderate slope. The watersheds covering the Angat Reservoir are fully vegetated with primary forest trees and shrubs, and appear to be well maintained and protected from human activities such as deforestation, agrochemical application and urban encroachment. The potential contamination of the reservoir by non-point source pollutants is therefore believed to be minimal. However, the hills around the reservoir are characterized as having an undulating and sloping topography that can cause runoff and soil erosion. To verify this possibility simulation runs were carried out using available rainfall data and soil physical properties of the watershed.

Watershed in Mt Banahaw, Quezon

Mt Banahaw is located in the province of Quezon and characterized as having moderate to steep topography with varying land use. Because of the intensive clearing and grazing of the forest, a representative area measuring 254.3 ha has been considered a bare land in the simulations.

Table 1 presents a summary of the characteristics and practices employed at the different land use areas considered in this study and Table 2 presents a summary of the input parameters used in the simulations.

Results and discussions

Siniloan Watershed

Runoff and soil erosion in the grassland area

The results of the simulation for this area indicate that the site was quite vulnerable to runoff and erosion. In the relationship between rainfall and runoff during the rainy months of June, July, and August it was found that the grassland area was sensitive to high rainfall events as reflected in the rise in runoff which also resulted in high loss rates, especially for the high CN value of 89. For instance, the total soil loss from the grassland area over the 10-month period was 74.73 tons per hectare. This soil loss rate belongs to the high category in the erosion classification system (50 -120 tons/ha/year). If this rate is translated into depth of soil lost from the area, a value of around 1 cm of soil lost every year is obtained. This situation has been attributed to the steep slope (25%) of the grassland area. The environmental implication is that erosion can reduce the fertility of the top soil while the eroded soil can cause sedimentation of the receiving water downstream of the grassland area (e.g., Laguna Lake). A best management practice (BMP) is therefore required to alleviate the runoff/erosion problem in the area.

Pineapple Plantation Area

Runoff and Soil Erosion: In this land use unit, it was found that the area was also very susceptible to runoff and erosion. Specifically, a soil loss of 322.64 tons/ha/year was obtained, which is roughly equivalent to 3.39 cm of top soil lost every year. Relative to the Grassland area, the higher soil loss rate is mainly due to higher watershed factors such as Curve Number, length-slope, etc. Also, a total of 88 runoff events occurred during the one year period compared to the 70 rainfall events that caused runoff and soil erosion in the grassland area. In this context the sedimentation of the receiving surface waters (i.e., Laguna Lake) and the possible flooding of the lowland areas are issues of major concern.

Considering the sloping topography and rainfall patterns in this watershed, the soil loss rate of 322.64 tons/ha/year, however, is not surprising especially when compared with some values reported for other areas across the globe. A soil loss rate of 186 tons/ha/year was measured in a cultivated area with slope of 18% in Taiwan. At a continuous potato production area in New Brunswick, Canada values of soil loss reaching 190 tons/ha/year were measured (Cao *et al*., 1992), translating into 12.5 cm of top soil lost during the past 20 years. Although the topography of the production area was not mentioned, Canadian farms are generally flat compared to the upland farming systems in the Philippines. In the U.S.A., wind erosion from a grassed area was simulated and a soil loss value of up to 800 tons/acre was obtained.

In a field study on soil erosion at the Upper Peninsula Los Banos, a soil loss rate of 79.6 tons/ha/year from a grassland area was obtained, a value that compares very well with the soil loss rate simulated for the grassland area in the Siniloan watershed. Therefore, the predicted values of soil loss from the Siniloan watershed (i.e., 75.47 and 322.64 tons/ha/year from the grassland and pineapple plantation areas, respectively) are reasonably comparable with published data.

Chemical Dissipation at the Pineapple Plantation: It was found that the herbicide Diuron used in this area was dissipated quickly at the soil surface. Although the chemical is quite persistent (i.e. half-life of 330 days), 50% of the chemical applied already disappeared in less than 15 days. Specifically, from the initial concentration of 67.36 mg/L, only 30.86 mg/L remained at the soil surface after 15 days. This fast disappearance of the chemical was attributed to the combined loss due to exponential decay, runoff and soil erosion which is a function of various interacting factors such as rainfall intensity, soil texture, rate constant, sorption coefficient, length/slope, erodibility, etc.

Table 3 shows a partial output from the runoff model which gives the amounts of chemical lost in runoff (PQT) and sediment (PXT), and the amount remaining at the soil surface (PREM). It can be seen that during the first onset of rainfall on day 4, 2.3 mg/L was lost through runoff and 10 mg/L was adsorbed by the sediment. The environmental implication of this situation is that the chemical-laden runoff can reach and contaminate adjacent surface water bodies in a matter of a few days after application.

In his study of the “edge-of-field” runoff loss of chemicals, Wauchope (1978) has considered runoff events as catastrophic if the loss of chemical through runoff exceeds 2% of the applied amount. He added that these events, almost without exception, are first events after application. In the present study, the intermittent rain during the first two weeks after application ranging from 1 to 5 cm has resulted in edge-of-field losses of the chemical ranging from 0.307 to 2.32 mg/L, concentrations corresponding to 0.045 to 3.44% of the applied amount of 67.3 mg/L. These values are comparable to those reported by Wauchope (1978) where the runoff loss of Atrazine ranged from 0.22 to 2.24% of the applied amount during the first 26 days after

TABLE 3
Representative output of the runoff sub-model for the pineapple plantation

DAY	RAIN (cm)	DURATION (hr)	PQT (mg/l)	PXT (mg/l)	TOTAL (mg/l)	PREM (mg/l)
1	0.25	2.0	0.00000	0.00000	0.00000	67.2271
2	1.13	3.0	0.504723	0.725581	1.23030	62.7032
3	1.03	3.0	0.376995	0.497739	0.874734	58.7433
4	5.02	7.0	2.297530	10.15780	12.45540	44.6644
5	0.00	0.0	0.00000	0.00000	0.00000	44.5707
6	0.00	0.0	0.00000	0.00000	0.00000	44.4772
7	1.03	4.0	0.267414	0.300527	0.567941	41.7208
8	0.00	0.0	0.00000	0.00000	0.00000	41.6333
9	0.00	0.0	0.00000	0.00000	0.00000	41.5460
10	0.00	0.0	0.00000	0.00000	0.00000	41.4588
11	0.00	0.0	0.00000	0.00000	0.00000	41.3718
12	0.00	0.0	0.00000	0.00000	0.00000	41.2850
13	0.52	3.0	0.000656163	0.000905515	0.00156168	39.5921
14	1.08	3.0	0.267689	0.368958	0.636647	37.0104
15	3.65	7.0	1.200390	3.719270	4.919660	30.8621

application. So the runoff loading of chemical residues in surface waters adjacent to the Siniloan watershed needs to be controlled to prevent further contamination of the water bodies.

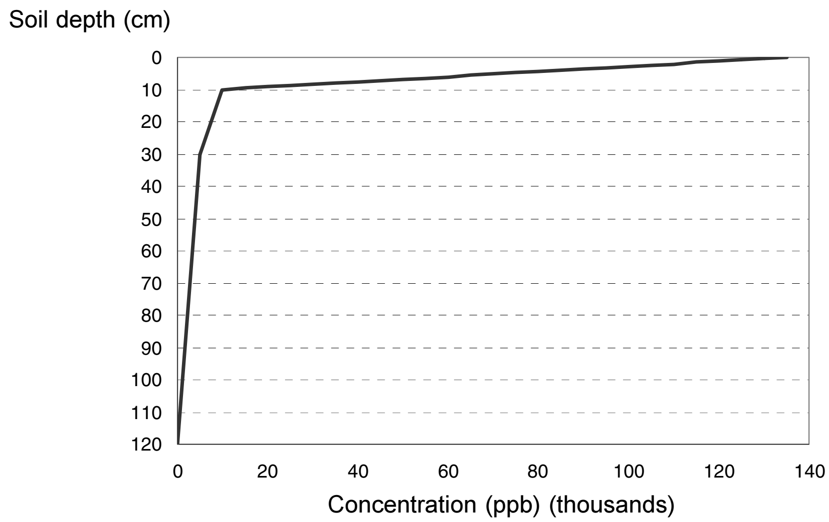
As for the soil leaching process, the chemical applied only reached the 50 cm mark after one month with a concentration of 11.5 ppb, but it was found that it reached the bottom layer after 3 months with a concentration of around 10 ppb. This slow leaching of the chemical can be due to the considerable loss at the surface in runoff and sediment. However, the soil leaching data point to a threat to groundwater underlying upland watersheds as the observed pesticide concentrations exceed the tolerable limit of 3 ppb for most agrochemicals.

Chemical leaching in lowland rice farming systems in Nueva Ecija

Since the areas where lowland rice farming is carried out are commonly levelled, the water runoff is due to overflows from paddy to paddy and the soil erosion can be expected to be minimal and contained within the paddy area. This assumption has been verified by running the Runoff sub-model with input based on the prevailing conditions associated with lowland rice farming (e.g. small values of length-slope and curve number). It was found that runoff and soil erosion were almost negligible. The controlled water application through irrigation coupled with light rainfall events during the period could explain why little runoff and consequently minimal loss of chemical at the surface were observed. However, one implication of this situation is that most of the chemical applied is dissolved in the paddy water and is available for leaching through the soil profile.

The results of the modelling indicate that the chemical has moved readily down the soil profile during the first few weeks after application. Specifically the chemical has reached the water table only 6 days with a concentration of 2.24 ppb (see Figure 1) while the bottom layer (300 cm) was reached just after 47 days with a concentration of 3.29 ppb. Since the tolerable limit for Carbofuran is 2 ppb, this suggests that groundwater resources under lowland rice areas can be threatened by chemical residues associated with this type of farming. In fact, the study area has a shallow water table which fluctuates from 0.9 to 8.53 m during the year. A

FIGURE 1
Concentration profile with depth six days after application



Lowland rice treated with Carbofuran

TABLE 4
Representative output of the runoff sub-model for the pesticide spill simulation

DAY	RAIN (cm)	DURATION (hr)	PQT (mg/l)	PXT (mg/l)	TOTAL (mg/l)	PREM (mg/l)
1	0.00	0.00	0.00000	0.00000	0.00000	1248.22
2	3.16	2.00	16.43460	1.29063	17.7253	1084.59
3	0.20	4.50	0.00000	0.00000	0.00000	1069.51
4	4.02	3.00	22.646100	1.79283	24.4390	926.822
5	0.84	3.00	0.00000	0.00000	0.00000	913.937
6	0.94	1.00	0.00000	0.00000	0.00000	901.231
7	3.14	4.00	11.69290	0.619187	12.31210	783.442
8	0.00	0.00	0.00000	0.00000	0.00000	772.551
9	0.10	1.50	0.00000	0.00000	0.00000	761.810
10	0.14	0.25	0.00000	0.00000	0.00000	751.219
11	0.00	0.00	0.00000	0.00000	0.00000	740.776
12	0.00	0.00	0.00000	0.00000	0.00000	730.477
13	2.40	3.00	4.342040	0.215271	4.55731	637.071
14	0.30	0.75	0.00000	0.00000	0.00000	628.214
15	0.26	1.00	0.00000	0.00000	0.00000	619.481

management practice capable of confining or retarding the leaching of the chemical is therefore necessary to control chemical residue loading in groundwater.

Agricultural watersheds draining into Laguna Lake

Soil loss in vegetable production area

For this sub-area, a high soil loss of 119.0 tons/ha during the 90-day simulation period was obtained for a Curve Number of 80. When soil conservation and terracing was incorporated in the model by using a Curve Number of 60, the soil loss was considerably reduced by 60 % to only 48 tons/ha. So it is recommended to employ practices that will reduce the slope of the watershed as well as improve the infiltration capacity of the top soil in order to reduce the potential risk of siltation in receiving surface waters.

Subsurface transport of chemical at thevegetable farm

In the study area where vegetable farming is practised, it was found that the chemical is leaching quite fast through the root zone. For instance the chemical has reached the 100 cm depth (i.e. the groundwater level) in a matter of 40 days with a concentration of 4 ppb (Figure 2. Also, it has reached the bottom layer only after 59 days with a concentration of 3.7 ppb, a level exceeding the tolerable limit of 3 ppb for the herbicide Diuron. At the end of the 90-day growing period, the chemical has reached the bottom layer (i.e., 150 cm depth) with a concentration of 10 ppb. This fast movement of the chemical down the soil profile is attributed again to the low sorption capacity of mineral soils as well as due to the high water table conditions causing wetter conditions of the vadose zone. To alleviate this leaching problem, a soil management practice that will increase its sorption capacity and thus retard or prevent rapid leaching is required.

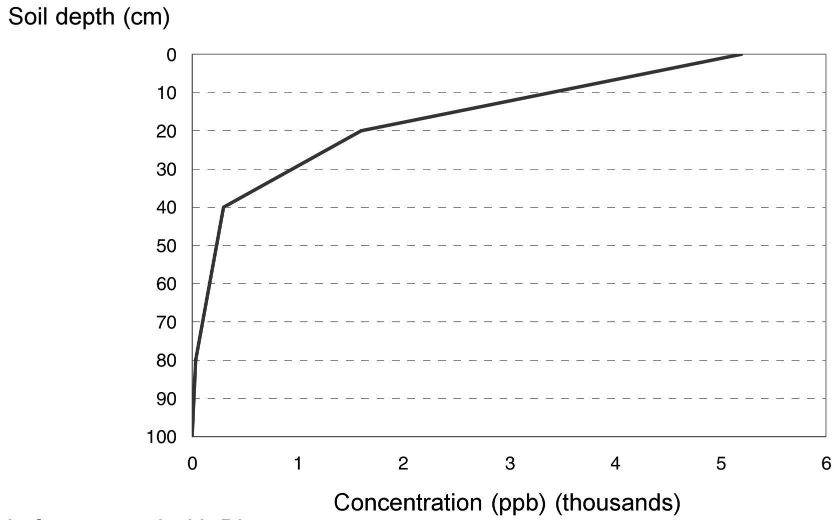
Forested watershed draining into the Angat Reservoir

The simulation results for this area indicate that the watershed is slightly susceptible to runoff and soil erosion judging from the relatively small soil loss from the watershed during the 5-month simulation period. Specifically, a total soil loss of 46.9 tons/ha was obtained which is equivalent to 0.35 cm of soil lost during this period. The dense vegetation in the area is regarded as the factor controlling the runoff/erosion process. Nevertheless, this level of soil loss remains a cause for concern since it can pose sedimentation problem to the reservoir on a long term basis and appropriate management practices need to be implemented to alleviate this problem.

Mt Banahaw Watershed

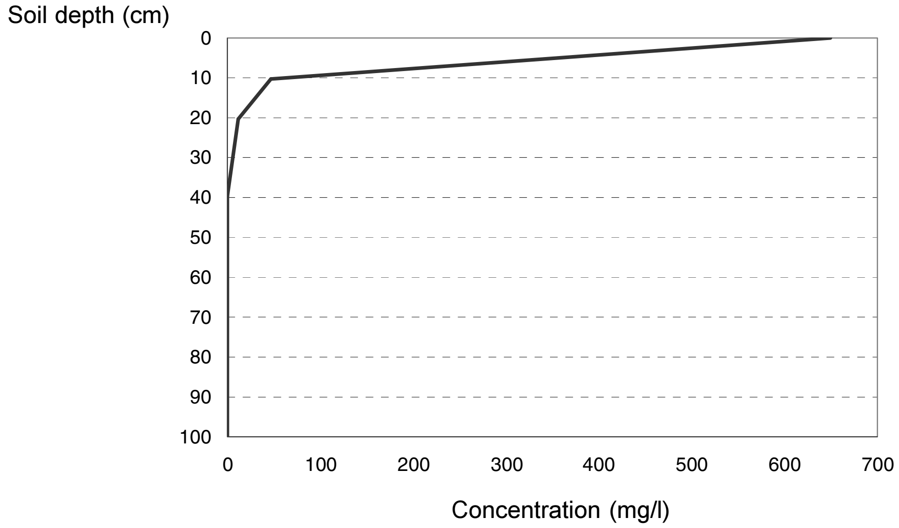
With most portions of the Mt. Banahaw watershed cleared of vegetation, this situation has become a major concern for nearby communities because of the occurrence of flash floods

FIGURE 2
Concentration profile with depth forty days after application



Vegetable farm treated with Diuron

Figure 3
Pesticide concentration profile with depth as twelve days after spill



during heavy rainstorms. A particular catastrophic event was the flooding of the lowland areas downstream of the watershed during a strong typhoon in November 1995. Using the rainfall data from the watershed for that year, a simulation run of the model was executed to determine the extent of runoff that caused the devastating floods during the later part of the year. It was found that during the heavy storms in October and November 1995, the runoff reached levels as high as 11.0 and 8.8 cm. The high runoff events in the watershed in 1995 also resulted in a considerable soil loss. When using a CN value of 87, the total amount of soil lost after one year was calculated to be 120.3 tons/ha. It is therefore recommended to employ soil conservation practices and to improve vegetation within the watershed to reduce the risk of further sedimentation and flooding of the lowland areas adjacent to the Mt Banahaw watershed.

Simulation of pesticide spill

In order to assess the environmental impact of chemical spills, the model was run using actual soil/hydrologic data for the Bulacan watershed. A pesticide spill scenario was defined as having a concentration 100 times the normal rate of 2 kg/ha applied to a 100 m^2 lot near a lake. The purpose of the simulation is to determine whether the lake or the underlying groundwater is threatened by the spill. The partial data generated by the model for a month simulation are provided in Table 4 and they show that during the first onset of rain on day 2, 16 mg/L or 16 000 ppb of the chemical has been dissipated through runoff and that the amount available for leaching is 1084 mg/L or 1 x 10^6 ppb. These values are in good agreement with other results showing that after only 12 days, the chemical has reached the water table at a depth of 100 cm with a concentration of 5 ppb, as can be seen in Figure 3. The simulation results demonstrate the high risk of groundwater contamination during chemical spills in farmland areas.

Evaluation of BMPs

The simulation results presented in this paper can be regarded as environmental indicators of the potential susceptibility of the watersheds studied to runoff/erosion and agrochemical contamination. These initial findings suggest that the surface water resources adjacent to the Siniloan watershed, Mt Banahaw, and the Angat watershed can be subject to sedimentation and contamination. Since the Laguna Lake lies in the southern portion of the Siniloan watershed and is surrounded by agricultural lands and communities, this situation implies that the Lake has been and will be threatened by chemicals, sediments, and other toxic wastes if Best Management Practices (BMPs) are not implemented in the area. To determine the most appropriate BMPs for a particular area, various scenarios such as different agricultural practices were considered. Specifically, BMPs for some land use areas with high soil loss and chemical leaching were evaluated, namely pineapple plantation, grassland, lowland rice and vegetable production areas.

Pineapple plantation

The high runoff events in this sub-area resulted in a considerable soil loss of 322.64 tons/ha/year. A scenario was therefore simulated to represent good infiltration and a soil conservation practice such as terracing as reflected in the Curve Number value used. So when the CN value was changed from 91 to 80, 70 and 60, the soil loss was reduced from 322.64 to 184.14, 117.3, and 74.4 tons/ha/year, respectively (see Figure 4). These results indicate that increasing the infiltration capacity of the soil (which is accounted for by using a low CN value) coupled with the application of soil conservation such as terracing can significantly reduce the amount of soil loss from the watershed. Consequently, the potential risk of sedimentation in the receiving surface waters is greatly minimized.

It should be noted that the model is not only sensitive to the Curve Number value but also to the erodibility, length-slope and contouring factors. So it is highly recommended that proper values of these parameters be fed into the model in order to ensure accurate calculations of runoff and soil loss.

Grassland area

Similar to the results obtained for the pineapple plantation area, those shown in Figure 5 for a grassland area indicate that when the CN value was reduced from 89 to 80, 70 and 60, the total soil loss over a 10-month period was also reduced from 74.73, to 51.52, 34.55 and 26.1tons/ha,

Figure 4
Soil loss from the pineapple plantation in the Siniloan Watershed

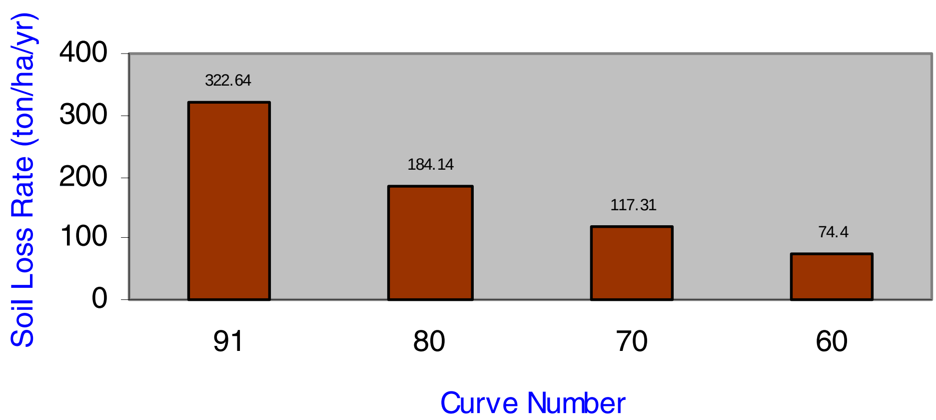
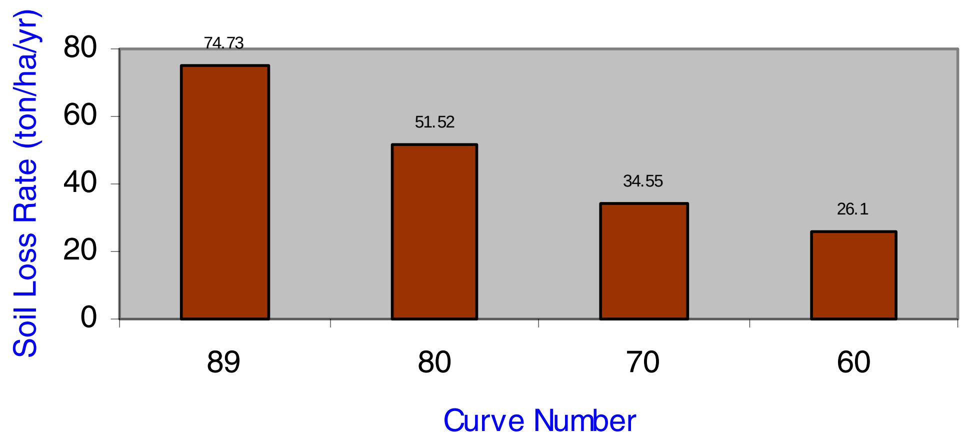


FIGURE 5
Soil loss from thegrassland area in the Siniloan Watershed



respectively. These soil loss reductions of 31%, 53.8% and 65% illustrate the importance of soil conservation practices (e.g., terracing) for reducing the runoff potential of watersheds. The results also suggest that a soil amelioration to improve the permeability of the top soil will reduce the runoff and consequently result in less soil erosion. This, however, implies that more chemical becomes available for leaching down the vadose zone, a scenario discussed in the next sections.

Lowland rice

One pathway that can reduce chemical movement is through adsorption which is reflected in the soil sorption capacity value. Thus a high sorption coefficient will induce more partitioning of the chemical into the adsorbed phase and consequently reduce leaching. So different scenarios reflecting different soil conditions were evaluated by running the model using sorption coefficient (K_d) values 25% higher or 25% lower than the normal value of 0.88 cm^3/g for the study area. When the K_d value was lowered to 0.66 cm^3/g, the chemical has reached the water level just after 6 days with a greater concentration of 5.06 ppb compared to 2.24 cm^3/g for a K_d value of 0.88. The bottom profile on the other hand was reached 3 days earlier. But when the K_d value was increased to 1.10 cm^3/g, the chemical has reached the water table and the bottom profile 2 days and 8 days later, respectively, compared to the normal situation with a K_d value of 0.88. This simply indicates that the sorption capacity of soils which is associated with organic matter content is a soil property that can be amended for the purpose of retarding the migration of chemicals into groundwater resources.

Vegetable farm

As mentioned earlier, the fast movement of the chemical down the soil profile was attributed to the low sorption capacity of mineral soils as well as due to the high water table conditions resulting in saturated conditions of the vadose zone. To alleviate this chemical leaching problem, an adequate soil management practice is required to increase the sorption capacity of the soil and thus retard or prevent rapid leaching. A scenario was therefore simulated where the sorption coefficient was increased from 3.2 to 10.0 cm^3/g to reflect an increase in the organic matter content of the soil. The simulation results indicate that the chemical would never reached the bottom layer during the growing period.

The simulation of different management scenarios has indicated that different tillage systems which are reflected in the choice of Curve Number values have a major effect on the amount of runoff and soil loss from the soil surface. Specifically, the amount of runoff and erosion increases as the CN value was increased from 60 to 89. Likewise, the dissipation of the chemical through runoff and erosion followed the same trend. From these simulation runs, we have identified the BMP which will control runoff and soil erosion as the practice that involves improving the permeability of the top soil to allow more percolation down the soil profile. Also, conservation practices such as terracing and increased vegetation can reduce the momentum and impact of rainfall on the soil surface and can therefore be regarded as remedial measures for controlling runoff and soil erosion. However, controlling runoff at the soil surface can have a major effect on the subsurface transport of chemical. Less runoff means that more water and dissolved chemicals are available for leaching and this has a serious implication on the underlying groundwater. So a management practice which will increase the sorption capacity of the soil can reduce deep percolation of chemicals. The BMP that can accomplish this task is one that can improve the organic matter content of the crop root zone and thus increase its sorption as well as water holding capacity.

Conclusions

The description of the PESTFADE model as well as the simulation of various field scenarios have been presented in this paper, namely runoff/erosion in agricultural watersheds, herbicide and insecticide fate and transport under different land use systems, surface/subsurface transport of pesticide during accidental spills. The hydrologic and physico-chemical modelling of the different land use areas in selected watersheds in the Philippines has demonstrated both the applicability and flexibility of the computer-assisted techniques. The results of the simulations have shown that the watersheds were quite susceptible to runoff and soil erosion, thus pointing to the eminent problems of the sedimentation and contamination of receiving water bodies downstream of the watershed. Since the Laguna Lake is situated in the southern portion of the Siniloan watershed, the lake is the receiving sink of the chemicals and sediments coming from that watershed. Considering that the simulated values of Diuron and Carbofuran for most of the watersheds exceeded the tolerable limits set by the EEC and WHO, surface water and groundwater should be considered as seriously threatened, especially during high rainfall when runoff and leaching can increase considerably. This paper includes an evaluation of BMPs that would control runoff and soil erosion from the study area sites as well as the leaching of chemical residues to the groundwater. It was found that a management practice that would improve the infiltration capacity of the top soil and reduce the length of slope (e.g., terracing) can improve the current situation. However, controlling runoff would mean more percolation and as a result chemicals might leach down the bottom profile and contaminate the groundwater. Therefore, improving the water holding and sorption capacity in the crop root zone can be a management practice that can circumvent this difficulty and control groundwater contamination.

Based on these modelling studies, it can be generalized that agrochemical use poses a serious threat to the quality of surface water and groundwater, even under normal application. Also, high rates of erosion were found and these can pose sedimentation problems in adjacent water bodies. All these problems can be attributed to certain anthropogenic activities in the watershed and to some topographic and climatic factors that enhance runoff/erosion and leaching rates.

References

Cao, Y.Z., Coote, D.R., Rees, H.W., Wang, C. and Chow T.L. 1992. *Effects of intensive potato production on soil quality and yield at a benchmark site in New Brunswick*. Submitted for publication at the Soil and Tillage Research Journal.

Clemente, R.S. 1991 *A Mathematical Model for Simulating Pesticide Fate and Dynamics in the Environment (PESTFADE)*. PhD Thesis. Department of Agricultural Engineering, McGill University, Montreal, Quebec, Canada.

Clemente, R.S. and Prasher, S.O. 1993. *PESTFADE Model User's Guide and Documentation*. Dept. of Agricultural Engineering, Macdonald Campus of McGill University, Ste Anne de Bellevue Quebec, Canada.

Clemente, R.S. Prasher, S.O. and Barrington, S.F. 1993. PESTFADE, a new pesticide fate and transport model: Model development and verification. *Transactions of the ASAE*: 36:357-367.

Clemente, R.S., De Jong, R., Hayhoe, H.N., Reynolds, W.D. and Hares, M. 1994. Testing and comparison of three unsaturated soil water flow models. *Agric. Water Management Journal:* 25(1994) 135-152.

Clemente, R.S., Prasher, S.O., Salehi, F. 1998. Performance testing and validation of PESTFADE. *Agric. Water Management J.*: 37(1998):205-224.

Clemente, R.S., Prasher, S.O., Madramootoo, C.A., Bonnell, R.B., and I.N. Mathur. 1997. Application of PESTFADE to simulate salt movement in soils. *Canadian Water Resources Journal*: 22(2):63-80.

Clemente, R.S., A.Baloloy, M.Collado, J. Manguera. 1998b. *Computer modelling of runoff/erosion and surface transport of agrochemicals at the Siniloan watershed, Philippines*. Paper submitted to the ASOCON CONTOUR for publication.

Gold, A.J. and Loudon, T.L. 1982. *Nutrient, sediment and herbicide losses in tile drainage under conservation and conventional tillage*. ASAE, St. Joseph MI Paper No. 82-254.

Junk, G.A., Spalding, R.F. and Richard, J.J. 1980. Areal, vertical and temporal differences in groundwater chemistry:II. Organic contents. *J. Environmental Quality* 9:479-482.

Mockus, V. 1975. Estimation of direct runoff from storm rainfall. *National Engineering Handbook*, Sec. 4, Hydrology. US Soil Conservation Service, Washington, D.C. p.10.1-10.24.

LREP. 1987. *Soil/Land Resources Evaluation Project (LREP). The physical and socio-economic environment for the province of Nueva Ecija*. Bureau of Soils and Water Management, Manila Philippines.

Nkedi-Kizza, P., J.W. Biggar, H.M. Selim, M.Th. van Genuchten, P.J. Wierenga, J.M. Davidson, and D.R. Nielsen. 1984. On the equivalence of two conceptual models for describing ion exchange during transport through an aggregated oxisol. *Water Resources Res.*: 20:1123-1130.

Schiesser, W.E. 1983. *DSS/2, An introduction to the use of mathematical software for ordinary and partial differential equations. Guidelines for the programming of a numerical method of lines code*. Leheigh University,Bethlehem, PA, 316 p.

US Environmental Protection Agency (EPA). 1978. *National Water Quality Inventory*.

Wauchope, R.D. 1978. The pesticide content of surface water draining from agricultural fields: a review. *J. Environ. Qual.*: 7, 459.

Wesseling, J.G., Kabat, P., Van den Broek, B.J. and Feddes, R.A. 1989. *Simulation model of the water balance of a cropped soil providing different types of boundary conditions, including the possibility to simulate crop yield and irrigation (SWACROP).* The Winand Staring Centre, P.O. Box 35, 6700 AA Wageningen, The Netherlands.

Williams, J.R. 1975. *Sediment-yield prediction with universal equation using runoff energy factor. Present and prospective technology for predicting sediments yields and sources.* USDA-ARS, Washington, D.C.

Utilization of spent distillery wash liquor in paddy fields

ABSTRACT

Spent wash liquor or stillage from the Thai Excise Department's Distillery Plant in Ubonratchathani Province has a flow rate of 500 m^3/day and has been stored in six anaerobic lagoons. It has the following characteristics: pH 4.1 - 4.6 , COD 100 000–120 000 mg/l , BOD 35 000–40 000 mg/l , N 1 500–2 000 mg/l , P 100-200 mg/l, K 2 500–8 000 mg/l, TS 80 000–120 000 mg/l, electrical conductivity (EC) 20 millimhos, temperature 37–40°C. The digested spent wash liquor, with a volume of 300 000 m^3, is pumped over a period of 6-7 months during the dry season (January - July) to 3 500 – 4 000 rais of paddy fields in four villages (Thung Phieng, Khok Sa-ad, Saphan Dome and Kham Saming) in the Sawang Weerawong District, Ubonratchathani. The amount of liquor is applied at an approximate rate of 100 - 125 m^3/rai (1 rai = 1 600 m^2 = 0.4 acre). The rice yield has increased 2-3 times in comparison with no liquor application. This direct use of spent wash liquor as organic fertilizer in paddy filed is a promising trend for the re-cycling of resources that will contribute to sustainable development in developing countries.

During the present economic crisis (beginning in July 1997) most Thai scientists and engineers have had to review their responsibilities for identifying national pollution control methods that are more suitable for to their needs and which contribute to sustainable development. Thailand is an agriculturally-based country with cultivated land of 150 million rais; this compares with less than 100 000 rais of industrial areas. Many industries are located within the green cultivated area which leads to the potential for use of industrial wastewater as organic fertilizer for the cultivated land which surrounds the industrial plants.

Farmers are generally too poor to buy enough chemical fertilizer to apply to their paddy and the amount that they can afford is generally 20 - 40 kg. of 15-15-15 (N, P_2O_5 , K_2O) chemical fertilizer per rai. The proper amount should be about 3 - 4 times this amount. However, increased use of chemical fertilizer also has an adverse effect in that it hardens the soil. Chemical fertilizer is considered to be a substantial portion of the total cost in growing rice.

The Excise Department's distillery plant at Ubonratchathani was commissioned some 14 years ago in the middle of the green area of paddy fields among the four villages of Thung Phieng, Khok Sa-ad, Saphan Dome and Kham Saming of Sawang Weerawong Districts of Ubonratchathani, some 520 km northeast of Bangkok. The distillery plant utitizes sugar cane molasses as its raw material to produce white liquor (or rum) as well as coloured liquor having an ethyl alcohol content of 28 - 35%. The spent wash liquor is the byproduct after the first distillation of beer or mash, having an initial alcohol content of 8.5 - 9.0% and reaches 60%.

Suchint Phanapavudhikul
Managing Director, Water & Environment COnsultant Corp., Bangkok, Thailand

Beer or mash is produced by diluting molasses having its initial sugar content of 51% with water to 17% and allowing yeast to convert sugar to ethyl alcohol within 72 hours under the fermentation process.

Legal and standard issues

In general, the plant's wastewater treatment facility should keep the effluent quality at a level that is better than the Standard of BOD:SS = 20:30 mg/l. However, for this particular distillery plant, there is zero discharge which is achieved by utilizing a Composting Method of wastewater disposal so that the effluent quality standard does not apply. Moreover, conditions are also imposed in that no wastewater can be moved or discharged outside the factory compound except as a compost product for sale. Since the compost has a low NPK values (0.5:0.5:0.5 %) and is too bulky to use in the paddy fields in large quantity per unit area, dried solids recovered from Land Application are used instead. However, because the quantity of dried solids is limited, liquid liquor is used directly for Direct Agricultural Use (DAU) with the farmers' permission providing that the liquor that is applied on their land has value as an organic fertilizer.

Quantity and characteristics of the liquor

The amount of spent wash liquor, or simply liquor, is produced at a rate of approximately 500 m^3/day and has the following characteristics: pH 4.1 - 4.6 , COD 100 000-120 000 mg/l , N 1500-2 000 mg/l , PO_4-P 100-200 mg/l , K 2 500-8 000 mg/l , TS 80 000-120 000 mg/l , temperature 37 – 40^o C.

Treatment and disposal of the liquor

Treatment and disposal of the liquor consists of (a) anaerobic digestion by Upflow Anaerobic Sludge Blanket (UASB), (b) Storage Lagoon (SL), (c) Land Application (LA), and (d) Direct Pumping to Paddy Fields or Direct Agricultural Use (DAU). Other methods of disposal have been tried such as composting, fish feed, road spray, storage lagoon and land applications, in the early year (1985-1992) with less success as compared to SL+LA+DAU. (see Figure. 1)

Anaerobic Digestion (UASB) This UASB is licensed by a Dutch firm (ESMIL International BV). It consists of: (a) acid tank (450 m^3 volume), (b) biothane or methane tank (3 000 m^3) and (c) gas holders (450 m^3). The system is designed to handle 450 m^3/day of the liquor but the actual possible feed rate is limited to only 100 m^3/day. The liquor is normally diluted with 25-100% (25-100 m^3/day) bottle washing wastewater and this portion will then amount to 125-200 m^3/day or average 150 m^3/day. As a result the amount of the liquor increases to 550 m^3/day. The higher feed rate will result in the overflow of the microbial mass. Biogas production is generally 3 000 m^3/day and it is used as a source of fuel in the boiler to replace fuel oil by an equivalent of 4,100 Baht/day or 1.5 M Baht/year as compared to the cost of 20 M Baht for the UASB during the erection and the improvement per plant. There are 12 Excise Department Distillery Plants in Thailand and each is equipped with UASB facility.

Storage Lagoon (SL): At the Ubonratchathani Distillery Plant , the remaining 400 m^3/ day of raw liquor, as well as the effluent from UASB (150 m^3/day), will finally flow to the SL. The SL consists of 6 lagoons, each having a depth of 3.4 - 3.6 m. and a total area of 70.0 rais and 411 000 m^3 capacity. Normally, raw spentwash liquor is fed to both raw (SL) pond (SL 314) having

TABLE 1
Result of rice yield production at different liquor rate

Run No.	Chemical Fertilizer $N-P_2O_5-K_2O$ kg./rai	Spent wash Liquor m^3/rai	Rice yield kg./rai			Time compared to control
			Year 1989	Year 1990	Average	
1	0 - 0 - 0	-	131	188	159	1.0
2	6 - 6 - 6	-	286	299	293	1.84
3	0 - 0 - 0	30.0	312	389	351	2.21
4	0 - 6 - 0	30.0	312	365	339	2.13
5	0 - 0 - 0	60.0	384	380	382	2.40

Remarks
Liquor characteristics pH 7.8 , COD 45 000 mg/l , TS 51 000 mg/l, EC 19 500 (μ mhos at 25° C)
Plant nutrients in the liquor (mg/l): N 1 533 , P_2O_5 183 , K_2O 7,230 , Ca 900, Mg 680 , Na 52 , Fe 40, Mn 2 , Zn 4 , Cu < 1.0

a volume of 3,800 m^3 and SL 5 to be used for feeding the UASB unit. The effluent from UASB is then fed to 318 (1). The remaining raw spentwash liquor of 400 m^3/day is equally distributed to SL 318 (2), (3) and 318 (6), or it is pumped during the dry season to the paddy fields to reduce the smell problem. The smell is generally H_2S gas when the raw liquor is in contact with the digested liquor in an open lagoon. The smell from these SL can be reduced by pumping the digested liquor from the last lagoon to circulate and dilute the content of the upper lagoons with lower COD, BOD flowing to the lower lagoons. However the smell from the raw liquor in SL 314, SL 318 (5) is quite strong because of its acidic pH before it is fed to UASB unit. A concrete tank having a volume of 1 000 m^3 with full cover should be used to store raw liquor before feeding to UASB unit.

The initial intention for Land Application (LA) was to dry the liquor in the dry season in the LA site (30 rais), then to recover dry solids for initial use as organic fertilizer having an NPK content of 4:1:3 %. Later, it was shown that although dry solids were in greater demand, the land area is too small to recover enough solids, in which case liquid liquor is more useful due to the low expense in the long term. Then finally LA is used as an SL.

It is interesting to note that before DAU was found to be a better means for the disposal of the liquor in comparison with other methods such as composting, road spray, and fish feed, SL+LA were practised, including DAU, at a small scale (5 - 10 rais). Since 1989, when farmers became aware that DAU of the liquor in paddy fields produced higher rice yield, DAU became very popular.

Direct Agricultural Use (DAU): Before the liquor could be used by the DAU method in the field, research was carried out in 1989 - 90. The type of rice used in the experiment was Dok Mali 105 (or fragrant rice). The liquor is normally the digested effluent from the last lagoon with the characteristics shown in Table 1. The amount of digested liquor varies from 0 - 30, 60 m^3/rai. It can be seen from the result in Table 1 that the rice yield does not increase significantly between 30 and 60 m^3/rai of the liquor (only 10% increase of rice yield). This result indicates that it is far safer to apply the liquor once in every other year on the same plot. Secondly the addition of 6 kg. of P_2O_5 in one of the Runs (Run No. 4) does not significantly increase the rice yield compared with Run No. 3 when no P_2O_5 was added. These results indicate that P is just sufficient in the liquor and that there is no need for additional P_2O_5.

From the results obtained, full scale application of the liquor at a rate of 50 - 100 m^3/rai was initially applied to the paddy fields to cover only 5-10 rais. When these farmers found that rice yield increased 2-3 times over that without the liquor, farmer demand increased greatly with the result that in the last 5 years (1992 - 7) more than 5 000 rais are now fertilized with the liquor at the rate of 300 000 m^3 of liquor per year (over the 8 month period, December - July). The fertilized area can be divided into two parts (A and B) having a total area of 3 500 rais on each side of the small road. (Figure. 2). The digested or raw liquor is pumped through a 4^2 diameter GS pipe (hard pipe) across the road where it is further distributed to each plot by a flexible fire hose with a $2½^2$ diameter. A higher dosage rate of liquor has been applied i.e. 100-125 m^3/rai per 2 years due to three factors : a) the liquor is diluted 50% by rain b) the liquor has been partially digested on land for 4-5 months before growing rice, and c) the application of liquor is once in every other year. The rice is grown in the wet season only once a year (between August - November). The harvesting of rice generally takes two weeks in December . The yield generally increases between 2-3 times (or 300-400 kg./rai of rice yield). This result indicates that the liquor serves as organic fertilizer to replace chemical fertilizer. Moreover the soil becomes soft with the liquor as compared to chemical fertilizer which hardens the soil.

The beneficial byproducts of the liquor also includes: a) reduction in the number of insects (thrips) that eat the young leaves, and b) a reduction or destruction of field crabs as well as cherry stones that feed on plant leaves. The result is that farmers have eliminated use of insecticides to kill thrips as well as (Furadan) for field crabs or aldosulfane for cherry stones or Golden Apple Snails or Pomacea Canaliculata Lamarck. The liquor takes care of these problems by reducing the oxygen level as well as by high salinity (20 milli mho). In short, the liquor serves as an organic fertilizer as well as insecticide for thrips , crabs and cherry stones.

The amount of liquor pumped to the paddy fields is approximately 300 000 m^3/year on 7 000-8 000 rais of land, and it takes 3 - 4 days only to dry up on sandy-clay soil. Odour is, threfore, kept to a minimum. Farmers plough through their land during early rainy season in June - July until the heavy rain in August - September. Then, farmers will start to grow their paddy rice. The rain dilutes the liquor considerably so that there is only a trace, if not zero colour, of the liquor that is noticeable towards the growing period of paddies.

Farmers from the other 13 distillery plants visited and learned from Ubonratchathani's experience in early 1997 (2540) and it is estimated that now the liquor has been applied to 30 000 rais of paddy and other crops nationwide (as of December, 1998).

Soil characteristics with and without spent wash liquor

Three soil samples were collected in June 1998: 1.) from paddy field without applying SWL; 2) from the plot after 7 years after SWL had been applied (every other year), and 3) from a plot where SWL had been applied for only one year. The result of soil characteristics is shown in Table 2. It can be seen that N disappears in the soil in #2 and #3 before the paddy was growing in July 1998. However the yield still showed an increase of x2-3 compared with the control. The results indicate that N, P are not the source of increased yield. Yield increase may be due to two factors: a) the soil structure improves with utilization of SWL hence improves root ventilation, and b) soil bacteria at 30^o C easily releases nitrogen from the soil through denitrification. Nevertheless, the results are surprising insofar as N and P in industrial wastewater might be expected to behave similar to organic fertilizer and it is surprising that N, P are not the key factors in increased yield. In any caset, chemical fertilizer is less popular than industrial wastewater.

In order to avoid accumulation of K in the soil the amount of 20 - 30 m^3/ rai of SWL is gernerally adopted for growing rice and other plants. Dilution water for SWL is generally 20

TABLE 2
Comparative soil analysis using swl (spent wash liquor)

1. CONTROL: no SWL			2. Utilize SWL for 7 years (every other year)			3. Utilize SWL for one year (in 1998)		
	Before rice begins growing (June/98)			Before rice begins growing (June/98)	After rice is grown (Dec/98)		Before rice begins growing (June/98)	After rice is grown (Dec/98)
ph	5.0	-	ph	8.8	7.5	ph	7.7	7.7
N mg/l	435	-	N	200	170	N	300	335
P mg/l	3	-	P	9	2	P	17	9
K mg/l	10	-	K	340	220	K	1000	237
Rice begins growing in July 1998			Apply SWL betweeen Dec-May each year, with 150 kg N/rai. Start growing rice in July/98 for harvest in Nov/98.			Apply SWL between Dec-May with 150kg N/rai. Start growing rice in July/98 for harvest in Nov/98.		

Notes: 1 rai = 1600 m^2; SWL contains: N=1 500 mg/l, P=150 mg/l, K=4000 mg/l.

times that of SWL and thorough mixing of SWL and dilution water before applying to the paddy fields is also crucial for higher yield of crop.

Cost of operation

It is estimated that the operation, maintenance and labour for pumps to deliver liquor to 3 500-4 000 rais is 1.5 Baht/m^3 (US$1 = approx. 38 Baht). This does not include land and construction cost for the Storage Lagoon and Land Application simply because the land cost rises substantially to cover construction cost due to inflation rate. However, the benefit obtained is equivalent to 50 Baht/m^3 of chemical fertilizer for the same yield. The benefit accrues to the farmers and not to the Distillery Plant because the plant delivers the liquor at no cost to the farmers. However the real benefit to the Plant is that the cost of liquid wastewater disposal using paddy field disposal is the lowest - i.e. 4.0 Baht/m^3 or 1,200 000 Baht per annum as compared to other means (composting , road spray , fish feed , UASB etc.) (see Table 3)

TABLE 3
Cost of treatment in relation to spent wash liquor

Activity in relation to Spent Wash Liquor Treatment	Cost to Distiller Baht/m^3 (US$/$m^3$)	Benefit to farmer Baht/m^3 (US$/$m^3$)
Composting (C) (give away free)	40 (1.0)	30 (0.75)
Composting (C) (after sale)	20 (0.5)	10 (0.25)
Land Application (LA) (give away free) to recover dried organic solids	20 (0.5)	100 (2.5)
Road Spray (RS)	40 (1.0)	no dust
Direct Agricultural Use (DAU)		
- delivered by direct pumping	4.0 (0.1)	50 - 100 (1.25-2.5)
- delivered by truck	20 (1.0)	50 - 100 (1.25-2.5)
Fish Feed (FF)	40 (1.0)	500 - 1 000 (12.5-25)
Evaporation & Incineration (E&I)	800 (20)	-
Anaerobic Digestion+TF+AS+PCT	300 (7.5)	-

TF = Trickling Filter; AS= Activated Sludge; PCT = Physical Chemical Treatment

How does wastewater benefit the Thai economy?

Each distillery plant can supply the liquor to 4 000 rais of paddies; therefore, with 13 plants the total area of paddy fields will be only 52 000 rais. This represents only 0.04% of 150 million rais of cultivated land. In order to supply a large part of all cultivated land a large quantity of SWL would be needed (2 000 x 10^6 m^3 per year).

Thailand is importing most of its oil from abroad and car fuel consumption is estimated to be 20 x 10^6 m^3 per year and the foreign exchange loss of 200 Billion Baht/year. We should utilize this portion of money growing sugar cane as well as producing pure alcohol for car fuel. We would then produce 200 x 10^6 m^3 of the spent wash liquor per year and sugar cane of 200 x 10^6 tons/year. This amount of liquor will be sufficient to use as organic fertilizer for 10 x 10^6 rais.

Conclusion

It is clear from the method of Direct Agricultural Use (DAU) of the spent-wash liquor from Ubonratchathani Distillery Plant that 300 000 m^3 of liquor can be applied directly to 5 000-6 000 rais of paddy field each year during the dry season. This will increase the rice yield by 2-3 times. The liquor will act as an organic fertilizer as well as an insecticide to prevent insects, thrips, field crabs, and cherry stones from destroying the rice. The cost of DAU is 2.0 Baht/m^3 of liquor whereas the farmers' benefit is 50 Baht/m^3 which is equivalent to the cost of purchased chemical fertilizer that would otherwise be required by the farmers. This DAU method proves to be successful for the farmers who are very glad to receive the free liquor. There is not, however, enough liquor for delivery to farmers outside the committed area. This is one of the good examples of how to deal with strong organic wastewater, in an environmentally and economically sustainable manner, in the green area surrounding the Distillery Plant. Thailand is an agricultural country, therefore any organic wastewater that can be used to supplement commercial fertilizer will contribute to Thailand's efforts to achieve sustainable development at low cost and with demonstrable benefits to local farmers.

Agriculture's influence on water quality in lower northeastern Thailand

ABSTRACT

For the past three decades the Thai policy of rapidly increase agricultural production for exports has led to an enormous increase in agricultural land and over-utilization of chemical fertilizer and pesticides. The water quality of many main rivers has been affected by agricultural development. This paper review the situation and consequences of agricultural development on water quality in lower northeastern Thailand. As well, the water quality of Lam Takong River Basin is presented as a case study.

Since the adoption of the First National Economic and Social Development Plan the economic development rate of Thailand has been growing at an average of more than 8% per year. Especially during the 6th National Economic and Social Development Plan (1987-1991), the economic growth of the country was more than 11% per year, one of the highest in the world. During the early period of the 8th National Economic and Social Development Plan (1997-2001), Thailand has faced an economic crisis caused by a reduction in exports, a drop in investment and serious problems in the financial sector. However, it is still believed that with the solid fundamental structure of the Thai economy, the situation will recover and the economy will continue to grow in the foreseeable future.

The economic development over the past three decades has caused increasing problems on natural resources, environment and quality of life of the people in Thailand. Although efforts have been taken by all the governments, success has been only partial. Environmental quality problems have become a persistent issue. Without appropriate and efficient management to solve these problems, resources and environment will be the major constraint to the sustainable development of the country.

Natural resource and environmental degradation in the past has been directly caused by the expansion of agricultural and agro-industrial production. The increasing exploitation of natural resources, including forest, water, land, marine resources, mineral and energy, has exceeded the carrying capacity and the renewability of the resources. The expansion of agricultural and industrial area, without appropriate land use zoning has resulted in soil degradation and water pollution. Policies that promote monoculture of commercial crops has increased the use of chemical pesticides. Costs of production have increased and the health of the farmers has deteriorated, and caused environmental and pollution problems including, water, air and various hazardous matters, which further affected the quality of life for the Thai people.

Vipada Apinan
Chief, Water Resource Development Projects, Office of Environmental Policy and Planning, Bangkok, Thailand

Water resources

Demand for water from domestic and economic activities is on an increasing trend, following the expansion of the economy and population, while the sources of water supply are limited. Scarce water resources have been the main constraints for production acceleration, especially in the agricultural sector. At present, about 29 million rai or about 22% of agricultural land is irrigated. Thailand has a total of 392 reservoirs of large, medium and small size with a total storage capacity of 70 thousand million cubic metres. Seasonal fluctuation of annual rainfall results in variation of water quantity in the reservoirs. This affects management capability to support the increasing water demand, especially during the drought period. Water shortage lowers agricultural productivity and increases conflicts between different agencies dealing with water resources causing inefficiency in water use. The potential to expand large reservoirs in Thailand is now limited, due to their physical and environmental constraints. Yet there are still 28,750 villages which are short of water supply for domestic use. Nearly 50% of the total number of villages in the country have insufficient water for their dry-season crops and urgently need assistance. Water quality of surface, groundwater and aquifers, both natural and artificial, has increasingly deteriorated, due to the inefficient use and management. There is wasteful use and conflict of use of water amongst agriculture, industry, service and domestic sectors.

Water pollution

At present, water quality of major water resources of the country has deteriorated significantly. Information gathered continuously by the Department of Pollution Control reveals that the water quality of several major rivers such as Chao Phraya River and lower Tha Chine River is lower than the minimum standard quality for Type 4 water resource prescribed for water usage. Water quality of several rivers has been deteriorating noticeably such as the water quality of Sakaekrang River, Lopburi River, and Lampao River. Water quality of many other rivers such as Ping River, Wang River, Yom River, Nan River, Chi River, Mun River, Mae Klong River, Bangpakong River, Petchburi River, Kwae Noi River, Tapi-Poomduang River, decline when they flow through densely populated areas. Coastal sea water quality is also found to be deteriorating such as in Chonburi, Pattaya, southern part of Patong Beach, the mouth of Pakpanang River, the mouth of Khlong Tha Soong of Nakhon Si Thammarat province, and at Koh Loi of Sriracha, Chonburi Province. The quality of groundwater nationwide is also declining due to pollution.

Water pollution is due to industrial expansion which has increased by more than 10% during the past ten years, as well as by population increase and urban migration. Swine farming and fish and prawn farming also contribute to water pollution by their waste water discharges. Insufficient natural runoff caused by deforestation, as well as lack of efficiency in the administration, management and control of pollution both in the legislation and its enforcement, and lack of coordinated monitoring by several agencies are also contributing factors.

Agriculture in the lower northeast of Thailand

The total farmland in the lower northeastern part of Thailand is about 4.7 million ha corresponding to 62.69 % of the total land area (Table1). This includes activities such as paddy, fruit crops, vegetables/ flowers and pasture land.

Agriculture in the area is characterized by subsistence and traditional farms. Farmers grow the main crop of paddy mainly for self-consumption except in the Thung Kula Ronghai plain

TABLE 1
Agricultural area (ha) in lower northeast Thailand

Province	Total area	Farm land	%
Nakhonratchasima	2 049 396	1 413 129	68.95
Buriram	1 032 188	673 588	65.26
Ubonratchatani	1 890 610	997 708	52.77
Yasothon	416 166	335 904	80.71
Mukdahan	433 983	128 121	29.52
Surin	812 406	609 692	75.05
Sisaket	883 998	555 225	62.81
Total	7 518 747	4 713 367	62.69

where rice production supplies the highest quality export in the country. Technologies applied in the area are primitive. Capital intensive farming such as rice cultivation using high-yielding varieties under high input of fertilizers/chemicals, year-round irrigation and intensive agricultural extension services have not worked well under the prevailing rainfed conditions. In respect to rice, farmers grow photoperiod sensitive varieties which have low response to fertilizer application and are generally low in yields. However, this photoperiod sensitivity is an indispensable characteristic that stabilizes rice yield under erratic rainfall conditions. When transplanting of a photoperiod sensitive variety is delayed due to the delayed onset of the rainy season, seedlings may have to be kept in the seed bed for 50 to 70 days, which cause the beginning of tillering in the seed bed and loss of tillering capacity when transplanted, thus resulting in reduction in yield. On the other hand photo-sensitive varieties have a longer vegetative period and 60 to 90 days-old seedlings continue to tiller after transplanting and give stable yields.

Farm mechanization is rapidlly progressing in the area due to labour shortage caused by the increasing job opportunities in non-agricultral sectors. More than 90% of farm land in the suburb of Korat is plowed by machine. It is nowadays rare to find farmers cultivating paddy fields by buffalo. Fertilizer application is common practice. About 86% of farmers use fertilizer in either chemical or organic forms. Generally, farmers do not know the appropriate application methods. Pesticides are also over-utilized due to the introduction of varieties and monocultures.

Water resources

The lower northeastern region is one of dry parts of the country with an average annual rainfall of approximately 1 100-1 300 mm under a savanna climate. Approximately 90% of the total annual precipitation is concentrated in the rainy season of May through October. Extended droughts are common during the dry months. The provinces of Nakhon Ratchasima and Buri Ram on the Khorat plateau have the lowest average percipitation with approximately 1 100 mm per annum. The catchment area of the Mekong river can be devided into the Mun River basin and the Chi River basin. The Lam Takong River flows into the downstream reach of the Mun River, and small rivers drain directly into the Mekong. This report will concentrate on the Lam Takong River basin which flows downstream to the Mun river.

The **Lam Takong** originates in the southern part of the Dongrak Range in the Khao Yai National Park and runs through Pak Chong District before flowing into Lam Takong Reservoir, then to the Mun River . This reservoir irrigates almost 22 000 acres of farmland downstream, including the Soong Nern district and Nakhon Ratchasima municipality. EGAT is undertaking the construction of Lam Takong Pumped Storage Project from the Lam Takong Dam.

Agriculture' s influence on water quality

Agricultural wastes are the predominant pollutants in Lam Takong River as most of the land use in this basin is farmland, pasture land and livestock. Livestock, especially, is the main

TABLE 2
Water quality in Lam Takong River - dry season (January 1997)

Sampling Point	Time	Temp.	pH	EC	SS	TDS	DO	BOD	COD	NO3-N	Cl	PO4-N	H2S	Total Coliform	Fecal Coliform
		(oC)		(mhos/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(MPN/100 ml)	(MPN/100 ml)
1. After Khao Yai	10.25	22	7.74	508	6	328	8.45	1.5	7.3	0.32	-	0.04	-	110	110
2. Before Reservoir	12.20	22	7.74	568	2	356	7.25	1.2	18.2	0.47	-	0.08	-	1 100	1 100
3. In the Reservoir	15.05	25	8.41	315	4	186	10.8	2	21.8	0.03	-	0.03	-	0	0
4. Dam Front	14.00	26	8.35	310	2	7	10.6	1.5	32.8	0.01	-	0.06	-	350	350
5. After Soong Nern District	16.15	24	7.89	311	24	192	8.3	0.9	21.8	0.08	-	0.1	-	2 700	2 200
6. Before Nakorn Ratchasima	16.5	24	7.75	332	112	204	7.4	0.9	18.2	0.11	-	0.12	-	1 600	1 600
Municipality															
7. After Municipality	18.2	22	7	597	22	332	2.4	10.8	47.3	0.08	-	0.71	-	3 100	3 100

TABLE 3
Water quality in Lam Takong - rainy season (August 1997)

Sampling Point	˙˜	Temp.	pH	EC	SS	TDS	DO	BOD	COD	NO3-N	Cl	PO4-N	H2S	Total Coliform	Fecal Coliform
	(„.)	(oC)		(mhos/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(MPN/100 ml)	(MPN/100 ml)
1. After Khao Yai	10.3	27	7.62	156	64	112	7.7	2.0	20.0	0.42	-	0.07	-	> 2 400	> 2 400
2. Before Reservoir	11.00	28	7.66	153	176	112	7.1	2.5	63.7	0.62	-	0.16	-	> 2 400	> 2 400
3. In the Reservoir	11.4	30	8.31	329	246	196	8.4	1.4	69.3	0.26	-	0.04	-	1 600	920
4. Dam Front	12.00	31	8.37	331	130	182	9	1.4	67.3	0.19	-	0.02	-	130	130
5. After Soong Nern District	12.30	30	7.81	346	20	196	6.8	1.1	61.9	0.22	-	0.03	-	920	920
6. Before Nakorn Ratchasima	13.2	21	7.53	445	14	262	5.5	1.5	67.3	0.15	-	0.02	-	220	220
Municipality															
7. After Municipality	14.5	32	8.18	689	22	390	9.6	20.4	92.8	4.38	-	0.86	-	> 2 400	> 2 400

cause of algal blooms in Lam Takong Reservoir almost every year. Moreover,the restuarants along the roadside also directly discharge wastewater into the Lam Takong Reservoir. Nakhon Ratchasima Municipality consume water supplied from this Reservoir and have been affected by eutrophication of water in the reservoir during the dry season almost every year.

Studies of water quality of Lam Takong carried out by office of Environmental Policy and Planning (OEPP) covered the area from Khao Yai to the confluence with the Mun River. Representative data are provided in Tables 2 and 3. The area where the water quality is comparatively low is behind Nakhon Ratchasima Municipality where DO ranges from 2.4 - 9.6 mg/l and BOD between 3.1 - 20.4 mg/l. The cause of the lower water quality is run-off from vegetable gardens along the riverside. The poorest water quality occurred in August accompanied by eutrophication and algal blooms. In addition total coliform there was as high as 3,100 MPN/L, indicating that the community wastewater is a major cause of low water quality downstream of Lam Takong.

During the period that Lam Takong Pumped Storage was constructed (1996-1999), OEPP also studied water quality within the reservoir, and water quality from each sampling point had similar problems. The pH, BOD and DO are low, indicating poor water quality in the dry season.

Recommendations

Agriculture and water quality are related in many ways. On one hand, agriculture demands good water quality. On the other hand, agriculture is a major cause of habitat loss, extensive water use, eutrophication, and release of nutrients, trace elements and pesticides. Due to the strong mutual dependency of agriculture and water quality and the adverse effect of water pollution to human use, the integration of environmental aspects in agricultural projects has been initiated. The following are the principal recommendations.

1. Sustainable agricultural development or so-called “Royal Project” should be encouraged in the watershed.
2. Over-use of fertilizer should be prevented by application methods that reduce leaching, denitrification and nitrification, and by better adaption to the actual needs of the crop.
3. Swine farming and fish and prawn farming contributed to water pollution by discharges of waste water. More comprehensive approaches are required, as has been undertaken in the industrial sectors.
4. Irrigation projects should include proper drainage to avoid soil salinization.
5. Control of land use in the watershed should be strictly applied by the government agencies, and should require the farmer to follow appropriate land management strategies.

Conclusions

Although water quality of major water sources of lower northeastern Thailand is acceptable compared to other major water resource of the country, there are some parts where the water quality has deterioted such as Lam Takong River. The main causes of water pollution are due to agro-industry, agriculture and community waste. Moreover, insufficient natural water from uplands as well as lack of efficiency in the administration, management and control of pollution from agriculture both in the legislation and its enforcement, are also contributing factors. Most of the effort in dealing with water pollution has been focused on industrial waste and community wastewater with very little attention to agricultural wastewater. Most of the people in the agricultural sectors are illiterate and/or lack awareness of the problem. It is, therefore, recommended that strategies for public participation and sustainable agriculture should be promoted to help solve this problem rather than using command and control strategies. Agencies and private organizations should be encouraged to use technologies/processes/operations which create no contaminating waste. The government sector should reduce incentives for use of chemical fertilizers and other agricultural chemicals and, instead, encourage the use of technologies not hazardous to health and the environment such as the use of bio-technology for fertilizers and pesticides, and the encouragement of production of non-toxic goods including quality certification.

References

JICA, 1993. The Study on the Regional Development Plan for the Lower Northeast and the Upper East Regions in the Kingdom of Thailand. (n.p.)

Office of Environmental Policy and Planning, 1997. Environmental Quality Management Plan. (n.p.)

Northeastern Region Environmental Office, 1997. Final Report of Northeastern Environmental Quality Monitoring Project. (n.p.) (in Thai).

Royal Irrigaton Department, 1995. Mun River Basin Development Master Plan Project. Bangkok : Royal Irrigation Department.

Envrionmental Care Center, Co.,Ltd. and University of Technology Suranaree, 1997. Final Report of Environmental Management to Rehabilitate the Water Resource in Lam Takong Basin, prepared for Nakorn Ratchasima Province. Bangkok : Environmental Care Center Co., Ltd. (in Thai).

Water quality and agriculture production in the Mekong Delta

ABSTRACT

The Mekong Delta is the main granary for Viet Nam and plays an important role for national economic development. Located in the tropical area, the Mekong Delta offers favorable conditions for agriculture production such as light and water. The abundant availability of water is contributed by surface water, rainwater and groundwater in large quantity and of good quality. Even with an abundance of water, the Mekong Delta is experiencing a number of difficulties in meeting the requirements for domestic as well as agriculture purposes due to a salinity intrusion problem that occurs during the dry season. Also, the acidic water which characterizes the Mekong Delta is unsuitable for irrigation The impact on water quality of agriculture development activities such the use of fertilizers and pesticides is discussed. The development of a canal system as well as other water control measures are effective solutions to reduce to a certain extent the disadvantages due to poor water quality in the Mekong Delta.

Covering an area of 39,000 km^2 equivalent to about 12% of the total area of Viet Nam, the Mekong Delta [Figure1] is the main granary for Viet Nam of which the rice production (about 16 million tonnes) occupies 50% of all country's production (Truong, 1998). The Mekong Delta also contributes a large part of the products exported from Viet Nam, especially rice and aquaculture products. Currently more than 30% of Viet Nam's GDP are linked to the Mekong Delta, pointing the important role of this region in the economic development of the country. The region holds potential for further economic development that could bring both local and national benefits.

NATURAL AND SOCIAL CHARACTERISTICS OF THE MEKONG DELTA

Hydrometeorological characteristics

There are two distinct seasons in the Mekong delta, the rainy season lasting from May to November and the dry season from December to April. The average annual rainfall totals 2,400 mm in the western part of the delta, 1 300 mm in the central part and 1 600 mm in the eastern part. During the dry season, the flow at Tan Chau on the Mekong River and at Chau Doc on the Bassac River is at its lowest, namely less than 3 000 m^3/s. In contrast, during the rainy season the highest flow is reached at about 30,000 m^3/s. The data for the average montlhy flow recorded in a typical year at Tan Chau and Chau Doc are presented in Table 1.

Truong To Van and Hien Pham Gia
Centre for Water Quality and Environment, Ho Chi Min City, Viet Nam

FIGURE 1
Variations in the main ion levels in the Mekong River, at Tan Chau (meq/L)

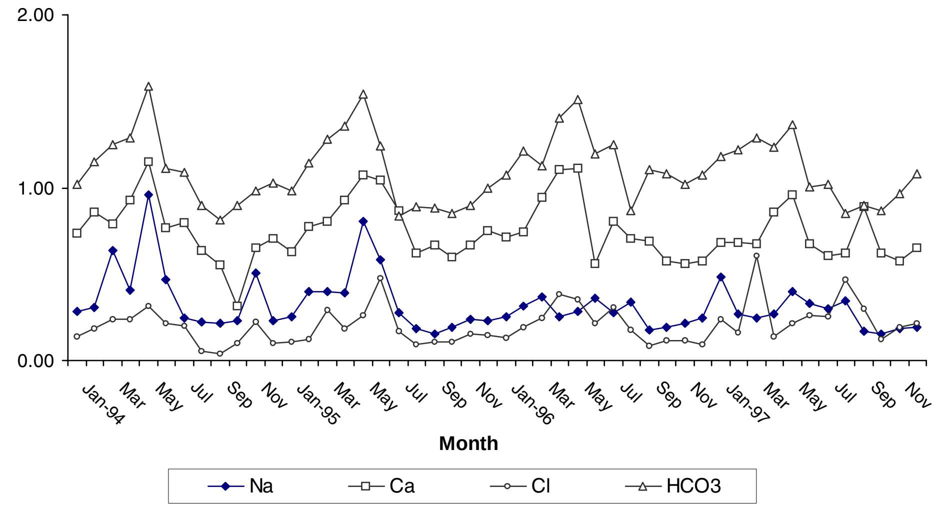


TABLE 1
Average monthly flow at Tan Chau and Chau Doc (m^3/s)

Location	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tan Chau	6220	3720	2600	2010	2640	7180	11270	16390	20140	20340	15260	10180
Chau Doc	1360	700	420	330	460	1450	2390	3970	5290	5480	4700	2710
Total	7580	4420	3020	2340	3100	8630	13600	20360	25430	25820	19960	12890

Midway through the rainy season, upstream heavy rainfall causes a significant increase in the level of the Mekong River and as a result a large area of the Mekong Delta becomes flooded. The inundation often starts in July or August and ends in November or December. There is an extensive canal system in the Mekong Delta and it plays an extremely important role for the economy of the region in ensuring the supply of irrigation water, providing flood control and serving as a waterway for transport. Flow regimes in the Mekong Delta are strongly impacted by the surrounding seas, namely the East sea with dominant a semi-diurnal tidal regime and a tidal amplitude of about 300-350 cm, and the West sea with a mixed semi and diurnal (dominant) tidal regime and a tidal amplitude of about 80-100 cm.

Soil

The Mekong Delta occupies an area of about 3.9 million ha, with 2.4 million ha used for agriculture and aquaculture. The region is characterized by the following soil types (NEDECO, 1993):

- Alluvial soil (1.2 million ha): This soil type is concentrated in the middle portion of the Mekong Delta, it has a high natural fertility and it presents no production restrictions. Many kinds of crops and fruits can be cultivated in this soil.
- Acidic sulphate soil (1.6 million ha): This soil is characterized by a high degree of acidity, possible levels of aluminum and poor fertility. This soil can be classified into strongly acidic soil (0.55 million ha) and moderately to slightly acidic soil (1.05 million ha). While the strongly acidic soil has very little capacity for agricultural utilization, the moderately to slightly acidic one can be used for agriculture purposes under sufficient water and fertilizer conditions. This type of soil also includes the acidic soil affected by salts. Acidic soil is

concentrated in the Plain of Reeds, Long Xuyen Quadrangle, and the acidic soil affected by salts is found mainly in Ca Mau Peninsula.

- Saline soil (0.75 million ha): Permanent saline soil (0.15 million ha) is formed along the narrow coastal bands while non-permanent and occasionally saline soil (0.6 million ha) is found quite inland in the center of the Ca Mau peninsula and along the East sea coastal area. This type of soil is partly used for rice cultivation during the rainy season and partly for shrimp farming during the dry season.
- Other soil types (0.35 milion ha): These types of soil include peat (in the U Minh area), gray soil on ancient alluvial areas (in the furthermost northern part of the Mekong Delta) and on hills, and mountain soil (in the northwestern portion of the Mekong Delta).

Socio-economic characteristics

Presently, about 16 million people live in the Mekong Delta region and approximately 85% of that population are living in rural areas. While the population is dispersed over the area, significant concentrations of people live along canals. The agricultural production in the delta involved mainly private individuals and rice cultivation is predominant.

The water supply for domestic purposes in the Mekong Delta has been and continues to be a serious problem, more in terms of quality than quantity. People in rural area rely on rivers, canals, wells and rainwater as their source of water for domestic purposes. In general living conditions in the Mekong Delta are still difficult but the new economic policy of the Government has brought significant improvement.

WATER RESOURCES OF THE MEKONG DELTA

Surface water sources

The main source of surface water source in the delta is the Mekong River, flowing into Viet Nam through two branches, namely the Mekong River at Tan Chau and the Bassac River at Chau Doc. Two distinct flow regimes are observed on account of the existence of the flood and dry seasons. During the annual flood season, often from July to December, the total flow coming to the Mekong Delta can reach 40,000-42,000 m^3/s and be contributed as follows: 25,000 – 26,000 m^3/s by the Mekong River at Tan Chau, 7,000-8.000 m^3/s by the Bassac River at Chau Doc, and 7,000-10,000 m^3/s by the surface runoff entering through the boundary line with Cambodia (Anh, 1996). In the dry season, the flow lowers very much and during the driest month, often April or May, the average flow can be less than 3,000 m^3/s. The low flow in the dry season causes severe constraints in the water supply, especially for irrigation purposes. The high water demand together with low upstream flow during the dry season form favorable conditions for sea water intrusion into fields, from the East and West seas via the Mekong, Bassac and Vaico rivers and through the canal system. This situation will be analyzed in detail later on in this paper.

The water quality of the Mekong River is quite good. According to a published classification of the mechanisms controlling the chemical composition of water (Gibbs, 1970), the mechanism applicable to the Mekong River belongs to the second kind whereby the chemical composition is linked to rock erosion pro-cesses. Accordingly, meteoro-logical conditions, topography characteristics and the main types of material found in the river catchment area must be considered factors influencing the composition. The levels of main water constituents such as the Na, K, Ca, Mg, SO_4, Cl ions have been shown to exhibit a clear seasonal periodic variation

TABLE 2
Values of SAR and EC in the Mekong river

	EC (dS/m)		SAR	
	Min	Max	Min	Max
Mekong (Taân Chaâu)	1.02	2.10	0.235	0.967
Bassac (Chau Doc)	1.19	2.88	0.269	0.850

(Hien, 1993). As can be seen in Figure 1, maximum values for these constituents occur during the dry season and minimum ones during the rainy season due to dilution by rain; naturally, the values are directly dependent on those present in the river upstream. The observed variations have been quite stable through the years during which monitoring has been carried out. Table 2 presents some values of the SAR (Sodium Adsorption Ratio) and EC (electrical conductivity) parameters obtained for the Mekong River. According to the FAO classification of water quality for agriculture (FAO, 1985), the observed values show that the water quality of the Mekong River is suitable for irrigation.

The levels of nutrients such as the NO_3^-,NH_4^+, and PO_4^{-3} ions are often high in the rainy season and the maximum value measured for the Total Nitrogen and Total Phosphorus parameter are about 1 and 0.2 mg/L, respectively. This situation is due to the fact that during the rainy season, these constituents get washed from the soil and are transported into the river with the surface runoff. As for the total suspended solid (TSS) content of the Mekong River, at about 0.05 g/L during the dry season and up to about 1.0 g/L during the rainy season, it constitutes an important annual source of alluvia responsible for the fertility of the Mekong Delta. In general, the water of the Mekong River has a slightly alkaline character and presently there has not been any signs of chemical pollution in this water body.

Groundwater

The groundwater reserve of the Mekong Delta is rather high and it has been estimated that these resources can be safely exploited at a rate of about 1 million m^3/day, mainly based from the upper pleistocene layer, one of the five layers where groundwater is stored in the Mekong Delta area. Groundwater is presently used mainly for domestic purposes, at an estimated rate of about 250 000 m^3/day (La, 1995). The quality of the groundwater is generally suitable for domestic and drinking water purposes. In some places, however, the levels of some constituents exceed those considered safe, for instance iron (Fe) in the Plain of Reeds and sulphate (SO_4^{-2}) in the Can Tho province. At present the exploitation of groundwater resources is seriously increasing, especially as households rely on this water source for domestic purposes.

Rainwater

The rainy season often lasts from May to November when 85% of the annual rainfall is recorded. The annual rainfall has been abundant and rather stable through the years, but the spatial distribution is evident. The rainwater in the Mekong Delta contains quite a low level of total soluble solids, at about 21 mg/L, it has a chemical composition similar to sea water in terms of sodium and calcium ions, and its pH ranges between 5 and 7. The rainwater is of very good quality and it is used domestically as well as for irrigation in areas where there is a shortage of fresh water in the dry season. In order to take full advantage of rainwater, it would be very important to set up collection devices during the rainy season when it is most abundant.

Water quality issues in the Mekong Delta

Although water resources in the Mekong Delta are very abundant, the geological structure and topographical characteristics of this region as well as human activities are factors that have an impact on water quality and consequently are restricting the utilization of these resources. The acidity of the water, the salinity intrusion and other impacts from human activities are the main causes of the utilization constraints.

Acidic water

The acidity of the water in the Mekong Delta is a typical characteristic and this situation is due to the occurrence of acid sulphate soil (ASS) and its content of pyrite (FeS_2). Some 1.6 million ha or 41.1 % of the Mekong Delta area is characterized by acid sulphate soil and this is particularly pronounced in some 0.55 million ha found in the Plain of Reeds and the Long Xuyen Quadrangle. A case of intermediate severity is also found in the Ca Mau Peninsula the acid sulphate soil is affected by saline water during the dry season. The acid sulphate soil is responsible for the acidification of the water through a the process described below.

During the dry season, the acid sulphate soil dries out and cracks form, giving way for oxygen to penetrate into the deeper layers of the soil. As a result, the oxidation of pyrite will occur and produce the substances responsible for the acidification process. Then at the beginning of the rainy season, the acidification products are washed out or leached into the water of canals where low pH values of about 4 or even less are measured as well as high concentrations of toxic ions. The oxidation of pyrite is quite a complicated process involving both chemical and microbiological reactions. The process involves several stages and it can be summarised by the following chemical equations (Dent, 1986):

$$FeS_2 + 7/2\ O_2 + H_2O = Fe^{2+} + 2\ SO_4^{2-} + 2H^+ \qquad (1)$$
$$Fe^{2+} + 1/4\ O_2 + H^+ = Fe^{3+} + 1/2\ H_2O \qquad (2)$$
$$Fe^{3+} + 3\ H_2O = Fe(OH)_3 + 3\ H^+ \qquad (3)$$

substituting (2) and (3) into (1) gives the overall reaction

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O = Fe(OH)_3 + 2\ SO_4^{2-} + 4\ H^+ \qquad (4)$$

dissolved Fe^{3+} can be reduced by FeS_2 to produce more acid into the stream

$$FeS_2 + 14\ Fe^{3+} + 8\ H_2O = 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+ \qquad (5)$$

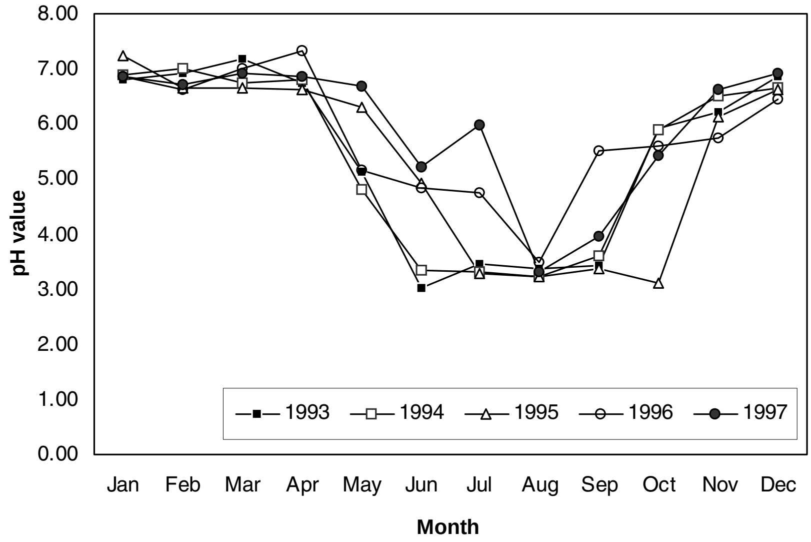
The released acid will react with aluminosilicate minerals to form soluble products such as aluminum sulphate and some secondary minerals such as kaolinite. These products will be washed out into the canal upon the first precipitation during the rainy season. Consequently, the water in canals will be heavily polluted by high concentration of Al^{3+}, Fe^{2+}, Fe^{3+}, and SO_4^{2-} and a pH value as low as 3 or less.

As mentioned above, the Mekong Delta comprises three areas characterized by acid sulphate soil structure and they are delineated as follows (see Figure 1):

a. One area is the Plain of Reeds located in the northeastern part of the Mekong Delta, where 378,185 ha or about 50% of the total area of 738,000 ha are affected by acid sulphate soil. In the Tram Chim (Dong Thap province) area, the pH of the water is quite low at about below 4, it contains a high concentration of aluminum of about 50 mg/L and the duration of the acidic water period is very short. In Kien Binh (Long An province), on account of a depressed topography and poor drainage conditions the duration of the acidic water period is rather long (for some months) and the aluminum concentration in the water reaches about 30 mg/L. Acidic water is encountered all year around in the Bo Bo region because the acid sulphate soil covers a large area and there is a shortage of freshwater at the beginning of the rainy season to wash out the acidic water.

b. In the Ca Mau peninsula, the highest concentration of aluminum observed in the water is about 40 mg/L. The most severe cases of acidic water are found at Thoi Binh, Viõnh Thuan

FIGURE 2
Variations of pH in the Chac Bang canal in the Ca Mau peninsula



on the Trac Bang canal. Every year at Thoi Binh, the canal water is acidic with pH values in the range of 3 to 4.5 for 4 months or 5 months (from June to October) [Figure 2]. Drainage conditions are poor and the duration of the acidic water period is prolonged.

c. Located in the northwestern part of the Mekong Delta, the Long Xuyen Quadrangle occupies an area of about 492,000 ha and regions with acid sulphate soil are concentrated between the Ba The and Tri Ton canals. The acidic water appears at the beginning of the rainy season at the end of the Vinh Te and Tam Ngan canals and lasts from May to August. Moreover, these areas have also been affected by saline water intrusion, thus the water is not only acidic but also saline.

Besides having low pH values and high contents of ions such as Al, Fe, and SO_4, the acidic water has also a rather high concentration of total Nitrogen with an observed maximum value of about 3.5 mg/L. Because the acid sulphate soil has a surface soil layer with a rather high nitrogen content, typically from 0.15-0.50%, at the beginning of the rainy season this nitrogen content gets washed out also into canal water. In contrast, the phosphorus content in the acidic water is low at about 0.2 mg/L as the phosphorus present in the acid sulphate soil reacts with aluminum and iron to form insoluble compounds.

The occurrence of acidic water is a natural phenomenon in the Mekong Delta that has caused great damages not only in terms of water quality but also in terms of ecosystem conservation. This situation has impact on the mangrove forest and its biota, on the sedimentation of suspended solids in the water, and on the health and living conditions of inhabitants using this water.

Salinity intrusion

In the Mekong Delta, the rainfall during the dry season is quite low with about 15% of the annual rainfall recorded during that period. For the months at the beginning and the end of the dry season (April and December) the rainfall is about 50 mm and about 10 mm for the other months in this season. The driest period of the year often occurs toward the end of April until the first days in May. This dry season and situations of salinity intrusion occur in areas those are far away from the source of the Mekong River and located along the coast. In the Mekong Delta, an area of more than 1.7 million ha is affected by salinity intrusion in the dry season. Salinity intrusion is one of main obstacles for appropriate living conditions as well as adequate water supply demand for agricultural development in the Mekong Delta, especially for the coastal areas.

The East and West seas are the two main sources for salt intrusion. The East sea has a semi-diurnal tidal regime and the tides raise and recede twice daily with a high amplitude of 300-350 cm. The water level of the tidal foot fluctuates strongly (160-300 cm), while that of the tidal peak fluctuates weakly (80-100 cm). Seawater from the East sea intrudes into the Mekong Delta soil through the East Vaico, West Vaico, Mekong and Bassac rivers. The West Sea tidal regime is a mixed one and the dominant diurnal tidal regime has an amplitude of about 80-100 cm, with little fluctuation of the tidal foot (20-40 cm) and a larger one for the tidal peak (60-80 cm). The seawater of the West Sea intrudes into fields through canals from the Ca Mau Cape to Ha Tien. The salinity intrusion problem is a more important with the East Sea than with the West Sea.

The salinity intrusion in the Mekong Delta can be linked to several main factors, namely meteorological conditions, tidal activity, changes of water level and flow in the estuary area, and other localized characteristics. This process is a very complicated one as the factors enumerated vary not only periodically and unpredictably, but also in time and space.

Considering natural conditions such as topography, water sources, and the existence of canal systems, the area affected by salinity intrusion in the Mekong Delta can be divided into the following sub-regions :

- The Plain of Reeds with the East Sea acting as a source of salt water through the East Vico and West Vico rivers.
- The area between the Mekong and Bassac rivers impacted by the East Sea tide through river mouths at Cua Tieu, Cua Ñai, Ba Lai, Ham Luong, Cung Hau, Co Chien, Ñinh An and Tran Ñe.
- The Long Xuyeân Quadrangle with the West Sea as the source of saline water through canals Giang Thanh Creek to Cai San Canal.
- The Ca Mau Peninsula with both the East and West seas providing the source of saline water.

Some the areas mentioned above are impacted by salinity intrusion for 5 or 6 months per year and during that period rainwater is the sole source of freshwater source for local inhabitants.

While in recent years a small increase rise in the extent of the salinity intrusion in main rivers has been observed on account of increases in the water consumption in their upstream area, generally the salinity intrusion phenomenon has not changed in that the maximum length of the salinity intrusion occurs in April when the upstream flow is lowest. Table 3 provides data about the distance of salinity intrusion in the main rivers during the period February to May (Anh *et al*., 1995).

Impacts caused by human activities

As mentioned previously, various human activities can have an impact on water quality and the main ones at play in the Mekong Delta are briefly described below.

TABLE 3
Monthly average length of salinity intrusion (1985 –1996) in main rivers (km)

River	Limit of 4 g/L				Limit of 1 g/L			
	Feb	Mar	Apr	May	Feb	Mar	Apr	May
Cua Tieu	23	32	37	32	43	51	59	56
Ham luong	22	30	34	26	46	51	57	54
Co Chien	22	31	35	27	44	48	55	51
Bassac	25	32	33	26	44	54	58	51

a) The utilization of fertilizer has direct impact on water quality. Nitrogen and phosphorus are vital nutrients for plant growth and the application of fertilizers on soil to supply these nutrients is increasing day by day. The discharge of these nutrients into the water of rivers and canals can favor the growth of algae and seaweed and lead to eutrophication, a water quality problem. Data collected over a long period as part of the project "Water Quality Monitoring Network in the Lower Mekong Basin" have indicated an increase of the nitrogen concentration in recent years.

b) Improvements in crop production are obtained by the application of new technical and scientific knowledge and the use of pesticides to protect crop from pest is a particular case in point. According to an investigation of carried out by the Department of Plant Protection (Ministry of Agriculture and Rural Development), there are 242 substances that have been approved by the responsible agency for use as plant protection chemicals. Some of the pesticides that have been used include: organophosphorus pesticides (methyl parathion, basudin, etc.), organochlorine pesticides (tindan, 2,4 D, lindane, etc.) ad carbamate pesticides (bassa, carbofuran, etc.)

c) The results obtained during the Pesticide Monitoring Network in the Mekong Delta carried out in 1995-1996 have shown that some types of organochlorine pesticides were in use, such as DDT, hexachlorohexane (HCH), endosulfan and their derivatives, pentachlorobenzene, heptachlo, technozene, and hexachlorobenzene (HCB). However the measured concentration were low, in the range of 100-400 ng/L. Over a three year period (1995-1997), 37 fish samples obtained in the Mekong Delta were analyzed for organochlorine pesticides and the average concentration of total pesticide residue reported was less than 9 mg/kg.

d) Shrimp culture in fresh and saline water is quite common because of the high income it can generate. With an area of about 250,000 ha, the permanent saline region along the coast has been used for mangrove forest and aquaculture. Presently, the mangrove forest occupies an area of about 90,000 ha and the shrimp culture, about 100,000 ha. Some areas adjacent to the permanent saline zone are used for both agricultural production and shrimp farming. During the dry season these areas are used for blackish shrimp farming and in the rainy season an area of about 15,000 ha is used for rice cultivation. In ponds used for shrimp culture, the water is significantly polluted by the decay of organic matter contributed by shrimp food. The results of an investigation carried out in 1997 (Ngu, 1998) in such ponds located in the Binh Dai district, Ben Tre province, have shown that during the dry months the dissolved oxygen content was very much reduced and rather low (from 2.61 to 2.35 mg O_2/L) and the hydrogen sulfide (H_2S) level at 0.019-0.079 mg/L. During the rainy season, the H_2S level was 0.019-0.079 mg/L. Unfortunately, the impact of these sources of wastewater has not been evaluated carefully, but the damage of shrimp culture to the mangrove forest has been clearly observed.

MEASURES TO SOLVE CONSTRAINTS OF WATER QUALITY

A number of measures could be taken to address the constraints on the use of water on account of poor water quality and some of these are described below.

a) The shortage of freshwater during the dry season is often a constraint for the development of agricultural production in the Mekong Delta. Many projects to prevent the salinity problem have been implemented such as the South MangThit and Quan Lo-Phung Hiep projects. They have been very successful in improving the supply of freshwater and reducing the salinity intrusion during the dry season. For instance, in the Quan Lo-Phung Hiep project a sluice system has been put in place with the following benefits:
   - an increase in the amount of incoming freshwater from the Bassac river to the project area to improve the supply of irrigation water;
   - an improvement of the drainage during the rainy season; and
   - an increase of the cultivated areas and crop production.

   The changes made during the Quan Lo-Phung Hiep project have created a new possibility for storing rainwater during the rainy season and using it later. The data assembled in Table 4 document the changes in the land area available for rice cultivation due to the implementation of this project (Haskoning, 1998).

   TABLE 4
   Changes in land area available for rice cultivation and the Quan Lo-Phung Hiep project (ha)

Items	existing (1996)	without project	with project
Three crops	0	14 000	20 000
Two crops	62 502	58 260	65 088
One crop	51 142	40 516	23 600

   It is worth noting that in areas where a complete system for salinity intrusion protection has been put into operation, the water level may be lower in the dry season and the flow will be restricted when the sluices are closed to stop the salinity intrusion. Therefore the water quality may be degraded and the navigation in the project area may be limited. This situation can be avoided by ensuring a proper operation of the sluice system.

b) The alum and other products that are formed and brought to the soil surface during the dry season will be washed out into canals when the first rain starts, thus causing the acidification of canal water to low pH values. Through propagation this acidic water can affect a large area and proper water resources management can be an effective way to solve the problem. For instance, a big canal system can be constructed to bring freshwater from main rivers to affected areas and drain the acidic water into the sea and the duration of the acidic water conditions is a directly related of the efficiency of the drainage. In the last 15 years, much progress has been realized through appropriate water resources management in the reclamation of acid sulphate soil in the Plain of Reeds. Before the 1980s, more than 500 000 ha in the Plain of Reeds were affected by acidic water for 5-10 months over a period including the beginning of rainy season and the end of flood season. The excavation of the main canals conveying water from the Mekong River (such as Hong Ngu) and the dredging of the Dong Tien-Lagrang and many other primary canals have resulted in significant improvement of the the acidic water situation. Presently in the Plain of Reeds, an area of about 120 000-150 000 ha is impacted by acidic water and this situation is lasting a single period of about three months; the second acidic water period that used to occur has been eliminated. In the Long Xuyen Quadrangle, in the past the contour area with a pH value of 5 used to be located next to the Bassac River, but now this contour area has moved upward far beyond the new Ba The road. In the Ca Mau Peninsula, a very large area previously impacted by acidic water has shrunk considerably and the severity of the acidic water situation has been reduced in the northern portion of the Quan Lo–Phung Hiep canal, a part of U Minh Thuong, U Minh Ha.

c) Improving the water resource situation is the first essential step toward increasing agricultural production in the Mekong Delta, by making possible the exploitation of deserted land and by creating conditions suitable for more crops and higher production. In 1976, the area use for rice cultivation was 2,053 million ha with a production of 4,7 million tons, but in 1997 the rice cultivated area has reached 3,47 million ha (1.7 times higher) and the rice production, about 16,0 million tons (3.4 times higher).

d) The development of a hydraulic system is needed to mitigate or to reduce the water quality damages observed. The hydraulic system must be synchronous and have a high capacity of integrated utilization. Also the exploitation of water resources has to be based on scientific knowledge.

References

Anh, Nguyen Ngoc. 1996. Hydrological Characteristics of Flood in the Mekong Delta (in Vietnamese). Ministry of Agriculture and Rural Development. p.26.

Anh, Nguyen Ngoc., and Luu Van Thuan, 1995. Salinity characteristics in the Mekong Delta (in Vietnamese). Ho Chi Minh City.

Dent, D., 1986. Acid sulphate soils : a baseline for research and development. The Netherlands, p.77.

FAO. 1985. Water Quality for Agriculture. p.8.

Gibbs, R.J. 1970. Mechanism Controlling World Water Chemistry. Northwestern University USA.

Haskoning B.V. Co. 1998. Feasibility Study Upgrading- MainReport. Project of Water Resources Development in the Mekong Delta (in Vietnamese). Ministry of Agriculture and Rural Development, Ho Chi Minh City, p.69.

Hien, P.G.. 1993. Water Quality in the Mekong Delta. Water Quality Workshop in Bangkok, International Mekong Committee, November -1993.

La, Tran Van. 1995. Groundwater in the Mekong Delta (in Vietnamese). Hydro-Geology Department N.8, p.10.

NEDECO. 1993. Master Plan of Mekong Delta (in Vietnamese). Ho Chi Minh City, p.13.

Ngu, M.. 1998. Assessment of impacts caused by shrimp culture in Binh Dai –Ben Tre province (in Viet Namese). Aquaculture Research Institute No.II, p.2.

Truong, To Van. 1998. Flood Control Planning in the Mekong Delta (in Vietnamese). Ho Chi Minh City. p.1.

Annex 1
Opening address

Distinguished Participants, Ladies and Gentlemen,

On behalf of the Director-General of FAO, Dr. Jacques Diouf and on my own behalf, I have the honour to welcome you to the Regional Workshop on "Water Quality Management and Control of Water Pollution in Asia and The Pacific**".**

I am grateful that you accepted our invitation to attend this important meeting. The presence here of a range of international and national experts, engineers as well as senior administrators concerned with the various aspects of water quality management and water pollution prevention, indicates the keen interest being taken by the various countries of the region and the international organizations in this important subject.

I am particularly pleased to welcome you here on the premises of our Regional Office in Bangkok. I hope you have a pleasant stay and a fruitful exchange of ideas.

We are now approaching the second millennium which brings with it the unparalleled concern over the scarcity of freshwater resources to meet the future demand of our growing population. Overall, the region is relatively well endowed with water resources. However, if we look at the amount of water available per inhabitant, the situation is less promising. In terms of water resources per person, the figure is just slightly above half of the world's average. Countries of the Indian subcontinent, Eastern Asia and the Far East show the lowest figures while Southeast Asia has still more water resources per person than the world average. The figure of 2000 m3/inhabitant/year is usually used as an indicator of water scarcity: India and China are approaching this limit, while the Republic of Korea is already below it, at 1538 m3/inhabitant/year. The situation is even more alarming when we look at most of the small islands in the Pacific or the Maldives where, in the absence of any surface water the growing population is solely dependant on limited groundwater resources which due to over pumping are already subject to seawater intrusion with subsequent deterioration of its quality.

While recent droughts have significantly increased the awareness of many countries in the region that scarcity of fresh water resources will already become a serious issue in the next decade when the world population is expected to exceed 7 billion people, the alarming deterioation of the water quality, however, is still not attracting sufficient attention and appropriate counter-measures.

At present water quality is being affected by harmful effects caused by many sectors of human activity. Agricultural, industrial, mining and urban by-products and residues are the principal pollutants of inland waters and oceans. Less than 2% of the cities of the world have treatment plants, and in rural areas most agro-industries, dairies, feedlots and small communities simply dump their wastes into streams and other water bodies polluting them with nutrients, bacteria and parasites. The World Health Organization (WHO) carried out a survey in 1989 on 110 rivers throughout the world and found that in 49 of them, the faecal coliform levels exceeded the recommended WHO level. Also in Asia and the Pacific, 15 out of 32 rivers tested exceeded the

Prem Nath
Assistant Director-General/Regional Representative for Asia and the Pacific

faecal coliform guideline significantly. Now, 10 years later the results would be even worst if the survey was repeated.

As a consequence of this pollution, researchers have estimated that 80% of all diseases and 33% of deaths in developing countries are linked to poor water quality. The outbreak of cholera in Peru in 1991-92, in addition to the loss of countless human lives, was estimated to have cost US$460 million in lost exports and tourism. Furthermore, over-exploitation of groundwater resources has resulted in the extraction of water from deeper aquifers with sometimes high arsenic content which has a serious toxic effect on human beings. Water with high levels of arsenic are the only source of drinking water in a number of cities and rural communities of the world. Well documented examples of arsenic poisoning are reported from Chile, China, Mexico, Peru and Bangladesh.

As already mentioned, there are several sources that contribute to water pollution and these may be broadly grouped into agricultural sources and non-agricultural sources. In this connection, it should be noted that agriculture, in addition to being the largest consumer of water, is also listed, with increasing frequency, as a major contributor to water pollution. Irrigation return flows to surface and groundwater resources contain heavy loads of salts, nutrients and agro-chemicals, thus contributing essentially to the deterioration of water quality.

There is still ample room for politicians and decision makers all over the world to pay greater attention to the increasing imbalance between our steadily growing population and the limited but not renewable natural resources at our disposal in particular soil and water. This imbalance, which has already caused past difficulties and problems in the conservation of specific ecosystems, has nowadays reached unexpected dimensions in many places of the world. There are clear signs of exhaustion of natural resources. In relation to water, there are serious pollution problems not only with inland waters - most closely connected with the population - but also with the oceans, which have always been considered unlimited and inexhaustible because of their immensity. Symptoms of deterioration are not only evident in Exclusive Economic Zones or in the continental shelves, but also on the high seas, whose resources are currently being affected.

FAO, together with many other institutions, has been working for many years to raise awareness on the issue of deteriorating water quality as well as on the identification of causes and the proposal of solutions to prevent or at least to minimise water pollution. This has been achieved through numerous technical publications, the conduct of seminars and expert consultations with the objectives of promoting an exchange of experiences on water pollution by agriculture, agro-industry and mining and in particular on the safe use of wastewater and highly saline waters for irrigation, which in view of the increasing water scarcity will gain more and more importance in the future.

A first regional workshop on the subject and organized by FAO was held in Chile in 1998, gathering participants from the Latin-America and Caribbean Region. This second workshop focuses on Asia and the Pacific. The presence of specialists from the various national and international agencies and institutions in this Workshop will no doubt provide an important opportunity to exchange and consolidate experiences and to indicate ways for further follow-up and regional collaboration.

I am confident that with your active participation and technical contributions, solutions to the many water quality management problems in the region will be proposed in order to protect and to sustain our scarce water resources for the generations to come. FAO is happy to be a part of this, and I am anxious to learn of your reactions and recommendations at the end of your three days of deliberations.

I wish you a very successful meeting and a pleasant stay in Bangkok.

Thank you.

Annex 2
Provisional agenda

Date	Time	Activity
Tuesday 26/10/99	08:00	Registration
	08:45	Opening address by Dr. Prem Nath, Assistant Director-General /Regional Representative for Asia and the Pacific. Welcome and general information on the workshop by Dr. Klaus Siegert, FAO, Secretary of the meeting
	09:15	Fernando Chanduví, FAO Technical Officer, Water Resources Development and Management Service (AGLW): Results of the Survey on Water Quality and Pollution Control in the Region.
	09:30	Coffee break
		Technical Session I: Water Pollution by Agriculture, Agro-Industries and Mining **Chair: Dr. Ioannis Papadopoulus, Cyprus**
	10:00	**Keynote speech** "Water Quality Management in Asia and the Pacific" by Mr. Edwin Ongley, Canada.
	10:30	**China**, "Quality of Irrigation Water in China" by Mr. Weng Jianhua.
	11:00	**Laos**, "Water Quality Management in LAO PDR" by Ms. Keobang A. Keola.
	11:30	**Vietnam**, "Water Quality and Agriculture Production in the Mekong Delta" by Messrs. To Van Truong and Pham Gia Hien.
	12:00	Plenary Discussion
	12:30	LUNCH
		Technical Session I continued….. **Chair:** Mr.**Fernando Chanduvi, FAO**
	14:00	**Malaysia**, "Water Pollution by Agriculture, Agro-industry and Mining in Malaysia" by Mr. Tan Choo Yong.
	14:30	**Pakistan**, "Agriculture's influence on water quality" by Mr. Bashir Ahmad.
	15:00	**Japan**, "The impact of agriculture on water quality and its improvement methodology in Japan" by Mr. Yoshito Yuyama
	15:30	Coffee Break.
	16:00	A case matching Decision-Support System to predict agricultural impacts on water quality by Mr. Edwin Ongley.
	16:30	Plenary Discussion
	19:00	Welcome Dinner at Siam City Hotel hosted by Dr. Prem Nath

Wednesday 27/10/99		**Technical Session II: Use of Wastewater and highly saline Water for Irrigation** **Chair: Mr. Edwin Ongley, Canada**
	08:30	**Keynote speech**, "Use of Wastewater for irrigation with reference to Asia and the Pacific" by Mr. Ioannis Papadopoulos
	09:00	**Bangladesh**, "Crop Production in the Southern Saline Belt of Bangladesh" by Mr. Md. Abu Bakar.
	09:30	**India**, "Agriculture and Water Quality in India towards Sustainable Management" by Mr. R.P.S. Malik.
	10:00	Plenary Discussion
	10:30	Coffee break.
	11:00	**Indonesia**, "The Biochemical Effectiveness of Herb Bed Treatment System with Bulrush, Water Morning Glory and Garden Cormous Herb in Waste water Improvement" by Messrs. Soedodo Hardjoamidjoyo and M.S. Saeni.
	11:30	**Korea**, "Status of Agricultural Water Quality in Korea" by Mr. Lee Jong-Sik.
	12:00	**Thailand**, Agriculture's Influence on Water Quality in Lower Northeastern Thailand" by Ms. Vipada Apinan
	12:30	Lunch
		Technical Session II continued….. **Chair: Mr. Bashir Ahmad**
	14:00	**Keynote speech**, "Organic Sewage Treatments" by Mr. Maurizio Giannotti
	14:30	**Philippines**, "Modelling Non-point Source of surface and ground water systems in selected agricultural watersheds in the Philippines" by Messrs. R.S. Clemente and E. Wilson.
	15:00	**Thailand,** "Utilisation of Spent Distillery Wash Liquor in Paddy Fields" by Mr. Suchint Phanapavudhikul.
	15:30	Coffee break
	16:00	"Phytodepuration treatment of wastewater from agro-industries to avoid water pollution" by Maurizio Giannotti.
	16:30	Plenary Discussion
Thursday	08:30	Work in two groups drafting (i) conclusions and (ii) recommendations
28/10/99	10:00	Coffee break.
	10:30	Group Work continued
	12:30	Lunch
	14:00	Video session
	16:00	Break
		Closing Session: Chair: Dr. Klaus Siegert, FAO
	16:30	Presentation of Conclusions and Recommendations Adoption of workshop report Close of Workshop
Friday 29/10/99	07:00	**Field trip**

Annex 3
List of participants

BANGLADESH	Mr. M. Abu Bakar Deputy Director Field Service Wing Department of Agricultural Extension Khamarbari, Farmgate Dhaka 1215
CHINA	Dr. Weng Jianhua Senior Engineer Water Quality Research Centre China Institute of Water Resources and Hydropower Research 20 Chegongzhuang West Road P.O. Box 366 Beijing 100044 Tel: 86-10-6841-5522 Ext. 3203 Fax: 86-10-6842-5954 E-mail: wengjh@public.east.cn.net
INDIA	Dr. R.P.S. Malik Agricultural Economics Research Center University of Delhi New Delhi 110007 Tel: 91-11-7257648 Fax: 91-11-6103987 E-mail: malik@aercdu.ren.nic.in
INDONESIA	Prof. Soedodo Hardjoamidijoyo Bogor Agricultural University P.O. Box 220 Bogor 16002 Tel/Fax: 0251 627225 E-mail: soedodo@wasantara.net.id
JAPAN	Dr. Yoshito Yayuma Expert of Water Management The Modernization of Water Management System Project JICA, Irrigation Engineer Center Royal Irrigation Department 811 Samsen Road Bangkok 10300 Tel: 2431098, 2431318 Fax: 2431317

REPUBLIC OF KOREA
Dr. Lee Jong-Sik
Researcher
National Institute of Agricultural Science and Technology
249 Soedun-dong
Kweonseon-ku, Suwon
Tel: 82-331-2900214
Fax: 82-331-2900277
E-mail: jongslee@niast.go.kr

LAO PDR
Mrs. Keobang A. Keola
Deputy Chief of Cabinet
Prime Minister's Office
Science Technology and Environmental Agency (STEA)
P.O. Box 2279
Vientiane
Tel: 856-21-213472
Fax: 852-21-213470

MALAYSIA
Mr. Tan Choo Yong
Project Engineer
Department of Irrigation and Drainage
Pejabat Jurutera Projek
IADP Seberang
Perak/Tumboh Blok
Jabatan Pengariran dan Slairan
Sungai Dedap
3600 Kampong Gajah
Perak
Tel: 05-6551362
Fax: 05-6552208
E-mail: jpssptb@tm.net.my

VIET NAM
Mr. Pham Gia Hien
Water Quality Laboratory
Sub-Institute of Water Resources Planning and Management
Ho Chi Minh City
Fax: 84-4-8351721
E-mail: giahien@hem.fpt.vn

RESOURCE PERSONS

CANADA
Mr. Edwin D. Ongley
Senior Advisor
United Nation's GEMS/Water Programme
3486 Burlington
Ontario L7M 1Z6

CYPRUS	Mr. Ioannis Papadopoulos Agricultural Research Institute Nicosia Email: papado@arinet.ari.gov.cy
ITALY	Mr. Maurizio Giannotti Waste Water Treatment Consultant Viterbo Email: sifvt@tin.it

OBSERVERS

WHO	Dr. Kanchanasak Phonboon WHO National Consultant on Health Promotion Environment and Health Programme Office of Environmental Policy and Planning (OEPP) Soi Pibulwatana 7, Rama VI Road Bangkok 10400
	Ms. Raweewan Ratanavaraha Environmental Officer Natural Resources and Environmental Management Division Office of Environmental Policy and Planning (OEPP) Soi Pibulwatana 7, Rama VI Road Bangkok 10400
	Mr. Pirun Saiyasitpanich Environmental Officer Environmental Impact Assessment Evaluation Division Office of Environmental Policy and Planning (OEPP) Soi Pibulwatana 7, Rama VI Road Bangkok 10400
GTZ	Dr. Gustav M. Maurer Principal Adviser/Team Leader Agricultural Toxic Substance Division Building (4th Fl.) Department of Agriculture (DOA) Chatuchak, Bangkok
AIT	Dr. Preeda Parkpian Coordinator Environmental Engineering Programme Asian Institute of Technology P.O. Box 4, Klngluang Pathumthani 12120

UNICEF

Dr. T.V. Luong
Consultant
19 Phra Atit Road
Bangkok 10200

FAO

Mr. Mathias Halwart
Technical Officer
Inland Water Resources and Aquaculture Service (FIRI)
Fishery Resources Division
FAO, Rome
Iraly

FAO SECRETARIAT

Dr. Klaus Siegert
Secretary of the Workshop
Regional Water Resources Development Officer
RAP/FAO
Bangkok 10200

Tel: 2817844 ext. 298
Fax: 2800445
E-mail: klaus.siegert@fao.org

Mr. F. Chanduvi
Technical Officer
Water Quality and Environmental Impact Group
Water Resources, Development and Management Service
AGLW
FAO, Rome
Italy

In its recent examination of global water scarcity (1997) the United Nations system identified water quality as one of the key concerns in Asia in the next century. This concern is based on the fact that water quality degradation is so severe in many Asian countries that it is placing serious constraints on economic growth; it continues to be a serious problem for human health and it is causing widespread negative environmental effects. The problem of future management of water quality in Asia is a complex one, and requires re-examination of a number of key areas – including technical, institutional, legal and governance issues. Within this context, FAO organized a Regional Workshop on Water Quality Management and Control of Water Pollution which took place in Bangkok, Thailand from 26 to 30 October 1999. This publication contains the report and recommendations of the Workshop and the edited versions of 18 papers presented and discussed during the meeting.

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