Water Pollution in Jordan

Causes and Effects

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Foreword

Water shortage and population explosion are the two parameters which at present are greatly affecting the water sector in Jordan. During the last three decades, industrialization, urbanization and agricultural activities have been growing at very fast rates, resulting in the increasing production of large amounts of wastes in the form of wastewater, solid wastes and emission gases.

The limited and scarce water resources of the country have showed continual quality degradation due to the effects of wastewater, solid wastes and gas emissions, thereby reducing the available amounts of water for uses demanding high quality.

This situation motivated the Friedrich Ebert Foundation, Goethe-Institut Amman and the University of Jordan to cooperate in organizing this symposium with the aim of evaluating the water pollution situation in the country and the factors which led and are leading to its deterioration and also to suggest ways and methods to improve the present situation of water quality.

The case studies for discussion refer to the impacts of wastewater treatment plants on surface and groundwater qualities, the effects of urbanization and industrialization on water quality and the leaching from agrarian lands and solid waste disposal sites to the surface and groundwater resources.

The review of the present situation of water quality deterioration in Jordan is followed by discussion of German experiences in alleviating similar water pollution problems.

As a result of this symposium relevant ways and adequate measures are recommended for a better utilization of the scarce water resources endangered by over-exploitation and pollution.

The organizers and contributers to the symposium hope that the recommendations will form a basis for sounder water resources and environmental management.

The Organizing Committee

Dr. Matthes Buhbe
Friedrich Ebert Foundation, Amman

Hinrich Reinstrom
Goethe-Institut Amman

Dr. Elias Salameh
University of Jordan, Amman

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Opening Address

Excellencies, ladies and gentlemen:

On the 14th of October 1990, Jordan and the Arab countries celebrate the "Day of the Environment", underscoring the internationality of the subject and the longing of Jordan to preserve nature and to restore what has been damaged.

Truly, environmental problems have become central issues imposing themselves on mankind, regardless of race or social status. Scientists are now concerned about pollution, exhaustion of natural resources and imbalance in the equation of socio-economics and population growth.

Nowadays, an individual on one side of the Earth affects the natural environment of another on the other side. Environmental issues and their technological solutions have moved to the forefront all over the world. On this basis Jordan is co-operating with two German institutions, Goethe-Institut and Friedrich Ebert Foundation, to hold this conference. The exchange of ideas among scientists is very useful for all partners and facilitates solutions to and avoidance of environmental problems.

Industrial development and industrial refuse have affected water resources, as their wastes appear in surface and groundwaters. Also, domestic waste, algaecides, insecticides and fertilizers have reached various water resources, rendering them unsuitable for certain uses and making their treatment complicated and expensive.

The continuous disposal of wastes into water resources at the present rate will certainly lead to uncontrollable damage of resources, until we reach a stage where the damage cannot be reversed. The atmosphere, the rivers, the natural and artificial lakes and the oceans are able to resist much pressure before becoming unable to clean themselves. Therefore, we must try not to put nature under experimentation; we know that nature has limits and that its revenge is severe.

The variations in the approaches to environmental problems in the world are only a matter of administrative arrangements, instructions and environmental by-laws. We believe that Jordan has achieved a relatively high level in this concern. It is one of the few developing countries which have established departments and associations for studying, conserving and protecting nature. In Jordan, wastewater treatment plants for the different urban and industrial wastes have been constructed. Solid wastes are also being disposed of hygienically. Standards and legislation for the disposal of all types of waste are under continuous improvement.

In Jordan our concern at present is to reach for a balanced development between economic growth -- as one of the national policy targets -- and a clean environment, as a prerequisite for natural, renewable life.

The various agencies in Jordan are employing all their abilities and potentials to solve environmental problems rapidly and effectively, since the continuous exhaustion of natural resources, environmental pollution, and the imbalance between socio-economic equilibrium and population growth will all lead to unbearable situations.

We hope that researchers and interested people will find in this conference guidance to help them in understanding the environmental problems facing Jordan, especially in the field of water pollution.

Also, we hope that this conference will be a meeting of thoughts, resulting in fruitful policies and methods to achieve clean water suitable for various requirements.

The University of Jordan would like to sincerely thank Friedrich Ebert Foundation and Goethe-Institut for their contribution and help in preparing for this conference. Also, our guests from abroad are cordially welcome in Jordan and sincerely thanked for their efforts to join us despite the prevailing conditions in the Middle East.

I wish you every success; may God bless you.

Prof. Dr. Mahmud es-Samra
President of the University of Jordan

Organizing Committee Speech

President of the University Prof. Dr. Mahmud es-Samra, Your Excellencies, ladies and gentlemen:

Jordan is suffering from water shortage problems that can be classified as chronic. The reason for this is the meager rainfall the country receives, situated as it is in the semi-arid to arid climatic zone.

The increasing population has led to the exploitation of all available water resources. The issue of water resources has developed gradually and represents an imbalance in the equation of resources and population, from which the country has been suffering for more than four decades.

Water, in addition to soil and air, is one of the major elements of the natural environment, giving it a dimension that distinguishes it from natural resources such as oil, iron and copper. Water is a natural resource which can be affected by all urban, industrial and agricultural activities.

The last few decades of development in Jordan have seen an increase in the population and new small, medium and heavy industries. Agricultural land has been enlarged, and there have been changes and advances in the use of production facilities. The amount of wastewater and solid wastes increased to around 100 times over their levels three decades ago.

This point demands measures to alleviate the environmental state's degrading, especially since the natural system's ability to purify itself is exhausted. Wastewater treatment plants were constructed in various parts of the country, but some of them proved inadequate and unable to fulfill the task for which they were constructed, as can be seen from the papers of the conference.

The effluent of these plants gradually became the main polluter of both surface and groundwater resources. In addition, solid waste disposal was not up to standard and also led to the pollution of the different surface and groundwater resources.

Various industries disposed of their solid and liquid wastes carelessly in different parts of the countryside, causing them to leach to surface and groundwater resources and rendering the latter unsuitable for their previous uses, especially domestic uses. As use of biocides and fertilizers increased, these eventually reached the water resources, threatening their quality. In addition to the above, overexploitation of some groundwater basins overstepped the abilities of their natural system to clean themselves and caused their depletion and salinization.

The above-mentioned pollution processes caused the present imbalance in Jordan's water resources and limited their potential uses. This meant that

meager water resources were pushed into more severe edges, with the consequence that water resources will diminish with time, due to pollution.

The above aspects have been discussed in different symposia in Jordan, for which the University of Jordan was either the initiator or a contributor. In this symposium we consider a new dimension: the economic aspects of water pollution. The effects of pollution are certainly reflected in the economy, occasionally spontaneously or -- as in most cases -- after a while, to be felt perhaps even by future generations.

The University of Jordan has drawn attention to water pollution through various conferences held on its campus and through different reports submitted to the concerned agencies. To this we can add the published work and theses of many students.

In this symposium the University is cooperating with Friedrich Ebert Foundation and Goethe-Institut to discuss water pollution issues and their economic aspects. We hope to gain from our guests' experience in pollution control, avoidance and prohibition, and environmental impact assessment.

This is not the first symposium in which we have cooperated with Friedrich Ebert Foundation and Goethe-Institut. On this occasion we want to express our sincere thanks to both institutions.

On behalf of the organizing committee, I would like to welcome our audience and express my thanks to the president of the University of Jordan and its administraiton for supporting this and other conferences. Lastly, I would like to close my speech asking the Holy Spirit to help us in the benefit of this society as a part of mankind and to give us wisdom and insight in our deeds.

Prof. Dr. Elias Salameh

1

Impact of liquid wastes on surface and groundwater resources and their elimination through proper treatment and reuse

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Karlsruhe, Germany

Definitions

To cover the full title of this paper would require at least a full semester of a two-credit-hour class. But as only roughly one hour is available, we shall restrict our discussion to a few selected details. Therefore, let us understand the title as follows: by "liquid wastes" we mean municipal wastewaters of a somewhat standardized township with mainly domestic wastes and no sophisticated chemical industry; the term "elimination" is restricted to those physical, chemical and biological processes appearing in a normal plant; and by "impact" we mean the import of pollutants into natural ecosystems and the changes caused by these imports.

Pollution and pollutants

Our first task is to analyze wastewaters with respect to their polluting potentials. The best way to do this is to make a short journey through the history of wastewater treatment, in which we will quickly find that treatment has always been done only to cover the minimum needs. Man has never done more than he was forced to do.

- When epidemic appearances of cholera and typhoid fever were understood to result from pollution of drinking water through human wastes, the response was to export human wastes into nearby rivers by establishing sewer systems.
- When, as a consequence of this, it was observed that rivers were polluted at the inlets by big particulated matter, the technical response was to install screens.
- When it was learned later that settleable solids of organic nature still created putresciple sediments, the technical response was to build sedimentation tanks.
- When it was learned that in spite of these technical instruments, rivers still were polluted to a high degree by unsettleable organic materials, the technical response was to develop and install technologies to oxidize the organics within the treatment unit. The instruments were "activated sludge plants" and "trickling filters".
- When it was learned that despite these installations, the rivers now became polluted with oxidation products, which cause heavy eutrophication, man tried to develop methods for phosphate precipitation and denitrification.

But the problems are still not solved. Now we learn that roughly 30% of the organics pass our treatment units unchanged, that heavy metals cause other problems, and that the integration of nitrogen removal and phosphorous removal into municipal plants is a problem in which we do not see much progress. We have learned that the main problems we face are:

- elimination of pathogens and intestinal worms;
- elimination of settleable organics to prevent putresciple sediments;
- elimination of dissolved organics to prevent oxidation processes in the flowing waters and the production of toxic ammonia and oxygen depletions;
- elimination of eutrophying substances like nitrates and phosphates;
- elimination of heavy metals and halogenated hydrocarbons and other organics of low degradability, to prevent permanent changes in our ecosystems and also to prevent deterioration of our natural water reserves.

Some of the problems are created as a consequence of treatment. For example, oxidation of organics in the aerobic or anaerobic biological processes increases the concentration of inorganics in the effluents and also causes river pollution. Our treatment plants employ a great variety of tools which are in many cases not coordinated and not integrated; new tasks call for new tools, which will be difficult to integrate into existing plants.

Potentials and constraints of aerobic treatment units

The natural self-purification system. To gain clearer insight into the tasks we are facing, we should analyze the main instruments of our treatment plants

according to their potentials and constraints and try to build a new approach around them. The question is: What can be achieved with the classical instruments of aerobic treatment, the activated sludge systems and trickling filters, and is it possible to arrange additional elements for other tasks around these tools? The basis of all aerobic treatment is the system of natural self-purification in aquatic systems. Natural self-purification is the tool nature has developed to re-establish original conditions if natural or outside impacts disturb the equilibrium between production and degradability.

Under such conditions we observe the following (Figure 1):

- At the beginning we have conditions characterized by a high nutrient concentration for chemo-organotrophic bacteria and a low number of feeders. The natural consequence is that this high organic load initiates proliferation of those bacteria able to feed on it, resulting in the highest yield possible. (By the term *yield* we understand the transformation of organic feed into bacterial cells.) Roughly 50% of the nutrients will be incorporated into bacterial cells.
- After this first reaction, the situation is characterized by a high concentration of bacteria-lacking nutrients. The consequence is that bacteria have to undergo self-respiration to cover the energy demands, and new organisms, ciliates, will appear, decimating the bacteria. Through the self-oxidation of bacteria and through the activity of ciliates, organically fixed nitrogen and phosphorous are released again into the liquid.

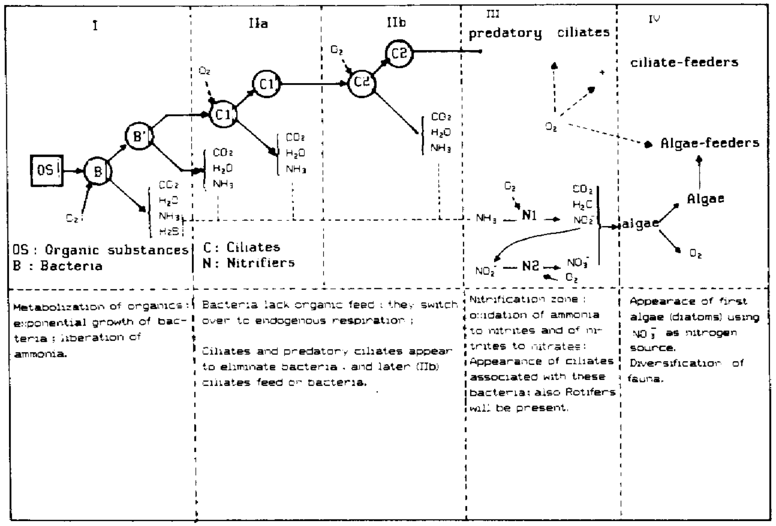

Figure 1. Biological reaction chain for self-purification of organically polluted waters.

- Phase III is characterized by an almost complete oxidation of the organics and by high concentrations of ammonia. This ammonia induces proliferation of nitrogen-oxidizing bacteria, which leads to nitrates.
- In phase IV we find high concentrations of the oxidation products (nitrates and phosphates), which stimulate algae proliferation. The inorganics will again be transformed into organics. The cycle is closed.

Observing the oxygen consumption along this process we find proof for our theoretical explanation. The DOC is almost completely eliminated in phase I; the following oxygen consumptions are caused by secondary reactions (Figure 2). Here it is also necessary to correct the original BOD theory. BOD reactions never were and never are, as is understood and outlined in most text-books, first-order reactions. They can never be first-order reactions, but are, as a result of the biological reaction chain, also a chain of individual oxygen consumptions, as described.

Technical aerobic biological treatment of liquid wastes can be nothing but the technical operation of this reaction chain, or at least parts of it.

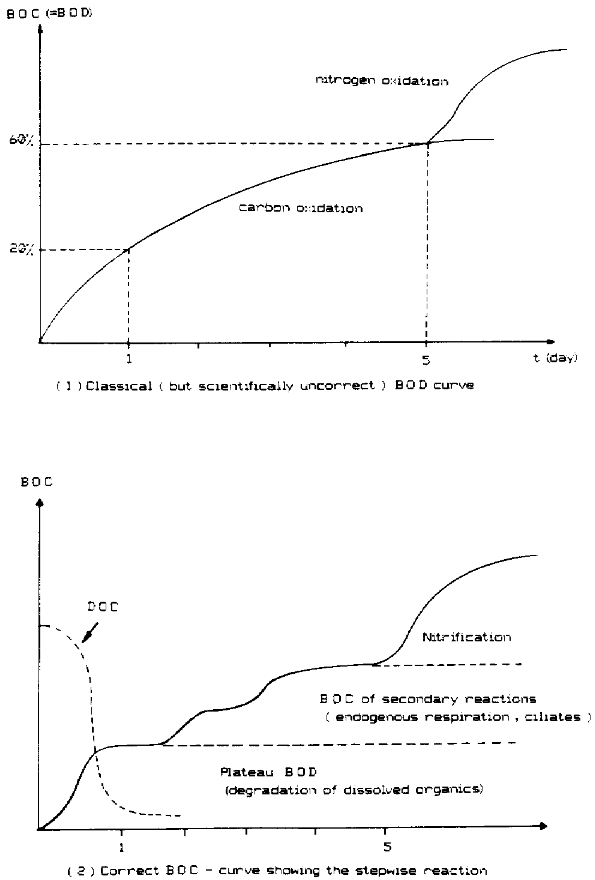

Figure 2. BOC curve.

The activated sludge process. Let us see how the activated sludge process tries to copy the natural process (Figure 3). An activated sludge unit consists of the reaction chamber to house the biological process and a sedimentation tank to separate the settleable products from the liquid. The settleable products, the sludge, is harvested and partly recycled into the reactor to keep the process in operation. The daily surplus is removed and brought into sludge-handling tools.

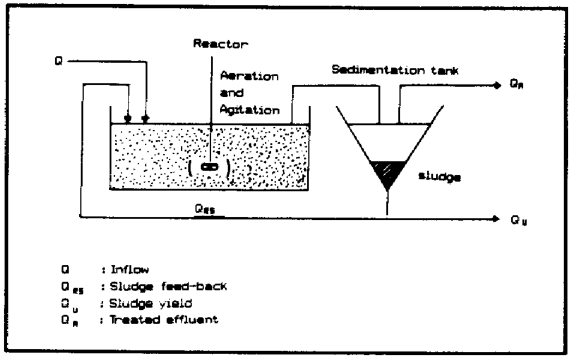

Figure 3. Activated sludge system.

The biological system permits operation between two extremes (Figure 4). One extreme would be full oxidation of organics; the other extreme would be to cut the reaction chain after the first phase and to aim for the highest sludge yield possible. In the first case, we would have a low-rate system with a high diversity of organisms doing the task. In the second case, we have a very short reaction chain, with a

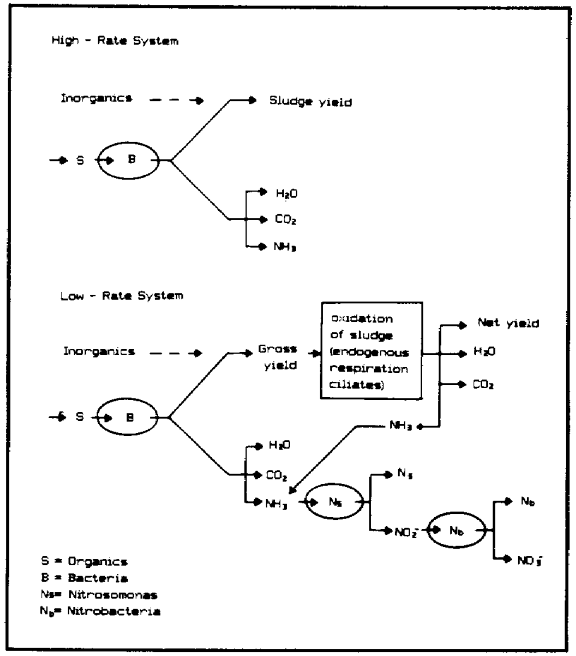

Figure 4. Biological system of activated sludge treatment.

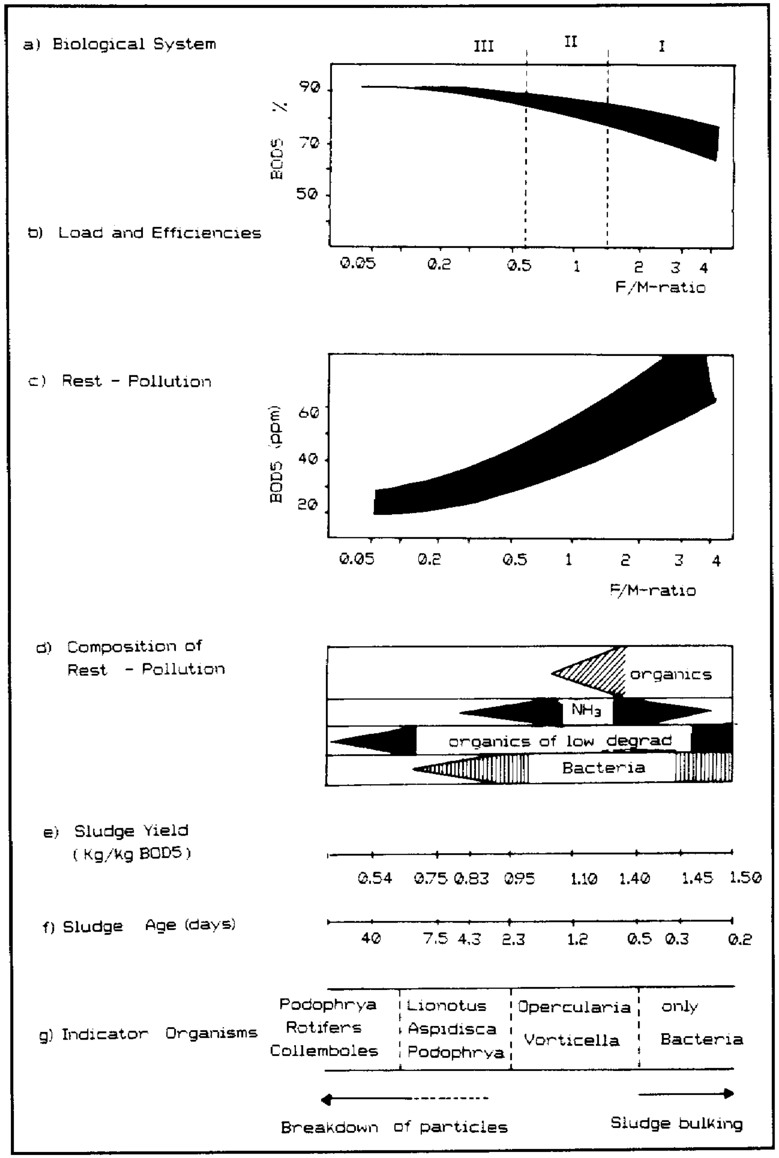

Figure 5. The activated sludge system depending on the F/M ratio.

biocommunity consisting mainly of chemo-organotrophic bacteria. But of course, this is not the full answer. The system is much more complicated and has many more facets to be observed.

Additional information is given in Figure 5. Which system we employ depends on the amounts of organics fed to the amount of bacteria per time, expressed here as the F/M ratio. At high load ratios we find conditions as they are expressed in phase I of the natural self-purification process, as illustrated in Figure 1. The result is a mass increase in bacteria. Lowering the F/M ratio means approaching phase II of the self-purification system, characterized by lack of food for the bacteria, by self-oxidation and by the appearance of ciliates. Further lowering the load leads to the oxidation of ammonia into nitrates.

All these options are technically realized in various forms. The two extremes we find in high-rate plants on the right side, followed by low-rate plants in the middle, and by oxidation ponds to the far left.

The numerical values for the F/M ratios are those for climatic conditions as they exist in Germany, with wastewater temperatures between 15°C. and 17°C. in summer. In a subtropical country, with temperatures expected to be in the high 20s, the F/M value for the same biological system should be multiplied by a factor of 3 to 3.5.

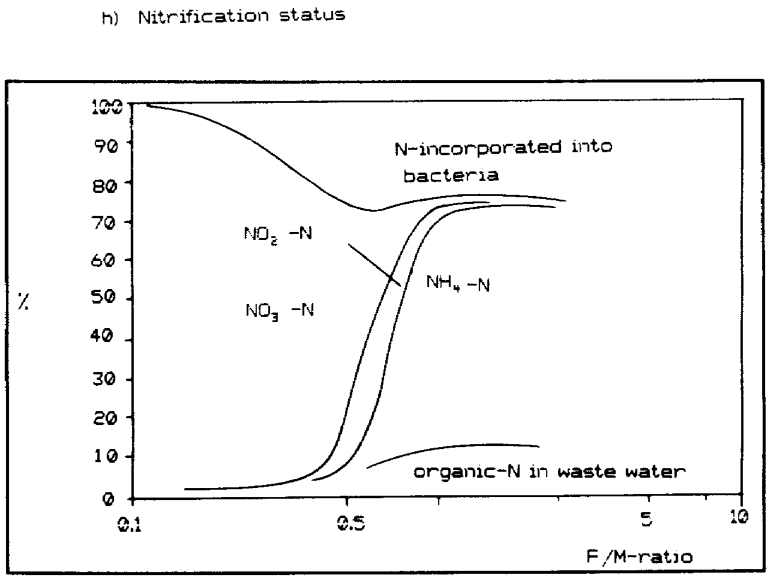

Figure 5, continued.

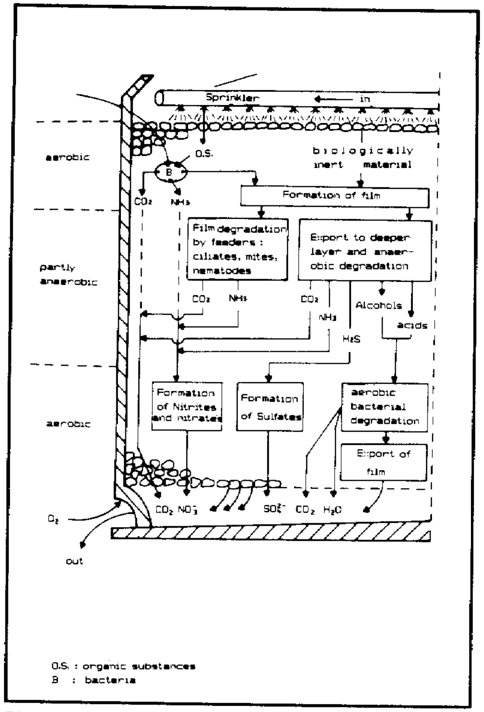

Figure 6. Biological system and mass transfer in a trickling filter.

The trickling filter. The same information can be found in the biology of a trickling filter (Figure 6) as in an activated sludge process. The biodegradation follows the same patterns and, depending on the load, we reach either full oxidation or high transformation of dissolved organics into bacterial masses.

Integration of tools into treatment plants

The first task in integrating treatment tools into treatment plants is to select the proper aerobic unit and the conditions of operation. This, of course, depends on the local situation, especially on the economical and ecological frame.

In this text conditions are given which lead to selection of a high-rate activated sludge plant as the main tool. This high-rate activated sludge plant will have a treatment efficiency of roughly 80% BOD5 elimination, the remaining BOD mainly stemming from the endogenous respiration of free-floating bacteria, from nitrification and from oxidation of organics with low degradability. Therefore, additional tools have to be added.

Integration of polishing instruments. Polishing means the elimination of free-floating bacteria and microflocs and the oxidation of ammonia. These tasks can be performed by several tools. For rural areas in subtropical and tropical environments, agricultural use of effluents may be the best choice, as well as introduction of the activated sludge effluent into fish-ponds and algae-ponds.

Under different conditions, especially for big municipalities, the combination with a trickling filter is a better choice (Figure 7).

Practical experience proves that a combination of high-rate activated

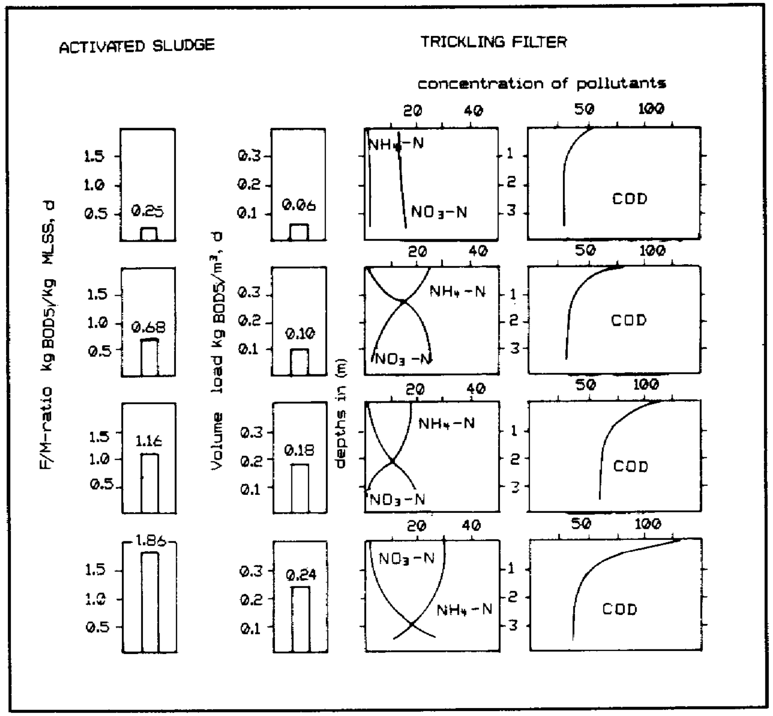

Figure 7. Trickling filter efficiency for polishing activated sludge effluents.

sludge with polishing through trickling filter yields effluent qualities far above official requirements, with BOD5 concentrations below 5 ppm in summer, and COD concentrations below 50 ppm.

The task is done by different natural elements: bacteria are eliminated by ciliates, ammonia is oxidized by nitrifiers, and even halogenated hydrocarbons may be attacked and degraded by special forms of bacteria.

Integration of presedimentation. Primary clarifiers to eliminate settleable solids before biological treatment are a traditional tool in treatment plants. However, biological and technical observations reveal they are not needed anymore, especially in high-rate plants. The sludge to be settled in primary tanks consists of a high percentage of bacteria needed in the aerobic unit. Furthermore mixing primary and secondary sludges improves physical characteristics without hampering biological efficiency.

The argument that presedimentation is necessary to reduce the load for aerobic units is not valid, as the aerobic unit is operated under conditions which prevent oxidation of particulate organics.

Integration of phosphate removal. There is much discussion about biologically induced P-removal. I will not go deeper into this matter, as the scientific background is not yet understood. For the removal of phospates in combination with aerobic treatment units, we have the following options:

- fixation in bacterial masses (The amount and efficiency is controlled by the production potentials of biomass, which in turn is controlled by the concentration of organics);
- bio-precipitation in flocs and films in connection with the anaerobic release of phosphates;
- biological fixation through algae and green plants, which can be performed by agricultural irrigation of wastewaters respectively in fish-ponds and algae-ponds;
- chemical precipitation (the most common practice). In connection with the "activated sludge-trickling filter system" proposed here, chemical precipitation should follow the trickling filter.

Integration of nitrogen elimination. As is the case for phosphorous, there are various options for eliminating nitrogen:

- The first is incorporation into bacterial masses in high-rate plants. With the composition of wastewaters we have in normal municipalities, this amounts only to roughly 17-20%, as the C/N ratio is around only 4/1. For an optimal N-assimilation in bacteria, a C/N ratio of 12/1 to 15/1 should be present. This means most of the nitrogen has to be transformed into nitrates.
- Elimination of nitrates follows that of phosphates in biological systems on land or in ponds and occurs through transformation into plant masses.
- Other, technical elimination in treatment plants is performed by biological denitrification. The treated effluents of nitrifying units, in our case the trickling filter, is mixed with the raw wastewaters and used as an oxygen source. The nitrogen will be transformed in gaseous nitrogen and released into the atmosphere.
- A new technical method is currently under survey. It involves the chemical transformation of ammonia into ammoniumsulphates and removal of the reaction product.

Elimination of pathogens. Pathogens will not be eliminated to a high degree in high-rate plants, but need additional polishing units, such as trickling filters, land treatment and ponds.

Elimination of intestinal worms. The eggs of intestinal worms are eliminated traditionally in primary sedimentation. If primary sedimentation is skipped, sediment elimination occurs in the sedimentation tanks following the activated sludge unit; destruction is performed by most sludge treatment operations, especially through anaerobic digestion.

Elimination of organics with low degradability. Such organics, especially halogenated hydrocarbons, need highly specialized bacteria which exercise only low degradation velocities and therefore need long generation times. Such organisms cannot be held in activated sludge plants, but they can establish themselves under conditions that are also optimal for other bacteria and the ciliates with long generation times; this is either a terrestrial environment or a trickling filter.

Elimination of heavy metals and other toxicants. Elimination of heavy metals in biological plants is possible, but not advisable. Elimination occurs as a result of chemical reactions between cell surfaces and metals. In higher concentrations, this leads to inhibitions of the non-competitive type, with a reduction of degradation potentials. Also, sludges enriched with heavy metals need special treatment and cannot be used for further integration into natural systems. Elimination of heavy metals has to be performed at the place of their origin. A municipal waste treatment plant is not the place to deal with this matter.

Recycling of wastes

Waste treatment can be connected with agricultural use or can be used to feed fish-ponds. This applies to a greater extent when wastewaters are more defined. Wastewaters with a well-defined composition of pollutants are found especially in agro-industries. Such wastes do not contain human parasites or pathogens and only seldom contain other toxicants. The recycling potentials show a high variety of options, which include the creation of fuel and many possible fermentations into biochemical products, as well as application on land and for aquatic production systems (Figure 8).

Waste prevention

Wastes are normal by-products of all technical processes and can never be fully prevented. Still, the best way to prevent environmental pollution is to prevent wastes. Practical experience proves that whenever the need arises, solutions can be found to improve technologies so that fewer or less harmful wastes are produced. For example, in a chemical factory known to the author, the amount of liquid wastes was reduced from 50 cubic metres per day (with halogenated hydrocarbons) to less than 2 cubic metres per day. This occurred after new limits were set up by the administration and represents the rule, not an exception, in industry.

Another important problem we face increasingly is the production of more and more synthetic substances with low degradability. It should be required that all new synthetic substances be tested with respect to their environmental

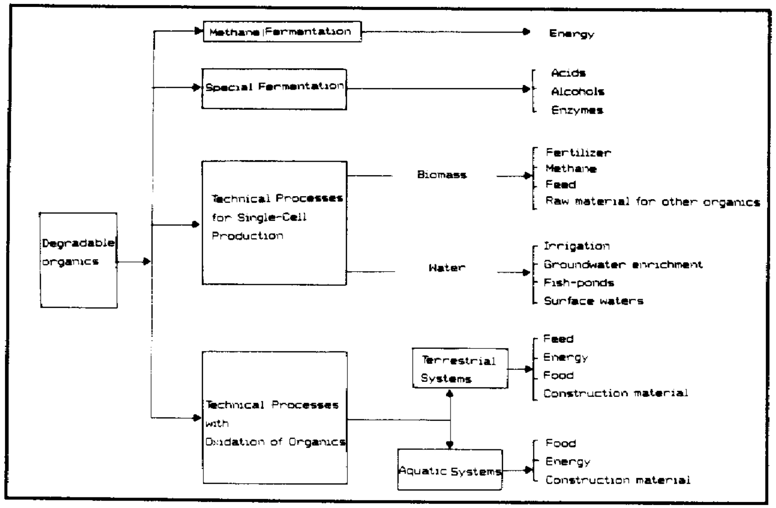

Figure 8. Potentials for transformation and use of organically polluted wastewaters.

stress potentials. For substances in wastewaters, such a test should not only include a simple BOD test, but should also analyze the kinetics of degradation and the optimal biological conditions for degradation. For example, literature in the field indicates that the substance NTA (nitrilo-tri-acetic-acid), used to replace polyphosphates in washing agents, is degraded in all activated sludge plants. Closer analytical tests, however, prove that degradation is possible only in low-rate plants, or in polishing units. Only under such conditions can the bacterial specialists survive.

Summary

A short historical review shows that treatment plants have been developed only after problems have occurred. There was never a time when we were fully prepared to cope with a new task. Wastewater engineering is always one step behind the needs.

The high diversity of pollutants of totally different origins and natures and with varying physical, chemical and biological characteristics requires different tools. There is no plant existing or envisaged in the near future which would be able to cover all the problems.

A good approach is to select one basic tool and try to integrate tools for other tasks within this main tool. The main tool will be in almost every case (for municipal wastewaters) an activated sludge plant surrounded by other ele-

ments for polishing, or for the elimination of nitrogen, phosphorous, etc., according to the local situation. Some tasks, like elimination of pathogens or eggs of intestinal worms, are automatically performed to a high degree in connection with the task of eliminating degradable organics.

- Special wastewaters with certain pollutants have to be treated at the place of their origins. For wastewater of agricultural production, direct or indirect recycling should be favoured. For wastewater of industrial background containing toxicants, treatment must be economically included in the production process of the main product.
- Besides this, there appears a multitude of organics of unknown chemical composition and environmental significance. They should be permitted for public application only after lab tests have proved their degradability and the conditions of their degradation.
- Finally, we should always be aware that treatment plants have to be composed according to local conditions. Depending on the amount and composition of wastes, an integration of tools has to be found that not only meets the demands stemming from the wastewaters but also can be integrated into the existing economical and ecological frame. This integration demands a high degree of additional knowledge.

2

The inadequacy of stabilization ponds treatment as manifested by the effects of Khirbet es-Samra effluent on the groundwater quality of the surrounding area

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Abstract

Jordan has a semi-arid climate, hot summers and very scarce water resources. The growing consumption of water has surpassed all needs of the country and is due to the remarkably high population growth rate and continual upgrading in the standard of living. Agricultural and industrial needs are also increasing rapidly. Jordan's water resources are nearly exhausted, and by the year 2000, the country will be suffering from a water shortage. Even the valuable fossil water has been used for irrigation in certain areas of the country. Also, due to unsound planning and lack of proper insight, wastewater from sewage treatment plants such as Khirbet es-Samra (KS) waste stabilization ponds, some 40 kilometres north-east of Amman, is disposed of into Wadi Dhuleil. Before 1985, when the KS plant was established, the groundwater in Wadi Dhuleil was of high quality and was used by the inhabitants of the area for their domestic and irrigational needs. After 1985, many well owners started to complain about the quality of their well water; many wells, such as the Tillawi and Hashmiyeh wells were rendered unusable, even for irrigation.

In this study, three wells lying downstream of the KS plant outlet and two wells lying upstream of it were monitored. Historic results over the past one or two decades were used in evaluating the effects of KS effluent on the groundwater resources of the area.

Prior to 1985, the downstream wells were of high quality, but later the water started to deteriorate. Increases in all parameters are encountered, although initially (prior to 1985), increases in certain parameters were mild and were due to overpumping of the well water. Later these increases continued at a much higher rate, although the water table in the area has risen by some 20 metres with a variety of indications showing domestic wastewater pollution effects. Groundwater level measurements indicate a recharge mouth in the KS area and along Wadi Dhuleil. Hence, it can be deduced that a source of inferior water quality is recharging the groundwater and causing these increases in parameters. Since no source of pollution other than the KS plant is encountered in the area, and because the parameters in the groundwater increase towards the KS plant and Wadi Dhuleil, it can be deduced that the effluent from the KS plant is polluting the groundwater and rendering it unsuitable for almost all purposes. Such disposals impose yet another constraint on the country's water supply.

Comparatively, the two sample wells taken upstream of KS showed mild increases in the water quality parameters until 1981-1982, due to overpumping of the well water. But due to several wet years, the water table rose and these values decreased and then continued at a constant level.

Since the groundwater flow is in the direction of Wadi Dhuleil, the negative effects of KS on groundwater resources can be clearly seen. If not stopped, this continuous manipulation of the groundwater resources will further pollute the groundwater resources of the entire area.

Introduction

In the past, water contamination was primarily due to the presence of microbiological agents. However, with the modern style of living, entailing the great expansion of industry and use of many artificial and chemical products, water became affected by pollutants. Although many advances in public health have been made, incidences of waterborne diseases still occur even in developed countries rich in water resources. Use of untreated, contaminated groundwater has been responsible for a large percentage of disease outbreaks.

The chemical and microbiological agents that adversely affect the quality of groundwater come from a variety of sources, including land application of agricultural chemicals and organic wastes, infiltration of irrigation water, septic tank disposals, and infiltration of effluents from sewage treatment plants, pits, lagoons and ponds used for storage.

In Jordan, major water problems are being encountered nowadays and these are expected to increase in the near future unless proper solutions are forthcoming. Jordan is suffering from scarcity of water both in its ground and surface resources, especially with its high population growth rate and continuous upgrading in the standard of living, not to mention the remarkable pace of development in the fields of agriculture and industry. So far, even the priceless fossil water available in certain areas in the country is currently being exploited and used for irrigation.[1] Some groundwater resources as well are being polluted by irresponsible and careless disposal of sewage treatment plant effluents, where the degree of sewage treatment is not high enough to produce an effluent quality suitable for the recipient groundwater.

In general, sewage treatment plants aim at getting rid of chemical and organic pollutants so that the treated effluent can be safely disposed of in surface water resources, lakes, or dams, or used in agriculture and industry, or used to directly or indirectly recharge groundwater without affecting its quality. The method and extent of sewage treatment to be used depend on many conditions, such as the degree to which the effluent affects its recipient water course and the consequent advantages and disadvantages to other environmental elements. In no case can a country scarce in water resources adopt the standards of one rich in surface and groundwater resources. Since most countries which have established guidelines are rich in water, it will not be feasible for a country like Jordan to adopt them.

Treated effluents can be discharged into valleys if:

- the effluent quality is very high;
- the amount of surface water is large enough to dilute the effluent;
- the groundwater feeds the surface water and not visa versa.

Therefore the decision to construct a treatment plant is a difficult one to take; it has to be considered very carefully in terms of environmental impact upon elements such as water resources and the general needs of the country. The environmental impact assessment should also be in accordance with the sustainable environmental management of the country, which depends on sound and appropriate environmental policies and strategies.

Prior to 1969, the sole wastewater disposal method in Amman was the use of cesspools and septic tanks, which posed a threat to drinking water supplied by the groundwater resources underlying the inhabited area of the city. The Jordanian government therefore started to connect houses through a network of sewers to a conventional treatment plant, Ain Ghazal Treatment Plant (AGTP). By 1980, the high BOD5 concentration of 960 mg/l in the influent resulted in organic overloading which necessitated remedial measures. The Water Authority thought that constructing another treatment plant to serve the cities of Amman, Zarka and Ruseifa, i.e. 40% of the population of Jordan, would be more appropriate than enlarging AGTP.

But as an immediate relief to the overloaded AGTP, waste stabilization ponds were considered most suitable, and Khirbet es-Samra (KS) was constructed. The system consists of three parallel trains, each a series of two anaerobic, four facultative and four maturation ponds.

The es-Samra ponds were designed to handle loads projected for the year 2000. Design parameters are:

Average dry-weather flow	= 68,000 cu.m./d.
Peak wet-weather flow	= 148,000 cu.m./d.
BOD5 loading	= 35,750 kg/d.
BOD5 of raw sewage	= 526 mg/l.
Suspended solids loading	= 42,000 kg/d.

The anaerobic ponds' total surface area was 19 hectares with 8 days' hydraulic retention time. Maturation ponds occupied another 75 hectares with 14 days' retention time. Although it was well known that the raw sewage BOD5 was in excess of 900 mg/l, KS was designed to handle a BOD5 of 526 mg/l.

The effluent from KS flows into Wadi Dhuleil, which joins the Zarka River and King Talal Dam, where it is stored and used for irrigating crops in the Jordan Valley area (Figure 1).

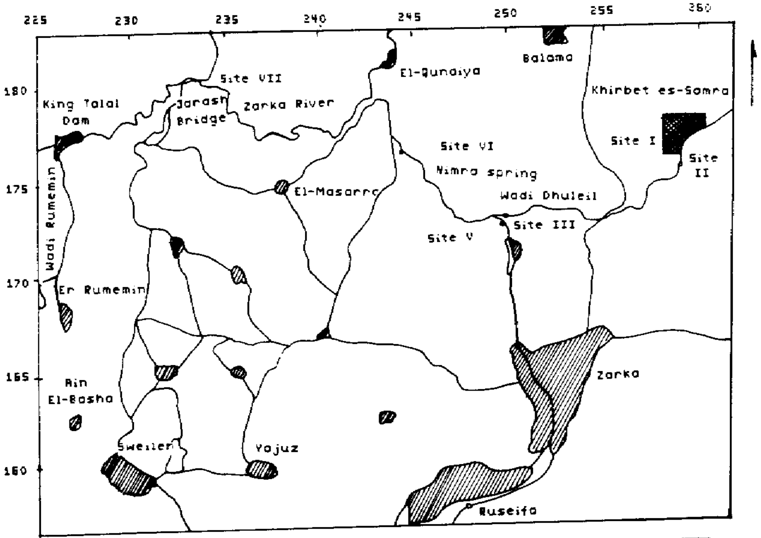


Figure 1. Location of Khirbet es-Samra, Wadi Dhuleil and Zarka.

The design of the treatment plant is such that the ponds occupy 181 hectares of land with an effective volume of 2.8 million cubic metres. During construction, the floor and embankments of the ponds were not lined. They were expected to self-seal within the first year of their use. The infiltration rate initially was very high, which meant that large quantities of polluted water have seeped through to the underground. Now even five years later, the ponds have not sealed off completely.

Residents of the Dhuleil and Zarka area started to complain about the quality of water flowing in the Zarka River, which they had used over a long period of time for various purposes, including domestic uses. Moreover, Seil ez-Zarka and Wadi Dhuleil became breeding sites for insects and developed a foul odour. A number of official complaints was registered with the government concerning the taste, odour and salinity of groundwater in the area, which the inhabitants used for drinking, watering cattle and irrigating their land along the Zarka River.

Performance of Khirbet es-Samra

The flow of KS exceeded 73,000 cu.m./d in 1987, with a BOD5 loading of more than 750 mg/l. By 1990, however both the hydraulic flow and organic loading were much higher. Other parameters such as TSS, TOC and COD were also very high at the inlet and accordingly at the outlet. It can be concluded that the plant is already overloaded and would in no way withstand the projected loads of the year 2000. Moreover, this method of natural treatment is not recognised as suitable for dry, arid or semi-arid regions.[2]

Not only is the plant handling very high organic and hydraulic loadings, but the sludge accumulation at the bottom of the ponds leaves us with even less effective depths, i.e. less retention time and therefore less treatment efficiency.

The BOD5 in the effluent of the plant exceeds 100 mg/l, which is more than the 30 mg/l value set by the adopted Jordanian guidelines. Suspended solids are above 185 mg/l in the effluent, again nearly more than triple the value of 50 mg/l set by the guidelines. COD leaving the plant exceeds 400 mg/l. The number of faecal coliforms leaving the plant varied between 34,000 and 100/100 ml, depending on the extent and effectiveness of chlorination taking place at the outlet of the pond system. The values of TOC, PO_4 and NH_4 are also high in the effluent, which shows that treatment at KS is incomplete. The fact that it contains NH_4 and not NO_3 indicates that no nitrification is taking place. The effluent also contains Purple Sulphur bacteria, which proves that anaerobic conditions are prevailing in all treatment stages at KS as a result of overloading the plant.

The designers of KS anticipated that further tertiary treatment would surely take place along Wadi Dhuleil and in King Talal Dam. Comparing pollution parameters of KS effluent with the flow in Wadi Dhuleil some 12 kilometres downstream of the KS plant shows that there are some increases in these pollutants along the course of Wadi Dhuleil (Table 1).[3] Usually the effluent of KS plant is the only surface water that flows through Wadi Dhuleil. Even during the winter season, which is Jordan's only rainy season, there are no more than 30 rainy days. Therefore no dilution of this relatively strong sewage takes place.

Table 1
Concentration of pollutants at KS outlet and 12 kilometres downstream

Parameter mg/1	Annual average KS outlet	Concentration at 12 km downstream
BOD5	115	92
COD	406	330
TOC	140	123
TSS	183	283
Total coliform count/100 ml	2976	8443
Faecal coliform count/100 ml	217	1143

Moreover, the water table in that area is close to the surface, and the surface aquifer is unconfined and consists in its upper portions of highly permeable wadi deposits. The surface water feeds the underground water (Figure 2). Consequently, the water table has risen by some 20 metres in the immediate

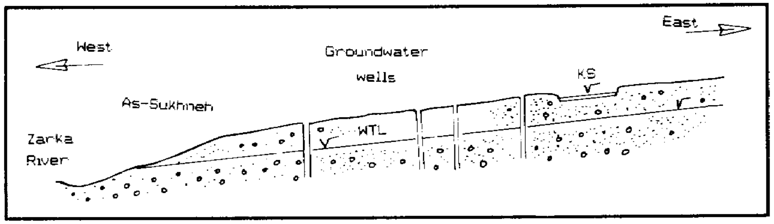


Figure 2. Water flow downstream of Khirbet es-Samra.

surroundings of KS, as a result of the formation of this recharge mouth. This rise dies off gradually in a radial way. The groundwater quality along Seil ez-Zarka has greatly deteriorated due to this recharge with polluted water from KS effluent and from the seepage of irrigation water used in KS area; it is no longer suitable for drinking.

This continual seepage into the underground may reverse the direction of underground water flow and thus negatively affect the entire Zarka area, Khaou, es-Sukhneh and along Seil ez-Zarka. Also, organic amounts have greatly increased along the Zarka River course, and the amount of oxygen has

decreased until Jerash bridge. Coliform and faecal coliform numbers increased greatly along Wadi Dhuleil and Seil ez-Zarka as a result of regrowth of these microorganisms. Table 1 shows the ineffectiveness of chlorination at the KS outlet. The effluent of KS contains large amount of non-biodegradable matter, which remains as such even after it reaches King Talal Dam and King Abdullah Canal. The nature of pollutants reaching Seil ez-Zarka, such as ABS and NH_4, hinders bio-life in the water, especially algae and aerobic bacteria, and this retards self-purification of the water.

The groundwater quality along Seil ez-Zarka has been negatively affected since the start of the KS plant. Also, the water quality of King Talal Dam, the recipient water body of KS effluent, has deteriorated to the extent that it can no longer be used for unrestricted irrigation. Hence, the government has issued a defence decree prohibiting the irrigation of edible vegetables with its water.

Comparison of the quality of groundwater in Zarka area with that of Wadi Dhuleil is shown in Table 2. The great increase in the amount of pollutants in Wadi Dhuleil can be readily seen, and this is primarily due to the presence of the KS sewage treatment plant in the area and discharge of its effluent into the wadi. The dramatic change in Wadi Dhuleil water quality can also be seen when comparing results prior to 1985, i.e. the commencement of the KS plant, with those after 1985 (Table 2).

Table 2
Average chemical parameter values for groundwater in Wadi Dhuleil and Zarka areas

Parameter	Zarka area	Wadi Dhuleil area 1985	Wadi Dhuleil area post 1985
ECμs/cm	1700	1706	3359
pH-value	7.25	7.56	7.34
Ca meq/l	5.55	6.08	11.15
Mg meq/l	3.9	4.64	10.04
Na meq/l	7.57	6.74	14.13
K meq/l	0.157	0.163	0.216
HCO_3 meq/l	4.35	3.5	3.08
SO_4 meq/l	2.2	4.67	7.34
Cl meq/l	9.66	9.2	21.88
Br mg/l	3.303	--	8.51
I mg/l	1.141	--	3.018
PO_4 mg/l	0.266	--	0.375
TOC mg/l	4.86	--	7.816
COD mg/l	2.46	--	16.19

Table 2 emphasizes the fact that there must be a source of pollution affecting the water in Wadi Dhuleil area: salinity almost doubled over the past five years, and the same applies to nearly all the other chemical parameters with the exception of bicarbonate.[4]

The effects of KS effluent on the groundwater in Dhuleil area

The effects of KS effluent on the surface water resources of Wadi Dhuleil and Zarka River until King Talal Dam were discussed in Bulletin No. 10 of the WRSC, 1987.[5] In this report, the effects of seepages from KS treatment ponds and the infiltration of its effluent along Wadi Dhuleil to the groundwater are discussed.

In the immediate surrounding of KS, no groundwater wells are present, but some two kilometres west of it is situated a series of productive wells, which were used to satisfy domestic as well as irrigation needs of the inhabitants around them. The closest well to KS is the Tillawi well, which produces water from the upper unconfined aquifer. Until 1987-1988, the well water was used for domestic purposes and to irrigate around 40 hectares of vegatable producing land. Later, the well was abandoned due to the deterioration of its water quality. In 1986, the owner of the well started complaining about the bad odour and taste of its water, which rapidly worsened. The crops of 1987-1988 were so bad that the land was ascribed zero productivity. Table 3 shows the available results of this well water; no earlier results were available at the Water Authority of Jordan or from the well owner. The water level of the well rose by some 19 metres after operations began at the KS plant, which is beyond any historical level for this well. Salinity reached > 12,000 μs/cm during 1989. Calcium, magnesium, sodium and potassium levels were extremely high, reaching 73 meq/l, 77 meq/l, 45 meq/l and >1.0 meg/l, respectively. Chloride and bicarbonate levels were also very high, reaching 120 meq/l and 2.9 meq/l at times. Sulphate levels of >30 meq/l were detected frequently. Nitrate reached a value of 477.4 mg/l during 1989. Even ammonia and nitrite levels of 0.6 meq/l and 0.025 meq/l were detected in the well water during 1989. Total dissolved solids of up to 13 g/l were also found in the well water. These extremely high values in all the parameters rendered the well unsuitable for all purposes; it was abandoned.

Another recently abandoned well, the Hashmiyeh well, formerly supplied Hashmiyeh village with drinking and irrigation water. With the commencement of KS, this well's water quality deteriorated to the point that its use was stopped. Results of recent analysis of the well water are shown in Table 4.

Although KS effluent has a salinity in the range of 2700-3500 μs/cm, that of the Tillawi well and the groundwater in the area reached a value of >10,000 μs/cm. This behaviour was explained by Salameh and Rimawi 1988[7] through an experiment where KS effluent was applied onto land. The interaction of the water and soil was measured at different depths. During their experiment, which lasted 18 months, they were able to show that the salinity of the applied water increased to 12,000 μs/cm at a depth of 140 cm. This demonstrated the aggressive nature of KS effluent and the solubility of the soil in the area, leading to the increase in the groundwater salinity.

Table 3
Water quality of Tillawi well[6]

Date	EC μs/cm K meq/l	pH-value Cl meq/l	Ca meq/l HCO_3 meq/l	Mg meq/l SO_4 meq/l	Na meq/l NO_3 meq/l
3.7.86	7140 0.4	7.24 70.6	40.5 2.07	36.5 9.46	8.32 2.58
22.7.86	8060 0.44	7.35 77.75	43 2.15	40 10	9.47 2.9
24.9.86	9520 0.49	7.25 105	63 1.3	54 20.6	12.9 3.38
28.10.86	10060 0.43	7.17 109.5	65.6 1.22	55.8 20.29	13.39 3.22
28.12.86	10520 0.58	7.47 114	70.38 1.94	65.28 24.76	18.89 4.75
20.1.87	9500 0.62	7.3 100	56.5 1.74	50.1 20	19.09 4.1
7.3.87	10490 0.64	7.14 121.38	71.7 1.75	54.55 26.29	19.53 2.3
7.4.87	8720 0.68	7.16 97.83	-- 1.86	77.7 34.43	27.14 4.77
13.5.87	10150 0.33	7.13 110.74	69.5 2.28	52.5 30.77	25.7 4.49
16.9.87	11190 0.5	7.11 117.6	71.6 2.6	62.4 32.52	24.49 --
3.11.87	10440 0.52	7.25 115.8	68.48 1.92	64.06 26.52	15.87 4.16
26.2.89	10110 1.10	5.39 103	59.5 2.91	50.5 16.69	35.48 7.1
26.4.89	12020 0.84	4.51 120	73 2.91	65 20.06	45.26 7.7

The effect of KS plant effluent on the groundwater quality in the area can be readily detected when comparing the water quality of the various wells along Wadi Dhuleil over the past 15-20 years. For this purpose, three wells downstream (Dr. Taha Sultan well, Jordan Pipes Manufacturing Company well and Masoud Atiyah well) and another two upstream (Arnous Aquel 1 well and DP17 well) of KS plant were chosen for closer study and comparison. The direction of the groundwater flow in the entire area is toward Wadi Dhuleil.

Table 4
Water quality of Hashmiyeh well[8]

Date	8.7.87	13.11.88	26.2.89
EC µs/cm	1830	2040	1940
pH-value	7.83	6.75	5.38
Ca meq/l	4.8	5.2	--
Mg meq/l	3.8	4.6	--
Na meq/l	9.9	11.99	13.04
K meq/l	0.2	0.25	0.27
Cl meq/l	10.88	12.05	13.25
HCO_3 meq/l	3.72	4.36	4.19
SO_4 meq/l	3.44	3.45	5.99
NO_3 meq/l	0.46	0.85	--
TDS gm/l	--	--	1.47

These wells are taken only as indicators of the situation in the area. There are many other wells under similar conditions. Results used in this report were obtained in part from the Water Authority of Jordan.

Dr. Taha Sultan well lies very close to the course of Wadi Dhuleil and is situated near es-Sukhneh, i.e. where Wadi Dhuleil meets with the Zarka River. This well has been sampled since 1973; the diluting effect of the relatively clean water of Zarka River can be readily seen during the earlier samples. Sampling of this well stopped in 1976 and was resumed early 1987. Comparison of the results between samples prior to 1976 and those of 1987-1988 shows a dramatic increase in all parameters (Table 5).

Table 5
Average results of Sultan well

Parameter	Av. 1973-1976	Av. 1987-1988	Increase
EC µs/cm	1117	2049	83%
pH-value	7.63	7.16	-6.16%
Ca meq/l	3.98	7.59	90%
Mg meq/l	0.77	4.86	534.46%
Na meql	4.51	9.14	102.7%
K meq/l	0.107	0.383	258%
Cl meq/l	4.98	11.9	139%
HCO_3 meq/l	3.85	5.58	45%
SO_4 meq/l	1.813	3.074	69.5%
NO_3 meq/l	0.564	1.2	112.8%

An increase in salinity of 83% is found in the well water, and a drop in pH is also encountered. Mg, Na, K, Cl and NO_3 increases are more than 100%; in the case of Mg it is about 500%. Ca, HCO_3 and SO_4 increases are also very high. The increase in NO_3 is indicative of a nitrate-rich source of pollution affecting the well water quality. In 1985, the effluent of KS was discharged into Wadi Dhuleil, where it started to seep through to the underground, polluting its water. The only explanation for this dramatic change in the well water quality is that it has been affected by KS-discharged effluent.

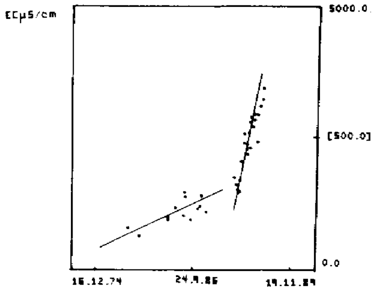
Jordan Pipes Manufacturing Company well belongs to the pipes manufacturing company and lies at co-ordinates 255.200 east and 172.950 north, i.e. very close to the Wadi Dhuleil watercourse. Continuous sampling of the well water has been taking place since late 1974 till the present. Hence, available information is reasonably spread out over the past one and a half decades, and therefore we can detect changes in the well's water quality and whether and when an external factor has affected it. Annual averages of the available data are listed in Table 6.

Table 6
Average values of parameters per year for the Jordan Pipes Manufacturing well

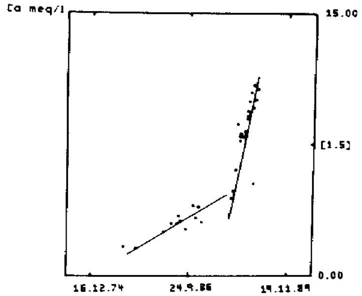
Year	EC µs/cm Cl meq/l	pH-value HCO_3 meq/l	Ca meq/l SO_4 meq/l	Mg meq/l NO_3 meq/l	Na meq/l TDS mg/l	K meq/l
1974	810 3	7.8 3.2	1.65 1.68	2.33 0.27	4 0.52	0.17
1976	660 2.76	7.8 2.42	1.55 1.14	1.58 --	3.26 0.42	0.14
1979	990 5.97	8 2	2.5 1.4	3 --	4.26 0.63	0.12
1980	1125 6.28	7.85 2.71	2.73 2.52	3.25 0.47	5.04 0.72	0.14
1981	1130 6.32	7.8 2.28	3.08 2.42	3.2 0.46	4.97 0.72	0.14
1982	1200 7.5	7.6 2.29	4 2.1	3.4 0.45	4.91 0.77	0.1
1983	1240 7.69	7.9 2.34	3.5 2.41	3.61 0.45	5.3 0.79	0.1
1986	1658 10.24	7.77 2.39	4.52 2.54	4.75 0.81	6.52 --	0.16
1987	1902 12.94	7.75 2.49	6.35 3.5	6 0.92	8.18 1.4	0.18
1988	2520 18.38	7.44 2.65	8.47 4.49	8.14 1.33	10.34 1.8	0.22
1989	2943 21	7.44 2.35	9.71 5.27	9.45 1.46	10.87 2.34	0.29

If we plot the available results of parameters against time (graphs GP 1 through GP 7), we see noticeable changes in the well's characteristics in all the graphs between the years 1983 and 1986. The values prior to 1983 show reasonable consistency with explainable gradual increases, i.e., the increase in salinity and the other parametres is due to the discharge rate from the well and possible decrease in the water table level. After 1986, although the water table has risen due to the recharge by Wadi Dhuleil flow, a dramatic increase in salinity and all other parameters, including sulphate, nitrate, and total dissolved solids can be clearly observed. The results rise at a mild, gradual rate until the 1983-1986 point, after which they increase at a much higher rate. This sudden deterioration in the well water quality cannot be due to overpumping, because water levels are rising. It is rather due to some external source of poor water quality feeding the groundwater. The timing of this sudden change coincides with the start of KS effluent discharge into Wadi Dhuleil and its infiltration to the underground water in the area.

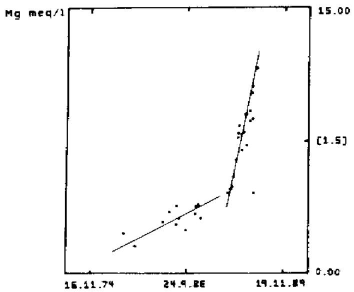
From Table 6, it can be seen that salinity has increased from 1100-1200 µs/cm before 1983, to around 1700 µs/cm in 1986, reaching 3000 µs/cm in 1989, which is more than double the original salinity of the well. The pH values grew slightly more acidic over the years, accompanied by a slight decrease in bicarbonate levels. Calcium and magnesium values increased from 3.5 meq/l prior to 1983, to 4.5-



Graph GP 1: Electrical conductivity against time for the pipes factory well.

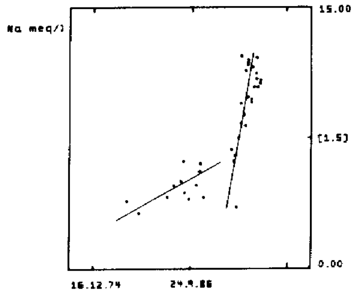


Graph GP 2: Calcium concentration against time for the pipes factory well.

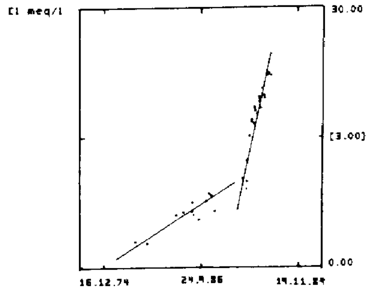


Graph GP 3: Magnesium concentration against time for the pipes factory well.

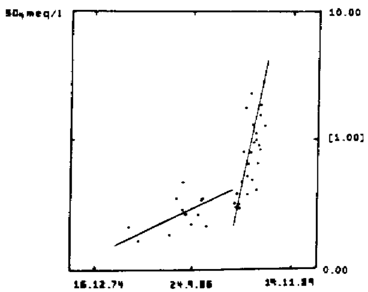
4.75 meq/l in 1986 reaching 9.5 meq/l by 1989, which is nearly triple the values prior to 1983. Sodium, potassium and chloride values increase steadily until 1983, then increase suddenly from 1986 to 1989. Chloride has increased sevenfold since 1974 and threefold since 1983. Sulphate, nitrate and total dissolved solids have shown a similar increasing pattern. In 1989, nitrate values reached a concentration five times that of 1974, which suggests that a source of nitrate-rich pollutant has affected the well water. The chemical oxygen demand of this originally clean well was found on several occasions lately to be almost 50 mg/l. Also, microbiological analysis of the well water during 1988 has shown the presence of heterotrophic bacteria counts of the order of 13,000/100 ml. Moreover, total coliform counts, which are indicative of faecal pollution, were detected during January 1988 at a level of 320/100 ml, which greatly exceeds the allowable counts for groundwater quality.



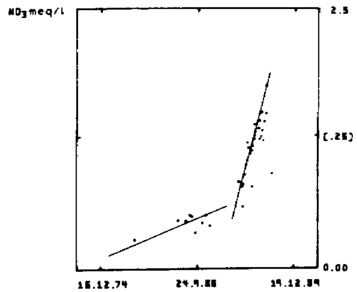
Graph GP 4: Sodium concentration against time for the pipes factory well.



Graph GP 5: Chloride concentration against time for the pipes factory well.



Graph GP 6: Sulphate concentration against time for the pipes factory well.



Graph GP 7: Nitrate concentration against time for the pipes factory well.

Considering that water needs time to seep into the underground, depending on the geological structure of the area, the effect of a polluting source may not necessarily be detected immediately; this is the case in the Pipes Manufacturing Company well. By 1986, part of the effluent of KS reached the well and started to pollute its water. This effect has been increasing rapidly until the present time, as can be seen from graphs GP 1 - GP 7.

Masoud Atiyah well is privately owned, with an altitude of 490 metres above sea level and co-ordinates 252.720 east and 172.545 north. It lies further downstream from KS than the Jordan Pipes Manufacturing Company well and is close to Seil Khirbet es-Samra (Wadi Dhuleil).

Data on the well water quality are available from 1972 until the present. The annual averages of the different parameters are listed in Table 7.

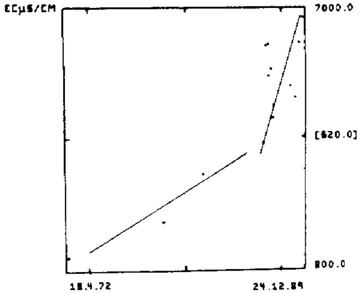
Table 7
Annual averages of parameters for Masoud Atiyah well

Date	EC μs/cm K meq/l	pH-value Cl meq/l	Ca meq/l HCO_3 meq/l	Mg meq/l SO_4 meq/l	Na meq/l NO_3 meq/l
1972	963	7.63	3.3	2.16	3.89
	0.103	4.05	3.7	2.3	0.62
1979	1915	--	5.35	5.3	7.47
	0.24	11.88	.29	3.39	--
1982	--	7.5	11.25	7	12.3
	0.2	19.86	2.27	7.18	1.15
1986	3505	7.74	12.92	11.65	12.86
	0.23	26	2.15	--	1.98
1987	5312	7.48	21.77	18.78	24.28
	0.34	46.3	2.08	15.82	3.44
1988	5080	7.04	22.7	19.9	17.76
	0.36	42.33	2.4	10.09	3.23
1989	5212	7.19	25.73	22.6	22.58
	0.42	49.92	2.02	15	3.65

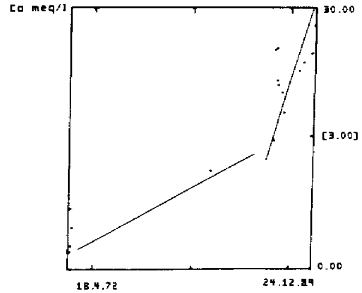
When plotting the available results of the different parameters over time, (graphs GA 1 through GA 7), a dramatic change in the behaviour of well water quality can be seen around the year 1985. The slopes of the lines joining results of the years 1986-1989 are much steeper than the lines joining the first set of results, i.e. 1972-1982. Both lines intersect at a point around the year 1985-1986, which suggests that at that time an external source affected the well water characteristics. The increase in the various well parameters, until 1982, was steady and was due to overpumping of the aquifer. But since 1986, with the percolation of water from the seil into the underground, this steady increase should have at least faded away. Yet the values of the parameters have continued

to increase at a higher rate, suggesting that the recharge water is of inferior quality to the well water.

The well's water has been continuously deteriorating over the past five years. Salinity in the period 1972-1979 was around 1000-1900 μs/cm; it is now in excess of 6200 μs/cm, i.e. a sixfold increase since 1972. The pH of the water has decreased over the years, marked by a decrease in bicarbonate and accompanying increase in CO_2 formation. Calcium, magnesium, sodium, potassium, chloride, sulphate and nitrate values are all marked by a steady increase till 1982; they jump slightly in 1986, significantly by 1987 and are still increasing. The amount of sulphate in the water during 1987 was more than double its value in 1982; the same goes for nitrate. These increases suggest that the pollutant source is rich in sulphate and nitrate. Since this well lies further downstream from KS, the effect of KS effluent on its water quality takes longer time to appear, due to the time needed for seepage and horizontal flow. The total dissolved solids have increased over the years to reach 4.5 mg/l in 1989.

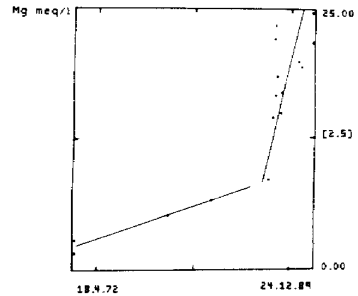


GA 1: Graph of electrical conductivity against time for M.M. Atiyah well.

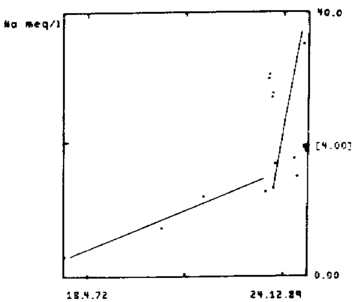


GA 2: Graph of calcium concentration against time for M.M. Atiyah well.

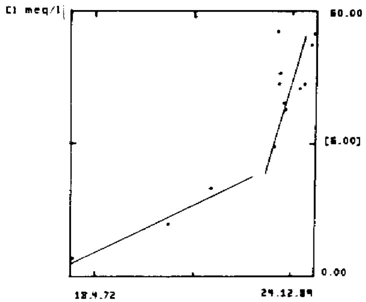
During 1989, the chemical oxygen demand in the well water reached up to 92 mg/l. Also, microbiological analysis of the water samples indicated the presence of total heterotrophic bacteria and total coliforms in the order of 23,000/100 ml and 7500/100 ml respectively. The presence of such high numbers of total coliforms suggests that the polluting source is of faecal origin, since groundwater does not naturally contain coliforms unless affected by sewage water.



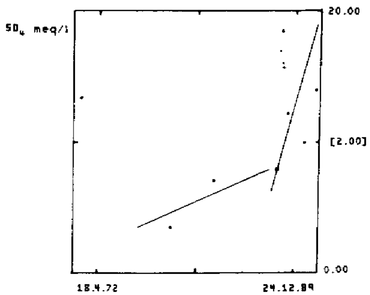
GA 3: Graph of magnesium concentration against time for M.M. Atiyah well.



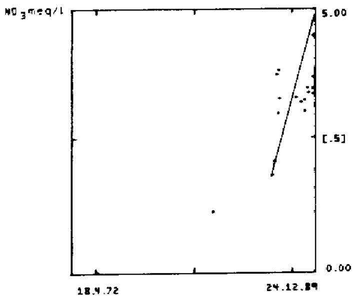
GA 4: Graph of sodium concentration against time for M.M. Atiyah well.



GA 5: Graph of chloride concentration against time for M.M. Atiyah well.



GA 6: Graph of sulphate concentration against time for M.M. Atiyah well.



GA 7: Graph of nitrate concentration against time for M.M. Atiyah well.

From these results, it can be deduced that a polluting source of inferior quality to this well water and of faecal origin has been polluting the well since 1985-1986. Since no other polluting source has been affecting the area except the effluent of KS sewage treatment plant, the negative effects of such disposal on the groundwater can be clearly seen.

The DP 17 well lies upstream of KS plant at an altitude of 582 metres above sea level and co-ordinates 175.165 north and 272.236 east. Available data on this well's water characteristics run from 1971 till 1990. Annual averages of the different parameters are listed in Table 8.

Graphs GD 1 through GD 7 represent the change in each parameter with time. It can be seen that in most of the graphs a gradual increase is encountered up till the year 1980-1981, after which the values decrease and continue at a more or less constant level until the present. At the same time no changes in the water level of the well were observed, contrary to the wells along Wadi Dhuleil, in a downgradient direction.

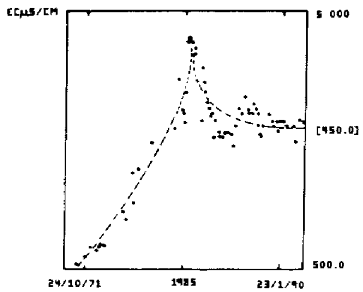
Table 8
Annual averages of parameters of DP 17 well

Date	EC µs/cm K meq/l NO_3 meq/l	pH-value Cl meq/l TDS g/l	Ca meq/l CO_3 meq/l	Mg meq/l HCO_3 meq/l	Na meq/l SO_4 meq/l
1971	500 0.16 --	8.1 2.14 0.32	0.7 0.177	1.5 1.09	2.43 1
1972	620 0.23 --	8 2.85 0.4	1.1 0.177	1.92 1.61	2.91 1.56
1973	808 0.24 --	8 4.62 0.52	1.58 0	2.38 1.47	3.87 1.74
1974	915 0.2	7.9 6.09 0.75	1.85 0.103	2.69 1.39 0.59	4.48 1.41
1975	1500 0.51 --	7.4 9.72 0.96	3.3 0	5 1.16	4.91 2.13
1976	1688 0.37 0.65	7.5 11.6 1.08	4.5 0	5.6 1.58	5.78 2.48
1977	2250 0.41 0.65	6.6 15.49 1.44	5.6 0	7.92 1.3	6.61 3.25
1978	2700 0.41 0.65	7.8 19.35 1.73	6.35 0	9.67 1.16	8.09 3.19
1979	2930 0.56 1.13	7.8 22.33 1.88	7.05 0	12.58 1.1	8.7 4.04
1980	3372 0.52 1.36	7.7 27.35 2.16	8.77 0	14.57 1.08	10.54 4.96
1981	4368 0.59 1.9	7.8 35.61 2.8	12.06 0	18.56 0.97	13.86 6.9

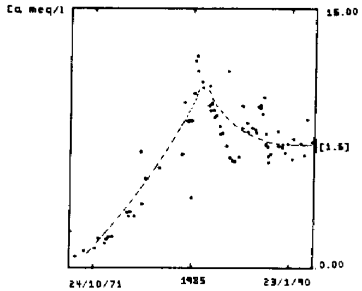
continued .....

Date	EC μs/cm K meq/l NO_3 meq/l	pH-value Cl meq/l TDS g/l	Ca meq/l CO_3 meq/l	Mg meq/l HCO_3 meq/l	Na meq/l SO_4 meq/l
...continued from page 41					
1982	3429	7.8	10.3	14.13	10.84
	0.51	27.28	0	1.02	5.2
	0.94	2.19			
1983	2896	7.7	8.37	11.3	9.58
	0.37	21.87	0	1.07	4
	1.17	1.85			
1984	2870	8	8.11	10.64	9.55
	0.41	21.38	0	1.05	4
	0.86	1.84			
1985	3283	7.9	8.84	15.4	10.4
	0.34	24.45	0	1.17	5.6
	1.24	2.11			
1986	3099	7.9	8.44	11.77	11.56
	0.43	23.49	0.01	1.23	5.45
	1.36	1.98			
1987	3100	7.82	7.85	11.7	10.73
	0.46	23.64	0	1.16	4.62
	1.36	1.98			
1988	3027	7.76	7.44	11.82	10.28
	0.43	22.63	0	1.22	4.83
	1.32	1.94			
1989	2943	7.84	7.99	8.64	10.47
	0.4	23.45	0	1.1	5.66
	1.32	1.9			
1990	3100	7.62	7.88	11.76	9.7
	0.45	21.95	0	1.01	5.26
	1.53	2.02			

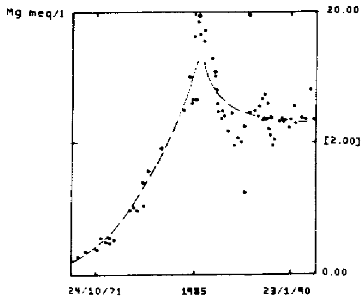
Salinity of this well increased from 500μs/cm in 1971 to 4300μs/cm in 1981, after which it decreased slightly and continued at a constant level of around 3000 μs/cm until 1990. Calcium, magnesium, sodium, potassium and chloride values reach their maximum during 1981, a slight drop in these values is encountered during 1982, and then they remain at a nearly constant level. A drop in pH values in 1981 is matched by a drop in the level of bicarbonate; however, the bicarbonate levels remain constant after that. The concentra-



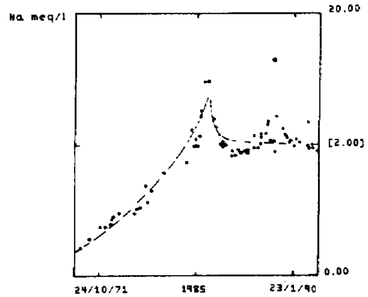
Graph GD 1: Electrical conductivity in μs/cm over time for DP 17 well.



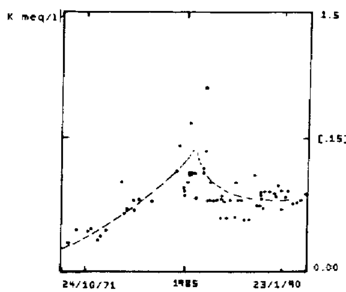
Graph GD 2: Calcium concentration in meq/l over time for DP 17 well.



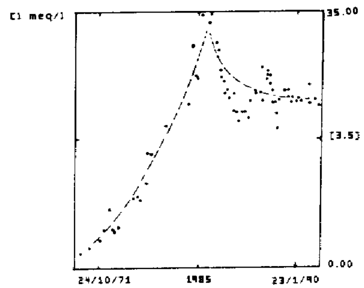
Graph GD 3: Magnesium concentration in meq/l over time for DP 17 well.



Graph GD 4: Sodium concentration in meq/l over time for DP 17 well.

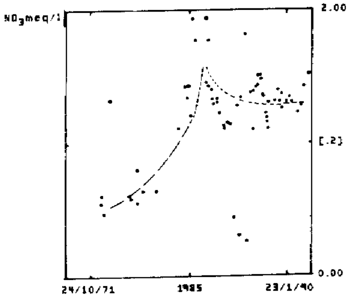


Graph GD 5: Potassium concentration in meq/l over time for DP 17 well.



Graph GD 6: Chloride concentration in meq/l over time for DP 17 well.

tion of sulphate in the well water reaches 6.9 meq/l in 1981, but later resumes a constant rate of 4-5.5 meq/l. Nitrate concentrations follow the same pattern, which suggests that the water has not been affected by an external source rich in nitrate as was the case downstream of the KS plant. Total dissolved solids increased to 2800 mg/l in 1981 and dropped to 2000 mg/l after that until 1990.



Graph GD 7: Nitrate concentration in meq/l over time for DP 17 well.

From these annual averages covering the well history and from graphs GD1 to GD7, it can be deduced that the well water has not been affected by any external factor which might cause a deterioration in its quality. The initial rise might be due to overpumping of the well water or due to the dry years 1978-1980. After that, these increases faded away, and the values of the different parameters resumed a constant rate. This case is most unlike the situation downstream of KS, where dramatic increases in the water characteristics and the water levels of the wells have been encountered during 1985-1986, i.e. the commencement of KS sewage treatment plant.

Arnous Aquel 1 well lies upstream of KS plant at an altitude of 557 metres above sea level with co-ordintes 171.549 north and 266.429 east. This well is the closest to the KS site. Data is available on the well's water quality from 1971 until late 1987. Annual averages of the different parameters are listed in Table 9.

From Table 9, it can be seen that the salinity of the well water increased slightly in 1983 to around 800 μs/cm, but carried on at an almost constant rate of 645 μs/cm till 1987. Calcium concentration increased in 1985, but remained stable since. Magnesium levels were increasing at a mild rate until 1985, after which they remained almost constant. Sodium, potassium and chloride levels decreased during 1983-1985, but remained constant since. Sulphate levels decreased during 1985 to around 0.45 meq/l and remained as such until 1987. Nitrate levels did not change from 1979 until the present time, which assures us that no external source rich in nitrate has been affecting the well. The water table in the area has risen over the past few years, accounting for this consistency in the results. The reason for the initial rise in the values of the parameters is probably the overpumping of the well water or the dry years 1978-1980. However, this increase faded away by 1981-1983 due to the rise in the water table caused by the wet years 1980-1982. This is another case emphasizing the contrast in the situation of the groundwater quality upstream and downstream of KS plant (groundwater up and downgradients).

Table 9
Annual averages of parameters of Arnous Aquel 1 Well

Date	EC μs/cm K meq/l	pH-value Cl meq/l	Ca meq/l HCO_3 meq/l	Mg meq/l SO_4 meq/l	Na meq/l NO_3 meq/l
1971	460 0.11	7.9 1.75	0.85 2	1 0.81	2.435 --
1974	480 0.12	8.3 1.86	1.3 1.56	0.66 0.96	2.61 --
1975	550 0.18	7.7 1.97	1.2 2.25	1.17 1.04	3 --
1979	630 0.12	8.3 3.01	1.15 2.38	1.33 0.67	3.96 0.4
1983	805 0.1	8 4.17	1.55 1.7	1.67 0.92	4 0.3
1985	657 0	7.17 1.6	3.34 4.06	1.72 0.45	1.54 0.33
1986	642 0.07	7.61 1.65	3.27 4.12	1.71 0.45	1.58 0.34
1987	648 0.04	7.39 1.58	3.24 4.08	1.78 0.5	1.48 0.35

Discussion and Conclusions

- The deterioration in the groundwater quality increases towards Wadi Dhuleil area and KS plant. The closer the well to KS and Wadi Dhuleil, the more saline, hard, rich in anions and cations the water becomes, rendering it less suitable for drinking purposes.
- The relatively high nitrate concentrations in these wells were found in the water prior to the commencement of KS treatment plant, due to the recycling of irrigation water in the area. However, these values did not exceed 30 mg/l. After the 1985 commencement of KS, on the other hand, the nitrate concentrations in the groundwater increased dramatically: for example, in Masoud Atiyah's well, the levels of nitrate reached 227 mg/l and in Tillawi well 300 mg/l during 1989. This high level of nitrate in the groundwater could be due to the high ammonium level in KS effluent, which converts to nitrate as it infiltrates to the aquifer. The recycling of irrigation water and the discharge of industrial wastewater along Wadi Dhuleil can only have slight effects as experienced by the NO_3 values before the commencement of the KS treatment plant.

- The low nitrate concentration in KS effluent is an indication of anaerobic conditions prevailing in the treatment, which suggests overloading of the plant.
- The wells upstream of KS have shown relatively lower concentrations of nitrate, because there is no external polluting source affecting them.
- Sulphate levels in the upstream wells are generally lower than those in the downstream wells, especially after 1985. The wells downstream of KS have experienced dramatic increases in sulphate values since the commencement of the KS plant.
- Chloride concentrations in the downstream wells increased rapidly after KS was established. The levels of chloride in the upstream wells are relatively less than those in the downstream wells, especially when comparing post-1985 results, which strongly indicate the effect of KS effluent on the groundwater quality.
- Chemical oxygen demand in the downstream wells increased considerably after 1985, reaching up to 50 mg/l in some of them. This value is far above the zero guideline value and renders these wells unsuitable for drinking purposes.
- Salinity increased greatly in the downstream wells, especially after 1985, reaching around 6000 μs/cm in some wells. This case is not encountered in the upstream well water, which consists of less saline water with no major changes in its value over the past few years. This dramatic increase in salinity is attributed to the effluent of KS plant which recharges the aquifers of Wadi Dhuleil or the recycling of irrigation water using KS effluent.
- Wastewater in KS ponds themselves, as well as its effluent along Wadi Dhuleil, infiltrates to the underground and has caused a rise of some 20 metres in the groundwater table since 1985. Therefore, the major recent increases in EC, Na, K, Ca, SO_4, NO_3, Cl and TDS cannot be attributed to overpumping of the well water.
- The increase in organic and inorganic matter in the groundwater suggests a source of domestic origin, and can never be the result of overpumping.
- The fact that total coliforms are present in the well water and in such high numbers indicates strongly the effect of domestic sewage on this water; this is due to KS effluent.
- The groundwater towards the Wadi Dhuleil area became more polluted after the commencement of the KS plant and is becoming still more polluted and less suitable for drinking purposes and, in many cases, even for irrigation, such as in the Tillawi well. The effluent of KS along Wadi Dhuleil is causing a health hazard for the inhabitants and farmers using the water, besides creating a nuisance of malodour and insect breeding in the area.
- Comparison of the water quality of wells lying upstream of KS plant and those lying downstream shows the drastic effect KS has on ground and surface water quality in the Dhuleil area.

- An experiment with suction cups in KS area has shown, under continuous irrigation conditions, a two-to-threefold increase in the concentration of all parameters at a depth of 1.0-1.5 metres. The increase is controlled by dissolution of halite, gypsum, calcite and brucite minerals present in the soil. This explains the high concentrations of these parameters in the wells. Even if KS effluent has less electrical conductivity than that of some wells, the reason for the increase in groundwater salinity is the agressiveness of KS effluent on the bedrock and surrounding soils as it is used for irrigation.

Addendum
Aqaba Wastewater Treatment Plant

Another sewage treatment plant was constructed in the city of Aqaba to meet the city's domestic needs, which are very irregular due to the presence of tourists during certain seasons. The treatment is achieved through a natural treatment plant, i.e. waste stabilization ponds. These ponds are constructed some two kilometres north-northeast of the shore of Aqaba, in Wadi Araba, on unconsolidated wadi fills.

The ponds were designed to achieve effluents of high quality. Yet the sizes of these ponds are much larger than needed, and their bottoms and embankments were not lined. They were expected to seal off completely soon after being put in use, yet the pond site is composed of friable sediments which are highly permeable. So far, the effluent from the treatment plant seeps into the underground before reaching the outlet of the ponds.

Wells in the nearby area of en-Nakhel forest have shown a rise in the water table, which indicates that the groundwater there has been fed by another source of water.

Analyses of the effluent from the different stages of treatment and the Nakhel wells are presented in Table 10. Chemical and biological results prove that a water source of inferior quality has seeped through to the underground water in the area and has already reached the Nakhel forest wells. Since groundwater flows towards the shore (Figure 3), the risk that this water will reach the Gulf of Aqaba and pollute it is high. Moreover, the relatively high content of PO_4, NO_3, K, trace elements and micronutrients in the groundwater reaching the shore will enhance eutrophication at the beach.

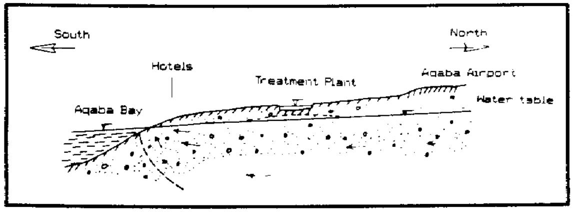


Figure 3. Groundwater flow in Aqaba area.

Table 10
Analysis of effluent from various stages of Aqaba wastewater treatment plant and Nakhel forest wells

	Inlet	Facultative	Maturation	Effluent	Nakhel well no. 1	Nakhel well no. 2
EC $\mu s/cm$	1420	1620	1680	1685	1980	2190
pH-value	7.37	7.48	8.19	8.28	8.05	7.90
Temp.°C	10.9	17.8	18.0	18.1	20.4	29.6
DO	1.3	2.45	0.85	2.3	2.15	1.82
BOD5	461.6	199.8	161.8	145.7	86.8	n.d.
COD6	600	550	--	500	125	n.d.
TOC	284.4	247	--	183.67	29.2	n.d.
NH_4 meq/l	--	3.15	2.98	2.38	0.021	0.03
NO_3 meq/l	--	0.70	0.63	0.55	0.77	0.795
HCO_3 meq/l	--	6.8	7.52	7.72	2.67	1.782
Cl meq/l	--	8.56	8.20	8.40	12.9	16.32
Cu meq/l	--	2.80	3.30	3.50	3.60	7.5
Mg meq/l	--	2.26	2.20	2.30	2.70	3.8
Na meq/l	--	10.39	10.84	10.74	13.1	11.50
K meq/l	--	0.6	0.702	0.702	0.14	0.2
SO_4 meq/l	--	3.10	3.70	2.91	2.97	2.916
CO_3 meq/l	--	--	0.0	0.20	--	0.00

Source: Aqaba Wastewater Treatment Plant
Date: 24.3.1988
n.d. = not determined

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3

The potential impact of industrial wastes on water resources in Amman-Zarka basin

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Ever-increasing quantities of industrial wastes will result in the release of heavy metals into Amman-Zarka basin. Groundwater pollution from abandoned and existing landfills of solid and liquid waste material in the area may further damage the freshwater quality and will be a particularly difficult problem in the future, especially considering that the aquifer is already overexploited by 66 million cubic metres per year, with almost 50 metres depletion in the static water level.

Entering the 1990s, population growth in Jordan remains unchecked. The bulk of evidence shows that uncontrolled pollution puts further stress on the fragile environment and aggravates competition for increasingly expensive water resources. Without fundamentally new approaches, the government's commitment to provide sustainable water and environmental sanitation systems for all people may be jeopardized. A major problem of industrial development is the quantity and diversity of wastes it generates. Toxic chemical loads of industrial origin have been discharged into the environment in considerable quantities (Table 1). Biochemical industrial effluents in the area now amount to several thousands of tons per year (Table 2). Some industries, for example, discharge dissolved chromium into communal sewerage systems at a rate of 25 mg/l and an average salt content of 1700 mg/l daily.

These issues have not been given high enough priority, partly due to lack of funds and partly because of the widely believed fallacy that environmental deterioration is not an issue of immediate concern. However, we can indeed examine the issue in terms of its long-term magnitude and importance to Jordan and in particular to Amman-Zarka basin, where almost 60% of the country's economic development is taking place. The chronic waste production in an upstream watershed of Amman-Zarka basin, which pollutes a reservoir, constitutes a strategic issue where both magnitude and importance are of high priority.

Considering the potential industrial growth in the Amman-Zarka area and the corresponding accumulative pollutants released into the environment, as demonstrated in tables 1 and 2, the need to pursue sustainable development while at the same time controlling sources of pollution assumes high priority.

This assessment of the extent, trend and behaviour of pollutants in receiving water courses and underground water will constitute baseline information that could be used by executive management to determine when to take action against pollutants. An attempt has been made to monitor and evaluate the emerging environmental problems with a view to determining how to provide for sustainable growth, with the least environmental and fresh water degradation.[1,2,3]

Table 1
Toxic chemical loads of industrial origin in Amman - Zarka basin (Jan. 1990-July 1990)

Parameter	Load (ton/yr)
Mn	0.55
Zn	1.2
Fe	3.2
Cu	0.087
Cr	0.65
Cd	0.12
PO_4	33.2
ABS	266
NH_4	206

Table 2
Biochemical loads of industrial origin in Amman - Zarka basin (Jan.1990-July 1990)

Parameter	Load (ton/yr)
TDS	7113
SS	3197
COD	5150
BOD	2257

Note: Estimation made on mean values of measured parameters and emissions for industries monitored by WAJ.

Sources of pollution

Any human activity can be considered a potential source of water pollution, since it may cause a change in concentration and/or a variation in the pattern of natural substances found in water. As a general rule, pollution is proportional to the state of development of a country. However, Jordan has specific sources of concern, among which are the following:

- Organic and industrial pollution is directly linked to population density and also to development of wastewater treatment and the self-assimilative capacity of each water body, e.g., Zarka River and King Talal Reservoir.
- Significant environmental pollution, particularly of aquatic systems and of underground water, is predictable in Jordan's case of emerging economic growth, due either to lack of environmental laws or lack of enforcement of existing laws and regulations. The absence of an information management system makes it difficult to advocate a mechanism for pollution control at the national level.

Sources of toxic metal elements

As a consequence of increasing emissions from anthropogenic sources, e.g., industrial processing, fertilizers, and municipal wastes, the general abundance of toxic metals in Amman-Zarka basin has reached intolerable and alarming levels. Tables 8 (p. 58) and 3 show the effect on recipient water courses and underground water, respectively.

A special feature of toxic metals is that they are not biodegradable and have a pronounced tendency to accumulate in vital organisms and plants that may form part of the human food chain. Thus, once they have entered the environment, their potential toxicity is controlled to a large extent by their physico-chemical form.[4] The potential sources of heavy metals can be summarized as follows[5]:

- Geological weathering. This is the source of "background levels" characteristic to the metal-bearing rock formation of the area under study.
- Industrial processing and use of metal compounds. The use of chromium salt in tanneries, often discharged in violation of regulatory standards, is an evident example.

Table 3
Pollution indicators at observation wells located near STP (1990)

Well No.	TDS	NH_4	PO_4	Fe	Mn	Zn	ABS *
1	3380	115.00	11.10	0.26	0.69	1.98	250.00
2	3250	38.00	1.55	1.54	<0.1	3.80	0.70
6	2275	26.00	0.25	1.34	0.36	5.00	10.00
9	1482	83.00	39.00	0.35	<0.1	0.62	12.50

Note: All results in mg/l.
* Alkyl Benzene Sulphonate, the active ingredient in hard detergent.

Table 4
Mean values for organic loads of industrial effluent *
(Jan.1990-July1990)

Designation **	Flow (m^3/d)	pH units	TDS kg/d	SS kg/d	COD kg/d	BOD kg/d
Jordan Yeast Co.	350	6.6	7000	6975	11690	5309
Arab Detergent Mfg.	40	10.3	3.72	64	89	28
ICA Co. (INTAJ)	120	7.5	4256	303	580	177
Jordan Mineral Exploration	100	7.7	142.5	93	7.2	1.1
Overall Co. (oven mfg)	125	8.4	315.1	32.4	57	23
Chem. Polymers Co.	4	6.3	92	153	372	39
Jordan Tiles Co.	55	12.1	187	84	2.5	0.33
Jor. Imperial Underwear	50	7.8	92	17.5	32.3	8.4
Textile Co. (TBAKHI)	20	7.9	23	6.7	14.42	5.3
Tent & Blanket Factory	80	8.0	65	8.2	21.4	6.7
Pulp and Mill Mfg. Co.	2000	7.6	2672	252	760	306
Jordan Ceramics Co.	85	7.7	243	60.2	11	3.3
Jordan Chemical Ind. Co.	1	11.2	13.73	0.2	1.63	0.52
Intermediate Petrochem.	2	7.9	3.11	0.31	14.76	0.36
Hussein Iron & Steel Ind.	50	8.2	333	31.2	16.5	3.9
Jordan Matches Mfg. Co.	4	7.0	42.6	8.0	17.2	6.3
Jordan Sulphochem. Co.	30	9.2	717	345.5	44.7	14
Warehouse Mfg. Co. (Refrig)	10	8.3	7.9	0.5	1.11	0.3
Rock Wool Factory	1	8.0	1.9	0.16	0.09	0.02
Jordan Petroleum Refinery	1600	7.53	3749	117	282	74
Hussein Thermal Station	1700	7	2733	56	102	34
Arab Iron & Steel Co.	300	8.8	452	32.4	16	2.4
Jordan Hygienic Paper Co.	100	7.3	224	197	164	60

* The findings contained in this and other tables are meant for research purposes only and do not constitute prejudice towards the integrity of industrial concerns vis-à-vis compliance with government regulations. The industrial designations employed and the presentation of material are solely for study purposes and do not imply any inculpation whatsoever by the author concerning the status of any industry. They

- Heavy metals in animal and human excretions. These metals become concentrated in excretion and find their way to the water environment. For example, the adult human excretes between 7 and 20 mg of zinc per day.
- Leaching of metals from domestic wastes and solid waste dumps. Industrial dumps can be a hazardous source of pollution in connection with acidic solutions. The observed excessive content of Cd, Pb, and Ni in soils and plants in the Amman-Zarka metropolitan area confirms that urban and industrial pollution is threatening the immediate environment.[6]

Factors affecting the magnitude of pollution

The use of different elements and chemical compounds can give only a general impression of potential pollution, since the amount and concentration of pollutants in water resources depend on many factors, including:

- **The intensity and nature of the source.** Table 4 shows the biochemical loads of the effluents discharged from 23 Jordanian industries into the ecosystem. The diversity of the industrial sources along with the amount of flow in a limited area may be a serious threat to the fragile environment and receiving water bodies. Certainly, the accumulation of toxic elements from industrial effluents (see Table 5) will have a significant detrimental impact on the environment.
- **The size and renewal time of the water body.** The concentration levels of potentially toxic organic loads of both Zarka stream and King Talal Reservoir may diminish the assimilative capacity of water bodies, and their self-purification abilities, as shown in Figures 1 and 2.

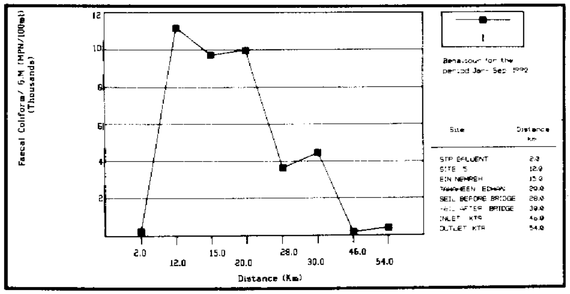

Figure 1. Seil Zarka - STP flow system, faecal coliform (geometric mean), 1990.

are meant to identify sources of the problem, aiming at sustaining the water supply for domestic, industrial and agricultural uses.

** Some industries may have taken corrective measures to comply with relevant standards since this paper was presented.

The bacterial growth along the Zarka River has persisted for the last two years without any sign of improvement. This proves that increasing organic loads can adversely affect the different types of naturally occurring organisms, perturbing the ecosystems and prolonging the time required for self-purification of the affected body of water. Also affecting renewal time are the elevated levels of toxic metals associated with continuous man-made inputs and biological productivity. Recent studies by Gregori (1988) and

Table 5
Mean values for toxic elements of industrial effluents *
(Jan. 1990-July 1990)

Designation	Flow (m^3/d)	Mn kg/d	Zn kg/d	Fe kg/d	Cr kg/d	Cu kg/d	PO_4 kg/d	ABS kg/d	NH_4 kg/d
Jordan Yeast Co.	350	0.2	0.11	1.21	n.d.	n.d.	3.5	2.24	295
Arab Detergent	40	n.d.	0.005	0.013	0.006	0.006	1.61	50.52	0.058
ICA Co. (INTAJ)	120	n.d.	0.078	0.154	0.013	n.d.	67.08	83.88	0.996
Jord. Mineral Expl.	100	n.d.	n.d.	0.002	n.d.	n.d.	0.002	0.021	0.005
Overall Co. (oven mfg)	125	0.106	0.125	1.602	n.d.	n.d.	0.192	1.245	0.197
Chem. Polymers Co.	4	n.d.	0.006	0.075	n.d.	n.d.	0.54	0.5	0.78
Jordan Tiles Co.	55	n.d.	n.d.	0.015	0.032	n.d.	0.005	0.028	0.195
Imperial Co.	50	0.025	0.055	0.033	n.d.	n.d.	0.93	0.018	0.545
Textile Co.	20	n.d.	0.016	0.01	n.d.	n.d.	0.034	0.028	0.112
Blankets Factory	80	0.009	0.025	0.032	0.17	n.d.	n.d.	0.024	0.68
Pulp & Mill Co.	2000	0.81	0.24	0.8	n.d	n.d.	4.58	0.9	2.32
Jordan Ceramics Co.	85	n.d.	0.133	0.019	0.12	n.d.	0.123	0.117	0.238
Hussein Iron & Steel	50	0.036	n.d.	0.51	n.d.	n.d.	0.093	1.43	0.177
Jordan Matches Co.	4	0.03	0.60	0.01	0.01	0.005	0.06	0.004	0.016
Jordan Sulphochem. Co.**	30	0.006	0.043	0.017	0.03	0.08	0.63	0.309	0.014
Warehouse Mfg. Co.	10	n.d.	0.009	0.002	n.d.	n.d.	0.223	0.003	0.007
Jordan Petroleum Ref.	1600	n.d.	n.d.	0.52	n.d.	0.02	1.6	72	3.2
Hussein Thermal Station	1700	n.d.	0.68	1.2	n.d.	n.d.	0.544	3.026	1.105
Arab Iron & Steel Co.#	350	n.d.	0.06	0.318	0.063	0.27	0.027	0.195	0.48
Jordan Hygienic Paper Co.##	100	n.d.	0.02	n.d.	0.24	n.d.	0.978	0.078	0.186

n.d.=not detected.
* See note to Table 4.
** Cd 0.005 kg/d.
\# Cd 0.25 kg/d.
\#\# Cd 0.04 kg/d.

Gedeon (1990) show that organic matter may affect the solubility of heavy metals in similar polluted environments by selective complexation. When heavy metals, such as Cd and Cu, are present, they tend to form rather stable complexes with many organic ligands of man-made inputs. Tables 6, 7 and

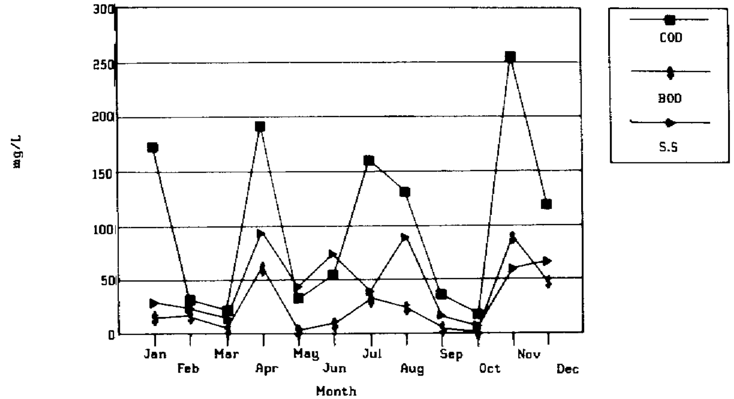

Figure 2. Seil Zarka, Site 6, biochemical behaviour, 1989.

Table 6
Selected Trace Metals* at Zarka Stream Flow

Sampling Site	Zn mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Mn mg/l	Fe mg/l
Zarka River before Confluence site 6	0.12	0.015	0.06	0.015	0.025	0.35

* Data represent average concentration Jan-Sep. 1990.
Avg. ABS conc. (hard detergent) 0.4 mg/l, min 0.2 mg/l & max 2.6 mg/l.

Table 7
Selected Trace Metals at Jerash T.P.Flow*

Zn mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Mn mg/l	Fe mg/l
0.25	n.d.	0.07	0.03	0.09	0.39

* ABS (active ingredient in hard detergent) average concentration 2.1 mg/l, min 0.5 mg/l, max. 6.2 mg/l, for the period Jan.-Sep. 1990.

8 provide examples of dissolution or precipitation of toxic metals in a favourable biochemical environment. Co-precipitation of other heavy metals such as lead and nickel cannot be ruled out under such conditions. The combination of heavy metals already present in the surrounding environment could induce synergestic effects on the biota of the water reservoir due to intrinsic changes in selective compounds. Further applied research is needed in this field to identify the potential impact on water quality behaviour with a view to adapting indigenous criteria for various end users.

Besides the dangers from heavy metals, Zarka River and KTR have suffered from long-term dry weather, which means that there is no dilution effect to counter the increasing contribution of treated wastewater from Khirbet es-Samra.

Table 8
Selected Trace Metal Elements at Zarka Stream-KTR

Sampling Site	Zn mg/l	Cd mg/l	Cr mg/l	Cu mg/l	Mn mg/l	Fe mg/l
STP Effluent	0.065	0.015	0.07	0.015	0.095	0.52
Site 12 km off STP Outlet	0.10	0.015	0.06	0.015	0.085	0.50
Confluence at Zarka & STP Effluent (15 km) Stream	0.045	0.015	0.065	0.020	0.075	0.47
Tawaheen Edwan; 20 km	0.045	0.015	0.065	0.015	0.060	0.44
KTR Influent (Inlet)						
Av.	0.055	0.013	0.075	0.008	0.16	0.30
Min.	0.030	0.010	0.040	0.00	0.03	0.12
Max.	0.090	0.020	0.130	0.02	0.24	0.55
KTR Effluent (Outlet)						
Av.	0.08	0.013	0.08	0.005	0.23	0.23
Min.	0.03	0.010	0.04	0.00	0.08	0.13
Max.	0.19	0.020	0.16	0.02	0.32	0.42

Note: KTR- King Talal Reservoir, recipient of Zarka River and STP flow.
Data represent average conc. during Jan.-Sep. 1990.
Al=0.2 mg/l; Co=0.03 mg/l at KTR inlet.
Boron=1.1-1.4 mg/l at STP eff.; 0.5-0.9 mg/l and 0.4-0.6 mg/l at inlet and outlet of KTR, respectively (June-Sep. 1990).
Fungicide Hexachloro-benzene (HCB)=0.5 ppb at STP effluent; 0.34 and 0.4 ppb at the inlet and outlet of KTR respectively.

Table 9
Parameter levels permitted by Standard 202 *
vs. industrial discharges

Parameter levels permitted by Standard 202 **
pH=6.5-9.0, BOD=50, COD=150, TDS=3000, SS=50, NH_4=5, PO_4=15, ABS=25, Fe=1, Cr= 0.1, Al=5, Cu=2, Mn=0.2, Zn=15

Industrial discharges violating Standard 202

White Cement Factory	pH= 11.9 Unit, TDS= 9734, SS= 702
Poultry Marketing Co.	SS=541, NH_4= 26, COD= 1879, BOD= 995, PO_4= 56.4.
Jordan Pipes Mfg. Factory	TDS= 2572, SS= 76, NH_4= 33
Ind. Cities Refinery Station	SS= 67, NH_4= 45, COD= 247, ABS= 2.7.
Jordan Hygienic Paper Co.	TDS= 2272, SS= 1972, COD= 1634, BOD= 598.
UMIC/ Vegetable Oil	pH=3.7, TDS= 17906, SS= 39313, NH_4= 44.1, COD=7617, PO_4= 4809.
Jordan Petroleum Refinery	TDS=2343, SS= 73, COD= 176, ABS= 45.
Hussein Iron & Steel Co.	SS= 104, Fe= 1.73, ABS= 4.78.
Hussein Thermal Station	ABS= 1.78
Chemical Industries Co.	pH= 11.2, TDS= 13738, SS= 194, COD= 1635, BOD=517, ABS= 77.2, NH_4 = 6.4
ICA Co. (INTAJ)	TDS= 35466, SS= 2526, NH_4= 8.3, BOD= 4834, Mn=1475, Fe=1.29, Cr=0.11, PO_4=559, ABS=669.
Arab Detergent Co.	pH= 10.3, TDS= 2326, SS= 1585, COD= 2221, BOD= 695, ABS= 1263, PO_4= 41.
Jordan Tiles Co.	pH=12.6, SS= 1521, TDS= 3398, Cr= 0.18.
Aluminium Co. (ARAL)	TDS=6543, SS= 137, Al^{+3}= 28.1, ABS= 4.9.
Jordan Yeast Co.	T.D.S= 2005, S.S= 19929, Al^{+3}=843, COD= 33400, BOD= 15168, Fe= 3.49, PO_4= 10.6, ABS= 6.4.

continued ...

* All results are in mg/l unless otherwise noted.
** If the water is to be used for irrigation, Standard 202 permits TDS, SS, Cu and Zn levels of 2000, 100, 0.2, and 2 mg/l, respectively.

... continued from page 59

United Industries Co.	pH= 5.7, TDS= 1731, SS= 786, NH_4= 10.6, PO_4= 140, COD= 4454, Fe= 5.3, Cu= 1.24, BOD= 1597.
Modern Chem Ind.	TDS= 1898, SS= 2683, COD= 8235, BOD=539, ABS= 2253, NH_4= 4.5, PO_4= 23.7
Wool Rock Factory	TDS= 1918, SS= 157
Tri Dairy Factory	pH= 3.89, TDS= 27517, SS= 22153, NH_4= 414, COD= 300000, BOD= 27286, PO_4= 1910, ABS= 3.53.
Jordan Sulphochem. Co.	PO_4= 21, TDS= 23894, SS= 11511, COD= 1490, BOD= 464, ABS= 10.3
Intermediate Petrochem. Co.	SS= 155, COD= 1571, BOD= 178.
Chemical Polymers Co.	TDS= 23063, SS= 38219, NH_4= 193, COD= 92847, BOD= 9691, Fe= 18.6, PO_4= 135, ABS= 121.
Jordan Matches Co.	TDS= 10586, SS= 1989, COD= 4266, BOD= 1571, Mn= 7.4, ABS= 1.3, Zn= 151, Fe= 2.85. Cu= 1.36, Cr= 24.1, PO_4= 14.
Jordan Ceramics Co.	TDS= 2861, SS= 709, ABS= 1.4.
Cooperative Dairy Factory	TDS= 4242, SS= 2828, COD=9914, BOD= 2494, ABS= 2.2.
Jordanian Paper and Carton Factory	SS= 126, COD= 380, BOD= 153.
Jordan Mineral Exploration	SS= 929, ABS= 2.1.
Najah Soap Factory	TDS=2584, SS=679, COD= 6240, BOD=2931, ABS= 2760.
Food Industries Co.	SS= 262, NH_4= 1.8, COD= 951, BOD= 327, Fe=1.5.

- **The occurrence, availability and cost of treatment measures at any step from pollutant source to the water.** Table 9 -- which compares parameter levels of national standard 202 (the regulation governing discharge of industrial effluents) against actual industrial discharges -- highlights the existing status of pollution in Jordan. The proper treatment and safe disposal of most industrial wastes are not carried out in most cases. This is due to several reasons:
  - lack of trained and skilled workers;
  - high cost of building and operating pre-treatment facilities at industrial source;

  - hesitation by industrialists to invest in low and no-waste technology; and
  - lack of awareness of potential hazards of heavy metals to human environment on the part of industrialists (e.g. the recent incident of a chlorine factory discharging mercury into the inhabited area of Amman-Zarka basin).

Assessment of water quality

In studying cycles, we have to measure the amount of a substance and its rate of change with time, while in studying pollution we also need to measure the rates of change of rates of change.[7] In practice, attempts have been made to follow pathway and pattern, and thereby to monitor the behaviour of selected parameters over time in order to assess and quantify the degree and magnitude of pollution emanating from industries in Amman-Zarka basin. To assess Jordan's environmental problems, a diagnostic approach is needed to distinguish between contamination and pollution. Contamination is the re-

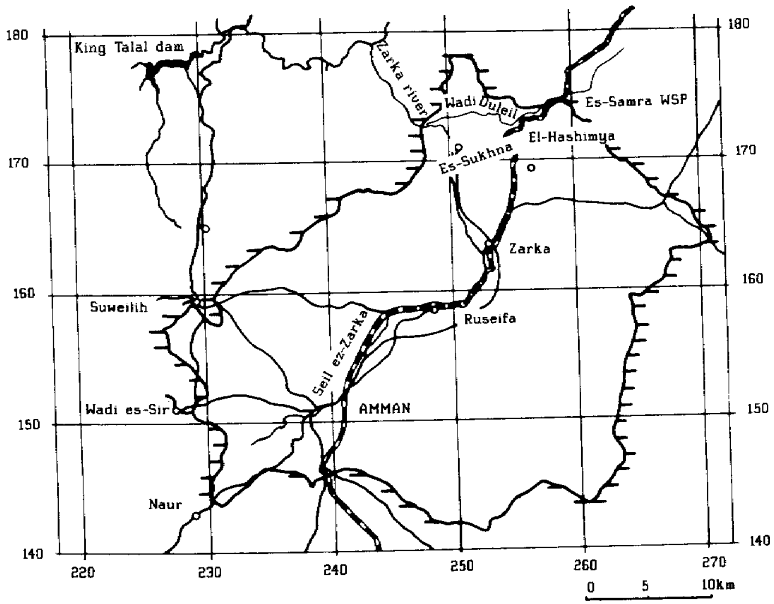

Figure 3. Overview of Amman-Zarka groundwater basin.

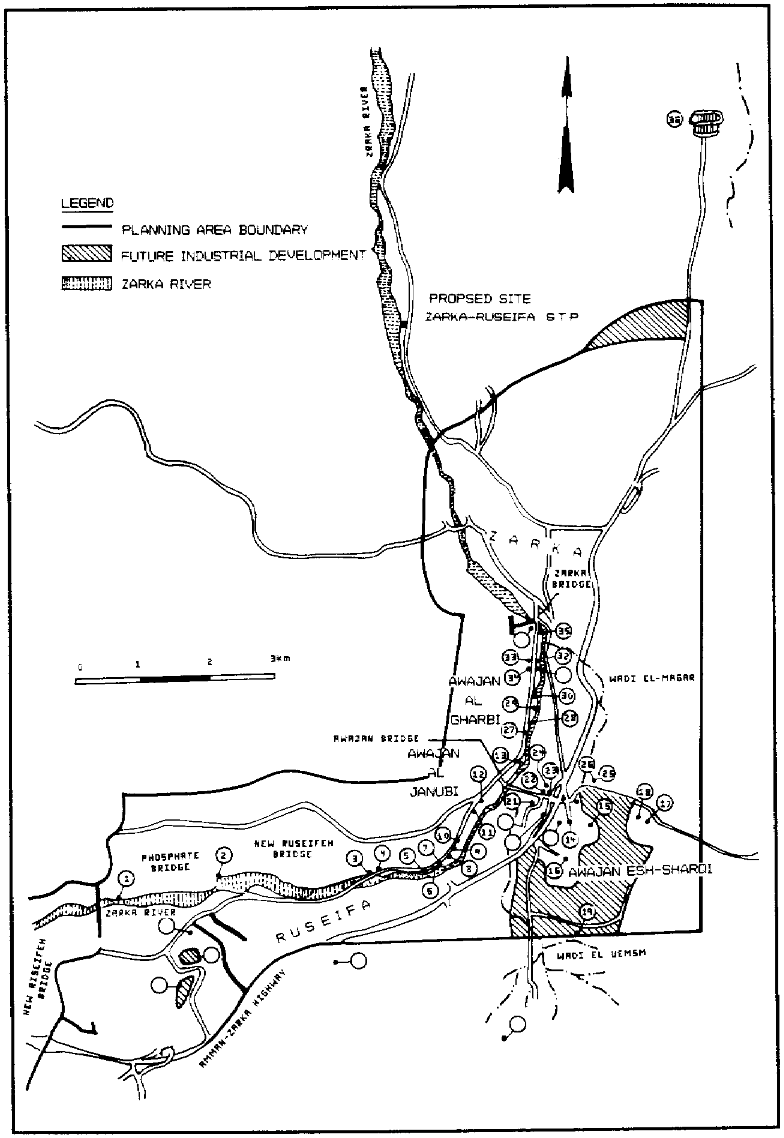

Figure 4. Industrial location map of Amman-Zarka catchment area.

lease of a substance into the environment at measurable concentrations, while pollution is contamination which has measurable effects on living organisms.

Scope and dimensions of the present work

The scarcity of the water supply and the increasing demand for water in a densely populated area like Amman-Zarka, as well as new threats and contaminants, have emerged, leaving us with such diverse water quality problems as eutrophication in surface waters and nitrates in groundwaters. The problem has been aggravated by increasing emissions of industrial effluents from more than 60 industries located in the catchment area of Amman-Zarka, as shown in Figures 3 and 4. Thus the present work has been confined to assessing industrial wastes and their impact on water resources.

Water, as part of the human environment, occurs in four main forms -- as groundwater, in surface water bodies, in the sea and as vapour in the atmosphere. The present work deals with the first two forms only.

Objective of the present study

- Assessment of man-made impacts on water quality in the area.

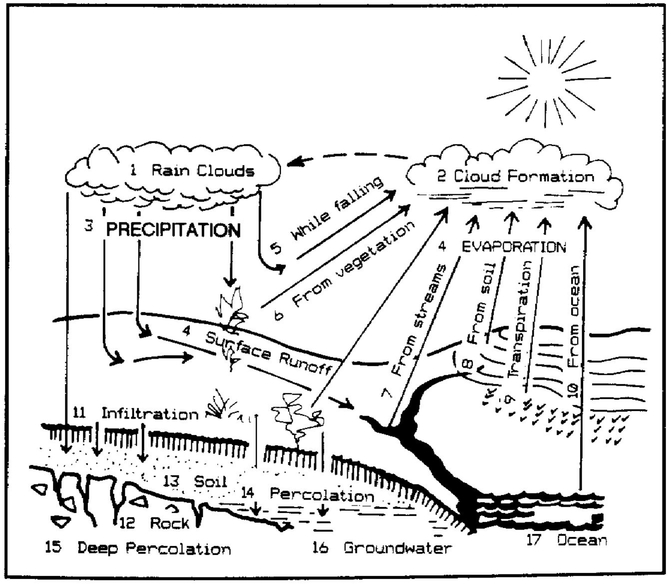

Figure 5. The hydrological cycle.

- Identification of sources of pollution and pollutant pathways and behaviour.
- Determination of trends of chemical constituents and organic pollutants in water resources.

Water quality in perspective

In considering the availability of water, the hydrological cycle may shed some light on the mechanism and flow of groundwater in the catchment area. Figure 5 shows the behaviour and fate of precipitation. Hydrogeological studies[8,9] have indicated that the underground water is locally rechargeable from precipitation in the order of 375 mm per annum. According to recent data[10], 24.5 MCM are estimated to be infiltrated above the catchment area every year. The water in the basin circulates in two types of aquifers. The major one is the upper aquifer, which consists of alluvium and carbonate formation. Some wells in this aquifer discharge from two hydraulically connected layers. The groundwater moves from the highlands of Amman towards Sukhneh along the Zarka River. This phenomenon helps us assess the pathways and fate of water quality variables.

Below-average rainfall in time and space, high evaporation rates, unreliable variation in climate, and the conversion of precipitation to runoff will compromise the quality of the rechargeable water resources at the upper and downstream Zarka River catchment areas.

It is also worth noting that the unexpectedly elevated levels of heavy metals like Cd, Pb and Ni observed in native and economic plants of the upper catchment area in Zarka River basin (Khattari 1986) will further complicate the hydrological cycle. And addressing the complex issue of water quality preservation with regard to pathway, pattern and behaviour of heavy metals

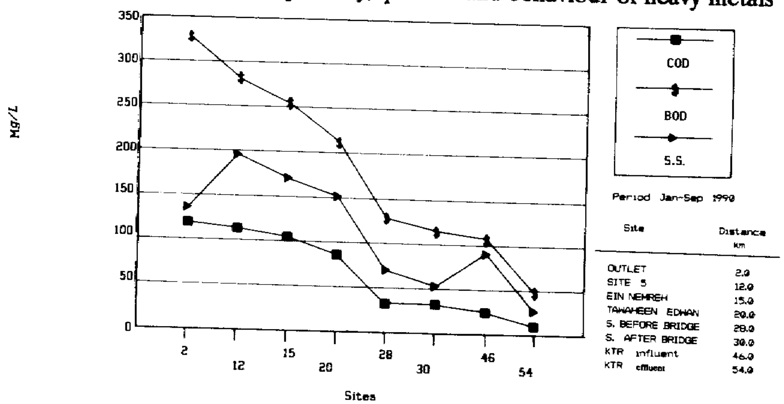

Figure 6. Seil Zarka - STP flow system, assessment of biochemical loadings, 1990.

generated from industrial sources will become even more difficult. For example, in monitoring the stratified zones of KTR and the groundwater of Zarka River basin, we have observed -- particularly near industrial zones -- that factors such as alkalinity, hardness, pH, dissolved oxygen, temperature, carbon dioxide, redox potentials, phosphates and chelating agents of man-made origin undergo significant seasonal variations. Certain levels and combinations of environmental factors greatly disrupt metal toxicity to aquatic organisms and plant uptake. To deal with this problem, we need an overall environmental management scheme for the whole catchment area which would include a long-term environmental hazard assessment of this complex phenomenon, as well as of current industrial practices in solid waste disposal.

Pollutant pathways and behaviour

As mentioned earlier, the upper aquifer is annually rechargeable with a short transit time, while the deep aquifer (A4) is believed to have been charged before 1952. Therefore, the upper aquifer is threatened due to infiltration through the soil zone by several industrial and man-made sources. The location of industrial concerns in the catchment area could lead to infiltration of heavy metals into a new environment or could lead to reactions between native and introduced solutes from industrial discharges.

The generation of partial pressure of carbon dioxide (PCO_2) along with changes in redox potential (E_h) and in pH may occur, altering solubility of solutes, or a new solution may dissolve objectionable amounts of impurities from solids that were stable in the previously existing environment. The rising salinity and elevated values of organic pollutants in underground water along Zarka River till the outreach of KTR have demonstrated the pathway of penetration and infiltration of biochemical substances along with the movement of groundwater flow. Unless removed, heavy metals could accumulate in the soil or percolate to groundwater, possibly contaminating the community's drinking water supply.

Indicators of pollution: discussion

1) Table 8 (p. 58) outlines some undesirable chemical effects in King Talal Reservoir. Most significant perhaps is the tendency for water to become stratified at times and for previously accumulated sediments to contribute undesirable impurities to the water near the reservoir bottom. According to RSS reports[11], certain heavy metals and organic pollutants are already reaching levels sufficient to be detrimental to biota because of their potential synergistic effect and their tendency for complexation with organic ligands emanating from man-made sources as shown in Figures 1 and 6. The inconsistent

Table 10
Selected boreholes in Amman-Zarka catchment area (1990)

No.	Well designation	TDS mg/l	Na mg/l	Cl mg/l	NO_3 mg/l
1	Ruseifa Well No. 4	787	98	195	70
2	Ain Ghazal Well	730	72	156	85
3	Ruseifa Well No. 2	845	129	222	64
4	Phosphate Well No. 2	730	85	154	76
5	ICA Co. Well	1632	266	539	121
6	Jordan Dairy Co. Well	960	130	268	75
7	Jordan Worsted Co. Well	902	113	234	65
8	Hashem Bolad Well	806	119	234	50
9	Nour Edden Mohamad Well	653	56	163	47
10	Mohamad Mutaw'e Well	922	105	271	81
11	Ramadan Swadani Well	941	128	280	59
12	Nather Sultan Well	1075	134	294	87
13	Awajan Well No. 23	806	81	223	62
14	Awajan Well No. 22	998	139	315	56
15	Awajan Well No. 21	1190	176	360	60
16	Arab Beer Co. Well	883	135	255	37
17	Salameh Abu Khurma Well	1229	199	413	49
18	Modern Mill Well	749	65	144	95
19	Jabri Co. Well	979	117	255	74
20	Tanning Well No. 2	998	141	296	51
21	Muhajreen Well	653	49	114	95
22	Maqar Well	730	68	135	90
23	Pepsi Cola Well No. 4	806	98	185	78
24	Amman West. Well No. 3	653	52	106	93
25	Petroleum Ref. Well No. 3	1824	322	639	25
26	Petroleum Ref. Well No. 7	1555	271	476	50
27	Petroleum Ref. Well No. 10	1498	261	504	42
28	Petroleum Ref. Well No. 4	3072	553	1154	45
29	Hashemya Well No. 2	1344	242	403	54
30	Hashemya Well No. 3	1536	281	474	46
31	Hashemya Well No. 5	1632	293	487	55
32	Sa'adeh Ayyash Well	1805	333	547	67
33	Hussein Thermal Ste. Well No. 2	1267	215	405	42
34	Hussein Thermal Ste. Well No. 3	1459	249	477	48
35	Hussein Thermal Ste. Well No. 8	1594	295	476	19
36	Hussein Thermal Ste. Well No. 9	1651	306	526	38
37	Hussein Thermal Ste. Well No. 1	2880	519	1115	50

continued ...

No.	Well designation	TDS mg/l	Na mg/l	Cl mg/l	NO_3 mg/l
	... continued				
38	Jordan Pipes Co. Well	2240	241	869	92
39	Mohamad Muqbil Well	4160	523	1678	137
40	Nizar Sha'sha'a Well No. 1	1306	167	422	60
41	Fine Hygienic Paper Well	1920	265	708	78

performance of STP effluent (east of Amman), vis-à-vis biochemical quality standards and pathogenic organisms' survival and regrowth, may eventually perturb the natural mechanism of the self-purification process at the receiving reservoir.

However, prevailing patterns of physico-chemical conditions in the KTR will alter the solubility of heavy metals shown in Table 8 and could lead to elevated toxicity of selected metals, especially in the presence of chelating ligands originating from organic contamination along the stream flow.[12,13,14]

2) The behaviour and trend of Zarka River show pronounced pollution expressed in terms of high oxygen-consuming substances, chloride concentration levels ranging from 300-500 mg/l, and persistence of heavy metals along the stream flowing to KTR (see Figures 1 and 2 and Table 6).

3) The presence of several sources of pollution in the catchment area, i.e. industrial and commercial entities, has put stress upon the fragile ecosystem (see Table 9 and Table 4).

The groundwater, particularly in the upper aquifer system, demonstrates that the partial pressure of carbon dioxide (PCO_2) values as calculated for more

Table 11
Selected toxic elements in KTR sediments *
Trend of average values, in mg/kg

Designation	1987	1988	1989
Iron	17392	19094	25110
Aluminium	12275	17869	22077
Arsenic	2.80	1.53	4.36
Cadmium	11.80	6.66	8.78
Chromium	36.0	36.0	42.3
Lead	35.0	41	44.0
Manganese	362	413	442
Zinc	90	97	108

* Compiled from data in RSS annual reports on KTR.

than 60 wells located in the area are greater than those prevailing in the atmosphere, i.e. $10^{-3.5}$. The values of log PCO_2 ranged from -1.3 to -2.0 in almost 85% of the wells studied[15].

It is interesting to note that the increase of PCO_2 is associated with higher concentration levels of nitrates and salinity. This is particularly true of those wells located along the Zarka stream close to industries with high biochemical content in their emissions.

Available information indicates that PCO_2 values are higher in wells located downstream of the liquid waste landfill at Ruseifa. This could be due to decomposition of organic pollutants penetrating the shallow aquifer in which carbon dioxide is generated. There is ample evidence that several producing wells in the catchment area have shown unexpectedly increasing values of salinity and chlorides that may have significant effects on palatability and possible uses (see Table 10). Some wells have shown a tenfold increase in salinity and chloride in the last decade.

4) The distribution of the isotopic composition of the shallow groundwater and its tritium levels suggest that Amman-Zarka basin is rechargeable during the winter season, while the deep aquifer is less vulnerable to direct recharge, since the transit time of infiltration is more than 40 years.

Recorded data at the Water Authority's Environmental Isotope Laboratory illustrates that the upper aquifer is threatened from sources of industrial and domestic wastewater, as the groundwater is already showing signs of enrichment with stable isotopes.

5) Although there are no definite signs of the presence of elevated toxic elements in the groundwater as yet, preliminary investigations carried out recently at WAJ laboratories on subsoil samples collected at Awajan area near the industrial zones showed that the type of clay minerals in the area has the tendency to absorb and adsorb toxic elements within its structure and that it possesses high exchange capacity.[16] Furthermore, Table 3 demonstrates the effect of point-source pollution on underground water near STP.

Due to continuous penetration of toxic metal elements from industrial emissions through the soil mantle, the clay may reach a saturation point. However, under observed changes in PCO_2, E_h and pH, a release of selected hazardous elements may occur, which will infiltrate to settle in the groundwater in soluble form. These conditions may favour dissolution of more minerals and toxic elements that are known to be nonbiodegradable, once they reach the underground water reservoir. The rising concentration levels of industry-emitted toxic elements in KTR sediments are presented Table 11.

Facing the challenge

- Jordan places a high priority on industrial development in order to attain rapid returns on its investment. However, environmental pollution caused by hazardous industrial emissions is emerging as a national concern, especially in the metropolitan area of Greater Amman. In confronting the challenge this poses, serious attempts must be made by the relevant regulatory bodies to outline anti-pollution legislation that will allow for sustainable development. We can attribute the sluggish progress in accomplishing this ambitious task to unclear authority of the concerned bodies, conflicting regulations and socio-economic constraints. In fact, even the theoretical underpinnings of the needed legislation presently consists of unfocused studies carried out by various researchers with conflicting perspectives. Only an evolutionary, multidisciplinary approach to setting up environmental institutions can cope with these problems and implement measures that will preserve Jordan's fragile ecological system and protect surface and groundwater resources.[17, 18]
- Industries should be encouraged to build integrated facilities that could be used by several companies in proximity. The shared use of one pre-treatment plant would produce effluents of better standards, so that all participating companies could be connected to the sewer system, in compliance with environmental regulations governing the discharge of industrial effluents.
- The concept of environmental management should gain more ground at all levels in Jordan. The presumption is that setting up environmental machinery and developing quality standards for curbing industrial pollution would be irrational if enforcement mechanisms and compliance are not consistently and persistently pursued.
- Adaptive monitoring schemes have been developed depending on the magnitude of the industrial pollution level and the various sources of potential contamination.[19,20] The Water Authority of Jordan has instituted plans and programmes to enable executive management to assess and evaluate the management impact on water resources in anticipation of any potential environmental crisis. Strengthening the monitoring plan to cover water supplies, industrial effluents and streams will act as a management tool in achieving the goals of WAJ.[21, 22]
- The outcome of the present study should be used to preparing a basin-wide plan for water quality management. Most of the commercial and industrial discharges in the kingdom are in Amman and Zarka. Control of these emissions will have a material benefit to water quality in Jordan. Activities such as monitoring programmes are already in progress, and substantive support of WAJ management has proved useful in sustaining a water supply of the highest standards to consumers. However, developing information management systems at the national level is essential to effective pollution controls over the long term.

In considering the current status of treatment plants, in particular the STP at es-Samra east of Amman, it may be assumed that in future all organically polluted effluents will have to be treated biologically or with comparable treatment.[23] Such treatment of industrial wastewater alone, although necessary, has been found for many reasons to be not always applicable, whereas when applied to combined sewage and wastewater it has achieved excellent results.

A recent assessment of biochemical loadings and heavy metals discharged from industries along the Zarka River concludes that capital cost, affordable technologies and environmental management must be weighed when considering the issue of connecting all industrial effluent to the sewage system. Current emissions, as reflected in biological oxygen demand, could be raised to about 60 mg/l at the inlet of STP. This will amount to a 9% increase at the influent, while the total dissolved solids will increase to 170 mg/l, or a 17% increase over current levels.

The total emissions of heavy metals from the entire basin are estimated as follows: 0.62 kg/day manganese; 1.67 kg/day zinc, 5.0 kg/day iron, 0.98 kg/day copper, 1.03 kg/day chromium, and 0.49kg/day cadmium.

Although even the compromised effluent quality might not exceed the limits allowed for irrigation purposes at the present flow rate of 90,000 m^3/day, nevertheless upgrading the existing treatment facilities and introducing technologies such as natural zeolite minerals* could eliminate many of the risks and uncertainties associated with heavy metals and would improve effluent quality for the end users.

The issue of how to deal with waste products and achieve a sustainable water supply is highly complex, and its many facets must be studied thoroughly before action is taken. Combining communal sewage and industrial wastewater treatment facilities in one plant is one option, which, of course, has advantages and disadvantages:

Advantages of combined communal sewage and industrial wastewater

- The excess of nitrogen and phosphorous compounds in domestic sewage can counterbalance deficiencies of nutrients in industrial effluents.
- In domestic effluents, all trace elements that are necessary for biological treatment are present.
- Organic toxic substances such as phenols and cyanides are biodegradable when diluted with domestic sewage.

* A promising field of research in point-source treatment of industrial and municipal effluents is the use of natural zeolite minerals, found in abundance in Jordan's Azraq area. Zeolites can serve as both an ion exchange system and secondary filtration medium and are fast becoming standard components in facilities for treating wastewater. They reduce oxygen-demanding constituents, bacteria and other pollutants and appear to be able to extract trace amounts of heavy metals from wastewater.

- Slow biodegradable compounds can be more efficiently removed from wastewater through absorption processes if production of biomass is high, as in combined plants. Additional advantages of a technical and economic nature may result from the increased size of the treatment plants.

Disadvantages and problems of combined treatment

- In order to achieve good treatment results in combined plants, provision has to be made for sufficient contact time and a high sludge age, which increases construction and operation costs.
- Effluents that are polluted mainly by inorganic compounds contain mostly settleable and filterable solids, cooling water, etc., which should be kept apart from combined treatment. This requires costly separate sewerage systems in industries.
- Potential discharge of highly toxic wastewater may hinder biological treatment, even if equipped with extended aeration.
- Expensive pre-treatment in industries is needed to meet regulations for discharge into communal sewerage systems.
- Increased administrative difficulty arises in managing treatment plants for wastewaters from different sources.

One condition[24] for efficient treatment of industrial wastewater, whether in combination with domestic sewage or alone, is the segregation of process water from cooling water and surface run-off into separate sewerage systems.

Acknowledgement

The collaboration of many colleagues in the development of the work programme presented here is gratefully acknowledged. Special acknowledgement should be made to the Water Quality Monitoring Division and all staff at the Department of Laboratories and Quality Control, WAJ. The author wishes also to thank Engineer Ahmad Eleimat and Mr. Taha Samara for their efforts in compiling information and computer support.

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4

Impacts of urbanization and industrialization on water reservoirs: King Talal Reservoir, a case study

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Introduction

King Talal Reservoir (KTR) is a rock fill dam finished in 1977 with an estimated useful lifetime of 50 years. The main purpose of this dam was to supply irrigation water for the Jordan Valley (JV), to supply drinking water to the city of Amman, and to regulate storm water. Its storage capacity was 50 million cubic metres (MCM) and was increased in 1988 to 86 MCM by elevating the dam to 108 metres. This expansion was to compensate for the sediment build-up in the reservoir, estimated at 0.5 MCM per annum, and also to install hydro-powered turbines with a rated output of four megawatts per hour of electric energy.

The drainage basin of KTR (Figure 1) is 3157 square kilometres and extends east of the Jordan Valley. Zarka basin is an important basin in terms of urban and industrial pollution loads that reach KTR and is the only permanent water flow that reaches KTR. Urbanization of this area expanded very rapidly over the last 20 years; it is now one of the most densely populated areas

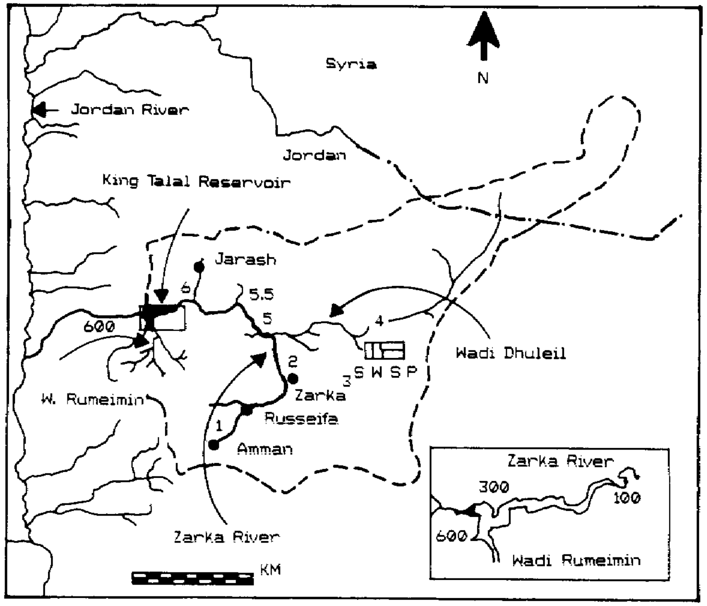

Figure 1. Basin of King Talal Reservoir.

of Jordan (with about 1.8 million inhabitants). Ninety percent of the country's light industries and services are located in this area as well.

Urbanization and other developments have exerted severe stresses on the water resources of this area, with domestic and industrial water supplies relying on groundwater. Since 1975 over-pumping resulted in depleting the groundwater resources and caused salt intrusion and deterioration of water quality of the basin. Water is now transported long distances from Azraq, Mafraq, Suwaka and the Jordan Valley to the demand centres in Greater Amman, Ruseifa, Zarka and many other nearby cities and towns at considerable cost in terms of capital investments and operational expenses. Major water-consuming industries in Zarka area include Jordan Petroleum Refinery Company (JPRC) and Al Hussien Thermal Power Station (HTPS). These industries depend on groundwater for their water needs.

Sources of pollution

The major sources of pollution that directly or indirectly affect the water quality of KTR are the following:

- sewage treatment plant effluents,

- industrial wastewater discharges,
- over-pumping from groundwater wells,
- urban activities: cesspools, runoff, transportation,
- agriculture runoff, and
- leachate from landfills.

Sewage treatment plant effluents

The considerations in the management of wastewater in the past 20 years or so were based, among other factors, on the cost of constructing treatment plants, availability of skilled labour, and the running cost of plants. As a result, sewage treatment plants in Jordan were generally based on waste stabilization principles or activated sludge or trickling filter as a second process. Tertiary treatment plants are not constructed due to increased cost of treatment. It is well known that tertiary treatment of sewage greatly improves product water quality, especially with regard to total suspended solids (TSS) content, and reduces bacterial and helminths eggs.

Effluent from the following sewage treatment plants reach KTR:

- Es-Samra Waste Stabilization Ponds (SWSP);
- Bakaa treatment plan: a trickling filter plant;
- Abu Nusair plant: RBC plus extended aeration plant; and
- Jerash treatment plant, oxidation ditch.

The SWSP relief discharge at Sukhna, with estimated capacity of more than 40,000 cubic metres of raw sewage, could be a serious pollution load when used, especially during the dry season. Besides that, there are plants which indirectly discharge into wadis reaching KTR. These are operated mainly by the Jordan Armed Forces and some industrial firms and have no permanent flows but pollution products such as organic pollutants, nitrates, phosphorous and sludges which could be flushed along wadis into KTR every winter.

SWSP receives very strong sewage influents in terms of five-day biological oxygen demand (BOD5), TSS and other organic parameters. The nature of treatment in waste stabilization is capable of reducing biological waste loads and removing most of the bacteria and helminth eggs, but it is not capable of producing effluents comparable to activated sludge processes in terms of BOD and TSS. Therefore, in relation to received sewage strength, which is considered among the highest in the world, the quality of SWSP effluent at the point of discharge is considered weak to moderate raw sewage. SWSP is located 40 kilometres upstream of KTR. Table 1 shows the chemical and biological quality of the effluents from SWSP.

It is common practice that sewage treatment plants in many parts of the world are designed to receive raw sewage comparable to the effluent discharged from SWSP. About 90% of all sewage treatment plant discharges in the Zarka

Table 1
Quality of effluents of SWSP 1986 to 1989/90 (units in mg/l)

Year	BOD5	Filtered BOD5	COD	TSS	Flow m³/day
1986	115	54	385	161	48198
1987	109	43	406	183	31140
1988	138	59	352	190	67148
1989/90*	106	46	333	159	73529

* From Feb. 1989 to Feb. 1990

Table 2
Contribution of SWSP effluents to KTR in 1989

Period	KTR inflow MCM/year	SWSP effluent MCM/year
May 86 - April 87	68.809	15.518
May 87 - April 88	99.037	16.606
May 88 - April 89	73.447	25.524

basin originate from SWSP. Table 2 shows the contribution of SWSP effluents to KTR in 1989 along with the total inflow into KTR.

Industrial wastewater discharges

JPRC is the biggest single industry in the area. It is the only refinery in Jordan and processes 2.5 million tons of crude oil every year. The water needs of the refinery, estimated at 5000 cubic metres per day, are pumped from wells on the premises of the refinery. Water is used mainly for steam generation and process cooling and for domestic needs by residents in the housing estate near the refinery. The industrial wastewater is subject to primary treatment only. Pollutants, such as petroleum residues, are not removed. Resistant chemicals in wastewater will eventually reappear in surface or ground waters used for irrigation or drinking. Some metals, such as cadmium, have high mobility in the soil and will reappear in crops and thus constitute a risk to humans through the food chain. The treated water from JPRC is used for irrigating a small forest inside the fence of the refinery. Due to the contamination of the treated effluent with oil, some of the water wells of the refinery are contaminated with hydrocarbon residues and are reported being shut down by the refinery.

The other major industry in this area is the Al Hussein Thermal Power Station (HTPS), which is capable of producing 4000 mega-watts of electricity per hour. The HTPS water discharges originate mainly from the water demineralization plant and some steam condensate purges which are usually contaminated with oils. HTPS uses 1300 tons/day of fuel oil for power production; this fuel has a high sulphur content, in the range of 3.5 - 4% by weight. Therefore, an estimated 15,000 tons/year of sulphur oxides are dispersed by HTPS in the area, affecting KTR basin. However, it is important to mention that the soil type in KTR basin is highly alkaline and thus is tolerant to acidity from such sources.

Industrial accidents are likely to happen, and the involvement of poisonous chemicals renders the cost of repairing damages caused to the environment by such accidents very high. This is what happened in 1988 when unquantified amounts of mercury contaminated more than 6000 cubic metres of soil near the Jordan Chemical Industries in Awajan-Zarka; the mercury was used to produce chlorine by the chloralkali process. Now, two years later, the contaminated soil is still in its place in the vicinity of the plant and poses a potential hazard in the KTR basin and also to some groundwater aquifers in the area.

There are many other industries in the area near Amman, Ruseifa and Zarka. Most of them operate some form of wastewater treatment facilities, but the effluents of these facilities do not comply with the existing Jordanian Wastewater Standard 202. The Water Authority of Jordan (WAJ) determines whether industries in the Greater Amman area are permitted to connect to the sewers or not, according to their organic or TSS content. Some industries, such as the Jordan Yeast Company, Arab Detergents, Jordan Dairy Company, and car wash service stations, dispose of their wastewater in wadis near Amman. This practice, recognized by WAJ and other agencies, results in polluting aquifers and KTR.

The Greater Amman solid waste disposal site is located over the Zarka aquifer south-east of Ruseifa. A new site went into operation in May 1989 serving 1.8 million inhabitants with an annual solid waste generation per person of around 100 kilogrammes. Figure 2 shows the location of this landfill

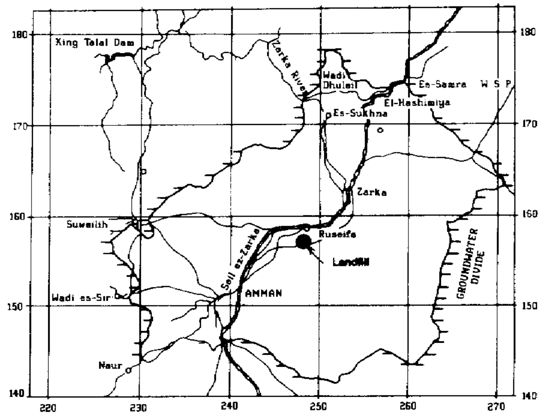

Figure 2. Solid waste disposal site location.

site. There was concern about the selection of the site in this area and about the measures taken to prevent groundwater pollution. It is well known that leachates could pose dangers to aquifers. The Royal Scientific Society (RSS) has recently collected samples of leachates from this new site and analyzed them at its Environmental Research Centre. Table 3 shows the results of the chemical analysis, indicating polluted leachates typical of new sanitary landfills.

Table 3
Typical analysis of leachate from Ruseifa landfill *

Parameters	Units	Results
pH	SU	6.35
EC	US/cm	49000
TDS	mg/l	78455
TSS	mg/l	1755
BOD5	mg/l	197500
COD	mg/l	208800
NH_3N	mg/l	5117
O&G	mg/l	3161
MBAS	mg/l	3.11
Phenols	mg/l	0.007
PCBs	mg/l	0.089
Al	mg/l	1.00
As	mg/l	<0.005
Ca	mg/l	17.57
Cd	mg/l	0.27
Cr	mg/l	0.60
Cu	mg/l	0.30
Fe	mg/l	80.00
Hg	mg/l	<0.005
Mg	mg/l	2594.00
Na	mg/l	11000.00
Ni	mg/l	8.50
Pb	mg/l	1.50

* Analysis of sample collected by RSS on 22/5/1990.

Impacts on water quality of KTR

KTR water has been under continuous monitoring by RSS since its construction in 1978. Many changes have taken place since that time with regard to the management of the drainage basin of this reservoir. The most significant of these changes was the construction of SWSP and the decision to connect Zarka and Ruseifa to that treatment plant. Due to the increase in quantity of sewage connected to es-Samra and the inability of this type of treatment plant to efficiently remove suspended matter and some oxygen-demanding pollutants such as ammonia and detergents, the effluents reaching KTR are deteriorating. Table 4 shows the increased quantity of organic pollutants reaching KTR since 1986.

On the other hand, the natural capacity of the reservoir to reduce biological and bacterial contamination is still sufficient to cope with the quality of the incoming water and to make it suitable for unrestricted irrigation. But this capacity has limits, and it can not reduce heavy metals or refractory chemicals. The heavy metals are mainly taken up and concentrated in the tissues of algae that grow in the reservoir and that end up as sediments when they die off. Some of the dead algae is carried away in the form of suspended matter with the discharged water from KTR. Refractory or non-biodegradable

Table 4
Amount of pollutants reaching KTR from Zarka stream
1984 - 1989 flow

Year	Flow MCM	TSS tons/year	BOD5 tons/year	COD tons/year	Total P tons/year	Nitrogen-N tons/year
1984	53.865	8568	414	3052	73	486
1985	48.638	2498	411	3296	59	647
1986	63.019	7840	1018	4577	121	1332
1987	53.291	41198	1165	5197	634	1034
1988	100.821	7294	2460	7755	419	2787
1989*	51.619	2714	984	4078	338	1691
6 year av.	61.876	13222	1290	5591	329	1595

* In this year, the third train in SWSP was started.

chemicals, some types of detergents, polychlorinated biphenyls and similar chemicals persist in the water and are discharged with the irrigation water.

The concentration of boron, a chemical present in some powder detergents, is increasing in the water. It is known that citrus trees are sensitive to boron, especially when it is present in concentrations greater than 0.5 mg/l. Most Jordan Valley agricultural produce is sensitive to boron in excess of 1-2 mg/l.

Nitrogen and phosphorous are chemicals that make surface water eutrophic. KTR records show that these chemicals are building up in the water and sediments of the reservoir. Figure 3 shows this trend over the years 1987 to 1989. There are other pollutants of concern which are not monitored due to lack

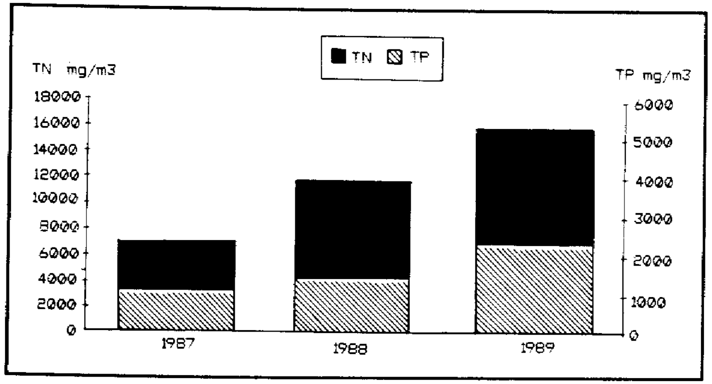

Figure 3. Trend of total nitrogen and total phosphorous in King Talal Reservoir (Site 300).

of experience, proper equipment or financial resources. These are pesticides and certain chlorinated organic chemicals and non-degradable hydrocarbons. Proper water quality management requires the monitoring and control of such chemicals in KTR.

Interventions to improve water quality of KTR

Upstream interventions

The sources of pollution of KTR are man-made and come mainly from sewage treatment plants or from industrial effluents. Since SWSP is the largest source affecting KTR water quality, improvements in its quality of water will have positive impacts on receiving water bodies such as KTR and Zarka stream. SWSP effluents are comparable to raw sewage of medium to weak strength in terms of BOD or COD and are laden with suspended matter in the form of algae. The low quality of SWSP effluents, indicated in Table 1, makes them inadequate for long-distance open-channel flow. Discharge of such effluents into dry wadis or small natural streams (like the Zarka stream), especially when there is no dilution effect, is likewise not suitable.

One should not, however, undermine the fact that SWSP product water is suitable and safe for irrigating different types of crops and does not carry many of the bacterial or helminth eggs common in activated sludge treatment plant effluents. For effluents similar to those of SWSP, it is preferable to practice irrigation at close distances to the discharge site rather than to convey water elsewhere in closed systems such as pipes.

Improvement in the quality of SWSP water would be achieved by improving the oxidation of the organic waste in the discharged wastewater from this plant by adding stages of aeration equipment which are common in activated sludge processes. The cost of such modification and upgrading of the SWSP system will probably be high, but with direct and indirect gains in return, among them improvement in the quality of Zarka stream, a cleaner wadi along the flow from es-Samra to KTR, and improvement in the KTR water quality.

Industrial water discharges will have to be monitored and their quality controlled. Many industrial firms at the present time do not comply with the Jordan Standard for Wastewater 202, because it is very strict. RSS has called for the revision of this standard. The modified standard, which should be issued soon, is expected to be more practical and easier to comply with. In this case it will be possible to ask the industry to treat their wastewater without subjecting them to unreasonable costs.

Lake interventions

Improvements in the water quality of a reservoir are dictated by the intended use of the water, for example, fish farming, sports or irrigation. At its present

state the water is quite suitable for all forms of unrestricted irrigation. Drip irrigation methods may, however, be more efficient to use with water of less suspended matter of algae origin. Sporting and recreation requires water which is more transparent and aesthetically cleaner. Fish farming requires clean water free from poisonous chemicals and with high dissolved oxygen content and is sensitive to minute amounts of ammonia and hydrogen sulfide. Bacterial contamination of the water is also a limiting factor in fish farming. At the present state of KTR all these qualities are lacking at certain times of the year.

For on-site improvement of the water in the reservoir it is necessary to aerate the water at certain locations using limno aerators, shown in Figure 4. In this method compressed air is diffused through a special device into these aerators, which are submerged in the lake. Oxygen is transfered to the water where it mixes with the different water layers of the lake. As oxygen becomes available, organic matter is oxidized, some heavy metals precipitate, and phosphorous and nitrogen are removed, as indicated in Figure 5. The cost of one limno unit with oxygen capacity of 2000 kilogrammes of oxygen is $250,000, and two or three such units may be needed. The results of this kind of intervention would be water quality suitable for fish farming and recreation.

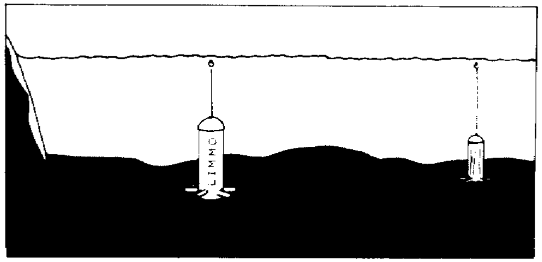

Figure 4. Submerged limno aerators.

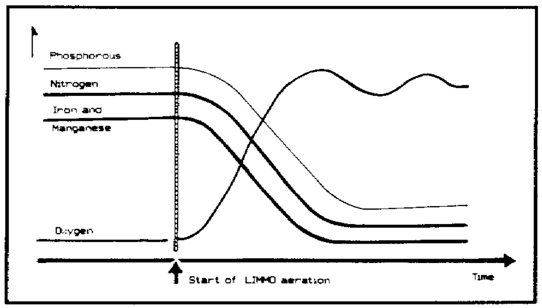

Figure 5. Diagram showing results of limno aeration.

Cost-benefit analysis

Cost-benefit analysis is a systematic method of identifying and measuring the economic benefits and costs of a project or programme. The benefits of a project are the values of incremental outputs of goods, products, and services, including environmental services, made possible by the project. The costs are the values of incremental real resources used by the project. Both project costs and benefits are appropriately discounted over time. Benefits are of two types: direct benefits such as the value of the products provided, and secondary benefits such as wages earned by workers on the project, environmental benefits such as quality improvement for uses like fishing, boating and swimming, or even aesthetic appreciation.

At this stage, data are lacking to make a reasonably accurate cost-benefit analysis for improving KTR water quality through upgrading SWSP effluents. An attempt is made at analysis by a simple and straightforward manner, in which the cost of SWSP improvement is calculated based on some existing WAJ wastewater plants. Table 5 shows some details of this calculation, which gives a net loss of more than two million Jordanian dinars per year; however, not all the benefits of this improvement can be estimated.

Table 5
Cost-benefit analysis of improving SWSP
(Basis 100,000 m³/day in JD)

Parameter	SWSP influent	SWSP effluent	Desired quality
TDS	1,005	1,074	<1074
BOD5	854	138	20
TSS	584	190	30
COD	1,332	352	75
NH_4-N	91	88	>1
TFCC	1.00E+11	1.50E+02	1.50E+02
			Cost JD/year
a-Electricity 0.000182/M³			6,643
b-Oper. cost 0.00382/M³			139,430
c-C12+des. cost .00122/M³			44,530
d-Plant			812,450
Cost/m³ @ 20 years/y			
Total costs/year			1,003,053
New cost after improvement			Cost JD/year
a-Elect. power 0.0127			624,150
b-Operation @ 100%			1,658,560
c-Chlorine + disinfection			215,718
d-Plant maintenance @5%			133,827
e- Current cost of SWSP			1,003,053
Total new estimated cost/year			3,635,308
I. Benefits wage % of costs			165,856
II. (Benefits) Seil Zarka			100,000
III. Benefits KTR as fishing			750,000
Total est. benefits/year			1,015,856
NET COST JD/YEAR			-2,619,452

5

Overexploitation and salinization of groundwater resources and accompanying saltwater intrusions

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Introduction

The Disi-Mudawwara aquifer system crops out in south Jordan and extends into Saudi Arabia and the underground of Jordan, where it overlies the Basement Complex, which consists of intrusive igneous rocks functioning as an aquiclude (Figures 1 and 2). This sequence of sandstones and shales underlies the entire area of Jordan at different depths, generally increasing in northerly and north-easterly directions. The Disi aquifer consists of medium- to fine-grained sandstones with a total thickness of about 1000 metres. The average precipitation over the area is around 80 mm/yr., with an average potential evaporation of 2000 mm/yr. The daily temperatures range from zero to 45°C, with a yearly average of 24°C.

Groundwater in the Disi-Mudawwara area

The groundwater in the Disi area is unconfined (Figure 3) and lies at a depth of around 80 metres below the surface, whereas in the Mudawwara area, the water is confined and partly artisian. The groundwater flow is directed towards the north and north-east. The average permeability of the aquifer is 1.68×10^{-5} m/s with a gradient of 1.43%. Assuming a flow of 40 kilometres in width and a maximized saturation depth of 1000 metres, the throughput of the aquifer is calculated to be equal to: $1.68 \times 10^{-5} \times 1.43 \times 10^{-3} \times 40 \times 10^{3} \times 10^{3} \times 30.5 \times 10^{6} = 30.5$ MCM/yr.

This figure could be indicative of average recharge or the total flow as a result of fossil gradient adjustment.

The C^{14} ages of samples collected from that area range from 11,000-13,000 years. Presently, it is generally accepted that the groundwater in Disi-Mudawwara area does not receive major replenishment. This means that the groundwater in the aquifer is fossil and that its extraction is at the expense of storage; in other words, this extraction is a mining process.

The Disi-Mudawwara aquifer, extending over the entire country, underlies all geologic units, and is on a regional scale hydraulically interconnected with the aquifers of the different units. This implies that any extraction from

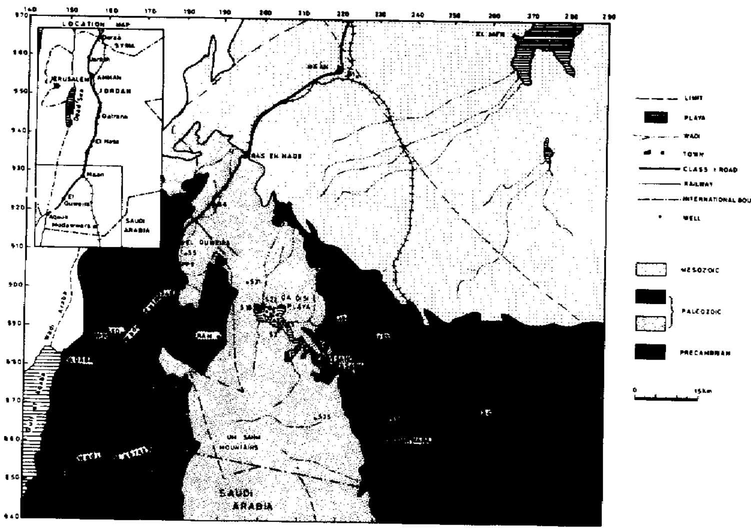

Figure 1. Location map of Disi-Mudawwara aquifer system.

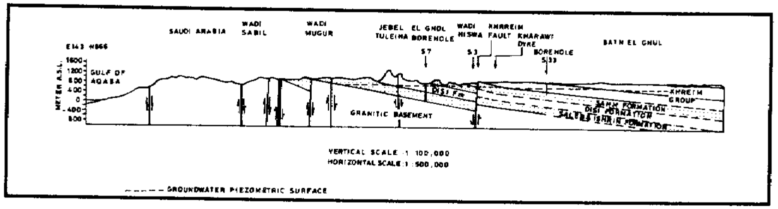

Figure 2. Groundwater Piezometric surface.

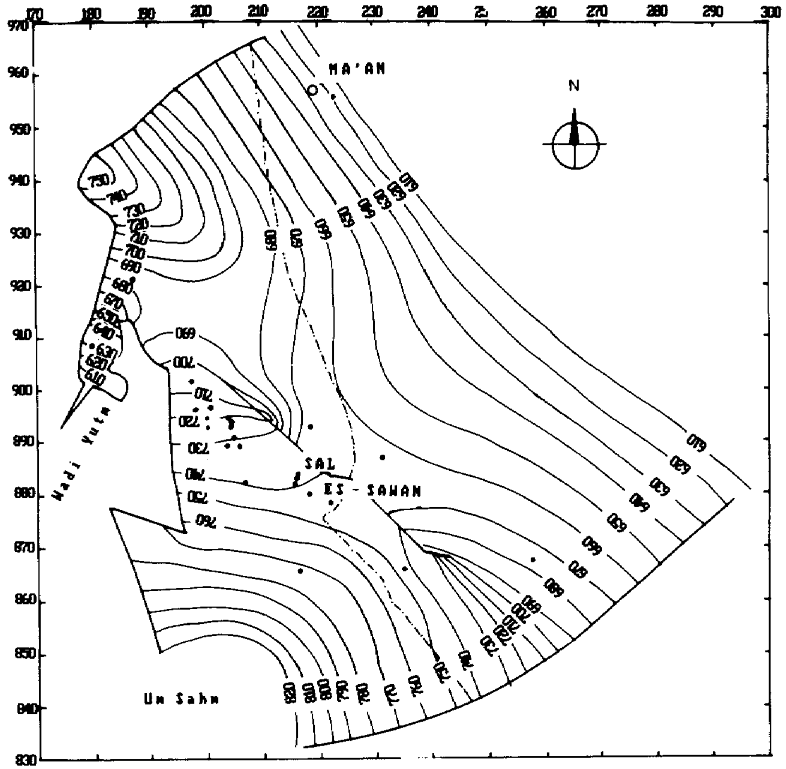

Figure 3. Equipotential lines of the groundwater in Disi-Mudawwara area.

this aquifer at any location in Jordan is going to be reflected in lowering the water level in the upper aquifers.

Extraction of water increased from 15 MCM/yr. in 1983 to 60 MCM/yr. in 1989. The total amount of extraction during this period was around 300 MCM, causing a nonrecoverable drawdown in water levels ranging from 1.13 to 9.1 metres. This nonrecoverable, irreversible decline is a major warning concerning the persistence of water resources (Figures 4 and 5).

During the last few years, the salinity of the groundwater started to show some increase in the different constituents, indicating a rise and upcoming of deeper aquifer waters.

The final results of the hydrological studies on the Disi-Mudawwara aquifer can be summarized as follows:

- The groundwater is fossil and the recharge is estimated at 30 MCM/yr. The age of the groundwater is estimated to be more than 10,000 years.

- The total pumping of about 300 MCM in the last few years caused a drop in water level amounting to more than nine metres in some areas.
- The groundwater body of Disi-Mudawwara underlies the entire area of Jordan and is, on a regional scale, hydraulically interconnected with all overlying aquifers. Hence, extraction from this water body will affect the groundwater resources in Jordan, as it lies in the upstream direction, and will ultimately cause a general drop in the water levels.

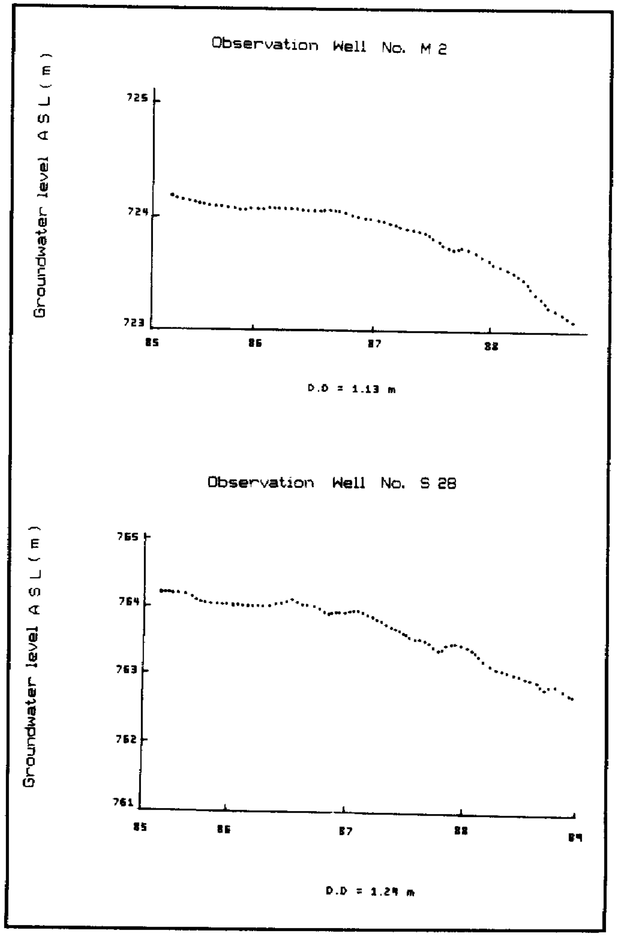

Figure 4. Drawdown in Disi-Mudawwara observation wells (M2, S 28).

- There are indications that the water salinity has started to increase.
- The Disi-Mudawwara aquifer water is the only strategic water reserve of Jordan.
- This water is the only long-term source for the water supply of Aqaba.

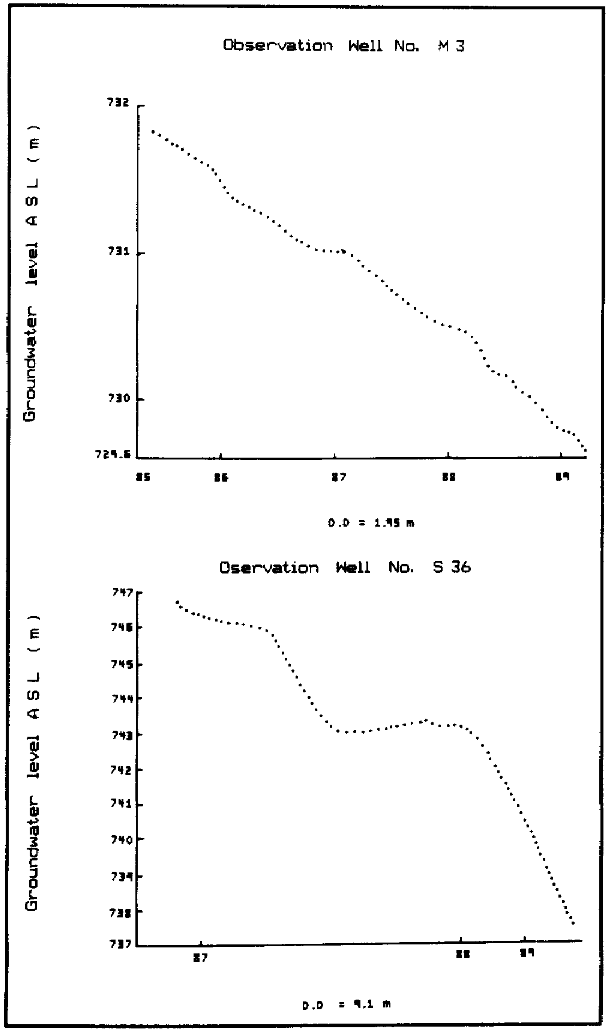

Figure 5. Drawdown in Disi-Mudawwara observation wells (M 3, S 36).

Azraq area

The Azraq area lies around 80 kilometres to the east of Amman. It forms the northern part of an elongated geological depression known as Sirhan Depression. Azraq and its extension to the south-east function as a base level for both surface and groundwater which collects there to form an oasis.

The quantity of groundwater discharged into the oasis from springs is around 16 MCM/yr. (Arsalan 1973).

Shallow wells were drilled in the seventies in the Azraq area to supply water for irrigating the northern and north-eastern parts of that area. Also, around 3 MCM/yr. were pumped from North Azraq pools to Irbid district to supplement its domestic water supply.

Since 1982, water produced from a series of wells located to the north of Azraq has been pumped to Amman to alleviate increasing demand. The amount of water pumped to Amman ranged from 12-16 MCM/yr. Already in 1986 the drawdown in the groundwater table reached three metres (Figures 6 and 7).

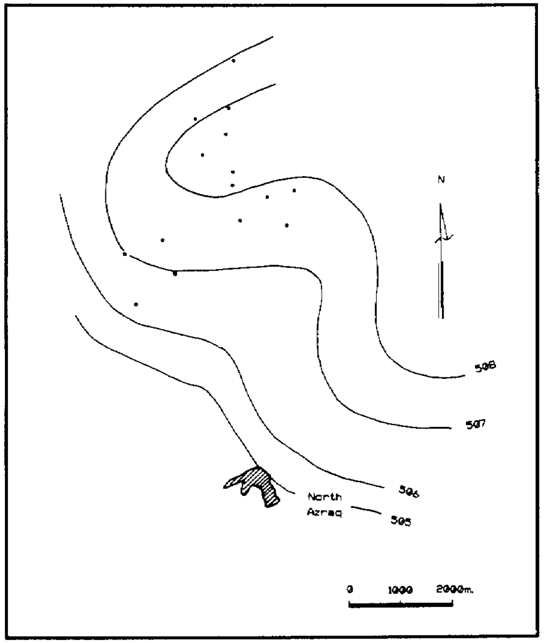

Figure 6. Groundwater levels prior to 1982.

At present the general drawdown is around six metres. The spring discharges in South Azraq stopped, and those of Qaysiya and Soda springs decreased rapidly. The total groundwater discharge of 16 MCM/yr., measured by Arsalan in 1973, decreased due to overpumping to 10 MCM/yr. in 1983, to 6 MCM/yr. in 1986, and to less than 1 MCM/yr. in the past two years (Figure 8).

Tritium, which has a half-life of 12.3 years, has never been detected in Azraq well water, indicating that no recent recharge to the groundwater is taking place. C^{14}-age determinations gave a recharge age of 5,000 to 12,000 years.

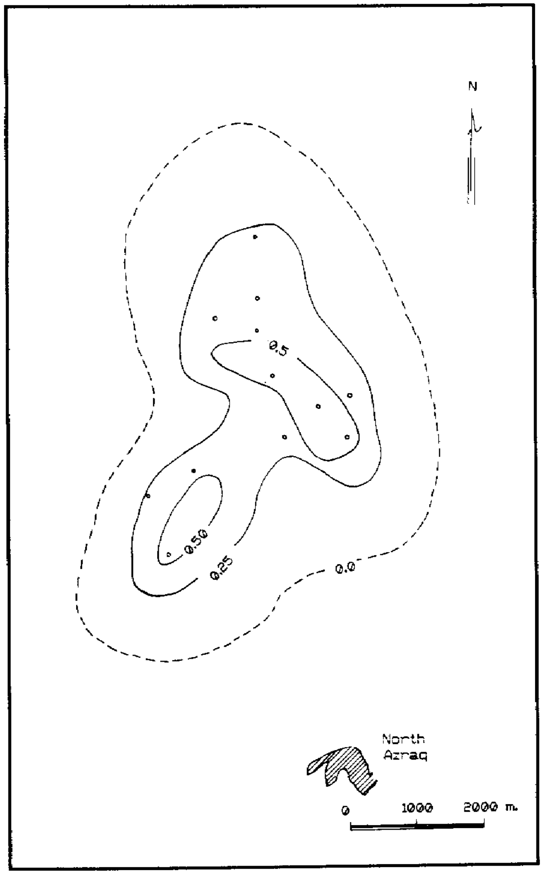

Figure 7. Water level decreases, 1982.

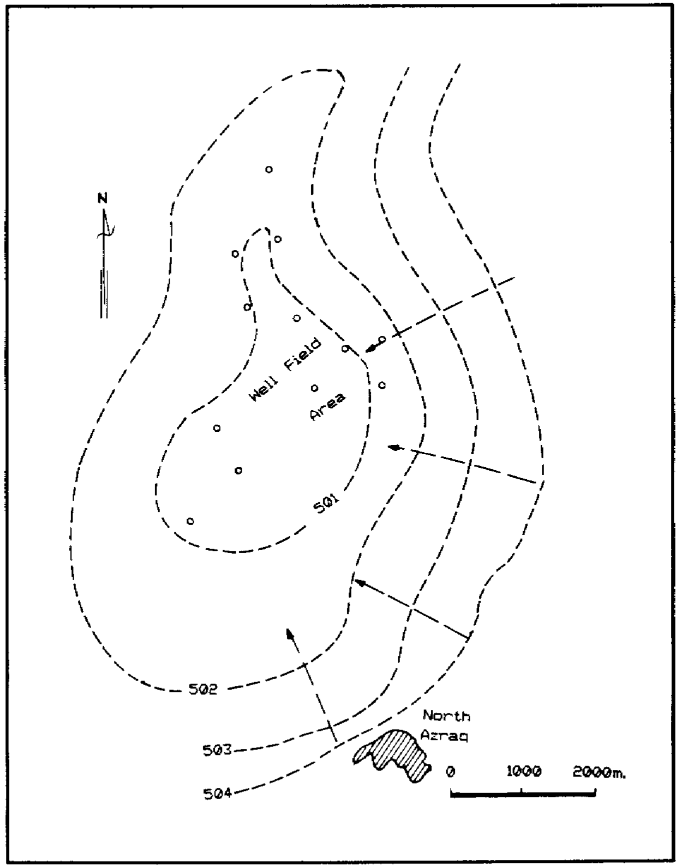

Figure 8. Water levels in 1989.

The salinity of Aura pool and Qaysiya springs has increased rapidly during the last few years, too, and is now in the range of brackish water.

At present the groundwater level in the well field area and its surroundings lies two to three metres below the level of the pool's surface in North and South Azraq. It is now feared that water will start moving from the salty marshes which are located between North and South Azraq and east of the line connecting them to the well field area.

The problem of saltwater intrusions did not surface until now because of the periodic seasonal pumping of the aquifer. Water is not pumped during the winter season, which allows the groundwater to recover.

The results of such practices are the following:

- If a proper balance between the seasonally pumped amounts and the recovery of water levels is maintained, only the oasis will dry, and no salt intrusions are expected to occur.
- If pumping goes beyond its present amounts but with the same seasonality, the water levels in the area will drop further, making recovery more difficult and resulting in saltwater intrusions.
- If pumping is practiced, whether at the present rates (same amount but distributed all over the year) or at an increased rate, salt water will start moving towards the well field, leading to the salinization of the groundwater.

Conclusion

Extraction from Azraq wells led to the dryness of the oasis and negatively affected the environment in Azraq. This unique oasis, which served as a sanctuary for migrating birds during all seasons of the year, has dried out and lost its natural function.

If the present pumping-recovery equilibrium is disturbed by increasing the pumped amount of water or by extending the pumping season, saltwater intrusions will be the ultimate result, and the groundwater system will eventually collapse.

Economic value of water resources

The two above-cited examples of overexploitation of groundwater resources should be exposed to certain economical analyses, taking into consideration the following aspects:

- The groundwater resources in both areas are fossil.
- The water levels are continuously dropping.
- The water quality has started to show signs of deterioration.
- Water in Jordan is scarce and precious, and its allocation for various uses should undergo very critical evaluation from different aspects.

The assessment of the economic value of water resources is a very complicated and difficult issue, especially if the long-term environmental impacts are not clear. Also, the value of water resources differs from one country to another and even from one community to another. Therefore, a cost-benefit analysis of the utilization for a certain community is the best and most reliable way to appraise the social value of water.

Based on the aforementioned aspects, it can be derived that the real cost to the community of using Disi or Azraq water is equal to the real value of benefits that would be obtained if these resources were allocated to other uses than those at present. However, cost-benefit analysis should be carried out in terms of environmental management and sustainable development.

If the cost-benefit analysis and real cost concepts are not considered, the ultimate results will be physical and economic constraints on water resources and their uses. But if they are considered as the base for any water use and allocation policy (optimal uses), then their yields will be greater and they will help in achieving the socio-economic objectives of developing water resources.

An economic perspective of Disi water

- To irrigate 1000 square metres, i.e. one dunum of land, 1200 cubic metres of water are needed.
  According to the producers in the area, one dunum of land yields an average of 600 kg wheat.
- The cost of imported wheat is $155/ton, C&F Aqaba, which equals JD 104 ton at the present exchange rate (1990).
- The subsidized price the government pays for producers is JD 140/ton of wheat.
- According to producers, the cost of wheat production (fuel, seeds, machinery, spare parts, fertilizers, biocides and labourers) amounts to some JD 110/ton, 80% of which are imported facilities.

Summary:

Imported wheat	JD 104/T
Local wheat	JD 140/T
Cost of production of local wheat	JD 110/T
Imports to facilitate production	JD 88/T
Water used to produce 1 ton of wheat	2000 m^3

Results:

- Producing wheat needs JD 88/ton of imports to facilitate production, whereas importing wheat itself would cost JD 104/ton.
- Each ton of produced wheat consumes 2000 cubic metres of high-quality, precious and nonrenewable water.
- The government pays (140-104) = 36 JD/ton as subsidy.
- The price for one cubic metre of water in Aqaba is 120 fils, with running cost of some 50 fils/m. Hence selling 2000 cubic metres of water (the amount needed to produce one ton of wheat) in Aqaba means a gain of JD 140.

If the present usage of water in wheat production continues, the following is valid:

- In terms of hard currency, the annual difference if wheat is imported will be around one quarter of a million US dollars more than when production facilities to produce the same amount of wheat are imported.
- Since the only available future supply of Aqaba is Disi, exhausting its water resources would mean that sea water has to be desalinated to guarantee the continuous supply of water to the city. But desalination of one cubic metre of water costs at present a minimum of $2.00, which would mean that producing one ton of wheat deprives the country of $4000, to be paid in water desalination, the major portion of which will be spent for imported fuel and machinery in hard currency.

Conclusions

- The current water situation with its various problems demands improvements in the resources-human activity relationship.
- Water management should expand to involve a larger range of alternatives to assess a wider range of impacts, including costs and benefits to society.

If water management programmes are not sound in environmental and socio-economic terms, major constraints on the whole development process may result, because water resources are complementary to most of the development inputs.

6

Solid waste disposal sites and their effects on ground and surface water

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Amman, Jordan

Introduction

It does not make sense to rid ourselves of any disposal from one place by polluting another. We must select with care a suitable place for dumping; at landfill disposal sites, for example, the unsaturated zone forms an important buffer between hazardous wastes and the water table.

Understanding the mechanism and rates of movements of pollutants in sedimentary rocks is an important step in groundwater protection. Ideally, there should be a hydrogeological input into the planning of any fixed installation that will have or could cause discharges to the groundwater. In the absence of an aquifer protection policy, the risk of contamination from an installation must be addressed using standard hydrogeological methods. As a minimum the following should be determined:

- geology: lithology, thickness, physical properties;
- hydrogeology of the aquifers and flow paths, aquifer properties;
- vadose zone, thickness and properties of the unsaturated zone;
- meteorology: rainfall, evaporation, evapotranspiration; and
- local groundwater usage.

Surface and groundwater pollution

If waste buried in a landfill comes into contact with water from infiltration, a highly mineralized leachate will be produced. Leachate from domestic wastes is usually characterized by high concentrations of soluble organic compounds, particularly short chain carboxil acids, with ammonia, chloride, sulphate and metals such as iron, calcium, sodium and potassium being found at elevated concentrations. However, the relative proportions of these contaminants will vary, reflecting a shift in the microbial population, from aerobic through facultative to anaerobic organisms, as oxygen becomes depleted and the moisture content of the landfill increases with time. If industrial or hazardous wastes are codisposed with domestic refuse, traces of these materials or their breakdown products may also be found in the leachate. The movement of this leachate may cause pollution of both surface and groundwaters. The rate of fluid migration may be considerably reduced under unsaturated conditions.

Evaluation

The following basic data are required to assess what measures should be taken to protect groundwater:

- total thickness of materials above the aquifer,
- total thickness of the unsaturated zone,
- travel time through the unsaturated zone,
- travel time through the saturated zone,
- clay content of the unsaturated zone,
- water quality of the aquifer,
- the aquifer parameters transmissivity, storage capacity and porosity,
- abstraction from the aquifer,
- meteorology of the arch, and
- groundwater level fluctuation.

Monitoring

Any monitoring scheme must be designed specifically for the job at hand and with a clear knowledge of the existing hydrogeological situation and of the potential flow path and the pollutants involved.

a. **Saturated zone monitoring.** There is now a wide range of equipment available for representative sampling of the saturated zone. The most common cause of poor sampling occurs when the static column of water in a cased borehole is sampled many metres above the screened section with little or no flushing of the water in the column. A borehole drilled purely as a sampling well should be completed in such a way as to avoid this problem. However, it is often the case that a borehole must serve multiple functions, say for water level recording, water sampling and water pumping for use or disposal. In this event, greater care would be needed to obtain a representative sample by pumping or extensive baling.

b. **Unsaturated zone monitoring.** There has been a move in recent years towards monitoring the unsaturated zone as well as the saturated zone in order to obtain early-warning data about pollutant transport through the unsaturated zone and to increase our knowledge of the processes involved in the attenuation of pollutants as they travel through the vadose zone.

Monitoring the unsaturated zone requires good planning, as relevant equipment often must be installed prior to site construction. A typical range of equipment for measuring the movement of pollutants in the unsaturated zone would include:

- pressure vacuum lysimeters, which can sample from the saturated and unsaturated zones;
- gas samplers: changes in soil gas can indicate a pollution front or the presence of the vapour phase of pollutants in the saturated zones;
- gypsum blocks, which measure changes in soil moisture;
- tensiometers, which measure soil moisture suction;
- salinity sensors, which measure electrical conductivity and temperature;
- infiltration cells, which measure the contaminant flux in the unsaturated zone; and
- pneumatic piezometers, which measure the water pressure in the saturated zone.

Landfill site selection

Two measures are necessary in selecting a landfill site:

- identification of site characteristics: permeable, semi-permeable, or impermeable, and
- a hydrogeological survey, using appropriate investigative methods.

Enough data must be collected to allow the following elements to be accurately assessed:

- leachate production rate,
- leachate quality,
- groundwater levels and fluctuations,
- groundwater flow directions,
- groundwater flux,
- groundwater discharge points, and

- surface hydrology parameters:
  - stream flow average and
  - catchment run-off.

Case study: new Greater Amman solid waste disposal site

The existing solid waste disposal site lies about half a kilometre north-east of the old site. In this case, it is very difficult to determine the impact of the new location on the quality of surface and groundwater, as these are already polluted. The impact of the new location will be determined in the future through monitoring wells in the vicinity.

The geological setting of the new location consists of highly fractured limestone and chert. This situation facilitates the percolation of the leachate to the groundwater, which is at a maximum depth of about 50 metres in the upper aquifer. The groundwater movement here is from south-east to north-west. The thickness of the unsaturated zone ranges from 30-50 metres. There is no soil cover, because this location was a phosphate mine. In this area, the main sources of pollution to surface and groundwater are the deposit of solid wastes, industrial effluents and untreated sewage wastes.

The historical data collected from monitoring wells (Annex 1) shows the evolution of water quality during the last ten years, and the fluctuation in groundwater level (Annex 2).

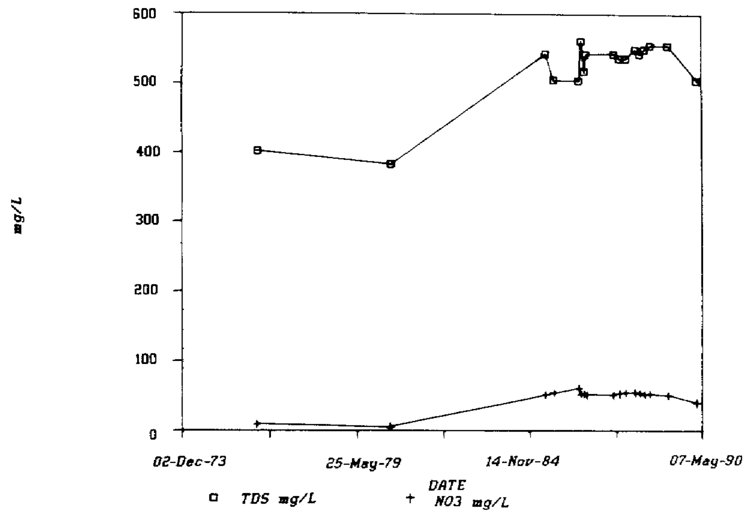
In order to prevent pollutants from reaching the groundwater, the municipality of Greater Amman designed the drainage system to collect the leachate in a collection pond and then to be pumped and discharged.

Besides the surface and groundwater pollution in the area, air and oil pollution are harmful to the health of inhabitants. The following measures are therefore recommended:

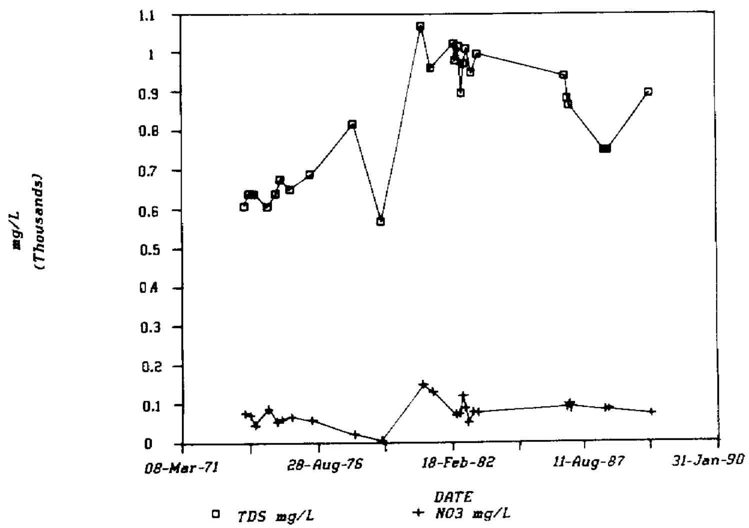
- Drilling a monitoring well inside the fenced location to be used as guidance for percolation of leachate to the groundwater.
- Drilling stem holes in the unsaturated zone downstream of the dumping location in order to study the content and behaviour of the leachate and its impact on groundwater.
- Intensive monitoring of pumping wells upstream and downstream of the dumping site for chemical and bacteriological parameters.
- Intensive monitoring of water-level fluctuations.

Annex 1

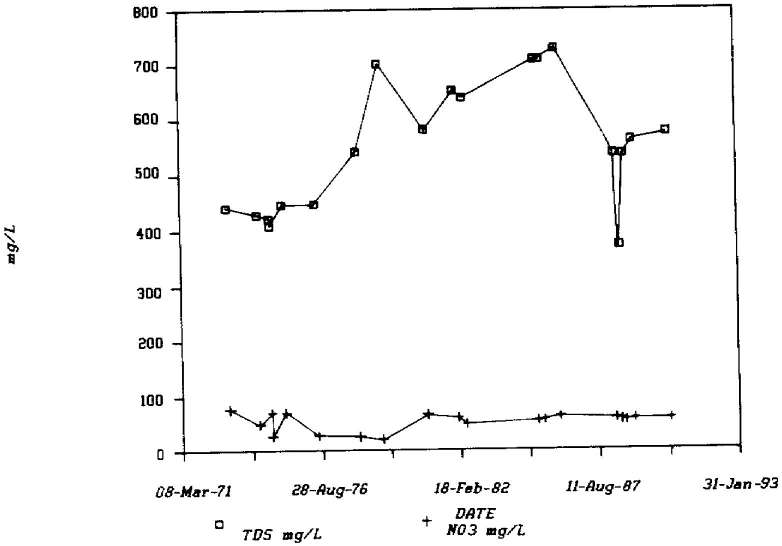
POLYTECHNIC WELL



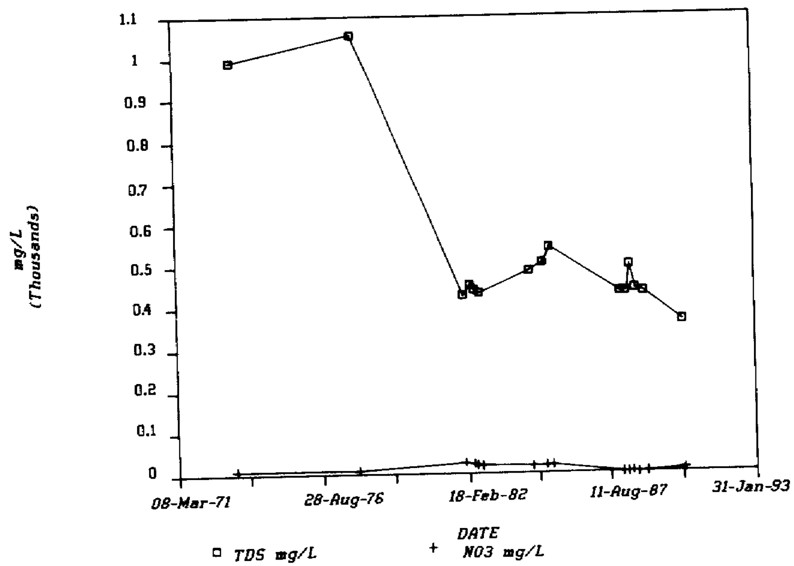
PHOSPHATE WELL NO.2



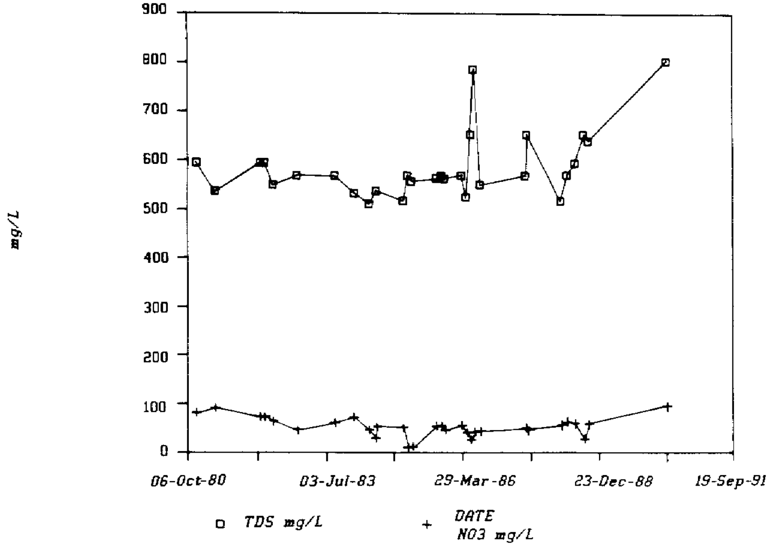
PEPSI WELL NO.2



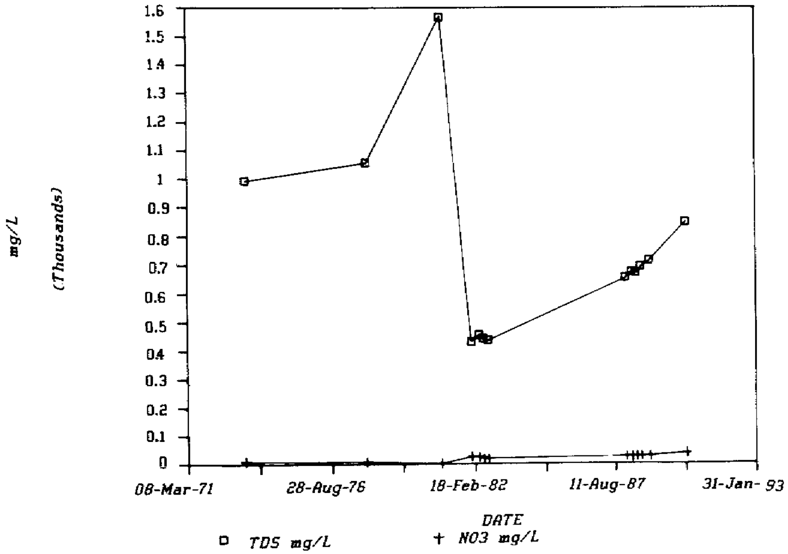
JORDAN BEER WELL



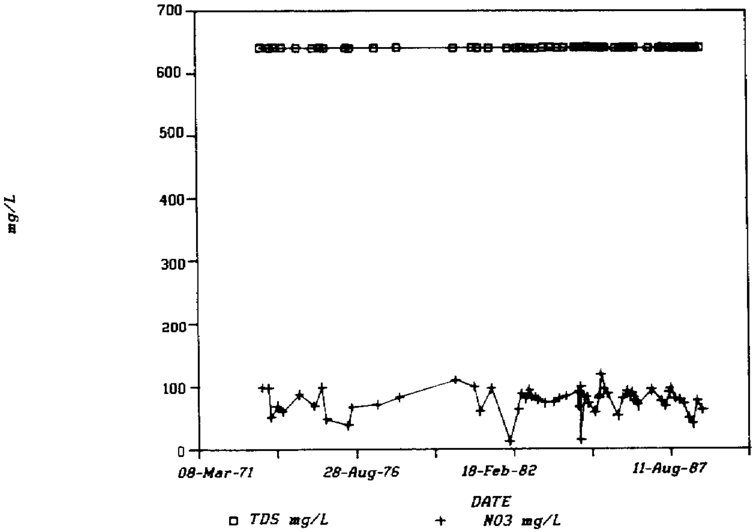
AIN GHAZAL NO.32



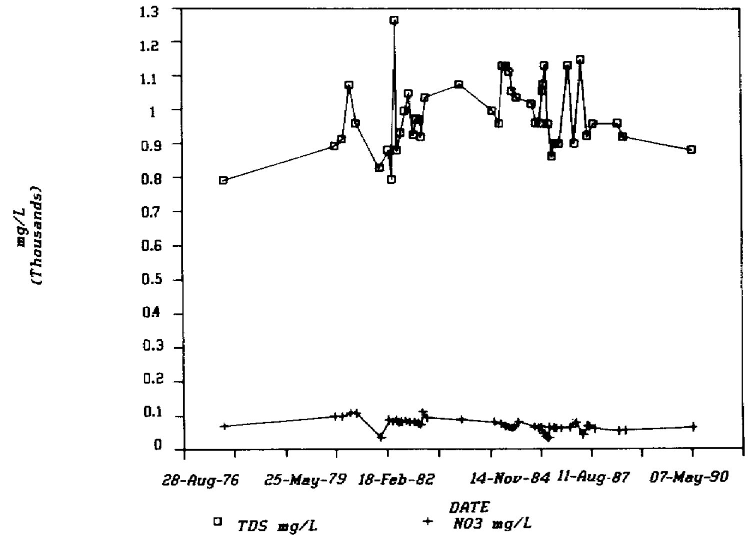
ARAB BEER WELL



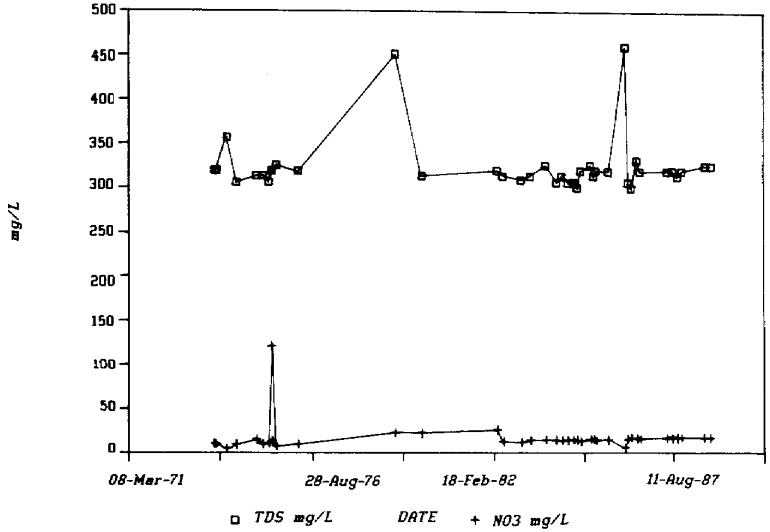
RUSEIFA WELL NO.1



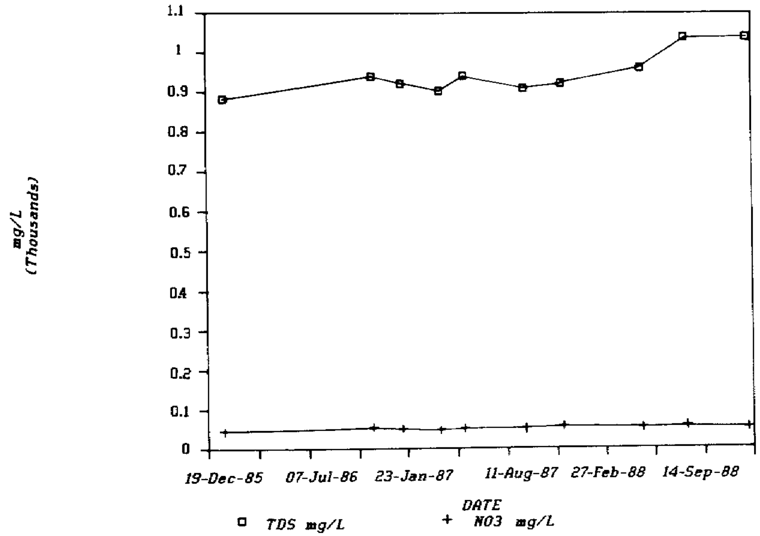
RUSEIFA NO.2



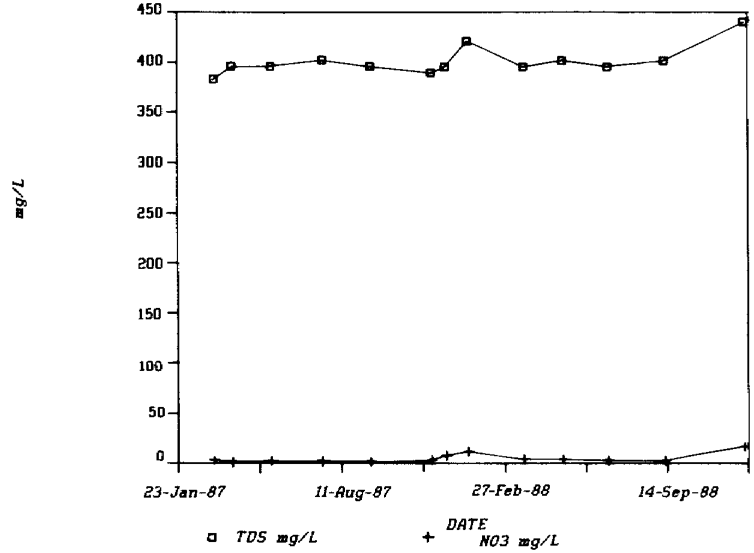
TABARBOUR / AMMAN WELL



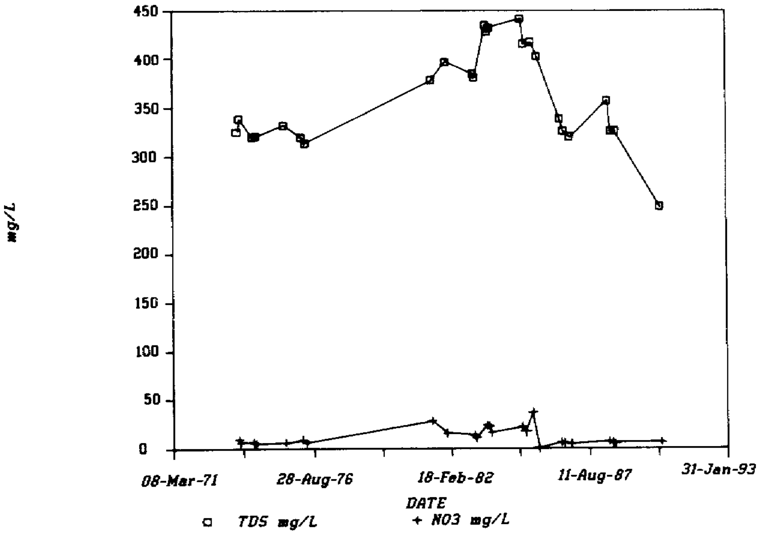
AWAJAN WELL NO.21



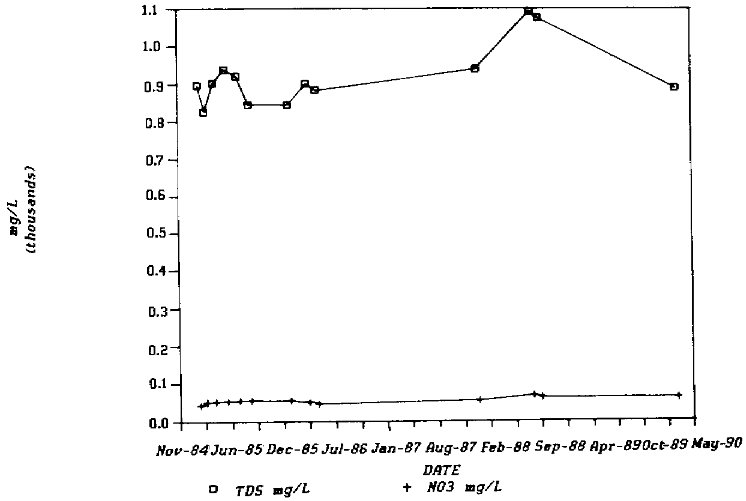
SCHNELAR WELL



EL- MAZRA'A WELL S-8



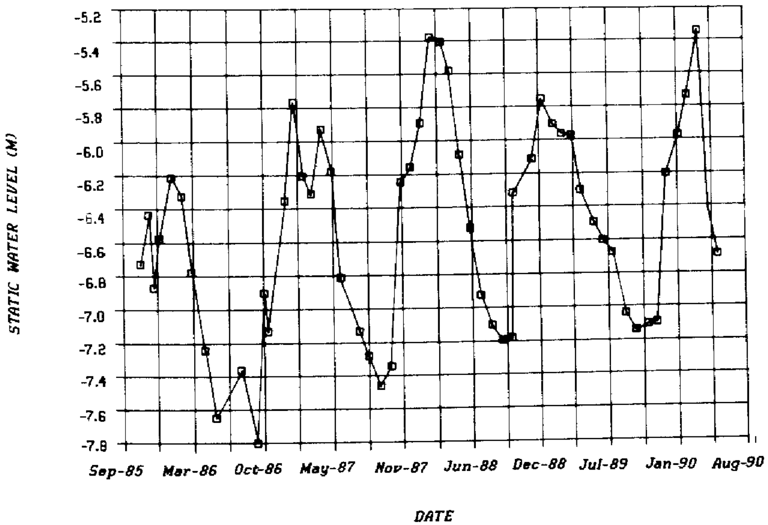
AWAJAN WELL NO.22

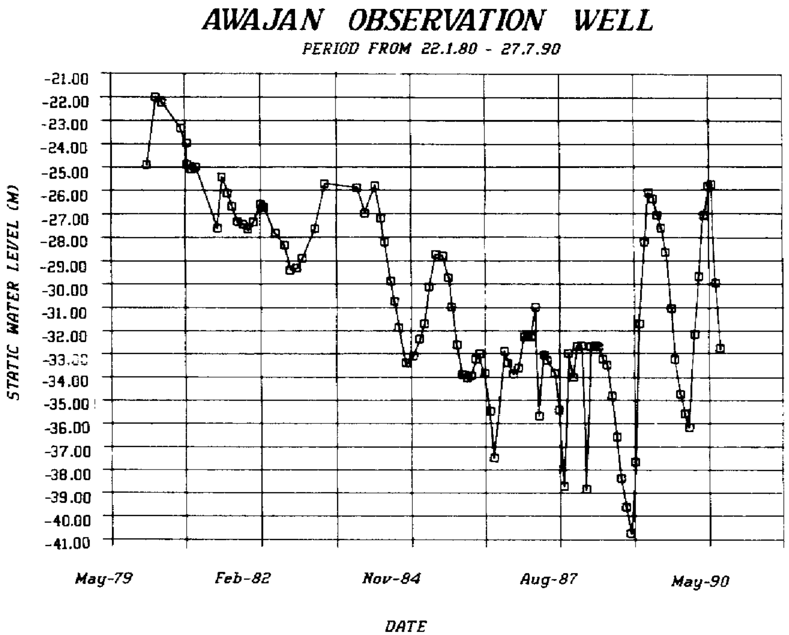


Annex 2

RUSEIFA SPR. OBSERVATION WELL NO.8

PERIOD FROM 3.10.85 - 27.5.90





7

Impact of biocides on ground and surface water pollution in Jordan

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Introduction

Man is in constant struggle with nature to achieve higher agricultural productivity through increased acreage yields. These can be obtained for most crops with the proper use of fertilizers and pesticides. Such chemicals have been useful in greatly reducing crop and livestock damage.

However, the use of pesticides to bring greater agricultural productivity is not risk-free; fatalities have occurred, directly or indirectly, from poisoning by pesticides. But of greater significance is the transport of these toxic substances in minute amounts by water and air to locations far removed from the area being treated. This is important, for the cumulative effects of certain pesticides on the well-being of man and animals are still unknown.

Sources of water-borne pesticides

Control of disease vectors. Ever since recorded time, mankind has been plagued by insects. Millions of persons have died from diseases carried by these pests. However, the incidence of diseases carried by mosquitoes, flies, fleas, and lice has been greatly reduced since the introduction of DDT as an insecticide.

Slow-moving or stagnant bodies of water, common breeding places for mosquitoes and flies, may be treated with insecticides to eliminate or reduce the larva and pupa population. Application of insecticides to such waters is intentional and with a justifiable purpose, although it introduces pesticide into the aquatic environment. Large amounts of DDT were and still are being used by the Ministry of Health in Jordan for this specific purpose.

Field application. It is unavoidable that during application of pesticides to crops a portion of the applied chemical will be carried outside of the treated area by wind currents. The transport and deposition of pesticides outside of the intended area is known as *drift*. If a stream is in the area of drift deposition, the water will be blanketed by the formulation.

On occasion, insecticides have been accidentally applied to ponds and water channels adjacent to treated areas.

Surface drainage from treated croplands will contain pesticides in concentrations ranging from picograms to micrograms per litre of water. Irrigating by the rill method causes the pesticide to be carried off by the run-off water. Where sprinkler irrigation is used, little surface run-off occurs. In sprinkler application of irrigation water, as well as in gentle precipitation, the downward movement of water-soluble pesticides through the soil and into groundwater will occur.

Precipitation of greater intensity will not only cause pesticides to be carried away by desorption from soil pesticides but will transport the eroded soil from the treated area. During a period of heavy run-off, such as prolonged rains or floods, the translocation of water-borne silt containing pesticides would be at its greatest.

Atmospheric deposition. Evidence exists indicating that pesticides can become airborne either as a vapor or adsorbed onto dust particles and translocated far from the treated area.

Jordan's imports of pesticides reached 1216 tons in 1988. Of these, 60 tons were herbicides, 66 tons insecticides for public health use, and 280 tons insecticides for general agricultural use; the others are either fungicides or acaricides.

In a 1987 study done in the Centre for Pesticide Formulation and Residue Analysis, it was concluded that pyrethroid pesticides are the most frequently used group in Jordan. This represents about 32% of the total pesticides. Organo-phosphates reached 23%, dithiocarbamates 17%, haloginated hydrocarbons 7% (even though they were banned eight years previously), and carbamates 5%. Other miscellaneous pesticides make up the balance.

It is also a fact that DDT is still used by the Ministry of Health. The malaria control section sprayed about 159 tons in the period 1976-1988. Also, the BHC chlorinated hydrocarbon pesticide for veterinary use is still marketed in Jordan and can be bought by farmers in pesticide shops. Many other persistent pesticides are still smuggled to Jordan from surrounding countries.

Table 1 shows general persistence of chlorinated hydrocarbon insecticides in soils; we see that some of these persistence pesticides like Aldrin, DDT, and Lindane may stay up to 25-30 years in soil. The hazard of their transfer to our ground and surface water still exists. Many herbicides used in Jordan are also persistent and might reach surface and groundwater resources.

Table 1
General persistence of chlorinated hydrocarbon insecticides in soils

	95% disappearance* (years)	75-100% disappearance** (years)
Aldrin	1-6 (3)	3
Chlordane	3-5 (4)	5
DDT	4-30 (10)	4
Dieldrin	5-25 (8)	3
Heptachlor	3-5 (3 1/2)	2
Lindane	3-10 (6 1/2)	3
Telodrin®	2-4 (4)	--

* From Edwards (1966). Averages given in parentheses.
** From Kearney et al. (1969).

Little work is done in Jordan in analyzing residues of pesticides in water, because of lack of specialized labs and/or personnel. In our centre, which is mainly specialized in routine pesticide residue analysis of foodstuffs and quality control of pesticide formulations, an attempt was made to analyze some water samples for residues of chlorinated hydrocarbon pesticides in running, sewage, and dam water. Twenty-five water samples were collected in May and June 1990, six of them from King Talal Reservoir, at different depths and from the dam entrance.

Table 2
Concentration (ppb) of chlorinated hydrocarbons for water samples* in the western locations of Jordan

Location	Chemical found	Concentration (ppb)
Jerash gully (before the bridge)	HCB	0.19
Jerash gully (after the bridge)	HCB	0.26
Outlet of Jerash water treatment plant	HCB	0.08
Zarka gully location (gully no.2)	HCB	0.37
Entrance of King Talal dam	HCB	0.34
Outlet of King Talal dam	HCB	0.4
Outlet of Khirbet es-Samra water treatment plant	HCB	0.5
Khirbet es-Samra gully (Adwan Mills)	HCB	0.37
Khirbet es-Samra gully (Fine Factory)	HCB	0.4
Linking location of the Khirbet gully with Zarka gully	HCB	0.07

* Samples were collected by Dr. Raja Gedeon (Water Authority) in April 1990.

Another 10 samples were collected by the Jordan Water Authority from different locations and are represented by the results of analysis in Table 2. Another nine samples were collected by Dr. Sameh Gharaibeh from Yarmouk University and are illustrated in Table 3.

Table 3
Concentration (ppb) of chlorinated hydrocarbons for water samples* in northern locations in Jordan

Location	Chemical found	Concentration (ppb)
Kufranja 10	gamma HCH	0.3
Kufranja 12	gamma HCH	1.5
Jerash 15	gamma HCH	0.4
Jerash 13	gamma HCH	1.0
	PPDDE	0.5
Kufranja 11	gamma HCH	0.02
Jerash 14	gamma HCH	0.02
Yarmouk University 4	chlordane	1.5
Yarmouk University 5	gamma HCH	0.8
Yarmouk University 6	gamma HCH	1.9
	chlordane	1.8

* Samples were collected by Dr. Sameh Gharaibeh in December 1989.

Analysis of samples

The samples were analyzed in the Centre for Pesticide Formulation and Residue Analysis.

Extraction. Five-hundred millilitres of each water sample was extracted with hexane for three times, then concentrated to 2 ml.

Clean up. The water sample extracts were cleaned up according to the Beckers method, which involves the use of 0.5 gm silicagel + 5 ml of elution mixture (Aceton : petroleum benzine : dichloromethane). Samples were then injected into a gas chromatograph equipped with an ECD detector.

Gas chromatographic conditions. Hewlett-Packard gas chromatograph 5890A - ECD detector capillary column: DB-1 liquid phase, 0.25 um film, 30 metres 0.251mm.

Oven temperature programme: 200°C. for 20 minutes, then 4°C./minute rise to 260°C.
Injector Temp: 260°C.
Detector Temp: 280°C.
Flow: Carrier gas in column 1.8 ml/min.

Carrier gas + auxiliary 33 ml/min.
Total flow split 85.6 ml/min. Ratio 2%.

Results and discussion

The results of analysis (Tables 2 and 3) show significant concentrations of chlorinated hydrocarbons in some of the water samples, mainly Kufranja waste water (1.5, 1.8 ppb of gamma-HCH, chlordane), Yarmouk University Polishing School (1.5, ppb chlordane), Jerash treatment plant (1 ppb gamma-HCH), Zarka gully (0.4 ppb and 0.3 ppb), Khirbet es-Samra (0.4 and 0.37 ppb of HCB), and the entrance of King Talal Reservoir (0.4 ppb of HCB).

Even though the number of samples analyzed in this study is not great (26), the findings indicate that some persistent pesticides are present in our waste gullies and dam waters in significant concentrations relative to the new European Community's permissible level of pesticides and PCBs in drinking water (0.1 ppb). This calls for more analysis of pesticides and PCBs in our ground and surface water, especially considering the excessive use of insecticides and herbicides in Jordan in agriculture and industry.

Recommendations

1. Alternatives to the chemical control of pests, such as biological control and integrated pest management, should be developed.
2. The proper and safe use of pesticides must be emphasized -- this should be done through a strong extension service.
3. Control the quality of pesticides used in Jordan and try to use only those relatively safe for the environment and human beings. Strictly control smuggled pesticides (persistent ones).
4. More studies and monitoring of water in Jordan are needed regarding pesticide residues and PCBs, in addition to nitrate monitoring of our water resources.
5. Fertilizers should be used properly and according to experts' recommendations.

8

Protective measures of water resources in the Federal Republic of Germany

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This paper aims to provide an introduction into the attempts of a Middle European industrialized country with overabundant water resources to cope with problems of water pollution over the last two decades. I chose this period of time, not only because it was 20 years ago that I was charged with the responsibility for water management in the Federal Ministry for the Interior (then responsible for water and environmental protection), but also because the years 1969-1970 can be considered as the starting point of a modern, global environmental policy, at least in industrialized countries. It is not a coincidence that this was also the time when a human being stepped for the first time on extra-terrestrial land (July 1969), demonstrating to all that our planet is finite and relatively small.

Looking back at these 20 years of modern environmental and water protection policy, I am reminded of the saying about putting the cart before the horse. When we started, water protection was managed like in ancient times. Wastewater was collected in channels and discharged into rivers and then into the seas. Waste gases were dispersed into the air by means of larger and larger stacks, and refuse was dumped on land and at best covered with some soil.

When we recognized that water, soil and air could not cope with these growing amounts of the residues of our life, which are polluted with ever-increasing numbers of substances, we proceeded to the second step, reduction of emission at the source. Purification plants, flue gas treatment plants and waste disposal and treatment plants were built. Only when the limits of these reduction strategies were reached did we go back to the point at which -- from a logical point of view -- we should have started, *viz.*, avoiding emissions by modifying production processes or abandoning certain products.

The most environmentally friendly energy is the one which remains unused. Even the most advanced automobile with catalytic converter and diesel soot filters is not as good as walking or using a bicycle. This principle also holds true for water. Water is wasted everywhere, not only in countries like Germany with abundant water resources.

We have laid out clear priorities in our Waste Management Act: avoidance of emission has priority over reduction at the source, which in turn has priority over passive protection. This sequence is called *avoidance before recycling, recycling before waste disposal*. However, we must accept exceptions. There are wastes which are more properly disposed of rather than recycled and their hazardous components dispersed into the environment. This is equally true of water management, where discharge of wastewater into the sea is sometimes to be prêferred to recirculation. I shall provide examples later.

Germany's water situation

Let us now review our experiences in water protection in a highly industrialized country with rich water resources. Annual precipitation in Germany amounts to 837 mm, which is more than ten times what Dr. Salameh has noted for the Disi aquifer (see p. 85). Of the precipitation in Germany, about 62% is lost by evaporation; in Jordan the figure is much higher. Germany has about 3000 cubic metres of water annually for every inhabitant. This is a dreamlike condition compared to Jordan and confirms Helen Bannayan's statement that countries poor in water resources cannot adopt the standards of countries rich in water (see p. 27), (Being a lawyer, I would say "not adopt without prior consideration".)

Leaving aside certain regional features, Germany has no problems with water quantity, but rather with water quality. Likewise, if problems arise with respect to amounts, they are generally caused by qualitative problems.

Twenty years ago, Germany began connecting as many residences as possible to sewage collection and biological or equivalent water purification plants. In 1968, wastewater from 38% of the West German population underwent satisfactory biological treatment. Today, this figure stands at 92%. The public sewage network was enlarged from 61,000 to 270,000 kilometres. The main problem in what was West Germany is the repair or renovation of defective sewage systems which in many places cause groundwater pollution. In former East Germany, the percentage of inhabitants connected to central treatment plants is much lower -- 58%.

With respect to legal requirements for wastewater discharged into surface waters or ground water, we in Germany are pursuing, oddly enough, a philosophy totally different from that which we follow with respect to discharges of waste gases into the air.

The principle of reduction of emissions to a minimum governs air quality control regulations, which require every emitter to clean waste gases according to the available state of technology, irrespective of the pollutant concentration of the receiving environmental medium. German water regulations, however, are based on the principle of emission, in which the pollution concentration of the receiving medium is taken into account.

Discharges of wastewater are prohibited in principle, but may be permitted if the public well-being, in particular the drinking water supply, is not endangered. For precautionary reasons and because one can never know fully the effects of a substance released into the environment, we in Germany attempted a combination of both principles in our water legislation.

In 1976 we introduced into the Water Act a provision that all emissions of wastewaters must be purified prior to their discharge, according to "generally adopted technologies". This provision is established by the federal government for both municipal wastewaters and direct industrial emissions; the representatives of the federal states in the parliament have to grant their approval as well. As of the present writing, 50 different wastewater requirements have been established which are being subsumed step by step into one regulation.

In 1986, the Water Act was enacted. It stipulates that treatment for certain hazardous substances which are listed by the federal government has to follow the "best available state of technology", as opposed to "the generally adopted technologies". Accordingly, it is sufficient that a certain treatment process has proven successful in a single case -- be it in Jordan or Japan. The government then can make it mandatory for all. This provision of the act is valid irrespective of the quality of the receiving medium.

However, when the government makes every successful but potentially costly innovation mandatory for everybody, it is not inconceivable that "innovation deniers cartels" could spring up, in which representatives of a certain branch, say of industry, meet in a pub and agree that none of them takes any step that might lead to an innovation. To avoid this, the German parliament has created an annual fund, presently amounting to $85 million, to provide financial grants of up to 50% for the development of processes for environmental improvement (not exclusively water management). This has been used successfully against the reluctance of industrial emitters to deal with environmental pollution. Also helpful is industry's growing recognition that in an environmentally conscious world market, whoever is first to apply advanced treatment techniques can increase sales.

Another economic instrument for water protection in Germany has been used since 1978, and not only for industrial emitters: every emitter of wastewater must pay a wastewater fee, which corresponds to the degree of pollutant concentration in his wastewater. The pollution parameters chemical oxygen demand (COD), fish toxicity, mercury and cadmium are used to calculate "pollution units", for which the emitter has to pay an annually increasing fee. Effective as of January 1990, organo-halogen compounds as well as the trace metals chromium, nickel, lead and copper were added as parameters.

An emitter's fee can be reduced by 50% if he applies generally adopted technologies and by 80% if the best available state of reduction technology is applied.

Parliament is discussing a further decrease in this fee, income from which is to be spent for water protection measures only. In 1987, the earnings of the federal states from this fee amounted to approximately $290 million. Investment costs for water treatment plants, however, were in the neighbourhood of $3.6 billion (1985 figures). These figures clearly show that the idea behind the regulation to impose fees, namely that the fee is to be higher than the costs of a modern treatment plan, has not been realized. However, this economic instrument has incited municipalities as well as industry to take further measures towards wastewater reduction, and the issue of reducing wastewater has become important for the highest officials. This is especially true for municipalities that have scaled wastewater charges according to pollutant content.

Another decisive step in improving surface waters which are polluted by wastewater was set off by measures to protect the marine environment. The largest amounts of water from Germany are emptied by the Rhine and Elbe rivers into the North Sea; a smaller part is emptied into the Baltic Sea or through the Danube into the Black Sea. Since these three rivers pass through several states, it is only natural that the downstream state is always the "motor" in the various international river commissions, urging the states upstream to make greater efforts to protect the quality of river water.

In the case of the Rhine, the Dutch assumed the role of "motor"; for the Elbe -- the international river commission for which was founded only recently -- it is the Germans; and on the Danube, it ought to be the Soviets and Romanians -- their role, however, has hitherto failed to yield any greater political effects.

The most important initiative for inland wastewater purification related to marine protection efforts was in response to an increasing growth of algae in the North Sea and its implications for tourism in that area. This was aggravated two years ago when an insidious and infectious illness hit the seals in the North Sea. Although the causes of it could not be clearly attributed to wastewater pollution, the painful dying of these beloved animals received widespread publicity, particularly on television.

In 1988 the government established a programme of ten items for the recovery of the North Sea and the Baltic Sea, which stipulated the greatest possible elimination of the nutrients phosphorous and nitrogen. Since the beginning of 1990, municipal treatment plants have been required to install denitrification facilities. Requirements on industrial wastewaters are being tightened as well.

Protecting rivers and lakes

The more sophisticated the second step of the above-mentioned sequence of priorities becomes, i.e. reduction of emissions at the source, the greater becomes the necessity to take the first step, i.e. avoidance of pollution.

There are numerous chemical substances which even the best reduction technique cannot eliminate, and there are numerous releases of substances into waters from diffuse sources such as agriculture, horticulture, streets and roads, as well as airborne emissions, which can be reduced only by modification of products or behaviour. From the historical viewpoint, instruments of avoidance, such as product modification, were applied for the first time to washing and cleaning agents.

Even forty years ago, foam patches on rivers and growth of algae disturbed the aesthetic value of natural settings and posed a problem for treatment plants as well as the balance of water ecosystems.

In 1961, Parliament passed the first Detergents Act. In 1968, a European agreement on this subject was signed. As a first step, the biodegradability of substances in laundry products had to be increased. Later measures that prohibited and reduced certain substances in cleansing agents came into force. In 1980 the phosphate content of textile cleansing agents was reduced in two steps. For the time being, a minimum degradability rate of 80% is being stipulated for surfactants according to a specifically determined process.

Industry sometimes has voluntarily dropped the use of certain environmentally harmful substances in order to avoid regulatory action. One helpful tool in this context is the mandatory registration of the specification of all laundry and cleansing products by the producers and distributors with the Umweltbundesamt (Federal Environmental Agency).

Various directives of the European Communities attempt corresponding measures which will gain importance with the impending introduction of the common internal market in Europe. Germany's water protection policy, however, not only relies on prohibitive public measures -- which generally have only limited effects -- but also makes use of various means of informing the public; for instance, we use the symbol of the United Nations as a label for environmentally friendly products to encourage the consumer to prefer certain products. The most sophisticated laws and most attentive policemen do not serve any purpose if the citizen does not know what to do and not to do.

Other regulatory instruments to prevent emission of chemical substances into waters (the Chemicals Act, for example) prohibits certain chemical substances or puts restrictions on their use if they have proven to be hazardous to water. Regulatory measures on air quality control and waste disposal provide similar requirements.

The ban on lead additives in petrol was not only necessary to protect the catalytic converters which control air pollution, but also to protect water and soil.

For the sake of prevention, it is our goal to keep chemical substances which are not easily degradable away from our waters.

Protecting groundwater

Since many of these measures apply to protection of groundwater as well as surface water, let us now turn to Germany's attempts to protect its groundwater.

In 1989 around 4 billion cubic metres of water were supplied by the public water supply. Seventy-five precent of this was taken directly from groundwater, and 15% from enriched groundwater or surface waters through bank filtration systems.

The regulatory requirements on the protection of groundwater have always been very severely formulated. (In fact, since ancient times man expected ground and well water to be the incarnation of purity -- which is the reason that in mythological narratives only women were allowed to live in water -- men were only allowed to use it for their reflection). Germany's Water Act prohibits any discharge of substances into groundwater which could potentially deteriorate its quality.

The relevant instruments are quite different from each other and not all of them have proven successful so far. The oldest instrument is the designation of water protection areas, in which German states can order monitoring or outright restrictions on the use of certain areas. These apply specifically to the restriction of agricultural activities such as fertilization and prohibition of building activities and also of transporting substances hazardous to water through the area (e.g., a ban on tanker trucks).

In 1988, more than 9000 areas were so designated, totalling an area of approximately 2 million hectares, which is 7.6% of Germany's surface area.

We consider it necessary to designate at least 3.5 million hectares (13% of the total surface); and, of course, the designation itself is not as important as the pertaining conditions.

Agricultural activity is one of the major contributors to pollution in Germany, and fairly severe requirements have been set with respect to those areas not designated water-protection zones.

The increase of animal-breeding farms has led to growing amounts of liquid manure touching the limits of the fertilizer-absorbing capacity of plants. Many federal states have therefore enacted specific ordinances on liquid manure and dung, banning their use outside the growing season, or restricting it severely. In particular the nitrate content of drinking water is to be reduced by these measures to 50 mg/l by the Commission of the European Communities (the desired value is 25 mg/l).

Another problem being introduced into political discussions is the pesticide content of groundwater that is used for the drinking water supply. The Commission of the European Communities has set very strong standards for pesticides (0.1 mg/l per single substance, 0.5 mg/l total). These standards are obviously fairly global and are not backed by toxicological findings. They have been set based on the principle that no pesticides or other chemical substances be found in groundwater which is used for the drinking water supply.

Since a zero standard cannot be implemented with the present state of measuring techniques, the choice of these standards was limited by the greatest accuracy of measurements possible in 1980 when standards were set. It is no secret that they are exceeded considerably, in Germany as well as elsewhere. However, if excess is detected in the process of intensive monitoring programmes, two actions follow:

First, the waterworks are forced to purify the drinking water; this can involve very costly processes.

Second, as soon as the federal government determines that a pesticide concentration exceeds the allowable limits at several monitoring points in the groundwater, its use is either banned by ordinance or -- if it is not hazardous to health -- the licence for the pesticide in question (which has to be renewed at least every ten years by the Umweltbundesamt) is denied.

Health effects are not the only consideration in licensing. The non-degradability of a pesticide on its pathway into the groundwater is sufficient cause for denial of the licence.

This regulatory picture could lead one to believe that everything is perfect in Germany; however, anyone familiar with the situation of water quality there knows that there are still considerable deficiencies in enforcement.

In such a densely populated and industrialized country as Germany (246 inhabitants/km^2; in comparison, Jordan has 36/km^2, or one-seventh the density), considerable dangers to groundwater develop from storage and transportation of substances hazardous to water, from related accidents, and also from process failures in industrial plants.

An accident in the Sandoz plant in Basle two years ago had a severe impact on the Rhine River and led all European states to a review of their relevant provisions. I cannot explain here the whole set of instruments of regulatory requirements on storage, handling and shipping of substances which are hazardous to water. (My agency runs a data base which police and fire brigades can use for information on properties of chemical substances and precautionary measures, but even an expert in Germany often has difficulties keeping up to date.)

Transportation through pipelines also involves risks that are difficult to handle. I mentioned earlier the pipelines for domestic wastewater which often are damaged and which endanger our groundwater.

Prospects for further action

By means of various monitoring systems, we in Germany examine regularly the quality of groundwater as well as rivers and seas. This is easier said than done, however. Many comparisons fail due to lack of validation of measurement methods and statistics. The quality data from the Elbe are still not comparable to those of the Rhine River, for instance. In addition, not everybody takes measurements of the same substances in groundwater.

To publish the data is even more difficult, because very often the industrial company which takes measurements, and also waterworks and municipalities, are afraid of damaging their reputations.

But we environmentalists know that continuous publication of environmental data gets us half-way to the point of controlling them, especially in a democracy where the voter can hold the government accountable to keep its promises. We therefore endeavour to obtain maximum transparency of all available measuring results.

In conclusion, I would like to present some data demonstrating the situation of water protection in Germany:

The oxygen content in our largest river, the Rhine, improved over the last 20 years slowly but very significantly. The content has not fallen below 5 mg/l, a level dangerous for fish, for 10 years now.

All other parameters of water quality in the Rhine were improved significantly over the last 20 years, including biological (BOD) as well as chemical oxygen demand (COD), and heavy metals as well as chlorinated hydrocarbons.

NO_3-N only (nitrogen nitrate) shows a negative trend, which is due not only to agricultural activities but also to biological wastewater treatment plants; therefore, denitrification is particularly necessary.

Water quality data of almost all substances in the Elbe, however, is similar to the quality data of the Rhine 20 years ago. We hope that after the unification with East Germany we will quickly be able to raise it to the level of the water quality of the Rhine.

The trends of the water quality of our marine environment, the North Sea and the Baltic Sea, which receive the pollution loads of our rivers (with the exception of the Danube), do not look so optimistic. While the discharges of heavy metals such as cadmium and mercury decreased, the concentration of nutrients is much too high in both regional seas and is still not dropping.

Oil pollution, which increased markedly until 1986 and particularly affected sea-birds, seems at least to have remained stagnant.

For a long time, we also underestimated the emission of airborne pollutants. And for decades, wastes were dumped on the high sea, a practice which is phasing out now. The Helsinki Convention on the Protection of the Baltic Sea specifically prohibits this practice. In the case of the North Sea, dumping activities from German harbours were stopped, whereas it is still practiced under certain conditions from harbours in other countries.

With respect to groundwater quality, we lack long-term representative data sets, because larger monitoring networks were established only over the last few years. However, we know that the average nitrate concentration in drinking water has significantly increased since 1915. In 1982/1983, 75% of the samples had nitrate concentration above the target value of 25 mg, and 5% even above the European standard of 50 mg/l.

It can be assumed, however, that with respect to those substances which are now measured, an improvment will be detectable soon. As I mentioned, continuous measurements and publication of data mean the battle is half won.

On the whole, water protection measures of the last decades in Germany were successful. This positive picture has to be qualified, however in two repects:

We have set yardsticks in the past which were considered harmful, and against which we judge success or failure. Substances about the danger potential of which we have not yet reached agreement do not figure in those yardsticks. We therefore have to take into account that within ten years the monitoring programmes will be based on quite different parameters from now.

As a second reservation, I must point out that my presentation covers the hydrological situation of a very small part of the surface of the earth.

Apart from the development from passive protection toward precaution and prevention, another trend becomes evident in environmental priority setting: the orientation from local and national problems towards regional and global ones. I am quite sure that the global ecological problems of climate modification, desertification and also of marine protection will have more implications on our national water protection policy. Professor Elias Salameh has elaborated on the relationships between energy policy and water protection (see Chapter 5).

However great the differences between the water protection problems of my country and those of our host country might be, they are problems of this one world. At a conference in Cairo last June, Joyce Starr from the United States remarked that water will become the most important subject of foreign policy of our decade. And by the year 2000, about 49% of the African population will be suffering from lack of water. I therefore greatly appreciate the willingness of this symposium to deal with these common problems.

9

Protective measures for water resources

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The present treatment of the subject

We learn to solve practical problems not just by studying mathematics, natural sciences, and engineering, but also from other people's experience and by comparing their approaches. The technical solution to the problems of water pollution is comparable across countries, making allowances for different conditions. There is also a constant exchange of know-how via the specialist literature and congresses such as this one.

The political, legal, organizational, and financial aspects of water pollution, on the other hand, show far greater differences.

I will therefore be concerned with technical matters of collecting and treating wastewater, or avoiding distributed pollution of the environment, rather than outlining a basis of effective water protection policy and the conditions which must be present (or be created) in society in order to assure successful application of technical resources.

I would like to sketch just one of many ways in which a water protection policy can be developed from the aims of environmental protection, how it can be translated into technical specifications, and what boundary conditions are useful for its successful implementation. I would also like to go into some details of financing environmental protection projects.

Pollution -- a threat to the survival of mankind

In Germany, reports on pollution are an everyday event. Newspapers, magazines, and television programmes are preoccupied with the subject. Major environmental disasters, in particular, are familiar to practically every citizen, among them the ozone hole, global warming, dying seals in the North Sea, algae bloom in the Mediterranean, Chernobyl, and forest decline.

What is special about environmental pollution nowadays, compared to that of past centuries, is that its effects are no longer local, with local solutions; rather, the consequences are world-wide. Human beings, wherever they may live on earth, can no longer escape the effects of a polluted environment. Many scientists state, and many ordinary people also have the feeling, that the self-eradication of the human species, as a result of the changes in the biosphere, is no longer out of the question. We could not however, destroy Nature, as many people think; it is much too powerful. But we could alter the biosphere to such an extent that mankind no longer has the conditions it needs to survive.

We scientists and engineers possess the knowledge that allows us to recognize threats and dangers to the environment. That means we also have a duty to inform our fellow men and those with political responsiblility, and to work out suggestions for averting the catastrophe hanging over us. Above all, we must cooperate on a world-wide scale, for no one country can solve environmental problems on its own. That is why I am very pleased to be here to share my experience with you, and at the same time to learn from you.

Utopia as a basis for our goals and approach to a water protection policy

Before one can formulate environmental policies and implement them, it is essential to uncover the causes of the problems and reduce them to as simple a description as possible. The main causes here are:

- the large number of humans who live in a relatively confined space, and
- the products they create, which do not occur in nature.

The consequences are an imbalance, or even breakdown, of the natural food cycles.

Let us summarize what we all learned as schoolchildren: The living world is a continuous cycle of materials. Inorganic materials are converted into organic with the aid of sunlight, and they in turn serve as nutrients for living creatures. When they die, the organic materials are broken down again, and are once more available as inorganic materials to form the basis of new organic materials. We should note one point in particular because it provides us with a basis for our environmental policy: in its life cycles and product cycles, nature does not recognize "waste" in the sense of substances that must be excluded from the environment in the long term because they damage the environment.

We interfere in these nutrient cycles, through our life and the goods we produce, in three different ways:

1) High concentrations of human beings mean that an excess of metabolic products overload the nutrient cycles and alter the ecosystems to the extent that they become unusable for mankind. I am thinking mainly of the overloading of rivers and lakes by excreta.

2) Artificial substances, mainly those produced in chemical factories, upset the nutrient cycles or even destroy them. These substances are not broken down by nature, or require a long time for nature to adapt to. Such substances often pose an immediate threat to man as well. Examples are pesticides and chlorinated hydrocarbons, such as those used for degreasing in the metal industry.

3) The mining, production, and use of metals, particularly heavy metals, concentrate materials to the extent that they become harmful to man and the environment.

These considerations lead directly to the goals that we must set for our water protection policy. We must restore Nature's nutrient cycles to health, and develop a way of life and production methods that do not create waste which needs to be excluded from the environment over long periods.

For now, these goals appear utopic. Our present scientific and technical knowledge is not sufficiently advanced to attain the goal. Even so, all the steps we now take should be directed towards that goal. At the same time, we should take great pains to increase our scientific knowledge and improve our technical skills. Only then can we hope that our descendants will one day reach the goal. Let us not be under any delusion: it is a matter of life and death. We have to learn to live in harmony with Nature. Otherwise the human species will not survive in its present form. Let us hope that we are in time. I would also like to add that we can solve the problems only with the aid of technology. Any suggestions that we return to a pre-industrial lifestyle I consider unrealistic and impracticable. Technical plans, on the other hand, are both feasible and practicable as concrete policies.

The following are a few possible approaches for a policy of technical solutions to environmental problems:

- the precautionary principle, which involves doing everything in our power to prevent the strain on the environment from happening in the first place;
- the liability principle, which holds that those who produce a strain on the environment are responsible for removing it;
- the cooperation principle, meaning that everyone concerned cooperates on an equal footing to solve environmental problems.

These approaches form the basis of water protection policies in Germany, and they can be seen in all associated activities. They have certainly made a considerable contribution to our significant progress in the last 30 years.

Demands for a progressive water protection policy

Thus far, I have focused on preliminary considerations, analyses, and objectives which are indispensable for a rational water protection policy. However, they need to be translated into concrete plans of action if they are to be effective in politics and society. Following are some of the requirements which have become the basis for water protection policy in Germany.

General principles:

- Water is a part of nature and the countryside, and as such must be protected. It must be husbanded to serve the common good as well as the needs of individuals, when their aims coincide with the common good, and also to exclude every avoidable impairment. Prevention of water pollution must start at the source, and must take account of the environment throughout all steps of extraction to the end use.
- All water undertakings require official approval. In the case of extraction, the type and extent must be laid down by the authorities. Adherence to the requirements must be regularly and adequately checked by the users (self-check) and monitored by the authorities (state supervision).
- Water pollution control cannot stop at national boundaries. Cooperation with neighbouring countries must be intensified.
- Environmental data must be published in a suitable form in accordance with the need for information.

Protection of surface waters:

- Wastewater discharged into a body of water must comply with certain requirements, regardless of the quality of the receiving body of water. These minimum requirements concern sewage treatment and the avoidance of pollutants; available technical possibilities must be exploited to the full extent. Key quality parameters, those with an integral function, and effective biological criteria for the appropriate field of origin (bio-monitoring) must be preferred to limits for individual pollutants when enforcing the water laws.
- The same strict requirements must be set on discharges into inland waters, coastal waters, and the high seas. The dumping of solid wastes in water bodies must be excluded.
- More extensive requirements on wastewater discharges, even leading to prohibitions in individual cases, are to be placed when the protection of the body of water or its use requires such measures. The criterion of quality objectives is the most sensitive part of the system.
- Water quality must be monitored regularly by representative and internationally comparable measurements of suitable chemical, physical, and biological characteristics, and by means of key parameters, those with an integral function, and effective biological criteria, using a sufficiently dense network of measurement stations.

- Streams, rivers, and lakes, including river banks, must be preserved in a natural state or remodelled to make them more natural.

Groundwater protection:

- Groundwater may be extracted only when extractions have no adverse effect on the water table, unless otherwise demanded by prevailing needs of the common good, or of individuals where they are in coincidence with the common good.
- Groundwater must be protected everywhere from detrimental changes. This is to be achieved by preventive measures that tackle threats at the source. Drinking-water extraction areas and other sensitive areas must be identified as such, and be subject to special requirements of protection.
- The quality of groundwater must be checked systematically and assessed over a country as a whole.

Future points of emphasis for water pollution control:

- All industrial plants dealing with substances that endanger water must be equipped or retrofitted and operated so that contamination of water is not to be feared. Appropriate measures must also be taken against faults and accidents. The plant in question must be fitted with closed-loop controls.
- Wastewater treatment plants and equipment must be of agreed watertightness and must be checked and controlled regularly.
- Waste tips must be constructed and operated so as not to endanger surface and groundwaters. Their size must be limited to the smallest necessary by waste reduction and recycling. Before tipping, waste must be treated biologically, physically, chemically, or thermally as far as is technically feasible to reduce the mobilizable pollutants.
- The use of industrial by-products, treated residues, and excavated soil must be regulated so as not to allow any water pollution.
- The effect on water resources of old solid disposal sites must be checked regularly, and all technical possibilities must be made use of to clean or decontaminate them.
- Farming places a strain on water resources through the application of fertilizers and pesticides. This burden must be reduced by:
  - land use appropriate to local conditions;
  - prevention of soil erosion;
  - fertilization in line with the needs of crops;
  - integrated plant-protection schemes;
  - cultivation methods based on advanced farming practice;
  - marginal strips along rivers and streams; and
  - training and education of farmers.

  Agricultural and economic policies must bear these objectives in mind.

- Emissions from industrial and commercial plants, power stations, domestic heating and motor traffic affect surface and groundwaters. These detrimental effects must be considerably reduced by means of further clean-air measures.
- It must be ensured that the production and use of substances which are particularly harmful or which are not naturally degraded, such as certain pesticides, do not reach surface and groundwaters.

Technical implementation of the water pollution control policy

The requirements outlined above must, of course, be adapted or supplemented in each individual country in accordance with local conditions; they also need to be translated into concrete specialist work by scientists and engineers. Let us discuss this briefly.

Protecting surface waters. Protection of surface waters -- by which we mean streams, rivers, lakes, estuaries, and the open sea -- depends first and foremost on adequate treatment of municipal and industrial sewage. The wastewater collected in sewers must be purified in treatment works, and the resulting sludge disposed of without damage to the environment. This is a classic field for engineers, and considerable success has already been achieved in many countries around the world.

However, there is still much to be done even in countries like Germany, which has already reached a high level of waste treatment. For example, of the 11 million inhabitants of Bavaria, the houses of 9.1 million are connected to municipal sewage works. The rest treat their sewage in some 330,000 small, private plants, which are generally less efficient than the larger ones. Altogether there are 3001 municipal sewage works, sufficient for over 26 million population equivalents. Of them, 97% use both mechanical and biological treatment, while 4.2 million of population equivalents have already been equipped for nitrification and 2.7 million for phosphorous removal.

It is not possible here to go into the many problems connected with planning and building municipal sewage works. I would, however, like to mention three points.

1) The choice of sewer system is very important. In Bavaria, combined wastewater sewers predominate; that is to say, sewage and storm water run-off are handled in one sewer. The treatment works have to be sized accordingly, but they cannot cope with an unlimited amount of rainwater. In the event of a cloudburst, a proportion of more or less untreated sewage has to be diverted into the rivers to relieve the load on the works. As the treatment quality improves, the load placed on the works by combined sewers becomes more and more significant.

It is my opinion that separate systems, with as little rainwater as possible going into the sewers, have three important advantages:

- Modern treatment works, technically very complicated, can be operated more efficiently and can better fulfill the demands placed on the quality of the outflow.
- Allowing as much as possible of the rain water that falls on roofs and paved areas to infiltrate into the ground increases the stored groundwater.
- The remaining rainwater, or surface runoff, can be treated, if necessary, to remove specific substances.

2) Sewage treatment works (municipal, private, and industrial), should be dimensioned in accordance with the emission standard principle. This states that all wastewater must be treated to the minimum standards prescribed for all eventualities before being discharged into a body of water. The existing quality of the body of water is immaterial. If treatment to these minimum standards is not sufficient to protect the particular body of water, then additional purification measures must be taken. If that is not technically possible, then the discharge can be prohibited. The minimum standard all over the world should be mechanical and biological treatment. In Germany, the minimum standard valid from January 1st, 1990 includes denitrification for 5000 population equivalents and more, and phosphorous elimination for over 20,000 population equivalents. If hazardous substances are present in industrial wastewater, then they must be reduced in accordance with even stricter criteria, or totally removed if possible.

3) Sewage sludge has become a special problem, due to the presence of toxic substances. The better the treatment in the sewage works, the more such substances are concentrated in the sludge. In Germany this has led to a trend for farmers to decline using sewage sludge. This is unfortunate, because an almost perfect recycling of organic material back to the soil, with the additional effect of fertilizing, will sooner or later come to an end, at least in the majority of cases. The remaining alternatives are drying with subsequent landfill, incineration with the ash being disposed of by landfill, or use in building materials after appropriate treatment. We are still working on this problem, and results are not yet available.

In spite of the already good state of affairs in Bavaria, we have to spend some 20,000 million marks in the next ten years -- that is, over $12,000 million -- on extending the public sewer system and building treatment works and storm-water tanks, as well as repairing defective sewers.

Protecting the groundwater. Groundwater is particularly sensitive to pollution by toxic materials, which either do not break down, or require a very long time to break down. The mobility of toxic substances is very difficult to predict.

Treating groundwater, if at all possible, is extremely expensive. In view of the great importance of groundwater for drinking purposes and industrial uses as well as irrigation, there can be only one principle when it comes to its protection: Any discharge of substances that gives rise to concern for the quality of groundwater must be avoided. Although this principle has legal status in Germany, and any infringement is severely punished, the quality of the groundwater is declining in many areas because of distributed pollution sources.

The problem of distributed pollution sources. We come to a problem that is acquiring ever greater significance. It is caused primarily by intensive farming, including animal husbandry, by the widespread use of hazardous substances in industry, and by the air pollution resulting from any form of energy production. These affect groundwater resources. In Germany this is manifested in increasing concentrations of nitrate, pesticides, and chlorinated hydrocarbons in the water. But surface waters are also affected, especially by over-acidity.

What is special about this problem is that it cannot be solved by the methods of sewage engineering. It is physically out of our hands. What we need are new approaches for environmentally compatible farming, replacing hazardous substances in industry by harmless ones or by different production methods, and better filtering of exhaust gases or even new forms of energy. Our duty as sewage engineers is to call attention to these problems and to demand new solutions.

Prerequisites for successful implementation

An engineer's responsibility goes further than the correct use of scientific knowledge by means of sensible technology. Implementing technical solutions requires more than just a good plan. We engineers need to recognize this and must assist in creating the appropriate boundary conditions:

- Environmental protection is expensive. Those affected are prepared to pay for it only if they understand why it is necessary to make sacrifices. It is the duty of scientists and engineers to educate politicians and the public at large.
- Environmental protection cannot be put into practice without the appropriate laws. We must advise the politicians responsible, so that they can create the necessary laws based on scientific objectives. Close cooperation between lawmakers, scientists, and engineers is particularly important for success in this area.
- The job of protecting the environment is so complex that it can best be accomplished by an organization based on division of labour and decentralized decision-making powers. Tasks should be carried out autonomously at the lowest level which has the sufficient technical qualifications. In our experience, centralized systems are less suitable for solving complex problems than decentralized ones. The decision on the degree of decentralization will have considerable influence over administration and management principles.

Methods of financing

We engineers must also consider the issue of financing environmental protection. Of course, we attempt to strike a reasonable balance between costs and benefits. The basis in Germany for financing environmental protection is the liability principle mentioned earlier. In practice, the users allocate the required money by one-off levies and/or by regular contributions to pay off the capital costs of plant and equipment. Users also make regular payments for costs.

The state makes grants only for public installations and only toward the capital costs,and then only in certain cases. General subsidies would run counter to the liability principle. Grants are justified solely because the costs of sewerage vary greatly with local conditions. In Bavaria the costs of state-subsidized sewage treatment schemes currently lie between 1500 and 10,000 DM per population equivalent, that is, somewhere from $900-6,000. In exceptional cases it can be even higher. State subsidies are intended to ensure that the differences should not unduly burden individual citizens. Incidentally,the yardsticks for determining the one-off payments are the area of the plot of land connected to the sewer system and the floor space of the buildings on it.

The regular payments are based on water consumption. A normal order of magnitude for payments for the use of public sewage facilities would be 1 to 3 DM per cubic metre consumed, which is about $0.60-1.80. To finance the investments not covered by one-off payments and state grants, the regular payments include amortization costs and interest at the rate of 6-7%.

Priorities and timescales

To finish up, I would like to discuss priorities and timescales. Sewers and sewage treatment works are some of the most expensive installations in our infrastructure. It is clear that they cannot be built overnight, however desirable that might be. Besides the limited money available, we should not forget that the capacities for planning and construction work cannot be extended at will. In Germany these are more of a limitation than money. Therefore, we need consistent work over many decades if the goal of clean water is to be attained. In Bavaria we have been at it for over 30 years to get where we are today. There can be no letting up in future, either.

In view of these long timescales, obviously priorities have to be set to ensure that the investment always brings the greatest possible benefit. First of all we must take steps to stop negative effects on groundwater. Discharges into the groundwater must be replaced by discharges into surface waters or appropriate agricultural use. In the case of surface waters, restoring the oxygen content has absolute priority. Here, it may be sensible to build the mechanical section of a sewage works first, including the sludge treatment. Of course, the biological section, nutrient removal, and possibly also filtration, must be taken into account in the planning phase; these sections can, if necessary, be added later. The training and instruction of staff must also be considered from the start. Modern treatment works contain very sensitive pieces of equipment and are not easy to control.

All in all, it is scarcely possible to make general recommendations on the choice of priorities. That requires precise knowledge of the local conditions.

Closing remarks

I hope I have managed to offer the reader one or two thoughts that might be useful. Let me close with a remark that arises from the tradition and religion of my country: God has entrusted us humans with His land to make our home in. We owe it to Him to look after it and pass it on to our children as intact as possible. Where we have harmed Nature, we must do all in our power to heal the wounds.

Together, let us devote our energies to that cause.

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Symposium recommendations

General principles

1) Water is part of nature and the countryside. It must be protected and husbanded in such a way that will serve the common good, meet the needs of individuals, and exclude every avoidable impairment.

   Prevention of water pollution must start at the source; the impact on the environment must be taken into account throughout all steps of extraction until the end use.
2) All water undertakings require official approval. The type and extent of extraction must be regularly and adequately checked by the users (self-check) and monitored by the authorities (state supervision).
3) Water pollution control cannot stop at national boundaries. Cooperation with neighbouring countries must be intensified.
4) Environmental data about water must be published in a form that meets the need for information.

Protection of surface waters

5) Wastewater discharged into a body of water must comply with certain requirements, regardless of the quality of the receiving body of water. These minimum requirements concern sewage treatment and the avoidance of pollution. The available technical possibilities must be exploited to the full extent. Key quality parameters, like those with an integral function, and effective biological criteria for the appropriate field of origin (bio-monitoring) must be preferred to limits for individual pollutants when enforcing the water laws.
6) The same strict requirements must be placed on discharges into inland and coastal waters. The dumping of solid wastes in water bodies must be excluded.
7) More extensive restrictions on wastewater discharges, even leading to prohibitions in individual cases, are to be put into effect when the protection of the receiving body of water or its use requires these measures. The

criterion of quality objectives is the most sensitive part of a water system, including the sea.

8) Water quality must be monitored regularly by representative and internationally comparable measurements of suitable chemical, physical, and biological characteristics, and by means of key quality parameters, those with an integral function, and effective biological criteria, using a sufficiently dense network of measurement stations.

9) Streams, rivers, and lakes, including river banks, must be preserved in a natural state or remodelled to make them more natural.

Groundwater protection

10) Groundwater may be extracted only when extractions have no adverse effects on the water table, unless otherwise demanded by prevailing needs of the common good, or of the individual where they are in coincidence with the common good.

11) Groundwater must be protected everywhere from detrimental changes. This is to be achieved by preventive measures which satisfy the basic principle of concern and by tackling threats at the source.

Drinking water extraction areas and other sensitive areas must be identified as such, and be subject to special requirements of protection.

12) The quality of groundwater must be checked systematically and assessed over a country as a whole.

Future points of emphasis for water pollution control

13) All plants dealing with substances that endanger water must be equipped (or retrofitted) and operated in a manner such that contamination of water is not to be feared. Appropriate measures must also be taken against faults and accidents. Plants must be fitted with closed-loop controls.

14) Wastewater treatment plants and other equipment must be of agreed watertightness and must be checked and controlled regularly.

15) Waste tips must be constructed and operated in a manner so as not to endanger surface and groundwaters. Their size must be limited to the necessary size for waste reduction and recycling. Before tipping, waste must be treated biologically, physically, chemically, or thermally as far as is technically feasible to reduce the mobilizable pollutants.

16) The use of industrial by-products, treated residues, and excavated soil must be regulated so as not to allow any water pollution.

17) The effect of old solid disposal sites on water resources must be checked regularly, and all technical possibilities must be made use of to clean up and decontaminate them.

18) Farming places a strain on water resources, through the application of fertilizers and pesticides. This burden must be reduced by:
   - land use appropriate to local conditions,
   - prevention of soil erosion,
   - fertilization in line with the needs of crops,
   - integrated plant-protection schemes,
   - cultivation methods based on advanced farming practices,
   - delineating marginal strips along rivers and streams, and
   - training and education of farmers.

   Agricultural and economic policies must bear these objectives in mind.

19) The detrimental effects of emissions from industrial and commercial plants, power stations, domestic heating and motor traffic on surface and groundwater must be considerably reduced by means of further clean-air measures.

20) The production and use of substances which are particularly harmful or which are not naturally degraded, such as certain pesticides, should take place in a way such that they do not reach surface and groundwaters.

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