# CHEMRAWN XV

## Perspectives and Recommendations

# CHEMISTRY FOR WATER

IUPAC

Editor: A.C.E. – Association Chimie et Eau

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IUPAC

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY
AND
ASSOCIATION CHIMIE ET EAU

# CHEMISTRY FOR WATER
## CHEMRAWN XV

### Perspectives and Recommendations

Plenary Lectures and Perspectives
from the International Conference on Chemistry for Water,
Paris, France, 21-23 June 2004

Edited by Association Chimie et Eau
Maison de la Chimie
28, rue Saint-Dominique
F-75007 Paris

## The “Maison de la Chimie” Foundation

Created in 1928 when the chemists were celebrating the centenary of Marcelin Berthelot’s birthday, the Foundation has two main purposes:

• to build and maintain in Paris, France, a place designed for meetings and congresses, for the use of people working in universities, chemical laboratories, chemical industries or any industry linked with chemistry and its applications;

• to enhance the development of chemical science and its applications.

The Foundation is international and has received funding from more than sixty countries around the world. Eight members of its Board are from countries other than France.

The “Maison de la Chimie” is the registered office for several scientific organisations: the “Société de Chimie Industrielle”, the “Société Française de Génie des Procédés”, Eurocase (European Council of Applied Science and Engineering), and the “Académie des Technologies”.

The “Maison de la Chimie” offers numerous meeting rooms of various sizes (up to 1,000 seats) for congresses or working sessions.

Every second year, the Foundation gives an international award of €30,000 to one or several recipients who are selected by an international jury. This award is intended to reward original work in chemistry that is of benefit to mankind, society or nature.

The Foundation periodically holds scientific meetings related to chemistry and its applications: Chemistry and Space, Chemistry and Brain, Chemistry and Automotive, Chemistry and Nutrition, Chemistry and Ageing, Art, Chemistry and Polymers are some of the topics of recent meetings.

The “Club de la Chimie” includes over 500 members from Universities, Public Research, Chemical and other industries, Chemical Engineering Schools. It is an excellent place for members to meet in one of the most prestigious areas in Paris, close to Invalides and the nearby Air Terminal.

In 2003, the Foundation initiated the “Conference Pasteur” which gathers the main French organisations in the chemical arena, enabling them to collaborate on important items related to chemistry: information and communication, teaching of science – particularly chemistry – in schools, research and innovation, organisation of meetings and congresses. The “Conference Pasteur” is managed by a steering committee chaired by the President of the Foundation. One of the working groups, “Chimie et Société”, has regional teams throughout the country.

In 1999, the Foundation organised a symposium on Water and in 2004, was proud to contribute to and welcome in Paris CHEMRAWN XV – Chemistry for Water.

The “Maison de la Chimie” is the house of all chemists from any part of the world and is pleased to welcome them when they are visiting France.

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## In Memoriam Prof. Pierre Potier (1934 – 2006)

President Pierre Potier, Member of the *“Académie des Sciences”*, President of the *Fondation de la Maison de la Chimie*, passed away on 3rd February 2006. When the *Association Chimie et Eau* turned to him to organize the CHEMRAWN XV Conference at the *Maison de la Chimie*, Pierre Potier gave his agreement, and committed the Foundation’s material and financial resources to sponsor the event. He also agreed to assume the Presidency of the Conference, a sign of his keen interest in the issue at stake.

President of the *Fondation de la Maison de la Chimie* since 1995, Pierre Potier had given the Foundation renewed dynamism, while contributing to the national and international recognition of an institution that is exceptional through its history and its missions.

Pierre Potier was an outstanding researcher. Director for many years of the *Institut de Chimie des Substances Naturelles* at Gif-sur-Yvette, one of the CNRS’s major laboratories, he developed two very important anti-tumour medicines in particular: Taxotere and Navelbine. His research also focused specifically on the fight against diabetes, as reported at the event organised by the Foundation on 21st April of last year.

Pierre Potier also held major functions at the Ministry for Research, as Director General for Research and Technology, from 1994 to 1996.

A man of heart and conviction, with an insatiable interest in science, he knew how to convey his enthusiasm and zest for life to everyone around him.

His death has left a huge void within the national and international scientific community.

# FOREWORD

## CHEMRAWN XV: A New Chemistry at the Service of Water

Because 5000 children die of a lack of water every day, the International Union of Pure and Applied Chemistry (IUPAC) has deemed it imperative to mobilise its skills and strengths at the service of water. Mindful of the repeatedly negative image of chemistry, at odds with that of pure water, the association considers its duty to take action in the face of the major challenge that water now presents to mankind.

Accordingly, IUPAC and its CHEMRAWN (Chemical Research Applied to World Needs) Committee decided to hold an international conference on "Chemistry for Water". This took place in Paris, at the *Maison de la Chimie*, from 21 to 23 June 2004, under the presidency of Pierre Potier, who sadly passed away recently, and the patronage of M. Jacques Chirac, President of the French Republic. The "CHIMIE et EAU" Association (ACE) was responsible for the event's organization.

Three hundred specialists attended the three-day event. Plenary conferences, as well as six workshops on major scientific and technical issues, relating to water, saw inspiring and highly informative presentations and exchanges. In its report, **"Chemistry for Water: Perspectives and Recommendations"**, ACE reviews the conference's highlights to lay the foundations for a debate on the future, identifying the main research and development prospects and formulating appropriate recommendations.

ACE will distribute this report extensively, not only among water specialists and professionals, but also within the world of education, political circles, the authorities and the media.

In conjunction with CHEMRAWN's "Future Action Committee", ACE will endeavour to rally chemists round the various recommendations.

The CHEMRAWN XV Conference was funded by IUPAC, CNRS [French National Centre for Scientific Research], the French Ministry for Research and Technology, the *Maison de la Chimie* Foundation, as well as sponsors from industry. The Société de Chimie industrielle was in charge of its organization.

The mounting problems of water management around the world, exacerbated by an ever growing population and equally increasing vital needs, coupled with a finite natural resource, demand concrete, collective and strategic actions which chemists are ready to undertake, over and above meetings and debates.

Using various examples, the CHEMRAWN XV Conference shed new light on the huge, often unsuspected potential offered by chemistry disciplines, which can bring new solutions to countless known problems.

The prospects opened up by CHEMRAWN XV imply an asserted will to share the expected progress based on a more proactive, more confident and more united development model. Precautionary principle and sustainable development can only be truly meaningful if they are applied to actual facts. The CHEMRAWN XV Conference set out these realities together with analyses which underline the need for research strategies with a wider multidisciplinary approach. New technologies in order to protect reserves of pure water more effectively, create new resources, optimise the various uses of water, and treat effluents efficiently are urgently needed.

CHEMRAWN XV has highlighted the emergence of a new chemistry as an essential component of sustainable development. This new chemistry implies more science, more technology, more innovation, more solidarity. It requires the simultaneous combination of basic research, technological research, environmental research and sociological research within strategies centred on major objectives such as water.

The Conference has illustrated the value of this new chemistry using concrete cases by giving a real content to a kind of development that is more sparing with materials and energy, and more mindful of environmental impacts and the needs of mankind. It has shown that chemical science and technology offer a huge font of knowledge and know-how.

The various contributions to CHEMRAWN XV express the enthusiasm of a community on the road to a more controlled future, a community in search of solidarity and confidence, and intent on taking action in order to deserve all this.

The success of CHEMRAWN XV will be to have been able to restore a new, more giving direction to a discipline which has brought so much to mankind since Lavoisier and Pasteur, and which keeps on surprising us by its ability to renew itself.

**Pierre Fillet**
Chairman, Association Chimie et Eau
Member of the “Académie des Technologies” of France

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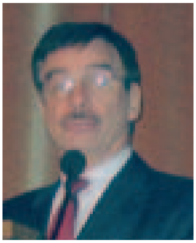
IFREMER

# I – ADDRESSES



## John Malin

*Chairman of the CHEMRAWN Committee*

It was in 1976 that the International Union of Pure and Applied Chemistry (IUPAC) established CHEMRAWN – CHEMical Research Applied to World Needs – based on suggestions of how IUPAC could employ chemistry to help solve world problems. Now, 28 years later, CHEMRAWN continues to produce conferences that are jewels in the crown of IUPAC.

Like the current conference, CHEMRAWN XV: Chemistry for Water, CHEMRAWN conferences have become models worldwide for all others to follow. CHEMRAWN brings together private and public sector scientists, regulators, environmentalists, government representatives and citizens.

CHEMRAWN Conferences allow the International Union of Pure and Applied Chemistry to address issues with important political and social applications, transcending pure science. Over 28 years, CHEMRAWN conferences have dealt with significant issues concerning chemical scientists and engineers and the broad world community. These include:

1) Four major conferences on materials. The Future Sources of Organic Raw Materials (Toronto, 1978); Resource Material Conversion (The Hague, 1984); Advanced Materials for Innovations in Energy, Transportation and Communications (Tokyo, 1987); and Advanced Materials and Sustainable Development (Seoul, 1996).

2) A groundbreaking conference on the rule of chemistry in improving food accessibility, CHEMRAWN II: Chemistry and World Food Supplies: the New Frontiers (Manila, 1982).

3) CHEMRAWN conferences on health (Heidelberg, 1986), chemical education (a movable feast held in Budapest, Honolulu and Brisbane in the late 1990s), and innovation in the chemical industry (Ottawa, 2003).

4) Four major conferences on chemistry in the environment, including CHEMRAWN IV: Modern Chemistry and Chemical Technology Applied to the Ocean and Its Resources (Colorado, 1985); CHEMRAWN VII: The Chemistry of the Atmosphere, Its Impact on Global Change (Baltimore, 1991);

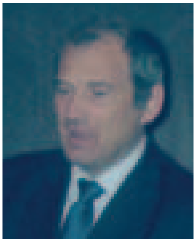
CHEMRAWN XI: The Latin American Symposium on Environmental Analytical Chemistry (Montevideo, 1998); and CHEMRAWN XIV: Toward Environmentally Benign Chemical Products and Processes (Colorado, 2001). Other environmental conferences are planned.

A major challenge for chemical scientists and engineers lies in helping our citizens and policymakers to understand the many ways in which chemistry benefits humanity. CHEMRAWN conferences have been doing this from the beginning through their Future Actions Committees (FACs). CHEMRAWN pioneered the use of these committees, formed at every conference, to develop a set of Perspectives and Recommendations that are presented to researchers, citizens and policymakers to inspire future activity. One notable result of such activity was a project using high-flying kites to sample the atmosphere at locations over the Amazon basin, a recommendation from CHEMRAWN VII.

Now we are preparing to hear from scientists and leaders on the important topic of how chemistry can improve the supply of clean water for the entire world's people. I am sure that during the next three days we will learn much significant new knowledge and develop new concepts related to this crucial problem.

Certainly CHEMRAWN XV will be another shining jewel in the crown of IUPAC, and a triumph for all those involved. It is not easy to organize such a major international conference.

## François Loos
*French Industry Minister*



I appreciate very much your kind invitation, to speak at the conclusion of the CHEMRAWN XV conference on "Chemistry for Water", and even more so because, 15 years ago, I was in charge of a world-wide chemical company. Yes, chemistry is the main key to guaranteeing, directly or not, water quality from source to ultimate use. But, we should also acknowledge that chemistry can be the cause of contaminations and pollutions whether they come from nature or from human activities.

So I thank you for allowing me to express, with regard to this conference, my total concern for this essential problem – to access water for a large part of humanity that is currently lacking it; but also to protect resources and provide quality. The answer to this situation will satisfy other needs such as food supply, sanitation and health, and also for access to energy and to the development of traditionnal activities and more important industries. No other field has such a large human and economical impact.

Today, due to the fact that in the last hundred years the population in the world has increased three fold and the needs in water have increased six fold, 20% of the world population have no access to water. All of us know that many studies have been published by international organizations, and their conclusions are converging, through meetings such as the World Water Forum in 2000 at La Haye, and in 2003 in Kyoto (with the next one in 2006 at Mexico). We should mention in particular the world summit in Johannesburg in 2002, where the French President was strongly involved in the round table dedicated to financing development in poor countries.

Orientations and trails have been proposed and some decisions taken; in particular to take 0.7% of the world gross product and to increase by 25% world development held before 2007. In fact, it will be necessary to spend $180 billion per year, instead of $80 billion today, to decrease by 50% the number of people without access to water by 2015. Solving this problem is the condition for all others.

So, what do we do, and how do we do it?

The report published by M. Camdessus presented proposals validated by the G8 summit.

On the technical plan, CHEMRAWN XV has shown that we have methods and analytical technologies available to answer and often to solve most of the problems due to contamination, and with regard to quality validation. It is the same for industrial technologies which can be used to find and to exploit new resources (desalination of sea water, submarine fresh water) and moreover for purification of natural water, and used water. However, politicians know that political and financial problems are the most difficult to solve. Despite that situation, the tragedy predicted is avoidable. For achieving it, many proposals have been agreed.

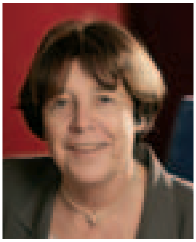
Firstly, to set up new governance in the countries concerned, in terms of education and of investments which should be delivered to local organizations as close as possible to the population. Therefore, the great multilateral financial institutions should work directly at the local level and not at the state one. However, this needs local financial markets.

Secondly, there is a need to build decentralized water policies and to develop local installations.

Finally, key factors of sustainable development are to promote public-private partnership, access to water and quality guarantee and protection of resources.

Chemistry, and the science of water, is in the best position to guarantee and to validate usage properties. It is necessary to mobilize all the resources of research for achieving the progress expected. The European Commission has implemented a "platform for water" and the French government a "French partnership for water", and a law on water and aquatic media is being prepared.

This CHEMRAWN XV conference has the great virtue to show the important problems to be overcome, and also to show how powerful chemical science and technologies are in providing solutions.



# Catherine Brechignac

## The CNRS Rallies Its Chemical Resources in Support of Water World Issues

***President of the CNRS***

The CHEMRAWN XV Conference has helped collect converging and specific data on the current state of affairs regarding water in the world. Deemed to be an unlimited resource until recently, water has now become a rare and precious commodity governing the development of humanity and above all, health.

The crisis already seriously affects countless populations in the least developed countries, and the need to protect resources, develop new ones, and control every use of water is now a pressing collective duty for us all.

However, although the questions are clearly set, those in charge of managing water still do not have all the elements to answer them, and in particular science and technology have yet to be perceived as essential engines of progress.

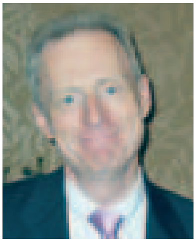
CHEMRAWN XV has highlighted the degree of urgency with which research and development resources need mobilizing on a worldwide scale in an area that offers particular innovation potential: Chemistry. Many initiatives have shown that the technological progress achieved by chemists will now govern funding decisions based on a new rationale that will help simplify the mechanisms involved. These initiatives have also brought to light the huge potential offered by the various disciplines of chemistry, a potential which deserves to be exploited more effectively by new organizations as well as a rather more dynamic and concerted dialog on an international scale.

CNRS (French National Center for Scientific Research) is the custodian of a sizeable part of this potential through the knowledge and expertise of its researchers. This inventory has even surprised the chemists themselves, but even more so those for whom Chemistry still conjures up the obsolete image of an essentially polluting activity. A vast scope is opening up to a "new chemistry", a more united and responsible chemistry at the crossroads of many scientific disciplines.

It is now to the regional bodies acting as decision-making centers for water management that this new chemistry has to convey its messages and pass on its know-how.

Chosen by the International Union of Pure and Applied Chemistry (IUPAC) to host CHEMRAWN XV, France indeed holds world-ranking positions through both its industry and its research. Its ability as a driving force in focusing chemists on the water issue is beyond question.

With its wealth of assets, CNRS is well placed to launch initiatives that will drive a global mobilization of researchers, which would convey to Chemistry, much more effectively than all the speeches, the image it so deserves as a complete art at the service of mankind.



## William F. Carroll, Jr.

*Chairman (2005) American Chemical Society*

On behalf of Dr. James Burke, Chair of the Board, and Madeleine Jacobs, Executive Director and CEO, it is my distinct pleasure to bring best wishes from the American Chemical Society to the attendees of CHEMRAWN XV: Chemistry for Water. From our historical involvement with IUPAC in the CHEMRAWN series, ACS takes the responsibility to use chemistry for the benefit of humankind seriously. Our members are very anxious that their non-chemist neighbors understand the benefits of chemistry in the same way that we all do; there is no better way to make the case for chemistry as a vital contributor to a sustainable world system than to demonstrate how it serves humanity without preference for heritage or geography, and how it could take such service to a higher level in the future.

As chair of the International Scientific Committee, I would like to take this opportunity to thank the members of the committee who have worked diligently in previous months to identify, review and bring forward the challenging and inspiring presentations you have before you. I particularly would like to thank Dr. Yves Levi, secretary of the committee, who has been the heart and soul of this process.

I would be remiss at this time if I did not remind you of why CHEMRAWN conferences are different from others. CHEMRAWN is a conference with a purpose; our goal is to leave Paris not just informed but energized to utilize what we have learned and the contacts we have made to make a difference for the 1.5 billion people in the world who lack safe water for drinking and agriculture, to say nothing of those hundreds of millions more who lack decent sanitation. For that reason, all CHEMRAWN conferences have a Future Actions Committee, tasked with reducing the intellectual activity to action, applicable to world need. I would like to thank in advance the members of the Future Actions Committee, chaired by Dr. Alan Smith, who come from seven countries on four continents, for their contributions of time and talent.

Finally, I would like to add a personal note. Water relief projects have been important to my company, OxyChem, and to the World Chlorine Council, of which it is a member. We have brought emergency sanitation to local areas after disasters and also have been a small part of larger efforts, like the West Africa Water Initiative, a Type-2 partnership led by the Hilton Foundation and World Vision, and announced at the World Summit on Sustainable Development.

For this reason, I am particularly interested in Workshop 6: Case Studies. In this workshop, solutions are presented for difficult problems on a large and technological scale as well as a small and "low tech" scale. We will need to adapt tools of all kinds if we are to succeed in the conference goal of bringing water to all humankind in the 21$^{st}$ century.

## Alain Perroy

***Cefic Director General***

Allow me, on behalf of the chemical industry community I represent through Cefic, the European Chemical Industry Council, to congratulate you on having taken the initiative of convening this conference. I am convinced these debates will enable us to gauge the potential the chemicals sector has to help resolve one of the major problems facing mankind: access to secure, reliable and durable water resources.

All those – scientists and industrialists – identifying themselves with the chemicals sector can be legitimately proud to belong to that community. I sincerely believe the chemical industry is a reliable asset. The European chemicals sector is still today the foremost chemical industry in the world. It contributes to the creation of wealth with its products that represent over 500 billion euros in annual turnover. It contributes to employment – directly with its 2 million employees – and through the indirect jobs it generates in numerous industrial sectors where chemical innovation contributes to technological advances we consider essential today to satisfy our needs.

Admittedly, this strong position of the European chemicals sector cannot be regarded as definitively acquired. We have every reason to be confident because the chemicals sector knows how to take advantage of the opportunities that come its way and – just as much – how to live up to its responsibilities.

Over the past 20 or 30 years, the chemicals sector has managed to weigh up the problems generated by its formidable development. It has sized up the environmental burden its activities could result in and threats they could constitute to the preservation of eco-system balances.

Water quality – one of the themes of your conference – together with air quality, the build-up of waste and the controlling of industrial risks were, from the outset, the focus of our concerns.

Reducing the impact of chemical activities on natural environments was the prime objective when in the mid ‘80s the world chemicals community launched its Responsible Care programme – a unique example of an industrial sector taking the global commitment to achieve continuous progress going beyond regulatory obligations if necessary.

The reports we publish every year testify to the progress accomplished. This progress is exemplary and recognised as such by the international community. At the Johannesburg summit, the chemical industry was pleased to receive an award from UNEP for its contribution to sustainable development – via Responsible Care.

At the end of 1998, we undertook another commitment: to deliver, in line with OECD standards, an updated risk analysis for 1,000 so-called “high volume” substances accounting for over 90% of world chemicals output. Today, more than 960 substances have been the subject of specific commitments by companies volunteering to do this work – commitments that are duly listed on an internet site, open to the public out of a concern for transparency. This programme is well underway, and our initiative has led to an unprecedented acceleration in the rate of analysis of dossiers for chemical substances by the OECD’s special committees.

The European chemical industry’s constructive attitude in the current debate on new regulations for chemicals is another example of our desire to be in tune with societal expectations. As soon as the Commission White Paper was published in February 2001, we made proposals for the implementation of effective legislation. Throughout the regulatory drafting process we contributed concrete ideas, based on our experience of risk analysis and management.

And even now that a legislative proposal is available, we are engaged in partnerships with the Commission. The aim is to subject the envisaged regulatory mechanisms to full-scale testing to further improve them and make sure the legislation emerging from the debate is a real success both in terms of health and environment protection and preserving our innovative capacity.

I see no other future for our chemical industry than resolutely striving to meet society’s expectations, to satisfy mankind’s essential needs, in a world where serious question marks remain over access to basic resources – water and energy – for a very high number of individuals.

In Johannesburg, I chaired a conference on the theme of capacity building where the world chemical industry set out its ideas for devoting its expertise and resources to the goal of sustainable development. Since then, we have entered into a partnership with the United Nations special agency to put these ideas into practice.

This goes well beyond the dissemination of customary good practices on safe use of chemicals. Fortified by the contribution the chemicals sector has made in all compartments of modern society from everyday comfort to health, mobility, communications, information processing, and performance in all areas, we can be confident it holds enormous potential to bring solutions to water problems in the world.

I am sure the debates to follow will afford multiple examples of this. And I’m convinced this strong expression of our will to meet expectations will enable a reputation-conscious chemical industry to be seen in a different light.

# II – LECTURES

## IUPAC and Safe Water Supply

**Leiv K. Sydnes**
*President of IUPAC*

It is an honor and a significant pleasure for me to represent the International Union of Pure and Applied Chemistry, IUPAC, on this occasion and address you at the opening of the 15th conference on Chemical Research Applied to World Needs, CHEMRAWN XV. The conference has been organized under the auspices of IUPAC, OECD and UNESCO, but it is really the CHEMRAWN committee, under the leadership of Dr. John Malin, that has carried the idea through. I would like to use this opportunity to thank the committee and Dr. Malin so much for their efforts!

But without significant contributions from and cooperation with Académie des sciences and Académie des technologies, and the support of Académie d'agriculture de France, Académie nationale de medicine, Académie francaise de pharmacie, as well as Fondation de la Maison de la Chimie, Royal Society of Chemistry, Société Francaise de Chimie, Société de Chimie Industrielle and Société Francaise du Génie des Procédés, this gathering would quite frankly not have taken place. I am therefore very pleased to be able to extend my sincere thanks to the academies, the societies, and the foundation as well as all the dedicated members of scientific and organizing committees for a task very well executed. Thank you very much indeed!

The title of this CHEMRAWN conference, "Chemistry for Water", indicates that chemistry and the chemical sciences, and therefore IUPAC, have something to offer that the "water community" needs. Before looking into what this offer consists of, let us consider water and the global water situation for a moment.

First an obvious observation: Water is special because all life forms on earth are totally water dependent. Water amounts to up to 80% of our bodies and plays diverse chemical roles in humans as well as in flora, fauna, soil and air.

Furthermore, water is one of the few natural resources easily available and present in abundance. The total global supply of water is astronomical ($1.38 . 10^9$ $km^3$), but from the consumers' point of view it is a pity that more than 97% of this is found in the oceans and can, therefore, not be directly used for drinking. Of the remaining 2.5% approximately 1/8 ($3.6 . 10^6$ $km^3$) is suitable for drinking.

Another important fact is that the water, unlike other natural resources such as coal and oil, is infinitely renewable: Rainwater falls from the clouds on to the land, nourishes life, returns through rivers to the ocean, and evaporates as fresh water back into the clouds.

But in spite of this, efficient recycling we are facing a global water problem, which to a large extent is due to the fact that the world's population has been growing at an exponential rate for decades. In 1820 there were 1 billion people, in 1960 some 3 billion, and today there are approximately 8 billion of us. As a result the formal average amount of drinking water available per person has been and is still decreasing.

But just as important is the fact that the water distribution and the population distribution are far from identical. In fact the discrepancy is such that it is fair to say that much of the water in the world is in the wrong location. Some places have more water than they can possibly use, whereas others have too little. And in many regions the rainfall is highly seasonal: almost all the year's supply may arrive within a few months, which is also a significant problem.

As a result, the management of water has been a major operation and a significant challenge in many countries for decades. Frequently too little water has had to meet simultaneous demands for delivery of drinking water, water for agriculture, and water for industry. In many regions the solution has been to utilize ground water, but this has not been unproblematic. As more and more water has been pumped out of the ground, the ground water has been replaced by brackish water and water containing pollutants due to all sorts of human activities in the region. (In Europe some 80% of the population depends on groundwater, a resource described as overexploited in more than 60% of European industrial and urban centres and threatened by pollutants.) The use of ground water has therefore many places become less and less attractive, and surface water is increasingly being used for the provision of drinking water, in spite of the fact that its quality may be far below the recommended standards.

Add to this the following observations: 1) The general level of pollutants in the environment, even in the Arctic, has increased considerably in recent years due to influx of waste from industrial, urban and agricultural activities. 2) Poor drainage and irrigation practices have led to water logging and salinization of roughly 20% percent of the world's irrigated lands.

The consequences of this development are obvious: The lack of water resources of adequate quality has become a serious global threat to a sustainable development and a safe food production in many areas, with health problems as a result. As summarized recently in an article by Alex Kirby, a BBC News Online environment correspondent:

“Two-fifths of the world's people already face serious shortages [of water], and water-borne diseases fill half [of the] hospital beds [in many countries].

People in rich countries use 10 times more water than those in poor ones.

And water-borne diseases already kill one child every eight seconds, as day follows day.”

From this sketchy description it is evident that there is an increasing need for scientific involvement to solve pressing problems, and to contribute to the development and introduction of new practices. This is where chemistry comes in and naturally has a predominant role to play:

1) through chemical analysis the nature of contaminants can be determined and their concentrations can be measured in all environmental compartments;

2) chemical processes can be used to remove pollutants from natural waters;

3) chemical technology is crucial to improve the efficiency of waste-water treatment;

4) knowledge, at the cutting edge of the chemical sciences, is instrumental to develop new industrial processes that are environmentally safer and sounder and generate less hazardous waste.

In this perspective this CHEMRAWN conference is exceedingly important. In order to make global progress in total water management it is paramount that chemists meet people from the “water community” that rely on and have to trust our practices. That happens here; the list of participants shows that the main stakeholders in the field, governments, academia, and industry, are present. This is encouraging because after having been closely associated with scientific meetings for a number of decades to foster communication among individual chemists and scientific organizations, IUPAC has experienced that conferences like this one make a difference and has impact.

It is a consistent IUPAC attitude to support activities to advance the worldwide aspects of chemistry and the chemical sciences, and to contribute to the application of chemistry in the service of Mankind. This is clearly reflected in IUPAC’s long-range goals, which are implemented through a number of concrete actions. In the pursuit of these goals IUPAC supports initiatives and projects that objectively address global issues involving the chemical sciences through a project-driven system. Within the framework of this system, any chemist can apply for financial support to carry out scientific projects related to the Union’s core activities. The purpose with the new system is to make IUPAC more responsive to the increasingly interdisciplinary character of chemistry and related sciences, and to ensure faster response, more rapid completion of projects, and broader dissemination of IUPAC’s recommendations. The majority of the projects currently funded are related to validation, evaluation and/or standardization of data, methods, and concepts.

However, projects related to the “Chemistry-for-Water”–theme are also being funded. Several projects are devoted to validation of data and methods of importance in water analysis. A project related to copper analysis and copper contamination of ground water in Africa has also been supported. For the time being the Chemistry and the Environment Division has a project on evaluation of remote sensing techniques for real time control of water quality in surface water bodies. A final example which is highly relevant, is entitled “Solving the problem of arsenic contamination in water in Bangladesh”. As part of the task-group activity a meeting was held in Dhaka earlier this year to interact with the Bangladesh authorities. Collectively these examples show how dynamic the IUPAC project portfolio can work, but also that IUPAC is dedicated to the conference theme. But much more can be done, and I therefore urge you to approach IUPAC if you have ideas that you think might become a suitable IUPAC project (see **http://www.iupac.org**). Use also the opportunities this conference gives to discuss project ideas and start interacting.

Two conference topics significantly influenced by chemists involved in IUPAC–funded activities are “Green chemistry” and “Innovative industrial processes to prevent water pollution”. Within IUPAC this work is carried out under the umbrella of the “Subcommittee on Green Chemistry”, and encompasses a variety of disciplines of fundamental chemistry. So far most projects have been focused on the development of chemistry that simultaneously improves the efficiency of chemical processes and reduces the formation of hazardous waste. In this way IUPAC assists the chemistry-related industry in its contribution to sustainable development, wealth creation, and improvement in the quality of life. It is obvious that significantly more activity is needed in this field, and again I urge you, in particular chemists working in the chemical industry, to get involved in IUPAC if you have ideas that you think might become a suitable IUPAC project.

The next three days here in Paris are mainly dedicated to our professional development, through lectures, poster presentations, workshops, and discussions dealing with recent advances in the chemical sciences with focus on water. On behalf of IUPAC I wish the local organizers a very successful and inspiring meeting, and I wish all of us fruitful days here in Paris.

And when the meeting is over, let this event inspire us to keep up the good work and prove that chemistry and other chemical sciences are of outmost importance for the future, for all of us.

# The role of UNESCO


## András Szöllösi – Nagy

***Deputy Assistant Director General.***
***Director, Division of Water Sciences.***
***Secretary of the International Hydrogical Programme.***


Water is increasingly acknowledged as being THE basis for sustainable development. The importance of this scarce resource was re-emphasised at the recent World Summit on Sustainable Development held in Johannesburg, South Africa. The leaders of the world recognised the role of water in basic survival, for the sustainability of supporting ecosystems and for socio-economic development. They have all shown their concern over dwindling supplies and the deterioration of water quality. One of the key issues identified is the increasing competition between uses and users of water, which has made it more urgent than ever before to act in unison so that water resources can be managed as wisely as possible.

Freshwater issues congregate where questions of health security food security and environmental sustainability meet. It was most appropriate, in fact, that the recent World Summit on Sustainable Development placed water at the centre of global debate: water for sanitation, for energy, for health, for agriculture and for bio-diversity.

UNESCO has been proactive in recognising as a global issue requiring immediate action. The 31st session of the General Conference of UNESCO selected "Water Resources and supporting Ecosystems" as the principal priority of the Natural Sciences sector for the current biennium (2004–2005) and beyond.

UNESCO's International Hydrological Programme has been in the forefront of water science and education for the past three decades and continues to be a strong pillar of our environmental programmes. IHP has contributed in a large extent to the recognition that freshwater issues should be in the centre of interest in the 21st century. The World Water Assessment Programme is an important initiative that brings together all the agencies of the UN system having an interest in freshwater issues with the principal objective of monitoring the state and use of freshwater resources of the world.

UNESCO is very proud to lead this Programme and to host its Secretariat, thereby facilitating the process of integrating the efforts of all the agencies involved. The World Water Development Report (a key product of the World Water Assessment Programme) is a global overview of the status of our water resources, both in terms of quality and quantity, and of how well we manage them. It will be particularly important in the years ahead that the Programme provides capacity-building and other support to many nations in need so that they can undertake water resource assessments within their countries and take the actions needed to alleviate poverty and enhance social and economic development.

The analytical precision at our disposal and the general awareness about the impact of our use of chemicals on the watercourses has increased. The increased knowledge of chemical process and improved technology for treating water allow us to extend the boundaries of water resources: toxic elements can be removed and saline water can be made potable. With the development of these technologies and increasingly common use, they also become more widely available. To relieve the problems of safe water supply in the developing countries, robust, affordable and easy-to-use technologies should be made available. Decreasing quantity of water commonly leads to deterioration of quality as well.

UNESCO's efforts are aimed at education and capacity-building in the field of natural sciences. Teaching chemistry among the other sciences is crucial for building the essential knowledge base for future professionals. UNESCO-IHE Institute for Water Education in Delft, the Netherlands is the leading international graduate school for training water professionals, particularly those from the developing countries. Basic information on pollution and chemistry of the environment should also be conveyed to public at large.

Increased or more concentrated pollution loads result from the intensified urbanisation, which puts pressure on the water resources.

According to the first World Water Development Report published in 2003, water quality appears to have declined worldwide in almost all regions with intensive agriculture and large urban or industrial areas.

Pesticides, nutrients, heavy metals and fuel additives threaten the quality of our drinking water. A policy shift in lower-income countries towards better household water-quality management is needed, coupled with improved individual and family hygiene, as well as the continued expansion of water supply and sanitation coverage, linked to upgraded service levels, that ensure reliable supplies and acceptable water quality. Co-operation across boundaries and within river basins is necessary to apply protective measures to ensure water quality.
The preparation of the Second Edition has already been initiated for publishing in 2006, and in the process the sparcity of global information on water quality is evident, resulting from inadequate monitoring data and discontinuous times series of observations. The methods of measurements and sampling should be standardised at the international level as much as possible. Particularly in the case of transboundary watercourses and aquifers, comparing the results requires consistency and standardisation in methods across political boundaries.

UNESCO's International Hydrological Programme is responding to these challenges through a number of activities that study water quality processes in an integrated manner, through a new Integrated Science initiative which couples surface water-groundwater-ecohydrology of the IHP. A series of expert workshops is being organised, for example one in December on transport and fate of diffuse organic contaminants in catchments with special emphasis on stable isotope applications. Other main fields of activity include: the recently established International Groundwater Resources Assessment Centre (IGRAC) which is developing a Global Groundwater Information System and which is already in the process of collecting data on groundwater quality globally; the joint International Isotopes in Hydrology Programme (JIIHP) together with International Atomic Energy Agency (IAEA) development of tools for better understanding of specific hydrological processes; the Ecohydrology component of the IHP studies water quality from the point of view of ecosystems. Looking into the future, water quality is one of the proposed themes of the next, 7$^{th}$ phase of the IHP (2008–2013), the HELP (Hydrology for the Environment, Life and Policy) network of 66 basins will take water quality as a priority action as part of the management of water resources in real basins.

In closing, let me congratulate you in your efforts as professionals to improve our knowledge on the chemistry of water, and hence to help us in ensuring a sufficient quality of this precious resource. I invite you to support the projects of the International Hydrologic Programme contributing to the quality management and protection of water resources as well as the World Water Assessment Programme. For our part; please be assured that UNESCO is fully committed to ensuring the future of the Programmes and their success. We must raise awareness among the peoples of the world and their leaders that freshwater is a vital but vulnerable resource.

# The World's Water

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## The Impact of Human Activities on Water

Increasingly humans find ways to transform the natural resources of the planet to meet not only our basic life-sustaining needs of food and water, but to improve the quality of our human existence. We continuously seek to improve our physical comfort and to satisfy our intellectual, cultural and social needs. Ultimately we seek security of this way of life.

Until a century ago, with a few local exceptions, our behavior continued to have little impact on the environment. This situation changed drastically in the past century. During that period the world's population more than tripled, placing unprecedented demands on natural resources to provide sustenance and shelter. At the same time, we developed new processes to produce goods and services that are perceived to improve the quality of life. These placed new demands on our limited natural resources, both non-renewable and renewable. The result has been exponentially increasing demand on the services provided by the land, air and water of the planet. Under current trends, these demands will continue to increase to satisfy the life-sustaining needs of the still growing global population and to improve the quality of life not only for them, but also for the large majority of mankind who can only dream of such an existence.

During the 20$^{th}$ century the world population tripled, but water use for human purposes multiplied more than six-fold! The most obvious uses of water for people are drinking, cooking, bathing, cleaning, and – for some – watering family food plots. This domestic water, though crucial, is only a small part of the total – an estimated 350 cubic kilometers in 1995. Worldwide, industry uses about twice the water of households, mostly for cooling in the production of electricity. Far more water is needed to produce food and fiber (cereals, fruits, meat, and cotton) – 2500 cubic kilometers in 1995. The amount of water that must remain in our ecosystems to maintain them obviously varies form place to place. Indications are that we are approaching – and have surpassed in many places – the limits of how much we can divert.

## The world's water resources

A key characteristic of the world's freshwater resources is their uneven distribution in time and space. Until recently water resource management focused almost exclusively on redistributing water to when and where people want it for their use. This is a supply-side (engineering) approach. But there are many signs that water is running out – or at least getting a lot less plentiful in more places as populations and per capita water use grow – and damaging ecosystems from which it is withdrawn. So, we need to look at what water is used for and to manage these competing claims in an integrated framework.

Freshwater can be considered green or blue. Green water – the rainfall that is stored in the soil and then evaporates or is incorporated in plants and organisms – is the main source of water for natural ecosystems and for rain-fed agriculture, which produces 60% of the world's food. *Blue water* – renewable surface water runoff and groundwater recharge – is the main source for human withdrawals and the traditional focus of water resource management.

The blue water available totals about 40,000 cubic kilometres a year. Of this, an estimated 3,800 cubic kilometres, roughly 10%, were withdrawn (diverted or pumped) for human uses in 1995. Of the water withdrawn, about 2,100 cubic kilometres were consumed. The remainder was returned to streams and aquifers, usually with significant reductions in quality.

If we are withdrawing only 10% of renewable water resources, and consuming only 5%, what then is the problem? The numbers may suggest that we are using only a small fraction of the available resources and that we should be able to increase this share fairly easily. Not so, for the following reasons:

- of global water resources, a large fraction is available where human demands are small, such as in the Amazon basin, Canada, and Alaska;

- rainfall and river runoffs occur in large amounts during very short periods, such as during the monsoon periods in Asia, and are not available for human use unless stored in aquifers, reservoirs, or tanks (the traditional system in the Indian subcontinent);

- the withdrawal and consumption figures do not show the much larger share of water resources "used" through degradation in quality – that is, polluted and of lower value for downstream functions;

- water not used by humans generally does not flow to the sea unused. Instead, it is used in myriad ways by aquatic and terrestrial ecosystems – forests, lakes, wetlands, coastal lagoons – and is essential to their well being.

This leads to the following conclusions:

- even though people use only a small fraction of renewable water resources globally, this fraction is much higher – up to 80–90% – in many arid and semiarid river basins where water is scarce;
- in many tropical river basins a large amount of water is available on average over the year. However its unequal temporal distribution means that it is not usable or that massive infrastructure is required to protect people from it and to store it for later use, with considerable social and environmental impacts;
- in many temperate zone river basins, adequate water resources are relatively evenly distributed over the year, but they are used so intensively that surface and groundwater resources become polluted and good-quality water becomes scarce.

## Surface and groundwater quality

Rapidly growing cities, burgeoning industries, and rapidly rising use of chemicals in agriculture and the production and use of energy have undermined the quality of many rivers, lakes, and aquifers. The industrial revolution turned the Thames into a stinking, black health hazard as it ran through London in the late 19th century. Major investments in wastewater treatment and cleaner production have gradually restored its recreational and environmental value.

Most large cities in newly industrialising and developing countries have rivers in the same condition as the Thames in the 19th century. They are a health hazard. They threaten down-stream irrigation areas. And they destroy ecosystems. Because of inadequate management, water quality is deteriorating at an increasing rate throughout a large part of the world. Much is unknown about the impacts of water resource development on ecosystems, and even basic data on water quality are not available on a global scale.

Spreading urban areas occupy increasingly larger percentages of the basins or catchments within which they are situated. As they grow they destroy forests, agricultural land and grasslands. They also create impervious areas that block groundwater recharge and modify the hydraulic behavior of basins, accentuating both floods and water scarcity. Water pollution from human activity makes water unsuitable for many downstream uses. They become increasingly dependent on upstream areas to provide them with freshwater for human use and to maintain the ecosystems within and surrounding them. They therefore have reason to be concerned in turn about upstream land use changes. Malin Falkenmark has coined the term *hydrosolidarity* to refer to this upstream-downstream interdependence and the cooperative integrated management required. Failure to care for the health of watersheds and recharge areas could result in the collapse of the surrounding ecosystem, and certainly will cause increased financial, economic and social costs.

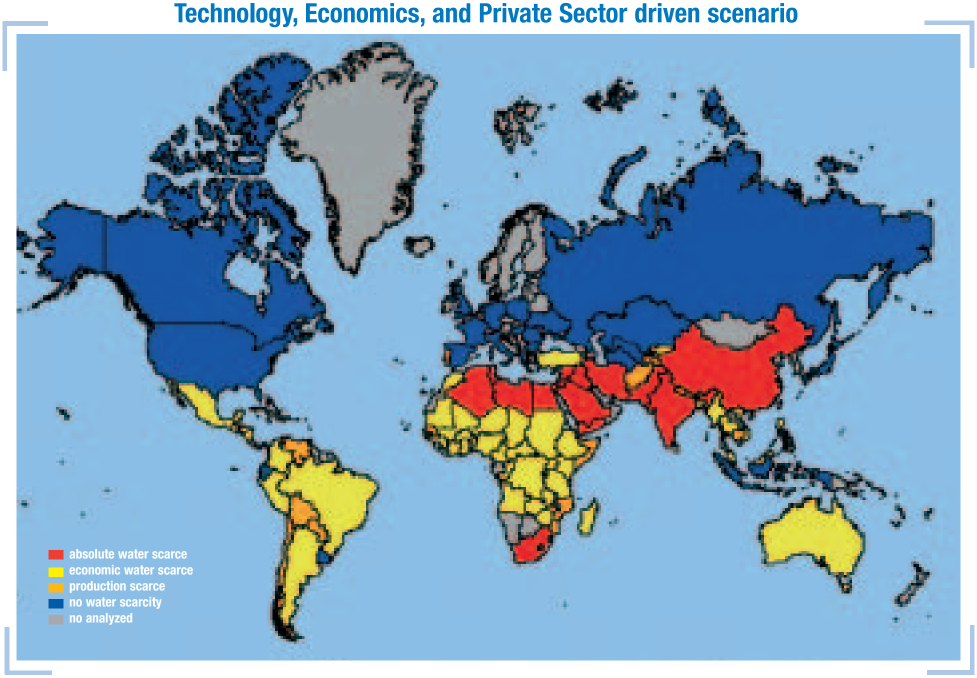
## Water Futures

During the World Water Vision [1] exercise, a scenario development panel of 14 distinguished water experts, modellers and futurists developed three global level water scenarios.

Under the business as usual scenario – a continuation of current policies and extrapolation of trends – about 4 billion people or half the world's population would live in countries with high water stress by 2025. Limited investments in new water infrastructure would reduce irrigation expansion and limit water scarcity to some extent. But food scarcity would be the result. There would be an annual global deficit of 200 million tons of grain, with major deficits in many countries in Africa and the Middle East.

Under the Technology, Economics, and Private Sector driven scenario, private sector initiatives would lead research and development, and globalization would drive economic growth. However, the poorest countries would be left behind. Emphasis on technology and investments would increase primary water supply by 24%. China and India would become water short due to the expansion of irrigation. Several other countries would face economic water scarcity. While there would be a global surplus of 70 million tons of grain, the surplus would be in OECD and high-income developing countries while there would be a growing deficit in low-income countries.

**Technology, Economics, and Private Sector driven scenario**



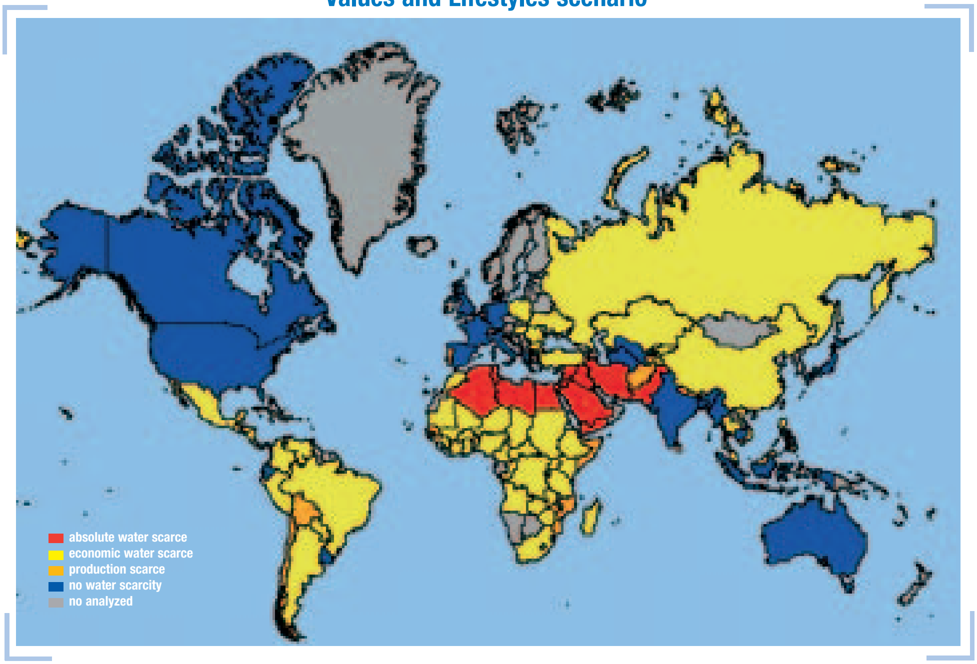
Under the Values and Lifestyles scenario, development would focus on low-income countries that face economic water scarcity. The emphasis would be on sustainable development and on research and development of technologies in the poorest countries to meet their particular needs. Through closing the yield gap, raising productivity in low-income countries, lower population growth, and more concern about the environment, the food deficit in low-income countries would be reduced while water scarcity is limited. However, the food deficit would not be eliminated everywhere. Many of these countries simply don't have sufficient economic growth to provide the funding for the infrastructure they need or the purchasing power to import the food they require. Even forgiving these countries' external debt will not be enough to make their national and regional economies viable in a global economy.

As we worked on the scenarios, I could not help but remember science fiction stories that I have read. Probably some of you are familiar with the plot. The setting is one in which the cast is located on a space platform circling Earth. Those on the platform benefit from the most advanced medical and communications technologies. In perfect health they enjoy the optimum of real and virtual intellectual, cultural and physical entertainment. From time to time they must visit the surface of the planet below to maintain the automated systems that extract the raw materials they need on the platform.

One of their few fears is that during one of their visits they may fall victim to physical attack or an unknown illness from the few millions of savages down there – the poor who have survived on the basically dead surface of the planet. It seemed to me that this would be the ultimate conclusion of a scenario in which the rich can afford to buy the technology they need to avoid any catastrophe, including those they bring upon themselves.

Is this picture so unrealistic? Former President of the United States Jimmy Carter, in accepting the Nobel Peace Prize in 2002 reminded us that "citizens of the 10 wealthiest countries are now 75 times richer than those who live in the 10 poorest ones." And he added "the separation is increasing every year. Not only between nations, but within them[2]."

Values and Lifestyles scenario




## The World's Water Challenges

The World Water Vision report came to the conclusion that the water crisis we face is not one of water shortage, but of governance. Since the report was written several specific challenges have been more clearly identified.

### Access to Water supply and Sanitation

Journalists often misquote the most recent report of the Joint Monitoring committee of UNICEF and WHO to say that 1.2 billion people on the planet lack access to a safe water supply. The report actually says that this many people lack access to an "improved" water supply, and the definition of "access" itself is quite variable. The reality is that probably two billion people lack reasonable access to a safe, reliable water supply, and close to half the world population is without hygienic sanitation facilities.

### Freshwater Ecosystems and Biodiversity vs Food Production

Freshwater and terrestrial ecosystems are integral parts of the water cycle. Their protection requires careful management of the entire ecosystem. For freshwater ecosystems, this implies integrated planning and management of all land and water use activities in the basin, from headwater forests to coastal deltas.

Freshwater biodiversity is high relative to the limited portion of the earth's surface covered by freshwater. Freshwater fish, for example, make up 40% of all fish, and freshwater molluscs make up 25% of all molluscs. Freshwater biodiversity tends to be greatest in tropical regions – with a large number of species in northern South America, central Africa, and Southeast Asia. Worldwide the number of fresh-water species is estimated to be up to 25,000.

Until recently no estimates had been made of how much water is required for the maintenance of Ecosystems. A report produced by the World Conservation Union (IUCN) about a year ago showed that this amount may vary from 20% to 50% of available runoff – thus rivalling the quantities of water required to grow our food using to-days practices.

## Climate Change, including Increasing Climate Variability

Very few people, including scientists, now doubt that we are entering a period of global warming. Most have few doubts that we have brought this change upon ourselves. Extreme meteorological events are increasing in number and in cost. Sea level rise is inexorable and apparently inevitable.

Floods sometimes provide benefits in a natural system, and some ecosystems depend on them. Moreover, some people rely on floods for irrigation and fertilisation. But floods are better known for their devastation of human lives and infrastructure. In the 1990s severe flooding devastated the Mississippi River basin, and thousands of lives were lost to flooding in Bangladesh, China, Guatemala, Honduras, Somalia, South Africa, and most recently in Venezuela. Between 1973 and 1997, an average of 66 million people a year suffered flood damage. This makes flooding the most damaging of all natural disasters (including earthquakes and drought). The average annual number of flood victims jumped from 19 million to 131 million in 1993–97. Economic losses totalling $700 billion from the great floods of the 1990s are 10 times those of the 1960s in real terms. There has been a 37-fold increase in insured losses since the 1960s. Given the trend towards multiple risk insurance cover, which normally includes flood losses, insurance losses will go up even more. Yet the majority without flood insurance will continue to suffer more.

Models used by scientists participating in the process of the Intergovernmental Panel on Climate Change show that rainfall will likely be reduced in areas already suffering from water stress, that agricultural production will be reduced in many parts of the world, and that temperature change and rainfall variability will bring diseases to regions where they have not existed in recent history.

Other human-induced changes to the global water system are now globally significant and are being modified without adequate understanding of how the system works.

## Transboundary Waters

Nearly half the world's population live in international river basins or share aquifers across international boundaries. All water professionals agree that water should be managed as a resource at the basin or aquifer level. This is a difficult enough task when all of the actors are within one country. When more than one country is involved the difficulty of the task is multiplied. Some argue that increasing competition for water will lead to increased dangers of conflict. Until now, experience has shown that water was more often the subject of special efforts at agreement than a source of conflict (3). Nevertheless, as the situation deteriorates collaboration to achieve such agreement will require commitment, time, patience, significant financial resources and often outside third party assistance.

## Water Infrastructure and Services Essential for Development

As work has proceeded on analysing what will be required to achieve the Millennium Development Goals it has become clear that water is a critical component in the achievement of all of the goals. Reducing the under age five child mortality rate will require safe drinking water and sanitation, as will attendance in schools to improve levels of education. It is obvious that water is a critical factor in food production. Water is also often a component in the production of energy and other industrial activities that are required to improve economic well-being. In fact, it is clear that there is a direct correlation between development of water infrastructure and the level of economic activity. Perhaps there is even a minimum level of water infrastructure and services required to raise average incomes in a country above the poverty level.

## Financing of Water Infrastructure and Services

If this is the case, why is it that investment in water-related infrastructure has been declining in recent years? This is a complex question. It involves issues such as water pricing, human right to water, water rights, the roles of the private and public sectors, political stability and transparency of government and private sector transactions. It is above all a political question: how to influence the power structure so that those who make planning and investment decisions recognize need for and value of investments in water?

## Where Do We Go From Here?

The above basic assessment of the state of the world's water and possible future scenarios were discussed and debated at the Second world Water Forum in The Hague in March 2000 and in the subsequent Third Forum in Japan in 2003. The initial five years of the three scenarios were assumed to be the same because of unavoidable lags in decision-making, the inertia of some processes, and the time required for investments to mature. It was anticipated that awareness of the impending water crisis would increase in the first years of the 21st Century. In response, governments would start putting water higher on the agenda. Now, nearly five years after work began on the development of these scenarios, recognition of the problem by the G-8 leaders and others almost ensures that we will not follow the Business-as-Usual scenario. The approaches being proposed would seem to be those that will follow the path of the Technology, Economics, and Private Sector driven scenario. If the analysis of the scenario modellers was correct, this still would leave us a long way from achieving the Millennium Development Goals.

But there are signs that elements of the Values and Lifestyles scenario are beginning to take root. The international research system has recognised the interactions composing a global water system (GWS):

- water in all its forms as part of the *physical hydrologic cycle*;

- the natural and anthropogenic substances that determine biogeochemical state and water quality;

- *living organisms and ecosystems*, as integral users and transformers of the chemistry and water fluxes in the GWS; and,

- *human beings and their institutions*, acting as agents of environmental change, and as entities that experience and respond to both natural and human-derived changes in the GWS.

Another group of researchers are increasing focus of research and development of technologies within the developing countries and focusing on their specific needs.

But most important is the recognition that local communities, urban and rural, are capable of solving their own problems. Thousands of examples of local actions related to water were collected prior to the 3rd World Water Forum in Kyoto. President Carter said in his lecture:

"I have witnessed the capacity of destitute people to persevere under heartbreaking conditions. I have come to admire their judgment and wisdom, their courage and faith, and their awesome accomplishments when given a chance to use their innate abilities."

The challenge of national governments and the international community is to ensure that no community lacks the often minimal opportunities and resources required to use such initiative and innate ability.

There is a world-wide movement underway to act to resolve water management issues. It involves cross-disciplinary partnerships and closer collaboration among international organizations. To provide a better platform for action the World Water Council itself has adopted a structure of five colleges including international and intergovernmental institutions of public nature, governments, parliamentarians and local authorities; commercial entities; civil society; and professional associations and knowledge institutions.

But most importantly, the movement underway is based on learning by doing at the local level, so that those so badly hurt by problems of lack of access to water, food and healthy environments may benefit from ACTION. The 4th World Water Forum in Mexico City in March 2006 has adopted as its theme "Local Actions to Meet a Global challenge". Through participation of all of the stakeholders mentioned earlier in preparations for the Forum, the Mexican government and the Council are intent on raising awareness that solutions are available and actions are being taken by many. We believe this will lead to commitment to multiply such actions throughout the world.

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# Water: Problems of Stable Progress of Civilization in XXI Century

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## The Role of Water in the Life of Humanity

Water is the most abundant substance on the Earth, and is indispensable to life's very existence, and representing an indispensable component for every living creature from the time of birth to death.

The more we learn about our world, the more amazed we are with unique qualities of water. No other substance on the globe can exist simultaneously in all three phase states: liquid, solid, and gas. Liquid water is also characterized by an amazing variety of states : supercooled to –70°C, fresh, brines, hydrates, fog, clouds, water bound in cells of an organism, and pseudo liquefied water, as the boundaries between the gaseous and liquid states disappear while moving from distilled water to salt solutions and gas-hydrated water. Also we must remember that water is a "universal solvent" capable of dissolving many kinds of substances; natural water is never absolutely pure. Ice displays an enormous versatility in its structure and properties. Who can claim to have seen two identical snowflakes?

In any of its phase states water exists as supramolecular self-organizing structures and consists of unique cluster formations, including both liquid crystals and gas- and solid-phase crystal nanosize particles. Membranes in cells of some creatures possess the unique property to extract only fresh water from the salty sea. The salt composition of the Black Sea is equivalent to that of human blood, adding to the unraveled mysteries of the life origin on the Earth.

Drinking water is noted by its taste qualities, though desalinated water has neither taste nor smell. What determines this perception? Water can be fresh, salty, sweet, bitter, sour, harsh, etc. These properties are determined not by salt or sugar but by other substances that react in solution. Recognition of this fact is important when we speak of water quality. Solid salt and sugar are tasteless. Only in water solution do they exhibit their properties! Only substances dissolved in water may form taste perceptions.

And now, the key point! Water as a medium for chemical reactions, biological processes, and various physical phenomena is not just a solvent, but also the main principal participant of reactions and processes.

A discussion of the origin of life, as well as the preservation and development of life and civilization on our planet is not possible without considering the role of water. Water is a critical link in the development of mankind, from the earliest times, people settled along rivers, lakes, seas, and oceans. The standard of living has always been determined to a great extent by the quality of water available. The quality of fresh drinking water, which depends on the purification level of all waste waters was and is important. A developed civilization cannot exist without an excellent sewage system.

The planet's water system is its "immune system" against negative technogenic effects of human activities. The water system is a powerful buffer zone that, until recently, has resisted and compensated for major temperature, concentration, and technogenic fluctuations produced by humans.

The sun's energy is not accumulating primarily through "the planet's green lungs", but through its absorption and transformation by the world's ocean through the physicochemical and biological processes taking place in water, that mostly provide for the photochemical and photocatalytic assimilation of energy.

Before the XX century, human activities on Earth were of much smaller scope than the biological, chemical, and physical natural processes of self-recovery and self-purification occurring in the environment. At the beginning of the XXI century, our planet is undergoing a global transformation of enormous scope.

## Water is a Global Buffer of the Planet; its «Immune System»

Three quarters of the planet's surface is covered with water. All this water is in continuous motion, a great circulation around the Earth of water and the substances dissolved and suspended in it. The seasons are a consequence of global circulation of water. It is the basis for the renewal, purge, and recovery of life on the planet.

Climate is one of the most critical natural phenomena producing a major impact on the living conditions of all species on the planet. Insignificant climate changes can lead to significant ecological consequences and drastic qualitative and quantitative changes of the biota.

A major impact on climate conditions in a particular region is produced by changes in its water resources such as creation of large megapoles, artificial water reservoirs, large-scale soil reclamation projects, construction of canals. The future of our civilization is determined by the level of the comprehension of those changes. It is the stable water resources in the regions that form a buffer zone providing for a mild climate. Sharp continental climate changes with large fluctuations between day and night temperatures and large seasonal fluctuations are caused by the lack of a sufficient quantity of water resources. It is these resources that reduce the negative effect of anthropogenic loads associated with human activity by decontaminating soil and air of harmful substances.

## The Quality of Water Resources of the Planet

For the first time humans are confronted with a completely new, unexpected and not quite comprehended problem of fresh water deficits. The future development of civilization is under a real threat of catastrophic deficit of fresh water, as well as many other raw materials (oil, gas, coal, metals, etc.).

International Forums should be used to determine main priorities for human survival on the planet. Water resources have already become a strategic raw material. I anticipate colossal conflicts between countries for the control of these resources. The price of water tends to become higher than that of oil! There is an urgent need to develop international agreements specifying the rights and rules for use and management of specific water areas of seas, lakes, underground water fields (similar to oil).

Some attempts to elaborate priorities in preservation and functioning of viable natural processes were defined in documents of the UNCED Conference in Rio de Janeiro (June1992) and the World Summit on Sustainable Development in Johannesburg (August 2002).

“Every inhabitant of the planet has a right to pure drinking water” was the formula proclaimed by the UN. Unfortunately, the declaration has not been supported with particular deeds. Resources of “the mineral of life” on the globe are distributed in an extremely non-uniform way. Unwise and inefficient management, pursuit of profits, neglect of ecological problems, and severe competition among monopolies have resulted in the exhaustion of water resources and strong pollution of most of the surface and underground sources of drinking water. In fact, nearly all this polluted water finally makes its way to rivers, seas, and oceans. The four-fold rise of the world population during the XX century (from 1.5 to 6 billion) sharply aggravated the fresh water deficit which was used not only for drinking, but also for industrial needs all resulting in the deterioration of global ecological system.

More than 40 countries of the world in the Middle East, Africa, Indochina, and Australia currently suffer from an absolute water deficit. One-fifth of the population in Europe and America drink polluted water that does not meet international standards. According to official data of the World Health Organization, about 80% of diseases on the globe are related to the consumption of low quality drinking water.

Why do we speak about a great ecological crisis now? Scientific and technical progress has never reached such heights. Humans have made a gigantic intellectual leap just in the XX century. In 1926 the prominent scientist of encyclopedic knowledge, thinker, genius, seer of mankind, Academician V.I. Vernadsky wrote in its treatise “Biosphere”: “The time we are living in is an astonishing period in the history of mankind. This is the time of intensive renovation of our scientific world outlook, profound modification of the world picture, introducing crucial changes into the philosophy of modern life, into concepts of matter and energy, time and space.”

The concept of the biosphere should be understood as a live dynamic system, featuring the properties of interrelated integral education capable of self-improvement and development. The noosphere may be a product of biosphere development, including humans who are in harmony with the environment. But this implies the necessity to preserve principles of harmonic development of intellect and the planet's ecology.

The XXI century has inherited a difficult ecological heritage. The rate of anthropogenic pollution has become so high that we have no right to speak of the biosphere that Academician V.I. Vernadsky was writing about. In fact, we have entered the period of creating a technosphere on the Earth. At present all water resources of the planet fundamentally differ by their quality from original natural water (except water from artesian wells), and have been transformed into a technogenic situation.

Human understanding in general is lagging far behind the pace of scientific and technical progress and consequently people fail to comprehend and assess the consequences of great discoveries by scientists. “People perish because they lack skills to use the forces of nature and lack knowledge of the true world” is written on the Pyramid of Cheops. Mankind, by joint efforts, must make a correct diagnosis of the ailing planet, Earth, and our society and determine the strategy of its future development in harmony with nature. The present-day world is moving to a future described as a “nuclear winter” and “ecological desert.”

## Sources of Drinking Water Supply and their Characteristics

The problem of providing the entire population of the planet with good-quality drinking water is quite urgent. It is the all-important and top-priority for mankind. To solve this problem, first of all, we need to define the strategy of water consumption and water management. Drinking water supply sources having the most reliable protection from anthropogenic impact are artesian wells and underground waters.

Nowadays we know of more than 150 types of different fresh and mineralized drinking and healing waters all over the world. It would be incorrect to work out a single standard for drinking water, as well as food-stuffs. People adapt to the same source of drinking water supply, where their ancestors lived for many years. Moreover, Nature provides for the natural harmonization of the drinking water quality and foodstuffs grown in a given area with the microflora in the digestive tract of people living there.

Usually the concentrations of the substances dissolved in underground waters are much higher than the admissible concentrations for drinking water. The presence of these substances is determined by natural geological factors. On the other hand, we must remember that high-quality and healthy water will contain a wide spectrum of active substances, as well as natural organic compounds. It is these components dissolved in the water that create its taste, smell, clarity, and physiological properties.

In the first half of the XX century people used the ground water from springs and wells for drinking. The high quality of this water was determined by the fact that it abounded with biological life from lower to higher organisms, including fish and frogs. This water corresponded to the legends about "live water" in contrast to "dead water", that is, tap water treated with chlorine, or to distilled water.

The second source of drinking water supply is fresh surface water. However, the development of the industrial sector, agricultural complexes, methods of mass transport, utilities, communal infrastructures; the growth of cities and settlements all result in the mass pollution of surface water. The composition of waste water is more and more complicated because of the synthesis of new chemicals, often having toxic, carcinogenic or mutagenic properties, resistant to biological removal. In practice, the self-purification of water reservoirs by the natural process is virtually eliminated.

The third source of drinking water supply can be seas and oceans, where the average salinity is about 30 g/l. Three main desalination technologies are viable: distillation, membrane technology, and electrochemical methods. The desalinated water is not drinking water. It is necessary to make adjustments to modify the salt composition. Such waters ought to be "conditioned". This is hardly the best option, but it is important in those cases where there is no alternative source of fresh water.

Let's quote the Great Russian Tsar, Peter the First. In 1717, when mineral water was found for the first time in the town of Piatigorsk in the Caucasus, he wrote, "Since the God in his mercy had kindly showed us the healing water, for this purpose... we have ordered to write the doctor rules specifying which waters to drink, in what order and how to combine their use with food in order to prevent possible harm to health due to lack of knowledge… and prevent spoiling of the water."

## Possible Solutions to the Supply Problems of Drinking Water

The first countries that developed state standards for the drinking water quality were the USA and the USSR. With due regard, primarily, for a high level of bacterial pollution of surface water, the international strategy of drinking water disinfection with chlorine was adopted. In my view, it was the worst mistake of mankind since water always contained organic compounds. Chlorination of water inevitably results in formation of highly toxic, mutagenic, and carcinogenic compounds that were not present in intrinsic natural environment. People began to drink chlorinated water – technogenic water is dangerous to human health! At the beginning of the XX century the pollution level did not reach a critical level either by chemical or by bacterial components. Therefore, small dosages of chlorine did not result in formation of significant concentrations of dangerous compounds. However, rapid growth of industry, agriculture, creation of megapoles, and rise of the population resulted, as was mentioned above, in a catastrophic level of bacterial and chemical pollutions of water sources used for drinking water. This necessitated the use of large dosages of chlorine in the drinking water. With due regard for this dangerous factor, new more sophisticated water treatment technologies started to be developed. They included preliminary filtration of suspended particles, primary chlorination, chemical water treatment by coagulation with the use of salts of aluminum, iron, and also the use of flocculants of organic and inorganic origin, and subsequent filtration using sand and carbon filters. To inhibit the growth of microorganisms in pipelines, the water was again treated with an appropriate chlorine concentration so that the content of residual active chlorine in the tap water of every end user was in the range 0.3 – 0.5 mg/l.

A number of countries used chlorine dioxide instead of chlorine, because the former has a higher oxidation potential. This technology has both advantages and disadvantages. The advantages include the fact that the decontamination process proceeds more effectively. However, chlorine dioxide may produce a wider series of chlororganic compounds.

A negative side of these technologies is the use of aluminum-containing coagulants. On the one hand, this necessary stage of water treatment results in deep purification of the initial water from many kinds of pollutions, on the other hand, it introduces new very dangerous pollution of drinking water with residual compounds of aluminum. That the extreme toxicity of aluminum ions present in drinking water adversely affects human health is a well known fact. The International Health Organization continues to introduce more strict limitations on aluminum in drinking water.

Tap water is not drinking water, but technogenic water. It contains highly toxic chlororganic compounds and also aluminum ions that are a product of the water treatment technology. These problems stimulate the search for alternative water treatment technologies. First of all, we should pay attention to natural ecologically safe oxidants.

At the beginning of the last century Russian scientists were first to propose the use of ozone instead of chlorine. The first ozonizer for industrial production was designed in the M.V. Lomonosov Moscow State University, and the first ozonization water treatment plant was built in the city of Saint Petersburg before the First World War. Hydroxyl radicals can oxidize any organic compound to carbon dioxide and water. They are formed as a result of interaction of ozone or hydrogen peroxide and water.The active species formed in those reactions can be placed in the following order $HO^{\bullet} > O_2^{-\bullet} > O_3^{-\bullet} > O^{-\bullet} > HO_2^{\bullet}$.

Ozone has a significantly high oxidation potential. Its rate of interaction with all classes of organic compounds is much higher. It ensures a perfect discoloration of water, removes undesirable smells and tastes, removes iron and manganese, inhibits growth of water plants, etc. Nevertheless, ozone application in water treatment is only possible in combination with other physico-chemical methods. These processes are significantly accelerated by catalysts (both homogeneous and heterogeneous) and ultraviolet irradiation. On that basis we developed new water treatment technologies to produce high-quality drinking water from practically any source of drinking water supply irrespective of its pollution level. We are unaware of more effective and ecologically clean methods of water treatment.

## Bottled Water – a Problem of Disinfection and Conservation

The technology of bottled water has become popular. Few worried about the scientific and technical problems associated with the need to preserve quality of such waters. The water subjected to bottling must be ideal in terms of its chemical, biological, and organoleptic characteristics. It should maintain its quality when bottled.

The most common conserving agent used is carbon dioxide, which dissolves in water forming carbonic acid. The taste of such acidic water is familiar to anyone. This water is intended for quenching thirst in emergency situations rather than for systematic use.

Another effective reagent suitable for conserving water is silver ions. The technology of keeping water in silver vessels has been known from ancient times. We can drink such water without fear, because the concentration of silver ions in such water is negligible, however the disinfection process is rather long. But the excessive concentration of silver is dangerous and in the course of time the silver ions are well absorbed by the vessel walls and rather quickly lose their disinfection properties.

In recent years membrane technologies have gained a wide recognition in many countries. Such technologies are used for afterpurification of water before its bottling, by removing from the water virtually all organic and inorganic compounds, i.e., biogenic elements without which the normal development of organism is not possible. This technology gives distilled water, which, indeed, can be stored for very long periods of time. However, it is not drinking water; this is technical water, not suitable for drinking water and is even dangerous for human health.

Dishonest companies may add conservatives to drinking water, they are substances, whose functional properties are similar to the action of antibiotics, inhibiting and killing microorganisms. Such substances pose a major threat to human health.

A very serious problem in the process of water bottling is the chemical nature of the containers used. A number of investigations indicate that polymer containers might be toxic. The safest containers include glass vessels, enamelware, and ceramic ware.

## Biotesting

**Biotesting** involves the target use of test-organisms and methods to determine the toxic level of waste water, of individual pollutants in natural water reservoirs. Biotesting represents a methodical procedure based on estimating the effect of medium factor on an organism, an organism's individual function, or a system of organisms. The prospects and efficiency of this approach are well established.

In the last decades, estimation of the quality of natural waters by biotest methods has become particularly relevant because of the rapid rise in the number of potentially dangerous chemical compounds: 24 million chemical substances were known by the year 2000; about 60,000 substances are used in our everyday life.

The use of chemical methods to estimate the quality of waters does not always provide a useful result because of the lack of information about the biological components of substances under investigation. Thus, biotesting may indicate the toxicity of water even if chemical analysis does not include harmful impurities, it does not necessarily indicate a toxicity of water by biological criteria. In addition, hydro-chemical investigations do not take into account inter-actions of polluting substances, or their transformation in both the medium and the organism. Biodestruction methods provide an objective but complex estimation of the effects produced by substances on an organism and its vital processes. In many cases, biomonitoring in technical terms is simpler and less expensive, free from any need in special instrumentation support; they are limited in time and more accurate and sensitive in comparison with chemical analysis.

In our Institute, various types of toxicity are studied on both the organism and the cellular levels. At each of these levels we use approaches that enable us to obtain a detailed estimate of toxic action. In particular, at the level of the organism we analyze reactions of representative types of different systematic groups at trophic levels (general and acute toxicity); and at the cellular level, i.e., the structural and functional changes of genome (geno- and cytotoxicity).

A set of cellular criteria includes a share of cells with micronuclei (to register structural disorders in the hereditary mechanism of a cell) and quantitative characteristics of nucleoluses (to reflect functional changes). In addition, because of technical opportunities provided by the methods applied we determined the mitotic index (changes in a share of dividing cells as cytotoxicity indicator), and the number of cells with double nuclei and nuclei disorders (genotoxicity indicators).

These approaches are critical for practical implementation. Biomonitoring of natural and drinking waters is an urgent task at the current stage of social evolution, which is corroborated by studies conducted by research teams in many different countries (Sweden, Spain, Italy, China, Japan, etc.).

However, many other urgent problems, both general and partial, in this field still need to be addressed. To the latter we can refer "blooming" of water, or vigorous growth of blue-green algae; the genotoxicity of products, the vital activity of which requires a detailed study; the search for sensitive and simple biomarkers for estimating different types of toxicity; and problems of biological regeneration of polluted water, soils, sediments, etc.

Further studies are needed on issues of the genotoxicity, the cytotoxicity, and the mutagenicity of substances and preparations used at various stages of water treatment. Primary orientation on chemical approaches in determining drinking water quality is not fully justified from the viewpoint of man as the main consumer of drinking water. Chemical methods cannot detect the entire set of elements present in an aqueous solution and estimate their interaction and transformation in the medium and the organism. Biotesting provides an objective characteristic of the biological component of water quality. Biomonitoring of drinking water, including various stages of water treatment, purification, and disinfection should be performed using toxicological (acute and chronic toxicity), geno- and cytotoxic, and also mutagenic parameters. In general, biological criteria for estimating quality of drinking water have to be used on a par with approved chemical standards.

## The Biosphere and Civilization – A Compatibility Problem

Among a variety of aspects of protecting the water basin from technogenic pollutions, provision of effective decontamination from various types of pollutions, including radioactive ones, is most important. The implementation of this task becomes more and more difficult because of the general deterioration of the ecological situation, and is accompanied by the emergence in natural waters of ever growing amounts of different toxicants of organic and inorganic nature. This situation with the necessity to develop and utilize increasingly more complex and sophisticated technologies for achieving the purification levels specified by existing standards, raises a question about these standards. We can observe growing limitations of their applicability, despite an adequate theoretical and practical substantiation at the time of their adoption. The possible undesirable effects of various toxicants on a live organism under the conditions of their combined action has been insufficiently studied. One of the most dangerous actions for human health is the combined action of pollutants of various kinds in conjunction with radionuclides.

The biosphere in its classical state ceased to exist. We are the eyewitnesses of the biosphere apocalypse, which began in the middle of the XX century. By transforming the environment, society ignores the fact that the creation of a technological environment violates the basic laws of the biosphere, the laws of the universe. We now live in the transitional period of coexistence of two worlds, the biosphere and the noosphere. There is no return path to the biosphere.

Though man has designed a new artificial habitat, the technosphere, he has preserved in his being all biological processes from the biosphere, the ties with which are critically important for humanity's survival.

Man as a creature of the biosphere must find new ways for his survival and development. The gene pool of the biosphere is involved in a vigorous evolutionary process generating ecological changes on a global scale. We can observe the general process of the extinction of existing species and emergence of new ones. The evolution of infections features a particularly high intensity as indicated by the adaptation of pathogenic microflora to antibiotics. Nature creates complex genomes in millions of years, while modern laboratories perform similar changes in one year.

The impact of anthropogenic pressures has led to a disastrous process of genome degradation, the initial symptoms of which were observed in the studies of the water quality by the biotest method using cell biomarkers.

# Chemistry for Water


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Research in chemistry has always contributed to improve our understanding of the natural environment (water, air, soil), but it has also led to the development of an industry generating the pollution of this environment, notably water, thereby conveying an image of "polluter" which it still retains today.

Admittedly, during its development in the years that followed the second world war, the chemical industry was a major pollutor, either directly through emissions from factories or indirectly through the products it invented to meet demand: nitrates and phosphates in water, "organic micropollutants" (pesticides, hydrocarbons, detergents, pharmaceuticals, etc.). Fresh water and the coastal environment have in fact been threatened in various ways for a number of years, and every study on sustainable development anticipates major shortages of quality water in the coming decades, which tragically threaten many countries.

**Chemistry has to take into account the expectations of citizens in terms of protection of water and remediation of contaminated resources.** It quickly has to make an increasing contribution to the hoped-for return to a good ecological quality of the aquatic environment. Combined with other vital scientific disciplines (geosciences, life sciences, engineering sciences), **chemistry is by nature the basic discipline for research into the protection of water resources,** not only at eco-design level (green chemistry), but also through its essential contribution to the progress of technologies for the treatment and purification of (end-of-pipe) polluting emissions and the improvement of our understanding of the aquatic environment, in terms of monitoring and understanding the various phenomena.

## Effective analytical chemistry in aquatic environment

Metrology based on successful, i.e. reliable, accurate and sensitive, analytical chemistry, remains an indispensable tool when diagnosis and/or forecast are necessary if not essential:

- to appraise the quality of groundwater, surface water and sea water as well as their evolution resulting from natural activities and from the pressures of their use by mankind;

- to monitor the quality of water intended for human consumption and of waste water;

- to diagnose the operation of processes (traditional and under development) for treating water and purifying (municipal and industrial) effluents in the broad sense of the term.

Organic and mineral micropollution

"Micropollutants" refer to any form of specific (mineral or organic) pollutant found in trace quantities (ppb scale) or even ultra-trace quantities (ppt scale) in water. In this field, analytical chemistry must obviously be extremely sensitive. Considerable progress has been made in the field of water in recent decades. In the 60s and 70s, pollutants were generally analysed by absorptiometry (after formation of coloured compounds) or by UV or IR spectroscopy. Today, traces of pesticides (to the nearest hundredth of a µg/L) and of heavy metals (to the nearest ng/L) are routinely analysed in many laboratories, together with dioxins which can commonly be detected at femtogram level.

However, regulations on public health (water intended for human consumption) or the quality of water resources (Water Framework Directive) bear such pressure on analytical chemistry that new demands constantly arise to analyse "emerging" pollutants that are mainly organic and with an increasingly complex structure. The most revealing example at present is that of endocrine disruptors (natural and synthetic hormones) and pharmaceutical products (antibiotics, analgesic, anti-inflammatory, anti-hypertensive drugs) present in natural water on the same mass concentration scale as pesticides.

**Chemists must be ready to face up to this challenge of being able to detect and quantify increasingly smaller traces of very many new compounds in water, as well as their metabolites and reaction products.** Additionally, tools have to become miniaturised, while providing answers in real time. This field of ultra-traces in water is a particular area in which analytical chemistry has much progress to make still, mainly in techniques, and/or the coupling of methods (in particular in the field of vibration spectroscopy, electrochemistry, etc.). Separative microsystems, coupled with a sensitive and selective detection method, based on the use of new technologies, should make a considerable contribution to the development of analytical chemistry in the field of water. In this regard, the design of microsensors adapted to the analysis of dilute media in the presence of a complex matrix remains a challenge.

Organic matter

One area in which analytical chemistry in aqueous media is truly lagging behind is that of organic "macropollution". Organic matter present in water in quantities of several mg/L (ppm), be it of natural or anthropic origin, is not necessarily toxic; this is probably why chemists have tended to overlook the issue somewhat. And yet this organic matter plays a major role in the natural evolutionary mechanisms of water resources (in particular surface water). Furthermore, it often constitutes a precursor for the formation of toxic compounds during water purification (e.g. by chlorination), it boosts the development of biofilm, a potential seat of pathogenic microorganisms (e.g. in cooling towers), and can really hinder the development of some purification processes (e.g. using membranes).

Organic matter in water resources is mainly of natural origin (decay of aquatic organisms and lixiviation of soil followed by humification process), but also of anthropic origin (effluents from municipal water treatment plants or industrial water treatment plants, e.g. from food processing, paper mills, chemical plants, etc.). We have known how to analyse it globally for a very long time, through COD, KMnO4 demand, BOD5 and TOC, which are the most common global organic pollution criteria used by water agencies and regulatory bodies. However, chemists still have no precise answer to the recurring question on the exact chemical structures of organic matter present in specific water, or they only have a partial answer to the question of the content of humic substances, proteins, carbohydrates and amino sugars in specific water.

Not so long ago, this aspect of analytical chemistry was still ignored by researchers. Today they are conscious of the importance of this aquatic organic matter. **The understanding and quantification of the various classes of natural and anthropic organic matter in water are now part of the most pressing challenges of the physico-chemistry of water. CHEMRAWN XV has highlighted ways of international cooperation to fill a recognised knowledge gap.**

## Physico-chemistry of water (or for water) indispensable for a better understanding of the aquatic environment and its evolution

The knowledge of the natural aquatic environment has for a long time been the preserve of researchers in the field of Sciences of the Universe, the probable reason for this being the need to understand the hydrodynamics of aquifers and surface water. However, **the dynamics of pollutants in the natural environment is necessarily reactive, and water physico-chemists (like microbiologists and biologists in general) must make a much more significant contribution than is clearly the case at present.**

The reactions of dissipation / transformation of mineral or organic pollutants in water are like any chemical reactions controlled by the reaction speed, and often generate reaction products, called in this case "metabolites" by adsorption-desorption on colloids and suspended particles (in the body of water or in the sediments), transformation through oxidation-reduction reactions, photolysis (for surface water), biodegradation through microorganisms or assimilation by superior organisms.

There are (past and current) studies on the physico-chemistry of water in this field, but these are sometimes too remote from natural conditions, as autochtonous microorganisms and natural organic matter are not taken into account.

Hence a policy to develop "experimental sites", "working zones", "environmental research observatories" has to be pursued and developed, notably in the field of water quality and the protection thereof.

The intraparticular sorption-desorption/diffusion mechanisms which control the transport and transformation of pollutants in aquatic media and the build-up of microorganisms on surfaces represent one of the obstacles to knowledge in this domain that will have to be overcome in the next few years. The initiative necessarily requires the characterization of reaction heterogeneities of the surfaces of materials (minerals, biological surfaces, etc.) and of the genuine sites controlling the trapping of pollutants by the surfaces, an initiative to which chemistry has to make a very effective contribution.

**Analytical chemists, geochemists, specialists in coordination chemistry, in photolysis, and theoretical chemists are all concerned by these on-site studies, an interdisciplinary approach being essential in this area.**

## Chemistry to protect water

The development of metrology entails increasingly stringent rules for more effective treatment technologies.

In the 60s and 70s for example, a gas chromatography electron capture detector was developed that helped identify traces of chloroform in drinking water (the result of the reaction of chlorine or hypochlorous acid with natural organic matter), or the presence of organo-chlorinated pesticides in groundwater tables. This led the European Union (and later its member States) to issue new regulations on water intended for human consumption, and as a result to undertake (mainly industrial) research into water finishing processes by ozonation and/or adsorption using activated carbon. Meanwhile, an alarming increase in nitrate concentration in natural waters led researchers to develop denitratation physico-chemical processes and denitrification biological processes. It was then that private R&D centres were set up in France, notably CIRSEE for Compagnie Lyonnaise des Eaux (now SUEZ) and ANJOU RECHERCHE for Compagnie Générale des Eaux (now VEOLIA).

Today, the perception of the concept of water chemistry is improving all the time, and, accordingly, is prompting calls for European and national projects (e.g. RITEAU and PRECODD-ANR) for innovative works recognised the world over. Concerning the elimination or tarnsformation of polluants, often coupled with disinfection or elimination of pathogenic microorganisms even with a toxicological or ecotoxicological approach, one can distinguish non-destructive processes (complexation, adsorption and membrane technologies) and destructive processes (chemical oxidation, photochemistry, aerobic or anaerobic biologicial processes).

**Whatever type of process is involved, water chemists are indispensable as they are the only chemists able to provide the necessary elements for an understanding of the mechanisms involved as well as the design of equipment.** French chemists are involved in oxidation processes (electrophilic oxidants, hydroxyl radicals, photolysis, catalytic oxidation), and are among the most productive in this field. Chemical research provides indispensable data such as reaction rate constants and the nature (and persistance) of reaction products. Membrane separation technologies will probably represent the core of every water treatment and purification plant in the coming decades. The problem of clogging (or fouling) by organic and mineral matter is currently the subject of very promising work. This requires us to improve our knowledge of natural and man-induced organic matter.

Another particularly important area concerns the knowledge of water/materials exchanges (diffusion, solubilisation, etc., speed) which condition the technical choices of materials in contact with water (food suitability, potential of biofilm formation).

**Finally, a need arises for alternative and innovative low-cost technologies, using renewable energies where possible** (i.e. photocatalysis producing hydroxyl radicals and photosensitisation producing singulet oxygen). Developing countries represent a huge market, which is the responsibility of us all to supply. This is a major challenge for water treatment and purification chemists as these technologies, which the Anglo-Saxons call robust, require top research to achieve the objectives of cost-effectiveness.

## Conclusion and Recommendations

Chemistry, and each of its fields, have to join forces with many other disciplines to take into account the expectations of citizens in terms of water protection, and, in response, to provide effective global solutions. What is at stake is the future of water and a return to the “good quality” (chemical and ecological) of the aquatic environment.

To take up these challenges, analytical chemistry is at the “core of the profession”. It must continue to develop techniques capable of detecting and quantifying traces of very many new compounds present in water as well as their metabolites, and with the utmost reliability, automaticity and speed of response. In association with physico-chemists, it must allow a new instrumental development. It must also contribute to a better definition of the speciation of significant compounds to allow in particular a better approach to treatment or risk assessment technologies. Additionally, it must necessarily improve our knowledge of the various classes of natural and anthropic organic matter in water. This latter aspect of analytical chemistry is one of the major issues of the physico-chemistry of water.

This knowledge developed by chemists should allow them to achieve a closer integration than is currenty the case within inter-disciplinary studies conducted on aquatic media as part of “working zones” and “environmental research observatories”. The mechanisms which control the build-up, transport and transformation of pollutants in aquatic media represent one of the obstacles to knowledge in this domain which will need overcoming in the next few years. The initiative necessarily implies a better understanding of natural and anthropogenic organic matter, as well as a characterisation of reaction heterogeneities of the surfaces of materials (minerals, biological surfaces, etc.).

Water chemistry has to develop as a central science in the study of alternative and innovative technologies for water treatment and effluent purification. Its contribution to the understanding of reaction mechanisms will help optimise the processes involved, and better control the “water/materials” interactions which govern the quality of the water supplied to users.

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# Water, Chemistry and Public Health

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The period of boom and huge development of chemistry in the wake of the second world war has led to exceptional consequences in terms of economic development, hygiene, longer life expectancy, creativity and innovation. Unfortunately, since its origin, the planet has never been so heavily exposed to a multitude of new molecules that are biodegradable or toxic to a greater or lesser degree, and this is leading to undesirable impacts in terms of pollution and health risks. In parallel, the exceptional demography of the human race within our biosphere represents a new situation which the global environment is finding increasingly difficult to accommodate. The hydrosphere comprises a finite amount of fresh water available to meet the growing needs of the world's population, and upsets in our climate lead us to expect new problems.

## Some basic reminders

Life comes from water and water is indispensable to life. Water thereby constitutes one of the most important chemical elements, and any impairment of its quality inevitably not only impacts on the relevant ecosystems, but, in man, also increases morbidity, if not mortality, and therefore a drop in life expectancy. The food chain is also responsible for transferring, sometimes through bioaccumulation, pollutants from the aquatic environment to major predators which include the human species.

Water is an excellent solvent capable of dissolving a very large number of molecules in concentrations that are sometimes minute but sufficient to trigger biological or biochemical effects on organisms. The physico-chemical composition of water is extremely diversified depending on the geographic location, the depth of the sampling and the period; this precludes any generalisation of the phenomena, and allows us to observe pollutions which can be highly punctual or extremely diffuse over very large areas. Each water supply site or each system supplying water for human consumption has its own characteristics of water quality in terms of organic and mineral components, so that observations should not be generalised. Additionally, the characteristics of the resource are linked to the various influences acting upstream across the whole catchment area.

## Water and public health

According to the World Health Organisation, health is “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”.
In any case, the general increase in the pollution of resources leads to a general cost to communities, in particular as regards mortality and morbidity, as well as in terms of the implementation of regulations, the control and monitoring of quality, and the treatment of accidental pollution and persistent contamination through the purification of wastewater and the production of drinking water.

The three basic causes responsible for the quite significant investments in the field of technologies and water management are:

- the preservation of the quality of the environment;
- the protection and maintenance of plant and equipment used for supplying water to populations;
- public health.

Public health truly represents the major cause, while the other two are closely linked since the quality of resources constitutes a key component of the quality of drinking water, and the state of repair and reliability of equipment also present major risks of impact on drinking water.
Over 2 million people, most of them children, die every year of diarrhoeal disease linked to inadequate water supply and hygiene, while a further million die of malaria. China alone has 30 million cases of chronic fluorosis and 1.5 million hepatitis A. Improved water quality, sanitation and personal hygiene significantly reduce the spread of water-related diseases. Better water resources planning and management have a similar beneficial impact on the incidence of malaria, schistosomiasis and other vector-borne diseases.

Preventing disease helps alleviate poverty. The 1.1 billion people without access to even improved water sources and the 2.4 billion without basic sanitation include the poorest people in the world – and some of the unhealthiest. A first step towards alleviating poverty is to acknowledge the many components, as well as acknowledge the major contribution of water and sanitation to poverty alleviation and to development.

Safe water, adequate sanitation and hygiene education are basic human rights that protect health, enhance a sense of well-being, and improve economic and social productivity.
Water-related leisure activities, such as sports and spas, contribute to healthy lifestyles and to longevity.

It is not enough to study problems related to water intended for consumption as water is present in many situations in relation with our health:

- in agriculture, for irrigation and stockbreeding, and in the food production and processing industry for the manufacture or the composition of food products;
- in healthcare establishments, e.g. hospitals, thermal cure centres and treatment baths;
- in very many industrial sectors, transport, and energy production;
- in water leisure pursuits.

The main sanitary problems linked to water are linked to hazards of a natural or an anthropic nature. Contamination can come from the resource or from a release of components from materials in contact with water or generated in the form of byproducts from chemical processes used for decontamination.
The hazards presenting health risks are mineral (arsenic, lead, chromium, radon, mercury, fluorides, nitrates, etc.), organic (pesticides, plasticisers, detergents, disinfection byproducts, solvents, hydrocarbons, etc.) or microbiological (bacteria, viruses, protozoans, parasites, biofilms, etc.).

## Water and chemistry

Water is a very powerful solvent; it picks up mineral compounds in variable proportions based on the conditions of its movements on the planet, but it is also capable of dissolving a huge variety of organic molecules, even those globally referred to "water insoluble" in reference data. The low concentrations of the order of the nanogram or microgram found per litre are often enough to make water toxic or unfit for consumption.

To carry out disinfection, cleaning or cooling operations, our modern world needs quality water in sufficient quantity. Clean water needs transporting and wastewater needs collecting through pipes across thousands of kilometers, and the nature of the materials of these pipes must not cause corrosion or the build-up of bacteria at an unacceptable level. Wastewater collects all our waste and the residues of everything that industry produces, e.g. chemical compounds used in agriculture, in industry and in our homes: medicines, fertilisers, hydrocarbons, detergents, biocides, solvents, pesticides, paints, etc.

Fortunately the ecosystem succeeds in mineralising part of these pollutants, but the water which is the final environmental compartment no longer manages to eliminate everything, or cope with the increase in waste linked to the growing demography of the human species and its needs in energy and food.

The chemical composition of water is therefore a result of its travels within its natural cycle. Chemistry and biochemistry need water, but the interactions are reflected in the residues which the water will be carrying.

## Problems related to resources

The major problem lies in the management of quantities. Of course, there is a real difficulty in managing major influx caused by swell and flooding, but beyond this, there are also the major issues related to situations of water stress and shortage in the world.

To try and solve these problems, man instals storage dams, develops seawater desalination plants, transports huge volumes over very long distances, makes optimum use of underground reserves which are sometimes very difficult to replenish, and develops technologies and processes for reusing wastewater.

All these actions have a direct or indirect impact on human health.

From a microbiological angle, an increasing build-up of cyanobacteria can be observed in stretches of water especially in the eutrophication phase. Some of these cyanobacteria produce hepatotoxins and neurotoxins which cause animal death as well as accidental death in man. The management of quantities entails the development of dams, and the addition of phosphorus and nitrogen contributes to these toxic risk phenomena. It is therefore necessary to control eutrophication situations by reducing the addition of nitrogen and phosphorus, and by promoting oxygenation and developing innovations in terms of preventing the proliferation of cyanobacteria without resorting to biocides which could cause cell lysis and the spread of toxins in the water. The control of iron and manganese in sediments is also a major issue.

Resources are contaminated by bacteria, viruses and protozoans, some of which are pathogenic or opportunistic, and attention should also be paid to what becomes of bacteria resistant to antibiotics and their risk of transmission.

As regards global phenomena and physico-chemical variations, resources are deeply disrupted by the presence of punctual and diffuse discharges which very often contain hydrocarbons, solvents, persistent organic pollutants (POPs), heavy metals, residues from medicines, and plasticisers.

This pollution requires major investments to develop and improve the collection and treatment of wastewater with an increasingly focused objective of reducing traces of undesirable micropollutants. Purification systems which have been optimised for the reduction of global parameters like COD, BOD and suspended matter will need to eliminate nano- or micrograms of molecules per litre, which will require them to shift towards the same kind of technologies as those used in drinking water plants. However, this assumes that the residues and wastes from these treatments can be eliminated at an acceptable cost.

As regards effects that are ecotoxicological and potentially a health hazard to populations exposed to them, the most complex issue consists in evaluating the biological risks of these complex blends of trace compounds. It has in fact been shown that endocrine disruptive effects are the cause of reproductive damage, hormonally associated cancers, and malformations of genital organs in exposed fauna. The analysis of the risk is not yet possible for man, but there is major concern about these many substances in every developed country (alkyl phenols, phthalates, bisphenol A, PCBs, oestrogens, lead, etc.).

These issues are therefore extremely delicate to tackle as they have to take into account health and environmental constraints as well as the levels of risk acceptability both in terms of public health and economic development.

It is therefore obvious that the best sustainable policy consists in reducing where possible emissions from watersheds in order to restore a sound chemical and ecological standard to surface water and groundwater, as required by the European water directive.

It is absolutely necessary for evaluations of the environmental impact to be carried out on molecules available on the market, and the European programme REACH, should it become reality, is a positive element which will help consolidate existing databases and the inclusion of environmental risks from the design stage of new products. Motivations for the development of green chemistry will be major points for the protection of water resources, but consumers must also be able to have simple and inexpensive means to ensure they do not discharge many undesirable molecules into drains, and so dispel the highly negative concept of the “all sewage solution”.

Companies will have to contribute to the future of a product’s entire life, including after its marketing and use, by assisting with its collection, recycling and waste destruction.

## Treatments

Chemistry and biology are the key elements of purification and potabilisation. Requirements in terms of the quality of safe water and the development of the reuse of wastewater are the driving force required to ensure that purification technologies match up with potabilisation technologies, at least in those countries which can afford it.

Chemistry must play a role to help reduce treatment costs and improve technologies, in particular regarding the elimination of organic micropollutants, and to offer reliable and inexpensive processes to emerging countries.

Further progress must be made in improving the reliability of treatment activities which have to fulfil the latest quality requirements at all times. Disinfection processes require improvements in order to continue to ensure the microbiological safety of the water produced but without the formation of byproducts with genotoxic effects or undesirable flavours.

Chlorine and its derivatives account for one of the biggest successes in terms of relation between water quality and public health. Mankind owes immense progress to chlorine in the average life expectancy, and if every home on our planet were to have access to properly disinfected water, the unacceptable number of deaths related to diarrhoea, in particular in children, would be greatly reduced.

This is however not a reason for avoiding dealing with the byproducts generated by the action of halogens on certain, often natural, organic materials. The flavours of chlorine are deemed unacceptable by many consumers around the world, who, as a result, drink bottled water, or use wells in their garden whose microbiological quality often leaves something to be desired. We then have a paradoxical situation whereby individuals increase risks to their health by refusing to consume safe water because of odorous byproducts which, in their mind, put chlorinated water on a par with water contaminated by chemicals.

Chemistry therefore must help the world community to have access to basic chlorination, as well as promote innovation so that chlorination is more readily accepted and without drawbacks.

Cancer risks related to chlorinated and brominated byproducts, even if they have been shown to be significant to the bladder in high-chlorination areas, must not detract from the major risks related to microbiology, and an intelligent, appropriate and regulated approach to chlorination must be adopted in sectors in which dissolved organic matter has been reduced as much as possible beforehand. The IARC has rated dichloroacetic acid as *"possibly carcinogenic to humans, sufficient evidence of* its carcinogenicity in experimental animals*"* and MX as *"limited evidence* for its carcinogenicity in experimental animals, *possibly carcinogenic to humans"*.

Ozonation, which is so effective in disinfection and the oxidation of micropollutants, can generate the formation of bromates for which the European Union has set a threshold of 10 µg/L in drinking water. Oxidation by ozonation is also the origin of molecules stemming from original pollutants, and European standards for phytosanitary substances now take into account original molecules and metabolites in a common value of 0.5 µg/L in total and 0.1 µg/L per individualised substance in water intended for human consumption.

In terms of disinfection, modern chemistry must help provide everyone with access to safe and disinfected water, participate in improving processes by minimising byproducts and optimising the design and installation of membranes to allow them to carry out guaranteed disinfections without the need for an additional chlorination stage.

Membranes represent a genuine progress in the reliability of treatment activities, and, despite the need for further development to prevent them from clogging as far as possible while also reducing costs, they represent a huge contribution from modern chemistry.

## Transport and storage of drinking water

A great many chemical, physical and biological phenomena contribute to the decay of plant and equipment and the corrosion of materials. It is therefore necessary to improve the structure, strength and resistance of materials in terms of various deterioration factors in order to prevent the release of undesirable compounds like metals (lead, copper, etc.) and resin compounds (solvents, phenols, bisphenol A, plasticisers, etc.). Adherent bacterial biomasses and biofilms constitute a major problem, in particular in interior networks and especially in healthcare establishments; this requires new materials to be invented that are capable of minimising biofilms or are suitable for optimised and easier cleaning and disinfection processes, while of course still being available at a widely acceptable cost.

Innovations are possible to produce the ideal material for pipework which would be tough, lightweight, inexpensive, biocidal, inert and recyclable, and which could even be fitted with microsensors capable of analysing water quality throughout its distribution so as to raise the alarm should it deteriorate.

Further progress should be made in the formulation of blends designed to ensure the quality of water in the loops of water cooling towers, as well as hot water for domestic use and for central heating, and in the design of resins for the manufacture of watertight tanks and the refurbishment of old pipes.

## Analytical chemistry applied to water checks

The huge progress made in the last few decades, in particular thanks to techniques such as chromatography and molecular biology, have helped us access trace elements and devise new standards which themselves have promoted the development of increasingly reliable and effective treatments.

As regards the protection of public health, controls take place on three levels: on resources upstream from water intake points in order to detect pollutions, during treatment in order to optimise the operation of plants, and in the distribution networks in order to ensure the quality of drinking water up to the consumer's tap.

Three types of analytical tools are required: on-line sensors, which are in very short supply, analysers installed on site and capable of transmitting information, and laboratory equipment which is smaller but more efficient.

The progress to be made in these areas is highly important as it contributes to the sound overall operation of supply systems and the evaluation of risks. There is still much research and development work to be done to be able to detect very quickly all pathogenic microorganisms in water while providing reliable information on their viability and infectiosity. Analytical costs must be reduced bearing in mind the very large number of different molecules and microorganisms to be studied and quantified. An entire sector has yet to be promoted, which is the global analysis of the biological effects induced by micropollutant blends. The increasing number of molecules to be studied, the high cost of chromatography analysis, and the impossibility of evaluating the health impact related to synergies and antagonisms between molecules just by examining physico-chemical analytical data, all mean that we must have simple methods in the form of kits or analysers to help us approach, for example, the effects of endocrine disruptor and mutagenic blends.

We do have pH, temperature and conductivity sensors, but innovative sensors are few and far between, and although microsensors for analysing free chlorine have been available on the market in recent years, we need to enhance the range of equipment further in particular to monitor distribution networks.

## Conclusion

Water is a major element of public health and a basic element of life. It must cause no undesirable effect on flora or fauna, and, accordingly, the entire planet spends huge sums of money to decontaminate industrial effluents, municipal wastewater and farming effluents linked to the demographic development of mankind and all its needs.

Chemistry also plays a large part in diffuse pollution and punctual pollution, but it also provides considerable tools that allow disinfection, purification, desalination and potabilisation. This ambivalence must therefore prompt major players in the chemical and environmental sectors to realise that cooperation in research and development is vital to achieve the progress needed to minimise the degradation of resources on the one hand, and to offer sanitation and drinking water to every individual on the other, based on the financial capacities available.

We must remember that water is not the only pollutant exposure route for man, and that all issues must be taken into account in order to conduct as accurate an evaluation as possible of health risks. Throughout its history and until the 1940s, our planet was never exposed to such a large number and such large amounts of molecules developed from chemistry. Meanwhile, life expectancy has never been as high, but unfortunately, still, with excessive disparities between developed countries and the rest.

Consequently, new products developed from chemistry must take into account, from their design phase, their impact on the environment and in particular on the aquatic environment. Toxicology and ecotoxicology must evaluate the undesirable effects not just of pure molecules but also of complex blends which ecosystems are exposed to. The health effects of these blends are extremely difficult to evaluate for a lifetime exposure and at the various phases in man's development (embryo, infant, adolescent, adult). Amidst disagreements between the advocates of a ubiquitous chemistry and those in favour of a return to as natural a type of biology as possible, a well-informed debate requires everyone to have an evaluation of the risks that is as accurate, as scientific and as objective as possible. Water is the final compartment for most of our wastes, and clearly everything that is designed as a substance resistant to biodegradation and with a biocidal or toxic activity represents a potential environmental and health risk.

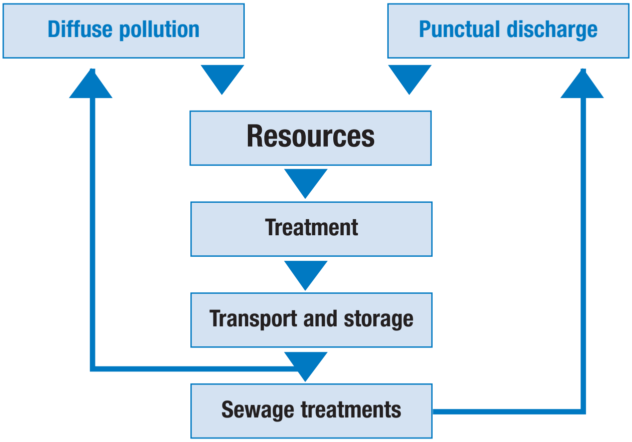
Except for major accidental pollutions (oil slicks, explosions, major dischages, etc.), little or nothing is known about health risks related to water micropollutants; accordingly, epidemiological, toxicological and analytical studies must be conducted to invalidate or confirm the risks, for example on the byproducts of chlorination, lead, pesticides, plasticisers and blends thereof.

In terms of resources, we need to tackle the management of eutrophication, the input of nitrogen and phosphorus, arsenic and diffuse discharges in which we need to minimise persistent, cumulative toxic substances, priority molecules according to European directives, as well as medicines and other substances like detergent metabolites.

As regards the treatments which must be capable of being available to everyone, although effectiveness and reliability must be improved significantly, it is necessary to reduce byproducts, treat wastes, and improve the safety of distribution in particular by creating new materials. Sanitation must be able to rely on new methods to eliminate pollutant traces within highly charged and complex organic matrices.

To meet all these needs, analytical chemistry must continue to achieve major progress through innovation in the design of sensors and analysers, and by capitalising on progress in the field of chemistry-biology interface, while becoming even more reliable and cheaper.

Between the drinking water of developed countries where populations know that their waste is purified properly and those of poor countries which enjoy none of these benefits, between the high-tech membrane and desalination systems and the simple chlorine supply requirements, the challenges are countless and complex, but the funds spent are huge and the risks of conflict major. Chemistry lies at the centre of all these issues and cannot ignore its responsibilities both in terms of its pollutions and in terms of its outstanding technological contributions to improving our health.




# Present Status and Future of Desalination


## Jean-Marie ROVEL

*ex-Senior Vice President Degremont Co.*


## I. STATUS OF THE MARKETS

### I.1. Distillation – Reverse osmosis competition

Distillation through its different variants : MSF (Multi stage Flash), MED (Multi Effect Distillation), VC (Vapor Compression) is in competition with Reverse Osmosis (RO) since 1970 for the desalination of brackish water (< 15 g/L TDS) and 1985 for the desalination of sea water.

Presently RO represents roughly:

- 100% of the brackish water market;
- 40% of the sea water market with a clear discrepancy;
- 10% only of the middle east market characterized by large systems all coupled with electricity generation plants and still low energy prices;
- 85% in the rest of the world.

Globally data bases show a constructed capacity of more than 30 M $m^3$/d of soft water and new orders within 1,4 to 1,8 $Mm^3$/d every year (for the last 5 years) which represents annual addition of potable water for roughly 10 M people (in fact 1/3 of the desalted water is used by industries or agriculture).

### I.2. A fast growing market – Its driving forces

**a. Demand** is growing at a double digit pace as**:**

- global availability of good (unpolluted) soft (low salinity) water is decreasing mainly due to pollution of surface water and over pumping of ground waters;
- demographic growth and particularly within the 150 km band along the coasts where we can count some 70 cities with more than 1 Million inhabitants and with severe water stress.

**b. Offer**

Offer has also changed rapidly in the last decade as costs have gone down significantly, specially with Sea Water RO (SWRO) where they have been halved. There are 3 main reasons for this :

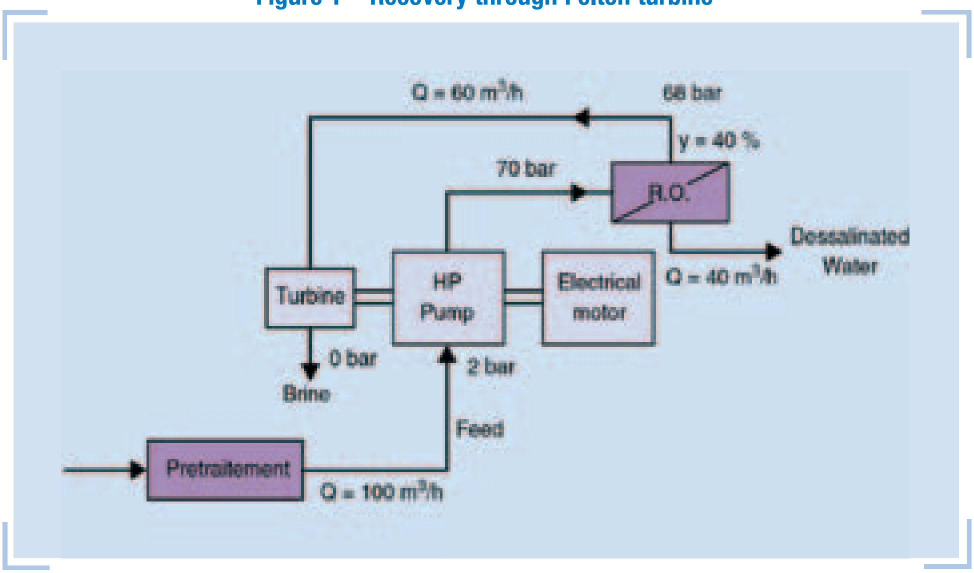
**1. Due to improvements in their chemistry, casting method, quality control…** Membranes performances have improved:

- salt rejection has improved (from 99.3 to 99.7) giving us the possibility to design more and more SWRO with 1 pass only;
- permeability at a given net pressure has increased meaning lower pressure system or lower membrane area for a given production.

**2. Their cost has been reduced:** larger production and improvement in their manufacturing procedure (automation of the manufacturing plants recently started…)

**3. In the same time applying chemical engineering methods has lead to improve schemes.** Energy utilisation has also improved through better energy recovery devices used to crop as efficiently as possible the energy of the rejected brine (50 to 60 % of the pressurised flow rejected at a pressure over 60 bar) progress has been made first by improvements of recovery turbines (mainly Pelton type) then by the switch to work exchangers which directly produce "new" pressurised sea water **(see fig. 1 and 2)** resulting in : ~ 2 kWh/m$^3$ consumed on 1 pass systems when used on 34 to 36 g/L ocean water on which 0.8 to 1.5 kWh/m$^3$ have usually to be added for annexes : pre-treatments, sea water and produced water pumping, air conditioning when needed….

**Figure 1 – Recovery through Pelton turbine**



## Figure 2 – Recovery through work exchanger

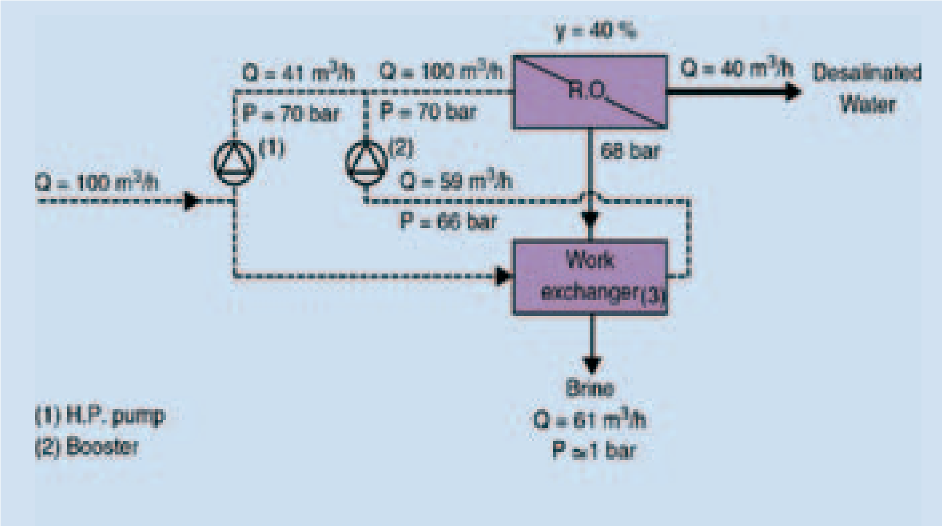
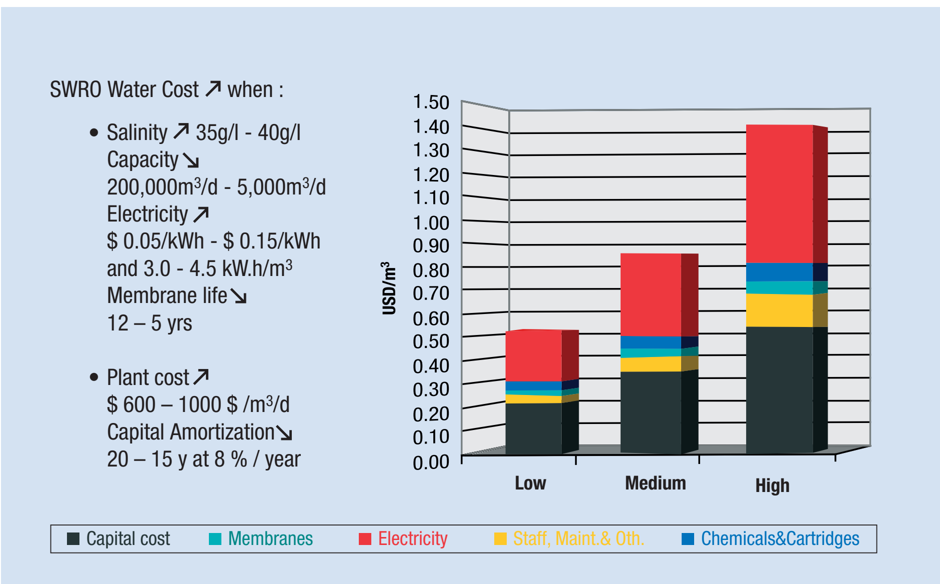



**Fig. 3.a** shows typical split of sea water desalination cost from recent orders classified as low medium and high according to their place in the different brackets (size – energy cost…) characterizing each project.

## Figure 3a – Present range of costs for Sea Water RO



**4. Table (see fig. 3.b) gathers the main Sea Water RO plants recently started or under erection and shows the spreading of this technology throughout the world.**

Figure 3b – Some recent SWRO

| Country | Site | Flow ($m^3/j$) | Status |
|---|---|---|---|
| U.A.E. | Fujairah | 170.000 | Working |
| Spain | Carboneras | 120.000 | Working |
| Australia | Perth | 137.000 | Under construction |
| Dutch Antilles | Curaçao | 18.000 | Working |
| Chili | Antofagasta | 45.000 | Under commissioning |
| Spain | Cartagena | 65.000 | Under construction |
| | Campo Cartagena | 140.000 | Under construction |
| Israel | Askhelon | 137.000 x 2 | Working |
| Saudi Arabia | Rabigh | 270.000 | Under construction |
| Singapour | Tuas | 135.000 | Working |

## II. SEA WATER QUALITY *versus* REVERSE OSMOSIS

Even unpolluted sea water are quite different from place to place through the world and not only by their salinities (35 to 45 g/L) but also by their content in:

- colloids: generally estimated by the SDI (salt density index) varying easily from 2 to 35% clogging/min;
- phyto and zooplankton ie algae from 10 to $10^5$ cells/mL;
- organic matter TOC : 2 to 10 mg/L.

When you add all the unmetabolized pollutants from nearby human activities (urban or industrial effluents, harbour activities, oil spills...) you end up with a wide spread going from almost harmless to very bad sea water in regard to what these sea waters can leave along the membranes in a reverse osmosis module.

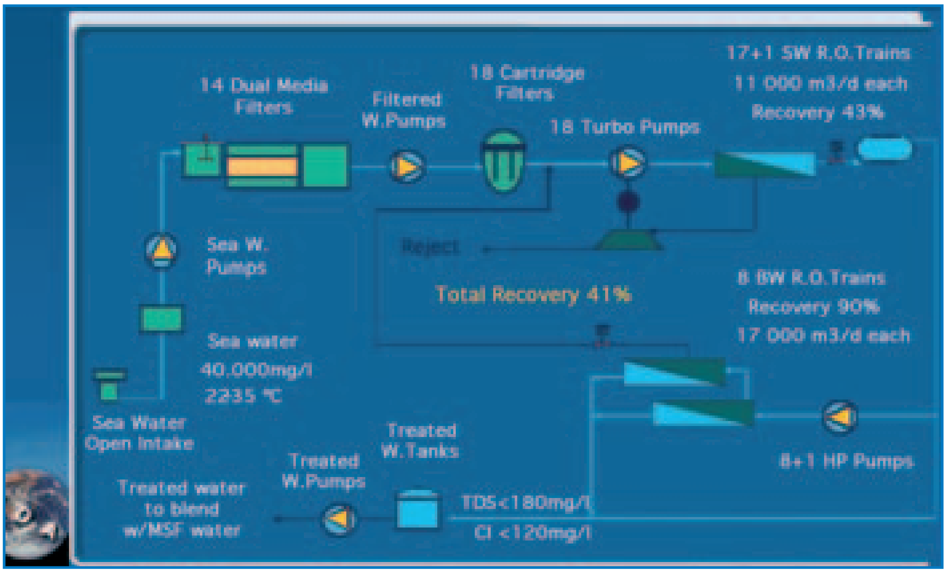
Thus imposing in all “open sea” inlet cases to adapt a pre-treatment (incorporating some of the known technologies to clarify (remove any particulate matter) from traditional settlers or flottaters and filters… to clarification membranes (ultrafiltration or microfiltration).

A special care has to be drawn to biofouling (colonisation of membrane by bacteria) which has to be monitored and controlled by avoiding to feed biodegradable organics and/or disinfecting regularly the system. All this explain that, when distillation is not too sensitive to sea water conditions (but salinity and temperature) reverse osmosis systems depend much more on their pre-treatment line which has to be designed properly including necessary steps to resist to excursions mainly due to either very rough sea conditions or abnormal local pollutions. It's worth to note that the cost of such pre-treatment chain generally varies from 5 to 15% of total investment for a SWRO systems.

## III. A CASE HISTORY : FUJAIRAH IN UNITED ARAB EMIRATES (2002)

Schema **(Fig. 4)** and table **(Fig. 5)** show the RO part of this plant (designed and commissioned by Degremont) and its results after 2 years of operation. The 170.000 m$^3$/d produced by the SWRO are mixed with the 285.000 m$^3$/d produced by 5 MSF which received their energy from low pressure steam extracted from the 600 MW power plant (Doosan responsibility).

Figure 4 – Fujairah flow sheet –> 170 500 m$^3$/d = 45 MGD




The main interest of such hybrid system is to be much more flexible in its water/electricity out-put ratio with for example:

- possibility in peak summer condition to use 100% of power and MSF capacity by shutting down the SWRO at least during electricity demand peaks;
- in winter time when electricity demand is low to use 100% RO and just the part of MSF corresponding to electricity exported + SWRO demand.

And thus reaching minimum costs for both kWh and m$^3$ of soft water.

**Figure 5 – Fujairah: Operational Results**

| | | Projected | Results |
|---|---|---|---|
| Seawater SDI % / min | | < 20 | 10 – 40 |
| Seawater Salinity, mg/l | | 40000 | 37000–39500 |
| Temperature, °C | | 22 –35 | 25–35 |
| Pretreated water pH | | 6.5 – 7.2 | 6.7 – 7.1 |
| Pretreated water SDI | | < 3.5 | 2.0–3.6 |
| RO 1st pass TDS, mg/l | | < 650 | 420 – 550 |
| RO 2nd pass TDS, mg/l | | < 50 | 10 – 25 |
| Blended 1st pass and 2nd pass TDS, mg/l | | < 180 | 110 – 140 |
| Total Energy, | $kW.h/m^3$ | < 5.3 | 4.4 – 4.6 |
| RO 1 Energy, | $kW.h/m^3$ | | 2.9 – 3.0 |
| RO 1 + 2 Energy, | $kW.h/m^3$ | | 3.7 – 3.9 |

## IV. FUTUR OF SEA WATER REVERSE OSMOSIS

As demand will continue to grow, our main objective is to keep the total water cost diminishing and for this we need:

- better desalination membranes with improved permeabilities and salt rejection up to 99.85% which seem realistic goals and they can also hopefully have better fouling resistance (through membrane surface modification);
- better clarification membranes which have the potential to be the base of the future pre-treatment lines but still have to be more cost attractive and need more application research in sea water environment;
- to have new (or improved) polymer coagulant and specifically polymers with a better compatibility with RO membranes (today with most of those available a residual of 0.1 ppm will clog a RO module in a few weeks);
- to have better scale inhibitors, needed if we want to push-up water recovery or work at higher pH;
- to have specific absorbent of boric acids.

And all these claims have to be addressed to the chemist community, in which we trust!

## SW RO Fujairah – 170 500 m³/d

## SW RO Carboneras – 120 000 m³/d

# Green Chemistry and Water Resources Management

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## Goal and Scope

Green Chemistry combines critical elements of environmental improvement, economic performance and social responsibility to address global problems. Among environmental issues facing the world today, land-based sources of water pollution is one of the most pressing. Adequate supplies of satisfactory quality water are essential for the natural resources and ecological systems on which all life depends. Agricultural chemistry is a second area where human sustainability is brought into question by pollution. Green Chemistry offers a scientifically based set of solutions to protect environmental quality.

## Features

Among environmental issues facing the world today, land-based sources of water pollution is one of the most pressing. Adequate supplies of satisfactory quality water are essential for the natural resources and ecological systems on which all life depends. Green Chemistry offers a scientifically based set of solutions to protect water quality. The growing global crisis in water resources provides an important illustration of the influence of upstream pollution prevention. For the past decade scientists have sought to raise an alarm concerning the unsustainable use of the planet's water resources [1–4]. A key United Nations report indicates that water shortages will touch 2.3 billion people, or 30 percent of the world population, in four dozen nations in 2025 [1]. Exacerbating the shortfall is the extensive pollution of water resources, rendering significant amounts of water unfit for human use. This talk will highlight examples of green chemistry approaches using water quality as an illustrative example.

Green Chemistry can provide tools to protect water quality in the face of increasing global pressures on water quantity. A 2001 report by the Organization for Economic Cooperation and Development (OECD) [5] indicates that within the industrialized (OECD) countries the chemical industry was the single largest consumer of water (43%) followed by metals processing (26%), pulp and paper (11%) with other uses accounting for 20%. Critical sources of water pollution include chlorine for both water treatment and pulp and paper bleaching, metals processing, pharmaceutical manufacturing, textile dying and cleaning, corrosion control and processes as varied as photography and photolithography.

### Industrial Water Treatment

There is no questioning that chlorine, as a domestic water treatment has been effective and a mainstay in reducing water-borne diseases worldwide. However, chlorine from manufacturing almost inevitably makes its way to aquatic ecosystems and impacts organisms that are integral to food chains. Once present in the environment chorine compounds interact with other compounds, which can lead to the formation of carcinogenic chloramines, which bioaccumulate within the food chain. Examples of alternatives to chlorine will be presented.

### Pulp and paper Processing

The annual world market for bleached pulp approximates $50 billion. The bleaching of pulp depends on the systematic separation of lignin from cellulose. The chemical processes of the pulp and paper industry are primarily directed to separating these two components. In nature the biodegradation process accomplishes this using a limited suite of enzymes: ligninase, glyoxal oxidase and Mn peroxidase. To achieve the same oxidation that nature uses $O_2$ for, industry has substituted chlorine compounds resulting in the release of phenoloic compounds and environmentally persistent organochorine compounds. A new generation of catalytic Green Chemistry approaches will be presented.

### Semi-conductor manufacturing

Much of the enormous amounts of water consumed in the manufacturing of semiconductors are utilized for cleaning at multiple stages of the photolithography process. This water is typically deionized and therefore has a significant energy investment as well. As chip architecture moves to finer and finer scaled structures the surface tension of the liquids no longer permits ready diffusion. Surfactants can be used to reduce surface tension, but this necessitates a subsequent rinsing and drying step, requiring additional amounts of ultrapure water. An approach developed by Los Alamos National Laboratory working with semiconductor and equipment manufacturers has been with the replacement of conventional clean techniques with supercritical $CO_2$ ($SCCO_2$). $SCCO_2$ offers a variety of advantages to address the new processes in this area. The gas like properties, high diffusivity and low viscosity allow the $SCCO_2$ fluid to reach the small architectural features of the new wafer designs.

## Photographic Processing

The billions of photographs developed every year via the silver halide process use primarily aqueous processes that produce huge amounts of chemical, solid and liquid waste. In the U.S. alone over 400 million gallons of fresh water is sent to treatment works after single use in the developing process. This water contains up to 15 million gallons of chemical photographic developer laden with contaminants such as hydroquinone, ammonia and silver. Two new Green Chemistry alternatives will be presented.

## Agricultural Chemicals

Few Green Chemistry applications are more important than those for the agricultural chemicals industry. The economic and human costs of crop losses on a global scale drive the estimated $12 billion annual market for insect control chemicals. The persistence of many pesticides, herbicides and fertilizers in the ecosystem and the evidence of their biological impacts are a significant consequence of the synthetic organic chemical approach to the problem. Further, the resistance that develops among insect species to these pesticides also argues for a fresh approach. Examples of biomimetic pesticides, protein systems and bioengineered approaches will be presented.

## Recommendations and Outlook

Green Chemistry offers a variety of mechanisms to address globally important environmental problems such as water contamination at their source. Such source reduction has proven more cost effective than either abatement or remediation approaches.

## Key Words

Agriculture; catalysis; green chemistry; water resources.


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# Distribution: the Growing Role of Plastics in Infrastructures
## (Extracts)

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1.1 billion people, i.e. 16% of the world's population, do not even have access to water for their vital needs, and 2.4 billion, i.e. 40%, live in insalubrious conditions and endure a lack of hygiene.
Every year, 3.5 million people, two thirds of whom are children, die from diseases linked to water quality and to related sanitary conditions. This represents 15% of infant mortality for the under-fives in developing countries.
The United Nations Johannesburg objectives aim to cut these figures by 50% by the year 2015.
This objective is necessary, proactive and ambitious. It aims to solve problems of access to water and hygiene for 100 million people every year at an annual cost of between 20 and 40 billion dollars, compared to a global water market of 800 billion dollars per year.

The issue of water is a universal one; it is not confined to developing countries. Unlike problems of air quality which can only be solved on a global scale, the solutions needed to solve problems of water are highly regional or local.
We are faced with two kinds of problems: a major problem of quality, and a problem of infrastructures. The problem of availability of water as a raw material does not in fact arise on a global scale. However, this water has to be brought in to the point of consumption or use, and it must be given the right qualitative properties for the intended use, and subsequently, again, the necessary qualitative properties to be released back into the natural environment after domestic, industrial or farming use.

The technical solutions exist. Funding can be provided through international organisations and through the private sector. However, the launch of programmes liable to lead to long-lasting progress requires both commitment and political action in every region concerned, the development of infrastructures suited to specific local problems, the management of resources available quantitatively and qualitatively, and the education in respect of water and in basic hygiene of the populations to be protected. Without this last educational aspect, the most ambitious programmes would add up to nothing more than utopia, an attempt to win popularity, and waste.

In this context, chemistry can make countless contributions, in terms of both technology and infrastructure. But chemistry alone can never provide the full and final solution. It can provide treatment products, processes that cut consumption and waste, and play a major role in distribution itself. Although a major and vital contribution, this is but one facet of a complex issue.

It is mainly in the field of distribution, and, in a wider context, infrastructures, that commodity plastics play an increasingly vital role, as shown by a few facts and figures:

In 2003, over 5 million kilometers of plastic pipes were laid, 70% of these for water transport, distribution or collection.

What are these pipes used for?

- first to collect water from fresh and salt water natural resources;
- then transport this water to treatment and purification plants where it is made fit for use, and a certain quota fit for drinking;
- distribute it to users, consumers, communities, industry and farming;
- collect waste water and contaminated water, and transport it to treatment plants;
- recycle the treated water into the natural environment or into a new use;
- also ensure the drainage of areas exposed to risks of flooding or collection.

Why are plastics gradually taking over from traditional metal or mineral materials, and why do they already account for over 40% of all new pipes installed every year?

Plastics offer a combination of characteristics in terms of technology, cost-effectiveness, installation, lifetime and compatibility with the environment which is highly favourable in the case of major infrastructures.

The following non-exhaustive list of their assets is impressive:

- hydrostatic behaviour, resistance to external impact during both installation and long-term use;
- inherent short- and long-term hardness;
- resistance to fatigue;
- flexibility in long lengths;
- lack of corrosion and hence long-term water tightness;
- surface finish minimising pressure drops;

- production and installation of long lengths with capacities to extrude basic units of up to 1 kilometer long on the installation site itself;
- straightforward welding and connection;
- etc.

not to mention their use in the refurbishment of old networks consisting of traditional materials by the laying of a watertight lining. The latter, fast-growing application requires specific know-how and may appear costly. However, it affords substantial cost savings compared to full replacement, and helps extend the life of old leaky pipes.

High density polyethylene holds a special place in the transport of sea water to desalination plants as it can be processed into large diameter pipes, up to 30 centimeters, without losing its physical characteristics. This development is essential as part of a reverse osmosis desalination activity, the cost of which per cubic meter was cut by a factor of 4 from 1990 to 2000 and should again be cut by the same factor by 2010.

Polyethylene film is also used increasingly as watertight sheathing for irrigation pipes in which they help minimise losses of volume on line. These losses can be cut by 70% on networks stretching from 500 to 1000 kilometers.

Another example is the growing use of polyethylene watertight film in arid regions of the world to help collect small quantities of rainwater to develop crops or animal breeding with minimum outside backup.

Thicker films, called geomembranes, help prevent water collected in intermediate pools for decanting prior to purification from leaching into the ground, and especially into groundwater tables.

Finally, the growing use of plastics in the manufacture of containers, from tanks to bottles, combining their physico-chemical non-toxicity and their light weight, has already helped curb the impact of a shortage of drinking water in several regions with a high concentration of rural population in developing countries.

In conclusion, we must bear in mind the role of plastics which provide cost-efficient solutions for the construction of large-scale infrastructures, bringing in water to disadvantaged a population that is fit for drinking or for household use, for farming or for industrial use, not to mention their contribution to removing waste water and unsafe water.

However, this presentation does not answer the question of financing the appropriate investment, or the question of the necessary training of those involved in the construction and maintenance of networks, or the essential education of the populations who benefit from these improvements.

Chemicals manufacturers, beyond a few humanitarian sponsorship initiatives, are not engaged in philanthropy. They need to remain profitable to pursue their research into better materials, finance their own investment projects needed for the production of growing quantities, and develop the human resources involved in the distribution and use of their products.

The huge constraints of funding these projects can only be solved through international organisations and targeted private initiatives. The implementation of programmes requires responsibilities to be assumed by those local or regional authorities in charge of managing in the long term the solutions they will be given. We repeat what has already been stressed, which is that training and educating populations in the proper use of water and in the basic principles of hygiene is and will be the main factor of success, or otherwise.

In the comfort of our industrialised countries, we wish in all good faith for a massive reduction in infant mortality caused by lack of drinking water or by poor hygiene. But it is locally, in the developing countries, or in countries with a growing industrialisation where the situation sometimes gets worse because of poorly controlled pollution, that action needs to be taken.

What is the point of our fine pipes if they are being tapped into freely? What is the point of drinking water being available if this water is stored in a dirty container?

The ambition of Johannesburg is most noble. Its implementation will require a great deal more than the many contributions of chemistry.

# Chemistry and Water Management in Nigeria

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## Introduction

Effective management of water resources has gained worldwide recognition as an important strategy for sustainable socio-economic development **(Mitchell 1990)**, which is especially critical for developing countries. In Nigeria, this recognition has only recently received the deserved attention. Historically, management of water resources in Nigeria had focused mainly on the availability of water and the adequacy to meet domestic, agricultural and industrial needs, as well as anticipating shortages in drought-prone areas in the northern parts of the country **(Oyebande, 1975; Salau 1990)**. Issues of accessibility and especially, quality have not been emphasized in this management regimen. However, with the new realization, planners of water management have integrated water management in the overall national millennium development goals aimed at poverty reduction and improved community health. This is captured in the Nigeria Water Resources Vision 2025, which is itself an offshoot of the larger African Vision that has water quality and sanitation as key components. It is our thesis in this paper that this new scenario provides opportunities for chemistry professionals to be major stakeholders in the water management enterprise.

## Nigeria's Water Resources

Nigeria is a tropical African country (4°1'–3° 9' N and 2° 2'–14°30'E) with an estimated population of ca. 120 million people and approximately 924, 000 sq. km land area, whose landscape is defined by two major rivers, Rivers Niger and Benue. Along with their major tributaries, there are literally hundreds of streams and other smaller rivers in the hinterland, with many creeks also covering much of the Niger Delta area. These represent the major sources of surface water reservoirs in the country.

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Other sources of water include (3-5 months) seasonal rainwater (> 3500mm in the south of the country; 1000-1500 mm in the middle belt; < 500mm in the far north) and underground aquifers, located 20-80 meters (average 50 meters) depth. In the case of ground water reserves, it has been reported that only 40% of the landmass accounts for 30,000 L/h aquifer yield, while 60% accounts for just 4,000 L/h **(Iwugo, 1986; Kowal and Knabe, 1972)**. Overall, domestic supply sources are not significantly different for rural and urban dwellers, except that piped water is more available in the urban and peri-urban centers than in rural areas. Generally speaking, the main source of water, especially for the rural population, is from rainfall, surface (stream, river) and hand-dug wells or, in some cases, deep-wells (bore holes).

## Previous Management Approaches

To meet the rapidly increasing demand for water with the growth in population, government strategy resorted to river basin development in the 1970s and 1980s. Thus, twelve River Basin Development Authorities (RBDAs) were created with an all-embracing mandate on water management. This was at the time seen as an integrated water management approach, capable of achieving optimum use of natural water sources on a basin-wide scale (Salau 1990). The thrust here was the construction of dams, canals and levees for irrigation, navigation and hydroelectric power generation, etc. However, inadequate or non-availability of technical capacity and poor management skills, in addition to the overburdening and omnibus nature of the mandate of these state agencies, hampered the success of this strategy. The evidence is that although these RBDAs still exist two and a half decades on, there are yet the problems of inadequacy, inaccessibility and poor quality water in Nigeria. According to Government records, only 39% of the population has access to safe water **(FOS 2001)**.

Other attempts at managing Nigeria's water resources are embedded in Decrees (or Acts of the National Assembly), the creation of a National Inland Waterways Authority, the Federal Ministry of Water Resources, the National Water Resources Institute; National Water Supply and Sanitation Policy **(2000)**; regional (or State) water corporations and utilities or authorities, etc. It can be said that institutional arrangements exist to tackle Nigeria's water problem. What remains are focused programs and the requisite human capital to implement such programs.

## Current Constraints

Some of the constraints to effective planning and efficient implementation of water resources management have been identified **(Salau 1990)** as:

- lack of accurate basic planning data on the quality and quantity of the nation's water resources;

- absence of specific information about the population of consumers and their water needs;
- fragmented, shared or conflicting mandates of institutions and other systemic apparatus charged with managing water resources or related issues, leading to lack of focus or coordination;
- high installation and maintenance costs of metering and monitoring systems, needed for rapid quality and quantity evaluation, on-site data gathering, processing and storage;
- inadequacy of competent management personnel;
- absence of low-cost treatment (purification) technologies;
- low public sensitization/ownership of water-related issues; and
- absence of an effective water and environmental management information system, amongst others.

## The National Water Vision 2025

It thus appears that the National Water Vision 2025 is a direct response and blueprint to tackling the afore-mentioned constraints. The vision has six key elements:

1) welfare of the people and social equity;
2) economic growth and development;
3) efficient use of water resources for agriculture and environment;
4) sustainability of water resources and environment;
5) policy and institutions and issues of governance;
6) increasing role of the market in water resources management (i.e. private sector participation).

## Entry Points For Chemistry and its Professionals

In order to fully realize the national water vision, a coordinated and integrated approach is required, which is wholesome in its execution even as it specifically addresses the key elements of the vision. For chemistry professionals, achieving 1-6 above requires research and development into current water management problems and emerging ones, while anticipating changing scenarios for the future. These pose current challenges for chemists and other scientists associated with water management in Nigeria.

At present, however, research into water management issues is not organized or coordinated at a national scale; at best, it is domiciled largely in the academia. Dissemination of research results is poor. For example, rainwater harvesting (as run-off from thatched roofs) in peri-urban/rural areas is unsafe; still, it is common practice and constitutes a major water supply route for many families. Such harvest is not given any treatment prior to drinking, largely because of ignorance. Pond and lake waters in rural agrarian settlements are often contaminated with nitrates, pesticide residues and human and animal wastes, the extent of which is usually unknown. On-going public projects still focus more on water availability and accessibility; quality and sanitation are only now being mainstreamed. These could be the major entry points for chemistry, mainly in the development of low-cost test kits for water contaminants and inexpensive low-cost technologies for water treatment. At present, these are virtually non-existent.

Of immediate concern is the proliferation of cottage industries concerned with the production of packaged water. First, the ubiquity of these industries point to the fact that the general public recognizes the need for good quality water to be readily available to the general public. The fact that this industry enjoys heavy patronage, especially from the not-too-wealthy members of the public, is indicative that good private sector initiatives in this regard, with modern and reliable water processing methodologies, will thrive and perhaps be economically rewarding to entrepreneurs. Second, even though the National Food and Drugs Administration Control (NAFDAC) is making spirited efforts to ensure public safety through monitoring the quality of water produced and sold through this mechanism, the efforts of this Government agency fall far short of the magnitude and volume of the enterprise. It is not uncommon, therefore, for unscrupulous people in this business to sell water of doubtful quality to the public, thus exacerbating the health problems associated with water that they indeed set out to eliminate. Third, is the environmental problem posed by the polythene bags in which the product, packaged water, is sold. The litter resulting from uncontrolled after-use disposal is an environmental issue that will linger for a while. A comprehensive policy on the production, distribution and sale of packaged water is called for since this has become an important source of water to the public.

Nonetheless, it is common knowledge that many city and rural dwellers alike, tend to clarify turbid water by addition of uncontrolled amounts of alum, the resultant clarity being the only measure of the success of this attempt at water treatment. The level of residual aluminum is never a concern, again, due to ignorance. However, use of the powder from seeds of the drumstick tree *(Moringa oleifera)*, has been suggested to serve the same purpose, possibly with better and safer results **(Anon. 1996)**. This is an area in which the chemical sciences can play meaningful roles. Perhaps there are many more sources of natural (organic) polyelectrolytes for water purification yet to be discovered? There is also the need to develop rural-friendly water disinfection and other treatment technologies as for example, Freese *et al*

2003; Koestler *et al* 2003; Siabi, 2003. These are all in the ambit of the chemical sciences.

## Donor Agencies and the Water Problem

In our opinion, the most important task of donor agencies that wish to intervene in this sector is that of promoting low technology for water treatment and sanitation, technologies that are easy to use and inexpensive to maintain. In this regard, a significant amount of energies should be devoted to education of the rural masses, not only on the dangers of bad quality water but on how to acquire, maintain and use available low-cost technologies. It is suggested that a form of local enterprise be made to spring around the issue of rural water treatment; this will drive private sector initiatives in this regard.

The route of aid to the rural communities should change from the traditional mechanism of channeling aid through Government agencies. The questionable results obtained in the massive aid to the agricultural and health sectors in the past, resulting from inefficiencies of the implementers of the aid programs, ill-defined intervention mechanisms, and, most important, corruption at the level of Government officials whereby resources meant for aid beneficiaries are diverted for personal use, should inform a new approach. We recommend that aid meant for solutions to water problems goes directly to community levels where the inherent social structures provide an organizational framework for administering the aid and monitoring performance, to include sanctions for aberrant behavior on the part of local administrators.

## Conclusion

This paper has outlined Nigeria's water resources potentials and the attempts and strategies by governments aimed at their management for poverty reduction and sustainable development, as captured in a national water vision. In the latter, entry points for chemistry professionals have been identified to include prioritization of water quality issues in national water management programs and projects, and the development of:

- water quality monitoring or surveillance protocols;
- low-cost, safe and user-friendly technologies for water treatment;
- low technology water quality test kits.

Some examples of these interventions, at the research and development (R & D) level, are already in the literature and they all require input from the chemical sciences. We have also suggested a new mechanism for delivering aid directly to rural communities by donor agencies. This suggested route cuts out huge overheads and minimizes losses occasioned by inefficient handling of resources and pervasive corruption.

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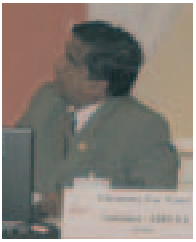
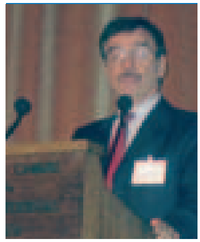


# A Search for Solution to the Problem of Arsenic Contamination of Water in Bangladesh



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## Nature of the problem

Naturally occurring arsenic is contaminating groundwater in Bangladesh, where thousands of shallow (10–40 m) tube wells sunk in the 1970s were found to be contaminated in the 1980s. The arsenic concentration range in Bangladesh water in the contaminated areas ranges from 10 to 14,000 ppb (parts per billion). The proposed safe levels of arsenic in water are 10 ppb. In Bangladesh 61 out of 64 districts are affected by this problem.

## Geographical impact

Arsenicosis now seriously affects the health of more than 60 million people in Bangladesh and probably several hundred million persons worldwide [1, 3]. Arsenic contamination has been found in regional water supplies in Argentina, Australia, Chile, France, Ghana, Hungary, Mexico, and the U.K. Dangerous concentrations higher than 50 ppb occur in the northeastern, mid-western and western United States [4, 5].

One of the authors (Sut Ahuja) made a worldwide appeal in a letter to the editor of *C&E News* [6], wherein chemists and chemical engineers were asked to offer their advice. Numerous responses and suggestions were received from various parts of the world. This implies that chemists and chemical engineers worldwide would like to play a significant role in helping to purify water that has been contaminated.

Supported by the International Union of Pure and Applied Chemistry (IUPAC proposal 2003–050–01) and the American Chemical Society (ACS), the authors visited Dhaka and Kushtia, Bangladesh, in April 2004 to investigate the problem. Although considerable attention has been devoted to the arsenic problem, local scientists maintain that it is still not clearly known how arsenic enters into ground water. It is generally recognized that sources involve a variety of hosts, including iron oxides, organic matter, or sulfides, and that high aqueous concentrations are obtained when the arsenic is bound weakly in the host phase. Although speciation in natural waters may be complex, As is found in two oxidation states (III and V), depending on both pH and Eh.

It is generally known that arsenic is released in the soil as a result of weathering of the arsenopyrite or other primary sulfide minerals. Important factors controlling this phenomenon are listed below.

• Moisture (hydrolysis)

• pH

• Temperature

• Solubility

• Redox characteristic of the species

• Reactivity of the species with $CO_2/H_2O$

It has been reported that weathering of arsenopyrite [7] in the presence of oxygen and water involves oxidation of S to $SO_4^{-2}$ and As(III) to As(V):

$$4FeAsS + 13O_2 + 6H_2O \leftrightarrow 4SO_4^{-2} + 4AsO_4^{-3} + 4Fe^{+3} + 12H^+$$

The process of release of As from subsurface strata has been widely discussed. A commonly accepted mechanism is bacterially mediated reductive mobilization of As from Fe-S containing minerals [8]. However, the observation that water from tube wells that are near each other may differ substantially in As content has not been fully explained.

Interviews by the authors with workers in the area indicate that more fieldwork is needed before all factors influencing the distribution of arsenic in groundwater are understood. There is need to consider the fundamental issue of arsenic remediation (i.e., eliminating As at the source) in addressing the problem. The solutions that have been suggested, e.g., using of surface water or drilling deeper wells, appear to be long-term strategies. The primary purpose of the planned workshop will be to assess techniques of remediation and measurement in order to find immediate solutions to the arsenicosis problem.

Dr. Dipankar Chakraborti of Jadavpur University, Calcutta (the scientist who first uncovered the As epidemic), has noted that the remediation problem is far from solved. Of the 2000 arsenic removal devices installed in villages in West Bengal, India, four out of five are either abandoned or deliver odorous or discolored water [9].

## Methods of arsenic determination

A number of relatively costly methods can be used for determining arsenic in water at the parts-per-billion level, among them

• flame atomic absorption spectrometry;

• graphite furnace atomic absorption spectrometry;

• inductively coupled plasma–mass spectrometry;

• atomic fluorescence spectrometry;

• neutron activation analysis;

• HPLC-ICP-MS.

However, much remains to be accomplished in developing analytical techniques for use in the field and in the household. Speciation of As requires separations based on solvent extraction, chromatography, and selective hydride generation. Most of these methods require expensive instrumentation, and the cost of training can be high.

Colorimetric methods are less expensive; however, they are not reliable for measurements at low parts per billion levels. Moderately priced techniques such as differential pulse polarography or anodic stripping voltammetry have been found useful; however, they have not found general acceptance.

The difficulty is exacerbated by the fact that, while thousands of measurements have been made on well water in Bangladesh, there has been almost no standardization of measurement techniques. Also, availability of a workable field unit would be very desirable.

## Methods for removing arsenic

The solutions to the problem range from chemical reaction to various separation techniques that entail adsorption, ion exchange, or membrane filtration. Remedial methods [10] remove arsenic or reduce its toxicity through chemical reactions and a variety of separation techniques, including:

1) chemical precipitation – Coprecipitation onto $Fe(OH)_3$ phase;.

2) coagulation – Use of ferric sulfate or ferric chloride;

3) oxidation – Oxidation of arsenite to arsenate with $Cl_2$, $FeCl_3$, $KMnO_4$, or $H_2O_2/Fe^{+2}$;

4) adsorption on alumina—Various grades of alumina have been used;

5) adsorption on supported iron oxides and hydroxides;

6) membrane separations—Reverse osmosis through semipermeable membranes (neutral and charged particles are rejected);

7) ion exchange—Strong base anion exchange at pH 8–9.

## Present status in Bangladesh

The Bangladesh government has approached the solution of the problem by meeting the needs of a single family unit first. To this end, they temporarily approved on February 25, 2004, four commercially useful technologies to remove arsenic from contaminated water

ALCAN: Activated alumina

REED-F: Ion exchange with Ce

SIDKO: Synthetic iron oxide.

SONO: Composite iron matrix

Some of these promising processes were observed and discussed during the authors' 2004 visit to Bangladesh. Of these devices, SONO is based on Bangladesh resources, and it is the most economical one. Discussions with various scientists indicated that the four devices approved provisionally by BCSIR do not perform optimally under all conditions in Bangladesh. The planned workshop will identify an optimal approach that can be refined further and validated to provide reliable technology for scale up to larger applications.

The authors reported on their interactions with scientists, health workers, and victims at the conference *CHEMRAWN XV: Chemistry for Water*, held June 21-23, 2004 in Paris. The report was specifically highlighted in the conference article in the July 19, 2004, issue of *Chemical and Engineering News* (C&EN) and was also featured in *Chemistry International* in September–October, 2004 issue.

## Future actions

The authors have developed a list of notable international scientists to be invited to the workshop to meet with local scientists and engineers who are addressing the problem. In this process relevant sources of expertise were consulted, including IUPAC's Analytical Division, the US Geological Survey office, and the international team, which is planning to write an assessment report on current methods of As remediation. The organizers also have consulted local institutions and government agencies in Bangladesh to develop interest in implementation of the solutions that will be developed in the workshop on December 11–13, 2005.

A plan for implementing appropriate remediation technologies will be designed at the workshop, based on the following considerations:

(1) what arsenic mitigation technique has been demonstrated to work beyond the research scale?

(2) which of these forms of mitigation, or promising but untested approaches, could be scaled up?

(3) what are the best methods of disposal of arsenic-laden concentrates or adsorbants?

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# Case Studies in Developing Regions
# Use of Dry Chlorine for Low Tech Sanitation

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In order to formulate a path to provide fresh water to all human beings during the 21st century through the appropriate development of the relevant chemical and biochemical sciences and technology, it is first necessary to understand the relevant chemical technologies and the practical considerations for their use. The objective of this paper is to provide some of the chemical knowledge required for understanding the role of chlorine chemistry in solving water-related problems such as drinking water disinfection. This paper will discuss the chemistry, manufacturing and use of chlorine for drinking water disinfection. Three case studies will be presented to show the real world application of chlorine in drinking water systems in developing regions.

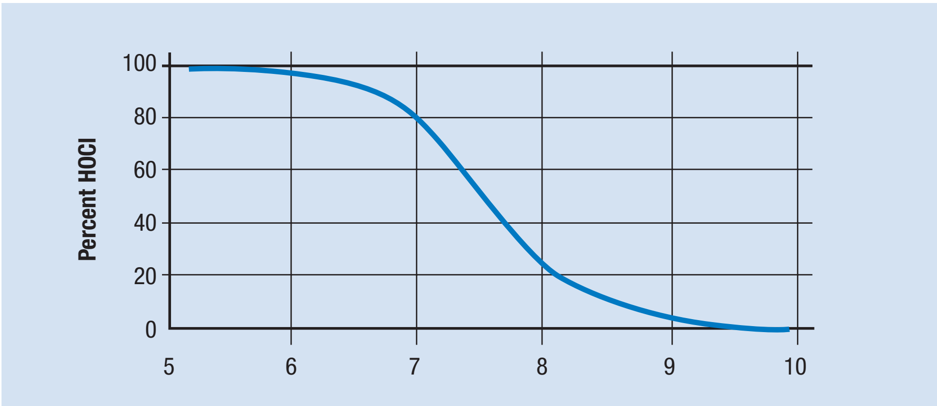
## Disinfection and Chlorine Chemistry

Water disinfection techniques began as early as 500 B.C. with the boiling of water. People have used a variety of techniques besides boiling to sanitize drinking water, including physical methods such as filtration, metal ions such as silver, ultraviolet radiation, ozone, iodine and chlorine. Used to combat illness carrying pathogens which occur in all sources of fresh water, disinfection has become the norm for drinking water systems in developed societies. Health professionals track improvements in overall mortality, from infants to seniors, with the availability of disease-free drinking water. According to the U.S. Environmental Protection Agency(1), "it was disinfectants like chlorine that played the largest role in reducing the number of waterborne disease outbreaks in the early 1900's." Chlorine has been the most common water disinfectant because of its ability to kill a wide range of pathogens and the fact that a residual chlorine concentration can be maintained so that the water does not become re-contaminated after it is treated.
Chlorine is effective in killing a wide range of pathogens. It has been shown to damage the cell wall membrane, promote leakage through the cell membrane, and produce lower levels of DNA synthesis for bacteria. It has also been shown that

chlorine inactivation is rapid and does not require bacteria reproduction[2]. This talk will not go into detail about the mechanism of disinfection; however a few basics are important. We are generally talking about single-celled organisms with a negatively charged slime coating on the exterior wall. Chemical disinfectants must overcome the electrical charge in order to penetrate the slime coating. Disinfectants with a neutral or positive charge will act more rapidly. The result being that the organism either dies or cannot reproduce and the water is microbiologically safe.

The most active form of chlorine is hypochlorous acid (HOCl). In water, hypochlorous acid undergoes a reversible dissociation reaction to give hypochlorite ion ($OCl^-$): $HOCl \leftrightarrow H^+ + OCl^-$. As shown in **Figure 1**, the amount of dissociation is pH dependent. Since hypochlorite ions are not as effective as hypochlorous acid in killing pathogens, it is important to maintain the pH of the water in the range where hypochlorous acid is present.

Figure 1 – Change in HOCl concentration with pH




Another very important concept for water disinfection is the (Concentration x Time), or CT, requirement. CT is simply the product of the concentration (ppm) and time (minutes) needed to kill a certain organism. Depending on the life cycle of organisms, the concentration of hypochlorous acid required will vary with the contact time in the system. The following tables show the disinfecting power of chlorine compared to other disinfectants[3]. Table 1 also shows the effect of pH on chlorine efficacy. For some organisms, ozone and chlorine dioxide may be effective a lower dosages than chlorine, however, neither of these is readily available in developing countries because they are not stable for transportation and so must be generated on-site.

**Table 1. CT values for 99.9 percent reduction of Giardia lamblia at 20º C**

| Disinfectant | pH | CT |
|---|---|---|
| Chlorine | 6 | 44 |
| | 7 | 62 |
| | 8 | 91 |
| | 9 | 132 |
| Ozone | 6-9 | 0.72 |
| Chlorine Dioxide | 6-9 | 15 |
| Chloramines | 6-9 | 1,100 |

**Table 2. CT values for 3 Log inactivation of virus at 20º C, pH 6-9**

| Disinfectant | CT |
|---|---|
| Chlorine | 2 |
| Ozone | 0,4 |
| Chlorine Dioxide | 6,4 |
| Chloramines | 534 |

## Chlorine Production

Hypochlorous acid, the active form of chlorine, can be produced in solution by addition of solid, liquid or gaseous chlorine products to water. Calcium hypochlorite, a solid form of chlorine, is uniquely suited to solving real world needs in developing countries due to its stability and ease of use. Liquid bleach looses its efficacy with time, particularly when exposed to sunlight or heat. Chlorine gas requires the use of trained personnel and specialized equipment such as gas cylinders and regulators. Solid calcium hypochlorite has a 1 year shelf life and may be dissolved in water without specialized equipment. Arch Chemicals has production plants strategically located in the United States (Charleston TN), South Africa, and Brazil, giving global access to calcium hypochlorite. Calcium hypochlorite is used in over 100 countries for all types of water treatment needs, including drinking water and waste water treatment.

Chlorine gas is derived from sodium chloride by electrochemical means using commercially developed methods that date back to the beginning of the twentieth century. The first use of chlorine in water treatment is believed to have been in England in the 1880s with the application of "chloride of lime" or calcium hypochlorite. Calcium hypochlorite was found to be a convenient way to bring the chemistry of chlorine, in concentrated form, to the application site. Calcium hypochlorite of the twenty-first century differs significantly from that of 120 years ago. The chemistry of the majority of current commercial calcium hypochlorite production processes relies on three basic equations:

Sodium hypochlorite is made by chlorination of caustic:
$2NaOH + Cl_2 \Rightarrow NaOCl + NaCl + H_2O$

Chlorination of lime produces calcium hypochlorite and calcium chloride:
$2Ca(OH)_2 + 2Cl_2 => Ca(OCl)_2 + CaCl_2 + 2H_2O$
Calcium chloride is converted to calcium hypochlorite by sodium hypochlorite:
$2NaOCl + CaCl_2 => Ca(OCl)_2 + 2NaCl$

Another patented process for producing calcium hypochlorite that is unique to the Arch Charleston facility, may be described by the following equations:

Hypochlorous acid is made by chlorination of caustic:
$Cl_2 + NaOH => HOCl + NaCl$
Calcium hypochlorite is then made by reaction of hypochlorous acid with lime:
$2HOCl + Ca(OH)_2 => Ca(OCl)_2 + 2H_2O$

The only two byproducts in this reaction are water and very pure salt (NaCl). The salt is recycled back to the chlor-alkali electrolytic cell for production of more chlorine gas. The calcium hypochlorite made with this process is the most pure product available on the market because it contains only calcium hypochlorite and water. It also has the highest available chlorine (78%) of any calcium hypochlorite product on the market.

Arch is a proponent of the American Chemistry Council (ACC) Responsible Care initiative. Two of the main goals are to "prevent accidents, injuries or harm to the environment" and to lead in "ethical ways that increasingly benefit society, the economy and the environment". Throughout production, as the calcium hypochlorite material is made, filtered and dried, Arch takes advantage of the many opportunities to recycle process streams, to minimize waste production and maximize raw material usage and efficiencies. The following case studies illustrate the commitment of the Chlorine Chemistry Council (CCC) of the ACC and Arch Chemicals to use the chemistry of chlorine for the benefit of society.

## Case Studies

Safe clean drinking water is one of life's fundamental needs. However, today there are at least a billion people who are deprived of this basic necessity. The result is illness, disease and death. Researchers at the World Health Organization estimate that the disease burden from inadequate water, sanitation, and hygiene to be 4.0% of all deaths occurring worldwide[4]. The immediate need of people in developing nations is water that is free of microbiological contaminants. Experience has taught that low cost, low technology applications work most effectively in these impoverished areas.

## Malawi [5, 6, 7]

Quoting literature from the U.S. Centers for Disease Control and Prevention (CDC): "Unclean water can carry a variety of parasites and infectious diseases. Cholera is one of the most dreaded. It sweeps into communities, beginning with just a case or two. By the afternoon, there are a hundred. The next day, there are a thousand... Cholera brings on debilitating cramps, vomiting, and diarrhea, draining the body of fluids, salts and electrolytes. In severe cases, cholera victims can lose up to one liter of fluid per hour. It can cause death in 12 hours. People can change from being perfectly healthy to being so dehydrated that they go into shock."

A safe water system (SWS) was developed by the CDC, and is promoted and distributed by Population Services International (PSI) with support from the U.S. Agency for International Development (USAID), the Dutch government, UNICEF, CARE and the World Health Organization.The SWS consists of a bottle of bleach solution that disinfects water at point of use. The disinfected water is stored in a simple, narrow-mouthed plastic container to help prevent re-contamination of the water.

Access to chlorine is an important issue for this and many other projects in remote areas. Initially the SWS kits were based on small solar powered chlorine generators that produced chlorine from salt solutions. The theoretical limit for the systems was 1% chlorine, but in practice, the CDC has found that they could only get 0.5–0.6% chlorine solutions. The CDC has switched to using private companies to generate more concentrated bleach solutions which are then sold at very low cost to the end users. In some countries, sodium hypochlorite is used as the bleach solution. In Malawi, they use Arch calcium hypochlorite to make the bleach solution. Arch has provided CDC epidemiologist Rob Quick with a simple formula for making the bleach solution.

Another important issue is education of the people so that they understand the link between contaminated water and diarrhea. A great advantage of the SWS is the immediacy of the health impact. Improvements in infrastructure, though important, are costly and take years to complete. The SWS can be provided inexpensively and quickly. Along with safe water, the disinfecting system creates a sense of empowerment in small villages and communities. According to Rob Quick, "They realize they can do something to improve their lives."

Although it is difficult to track the absence of an event such as a cholera outbreak, CDC field trials from several countries show a 44–85% reduction in diarrhea episodes when the SWS is used correctly. A substantial reduction in the number of diarrhea episodes directly improves children's health, nutrition, growth and development, and has the potential to reduce dramatically the fatality rate. Lively, healthy children are more likely to grow into active, bright adults that can take action to bring themselves and their country out of poverty.

**Guatemala** (8, 9)

Less than half of rural Guatemalans have access to running water, only a quarter have access to electricity and less than one in ten have access to modern sanitary facilities. Infant, child and maternal mortality rates are among the highest in Latin America, despite decreases in recent years. Infant mortality for the country is 40 per 1,000 live births, but for indigenous children it reaches 46 per 1,000 live births and doubles in isolated rural indigenous areas(10). Diarrhea accounts for 25% of these deaths, making it, along with acute respiratory illness, the leading cause of under-five deaths. Intestinal infections are the leading cause of death among females and the leading cause of morbidity for both sexes. Diarrhea is a serious health problem in Guatemala and can be significantly reduced. It is estimated that approximately 90% of the diarrhea disease burden is related to the environmental factors of poor sanitation and lack of access to clean water and safe food.

With funding from CCC and Arch, the American Red Cross is working with the Guatemalan Red Cross in helping communities to implement locally-appropriate and sustainable water and sanitation systems. Many of these communities are inaccessible to four-wheel drive vehicles, and the only way to reach them is on foot. As discussed previously in the Malawi case study, access to chlorine and education are key issues in Guatemala. Many of the people in rural Guatemala have never been to a city where chlorine is made. Often bleach solutions are bought and distributed by a local merchant who will make the two day round trip to the city approximately once a month.

Guatemalans are familiar with bleach because they use it to clean clothing such as the shirts of their school children. The Red Cross has built upon this familiarity and has been educating the people about the disinfection capabilities of bleach and the proper techniques for sanitizing their drinking water. They have also been assisting the Guatemalans in building domestic roof water harvesting systems. Much of the rain water is used for washing and cooking, and a small percentage is sanitized with chlorine for drinking water. Unfortunately, the amount of water collected during the rainy season is not enough to last through the rest of the year, so that the people often go back to using the river water which is contaminated by upstream oil production facilities and cows. Education of the Guatemalans is important to show them the value of retaining some of the rain water for drinking water so that they will not have to drink the river water even if they will have to use it for washing and cooking. In remote rural villages where literacy rates are extremely low and local dialects are spoken, education of the people is very difficult. However, it is important to communicate the link between contaminated water and illness so that the people will understand what they need to do.

**Honduras** [11, 12]

In rural Central America, government agencies and international organizations have built some basic water treatment systems. Typically, an electric pump is used to get the water from the source to a hill-top storage tank. Chlorine solutions are dripped into the storage tanks, and the water is distributed to the community by gravity feed. The systems are not very complicated, however without the institutional capacity to manage water systems, the proper training of locals to provide maintenance, or the generation of revenues to operate the system, community water system infrastructure falls into disrepair and often quits operating. The result is predictable and tragic. Systems are often in disrepair or inoperative leaving communities in peril. The following statistics illustrate the situation in Central America:

- the Pan American Health Organization estimates that 77 million people have no access to drinking water in their homes and 54 million additional people obtain water from unreliable sources that represent a significant health risk;

- between 1990 and 1995, diarrheal diseases were the cause of 55% of all deaths among young people in Honduras, 50 % in El Salvador, and 45% in both Nicaragua and Guatemala. By comparison, the estimated mortality rate in the same period of time in countries with more advanced water treatment was much lower with Puerto Rico at 0% and < 3% in Chile.

The need for water treatment in Honduras is particularly acute where 54% of the population of 8 million is rural. Arch has been able to play a role in Honduras by co-sponsoring with the International Center the Johns Hopkins School of Public Health to conduct field research on the use of calcium hypochlorite feeders by Honduran villages. Amy Henderson and Dr. Bradley Sack from the Johns Hopkins School of Public Health have been performing a study to determine the optimum sanitizer feed system in Honduran villages. The Honduran government has installed Sanna systems in many of the villages. The Sanna system is composed of a small dilution tank which drips into the community water storage tank. These systems are locally produced and are very inexpensive. Water flow into and out of the dilution tank and storage tank is continuous. However, addition of granular calcium hypochlorite to the dilution tank is typically performed only once a week. As expected, the chlorine dosage can vary significantly with this system. An added disadvantage is that the calcium hypochlorite slurry is not stirred, so the granules settle to the bottom of the tank, do not dissolve fully, and block the drainage tube.

An alternative tablet feeder supplied by NORWECO and the Honduran Association of Water Boards (AHJASA) is being evaluated by the Johns Hopkins team to determine if the operation would be more reliable. The tablet feeders may be loaded with chlorine tablets that dissolve slowly and provide a more consistent chlorine dosage. Preliminary data from the Johns Hopkins study indicates that new calcium hypochlorite tablet feeders may be an improvement over the granular system. With the tablet feeders, average chlorine concentrations at the storage tank were 1.2 ppm, whereas the Sanna system storage tanks had an average of 0.67 ppm chlorine. The tablet systems had chlorine measurements at the tank within acceptable ranges for 90% of the samples taken, while the Sanna systems were only sanitized sufficiently for 13% of the samples taken. For four of the five communities using the tablet feeder, the chlorine concentration was >1 ppm for 100% of the samples taken at the tank. The Sanna systems in the other communities were much less reliable.

A disadvantage of the tablet feeders is that they are more expensive than the granular feeders, and the tablets themselves are more expensive and not as readily available as the granular material. The tablet feeders are able to disinfect 30 gallons of water per person per day for 1.5 USD for systems providing 500 to 200,000 gallons per day. The equivalent cost of using the Sanna system is 0.60 USD per person.

Again the two key issues of education and availability are central to this project.

Working with the International Rural Water Association, the Honduran Association of Water Boards (AHJASA) has established a "circuit rider" program where traveling professionals conduct formal training sessions and provide technical assistance to communities. As part of the program, one or more chlorinators is purchased and installed locally with the help of the circuit rider. A democratically elected water board is established, and the community thereby takes responsibility for buying the chlorine and maintaining the system. The data from the Johns Hopkins study is now providing guidance to the circuit riders to be of greater service. Part of the success of the tablet feeders may be due to the fact that these systems are managed locally with more accountability and intrinsic commitment, in addition to the technical advantages.

## Conclusion

Any global water strategy must take into consideration low cost, low tech water treatment that may be put into the hands and under the control of local people, as well as training of citizens on the need, application, and benefits of drinking water treatment. Because access to clean water sources is virtually non-existent in many parts of the world, chlorination of contaminated water is often the only practical choice to address an extremely acute need that must be met while source protection efforts are pursued.

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# III. PERSPECTIVES

One human being out of six, i.e. one billion people lack access to any form of fresh water supply within one kilometre of his home. Two billion people do not have enough water to cope with elementary sanitation needs. The World Health Organisation (WHO) estimates that 1.7 million people, mostly children under five, die every year of diarrhoea. ***Fresh water is life!***

Water is needed for all kind of human activity : food, sanitation, health, leasure, agriculture, energy, industry. Protection and management of water resources are key factors for economic and social development. ***Water availability is THE mandatory basis for a sustainable development.***

During the XX$^{th}$ Century, the world population has tripled but water consumption has sextupled. The industrial revolution has brought an incredible change in the way of life: life expectancy, comfort, well being, access to culture, to information, to travel have reached an unprecedented level in developed countries and progressively in the rest of the planet. But this progress has been accompanied by a major pressure on the environment. To cite only one example, it is estimated that more than 80% of all urban waste water in South America, about 60% in Asia, are discharged to water reservoirs without treatment! This impact should worsen because the world population is still increasing at a fast pace. Therefore, access to water of good quality and to sanitation is now a vital international issue.

The United Nations Millennium Development Goals and the World Summit on Sustainable Development (Johannesburg, December 2002) have fixed a major objective : to halve the proportion of people unable to reach or afford safe drinking water or improved sanitation by 2015. To achieve such an objective, more water must be found, analysed, purified, saved, stored, distributed. Available resources must be protected from potential pollution due to improper domestic, agricultural or industrial use. Pesticides, nutrients, heavy metals, urban or transportation wastes put our drinking water into jeopardy. Chemistry, biotechnology, chemical engineering, environmental sciences in general are key players in that formidable challenge.

## Basic Research

Water is the most important material in Earth history, in human culture, in all present and future social activities. $H_2O$ is the most important biomolecule: *no life form is known in a water-free environment.* Liquid water is the most abundant form of water on Earth. In that respect, our planet seems to be an anomaly in the Universe.

Detecting the presence of water on other space bodies is a permanent challenge, as is considered as a prerequisite for the maintenance of life.
Water is currently taught to be a small molecule: its molecule, depicted as a "Mickey Mouse head", is composed of two atoms of hydrogen bound to one of oxygen. In fact, this is not a fully correct representation because it does not take into account the hydrogen bonds. In liquid and solid water, each oxygen atom is closely associated with three or four other oxygen atoms by a "hydrogen bond", due to dipolar interactions. It has been said that all the oceans represent only one gigantic molecule of water. Consequently, water has very abnormal properties. To cite just a few : it is the only compound to exist on Earth as a solid, a liquid and a gas; strangely enough, the density of the solid, ice, is lower than that of liquid water and therefore ice floats on liquid water; also, compared to other binary oxygen-compounds such as $CO_2$ or $SO_2$, or to other binary hydrides such as $H_2S$ or $H_3N$, water has anomalously high melting and boiling points, and exceptionally high latent heats of fusion and of vaporisation, so that oceans, lakes, glaciers act as thermal buffers ; etc.

The apparent simplicity of the water molecule contrasts with the complexity of the water material and of the chemical/biochemical aqueous systems. The remarkable properties of liquid water stem from its ability to form dynamic, labile H-bond networks, constantly changing, giving an exceptional structural flexibility to the water "molecule". Research in that field is very active thanks to novel and powerful tools such as time-resolved infrared laser spectroscopy and ultrafast electron diffraction. The femtosecond time resolution attained allows detailed study of the behaviour of the H-bond networks. Instantaneous "snapshots" (on the attosecond – $10^{-18}$ s – time scale) may now be obtained by X-ray absorption spectroscopy and Raman scattering. We may expect some new startling results, determinant for our understanding of the origin of life, of the structure of biological systems, of atmospheric phenomena or for the development of new environmentally attractive processes. Thousands of books, treatises, reviews and monographs deal with water peculiarities.(*)

We know a dozen or more crystalline forms of solid water, not just the ordinary ice (plus several amorphous ones). Their structures are still under scrutiny by X-ray and neutron scattering and computer simulation. The topology of the hydrogen-bonded network is only partially understood, many molecular details remain elusive. Liquid water preserves, near 0°C, much of its ice-like tetrahedral structuring with differences in hydrogen-bonding patterns (chains or rings).

The interaction of a water molecule with its neighbours – i.e. the "water structure"- is of key importance for understanding the properties of aqueous systems. The simplest system is the solvated proton $H^+$, $nH_2O$, characteristic of the aqueous acid-base reactions. The proton seems to be surrounded by n molecules of water forming

*(*) See, for example, the special issue on Water of Chemical Reviews (Aug. 2002, Vol. 102, n° 8)*

"clusters". Such clusters have been individually studied with n = 4 to 27. The smallest (n = 4) seems to be the usual form of the hydronium ion ($H_3O^+$,3 $H_2O$). The case n = 21 is the most frequent structure, so that we may consider that the hydronium ion has a great probability to be in the middle (or on the edge) of a cluster having the shape of a highly symmetrical pentagonal dodecahedron. We may remember that it is also the case for clathrates, cages formed by water molecules surrounding non-polar molecules (such as methane).

The study of the methane clathrates is particularly important. We know that huge quantities exist either in the Siberia permafrost or on the ocean bottoms along continental margins. They represent either an exciting new source of natural gas, if we succeed to find an adapted recovery process, or a potential source of catastrophic increases of the greenhouse effect if they were to leak. These gas hydrates, stable in the bottom of the oceans, induced the idea of storing the greenhouses gas as $CO_2$ hydrates in the deep ocean. First tests have been encouraging. An evaluation of the biological impacts is under scrutiny. Effects on the wildlife will have to be compared to the consequences of the present increase of $CO_2$ concentration in surface waters.

The study of the contact between water and materials is of utmost importance. Stability of molecular assemblies in aqueous solutions is a central topic in biological discussions. Hydrophobic effects are believed to stabilize globular proteins, to drive the formation of micelles, to explain the role of bilayer membranes and many other aspects of life science. During the recent decades a great interest was given to the interfaces between water and membrane systems including biological relevant surfaces. These questions are important in biotechnology and nanotechnology. The understanding of the hydrophobic effects plays a role in determining the structures and behaviour of biological macromolecules such as proteins.

On the planet, water is constantly cycling. It vaporises from the oceans to be dispersed in the atmosphere as a gas, water vapour, or as droplets or solid crystals in clouds and then returns to the surface by means of precipitations, rainfall, snow or hail. Solar energy is the engine of this huge "heat pump". Water is the most important agent in the heat cycle affecting the atmosphere, not $CO_2$, nor $CH_4$ . As such it plays the major role – affected by the greatest uncertainty – of any climate prediction. The latent energy of the water vapour plays a very important role. When water vapour condenses, this energy is released, but not at the place where it was absorbed by evaporation. In addition, this heat depends on the local temperature and is a driving force for atmospheric circulation. Each step of this "water cycle" is being carefully studied.

Researchers are debating the impact of clouds on the climate. They cover about two-thirds of the global surface, they trap some heat and reduce outgoing infrared emission to space but they also increase the reflection of solar radiation. These effects partially cancel each other in certain areas, but not everywhere. In Europe, about three fourths of the greenhouse effect is due to water vapour or clouds. Water concentrations vary widely in the atmosphere and with the temperature. Winds have a strong influence on the condensation, the evaporation and the transport of water vapour, causing a considerable variability of humidity from place to place. Presently the net effect of clouds is to cool the planet but nobody knows how that balance will change in the future.

The physico-chemistry of clouds is a field of intense research on the nucleation processes, the coexistence of supercooled water droplets and ice particles, the mechanism of ice-particle formation and growth, the precipitation formation, the adsorption of pollutants and the chemical reactions catalysed by the surfaces of ice crystals in stratospheric clouds, etc. The presence of aerosols has a large effect on the atmospheric chemistry and on climate, indirectly by increasing the number of droplets in a cloud. The aerosols may be anthropogenic or biogenic (e.g. sulfates due to oxidation of dimethyl sulphide produced by the phytoplankton, or non-methane hydrocarbons and other organic compounds from terrestrial vegetation). Aerosols may exert a climate forcing comparable in magnitude, but opposite in sign, to that of the greenhouse effect. The aerosol production is dependant on several factors, e.g. the plankton dynamics which is influenced by ocean circulation.

Another factor of change of Earth's temperature is the behaviour of the huge ice sheets of Greenland, the Arctic Ocean and Antarctica, the largest reserves of fresh water on Earth. During the last decade an accelerating decay of the sheets was detected. A reason for this is the increased melting of the ice due to an increased temperature during summers, in some places compensated by an increase of snowfall in winter, but this is no longer balanced. Still more important is the accelerated melting of continental glaciers into the ocean. The cause and the mechanism of this phenomenon are not understood. It represents a major threat for humans, because it leads sea-levels to rise more rapidly than predicted from purely thermal models. Presently, the sea-level rise is in the range of 2 millimetres by year. Because of the accelerated decay of the ice sheets, it might become much higher in the future, for example 5 to 10 metres in two centuries (if the Greenland ice sheets melted completely, South Florida and a large part of the Netherlands, not to speak of many small oceanic islands, would be flooded). The physical system glaciers / sea currents / sea-water temperature might be more important for Earth's climate than the greenhouse effect of atmospheric gases. In fact, the two systems are not independent; their interaction needs to be seriously studied. The oceans are the major repository of anthropogenic $CO_2$, they store nearly fifty percent of the $CO_2$ emitted into the atmosphere mainly as the result of fossil-fuel burning.

One fourth of the world population (50% in the USA) rely on groundwater for their primary source of drinking water. During recent decades we have observed a significant depletion of the aquifers in many countries: North China, India, Saudi Arabia, the High Plains in Central USA, etc. This depletion is a serious threat to irrigated agriculture. A better knowledge of the groundwater systems, their boundaries, their sources, their storage capacities, their pollution, etc., is absolutely required. Some aquifers are non-renewable, their water accumulated thousand of years ago and they get little or no replenishment from precipitations. Fortunately most aquifers are replenished by rainwater seeping into the ground but some are overdrawn. The predictive capability of the computer flow models permits forecasting of the aquifer response to the increasing consumption and to envisaged climatic stresses. Obviously, the potential validity of such predictions depends on the correctness of the models, on advances in instrumentation and, above all, on the quality of the available data at various scales. The results can be very sensitive to minor uncertainties. A lot of research remains to be done.

Aqueous interfaces are important in many physical, chemical and biological processes. In particular the contact between atmospheric gases and oceanic waters play a key role in the composition of our atmosphere and consequently in the "greenhouse effect". The exchange of ions and solutes between an aqueous solution and a hydrophobic surface are among the most important processes in living organisms (respiration, ion transport, protein folding, anaesthesia, etc.) and in some technological areas (oil extraction, lubrication, semiconductor processing, etc.). We are far from a full understanding of surface water hydrogen bonding and adsorption at aqueous interfaces. In that field, according to the specialists, we are "in the dark ages".

Thanks to its polar structure, water is a good solvent. In Nature, water is never pure: it always contains dissolved substances giving their qualities to the "mineral" waters or their danger to contaminated ones. In its processes, the industrial organic chemistry was developed almost exclusively using organic solvents because of the poor solubility in water of many reactants; many but not all (carbohydrates, peptides, nucleotides, many alkaloids, etc.). In the last two decades, chemists have investigated with some success the possibility of using water, in particular supercritical water, as a solvent in classical organic reactions. There are three types of advantages: lower costs, improved safety and lower environmental concerns. This new chemistry may also aid our understanding of biological processes. It may have biotechnological applications. The use of water as an organic-reaction solvent is an active chapter of the newly developed "green chemistry".

High-temperature water (HTW) – i.e. above 200°C – is attracting attention as a medium for organic chemistry. It includes supercritical water (SCW, $T > 374°C$, $P > 218$atm.). The use of HTW is motivated by the wish to develop more environmentally benign chemical processes. HTW is been extensively studied. Nevertheless its structure is not adequately reproduced by existing models.

It exhibits properties different from those of ambient water: for example, some organic molecules become completely miscible in SCW, the solubility of most gases in water decreases as temperature increases but a minimum is reached (for $O_2$ around 100°C). In HTW hydrogen bonding decreases but does not disappear. The structure of SCW is not yet understood. The reactions in HTW are principally hydrolysis (ethers, esters, amines, halides, amides), hydrations (nitriles), hydrogenations and free-radical oxidations.

In short, despite the wealth of very valuable information available, much remains to be studied and understood about water!

## Analytical Sciences and Technologies for Water

### *Table 1: Workshop 1 – Analytical Sciences and Technologies for Water*

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Dr. Jacques GOUPY – ReConFor – *Chemometrics: a Tool to improve Water Quality.* (jacques.goupy@wanadoo.fr)

Dr. Olivier DONARD – *Université de Pau et des Pays de l'Adour – Speciation of metals and metalloids in waters: stakes and perspectives. From research to regulation.* (olivier.donard@univ-pau.fr)

Dr. Philippe GARRIGUES – Université de Bordeaux 1 – *Determination of new contaminants in waters.* (p.garrigues@lptc.u-bordeaux1.fr)

Prof. Damia BARCELO – CSIC – *LC-tandem mass spectrometric determination and removal of pharmaceuticals in waste-water treatment plants.* (dbcqam@cid.csic.es)

Prof. Philippe HARTEMANN – Université Nancy 1 – *Potable water supply system: When genotoxical testing overtakes analytical chemisty.* (philippe.hartemann@medecine.uhp-nancy.fr)

Mrs. Barbara LE BOT – ENSP – *Multi-residue analysis of pesticides in water by liquid phase chromatography coupled with mass spectrometry after solid phase extraction.* (blebot@ensp.fr)

Dr. Florence BERNE – Université de Potiers – *Specific analysis of monochloramine using HPLC.* (berne@esip.univ-poitiers.fr)

Dr. Christine DALMAZONE – IFP – *Analysis of hydrocarbons traces in aquifers.* (christine.dalmazzone@ifp.fr)

Dr. Jean-Jacques EHRHARDT – Université de Nancy 1 – *Are the water/solid interfaces a sink or a reservoir for contaminants?* (ehrhardt@lcpe.cnrs-nancy.fr)

Prof. Marie-Claire HENNION – ESPCI – *Development of bioanalytical assay and biosensor for the rapid detection of toxic cyanobacterial blooms.* (marie-claire.hennion@espci.fr)

Mrs. Chantal COMPERE *et al.*, IFREMER – *Biosensors for the detection and monitoring of toxic algae.* (chantal.compere@ifremer.fr)

Mr. Nabil EL MURR – Université de Nantes – *Is it time to take seriously the researches on biosensors for water quality?* (nabil.elmurr@chimbio.univ-nantes.fr)

Mrs. Geneviève ARZUL *et al.* – IFREMER – *The use of phytoplankton in marine water quality assessment.* (Geneviève.Arzul@ifremer.fr)

Everywhere it is essential to know and to measure the quality of water in terms of inorganic or organic chemicals coming from natural or anthropological sources. Analytical sciences and technologies are involved in all phases of the water cycle, first in contaminant identification, then in the chemical or physical purification process, and finally in quality validation, according to various uses and regulations. Analytical sciences are clearly the basis of environmental chemistry. Their sophistication, although very high, is being continually developed. New fields have been opened at the interfaces between chemistry, biology, earth science, in order to understand how molecules behave in water in all kinds of situations. Signal capture, measurement, identification, screening, analysis, data processing / modelling, quality insurance and simulation are the elements of the "analytical chain". Through 16 papers and 9 posters, the workshop I gave some examples of the intensive research in this domain (see Table I).

A few years ago a major problem emerged, due to medicinal and chemical organic pollutants residues in water. Pharmaceuticals removal, identification and elimination of biocontaminants have been extensively investigated. Sophisticated methods such as the integrated chain SPE/LC/ESI/MS–MS were developed and successfully applied to betablockers, anti-inflammatory agents, etc. Selectivity and sensitivity are from 10 μg to 10 ng/L. Recent experiments carried out with a membrane bioreactor as an additional treatment show how to remove drugs in waste water effluents. The detection of toxins in blooms found in eutrophic fresh water using disposable kits is promising and a cheap way specially adapted to countries in development. So microcystins act as tumor promoters at the nanomole level. But the analytical detection is difficult due to the number of variants and also to the lack of commercially available standards. A highly sensitive bioassay has been developed and a model based on pure additivity of microcystins effects, was established and is fully in agreement with experimental observations.

Special attention should be focused on bacterian / microbian contamination in tropical and equatorial countries leading to hard infectious diseases.

Genotoxicity testing is an approach which could even overtake analytical chemistry. Indeed, the use of organic materials takes an important role in drinking water systems distribution. Based on complex formulations, migration to drinking water may occur and the potential effect of a mixture of such molecules on health remains entire, and synergy between those compounds released at very low concentration, can produce hazardous effects. So it is necessary to identify the long-term genotoxicity and not only the acute toxicity of each compound.
Papers have been published on selective extraction and on treatment by an advanced oxidative process such as the electrophoto Fenton reaction producing a total mineralization of pollutants. It has been applied to pesticides and phenols. These techniques are still in development and in optimization phase. But their future is very promising, in particular by coupling with other process.

Another important field is concerning the chemical speciation of metal traces in water. The recent development of hyphenated techniques mixing chromatography and atomic spectrometry has produced successful results to follow the behavior and the fate of metal traces in the environment. The sensitivity is now at the level of femtogramme per litre. All systems using ICP/MS detector enable one to follow the transformations of metal complexes (precipitation, dissolution, coagulation).

Disinfection of drinking water frequently uses monochloramine instead of chlorine. A specific method has been implemented and calibrated on the traditional TRC method. Screening methods play a key role in monitoring and in quality assessment in water bodies, either large or small, where the chemical risk is strong. In that case in situ sensors allow on-line measurements. The challenge is based on low cost sensors and on validation of the methods which is the key of analytical process. The demonstration of this validation in terms of viability and of robustness is now a fundamental program, as is the socio-economical impact of the tools developed. This remark is particularly important as far as the developing countries are concerned.

The concept of "home-made methods" is now taking place on a parallel way to that of standardized method and to that of international validated reference methods which are not yet archived. The development of new analytical methods is now necessary for identification and survey of new contaminants in water. That is why one can propose various types of laboratory accreditation, as well as accreditation of restricted lists of compounds and methods. For the future, these new approaches are believed to be more economic and highly productive. This point is also important for developing countries.

Another important area is the analysis of hydrocarbon traces in aquifers, focusing in particular on all the information concerning the fate of the hydrocarbon pollutants which can be processed by simulating flow in the subsurface and transportation in ground water.

Finally, special attention should focus on research, development, and promotion of biosensors. Despite the fact that sophisticated analytical tools are available in laboratories to perform such measurements, inexpensive new analytical tools are still required to answer the industrial needs; and they must be reliable and usable on site by unskilled people, especially in poor countries. Amperometric biosensors, particularly those based on an enzyme-modified carbon paste working electrode, are good candidates to respond to such requirements. Indeed, very promising biosensors were developed using organic-phase modified electrodes (carbon paste, binder paste or graphite epoxy resins). The carbon paste design allows bulk modification of the entire electrode material with different receptors. It also enables the incorporation of a variety of different additives such as enzyme stabilisers, mediators, activators or other compounds that can increase the stability, amplitude, and selectivity of the response signal. Reagentless sensors offer the advantage of fast and high amplitude responses. Numerous biosensors have been developed and their analytical characteristics have very often been established as corresponding to the demands of the modern analysis while very few are available on the market. Such discrepancy may be attributed to the lack, in many cases, of operational as well as long-term storage stabilities convincing enough to persuade potential biosensor producers. A new application of biosensors is to struggle against toxic algae which rapidly expand and become a real danger for seas and a social problem.

Some strains produce neurotoxins responsible for paralytic poisoning, whose accumulation in shellfish represents a real risk for human health. The current analytical method is too time-consuming and need experts. So, a fast, selective and sensitive detection of toxic algae would represent a major contribution for solving that problem which is as much sanitary as economic. IFREMER Institute has developed and tested two types of molecules, monoclonal antibodies, of the cell wall, and nuclei acid probes of the target species used as biological components.

From papers and posters presented at CHEMRAWN XV it appears clearly that many efficient, versatile and reliable analytical techniques are already available. But new medicinal and biological contaminants regularly come out. Their detection, their danger, their extraction should be studied. New biosensors and other biological tools are investigated. Another problem is due to the transfer of atmospheric pollutants into surface and subsurface waters. They may develop undesirable effects, inducing new sanitary risks. Analytical research is endless.

## Agriculture and Water

### *Table 2: Workshop 2 – Chemistry, Agriculture, Soil and Water*

***Chairman: Dr. Guy PAILLOTIN – Conseiller du Directeur général de l'INRA (provost@paris.inra.fr)***

***Secretary: Dr. Gérard PASCAL – INRA (pascal@paris.inra.fr)***

Dr. Enrique BARRIUSO – INRA – *Methods and equipment to study pesticides behaviour in the environment.* (barriuso@grignon.inra.fr)

Dr. Christian GUYOT – Bayer Crop Science – *Risk reduction in use of agrochemicals: new molecules, new practices.* (christian.guyot@bayercropscience.com)

Dr. Philippe JEAN – SOGREAH – *Risk evaluation of ground bioremediation: case study.* (philippe.jean@sogreah.fr)

Dr. Romain BRIANDET – INRA – *Biofilms: microbial ecology, resistance to treatments and impact on water quality.* (romain.briandet@jouy.inra.fr)

Mrs. Christiane LAMBERT – *Forum de l'Agriculture Raisonnée et Respectueuse de l'Environnement (FARRE) – Integrated farming, one example: pig farming in Brittany and the Netherlands.* (christiane.lambert4@wanadoo.fr)

Dr. Virginie DANCEL – NESTLE-France – *Composition, treatments and specificities of effluents in food industry.* (Virginie.dancel@fr.nestle.com)

Mr. Didier RAT – *Direction générale de la forêt et des affaires rurales, Ministère de l'Agriculture – Use of sewage sludge in agriculture : evolution and international situation.* (Didier.rat@agriculture.gouv.fr)

If world population continues to increase in line with forecasts, it will reach nine billion people within 20 years. From a nutritional angle, this will lead, especially in poor countries, to an increase in food production of animal origin, as well as of vegetable origin estimated at 2% a year for the same period. This increase is not out of reach, but to be achieved it will require innovations that will inevitably have to rely on chemistry and on technologies ensuing from it.

However, this would not be enough as two fundamental constraints will need to be lifted: availability of arable land, and access to water.

Water, regarded as the most precious commodity of all, now raises a problem worldwide in terms of resources, accessibility, quality and distribution.

All around the world the need for a wise "management" of water, a vital element for the protection of health and the environment, is inevitably becoming paramount. Agricultural production, health, environment are three cornerstones of sustainable development, with water as the "vector".

It was not until the early 80s that we came to realise the gap between the economic objectives and the necessity, hardly voiced until then, for the protection of the environment in terms of a rational use of fertilisers (use of pesticides) and water pollution by nitrates, phosphates and plant protection products. This is what is known as supervised agriculture, itself stemming from the 70s' concept of integrated agriculture.

Supervised agriculture aims at controlling the impact of farming production on the environment (and not the other way round), while retaining economically viable conditions, without any technological prohibitions, but with every decision needing to be justified. It is an expectation of society that has resulted in the establishment of an "agriconfiance" [agritrust] reference.

The controlled agriculture approach naturally ties in with the current sustainable development initiative which is the subject of many projects and actions.
The application of these rules concerns primarily:

- inputs: energy – water – other production factors;
- outputs: waste – discharges (liquid manure);
- treatment products and their metabolites.

Inbetween lies the soil, the earth sustaining agricultural production.

**Analysis of the earth and process engineering: a "supervised" agriculture perspective**

An analysis of the earth is required not just to meet the needs of traditional crops in terms of yield, but also to better control the management of inputs, prevent an imbalance of soils and their decay, control emissions liable of having negative effects on the environment, and ensure the quality of crops nutrition- and healthwise.

Water is the vehicle transporting both nutrients and discharges. Analysing and monitoring its progress in the ground is indispensable for the proper control of its consumption. It is clear that chemical, physico-chemical and biological analysis has a real sense only as an integral part of a global vision of the agricultural process. It is indispensable to explain the kinetics of the transfer of water and nutrients to the interfaces of the radicular systems that govern the various stages of a plant's growth.

The ground is in reality a chemical and biochemical reactor whose mechanisms are not unlike those of process engineering with the consideration of the parameters which command the transfer of nutrients in the ground and their penetration in the roots. The development of a mathematical model of the ground reactor would be a means of progress in every area of controlled agriculture.

In a wider context, the issues concerning the environment are not virtual: quality of water (salinisation of groundwater, biodiversity in streams, various pollutions, eutrophication, floods, etc.), conservation of the ground, fight against the greenhouse effect, biodiversity, animal wellbeing, respect for the constituent elements of the landscape, energy saving.

The problem of inputs cannot be reduced to a technical issue alone, their cost being a major and critical factor for developing countries. To want to curb their use by raising their cost is an attractive, "economically correct" avenue, but with singular limits. It can for example deal partly with the question of water quality, but not entirely; so how could it resolve the problem of the effects of irrigation on soil erosion or the proliferation of crop pests? Additionally, neither the case of nitrogen nor that of plant protection products can be settled by costs related to the scarcity of resources. Some people dismiss this point as unimportant, and this makes a good case for the true challenge of sustainable development that consists in articulating in optimum terms economic, social and environmental constraints.

From a rather more concrete angle, it is the control of production risks that, for the main part, provides the link between the productive and the environmental dimensions of agriculture. How to satisfy the nutritional needs of plants and animals, without excess or scarcity? How to take reasonable action against plant pests, parasites and pathogenic agents in animals? These are some of the questions tackled by controlled agriculture. Only research can answer these questions, and it has already provided some answers.

For example, we know today how to reason, by splitting it, the contribution of nitrogen fertilisers to meet the needs of crops without excess that would harm the environment. On the other hand, it is much more difficult to control the leaching of nitrogen occurring in winter in the absence of crops. However, research has produced early rape varieties which, sowed in winter, act as fairly good nitrate pumps.

Upstream from agriculture are the “agro-supply” industries which produce most of the input, and which all have a direct and indirect impact on the environment. For the former, these industries must acquire ISO type quality assurance procedures. But it is the indirect impact which depends on product quality (poor coating of seeds, incorrect dosage, etc.) and especially information given to farmers. The solution first consists of a quality assurance procedure, coupled with advice independent from the commercial side. This is obviously essential for developing countries.

Workshop n° 2 (see table 2) dedicated half a day to the reduction of risks related to farming inputs. This point is the subject of much debate by the general public in industrialised nations, but it also poses, maybe especially, serious problems in poor countries.

Agriculture is indeed an activity that, for the main part, develops in an open environment in which products can spread, thereby bringing potential risks to health and the environment. The main “vector” of these risks is water, although it is not the only one. The possible pollution of the air by greenhouse gases is increasingly taken into account. Several initiatives are being developed to curb these risks:

- look for more effective molecules, notably in the phytosanitary field, to reduce the doses used. Two options are available, which should not contradict each other: the search for very specific molecules and the chemical option, the genetic transformation of plants to make them tolerant to non-specific molecules. The idea that the first option may be obsolete is not obvious;

- allow straightforward but risk-free use for the users of inputs. It should be noted that, for the main part, pollution from plant protection products is found on the farms themselves or nearby;

- optimise the decay of active molecules in the environment while protecting their effectiveness. The processes involved in this decay are extremely varied, therefore making the use of modelling inevitable;

- finally, these various points should be debated in a global dimension, i.e. without omitting the part played by the farmer in the actual implementation of the solutions he is given.

The second half-day was allocated to case studies, giving a concrete approach to ways of implementing sustainable development:

- one of the strategic objectives of modern farming is to reduce very significantly pollution generated by this activity. The main vector of this pollution is unquestionably water. Hence the idea of reducing drastically the outflows of water and, in parallel, recycle various products, including catalysts. What is striking is that a strategy of this sort implies calling into question the process normally used. This therefore means a genuine revolution of process engineering which particularly calls upon research, innovation ... and organisation of labour;

- the same trend is apparent in the most responsible face of agricultural production. Every basic phase of farming production needs a rethink, except that farmers very heavily depend on the attention which their suppliers pay to environmental issues;

- finally, the major and much debated problem today is that of the spreading of residual sludge from water-treatment plants.

## Conclusion

The role of and need for chemistry in all aspects of life and in its very existence cannot be disputed, even though some scientists and pressure groups have doubts about it.

On the other hand, on the subject of agricultural production for food, controversies remain. Conventional agriculture, biological agriculture and controlled agriculture are set against each other in vain, while in fact the latter is the only one that can reconcile environmental protection, health and the economy all at the same time.

In this approach, chemistry and water are very closely linked and unavoidable, water being the vector for the transport of inputs, although it, too, requires purifying through chemistry.

The workshop set out three main points:

1) identify the risks inherent in the use of chemical substances, and initiate research to reduce them to a level that carries no consequence;

2) acquire effective active molecules, study their implementation and mode of action, understand their post-action fate, and finally devise their production in line with the principles of sustainable development;

3) the third point, by no means the least important, concerns the knowledge of "soil chemistry", both a kinetic and a dynamic process, because of the water which transports inputs. In this field, the modelling of input behaviour in the soil from their introduction through to their consumption must be a powerful implementation tool for farmers, and in the end a guarantee for consumers.

# Industry and Water

After usage, water is generally contaminated. Waste water may contain organic and inorganic matters, dissolved or in suspension, pathogenic micro-organisms, nutrients such as nitrogen and phosphates compounds, toxic substances. Due to the population increase since the nineteenth century and an extensive water usage, water becomes more and more in short supply. It is now a limited resource. In addition, the ecosystem can hardly absorb the pollutant load of contaminated waters. Waters need to be treated to a level acceptable for specific applications. Most of the pollution ends in the ocean. There is no border to pollution.

Water is essential to all living organisms. It is extremely important to know the impact to the environment of pollutants in waste waters; it is vital not to disrupt the fragile equilibrium which governs it. This is the field of the environmental sciences which includes many disciplines like chemistry, physics, biology, ecology. Biotechnology, which uses organisms to degrade chemical species into non-toxic ones, is more and more used in water treatment and soil remediation. This type of process represents an acceleration of processes which often take place naturally in the environment.

To meet the United Nations Millennium Development Goal of halving the proportion of people not having safe drinking water by 2015 requires a new technical approach in addition to proper government policies and proper management in general. Chemistry, environmental sciences, chemical engineering, industrial engineering are key drivers to meet this global challenge.

The first imperative goal is to preserve the water resources; this can only be achieved by proper usage of chemicals and by avoiding contaminant release to the environment. The overall approach should be a sustainable development type approach, "sustainable development" being defined as development which is socially desirable, ecologically sustainable and economically viable. The key issue is to find the best compromise. The best solutions might greatly vary from industrialised nations to developing countries.

**Green Chemistry** is about preventing upstream pollution: "it is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products" (D. HJERESEN). Green chemistry basic concepts should be used in developing new chemical routes or reviewing and upgrading existing ones.)

**Table 3: Workshop 3 – Chemistry, Industry and Water**

***Chairman:* *Dr Alan SMITH – Member of the Bureau for IUPAC and Past President of the Industrial Affairs, Division for the Royal Society of Chemistry (smithazt@aol.com)***

***Secretary:* *Mr Jean-Pierre DAL PONT – General Manager Société de Chimie Industrielle (SCI) and Société Française de Génie des Procédés (SFGP) (del.gen@sfgp.asso.fr)***

Dr. Pascal VIZIER – DEGREMONT – *Advanced techniques in water treatment.* (pascal.vizier@degremont.com)

Dr. Philippe HUBERT – INERIS – *Bioindicators, contribution to monitoring and alert.* (philippe.hubert.directeur@ineris.fr)

Mr. Yves MOTTOT – RHODIA Water – *Challenge for new chemicals in water treatment.* (yves.mottot@eu.rhodia.com)

Mr. Philippe JEAN – SOGREAH Magelis – *Health risks and contaminated soils.* (philippe.jean@sogreah.fr)

Prof. Michel ROUSTAN – INSA – *Chemical Engineering challenges in the field of waste-water treatment* (roustan@insa-tlse.fr)

Prof. Michel SARDIN – CNRS – *Chemical Engineering versus challenge in industrial soil remediation.* (sardin@ensi.inpl-nancy.fr.fr)

Prof. Michael SORIN – CANMET – *Industrial Water and Energy Minimization.* (spinner@univ-perp.fr)

**Chemicals** are widely used in water treatment all along the process from water capture to release.

- Flocculants, coagulants, dispersants are employed to clarify water, i.e. to separate water from suspended solids.
- Chlorine, ozone, biocides are needed for water disinfection. Although chlorine is not totally friendly to the environment, it has largely contributed to improve economically the quality of drinking water.
- Plastics are widely used in water storage, distribution, crop irrigation, sewage. Five million kilometres of pipe have been used in 2003. Plastic pipes are light, durable, easy to transport and to install.
- Plastic sheets are used to fight evaporation in the fields, to control pollution in landfills. Geomembranes in canal lining avoid water losses by leakage.
- Membranes are essential in the process of ultrafiltration, reverse osmosis and in general in water desalination.

There is a need to find substitution to chlorine for disinfection and to find friendly corrosion, scaling and antibacterial products and to develop chemicals capable of eliminating biofilms without side effects on environment and human digestive flora.

**Materials of construction** and, more generally, any materials in contact with water like liners for cast-iron pipes, are submitted to national and international legislations which is becoming more of a constraint. Thanks to the continuous progress of the analytical techniques the threshold of presence of a large number of molecules is regularly reduced. Water industrialists complain about the difficulty to find new authorized materials, e.g. paints, elastomers. The producers are reluctant to be engaged for the requested specifications (at least for fifty years) and the duration of the mandatory toxicological tests is very long (2 to 4 years). During CHEMRAWN XV the water engineers asked the chemists to cooperate in the permanent research of new materials more and more inert in contact with drinking water

**Chemical Engineering** has introduced new concepts like the multiscale approach from nano to megascale and modelling at each scale. For instance, activities of microorganisms at nanoscale growth of bacteria are key to the design of bioreactors. CFD (Computer Fluid Dynamics) is used to visualise the flow pattern processing equipment (at meso and macroscale). Modelling of reactors, plants, systems is largely used to save on experimentation, to zero in quickly to final design.

In the domain of water treatment, engineering challenges of the future are the following:

- design of bioreactors with a high biomass concentration;
- removal of nitrates and phosphorous compounds;
- valorisation of waste water-treatment unit sludge;
- development of new membranes and membranes technology to reduce cost and energy consumption of desalination plants;
- reduction of odorous gases;
- design of new equipment which is more compact, more efficient and safer.

Such a program can only be achieved by a multidisciplinary approach.

A sound industrial water management requires the implementation of efficiency factors like quantity of water used per quantity of fabricated product, BOD per day and so on. (there is no management without measurement ). Also cost analysis, benchmarking, process review, process development, safety analysis, reliability engineering techniques, i.e. the principal tools developed by the chemical industry, must not be forgotten.

**Education and training** at all levels are obviously the basis of the formidable know-how needed to preserve our planet main resource. Moreover, emphasis should be given to differentiate techniques for industrialized countries and for developing countries which need a robust technology that can be implemented and maintained by local people.

# Water Supply and Treatment

Two main topics have been discussed at Workshop 4 (see Table 4):
• new technologies for water treatment and reuse;
• desalination, new developments in membranes treatments.

As it can be expected for an half-a-day meeting, no exhaustive overview could be reached. Nevertheless, the contributions presented during the workshop give a concise view of the modern trends in the field of the water treatments.

***Table 4: Workshop 4 – Water Treatments and Supply***

***Chairman:*** ***Prof. Michael DRÖSCHER – SVP Corporate Innovation Management DEGUSSA (Ge) – Member of the COCI Committee (michael.droescher@degussa.com)***

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***Dr. Philippe PICHAT – SARP Industries (ppichat@sarpindustries.fr)***

Prof. Marie-Florence GRENIER LOUSTALOT – CNRS – *Nouvelles technologies de purification des eaux de piscine.* (mf.grenier-loustalot@sca.cnrs.fr)

Dr. Renaud SUBLET, VEOLIA WATERS – *Optimization of water usage in industry: benefits of a global approach.* (renaud.sublet@groupve.com)

Dr. Maxime PONTIE – CNRS, ENSCP, VEOLIA, ESIP – *Contribution au développement durable des procédés de filtration MF/UF/NF dans les milieux environnementaux : présentation de nouveaux moyens analytiques pour une meilleure gestion du colmatage des membranes.* (pontie@ext.jussieu.fr)

Mr. Bertrand GONTARD – SPYPRED – *La gestion des déchets toxiques, pourquoi avoir dû créer un nouveau métier.* (gdjakovic@sarpindustries.fr)

Mr. Michel FARCY – PALL – *Avantages – inconvénients des différents systèmes membranaires.* (michel_farcy@europe.pall.com)

Prof. Gilbert RIOS – IEM CNRS – *Why and how a so brilliant future for membrane water treatment.* (gilbert.rios@iemm.univ-montp2.fr)

Mr. René PICH – SNF-FLOEGER – *Protection des ressources en eau potable vis-à-vis des déjections animales.* (jpletullier@snf.fr)

Mr. Pierre BECKER – NYMPHEA WATER Co. – *Fresh water production from submarine springs* (m-becker@nympheawater.com)

## Water treatment and reuse

In industrialised countries the water consumption of the industry represents 22% of the global water demand. What are the ways for the best management of industrial water? Different solutions are now used, e.g. a water treatment unit eliminates the pollution before the effluents are discharged, a specific treatment such as reverse osmosis allows water reuse inside the plant.

Veolia Water Co. introduced a new concept called *"Water Pinch"* for the optimization of water usage in industry. With this approach, the plant is designed for using a contaminated stream of water exiting one unit to provide some water to another unit. By thoroughly controlling the pollution of the various streams and mixing them, it is possible to optimize the water consumption inside the plant. That process must be studied with multicontaminant systems with economical and optimization algorithms specific for each industry under consideration.

An interesting approach is to consider the economical incentives offered by the value of the by-products rejected in the water effluents. With the example of the SARP Co., it was shown how an industry based on recycling and treatment of toxic aqueous solutions can be profitable. The pig farm produces an important quantity of waste containing 90% of water and 10% of organic matter with a high nitrogen content and other fertilizing agents. But using that manure for fertilization might pollute the surface and underground waters with chemicals and bacteria. A new process called "Evaflo" was presented for the manure treatment. Basically the process is simple; the first step is a filtration followed by a pH adjustment producing a precipitation of organic materials which are filtered. The liquid phase is distilled and the water obtained is pure enough to be rejected without other treatment (its oxygen chemical demand is only 150 mg/L). The dry matter is used for the formulation of fertilizing agents. By transformation of 800 kg of dung the "Evaflo" process gives 554 kg of clean water, and 215 kg of fertilizer. The cost of the process is about 10 euros per pig, and offer big units for farms with 250,000 pigs, or small mobile units for small farms.

Chlorine is the cheapest product for water disinfection. As a powerful oxidative agent it exhibits bactericide properties efficient to make water drinkable. Public and private swimming pools currently use chlorine for purification of water. However chlorine reacts with nitrogen organic compounds (urea, amino acids and other products) coming from the swimmers. Different types of reactions can take place but one important is the formation of trichloramine, volatile compound which strongly irritates the eyes and breathing organs and can lead to a professional disease for the swimming instructors.

An alternate process for the cleaning of the swimming pool water without chlorine treatment was presented. The process consists in a membrane ultrafiltration for elimination of virus and bacteria followed by a specific resin treatment which removes the basic nitrogen compounds. An experimental pilot unit up to 5 cubic meters showed the feasibility of such a process.

## Desalination, new developments in membranes treatments

The most important resource of water is the saline water found in seas and oceans. The desalination processes are more and more based on membrane treatments instead of evaporation. See Mr. Rovel's article (page 66). In 2001 the sea water desalination was performed by using distillation (65%) and reverse osmosis (35%). The choice is strongly depending on the energy resources of the considered country. Energy-rich nations like Gulf countries still use distillation processes whereas occidental nations, like Spain, use reverse-osmosis processes.

Reverse osmosis needs a water pre-treatment which can be either conventional such as coagulation, filtration on sand, or based on membrane technology. Pall France Co. discussed the scope of these processes. Hollow fibers are now broadly used for the pre-treatment in reverse osmosis units. They avoid the fouling and so increase the time between two cleaning of the osmosis unit. The membrane systems decrease the microbial and bacterial contaminations. It has been shown in USA that a membrane pre-treatment can save 40% of the operational costs. Comparing the costs for water desalination a conventional pre-treatment cost is 0.08 euros per cubic meter, instead of 0.05 for the membrane system. Fouling is a main drawback for a low maintenance use of the membrane technologies. The fouling is a deposit of organic compounds which reduces the permeation through the membrane. Humic acids, polysaccharides and proteins are the natural products mainly responsible for the fouling in low as well as high pressure technologies. The fouling formation in microfiltration, ultra filtration and nanofiltration was studied by an analytical method. The membrane hydrophobicity, the nature of the charge and roughness has been determined in correlation with the fouling. The study was performed with two types of polymeric membranes based on polysulfone and PVDF by using ESCA, AFM contact angle and zeta potential measurements. The microfiltration membranes are more fouling-sensitive than the ultrafiltration ones. On the other hand, the microfiltration membranes based on PVDF lead to a higher level of fouling than the polysulfone membranes. Considering the free enthalpy of adhesion between a foulant and a membrane surface, it is possible to optimize the choice of the chemical structure of a membrane for a specific foulant.

The most important incentives for the development of the membrane technologies are isothermal process, no chemical additives, flexibility and acceptable cost, including implementation and operation. The membrane technologies considering either the chemical structures or the process technology, started only 40 years ago and still are strongly improvable. A new and efficient research program within the European 6th Framewrok Program for Research and Technological Development should give to European countries a technological level similar to USA and Japan.

## Springs in the world

Photo from Nymphea Water - Aubagne - France

In many regions of the world there are springs coming out from under the level of the sea. Innovative technologies open the way for search and catchment of such springs.

Most of the submarine sites are located in calcareous quartzic massifs, which were fissured and then eroded by streaming rain, so creating natural pipes along time, leading finally to large underground networks. They were made during the messinian period, 5.5 million years ago, when the level of the sea was at the bottom. In that time, the Mediterranean Sea was almost dry and the Gibraltar Strait closed. Networks were created, then filled up by sediments about 12 000 years ago when water raised up. Certain springs stopped to run, but others, the nearest from shores continued to be active.

This fresh water is really a manne for certain countries, provided production and management are under control. The technology doesn't request a lot of energy and doesn’t disturb the hydrogeological equilibrium. It is necessary to know the characteristics of the spring by surveying several physicochemical parameters during at least one year. Some geochemistry is needed to identify the signature of the spring in order to know the drainage basin and then the relation between rainfall and spring flow.

## Fresh Water Production from submarine springs

Plateform of fresh water capture Nymphea Water – Aubagne - France

The first worldwide experiment has been realized during the 2003 summer in the Mediterranean Sea between the cities of Menton (France) and Ventimiglia (Italy) by 36 meters depth. The measured flow is 100 L/sec. That is enough to feed either one of these cities.

This first experiment is entirely successful. The technology is now extended and used on the east cost of the Mediterranean Sea and in the Persic Gulf.

## Case Studies

Workshops 5 and 6 were devoted to the presentation of a variety of specific problems. A general conclusion is that specific uses of water and interactions of human activities with water are highly multidisciplinary issues. Chemical processes are key factors dynamically interacting with many other factors, including the local social and individual behaviours. The complexity is increasing with the diversification of chemicals and the improving knowledge of their fate, their evolution and the understanding of the toxicological / ecotoxicological risks.

### *Table 5: Workshop 5 – Chemistry in specific Uses of Water*

***Chairman:*** ***Prof. Gheorghe DUCA – Member of the Academy of Sciences, Minister of Ecology, Constructions and Territorial Development of the Moldovan Republic (duca@mrda.md)***

***Secretary:*** ***Mr. Jean Marc USSEGLIO – Vice-President Consulting Branch SOGREAH (jean.marc.usseglio@sogreah.fr)***

Mr. Michel GIRIN – Research and Experimentation on Accidental Marine Pollution (CEDRE) – *Marine pollution: spills and illicit discharges.* (michel.girin@le-cedre.fr)

Dr. Jean Claude BLOCK – CNRS, Research and Experimentation on Accidental Marine Pollution (CEDRE) – *Assessment of the biofilm formation potential of plastic pipe materials.* (block@pharma.uhp-nancy.fr)

Dr. Birgit FRITZ – Kompetenzzentrum Veolia Berlin – *Cleaning capacity of bank filtration and artificial recharge with influence of treated waste water.* (birgit.fritz@kompetenz-wasser.de)

Dr. Marie-Veronique DURANCE – CASPEO – *Water and mineral industry : from the natural constraint to the processing fluid.* (mv.durance@caspeo.net)

Prof. Norma Sbarbati NUDELMAN – Buenos Aires University – *South America marine coasts contamination by TBTs.* (nudelman@qo.fcen.uba.ar)

## Marine pollution

Although they are given the highest media profile, large oil slicks caused by wrecked oil tankers have significantly decreased over the past thirty years. They are too often the result of unbelievable negligence or careless actions. However they are not the main source of hydrocarbon discharges at sea. As far as hydrocarbons are concerned, discharges from lawful or illicit releases, from land-based industrial activities, deballasting and degassing of ships, have much more environmental impacts on a worldwide level. Action would require challenging the globally established rights to pollute.

Furthermore, highly toxic substances are discharged into sea water by accidental leaks from the cargo of bulk carriers and tankers, as a result of running aground, collision or structural defects. Containers are increasingly falling overboard from decks of container carriers. These pollution sources are very diversified. There is definitely a need for more traceability of products. People who produce and ship chemicals should be obliged to investigate and know what happens to their products when they accidentally are in seawater. They should provide real-time access to relevant experts in case of emergency.

A distortion of environmental regulation between countries was pointed out. Tributyltin (TBT), a biocide component of antifouling paint, represents a high ecotoxicological risk, such as endocrine disorders, for marine ecosystems. TBT has been banned in most developed countries but no regulations have been taken in most developing countries.

TBT has recently been detected in gastropods and commercial mussels in South America, causing critical population decline of these species. This is definitely a global concern: effective and consistent regulatory actions should be decided between the stakeholders (academic and decision-makers) at a more global level.

In marine pollution, regulation, education, information and control issues are still priorities. It seems that chemists and biochemists might be more active in those fields of research and expertise.

## Materials and equipment in contact with water

Biofilm formation in pipes, affecting the quality of water, is a major issue (1 million working days lost per year in the European Union) and may occur on all kinds of materials (iron, copper, plastic). The biomass production leading to biofilm accumulation is a multiparametric phenomenon governed by the organics leaching from the pipes as well as from the biodegradable organic matter carried out by the flowing water. Static tests are often used but are misleading. Only systematic dynamic tests have predictive power and allow comparisons of different materials. The interactions between water and its conveyance systems are very complex but they are of the utmost importance in terms of water quality.

## Water conditioning in industrial systems

Intensive pumping is necessary for the exploitation of mineral resources, constituting a real constraint, generating high costs for the industry. Recycling is often implemented for cooling the drilling and boring equipments. However, a considerable volume of effluents, often contaminated with metals, fine particles, has to be managed. Techniques have been developed to reduce these effluents and convert them from a constraint into an efficient partner in the industrial process.

Water is used as the carrying medium in comminution (size reduction) and in most of the following processing steps : gravity and magnetic separation, flotation, leaching. Water may play a direct role in the transformation as a solvent or the life medium of bacteria degrading the mineral structure. The promising outcome is that these innovations aimed at saving money (through saving water and energy) generally generate lower impacts on the environment. This is an interesting example of convergence of economic and environmental concerns in the industry, in line with sustainable development objectives.

## Exploitation of fresh water resources in Berlin

The drinking water supply system of the city of Berlin presents a peculiarity: a network of waterworks pumps bank-filtered surface water (from rivers and lakes) and artificially recharged (from artificial ponds) groundwater. The underground passage during bank filtration is an efficient natural cleaning process through the interaction of complex biotic and abiotic processes (physical filtration, biodegradation, adsorption, chemical precipitation, redox reactions, etc.) acting during a minimum residence time in the aquifer. The natural attenuation of contaminants includes the elimination of suspended solids, particles, biodegradable compounds, bacteria, viruses, parasites as well as the partial elimination of adsorbable compounds. The increase in iron, manganese, hydrogen sulphide or ammonium can be easily dealt with in the waterworks. However, the development of some anthropogenic pollutants, in addition to new hydrological trends, may threaten this natural system. The emergence and removal of pharmaceutical residues and specific trace substances are new key issues to address thoroughly. In Berlin, a huge multidisciplinary joint research program (NASRI, Natural and Artificial Systems for Recharge and Infiltration) has been carried out in 2002-2005 by the Universities of Berlin. This example shows that there is room for a sound balance between natural cleaning processes and advanced water treatment techniques.

### *Table 6: Workshop 6 – Case studies*

***Chairman: Dr. John MALIN – ACS (j_malin@acs.org)***

***Secretary: Dr. Daniel BERNARD – ATOFINA (daniel.bernard@atofina.com)***

Dr. Ellen MEYER – Arch Chemicals Inc. Charleston – *Use of dry chlorine for low tech sanitation. Case studies in developing regions.* (emeyer@archchemicals.com)

Dr. Emile TANAWA *et al.* – Ecole nationale Supérieure Polytechnique, Yaoundé - *Productions de déchets liquides industriels et impacts potentiels sur la qualité des eaux dans la ville de Yaoundé au Cameroun.* (emile_tanawa@yahoo.fr)

Prof. Paul VERMANDE *et al.* – INSA – L'Eau en Haïti : *la mise en place d'une démarche scientifique comme préparation à la résolution des difficultés actuelles.* (vermandepaul@wanadoo.fr)

Prof. Ikenna ONYIDO – University of Agriculture, Makurdi – *Chemistry and Water management in Nigeria.* (ikennaonyido@yahoo.com)

Dr. Satinder AHUJA *et al.* – AHUJA Consulting, Calabash – *Solving the problem of Arsenic Contamination in Water in Bangladesh.* (sutahuja@atmc.net)

Prof. Feroze AHMED *et al.* – BUET – *Arsenic Contamination and Mitigation Strategy in Bangladesh.* (fahmed@ce.buet.ac.bd)

Dr. Jörg FELDMANN – University of Aberdeen – *Atacama-Chile : centuries of arsenic in their drinking water.* (j.feldmann@abdn.ac.uk)

Dr. Lidia ROMANCIUC *et al.* – State University of Moldova – *State of ground water quality in Republic of Moldova.* (mrda@mrda.md)

Dr. Gheorghe DUCA *et al.* – Moldova State University – *Fluorine problems and water de-fluorization in Moldova.* (duca@mrda.md)

## Water availability in developing countries

Several papers presented during Workshop 6 was so illustrative of the complexity of the problems found in developing countries and of the importance of the role played by chemistry that they are fully reproduced in that book: see the lectures by Dr. S. Ahuja and Dr. J. Malin, Dr. Ellen Meyer and Prof. I. Onyido.

The dramatic situation in two different countries were presented: in Yaounde, capital city of Cameroon, and in Haïti (a Carribbean Island). In Yaounde (1,5 million inhabitants) only 42,000 are connected to the public water network. Almost everybody finds water in numerous places where the rain water can be contaminated by all sorts of pollutants. The pollution by chemicals produced by industries and craftsmen located all over the city is increasing dangerously, becoming a serious menace for the population health. In Haïti the problem seems even worse because there is a high risk of insufficiency of drinking water (excess of fluorides, of sodium chloride, and the presence of bacteria). There is no water treatment facility. Used waters go to “ravines” with all kinds of solid wastes. These two cases are supported by a cooperative research program between a French engineering school (INSA, Lyon) and a local technical institute (Ecole Nationale Polytechnique in Yaounde and the University Quisqueya in Haïti). In both cases special courses of chemistry, adapted technical trainings, research activities (including Ph.D.) involve local people at all levels. A strong relationship with the local authorities help them in setting up reasonable regulation.

The Republic of Moldova has a difficult problem found in many regions of the country where more than 50% of groundwater contain amounts of toxic fluorides reaching up to 1 mol/L and more. The most widespread methods of water defluorization are based on fluorine sorption on various chemicals. The disadvantage of these methods is the exogenic introduction of chemicals into the water treated. Electrochemical methods are of special interest and use soluble aluminium electrodes. To avoid the problem of electrode passivation, original equipment was developed in which the electrode is activated by means of a mechanical abrasion (the so-called ELEFTOR equipment). The anodic current density is in the range of 20-30 $A/dm^2$ for a voltage of 15-18 V. The consumption of metallic aluminium is 6-8 kg per kg of removed fluorine. Thanks to that new electrochemical technology, Moldova is able to improve the groundwater quality making it acceptable for a public system.

# IV. RECOMMENDATIONS

## Scientific Matters

The commitments of the World Summit on Sustainable Development (Johannesburg, 2002) represent a global fight against extreme poverty. Clean water accessibility is one of the keys of that fight, and may be the most important. Water is an essential resource for which there are no substitutes. The commitments related to water will not be held without a world mobilization of the chemists and biochemists and a solid partnership with physical scientists, engineers, social scientists, policy-makers and business representatives. The challenge requires the knowledge and the talents of chemists to understand the basic causes of the problems and to develop innovative techniques to provide safe drinking water and adequate sanitation systems for all people. All chemical sciences are concerned: analysis, biochemistry, environmental sciences, green chemistry, material science, nanoscience, physicochemistry, polymer chemistry, process engineering [(*)].

▶ **The chemical community is able to, and must, help to meet the Millennium Development Goals [(**)]. The risk of a dispersion of efforts exists between disciplines or between groups. Emulation is useful but an international agenda for the main research and development objectives would be necessary, with incentives, evaluations and public recognition.** [(***)]

Water is a complex material with surprising properties which are still being intensively studied. That basic research must be encouraged. A better knowledge of the intimate structure of the water "molecule" will certainly be useful for a more profound understanding of its properties, e.g. its capacity of dissolving inorganic and organic substances and the mechanism of its chemical reactivity. This perspective is clearly academic but some industrial applications might soon be exploited because water is a non-pollutant solvent or reagent. It is a major agent of the developing "green chemistry".

▶ **We must encourage all fundamental researches on water-related problems and attract and retain more top students, scientists and engineers in that field.**

Water is the only substance present in nature in three physical phases: solid, liquid and gas. The natural "water cycle" is the only real source of water in all parts of the World. Not all characteristics of that cycle are fully understood.

*(*) In that text, most of the time, the word "Chemistry" means all branches of Chemistry, including Biochemistry, Chemical Engineering, etc. Similarly the word "chemists" means chemists, biochemists, chemical engineers, etc.*
*(**) For details on the eight UN Millennium Development Goals, see <www.un.org/milleniumgoals>.*
*(***) For further reading, see Parry Norling et al. "Water and Sustainable Development – Opportunities for the Chemical Sciences", National Research Council, 2004*

The energy involved in that cycle determines the mean temperature of the planet. Water is the most important substance in the atmosphere creating the so-called "greenhouse effect" (not $CO_2$) but is generally ignored in weather studies because the data on the water cycle are insufficiently known, fluctuating and too difficult to be introduced in the models. The water cycle strongly depends on the oceanic currents, their flows and their temperatures, and on the characteristics of the clouds, the nucleation process and their thermal effects on Earth temperature. A growing interest is given to the accelerating decay of ice sheets in Greenland and in West-Antarctic observed during the last decade. The decay is due to the melting of the ice sheets in summertime but also to the speeding of the glaciers moving into the oceans. This phenomenon is not well understood, and there is a vast domain of research only partly covered.

▶ **A better understanding of the water cycle is necessary for a credible evaluation of Earth warming, not only in the atmosphere but also in the oceans.**

The groundwater represents another huge domain of research. An inventory of the available reserves is uncertain in many places. The intensive use of this water for agricultural uses may lead to exhaustion in a number of years. The number is difficult to evaluate without serious knowledge of the natural capacity to restore the water layer. A major risk for the upper layers is the pollution by agricultural or industrial pollutants.

▶ **A complete understanding of the underground hydrology is necessary to avoid an excessive use of the groundwater. That is mandatory for preserving the future of the next generations.**

Surprisingly, pure water does not exist in nature because of its powerful dissolving power. To be "drinkable" pure water must be "remineralized". The natural "mineral waters" are appreciated for their taste due to certain dissolved mineral ions and for the absence of organic or bacteria contamination. The quality of the water distributed by public networks is regularly controlled for its content. All types of pollution of the water supply must be immediately detected and stopped. Through a few examples, CHEMRAWN XV showed up the diversity of the research in the field of water analysis. As examples let us cite: the identification of heavy elements microtraces and of new organic micropolluants ; the study of synergetic effects of different species in water medium (molecules, complexes; solid particles, etc.); the study of the fate of chemical pollutants (e.g. methyl mercury) and medicinal residues and their elimination in-situ; more generally, development of in-situ methods and metrology; the performances of the Fourier Transform-Ion Cyclotron Resonance-Mass spectrometry (FT-ICR-MS) open large perspectives; the search of models by using simulation and modelling methods; etc.

► **A priority must be given to all aspects of research into water analysis. Chemists are able to detect and evaluate ever increasing microtraces of numerous pollutants in ever more dilute concentrations in water. The methods must be reliable, automatized and rapid. At a greater scale, chemists are asked to develop a more precise knowledge (nature and chemical behaviour) of the different classes of organic compounds present in water from natural or anthropogenic origins. This raises questions on the transport and reactivity of pollutants in aquatic systems.**

Developing countries have the potential in existing universities and engineering schools to study water problems. They can be oriented toward the local issues of pollutants, natural products and tropical diseases: first, through the development and use of low-cost equipments and methods adapted to the real local needs and possibilities; and second, through international cooperation as needed. Among programs urgently requested (in fact, not only for poor countries) let's cite: the development of home-made methods, of low-cost and easy-to-use equipments, such as "rapid-impact" packages, especially portable and disposable biosensors.

► **An international policy effort is necessary to scale-up the research activity on water issues in laboratories located in developing countries. New programs must be internationally supported almost everywhere in the world.**

Presently, research on chemical aspects of water-related problems is spread among a very large number of teams, generally very small and often isolated. There is a serious need to facilitate the exchange of information both nationally and more importantly, internationally, vital to extend research in developing countries and avoid simple duplication of effort. That may take various forms, e.g. journals or internet sites. Still more important is the training of specialists in all developing countries. A larger number of Gordon-type conferences on water chemistry could be usefully organized every year in various places on the planet. Above all, some ambitious quantitative and qualitative objectives with datelines could be proposed by an authoritative body with real incentives for recognition of the efficient efforts, e.g. different international prestigious prizes, chairs or fellowships. What could be this "authoritative body"? Good question for the F.A.C. of CHEMRAWN XV.

► **An international coordination on information dissemination and particularly on planning of the research objectives in order to accelerate the solving of numerous problems could be thought of.**

## Technology

Water is different from any other chemical: under all circumstances water is never consumed, only polluted. After any use, its quality, essentially its purity, is degraded. Historically, the purification process is left to natural processes. That is still the case in a large part of the World, but that is less and less sufficient. Physical and chemical treatments, in substitution or accelerating the natural processes, are necessary for health reasons before any public distribution of water and for all types of used waters before disposal. Such industrial treatment appeared during the 20th century and it must be recalled that this is a top achievement of that century (*).

These treatments use chemical or physicochemical processes which have a cost. In ancient times water was considered as a gift from the sky, even from God. Water was symbolic, even sacred. Like the air we breathe, rain water is freely used by everybody. How could we speak of money for such a spiritual symbol? Clearly, this type of attitude can be found in the difficulty for fixing a fair price for public distribution of water, particularly for irrigated agriculture. Nevertheless, this is an economic necessity for financing equipment and operations. Someone or some structure must pay. Normally that must be the concerned population, if it cannot afford it a national or international mutualisation has to be arranged.

Conserving water is a clear necessity. Agriculture accounts for almost 70% of water use worldwide (20 and 10% respectively for industrial and domestic uses respectively) and even 80-90% in many developing countries. Overpumping of groundwater is the biggest threat to irrigated agriculture, exceeding even the build-up of salts in the soil. Water availability is declining everywhere. Increasing the productivity of irrigation water is critical. Techniques exist but are vastly under-used because water pricing does not encourage their adoption.

▶ **Water is undervalued the World over. Water must be valued and priced appropriately especially for irrigation. Users must pay a fair price for it. If they can't, a national or international subsidy could be established. An equitable distribution of the resource, a sustainable system operation and a clear and honest pricing system might be the conditions for having a better sense of economy of water in the public, particularly for agricultural uses.**

The chemical industry has some special responsibilities to assure water availability in suitable quality and quantity for itself, for other industries and for the public. For water purification, calcium hypochlorite and chlorine have been used as

*(*) When the U.S. National Academy of Engineering listed the top 20 engineering achievements of the 20th century, safe water was number four, behind electrification, automobiles and airplanes.*

disinfectant for many decades. Chlorine was said to be a "public health hero" for saving millions of lives. Other chemicals are used in purification processes, e.g. aluminum sulphate (alum) to coagulate and precipitate silt and other suspended organic matter that would make water cloudy. After filtration, water receives a second disinfection with chlorine and ammonia to form chloramines which tastes better than chlorine and lasts longer. Processes of that sort are continuously controlled, improved and updated. Source water and treated water are regularly tested for all types of substances or microorganisms causing health problems. Many waterborne pathogens, bacteria or viruses, are difficult to detect and to identify. Water may also be fluoridated prevent tooth decay.

► **Quality of water can be controlled before distribution only if correct equipment, prescribed chemical additives and a complete analytical protocol are available and are used. Microbial risks, a serious public health concern, must certainly be evaluated.**

Disinfection of water with chlorine or chloramine is accompanied by a series of reactions with naturally occurring organic matter. Chemists have realized that such halogenated by-products include trihalomethanes (e.g. chloroform), haloacetic acids, and other potentially hazardous substances. Toxicologists continue to study the possible health risks associated with traces of these by-products (cancers, effects on human reproductive systems, etc.). This has led to the widespread introduction of so-called "advanced disinfection processes": adsorption on granulated activated carbon and ozonation, the effectiveness of which can be enhanced with hydrogen peroxide or UV light.

► **The technology used to control persistent organic and inorganic pollutants and to minimize the presence of disinfection by-products is still in progress. Removing of more particles and organic matter before treatment is always advisable. New processes using membranes are under study: ultrafiltration and reverse osmosis show considerable promise.**

In addition, it must be reminded that rainwater carries into streams and lakes potentially hazardous natural substances, both organic or inorganic (cf. arsenic in Bangladesh or Chile, fluorides in Moldova, as discussed during the CHEMRAWN XV Conference) which need specific treatments. Arsenic currently threatens millions of people in many places. It is by far the most hazardous carcinogen in drinking water. The World Health Organization recommends a limit of 10 μg/L of As in drinking water. Such a low limit is very difficult to be reached in many developing countries for lack of money and expertise. Remediation techniques must be robust, easy to operate, adapted to the quality of the treated water (potable or irrigation) and inexpensive. Testing arsenic on site demands field test kits that are evaluated in terms of sensitivity, reliability, applicability, and... cost. This cost however must be compared to the potential health-care and social costs inflicted by the induced cancers.

- **The present international effort for solving the arsenic problem, not only in Bangladesh but also in Argentina, Chile, India, western USA, etc., is a clear illustration of the nature of water problems: work must be done locally, yet demands the talents of many experts difficult to find in an underdeveloped country. International co-operation becomes a general necessity.**

The treatment of used waters has changed enormously over the past century. After removing solids and denser particulate biological material, the water receives a biological treatment in a tank through which air is blown. After removing biomass by settlement there is another treatment with disinfection – when the effluent is to be re-used – provided by UV light, chlorination or ozonation. Such processes produce a high quality effluent but nowadays further improvements are required to remove traces of endocrine disrupters. These compounds include oestrogens and many other chemicals (alkyl phenols, bisphenol A, phthalates, etc.) having a concentration of the order of the nanogramme per litre. It has been shown that these compounds can affect fish, e.g. causing feminisation of certain male fish. For humans they are suspected to be the cause of cancers and reproduction troubles, but these potential risks are difficult to evaluate. For removing these micropollutants the best methods are the use of membranes.

- **The main challenge of the treatment of used waters is currently the evaluation of the health risks due to micropollutants, especially endocrine disrupters, for which new analytical and removal methods are under study.**

We can no longer take for granted an adequate supply of freshwater (e.g. South-Eastern England). In the future, changes in climate conditions might lead to serious water shortages, even in Europe, causing real scarcity and resulting in highly varying raw water quality. In many places it is vital to look after new sources of water. Two main solutions can be envisaged: for inland areas huge dams (e.g. the Three Gorges Dam in China, the Aswan Dam in Egypt or the Hoover Dam in the USA) or large desalination units near the coasts. Many dams have been built without much consideration for the environment. In addition to their function as hydroelectric generators they have changed the local economy by permitting irrigation of large areas bringing tremendous benefits to billions of people. With large distribution networks they represent what is called the "hard path", not popular nowadays. Desalination units remove dissolved ions along with suspended and colloidal matter, bacteria and viruses. Their size can be adapted to the need: small for a boat, medium for a small island, big for a megapolis or a region.

Desalination technology is already fairly well developed with several competing techniques such as multi-stage flash / multi-effect evaporation / mechanical vapour compression / reverse osmosis. Reverse osmosis seems to be most promising for further development. Attention is being given to membranes that minimize fouling and to hollow-fibre systems in which the feed-water is pumped though the fibres. Performance is improving with costs falling.

▶ **Membranes materials and technology are active subjects of chemical and process research not only for desalination but for other uses (e.g. nanofiltration) as well.**

Desalination could play a key role in sustainable development in many areas. Large units will need a source of energy – such as solar, wind or nuclear – which can also contribute to the local economic development, possibly including a chemical complex. So far an insufficient attention has been given to the brine, by-product of the desalination which contains some sixty different inorganic ions, about ten of which have some commercial interest (Cl, Br, I, Na, K, Cs, In, Ru, Ge, Mg, P, etc.).

▶ **The role of chemistry in a desalination plant could be greater than just technical support. The unit could in fact be the nucleus of an entire chemical complex exploiting the valuable elements present in the brine.**

Instead of the "hard path" the "soft path" is currently preferred: small-scale decentralized facilities adapted to isolated villages, using rainfall or local sources. CHEMRAWN XV discussed some good examples of such interesting programs and projects showing that the soft path can strive to improve productivity of water use, and even rethink it. The goal becomes not to use more water but to improve social and individual well-being per unit of water used. In agriculture changing irrigation technology (drip irrigation) or crop characteristics can produce more food or fiber per unit of water consumed; in industry, water can be conserved by redesigning the operating processes and recycling withdrawals. These efforts may require new domains of chemical research and engineering to be systematically explored such as "green chemistry" and chemical engineering. The opposition between hard and soft paths is fairly artificial because they are in fact complementary. The examples of large cities show that small units are not advisable for security reasons. Decentralized facilities can be connected to large networks. In arid areas distributed water has to come from distant sources, including a dam reservoir or a less remote desalination plant.

▶ **New chemical processes more economical in water use, more adaptable to remote places, more friendly to the environment or more attentive to water quality must be sought.**

Thermal power generation uses huge amounts of water as does oil refining. Critical to addressing water issues is having the energy needed to transport, manage, treat and desalinate water resources. In the future, nuclear and renewable energies are likely to play a major role in that domain.

► **Water and energy are tightly linked. Saving water is always saving energy.**

Water is too cheap to be exported over long distances. For example, Egypt doesn't import water but is actually importing it on another way, in the form of half of its grain use where each ton of grain represents 1000 tons of water. Several countries are already including this "<u>virtual water</u>" in their energy and water policies: e.g. Saudi Arabia reduced its grain production from 4.1 millions t. in 1992 to 1.2 million t. in 2004. A similar approach can be observed in the import by Japan of aluminum metal, rather than bauxite, for saving national energy resources.

► **For arid countries, "virtual water" is a new interesting concept in international business.**

## Societal Issues

The primary goal of the CHEMRAWN XV Conference was to engage the chemical community in addressing the question of how to ensure everywhere an adequate quantity and quality of water for public use, sustainable agriculture and all industrial activities.
Water is a matter, "absolutely vital for man and essential for its activities". Chemistry is the science of matter. However, even if water is industrially treated, the society does not consider it as a "chemical product". In the domain of water, responsibilities are shared, not always peacefully, between a specific industrial sector and the political and administrative authorities. Chemistry, ubiquitous in all operations of that sector, too often appears as a simple service provider.
The title of CHEMRAWN XV **"Chemistry for Water"** was almost an aggressive, a meddling, a declaration of parity. It shocked many accustomed to a more discreet attitude on the part of the chemists in that domain.

► **Chemists and biochemists must be conscious of the positive role they play in cooperating with water experts. They bring solutions to defined or obvious problems. The chemical world – academia and industry – must strengthen its commitment to dealing with water issues. Chemical engineering must be recognized by policy-makers as a major partner in establishing the strategy for any development of large water systems. Chemistry must play a central role in water management and notably in its security.**

At its 58th session, the UN General Assembly adopted a draft resolution (*) proclaiming 2005 to 2015 as the "International Decade for Action – Water for Life". The resolution calls for a greater focus on water-related issues and asks the UN system to "deliver a coordinated response".
By chance, the Decade "Water for Life" coincides with the UN Decade on Education for Sustainable Development. UNESCO was designated the lead agency for the planning and promotion of that Decade, with the function of mobilizing and facilitating action by all stakeholders. It is obvious to insist on the importance of the education and training at all levels on water issues. The UN resolution "Water for Life" calls for actions to ensure the participation of women in water-related development efforts. The necessary chemical background to be delivered to all kinds of people, particularly women, the most concerned persons in large areas, represents a huge challenge for the chemists. The active support given by UNESCO to CHEMRAWN XV is a significant sign of recognition of the major role to be played by the chemical community in that challenge.

► **The chemical community must be fully associated by the UN system to the program implementation of the decade "Water for Life". IUPAC could be an efficient partner in that mission.**

There are many problems related to information in the field of water science and technology. It is often difficult to know who is doing what and where, particularly in developing countries. For any international project, there may be a lack of reliable and comprehensive data on one country or more. It is difficult to identify, to assess or to compare national information needed for any international integrated water resource management. The information revolution promises to play a vital role in transforming the efficiency of water use. We may dream of a systematic global picture of freshwater information at the different levels: river basin, national or international connecting the existing databases or education programs. Networks of automated and computerized stations could collect local climate data, including humidity, temperature, wind speed, and transmit them to a central computer. Thanks to modern technology all kinds of information may reach everyone constituting a computer-aided "virtual" college to train men and women in remote isolated areas.

► **Chemists and biochemists have a major role to play in establishing a multilingual data exchange network on water-related questions with the goal to harmonize glossaries, thesaurus, standards and know-how and to ease the dissemination of specific information even to remote isolated places.**

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*(*) For details on UN Decades, see UN documents A/RES/58/217- 219 and http://portal.UNESCO.org.*

Presently all around the world, people hold a negative opinion of chemicals and chemistry, as a science and still more as an industry. A "chemical product" is not wanted. Chemistry is believed to be the basic cause of major environmental problems, through pollution, materials defects and hazardous practices. The supposed irresponsibility of chemists or, more particularly, of the chemical industry is seen as the cause of all kinds of diseases and of the disappearance of biodiversity. The responsibility of decision-makers or of the consumers is rarely mentioned. Curiously enough even the water industry avoids appearing as using chemical processes. In contrast, CHEMRAWN XV showed that all problems connected to water either have found or may find solutions through chemistry. This remark justifies the hope that a more balanced image of chemistry could result from a fair appreciation of its role in the water domain. That supposes a serious and coherent effort by the chemical community to correctly, objectively inform the media and the political leaders. Access to the media is not easy because drinking water might be vital but is not "glamorous". The media prefer to focus on accidents and their consequences, e.g. Seveso or Bhopal. Voluntary and intelligent action is mandatory. It may need international coordination (by IUPAC?) because if the water problems are common and well known, the solutions are also common and could merit active publicity.

This effort principally concerns the education of both children and adults. Education means not only a minimum understanding of the chemical concepts but also the consciousness of a responsible social behaviour. Obviously, schools and universities have their role to play, but also the media through articles, news reports, and advertising, written in an accessible language. A good understanding of the chemistry involved in that field of activity is a strategic challenge to reinforce the professional qualification of the personnel, at all levels. Each country needs a cadre of water resources management specialists. This is a clear necessity because of the rapid change of the technologies and the complexity of the techniques required to adapt to new standards and directives.

► **Information is not knowledge. The chemical community has the major mission to help the educators and the media not only to inform, but over all to teach and train children and adults in all parts of the world, to clearly explain the social, economical and technical aspects of the water issues. It must cooperate, under the aegis of the UN system, to changing attitudes and lifestyles in support of a sustainable development in water utilization. The success of that mission could greatly improve the image of chemistry.**

All over the world, regulatory agencies play a major role in minimizing the hazards of water contamination. They also deal with the public perception of safety and the resulting social, political and economic impacts. Regulatory actions can stimulate additional research such as development of a robust technology to monitor environmental problems, controls of persistent organics, improvements to membrane technology and a host of other water related initiatives.

► **Partnerships between all chemical disciplines and the regulatory agencies are essential.**

Initiatives to obtain or maintain fresh water can be a tricky endeavour in any locale. Any initiative should be the result of discussions and then partnerships involving corporations, government, local authorities, professional or environmental organizations, farmers, and other potential stakeholders. Improved access to fresh water is a basic requirement for sustainable development beneficial for everyone today and tomorrow. For example, in a developed country, it has been demonstrated that sustainable agricultural practices can reduce discharge of pesticides into surface and subsurface water by a factor of 10 thanks to a co-operation between a chemical company and the farmers associated with the study. Such partnerships are always specific. They work best when they are “grass roots up”, not “top down” driven. People must be able to take charge of their own destiny and less dependant on others.

► **Sustainable development demands new creative forms of partnerships not only between chemists, biochemists and water specialists, but also between the public and private sectors. This condition is required if the world’s water problems are to be tackled effectively. It is mandatory for poverty alleviation but also to avoid ecological and social conflicts.**

## Chemistry for a New Ethics

“The human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realisation of other human rights” (*)

“Our actions must ultimately be guided by more than technology or economics. The fact that water is essential to life lends an ethical dimension to every decision we make about how it is used, managed and distributed. We need new technologies but we also need a new ethic. All living things must get enough water before some get more than enough” (**).

Effective water resource development and management are basic to poverty reduction and sustainable growth. Access to clean water and proper sanitation and attention to wastewater disposal and treatment are minimal requirements for public

*(*) UN’s Committee on Economic, Social and Cultural Rights, 2002.*
*(**) Sandra POSTEL, director of the Global Water Policy Project, The Sciences, March 2000.*

health. As shown during CHEMRAWN XV, all those questions are in the domain of chemistry / biochemistry. The responsibility of the chemical community is well established. It must be acknowledged.

In principle all governments must give high priority to the water sector in deciding a clear policy taking international agreements in account. Too often in most countries water is still receiving a small part of public sector resources. As the questions related to water access and sanitation are essentially local, decentralisation of decision making are often crucial. A difficult balance must be found between the "hard path" decided at the national or international level (e.g. huge dams) and the "soft path", small facilities locally decided to satisfy the immediate needs of the customers. This opposition is fairly artificial. Ideally, the balance has to be found through serious discussion between all stakeholders, it must involve the potentially affected population. A correct chemical expertise has to be associated to all levels of decision. The dramatic experience of the wells built in Bangladesh in the 70's must not be repeated.

To respect the priority given to poverty eradication, the evaluation of any policy, or any project, must be based on the number of people newly connected to a clean water system and to improved sanitation and not only on the number of dollars spent or of cubic metres of water distributed. Water is not to be spent for itself. It must be given priority for the satisfaction of vital needs (health, nutrition). Sustainable development needs to be more than national development; it also implies economic and social equity.

Because of the growing scarcity and vulnerability of freshwater, future projects may focus on the water locally available to satisfy the need through creative use of those resources instead of endless trying to find new sources of water. This attitude will be imposed for the respect of the natural ecological cycles. New processes must use less water and plants must recycle waste water.

Ethical principles require appropriate pricing as well as clarity and accountability to the stakeholders. About the fear of corruption, high in that sector of activity, let's adopt the advice given by the Camdessus Report (p. 49): "Private and public companies are urged to cooperate with public clients and other parties to develop methods for promoting ethical behaviour. Private participation contracts should be fully transparent". A good introduction to such an ethical behaviour is given in a UNESCO booklet[(***)].

To conclude let us cite this optimistic comment of Michel Camdessus: "The dream of pure water for all is within the reach of humanity. It can be attained by continuing for a further ten years the effort to which we are committed from now to 2015. This is the challenging task for the generation of people now running the world!"

CHEMRAWN XV showed that the chemical community is ready to face that challenge.

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*(***) Lord SELBORNE "The ethics of Freshwater Use: Survey", UNESCO Nov. 2000.*

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