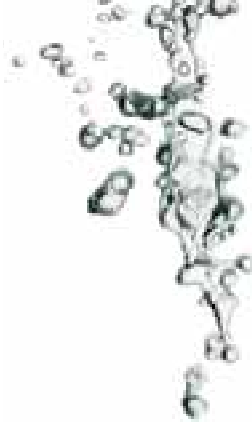
Water research – what's next?



Contents

Water research for sustainable development!

The history of water began more than four billion years ago. Humans have been part of the water cycle only for about two million years. To start with, we took water directly out of nature. When we organised ourselves in communities and moved into towns, we became dependent on water supply and sewerage. A sustainable society without pure water and healthy lakes is unthinkable.

Lisa Senneby Forsse
Secretary General, Formas

In Sweden, access to water is so taken for granted that we must be constantly reminded of its importance – as also of the threats to pure water. Water pollution, whether of microbial nature or caused by noxious chemicals, affects health and may threaten life. The importance of managing water in a sustainable manner is becoming increasingly evident to a growing number of people. In Sweden, at least nine of our fifteen environmental objectives relate to the water sector and the water cycle. To quote an example, leaching of nutrients from industrial processes and from agriculture is a serious environmental problem that causes eutrophication in lakes and in marine environments. Other threats are oil discharges at sea and on land, de-icing salts in groundwater, leaching from landfill sites, acidification – the list can be made very long. Access to pure drinking water and satisfactory sanitation is essential for the protection of human health and the environment. The EU, in the framework directive for water and in other initiatives, has acknowledged the importance of water quality as a link in promoting sustainable development. Internationally, issues to do with water figure high on the agenda, since 1.2 billion humans today lack access to drinking water of satisfactory quality, and 2.5 billion humans lack access to basic sanitation. These are considered to be some of the most important problems to be solved in the future.

Research concerning water is traditionally spread over a number of scientific disciplines, and the development of water management on national and regional level demands a complex knowledge base. Water issues are coupled with land use and ecosystem functions. Research on water must form part of an integrated process which demands collaboration among many areas of knowledge. Formas intends to ensure that issues to do with water are approached from a multidisciplinary and system analytical perspective which also comprises the role of humans as the users and managers of water. There is also need for method development which demands further fundamental research into ecosystem processes and the water cycle. It is also essential that Swedish research participates in international collaborative projects and contributes to the expansion of knowledge regarding water issues in a global perspective. The significance of water for our lives and for sustainable development of society cannot be too highly stressed, and research has an important role to play so that we can perform our obligations on both local and national, and on regional and global, levels.

What are the future challenges for water research? We have asked a number of people engaged in research relating to different parts of the water cycle in nature and society to put their personal visions on paper. Look on these visions as a contribution to the discussion regarding water issues and the role that research can play.

Lisa Sennerby Forsse
Secretary General, Formas

Water in development – perceptions and realities

Professor Jan Lundqvist, Department of Water and Environmental Studies, Linköping University.

Water issues are increasingly high on international and national agendas. For a majority of people in tropical and subtropical regions, it has always been a fundamental but unpredictable part of life. It is less of a dramatic issue in Sweden and in parts of Europe.

Also in water-rich countries, there are concerns about water. Within EU, the implementation of the Water Framework Directive illustrates this point. In less developed countries, water is at the heart of the development discourse. Sometimes and suddenly, there is too much of it but more and more often there is too little. Parched fields, desiccated rivers, empty wells and increasing distances to fetch the necessary few litres for daily survival is a harsh reality for at least a billion people. A look of the Millennium Development Goals agreed upon by the UN Millennium Assembly in 2000 reveals that water is a key element in various dimensions of development.

A water crisis or a crisis of society?

There are many of us who argue that we are facing a water crisis or, formulated differently, that water is in crisis. How is that possible on the "blue planet", where some 70 per cent is covered by water? We are talking about the tiny fraction that is freshwater and which is available in rivers, lakes, as groundwater and soil moisture. By and large, we have the same amount of water today as our parents and grandparents had, and roughly the same figures apply for the next generation. But as a result of demographic trends, increases in per capita demand and poor management, severe challenges have evolved.

Apart from dwindling sources of water, which are due to heavy abstractions, and a stiffening competition, human activities have contributed to a serious degradation of quality. Disposal of untreated sewage in recipients, use of chemicals, etc. have literally converted freshwater sources to toxic drains where any use should be prohibited and prevented. But preventing use in areas where people have no alternative is an impossible moral dilemma. Clearly, there is a crisis in these contexts. But, as lamented by a colleague: "the problem with water is often not water in itself". Rather, water problems are caused by mismanagement, misguided perceptions and missed opportunities.

Questions for the research community

Improving management, getting the perceptions right and seizing opportunities are important components of a water policy, which should be high on the research agenda. The primary task is to increase the overall value and the various benefits that are generated from water use, to distribute these in a socially fair manner and with a minimum of environmental impacts.

Water productivity

Particularly in the food sector, where huge quantities of water are depleted in terms of evaporation and transpiration, it is necessary to increase production without additional supplies of water. The amount of grains produced per cubic metre of evapotranspiration varies between about 0.2 to 2.5 kg. We need more systematic knowledge of what mix of agronomic, technical and management measures may give a boost to productivity. Improvements in productivity are essential in efforts to ensure an environmental flow. It seems that there is a special need for an improved understanding of institutional aspects, including legal and regulatory arrangements, incentives and sanctions etc. that will facilitate the most promising practices. These have to be accepted and used both by the poor and small farmers and by other groups.

Nutritional security

Nutritional security is a new question that begs for an answer. Apart from a national "food security", i.e. enough food for everyone, understanding is growing about the need to facilitate nutritional security at the household level. Whereas enough of food is produced in the world for everyone, the average calorie intake in Sub-Saharan Africa and in South Asia is much below the norm of 2,700 kcal per person per day. In other areas, it is much above the norm. Undernourishment and obesity are two vicious signs of maldevelopment in society, which also have implications for resource utilisation. Food security is not the solution for these kinds of problems.

Consumption

Conventionally, research on food and water issues has focused on hydrological issues and on production. With a growing proportion of the population who are consumers but not producers, it makes sense to ask what kind of food is demanded. It is relevant to estimate the implications from the trends in consumer preferences and choices in terms of resource utilisation.

Urban and industrial expansion

With the very rapid urban expansion, the agricultural sector is no longer enjoying a "privileged status" to borrow an eloquent concept from Albert Hirschman. The previous urban minority will soon make up a new majority and the previous rural majority will soon be a minority. What are the implications of urban and industrial expansion on resource competition and allocation? And how will it stimulate production of new food items and changes in management practices?

Water accounting

With a mounting demand on a finite volume of available water, it becomes important to have a proper accounting system. This should help to show how much water is available (in a basin), how much is with-drawn for various purposes, how much is depleted and degraded and what benefits and problems are generated. The links between hydrological realities, interventions of society in natural cycles and various aspects of development are surprisingly poorly understood.

Whose perceptions and what kind of reality?

An underlying assumption in the foregoing is that we need to pay more attention to human behaviour. I am not only referring to the behaviour of the producers or the political decision makers, who are generally not doing what the researcher thinks they should be doing. I am referring to the "world of consumers". An understanding of the dynamics of water is, of course, a primer in research on the role of water in development, in environmental sustainability, etc. And we do need enlightened and non-corrupt decision makers. But unless we are able to better understand and manage the strong social forces that are causing the water crisis, it is not likely to be effectively tackled.

As professor Malin Falkenmark puts it: "Facts are facts but perceptions are reality". We had better improve our knowledge not only about water facts, but also about the reality, which is made up of human perceptions.

Where does the water go when the ice melts?

Professor Per Holmlund, Department of Physical Geography
and Quaternary Geology, Stockholm University.

Glaciers can give information on the climate in times past, but they are themselves affected by the global climate changes we are seeing today. How are the discharges of rivers changed as a result of melting in the mountains? Flooding will be more common without glaciers in the mountains, and more sediment will be transported in the rivers. How much more fresh water is added to the oceans, and how much does the sea level rise? Why does an ice age occur at times? And who solves the riddle of the subglacial lakes in Antarctica? Glaciologists have a lot of questions to find answers to.

In Sweden, there is about 20 km^3 water stored in glaciers. How are the discharges of rivers changed as a result of increased melting in the mountains? In Norway and Iceland the quantity is greater, and the percentage effect on the flow is also expected to be greater in the near future because of a warmer climate. What will be the effect of this increase over time? Glaciers balance out peak flows, both over the day and between the seasons. Flooding will be more usual without glaciers in the mountains. The chief problem areas are the high mountains such as the Alps and Himalayas, but model experiments can be developed to advantage in the Swedish mountain areas.

Past climates (palaeoclimates) are studied with the help of glaciers. In places where mass balances have been drawn up and where long time series have been developed, the former extent of the glaciers can, via numerical modelling, give us new information on former climates. Knowledge of response times and changes in the viscosity of ice flow give us more detailed information. Long time series of weather and the mass balance of glaciers give us a sophisticated and reliable picture of the change in climate over time in the Arctic and sub-Arctic.

Increased sediment transport

How is sediment transport changed in rivers at high latitudes due to a decrease of permafrost, smaller glaciers and a change in temperature distribution in the glaciers?

Permafrost increases the stability of the soil. If the extent of permafrost decreases because of global climate change, this will have a negative effect on the stability of slopes, which may result in a greater frequency of slides and mud flows. When the size of a glacier is reduced, large areas of sediment and moraine are uncovered and are exposed to surface erosion. A change in climate alters the temperature distribution in the glaciers. When the climate becomes more humid and milder, larger parts of glaciers are at the pressure melting point and may erode at the bottom. There is therefore a great risk that the quantity of sediment in rivers will rise. New research is needed so that these amounts may be quantified.

Sea level rises

How much does the fresh water input to the oceans increase in time and space when glaciers melt? And by how much does the sea level rise?

Melting from Greenland and Scandinavia adds melt water to the North Sea. This may have an impact on the formation of deep water, which may in turn have a negative effect on the oceanic circulation, with the result that the climate in Northern Europe will be colder. An increase in the quantity of fresh water out of the Arctic Ocean has a positive effect on the formation of sea ice. Global melting of ice has an effect on overall sea level. If all Swedish glaciers were to melt, the sea level would rise by less than 0.1 mm. If the ice sheet on Greenland were to melt, sea level would rise by 5 metres. And if all ice in the Antarctic were to melt, sea level would rise by 60–70 metres.

When does the West Antarctic collapse?

The Antarctic ice sheet is sensitive to climatic disturbances. How rapidly can the West Antarctic collapse?

The West Antarctic is in unstable equilibrium between mass balance, motion dynamics and size. Large areas of West Antarctica lie much lower than the present sea level, and if the marginal zone thins out or if the ice shelves which provide a dynamic buffer break up, a collapse that is irreversible in a thousand year perspective may begin. Today, there are clear signs of how the marginal zone is thinning out, but no sign yet that the size of the ice shelf is decreasing. Research is concerned with the mass balance of the glacier basins into which ice from West Antarctica drains.

A frozen archive

Climatic changes over the past million years are documented in ice cores. Ice cores give information of exceptional accuracy regarding fluctuations in climate over time. In subarctic and temperate regions, they can provide information on industrialisation and historic changes in the environment. They also give information on any deviations from the climatic patterns that can be obtained from the ice sheets. Deep ice cores give us more exact information, but from a more remote place. The polar ice cores also enable us to make a special study of periods a long time ago.

The increased number of deep ice cores make dating more reliable, and they also enable us to study how representative the results are regionally. We want to take an active part in analysing the deep ice cores obtained in ongoing and planned drilling programmes.

Why does an ice age occur?

What reinforcement mechanisms are there in the climate which trigger large changes such as ice ages?

In the long ice cores from the polar ice, we can learn how climate changes over time. We can see the sequence of changes in ions and stable isotopes. We can follow the very large and rapid climatic fluctuations which characterised the most recent glacial, and we hope that we can solve the puzzle of what initiates ice ages in their entirety. The astronomical position of the earth in relation to the sun creates the conditions, but the climate is evidently also controlled by other mechanisms into which little study has been made.

The most remarkable lakes in the world

The subglacial lakes in the Antarctic are a puzzle. About ten years ago, the scientific community realised that there was a subglacial lake on the Antarctic continent, namely the 500 m deep Lake Vostok which lies below a 4 km thick ice cover. Up to then, the existence of such a lake was considered almost a physical impossibility, but the measurements were conclusive.

By now, almost one hundred lakes have been located. Their ages are not known, but if any of them has persisted through the entire glacial, they may contain life which was isolated from the biosphere that is available to us 10–20 million years ago. A drilling programme has begun to obtain samples from Lake Vostok.

How much does it rain?

PhD Gunn Persson, SMHI – Swedish Meteorological
and Hydrological Institute.

Rain gauges are found in many gardens. This shows that it is not that difficult to measure precipitation. But it is not so easy. Precipitation is uneven and is governed by a lot of factors at different scales. How much does it rain in actual fact? The answer is looked for in comparative studies – with data from satellites, radar, observations and modelling.

Rain is one of the most important climatic factors within the terrestrial atmospheric system. A lack of precipitation over a long period can give rise to serious drought, with dramatic consequences for the ecosystem and human life. On the other hand, extreme quantities of precipitation can damage the infrastructure and can cause catastrophic flooding.

The spatial and temporal structure of precipitation is extremely uneven and cannot really be determined by spot measurements. This is why we do not know very much of the spatial distribution of precipitation even in the densely populated industrialised countries. We need to know more of the dynamics of precipitation so that, for instance, advance warnings of flooding may be given more accurately. We need a reliable method for the spatial determination of precipitation, based on remote analysis from air and from land.

Measurements over a small area

Precipitation in the form of rain or snow is evident to everybody. It may be difficult to understand why so much effort is given to determining precipitation. True enough, it is easy to put out a gauge and collect the water – but what does such a measurement represent? It is difficult, not to say practically impossible, to collect the rain that falls over a certain area. We can generally assume that we collect too little of the water. The main reason is that wind quite simply blows away the water before it reaches the gauge. This error can be reduced by different kinds of wind shield. Other sources of error are wetting of the container, evaporation and choice of the wrong site.

But even if we manage to make a good measurement, the problem that remains is: What does it represent? Although there are almost 800 precipitation gauges over the whole of Sweden, the area over which measurements are made is very small. The aggregate area of all the precipitation gauges in Sweden is comparable to that of an ordinary living room.

Uneven precipitation

Precipitation forms when moist air rises to an altitude high enough for it to become saturated. The air cools down, the moisture condenses and a cloud is formed. The distribution of annual precipitation on earth depends on both small scale factors such as the nature of the terrain, and also on the large scale circulation. Generally speaking, areas where the air has to rise receive a lot of precipitation. Most deserts, on the other hand, are in areas with stable high pressure where the air descends and clouds are dispersed.

Global variation in precipitation is very large. The driest regions are found on the east side of the Antarctic peninsula and in the desert region of Chile where, in principle, there is no precipitation at all. The areas which receive the most precipitation are said to be the top of a volcano in Hawai and Assam in north-east India. The precipitation there is almost 12,000 mm annually. The town of Cherrapunji is the top of the league with the highest recorded monthly and annual precipitation, 9,300 and 26,000 mm. Annual precipitation in Sweden is ca 600 mm.

In Sweden, there is normally more rain and snow on the coast than inland, because the air masses from the sea rise when they meet land. But in the summer, there is more rain inland than on the coast because of the afternoon showers we get when the sun warms up the surface of the land and the air rises. The surface of the sea is not warmed up to the same extent during the day, but there are overnight showers at sea in late summer when the sea is warmest. Mountain areas are very important for the formation of precipitation, and the largest amounts of precipitation occur in the mountain chain bordering on Norway. Winds most often come from the west, so precipitation in Norway is even higher.

A lot of work has been done to try and find a relationship between different factors, so that measurements may be corrected and better input data obtained for hydrological models. The nature of the terrain is a very important factor for the amount of rain that falls. Height correction is the most essential factor, but wind velocity and wind direction are also of great significance for the distribution of precipitation. In regions with complex gradients and a sparse station network, the way the interpolation method is chosen is very important. In recent years the endeavour has been to decrease manual measurements in favour of automated methods. The hope lies in radar and satellites. These methods can yield good qualitative determinations, but more development is needed before they can be applied quantitatively.

Collaboration is required

Regional water resources are assuming increased importance. There is therefore greater need of quantitative precipitation analyses and forecasts. To be able to determine uncertainties in precipitation measurements and forecasts at all temporal and spatial scales, and the significance of uncertainties in meteorological and hydrological applications, collaboration between different disciplines is required.

Precipitation is produced by atmospheric processes that are nonlinear and interact at a large number of different scales. Both meteorologists and hydrologists have been interested in the problem of precipitation for a long time, but from different standpoints. Atmospheric researchers have mainly studied microphysics and the dynamics of precipitation formation. They have focused on numerical modelling and precipitation forecasts. Hydrologists have been interested in precipitation as a boundary condition for land surface processes and have therefore focused on precipitation measurement. Mutual understanding and future collaboration are desirable. The principal challenges are to measure, model and forecast precipitation in all its forms and at different scales.

Forecast models benefit from climate models

The question remains: How much does it rain today and how much will it rain in future?

Apart from the fact that research focuses on finding better methods for the spatial and temporal determination of precipitation, there is another absolutely overarching issue, that of climate change. The scenario calculations that are made for future climate are faced with two great uncertainties. One is the way in which society develops, i.e. human impact expressed in terms of emission scenarios, and the other the uncertainty in the climate models. Since there is no basic physical difference between climate models and forecast models, forecast models also benefit from model studies in climate research. Further development of climate models is to be expected with regard to process description and the spatial resolution with more detailed calculations.

The question remains: How much does it rain today and how much will it rain in future? To come closer to an answer, meteorologists and hydrologists collaborate in various comparative studies with satellites, radar, observations and modelling.

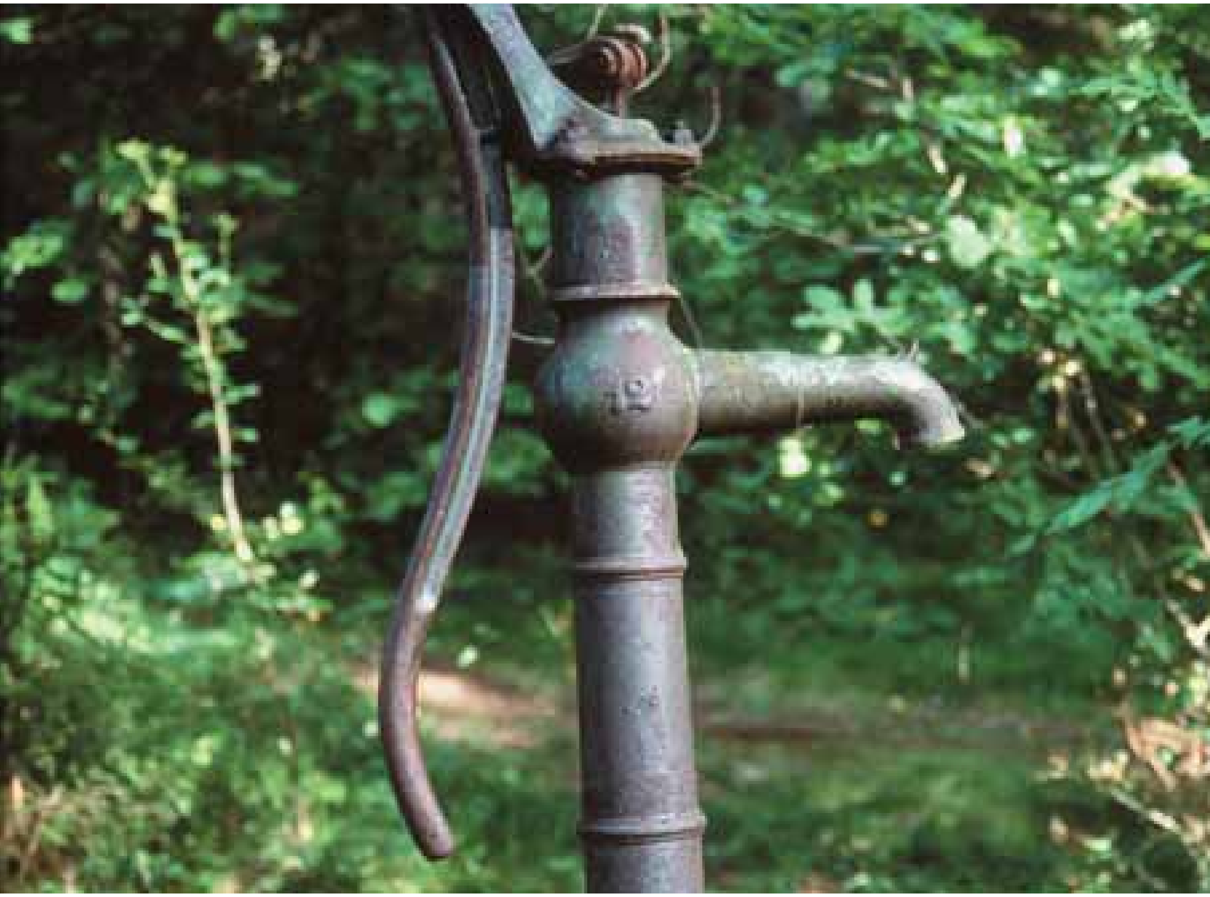
”No single drop of rain ever thinks it is responsible for flooding”

(From ”Written in Water” by Kenneth M Persson).

Is groundwater threatened?

Professor Gunnar Gustafson, Department of Geo-Engineering,
Chalmers University of Technology.

It is surprising that groundwater is so pure; the situation could be much worse. Problems concerning groundwater are most often solved on the basis of experience. To be able to make forecasts for the systems, we would need a better understanding of what happens – and why. Practical work and fundamental research are two sides of the same coin which are both needed. In research, cooperation is needed between hydrogeologists, chemists and biologists.



The perspective I will discuss is groundwater as a resource. I have worked as a hydrogeologist for 35 years, with the task of providing a secure groundwater supply for manifold needs. What I still find surprising after all these years is that the supply functions as well as it does. It is said in a lot of contexts that groundwater is under threat, but in actual fact we see little of this problem. My experience is that we are working with a very robust system. Are we perhaps asking the wrong questions? Should we perhaps ask: What is it that makes the system work so well? What margins do we have in the groundwater system? How do we make the best use of what there is?

I will therefore discuss some aspects of groundwater and groundwater supply from this perspective. I will not sound any alarms and what I will write will not give rise to any acute research, but these are nevertheless important issues for study. It can also be research that produces good results.

How is groundwater formed?

Empirically we know quite a lot, but can we forecast and model? Do we understand the processes?

We know far too little about groundwater formation in rock. We have made some model calculations which indicate that the mean groundwater formation in southern Sweden is 5–15 mm, unless the groundwater drains into tunnels or wells. If we utilise the groundwater or drain it, there will be much more, but there will be a change in quality, namely acidification that has nothing to do with precipitation. Empirically we know quite a lot, but can we forecast and model? Do we understand the processes?

Induced infiltration from surface waters is an important groundwater formation process for many water intake plants. We know this from experience; otherwise it is not possible to draw up a credible water budget for the plant. We know empirically that in most cases the result is water of good quality, but also that we often have elevated iron and manganese contents. We have also encountered some cases where the increased load caused the system to break down, with serious quality problems as the result. Do we understand the processes physically, chemically and biologically? On the basis of new knowledge, it should be possible to progress a lot further.

Artificial groundwater recharge has been successfully applied in Sweden for a long time. Many Swedish towns are supplied by an infiltration installation. But much of the knowledge of how this should be done is empirical. With modern knowledge of groundwater hydraulics, chemistry and biology, we should be able to learn what is actually happening and to model the processes so well that it is possible to optimise the systems. I have the feeling that today we do not fully exploit the possibilities.

Models for sand and gravel aquifers

Today, model calculation programs for flow and transport are commercially available, and these perform calculations that we could not even dream of a few decades ago. There is no doubt that the calculations are correct, but are we calculating the right things? In research on nuclear waste, we have worked over a long time to harmonise modelling with laboratory studies and field experiments. This work has provided a completely new insight into how fissures in rock function and how groundwater and its chemical constituents interact with the rock.

There is no doubt that the calculations are correct, but are we calculating the right things?

As far as I know, nothing similar has been done for sand and gravel aquifers. I think this is needed, since the progress in the modelling that has been carried out is limited in scope. An important part of this work, which also does not appear to have been done very well, is the conceptual modelling of the system. How can we be sure on the basis of field data that we are using the right processes, the right geometry and the right parameter values?

Pesticides and infiltration of sewage

In-situ treatment of groundwater is often economically advantageous. One good example is artificial groundwater recharge. There are also other methods such as reinfiltration and the VYR method for the removal of iron and manganese. A large proportion of the rules of thumb that are used to design these plants are based on experience and trial and error. There is need for an analysis to find which processes work hydraulically, chemically and biologically, so that it will be possible to make better forecasts for the systems than at present.

One current problem is posed by pesticide residues that have been found in groundwater intakes. In this case also, it is surprising that the situation is not worse. As in other cases, I am not convinced that laboratory investigations are enough to predict the degree of "self cleansing" that the subsoil can carry out. The system is more complex, and it is not fully understood. In the same way, we do not properly understand what happens to bacteria, viruses and other organisms in the groundwater. Why are there not more? Which transport mechanisms are involved and which are absent? How does decomposition take place? New chemical and biochemical (DNA) methods of analysis have been developed for this which should be able to make a substantial contribution in regard to both the origin and the fate of the biological and chemical residues in groundwater.

Infiltration of sewage is a treatment method which is extensively used but is regarded with deep suspicion by the authorities. Most of the research that has been done has been empirical analyses of experiments. As I have shown before, in this case also completely new knowledge ought to be developed with the help of new research methods. We may find that it is an excellent treatment method, or we may find that it must be discontinued. We must find out what the position is.

An abstraction well must be maintained

An abstraction well may appear to be a simple construction. But, in order to make it work, it must be adapted to the aquifer, undergo development pumping and be maintained. In the well, water of different origins is mixed together since the well draws water from the whole groundwater recharge area. This means that a lot happens, chemically and biologically, in and around the well.

It therefore becomes clogged at times, and strong chemicals and mechanical treatment are used to clean it. What in actual fact are the processes involved in clogging and cleaning? How are these affected by the construction of the well and by the different water qualities in different parts of the aquifer?

”We know the value of a well when it dries up”

(From ”Written in Water” by Kenneth M Persson)

Research and practice – two sides of the coin

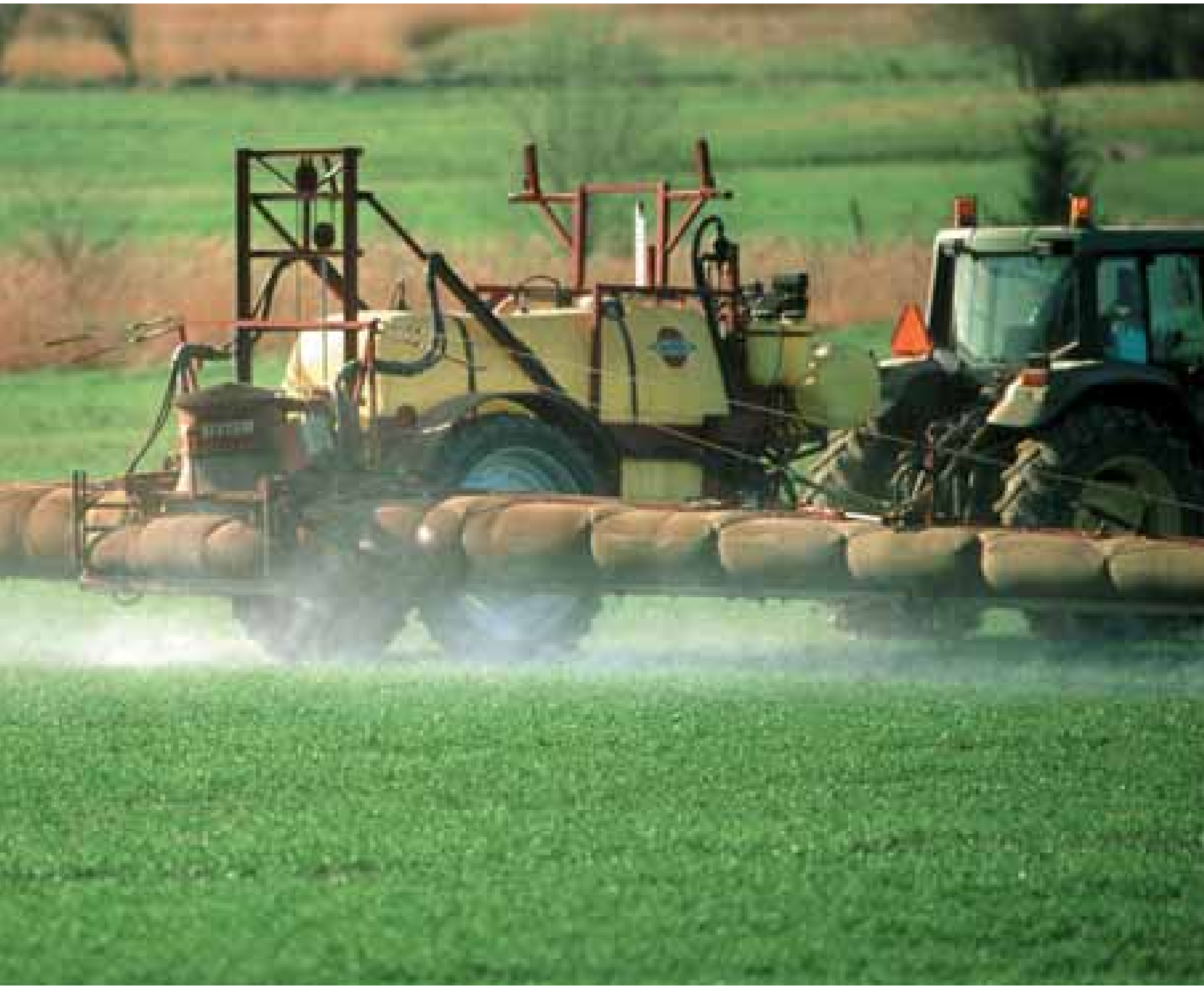
Much of what I have pointed out may at first sight appear to be applications of current knowledge concerning familiar problems. But it must be borne in mind that the research which has been done into these problems was done a long time ago. This means that new fundamental knowledge can be applied and utilised, mainly in regard to the flow and transport of groundwater and biochemical processes. I am also convinced that this will necessitate new fundamental research to enable us to understand what is happening and why.

I wish this could be done in cooperation this time, in collaboration between hydrogeologists, chemists and biologists. That applications are used to stimulate research into the fundamental issues. That we have the patience to allow the fundamental results to influence practical work. The coin has two sides, and both are needed.

What causes leaching?

Professor Lars Bergström, Department of Soil Science,
Swedish University of Agricultural Sciences.

Several critical environmental problems are associated with the leaching of nutrients and chemicals from agricultural soil. Examples are eutrophication of the Baltic Sea, pollution of surface water and groundwater by pesticides, and algal blooms in our lakes in the early autumn. In all cases, water acts as the carrier of the pollutants.



The aim of much of the research carried out so far has been to prevent that a potentially polluting compound is dissolved in soil water and may in this way be carried into environments where its presence is undesirable. The situation is most critical in spring and autumn, with large amounts of excess precipitation which can transport the dissolved compound through the soil or on the surface of the soil.

Water is transported in different ways in different soils. In a clayey soil, transport largely takes place through large pores and cracks (earthworm burrows and root channels), because clay material as such has very low permeability. In a sandy soil, on the other hand, water is transported more uniformly, i.e. water flows through almost all pores. The effect on the transport of dissolved substances is that in a clayey soil it occurs quickly and sporadically during a heavy rainfall, while in a sandy soil it takes a much longer time. But it is important to remember that over longer periods, e.g. a year, the total quantity of water and thus also the leaching of a pollutant is in most cases considerably larger in a sandy soil.

Nitrogen in a precarious balancing act

As regards nitrogen, its dissolution in soil water can be prevented by sowing catch crops that take up the nitrogen that remains in the soil after the main crop has been harvested in late summer. The catch crop acts as a biological filter for excess nitrogen. Another method is to spread organic material deficient in nitrogen, such as straw and fibres from the paper industry, which can be easily degraded by microorganisms. Nitrogen is then taken up by microbes from the soil water and is bound in the microbial biomass, thus preventing leaching.

When, on the other hand, plants need nitrogen in early summer, microbial degradation of the stock of humus in the soil should be accelerated so that the organically bound nitrogen is released. This can be achieved by liming which raises the pH value of the soil. This increases the solubility of humus and thus the release by microorganisms of nitrogen and other plant nutrients. Release, uptake by plants and leaching of nitrogen is in other words a precarious balancing act.

Nitrogen from organic fertilisers

Nitrogen is utilised less effectively in organic than in inorganic fertilisers, since the organic nitrogen must be transformed into inorganic nitrogen before it can be taken up by the plant. This often occurs at times when there are no crops growing. The use of organic fertilisers such as farmyard manure and green manure therefore often results in greater leaching of nitrogen than the use of inorganic fertilisers. Organic agriculture that uses only organic nitrogen fertilisers therefore offers no environmental advantages compared with conventional cultivation as regards leaching of nitrogen, rather the contrary.

One evident improvement in the use of organic fertilisers would be if release of nitrogen from the ploughed-in organic material could be controlled, so that it coincides with the uptake of nitrogen by the crop and does not occur when large quantities of water penetrate into the ground in spring and autumn. As regards green manure, the solution may be to grow a mixture of plant species in which nitrogen is released from the ploughed-in material at different times. Another possibility is to anaerobically digest the green manure material in order to obtain both energy in biogas and plant nutrients in digestion residues which can then be spread on the agricultural land.

Improve precision!

In cultivating agricultural crops, there are great possibilities to reduce further the leaching of plant nutrients. Soil tillage practices can be limited and more perennial crops can be grown. Exact dosage of inorganic plant nutrients to crops as a function of site, time of year and soil is a technique which can be developed further.

Traditionally, measures which are taken to prevent leaching from agricultural land are the same over quite large areas. But the great variation of the soil in the agricultural landscape must be taken into account. It influences the transport routes of the water and gives rise to large differences in leaching from individual fields and even parts of the same field. Exact adaptation of farming measures to the variable capacities of the individual fields to transport water helps to limit leaching of both plant nutrients and pesticides. Development of techniques to enhance precision in cultivation is therefore very important.

One important issue that is related to improved precision is the impact of agriculture on water sources, both municipal water supply intakes and individual wells. In the intake areas where aquifers are recharged with water, the spreading of both fertilisers and chemical pesticides should be subject to very restrictive conditions, or should even be prohibited.

New theory concerning the smallest pores in soil

That water is essential for all biological life on earth is well known. But what happens in detail in different aqueous environments is not known to the same extent. In the water in the cavities of the arable land there occur a large number of processes which control the transformation of various chemical compounds, both plant nutrients and pesticides. A lot of these processes are controlled by soil microorganisms which obtain their energy by degrading or transforming chemical compounds. The dominant theory today is that it is the chemical structure of the compounds that governs degradation and transformation.

But in recent years another theory has been proposed which places the focus on the access of microorganisms to these compounds. A large proportion of the pores of a clayey soil are so small that not even the soil microorganisms can get into them. Chemical pesticides which are spread on the land, for instance, can on the other hand diffuse into these pores and are in this way protected from degradation. In other words, it is the rate of diffusion in the aqueous phase of the very smallest pores, from the micropores to larger pores in which microorganisms are present, that largely controls the way chemical compounds are degraded and transformed. Nor can a chemical compound be transported down into the soil if it is inside the very smallest pores, since the velocity of water in these pores is negligible.

Although we are beginning to have a general understanding of how biodegradation and the transport of dissolved compounds occur in the soil pore system, we need much better knowledge of what controls these processes in detail and at what rate they occur. Such knowledge is absolutely essential for the biodecontamination of e.g. polluted soils. Mathematical modelling of the spread of chemicals in the environment will probably have greater importance in future. In this context also we need greater in-depth knowledge of the behaviour of chemicals in the smallest pores of the soil.

How is water affected by forestry?

PhD Eva Ring, The Forestry Research Institute of Sweden.
Associate Professor Willem Goedkoop, Department of Environmental Assessment, Swedish University of Agricultural Sciences.

What is the difference between discharge and water quality in managed and unmanaged forests? What effect do individual forest management measures have on water? Do environmental considerations in forestry have positive effects on the structure and function of aquatic ecosystems? These are examples of the questions which future research on the forest and water will have to answer.

In Sweden we have a lot of water and a lot of forests. We have 92,400 lakes larger than 0.01 km^2, and more than half the total surface of Sweden is forest land. Water is an important component of the forest landscape and is present almost everywhere, in lakes, rivers, land, vegetation, animals and air. Water is of great importance for life both in water and on land.

Nutrient transport between land and water

Water in the forest landscape is often brown in colour due to dissolved humic compounds; this shows the close coupling with the land ecosystem. The forest supplies the aquatic ecosystem with nutrients which are leached from the soil, and via needles and leaves that fall down into the water. Swedish studies have shown that more than half the carbon in pikes in forest lakes originates from the forest ecosystem. Owing to the close coupling with the forest ecosystem, watercourses in the forest landscape provide the habitat for many species of benthic animals which are unique.

Forests that surround lakes and watercourses receive some of the nutrients from the water through the deposition of particulate material during periods of high water. A very special example of the cycling of nutrient compounds between land and water comes from Alaska. It was found there that grizzly bears which live on migrating salmon represent an important part of the nutrient transport between the aquatic and land ecosystems. The bears leave half eaten salmon on the ground along the rivers, and these create a breeding ground for, and provide nutrients to, small trees in the soil that is otherwise poor in nutrients.

The forest is important as a place for egg laying and swarming for insects that spend their larval stages in water. Water in the forest landscape is thus of great significance for biodiversity.

Humans have an impact on forest water

Humans have had an impact on water in the forest for a long time, through swidden farming, ditching, timber floating and tree felling for energy. Even today, this has its traces in the chemistry, hydrology and biology of our forest waters. In recent times, human impact has also taken the form of emissions into the air which have increased acidification and eutrophication, and the concentration of heavy metals and other undesirable substances in the soil.

Modern forestry also alters forest water in different ways. We believe it is essential that in future research projects the following areas concerning forests and forestry should be investigated.

What does forestry mean for water?

Almost all forests in Sweden are managed. It is only a small proportion of forest land that consists of uncultivated natural forests. Owing to a different disturbance regime, for instance fire dynamics, these forests may to some extent have a species composition different from that in the managed forests of today. These forests are also important standards in assessing the effect which forestry has on the discharged water.

What is the difference in discharge patterns and water quality between managed and unmanaged forests?

Environmental monitoring today covers almost exclusively only managed forests. In order that we may be able to judge how today's forestry affects our water, we need to know more of the chemical and biological quality of water in unmanaged forests. Important questions that have to be answered are: Are there differences in discharge patterns? What is the difference in the leaching of nutrients (chiefly nitrogen and phosphorus) and humus between managed and unmanaged forests? How does forestry affect the aquatic biodiversity?

How does forestry affect the aquatic biodiversity?

Production and environment

According to the Forestry Act, forestry in Sweden shall be carried out in such a way that equal consideration is given to forest production and environment. This means that any effects on biodiversity, soil and water must be accorded the same importance as the achievement of a high level of forest production. The national environmental objectives give great attention to forests and forestry. In order that an assessment may be made whether forestry is carried out in line with the national environmental objectives and the Forestry Act, good knowledge of the environmental effects of various forestry measures is required.

Compared with agriculture, the effects of forestry are often small, but since forest land occupies such a large proportion of Sweden's area, it is important for the effects of forestry also to be elucidated. We must also know how different forestry measures affect the environment, so that we may estimate what contribution forestry makes to the leaching of various substances. Leaching of nitrogen from forest land can be instrumental in creating algal blooms in coastal waters. Greater knowledge will enable us to improve management methods so that negative effects on the environment are reduced and positive effects reinforced.

Final felling and site preparation

How do individual forest management measures affect water?

The effects of different forest management measures on soil and water have been studied in Sweden and internationally, but there are still great gaps in our knowledge. Final felling and site preparation are two measures that are practised in Sweden on a large scale and need to be further elucidated.

Final felling is a violent disturbance of the forest ecosystem that gives rise to increased leaching of nitrogen and other compounds. The effects of final felling have been studied in central and southern Sweden. But what is leaching like in the north of Sweden where the soils are generally less fertile and the climate is different? Can leaching of nitrogen to surface water be reduced by creating buffer zones in the forest along watercourses? Some research is carried out in these areas, but further research is desirable.

Site preparation is carried out mainly to facilitate the establishment and growth of seeds and seedlings, and to protect the seedlings from attacks by pine weevils. In Sweden, only mechanical methods such as disc trenching and mounding are used. Mechanical site preparation means that some of the organic horizon is inverted and mineral soil is exposed. Previous research suggested that site preparation increased the leaching of nitrogen, but more recent findings show that the effects on nitrogen leaching are probably small and may even be reversed in some soils. What we do not know very much about today is how ground vegetation, especially in northern Sweden, affects leaching. Two further questions which are important are how the cycling of heavy metals is affected and, in the long term perspective, whether the effects of future forestry measures and the deposition of acidifying or eutrophying compounds are affected by the site preparation methods of today.

Nature conservancy considerations

In different ways, nature conservancy considerations have become an integral part of modern forestry. But we do not know a lot of the effects of nature conservancy on the structure and function of aquatic ecosystems. Relatively little action is taken to improve the conditions for biological life in lakes and watercourses. One example is that buffer zones are left along the river banks. Another and more drastic example would be to create habitats by leaving dead wood in the watercourses.

The effects of different forms of nature conservancy measures on the aquatic ecosystems in the forest have not received a lot of study. There has been an absence of integrated ecosystem thinking with the focus on the drainage basin, where processes on land are coupled with biological effects in the aquatic ecosystems. These biological effects should comprise investigations of changes both in structure (species composition, trophic levels) and function, for instance the turnover of nutrients and decomposition of leaves. Studies of this kind are in line with the ongoing development of the 16th environmental objective on biodiversity and the EU framework directive on water.

Can new technology clean water for the city?

Professor emeritus Torsten Hedberg. Assistant professor Thomas Pettersson. Professor Gilbert Svensson. Assistant professor Britt-Marie Willén. All researchers are working at the Department of Water Environment Transport, Chalmers University of Technology.

Drug residues, antibiotics and hormone-disrupting compounds – all these affect the drinking water treatment and sewage disposal of the future. Will the households of the future perhaps purify their drinking water themselves? Not likely. But we are introducing new processes in water treatment plants, with more biology than chemistry, and also advanced membrane techniques. Water treatment technology of the future will be determined by local conditions.

Will we in future have a high-technology, greatly decentralised production of drinking water, where each individual or household treats its own water for different purposes? Not likely. Because even if the technology is available to utilise all the water circulating in the city, i.e. to treat all kinds of raw water or waste water to drinking water quality, it is not a desirable or economically viable development. Drinking water is cheap and has a high quality in the centralised system we have today.

The EU framework directive for water will control quality goals for many years to come. The quality standards focus on a healthy and microbiologically safe water. Through this directive, municipalities have had to assume greater responsibility for the protection of water sources and for the design of effective treatment processes with clear environmental goals.

New compounds demand new technology

The technical water treatment processes we use today have evolved over the past 50 years. In many processes, powerful chemical methods are used instead of natural biological processes, and this has resulted in the formation of undesirable residual products which, in turn, require further treatment. One example is the use of oxidation and disinfection agents which, although necessary, generate noxious by-products. The bacteria also develop resistance to the chemicals, which, in turn, renders these agents ineffective for their original purpose.

As regards a number of known and unknown organic compounds such as drug residues and hormone-disrupting compounds, and microorganisms such as parasites, bacteria and viruses, we must substantially increase our knowledge of how they can be removed.

Drinking water trends

• We can today see a trend that we need to remove easily degradable organic compounds in order to reduce the growth of microorganisms in our supply pipes.

• We can also see that we will have to remove natural organic materials, as a result of the fact that climatic changes appear to increase the Hazen Scale value of water.

• We can also discern a trend that we will need effective separation of very small particles (nanoparticles) and microorganisms, in such a way that the separation process does not give rise to any side effects.

It is essential that the authorities responsible for water supply set up clear goals for the supply of drinking water and, together with research organisations, make available research resources that focus on developing new and essential physical, chemical and biological processes for water treatment. This may seem strange since we have used biological and chemical processes for many years and should in actual fact have good knowledge of water treatment, but treatment involves complex dynamic processes which are not known in detail. This is shown by experience.

The water supply system of the future, over a perspective of 20–30 years, will probably look the same as today. But it will concentrate far more on protected areas for water sources, and we will see new processes at waterworks. They will employ more biology and less chemistry, and will in addition have more powerful separation processes in the form of membrane techniques.

Wastewater treatment

Wastewater treatment is a large and important process and modern urban areas are dependent on this for proper sanitation. The treatment is mainly biological, in which microorganisms degrade organic compounds and remove nutrients from the wastewater. As the authorities require stricter effluent discharge limits, new and more efficient process solutions are increasingly demanded. The cost of implementing new improvements in wastewater treatment is very high; in Sweden it is often of the order of billions of SEK.

Efficient treatment will be important for several environmental and sustainability issues. The Swedish parliament has recently set up the environmental objectives which shall result in ecologically sustainable development of society. Some of these are closely related to wastewater treatment: ”no eutrophication”, ”flourishing lakes and streams”, ”a balanced marine environment, flourishing coastal areas and archipelagos”, ”a good built environment”.

Treatment plants must produce treated water of high quality that can be discharged to recipients without harming the environment or public health, and be able to produce residual products that can be used as fertilisers and for energy generation. It is also desirable to minimise energy use and to use a smaller quantity of chemicals in the treatment process.

Local conditions determine technology

Often, many countries discharge polluted water into the same sea, for example the Baltic Sea. Improving the efficiency of treatment is therefore important not only nationally but also for the European Union and internationally. Together, we must work for better conditions in our common environment and must export our knowledge to countries with less developed techniques.

The best treatment technology can vary depending on local conditions. In some places centralised treatment is the best option, while in other areas decentralised treatment is a better choice. In the future, several alternative solutions to ”conventional” treatment will be developed and implemented in society. For a successful function, it is necessary to study the social aspects of the use of these systems. Due to its high investment costs and efficiency, the existing system will probably remain in use for many years, and it is therefore very important that we increase our knowledge of this system.

In-depth understanding

Owing to the high performance requirements and the complexity of modern wastewater treatment plants, in-depth understanding of the various biological, physical and chemical processes involved is essential. We are also confronted by new problems – the spread of drug residues, antibiotics and hormone-like molecules in the wastewater, which cause problems in the recipients.

In the past, the focus in treatment plants was on the engineering aspects. Today, there is greater focus on detailed studies of the fundamental mechanisms involved. For instance, recent advances in molecular techniques enable us to understand the complex biological processes in detail. The challenge for the future is to synthesise this detailed knowledge into engineering solutions. Research therefore requires collaboration among many disciplines in order that sustainable solutions to these problems may be produced.

Stormwater is a resource for the city

Future stormwater management must consider stormwater as a resource for the city. Stormwater is natural clean water and will not be polluted more than precipitation. Considering stormwater as wastewater is a tradition that has its origins in the time when stormwater was handled together with sanitary wastewater.

In modern urban drainage systems, stormwater is transported in separate pipes or in an open ditch. Unfortunately, stormwater is polluted by the surfaces over which it passes on its way to the recipient. It flows over roofs of different materials, parking areas, and streets and roads polluted by traffic. In many cases, stormwater from areas carrying traffic must be treated before it can be discharged to a recipient. It should definitely not be mixed with less polluted stormwater.

But it is possible to reduce the pollution of stormwater by using other materials for the surfaces and by reducing traffic emissions. More effective street cleaning and cleaning of catch basins will also reduce stormwater pollution to some extent.

Substance flow models

Substance flow models that describe the substances in stormwater and their origin are invaluable in the decision process for developing sustainable urban drainage systems. Research will improve the ability of the substance flow models to describe the runoff processes and thus the consequences of the different ways of handling stormwater.

Natural clean stormwater may be used for different purposes in the city, from open water surfaces to sanitary flushing, with improved environmental conditions as the result. But this cannot be done without research concerning the design of these new facilities and the risks connected with these new systems.

Without water – no food

Professor Kenneth M Persson, Department of Water
Resources Engineering, University of Lund.

Water is life, and food needs water. Water in food enhances flavour, consistency, succulence, and the enjoyment of food for all our senses. More water in food could reduce our energy intake. But is it possible to raise the water content of food without, at the same time, degrading flavour and smell? And for the sake of global food supply – can we reduce the need for fresh water in food production?

According to a summary that Annika Carlsson-Kanyama and Rebecka Engström have drawn up for the Swedish Environment Protection Agency, Swedish agriculture uses about 137 million cubic metres of water annually for irrigation and livestock husbandry. To this must be added the precipitation which the sun generates directly for the climate zone, about 600 mm annually in Sweden, and which is needed for all cultivation and soil conservation. The Swedish food industry uses about 69 million cubic metres of water in food processing. The edible fats industry needs the most water, but abattoirs, dairies, distilleries and breweries are also water-demanding activities.

When food is then to be turned into good and nutritious dishes, water is also required for cleaning, cooking, braising, in sauces, for coffee etc. After this, pots and pans, plates and cutlery must be washed up. The mean consumption of water in a Swedish household is 200 litres per person per day, about 10 litres of which are used daily as food or in food handling, and a further 20 litres for washing up and cleaning. If we add that every person in Sweden eats, on average, 800 kg of food every year, more than 60 per cent of which is considered to be made in Sweden, simple arithmetic will show that each kilogram of food that is handled in the kitchen or the restaurant implies direct water use amounting to at least 70 litres. Rain must be added to all this. Without water, no life – and no food.

Water gives food firm texture

But, if we look at food at micro scale, it is even more evident that water is crucial for good food. The water content of e.g. prime grade pork is 60 grams per 100 grams of food, while an apple contains about 90 per cent water. Without this water, the remaining food components would be quite tasteless. Water is needed to maintain a pressure in the cells that make up the food, and makes the food fresh and firm.

Water also takes part in the reactions with the other components of food. Salts and mineral compounds, and also low molecular organic compounds, are transported in water. The biochemical reactions in the cell occur in the aqueous phase. A few per cent of the water in the food take part in the stabilising reactions with nucleic acids, phospholipids and proteins, and enables these to form a molecular structure in two and three dimensions, so that cell membranes, RNA, enzymes and so on can function.

Microorganisms also need water for their metabolism. It is a common feature of all the methods used to conserve food that the available quantity of water is reduced in the food. Chemical preservatives which inhibit microbial growth are an exception. But salting, preserving, drying, smoking, bottling and deep freezing all decrease the ability of microorganisms to grow by inhibiting water activity.

A glass of water before food

Properly handled, water in food enhances flavour, consistency, succulence and enjoyment of food for all the five senses. Improperly handled, too much water can dilute food into a thin soup, while too little water will produce a dry and flavourless food.

Water has a concrete effect on nutritional value. Our often excessive energy intake in relation to energy use can be reduced if foods containing a lot of water displace those that contain little water. In Sweden, energy intake per person per day has been fairly constant between 12.2 and 12.5 MJ since 1980, while the consumption of fats has decreased. According to the calculations of the Swedish Food Administration, 36 per cent of energy was derived from fats in 2000, compared with 37 per cent in 1990 and ca 40 per cent in 1980. A higher proportion of the energy supply comes instead from proteins and carbohydrates. By increasing the intake of food of high water content, energy intake can be reduced. A glass of water before food is thus very good dietary advice for those who want to eat less.

Three main problems

But what must future research on water in food concentrate on? As will have been seen from the above, water is such a central concept when we talk about food that it is in actual fact futile to point out what is most important. If a water researcher were nevertheless given the task to suggest some important research subjects concerning water and food over the next 10–20 years, I believe that he or she could point to three main problems:

Storage of food

• What effect does water content have on the storage stability and texture of food and on the perceived food quality? When do perishables wither? The overall trend in the food industry is towards ever fresher raw materials, while at the same time Swedish food production is governed by the sun. Greater knowledge of storage at macro and micro level is presumably necessary if these conflicting forces are to be reconciled. All the reactions that alter food quality occur in the aqueous phase. Water is probably of crucial importance for food quality.

More water in the diet

• We are eating less fat, but we take in as much energy in our diet as our forefathers. The food industry is accused at present of giving consumers a sugar shock. Previously, it was said to give us too much butter. Imagine that the water content of the diet were instead to increase by 10 per cent – fats and carbohydrates would then be diluted. How can food raw materials and preparation methods be adapted to such a situation? What is needed to raise the water content of the diet without, at the same time, degrading flavour and smell?

Use of water for food production

• If we raise our eyes from the Swedish horizon, the global problem is that agricultural production demands water. In warmer growing zones, irrigation is in most cases necessary. How can crop farming be carried out with limited water resources? Food processing is water intensive. What can be done to reduce the need for fresh water in the food industry? The United Nations Food and Agricultural Organisation FAO is promoting the concept of virtual water – that water can be imported in processed form, as grain or fruit, to countries with a limited supply of water and the water volumes can be released there for purposes other than irrigation. What are the technical, economic and, not least, the legal obstacles to such a development?

Water perspectives in research projects

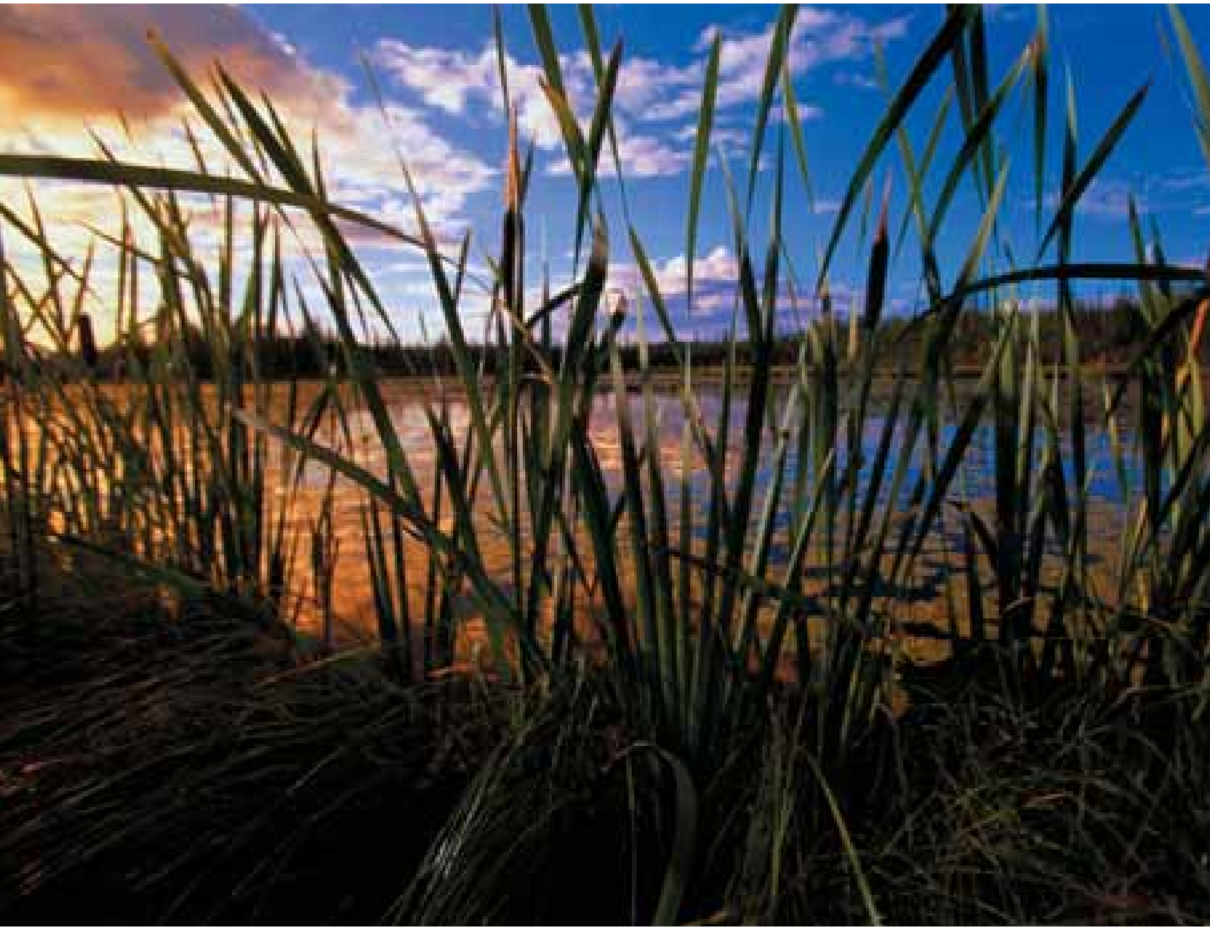
What I want to urge is that researchers should not forget water. In the same way as gender perspectives have become important in research, it is time to insert a hydroperspective into the applications for, and performance of, research projects.

There is a great need of knowledge about water in food, and this knowledge must be communicated to decision makers globally, to countries and to households. There is therefore a lot to be done by researchers, the food industry and the authorities. All who want to will probably have the opportunity to surf on this wave in future.

Ecological biotechnology in wetlands ?

Senior lecturer Karin Tonderski, Department of Physics and Measurement Technology, Biology and Chemistry, Linköping University. Professor Stefan Weisner, Ecology and Environmental Science, Halmstad University.

Is there a connection between biodiversity in wetlands and the ability of wetlands to filter out phosphorus and nitrogen? Can different functions be achieved in the same wetland? How do we maintain the function of wetlands in a long term perspective? Is the action we are taking to restore wetlands sufficient? And, to look further ahead – how shall we in future better utilise the potential of wetlands for production?



Through purposeful ditching and drainage to dry the land, many of the world's wetlands have disappeared. The land has been wanted for cultivation and other development. The loss of wetlands has resulted in impoverishment of the landscape which makes it more vulnerable in many ways. Among other things, biodiversity has been depleted and the transport of nutrients from land to water has increased, with eutrophication in lakes and seas as the result.

A tool in environmental work

Research in recent years has shown how wetlands can be used in different ways as a tool in environmental work. By restoring wetlands, or specially constructing wetlands for different purposes, useful functions are created for humans and the natural environment, such as water purification, biodiversity, balancing of water flows, improvements in the quality of life, production and recycling of resources.

Water purification

Wetlands filter out nitrogen and phosphorus, and also heavy metals and environmental toxins. Wetlands deal with diffuse discharges from e.g. agriculture, and also function as a stage in sewage treatment.

Biodiversity

Many species of plants and animals that have their habitats in wetlands have been driven out in the south of Sweden in the past two hundred years. By restoring wetlands, we have the opportunity to create increased living space for these species and to create greater diversity in the landscape. Wetlands are used, occasionally or permanently, by many species for e.g. foraging and breeding, or as a place to rest.

Balancing of water flows

Wetlands can help balance out variations in flow. Water that has been stored in wetlands can be used for e.g. irrigation.

Improved quality of life

Wetlands can be a great source of pleasure for all. Examples are outdoor activities, fishing, hunting, bird watching, enjoyment of nature, the scenery, tourism, school trips and education.

Production and recycling of resources

Wetlands offer the chance to produce e.g. bioenergy and to recycle nutrients to agricultural land.

Biodiversity and ecosystem function

Research in the future will have to address, inter alia, the relationship between biodiversity and the function of the ecosystem, a relationship that is of very great interest from both a scientific and applied point of view. Wetlands are excellent model ecosystems for research into such relationships. A great challenge for the future is to elucidate to what extent different functions can be achieved in the same wetland. Are there examples of a coupling between a high degree of biodiversity and the capacity for removal of nitrogen or phosphorus? How can we best create and maintain habitats for marginalised species that have their natural environments in wetlands? Can these wetlands also become effective nitrogen and phosphorus traps in the agricultural landscape? How do we maintain the function of wetlands in a long term perspective?

Other important areas of research are concerned with the acquisition of quantitative knowledge of the significance of wetlands on a larger scale. In many drainage basins, there are huge areas of wetlands that have been drained in the past centuries. Will the action we take in the next ten to twenty years be enough to achieve a noticeable effect, whether it concerns biodiversity, storage of water or removal of nitrogen and phosphorus?

Productive wetlands

An area of more visionary character is how we can in the future produce different useful functions in wetlands. In many parts of the world, wetlands are used in aquaculture. In Asia, it is usual for freshwater shrimps and different fishes to be farmed, and for aquatic plants to be grown which are harvested as vegetables. Wetland plants can be used as animal feed. Research is also carried out at present on various compounds which can be extracted from algae, some of which can be grown in shallow freshwater systems.

One example of other products which can be obtained from wetlands is starch, since many wetland plants have storage organs that are very rich in starch. Wetland plants also often contain a lot of fibre which can be used for the production of paper and rope. Wetland plants can be converted into building materials. For instance, reeds have been traditionally used as roof covering, and in Germany a high class insulation material has been produced from reedmace. Furniture can be made from e.g. papyrus.

The question in future will be how we can, in a sustainable manner, utilise the production potential of wetlands and at the same time maintain important ecological functions.

What importance do lakes have when the climate changes?

Professor Lars Tranvik, Department of Limnology,
Evolutionary Biology Centre, Uppsala University.

Lakes are sensitive to changes in climate and can therefore act as indicators of climate changes, which is something that limnology in future will make use of. There are signs that inland waters which cover only two per cent of the earth's surface store as much carbon as the oceans. Carbon is stored in the sediment, and at the same time carbon dioxide is emitted from the water. Lakes and reservoirs are therefore essential components of the global carbon cycle, and their role depends on the climate in future.

Limnology, the study of inland waters, has traditionally and successfully been occupied with the study of nutrients and eutrophication. This is an issue of great importance for water quality and lake management, and will be a main focus of limnology also in the future. However, there is a number of emerging topics in limnology which will be of increasing importance in the future. These new research issues emphasize the global dimension of limnology, and are listed below.

Lakes as global carbon sinks

The sediments of lakes, and in particular man-made reservoirs, store large amounts of organic and inorganic carbon that is imported from the surrounding drainage basins. There are indications that inland waters, although they cover only two per cent of the earth's surface, store as much carbon as the entire oceans. A large proportion of this carbon sequestration is due to sedimentation in man-made reservoirs.

The circumpolar northern boreal zone, in particular, is very rich in lakes. These lakes may be important sites for carbon sequestration. At present, there is a nearly complete lack of quantitative information on the role of lakes in carbon sequestration. In addition, the study of mechanisms leading to the storage of carbon will be necessary in order to predict the distribution in time and space of carbon sequestration in sediments.

Evasion of carbon dioxide

During retention in lakes and rivers, dissolved organic carbon that is transported from land to the sea is subject to microbial and photochemical transformations. Recent evidence suggests that this results in carbon dioxide evasion to the atmosphere that is similar to the entire riverine transport of carbon to the oceans. Most of the carbon dioxide evasion occurs during retention of water in lakes.

These results challenge the view of the freshwater environment as a neutral pipe for the transport of material from land to sea. Further study of the quantity and mechanisms of biogeochemical transformations in lakes will be crucial for the understanding of the linkages in the carbon cycle between land, oceans and atmosphere.

The changing role of lakes

Climate change will lead to increasing temperatures, and altered water balance. As described above, lakes and inland waters play important roles in the global carbon cycle, being hot spots for the storage of carbon, and at the same time sites of emission of carbon dioxide to the atmosphere. The role of lakes in these processes is highly dependent on water retention time, which is determined by the landscape water balance.

Changing temperature, water balance, land use, and distribution of water discharge in time and space will have major effects on lakes and their role in the carbon cycle. The prediction and understanding of these changes will be a major topic in future limnology. Comparison of lakes in watersheds with different land use and climate will be an important approach.

Lakes as indicators of global change

As described above, lakes and their function are very sensitive to climate change, since they integrate events in the watershed. The other side of the coin is that lakes are therefore sensitive indicators of global change. Future limnology will take advantage of this. Changes in biogeochemistry in lakes, as well as the success and loss of aquatic species, hence reflect the dynamics of the entire drainage basin of lakes.

Paleolimnological study of the historical record in sediment cores will aid the understanding of current change in lakes and their watersheds. Hence, understanding the dynamics of lakes will enhance knowledge of how the terrestrial environment responds to climate change.

”Water manages without fishes, but fishes cannot live without water”

(Chinese proverb. From ”Written in Water” by Kenneth M Persson)

Are rivers ecosystems going down the drain?

Professor Björn Malmqvist, Ecology and Environmental Science, Umeå University. Professor Anders Wörman, Department of Biometry and Engineering, Swedish University of Agricultural Sciences.

Running water is a freshwater resource of global importance which is subjected to such high pressure by human activities that the conditions for aquatic ecosystems are altered and biodiversity is impoverished. Research into our streams and rivers comprises many complex issues. Greater interdisciplinary cooperation and contact between scientific disciplines that have been traditionally distinct is therefore essential.

Streams and rivers have a crucial role for erosion and the redistribution of dissolved substances in the drainage basin. They also perform most of the global transport of nutrients, heavy metals and sediment from the continents to the seas, and, to quote an example, are of critical importance for eutrophication and the increase in the size of lifeless areas at the bottom of the Baltic Sea. In addition, the diversion of water, pollution, damming and the indirect impacts of urbanisation and agriculture, to mention but a few serious impacts, will reduce many stream and river ecosystems to simplified systems of low biodiversity. The political importance of water is underlined by the fact that most of the serious environmental threats identified at the UN Environmental Conference in Rio de Janeiro in 1992 are directly coupled with the circulation of water in nature.

Increased risk of flooding and dam failures

Engineering measures in rivers such as canalisation or the construction of dams affect not only solute transport but may also pose direct safety risks. Especially in conjunction with high water levels, there is increased risk of dam failures and flooding. Safety issues related to high water levels are of special timeliness due to the threat of climate change and greater variations in flow in streams and rivers. Extremely high peak flows may be expected to become more common in the future; because of this, we need to reassess the safety implications of structures such as dams and bridges.

Dam safety issues have also assumed greater importance owing to the collapse of several tailings dams in recent years in Sweden, Romania and Spain. These have given rise to a catastrophic dispersal of heavy metals over large areas and to serious pollution of arable land.

Surface water and groundwater

The coupling between the fast moving water in streams and rivers and the much slower groundwater is an important area of research which is under rapid expansion at present. A large number of mechanisms contribute to the exchange of water volumes, and we do not know enough at present of the mechanisms which dominate the various issues.

Alarm models which are used in connection with accidental contaminant discharges into large European rivers take account of the exchange processes, such as turbulence and dispersion, in the running water. Over long periods and in catchment areas with streams and rivers of different sizes, the transport of substances is affected to a high degree by the exchange with the bottom sediment under and beside the river, in the hyporheic zone. Research has shown that the topography of the catchment area and the irregularities in the bottoms of the streambeds, which are caused e.g. by benthic animals, influence the way in which chemical compounds and particulate material are "filtered" in the bottom sediment. These exchanges between surface and groundwater may be expected to have particular significance for all the transport that occurs over all the catchment areas, and therefore to be of great importance for the future management plans which are prescribed by the EU Water Directive.

Biodiversity and ecosystem functions

The value of various organisms, even small invertebrates, which inhabit running waters cannot be overestimated. They are needed, for example, to link energy from primary organic sources (algae, detritus) up through the food chains, leading to cleaner water with abundant fish and crayfish.

A research field of great importance is to determine whether ecosystem functions will deteriorate as a consequence of declining biodiversity. Examples of ecosystem functions are decomposition of organic material, biomass production, and aeration by aquatic plants. Studies have shown that changes in community structure, including species loss, may have significant impacts on such processes. So far most of our knowledge about biodiversity effects on ecosystem processes has been gathered for plants in grassland ecosystems while very little is known about corresponding processes in aquatic systems such as streams and rivers. Therefore, it is of considerable importance to learn more about diversity-related processes in these environments. If we understand them better we can also take stronger action to deal with threats that may lower the functionality of communities.

Key and keystone species

Biodiversity is not only a measure of the number of species. It also encompasses the entire breadth of genetic diversity and habitats, specific species having especially great importance for ecosystems either in terms of high frequency of occurrence (key species) or because of a disproportionate effect in relation to their abundance or biomass (keystone species), and other patterns of community structure.

Obviously, we need to develop predictive models that will consider the ecology of species under a changing climate regime.

Furthermore, as pressure on freshwater systems increases, habitat loss will be unavoidable thus actualizing the need for metapopulation and dispersal theory in order to predict future states of riverine species.

The present situation thus calls for intensified research not only on how the deterioration of habitats affects biodiversity but also how biodiversity influences processes in stream and river ecosystems. In particular, there is a need to find out for these systems which species are key and keystone species, and exactly how these are linked to the ecological functions of the system in food webs and in other relationships, and what factors affect the stability of their populations.

Remedial measures and recovery

Streams and rivers are vulnerable ecosystems but they also have a strong capacity for recovery, perhaps because they are often exposed to a great deal of strong flow changes, ice formation, silting and other stressors, even when unimpacted by man. Perhaps some organisms may be redundant, and if lost their roles are easily compensated for by remaining species which have similar biology. As a consequence of environmental changes, it is however likely that species that are abundant today will be replaced by others, now rare, but better adapted to the new situation. Therefore, as a general principle of precaution, it is of the utmost importance to prevent species from going extinct.

If severe habitat degradation is already a fact, restoration may be an option to bring back the functionality of a stream or river. At present there is an emerging interest in building up competences for restoring rivers; this includes the removal of dams, reshaping of simplified river channels and liming of acidified rivers. But restoration is no easy task, and there is a great need to develop methods that take into consideration both the engineering aspects and the physical, chemical and biological functions of streams and rivers, and to monitor the restoration measures to make sure that they actually work.

Interdisciplinary development

In future research into streams and rivers, it will be more important than today to work on an interdisciplinary basis so that the relationships between the utilisation of water resources and ecology may be better understood. Many important problems in this area necessitate development of the interfaces between chemistry, biology, physical processes, mathematics and social sciences. Through such integration, with new methods and a concerted effort, we should be better equipped to face up to the threat posed by an increasing pressure on water resources, due to global climate changes and population growth.

”He who does not know the way to the sea, must follow the river”
(From ”Written in Water” by Kenneth M Persson)

How do we keep the Baltic Sea alive?

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Marine coastal areas harbour most of the world's populations. Humans rely upon the ability of marine environments to generate goods and services of considerable economic value. It will therefore be crucial to understand the factors controlling sustainability of these highly diverse and productive ecosystems.

A typical example of a coastal sea is the Baltic Sea. This enclosed young brackish sea consists of a series of large basins, each with a unique combination of fresh water and marine species. Large scale human perturbation consisting of nutrient enrichment, toxic compounds, overfishing and habitat destruction threatens the species diversity and ecosystem functioning. The drainage basin of the Baltic Sea is densely populated and heavily industrialised, which adds a significant stress from marine pollution to animal and plant life. The low species number with lower genetic variation in combination with higher sensitivity to pollutants and the reduced ecosystem complexity will increase the risk of losing whole life functions.

Full scale evolutionary experiment

Compared to the 7 000 years that marine and fresh water species have had to adapt to the low saline and atidal conditions, the impact from human activities has occurred over a much shorter time scale, i.e. 10–100 years. The few studies performed so far indicate dramatic changes in life history characteristics in plant and animal populations living in the Baltic Sea, suggesting that adaptation is occurring much faster than expected.

Thus, the Baltic Sea presents us with the possibility to study evolutionary changes in species adaptation in response to for example salinity. This full scale evolutionary experiment will be particularly challenging and useful in the context of management and conservation, two important issues that we need to address more seriously in future research. The future Baltic Sea research on sustainable management and production of goods and services should therefore take advantage, to a larger extent than has been the case so far, of the unique opportunities this sea provides.

Three research areas have been selected as examples. In all three the Baltic Sea plays a central role due to its unique characteristics. It is one of the best investigated seas in the world and long term data sets of environmental factors are available covering time intervals of 1–100 years.

Salinity, climate and nutrient enrichment

In the time scale of the last 100 years (1900–2000) the salinity has varied over 1 per mille, which is expected to have a large scale impact on the geographical distribution limit of a number of marine species in the Baltic Sea. This salinity change may be used to model changes in the cover and recruitment success with time of a number of key species in the ecosystem. Research projects modelling long term changes in climatic factors, combined with studies of the distribution patterns of a set of key species in the Baltic, would be very important for the development of restoration strategies and as tools for coastal management.

In a shorter time scale (1–25 years) there is a need to focus more on the recovery processes of marine coastal ecosystems and the factors regulating recovery. Today, the effects of nutrient enrichment to coastal areas are well known and much effort has been put into reducing the nutrient load. Research is now highly needed to increase our understanding of the processes and time scales involved in the recovery of disturbed habitats, especially at what time scale the different parts of the ecosystem will respond to a reduction in nutrient load. This new knowledge will be of high importance for our understanding of the time span over which the different measures taken can be expected to give results and thereby will be essential for planning and management of coastal environments.

New methods for toxic substances

Many of the point-source pollution hot spots have been treated and we are now facing the problem of diffuse pollution, i.e. complex mixtures of toxic compounds and environmental factors affecting the ecosystem. To address these problems we are in need of a new strategy focusing on studies combining effects of multi stress factors, i.e. both combinations of mixtures of toxic compounds and also studies at sub lethal ecological levels under natural environmental conditions. Simple tests with one substance under controlled conditions will not be sufficient to clarify the effects on different stages of an organism or the transportation and transformation of a toxic compound in the food web.

Thus, there is a need to develop new methods to identify and characterise toxic substances, their dispersal and effects on plant and animal life stages and ecosystem functioning. Specifically important will be studies on key species, i.e. both habitat forming species, for example *Zostera* and *Fucus*, and species having a key function in the food web. Finally, since species of both marine and fresh water origin live near their salinity tolerance limit in the Baltic and younger stages are known to be more sensitive to additional stress, research efforts should be focusing on the reproductive stages of such species as well as risk assessment.

Formas, the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning, is a governmental research-funding agency. Formas encourages and supports scientifically significant research related to sustainable development.

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