SUSTAINABLE WATER MANAGEMENT IN THE BALTIC SEA BASIN

2

WATER USE AND MANAGEMENT

EDITOR:

Lars-Christer Lundin

The Baltic University Programme - Uppsala University

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Sustainable Water Management in the Baltic Sea Basin

Book II.

Water Use and Management

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Foreword

Water and water management have a very special place in the efforts of countries in the Baltic Sea region and universities participating in the Baltic University network. A concern for our common water, the Baltic Sea, was almost the only unifying point of departure when we met for the first time in 1991 during the break up of the old system. It will remain an important dimension of our work as illustrated by declarations from prime ministers in the region and intensification of activities e.g. within the Helcom co-operation. When work to improve the environmental situation started on a larger scale a few years later, water was by far the most important point on the agenda. In 1995, for example, as much as 95 % of the Latvian investments in the environmental field were directed towards water issues, especially wastewater treatment. Reducing emission into the air, soil remediation and natural protection were all secondary to water. The situation was similar in other countries in the newly independent states in Central and Eastern Europe. On the western side of the region investments to improve water quality have been substantial for several decades, which happily have yielded some good results.

This is not difficult to understand. Like all lifeforms, we depend on water for our daily life and well-being. We drink it, we wash ourselves in it, we enjoy seeing it flowing by, enjoy living in the beautiful "waterscape" of our Baltic region. To have good and clean water is a first priority, as it always was.

The Baltic University Programme has selected water management for the first master level course on issues on sustainable development. In this context water has a special role. It is a renewable resource, and the access to this resource is quite well defined, not only globally or regionally, but also locally, based on the drainage area concept. It will also be the first resource to be managed on the basis of this concept, since European Union directives recommend drainage- area based water administration. Sustainable water management is a first goal in our development towards a sustainable society.

The course material for Sustainable Water Management is, as with all Baltic University course material, interdisciplinary in its approach. We strive to present the problems of water management from a more holistic point of view. This transdisciplinary approach is intended to give students, regardless of background – natural scientists, engineers, social scientists etc. – a platform for working with water issues in their professional career. It treats the system rather than its components so naturally all specialists will be disappointed with the treatment of "their" specialities. The objective is to connect the specialities rather than to teach them.

The three books are the result of the combined effort of more than 50 researchers/teachers in some ten countries. They could not have been written by any single person, university or even country. They are a true result of the network and hopefully they will be used and studied in the entire Baltic region.

Uppsala January, 1999

Lars Rydén
Director, the Baltic University Programme

PREFACE

The textbook series

The current volume is the second in a series of three textbooks on sustainable water management. The prime purpose of the textbook series is to serve as reading material in the courses on Sustainable Water Management given at a number of universities in the Baltic region. The series builds on the input from teachers and students after the first course in 1998, which was a co-operative effort between Uppsala University, Tallinn Technical University, St. Petersburg Technical University and the Royal Institute of Technology in Stockholm. However, it should be pointed out that the textbooks are of a general nature and can therefore be useful in other courses on water management or as self-study material.

The finite size of the book precludes a complete presentation of all water management aspects and all possible problems found in the Baltic region. Instead, authors were selected from a number of places in the Baltic region and invited to present their expertise views of the problems and processes involved. It is thus up to the local teacher responsible for each course to include other texts that describe local conditions and local problems. Furthermore, it is up to the students to form their own opinions and develop their own understanding based on the varieties of presentations and viewpoints presented. Discussions with teachers and fellow students will be central in this process. The video and Internet conferences accompanying the course lectures are natural fora for this discussion.

The volume on Water Use and Management

The second volume presents the principles behind sustainable management of water use. The Baltic basin is the reference point and target, but most issues are equally valid in other parts of the world. Practical problems of water use in different sectors of society are presented and discussed. Part I discusses water availability and shows water resources in a systems perspective. It then goes on to define sustainable development as a basis for water management principles, also addressing the implementation and financing of management.

In Part II, the focus is on agricultural water use and management. The issues of water logging and draught are treated, leading on to drainage and irrigation. One improvement often made in plant productivity is to add nutrients to fields. Sustainable management of the use of nitrogen and phosphorus regards these nutrients as resources and aims to keep them in the soil solution, minimising leakage to surface water and groundwater. In the chapters, both the farm level and the urban-rural management perspective are presented. The environmental impact of leakage from nutrients and pesticides is discussed, as well as the long-standing relation between wetlands and agriculture.

Part III is devoted to the management of urban water use. The handling of stormwater and sewage water, of course, is central here. Another important issue is how to handle, and preferably use as a resource, the sludge produced in wastewater treatment plants. The basic rules of trying to avoid the creation of sewage and of separating stormwater, sewage water and heavily polluted industrial water are emphasised.

Parallel to the above problems run the processes and principles of management of industrial water use. These are the subject of Part IV of the book. Important processes in industrial water treatment are presented and discussed. Once again, the golden rule that if you don't create problems, you don't have to solve them, is applied and closed-system production is discussed and exemplified.

L-C Lundin
Editor

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Photo by Inga-May Lehman Nådin

Life originated in water and most of life on Earth still lives in the water itself. Life forms on land have developed various means to carry water with them – humans consist to some 70 % of water – and to secure a constant supply of water. Indeed, water is crucial. We humans, to take an example, can go for weeks without food, but only for a very short time without water. Our daily intake of water is about 2 litres. Some life forms have developed ingenious ways to produce their own water. The camel, for instance, uses metabolic water when consuming the fat in its hump.

Most of this water is needed to transport waste products, mainly nitrogen and phosphorus, out of the body, which happens when we urinate. In this perspective, the use of water for drinking and for flushing the toilet is not so disparate. Only birds are able to evade this requirement, by producing solid nitrogen waste, uric acid.

The life forms that constitute our food also require a constant supply of water. Counted per person this is in fact a much larger volume. A plant need many litres of water to grow, which in most cases it receives naturally from groundwater or surface water. In irrigation about 500 litres of water is used per kg of produced bread, while for vegetables it is closer to 50. Water is taken up by the roots, transported as nutrient to the growing plant and evaporating from the leaves. A growing head of cattle drinks about 50 litres of water for each litre of meat it produces, in addition to the water it receives with the food.

The two litres of water we drink ourselves, however, is by no means enough. In our households we use water for cooking, washing, cleaning, flushing toilets and so on. Even in areas where water is scarce there is still a need for some 30 litres a day to cover all these activities. In our region, where such scarcity is not even known, we frequently use 200 litres a day in an average household. To provide a city of thousands of households with water is thus a major technical undertaking, as is the removal of the wastewater.

But we have not yet mentioned the major consumer of water, which, in a modern society, is industry. Industries consume water for various chemical processes, such as cooling, and many other processes. However this enormous water consumption is now on the decrease. Minimisation technologies have been introduced to safeguard water. Industry is learning from biology to manage water more skilfully and efficiently. In the modern pulp and paper factory hardly any more water is needed than that which is introduced with the wood. Process water is recirculated, passing a system that may be compared to our kidneys, and used again. It is this more biological way of looking at water, water provision and water safety that paves the way to sustainable water use.

Lars Rydén
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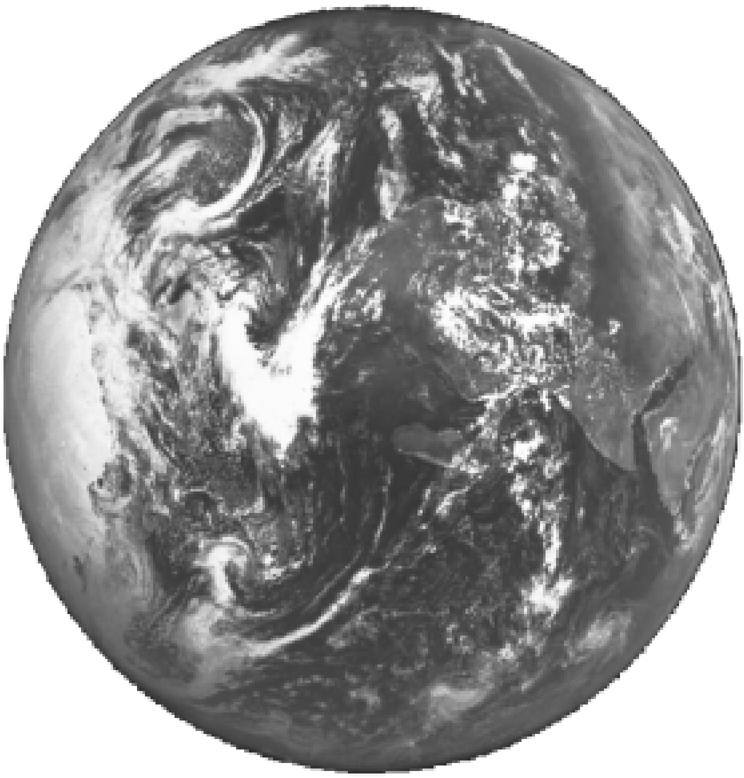
Part I

Sustainability and Water Management

WATER RESOURCES ON EARTH



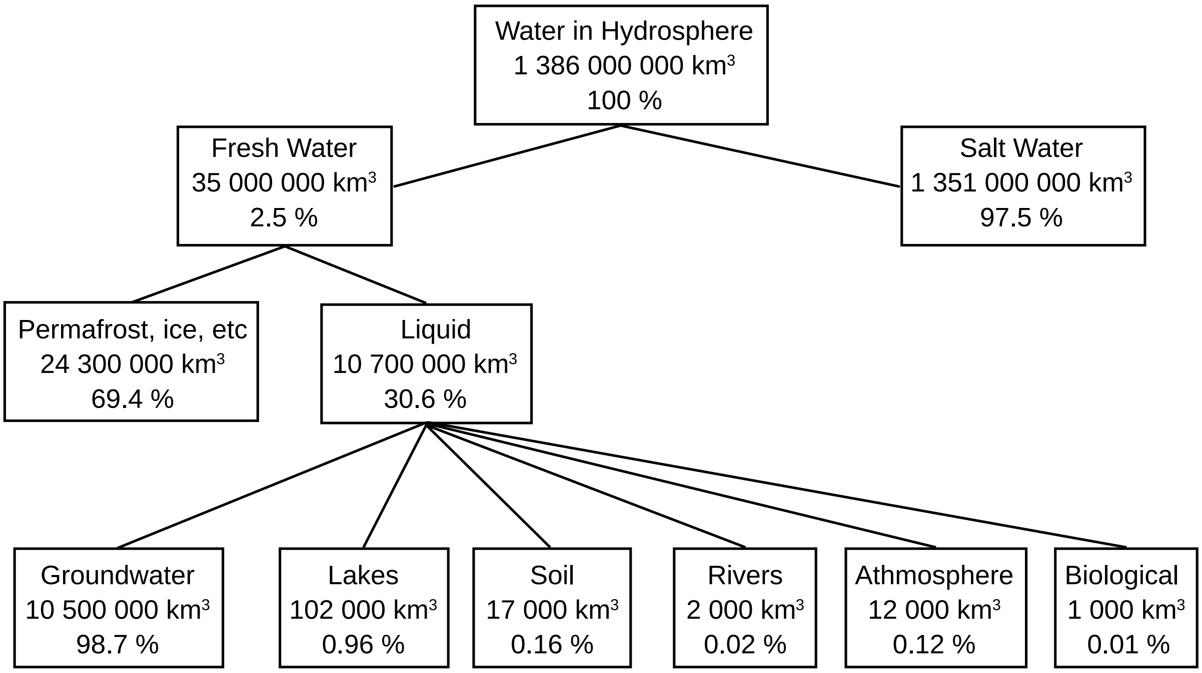


Figure 1.1. Water resources on Earth ($\cdot 10^6$ km^3) (Saiejs & van Berkel, 1995).

1.

WATER RESOURCES AND WATER SUPPLY

Lars-Christer Lundin, Harry Linnér, Bengt Hultman, Erik Levlin, Erik Eriksson[1] *&*

Sivert Johansson[1]

Green and blue water

The Earth is abundantly supplied with water. However 97.5 % of it consists of saltwater in the oceans and only 2.5 % of the water supply on Earth is freshwater. This water is contained in the ground or in rivers and lakes and in the permafrost of the polar caps or in glaciers high in the mountains. Of the fresh water 69.4 % exists in the form of ice, snow or permafrost and is not directly available for use. Almost 99 % of the remainder is groundwater. The amount of fresh water in lakes is not more than 1 % of the liquid water available on Earth (Saiejs & van Berkel, 1995; see Figure 1.1).

A global water balance is shown in Figure 1.2. The average annual rainfall over the continents amounts to 110 000 km^3 (Saiejs & van Berkel, 1995). Of this, 63 000 km^3 returns to the atmosphere in the form of evaporation and transpiration from forests, grasslands, farm crops and other plant communities. This portion of the water, utilised by natural vegetation and rain-fed agricultural crops, is sometimes called green water.

The difference between annual rainfall and evapotranspiration, referred to as the effective runoff, is approximately 47 000 km^3. This is the sustainable, annually renewable, freshwater in lakes, reservoirs, streams and aquifers. In theory this so-called blue water is available for human use. A sustainability rule is thus: The water demand should be met from effective runoff only (Pearce, 1994). Water however is unevenly distributed over space and time. A large part of the runoff is floodwater that is hard to contain. Reliable annual flow that is realistically accessible for human use is estimated to be at least 9 000 km^3. To this some 3 500 km^3 of runoff regulated by existing reservoirs is added. Thus the total runoff accessible for annual human use is 12 500 km^3. However, some of the available surface water must be left in streams and rivers to

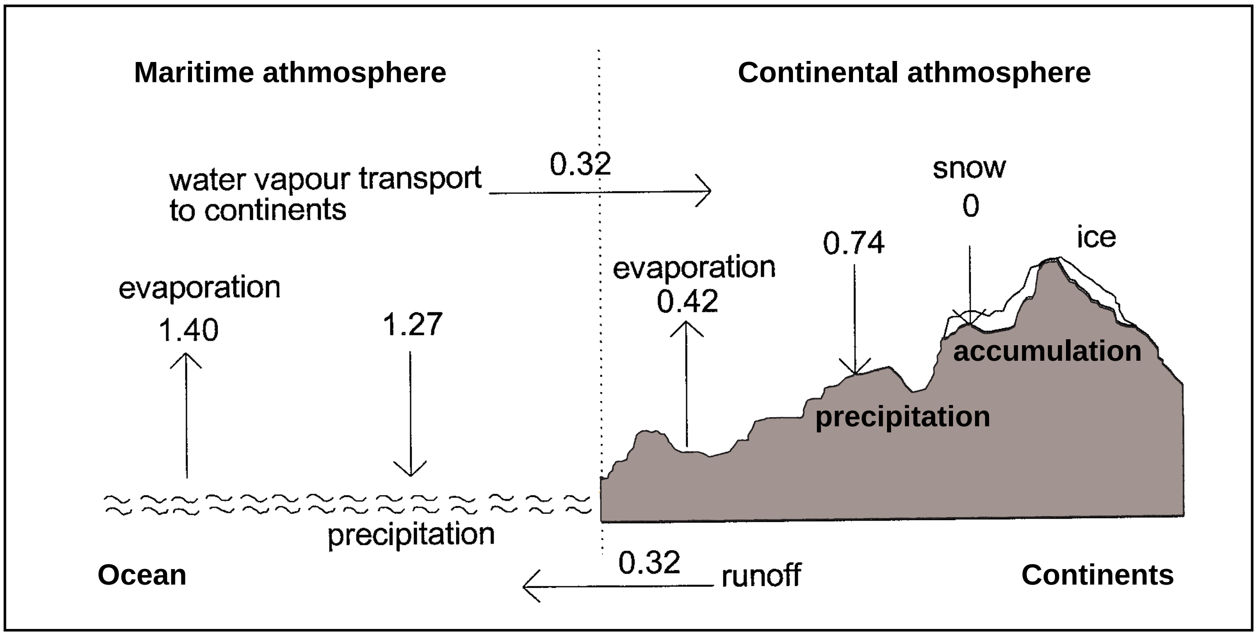


Figure 1.2. Global water budget estimates in 10^3 mm/year (after Saiejs & van Berkel, 1995).

[1] Responsible for Concepts of Water quality

safeguard conservation of the aquatic ecosystems and ensure effluent dilution, which in practise further reduces the amount of available water.

The remaining 34 500 km^3 of blue water is difficult and costly to utilise because of topography, long distances from population centres and social and environmental consequences.

More than half of the easily accessible freshwater resources are already utilised and in many regions of the world water supply is a critical issue. An increasing number of countries suffer from freshwater shortages and competition between different users is on the rise. More than 25 countries are already classified as water deficient and the number of countries facing severe water shortages during next decade is likely to increase dramatically.

In the Baltic drainage basin the annual volume of freshwater runoff is about 450 km^3. Due to relatively high precipitation and low evapotranspiration the water resources are much greater in the northern and western part of the region (Figure 1.3) than in the southern part, where water is a limiting factor in agricultural production.

In general, the Baltic region has good water resources compared to most regions of the world, although they are much more limited in the south than in the north. The region's agriculture is seldom subject to severe droughts or floods, natural rainfall normally gives good yields, rainfall intensity does not cause severe soil erosion, and salinity is not a problem. Likewise, a safe supply of water to urban centres is not, especially in the northern part of the region, a great problem, nor is industrial water supply a limiting factor. Norway's share of hydropower is one of the largest of all the national energy budgets of the world, and hydropower is important in Sweden and Finland as well. Instead, the water problems of the Baltic region are foremost connected to water quality.

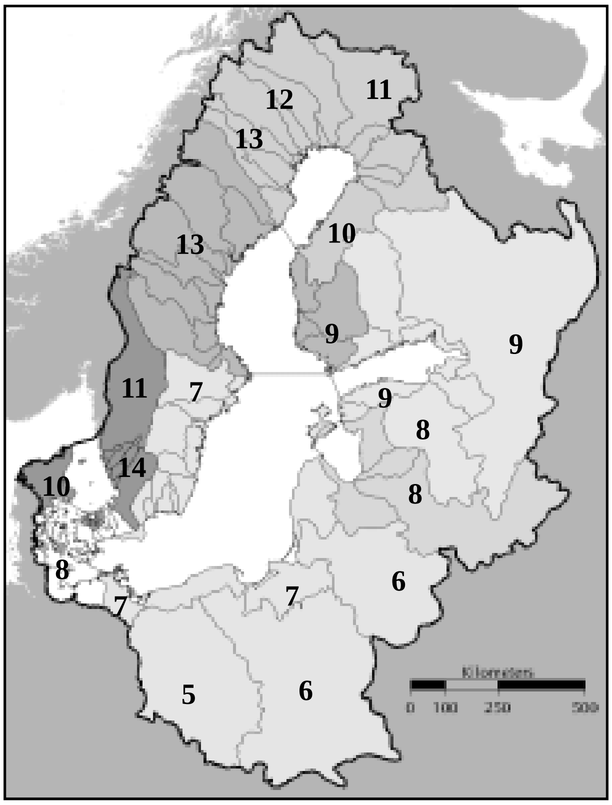


Figure 1.3. Mean annual specific runoff. (l/s km^2). Ballerina database at URL: http://www.baltic-region.net/

Water as a natural resource

Water resources have probably influenced humans more than any other natural resource and are still one of the most important prerequisites for civilisation. Since human beings first settled, easy access to drinking water and water as a transport medium has been necessary to stable and lasting settlements. A quick glance at a map still shows a concentration of villages and cities to coastlines and rivers. In areas where freshwater is scarce the inhabitants spend a considerable amount of time every day collecting water, and development of such societies has been slow.

In the developing countries, at least one fifth of the people living in cities and three quarters of the rural population lack access to reasonably safe supplies of water, while many of the industrialised countries are experiencing serious problems regarding water pollution, scarcity and wasteful use.

The availability of freshwater in terms of location and quantity is essential to all societies and consequently there are few natural resources of which our knowledge is more advanced (Table 1.1). Despite this extensive knowledge, the exploitation of water resources is done on such scales, ranging from individual households to cities of several million inhabitants, that even more detailed knowledge, especially concerning interaction between the different users, is called for.

A further complication is the variability of water availability, not only spatially but also temporally. In many areas of the world freshwater is scarce, which creates a problem if the population demand is not in harmony with the available resources, even if these areas normally have spots of high water availability, e.g. oases. Availability is also an issue in areas where water is plentiful, but where the quality is low because of pollution, or where the demand is extremely high. To a certain extent engineering solutions can be applied, but this is often at a considerable cost. The temporal variation consists of a seasonal variation, which is often quite predictable, and a variation between years that is more problematic. Most human activities have been adapted to, or made independent of, the seasonal variation, farming perhaps being the best example. However, if, e.g. the expected

Table 1.1. The availability of fresh water. Internal renewable water resources are domestically generated runoff. Note that all countries in the very-low category are dependent on withdrawing runoff generated in neighbouring countries (World Resources Institute, 2003)

Category Country	Per capita internal renewable water resources, m^3/yr (2001)	Annual withdrawals per capita, m^3/yr (year)
Very low:	**1 000 or less**	
Egypt	26	1 055 (1996)
Israel	119	287 (1997)
Jordan	131	255 (1993)
The Netherlands	688	519 (1991)
Low:	**1 000 - 5 000**	
South Africa	1 014	366 (1990)
Denmark	1 123	233 (1990)
India	1 211	592 (1990)
Germany	1 305	579 (1991)
Poland	1 391	321 (1991)
China	2 173	439 (1993)
United Kingdom	2 431	204 (1991)
Japan	3 372	735 (1992)
Medium:	**5 000 - 10 000**	
Switzerland	5 637	172 (1991)
United States	6 932	1 834 (1991)
High:	**10 000 and more**	
Sweden	19 391	340 (1991)
Finland	20 645	439 (1991)
Norway	84 787	489 (1985)
Canada	91 147	1 607 (1991)
Iceland	671 940	622 (1991)

summer precipitation does not occur at all or is considerably less than expected, a draught situation is immediately at hand. If this is repeated several years in a row, extremely severe situations with starvation, desertification and population migration may ensue. Note the use of the word 'expected,' because sometimes we expect more than the normal or mean value.

Sustainable water management must thus be a long-term undertaking, remembering that the variability of the water resources is such that what seems sustainable over a few years may not be sustainable over a ten- or thirty-year period. We should also bear this in mind in our humid part of the world when we expand our populated areas too close to rivers. Even if we experience it as a surprise that a river suddenly rises to a level that is much higher than anyone can remember, this is probably a situation that normally occurs every 30 years or so.

It should be noted that even in the humid conditions of the Baltic region, it is normal to experience a certain draught, or rather a water deficit, in early summer. At that time, the vegetation normally demands more water than there is at hand during this period. However, adaptation of the vegetation and, if the crop is valuable, irrigation keep the problem at a reasonable level.

Table 1.2. Water use by continent (See below).

Continent	Agriculture (%)	Domestic (%)	Industrial (%)	Total (km^3/yr)
Africa[1]	85	9	6	128
Asia1	84	6	10	1 444
Former USSR[1]	62	10	28	270
Europe[2]	30	14	62	551
N&C America[3]	43	11	46	686
Oceania&Australia[3]	51	11	38	30
South America[3]	62	17	21	167
World[1]	71	9	20	3 253

[1] FAO, 2004 (data from 1988)
[2] Krinner et al., 1999 (data from 1997)
[3] Shiklomanov, 1999 (data from 1995)

Water use for food production

Water is used for all life, including the farming that supplies us all with food. The basis is production of grain and other crops. Here water supply is the main limiting factor, along with e.g. temperature and soil conditions. The total world area of arable land is about 1 500 million hectares which means approximately 0.25 hectare per person. It is estimated that rain-fed farm crops and grasslands transpire about 18 000 km^3 of green water annually.

About 250 million hectares, or 17 % of all farmland, are irrigated. Global estimates indicate that irrigated farmlands produce nearly 40 % of the food on 17 % of the land. Half of the expansion of food production in the last thirty years has come from the expansion of irrigated farming. Half or even two thirds of future gains in crop production are expected to come from irrigated land.

The amount of water needed to produce the annual food requirement for one person is about 2 000 m^3 for a balanced diet with meat. This explains why agriculture is the major user of water globally. Almost 70 % of the water withdrawn from rivers, lakes and aquifers goes to the agricultural sector and mainly for irrigation purposes (Table 1.2). Domestic and industrial users account for the remaining 30 %. There are significant differences between different parts of the world. In developing countries in arid zones farming often claims more than 90 % of the water. In humid temperate industrial countries the figure is often less than 30 %. Most of the data in the table are from the 1980s. The total water use today is almost 50 % higher.

In the Baltic drainage basin the total land area is about 175 million hectares. About 20 % of the total land, or 35 million hectares, is arable. Some 10 million hectares are land for pasture. If we assume that the average annual evapotranspiration from farm crops and grassland is 400 mm (= 4 000 m^3/ha) the total use of green water in agriculture approaches a magnitude of 180 km^3.

Only 3-4 % of the arable land in the region is under irrigation. A rough estimate shows that the total water use for agriculture is approximately 3 km^3. The sectorial water use for the different countries in the Baltic region is shown in Table 1.3.

The agricultural sector contributes significantly to the pollution of the Baltic Sea. The total input of nutrients has been estimated at 1 600 000 tonnes of nitrogen and 60 000 tonnes of phosphorus per year. The major source of the nitrogen and phosphorus load is agricultural runoff, which accounts for about half. About 10 % of the phosphorus comes from agriculture itself.

The most important sources of nutrients related to agriculture in the Baltic Sea region are:

- leaching of nitrogen and phosphorus from arable land;
- leaching of nitrogen and phosphorus caused by inappropriate storage of manure from animal production;
- atmospheric emissions of ammonia from animal production and field application of manure; and
- inadequate treatment of wastewater in rural areas.

Water resources in a systems perspective

The healthy development of human domiciles, societies and human affairs is critically dependent on water supplies. Safe water provision is needed in households, agriculture and industries. As a rule of thumb we use 200 l/capita and day in households, and twice as much in industries in the Baltic region. In addition some agricultural productions depend not only on the natural water supply but also on irrigation. This book deals with many aspects of water use in these sectors. The overall intention is to describe how we can manage this resource so that society has a safe supply of water for all its various needs.

In this introductory chapter we will point out three perspectives on water use in society:

The systems perspective, whereby the individual components are all part of the same system, or are even using the same water.

The recirculation perspective, how the water we use is part of one or several hydrological cycles.

The 'downstreamer perspective', whereby the water that leaves one user is the water provided for the next.

Water is considered to be a renewable resource. This is of cause true in a regional sense but in a global perspective water resources are confined to a closed system. On a global scale there are no water incomes, except possibly the chemically bound water in meteorites, and there are no water expenses, either, except for the occasional water molecule entering free space.

There is a danger in viewing water resources from a narrow regional perspective. Since water is circulated globally in the hydrological cycle, all the water we use has a history and a past. If we pollute the water regionally, for example, the effects may show up in a totally different region with unforeseeable environmental effects. Pesticides used intentionally in farming in one region may cause the death of birds elsewhere, e.g. in the Baltic Sea. Another example is when sulphuric smoke pollution and the humidity in the air in coal-burning industrial regions kill the coniferous trees in forest regions. These causes and effects are well known today but were either not foreseen or were ignored at the time when the practise was initiated.

Table 1.3. Water resources and water use in the Baltic drainage basin (Source World Resources, 1994)

Country	Population[1] 2004 (millions)	Annual renewable water resources[2] (km^3)	Annual withdrawals (km^3)		Sectorial water withdrawals Agric. (%)	Domestic (%)	Industry (%)
Belarus	10.3	37	2.7	1990	35	22	43
Czech Republic	10.2	13	2.7	1991	2	41	57
Denmark	5.4	6	1.2	1990	43	30	27
Estonia	1.4	13	0.2	1995	5	56	39
Finland	5.2	110	3	1991	3	12	85
Germany	82.4	107	46.3	1991	20	11	69
Latvia	2.3	17	0.3	1994	13	55	32
Lithuania	3.6	16	0.3	1995	3	81	16
Poland	38.6	54	12.3	1991	11	13	76
Russia	144	4 313	77.1	1994	20	19	62
Slovakia	5.4	13	1.8	1991	0	-	-
Sweden	8.9	171	2.9	1991	9	36	55
Ukraine	47.7	53	26	1992	30	18	52

[1] PopulationData.net, 2004

[2] Mean of 1977-2001

The systems approach can also be taken when studying the main users of water resources: agriculture, industry, and urban areas.

In agriculture, the incomes are precipitation and irrigation. The expenses are evapotranspiration, drainage and groundwater formation. The strategy of water management is twofold: to deliver an appropriate amount of water to the growing plants and to distribute nutrients to the plant's roots using water as the transport medium. If there is a problem of water shortage, irrigation is applied using groundwater or a nearby river, while if there is too much water the field is drained. The principal action in both these respects is to divert the natural flow paths of the water. The second objective, increasing the nutrient status of the field, adds another dimension to water management, i.e. water quality. High nutrient content means high quality for plants but low quality for humans and animals. The 'good life' of the aquatic plants also causes lake eutrophication. Further issues are erosion and salinisation but these problems are minor in the Baltic region. The environmental issues in this system can thus be defined as i) minimising the harmful effects of the diversion of the natural flow paths and ii) keeping the nutrient-rich water inside the system, where it constitutes a resource.

In industry, water incomes and expenses are defined by the system of pipes entering and leaving the plant. The objective means using water either as a part, e.g. transport or cooling medium, or as an ingredient in the industrial process. The main problem is the addition of dissolved substances to the water, caused by the process. Another issue is the increased water temperature caused by some industrial processes, such as energy plants. If the water is exported to the same body of water from which it was imported, no significant diversion of the pathways has been made. However, used groundwater or surface water is normally redistributed via the municipal sewage treatment plant into a surface water body, often a different one that the one where the water originated. The main environmental issue is thus to i) minimise the impact of the industrial processes on the water and ii) minimise the water volumes handled. The optimal solution is of course to close the system totally, avoiding strain on water resources and export of polluted water.

Urbanised areas, i.e. cities and towns, have properties that constitute a mixture of agricultural and industrial systems. The water incomes are precipitation, discharge and water from local or municipal wells or waterworks. Expenses are evapotranspiration, sewage and stormflow from sewage treatment plants or individual houses, water lost in the distribution system, locally infiltrated precipitation and losses of groundwater. Note that the system can be defined in different ways, depending on the problem studied. If the problem is the damage to buildings caused by the lowered groundwater level, then locally infiltrated stormwater constitutes a systems income and a potential solution to the specific problem.

Several objectives can be identified. To deliver high quality drinking water and to treat sewage water are the main objectives, but to get stormwater off the streets, to avoid inundation by regulating surface water levels and in most cities preserving the groundwater level are also important objectives. Urban water planning and management is complex, involving the administration of both waterworks and sewage treatment plants as well as city and road planning. This area is of special importance since it interfaces directly with citizens and their need of household water for everyday activities. The environmental issues involved are those of supplying domestic water of sufficient quality and quantity, sanitation and the proper treatment of sewage water, handling of storm flows and prevention of inundation and lowering of the groundwater table.

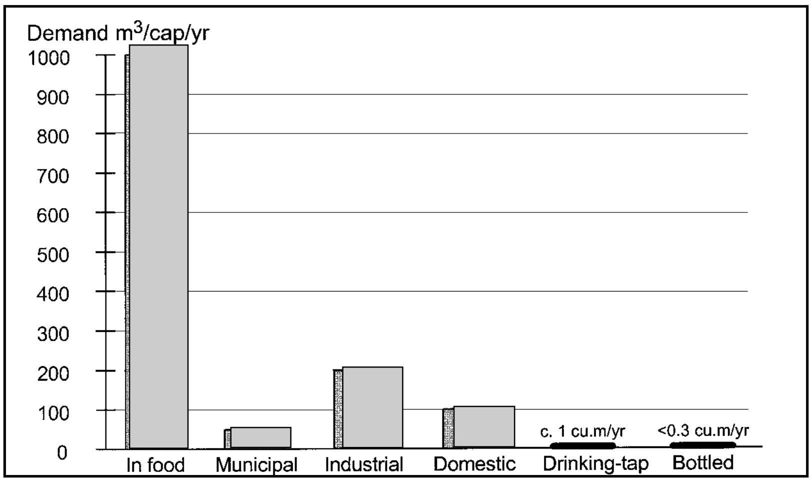


Figure 1.4. Demand for water (indicative for semi-arid circumstances) in cubic metres per capita per year (Allan, 1995b).

An individual person needs only one cubic metre of water per year for drinking, approximately 100 cubic metres for his or her household needs and roughly 1 000 cubic metres per year to produce the food he or she needs to eat. In addition an average of about 50 cubic metres are needed for municipal water used for general purposes and 200 cubic metres on average for industrial water (see Figure 1.4). These figures are indicative for semi-arid conditions and vary considerably in different regions. For an individual use of 1 300 cubic metres per year and a population of 6 billion, the total water need in the world is about 7.8 cubic kilometres or about 17 % of the sustainably available water. Many countries have a much smaller supply of sustainable water per capita than 1 300 cubic metres (see Table 1.1) and the situation will become worse in the future, especially in developing countries with their high population growth rates.

An important feature of water provision is the reuse of water inherent to the nature of the hydrological cycle. E.g. villages throughout a river stretch use water from the same stream, or water transpired by the plants is released as precipitation useful to plants in neighbouring fields. The runoff water into a river in a farm area might be used later for preparing drinking water for the city downstream. Groundwater used for domestic purposes is released to a river and reused downstream or is infiltrated to the benefit of the vegetation.

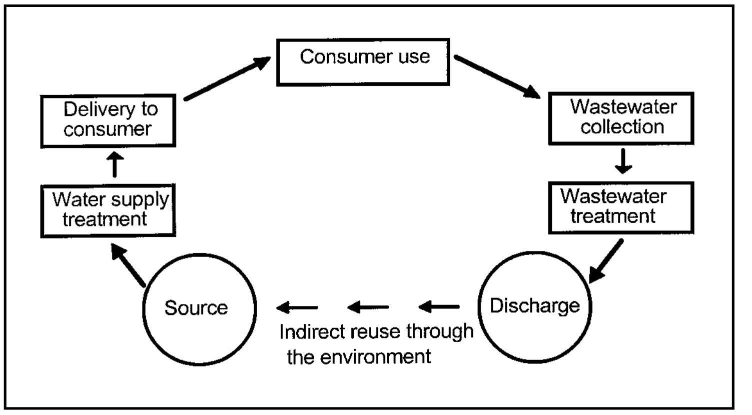


Figure 1.5. The hydrological cycle in society.

What this implies is that, with a systems view of water resources, the outflow in the system always constitutes someone else’s inflow. Among the creative ideas stemming from this implication is the suggestion that industrial water intake should be put downstream of the industry’s outlet, creating a self-regulating system in which the industry would be highly motivated to keep water quality high. The rational realisation of the idea is, of course, to create closed-system processes.

Another perspective is illustrated by the ‘urban’ or ‘societal’ water cycle which points out that water used for one purpose may soon be reused for another (Figure 1.5). After treatment, freshwater is normally transported into urban areas via water pipes in order to secure a high water quality. Treated wastewater is typically discharged into large receiving waters in order to avoid severe local pollution problems. However, in some regions, the wastewater quantity should instead be regarded as a possible resource for increasing the groundwater level, for irrigation use or other purposes. Obviously, this requires even more efficient wastewater treatment (Ødegaard et al., 1996). If water is scarce the water might have to be ‘reused,’ which means going through several rounds in an ever narrowing water cycle requiring more and more refined methods of treatment. In urban water management this might be quite expensive. In industry it is taken to the extreme in the closed factory, where the same water is used indefinitely.

Concepts of water quality

The quality of the water is related to the specific purpose of the water use, while the value and usefulness of a water source is dependent on this particular use. Water quality is thus a consumer term. Water quality depends on the chemistry, physical appearance (colour, taste and smell) and biological properties of the water. There are numerous ways of utilising water – as drinking water, for washing and bathing, as a carrier of domestic waste, for irrigation, in various industrial processes and as an object of recreation.

It is thus obvious that there is no universal, or even general, requirement on water quality. Each use requires its own set of standards. These standards are usually formulated as critical values of specific properties, which should not be exceeded. Water that is considered harmful as, e.g. drinking water, may be excellent for irrigation or even swimming. Examples of categories of use, some of which have been discussed above, are

- domestic use
- use in irrigation
- use in industry
- use in recreation

In all of these categories there is always the possibility of treating the water to make it acceptable for its particular use. This is well in line with the concept of sustainable use of water. Naturally, it should not be carried to the extreme that water must be saved, because it is a natural resource. Water is, after all, a renewable resource and it is the rate of natural renewal that sets the upper limit for its rate of use.

The need for adjusting water to its use has now been practised for decades within the category labelled recreational use. Surface water is allowed to carry a certain load of waste as long as this does not depreciate its recreational value. Monitoring is set up to make sure that all functions are as they should be. Recreational use is mainly a surface water concern. But surface water is not independent of groundwater, often being the source of the surface water.

The discussion in this introduction will be limited to water quality standards for domestic and irrigation water. Further treatment of industrial water use issues will be presented in later chapters.

Table 1.4 illustrates the work done in the past to create standards of guidance to society. It also shows some of the difficulties encountered in the effort to draw up an internationally unified set of standards for domestic use.

The table lists three categories of concern: toxic effects, human health and general use. A number of existing standards are also listed, first the one developed by the international WHO (World Health Organisation), then the one set by the European Community and lastly standards adopted by the U. S., Sweden, France, and Tanzania.

For toxic effects from various elements that normally occur in low concentrations, the differences between the different standards are small. As regards human health only fluoride and nitrate are listed. High fluoride concentrations occur in parts of the Mount Kilimanjaro complex due to old lava flows, which are very rich in sodium and poor in calcium, which normally counteracts the fluoride concentrations in water. It can be seen that Tanzania uses a concentration limit that is about eight times higher than other countries, which can be easily explained. If a limit of 1 mg/l were to be used, a large part of the population would simply have no drinking water.

The table has no standard values for biological variables. These would probably be difficult to apply in some of the countries.

High salinity in soil water restricts the growth of crops. Sensitivity to salt varies widely from crop to

Table 1.4. Water quality standards for domestic water

Substance	Unit	WHO[1]	EU[2]	USA[3]	Sweden[4]	France[5]	Tanzania[6]
Toxic effects							
Lead	μg/l	10	10	0	10	50	100
Arsenic	μg/l	10	10	0	10	50	50
Selenium	μg/l	10	10	50	10	10	50
Chromium	μg/l	50	50	100	50	50	100
Cyanide	μg/l	70	50	200	50	50	50
Cadmium	μg/l	3	5	5	5	5	30
Barium	μg/l	700	-	2 000	-	100	1 000
Mercury	μg/l	1	1	0	1	1	1
Silver	μg/l	-	-	100	-	10	50
Human health							
Fluoride	mg/l	1.5	1.5	4	1.5	1.5	8
Nitrate	mg/l	50	50	10	50	50	50
General use							
Colour	mg Pt/l	50	-	15	30	15	-
Turbidity		5[7]	-	5[8]	1.5[9]	2[7]	-
pH		-	6.5-9.5	6.5-8.5	6-8	6.5-9	6.5-8.5
Total dissolved matter	mg/l	-	-	500	-	1 500	2 000
Total hardness	mg_qv/l	-	12	-	-	-	-
Calcium	mg/l	-	150	-	-	100	-
Magnesium	mg/l	-	80	-	20	50	-
Sulphate	mg/l	500	250	250	100	250	-
Chloride	mg/l	-	250	250	100	200	200
Iron	mg/l	-	0.2	0.3	0.2	0.2	1[10]
Manganese	mg/l	0.5	0.05	0.05	0.05	0.05	0.5
Copper	mg/l	2	2	1	2	1	3
Zinc	mg/l	3	5	5	-	5	0.2
Phenolic substances as phenol	_g/l	2	-	1	-	0.5	2

[1] WHO (1998)
[2] EC (1998). These standards were also adopted by Bulgaria (that appeared in previous editions of this textbook) in 2001. A difference is the value for cupper where the Bulgarian source (Ministry of Health et al, 2001) reads 2.0 "_g/l" instead of "mg/l"; most likely a printing mistake.
[3] EPA (2002)
[4] SLV (2001)
[5] Ministère de la solidarité, de la santé et de la protection sociale (1989; 1990)
[6] The United Republic of Tanzania (1981)
[7] JTU (Jackson turbidity units)
[8] NTU (Nephelometric turbidity units)
[9] FNU (Formazin nephelometric units)
[10] The source reads "110" but it should most like be 1.0

crop. Of greater concern is often the effect that the salts can have on soil structure. A high fraction of sodium in irrigation water may decrease the exchangeable calcium, replacing it with sodium. This will turn the soil into mud when wetted and starve the plants due to oxygen deficiency. There is, however, a rather simple way of predicting this if the sodium/calcium ratio in irrigation water is known. The sodium adsorption ratio (SAR) can be computed according to the following:

$$SAR = [Na^+] ([Ca^{2+}] + [Mg^{2+}]) - 0.5$$

According to Bolt & Bruggenwert (1978) the following SAR values are valid:

safe water	EC < 25 mS/m and	SAR < 7
marginal	EC < 75 mS/m and	SAR < 13
unsuitable	EC < 225 mS/m and	SAR < 20

where EC is electric conductivity and SAR is the sodium adsorption ratio.

The functions of water management

A system for safe water provision should:

- provide water for a variety of uses, such as in agriculture, households, factories, offices and schools
- remove wastewater from users in order to prevent unhygienic conditions and treat this to remove environmentally harmful substances
- remove excess water from fields and other non-built areas, and storm water from urban areas to avoid damage from flooding

The essential function is thus to secure sufficient water of adequate quality to the various users without harming the environment. Further requirements may be related to other, very special demands, such as delivery security for hospitals, high flow rates in fire fighting etc.

In urban areas water use in buildings is the key issue. The choice of water-consuming devices (toilets, showers, washing machines and dishwashers) has great impact on water and sewage handling. Other technical factors, which could be influential in domestic use, include separation of grey water from black water and the use of garbage disposers. In addition, consumer behaviour has a major impact on domestic water and wastewater handling.

As a rule, industries in the Western world use efficient methods of water saving and recycling. However outdated technologies that require massive volumes of water are still in use in many places.

The challenge to managers of water systems is to find the best way to satisfy the demands of the water users and of those expressed in the political arena. Earlier, the choice of water, wastewater and runoff water handling was mainly determined by function efficiency and acceptability of cost. This choice was affected by factors such as climatic and topographical conditions, population density and convenience. Today, the choice of system must also take the long-term environmental impact and conservation of resources into consideration.

2.

Sustainability concepts

Bengt Hultman & Erik Levlin

Introduction

After the publication of the Brundtland Commission's report *Our Common Future* in 1987, the concept of sustainable development was rapidly accepted. The concept had great impact on the thinking of those who work professionally with water and has also influenced the aims of research, education and design, operation and management of water systems.

The purpose of this chapter is to introduce sustainability concepts, describe the principles of sustainable water management and discuss how sustainability can be implemented. Special evaluation methods such as environmental impact assessment (EIA), life cycle analysis (LCA) and standardisation of environmental management systems using ISO 14 000 or EMAS are described. These methods are important tools in the assessment and implementation of sustainability in water management.

A special emphasis is given the increasing problems of water scarcity and factors influencing water use, water saving, water reuse, etc. and the role of food production on water use. Different ways to meet future water scarcity and sanitation problems are discussed.

Defining sustainable development

The ideas behind sustainable development have a long history and can be found in many religions and philosophical systems (Harremoës, 1996). Gilbert White, who died in 1793, is regarded as the father of ecology and his book *The Natural History of Selbourne* forms the basis for the modern ecological movement.

Books such as Rachel Carson's *Silent Spring*, Edward Goldsmith's *Blueprint for Survival* and Paul Ehrlich's *The Population Bomb* awakened the attention of the present generation to environmental problems. They argued strongly that, unless today's society dramatically altered its approach to the consumption of resources and the pollution of the environment, the world faced disaster (Clarke, 1994). A similar view was given in the famous MIT report to the Club of Rome, entitled *Limits to Growth* and issued in 1972. The report was written by a group of 30 individuals from ten countries whose key conclusion was:

"If the present growth trends in world population, industrialization, pollution, food production, and resources depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrolled decline in both population and industrial capacity."

Against this background the concept of sustainable development was born and the definition of sustainability in the Brundtland report is:

"…development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Harremoës (1996) gives the following interpretation of sustainability using a resource component and a pollution component:

"Society should use its resources such that the society can continue its mode of operation without exhausting its resources."

The thermodynamic principle of entropy illustrates our present mode of operation. When mineral resources are mined and used, the final result is a conversion of the mineral from a concentrated to a dispersed state. It requires energy to reconcentrate the matter, which makes renewable energy basically the ultimate measure of sustainability. The practical solution is to approach the ideal, which makes sense in societies that have violated the principle of sustainability due to lack of concern in the past.

Society should protect the environment against irreversible damage, including protection of unique species and habitats.

The conflict is that the very basis for the success of human beings in modern society is our ability to change the environment to sustain larger populations. Humans have now pursued this development to the extent where the changes are a threat to their very being.

The sustainability definition also involves social and political aspects and the definition in the Brundtland report contains three key concepts (Clarke, 1994):

Agenda 21 and water

"Urban land-use planning and promoting the integrated provision of environmental infrastructure – water, sanitation, drainage and solid-waste management – in all human settlements is essential for environmental protection, increased productivity, better health and poverty alleviation. Developing countries should ensure that all municipal departments co-ordinate their efforts, such as capacity-building, monitoring, applied research, and using appropriate technology and technical expertise. In addition, developing countries should adopt an integrated approach to the provision of water supply, sanitation, drainage and solids waste management in all urban areas, including informal settlements, where standards and regulations are best adapted to the living conditions and resources of the poor."

"Early in the next century, more than half of the world's population will live in urban areas. By the year 2025, that portion will have risen to 60 per cent, comprising some 5 billion people. Rapid urban population growth and industrialisation are putting severe strengths for human consumption and industrial use. Special attention needs to be given to the growing effects of urbanisation on water demands and usage and to the critical role played by local and municipal authorities in managing the supply, use and overall treatment of water, particularly in developing countries for which special support is necessary."

"The overall strategy for water and sustainable urban development should identify and implement strategies and actions to ensure the continued supply of affordable water for present and future needs, and to reverse current trends of resource degradation and depletion. In particular, activities should aim to ensure that, by the year 2000, all urban residents have access to at least 40 litres per head per day of safe water, that 75 per cent of the urban population are provided with on-site or community facilities for sanitation, and that the solid waste generated in urban areas is collected and recycled or disposed of in an environmentally safe way."

"City development planning should be consistent with the sustainable management of water resources and satisfy the basic water needs of the urban population. This may involve the introduction of water tariffs, where affordable, to reflect the marginal and opportunity cost of water, especially in production. Throughout these programmes, the skills and potential of non-governmental organisations, the private sector and local people should be utilised, taking into account public and strategic interests in water resources. The public should also be made aware to the social and economic value of water, and encouraged to use it rationally and protect its quality. Governments should develop legislation and policies to promote investment in urban water supplies and solid waste and sewerage management by encouraging the autonomy and financial viability of utilities and providing training for professional personnel."

Find the complete text of Agenda 21 on the Internet: gopher://gopher.undp.org/00/unconfs/UNCED/English/. From there you can download Chapter 18 on protecting freshwater resources (gopher://gopher.un.org/00/conf/unced/English/a21_18.txt).

Citations from A Guide to Agenda 21: Post-Rio Edition (UN, 1993)

1. the concept of "needs", in particular the essential needs of the world's poor,
2. the implied concern for social equity between generations a concern that must logically be extended to equity within this generation; and
3. the truism that there are limitations imposed by the capabilities of technology and social organisation on the environment's ability to meet present and future needs.

Political participation is an essential element of sustainable development. Greater equality means basic changes in patterns of consumption, the allocation of resources and, consequently, life-styles. A sustainable environment cannot be achieved without the political commitment to make necessary changes.

The concept of sustainable development may be regarded as a key to understanding the relationships between environment and development. It calls for a sense of responsibility with respect to our actions that extends to every part of the world, and to future generations.

Conditions and goals

The United Nations Conference on Environment and Development ("the Earth Summit") in Rio de Janeiro 1992 followed up the Brundtland report. Five documents were produced: two international agreements, two statements of principles and a major action agenda for worldwide sustainable development (Sörlin, 1997):

1. The Rio Declaration on Environment and Development, defining the rights and responsibilities of nations as they pursue human development and well-being according to 27 principles.
2. Agenda 21, a blueprint on how to make development socially, economically and environmentally sustainable

IMPLEMENTING AGENDA 21

1. **Long-term foresight thinking**
   a) Use the long-term foresight thinking philosophy to identify ways in which innovative technology can be used to achieve the goal of sustainable development and to counter the expediency of short-terminus.
   b) Develop a method of economic appraisal that takes into account the needs of the present and future generations.
   c) Heighten awareness that everything that is done interacts with the environment.

2. **Education**
   a) Work to close the cultural divide in our society by working with all educational institutions to put forward the role of the water and environmental manager.
   b) Implement continuous professional development programmes.

3. **Communication**
   a) Acknowledge that public relations have a vital role in increasing status.
   b)Take the role of administrator when appropriate and become as politically aware as those in administrative jobs.

4. **Measurement**
   Work to establish measurement networks so that the decisions of tomorrow are based on sound information.

5. **Theory to reality**
   Work to turn the concept of sustainability into reality by striving for practical solutions to problems.

6. **Ethics**
   a) Accept sustainable development as a moral issue and strive to achieve it as efficiently and effectively as possible.
   b) Adopt ethical standards at both corporate and professional levels.

From An agenda for the Water and Environmental Manager (Clarke, 1994)

3. The Forest Principle
4. The Convention on Climate Change
5. The Convention on Biological Diversity

Agenda 21 is an action plan for the 1990s and the 21st century, elaborating strategies and integrated programme measures to halt and reverse the effects of the environmental degradation and to promote environmentally sound and sustainable development in all countries. The Agenda is comprised of some 40 chapters and totals over 800 pages. Important issues related to sustainable water management are described in Agenda 21 (UN, 1993):

- Urban water supplies
- Environmentally sound management of solid wastes and sewage-related issues
- Urban pollution and health
- Protection of the quality and supply of freshwater resources

Examples of different statements related to sustainable water management can be seen in the Box *Agenda 21 and Water*.

One chapter in Agenda 21 is titled *Local Authorities Initiatives in Support of Agenda 21* and recognises that local authorities have a crucial role in the implementation of the ideas in Agenda 21. Work with local Agenda 21 has become an important issue in Sweden and today all of the Swedish municipalities have started to work on processing and producing their own local Agenda 21. More than 90 % of the municipalities have started activities based on decisions taken in the municipal council, thus giving the project the highest political status (H. Andersson et al., 1997).

Many rules on the management of water and the environment have been written to implement the ideas of Agenda 21. Such rules are exemplified in the Box above

3.

Principles of sustainable water management

Bengt Hultman & Erik Levlin

Functions of urban water management

The challenge to managers of urban water systems is to find the best way to satisfy the demands of users of water services as well as those expressed in the political arena. As illustrated in Table 3.1, several factors must stand in the focus:

- Hygiene
- Environmental impact
- Conservation of resources (water, nutrients, energy etc.)
- Reliability and other technical aspects
- Costs and financing
- Social factors

Two thirds of the water removed from rivers, lakes, streams and aquifers is used for agriculture. A more efficient method of irrigation is a top priority in moving towards a more sustainable use of water. Possible savings of 10 to 50 % constitute a large and mostly unexploited new source of supply. Reducing irrigation needs by a tenth, for instance, would free enough water to roughly double domestic water use worldwide. Water saving methods include new and improved irrigation technologies, better management practices by farmers and water managers, and changes in the institutions that govern the distribution and use of irrigation water (Postel, 1993).

Role of population growth

The total demand for water in a country or region is equal to the population times the full demand of water for an individual. The population of the world has increased rapidly during the last decades, with the highest growth rate in Africa and the Middle East. The total population of the world was about 5 300 million in 1990 and is expected to be somewhere around 6 300 million in the year 2000 and 8 500 million by the year 2025 (see Table 3.2). The increase in population has also resulted in a rapid increase in water consumption, about nine-fold in the last century, and

Table 3.1. The functions of urban water management (Larsen & Gujer, 1997a)

1. *Urban hygiene*
   Traditionally, urban hygiene meant solving the problems of removing faecal matter from urban areas, thereby minimising the transfer of infectious agents. We would like to extend urban hygiene to include the supply of water for production and cleaning purposes within households, trade and industry, including the handling of wastewater.

2. *Drinking water and personal hygiene*
   Water for drinking, for cooking and for personal hygiene is subject to strict quality requirements. Urban water management must supply such quality water and protect the appropriate resources.

3. *Prevention of flooding in draining of urban areas*
   Urban drainage is fundamental in many urban areas for preventing flooding. Although urban drainage has serious consequences for the water cycle and for the quality of receiving waters during storm events, it is not possible to maintain present population densities in urban areas without this service. In many urban areas a continuous draining of groundwater is necessary.

4. *Integration of urban agriculture into urban water management*
   Traditionally, urban water management was assigned responsibility for recycling the nutrients between city and countryside. With the introduction of inexpensive fertilisers, this responsibility was lost. Urban agriculture is a new phenomenon with a good potential for simultaneously increasing life quality and the possibility of nutrient recycling in urban areas. Urban water management is regaining importance in this area.

5. *Providing water for pleasure and for recreational aspects of urban culture*
   Water has always been an important aspect of urban culture. Without fountains, ponds, public parks, etc. urban life would lose important qualities. In some parts of the world, the pleasure of taking a shower places a much higher demand on water than personal hygiene does.

Table 3.2. Projection of population and growth rates between 1985 and 2025 (Saeijs & van Berkel, 1995)

	Population (million)				**Growth rates (% per annum)**		
	1985	**1990**	**2000**	**2025**	**1985-1990**	**1990-2000**	**2000-2025**
World	4 851	5 292	6 260	8 504	1.87	1.86	1.54
Developing countries	3 677	4 086	4 996	7 150	2.26	2.21	1.76
Africa	553	642	866	1 597	3.05	3.13	2.87
Latin America & the Caribbean	404	448	538	757	2.14	2.01	1.65
Asia	2 605	2 981	3 420	4 569	2.05	2.04	1.42
Middle East	115	132	172	288	2.91	2.86	2.46
Developed countries	1 174	1 206	1 264	1 354	0.60	0.60	0.53

the total expected water consumption is about 5 200 km^3/yr for the year 2000 (see Table 3.3). This amount is about 12 % of the sustainable global available water (45 000 km^3/yr). A special problem related to population growth is increasing urbanisation. About four-fifths of the population growth takes place in urban areas (primarily in the Third World). The growth is so fast that very few actions can meet emerging needs (Grau, 1997).

Energy and material flows

The theoretical analysis of energy flows has its basis in thermodynamics. The first law is the conservation law that states that while energy can never be created or destroyed, it can be transformed from one form to another. The second law states that every time energy is transformed from one state to another, there is a loss in the amount of energy that can perform work of some kind in the future.

Energy was originally defined as a quantity and the definition paid no attention to the quality of the energy. The quality of a flow of energy could be defined as the useful part of the energy. The term for this energy is exergy, which is strictly defined as that part of energy that is convertible into all other forms of energy (Hellström & Kärrman, 1997).

Exchange of material between society and nature may be done on the one hand by extraction of resources, energy and matter from nature, and on the other by emissions (return flows) of energy and matter into nature. Resources are extracted from natural flows, funds and deposits for use in society (Karlsson, 1997):

Natural flows are continuously flowing materials and energy fluxes ultimately driven by the exergy flows (for example, sunlight and winds) coming into the ecosphere. If not used, they are eventually naturally dissipated.

The funds are pools of materials accumulated and regenerated with the help of natural flows (for example, forests, fish populations, clean air and water). Their capacity for regeneration gives an absolute potential for the long-run rate of extraction.

The deposits are pools of materials (for example, minerals and ores) with such long regeneration rates, if any, that they are gradually depleted during extraction.

By manipulation of resources, energy and matter from nature, various chemicals and materials may be produced. The options available for handling chemicals with respect to ultimate destiny are described by Harremoës (1996). They are no use, reuse, convert, contain and disperse. As Harremoës points out, there are no other options (except shooting into space).

No use

Stop use of an unwanted substance, because detrimental effects to the environment overshadow the advantages of its use. The historical example is the hard detergents in washing powder, which were banned in Germany in the early 1960s. Other examples are DDT, PCB, etc. The key is to find environmentally sound substitutes.

Table 3.3. Trends in water consumption (km^3/yr) (Saeijs & van Berkel, 1995)

Continent	**1900**	**1940**	**1950**	**1960**	**1970**	**1980**	**1990**	**2000**	**%**
Africa	42	49	56	86	116	168	232	217	6.1
North America	69	221	286	411	556	663	724	796	15.3
South America	15	28	59	64	85	111	150	216	4.2
Asia	414	682	859	1 220	1 520	1 910	2 440	3 140	60.5
Europe	38	71	94	185	294	435	545	673	13.0
Oceania	2	7	10	17	23	29	38	47	0.9
Total	579	1060	1 360	1 990	2 590	3 320	4 130	5 190	100.0

Reuse

Decrease the amount reaching the environment by internally reusing the substances. This approach is under development, and implementation is just beginning. Cleaner production together with mass balances and life cycle analyses will have a much greater effect on daily life than we can imagine today. This is a very viable solution, but we must be aware that there will still be a residue to be considered.

Convert

When a substance has been introduced it is important to control the route of that substance such that the transport can be identified and the flow treated. Treatment mostly means converting the substance from an objectionable form to a form that is acceptable for further transport by air or water or in solid form. Conversion by incineration converts solid matter into an inert solid form and into a gaseous form. Wastewater treatment has the function of converting waste into a separable solid form (mostly by sedimentation) or into a gaseous form. The essence in this context is that the solution is rarely a final one. It is just a conversion into something that can be transported acceptably on the next route.

Contain

One of the ultimate destinies is to contain the residues and leave them in place forever. The deposit of radioactive waste in old salt mines is the best example. The material is deposited in the hope that it will never seep, creep, leach or migrate out into the environment. The problems of this arrangement are evident in landfills, which were intended to be the ultimate solution. Leakage from landfills has been identified as a significant problem calling for serious treatment. Landfill works as a treatment unit for many years until ultimately an inert residue has found its final resting-place (when, of course, archaeologists may become interested in the remains, in wanting to learning about our behaviour).

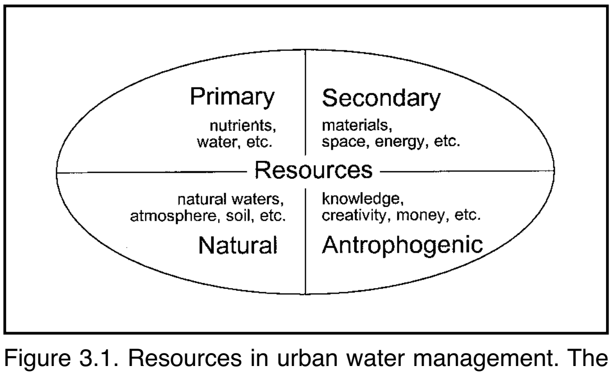


Figure 3.1. Resources in urban water management. The primary resources are the subjects of management in urban water management, secondary resources are used to carry this out. Urban water management of today is directed towards optimising natural resources and the antrophogenic resource of money (Larsen & Gujer, 1997b).

Disperse

The only other ultimate destiny is to disperse in the environment. Gas from incineration has to be treated in such a way that the residues in the flue-gas are acceptable from an environmental point of view. Wastewater treatment must only create effluents with residues acceptable to the aquatic environment. The treatment of solid waste should be such that the product can be recycled, dispersed or contained.

Holmberg et al. (1994) have formulated four general principles for the exchange flows between society and nature and for the manipulation that has to be undertaken in order to achieve a sustainable interaction between society and nature:

1. Substances extracted from the lithosphere must not systematically accumulate in the ecosphere.
2. Society-produced substances must not systematically accumulate in the ecosphere.
3. The physical conditions for production and diversity within the ecosphere must not systematically be deteriorated.
4. The use of resources must be efficient and just with respect to meeting human needs.

Energy conservation methods must be given high priority in the future. This will greatly improve the conditions for environmental care and reduce the demand for natural resources. The ideal for exergy efficiency is reasonably slow speed, no sudden acceleration, small differences (of speeds and temperatures) and “soft” techniques (Sörlin, 1997).

Different resources for urban water management can be divided into primary and secondary resources, while recipients as resources and anthropogenic resources (see Box *Urban Water Management Resources* and Figure 3.1). A more cautious handling of the primary resources could enhance our potential to save water, recycle nutrients and exploit energy better, whereas focusing on secondary resources could reduce the area of potential action. The recipient as a resource includes both the traditional aspect of environmental protection as well as the conscious exploitation of the natural self-purification capacity. The foremost anthropogenic resource, money, is normally considered as the one to put the greatest limits on our possibilities to act. However, it may be that man- and brainpower are of extreme importance in extending our possibilities in the future (Larsen & Gujer, 1997a).

Full demand of water for one individual

Calculations and forecasts of full water demand will be illustrated by use of data from South Africa. The major factors influencing full demand of water for an individual are (Schutte & Pretorius, 1997):

- Domestic purposes
- Food
- Consumer goods
- Job creation

Domestic use varies considerably with living index especially in developing countries as illustrated in Table 3.4 for South Africa 1994.

Water requirements for food could be divided into needs for protein (“red“ meat (from cattle), “white“ meat (from poultry, fish and milk), carbohydrates (bread, sugar and maize), vegetables and liquid beverages (beer, wine and soft drinks). Calculations for cattle can then be made as follows:

Cattle drinking-water requirements: The total water intake needed for a head of cattle to reach a body mass of 350 kg is approximately 9 300 l. At slaughter a live mass of 350 kg will yield a carcass plus offal of 224 kg for the 9 300 l consumed water, or 42 l/kg produced meat.

Slaughter: The mean specific intake of South African abattoirs is about 1 500 l/unit of cattle at 225 kg, or 7 l/kg meat produced.

Feed production: Feed can be produced on dry land (no irrigation) or under irrigation, e.g.

Table 3.4. Domestic use in South Africa 1994 (Schutte & Pretorius, 1997)

	Water use (l/capita/day)									
Level of living index	**Drink/ cook**	**Dish wash**	**House wash**	**Clothes wash**	**Bath/ shower**	**Garden**	**Toilet**	**Pool**	**Total**	**Corrected for 10% loss**
Very low	3	2	2	4	20	5	0	0	36	40
Low	4	5	3	6	35	20	20	0	93	102
Moderate	4	5	4	6	50	15	15	0	119	131
High	5	6	4	8	80	20	20	8	211	232
Very high	5	10	5	8	120	30	30	15	293	322

Very high: Very high income, very large house and stand with extensive gardening activity. Direct water use > 300 l per capita (l/c, d).
High: High income, large house or flat or cluster housing, moderate garden. Direct water use 200 - 300 l/c d.
Moderate: Moderate income. Small house or flat, small garden. Direct water use 100 - 250 l/c d.
Low: Low income. Very small house. Direct water use 50 - 150 l/c d.
Very low: Very low income. Shack type housing. The majority of rural dwellers living in traditional dwellings are included in this group. Direct water use <50 l/c d.

Table 3.5. Water requirements for different foods (based on data from Schutte & Pretorius, 1997)

Type of food	**Direct consumption**	**Processing**	**Feed production/ irrigation, %**		**Total/ irrigation, %**		
			a	100	0	a	100
Red meat, l/kg	42	7	300	3000	49	349	3049
Poultry, l/kg	10	17	146	1750	27	173	1777
Fish, l/kg	-	8.5	-	-	8.5	8.5	8.5
Milk, l/l	4	2	125	1250	6	131	1257
Bread, l/800 g	-	-	75	750	-	75	750
Sugar, l/kg	-	10	161	1070	10	171	1080
Maize, l/kg	-	-	25	500	-	25	500
Fruit & vegetables, l/kg	-	-	45	45	-	45	45
Beer, l/l	-	9	15	100	9	24	109
Wine, l/750 ml bottle	-	4	47	190	4	51	194
Soft drinks, l/l	-	3	21	128	3	24	131

a = 5% for maize, 10% for red meat, poultry, milk, 15% for sugar, beer, soft drinks, 25% for bread and wine, and 100% for fruit & vegetables.

lucerne. The total water requirement for feed production is about 500 l/kg. For a feed-to-carcass conversion ratio of 6, the total water requirement for 100 % irrigation is 225 kg · 6 (conversion) · 500 l/kg = 675 000 l per animal or 3 000 l/kg meat.

The total water requirements to produce 1 kg meat is then:

- on an extensive basis (no irrigation):42 + 7 = 49 l/kg
- on an extensive basis (assuming 10 % water needs supplied through irrigation: 42 + 7 + 300 = 349 l/kg
- on an extensive basis with 100 % water needs supplied through irrigation: 42 + 7 + 3 000 = 3 049 l/kg

The water requirements for other foods can be calculated in a similar fashion (see Table 3.5).

Water requirements for consumer goods include energy (with evaporative cooling accounting for about 1.8 l/kWh of electricity generated), paper, textiles and clothing. The water need for wood production is about 108 l/kg wood which translates to about 346 l/kg paper. Paper and paper products manufacturing adds a further 44 l/kg, yielding a total of 390 l/kg of paper. Textiles and clothing need water for raw materials (about 300 l/kg for cotton with 15 % irrigation and for wool) and for processing (about 300 l/kg), yielding a total of 600 l/kg of produced textile.

The water needed to support the economic and industrial activity that creates one employment opportunity varies considerably, from approximately 50 l per job and day in the administrative sector to more than 2 000 l per job and day in the industrial and mining sectors. An average of 35 l per job and day is assumed for South Africa in the year 2015 (Schutte & Pretorius, 1997).

Consumption of food products and consumer goods and use of services varies a good deal depending on income level (see Table 3.6). Based on varying assumptions the projected per capita water requirements can be calculated for those who have employment (see Table 3.7). The projected full water demand in South Africa in 2015 for employed people ranges from 461 l/(capita and day) for people at a very low income level to 1 106 l/(capita and day) for people with a very high income level.

Table 3.6. Projected consumption of food and consumer goods and use of services in South Africa in 2015 (Schutte & Pretorius, 1997)

Level item	Protein (g/c/d)	Milk (ml/c/d)	Sugar (g/c/d)	Bread & wheat products (g/c/d)	Maize (g/c/d)	Fruit & vegetables. fresh and canned	Liquid beverages (ml/c/d)	Paper (g/c/d)	Energy (kWh/c/d)	Textiles & related products (g/c/d)
Very low	100	100	20	120	100	100	100	50	2	5
Low	120	120	30	140	120	120	120	100	4	10
Moderate	150	150	50	160	140	140	150	150	10	20
High	200	200	80	170	160	160	200	250	15	35
Very high	200	200	100	180	130	180	250	350	20	50

Table 3.7. Projected per capita water requirements by the year 2015 in l/c,d in South Africa (Schutte & Pretorius, 1997)

Level	% of total population	Weighted domestic water demand		Weighted indirect water demand		Weighted full water demand	
		(l/c/d)	Sum (Ml/d)	(l/c/d)	Sum (Ml/d)	(l/c/d)	Sum (Ml/d)
Very low	25	40	10	421	105	461	115
Low	25	102	26	470	117	572	143
Moderate	35	131	46	549	192	680	238
High	10	232	23	641	64	868	87
Very high	5	322	13	784	39	1 106	55
Total	100	-	121	-	517	-	638

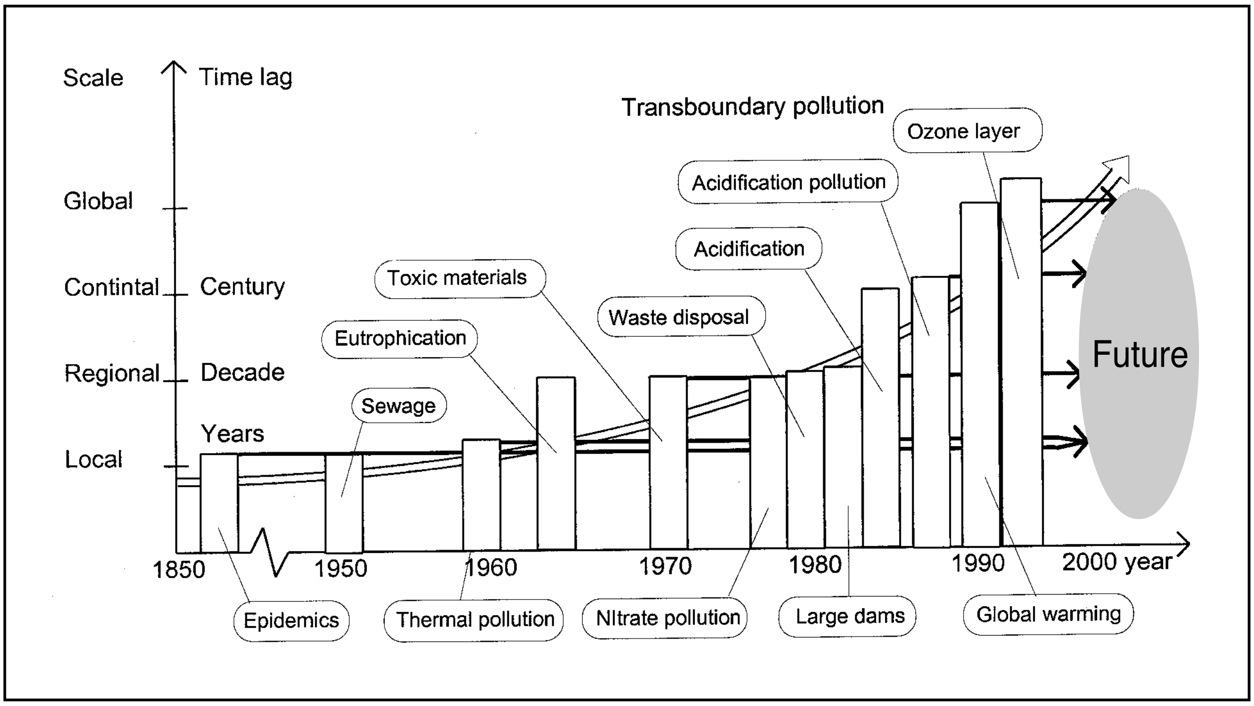


Figure 3.2. Trends in pollution problems (Somlyódy et al., 1993).

Scale and time aspects

There have been substantial changes in nature, as well as in the public and professional perception of nature, during the course of the past decades (see Figures 3.2 and 3.3).

The environmental problems prior to the 1950s were often of a local character. The discharge of sewage into rivers, causing hygienic risks and oxygen depletion in the recipients with fish kills and bad odour as effects, was one such local problem. The time delay between sewage discharge and negative effects was short and there was a clear connection between waste discharge and recipient effects. One way to solve the problems was to use a high rate of waste dilution, i.e. to use large recipients ("the solution to pollution is dilution").

Regional effects of pollutants in the form of acidification and eutrophication started to receive public attention in the 1960s and 70s. Various environmental technologies were used to solve the problems, including centralised wastewater treatment, flue-gas cleaning, incineration of solid wastes and sealed landfills for solid waste. These solutions aimed at removing the produced pollutants in an efficient way and were called "end-of-pipe solutions".

The global effects of pollutants on the environment first came into focus with atmospheric testing of nuclear weapons in the 1950s and the resulting global dissemination of radioactive fallout. It was later recognised that other pollutants, such as chlorinated organic compounds and even metals, were also spreading globally. Today it is mainly the large volumes of carbon dioxide and other greenhouse gases and the depletion of the ozone layer that are recognised as the most important global threats to our environment (Tiberg, 1993).

While the end-of-pipe solutions have proved to be effective for specific source control the diffusive pollutant sources have gradually become the major pollutant source affecting the global environment. Diffusive pollutants are partly formed from de-

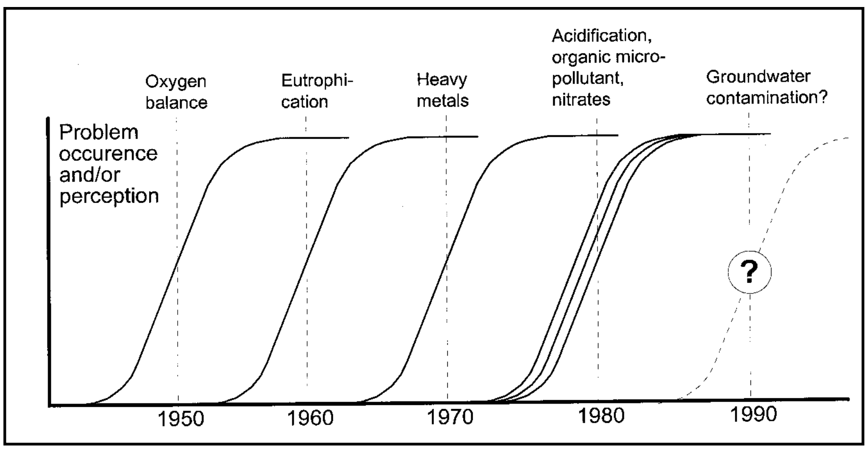


Figure 3.3. Occurrence in perception of water pollution problems in Europe (Somlyódy et al., 1993).

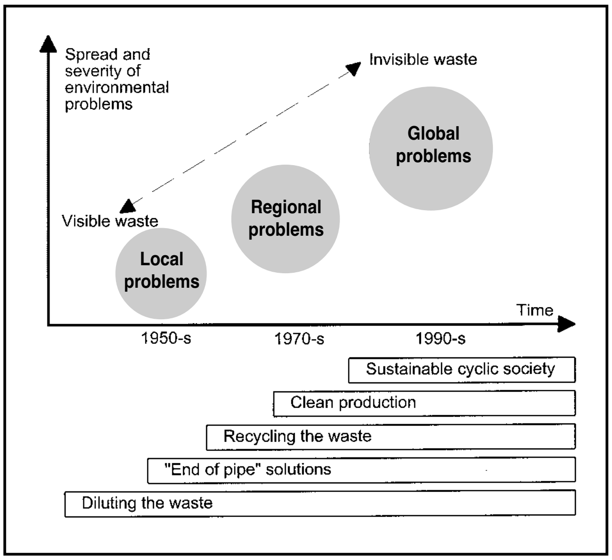


Figure 3.4. Development of environmental problems from the 1950s to today, and countermeasures (Tiberg, 1993).

posited wastes from plants using end-of-pipe solutions. Much more emphasis must therefore be placed on recycling and reuse of wastes and methods for source control and the use of environmentally safe production methods. The role of "life style" on environmental quality has also gradually become to be recognised. The major changes in environmental problems and corresponding countermeasures are illustrated in Figure 3.4.

The causal chains of environmental problems have become more complex. In the beginning, the effects of discharges of sewage on oxygen depletion in a recipient could be predicted with reasonable accuracy, while problems related to global pollution, caused by complex interactions of many pollutant sources, are difficult to quantify. Changes in early focus and future focus on water and wastewater treatment are shown in Table 3.8.

Guiding principles

Many general principles for environmental policy are relevant in the pursuit of sustainability, including ecocycling, critical loads, the precautionary principle, the substitution principle, best available technology and the polluter-pays principle (SOU, 1994):

The ecocycle society, a society within which flows of various materials have been reduced and enclosed to such degree that:

- Flows from society into nature can be added to the natural cycles without causing unacceptable environmental impact, even in a very long-term perspective.
- Extraction of non-renewable materials is done on a limited basis so as to preserve resources for coming generations.
- Biomass and water supplies satisfy human needs without extraction that exceeds growth or inflow.

The concept of critical load, i.e. the highest load of environmental impact at which no harm is caused to the environment, even after long-term exposure.

The precautionary principle: Where threats of serious or irreversible damage are involved, lack of total scientific certainty will not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

The substitution principle: Substances and products that represent a danger to health or the environment are to be substituted with less dangerous ones.

Best available technology principle: Anyone who causes pollution or places the environment at risk is obligated to take action to prevent — or where that is not practicable, to minimise — emission to the environment as a whole, using the latest technology in developed activities and processes and their methods of operation.

The polluter-pays principle: The polluter shall pay the costs, as decided by the public authorities, of pollution prevention and control measures, to:

- Ensure that the environment is in an acceptable state
- Encourage rational use of scarce environmental resources
- Avoid disturbances in international trade

Natural resources and the environment

The overall goals are:

- To retain production capacity of agricultural soils and other important natural resources
- To preserve the integrity of natural ecosystems (terrestrial as well as aquatic and marine ecosystems)
- To respect regional and global constraints on resource use, among other things, the need to curb the global use of fossil fuels to control global warming

Based on these goals and the long-term objectives set by Swedish authorities in relation to the main environmental threats, Table 3.9 identifies major environmental objectives of the water and wastewater sector as they were stated in 1996. With some exceptions, 1990 is the base year. If not otherwise stated, the reduction targets refer to total Swedish discharges and not to discharges from the water or wastewater sector. The Box *Sub-objectives for Water and Wastewater Handling* identifies sub-objectives that should be kept in mind even when focusing on the major objectives.

These early objectives are the basis for the fifteen environmental quality objectives (EQOs) that where formulated in 1999. They are further discussed in volume 3 (*River Basin Management*) of this textbook.

Table 3.8. Trends in water and wastewater handling (Ødegaard et al., 1996)

Factor	Earlier focus	Future focus
1. Pollutant sources	Increasing concern for source control	Intensified efforts to achieve source control
2. Pollution effects	(a) Increasing concern for regional, continental and global effects	Continued concern for regional, continental and global effects, i.e.: • eutrophication in marine environments (Baltic Sea, etc.) • salts and nitrate in groundwater • micropollutants in marine environments and groundwater. • climate change due to greenhouse gases
	(b) Concern about polluted areas	Increased concern about time lag effects (sediments, groundwater, etc.)
	(c) Main concern on single sources	Concern about combined effects of pollutants (municipalities, industries, etc.)
	(d) Hygienic pollution	Concern about new types of pollution (organic micropollutants, toxicity, resistant microorganism etc.) Development of measurement methods
3. Transport of drinking water	Hydraulics • Corrosion • Metal dissolution • Biological stability	Water quality change in network
4. Drinking water treatment	Traditional technology • Disinfection • Aesthetic improvement (colour, turbidity) • Viruses and disinfection resistant microorganisms	Organic and inorganic micropollutants • Disinfection by-products • Pesticides
5. Transport of wastewater	Traditional technology • Drainage without use of available storage	Flow equalisation for minimisation of overflows • Use of volumes for detention by real time control • Use of sewers as biological reactors Transport of separate wastewater streams
6. Wastewater treatment	(a) Low interest in product recovery (b) "Traditional technology" • Centralised treatment • Large plants	Increased application of reuse and recycling for eco-cycling and sustainability New treatment methods including: • Nature based treatment • Small-scale treatment • Compact processes • Technology for recovery More emphasis on preventing pollution. Combined treatment of urban water wastes and solid waste
7. Modelling	Models of certain process stages, etc. decision making	Model library, expert systems
8. Monitoring and data evaluation	(a) Local measurements (b) Grab samples (c) "Traditional parameters" rate constants, etc.)	Networks of measurements, remote sensing, etc. Continuous measurement of certain parameters Special parameters (micropollutants, toxicity, mutagenicity
9. Project evaluation	Costs to achieve a certain reduction of pollutants	Complementary analysis of, among other things, • Technology and environmental assessment • Assessment of sustainability • Assessment of social and political impacts • Risk assessment • Multiobjective assessment
10. Education/information	"Traditional school education"	Complementary use of: • Technology transfer • Continuous education at work (courses, etc.) • Expert systems • Improved communications and information exchange with interest groups, journalists, public, etc.
11. Decision procedure/ administrative structure	Decision mainly by administration and politicians	Increased importance of interest groups, greens, consumers, privatisation, public education and relations between politicians, consumers and professionals

Table 3.9. Major objectives for the water and wastewater sector in relation to the major environmental threats (Ødegaard et al., 1996)

1. Eutrophication of water and nitrogen saturation of soils	The national aim is to reduce the total Swedish discharge of anthropogenic nitrogen to the surrounding seas by 50 % (base-year 1987). The objectives for reduction of anthropogenic phosphorus to lakes, streams and surrounding seas depend on local eutrophication targets. The water and wastewater sector contributes some 40 % of anthropogenic P-discharge and some 30 %of anthropogenic N-discharge, which makes this sector the largest contributor of phosphorus and the second largest contributor of nitrogen to the surrounding seas.
2. Effects of metals	The national objective is to eliminate or significantly reduce use of mercury, cadmium and lead. Targets for other metals depend on local and regional conditions and the objectives agreed upon international convention. In the water and wastewater sector, the discharges of heavy metals are mainly due to stormwater, households and industrial discharges to public sewers. However, corrosion of drinking water pipes may be a major source of copper and some other metals. Measures in the water and wastewater sector plays a key role in sustainable recycling of resources from municipalities back to the agricultural sector.
3. Effects of persistent organic pollutants (POPs).	The national objective is to limit the emissions of POPs to sufficiently low levels so as not to damage the environment. Measures to abate POPs at source are crucial in implementing a sustainable recycling of urban waste to agriculture.
4. Land use practices and exploitation of resources	In some areas restrictions are necessary to protect quality and quantity of ground water. The objective should be to avoid exploitation of land and water if ground water resources may be threatened. Another important objective for the water and wastewater sector is to assure that resources is recycled from municipalities to agriculture without risking deterioration of agricultural land.
5. Non-cyclic material flows, wastes and environmentally hazardous residues	The overall objective is to promote an ecocyclic society. In the water and wastewater treatment sector, the recycling of nutrients is particularly important: P: Phosphorus is a non-renewable resource necessary for growing crops. The existing phosphate ores might, at current rate of mining, be depleted in 150 to 200 years. The objective is that phosphorus in the sewage should be recovered. N: Since 80 % of the air is nitrogen, the resource is unlimited. However, it is highly energy consuming to convert atmospheric nitrogen to a form suitable for crops. The objective is to recover nitrogen from sewage when the energy input for recovery is less than production of artificial fertilisers. K: Potassium is a common mineral in the ground necessary for growing crops. The objective is to recover potassium in sewage, in particular, when the energy consumption for recovery is lower than that for mining.
6. Greenhouse gases	In industrial countries, emissions of CO_2 may have to be reduced by as much as 80 % by year 2050. For the water and wastewater sector, the objective should be to make use of the existing energy potential, for example in wastewater streams, in order to reduce emissions in other sectors. Improved recycling of nutrients to agriculture is another route to overall energy savings. In addition, emissions from transport of, for example, chemicals and sludge should be reduced.

Integrated management

Water and wastewater management must be tackled in an integrated approach. There are three aspects involved (Blowers, 1993):

Trans-media nature. Pollution can adopt different natural states as a solid, liquid or gas and pass through different environmental pathways.

Trans-boundary effects. Pollution and waste can cross political borders either through deliberate export or through environmental pathways shared by different countries. Polluting industries or activities, prevented or unwanted in one country, are sometimes exported to other countries where pollution control is weak and the need for industrial investment is strong.

Trans-boundary transfers. Pollution knows no borders, travelling via different environmental media between countries that share air basins, rivers or oceans. All countries surrounding, for instance, the Baltic Sea or the North Sea experience pollution from the rivers that feed into it and from the dumping of sewage at sea. Such transfers are cases of international negative externalities, that is, costs imposed on one country by another.

Goals and principles for water allocation and integrated management are illustrated in Table 3.10.

Sustainable development will not be achievable unless an integrated approach to land use and water management is taken. Three categories of water problems, as follows, are closely linked to land use and ecosystems (Falkenmark, 1994):

Table 3.10. Goals and principles for water allocation and integrated management: A framework for the analysis and development of policy and instruments (Allan, 1995b)

Goals of activity	Guiding principles	Policies	Institutional Instruments	Engineering Instruments
Facilitation of political circumstances to enable optimum resource use	Minimisation of conflict; promotion of co-operation in the areas of water use at all levels	Conflict resolution; identification of reciprocal arrangements to promote economically and socially beneficial water use and the installation of such arrangements	Water-sharing arrangements (traditional and new); recognition of water rights and of the ownership of water; consultation among legislators, officials - local, national and international - "democratic" institutions; introduction of new economic and legal instruments to shift access to water to the most beneficial users and uses	Earth observation (remote sensing); in situ monitoring and information systems
Productivity ("Development"), Allocate efficiency, Productive efficiency,	Returns to water sustainability of water supplies	Investment in sectors, activities and crops that bring optimum returns, Demand management,	Water pricing, agricultural subsidies, crop pricing and other intervention, Advanced pricing systems imply water metering, Agreements both local and international, Subsidies and pricing imply water metering,	Large and small civil works for water abstraction, treatment, delivery and distribution; recycling; water metering, Water efficiency studies and water management programmes,
Equitable use	Social benefits	Identification of the social benefits and disadvantages of water use and the promotion of beneficial uses	Land reform, water regulation, new legislation, reduction of illegal water use, changes to traditional rights	Water control systems, irrigation management
Safe use	Provision of adequate quantity of water	Identification of appropriate systems (traditional and new) promoting the safe provision of water use, re-use and disposal	Monitoring, legislation, regulating institutions (traditional and new)	Planning for future demand, water control systems, water treatment, maintenance for reliability
Environmentally sound use ("Conservation: Cultivating the world as if you would live forever)	Sustainable use of landscape and amenities including intangibles	Identification of appropriate systems (traditional and new) for sustainable water use	Monitoring, legislation, regulating institutions (traditional and new)	Quality monitoring, water treatment, wastewater treatment, waste disposal

Multicause water scarcity due to

- population growth *per se* producing ever-increasing population pressure on a finite availability of water in rivers and aquifers,
- urban growth, resulting in ever-increasing point demands for water,
- desiccation of the landscape due to degradation of soil permeability, leading to drought-like conditions even in high rainfall areas.

Multicause water pollution due to

- airborne emissions,
- land-based pollution from agricultural land use, industrial activities and human waste,
- wastewater outlets.

Pollution from most of these sources gets caught up and carried by the water cycle and ends up, often with detrimental impact, in land and water ecosystems.

Multicause water-related land fertility degradation due to

- salinisation/water logging from poor irrigation management,
- effects of acid rain originating from air emissions,
- reduced water-holding capacity due to reduced use of organic fertilisers and the removal of organic matter from the soil,
- land permeability degradation due to mismanagement of land.

Sub-objectives for water and wastewater handling

1. Reduce depletion of ozone layer
The national objective is to completely phase out substances such as CFCs and HCFCs. In the water and wastewater sector, poor design and unsuitable operation of nitrification/denitrification processes or incomplete burning of CH_4 may cause emission CH_4 and N_2O. Even though the contribution is small compared to other sectors, the objective should be to significantly reduce the emission of substances that deplete the ozone layer.

2. Reduce acidification of water and soil
The long-term objective is to reduce national emissions of NH_3 by 70 %, emission of SO_x by 70 % and emission of NO_x by 80 % (base year 1990). In the water and wastewater sector, the emissions of NO_x and SO_x are mainly caused by the use of fossil fuels in transportation. Emission of NH_3 comes from sludge and, in the future, possibly from urine handling. New NH_3-emissions should be offset by NH_3 reductions in other sectors so as to achieve the overall objective of a reduction by 70 %. Even though the contribution of the water and wastewater sector is small, the objective should be to significantly reduce the emission of SO_x and NO_x.

3. Reduce emissions of photochemical oxidants and ground-level ozone
The long-term objective is to reduce national emission of volatile organic compounds (VOCs) and NO_x by 70 %. In the water and wastewater sector, such emissions are mainly caused by the use of fossil fuels for transportation. Even though these emissions are small, the objective should be to achieve a significant reduction.

4. Reduce urban air pollution and noise
In the water and wastewater sector, it is mainly transp that causes noise pollution. Odour may be a problem near pumping stations and wastewater treatment plants. Reduction targets must be set according to local conditions.

5. Prevent introduction and spread of alien organisms
Alien species and genetically modified organisms (GMOs) should be introduced very restrictively and under sufficiently reliable controls so as not to pose a threat to domestic flora and fauna. For the water and wastewater treatment sector, the objective should be to prevent the introduction of GMOs.

6. Protect areas of special conservation interest
To preserve biodiversity, it is important to protect valuable habitats, for example, natural wetlands. This means, among other things, that natural wetlands should not be used for wastewater treatment.

From Ødegaard et al., 1996

Emergency planning and risk assessment

Industrial production of chemicals involves accident risks that may cause injury and environmental damage. Examples of accidents in chemical industries before 1980 are listed in Table 3.11. Recent accidents are mentioned below.

Chemical plant accident in Bhopal, India

The release of methyl isocyanate culminated in the deaths of about 2 500 people and the long-term illness of many thousands more (Myers & Read, 1992).

Chernobyl nuclear power plant

The incident occurred on Saturday, 26 April 1986, but it was not until Monday, 28 April, that anyone outside a small group knew that a major disaster had taken place. The incident was a result of a controlled engineering experiment which went horrendously wrong and which led to an uncontrolled release of radioactive materials into the atmosphere. The Chernobyl plume posed both short-term and long-term threats to the environment. The levels of iodine-131 peaked in a matter of days but levels of caesium-134 (half-life 2.1 years) and caesium-137 (half-life 30 years) have persisted in some areas where

Table 3.11. Some major chemical emergencies between 1917 and 1979 (Myers & Read, 1992)

Year	Location	Emergency
1917	Wynandotte, USA	Chlorine release from storage tank; 1 death
1928	Hamburg, Germany	Phosgene release from storage tank; 10 deaths
1939	Zarnesti, Romania	Chlorine release from storage tank; c. 60 deaths
1947	Texas City, USA	Ammonium nitrate explosion; 532 deaths, 3 000 injuries
1962	Cornwall, Canada	Chlorine release from rail car; 89 injuries
1966	Feyzin, France	Propane fire and explosion; 13 deaths, 31 injuries
1967	Santos, Brazil	Coal gas explosion; 300 injuries
1969	Crete, USA	Ammonia release from a rail car; 3 deaths, 20 injuries
1974	Flixborough, USA	Cyclohexane explosion; 28 deaths, > 53 injuries, 3 000 evacuated
1976	Seveso, Italy	TCDD release from factory; Cost of damage: £ 10 million
1979	Bantry Bay, Ireland	Explosion on oil tanker at terminal; 50 deaths

precipitation was high during the passage of the plume (Myers & Read, 1992).

Pollution incidents in the Rhine

On 1 November 1986 a fire broke out in a chemical warehouse near the Swiss city of Basel. Some 1 300 t of chemicals were stored there, including 934 t of pesticide and 12 t of organic compounds containing mercury. Of these, some 30 t of chemicals including mercury and organo-phosphorus pesticides were washed out into the Rhine during the fire-fighting operation. The pollution slick happened to contain rhodamine, a red dye, which made it possible to monitor its passage down the river. Meanwhile, many water intakes into German towns were closed and other water had to be brought in by truck. In the same month 1 100 kg of the herbicide dichloro-phenoxylateacetic acid leaked into the Rhine River from a factory in Ludwigshafen, Germany, requiring the downstream water intakes to be shut off (Mason, 1991).

Safety first

In almost every instance catastrophic chemical or radioactive releases are caused by fire, explosion or accidental release. In order to avoid the effects of these releases, it is necessary to plan in advance to avoid such releases and to contain occurring incidents within the safest possible limits. A safety-first approach is characterised (Myers & Read, 1992) by:

- A concern for the depth of the technology and associated major hazards.
- An emphasis on management.
- A system rather than a trial-and-error approach.
- A concern to avoid loss of containment resulting in major fire, explosion or toxic release.

Special emergencies in water and wastewater handling may be related to:

- Oil spills and other pollutants from boats (into surface waters) or from trucks into groundwater.
- Release of toxic or explosive wastes from industries into the sewer net.

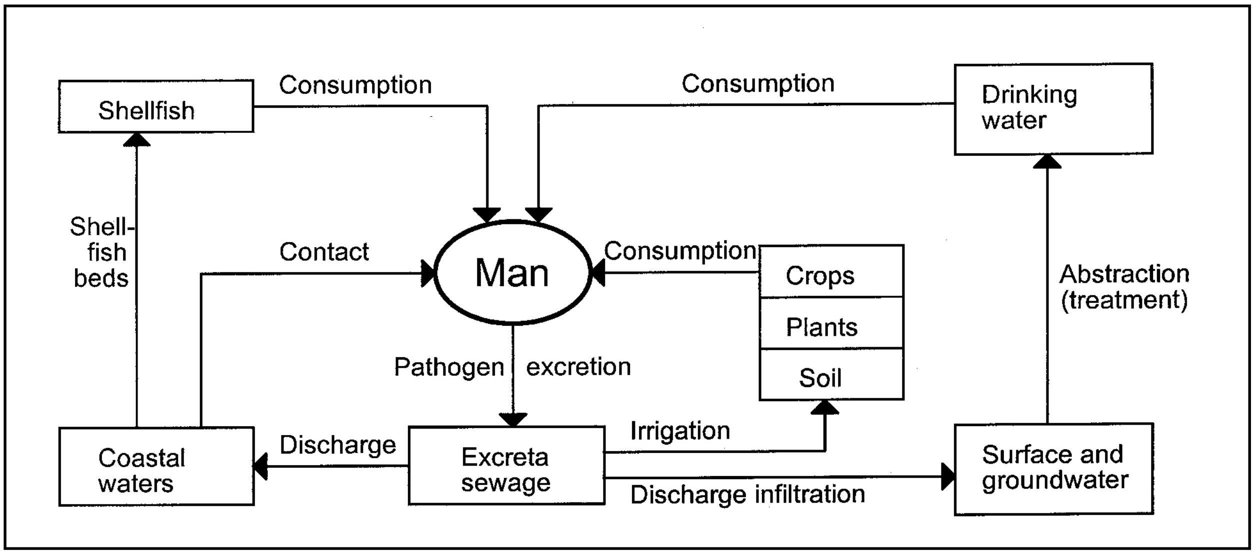


Figure 3.5. The main pathways of human exposure to pathogens in the aquatic environment (Meybeck et al., 1989).

Urban water management resources

Primary resources
We define primary resources as natural resources being directly taken care of by urban water management. These are primarily water, nutrients and energy (in the form of organic chemicals as well as potential energy). There may be situations where for instance heavy metals should also be considered as a primary resource (e.g. in heavily loaded industrial wastewater).

Secondary resources
We define secondary resources as natural resources used for fulfilling the assignments of urban water management. These are energy, space and materials of all sorts (construction and operating materials, chemicals, etc.).

Recipient as resources
The recipients, ground and surface waters, soil and air are regarded as resources on the same level as the primary and secondary resources.

Anthropogenic resources
Sustainable development requires anthropogenic resources such as capital, qualified labour, public acceptance, etc. Without these resources sustainable or any other form of development is not possible.

From Larsen & Gujer, 1997a

Safety and emergency planning in sanitation is a necessary condition for avoiding health effects. The number one killer of infants and children in the developing countries is diarrhoea, caused by a broad spectrum of pathogenic bacteria, viruses and protozoans of faecal origin that are spread indiscriminately in the environment and in the home through the lack of proper human body waste disposal systems. It has been estimated that there are at present close to one billion cases of diarrhoea per year, culminating in some 5 million deaths, most of them of children in the developing countries. Other important faecal-borne diseases, caused by the lack of proper excreta disposal and resulting in millions of cases of disease, debilitation and death in the developing countries include (Schuval, 1994):

- Ascariasis (900 million cases per year)
- Trachoma (500 million cases per year with 8 million ending in blindness)
- Hookworm (800 million cases per year)
- Shistosomiasis (200 million cases per year)
- Guinea worm (4 million cases per year)

A microbial barrier approach is used to manage water quality for downstream uses, which influences public health in the field of water supply, recreational pursuits and agricultural crop irrigation. Surface water is often laden with a variety of domestic and industrial wastes, as well as stormwater runoff, which also carries faecal waste from man and other animals. Groundwater may also become contaminated through seepage of landfill leachates, injection of poor-quality waste effluents and movement of polluted waters from waste lagoons through ground faults into the aquifer below. Possible pathways of infection are illustrated in Figure 3.5.

It is assumed that drinking water that meets current water regulations provides safe water. However, many outbreaks of diseases have occurred due to improper water handling. The recent outbreaks of cryptosporidiosis in Europe and North America have raised serious concerns about the safety of drinking water and have brought about an unprecedented awareness among the general public. While the seriousness of outbreaks cannot be disputed, they are often traceable to errors or substandard treatments. The Milwaukee outbreak, with an estimated 400 000 people out of a population of 1 600 000 sick for over two months, appears to have been due to a short burst of turbidity into one of the two water treatment plants in the city (Payment, 1997).

Photo, Inga-May Lehman Nådin.

4.

Implementing sustainable water systems

Bengt Hultman & Erik Levlin

The water management system

The prime task of the water industry, considered here in the broad sense, is to manage the hydrological cycle for the benefit of the users. Water is used extensively for recreation and amenities. The water industry is responsible for ensuring that the disposal of wastes causes the least possible damage to resources. Using dams and turbines, water can also be the source of electric power. The water industry is also responsible for reducing damage caused by flooding, which can be highly destructive to life, industry and agriculture. Navigation must be maintained in many watercourses (see Figure 4.1).

Overview of instruments

A possible classification of instruments is (Lijklema, 1995):

- Technical instruments
- Regulatory and economic instruments
- Political instruments

Technical instruments aim at cleaning water pollution directly or indirectly by methods such as (Strahl, 1997):

- Avoidance technologies
- Monitoring and assessment technologies
- Control technologies
- Remediation and restoration technologies

Options for analysing water systems may be based on different system levels, ranging from local handling inside buildings to global aspects (see Table 4.1).

Table 4.1 shows that technical actions may be taken on different levels to improve sustainability. Source control and recycling methods should be used as far as possible before resorting to external treatment. Pollution control should be accomplished to such a degree that remediation and restoration techniques could be avoided.

Regulatory and economic instruments include:

- Permits
- Standards
- Charges, levies and taxes
- Subsidies
- Liability

Behind the legal regulatory instruments lies the notion that risks should be curtailed, whereas financial instruments rely upon the functioning of market mechanisms. Modern water quality management rests upon a mix of economic and regulatory instruments in an effort to find an optimum of objectives while being cost-effective at the same time.

Effective water management requires a general governmental and even international policy that promotes a favourable climate for the protection of the water environment. This creates the necessary background for various regulatory measures. Water quality management needs public support, for which involvement, information and education are essential ingredients.

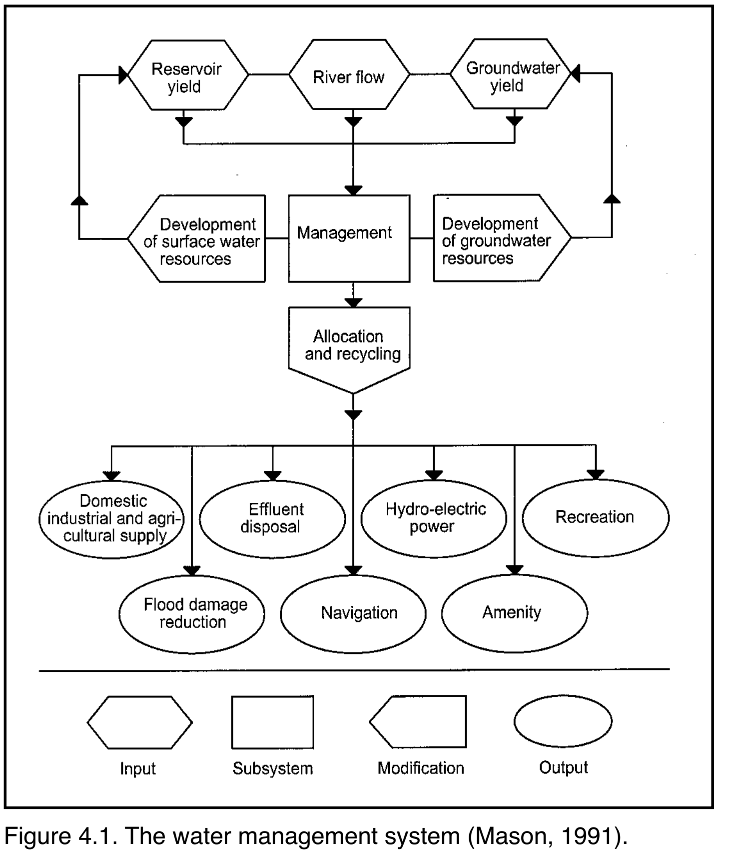


Figure 4.1. The water management system (Mason, 1991).

Table 4.1. System levels in water management

	System level	Examples
I.	Local handling	
	Inside buildings	Households in flats, single houses, etc., institutional buildings (schools, hospitals, etc.), commercial buildings (shops, restaurants, offices etc.), and industrial buildings (factories, power stations etc.)
	Outside buildings	Septic tanks, infiltration beds, wetlands, mini treatment plants etc.
II.	Central handling	System consisting of water treatment works, water networks, sewer networks and sewage treatment works; stormwater pipe net works; treatment plant for industrial combinates; etc.
III.	Regional handling	Water dams with multipurpose functions as urban water supply, electricity production and irrigation; water supply from rivers by use of tunnels or channels to areas with water scarcity
IV.	Global aspects	Effects of green house gases and climate changes on water management

Technical instruments - Avoidance technologies

The avoidance technologies have as a general goal to conserve resources. This includes (Strahl, 1997):

- Equipment, processes, and process sensors and controls designed to prevent or minimise the generation of pollutants, hazardous substances, or other damaging substances.
- Technologies used in product substitution or in recycling and recovery of useful raw materials, pro-ducts and energy waste streams.

Avoidance technologies emphasise source control, minimisation of produced wastes, savings of water and resources, and changes in use of chemicals or household products. Pollution prevention should be treated in the following order (Radecki, 1996; Cunningham & Duffy, 1997):

- Source reduction
- Reuse and recycling
- Treatment
- Safe disposal

Source reduction methods include process modifications, feedstock purity improvements, changes in conservation and management practices, increases in efficiency of equipment and recycling within a process. Recycling and reuse use an item of waste as an effective substitute for a commercial product or as an ingredient or feedstock in an industrial process.

Avoidance technologies have been implemented to a large extent in industries. Processes that have been developed to prevent pollution are commonly known as "clean" technologies. Some incentives for adopting clean technologies are improved process economies, reduced treatment costs, reduced disposal costs, reduced liability, reduced risk of fines for breaches and increased public satisfaction.

Waste minimisation strategies include a number of options, as shown in Figure 4.2. The main components are (Lindfors, 1993):

- Minimise quantity by minimising raw material consumption.
- Improve quality by eliminating or minimisation the content of known hazardous chemicals or by replacing them with more environmentally friendly chemicals.
- Increase direct recycling of material by means of closed loop processes, e.g. decrease specific waste generation and improve possibilities for reuse by preventing wastes from being mixed with other materials.

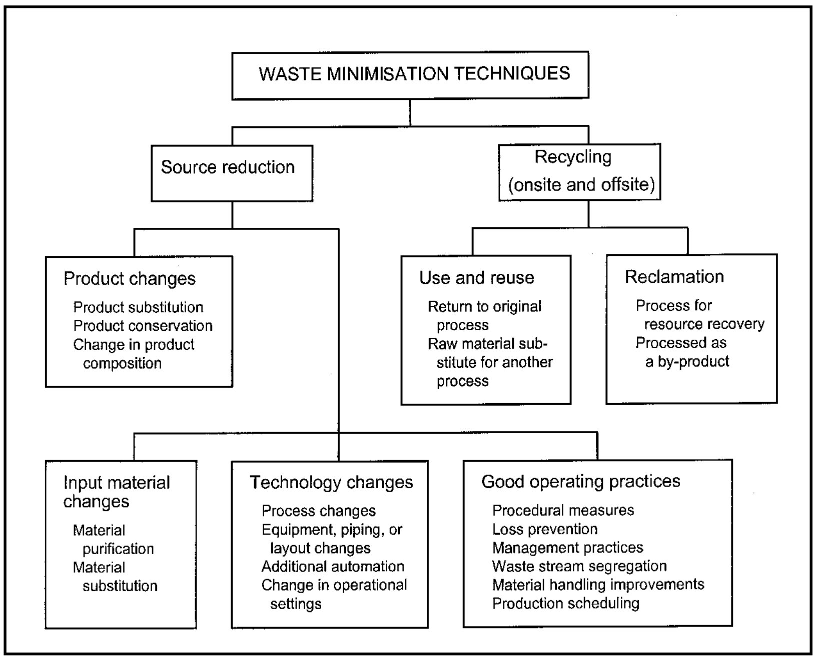


Figure 4.2. Waste minimisation techniques (EPA, 1988).

Urban water conservation initiative

City/Region	Activities/Accomplishment
Jerusalem, Israel	Installation of water saving devices, leak detection and repair and more efficient irrigation of parks contributed to a 14 % drop in per capita use between 1989 and 1991.
Mexico City	Replaced 350 000 toilets with six-litre models saved enough water to meet needs of 250 000 residents; goal of cutting per capita use by one sixth by 1996 through pricing, education, retrofitting and efficiency standards.
Southern California, USA	Metropolitan Water District pays its member agencies $US 125 for each 1 000 m^3 they save. Estimated savings as of June 1992 total nearly 33 million m^3 per year. Conservation efforts have cut annual demand by 541 million m^3, enough to supply about 885 000 households.
Beijing, China	New pricing system links charges to amount of water used; regulations from November 1992 set quotas on consumption and authorise fines for exceeding them.
Greater Boston, Massachusetts, USA	Comprehensive retrofit, water audit, leak detection and education program reduced total annual demand by 16 % in five years, bringing it back to the level of the late sixties.
Municipality of Waterloo, Canada	Delayed expansion of regional water supply through higher water rates, distribution of water conservation kits, and public education. Per capita water use has fallen 10 % during last three years.
Singapore	With water use rising more than twice as fast as population, the island nation cut down unaccounted-for water to 10 % through leak repairs, and promoted conservation with higher prices and public education.
Melbourne, Australia	Since 1982-83 drought, when water use dropped by 30 %, a conservation strategy has kept demand from climbing above the level of 1980, allowing construction of new water works to be postponed and saving $US 50 million.

Urban conservation initiative, selected cities (Postel, 1993)

Avoidance technologies have gradually come into use in other sectors, such as urban water use, stormwater handling and irrigation (cf. Henze, 1997). Urban water conservation in some cities is exemplified in the box above. Preventing runoff is the first objective in stormwater handling, and can be attained by avoiding or at least reducing imperviously paved surfaces in new developing areas and by using permeable instead of impermeable pavement materials.

In stormwater handling, priority should be given to those methods that strongly support the concept of sustainability. None the less, other factors must also be considered, including hygienic aspects and costs.

Different methods of source control and preventive pollution facilitating a control of agricultural non-pointsource pollution are shown in Figure 4.4.

Monitoring, control and remediation

Monitoring and assessment technologies include the design, development and operation of monitoring instrumentation, with associated quality assurance and risk evaluation aspects, such as microsensors, chemical sensors, biosensors, space- and aircraft-based remote sensors and advanced techniques for data collection and analysis. The systems may be strategically designed to provide information of broad international interest, such as climate change effects. They may be very specific, as in the case of a dedicated detector used to ensure compliance by tracking the levels of a hazardous chemical in an effluent, or they may be quite general, as in the case of sites contaminated with an unknown substance (Strahl, 1997). Dif-

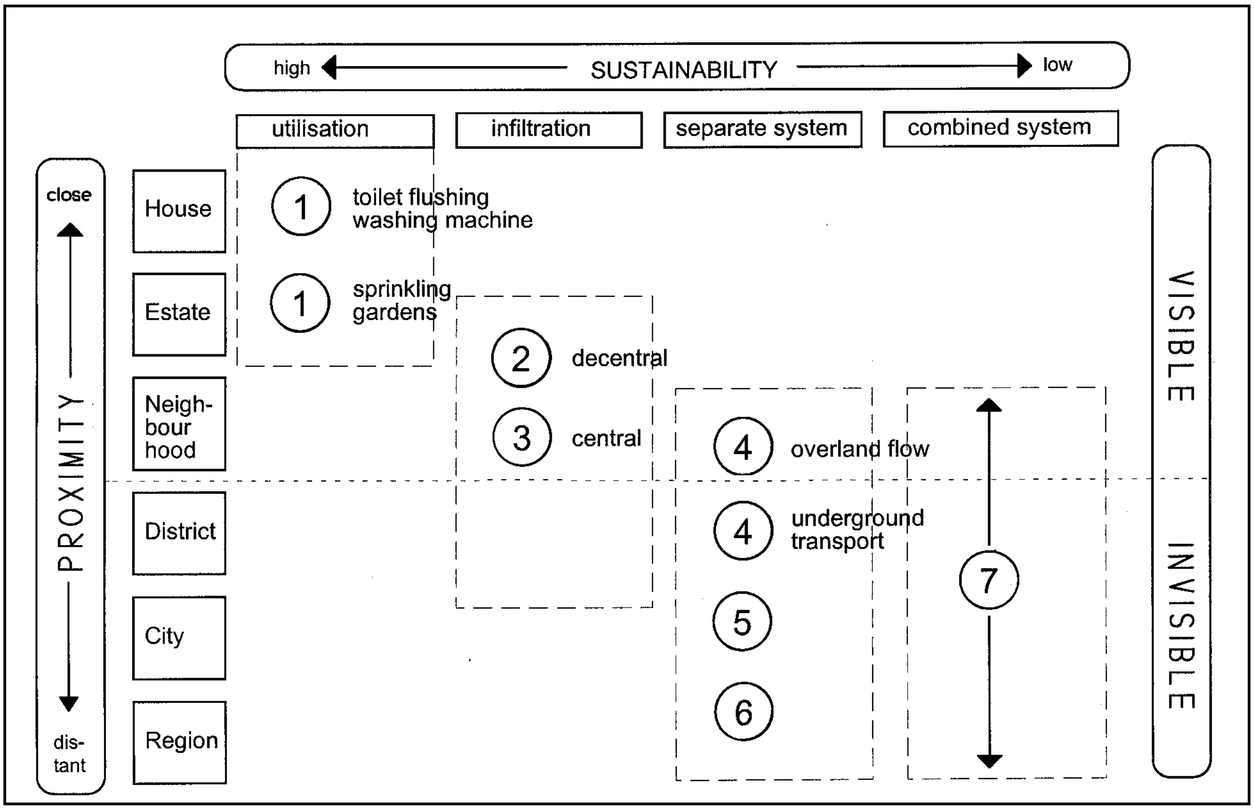


Figure 4.3. Stormwater handling priority diagram, based on sustainability, proximity and visibility. The priority of possible technologies for handling stormwater in urban areas is based on three factors: sustainability, proximity and visibility. Based on these principles a stormwater-handling priority programme may be designed in which each measure is given a priority ranging from 1 (most desirable) to 7 (least desirable) (Veldkamp et al., 1997).

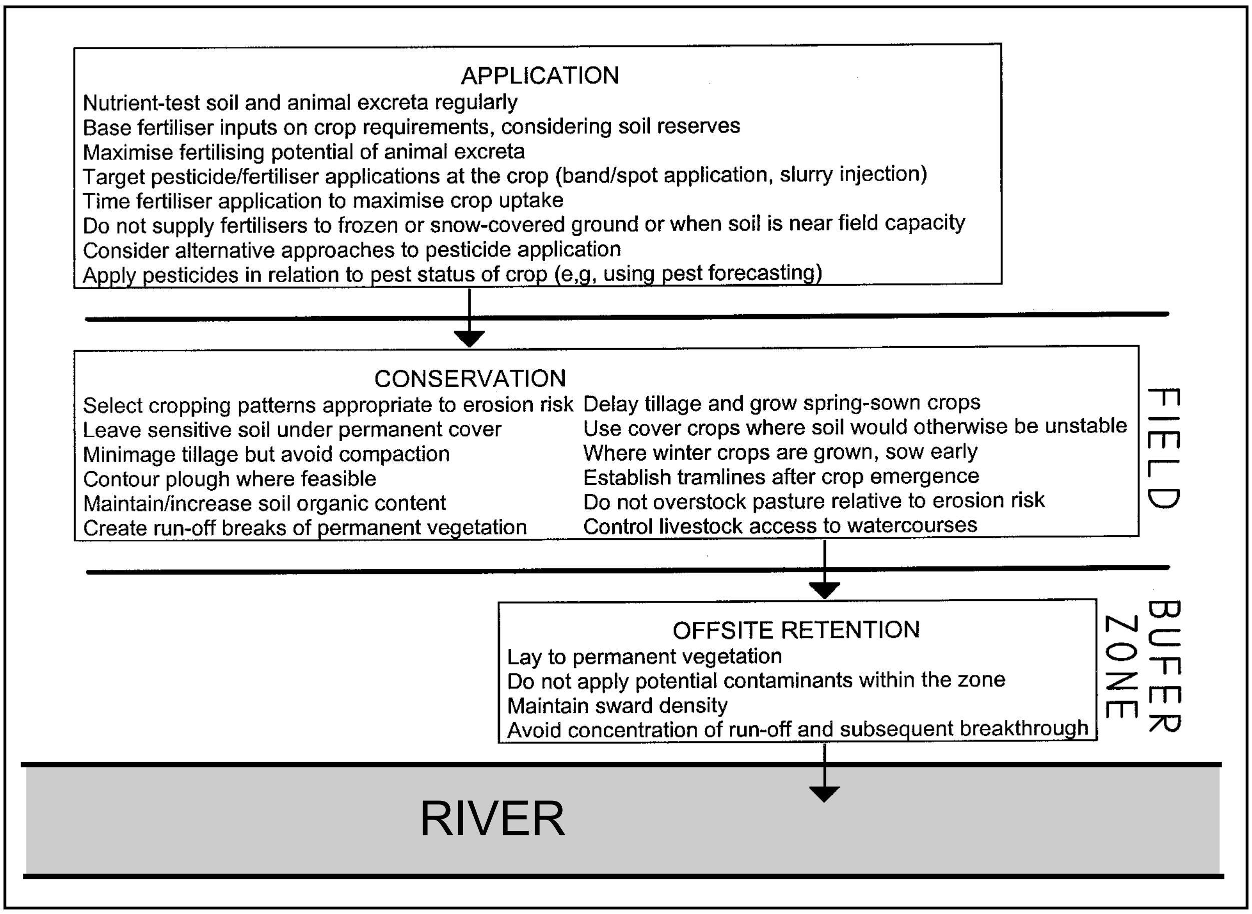


Figure 4.4. Methods of controlling agricultural non-pointsource pollution (Mainstone & Schofield, 1996).

Table 4.2. Activities in a water quality monitoring program (Helmer, 1996)

Monitoring objectives
1. Legislation
2. Mandate
3. Resources
4. Programs

Network design
1. Station location
2. Parameter selection
3. Sampling frequency

Sample collection
1. Sampling technique
2. Field measurements
3. Sampling preservation
4. Sampling point
5. Sample transport

Laboratory analysis
1. Analysis technique
2. Operational procedures
3. Quality control
4. Data recording

Data handling
1. Data reception: (a) laboratory; (b) outside sources
2. Screening and verification
3. Storage and retrieval
4. Reporting
5. Dissemination

Data analysis
1. Basic summary statistics
2. Regression analysis
3. Water quality indices
4. 'Quality-control' interpretation
5. Time series analysis
6. Water-quality methods

Information utilisation
1. Obtain other data and information. e.g.. land use. water use. socioeconomic data. aquatic life information. past. present or planned
2. Water-quality objectives
3. Impact assessment

Decision-making

ferent activities in a water-quality monitoring program are shown in Table 4.2.

Control technologies include both the treatment of pollutants or other materials to eliminate or reduce environmental or human health hazards and the reduction of pollutant/waste material and mobility to make subsequent management more effective. Control technologies are also called "end-of-pipe" or "add-on" technologies (Strahl, 1997).

Remediation and restoration technologies include eradication, encapsulation, and other cleanup technologies used after the hazardous substances have entered the environment. Restoration seeks to improve ecosystems that have declined due to naturally induced or anthropogenic effects. As a result, the natural ecosystem processes will be restored and sustained (Strahl, 1997).

Regulatory and economic instruments

Permits

Permits to discharge are powerful tools, used in many countries. Usually, such permits must be renewed periodically. These permits may apply to effluents from municipal wastewater treatment plants and to industrial discharges. The objective is mitigation of risks for the receiving water and/or the municipal sanitary system. The permits are generally conditional: the effluent may be discharged if (Lijklema, 1995):

- certain quality criteria or standards are met, and
- a minimum level of treatment has been applied.

Standards

Management decisions are based on a comparison of water quality data with criteria and standards. The following definitions are generally accepted (Mason, 1991):

Criteria: scientific specifications on which a decision or judgement may be based concerning the suitability of water quality to support a designated use.

Objectives: a set of levels of water-quality parameters to be attained in water-quality management programmes, which also involve cost/benefit considerations.

Standards: legally prescribed limits of pollution that are established under statutory authority. Standards may be divided into three broad classifications (Lamb, 1985):

- Design standards
- Performance standards
- Procedural standards

The broadest application of design standards is in defining the types of facilities that must be used, e.g. installation of a minimum of secondary treatment of municipal wastewater.

Performance standards can be applied to discharges (emission standards) or to receiving water (immision standards). Especially in the latter case, knowledge of the cause-effect relationships is presupposed. Emission standards ("end-of-pipe standards") are comparatively easy to apply and can be uniform and impartial.

Procedural standards are devoted mostly to administrative aspects of water quality control, ranging from the maintenance of proper working relationships between the discharger and the regulatory agency to procedures that must be followed in applying for permits and obtaining approval for treating and monitoring discharges.

Economic instruments

The economic instruments encompass more than just taxes and permits.
According to the OECD classification, the list include:

Environmental and resource charges
Such as:
- emission charges (levied e.g. on sulphur dioxide emissions)
- extraction fees (e.g. for groundwater)
- user charges (e.g. on disposable PET bottles)
- administrative fees (e.g. to recover costs of issuing permits)
- tax differentiation (e.g. unleaded versus leaded petrol)

Subsidies
- for fallowing agricultural land, for example

Deposit-refund systems
- deposits on car batteries, for example

Market creation
- declaring pollution permits to be transferable, for example

Enforcement incentives
- non-compliance fees (e.g. for emissions higher than allowable)
- performance bonds (e.g. to raise funds for remedial action)

Economic instruments for environmental policy (Zylicz, 1997)

Economic instruments

Charges, levies and taxes are used to compensate for the costs of pollution. They provide the necessary revenues for financing the treatment, subsidising clean technology, monitoring, administration etc. Economic instruments have gained increased use during the last decade and include many possibilities (see Box above).

5.

FINANCING WATER SUPPLY AND SANITATION

Bengt Hultman & Erik Levlin

Financing principles

Two basic principles of sound financial management are resources coverage and liquidity maintenance. Resources coverage means that at any given time all needs should be covered. Liquidity maintenance means that at any given time all cash needs should be covered. While full resources coverage (*inter alia* through cash raising) should be pursued as a matter of principle, the methods of achieving this will vary with circumstances. In most developing countries, liquidity maintenance is an essential condition for the attainment of permanent resources coverage and sustainability. General guiding principles for financing are given in Box on page 50.

Problems in management and financing of public water supply and sanitation systems have led to different partnerships with the private sector. The main types of public-private partnerships are (EPA, 1994):

- *Contract services*. The community contracts with a private company to provide a service (such as garbage collection) or to run a facility that is owned by the community (such as a wastewater treatment plant). Firms or experts also can be contracted to perform specific duties, such as accounting or maintenance of electrical systems.
- *Turnkey facilities*. The community owns a facility but contracts with a private company to design, construct and operate the facility. The community is responsible for funding the facility, while the private company is responsible for providing a certain level of service or regulatory compliance.
- *Leasing*. The company pays rent to a private owner in exchange for using a facility for a specified period. The community controls the facility until the lease is over, when the facility is returned to the owner. With a finance lease, however, the community pays to lease a facility but then owns the facility at the end of the lease.
- *Developer financing*. A private developer finances construction or upgrading of a facility to gain the right to build homes, stores or other buildings.
- *Privatisation*. A private firm owns, builds, operates and partially or totally finances a facility or service. The local community decides it wants the facility or service, and might partially fund it.
- *Merchant facility*. This is similar to privatisation except that the private firm also decides to provide the services.

Throughout the world, there is a strong growing trend towards the participation of the private sector in the management and operation of water and wastewater enterprises and increasing reliance on private finance for sector investments. In the United States, some 40 % of the water and wastewater sector is in private hands. In France, local governments own the infrastructure, but a growing number of governments – now accounting for about 75 % of all urban water connections in the country (though less for sewerage) have opted to delegate the operation to private firms under management contracts, leases or concessions. Similar arrangements are spreading in Spain and Italy and are also being adopted in cities in Latin America, East Asia and Africa.

In Germany, private firms serve only about a quarter of all users, but even municipally-owned utilities farm out a large share of their work, and a dynamic industry of specialised sub-contractors has developed. To accelerate the modernisation of the water sector in eastern Germany, private entry is being encouraged. During the 80s, all water and wastewater enterprises in England and Wales were converted into fully private stock companies. Their shares were floated on the stock market, transferring full ownership to private investors and limiting the public sector's role to one of standard setting and regulation. Private sector participation has already taken hold in the transforming economies of central and eastern Europe. Private joint venture companies with foreign and local interest manage water supply and wastewater services in Gdansk in Poland and Brno in the Czech Republic (Stottmann, 1994).

The global situation

The infrastructure challenges that face developing countries, particular in the water and sanitation sector, are enormous. Infrastructure in the industrialised world has been developed successively during the last century.

As a contrast a large proportion of people in the developing world does not have access to safe water and adequate sanitation (see figure 5.1). A billion people still lack access to an adequate supply of water and 1.7 billion do not have adequate

Principles for financing water supply and sanitation systems

- Water and sewerage agencies should be granted autonomy in order to provide an efficient and satisfactory service. While subject to public interest regulations, they should operate on a commercial basis.
- The agency's management should be such as to ensure overall efficiency (technical, commercial, financial, etc.), rather than high-level performance in any given field.
- The agency should focus on cost control – on the investment side by avoiding premature investment or investment on too large a scale and by selecting appropriate technology, and on the recurrent side by making best use of facilities. This should be achieved by minimising the amount of nonrevenue water, maximising the efficiency of billing and collection, and implementing adequate preventive maintenance measures.
- The services provided by the agency should be tailored to consumers' needs; this requires, in particular, consultation with consumers, market studies and good public relations.
- "Ability to pay" criteria can at best only be a broad guideline and represent an external assessment, whereas "willingness to pay" is far more relevant.
- The agency should provide a service for which the consumer is willing to pay. To achieve financial viability, the average tariff should be fixed at such a level that all cash needs (except sudden emergency needs, which, if included, would cause intolerable tariff fluctuations) are covered, including, where possible, an adequate self-financing margin to fund extensions (liquidity maintenance).
- Greater efforts should be made by the donor community to help the agency to reach a sound financial position; projects that may undermine financial viability should not be undertaken.
- The agency should improve its internal and external information systems (accounts, meters, etc,); it should know how much it finances, how much water it produces and where the water goes.
- Subject to average tariffs being sufficient to cover liquidity needs, the following principles should apply to specific consumers:
  - the public standpipe services should be financially autonomous, with an average tariff to the retailers (entrepreneurs, community organisations, other agencies) equivalent to the variable costs of supplying these connections; the rates should be such that, under normal supply conditions, the financial situation of the agency cannot be improved by closing these facilities;
  - pricing should be consistent with economic costs;
  - where the capacity of the natural drainage system is – or is expected to become – insufficient, the costs of a sewerage/drainage system (existent or future) should be gradually covered by a charge, e.g. a levy on water use, except for water used to satisfy minimum human needs; a similar charge should also be made for the private abstraction of water.

General guiding principles for financing water supply and sanitation systems (WHO, 1994)

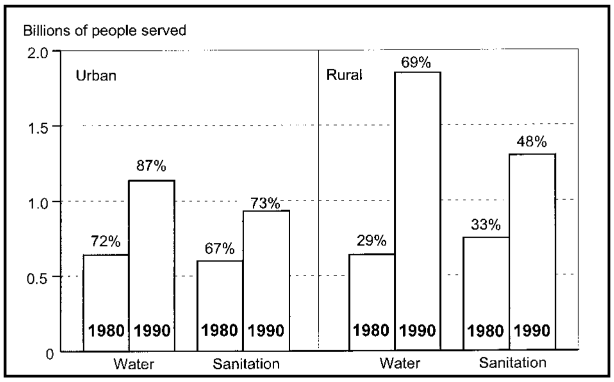


Figure 5.1. Access to safe water and adequate sanitation in developing countries, 1980 and 1990. Numbers above the bars are percentages of the relevant population (Serageldin, 1994).

sanitation facilities. Despite the fact that the number of urban people with adequate facilities increased by about 50 % between 1980 and 1990, due to growth in urban population, the number without access to adequate sanitation actually increased by about 70 million (Wall, 1997).

Developing countries have over the past 30 years allocated an increasing share of their Gross Domestic Product (GDP) to public spending on local domestic water and sanitation services (see Figure 5.2). Wall (1997) ascertains that it would appear that the proportion of public spending has not been appropriate for three reasons. First, the low contributions of domestic users have meant that supply agencies

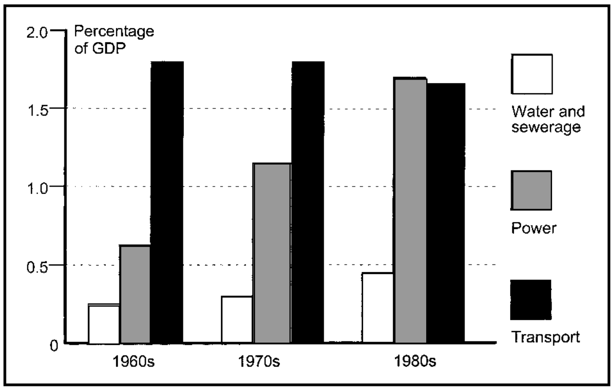


Figure 5.2. Public investment in infrastructure in developing countries over three decades (Serageldin, 1994).

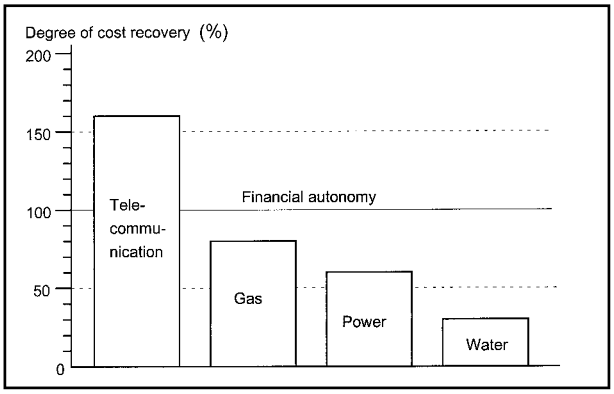


Figure 5.3. Degree of cost recovery in infrastructure sectors in developing countries (Serageldin, 1994).

have not felt obliged to provide adequate service, nor to provide it to all consumers (see Figure 5.3). Secondly, this spending has been used primarily to provide domestic services to the middle and upper classes. Thirdly, spending on domestic services has left few public resources available for wastewater treatment and management on a wider urban metropolitan scale.

A World Bank study of more than 120 urban water projects initiated between 1967 and 1989 concludes that despite capacity building for the public institutions concerned, only four countries – Botswana, the Republic of Korea, Singapore and Tunisia – have public water and sewerage utilities that have reached acceptable levels of performance (Serageldin, 1994). A few examples of the seriousness of the situation are: in Caracas and Mexico City, an estimated 30 % of connections are not registered. Unaccounted-for water constitutes 8 % of the total water supply in Singapore, with all of 58 % in Manilla and about 40 % in most Latin America cities. The number of employees per 1 000 water connections is between two and three in western Europe but between ten and twenty in most Latin American utilities.

Table 5.1 shows the GNP per capita and population of 133 countries with over 95 % of the world's population. Here we see different income levels, with low-income economies (most of Sub-Saharan Africa, South Asia, China, some SE Asian countries), low to middle income economies (some Latin America countries, most of the former USSR, some African countries), high middle income economies (most former socialist countries in Europe, most of Latin America, some SE/E Asian and a few African countries) and the high-income economies (OECD countries and a few others).

Willingness to pay

For a variety of reasons, water supply projects commonly fail to reach their anticipated goals. Little attention has been paid to consumer demand for water supply and sanitation. It is typical to assume either that everyone will want to connect to the system, at whatever price that is charged, or that public health benefits are so important to the community and the services will be so heavily subsidised that no one will have reason not to connect. Normally it is assumed that as long as financial requirements for new water-supply systems do not exceed 5 % of income, it is "affordable" and the household will make a connection to the system and be able to pay the subsequent recurrent charges. In sanitation planning, the general rule-of-thumb is that if the monthly charges are less than 3 % of household income, it is assumed that the household has the ability and willingness to pay for the improved service (Rogerson, 1996).

Another method to estimate the willingness to pay is to use contingent valuation surveys of the basic

Table 5.1. Gross National Product (GNP) per capita for different income levels (Varis & Somlyódy, 1997)

Income level	**GNP per capita, 1994** ($US)	**Number of inhabitants** (billions)	**Rate of urbanisation** (%)
Low-income economies	< 725	3.2	3.8
Low-middle-income economies	725 - 3 000	1.1	2.3
High-middle-income economies	3 000 - 9 000	0.5	2.6
High-income economies	> 9 000	0.9	0.3

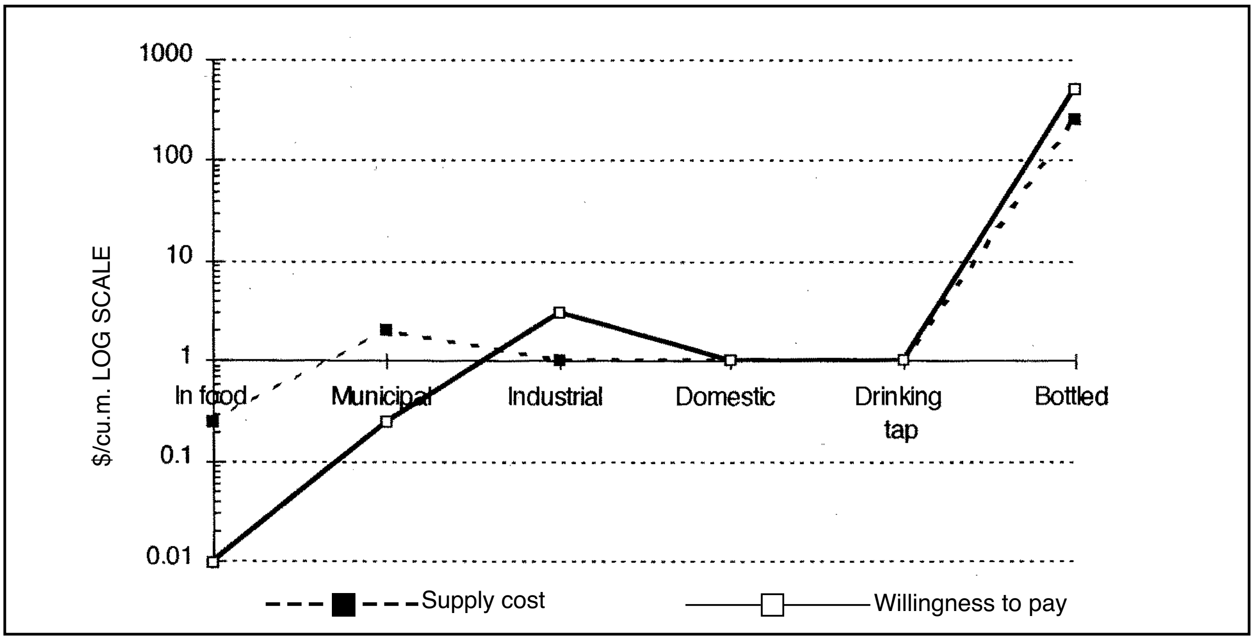


Figure 5.4. Supply costs of water (indicative) and levels of willingness to pay (indicative) in arid environments, (Allan, 1995a).

form to ask "If you were required to pay X per month for a connection, would you choose to connect to the system or would you prefer to use the alternative source?" The core criticism to this method is that for a variety of reasons respondents may not answer willingness-to-pay questions accurately and thus not reveal their "true" willingness to pay (Rogerson, 1996).

Probably the most reliable source of information concerning willingness to pay is to be derived from pursuing surveys of organised and informal water-vending activities in both cities and rural areas (Rogerson, 1996). Because of the difficulties associated with cost recovery for piped supplies with public outlets and despite the fact that they are often illegal, water-vending systems have been formalised as a means of supplementing or replacing piped distribution systems. This is suitable to communities where a socially beneficial vending system already exists and can be improved, and where other options are technically, economically or otherwise unsuitable. Water vending may also be appropriate in communities where other cost-recovery options have failed to operate satisfactorily. At water kiosks, water agency employees or licensed holders of a metered connection can sell by the litre or by type of container water. Wastage and vandalism can be minimised, and user payment is assured (WHO, 1994).

Water vendors who take water from an available source and subsequently deliver it in containers to households or fill household containers from their vehicle tanks serve millions of people in villages and cities throughout the developing world. In Jakarta roughly 32 % of the city's 8 million inhabitants purchase drinking water from street vendors. The distribution of water by vendors is expensive, regardless of whether vehicles are powered by people, animals or engines. It is generally the case that households served by vendors pay higher unit charges for water than those directly connected to a piped system. Beyond cost considerations, vending is sometimes also linked to health problems, as hawkers may sell from polluted sources or from fouled containers. People may obtain water by purchasing it from vendors who are licensed operators (kiosks) directly or from distributing vendors who buy water from the kiosks. In many cities where water vending takes place, the vendors themselves are employers rather than "independent entrepreneurs" and may be subject to highly exploitative wage and working conditions (Rogerson, 1996).

Studies on water vending have shown that households sometimes pay a higher fraction of their income for water compared with the common role-of-thumb analysis that households in the developing world can afford only 3 to 5 % of their income for improved water supplies. In Ukanda, Kenya, it was shown that water vendors supplied 45 % of the total water consumed in the village. The average per capita water expenditure was about 9 % of the average annual per capita income in Ukanda. In a similar study in Onitsha, Nigeria, with about 700 000 inhabitants, only about 8 000 households were connected to a public water supply system. Of these households the lowest income groups were estimated to be paying 18 % of their income on water during the dry season as compared to between 2 and 3 % for upper-income households (Rogerson, 1996).

The willingness to pay for water is closely related to water use. In arid environments the willingness to pay for industrial and domestic use (including drinking water) may be 1-2 $\$US/m^3$ and as high as 500 $US/m^3 for bottled water (see Figure 5.4). The willingness to pay for irrigation water for agriculture is much lower (about 1 US cent/m^3) and irrigation water is often heavily subsidised from the state. The supply costs of the water are in the same range as the willingness to pay, except for irrigation and municipal water (Allan, 1995b).

Financing and affordability

For water supply and sanitation systems to be sustainable, all their costs should be covered. In all countries, cost containment should be an important objective of public utilities. It is of crucial importance in developing countries, where too many people still do not have access to services. Risk-taking and deficit-spending measures, based on high technology and the assumption that at some future time either consumers or the government will pay, should not be ventured and should be discouraged (WHO, 1994).

Implementation of any sustainable policy should be affordable. The fastest urbanisation rates are in areas where there are very limited possibilities to design systems with a longer time perspective. Possibilities to implement different water and sanitary systems depend on willingness to pay, the gross domestic product per capita and costs involved in the different systems. Another important factor is time. There is very little time to do all that needs to be done to accommodate the one billion new people to be born in the next ten years. Very few actions of the magnitude needed can be completed in this period (Varis & Somlyódy, 1997).

The major features of water infrastructure in the industrialised world are summarised by Varis & Somlyódy (1997) as follows:

Water supply

- High coverage required, safety is a major concern (a part of living standard); willingness to pay is there.
- Inherited systems from past decades: no separation (high quality water is used for all purposes).
- Limited flexibility: infrastructure is given; a change would take 15-20 years (reconstruction period).

Sewerage

- Philosophy and often also systems from the 19th century.
- Public health and water borne/transmitted diseases original driving force.
- Long planning horizon and lifetime – difficult planning due to uncertainties in future flow estimates.
- Very expensive, investment- and money-driven (decisive element of the infrastructure) – lobbies.
- Functions: transport of pollutants (liquids); originally domestic wastewater; industrial (at a later stage); stormwater; linkage to road construction; an incremental part of city planning; change in function with time (19th century – very little industrial wastes, etc.); future changes are also anticipated.

Treatment

- Central plants dominate.
- Mostly activated sludge and its advanced versions.
- Increasing sophistication (operation etc.).
- Sludge management is often overlooked.

The western-world type of solutions characterised above, with centralised water and wastewater handling systems including water and sewer nets, costs a minimum of about $US 150 to 300 in capital costs per person (Varis & Somlyódy, 1997). It is estimated that the United Kingdom will have to invest about $US 60 billion in wastewater treatment over the next decade to meet the new European water quality standards. This amounts to about $US 1 000 per capita, or about 0.6 % of GDP spent on wastewater treatment alone over that ten-year period (Serageldin, 1994).

In Southeast Asia, the per capita cost of sewer connections in urban areas in 1985 varied from $US 45 to $US 400 with a median cost of approximately $US 80. To this must be added an annual water charge in the region of $US 5 per person served. Low-cost on-site alternatives cost $US 13-30 per person in urban areas, and $US 5-20 per person in rural areas. In Africa, south of the Sahara, sewer connections were reported to cost $US 120-300 with accompanying water costs in the region of $US 8 per year per person. The median sewer connection cost was $US 150, with urban on-site alternatives ranging from $US 25 to $US 70. Rural sanitation costs were in the range of $US 10-45 with a median of $US 25 per person. In Central and South America, sewer connection costs varied from $US 120 to $US 235 with a median cost of $US 150, the same as for Africa. Urban on-site sanitation cost citizens $US 20-80 and rural sanitation ranged from $US 10 to $US 50, with an average of about $US 25 per person served (Franceys et al., 1992).

Public investments in water infrastructure were typically around 0.4 % of the GDP from the 1960s to the 1980s (see Figure 5.2). For people on a low-income level, for instance below $US 500 per year, this would mean a yearly investment in water infrastructure of $US 20.

Many local expenses in low-income countries are much lower than in high-income economies. The GNP generally overestimates the difference between rich and poor countries. A number of alternative indices have been proposed to allow more realistic comparisons. The World Bank uses the purchasing power parity index (PPP). It typically exceeds the GNP by five- to ten-fold per capita in low-income and lower-middle-income economies (Varis & Somlyódy, 1997).

Application of low-cost handling methods

The central systems normally used in urban areas in the industrialised world do not seem affordable in many developing countries. Obviously, alternative, less capital-demanding solutions that fit together with available human resources and infrastructure are desperately needed. Different technologies that should be considered are (Varis & Somlyódy, 1997):

- *Saving water.* There are many ways to reduce water consumption by increased efficiency, including technical measures such as reducing leakage, economical incentives such as proper pricing, restrictions such as limiting water use for certain purposes and increased public awareness.
- *Recycling of organic matter*. In many traditional, integrated systems of farming, aquaculture and livestock-raising, manure is returned to the system as organic fertiliser. In many cases, especially in Asia, sophisticated and efficient systems with low emission rates have sustained for hundreds if not thousands of years. Although these issues are primarily rural, there are many lessons to be learned for cities needing an increased ecological balance through, e.g. urban agriculture development. On another level, sludge from wastewater treatment plant is relatively widely returned to terrestrial ecosystems.
- *Recycling of water*. Various options for industrial and municipal water recycling have been proposed. In the industrialised world, there are many examples; there are also examples from the developing countries. In municipal water supplies, the use of lower-quality water for flush toilets and other uses that require a lower standard have been applied.
- *Sanitation without water.* Many parts of the world have traditional or more recent solutions for sanitation through various types of latrines, mostly with a urine separation system. Water consumption is non-existent or much lower than in flush toilets and the waste can be returned to the land, but the really good dry systems are also expensive.
- *Appropriate technologies*. It has often been emphasised that the chosen technological level should be in balance with the available infrastructure, institutions, human resources and economic conditions. There is a pitfall in that appropriate technologies may turn out to be expensive and inappropriate.
- *The solution to pollution is dilution or to rely on self-purification.* This principle leads to open mass flows and should be avoided whenever possible. However, it is used very widely. The pollution is transported away and/or diluted into a lower concentration.

The application of low-cost and low-tech treatment systems lags behind what is believed to be the present potential of professional ability. Innovations have been marginal and progress slow, mainly because of the very limited research funding and feedback from existing systems. The need for low-cost systems, however, is gradually being realised by some (advanced) financing and regulatory institutions. During the last few years there has been a visible change in attitude and development seems to be accelerating (Grau, 1997).

Three examples of innovative technical development will be given below. The traditional way of treating surface water for production of drinking water is by use of precipitation chemicals (such as aluminium sulphate) followed by flocculation, sedimentation, rapid filtration, and disinfecting. The experiences in many countries are that these facilities are often inadequately operated, insufficiently maintained and frequently out of operation. A possible solution is to fill a sedimentation tank with coarse gravel, which significantly enhances the treatment efficiency of the sedimentation tank. After this step the water may be treated with slow filtration. This process combination yields a high removal efficiency of faecal coliforms. Another development is to use solar water disinfection where the simplest method is solar exposure of water-filled transparent and half-blackened bottles (Wegelin & Schertenleib, 1997).

A third example of recent technical development is the combination of low-cost nature-based treatment and a low-cost technical part. An example is the Petro process developed in South Africa, which combines three well-known low-tech treatment units (Grau, 1997; see Figure 5.5):

- pre-treatment in an anaerobic-aerobic pond reactor with fermentation pit
- treatment in oxidation ponds
- treatment on trickling filter

The main technological advantage of this process is its ability to remove algae from the pond effluent. Algae are immobilised and embodied in the trickling filter biofilm. Certain parts of the primary pond effluent are bypassed to the trickling filter to provide the desirable proportion between heterotrophs and algae. A trickling filter can be installed to supplement an existing pond system or an existing trickling filter can be supplemented by the pond system.

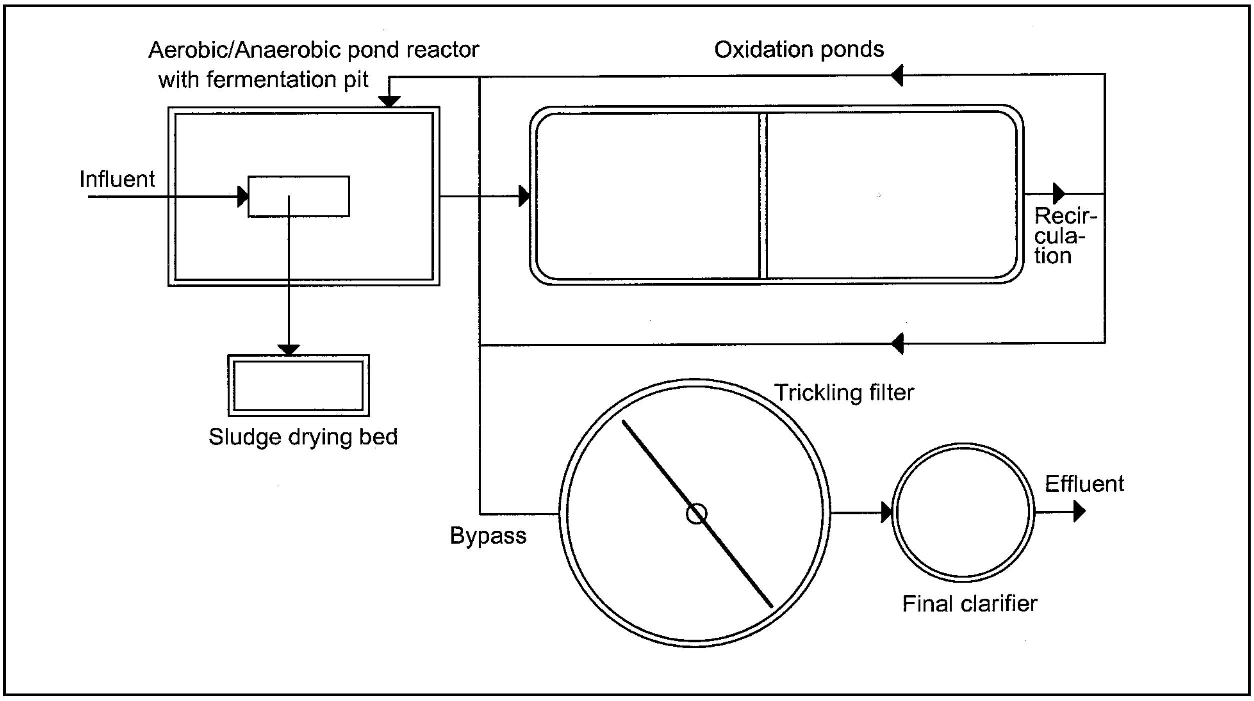


Figure 5.5. Example of a low-cost system combining natural-based and technical components – the Petro process (Grau, 1997).

Collectively, industries account for nearly a quarter of the world's water use. In most industrial countries, they are the bigger users – frequently accounting for 50-80 % of the total demand, compared with 10-30 % in much of the Third World. As developing countries industrialise, however, their water demands for thermoelectrical power generation, manufacturing, mining and materials processing are rising rapidly (Postel, 1993).

In contrast to the water used in agriculture, only a small fraction of industrial water is actually consumed. Most of it is used for cooling, processing and other activities that may heat or pollute water, but do not use it up. This allows a factory to recycle its supply, thereby getting more output from each cubic metre delivered or allocated to it. So far, the main impetus for industrial water recycling has come from pollution control laws. Most of the world's wealthier countries now require industries to meet specific water quality standards before releasing wastewater to the environment. As it turns out, the most effective and economical way to comply with these requirements is often to treat and recycle water, thereby discharging less. Pollution control laws have therefore not only helped to clean up rivers, lakes and streams, but they have also promoted conservation and more efficient water use (Postel, 1993).

Japanese industries are a good example of efficient implementation of water recycling. Industrial output, meanwhile, has been climbing steadily. As a result, in 1989, Japan attained a $US 77 worth of output from each cubic metre of water supplied to industries, compared with $US 21 (in real terms) in 1965. In just two decades, the nation more than doubled its industrial water productivity. Similarly, U.S. industry's total water use has fallen 36 % since 1950, while industrial output has risen 3.7-fold (in real terms). In western Germany, total industrial water use today is at the same level as in 1975, while industrial output has risen 44 % (Postel, 1993).

In advanced industries with an efficient water use, by using recycling and other water saving methods, the water supply cost is normally only a small fraction of the value of the produced goods. For this reason many industries are not seriously influenced by the price of water per cubic metre. These industries are often more dependent on the cost-efficiency of different internal water handling methods.

Food consumption and import

Water use in agriculture accounts for about two thirds of all water removed from rivers, lakes, streams and aquifers and makes efficient irrigation a key factor for sustainable water use. The choice of agricultural products is highly dependent on living standards and the type of agricultural products consumed will considerably influence the necessary water amount for the products. World economic growth exceeded that of population growth by more than 3 % during the 50s and 60s, providing a substantial gain in living standards for much of humanity.

Table 5.2 World economic growth by decade, 1950-92 (Brown, 1993)

Decade	Annual growth of world economy (%)	Annual growth per person (%)
1950-60	4.9	3.1
1960-70	5.2	3.2
1970-80	3.4	1.6
1980-90	2.9	1.1
1990-92	0.6	- 1.1

During the 70s economic growth was roughly cut in half and dropped further during the eighties. As a result of the recession the per capita income fell by over 2 % from 1990 to 1992, yielding a negative annual growth per person (see Table 5.2).

Similar tendencies can be found for growth in production of principal foods and use of agricultural resources. A rapid growth rate period occurred between 1950 and about 1980, after which a slow growth period began (see Table 5.3). The decline in fertiliser use is the result of a more efficient application of fertilisers and the observation that excessive fertiliser use causes nutrient-rich runoff that will cause eutrophication in the recipients. The rate of the world population growth declined from 2 % in 1970 to 1.6 % in 1995.

Water, like food, may command a modest price at the source, for example at the farm gate, in terms of agricultural products, and at the spring, pump or canal outlet, in the case of water use. In some markets, the value added to food products in the process of preparation and distribution in the market may be substantial. In the water sector, packaged water may be sold at prices that are 100 times the cost of delivery at the source (Allan, 1995b).

In the world trade of food, water has been combined in food staples in parts of the world where water is literally free. The comparative advantage of agriculture in such water-rich temperature tracts, along with the extraordinary levels of subsidy that the industrialised countries in these temperate latitudes have been prepared to devote to their agricultural sector, has resulted in a situation where free water, incorporated in food staples, is available on the world market with an additional subsidy. The importers of food staples have enjoyed immense economic benefits from these trading circumstances (Allan, 1995b).

The strategic importance of the "virtual" water in food is illustrated in Figure 5.6 for Israeli and Palestinian water import. The Middle East is the single most vulnerable region regarding water scarcity. It imports more food per head than any other major region, and its food balance is the most negative in terms of the value of agricultural imports and exports and especially in terms of the movement of "virtual water." (In the future, increased considerations must be given to the global system to continue to produce sufficient affordable food staples. Particular scrutiny has to be devoted to the economies of China and South Asia, where 40 % of the world's population lives. If these economies were to enter the world trade in food, they would seriously change market conditions to the detriment of regions irreversibly dependent on cheap food imports (Allan, 1995a). The gross domestic product is about $US 16 000 per person, the contribution from the agricultural sector is only 3 % of the GDP, and in Israel total water use is about 300 m^3 per capita and year (Arlosoroff, 1997).

Efficient housekeeping and water-saving methods in households and industries, reuse of wastewater for agriculture and possibilities to import foods with "virtual water" have made it possible to manage the water demand. A flexible water demand is needed to supply basic fresh food (e.g. dairy products, eggs and vegetables), which is estimated at 25-30 m^3 per capita. In the future, Israel may be forced to desalinate seawater unless large-scale regional transfers are achieved (Arlosoroff, 1997).

Table 5.3. Growth in production of principal foods and in use of agricultural resources, 1950-92 (Brown, 1993)

Commodity/Resources	Rapid growth period		Slow growth period	
	Years	Annual rate, %	Years	Annual rate, %
Principal food commodities				
Grain production	1950-84	+ 2.9	1984-92	+ 0.7
Soybean production	1950-80	+ 5.1	1980-92	+ 2.2
Meat production	1950-86	+ 3.4	1986-92	+ 2.0
World fish catch	1950-88	+ 4.0	1986-92	+ 0.6
Principal agricultural resources				
Grainland area	1950-81	+ 0.7	1981-94	- 0.5
Irrigated area	1950-78	+ 2.8	1978-92	+ 1.2
Fertiliser use	1950-84	+ 6.7	1984-92	+ 0.7

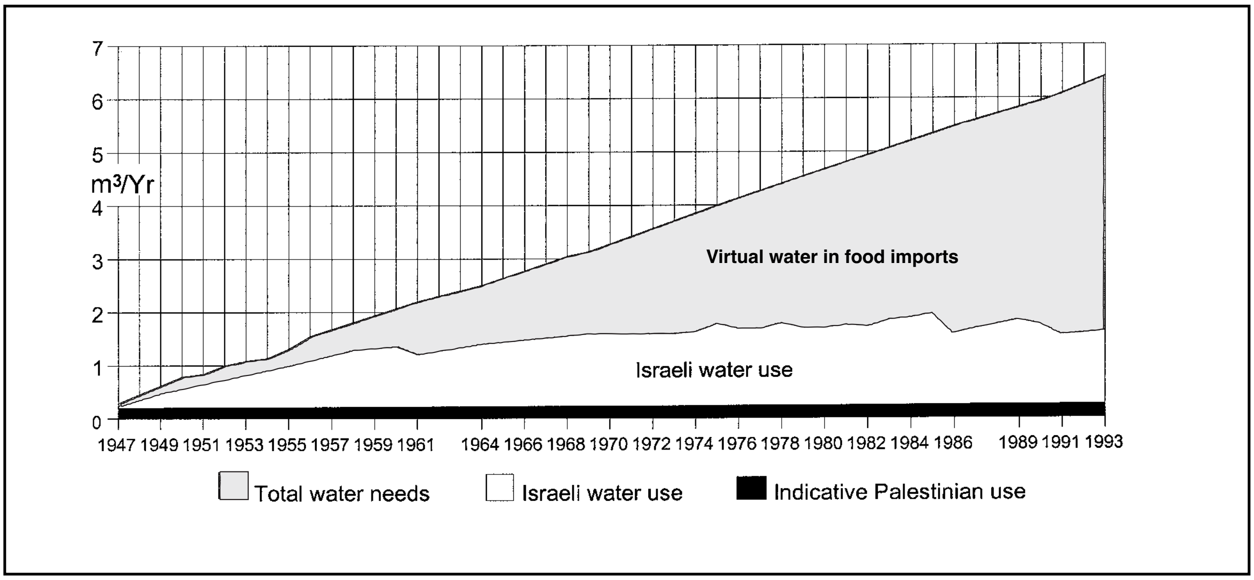


Figure 5.6. Israeli and Palestinian water use compared with the total water needed for food self-sufficiency – 1947-1993 (Allan, 1995a).

While there has been no growth in the last five years in ocean- or land-based food production in the world, the demand for food has continued to expand, influenced by population growth and rising affluence. In every society where incomes have risen, so has consumption of livestock products. Since incomes began to rise in 1950, world meat consumption has leaped four-fold, from 44 million tons to 184 million tons. Consumption per person has nearly doubled – from 17 kg in 1950 to 33 kg in 1994. Grain use per person measures both the amount of grain consumed directly, which accounts for half of the human caloric intake, and the amount consumed indirectly in the form of livestock products, which accounts for a large share of the remainder. Grain use varies from a high of roughly 800 kg per person in the more affluent societies, such as the United States, to a low of 200 kg per person in low-income societies, such as India. Within the last two years, rising meat consumption has transformed China from a net grain exporter of 8 million tons to a net importer of 16 million tons. Cessation of growth in the world fish catch is putting additional pressure on land-based food sources used by fish farmers, requiring roughly 4 million tons of grain per year (Brown, 1995).

The world's food economy may be shifting from a long-time period of overall abundance to one of scarcity. In 1995, a small amount of cropland was held out of production under commodity set-programs, including some 7.5 % of U.S. corn land and 12 % of the grain land in Europe. Putting this land in production again would increase the grain production by an additional 34 million tons. Competition takes place due to the use of agricultural land for other purposes than food production, such as biofuels (as ethanol from corn), production of tobacco and for urban or industrial areas. Environmental degradation including soil erosion, salination of soils, aquifer depletion, air pollution, ozone depletion and effects of climate changes has a negative effect on agricultural production (Brown, 1993; 1995).

The type of food consumed is a determining factor for food scarcity. The present world grain harvest is about 1.75 billion tons. A harvest of 2 million tons, equally distributed, could support 2.5 billion people on the American level, 5 billion on the Italian level or 10 billion on the Indian level. Current world grain exports add up to roughly 200 millions of tons per year, of which the United States accounts for close to one-half (Brown, 1995).

Global water resource needs

Water consumption in food production has been discussed earlier in Table 3.5. Zehnder (1997) gives the following role-of-thumb values:

2 kg of wheat (dry weight of the whole plant) yields 1 kg of bread. In order to produce this amount of plant material, 1 m^3 of water is needed. The plant absorbs this amount of water, but loses a large portion of it to the atmosphere through evapotranspi-ration. This loss is difficult to reduce, although selection of smaller plants and genetic engineering might reduce the loss by 25 %. American farmers use about 4 m^3 water per kg wheat, while farmers in tropical areas use about 5 m^3 of water to grow 1 kg of rice.

One kg of wheat flour provides approximately 3 500 kcal, which means that supplying a vegetarian diet of 1 000 kcal per person per day requires an annual water consumption of 100 m^3. This is a very optimistic estimate that ignores losses that occur during harvest and processing due to pests and spoilage, all of which increase water demand accordingly. Normal losses are between 20 and 50 %, with 40 % being the current average value.

To produce 1 kcal of meat, 4.5 to 16 kcal of plant material is needed, with 10 kcal being the average. A daily intake of 2 500 kcal requires an annual water consumption of 350 m^3 when the diet is completely vegetarian. If the diet is only 80 % vegetarian and 20 % is supplied by meat, water consumption increases to 980 m^3. These numbers include a 40 % overall loss in production and processing of the plant material for both humans and animals.

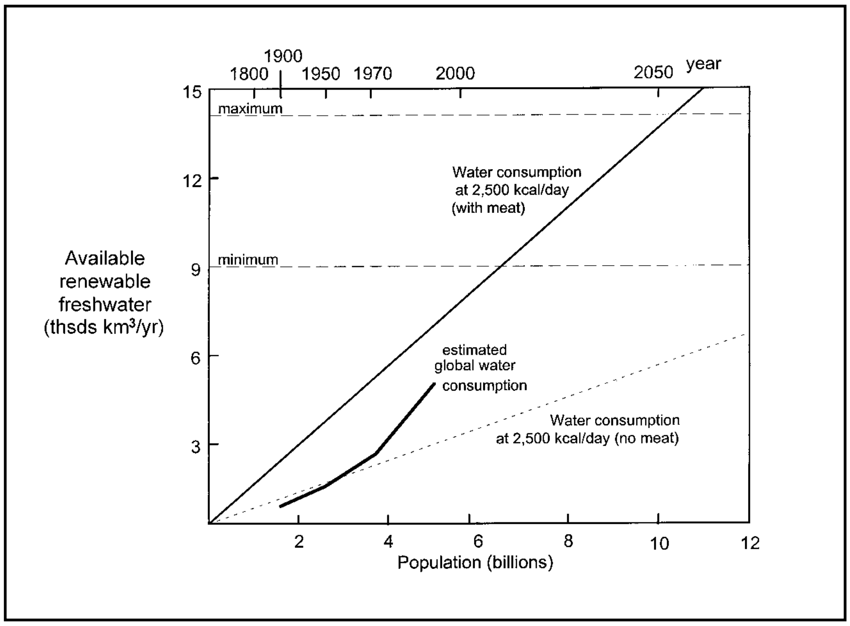


Figure 5.7. Annual water consumption for an increasing global population at a diet of 2 500 kcal per day. The solid line represents an 80 % vegetarian/20 % meat diet, while the dotted line represents a completely vegetarian diet. Both lines include an extra 250 m^3 water for households, the service sector and industry. The dashed lines at 9 000 and 14 000 km^3 indicate the minimum and the maximum annual value for the globally available volume of renewable fresh water. The heavy solid line represents the estimated actual global water consumption (Zehnder, 1997).

Annual water consumption for a region or related globally to water availability may be described by three factors:

- *Population* in the specific area or globally
- *Per capita direct use of water* for different purposes and per capita use of "virtual water" in food and other products
- *Available water* based on sustainability criteria and different restrictions

Different forecasts have been made regarding the future population of the world (see Table 3.2). Per capita direct water use varies with the level of income, water-saving methods etc. (see Tables 3.6 and 3.7) while the use of "virtual water" varies with type of food supply. Prediction of available water may be based on sustainability criteria and different restrictions. The sustainable water amount of the world is about 45 000 km^3 if all water precipitated on land minus evaporated water is available. However, about 25 % of the water reaches the ocean without ever being available as freshwater. Also, part of the precipitation falls in scarcely populated areas (e.g. Siberia) and is therefore difficult to access. In reality, only 9 000 to 12 000 km^3 of freshwater may be available for use in agriculture, as drinking water and in industrial processes (Zehnder, 1997).

Due to large uncertainties in predicting the population growth, in the per capita uses of direct water and "virtual water," and in the amount of available water, based on sustainability and different restrictions, estimations of "the water crisis" vary greatly. Figure 5.7 shows an example of such a prediction based on data from Zehnder (1997). The assumptions are:

- Direct consumption of water for households, the service sector and industry at 250 m^3 per capita and year (685 l/person and day).
- Water used for food ("virtual water") is 350 m^3 per person and year for vegetarian diets and 980 m^3 per person and year for 80 % vegetarian/20 % meat diets.
- The globally available volume of water per year is 9 000 km^3 as a minimum and 14 000 km^3 as a maximum.
- The population of the world will be 10 billion in the year 2050 (present population is approximately 5.7 billion).

The figure shows that there may already be a shortage of the supply of freshwater on a global scale in 20-40 years. Strict and careful reuse of water could, however, boost available supplies by as much as 70 % (Zehnder, 1997). Different methods of water transfer could increase the annually available and renewable freshwater supply and desalination in certain countries (e.g. Saudi Arabia) already has an important role in domestic and industrial water supply.

Parallel to how the type of food consumption influences the global water supply as compared to sustainable available water, the present amount of food production influences the number of people in the world who can be supported (see Table 5.4). The table shows the number of people who could be fed at the 1990 level of agricultural production if the dietary preferences and food system efficiencies in the country (or area) prevailed throughout the world.

Public participation

The key actor in achieving sustainable development is the individual. The most important ways to exert influence on this development are (M. Andersson, 1997):

Political vote. The most important way of acting politically is to vote in elections at the local, regional and national level. Another way is to participate in referendums (for example, in 1980, Sweden had a referendum about the future of the country's nuclear programme). Political participation may also include activities such as writing open letters to the press and contacting politicians.

Economic vote. As a consumer in a market economy, the individual can choose to buy the least environmentally harmful products, in other words, to vote with one's wallet. If so-called "green" products are not available in the shops, consumers can contact producers and environmental organisations to discuss how these products might become available.

Work for voluntary organisations. A third possibility for the individual is to join a non-governmental organisation involved in environmental protection. In Agenda 21 it is emphasised that these organisations "play a vital role in the shaping and implementation of participatory democracy. Formal and informal organisations, as well as grass-roots movements, should be recognised as partners in the implementation of Agenda 21."

Table 5.4. World Population supportable under different feeding cultures at the 1990 level of agricultural production (Bender, 1997)

Conditions in	Population (billion)
United States	2
Europe	4
Japan	6
Bangladesh	10
Subsidence only	15
1990 World population	5

Successful water management requires active participation on the part of consumers. By use of information campaigns the public can be encouraged to buy washing and cleaning products that are as environmentally safe as possible. They can also be encouraged to buy only the most necessary products, to use the correct dosage of certain products and to dispose hazardous waste at specially arranged collection points instead of pouring them into the sewage system (Brattberg, 1993).

Environmental labelling began in Germany and spread to many other countries. Its purpose is to satisfy the need of environmentally aware consumers who want to purchase products of increased environmental quality. If companies have products that meet the criteria and they believe that sales of these products will increase with an environmental label, it is likely that the company will seek this label. Environmental labelling together with governmental action to ban or phase out certain products can be very effective (Strahl, 1997).

Building and construction work may lead to pollution of water which is considered in environmental impact assessment (photo, Inga-May Lehman Nådin).

6.

Environmental impact assessment

Bengt Hultman & Erik Levlin

Environmental impact assessments

Books like *Silent Spring* by Rachel Carson (1962) gradually aroused public interest in issues such as environmental impact assessments. The National Environmental Policy Act (NEPA) was introduced in the United States in 1969, eventually becoming Public Law 91-190. The purpose of the act was to insure that environmental values would receive their proper placement among the socio-economic and technical priorities to be considered in making decisions that affect the quality of the environment. As a result, the new requirement for an environmental impact statement (EIS) was established. The act's goals for the nation are to (Rau, 1980):

- Fulfil the responsibilities of each generation as trustee of the environment for succeeding generations.
- Assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings.
- Attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences.
- Preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment, which supports diversity, and variety of individual choice.
- Achieve a balance between population and resource use, which will permit high standards of living and a wide sharing of life's amenities.
- Enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

In every recommendation or report on proposals for legislation and other major federal actions significantly affecting the quality of the human environment, all agencies of the federal government are to include a detailed statement on:

- The environmental impact of the proposed action.
- Any adverse environmental effects that cannot be avoided should the proposal be implemented.
- Alternatives to the proposed action.
- The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity.
- Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

Environmental impact assessment (EIA) is a process whereby consideration of the environment and public participation in the decision-making process of project development is required, while an EIS is a review document prepared for assessment in the EIA process. In some countries EIA is a direct legal requirement, while in others it is enforced indirectly under general planning, health or pollution control powers (O'Sullivan, 1997).

EIA can be described as a process of a) identifying the likely consequences for the biogeophysical environment and for people's health and welfare of implementing particular activities and b) of conveying this information, at a stage when it can materially affect their decision, to these responsible for sanctioning the proposals. The aim of EIA is to serve as support for decision-making on different levels. The two most common applications of EIA are proposed projects (construction of roads and bridges, locations of industries and landfills, changes in wastewater systems, etc.) and municipal planning. In Sweden, the term EIA (*Miljökonsekvensbeskrivning*) signifies both the assessment and the final document (the latter would be called EIS in USA) (Kärrman, 1997).

Environmental impacts are often categorised as primary or secondary. Primary impacts are those that can be attributed directly to the proposed action. If the actions involve construction of a facility, such as a wastewater treatment plant, an office building, or a laboratory, the primary impacts of the action would include the environmental impacts related to the construction and operation of the facility and land use changes at the facility site. Secondary impacts are indirect or induced changes, typically including associated investments and changed patterns of social and economic activities likely to be stimulated or induced by the proposed action. If the action involves the construction of a facility, the secondary impacts would include the environmental impacts related to induced changes in the pattern of land use, population density, and related effects on air and water quality or other natural resources (Rau, 1980).

Stages and methods

The stages of EIA include the following (O'Sullivan, 1997):

- *Screening*, to decide which projects should be subject to environmental assessment.
- *Scooping* is the process that defines key issues that should be included in the environmental assessment.
- *EIS preparation* is the scientific and objective analysis of the scale, significance and importance of impacts identified.
- *Review*. As the project proponent normally produces environmental assessments, it is usual for a review to be undertaken by a government agency or an independent review panel.

Many methods are used to select projects for EIA (O'Sullivan, 1997):

- *Positive and negative lists*. These are lists of projects that are considered to be candidates for EIA (positive) or projects for which EIA will not be required (negative).
- *Project thresholds*. Thresholds can assist in project screening, where projects exceeding predetermined thresholds are considered to be candidates for EIA.
- *Sensitive area criteria*.
- *Matrices*. The matrix compares project activities listed under the main headings of site investigation and preparation, construction, operation and maintenance, future and related activities, with the different environmental consequences.
- *Initial environmental evaluation (IEE)*, which may be regarded as a "mini EIA."

Procedures for writing an EIS

Ideally, an EIS must be thorough, interdisciplinary and as quantitative as possible. The writing of an EIS involves three distinct phases: inventory, assessment and evaluation. The first is a cataloguing of the factors that may be affected by the proposed action. In this step no effort is made to assess the importance of a particular variable, such as hydrology and geology, environmental quality of land, water and air, plant and animal life, and socio-economic factors (Vesilind et al., 1990).

The process of calculating projected effects that a proposed action or construction project will have on environmental quality is called environmental assessment. It is necessary to develop a methodical, reproducible and reasonable method for evaluating both the effect of the proposed project and the effects of alternatives that may achieve the same ends but may have different environmental impacts. A number of semiquantitative approaches have been used, among them the checklist, the interaction matrix and the checklist with weighed rankings (Vesilind et al., 1990).

The final part of the environmental impact assessment is an evaluation of the results of preceding studies. Typically, the evaluation phase is no longer in the hands of the engineers and scientists responsible

Table 6.1. Potential impacts of different projects on hydrological systems (Morris & Biggs, 1995)

Projects	Examples of potential impacts
Roads	Changes in drainage systems due to landscaping, changes in groundwater flow, increased runoff velocities and volumes, pollution of water sources through the use of de-icing salt, metals, organics, plant nutrients, and accidental spillages of toxic materials
Urban and commercial development	Changes in drainage systems and in groundwater flow, reduced groundwater recharge, increased runoff velocities and volumes, and pollution of water courses
Industrial development	Greater runoff effects, discharges of pollutants, and thermal pollution from power plants,
Wastewater treatment plants	Effects of different discharges as silts, nutrients, heavy metals, organics, and pathogens,
Landfill	Increased runoff if site is clay-capped and contamination of groundwater and near-surface run off by toxic leachates
Quarring and mining	Changes in drainage systems and groundwater flows, increased waterlogging and flood risks down stream, increased siltation downstream, chemical pollution from spoil heaps, and oil pollution from vehicles, machinery and stores
Deforestation	Increased runoff causing rapid changes in river flow rates and consequent channel erosion and flood risks, enhanced soil erosion and nutrient losses, and high stream-sediment loads and consequent siltation
Intensive agriculture	Enhanced runoff and erosion from bare soils, drainage or irrigation impacts, pollution of soils, groundwater and surface waters by a variety of pollutants, including nutrients, biocides, organics from soil erosion, and pathogens

for the inventory and assessment phases. Decisions made within the responsible governmental agency ultimately use the EIS to justify past decisions or support new alternatives (Vesilind et al., 1990).

Impacts on hydrological systems

Hydrological impacts can be divided into those arising from the direct utilisation of hydrological systems including river engineering/manipulation, reservoirs and dams, barrages, irrigation, drainage and water abstraction, and those not directly associated with such manipulation or utilisation. Potential impacts of such projects are shown in Table 6.1.

GIS applications in EIA

Geographical information systems (GIS) are computer-based databases that include spatial references for the different variables stored, so that maps of such variables can be displayed, combined and analysed with relative speed and ease. GIS may be used in an EIA and the applications include (Rodriguez-Bachiller, 1995):

- terrain use for slope and drainage analysis
- land-resource information systems for land management
- soil information for soil studies
- geoscientific modelling of geological formations
- disaster planning related to geographically localised catastrophes
- analysis of irrigation suitability
- monitoring of development
- contamination and pollution monitoring
- flood studies
- linking environmental databases
- constructing global databases for environmental modelling

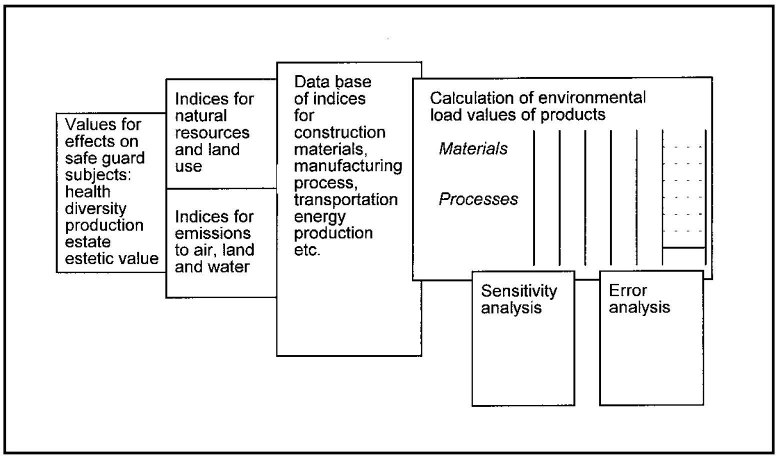


Figure 6.1. The principle of the EPS system applied to a particular product (Steen & Ryding, 1993).

Impact comparison methods

A table of calculated resource use and amount of emissions can be used to describe the environmental impact of a product or process. However, the results are difficult to compare when the products result in different types of emissions. Therefore, resource use and discharged substances need to be converted into comparable parameters. Three methods (Baumann et al., 1994) for these conversions are:

The ecological scarcity method (ECO). An environmental index (ecofactor) for a product or process is calculated by summarising different types of pollutants multiplied by a corresponding ecofactor, based on ecological scarcity. These ecofactors are defined for a given area by the relation between the critical level of pollutant set by the limiting carrying capacity of the natural environment and the actual level of anthropogenic emission of that pollutant.

The environmental theme method (ET). Resource use and emissions are grouped (classified) into a limited number of environmental themes, which are weighed against each other. Such a theme could be e.g. "greenhouse warming potential". The total impact is calculated in three steps. The environmental loads are grouped into selected themes, and by using a measure of the relative equivalence of pollutants, the impact caused by the product is calculated per theme. The classified loads are divided by the corresponding total contributions to the theme within the geographical delimitation relevant to the study, resulting in an impact fraction. The impact fractions may be summarised into a total impact factor by applying weight factors, depending on the relative importance or severity of different themes.

The environmental priority strategy method (EPS). The principle tools for an EPS are definitions of so-called environmental load indices for use of natural resources and energy and for pollutant emissions. Based on these inputs, environmental indices for materials and processes are calculated. Using the indices for materials and processes, an environmental load value is calculated. The load values are expressed in environmental load units, ELU (see Figure 6.1) (Steen & Ryding, 1993).

Environmental Management Systems (EMS)

All companies have some form of management to carry out leadership and administrative functions. During the last ten years a dramatic change has occurred in the area of environmental management. Firstly, consum-

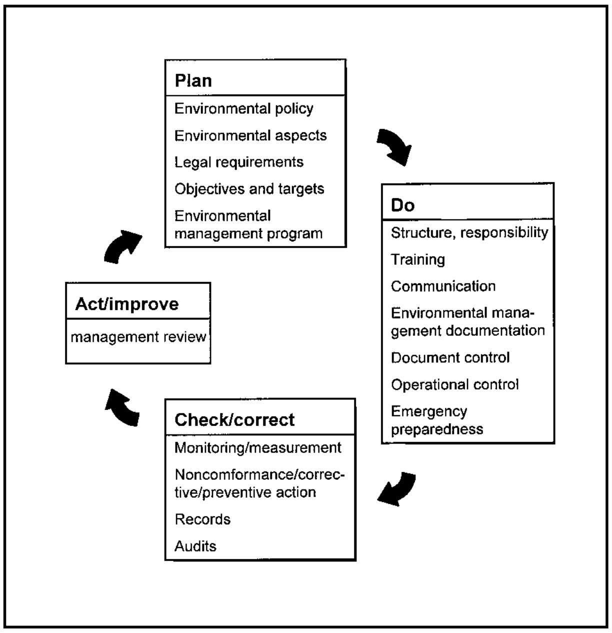


Figure 6.2. Environmental management systems: a continuous cycle (Begley, 1996).

ers have become increasingly environmentally aware when purchasing goods. Secondly, in several countries the notion of environmental liabilities has been extended. They now reach from the organisation fouling the environment to other actors such as insurance companies, banks and even a future purchaser. Environmental management arose from the need on the part of the management at particularly large firms to deal with environmental issues in a more systematic fashion (Strahl, 1997).

An environmental management system is part of a company's overall management system and strategic business planning. As illustrated in the classic management cycle of planning, doing, checking/correcting and acting/improving, environmental management includes several steps in a continuous process designed to improve a company's environmental conditions (see Figure 6.2).

Standardisation of EMS

Presently there are two main EMS standards that can be used by European companies: EMAS and ISO 14 000. Eco-Management and Auditing Scheme (EMAS) is an EU regulation which permits companies to be certified according to this standard. Certification is voluntary. Companies can be certified either according to ISO 14 000 or EMAS. ISO 14 000 has many similarities to the earlier, well-established ISO 9 000 quality standards series. The idea is to make environmental management appealing to companies that already have ISO 9 000 certification. Table 6.2 shows a comparison of selected parts of ISO 14 000 and EMAS.

Since EMS standards only deal with the management system, EMS certification may not necessarily reduce the environmental impact of the company's goods and production process.

Standardisation activities of the International Organisation of Standardisation (ISO) in the field of the environment are summarised under ISO TC (Technical Committee) 207 founded in May 1993 (Klüppel, 1997; Marsmann et al., 1997). Figure 6.3 shows the structure of ISO TC 207. Six subcommittees (SC) control six different main issues, with SC 5 responsible for LCA standardisation. The subcommittee for LCA, SC 5, is divided into five working groups (WG) creating standards for the different phases of LCA.

The standards for environmental management systems and auditing cover many areas, including (Begley, 1996):

Environmental management systems (ISO 14 001) is the only specification standard of the series. The others are guideline standards and do not have an option for registration. The EMS standard describes a business management system that includes a formal environmental policy, objectives and targets, programs for implementation, monitoring and measurement, and corrective action.

Environmental auditing (ISO 14 010, 14 011, 14 012) standards cover general principles, procedures for auditing an EMS, and qualification criteria for auditors. They do not focus on measuring environmental performance but on verifying that EMS incorporates the specifications laid out in 14 001.

Table 6.2. Comparison of selected parts of ISO 14 000 and EMAS (Strahl, 1997)

	EMAS	**ISO 14 000**
Environmental policy	Requires continuous improvement of environmental performance	Requires continuous improvement of the EMS
Communication with the public?	Requires statements designed for the public	The EMS must consider communication with the public
Environmental Audit includes environmental performance of the organisation?	Mandatory	Not necessary
Frequency of the audit	At least once every third year	´Periodic´
Issues to be taken up in the audit	Issues clearly stated in a binding Annex	Suggests some potential issues

Environmental labelling (ISO 14 024) outlines three kinds of labels. A general label is for products that meet specified requirements. A second label is for specific claims such as energy efficiency or recycled content, while a third label summarises a life cycle inventory so that consumers can compare products on the basis of environmental impacts in manufacturing and use.

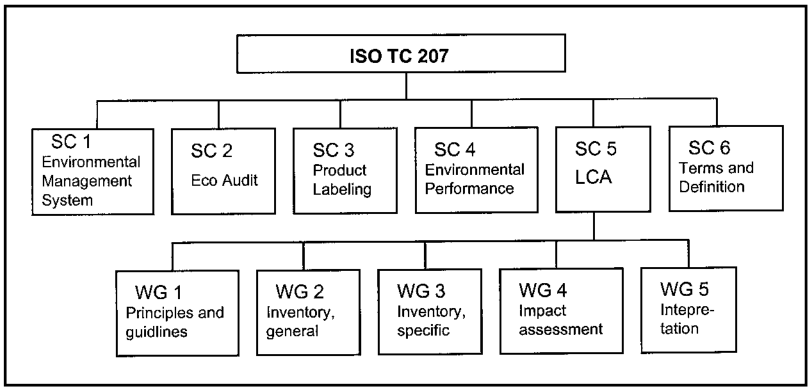


Figure 6.3. Structure of ISO TC 207 (Marsmann et al., 1997).

Environmental performance evaluation (ISO 14 031), when it begins to take effect, will provide guidelines for continuously measuring, analysing and assessing a company's environmental performance relative to established objectives and targets. It will also include procedures for communicating performance results internally to help companies track performance over time.

Life-cycle assessment (ISO 14 040) will assess the environmental attributes and effects of products, processes and services throughout their lifetime and examine all relevant inputs and outputs from raw material acquisition to final disposal.

ENVIRONMENTAL IMPACT

Influence of population, per capita consumption and technology

Environmental impact (I) may be described by the formula (Commoner, 1994):

$$I = P \cdot A \cdot T$$

in which
P = population
A = per capita consumption
T = a measure of the environmental damage done by technology employed in supplying each unit of consumption

The formula shows that for a constant environmental impact a lower per capita consumption or a more efficient technology to supply each unit of consumption must follow an increase in population. Applied to water supply, population growth must be met by a more efficient use of water (water savings, reuse etc.) and/or a more efficient technology to supply water (water distribution, water treatment etc.).

Environmental impact (Commoner, 1994)

The history of life cycle assessments (LCA)

A life-cycle assessment (LCA) assesses environmental impact caused by a product or a process through its lifetime, i.e. "from cradle to grave" (Sundqvist et al., 1994). In guidelines for life-cycle assessment by the Society of Environmental Toxicology and Chemistry (SETAC), LCA is described as:

"The Life-Cycle Assessment is an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and material uses and releases to the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extraction and processing raw materials; manufacturing, transportation and distribution; reuse, maintenance, recycling and final disposal.

The Life-Cycle Assessment addresses only environmental impacts and not other consequences of human activities such as economic and social effects."

The idea to begin assessing a comprehensive environmental life cycle took shape in the late 1960s and early 1970s (Hunt & Franklin, 1996). However, there was little written about LCA before 1990. The formal analytical scheme that was to become LCA was first conceived in the USA in a study made by the Coca-Cola Company in 1969. The study tried to quantify the energy, material and environmental consequences of the entire life cycle of a package from the extraction of raw material to disposal. One of the innovative ideas of the LCA was the inclusion of energy in the natu-

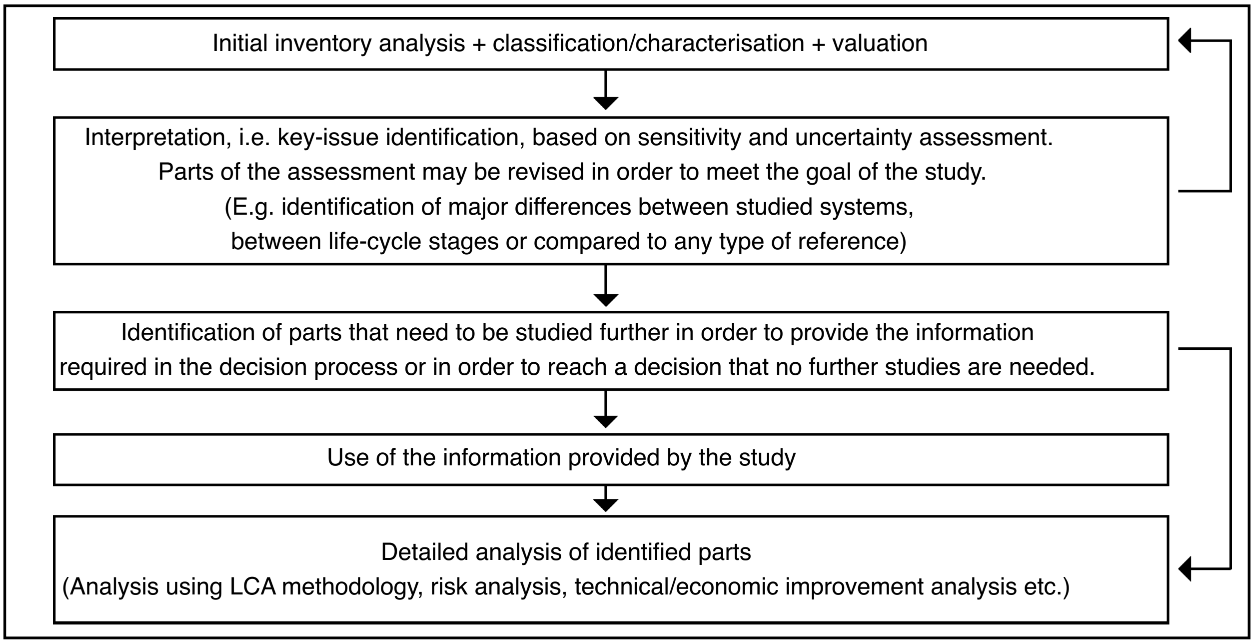


Figure 6.4. An LCA procedure (Finnveden & Lindfors, 1996).

ral resources category. The study was never published but was used by the company in the early 1970s in business and packaging decisions.

The concept of LCA was later developed through a series of studies made for different companies. The historical term for these studies was Resource and Environmental Profile Analysis (REPA). The studies made for private companies were used for business decisions and therefore not published. The U. S. Environmental Protection Agency (EPA) made some early studies, which were published. However in 1975 the EPA decided that using LCA as a regulatory tool was impractical, since LCA had to be done on thousands of products and involve extensive micro managing of private companies. If for instance it was important to reduce solid waste and conserve energy, then a comprehensive energy conservation and solid waste reduction goal should be set, rather than regulating thousands of specific products. However, in 1991 the EPA initiated activities in LCA for development of guidelines and databases for use by interested public and private parties.

In Scandinavia, the Nordic Councils of Ministers 1991 initiated a project to develop a code of practise for LCA built on Nordic consensus, to provide industries and other practitioners with a set of guidelines for LCA (Finnveden & Lindfors, 1996).

One LCA procedure is illustrated in Figure 6.4. A "key issue" identification is represented in the first two boxes. The interpretation of the results may lead to a revised assessment in which, for instance, the goal of the study might be changed. After the first two steps, the study might be followed up by a more detailed study of the identified "key-issues" using LCA methodology.

- *Initial inventory analysis + classification/ characterisation + valuation.*
- *Interpretation*, i.e. key-issue identification, based on sensitivity and uncertainty assessment. Parts of the assessment may be revised in order to meet the goal of the study (e.g. identification of major differences between studied systems, between life-cycle stages, or compared to any type of reference.)
- *Identification* of parts that need to be studied further in order to provide the information required in the decision process or a decision that no further studies are needed.
- *Detailed analysis of identified parts* (analysis using LCA methodology, risk analysis, technical/economic improvement analysis etc.) Use of the information provided by the study.

LCA Objectives

Two fundamental aims of LCA can be identified which give different specifications of the results (Grahl & Schmincke, 1996). The aims of LCA are to provide information, to assist in decision-making processes and to evaluate the impact of environmental influences.

Traditionally LCA has been used for comparing environmental impact of different alternatives (Brandel, 1995). LCA does not distinguish whether an alternative is good or bad for the environment, only the environmental advantages and disadvantages of the different alternatives. However there is another reason to make an analysis that elucidates the consequences of one product or process in relation to different environmental targets. This is called an environmental threat analysis.

Impact categories according to Nordic guidelines

1. Resources — Energy and materials[a]
2. Resources — Water
3. Resources — Land (including wetlands)
4. Human health — Toxicological impacts (excluding work environment)[b]
5. Human health — Non-toxicological impacts (excluding work environment)[b]
6. Human health impacts in work environment[b]
7. Global warming
8. Depletion of stratospheric ozone
9. Acidification
10. Eutrophication
11. Photo-oxidant formation
12. Ecotoxicological impacts
13. Habitat alterations and impacts on biological diversity[c]
14. Inflows that are not traced back to the system boundary between the technical system and nature[d]
15. Outflows that are not followed to the system boundary between the technical system and natured

[a] This impact category can be divided into several subcategories, e.g. a division can be made between energy and materials, and/or between renewable and non-renewable resources. These choices can be made in relation to the choice of characterisation methods.

[b] Work environment is one among other exposure situations for humans. The suggestion to treat this exposure situation separately is partly due to available characterisation methods.

[c] This impact category is related to activities and emissions which can have a direct impact. Several of the impact categories can, as a second order effect, cause this impact.

[d] Non-impact categories that should be included nevertheless.

A standard list of impact categories according to Nordic guidelines (Finnveden & Lindfors, 1996)

Procedures

The main LCA components or phases are:

Goal definition and scope. The purpose and scope of the study have to be defined. This includes a definition of system boundaries, data requirements, assumptions and limitations. The system boundaries in an LCA made for comparing alternatives is defined as the smallest system within which the conditions are altered between the different alternatives.

Inventory analysis. The product or service system needs to be defined and the inputs and outputs of the system are analysed. The system is usually a product and its lifetime, encompassing raw materials acquisition, production, use and waste management. Inputs could be, for example, energy and raw materials and the outputs could be emissions. The inventory analysis is presented in tables of inputs and outputs of the system under study. In some cases, when the system has several different functions that are difficult to separate, special functional units may be used. The system boundaries then have to be defined. Cut-off criteria for excluding processes as non-significant need to be discussed.

Impact assessment. This is a process of characterising and assessing the impacts of the inputs and outputs identified in the inventory analysis. Resource depletion, impact on human health and ecological impacts are three major categories that should thereby be considered. These major categories are further divided into several impact categories.

The impact assessment is divided into three steps:

- Classification
- Characterisation
- Valuation

In classification, the different inputs and outputs are assigned to different impact categories. A standard list of impact categories is shown in Box above, which can be used as a checklist. In characterisation, an analysis/quantification and, if possible, aggregation of the impacts within the given impact categories is carried out. Then, in valuation, the data of the different impact categories are weighed against each other so that they can be compared.

Improvement assessment. In this phase the options for reduction of the environmental impacts or burden of the studied system are identified and evaluated. In the Nordic guideline on LCA, the improvement assessment is not regarded as a part of LCA methodology but rather as an application of LCA.

LCA of wastewater treatment

Wastewater treatment processes

An example of an LCA related to water management is the evaluation of cost efficiency and sustainability of different wastewater treatment processes done by Ødegaard (1995). In this study treatment processes were evaluated with respect to both cost efficiency (cost in relation to improvement in receiving water) and sustainability (consumption of raw materials and energy). The different treatment processes are described in table 6.3.

The benefits of the treatment processes were expressed in terms of the reduction in oxygen consumption potential through reduction in nutrient discharge, that is as achieved by different treatment alternatives. However, the fraction of nutrient that will lead to algal growth depends on the depth of the discharge, and therefore two situations, with 50 % and 100 % of the nutrient leading to algal growth, were studied. The impact with respect to algal growth is also different in freshwater and saltwater. In freshwater only phosphorus is considered to be a limiting factor while in saltwater (the outer fjord or sea), phosphorus limits algal growth 20 % of the time and nitrogen limits it 80 % of t he time. In this way the treatment alternatives were studied in relation to four types of receiving waters.

An LCA analysis was also made of the treatment processes using the LCA software tool SimaPro. In SimaPro both raw materials and emissions that are airborne, waterborne and solid are included. A weighing factor is defined for each kind of impact so that all the varying impacts can be aggregated to produce a single indicator value. Table 6.3 shows the indicator values for the different treatment alternatives, divided into construction, chemicals and energy for aeration.

The environmental impact proved to be mainly an effect of the consumed and produced energy. Energy consumption consisted of energy in chemicals used, either for aeration of the biological basins or for transport, and energy produced as gas from digestion of the sludge. The largest energy consumption was for aeration, which, in the cases that included nitrogen reduction, consumed more energy than was produced. When energy production was much greater than consumption, the indicator value showed a reduced environmental impact, due to the fact that the produced energy reduced the environmental impact of energy that otherwise would have to be produced in other ways.

Small-scale sewage-treatment processes

Emmerson et al. (1995) made an LCA of small-scale sewage-treatment processes. In this study the lifecycle of a sewage-treatment plant was described in three phases of construction, operation and demolition. Figure 6.5 and Table 6.4 show input and output during the three phases. The analysis was simplified by considering only primary inputs of energy and materials, since

Table 6.3. LCA analysis of wastewater treatment processes (Ødegaard, 1995)

	Indicator value (• 10^{-3}) **Treatment process**	**Construction**	**Chemicals**	**Energy (air)**	**Biogas**	**Total**
1	Primary, mechanical	7	0	0	-450	-443
2a	Secondary, biological high load	26	0	840	-900	-34
2b	Secondary, chemical (primary precipitation)	13	120	0	-900	-767
2c	Advanced secondary, mechanical/ biological (incl. nitrification)	51	0	1 200	-560	691
2d	Advanced secondary, chemical/ biological (incl.nitrification)	41	120	780	-930	11
3a	Tertiary, mechanical/biological/ chemical (simultaneous precipitation)	42	83	580	-900	-195
3b	Tertiary, chemical/biological (pre-precipitation)	34	120	210	-1 100	-736
3c	Advanced tertiary, mechanical/ biological/chemical (pre-denitrification and simultaneous precipitation)	68	83	120	-640	711
3d	Advanced tertiary, chemical/ biological (post-denitrification and pre-precipitation)	44	230	800	-850	224
3e	Advanced tertiary, mechanical/ biological (biological P-removal and pre-denitrification)	75	31	1 100	-560	646

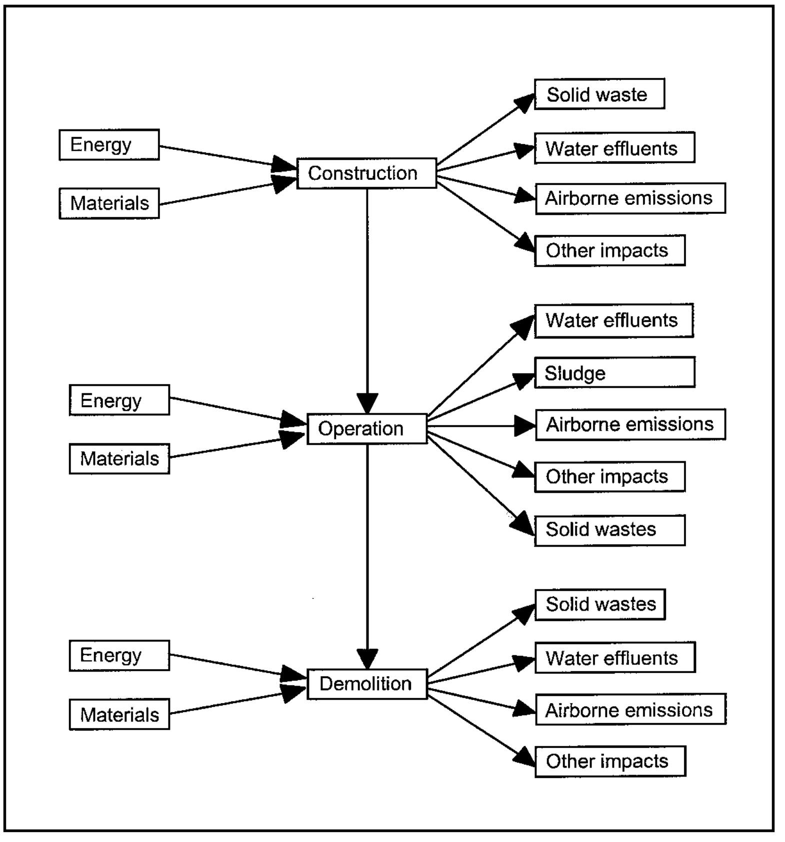


Figure 6.5. Flow chart representation of environmental inputs and outputs from a sewage-treatment works (Emmerson et al., 1995).

previous studies have shown that other effects account for less than 5 % of the total impact.

Three sewage treatment plants were studied with different processes:

An activated sludge plant with two steel aeration tanks and two steel secondary-settlement tanks.

A biological filter plant consisting of one primary radial-flow sedimentation tank, two circular biological filters with slag media and a secondary radial-flow settlement tank.

A biological filter plant like the above, but with vertical-flow instead of radial-flow.

The life cycle energy consumption profile (Figure 6.6) shows that, in the case of activated sludge plants, 95 % of the energy consumption occurs during the operational phase. For the biological-filter plants, energy use during operation is smaller than for the activated-sludge plant, and of the same magnitude as in the construction phase, where the energy use is larger. The study showed that during a lifetime of 15 years, the filter plants used 56 % less energy and caused 35 % less airborne emissions than the activated sludge plant.

Ethanol production from sorted waste with acid hydrolysis

Another example of an LCA is the one done by Finnveden et al. (1994) on ethanol production from sorted household waste with acid hydrolysis. The study was made to assist the decision-making process of building a plant for the production of ethanol from household waste. The produced ethanol was to be used as a fuel for busses. The alternative was incineration of the waste for district heating.

The system boundaries, as stated above, were defined as the smallest system within which the conditions can be altered between the different alternatives. Therefore fuel for the busses was included in the incineration example, while fuel for heating (industrial waste) was included in the case of ethanol production. Comparisons of the two alternatives were based on four similar functions:

- The same amount of transport work on the part of the busses
- Processing similar amounts of household waste
- Processing similar amounts of industrial waste
- Producing the same amount of energy for heating and electricity

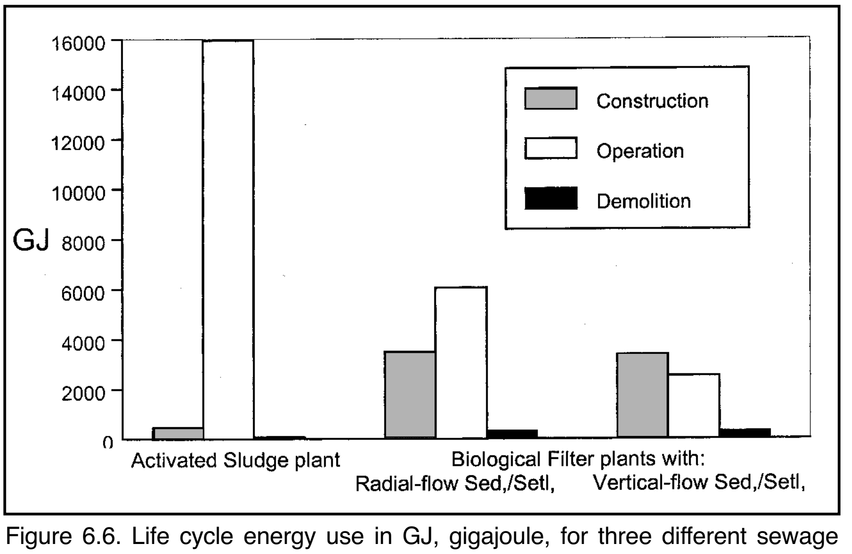


Figure 6.6. Life cycle energy use in GJ, gigajoule, for three different sewage treatment plants during construction, operation and demolition (Emmerson et al.,

Table 6.4. Overview of potential impacts on the life cycle of a sewage-treatment plant (Emmerson et al., 1995)

Construction	Operation	Demolition
Material Consumption		
Steel, iron, cement, water, aggregate, PVC, slag, copper, clay, pitch, epoxy, plywood	Negligible	Topsoil, bulkfill
Energy Consumption		
Air emissions		
CO_2, SO_2, NO_x, CO, hydrocarbons, particulates, organochlorines	CO_2, SO_2, NO_x, CO, particulates, ash, odourants	CO_2, SO_2, NO_x, CO, particulates, ash, odourants
Water emissions		
Mine waste, slag, dust, unspecified hydrocarbons, excavation wastes, wood	Sludge solids, sludge metal contents, contents, screenings, energy wastes	Steel, concrete, slag, copper, PVC
Other impacts		
Noise, vibration, traffic movements, visual impact, nuisance to wildlife	Noise, smell, visual impact, attraction of vermin, fly problems, traffic movements	Noise, vibration, disruption to wildlife, nuisance, traffic movements

The analysis showed that the ethanol alternative created a greater environmental impact and consumed much more energy than incineration. 80 % of the energy in the ethanol process was used for recovery of hydrochloric acid used for the hydratisation.

Developments in LCA

It has been claimed that LCA should be restricted to environmental matters and not consider socio-economic or political factors. However, it has been recognised that these factors are important in the interpretation of LCA results. An example of an LCA framework is given in Figure 6.7, in which the evaluation includes socio-economic, institutional, environmental, safety and health impacts as well as direct costs and benefits.

Due to the fact that environmental protection measures are often weighed against ecological, economical and technical considerations, different forms of evaluation may be used to supplement a life-cycle analysis. Two key components of quantitative information from a life-cycle inventory are energy consumption and waste generation. Energy cannot be consumed, only transformed into other forms. This quality of energy – called exergy – can be defined as the useful part of energy, i.e. that part of energy that is convertible into all forms of energy. Exergy analysis may be used to evaluate sustainability of different process systems (Hellström & Kärrman, 1997).

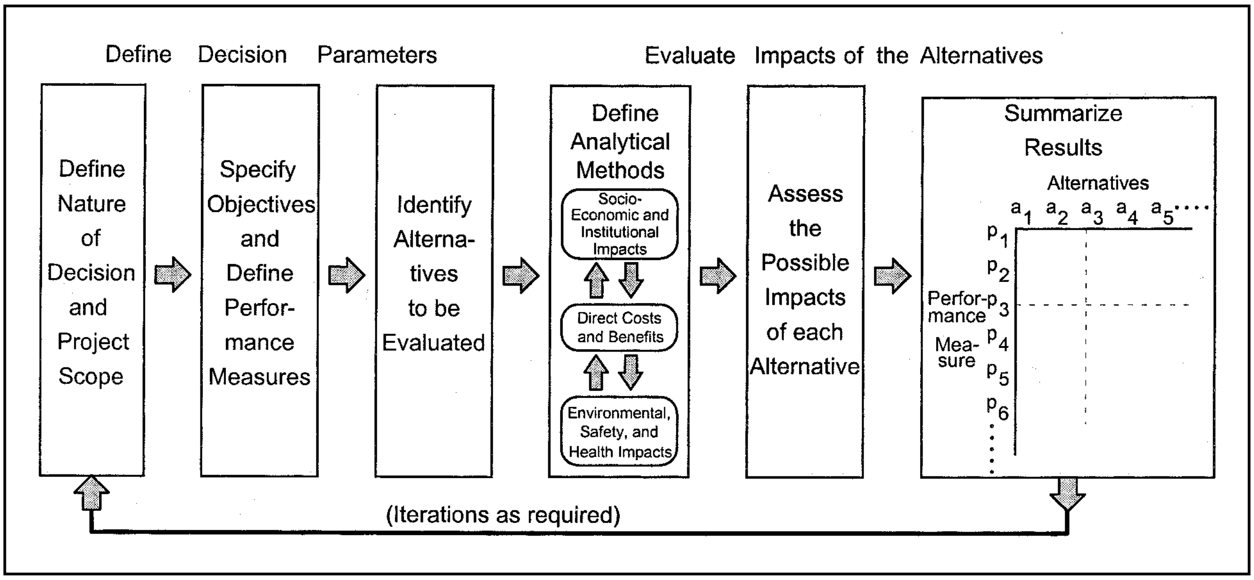


Figure 6.7. LCA framework (Yuracko et al., 1997).

Life-cycle costing (LCC) analysis aims to optimise the total cost of ownership over the life span of an asset. A USA survey indicated that 40 % of American municipalities use LCC analysis, for instance in water resources and transportation projects (Arditi & Messiha, 1996). For a wastewater treatment plant, costs should be considered for all three phases of planning, design and operation (Vanrolleghem et al., 1996).

As an aid in performing the different stages of an LCA, many software packages are available. Rice et al. (1997) have made a critical comparison of the packages based on several criteria. The key to choosing an appropriate software tool is knowing the application. Originally, LCA software was designed to be used by the packaging industry and some were later adapted for more general use.

Part II

Agricultural Water Use and Management

Use of water in food production

When addressing water use in agriculture it is important to take a wide view and consider land use and land management as well, since the choice of crop influences how much area is needed for crop production, the amounts of water needed and tillage and fertilisation practises. Another issue to keep in mind is the combination of agricultural land, forests, lakes and wetlands that constitutes many farms in the Baltic region. Converting forests into fields, a common practise in the 19th century, or vice versa, which is a common practise today in many regions, not only has a tremendous effect on the water management situation for the individual farm but also for the whole region. Clear-cutting of forests also affects groundwater formation and the downstream agricultural fields in the drainage basin. Drainage, or reclamation, of lakes and wetlands has a considerable impact on the hydrological cycle and thus the water management situation. In the Baltic region, erosion is a limited problem, mainly related to loss of phosphorus to surface waters, but in more arid regions the connection between land use and erosion is a very important issue.

Water use in agriculture can be divided into process and consumption water use on the one hand and soil water use on the other. Process water is needed to maintain the farm and to clean machinery and the like, similar to a common household or small industry, whereas consumption water is needed for the cattle, poultry etc. The magnitude of consumption water use is in the order of 10 m^3 per head of cattle for its lifetime. This water is normally extracted from a local well or nearby river. The soil water is provided primarily by precipitation or, if amounts are not sufficient, by irrigation. Oftentimes the problem is not a shortage of water, but that water is not available at the time needed. In the Baltic region, water stress is normal in early summer, the time when the crop is developing and has its highest demand for water. This means that although the climate is quite humid, irrigation may still be needed for sensitive crops.

In order to produce feed for cattle approximately 675 m^3 water per head, or 3 m^3/kg meat, is needed over an animal's lifetime. If a considerable amount of this water has to be supplied through irrigation, available water resources may be constrained. In order to produce 1 kg of crop, the needed amount of water is much less, e.g. one kilogram of maize requires only 0.5 m^3 of water. These amounts of water do not include process water needed to refine the raw products into food products. For pre-cooked deep frozen fast-food, naturally, this amount is considerable.

The main water management issue is thus to provide an optimal amount of water in relation to the crop, be it feed for cattle or grain for flour production. Some crops are very sensitive to water stress and need a reliable source of water for irrigation. The required amount of water differs from crop to crop. The soil type of the agricultural field is also important; clay soils are much less prone to dry out than sandy soils, which thus need more attention.

Another important issue is to supply the crop with sufficient amounts of nutrients. Here, too, different crops have varying sensitivity to nutrient shortage and thus, in addition to soil type and texture, organic and nutrient content is important.

Success in supplying the crop with water and nutrients is a way of minimising the use of pesticides. Avoiding water stress and nutrient shortage makes the crop less susceptible to attacks from pests and insects.

In sum a number of considerations have to be made in order to attain sustainable management of water in agriculture, producing a high-quality, healthy crop without endangering water quality for downstream users.

Lars-Christer Lundin

7.

Soil water management in agriculture

Harry Linnér

Land drainage

Seen on a yearly basis humid temperate regions are usually characterised by surplus water. In such regions, settlement and agriculture were first begun in the higher regions, with natural drainage in the form of rivers and brooks. With the increase in population more land was needed for food production, and people found that the best soils for agriculture were often those situated in river valleys and coastal plains, provided that they were protected from flooding.

Over the centuries, vast areas of wetland have been transformed into land for agriculture by means of river regulation, dike building and the digging of canals and ditches for the removal of excess water. These main drainage systems were often not enough for attaining good drainage conditions in the fields and thus additional field drainage with open ditches had to be applied.

In the middle of the 19th century subsurface drainage via wooden pipes, tile pipes and other materials was introduced. During the first decades of the 20th century drainage conditions were improved in many countries by enlarging the capacity of main drainage systems and by pumping out water from low areas. During this period many lakes and wetlands were also drained.

When the demand for food increased further and when an increased mechanisation of agriculture took place about 50 years ago, good drainage conditions became all the more important. Manual labour used in digging ditches was replaced with drainage machines. New pipe materials to replace clay and concrete were developed. The main material used today is corrugated plastic pipes for subsurface drainage.

To date, large areas of agricultural land have been provided with subsurface drainage systems (Table 7.1). This in combination with plant breeding, improved fertilisation and plant protection and better tillage methods has increased agricultural production considerably. Today, when many countries have a surplus in agricultural production and there is a heightened environmental concern, few new drainage systems are being built. Maintenance and improvement of existing systems however is still important. The present drainage sta-

Land drainage refers to the removal of excess surface and subsurface water from the land to enhance crop growth. Land drainage - or, in the case of dry areas, the combination of irrigation and land drainage - is one of the most important measures for maintaining or improving farm yields. Globally about 170 million hectares of agricultural land are served by drainage or flood control systems.

Drainage of excess water is the primary water management measure in northern European agriculture. In most areas the annual surplus of water is 100-500 mm which means that 1 000-5 000 cubic metres per hectare of excess water have to be removed from agricultural fields by natural or artificial drainage.

During the growing period the potential evapotranspiration often exceeds the amount of rainfall. On soils with low water-holding capacity supplementary irrigation may therefore be profitable, especially for high value cash crops. The need for irrigation during the growing season in northern Europe normally varies between 0-300 mm.

Table 7.1. Subsurface drainage of arable land in selected countries (data from different sources and different years, with uncertain figures for some countries)

Country	Drained area (10^6 ha)	Total area of arable land (10^6 ha)
Denmark	1.4	2.4
Estonia	0.7	1.1
Finland	1.0	2.6
Latvia	1.5	1.7
Lithuania	2.6	3.0
Poland	4.4	14.6
Sweden	1.2	2.8

Draining farmland as part of Swedish history

Several hundred years ago water was much more present in the Baltic region than today. Lakes, meandering rivers, marshes, mires, peat lands and coastal areas occupied about twice the area they do today. The waterscape experienced dramatic changes over the year, with seasonal flooding generally hitting low-lying land during rainy years. This was often beautiful and functional as well. Wetlands were (and are) productive biotopes. Fishing was important to the household. The annually flooded meadows provided a sustainable source of grass for animals and the water brought with it the nutrients needed to make annual harvests possible. In turn the animal's manure fertilised the then quite small fields where crops were grown, which were cleared on only the best and naturally drained lands.

This production system was of a low capacity. In the 18th century, the population increased and larger fields were needed to grow potatoes, turnips and rye. Several years of famine in the early 19th century made it painfully clear that those who had not emigrated to North America had to grow more food to survive. New forest areas were turned into farmland but more importantly; large wetland areas were turned into fields.

Drainage was always important to the farmer

Even as far back as the first legal texts from medieval times, drainage was encouraged and protected. The first simple drainage system was ditches – 0.6 m deep and 1.2 m wide as stipulated by law – where surface water could accumulate. They did not always empty into a watercourse but were kept as storage water for the drier period.

In the 18th and 19th centuries when drainage was undertaken on a larger scale the first measure was to channel the surface water. Cleaning and deepening the watercourse that drained the channels into nearby lakes dramatically diminished not only meadows but also several large lakes in Sweden. Thus Lake Hjälmaren, the fifth largest lake in Sweden, was lowered during the period from 1878-88, and considerable agricultural areas were recovered. In a total of 17 000 individual projects, almost 2 500 lakes were lowered, some of them several metres, during the period up to 1930. Often several consecutive drainage operations were needed. The land surface shrunk when it was drained, and thus the groundwater table again became too high for agriculture. Many of the lakes simply disappeared after several operations.

It was considered more important to keep the fields already in use in good shape. These were kept drained mostly through open ditches dug by hand, and close enough to divide the fields into strips, the traditional form of the village system. This was acceptable until larger connected properties began to be created in the early 1800s, when some ditches needed to be covered. This was possible, since they were filled with stones or wood constructions that allowed the water to percolate even when covered.

Mires and clay soils

After a while, mires were appointed as the next great, unexploited agricultural resource of the country. Over a one hundred year period, from the early 19th century, a number of large drainage operations were carried out in mires. The work required was extensive and the area was not always recovered in the best way. Of the estimated 600 000 ha recovered for agriculture only about half is still in use today.

The large plains of clay soil, which are sea bottoms from the Ice Age, constituted a different problem. They were subject to severe flooding during rainy summers and an extensive drainage system would be required to prevent that. Massive state-organised projects were launched to dig hundreds of kilometres of so-called central ditches over the plains. Later the smaller ditches for each field could be added. Gradually the ditches were covered. Ceramic tubes of burnt clay for subsoil drainage were introduced in the 19th century, but did not become important until domestic production was started in 1852. It took a hundred years to cover all the ditches, up until the 1960s. Covered ditches were decisive

Photo, Lars Rydén.

in creating the large continuous fields needed for the rational and machine-based agriculture we see today. They also gave us a very different landscape.

Drainage removed about 50 % of the wetlands in the southern part of the country. Today many regret that things went that far. Not one of the great mires in southern Sweden was left untouched. Several of the then well-known bird lakes have consequently turned into reed beds. In the 1990s several large projects, again with state money, were initiated to restore some of the lakes on the large plains to create bird sanctuaries and support biodiversity. In some of the rivers that had become too channel-like the old meanders are being restored again for large sums of money.

Drainage was one component in increasing Swedish agricultural production several-fold for more than 100 years. Other factors include better genetic varieties of crops, better tillage, artificial fertilisers and biocides. However, experts claim that the importance of technical and chemical measures is often exaggerated. What is more decisive is the professional skills of farmers, so called Good Agricultural Practice (GAP), of which water management is an essential part.

Lars Rydén & Hannes Palang (based on August Håkansson in ”Lärobok i agrarhistoria,” eds. B. M. P. Larsson, M. Morell & J. Myrdal. Swedish University of Agricultural Sciences, 1995) tus of many agricultural soils is not adequate, resulting in losses of yields and profits in wet years.

Why agricultural land drainage?

The main objective of agricultural land drainage is to remove excess water in order to improve the profitability of farming. Excess water has adverse effects on farming in several ways. Crops absorb oxygen in the root zone and release carbon dioxide. In waterlogged soils the air content is low, since most pores are filled with water. As a consequence respiration and growth are restricted by oxygen deficiency and sometimes carbon dioxide accumulates to toxic levels. Anaerobic conditions in the soil may also result in toxic concentrations of reduced iron and manganese compounds, sulphides and organic gases. Root-zone aeration generally becomes inadequate when the air-filled pore volume in the root-zone falls below 5-10 %.

Water logging also indirectly affects plant growth by its adverse effects on soil biological life and on the structure of the soil. Thus water logging during the winter in northern Europe impairs mineralisation and nitrification by microbes. It may also cause the soil structure to disintegrate or prevent it from being restored by the action of frost. Drainage is in fact largely done to overcome these adverse indirect effects.

Excess water on or in the soil adversely affects the soil workability. Farm operations like seedbed preparation, planting, weeding, spraying and harvesting may be delayed. If the operations are done under wet conditions compaction of the soil will occur, soil structure will deteriorate and infiltration capacity will be reduced.

Design of a land drainage system

Before a land drainage system is installed a number of surveys must be undertaken. The drainage engineer needs hydrogeological, hydropedological and topographical maps, precipitation and evapotranspiration data and data on hydraulic properties of the soils. Based on this information a water balance of the area and calculations of the volume of water to be drained can be made.

Usually the drainage facilities of an area consist of (Figure 7.1):

- A drainage outlet where the water discharges (sometimes by pumping) into a river, lake or sea.
- A main drainage canal that is often a canalised stream running through the lowest part of the area.
- Collector drains (open drains or pipe drains) for transport of water from the field
- Field drains at about 1 metre depth and 10-30 metres spacing for control of the depth of water table

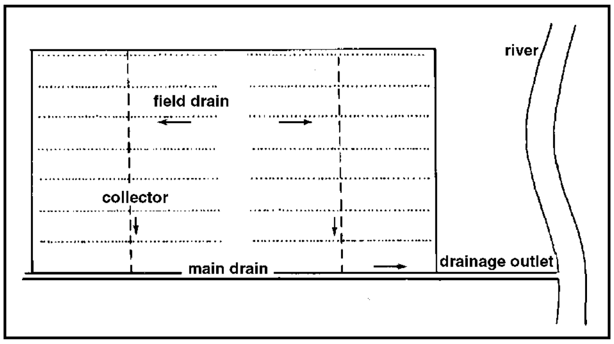


Figure 7.1. Schematic drainage system.

Different layouts of pipe drainage systems are illustrated in Figure 7.2. If the drainage problem is mainly confined to a number of depressions an adapted, irregular drainage system is sometimes sufficient (Figure 7.2. A). If the whole area needs drainage a regular drainage network must uniformly cover the area. This network can either be a parallel grid system (Figure 7.2 B) or a "herringbone" system (Figure 7.2 C).

Corrugated perforated plastic pipes of various types are used as field drains (Figure 7.3). The diameter of field drains is normally 0.05-0.10 metres. Water enters into the pipes through perforations distributed along the pipe circumference. A particular material (called envelope, filter or cover material or permeable fill) that prevents soil particles from entering the pipe and causing clogging in most cases surrounds the field drains. This material should have high permeability, which reduces entrance resistance and also protects the pipe from damage due to the soil load. A wide variety of materials such as gravel, coco-

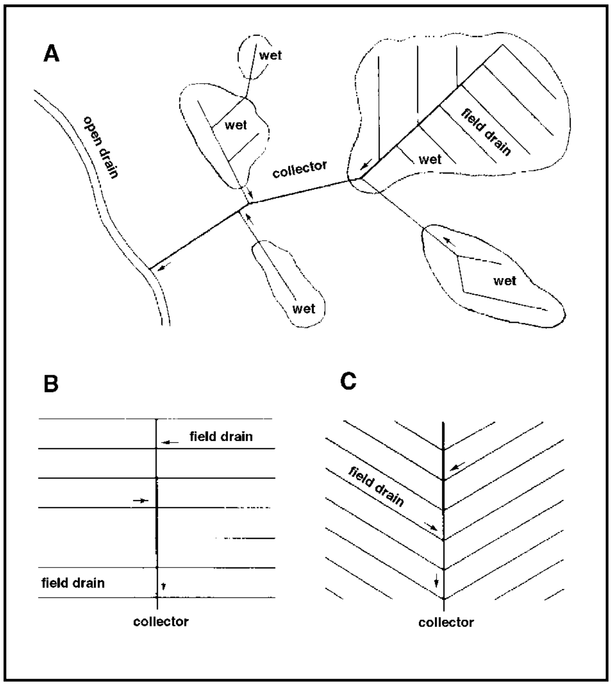


Figure 7.2. Different layouts for pipe drainage systems. A: Irregular system. B: Parallel grid system. C: Herringbone system (From Ritzema, 1994).

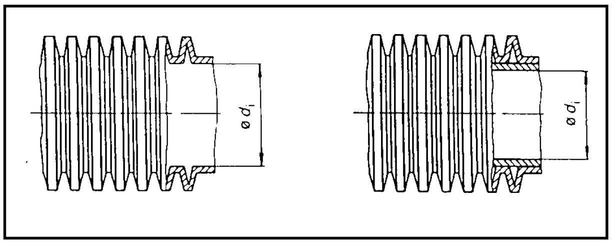


Figure 7.3. Corrugated and perforated plastic pipes used as field drains or collector drains. The pipe to the right is double-walled with a smooth inside wall.

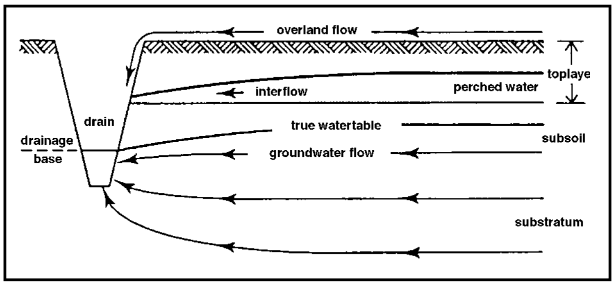


Figure 7.4. Types of drainage flow to an open ditch. The flow pattern is similar to subsurface drains (From Smedema, 1987).

nut fibre, peat fibre, straw, sawdust or various synthetic materials are used as envelopes for drain pipes.

Ditches

Open ditches form at least a part of most land drainage systems. A ditch is a man-made drainage channel that is open to the surface and is used to collect and carry water drained from the land. Larger channels constructed mainly for transport of water are called canals.

The advantages of ditches are that they allow easy entry of surface water (Figure 7.4) and that they have an overload capacity that allows them to cope with storm conditions. Open channels also allow easy access to associated pipe drainage systems. The disadvantages are that ditches occupy land, restrict field traffic and need regular maintenance to remain effective. Drainpipes or culverts have therefore replaced many ditches.

Most ditches of today are excavated with special digging buckets that have a suitable shape for forming ditch cross-sections with adequate bank gradients.

Subsurface drainage

Subsurface drainage is a system of covered piped channels often described as field drains or underdrainage. Under-drainage removes excess soil water without reducing the area of cropping land and without disturbing field operations. Because of the protective soil cover the drains can remain effective for many years with little need of maintenance. The difficulties associated with under-drainage are the need for channel gradients to be greater than the minimum gradient acceptable for ditches and the absence of overload capacity for flood conditions. Another common problem is that in poorly permeable soils excess soil water may not always flow fast enough towards pipe drains.

Under-drainage systems need to have the capacity to remove excess water from the soil profile in a reasonable amount of time. The main source of profile recharge is direct rainfall but there may be additional supplies from overland surface flow or groundwater flow. This must be taken into consideration in designing pipe sizes and distances between drains. The drain-flow capacity of an under-drainage system is based on the design drainage rate expressed in mm/day. The designed drainage-rate is based on rainfall conditions for the area and adjusted to site characteristics such as topography, soil type and patterns of surface and groundwater flow.

An example of a detailed drainage plan on a topographic map is shown in Figure 7.5. The map shows

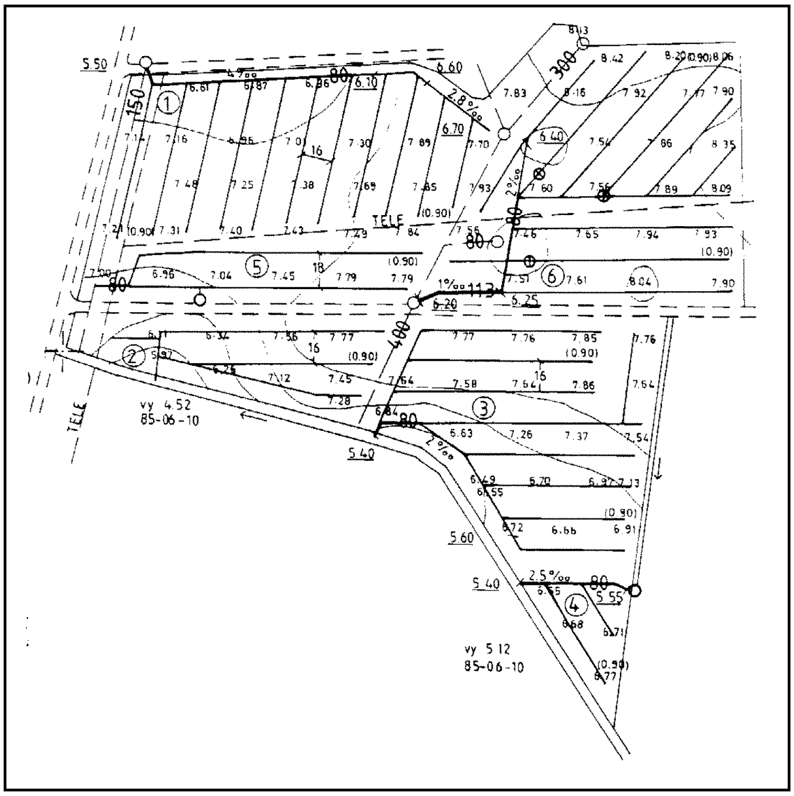


Figure 7.5. Detailed plan of drainage layout.

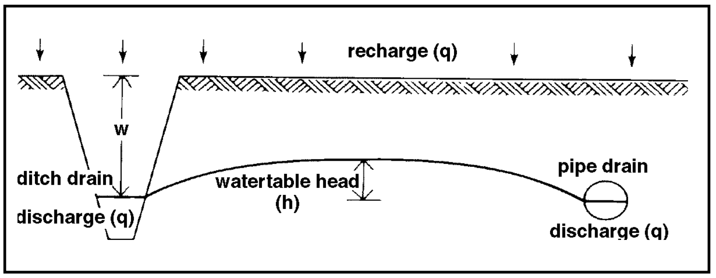


Figure 7.6. The main variables in groundwater drainage design (From Smedema & Rycroft, 1983).

the drainage contractor information regarding depth and spacing of drains, pipe diameters, gradient etc.

The basic design criterion for a pipe system for groundwater control specifies the recharge that the system should be able to cope with while maintaining a desired water-table depth. Required drain spacing may be calculated for different drain depths using one of the many steady-state or non-steady- state drain-spacing formulas available. The main variables in groundwater drainage design are illustrated in Figure 7.6.

Traditionally trenches and drains were dug by hand. High labour costs rule out this method of drain design in most countries and a wide range of draining machines has been developed instead. These machines can be grouped into three categories: excavator diggers, continuous trenchers and trenchless drainplows. Each kind of machine has its merits and limitations but all can do useful work if used correctly. In Figure 7.7 one kind of continuous trencher with a cutter chain and one kind of drainplow are illustrated.

It is essential that drains be laid with an even gradient to maintain a steady or increasing flow velocity towards the outlet. Modern drainage machines use laser-levelling equipment for grade control. A laser transmitter unit forms a plane of light that can be tilted with great accuracy to the required gradient. A receiver unit on the drainage machine senses the laser beam and indicates to the driver whether the digging depth is correct or not. Such equipment also permits automatic depth control by means of signals from the receiver, which directly activate the depth control mechanism of the drainage machine.

Many soil profiles have such low permeability that the downward water flow is too slow to solve the problem of excess soil water. This problem has increased as a result of soil compaction by heavy machinery. When this occurs it is necessary to try to improve subsoil permeability. The options available are various forms of soil cultivation including subsoiling, mole drainage (meaning the formation of unlined underground channels) and the placing of permeable material in the drain trenches.

Pumped drainage

Many sites in coastal lowlands, near inland waterways or in isolated upland hollows do not have an

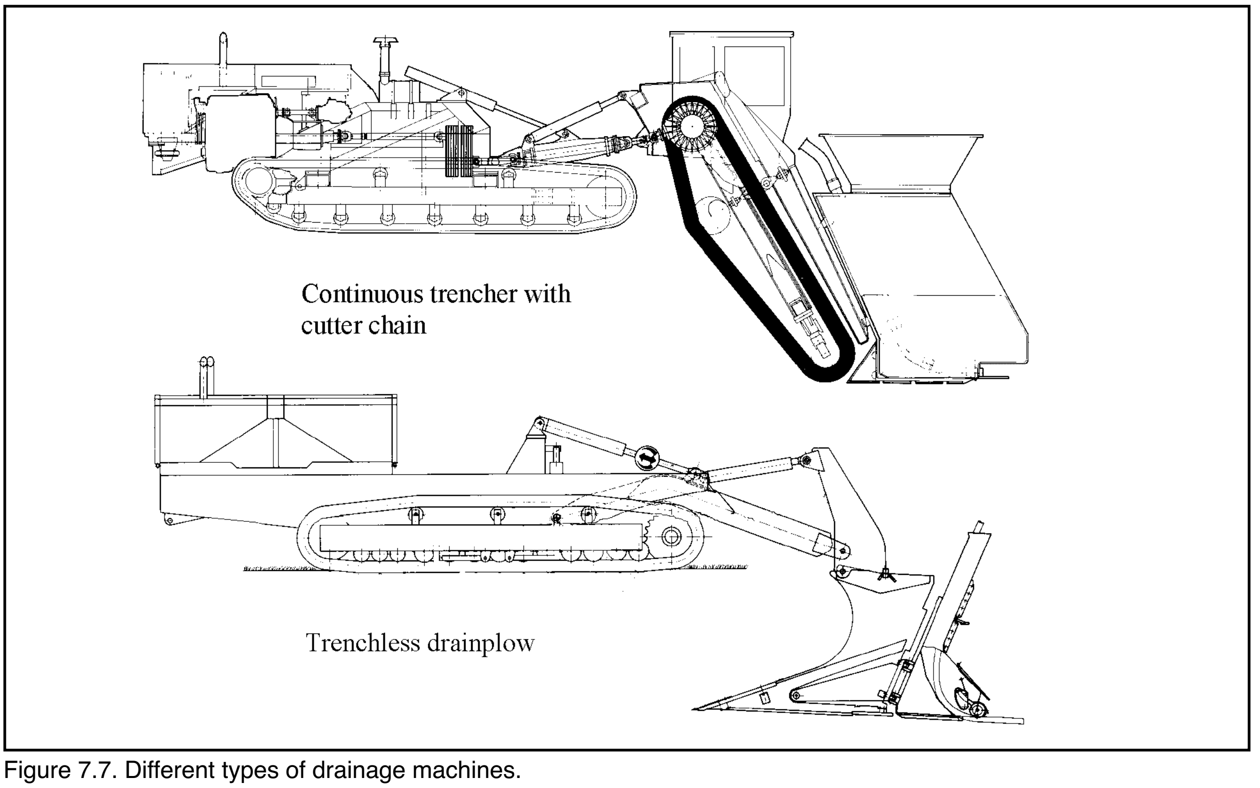


Figure 7.7. Different types of drainage machines.

outlet for drainage by gravity flow. In many of these cases the only method to get rid of excess water is to lift the water through pumping. Generally it is only the best sites with potential for high productivity of valuable cash crops that justify the high costs of pumped drainage. Today some pumped areas have been abandoned and the land has been returned as wetland or extensive pasture.

Drainage for salinity control

In temperate, humid climates there is usually sufficient excess water percolating downwards through the soil to maintain low salt levels in the upper layers. This means that accumulation of salts in the root zone of plants normally does not cause problems in northern Europe.

In arid areas however, where evapotranspiration exceeds precipitation, salts accumulate in the upper part of the soil and often reach levels that are toxic for plants. This salinisation is either natural, i.e. caused by capillary rise from groundwater, or has been caused by incorrect irrigation practices. Since all natural waters contain salts and since salts are left in the soil when water evaporates an accumulation of salts will take place in areas where the leaching is slight.

If soil salinisation is to be avoided, salts have to be leached out of the soil by water percolating to the subsoil. This percolation causes the water table to rise and capillary rise will then return salts to the upper layers. Drainage is therefore a necessary complement to irrigation. Whereas the aim of drainage in humid areas is to improve aeration and workability of the soil the primary aim in irrigated land is to control salinity.

Drainage and environment

Compared to natural conditions, improved drainage and conversion of land for agricultural production have effects on hydrology, sediment loss and water quality. Peak runoff rates increase and so do sediment loss and pollutant load.

However, once land has been converted for agricultural use, improved subsurface drainage is often found to reduce surface runoff, peak outflow rates and sediment loss. Some pollutants increase while others are reduced. In general it has been found that systems with subsurface drainage have lower surface runoff and lower peak outflow rates than systems that depend primarily on surface drainage. Subsurface systems lower water tables, which in turn increases the pore space available for infiltration of rainfall. This reduces the proportion of the total outflow occurring as surface runoff, which is rapid, and increases the proportion that is removed slowly by subsurface drainage over longer periods of time.

In general good subsurface drainage will decrease surface runoff and the loads of sediment, phosphorus, organic nitrogen and other pollutants, such as pesticides, that are attached to the sediment. Mobile constituents like nitrate will often increase since more water passes through the soil profile.

Developments in water management practices aimed at reducing negative impacts on water quality have taken place during the last few decades. One interesting method is controlled drainage with regulation structures in the drainage system, which allows water table management. Raising the water table above the drainage pipes during the winter period and thus creating anaerobic conditions in the soil profile can reduce outflow and losses of pollutants considerably. It has been shown that this change in water management strategy can in many cases reduce nitrogen and phosphorus outflow by 30-50 %.

Buffer zones between agricultural fields and ditches or streams draining the area may be effective in the removal of nitrogen, phosphorus and sediments. Natural or created wetlands can also be used for treatment of agricultural drainage water. Such systems can be effective in the removal of nutrients and sediments before the water reaches sensitive surface-water ecosystems.

It is becoming increasingly clear that drainage and related water management systems must be designed and managed to take into account both agricultural and environmental objectives. Today practically all drainage research is oriented towards determining hydrologic or water quality impacts. The challenge is to develop water management methods that will satisfy agricultural objectives and minimise negative environmental impact. Sometimes an increased subsurface drainage intensity that reduces surface runoff and sediment loss is the best method to control non point-source pollution. In other cases the use of controlled drainage to reduce nitrate outflow and to conserve water would be the best management practice. Although our knowledge of environmental impact and methods for managing water in agriculture has improved there is still much to learn about the complex mechanisms governing losses of pollutants from drained soils.

Irrigation

Irrigation has been practised in northern Europe since at least the 17th century, when for example systems for flooding fields were developed in Norway. It is however during the last 30-40 years that irrigation

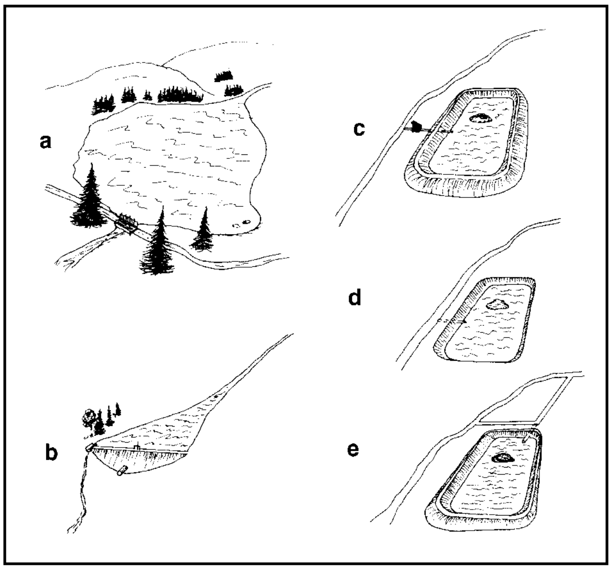


Figure 7.8. Water storage installations: a) lake regulation, b) impounding reservoir, c) off-stream reservoir filled by pumping, d) off-stream reservoir, excavated for gravity feed, e) off-stream reservoir, gravity fed from an inlet upstream (R. Persson, 1984).

has increased rapidly. The development of hose-reel irrigators during the 1970s reduced the high labour requirements for irrigation and many farmers then invested in new equipment. With the advent of increasingly market-focused crop specialisation, high and reliable yields of good quality must be obtained every year and good water supply thus becomes critical.

Many crops grown in northern Europe have their growth restricted by lack of water during most seasons. The extent to which this occurs depends on the rainfall pattern during the growing season and on the available water capacity of the soil. The rainfall pattern is characterised by variability from season to season and geographical variability both within seasons and between seasons. Soils in many areas are very variable in terms of capacity for available water in the root zone.

According to FAO, irrigation is practised in Denmark on 465 000 hectares, in Sweden on 115 000, in Poland on 100 000, in Norway on 97 000 and in Finland on 64 000 hectares. No figures are available for Estonia, Latvia or Lithuania.

Irrigated crops

Generally irrigation is most profitable for high value crops such as vegetables, fruit, berries and potatoes on soils with low available water capacity. Irrigation may also be profitable for sugar beets, grassland and cereals especially on farms already equipped with irrigation facilities for more valuable crops.

The market for vegetables demands reliable delivery and high quality. This applies for the fresh market as well as for processing and industrial customers. Customers often have specific demands on continuous supply and on quality factors like dry matter content and size, which are difficult to meet without irrigation in combination with good nutrient supply, pest control etc. In many countries most of the field vegetables, including lettuce, cucumber, beans, cabbage, carrots and onions, are irrigated. Many of these crops have shallow roots and just a few days of water stress during a critical period can restrict yields and damage quality.

Potatoes are also sensitive to drought stress. In Sweden for example more than 60 % of cultivated potatoes are irrigated. Yields in irrigated potato fields are on average 20-30 % higher than in non-irrigated fields; variation from year to year is thereby reduced and quality is generally improved. Different quality factors can be influenced by the irrigation strategy. The optimal soil moisture regime is therefore different for early potatoes, main-crop potatoes, seed potatoes and potatoes for industrial processing.

Berries like strawberries, raspberries and black currants need a good water supply. Irrigation is essential not only for high yields but also for control of frost damage in some areas. Frost during flowering can damage the crop severely. Continuous irrigation during frost nights can protect the crop from these damages.

Sugar beets grown on sandy soils often need irrigation. Old notions that early drought would promote deeper root development have been proven untrue. Many studies have shown that water is crucial to germination and emergence, for quick leaf expansion and to avoid wilting at later stages. In southern Sweden irrigation has increased sugar yields by on average 20-30 %.

Many diary farmers rely on irrigation to maintain an even supply of pasture during summer. On grassland for haymaking or silage, production can be increased and the variation between seasons is considerably reduced by irrigation.

Water for irrigation

Irrigation is dependent on required quantities of water and on an acceptable quality being available at the right time. Also supplemental irrigation in humid areas requires large quantities of water. Agriculture often has to compete with domestic, industrial, environmental and other interests for irrigation water. The main sources for irrigation water are surface water from lakes and streams, groundwater and domestic or industrial wastewater.

The availability of surface water tends to decrease in areas where the need for irrigation increases. In

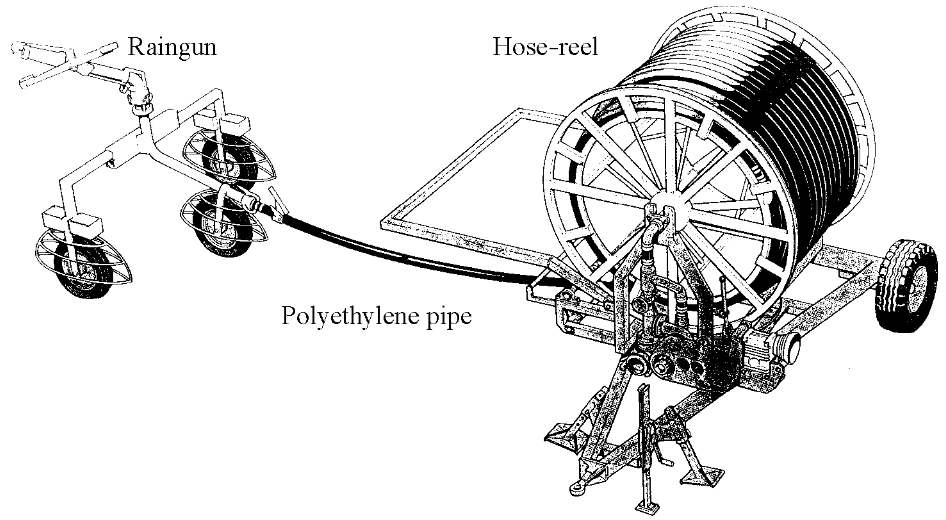


Figure 7.9. Hose-reel irrigation machine.

many areas sources of direct abstraction during summer are insufficient, unreliable or subject to legal restrictions. The solution to this problem in many cases is to build reservoirs so that water can be abstracted and stored when it is available and later used during the irrigation season (Figure 7.8). Many farmers have, individually or co-operatively, solved their water problems by constructing reservoirs for winter runoff. The reservoir can be placed either off-stream wherever suitable soil is available or in a small stream of suitable topography. In some cases drainage water from the farm can be stored for irrigation purposes.

In areas where geological conditions are favourable groundwater can be used for irrigation. Irrigation in Denmark for example is done mainly by groundwater abstraction.

Urban and industrial wastewater can sometimes be used for irrigation. Because wastewater contains impurities, careful consideration must be given to possible long-term effects on soils and plants from salinity, nutrients, trace elements etc. Pathogens can survive and be transported over long distances under windy conditions. The use of sewage water is not recommended for crops that are likely to be consumed without cooking.

Irrigation techniques

In many parts of the world irrigation is primarily carried out by surface methods using basins, borders or furrows to distribute water by gravity. In northern Europe where irrigation is a supplementary practise different types of sprinkler systems dominate. Sprinkler irrigation generally needs less water and labour than surface methods and can be adapted to all types of soils, crops and topographic conditions.

Hand-moved irrigation systems with rotary sprinklers on portable pipes were the most frequent system until twenty years ago. Their capital cost was low and they were simple to use. However the equipment had to be moved regularly, which required hard labour under wet, muddy and uncomfortable conditions.

Thus, labour-saving mobile raingun systems were developed in the 1970s. They quickly became popular because of their relatively low capital cost per hectare and their low demand for labour. The most popular type is the hose-reel machine, which has a raingun, mounted on a sledge or wheeled carriage (Figure 7.9). Water is supplied through a flexible polyethylene pipe that is wound onto a large reel. The hose is used to pull a raingun towards the machine positioned at the edge of the field. Machines are available with hose lengths ranging from 200-700 metres and hose diameters between 50-140 mm. One disadvantage common to all types of sprinkler systems is uneven water distribution under windy conditions. In order to improve water distribution uniformity, hose-reel machines can be equipped with a boom that has spray nozzles instead of a raingun. Booms produce a uniform distribution pattern even when used in relatively windy conditions.

Drip irrigation systems are used in wide-row crops like fruit and berries. The system consists of small-diameter plastic piping placed in rows with spaced emitters. The piping slowly delivers water to the root zone. The capital cost is high but the systems need very little labour since they are permanent. Water use efficiency is also higher than with other systems.

Draining for agriculture in the Baltic region

In the 1700s the rather dramatic increase of population in Europe gave cause for claims for more cultivated land to feed people. Wetlands were often seen as lands held in reserve that could be reclaimed for human needs. In the Netherlands, of course, we see the best example of this type of land management. However, in the Baltic region, too, the role of drainage for obtaining new agricultural land has been important.

In Denmark, the loss of the province of Schleswig-Holstein to Germany in 1864 instigated an intensive land reclamation campaign. The province had contained some of the country's best farmland, and the loss needed to be compensated. Special drainage schemes were commenced to drain the peat bogs of western Jylland. The country's sand heaths were also turned into agricultural land by planting shelterbelts and improving the soil conditions. Thus, between 1880 and 1950, most of the Danish peat lands and heaths gave way to fields and pastures in a tacit but sweeping national development (John, 1984).

In Sweden, reclamation of land through water drainage projects was most intensive during the second half of the 19th century. Since this coincided with the transformation of meadows into tilled lands and with the expansion of agricultural areas into forests, this time marks a turning point in Swedish landscape history. Altogether, the area of agricultural land grew from 1.5 million ha in 1800 to 3.4 million ha in 1880 and reached its peak at 3.8 million ha in 1930. Land was reclaimed mainly on the peripheral areas of villages. Intensive drainage lasted until the middle of the 20th century, when about one sixth of the total agricultural land was a transformed lake or wetland (Anderberg, 1991). Another driving force behind drainage was the belief that drainage could prevent frost damages. Despite using the best available knowledge of the times, these projects seldom led to improvements and sometimes even failed, due to poor soil condition, ecological side-effects or surface shrinking.

In Russia, drainage was used mostly to accommodate urban runoff. In agriculture, only small local schemes are to be found before the 19th century and only in the western regions of Russia. These schemes usually involved growing rye. In the 19th century, swamps were mostly turned into pastures, but also into land for cereal cultivation and peat mining. Tile draining was started in the mid 19th century. Drainage for agricultural purposes did not become important until the 1960s. Between 1800-1861, only some 7 400 ha of land had been drained in the western regions of Russia (Karavayeva et al., 1991).

In Estonia, amelioration activities were begun in the middle of the 19th century. In the beginning, only the large estates could afford ameliorations. In 1897, an ambitious plan to reclaim 366 000 ha was drawn up by the Estonian and Livonian Bureau for Land Culture. By 1917, 108 000 ha had been drained, mostly to improve forest areas, but also to improve meadows and fields. After the land reform of 1919, there was a rapid increase in land reclamation, supported by the initiatives of the Homestead Board. Altogether, more than 350 000 ha had been reclaimed by 1940 (Juske et al., 1991). During the Soviet period, this figure almost doubled. This increase was accomplished through two major campaigns, one in the 1950s and 1960s and one in the mid-seventies, when peat bogs and mires were proclaimed the enemies of Soviet agriculture, and large forces were sent in to fight them. In newspapers, there was talk of "conquering" the bogs, "taming" the rivers and "subduing" the sloughs. However, at present, many of these new lands stand abandoned in Estonia.

In Belarus, the same campaign gave slightly different results. In Estonia, the campaign triggered off a nature conservation movement that succeeded in keeping the reclamation activities in lands that really made sense to drain. Large bog areas were taken stock of and by 1981 most of them were under protection. In Belarus, however, the task of fighting the bogs was taken seriously. Before World War II Belarus had the biggest marshlands in Europe. Now, most of them have been put subjected to drainage, a few years of agricultural use and then abandonment.

In Finland, land reclamation and drainage reached its peak even later. During the 19th century, the Finns moved northwards, claiming new lands in the north and demonstrating their will and power to overcome the poor conditions and frosty and stony soils. Later, as a result of World War II, Finland lost its best agricultural areas in Karelia. Karelian refugees had to be settled somewhere and the country needed food. Consequently, a development similar to one in Denmark three-quarters of a century ago took place. During the 1950s and 60s, the Karelian refugees were settled in the newly reclaimed lands in the centre and south of Finland.

Hannes Palang

The method of attaining subsurface irrigation by maintaining high water levels in ditches during summer, thereby keeping the water table high in the fields, is used in some areas. Where conditions are favourable – flat land, permeable soils, and high natural water table – the method improves the crop water supply by capillary rise into the root zone. An example of successful subsurface irritation of this kind is the polder region in the Netherlands.

Irrigation and nitrate leaching

Improved crop water supply during dry periods enhances crop production and often increases the uptake of nitrogen from the soil. Although many studies have shown that good irrigation practise reduces nitrate leaching by reducing nitrate concentrations in drainage water, just the opposite can occur if too much water is applied or if the water distribution is non-uniform.

In traditional agriculture nutrients were removed as milk and finally meat, while simple manure handling resulted in considerable losses of ammonia (photo, Lars Rydén).

8.

AGRICULTURAL NUTRIENT MANAGEMENT

Christine Jakobsson, Staffan Steineck & Göran Carlson

Background

Agriculture is often a cause of nitrogen emission to both air and water. Ammonia is emitted to the air from animal manure either directly from the animals' dwellings or during storage and spreading. As much as 80 % of the total ammonia emissions in Sweden emanates from animal manure. Ammonia not only contributes to the acidification of land and in some limited areas to nitrogen saturation in forest soils, but also to eutrophication in lakes, rivers and the sea. Biological diversity is also affected negatively. In Sweden the largest proportion of ammonia deposition comes from the rest of Europe. Ammonia usually is deposited in the relative vicinity of the source and is therefore of significant in certain regions.

Fertilisation using mineral fertilisers started in the mid 1950s. In Sweden the average application rate at that time was 23 kg nitrogen per hectare. In 1973 the fertilisation rate of nitrogen per hectare had increased to 80 kg and even today this is the steady level. Fertilisation using nitrogen in both mineral fertilisers and animal manure, combined with extensive drainage of fields, resulted in increased leakage of nitrate nitrogen into our inland waters and the sea. In 1995 in Sweden, agriculture was responsible for 45 % of the total leakage to the marine waters, the Baltic Sea and the North Sea. In a comparison of other countries and sources, total input of nitrogen from Sweden into the Baltic Sea has been estimated to be 6-9 %

Measures to reduce the nutrient losses from agriculture

In 1988 the Swedish Parliament decided to launch a programme to reduce plant nutrient losses from agriculture. The aim was to reduce the amount of nitrogen that reached the Baltic Sea by 50 % from 1985 to 1995 and to substantially reduce the amount of phosphorus. This goal has not been reached, but 25 % reductions in nitrogen losses to the Baltic Sea have been calculated. In the province of Svealand, the reduction of nitrogen losses to the sea was as high as 40 % (SEPA, 1997). Since 1995 specific measures to reduce the ammonia losses from agriculture were successively elaborated and implemented. The local farmer is the central figure in this programme and as such is regarded as the instrument for reaching the government's goals. Measures for tackling the problems are: stipulations and guidelines, advisory service and information, research and development, and economic instruments of control. All the measures listed below are part of the programme.

Livestock density

To ensure that manure is not produced excessively in comparison to the amount of arable land on the farm, it is important that there is a balance between the number of animals on the farm and the amount of land available for spreading manure. In the programme, the maximum number of animals has been specified in relation to the amount of phosphorus and nitrogen in manure and a crop's normal requirements and removal of plant nutrients. The limiting factor for the Swedish legislation on livestock density is phosphorus, with a maximum amount of approximately 22 kg phosphorus per hectare. As the amount of manure per area will be moderate, the risk of nutrient leaching of both nitrogen and phosphorus should be substantially smaller. One advantage of using phosphorus instead of nitrogen is that the figures on content in manure are more reliable, since phosphorus losses in the stable and during storage are almost non-existent. The number of animals per hectare may not be higher than the numbers shown in Table 8.1.

The accessible land for the spreading of manure can consist of:

- suitable arable land used for crop production on the farm
- arable land elsewhere if there is at least a 5-year period contract for spreading manure
- grazing land and pastures on farms with grazing livestock

At most, 50 % of the area needed by grazing animals for spreading livestock manure may consist of pasture. Normally only 30 % is used, since this corresponds to the livestock waste production during a 4-month grazing period. The animal density

Practical solutions for soil and water problems in agriculture

Several national agricultural or environmental bodies have produced information material aimed at giving guidance to the individual farmer. Agriculture Canada, for example, has produced a series of booklets treating what has come to be termed “best management practices.” The booklets are easy to understand and give practical advice and inspiration. Some summary excerpts, focusing primarily on soil and water problems, are as below:

Problem solving

Where problems exist, farm managers must clearly identify the resources and options that are available to correct them. The next step is to choose the appropriate best management practice. Setting priorities involves striking a balance between production goals, economic costs and environmental production.

Manure and milking parlour effluents storage and handling

Livestock are an important part of agricultural production. The resulting crop rotation of grains with cattle feed as hay and pasture is beneficial for the soils. When managed effectively, the wastes from livestock production can be essential farm resources, but when managed improperly, they can pollute nearby waters.

Manure can be stored and handled as a solid or as a liquid. Manure spills and contaminated runoff are prime sources of agricultural pollution. The two critical features of manure storage design are adequate sizing and personal safety. Manure storages must contain nutrients and prevent runoff and be large enough to handle the volume of wastes generated until weather, soil and crop conditions allow spreading.

A properly sized concrete tank with safety fencing is an acceptable way to store liquid manure and other wastewaters. A concrete-walled solid storage area with a sloped floor handles both solid and liquid manure materials. Snowmelt and rainwater can be diverted from solid manure storages by eavestroughs or with a roofed structure. Contaminated water and milking parlour effluents can be contained with curbs and walls or stored in a separate earthen pond.

Milking parlour effluents are a source of pollution. Potential pollutants include phosphates and bacteria. The affluents can be treated in a properly designed and managed sediment tank and treatment trench system, similar to household septic systems. Locate treatment in a protected area with good drainage and no equipment traffic. To prolong the life of the system, remove milk solids before releasing the washwater to the sediment tank.

Manure application

Manure contains organic matter and nutrients. Both of these resources are important to sustain crop yield.

If crop needs and soil conditions are properly considered, manure becomes a valuable resource. Producers should test cropped soils and manure regularly for nutrient content. Factors to consider when determining application rates include: soil type, area, the crop to be grown and the type of manure.

If runoff from manure applied to fields enters waterways, nutrient and bacteria can pollute water. If more manure is applied than a growing crop can use, some of the excess nutrients may be leached into groundwater. Manure applied to frozen ground can run off with the spring meltwater. Solid manure should be spread when the soil is dry and completely thawed. Manure spread on pasture or forage fields near streams can also run off.

Too much manure can also lead to poor crop performance and create excessive odours. Since roots need air to breathe, too much manure can hinder crop vigour. When excessive rates are combined with poor timing, surface and groundwater may be polluted.

Timing and location are two of the most critical factors to ensure producers maximum benefit and minimum pollution. Well-timed applications of manure can provide nutrients for crop growth. In ideal situations, manure is tilled into the soil as it is applied, or at least within 24 hours. Keep the neighbours happy – spread at times that are acceptable to everyone.

Artificial fertiliser added to the soil in surplus cause nutrient leakage (photo, Inga-May Lehman Nådin).

Liquid manure can be injected into the root zone with a flexible-hose system to provide crop needs and reduce the risk of runoff. Manure is pumped directly from the liquid storage tank to the manure injector.

Under some conditions, liquid manure can move through the soil and enter tile drains. The magnitude of the problem varies with manure type, rates, timing, and soil conditions. Careful considerations of crop needs and soil conditions followed by frequent monitoring can prevent such problems.

Managing fragile lands

Fragile lands are especially susceptible, e.g., to erosion or flooding. Consideration should be given to permanently retiring such land from agricultural production and devoting the area to more appropriate use. It rarely makes the landowner money, and is likely costing someone else money downstream. Retirement of fragile and bottomlands is a best management practice.

Stream bottomlands and drainage ditchbanks are not good grazing and watering sites. Access to streams by cattle can lead to faecal coliform and sediment pollution of watercourses. Compaction and slumping of banks caused by hooves add unwanted soil to streams and ditches. Unrestricted livestock access means poorer drinking water for the users downstream.

Fencing cattle out of streams will prevent water pollution. It will keep livestock out of the water while allowing them to graze on bottomlands. Livestock crossings allow access to lands on both sides of the watercourse. Watering devices such as mechanical nose-pumps or solar-powered pumps meet livestock needs. Restricted cattle access is the most cost-effective way to reduce livestock-related pollution of ditches and creeks.

Getting the most from cropland is important to your bottom line but growing crops too close to ditchbanks will accelerate streambank erosion. The use of tillage and other heavy equipment near streams places excessive loads on the banks. This causes slumping, streambank erosion and could be a major safety hazard. Also, the closer producers work to the bank, the more likely it is that topsoil and fertilisers will run off into waterways. It is far better to do a good job on your best acres and retire fragile land.

Planting permanent grass buffer strips can protect ditchbanks and watercourses. An easily maintained grass buffer strip will keep tillage equipment away from fragile lands and filter runoff during storms. Fragile lands can be retired at low cost by planting tree and shrub seedlings. Vegetation that provides shade gives life to streams because cool, clean water is ideal for the fish habitat.

Block plantings of conifer or shrub seedlings are the beginning of future farm forests. At first, an improvement in the range and numbers of birds and wildlife will be noticeable. In time, the field that was once an eyesore will become beautiful.

Lars-Christer Lundin

Table 8.1. Limits for sustainable livestock density in Sweden

Type of animal	Animals/hectare
Dairy cows	1.6
Cows for breeding calves	2.3
Heifers, bulls, steers > 1 years age	4.6
Calves < 1 years age	5.8
Sheep and goats	15
Sows in production	2.2
Fattening pigs, pens	10.5
Laying hens, pens	100
Young hens, pens	250
Broilers, pens	470
Turkeys, ducks, geese, pens	140
Horses	3
Mink, breeding females	50

requirements apply to all farms in Sweden with more than ten animal units . One animal unit: 1 cow, 3 sows, 10 fattening pigs, 100 poultry or 1 horse.

Permits for farms with more than 200 animal units

Farms with more than 200 animal units are required to apply for a permit at the County Administrative Board. The permit usually consists of requirements regarding the maximum number of animals, the storage capacity and application of manure etc.

Nutrient reduction areas

Other solutions can be applied when it is impossible to reduce the nutrient losses at the source, which is always the best strategy, as it is better to use the nutrients as a resource in agriculture rather than having to get rid of them. Establishing buffer zones along rivers and ditches has led to substantial reductions of nutrient losses. These buffer zones should be covered with grass or bushes and trees and in this way they have been shown to reduce erosion and surface runoff. The size of the buffer zones depends upon the topography and the soil type.

Other types of nutrient-reduction areas to consider are wetlands and dams. During the last 200 years the agricultural landscape has been drained and a large part of wetlands and lakes no longer exist. Before, these areas took care of nutrients in three ways:

- Nitrogen was denitrified into the air as gaseous nitrogen
- Phosphorus and nitrogen were deposited in the sediment
- Phosphorus and nitrogen were taken up by plants

To ensure that the wetlands will function as nutrient-reduction areas in the future, certain considerations must be taken. If the nutrients in the sediment and plants are not removed from the wetland, they will be a deposit instead, since they will not be removed from the system. Both wetlands and dams can be created and recreated in the agricultural landscape to reduce nutrient losses and to improve biological diversity.

Advisory service

Plant nutrient balance – a tool for decisions on planning and the environment

Plant nutrient balances that show nutrient fluxes are an important tool for planning and decisions on all levels. Today it is possible for farmers in Sweden to obtain a plant nutrient balance for their particular farm. The balance, which can be compared to a technical flow chart, shows the flow of plant nutrients to, from and within the farm. The balance shows where plant nutrient storages are, how big they are and where they are prone to losses, and whether the amount of plant nutrients on the farm is on the rise or being depleted.

To make it possible to achieve a sustainable use of plant nutrients in agriculture, consisting of mineral fertilisers, animal fodder, animal manure and the recirculation of nutrients from food originating from agriculture back to agricultural use again, it is necessary to know exactly where and how big the plant nutrients are. The balance gives an immediate answer to whether there is surplus, deficit or leakage. From the balance it is also possible to estimate the size of plant nutrient flows and identify where deficits are imminent, for instance to prevent reductions in plant growth due to lack of a nutrient such as nitrogen, phosphorus or potassium. The farm balance is an optimal tool for the farmer in his planning and economy.

What information is necessary for a nutrient balance?

The first step in collecting data and information is to identify the substances and flows that are desired. Nitrogen and phosphorus, for example, are desirable because, besides the usual growth-promoting quality of these nutrients, they are also growth-limiting under aquatic conditions and thus they must be included when a balance is made, to reduce eutrophication in water bodies. On the other hand, a farmer who grows potatoes on potassium-deficient soils may be interested in including potassium, since grass, potatoes and sugar beets take up three to five times more potassium than grain. The following data is needed in the plant nutrient balance:

- input of fertilisers, seeds, animal manure, fodder and livestock, piglets, calves, etc.
- nitrogen fixation, clover, etc.
- deposition from air of nitrogen and phosphorus
- information on sales of plants and animal products and animal manure sold by the farm
- ammonia emissions from animal manure and soils and denitrification
- nitrate leakage and surface runoff of phosphorus
- imported and exported food

When all data above are calculated in the nutrient balance, further information may be needed in an interpretation of the balance, such as weather conditions, soil type, soil supply of nutrients and animal manure or human effluent handling system. Depending on the case studied, balances may show positive or negative trends or show the nutrient utilisation ratio and/or the impact on the environment.

Sources of information

Statistics Sweden, SCB, collects and publishes data on agricultural production of plants and animals, including keeping records of the content of the plant nutrients nitrogen, phosphorus and potassium in mineral fertilisers and animal manure for each county and year since 1927. They have also published nutrient balances on the field level since 1985 for each county and the whole nation. Losses of plant nutrients to the air and water from agriculture have also been published regularly since 1991 (e.g. SCB, 1995a; b; 1997; 1998a; b). Basic data is measured and compiled in co-operation with researchers from the Swedish Institute of Agricultural Engineering, JTI, and the Swedish University of Agriculture, SLU. Information and data on the farm level is collected in an enquiry form.

The farmer can find most of the information concerning production and bought and sold commodities in his own bookkeeping. Data on nutrient-losses is assessed in relation to manure handling systems, spreading strategies, soil types, precipitation, winter temperatures etc.

To measure ammonia emissions and nitrate leakage and to find relevant measures to reduce these losses continuous research and development is being carried out. Measuring losses of nitrogen by denitrification is difficult but there is at present an intensive activity regarding the measuring and estimation of the losses by denitrification from different soil types and crop rotation systems.

Plant nutrient balances on the farm level

The plant nutrient balance is a basic tool in planning the overall running of the farm to improve the economy and reduce the negative environmental impact. Experiences after 1987 of the use of farm nutrient balances in advisory service have shown that it is an important instrument in diagnosing the situation of the farm. Using the plant nutrient balance makes it easy to reduce unnecessary inputs of fertilisers and saves the farmer considerable expense, while at the same time reducing the pollution caused by the farm.

In Figures 8.2 and 8.3 nutrient fluxes and farm nutrient balances are shown from a cash crop farm in the middle of Sweden and from a pig farm in south-western Sweden. On the cash crop farm there is a small surplus of phosphorus input but input and output of nitrogen are in balance. At the pig farm a good deal of phosphorous is included in the cost of the pig feed. This yields a large net surplus of phosphorus in the farm balance. Many farmers do not include the amount of phosphorus they buy in the feed in their calculations. This phosphorous ends up in the manure, where it is a rich plant nutrient source for crop production.

Farmers in Sweden can have a plant nutrient balance drawn up for their farm, free of charge. The Swedish Board of Agriculture supplies a computer programme (Manure and plant nutrients in recirculation, STANK), which is used by the advisory service and at the local county boards. This advisory service is a part of Sweden's implementation of the EU's environmental programme.

Field balances

To study the nutrient fluxes on the farm, a field balance on each field is of great help. Animal manure is usually applied on the fields next to the barn and the distant fields are forgotten. In the long run, this leads to an imbalance of plant nutrients on the farm. A yearly field balance will remind the farmer of this and the imbalance can be remedied by spreading manure on the distant fields as well.

Since it has been easy to forget to count in the nutrients in the manure when fertilising crops, a surplus of from 400 to almost 2 000 kg of phosphorus has been added to arable land in Sweden from 1953 to 1995 (A. Andersson et al., 1998). The largest surpluses have been reported from areas where animal production has dominated. Surpluses in the yearly phosphorus balance, see Figure 8.4, from mainly mineral fertilisers are still common in most of the Swedish counties dominated by animal production with one exception in the south of Sweden. The advisory service is responsible for this.

In Figures 8.4 and 8.5 data from 1998 extracted from SCB and SEPA has been used to show the

Handling of manure to reduce nitrogen leakage

Manure storage requirements

Requirements regarding storage capacity for manure, slurry and urine have been increased for all farms with more than 10 animal units within a specified pollution-sensitive area consisting of southern Sweden and a 20 km broad strip of coastal zone from the Norwegian border to the county of Stockholm. These requirements also apply to all farms in Sweden with more than 100 animal units. Storage facilities must be of a size corresponding to the manure production for 8 months for animal production consisting of cattle, horses, sheep or goats and 10 months for other types of animal production.

In the rest of the country, the size of the storage facilities for manure should be able to handle, with good margin, the need for storage during the time period when livestock manure should not be spread. The storage space should therefore correspond to 6 months' production of manure for grazing animals and 8 months for the rest.

Reducing ammonia emissions

The magnitude of ammonia emissions during storage of manure depends on many factors, such as the ammonia-nitrogen content of the manure, temperature, dry matter content, pH-level, air humidity, length of storage period, size of the manure surface, air movement over the manure surface and amount of stirring. The largest ammonia losses take place during storage of urine, since urine has both high nitrogen content and high pH. It is of great importance to prevent air movements over the surface, since the wind removes gaseous ammonia emissions from the manure. Since ammonia emission from the manure surface is the result of a reaction of equilibrium, ammonia will continue to be produced and fill the air above the surface until it is removed again.

To reduce ammonia emissions during storage, slurry and urine pits must be covered with a stable surface crust layer or other cover that effectively reduces ammonia emissions. Filling must take place beneath the covering. Since 1995, this applies to farms with more than 10 animal units in three counties in southern Sweden, and in the rest of the Götaland region and on the plains of the Svealand region since 1997.

Slurry pits can either be covered with a natural crust, straw, peat, plastic, Leca pebbles, a roof or any other covering materials that effectively reduce ammonia emissions. Filling beneath the covering is done to prevent the slurry or urine from breaking the cover or ending up on top of it.

Requirements for manure application

To prevent nutrient leaching, manure and other organic wastes may not be applied to land in Sweden from 1 December to 28 February; unless they are incorporated in the soil the same day at a depth of at least 10 cm. Harrowing the surface is not enough.

Since January 1999, new measures regarding land application of manure have been implemented in the above-mentioned pollution-sensitive area in southern Sweden and along the coastal zone.

1. Fertilisers are not allowed to be spread in amounts exceeding the crop's nitrogen requirements for the growing season. The amount of fertiliser applied should be based on a balance between the crop's foreseeable nitrogen requirements and the nitrogen supply from all external potential nutrient sources, and the following should be taken into account:
   - soil conditions, soil type and slope,
   - climatic conditions, precipitation and irrigation,
   - land use and agricultural practices, including crop rotation systems.
2. Fertiliser may not be applied on water-saturated or flooded ground.
3. Fertiliser may not be applied on snow-covered or deeply frozen ground.
4. Nitrogen containing commercial fertilisers may not be applied from 1 November to 15 February.
5. Manure and other organic fertilisers may not be applied from 1 January to 15 February.
6. From 1 August to 30 November manure and other organic fertilisers may only be spread to a growing crop or before autumn sowing.

Reduction measures for application of manure

When applying manure, slurry and urine, it is of great importance that incorporation takes place as soon as possible, since the largest ammonia emissions take place immediately after application. Ammonia emissions are high when the contents of ammonia nitrogen in the urine, slurry or manure are high. It is not until the ammonia ion is adsorbed by soil particles or assimilated by crops, that the risk of ammonia emission is for all intents and purposes inhibited.

Since 1996, manure, slurry or urine must be incorporated within 4 hours after land application when spreading on bare soils. This applies to three counties in southern Sweden.

Application to growing crops

After 1998 in the same three counties in southern Sweden, slurry may only be spread to growing crops using one or more of the following techniques that efficiently reduce losses of ammonia:

- Band-spreading techniques or other similar techniques, where slurry is placed directly on the ground beneath the crop cover
- Injectors or other similar techniques, where slurry is placed directly in the ground
- Techniques where one part slurry is diluted with at least one half part water before application (broadcasting)
- Techniques that are followed by irrigation with at least 10 mm water within 4 hours (broadcasting)

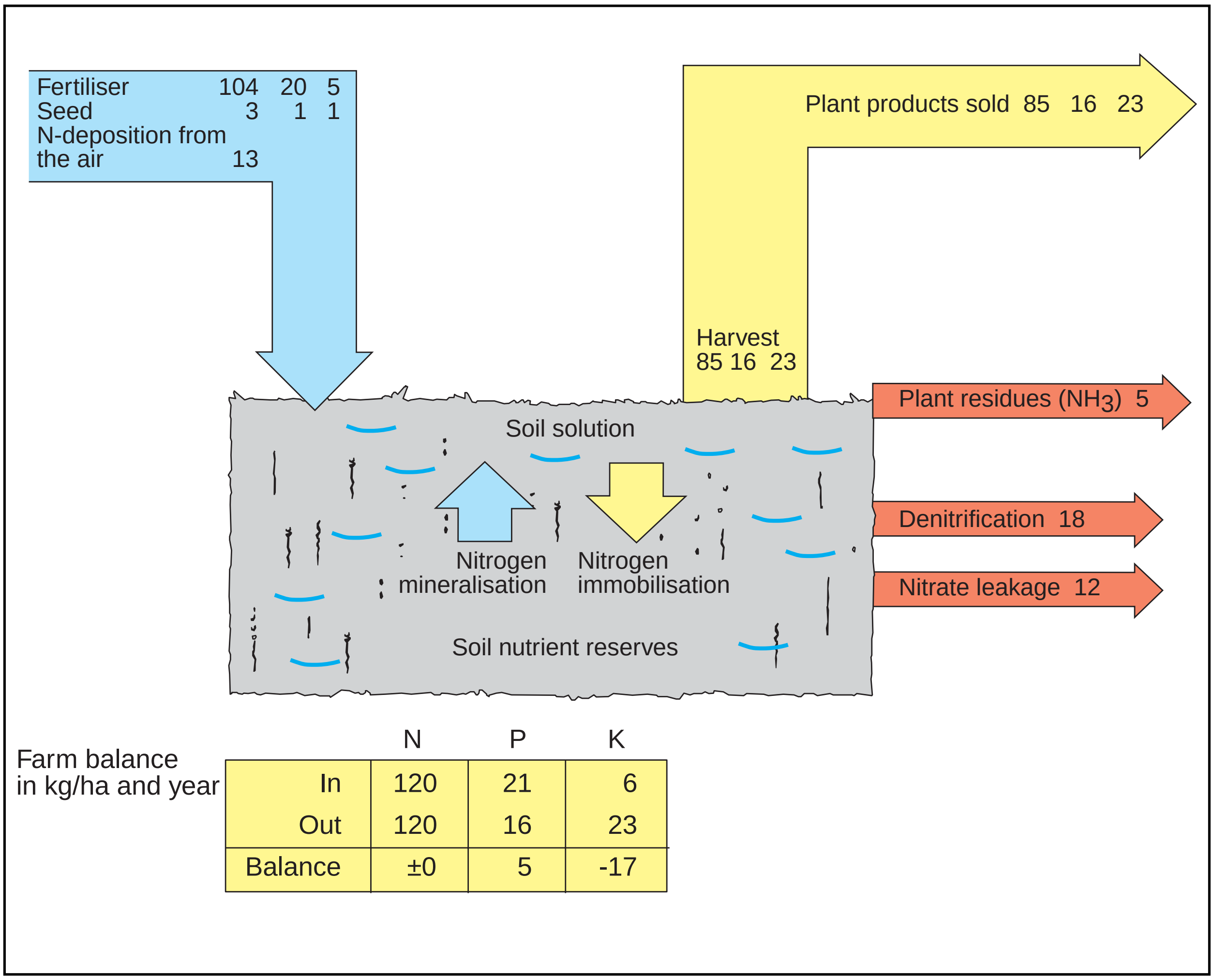
Minimum required amount of wintergreen land

Covering fields with crops during autumn and winter can effectively reduce nitrogen leaching. In most cases a well-established green cover can reduce leaching by at least 10 - 20 kg nitrogen per hectare.

A minimum of 60 - 50 % wintergreen land during autumn or winter is required on every farm with more than 5 hectares arable land in, respectively, the three most southern counties and the rest of the Götaland region. Only open fields, not natural pastures or grazing land, are affected by the requirements. The times for sowing and for interrupting plant growth are both regulated.

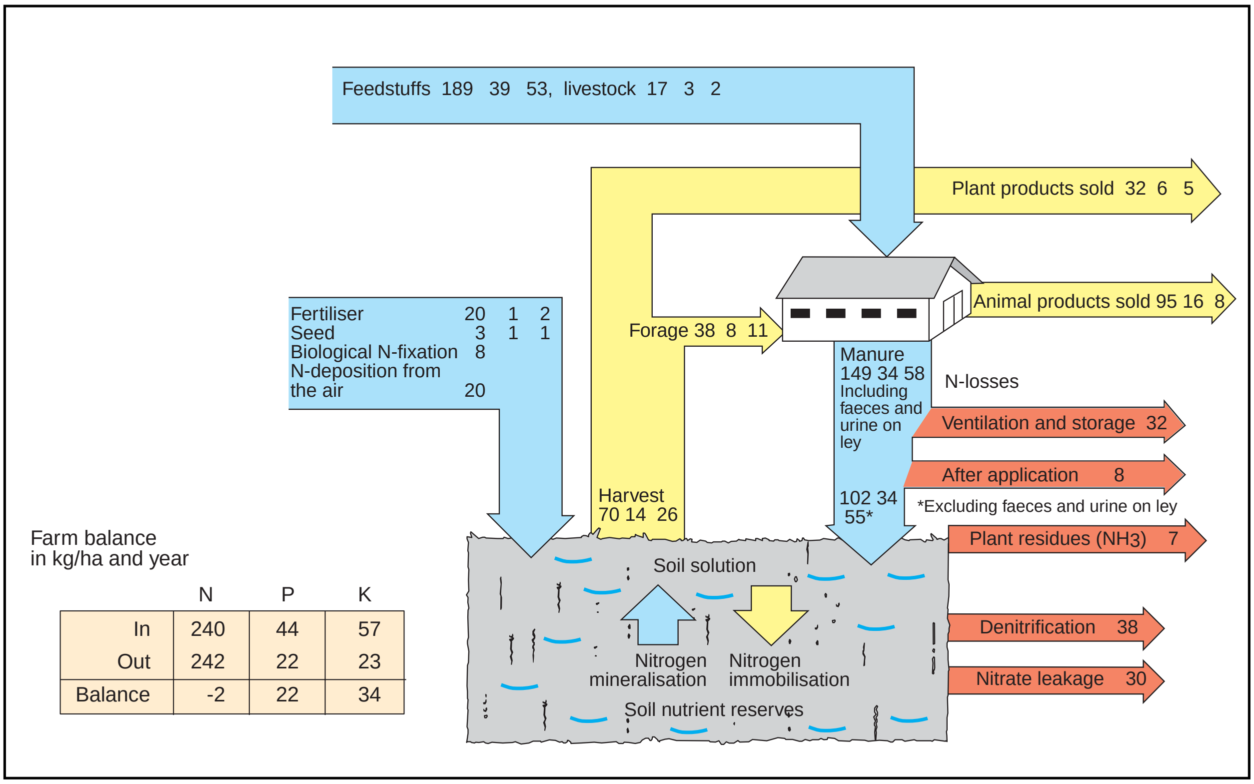
The following crops are accepted: grassland, winter cereals, winter oilseeds, energy forest (usually *Salix*), sugar beets, carrots or other similar root crops (not potatoes), perennial fruit and berry crops, special catch crops (usually perennial ryegrass, *Lolium perenne*) and set-aside arable land with covering plants.

Figure 8.1. Ammonia-measuring equipment at a farm near Elblag, Poland (Photo, Swedish University of Agricultural Sciences, 1998).



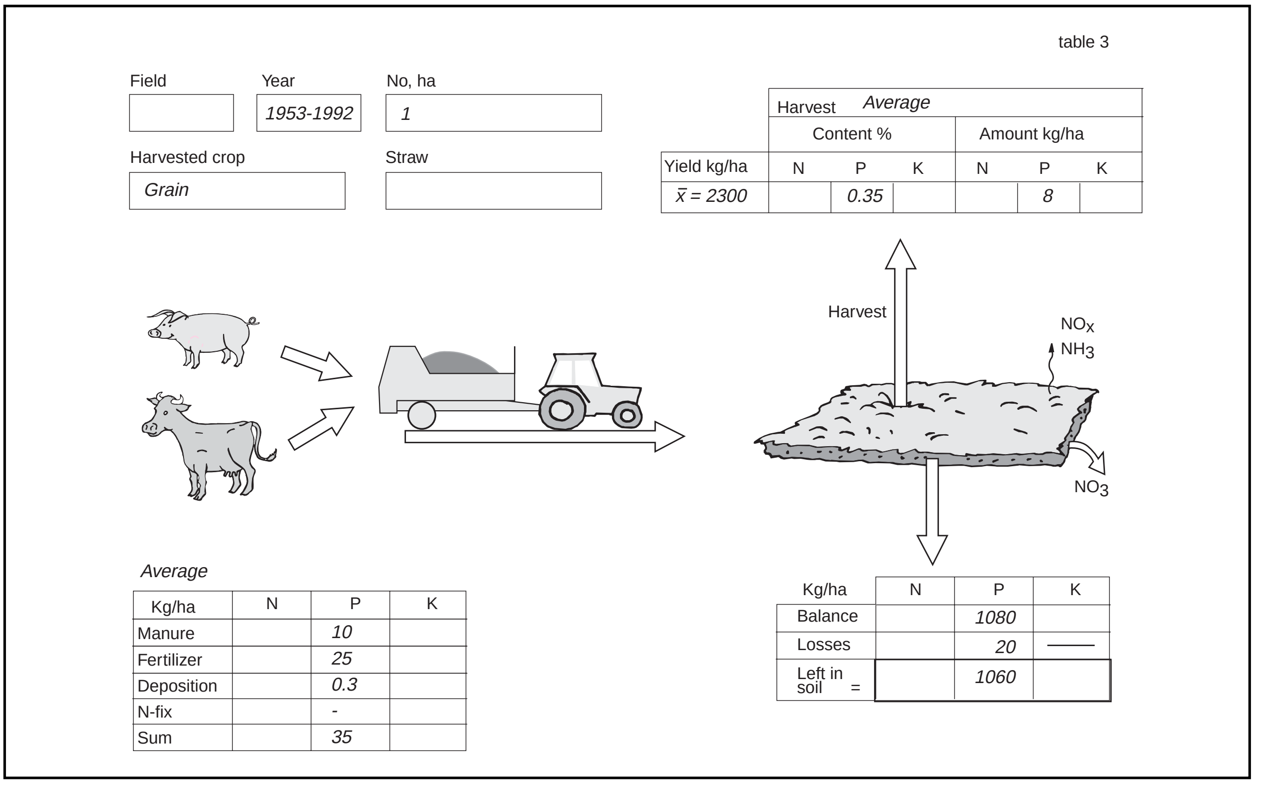
	N	P	K
In	120	21	6
Out	120	16	23
Balance	±0	5	-17

Figure 8.2. Plant nutrient balance (N, P and K in kg/ha/yr) on a cash crop farm in the middle of Sweden. Arable land 70 hectares.



	N	P	K
In	240	44	57
Out	242	22	23
Balance	-2	22	34

Figure 8.3. Plant nutrient balance (N, P and K in kg/ha/yr) on a pig farm in south-western Sweden. Arable land 95 hectares.



Harvest Average	Content %			Amount kg/ha		
Yield kg/ha	N	P	K	N	P	K
$\bar{x}$ = 2300		0.35			8	

Kg/ha	N	P	K
Manure		10	
Fertilizer		25	
Deposition		0.3	
N-fix		-	
Sum		35	

Kg/ha	N	P	K
Balance		1080	
Losses		20	——
Left in soil =		1060	

Figure 8.4. A field balance of the county of Blekinge in the south-eastern part of Sweden showing the accumulation of phosphorus (kg/ha/yr) in the arable soils from 1953 to 1992.

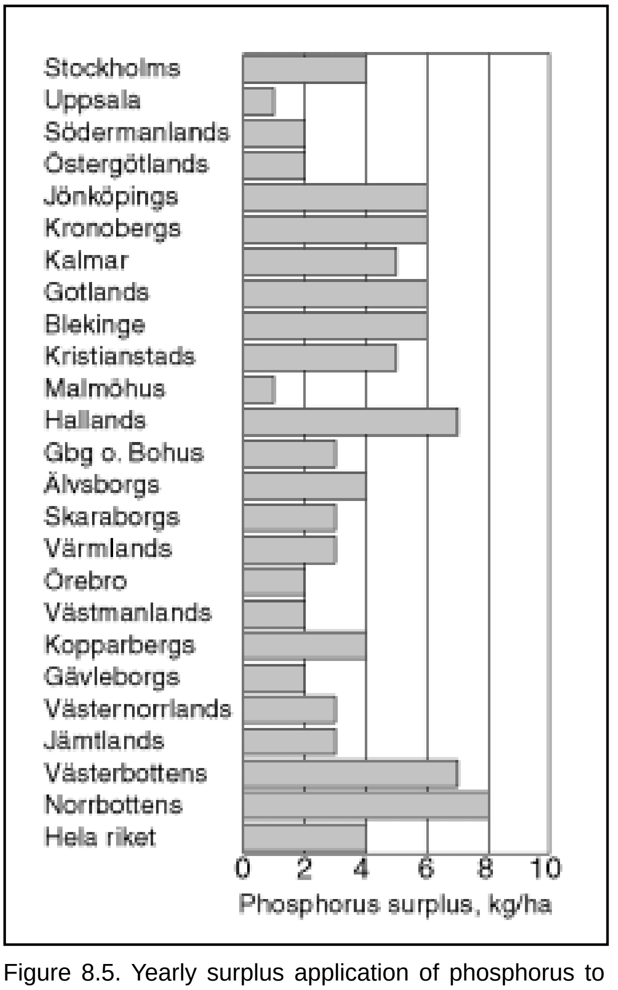


Figure 8.5. Yearly surplus application of phosphorus to arable soils in kg per hectare in Swedish counties, 1995 (data from SCB, 1996).

accumulated phosphorus surplus from 1953 to 1992 in one county on field level and in all counties in one year, 1995 (SCB, 1996). Phosphorus has been added to the soil in the form of animal manure and mineral fertilisers and as precipitation from the air (Figure 8.4). Phosphorus has been removed by cash crops. Grasslands are not included since there is a balance between phosphorus in cattle manure and grass consumed by the cows. On an average, an excess of 1 060 kg of phosphorus per hectare has been added. This large supply of phosphorus is then available in the soil for many years of crop production. All crops grown on farms normally remove some 15 to 25 kg of phosphorus per hectare and in this particular county no extra phosphorus is needed in agricultural production for the next 50 to 90 years. The yearly surplus of phosphorus applied to arable soils is presented in Figure 8.5. It gives the advisor and the farmer a reminder to keep an eye on and reduce any application of phosphorus in mineral fertilisers.

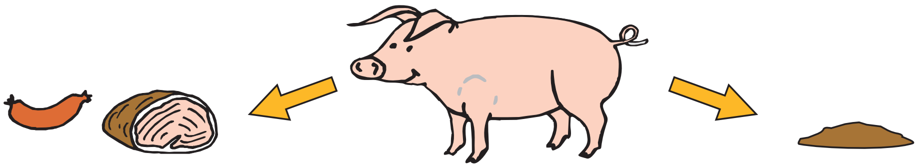
Animal plant nutrient balance

Feed added to one Swedish pigpen producing three fattening pigs per year is presented in Figure 8.6. There is very little variation in feeding regimes for fattening pigs in Sweden. The balance shows that less than one third of the phosphorus in the

Plant nutrients in manure from fattening pigs, 25-100 kg live weight, per animal and year

Feed kg/kg meat produced	2,8
Number of pigs per place and year	3
Growth per pig in kg	85

	N %	P %	K %	x kg =	Kg in total feed N	P	K
Pig feed, concentrate	2,6	0,6	0,5	720	18,7	4,3	3,6
Grain							
Sum					18,7	4,3	3,6



Pork, live weight

N %	P %	K %	x kg =	N	P	K
2,6	0,46	0,22	255	6,6	1,2	0,6

Urine + faeces, kg

Fresh N	N % *	P	K
12		3,1	3,0

*) minus ammonia losses

Figure 8.6. Plant nutrients in feed, pigs and faeces/urine per pigpen and year in a normal production of fattening pigs.

feed is used to build up the pig's bodies and the rest is found in the faeces and urine.

Crop production plans

The plant nutrient balance shows whether the amounts of plant nutrients on the farm are increasing or being depleted. After this has been shown to the farmer, changes in fertilisation of the crops on the farm can be discussed. The next step is to plot out the crops to be grown during the next farm season on a crop production plan. The concentration levels of phosphorus and potassium in the soil, which can be shown in an up-to-date soil map when calculating the crops nutrient requirements, are taken into consideration here. A complete crop production plan will refer especially to manure handling regarding timing, amounts and techniques. The plan also includes fertilisation according to the requirements of the crops, and the most appropriate fertilisers are suggested. Optimally a crop production plan should be performed every year, to ensure that the nutrients on the farm are recirculated in the best manner.

Strategies for manure spreading

Another way to facilitate the planning of manure handling is to look more closely at manure-handling strategies for the farm. This is especially valuable when a crop production plan is not drawn up every year. The strategies include recommendations regarding how to best utilise manure for specific crops on specific soil types. The farmer's strategy should be clear, including suitable timing and techniques for spreading manure, the recommended amounts of manure for specific crops and how to best supplement the manure with commercial fertilisers or other nutrient sources. Even the technical aspects of manure spreading, such as spreader type and tyre equipment should be discussed. It is also important for good spreading results to consider how the manure is handled prior to spreading. For solid manure, the use of chopped straw as bedding, instead of long straw or composting, affects the spreading results. For urine and slurry, it is of great importance that the storage be covered, to reduce ammonia losses.

Nutrient balance on the watershed level

For a realistic picture of the nutrient leakage from rural areas, it is important to integrate typical human activities in countryside living. For that reason, small watersheds are used as a reference. By integrating agriculture and households in the watershed into a plant nutrient balance, it is possible to predict the need for external additions of plant nutrients for farms

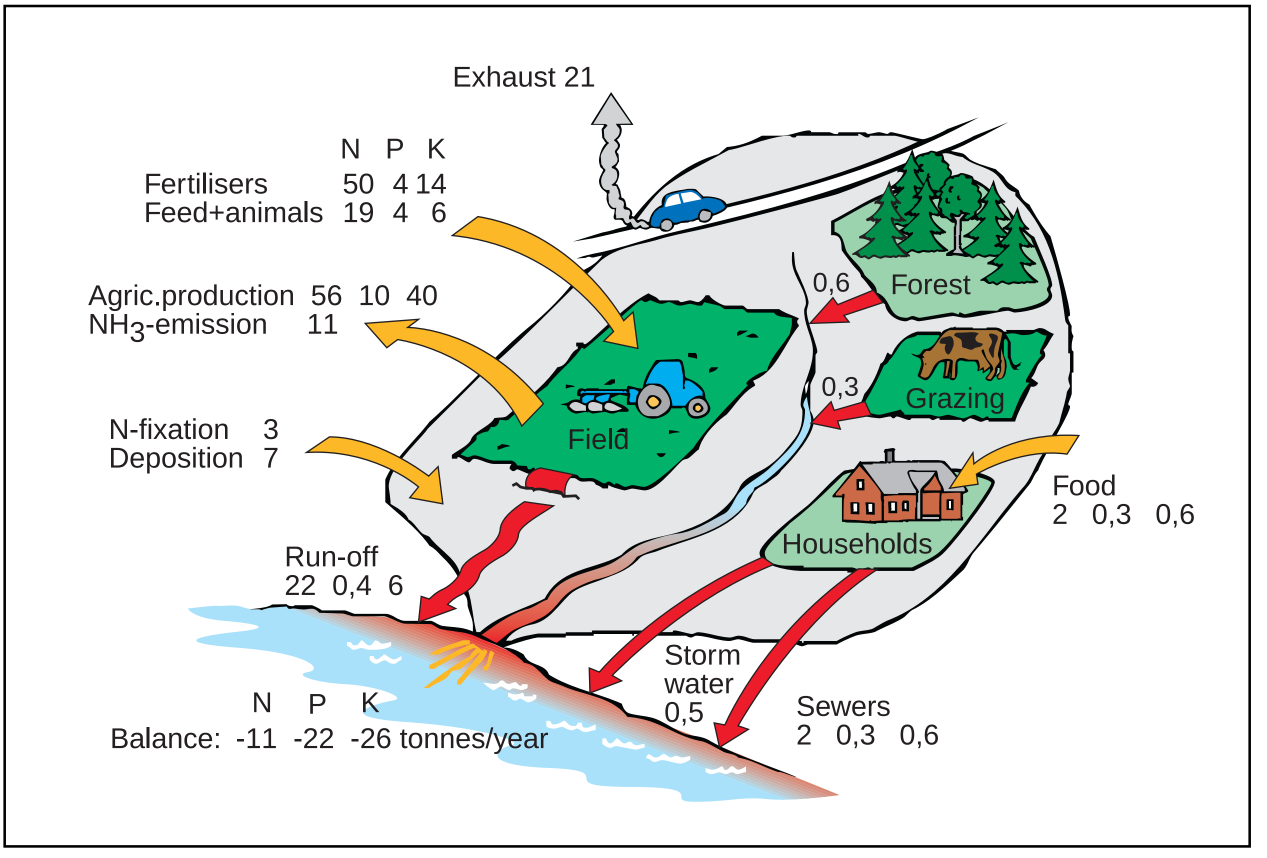


Figure 8.7. Plant nutrient fluxes (N, P and K in tonnes/yr) in a watershed in the south of Sweden.

in the area. The nutrient fluxes in a watershed demonstrate the fluxes and volumes of plant nutrients to, from and within the watershed. Special types of small watersheds, called demonstration watersheds, have been established in the Baltic countries. Demonstration watersheds are specially selected watersheds equipped with water monitoring facilities. This offers the possibility to study the changes in water quality due to implemented environmental measures on the farms in the watershed. In these watersheds, farmers are educated, supervised and supported to implement the proposed measures. The demonstration watersheds are then used to demonstrate to farmers, advisors, teachers and decision-makers how environmental measures work in practice.

The nutrient fluxes and the plant nutrient balance in a small watershed in the south of Sweden are presented in Figure 8.7.

Demonstration watersheds

The Baltic Run-off Action Programme

The development of agriculture in a more sustainable direction has been the focus of many projects during the past decade. One such project is the BAAP (Baltic Run-off Action Programme). The BAAP was set up to improve the water quality of the Baltic Sea and of local surface waters and groundwater in Poland, Lithuania, Latvia, Estonia and Russia. The project was run from 1994-2002. The programme consisted of seven subprojects, each incorporating farmers, advisors, teachers and scientists. The subprojects were aimed at demonstration farms and watersheds, information, education, advisory service, agri-environmental legislation and policy, buffer zones and investment loans for ecological farming. All subprojects were geographically focused, covering a region, country or several countries.

So far no practical results in terms of improved water quality have been observed but the undertaking should be regarded as a long-term investment and the involved parties plan to continue the undertaking in some form.

Demonstration watersheds

In one of the subprojects of the BAAP, four demonstration watersheds were set up: Kabala in Estonia, Mellupîte in Latvia, and Graisupis and Vardas in Lithuania. The catchments varied between 7.5 to 25.5 km^3 and covered 14 to 23 farms. The demonstration watersheds were the foci for demonstration, education and information activities aimed towards farmers both within the watershed and outside of it. Each watershed contained a demonstration farm equipped with field trial plots and water quality monitoring.

In the water quality monitoring of the watersheds, the effects of the implementation of good agricultural practice could be followed. (Figure 8.9).

Nutrient management is an important issue, especially since manure has traditionally been treated as waste and not accounted for when spread on the fields, resulting in a build-up of very high nutrient concentrations in the soils. The establishment of nutrient balances was thus an important aspect of the subproject (Table 8.2). The input of phosphorus at the Graisupis demonstration farm can be reduced by 11.5 kg/ha, but the farmer must be aware that the fields are being depleted of nitrogen. A reduction in nitrate leakage is recommended.

Good agricultural practice was also demonstrated in the trial plots, where different fertilisation practices were tested and balances for each plots analysed.

Efforts to assist in the storage and spreading of manure were also made. Storage facilities are important to a proper use of manure, since they facilitate spreading at the right time thereby minimising the need to purchase fertilisers. However this proved too costly for many farmers. The introduction of new spreaders with better accuracy in application rates and evenness in spreading, on the other hand, showed good results.

Lars-Christer Lundin

Table 8.2. Plant nutrient balance on the demonstration farm Graisupis in Lithuania (from Swedish University of Agricultural Sciences, 1998)

Nutrient input	**Type of nutrient** **N** (kg/ha)	**P** (kg/ha)
Mineral fertilisers + seeds	46	16
Fodder and animals	5	2
Deposition	8	0.1
Biological fixation	9	
Total input	68	18.1
Nutrient output		
Plant products	23	5
Animal products	6	1.3
Nutrient losses		
NH_4 losses, vent. and storage	5	
NH_4 losses, application	3	
NH_4 losses, plant residues	7	
Leaching	29	0.3
Denitrification	38	
Total output	111	6.6
Balance	-43	11.5

Ref: Swedish University of Agricultural Sciences, 1998. Baltic Agricultural Run-off Action Programme, BAAP, 1994-1997. Final report, International Office, Swedish University of Agricultural Sciences, Uppsala.

Figure 8.8. The new manure pad at the Mäo farm, Estonia (Swedish University of Agricultural Sciences, 1998).

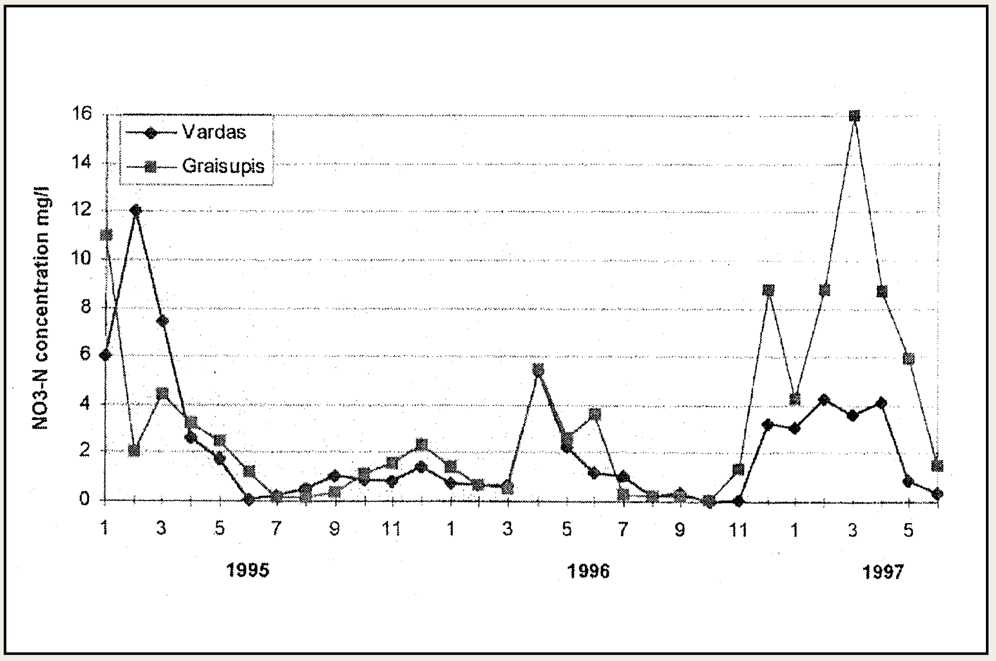


Figure 8.9. Typical variation of nitrate in the runoff water in the Vardas and Graisupis watersheds in Lithuania, which are dominated by agricultural activities. High nitrate peaks are present during winter and spring floods whilst the concentrations are low during low flows especially during the summer periods when the plants consume both water and nitrogen. (From Swedish University of Agricultural Sciences, 1998).

Household plots of cabbage near Minsk, Belarus (photo, Peter Ocskay).

9.

URBAN-RURAL NUTRIENT FLOWS

Göran Carlson, Christine Jakobsson & Staffan Steineck

Background

In 1995, human and industrial effluents were responsible for approximately 50 % of the total leakage of nitrogen in Sweden to marine waters, the Baltic Sea and the North Sea. Towns, industries and agriculture are not the only contributors of nitrogen to the environment. When water toilets were installed for hygienic reasons in the countryside, inland lakes and rivers also began to become severely polluted by the toilet effluents.

During the 1970s sewage works were improved to precipitate the phosphorus but nitrogen passed through into the rivers. The main part of the nitrogen entering the sewage works still passes through, but methods to reduce nitrogen are installed in some sewage works today. For single households, collection and purification of human effluents is still very primitive and nitrogen, as well as phosphorus, is lost to the environment. In Sweden today, single households in rural areas are one of the main polluters of water bodies.

Definition and goals of sustainable agriculture

Agriculture contributes significantly to the society of the future. Sustainable agriculture is the long-term production of high quality food and other agricultural products/services with economy and social structure taken into consideration, in such a way that the resource base of non-renewable and renewable resources is maintained. Important sub-goals are:

1. The farmer's income should be sufficient to provide a fair standard of living in the agricultural community.
2. The farmers should practise production methods that do not threaten human or animal health or degrade the environment, including its biodiversity, and at the same time minimise our environmental problems that future generations must assume responsibilities for.
3. Non-renewable resources have to gradually be replaced by renewable resources and the recirculation of non-renewable resources has to be maximised.
4. Sustainable agriculture will meet society's needs for food and recreation and preserve the landscape, the cultural values and the historical heritage of rural areas and contribute to creating stable, well-developed and secure rural communities.
5. The ethical aspects of agricultural production are secured.

Legislation on sewage sludge

Of great importance for sustainable agriculture is the recirculation of nutrients between urban and rural areas. This is especially important for phosphorus, as phosphorus is a finite deposit with different estimates regarding the available amounts varying between 80 to 400 years. Phosphorus is a prerequisite for growing food and fodder. Therefore, it is of utmost importance that:

- The available phosphorus content of arable topsoil should not exceed the requirements of an acceptable crop production.
- The annual phosphorus input should be calculated in relation to:
  - the phosphorus content in the field and
  - the crop's requirements.
- Good monitoring data on the phosphorus status of arable land is needed in every country, as well as nutrient balances to show if the supply of phosphorus in the soils increases or is depleted.

At the farm level, the phosphorus input should be of the same size as the amount of phosphorus removed. Phosphorus nutrient balances should be performed on the farm to show the size of the phosphorus surplus and should be used when planning fertilisation.

This also makes it necessary to have high quality rural area waste recirculated on agricultural land. It must not be polluted with heavy metals, organic compounds and other unwanted components. This also makes it important to involve the consumer in the process, as he or she must be aware that, depending on how he or she uses the toilet and sink, food quality can be affected.

Legislation is one means to make it possible to recycle human effluents back to agriculture. Different levels of legislation exist. For all countries in the EU, the EU directive (86/278/EEG) on protection of the environment (especially the soil), when sewage sludge is used in agriculture, is relevant and can be considered to be the minimum level for legislation. Most countries in Europe also have national legislation on sewage sludge, which for many countries is stricter.

EU Sewage Sludge Directive (86/278/EEG)

In the EU sewage sludge directive, the goal is to regulate the use of sewage sludge in agriculture so that negative effects on the soil, vegetation, animals and people are prevented, while at the same time the use of sewage sludge is promoted. The maximum levels of heavy metals regarding the contents in the soil and in the sewage sludge are stated in Tables 9.1 and 9.2, respectively. The maximum amount of sewage sludge to be spread per land area per year and the amounts of heavy metals in the sludge taken into consideration, are given in Table 9.3.

The directives also state that sewage sludge must be treated before use in agriculture, except in some cases if it is incorporated in the soil immediately. The producers of sewage sludge must give specified information on a regular basis about the quality and amounts spread, as well as where it is spread. It is also stated that sewage sludge must not be used on grasslands or pastures if the crop will be harvested within three weeks. All use on fruit and vegetables fields, except in fruit orchards, is prohibited. The use of sludge is also prohibited when growing fruit and vegetables that normally are in direct contact with the soil and normally are eaten raw, for 10 months before the harvest as well as during the harvest. Methods of analysis of both the soil and sewage sludge are described.

Table 9.1. EU limit values for the amounts of heavy metals in the soil

Parameter	Limit value (mg/kg dry weight)
Cadmium	1 – 3
Copper	50 – 140
Nickel	30 – 75
Lead	50 – 300
Zinc	150 – 300
Mercury	1 – 1.5
Chromium	-

Table 9.2. EU limit values for the amounts of heavy metals in sludge for agricultural use

Parameter	Limit value (mg/kg dry weight)
Cadmium	20 – 40
Copper	1 000 – 1 750
Nickel	300 – 400
Lead	750 – 1 200
Zinc	2 500 – 4 000
Mercury	16 – 25
Chromium	-

Table 9.3. EU limit values for the yearly amount of heavy metals that may be spread on agricultural land on average during a ten-year period

Parameter	Limit value (g/ha/year)
Cadmium	0.15
Copper	12
Nickel	3
Lead	15
Zinc	30
Mercury	0.1
Chromium	-

Swedish legislation concerning the utilisation of sewage sludge

The Swedish legislation consists of both an ordinance and regulations. In the ordinance (1985:840) about some products detrimental to health and the environment from the 18th of November 1993, maximum levels for the heavy metal content in sewage sludge for utilisation in agriculture are stated in Table 9.4. The Environmental Protection Agency issued the regulation on the protection of the environment and in particular of the soil, when sewage sludge is used in agriculture (SNSF 1994:2). The regulation corresponds to a large extent to the content of the EU sewage sludge directive, but is much stricter regarding the limit values of heavy metals permitted. Limit values for the annual amount of heavy metals that may be applied to soil on the average during a 10-year period are presented in Table 9.5.

The soils content of phosphorus and the content of both phosphorus and ammonia in the sewage sludge must also be taken into consideration. Sludge should be used in accordance with the plant nutrient requirements and in such a way that the quality of the soil, the surface water and the groundwater is not reduced. The maximum amount of total-P and NH_4-N per hectare to be spread per year with sludge is given in Table 9.6.

The maximum amount of total-phosphorus that can be spread on every occasion when sludge is spread is 175 kg on soils in P-classes I and II and 110 kg on soils in P-classes III – V. The maximum concentrations of heavy metals in the soil are also stricter in the Swedish legislation than in the EU sewage sludge directive.

The use of sewage sludge is stricter in the Swedish legislation. On grassland, use is totally prohibited, and the use on fields used for grazing or on fields

Table 9.4. Maximum concentrations for the heavy metal content in sewage sludge for utilisation in agriculture according to Swedish legislation

Metal	Max concentration (mg/kg dry weight)
Cadmium	2
Copper	600
Nickel	5
Lead	100
Zinc	800
Mercury	2.5
Chromium	100

Table 9.5. Maximum annual amount of heavy metals that may be applied on average to soil during a ten-year period according to Swedish legislation applying from 1995 and 2000

	Amount limit value applying from	
Metal	1995 (g/ha/yr)	2000 (g/ha/yr)
Cadmium	1.75	0.75
Copper	600	300
Nickel	50	25
Lead	100	25
Zinc	800	600
Mercury	2.5	1.5
Chromium	100	40

used for production of green fodder is prohibited if the fodder is to be harvested within 10 months after the sludge has been spread.

In order to stimulate the use of sewage sludge in agriculture, the Federation of Swedish Farmers (LRF), the Swedish Environmental Protection Agency (SEPA) and the Swedish Water and Wastewater Association (VAV) made a joint agreement on a series of measures and voluntary precautions. The measures are aimed at preventing undesirable substances and chemicals from being discharged into the sewer system. The precautions have been drawn up in order to meet the interests and concerns of the general public and agriculture, and consist of restrictions on the choice of crops and how much time should elapse between fertilisation with sewage sludge and harvesting of the crops.

Nutrient leakage - Nutrient balance

The idea of achieving a sustainable society, including recirculation of wastes, claims to change the entire approach on how to handle human effluents. To achieve a functioning recirculation system, efforts must be made on all levels, both nationally and internationally, from governments to individuals. In a sustainable society, the natural resources are restrictively used and recirculated to a high extent. Effective recirculation of nutrients in waste from people, livestock, and industries and other activities in the society is essential to reduce the leakage to water bodies and to avoid pollution. Since agriculture is the most natural and easy way to recirculate nutrients, it has a central role in this recirculation process. To avoid unnecessary leakage to water bodies, the nutrients in the recirculated wastes should be used for production of biomass. The application rates must not exceed the crop uptake and the chemical composition and the hygienic quality must follow permitted limits. Nutrient balances for the amount applied and the utilised nutrient can be made on different levels, e.g. national, regional and county, municipality etc.

Table 9.6. The maximum amount of total-P and NH_4-N per hectare to be spread per year with sludge for different soil phosphorus classes

The phosphorus class of the soil[1)]	total-P (kg)	NH_4-N (kg)
I and II	35	150
III - V	22	150

[1)]Easily soluble phosphorus (P-AL)

Class	mg per 100 gram dry soil
I	< 2
II	2.0 - 4.0
III	4.1 - 8.0
IV	8.1 - 16
V	> 16

[1] Retention: Denitrification (N) and changes in soil storage (N and P).

Nutrient balances on a national level

In Sweden, 50 kg of meat from pigs, cattle and chicken is consumed per person per year, which is a rather low consumption compared to the rest of Europe. Each person also consumes 400 kg of milk. Part of it is for everyday drinking purposes and part of the milk is consumed in butter, cheese, cooked dishes, chocolates and bread. Some 240 eggs or 17 kg of eggs per year and person is consumed, not only for breakfast but also in pastries and dishes. Swedes, who have a fancy for boiled potatoes with lunch and dinner, are the largest consumers of potatoes in the world with 100 kg per person and year. An increasing part of the potatoes are consumed as chips and french-fries. Grain for bread, 100 kg per person per year, is normally wheat. However, some rye is used for dark bread but it is mainly used for hard bread, a speciality of Sweden. Vegetables are consumed at an increasing pace and the consumption today averages 100 kg per person per year (Brangenfelt et al., 1993; Carlson et al., 1993a; 1993b).

Swedish agriculture is well suited to supplying basic food on a national basis, (SCB, 1996). Based on a limited input of fertiliser nitrogen, 80 kg per hectare, the agricultural output per hectare in Sweden is among the highest in the world (SCB, 1996). In 1995, agriculture could supply food for each person in Sweden from 0.16 hectares. Most of the agricultural land, about 90 %, is used for animal feed and only about 10 % for production of cereals for human consumption, potatoes, rapeseed for margarine and sugar beets.

National and international balances can be used to compare pollution of air and water in different nations. These balances can also be used as a reference for environmental measures and legislation.

In 1997, the Swedish Institute of Agricultural Engineering and the County Board for Dalecarlia carried out a study to calculate the contribution of nutrients to the Baltic Sea. This study is included in the background material to the Baltic 21 agricultural sector report, a co-operative activity to create an Agenda 21 for all countries around the Baltic Sea. Table 9.7 presents the plant nutrient balances (kg N and P per hectare and year) for agricultural areas in Sweden in 1994 and Denmark and Lithuania in 1995. The national balances are average values and do not take regional imbalances into account.

Agriculture in Denmark had almost twice as large an input of nitrogen as Sweden, but a nutrient utilisation ratio, NUR, similar to Sweden. Accordingly, Danish agriculture must have had very large losses of nitrogen, in absolute amounts, compared to Sweden. The balances indicate that ammonia emission and nitrogen retention were twice as high in Denmark as in Sweden, but that the two countries had similar levels of nitrogen runoff. The high nitrogen retention in Denmark and Sweden indicates that denitrification is an important process in removing nitrogen, but nitrogen might also to some extent accumulate in the soils. The latter process is obvious for phosphorus. The phosphorus utilisation seemed to be as efficient in Denmark as in Sweden, with a NUR of 56 % and 52 %, respectively.

Agriculture in Lithuania managed to have a small export of dairy products. Nutrient inputs in agriculture in Sweden were, however, four times greater and in Denmark eight times greater. It is most probable, however, that the crops are utilising the supply of organic nitrogen in the soils. The nitrogen balance indicates a loss of 6 kg N/ha/yr from the soils, while the phosphorus additions seem to be in balance with the removal. Negative nitrogen balances can be maintained for many years before the harvests drop dramatically. Both the nitrogen and phosphorus utilisation seemed to be more efficient in Lithuania than in Sweden and Denmark. The ammonia emissions and the N and P runoff seemed to be less than 50 % of the more intensively cultivated production systems in the countries compared.

Table 9.7. Nitrogen and phosphorus balances (kg per ha and year) for agricultural areas in Sweden in 1994 and in Denmark and Lithuania in 1995, based on official statistics and estimations

	Sweden		Denmark		Lithuania	
Nutrients added	**N**	**P**	**N**	**P**	**N**	**P**
Mineral fertiliser	78	9	117	8	12	2
Deposition	10	0.3	17	0.3	10	0.3
Biological fixation	7	–	14	-	1	-
Animal feed import	14	1.7	61	7.5	1	0.2
Total	**109**	**11.1**	**209**	**15.8**	**24**	**2.5**
Nutrients removed	**N**	**P**	**N**	**P**	**N**	**P**
Export, agr. products	5	1	35	6.9	2	0.3
Human consumption	24	4.8	10	1.9	7	1.4
NH3-emissions from						
manure	14	-	31	-	8	-
mineral fertiliser	2	-	3	-	0	-
plants	5	-	5	-	4	-
Nutrient runoff	17	0.3	23	0.4	9	0.3
Retention	42	5.0	102	6.6	-6	0.5
Total	**109**	**11.1**	**209**	**15.8**	**24**	**2.5**
Nutrient utilisation ratio (%)	**27**	**52**	**22**	**56**	**37**	**68**

Regional balance of production and consumption of food

In the middle of the 60s in Sweden, political decisions based on assumptions of efficiency in large units led to a specialisation in production, farm size and number of farms. All farms were to be rational and efficient and produce one main commodity. The farms were specialised in plant, milk or pork production and subsidised by the government. There was a trend for concentrating plant production in the plains areas; milk production in the hilly forest areas and pig production to the south on the plains along the coasts. Today, most of the feed grain is produced on the plains along the southern coasts, in the plains of Västergötland and Östergötland and in the area around Lake Mälaren. More than half of the pigs are produced in the south, while the feed-grain from other parts of Sweden has to be transported there, mainly by trucks. In Figure 9.2, the fluxes of nitrogen and phosphorus in feed grain and pork are shown for 1994; the situation has not changed to any great extent since.

The consumption of pork produced in southern Sweden is to a large extent concentrated in the Lake Mälaren region and the production of pork on the south plains. To feed one pig corresponding to 85 kg of pork, three times the carcass weight of pigs is transported to the south in barley and oats. After slaughter, the meat is transported back to the Lake Mälaren region and eaten. Another complication is that five times as much phosphorus is transported to the south compared to what is coming back in pork meat. This leads to an increasing concentration of phosphorus in the soils in the south (Figure 9.2).

Eggs are another commodity, where the production is concentrated in the south whereas the consumption and the production of animal feed are elsewhere. This is a large-scale example of regional imbalances in production and consumption of human food. These balances are based on statistics by Statistics Sweden (SCB, 1996).

As can be seen in Figure 9.2, which shows where food is produced, there is an imbalance in where people live and where food is produced. These are some examples of how politics have influenced the place for agricultural production of certain commodities, ignoring where they are consumed. It is natural that human food and animal feed should be produced in the most suitable places for plant production. Nature, soils and climate are the factors that determine where the most suitable agricultural production can take place. It is, however, also natural that meat, milk and eggs should be produced close to the consumers.

The leakage of nutrients and the amount of nutrients in the effluents delivered to water bodies can be calculated using nutrient balances on a municipal level. In 1993, such balances for nitrogen and phosphorus were worked out for the municipality of Östhammar situated on the east coast of Sweden. The municipality has a total land area of 1 452 km^2 and a population of 21 941 of which 14 408 lived in towns (figures for 1990, which did not change significantly during 1990-1998). These balances are the result of a co-operation between the municipality and researchers from the Swedish University of Agricultural Sciences in Uppsala and farmers in the municipality. In Figure 9.3, the balance for nitrogen is presented for this municipality and a corresponding balance for phosphorus is presented in Figure 9.4. This study showed that the largest contribution of nitrogen as nitrate to coastal water originates from agricultural production. The contribution from agriculture is nearly threefold higher than the contribution from single household wastewater, 202 tonnes compared to 83 tonnes per year. For phosphorus the contribution was more than threefold from single household wastewater as compared to agricultural production, 10 tonnes compared to 3 tonnes per year.

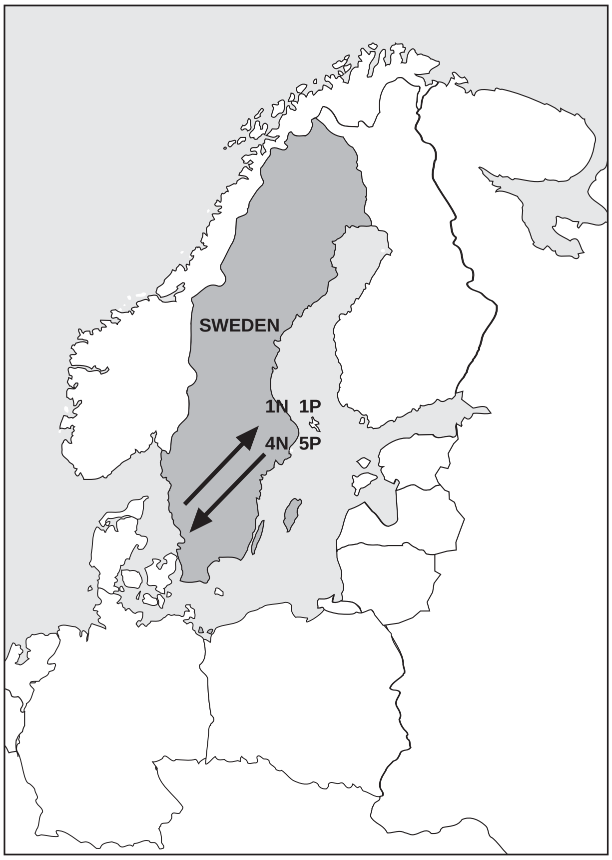


Figure 9.2. The flux of nitrogen and phosphorus in feedgrain and pork meat between the Lake Mälaren region and the south of Sweden in 1994 (Steineck et al., 1997).

Nutrient balance on town level

There is no agricultural production in the towns. People are supplied with plant nutrients in human food from agricultural areas. In the towns, areas exist without buildings, such as streets, squares and green areas. Green areas are often fertilised with mineral fertilisers or composted park refuse. Sometimes, but not normally, human refuse composted with park refuse is used in parks and flowerbeds. The flow of plant nutrients is linear and aimed at the city or the municipality. Plants' nutrients leave the towns as park-refuse and sewage sludge to go to landfills and the nitrogen can leak mainly to surrounding waters and the air. Phosphorus, used as fertiliser in the green areas, is stored in the soil, as phosphorus is fixed to soil particles and little is leached. Much of the nitrogen added is transformed to nitrate nitrogen in the soil and is leached when water percolates through the soil in the autumn and the spring.

Leaving the immediate surroundings of the town, we enter a more productive area where private gardens are numerous and some agricultural production may take place. In more forested areas some leisure activities are found. In the gardens fertilising is done according to norms set by professional gardeners and amateurs add some extra fertilisers and animal ma-

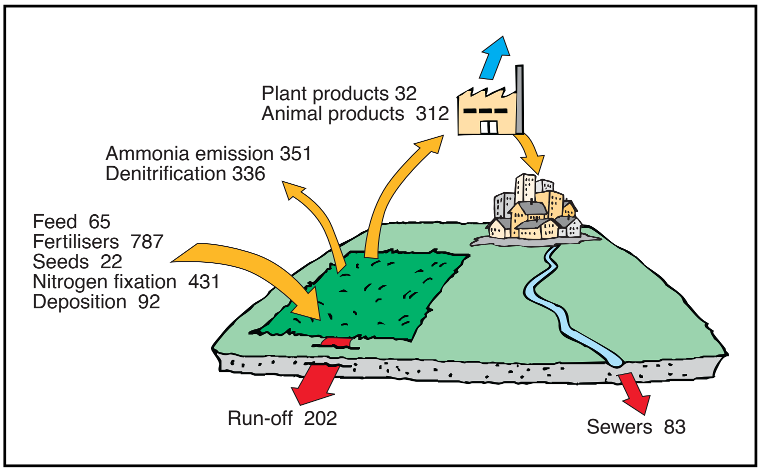


Figure 9.3. Input/output balance for nitrogen, tonnes per year, in the municipality of Östhammar, Sweden for the year 1992.

nure just to be sure. Added plant nutrients in fertilisers and manure exceed by far the plants' nutrient requirements that are removed by the produced vegetables. As a rule the overdose of nutrients per area in private gardens by far exceeds the overdoses found in traditional agriculture. There is considerable nitrate leaching from these gardens as they are heavily cultivated and left without covering plants most of the year.

Agriculture in these areas is extensive and animals, with the exception pets, are not usually raised. In the immediate vicinity of human living areas, especially in densely populated areas, very often restrictions on odour and allergy risks keep back animal production. From the private gardens and the extensive farming there is a small trickle of plant nutrients reaching the inhabitants in the living areas. Forests are not fertilised by more than the normal deposition of nitrogen and phosphorus from the atmosphere and nutrients are only removed when the trees are felled. Losses to the environment are small, except at and a few years after felling (Claesson & Steineck, 1991; 1996).

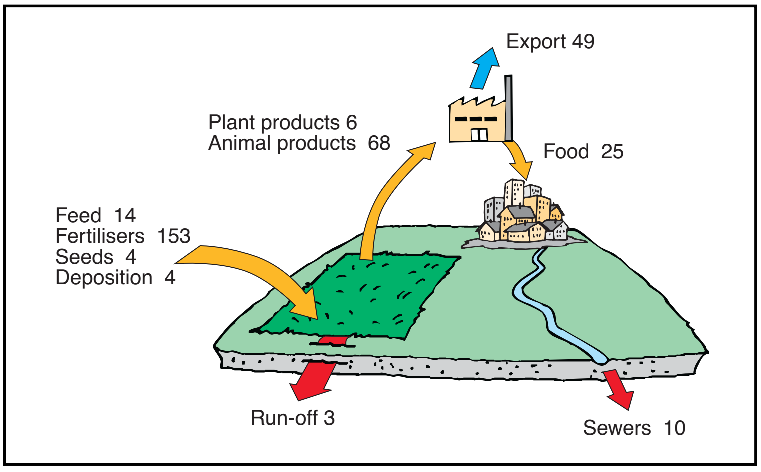


Figure 9.4. Input/output balance phosphorus, tonnes per year, in the municipality of Östhammar, Sweden for the year 1992.

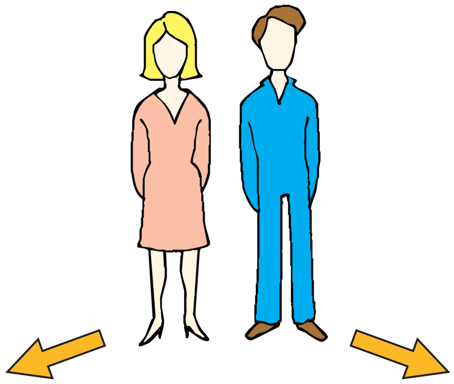
Plant nutrient balances for human beings are based on amounts of food that are consumed and amounts of urine and faeces that are expelled from the human body. The amount of plant nutrients in the urine and faeces varies with the amount of nutrients in the food, according to the same principles for animals. However, there is a slight difference in the amount and distribution of plant nutrients between vegetarians and omnivores. A vegetarian consumes less protein than the omnivore does, and thus leaves less nitrogen in the faeces and urine. On the other hand, the vegetarian diet contains more potassium than the diet with meat, which results in larger amounts of potassium in urine and faeces from the vegetarian.

Two balances have been created from the menus for a vegetarian and an omnivore. The balances show that the omnivore consumes 5.9 kg nitrogen, 0.75 kg phosphorous and 1.9 kg potassium during one year. The vegetarian consumes 5.2 kg nitrogen, 0.8 kg phosphorous and 2.5 kg potassium during one year.

Adult human beings do not store nitrogen, phosphorous or potassium in the body. Energy and micronutrients in the diet are absorbed and the rest pass right through the body. 85 % of the nitrogen is found in the urine and 15 % in the faeces, while phosphorous is distributed with 70 % in the urine and 30 % in the faeces. 70 % of the potassium is found in urine and 30 % in faeces. These figures relate only to the amounts of nutrients that pass through the body. The amount of nutrients passing through the sewage system may be higher, due for example to the use of detergents containing phosphorous.

Nutrient balances on village and small-municipality levels

The majority of the rural population lives in villages and small towns. Very often, toilet effluents are discharged into the closest recipient with unsatisfactory sewage treatment. Relatively often, the treated water passes through poorly functioning treatment plants or a kind of bio-pond before it reaches the recipient. With this treatment, nitrogen and phosphorus in the effluents are only reduced to a very low degree, 10-30 %, and large amounts of nutrients enter streams and lakes, causing severe eutrophication problems. In or-



Normal consumption

Urine+faeces, kg/year

	N	P	K
Urine	*5,2*	*0,5*	*1,3*
Faeces	*0,7*	*0,25*	*0,6*
Sum	*5,9*	*0,75*	*1,9*

Vegetarian

Urin+tr‰ck, kg/year

	N	P	K
Urine	*4,6*	*0,5*	*1,8*
Faeces	*0,6*	*0,3*	*0,7*
Sum	*5,2*	*0,8*	*2,5*

Figure 9.5. Fluxes of nitrogen, phosphorus and potassium, kg per person and year for people who are omnivores versus vegetarians.

der to reduce the environmental impact and to gain profit from these nutrients, as much as possible of these remnants should be returned to agricultural land and used as fertilisers.

Different sewage treatment techniques are available for cleaning sewage from households in small villages, but costs and nutrient reduction efficiency vary. Experience gained in Sweden from conventional small sewage treatment plants, with reduction of organic matter and phosphorus precipitation, shows that interruptions to the service often occur because of the uneven inflow of sewage water. It is also necessary to have well educated people to run the equipment.

It is, however, possible to improve the sewage water treatment by using other low-cost technologies. One possibility is to improve the removal of organic matter and phosphorus by precipitation with lime followed by sedimentation in ponds. The results show that BOD, biological oxygen demand, and phosphorus reduction are on the same levels as at conventional plants with mechanical, biological and chemical treatments. The investment needs and running budget is approximately one-third of the costs for a conventional plant in Sweden.

The sludge collected in the mechanical step could be reused on agricultural land after decomposition and dewatering, assuming that no toxic wastes have been allowed to enter the plant. Bio-ponds are already established in many rural villages and, where lime is easily available, this seems to be the most interesting sewage treatment technique for small (< 5 000 persons) rural villages.

Weak points in the situation today

As can be seen in Figure 9.6, there is a stream of plant nutrients leaving agriculture as human food. Today, little is returned and used in the production of more human food. Much of the nutrients are deposited but a fair share is lost to the environment where it causes pollution. In a sustainable society all human waste, containing plant nutrients, is recirculated to agriculture.

In Sweden sewage sludge constitutes a large part of the human waste, 240 000 tonnes of dry matter per year, causing severe problems. Recirculation to agriculture is today the only sustainable way to utilise the plant nutrients in the sludge from the sewage works. Sludge is not purely human effluents containing plant nutrients and organic matter. It also contains residues from all effluent sources in towns entering the sewage plants. These residues are more or less harmful. The three most important harmful groups are heavy metals, organic substances and pathogens, which cause disease.

Extensive research and experimental field trials regarding the nutrient efficiency of plant nutrients in sewage sludge in agricultural production have been going on since the 1960s. The work has been of limited and short perspective, and normally of a short duration. In the meantime the techniques to analyse and study the contents in sewage sludge, farm soils and food products have improved considerably. Other improvements concern the techniques of sewage treatment and the accuracy in applying sludge to

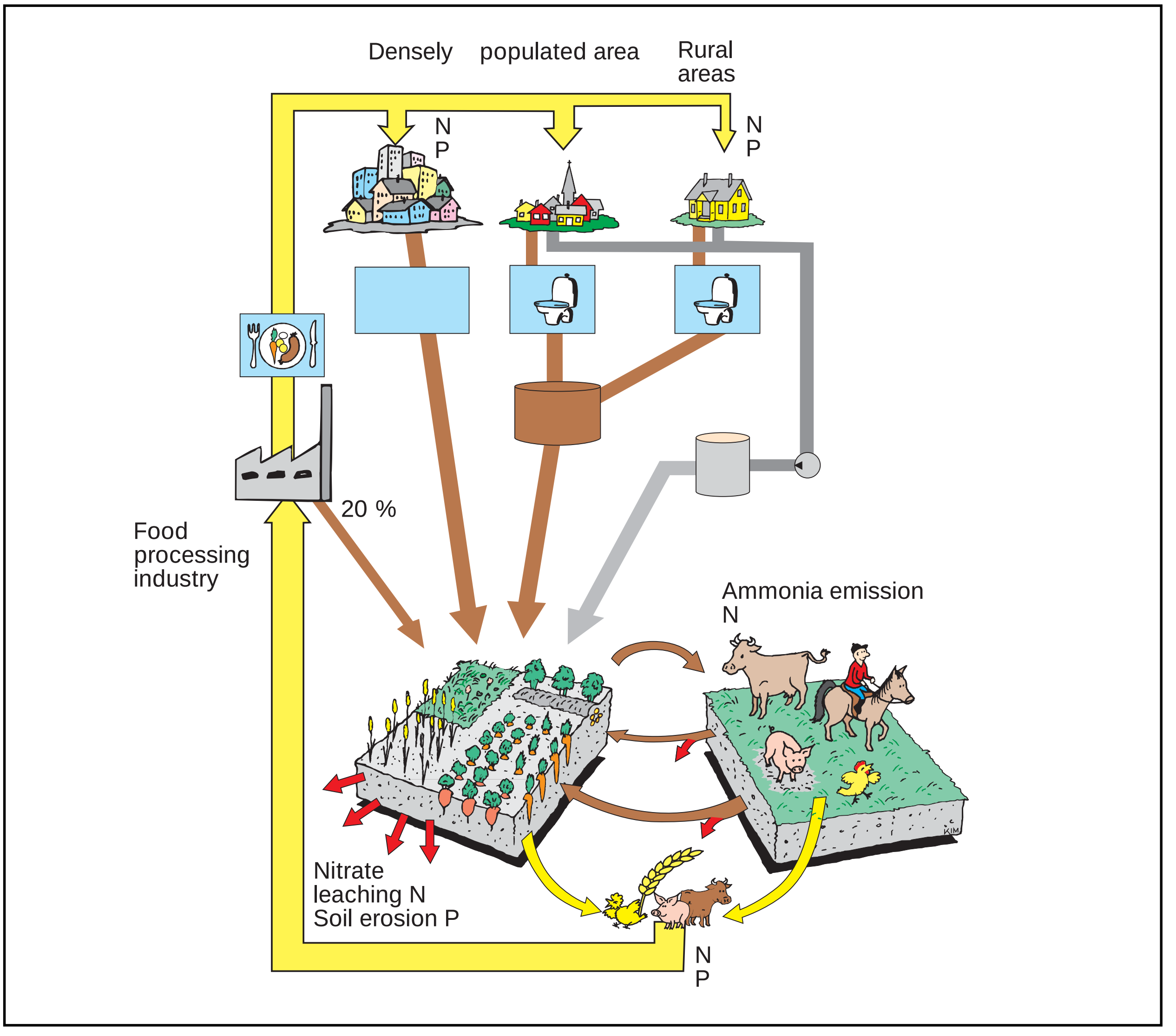


Figure 9.6. Overview of nutrient fluxes from agricultural production of animal feed and human food and the paths to recirculation of human effluents.

farmland. It is now technically possible to properly utilise plant nutrients in sewage sludge.

Applying sewage sludge to farmland is an issue much discussed in Sweden and abroad. In 1995, the Swedish Environmental Protection Agency, SEPA, the Federation of Swedish Farmers, LRF, and the producers of sewage sludge signed a special agreement on guidelines for maximum allowable amounts of heavy metals, organic substances and pathogens.

Attitudes towards the use of sewage sludge in agricultural production vary considerably between the EU-countries. Conditions for and the attitude toward recirculation of sewage sludge to farmland are much more positive in Sweden than in many other EU-countries. This is due to combined interests from many groups in the Swedish society for sustainable farming.

In spite of this, there are some large food processing industries in Sweden that hesitate to sell products from farmers receiving and using sewage sludge in their production. They feel that the consumers might be hesitant to buy food produced on farms using sewage sludge.

In 1995, it was estimated that 85 to 90 % of the sludge produced in Swedish sewage plants fulfilled all criteria according to the agreement, but only some 35 % of the sludge is used for agricultural production today. The remaining sludge is not used in agricultural production but stored in landfills or applied to non-farming land.

Actions to be taken

In the future, such as when political resolutions decide that plant nutrients should be recirculated to farmland, changes must take place. Nutrient balances on different levels, such as national, regional, watershed, city, municipality, town, farm and field, can be an important tool for policy making but also to find discrepancies and to make decisions and implement measures to improve the environment. In agriculture, plant nutrient balances are used as a tool to control environmental impact and to improve the farmer's use of his assets, thereby improving his economy.

To support recirculation of municipal organic waste it is important that national and international resources for research are allocated to research on the recirculation of organic wastes. The result must integrate the entire chain from processing and utilisation and involve experts covering processing, environment, agriculture, food hygiene, health and food-processing industries as well as consumers and other stakeholders.

It is important that the results of this research are reliable and accepted by the stakeholder; otherwise it will be difficult to predict the consumers' preferences. If these preferences are unclear there will be little hope for a high degree of recirculation of municipal organic waste, which is a basic prerequisite for a sustainable society. The consumer must be involved in the process, as he or she must be aware that depending on how he or she uses the toilet and sink, the quality of food can be affected. To make this possible, much effort must be put into public awareness, to inform and educate the consumers to make the right choices and to take the right measures.

Not long ago horses were used on farms in the entire region. Today they are almost entirely replaced by tractors which pack soil and increase runoff (Photo, Lars Rydén).

10.

LEACHING OF NITROGEN AND PHOSPHORUS

Arne Gustafsson, Katarina Kyllmar & Barbro Ulén[1]

Leaching of nitrogen to water from agricultural areas

Eutrophication by nitrogen of coastal zones and seas is a major and growing water problem for the Baltic Sea and the North Sea. Both point sources and diffuse sources contribute to the problems. In Sweden and other countries there is now an ongoing work to reduce the nitrogen-contribution from large sewage treatment plants, a programme that seems to be successful. But the programme for reduction of diffuse sources, mainly from agricultural activities, has so far, in spite of considerable efforts, shown no evidence of substantially decreasing the nitrogen-loads in streams draining agricultural land in Sweden.

This can be evaluated in the JRK (Agricultural recipient control) monitoring programme network of small agricultural watersheds throughout Sweden. The measurements have clearly demonstrated that the nitrogen losses from many agricultural areas are too large. There is a considerable difference in nitrogen losses in different parts of the country due to climate, agriculture intensity and production differences. The mean losses ranged from 6-62 kg/ha/yr of Tot-N during the period 1988-1994. The very large losses in many areas undoubtedly contribute to serious eutrophication of the surrounding seas and in some areas make groundwater unacceptable for drinking water purposes. But there is also evidence that in some areas we are not far from acceptable losses and with some extra efforts the goals might be achieved within a limited timescale with relevant countermeasures.

Of course there is in many instances a time lag between the implementation of countermeasures within the agriculture system and their full effect on the water quality. The large nitrogen-pool of agricultural soils, which constitutes a considerable source of, mineralised nitrogen, vulnerable to leaching, changes only slowly. Nevertheless some measures have an immediate effect. These include the introduction of catch crops. However the best catch crops are not in frequent use and much work remains to be done to make them fully acceptable to the farmers. The contribution from ammonia emissions is also substantial. Loss of greenhouse gases and other related regulating mechanisms and countermeasures are still poorly known.

Requirement and water quality goals for nitrogen

According to existing criteria from the Swedish EPA for lakes and rivers, nitrogen concentrations in surface waters should not exceed twice the estimated natural or original unaffected levels (Table 10.1). However, it may be necessary to modify this requirement in catchment areas dominated by intensive agricultural land use, since this goal cannot be met with agricultural systems known or currently in use today. Further research will be necessary to develop improved cultivation methods, which will help to achieve this goal. Such low nitrogen concentrations have, however, occasionally been observed, which suggests that this is a realistic goal.

For groundwater (and drinking water), the concentration specified by SLV (Swedish National Food

Table 10.1. Long-term quality goals for nitrogen in surface waters

Concentration ratio, current/original	**Original concentration,** (mgl^{-1})	**Twice-goal,** (mgl^{-1})	**Goal in agricultural areas,** (mgl^{-1})
Nitrogen, 1.5-2.0	0.2	0.4	5.0

1 Arne Gustafsson and Katarina Kyllmar are the main authors while Barbro Ulén contributed with the section on leakage of phosphorus.

Administration) is 5 mg/l of NO_3-N. Such a concentration may indicate impacts of sewage applications or other pollutant sources. NO_3-N concentrations smaller than 1 mgl^{-1} indicate no impact of man's activities. Children less than one year old should not be exposed to drinking water with nitrate concentrations larger than 10 mgl^{-1}.

From the above, it is clear that the ecological quality requirements/demands are greater than the human toxicological is.

A second important source of nitrogen from agriculture is ammonia exhausts. Ammonia ends up on land and in water through precipitation, either as such or after oxidation to nitrous oxides. The ten-year goal for Swedish agriculture is to reduce ammonia losses by 25 %A similar goal could be set for the following ten-year period, since research into management practices to limit ammonia losses are expected to be more advanced. Such practices should be highly cost-effective, considering the likely impacts on reducing nitrogen deposition in Sweden.

The goal to reduce greenhouse gases, in particular carbon dioxide, is partly in contradiction to efforts to reduce nitrogen leaching. The long-term Swedish goal is to modify production and transport systems, as well as consumption patterns, so that CO_2 discharge from fossil fuel use is reduced by 50-60 % in the next 50 years. One strategy is to exploit agricultural land as a CO_2 sink. However, an increase in soil carbon levels can result in increased losses of nitrogen. There is, therefore, a great need for more research. At present, however, there is a net loss of CO_2 from drained soils rich in organic matter. Increased losses are largely due to oxidation of organic material following oxygenation and are also linked to the frequency and intensity of soil tillage.

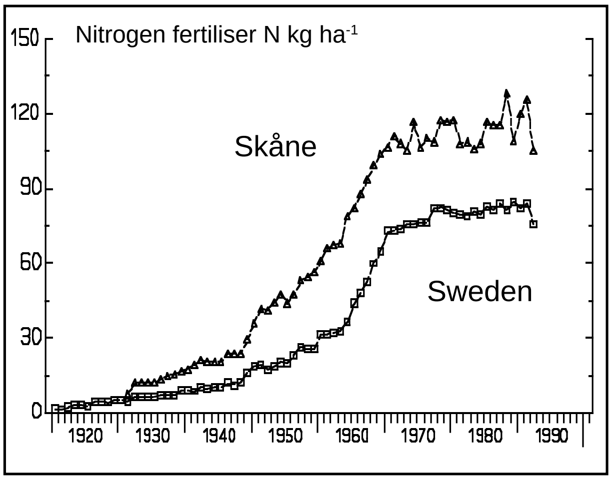


Figure 10.1. Purchase of inorganic nitrogen fertilisers in Sweden and the province of Skåne.

The complexity of nitrogen losses to water and air

Fluxes of nitrogen through the soil by drainage water vary greatly. Only a part of added nitrogen is removed with the harvest. In spite of successful cropping, the losses might be high due to intensive mineralisation of crop residues and easily decomposable organic material in the soil during the autumn period. Climatic conditions, pedological conditions, type of production and tillage management influence the mineralisation conditions.

Gas losses are also important but little is known in detail of how to manage these losses under field conditions. It is also necessary to optimise the agricultural system in such a way that a decrease in losses in one way does not increase losses in another way. Thus a holistic knowledge of nitrogen losses to water and air is of utmost importance to be able to manage an environmentally friendly food production system in the future.

Intensity of crop production increased after the Second World War. The breeding of high-yielding varieties of cereals and other crops, and chemical control of pests and diseases, required a higher input of mineral nitrogen, principally in the form of synthetic fertilisers. The amounts applied per hectare reached a plateau in the 1980s (Figure 10.1). For some crops there has been a marginal decline, and current agricultural policies are likely to cause further reductions, but overall the picture is not likely to change substantially, at least in the short-term.

The largest outputs are normally in the form of crop off-take, but quantities of readily mineralisationable nitrogen in the form of crop residues are also considerable in spite of greater percentual crop uptake in harvested products at actual fertilisation levels.

Animal-based systems have also been intensified over the same period, and large applications of nitrogen to land in the form of manure have become common. Losses of nitrogen from livestock-based agriculture have also increased with intensification, and contribute to a very significant part of total losses from soils.

Soil disturbance through cultivation also increases the rate of mineralisation. The result is an increased amount of mineral nitrogen in the soil profile, which is vulnerable to leaching and /or denitrification.

Of major importance for the balance between mineralisation and immobilisation is the C:N ratio in the decomposing organic substances. Although there is a general trend relating net mineralisation/ immobilisation to the C:N ratio, there is no precise critical value which marks the point at which reversal from immobilisation to mineralisation occurs. This is because other aspects of substrate quality have a major impact on the rate of decomposition. The rate of mineralisation of nitrogen from soil organic matter generally increases with increasing moisture content between permanent wilting point and field capacity. As the soil moisture content is raised above field capacity, however, mineralisation rates fall because of restricted aeration.

It is not only moisture content that is important; temporal changes in content, i.e. cycles of drying and wetting, have a profound effect on the rate of mineralisation. There is evidence that rewetting of a dried soil results in a burst of microbial activity associated with an expansion in microbial populations. The substrate responsible for the stimulation is partly microbial cells killed during the drying phase, with a low C:N ratio, and partly soil organic matter newly exposed to microbial attack as a result of physical disruption of aggregates due to swelling and shrinking of the soil.

Freezing and thawing have comparable effects to those brought about by drying and rewetting. The freezing process kills a substantial part of the soil microbial biomass, which is then available for decomposition by the surviving population, once the temperature increases to allow the resumption of microbial activity. In severe conditions such as those of a Swedish winter, the effects of freezing and thawing may exceed those of drying and rewetting.

Rates of organic matter decomposition generally rise rapidly with increasing temperature, above the range normally found in soils in the field. This may result in large differences in the rate of nitrogen mineralisation between typically cool conditions in early spring, especially in the north of Sweden, and conditions in midsummer. This is of considerable topical interest, because of the possible implications for organic farming systems.

In conclusion, mineralisation/immobilisation of nitrogen in soil is a complex process dependent on many factors. Much is known from laboratory experiments and much less from field experiments, especially for cold (autumn, winter, early spring) conditions. The conditions during the cold period, however, play an important role in the leaching of nitrate to the water bodies. Too little is known about the effect of catch crop management and the tillage regimes. More attention should be paid to this so that nitrogen leaching can be managed by proper control of the mobilisation/immobilisation processes.

Denitrification

Denitrification - the microbial reduction of nitrate to NO, N_2O and N_2 - is the major biological process by which the nitrogen cycle is completed and fixed nitrogen returned to the atmosphere. The environment in which the greatest quantities of nitrate, the essential substrate for denitrification, are likely to be found is agricultural land receiving substantial inputs of nitrogenous fertilisers or manure. Estimates of the quantities of nitrogen lost by denitrification from agricultural land differ widely; up to more than 50 % of the applied nitrogen has been reported. Concern about the loss of nitrogen by denitrification was originally inspired by apprehension of the agronomic and economic penalties stemming from the loss of a useful and costly nutrient. Now, however, such concerns have been supplemented by environmental problems resulting from the emission of nitrous oxide, N_2O. This gas is one of the more important contributors to the greenhouse effect and is also considered to be a partial cause of the depletion of the Earth's stratospheric ozone layer.

Recent work using modern methods of analysis for the gaseous products of denitrification confirms the greater losses in the presence of manure. Increased soil carbon contents after long-term manure applications also promote the process, as does straw incorporation. It appears to be a readily decomposable fraction of the organic matter that affects the capacity of soil to denitrify.

Denitrification rates are to some extent correlated with concentrations of nitrate in the soil. Where fertilisers containing nitrogen in the nitrate form are applied, much of the loss due to denitrification occurs in the period immediately following the application. This usually means that the maximum losses from cereal-growing land and grassland occur in spring, under Swedish conditions, with a tendency towards another peak in autumn from arable land, following the release of nitrate from the mineralisation of crop residues, and an increase in soil water content.

The effects of plants on denitrification are complex. On the one hand, they can promote it by providing carbon in the form of exudates and root cell material. On the other hand, water demand by the plants dries the soil and improves aeration; plant uptake of nitrate removes it from the danger of loss by denitrification.

Many studies have shown that denitrification activity in soils is correlated with water content. This dependence on water content is a direct consequence of the fact that the diffusion rate of oxygen through a water-filled pore is only one ten-thousandth of that through an air-filled pore. The potential for the development of anaerobic zones is thus to a greater degree dependent on water content than any other variable.

Agricultural land is a significant source of emissions of N_2O. Normally, but not always, increased fertiliser rates correspond to greater emissions. Several studies have shown that very high rates of N_2O emission may occur when peat soils are drained and cultivated.

A major factor contributing to the variability of N_2O emissions due to denitrification is the wide variation in the fraction of total gaseous flux emerging as N_2O (the remainder being N_2). It appears that soil structure and water content, affecting the balance between diffusive escape of N_2O and its further reduction to N_2, are important factors determining the proportions of the two gases.

Soil pH is another factor affecting the ratio of N_2O to N_2 in the gaseous products of denitrification. Inhibition of N_2O reduction to N_2 occurs at all concentrations of nitrate at low pH, resulting in an increased proportion of the emissions occurring as N_2O. Tracer studies have shown that the effect of acidity on N_2O is an immediate one, and thus not due to a change in the balance of microbial population.

In general, knowledge concerning losses of methane and dinitrous oxide emissions from agricultural systems must be improved and research into management practices to reduce losses must be conducted.

Conclusions: The possible risk for formation of N_2O lends great importance to the denitrification process and the manipulation strategies to avoid both major denitrification of a valuable N-resource and the formation of N_2O. Not much is done under Swedish conditions concerning this issue and even less when it comes to interactions between mineralisation/denitrification and countermeasures against nitrogen leaching through different field management strategies. This must be an important field of basic research in the future.

Ammonia volatilisation

Nitrogen can be lost from agricultural soils by the release of gaseous ammonia, NH_3, into the atmosphere. The predominant source of the ammonia in the farming systems is urea in the faeces and urine of livestock, either voided directly onto land by grazing animals or spread as slurry or farmyard manure. Ammoniac fertilisers also contribute to the release, when applied to calcareous soils. The ammonia lost to the atmosphere is a major contributor to acid deposition. Some of the NH_3 deposition is very local, within a few hundred meters of the source; at the other extreme, some is dispersed over large areas.

When urea is added to a soil, the urease enzyme rapidly hydrolyses it to ammonium and bicarbonate ions. The latter tend to raise the soil pH near the surface, and promote the loss of NH_3 by volatilisation. The amounts of ammonia lost are influenced by a number of factors, such as aerodynamic factors affecting the transfer of NH_3 from the soil surface to the atmosphere, the amount of urea applied, the rate of hydrolysis, the initial pH and the buffer capacity of the soil, the soil moisture level and the depth of application.

There exists rather good and detailed knowledge concerning individual processes regulating losses of NH_3 from arable soil but on the combined effect of all simultaneous ongoing processes there is still a considerable lack of knowledge. Research must therefore be directed towards a more complete understanding of the combined effect of all ongoing processes to reach the final goal of better utilisation of the nitrogen resource and thereby save the surrounding environment.

How nitrate moves in the soil

Of the various combined forms of nitrogen present in soils or added as fertiliser, only the nitrate ion is leached out in appreciable amounts by water passing through the soil profile. This is because there is no significant adsorption of nitrate onto soil surfaces, and there are no common insoluble nitrates. Thus nitrate in the soil solution is displaced downwards by rainfall or irrigation water and if sufficient water is added it can be carried beyond the root zone and eventually to the groundwater.

The water content of the soil affects the rate of downward movement of nitrate during leaching. The depth of displacement by a given quantity of rainfall is generally greater for sandy soils than for clays. However, nitrate movement in the field is a complex process, and the effect of soil structure increases as clay content increases. Variations in pore size, in the spatial distribution of pores and their continuity all contribute to irregular movement of water down the soil profile. The effect of this is to spread out the front between the resident soil solution and the displacing rainfall, a phenomenon known as hydrodynamic dispersion. Superimposed on this effect is diffusive dispersion of nitrate in the soil solution, due to differences in concentration within the soil profile.

Recognition of the high hydrodynamic dispersion in structured soils has led to the concept of mobile and immobile water. The immobile water is retained in the peds, from which nitrate can only be transferred to the mobile water phase by diffusive transfer across the mobile-immobile water interface. This concept has been used with good effects in improving simulation of solute transport in structured soils. However, under intensive rainfall, water and solute may completely bypass the mobile pore system and move via large macropores. The description of water movement under these conditions is being developed, but detailed analysis of solute transport under these conditions is still lacking. One problem with improving the description of bypass transport is the highly transient nature of this type of transport. Time steps during simulation need to be the same order as rainfall events (i.e. hours rather than days), and data with such high time resolution are often lacking.

Sources of leachable nitrogen

Obviously, the size of the sources of nitrogen available for leaching will vary as regards both place and time. An example from a 9-year-old experiment on a clay-till in Skåne (southern Sweden) may serve as an example of the relative size of the sources in this part of the country. The dominating crops were spring wheat, barley and sugar beets (Table 10.2).

The amount of residual nitrogen and mineralisation during the winter in this example were of about the same magnitude. Atmospheric deposition was by far the smallest component. Almost half of the nitrogen available for leaching was in fact leached. Discharge is, on the average, 237 mm. A larger discharge would have increased the leaching, while a smaller discharge would have decreased the leaching. Since the size of the discharge depends largely on the amount of precipitation and its distribution, we are unable to influence the factor that regulates leaching apart from using irrigation. However, the amount of nitrogen available for leaching can be controlled to some extent. In the short-term, attempts can be made to reduce the amount of residual nitrogen by better dosing of the fertiliser in both amount and time. The amount of organic material available for mineralisation can also be influenced. This is particularly important in a long-term perspective. It is essential to attack both sources in order to achieve a meaningful reduction in leaching. Another possibility is to make use of catch crops during the winter so that the mineral nitrogen becomes incorporated into the plant material instead of being leached; this will be discussed in greater detail below.

Table 10.2. Sources of nitrogen and nitrate leaching. Results from a 9-year investigation on a clay-till in southern Sweden. The dominating crops were spring wheat, barley and sugar beets

Nitrogen source	**Time**	**N** (kg/ha)
Nitrate in the soil, residual-N, down to a depth of 1 m in the soil	1 Sept.	31
From mineralisation of litter and other organic material in the soil	1 Sept. - 31 March	34
Atmospheric deposition	1 Sept. - 31 March	6
Total available		71
Leached through drainpipes		31

The role of soil organic material

The availability of relatively easily mineralised organic nitrogen in the soil is, as has been discussed, of major importance for the magnitude of the leaching. Soils given large amounts of organic material will, in the long-term perspective, have a larger capacity for net mineralisation. Agriculture with different lines of production and cropping systems will therefore, when “equilibrium” is finally reached after a fairly long period (decades), have clearly different contributions of net mineralisation from the soil. Both Swedish and foreign studies confirm this. It is mainly the semi-stable young humus pool in the soil that contributes to increased nitrogen mineralisation. This contributes to the nitrogen supply of the crops during the growing season but also to the formation of nitrate outside the growing season, which is less desirable from the leaching viewpoint.

Naturally, a good organic content has many positive effects on the soil, when regarded as an environment in which plants grow, but from the leaching viewpoint, the formation of organic material must not proceed too far. It is important to find an optimal situation. In a monoculture of grain crops where only fertilisers are applied there may, in the long run, be a reduction in the organic content, leading to undesirable effects on the soil structure, which may cause reduced crop growth and a decreased ability to utilise supplied and mineralised nitrogen. This should lead to increased leaching but if the monoculture is balanced with the ploughing-in of straw, the system can, nonetheless, survive for a long period and leaching losses may probably be kept at an acceptable level.

Mineralisation has been found to be greater on fields that are regularly treated with organic manure. Thus, leaching under otherwise similar conditions will be greater on fields spread with organic manure (Table 10.3).

Climate-related factors

Temperature and availability of water, oxygen and suitable nutrients control microbial processes. The longer the period between completed nitrogen up-

Table 10.3. Mean yearly leaching for a five-year period from sandy soils in southern Sweden when growing spring cereals with and without application of organic manure

Site	Runoff (mm)	Losses of nitrogen (kg/ha)			Concentrations of nitrogen (mg/l)		
		NH_4	NO_3	Tot.	NH_4	NO_3	Tot.
Fertiliser							
1.	239	0.09	31	33	0.04	13	14
2.	263	0.06	31	35	0.02	12	13
3.	232	0.06	31	35	0.03	14	15
Fertiliser + manure							
4.	291	0.10	41	44	0.03	14	15
5.*	290	0.31	62	67	0.11	22	23

* *Large application rates of manure*

take and the formation of frozen soil; the better will the possibilities for enrichment of nitrogen in the soil be. Both mineralisation and conversion to nitrate are favoured by good access to oxygen, heat and soil water. During summer, drought is often an inhibiting factor. Rainfall will then favour nitrogen mineralisation. In autumn, however, a shortage of water is fairly unusual and then it is the availability of heat and oxygen that mainly restrict mineralisation. A warm autumn and early soil tillage, that increases the availability of oxygen in the soil at a time when its temperature is relatively high, will increase the autumn mineralisation and thereby the availability of nitrate and, consequently, possibly lead to an increased leaching.

The colder conditions prevailing in the north of Sweden cause the formation of nitrate between the time of harvesting and the arrival of winter to decrease. Quite simply, there is insufficient time during autumn for particularly large quantities of nitrate to be formed, and as a result the leaching will be less the further to the north we proceed.

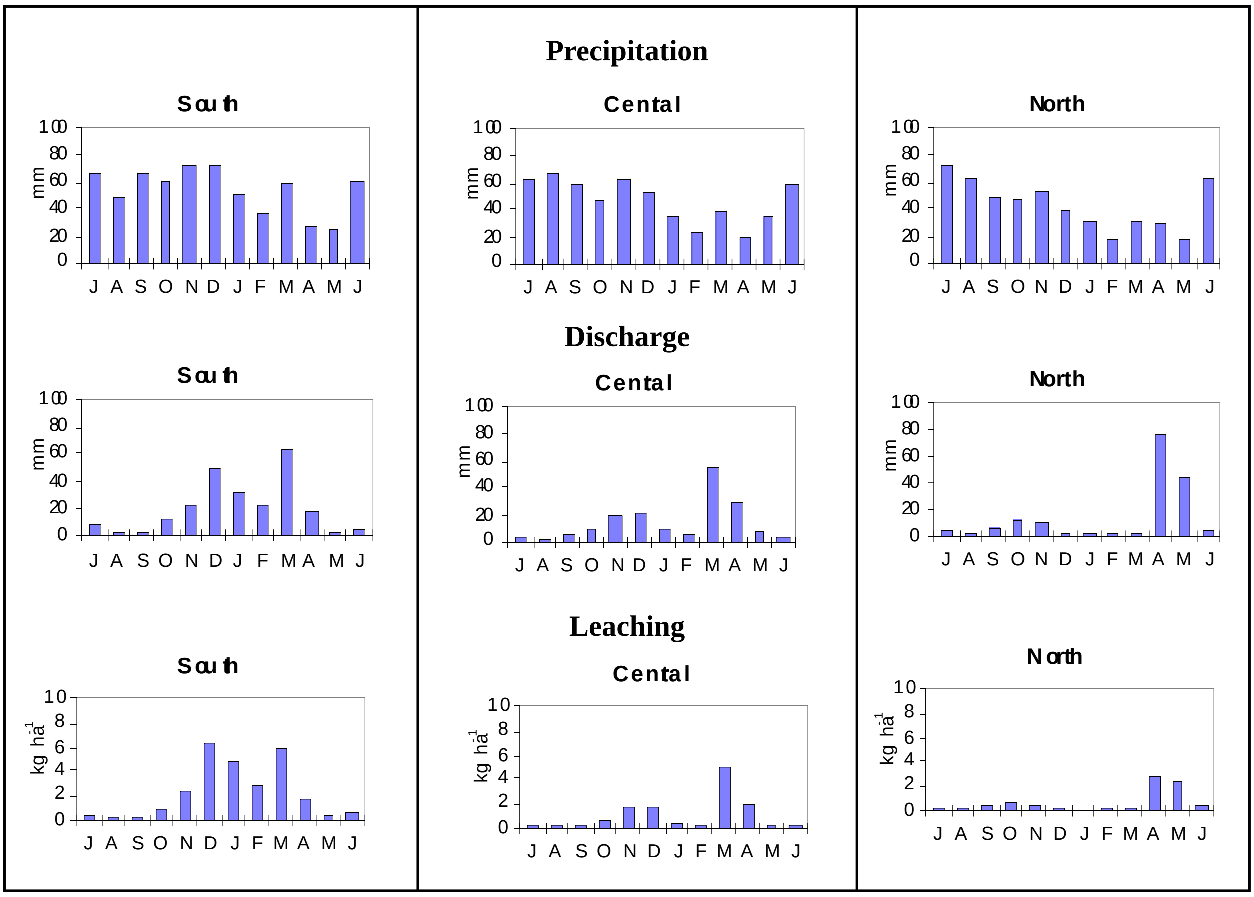


Figure 10.2. Precipitation, discharge and losses, as mean values, from experimental fields on clay and loamy soils in different parts of Sweden from 1977-1986.

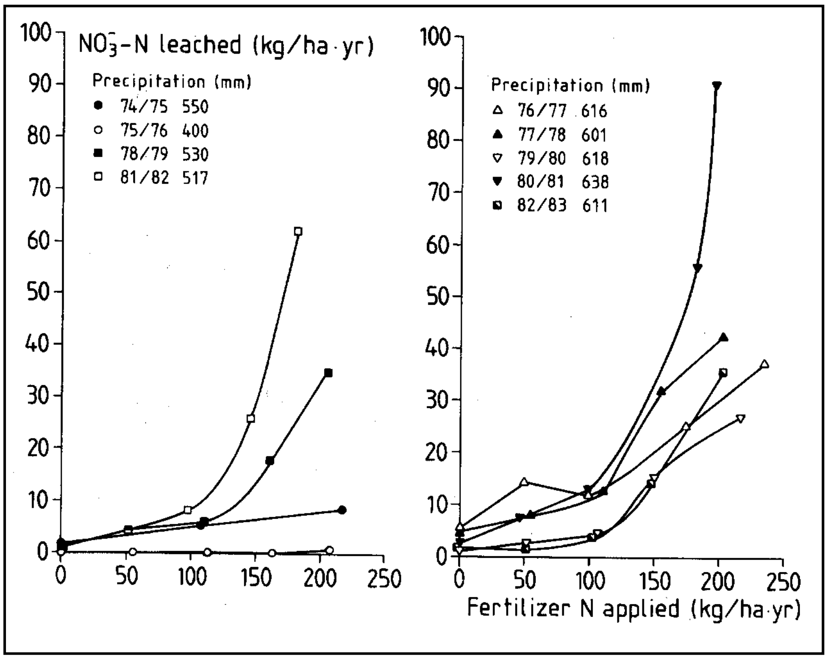


Figure 10.3. Nitrate leaching as a function of the N-fertilisation intensity during the years with precipitation over 600 mm/yr (right graphs) and during years with precipitation under 600 mm/yr (left graph) (Bergström & Brink, 1985).

Another reason for the smaller leaching in the north is the different flow patterns of water as a result of frequent and massive frozen ground. When the ground is frozen, a larger proportion of the water leaves as surface runoff and thus the soil is not leached of nitrate.

The increasing share of grassland in the north, where the soil has a crop cover during winter, together with late nitrogen uptake, also contributes to the leaching of nitrate in northern areas being relatively moderate. Consequently, there are considerable differences in leaching pattern and amount depending on the geographical location (Figure 10.2).

Overdoses of fertiliser

Experiments illustrating the increases in leaching following excessive applications of fertiliser have been conducted in several places in Sweden. Results from Björnstorp in southern Sweden may illustrate this (Table 10.4). Cereals were grown from 1984 to 1989, with the exception of 1988, when the land was set aside and no fertilisers were applied. In spite of this the leaching was high, illustrating the possibility of the soil delivering mineralised nitrogen from the organic N-pool. Modern methods of predicting nitrogen requirements are available to ensure that excessive applications of fertiliser are not made. The importance of finding the right fertilisation level each year must be stressed.

Table 10.4. N-leaching at different N-fertilisation rates. Recommended dose is 100 N kgha^{-1} and 150 N kgha^{-1} is an excessive dose. No nitrogen was applied to the Fallow in 1988

Year	Crop	Dose of nitrogen (kg N/ha/yr) 0	50	100	150	Discharge (mm)
84/85	Barley	36	28	30	39	300
85/86	Winter rye	52	44	55	86	380
86/87	Oats	11	11	15	27	170
87/88	Winter rye	30	29	44	74	425
88/89	Fallow	51	52	62	73	325
89/90	Winter rye	38	41	62	98	240

The results also clearly demonstrate that a reduction of the recommended dose by half, or not using fertilisers at all, does not reduce the leaching magnitude much, at least not in the short term. However by not using fertilisers, the yield will drop drastically (by half) the second year and even more in the long run, since the nitrogen delivery capacity of the soil will decrease. A field trial in the Laholm Bay area illustrates this. The second year the harvest of barley dropped by half in a zero-fertilised treatment compared to the control with a recommended dose of 90-10 N kgha^{-1}. After 8 years the harvest of barley was only 20 % of the control and the leaching 40 % of the control (Figure 10.4).

The results demonstrate that the farmer cannot reduce the nitrogen level too much since he will lose in yield. This is also meaningless from the leaching point of view. But still the leaching magnitude from an environmental point of view might be too high even when using recommended fertilisation levels. In such cases the use of catch crops, and in some cases increased use of winter crops, can constitute possibilities for further decreasing the leaching magnitudes.

Catch crops

However, many times not even optimal amounts of manure spread in the spring give an acceptable concentration in the groundwater. The leaching to the groundwater is, quite simply, too large. The nitrogen mineralised outside the cropping season

Nitrate and health

High nitrate content in wells is a well-known problem, especially in rural areas where many households use private wells. Most often, local over-fertilisation or bad management of manure piles causes the problem. The nitrate in itself, however, is quite harmless. Many vegetables, such as spinach, naturally contain high concentrations of nitrate. Doses of up to 9 g/day are being used medically in order to cure kidney stones.

The health risk of nitrate is that it may be converted to nitrite during certain circumstances. Microbes in the stomach can perform this conversion, if the stomach is not acid enough, which is the case with babies under one year of age. The nitrate formed in the stomach can then react with the haemoglobin in the blood, producing methaemoglobin instead of oxyhaemoglobin. The former has a strongly reduced capacity to carry oxygen. The problem is especially severe for very young babies who still have the foetal haemoglobin that has a stronger affinity for nitrite. The result is that the baby having consumed, for example, nitrate rich water will suffer from a "chemical suffocation", a condition called methaemoglobinaemia or simply the blue-baby syndrome, because the skin of the baby turns slate blue.

Fortunately, the blue-baby syndrome is very rare. The last known lethal case was reported in the UK in 1950 (Ewing & Mayon-White, 1951). In the UK a level of 100 mg NO_3 per litre is considered safe (Addiscott et al., 1992). Nevertheless, even concentrations well below this could be critical if the well is also contaminated with bacteria. Much lower levels may hamper babies, as their ability to take up oxygen is limited.

The second concern about nitrate is that it may cause stomach cancer. In this case the worry is mainly based on theoretical considerations. If small amounts of nitrate are produced, e.g., in the stomach, this could react with secondary amines, coming from the breakdown of meat. The result of this reaction would be an N-nitroso compound that is theoretically capable of modifying components of the DNA, thus causing cancer.

The adult stomach is too acid to allow any production of nitrite, so there may be no cause for worry. There are also theories that the conversion could take place in the mouth. However, the short travel time through the mouth as a glass of water is drunk seems not to support this hypothesis.

It may be that the risk is associated with the intake of nitrite and not with nitrate. In the mid-80s the British Government issued a statement saying there is no link between nitrate in water and stomach cancer (Acheson, 1985). Nitrite is an issue of concern as a preservative, e.g., giving increased preservation and red colour to sausages and meat. Adding nitrite as preservatives is regulated and even forbidden in some countries. The issue has not yet been solved in spite of numerous medical investigations of different categories of people with high exposure to nitrite, such as workers in fertiliser factories.

The EU has set the limit for nitrate in drinking water at 50 mg per litre, half the level suggested for the UK. The increased safety has a cost, though, for farmers in the drier parts of England. It is estimated that in order to keep the 50 mg limit, only 27 % of the land can be used for arable cropping, compared to 58 % if the suggested 100 mg limit could be used.

L-C Lundin

must therefore be utilised. An increased share of winter cereals or the growing of catch crops may be one solution. When growing winter rye that was harrowed in spring before the main crop was sown (Table 10.5), the concentrations in discharge water were satisfactory. Very good results were also obtained when growing Italian ryegrass as a catch crop. The grass was sown in the main crop in spring and remained during winter before being tilled during the spring operations (Table 10.6). The temporal effect of the ryegrass catch crop on nitrogen concentrations is shown in Figure 10.5.

Nitrogen leaching and soil type

Since nitrate nitrogen is dissolved in the soil solution, precipitation, the soil's water retention ability and its permeability are the factors that ultimately determine the amount of leaching. As the precipitation water penetrates down through the soil, it draws with it the soil solution and its content of nitrate, as well as other dissolved substances. Sandy and fine sand soils in particular have a large permeability and low water retention capacity, as well as usually having a shallow root depth. Consequently, these soils are easily exposed to leaching.

Clay soils, on the other hand, retain the water considerably better. The slower movement of water in these soils means that available nitrate is slowly transported downward through the soil profile. In macropores (fissures, root channels and worm galleries) the water will naturally move much faster, but a lot of the nitrate is present in the micropores and aggregates. This nitrate is thus "protected" since the dominating flow of water moves through the macropores. Since the roots in

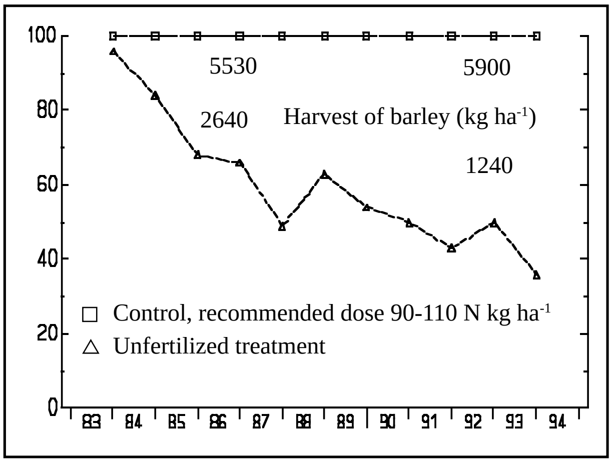


Figure 10.4. Relative N-leaching and harvest of barley in a treatment with recommended dose of fertiliser and a treatment without N-fertiliser.

Table 10.5. Mean yearly leaching for a six-year period on a sandy soil in southern Sweden

Winter state	NO_3-N (kg/ha)	NO_3-N (mg/l)
Pig slurry 90-110 kg Tot. N /ha and 45-55 kg N /ha commercial fertiliser in spring		
winter rye	22	8.4
ploughed	42	14

Table 10.6. Annual leaching on a sandy soil in southern Sweden (89/92)

Winter state	NO_3-N (kg/ha)	NO_3-N (mg/l)
Commercial fertiliser 90 kg N /ha in spring		
ploughed	48	15
ryegrass	9	3
Pig slurry 90-110 kg Tot. N /ha and 45-55 kg N /ha commercial fertiliser in spring		
ploughed	51	15
ryegrass	10	3

Crops: Oats, wheat, barley.

these soils generally penetrate to considerable depths, nitrate located even at such depths in the soil can be utilised by the crop in subsequent years. Consequently, nitrogen leaching is greater in light soils than in heavy mineral soils under conditions that are similar in other respects. Results of different investigations confirm this, e.g., a study in Skåne and southern Sweden (Table 10.7).

Leaching of phosphorus from agricultural land

Eutrophication of lakes and rivers by phosphorus is a major and growing water problem throughout Europe. There is now a radical switch in emphasis away from considering the impact of point sources of phosphorus towards the study of diffuse sources. This reflects, in part, the considerable success that has been achieved in decreasing the phosphorus loading from point sources such as sewage treatment plants. However, despite this improvement, it has been found that the decreases in point sources alone have not always been sufficient to achieve the desirable improvements in water quality. This is because diffuse phosphorus sources are often capable of causing eutrophic conditions to develop. Also there is no evidence so far of substantially decreasing phosphorus-loads in streams draining agricultural land.

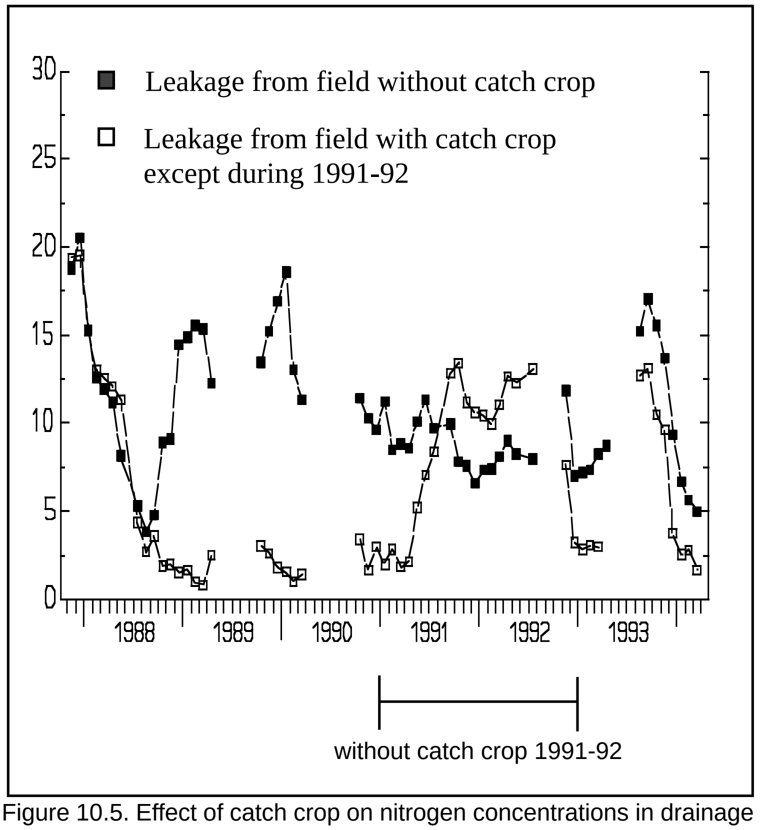


Figure 10.5. Effect of catch crop on nitrogen concentrations in drainage water from a sandy soil with cereal production in SW Sweden.

Table 10.7. Mean values for annual losses of nitrate (N, kg/ha) from a large number of fields in southern Sweden

Sand	Fine sand	Clayey till	Clay
36	34	23	6

This has been evaluated, e.g., in the JRK-network of small agricultural watersheds throughout Sweden. The measurements have clearly demonstrated that phosphorus losses from agricultural areas are too large. The mean losses ranged from 0.08-2.7 kg Tot.-P $ha^{-1}y^{-1}$ during the period 1988-1994. Such high losses undoubtedly contribute to serious eutrophication of streams and lakes in the agricultural landscape.

Early studies on phosphorus in agriculture were carried out against a background of severe phosphorus deficiency in soils and were primarily concerned with improving crop yields. When phosphorus losses to water were considered, emphasis was placed on the high capacity of soils to retain phosphorus inputs supplied as fertilisers and manure. Although this capacity is impressive, it is important to be aware of the differences in scale between net phosphorus inputs to land and the much smaller loss rates in drainage water which can easily cause appreciable enrichment of fresh water. The build up of the phosphorus pool by fertilisation has been substantial in modern European agriculture and there is today no need to build up further but to decrease the input to its lowest possible level and even to decrease the pool. The phosphorus pool is also fragmented and phosphorus is concentrated in certain agricultural areas. Much emphasis must be put into this concern to make it possible to reduce the losses to water bodies.

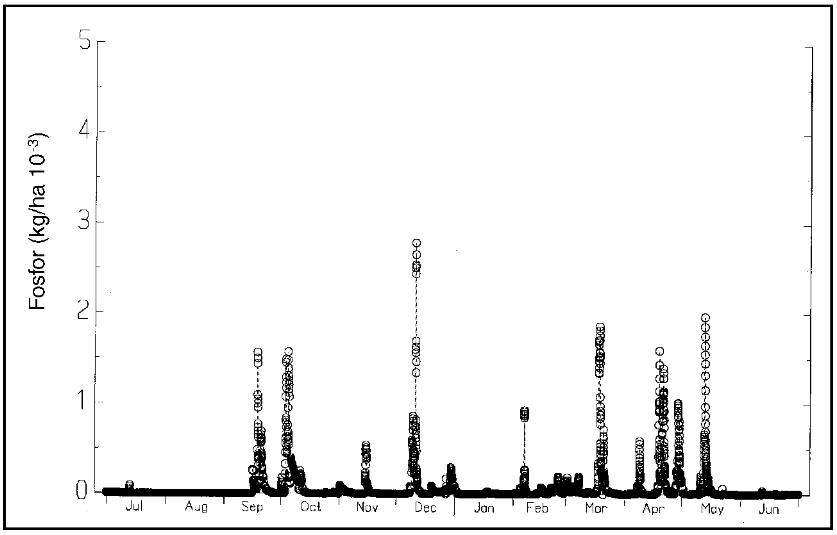


Figure 10.6. Example of transported amount of Total-P/hour from a field with clay soil.

Requirement and water quality goals for phosphorus

According to existing Swedish Environmental Protection Agency (SEPA) criteria for lakes and rivers, phosphorus concentrations in surface waters should not exceed twice the estimated natural or original unaffected levels (Table 10.8). It is necessary to modify this requirement in catchments that are dominated by intensive agricultural land use. Further research will be necessary to develop improved cultivation methods, which will help generally to achieve this goal. However, such low phosphorus concentrations have been observed, which suggests that it is a realistic long-term goal.

The complexity of phosphorus losses from agricultural soil

Fluxes of phosphorus through the soil by drainage water have often been discounted because of its considerable affinity to many soil components. Actions to reduce phosphorus losses from arable lands, therefore, have mainly been focused on reduction of surface losses of phosphorus. Research tells us, however, that considerable phosphorus losses occur through tile drains. It has been emphasised that water flow through heterogeneous soils is through the easiest path. Thus, high phosphorus concentrations in tile drains may result from water flowing directly through the unsaturated zone. This is the result of canalisation in meso- and macropores or along gravel filters and backfill around drainage pipes.

It is not really known how phosphorus is mobilised and transported through the soil. One possibility is that the surface soil acts as a source of phosphorus. Another is that phosphorus originates from erosion and desorption along macropore walls or from siltation of material in the vicinity of the drainage pipes when the groundwater level increases. The desorption might be of special importance if a layer of low hydraulic conductivity has been formed below the plough layer and the soil is water-saturated enough that active reducing conditions occur. The concentration of dissolved phosphorus may

Table 10.8. Long-term quality goals for phosphorus in surface waters

Concentration ratio, current/original	Original concentration (mgl^{-1})	Twice-goal (mgl^{-1})	Goal in agricultural areas (mgl^{-1})
Phosphorus, 1.5-2.0	0.01	0.02	0.05

also increase in the soil during water-saturated conditions as a result of chemical and microbial reduction of iron.

Phosphorus mobilisation from the soil surface is often related to erosion processes. The surface erosion processes depend on aggregate stability and other soil properties. In dry regions erosion most commonly results from surface crusting, which is closely related to aggregate breakdown. In colder climates erosion is strongly related to freezing of the soil surface. Dissolved phosphorus may desorb from stationary surface soil or from suspended soil particles. This is probably a very important process. Another source of phosphorus is crops - crop residues or weeds damaged by frost, dryness or herbicides (Table 10.9).

Especially after drying, the potential for dissolved phosphorus to be leached from plant material is great and thus a climate with long dry periods followed by heavy rain might lead to substantial phosphorus losses from crop residues.

During the spring a very high proportion of phosphorus transport in the Nordic countries may be in dissolved form. Many freezing and thawing cycles destroy the vegetation cell walls. It may also desegregate solid soil, thus offering a larger soil surface to be exposed for desorption and dissolution of phosphorus. Freezing and subsequent leaching of water releases more dissolved phosphorus from soil in comparison with frozen soil, as shown in laboratory experiments. Mobilisation of phosphorus may thus be triggered by a climate with much fluctuation around zero.

Phosphorus is found in drainage water both during fast and slow water flow. During submerged conditions, water saturation in meso- and micropores may cause overpressure in the macropores and cause fast water movement. The fast flow may cause water to be far from chemical equilibrium with the surrounding soil. During slow flow the walls of stable channels may be saturated with phosphorus, thus allowing transport from the surface.

Phosphorus loss through tile drains is known to be dependent on agricultural management practices and soil characteristics. Besides this, weather variations are extremely important. During dry periods more cracks are formed as a result of shrinkage of the soil. A dry profile would exhibit lower cohesive bounding and therefore might be more erosive until the soil matrix becomes wetter.

In the Northern Hemisphere, weather variations during winter are of special importance. Frozen soil and soil with just a very thin snow cover have been shown to have much higher concentrations of suspended solids in drainage water compared with unfrozen soil and soil with thick snow cover. The greenhouse effect might introduce a climate with more frequent snowing and melting during the winter period, thus enhancing phosphorus mobilisation. Much the same goes for transport through the soil, since the soil becomes bare more frequently during the winter, favouring this process.

In light of the complexity of processes favouring phosphorus losses, let us conclude that an effort must be made to reduce the amount of phosphorus in the soil profile necessary for crop production. Introducing crops with lower phosphorus demand than today's crops can do this. In spite of the success in reducing levels of phosphorus in the soil, better management practises at any phosphorus level is necessary to achieve the long-term goal of acceptable losses of phosphorus to water bodies.

How to address the problem of phosphorus leaching

Farmers in Europe continue to apply more phosphorus to their land than is removed by crops. Part of the

Table 10.9. Losses of dissolved phosphorus with surface runoff during two years from a plot with direct sowing compared to losses from plots ploughed in autumn or spring. The first year weeds in the direct sown plot were treated with herbicides

Year	1995/1996		1996/1997	
Treatment	Surface runoff (mm)	Phosphate P (kg/ha/yr)	Surface runoff (mm)	Phosphate P (kg/ha/yr)
Direct sawing spring	14.7	0.016	45.7	0.233
Ploughing autumn	10.4	0.003	28.5	0.005
Ploughing spring	14.7	0.007	45.7	0.007

Table 10.10. Losses of suspended solids and particulate phosphorus with surface runoff during two years from a plot receiving organic material compared to losses from plots ploughed in spring or green cover crops (ley and winter wheat, respectively)

Year	**1995/1996**		**1996/1997**	
Treatment	**Susp. solids** (kg/ha/yr)	**Particulate P** (kg/ha/yr)	**Susp. solids** (kg/ha/yr)	**Particulate P** (kg/ha/yr)
No plough. + org mat	19	0.022	24	0.039
Ploughing spring	24	0.023	59	0.051
Wintergreen	27	0.028	62	0.055

reason is that they cannot trust the soil-phosphorus test methods. Most soil-phosphorus test methods, including the P-AL method used in Sweden, simply do not correctly estimate the soil P status, i.e. the ability of the soil to supply the crops with phosphorus.

There are also some basic questions that require more knowledge. We need to better know the phosphorus demands of different agricultural crops in relation to root development and characteristics, with emphasis on getting breeds with less phosphorus demands at any yield level. We also need to find out to what extent mycorrhiza is important for phosphorus delivery to agricultural plants and its relation to the phosphorus status of the soil.

There are several measures we might introduce to improve phosphorus management. New phosphorus fertilisers and fertilising techniques can be used to avoid overdoses and overall soil enrichment of phosphorus. Some cultivation methods enhance the aggregate stability and will then reduce phosphorus ero-

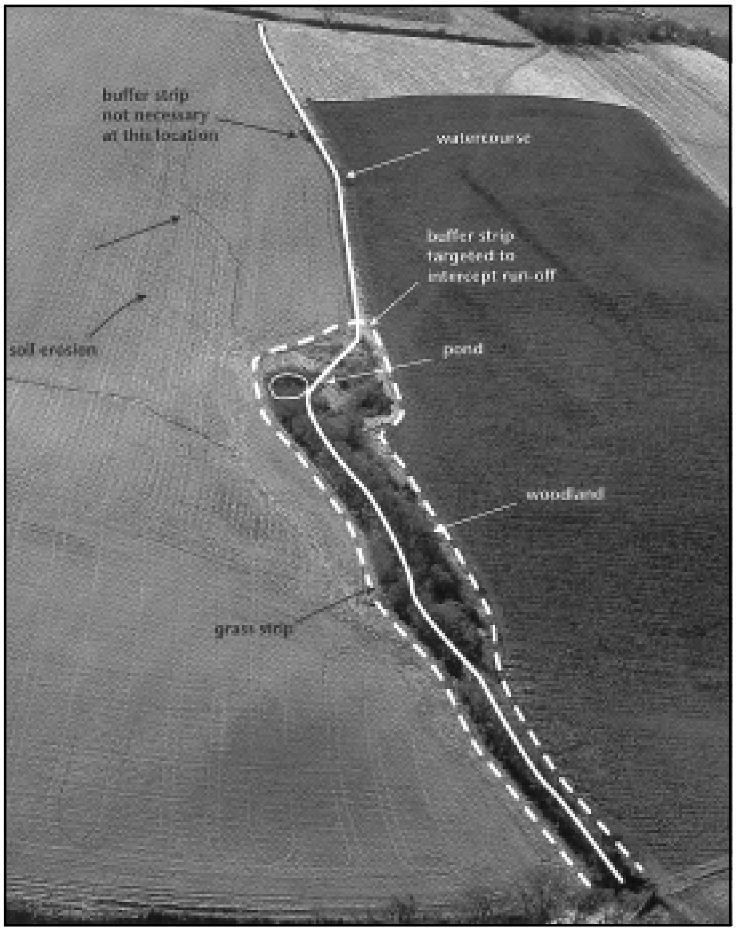


Figure 10.7. Buffer-strips.

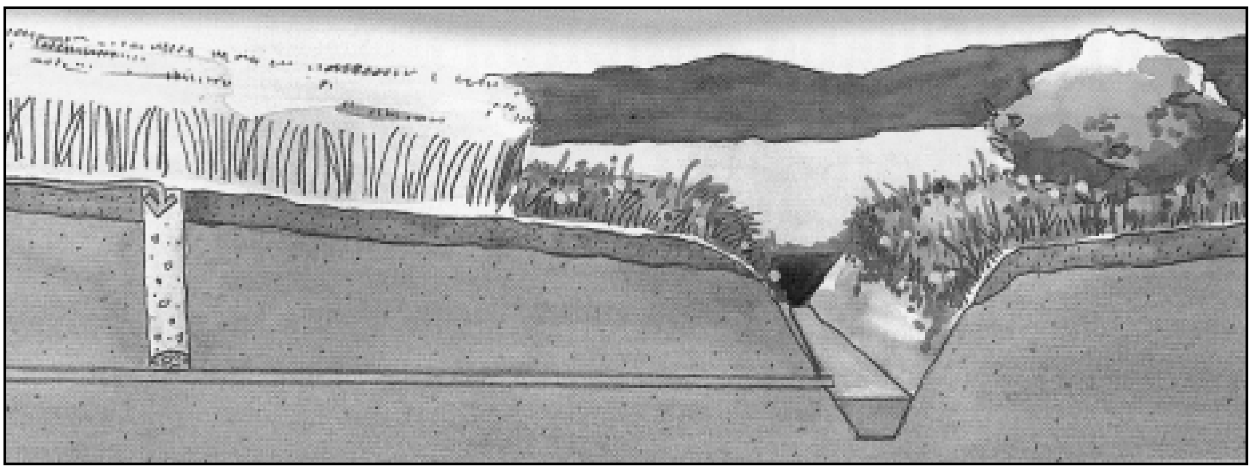


Figure 10.8. Ditch with calcareous filter.

sion. Increased input of organic material reduces losses of suspended solids and particulate phosphorus from a silty soil. On the other hand, cover crops do not reduce losses of particulate phosphorus (Table 10.10).

The drainage system is of course a key component. Very little is known about the role of the design of the tile drainage system for reducing phosphorus losses. Processes in the vicinity of the drainage pipes may be very important but there is a gap in knowledge about this.

Management of the land and surface-water interface is a different option to improve the situation. Correctly designed buffer or riparian zones (Figure 10.7) dramatically reduce soil and phosphorus loss from agricultural areas by surface runoff and erosion. It is also important that the interface between the tile outlet and the agricultural stream is designed to improve the sedimentation environment for particles in the drainage water. In special problem areas, calcareous filters may be a tool to reduce phosphorus (Figure 10.8).

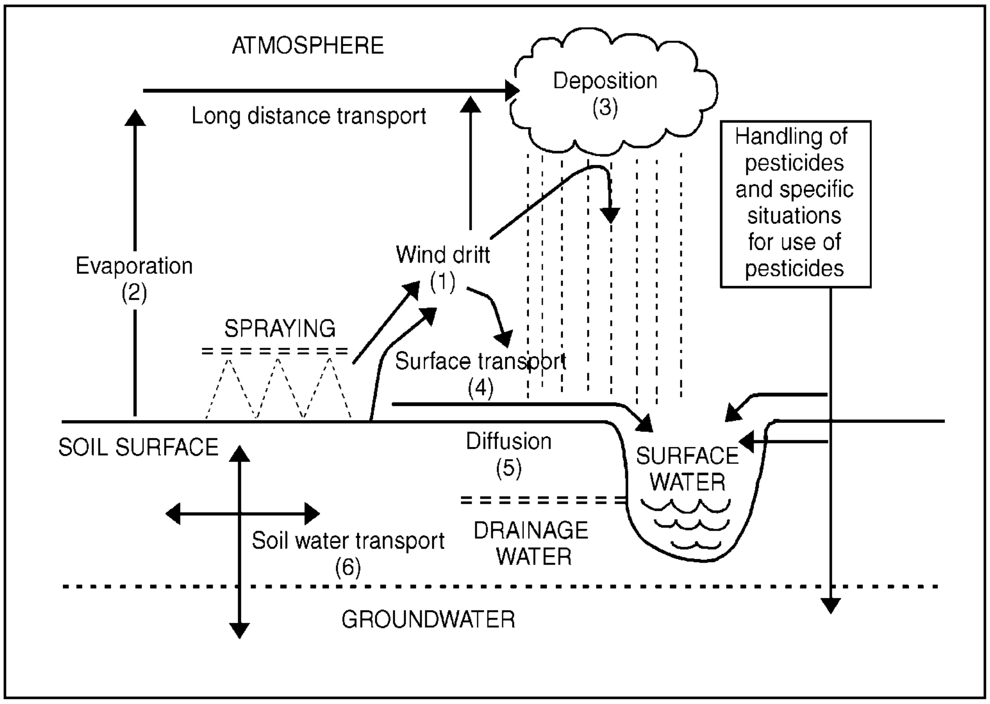


Figure 11.1. Important transport routes that may lead to the appearance of pesticides in the aquatic environment. The most important transformation and transport routes are:
1. wind drift
2. evaporation of a pesticide from a soil or water surface
3. deposition by precipitation or dry particles
4. transport of pesticides on the ground surface
5. diffusion in the gas and water phase, preferential flow and exudation from plant roots
6. pesticide transport with soil water
7. incorrect handling of pesticides

11.
Pesticide traces in water

Lars Bergström, Jenny Kreuger & Katarina Kyllmar[1]

The occurrence of pesticides in water

The widespread occurrence, distribution and deposition of pesticides in water are modern-day problems of great concern. In contrast to most anthropogenic chemicals, which are spread unintentionally through such incidents as spills, incomplete combustion or leaching from landfills, pesticides are probably the only group of chemicals that are intentionally released into the environment.

When looking at the pesticides that are present in rainwater it is obvious that some of them, e.g. DDT and toxaphene, have been transported from very remote places. Other substances, such as the phenoxy acid herbicides, were often used in the vicinity of the areas where they have been deposited. Looking at the levels of pesticides deposited in rainwater, we see that the amounts found in Sweden and the other Nordic countries are often lower than those reported from central Europe.

Many pesticides are frequently found in streams draining agricultural land. Although occurring predominantly during or shortly after the spraying season, some pesticides are also found several months after they have been applied. Many insecticides and fungicides are also detected in sediments. A study of southern Sweden showed that between 0.01-0.9 % of the amount of different pesticides applied within a watershed was transported in and by surface water leaving the catchment.

A few pesticides, such as atrazine, have also been found in groundwater, even in rather deep wells. The well-documented presence of many levels of pesticides in all kinds of environments should and must prompt us to take countermeasures to reduce concentrations to acceptable levels, a fact that is recognised in most European countries and elsewhere.

In all zones of the soil-vegetation-atmosphere system, the mobility of water is of great importance for the mobility and persistence of pesticides within that zone. Getting rid of a pesticide from a zone is, apart from transport, also dependent on photochemical, chemical and biological decomposition processes, as well as immobilisation by incorporation into soil organic matter. The amount of the substance is then reduced or eliminated. However, metabolites may appear, calling for constant surveillance of the environment. Important transport pathways are shown in Figure 11.1.

Effects of pesticide traces in water

When concentrations of detected pesticides are compared to available effect studies, it appears that single pesticides normally do not reach concentrations that will cause adverse effects on water-living organisms. However, local, temporary effects in small watercourses cannot be excluded. Among the pesticides that have been studied, propiconazole is of particular concern in this respect. Effect studies indicate that the maximum concentration of this fungicide, found in surface runoff, might affect the macroinvertebrate fauna and algae communities.

One uncertain aspect is the effect of combined exposure of ecosystems to complex mixtures of a number of pesticides. The exposure of organisms to mixtures of chemical compounds can lead to toxic effects, even when the individual compounds are present in concentrations well below toxic levels. Because the adverse effects of combined exposure are not normally included when testing pesticides, ecological damage may occur in regions where the concentration of individual pesticides is well below environmental criteria. Moreover, the potential for hazardous effects of pesticides can only be assessed for certain environmental effects. For example, pesticides with high leaching potential to groundwater can be identified on the basis of their physical and chemical properties. However there is still a lack of knowledge on how to predict the chronic toxic effects of pesticides on ecosystems, especially when non-target organisms are exposed to more than one chemical at a time, for example, in long-term exposure by wet deposition.

[1] Lars Bergström contributed with the introductory part and Jenny Kreuger and Katarina Kyllmar contributed with the part "Pesticides in surface water."

Requirement and goals for handling of pesticides

The goal should be for agricultural activities not to leave traces of chemical plant-protection products in surface waters and groundwater with adverse human toxicological or ecotoxicological effects. The safety margins should be ample. Over the short term, leachable compounds must be handled in such a way that the pollution risk is minimised.

This goal will not be reached without further research into the mechanisms governing pesticide fate and mobility in soils, so that improved test methods can be developed that will allow identification of high-risk compounds during registration procedures. Such research could also serve as a basis for the development of environmentally acceptable compounds, which requires co-operation with industry.

Studying pesticide losses to water and air

Several leaching studies in lysimeters have been performed in Sweden during the past few years. All these studies have been mainly focused on estimating a mass balance for the included compounds; to see how much will reach surface waters and groundwater, while focusing to a lesser degree on trying to elucidate transport mechanisms and important factors controlling leachability. Attempts to describe and predict contaminant transport cannot succeed if major pathways and mechanisms are not defined. For example, processes related to soil hydraulic properties, such as macropore flow, have been shown to have a major impact on pesticide leaching, but are relatively poorly investigated in this context.

In this respect, the leaching of pesticides in clay soils, which are normally quite impermeable, can be much larger than that in sandy soils. Soon after application in spring, when pesticide concentrations are high in the top centimetres of the soil, rapid movement in root and earthworm channels can bring about elevated pesticide concentrations in shallow groundwater in clay soil areas. This type of leaching behaviour does not occur in areas with sandy soils (Figure 11.2). However, macropores are not always continuous through the whole unsaturated zone; indeed, this is unlikely in most agricultural soils. Still, if a pesticide soon after application bypasses only the biologically active topsoil through macropores, it is often enough to increase leaching losses. Once the compound has reached the subsoil, degradation rates would likely be reduced and the compound would be retained for later leaching.

Moreover, the traditional way of classifying pesticides by determining their physical/chemical properties (e.g. adsorption constants and water solubility) as a basis for mobility estimations has proved questionable, since it does not reflect field conditions.

It has long been recognised that physical, chemical and biological factors are important in the distribution, degradation and transport of pesticides in the soil, as indicated above. As long as the chemical is either dissolved or in equilibrium with the solid and water phase of the soil, many of the acknowledged theories are applicable in describing its environmental fate (e.g. Monod, Michaelis-Menten and first order kinetics; equilibrium sorption; Darcian flow). Today, values from such properties are put into various screening schemes, which have been developed to assess whether a chemical is likely to leach through soil. Some of these schemes have attempted to set threshold values for a certain pesticide property or set of properties which, when exceeded, would then indicate that the compound will leach. Other approaches use properties of soil mobility and persistence, which are plotted together and examined graphically to define regions in a diagram representing compounds of different leachability. In addition to these simple screening methods, mathematical simulation models are now increasingly being used to predict leaching of pesticides and other chemicals in soil, and are also being built into various regulatory assessment procedures.

The magnitude of pesticide leaching in field soils is a reflection of chemical and biological processes occurring in a complex structure, often under non-steady state conditions. In a similar way as with macropore flow, pesticide sorption at different types of sites in the soil may be greatly affected by the range of aggregate and pore sizes in field soil. Also, degradation rates are influenced by microbial population size and the degree of contact between organisms and pesticides, both of which are affected by soil structure. In other words, to properly predict chemical movement in soils we need to improve our knowledge of biological and chemical processes of importance for pesticide fate in soil. This requires a creative mixture of laboratory and field research. The importance of spatial variability in leaching at different scales also needs further attention.

Pesticides in surface waters

Up until the mid-1980s, there has been little information in Sweden regarding exposure data for current generation pesticides in surface waters. This can partly be ascribed to restrictions in analytical methods that prevent scanning a wide variety of currently used pesticides in a single analytical run. In addition, no specific water quality standards for surface water, irrigation water or drinking water were ever established for commonly used pesticides. During the late 1980s various programs, with varying objectives, were set up to improve the knowledge of pesticide residues in surface waters. There are large differences among the programs regarding the number of selected sampling sites, the number of collected samples and the number of pesticides included in the analyses of the water samples. A summary of the results of the different studies follows.

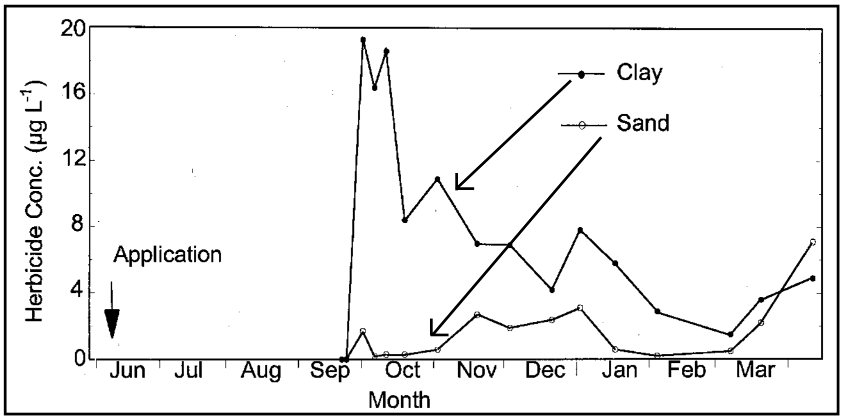


Figure 11.2. Concentrations of an agricultural herbicide in shallow groundwater.

During 1966-1969, samples were collected from 153 sampling sites along major rivers throughout Sweden (Erne, 1970). The samples were analysed for phenoxy acids and chlorinated phenols. The detection limit was 2 μgl^{-1} and positive samples of phenoxy acids were found in 29 % of the river water samples. Several very high residue values were encountered (>1 000 μgl^{-1}), but these, along with a major proportion of the smaller values, were already known to be the result of various kinds of discharges and accidental spills. In June 1983, five rivers in the far south of Sweden were sampled on one occasion and phenoxy acids were detected in all five samples at an average concentration of 14.7 μgl^{-1} (Öresundskommissionen, 1984).

During 1985-1987 a more intensive programme for pesticide monitoring in stream waters was undertaken (Kreuger & Brink, 1988). Methods for analysing approximately 80 currently used pesticides were developed (Åkerblom & Jansson, 1986). Streams in agricultural areas were selected and sampled at monthly intervals during May-September, with a total number of 260 samples eventually being analysed. The number of sampling sites increased from seven to 29 during the three-year period. Eighteen compounds were identified, including eleven herbicides, two fungicides and five insecticides. The most frequently found pesticides were the phenoxy acids (63 % of the positive samples) with peak concentrations at the time of spraying (May-June). During the non-spraying season the concentrations were lower, between 0.1 and 1.0 μgl^{-1}. Throughout the three years, positive samples of one or several compounds of phenoxy acids occurred in 37 % of the water samples taken in May, 78 % in June, 57 % in July, 24 % in August and 18 % in September. The maximum measured concentration of the total content of phenoxy acids in one single stream was 25 μgl^{-1}. Along with the phenoxy acids, the herbicide atrazine was found in some streams during the whole sampling season. In large catchments, or in catchments with only smaller parts of the area being used for agricultural production, no pesticides were found or only small amounts were detected on single occasions. Thirteen of the 18 identified compounds were only detected in water from streams in the far south of Sweden, an area that is intensely cultivated.

In 1988, the National Food Administration investigated pesticide concentrations in municipal drinking water originating from 56 surface water supplies all over Sweden (Sandberg & Erlandsson, 1990). Water from each supply was sampled on two different occasions, once in the beginning of summer and once in autumn. Seventeen pesticides were included in the analyses at the normal detection limits (0.1-0.5 μgl^{-1}), with an additional 60 pesticides being included in the analyses at levels 2-10 times above the normal (Åkerblom et al., 1990). Detectable amounts of pesticides were determined in three cases at low levels (0.1-0.9 μgl^{-1}) in early summer in untreated drinking water. However, no pesticides were detected in treated drinking water intended for human consumption. The pesticides found were MCPA, dichlorprop and bentazone.

During 1988-1990, many Swedish county administrations included pesticides in their environmental monitoring programs for water pollution control (Åkerblom, 1991). Samples were collected from a total of 170 sampling sites in 14 counties. There were differences among the counties in sampling intensity, from once a year to twice a week during the spraying season. A total of 840 surface water samples were collected throughout the three years. The number of substances included in the analyses also varied, ranging from only the phenoxy acids and related compounds up to as many as 80 substances. Twenty compounds were identified, including 15 herbicides, 1 fungicide and 4 insecticides. The most frequently detected pesticides were MCPA and bentazone, which were found in more than 20 % of the samples. Eleven of the twelve most frequently found pesticides, found in

Table 11.1. Monthly time weighted mean concentrations (TWMC) in the Vemmenhög catchment during May-November 1997

Substance	TWMC ($\mu g\ l^{-1}$)							
	May	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**May-Nov**
Aclonifen	0	0	0	-	-	-	-	
Atrazine	0.02	0.03	0.06	-	0.2	0.09	0.04	0.07
Atrazine-desethyl	0	0.03	0.03	-	0.1	0.08	0.07	0.05
BAM	0.01	0.04	0.05	-	0.2	0.05	0.05	0.07
Bentazone	0.5	3.01	1.34	-	1.7	0.21	0.17	1.15
Chloridazon	0	0	0	-	0	0	0	
Chlopyralid	0	0	0	-	0	0.04	0.08	0.02
Cyanazine	0.17	1.61	0.89	-	0.8	0.07	0.01	0.59
Cyfluthrin	0	0	0	-	0	0	0	
2,4-D	0	0.02	0	-	0	0.14	0	0.03
Deltamethrin	0	0	0	-	0	0	0	
Dichlobenil	0	0	0	-	0	0	0	
Dichlorprop	0.04	0.45	0.03	-	0.5	0.02	0.01	0.18
Diflufenican	0	0	0.02	-	0.1	0.09	0.05	0.04
Diuron	0	0.08	0.13	-	0.06	0.02	0.05	0.06
Esfenvalerate	0	0	0	-	0	0	0	
Ethofumesate	0.06	0.78	0.19	-	0.5	0.15	0.12	0.3
Fenpropimorph	0.03	0.05	0.06	-	0.1	0.05	0	0.05
Fluroxypyr	0.01	0.02	0.02	-	0.08	0.06	0.02	0.04
Isoproturon	0.12	0.51	0.22	-	0.4	0.3	0.65	0.37
Lambda-cyhalothrin	0	0	0	-	0	0	0	
MCPA	0.02	0.2	0.02	-	0.09	0	0	0.06
Mecoprop	0.23	0.5	0.65	-	0.2	0.03	0.05	0.28
Metamitron	1.26	4.09	0.31	-	0.6	0	0	1.04
Metazachlor	0.02	0.05	0.03	-	0.1	0.08	0.1	0.06
Methabenzthiazuron	0	0	0	-	0.1	0.02	0.07	0.03
Phenmedipham	-	0	0	-	0	0	0	
Pirimicarb	0	0.02	0.02	-	0.06	0.01	0.02	0.02
Propiconazole	0	0.18	0.34	-	0.6	0.28	0.13	0.26
Propyzamide	0.1	0.13	0.06	-	0.7	0.07	0.03	0.18
Simazine	0	0.01	0	-	0.04	0	0	0.01
Terbuthylazine	0.07	0.26	0.22	-	1	0.81	0.51	0.48
Tribenuron-methyl	0	0.02	0.02	-	0	0	-	0.01
Sum	**2.68**	**12.1**	**4.68**	**-**	**8.23**	**2.68**	**2.22**	**5.43**

0.6 % or more of the analysed samples, were also encountered in the previous investigation made in 1985-1987. Eight of the detected pesticides were found only once or twice throughout the three years. Pesticides occurred most frequently and at highest concentrations during the spraying season, but low concentrations were found during the whole year, especially of phenoxy acids and bentazone. The frequency of several of the pesticides (i.e. phenoxy acids, bentazone and metazachlor) decreased over the three years, seemingly due to a sales reduction of some of these substances and also to increased knowledge of the correct handling of pesticides among farmers. However, due to the variations in the samplings of both years and counties, it is difficult to make any definite statements concerning the reasons for this apparent decline in pesticide residues in water.

During 1989-1990 the Swedish industrial sector stood behind an investigation of chemicals in Swedish waters, including pesticides (Toll, 1993). Altogether 55 surface water samples were taken from five rivers and one lake that had a connection to drinking water supplies. The samples were analysed for approximately 80 different pesticides, including the low dose sulfonylurea herbicides chlorosulfuron and metsulfuron-methyl. Phenoxy acids, along with bentazone, were detected in eight of the samples at low concentrations (0.1-0.3 $\mu g l^{-1}$). No sulfonylureas were detected.

In the Vemmenhög catchment in the county of Scania, pesticides have been monitored during an eight-year period (Kreuger, 1998). Those found during May-November 1997 are presented in Table 11.1 (Kreuger & Hessel, 1998).

During the period from 1985-1997, 417 water samples classified as groundwater samples were gathered on behalf of municipalities, counties or research projects (Hessel et al., 1997). These included samples from drilled or dug wells. The most frequently found pesticides were bentazone, atrazine, dichlorprop, MCPA and chlopyralid.

12.

Wetlands and agricultural runoff

Lars Rydén & Józef Mosiej[1]

Wetlands – a key biotope

In pre-industrial times the landscape in the Baltic region was very different from today. In particular wetlands dominated many areas, which today has been drained to be used as agricultural land. Especially in the west the wetland area has drastically diminished during the last century. A modern figure for Sweden, with the largest part of the Baltic region wetlands, is 60-90 000 km^2, depending on the definition.

Most wetlands in the north are open areas but further south wetlands are very often overgrown with forest, i.e. they are forest swamps. The forest may be spruce or, especially close to open water, it may be deciduous. In the Baltic region wetlands typically drain into rivers and finally into the Baltic Sea. In other parts of the world wetlands may form terminal lakes that become quite salty and have very different properties.

There is a natural *succession* of the various wetland types, driven by a slow accumulation of organic material through vegetation. Open water surfaces become covered with plants, and the root zones accumulate material so that the lakes become shallower, eventually turning into marshes. These in turn develop over many years into mires and bogs. In the Baltic region, this succession typically ends in the production and accumulation of peat, which may grow to layers several metres thick. This slow accumulation of biomass has a remote similarity to the production of oil and coal, although the formation time for peat is in the thousands of years rather than the millions required for the formation of oil. It is thus a matter of definition if peat is to be regarded as a fossil resource or a renewable resource.

Functions of wetlands

The wetlands with their meandering rivers, streams and small lakes constitute a system of many functions.

Wetlands form an adaptable *reservoir of water* that is filled during snow melting and flooding events in the spring. In drier periods, during summer, they are emptied and thus dampen the variations in runoff from the catchment. Other areas add to this function as temporary wetlands, most often meadows adjacent to lakes, rivers and beaches. These become flooded during spring and dry up in summer. One consequence of draining wetlands, e.g. for agricultural purposes, is thus drastic variations in runoff and riverbed development. This may have more or less serious effects if precipitation becomes intense and results in flooding.

Secondly, wetlands have a large *filtering capacity* and retain and/or metabolise organic material as well as nutrients and several other kinds of polluting substances. They thus work as nature's filters, or "kidneys". Heavy metals may be precipitated as sulphides or adsorbed onto particles of organic material. Similarly phosphorus may be incorporated into biomass or precipitated out of solution on e.g. clay particles or as ferrous compounds. Nitrogen is first oxidised into nitrates and finally, in anaerobic areas, denitrified into molecular nitrogen and returned to the atmosphere.

Thirdly, wetlands have a *key ecological role*. Due to their productivity, wetlands have a rich biological life and constitute an important source of food for many species. They represent a considerable share of the biodiversity in the region, being rich both in species and numbers of animals. There are species that live permanently in wetlands and others that are dependent on wetlands for certain periods, such as many species of migrating birds. Insect biodiversity is also very large and botanical diversity is of importance. Naturally, amphibious species and many reptiles such as snakes are entirely dependent on wetlands.

Because of their unique biological role and as a means of counteracting the tendency to remove wetlands through ditching in modern society, several measures have been taken to protect wetlands. As far back as 1971, the Ramsar convention was signed in Ramsar, Iran, to protect wetlands as a biotope, not least for the sake of migrating birds. The Ramsar convention came to force in 1982 and 80 states has so far signed the convention. A supplementary protocol was agreed upon in 1987.

1 Lars Rydén is the main author while Józef Mosiej is responsible for the sections on wastewater irrigation and the Ner and Warta Rivers.

Load and retention

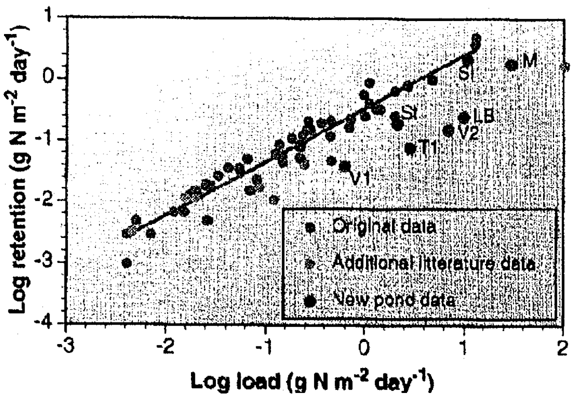


Figure 12.1. Original load-retention relationships (7) with additional lake and pond data (29, 30) and new pond data. V1 = Vallås 1st, V2 = Vallås 2nd, St = Stjärnarp, LB= Lilla Böslid, Sl = Slättåkra, M = Möllegård, T1 = Tjärby 1st (reference pond). (Ambio Vol. 23, No. 6, Sept. 1994).

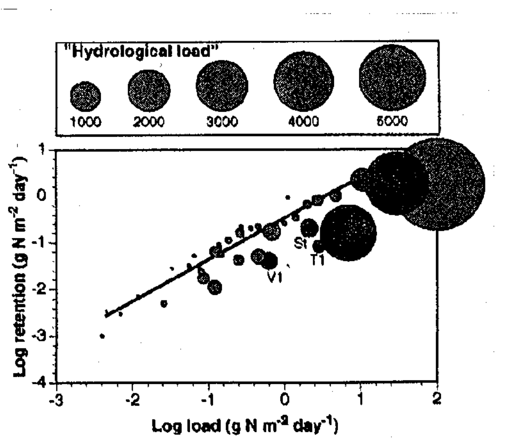


Figure 12.2. "Influence of hydrological load" on the load-retention relationship. "Hydrological load" is represented by the ratio drainage area/wetland area. For wetlands, data on drainage area is lacking, so data has been calculated "backwards," assuming a specific runoff of 12 $ls^{-1}km^{-2}$. V1 = Vallås 1st, V2 = Vallås 2nd, St = Stjärnarp, LB = Lilla Böslid, Sl = Slättåkra, M = Möllegård, T1 = Tjärby 1st (reference pond). Original regression line in black. (Ambio Vol. 23, No. 6, Sept. 1994).

Restoring and creating wetlands

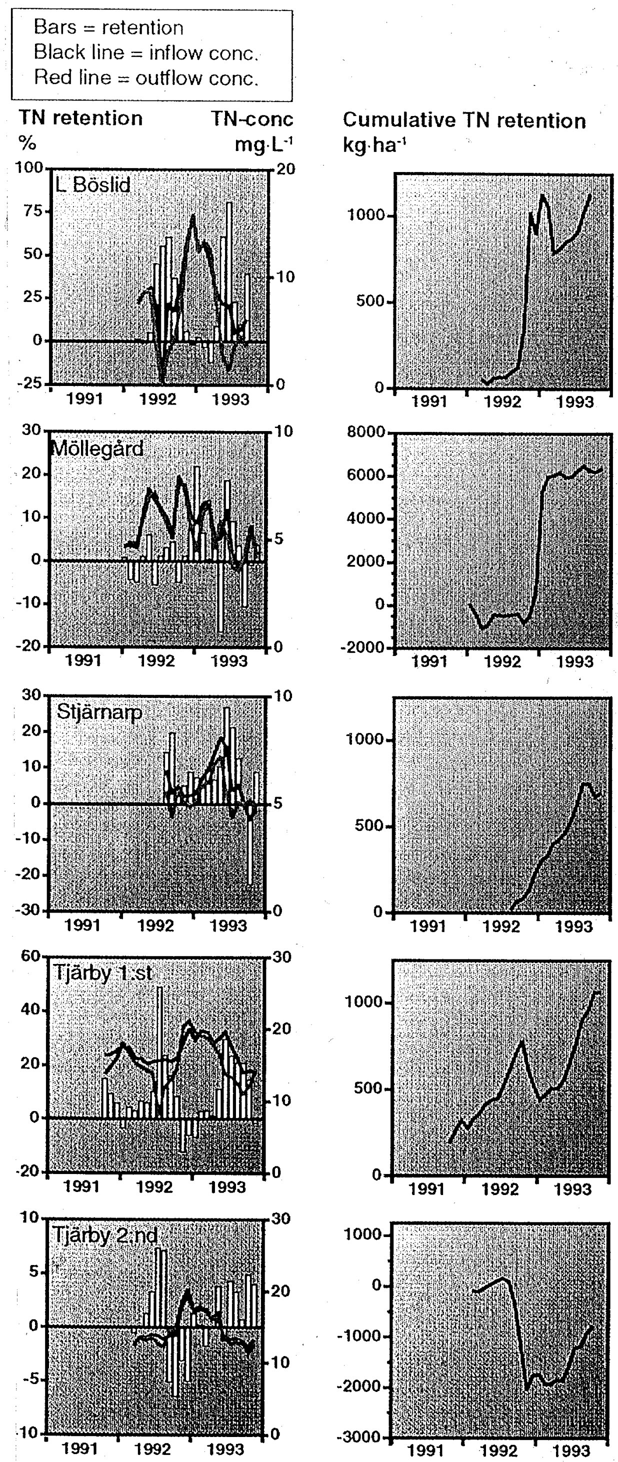
Formerly, when wetlands were used as productive areas in agriculture, they were properly maintained, e.g. through grazing by cattle or by the grass being cut. When, with changing production methods, they were abandoned or dried up, the result was overgrowth and an impoverished biotope. With the growing interest in nature conservation, some wetlands are being restored. The restoration measures focus on producing a more diverse landscape e.g. by removing shrubbery. For bird conservation purposes it is essential that free water surfaces are created and maintained. Machines able to cut reeds may be used, as well as other means of harvesting biomass, such as plants with large floating leaves. This requires considerable maintenance efforts, and yearly harvesting may be needed.

Recently we have seen a rising interest in creating new wetlands for mainly conservationist, that is ecological, but also technical purposes. In the latter case, it is the desire to utilise their capacity as filters that lies behind the interest. Recreating wetlands has often been found to be a less costly alternative to traditional wastewater treatment plants from the perspective of both construction and maintenance.

The simplest way to create a wetland is to increase the level of groundwater in an area, e.g. through damming. If the area is a forest, the trees have to be cut down and new vegetation introduced. The most commonly used wetland plants are reed, bulrush, cattail, reed mannagrass, sedge, rush and pale yellow iris. These can be found on existing wetlands. The transfer of plants also contributes to the right microbial flora.

An example of a newly created wetland of 22 ha is to be found at Oxelösund in Sweden, 100 km south of Stockholm. It was created to remove nitrogen from wastewater, but at the same time some parts were used to retain a total of 3.4 km of paths for pedestrians and cyclists. It consists of five different, connected open water surfaces. It took eight months to construct, from the cutting of the forests to letting in the first water. The total construc-

NITROGEN RETENTION IN FIVE WETLANDS



Spec hydrological load, $m^3 \cdot m^{-2} \cdot day^{-1}$	Wetland area, % of catchment	Spec load, $g N \cdot m^{-2} \cdot day^{-1}$	Spec retention, $g N \cdot m^{-2} \cdot day^{-1}$	Retention, %	Period
0.79	0.073	9.76	0.25	2.6	9209-9308
0.82		10.34	0.20	2.0	9204-9303
0.92		10.88	0.29	2.7	9203-9302
4.75	0.022	29.65	1.86	6.3	9209-9308
5.23		31.47	0.18	0.6	9201-9212
4.43		29.47	1.91	6.5	9205-9304
0.36	0.300	2.10	0.20	9.5	9209-9308
0.33		1.90	0.15	8.1	9212-9311
0.36		2.10	0.20	9.5	9209-9308
0.15	–	2.81	0.08	2.9	9209-9308
0.14		2.60	0.03	1.1	9205-9304
0.15		2.44	0.20	8.1	9110-9209
2.00	–	33.83	-0.38	-1.1	9209-9308
1.70		29.44	-0.52	-1.8	9207-9306
1.70		27.52	0.12	0.4	9212-9311

The 12 month period 9209-9308 is the same for all ponds. In addition, 12 month periods representing min. and max. areal retention, respectively, are also shown.

Figure 12.3. Nitrogen retention in five wetlands (Ambio Vol. 23, No. 6, Sept. 1994).

tion cost was 5 million SEK, while the yearly running costs is estimated to be 1.1 million SEK. About 2 million m^3 of wastewater is treated annually. The retention time of water in the system is about 7 days. It is estimated that 17 tonnes of nitrogen is turned into molecular nitrogen every year. It has already become an attractive habitat for waterfowl.

The Halmstad project

A careful study of the effects of the use of a wetland for nitrogen removal has been conducted close to Halmstad, in south-western Sweden. Here six sites were studied:

- *Vallås* was created in 1990. It is a 0.9 ha large and 0.5 m deep pond, rich in reeds, *Phragmites*, with a rich bird population and with a second much smaller pond about 1.5 m deep downstream. The ponds receive stormwater from an area populated by 7 000 people. The Vallås area has become a popular recreational site.
- *Stjärnarp* wetland was created in 1992 by damming a stream. Its surface area is 2.8 ha. The shallow area is mostly covered by sweetgrass, *Glyceria fluitans*. The drainage area of this wetland is 932 ha.
- *Lilla Böslid*, created in 1991, consists of two consecutive ponds with a total area of 0.47 ha. Depth varies between 0.9-2 m. Common duckweed, *Lemna minor*, covers large parts of the water surface. The area has several small islands with alder trees. 758 ha of agricultural land drain into the twin ponds, most of it containing nitrate.
- *Möllegård* is a former millpond overgrown by reed sweetgrass, *Glyceria maxima*. It was restored in 1991 by eliminating the macrophytes and making the pond deeper, resulting in an open water surface. A steep shoreline was created to prevent recolonisation of *Glyceria*. The pond is 1.0 ha with a mean depth of 1.5 m. The drainage area is 47 km^2 or 4 700 ha of farmland.
- *Slättåkra* is a tiny village of 220 inhabitants. The area's water, leaving the activated sludge process in the treatment plant, is led to one of three consecutive ponds of 113 m^2 (0.011 ha) with a mean depth 0.3 m, with reeds and an open water surface.
- *Lilla Tjärby* is a village with two old and "mature" ponds (0.091 ha with a mean depth of 1.5 m, and 0.33 ha with a mean depth of 2.1 m) receiving water from the Daggan River, which drains intensively farmed land. Nitrate concentrations in the water going to the first ponds are very high. *Potamogeton* and other macrophytes cover this pond. The second pond, with a free water surface, is used for sport fishing.

Nitrogen reduction in wetlands

These six wetland systems were carefully followed over several years by measuring nitrogen in incoming and outgoing water. The capacity of denitrification, expressed as kg N per ha for the five wetlands on four of the sites, is given in Figure 12.3.

There were considerable variations in retention time, nitrogen concentrations and hydrological load. Despite this, most of the sites had similar capacities for retaining nitrogen. As a rule of thumb one tonne of nitrogen was removed per year and ha of wetland. However, there were some remarkable exceptions to this average. The Slättåkra *Phragmites* pond, e.g., retained 8 650 kg N per ha and year, almost an order of magnitude more than the others.

The denitrification rates varied between 0.05 and 52.5 mg N per m^2 and hour. The Slättåkra pond had by far the highest value. The loss of nitrogen was entirely due to loss of N_2 gas as measured in gas bubbles from the ponds. If N_2O was created this was not lost from the system as gas. In addition methane was found in the measurements. The best result was achieved in the pond that received effluent from the activated sludge process, with a removal of close to 8 000 kg/ha and year, a very promising result for treatment plants in small villages.

A close relationship was found between denitrification rates and hydrological loads, i.e. the ratio drainage area/wetland area. The larger the hydrological load the more efficient the denitrification, i.e. when total nitrogen loading is increased the total areal retention also increases. The relative retention, however, is just the reverse, i.e. expressed as a percentage, it decreases.

It seems from these experiences that the outcome of constructing a wetland can be predicted quite well, which also applies to the costs. In general, wetlands to be used for nitrogen reduction are competitive when compared to conventional treatment plants and comprise an alternative that should be considered when planning nitrogen reduction measures.

The Polish experience

Poland has a long experience of using ponds and wetlands for wastewater treatment and nitrogen reduction. Some examples are as follows:

Wiezyca hill by Lake Ostrzyckie in the Gdansk district has a pond of 1.8 ha; divided in two parts, upper and lower, with a mean depth of 0.6 m. Reeds are planted over the entire area. The residence time is 46 days (1.5 months) in summer and 4 months in winter. By a system of dikes the water passes 16 times across the pond before it leaves. The water leaving

Agricultural waterscape in the Kashubian region, north-eastern Poland (photo, Lars Rydén).

the pond has 1.5-2.05 mg/l of total nitrogen while incoming water has 45-90 mg/l. The pond serves about 650 inhabitants.

The Sobiechy plant near Wegorzewo, in the area of Bialystok, was constructed in 1994. It is a 500 m^2 pond receiving 7 600 m^3 per day from the equivalent of 48 people. The second year the incoming water had 81 mg N and outgoing 28 mg N per litre. Here and in the above example too, a considerable reduction was achieved in other parameters as well, such as BOD and phosphate.

Coalition Clean Baltic, CCB, collected a series of descriptions of wastewater treatment in wetland ponds in 1997.

Irrigating agricultural land with wastewater

Of all the countries around the Baltic Sea, Poland still has the largest quantitative impact on the environment of this sea. There are several reasons for this. Almost all of Poland falls within the Baltic drainage basin, while half of the population and 40 % of the arable land of the basin as a whole are to be found within the country's borders. Poland as a whole is responsible for 36 % of the nitrogen, 38 % of the phosphorus and over 20 % of the organic matter entering the Baltic. As a result of actions undertaken in Poland in accordance with its national environment policy, a significant reduction in the riverine pollution load of point origin has been observed since 1988. The mean contribution of nitrogen and phosphorus loads, from non-point sources to the total load, is 51 % and 19 % respectively. It is estimated that agricultural sources account for about 30-35 % of the total nitrogen load and about 10 % of the total phosphorus load to the Baltic Sea.

Today the Vistula River basin contributes about 47 tonnes of ions per km^2 per year to the Baltic Sea as a non-point source of pollution. The corresponding natural outflow contributes approximately 24 tonnes. About 1 000 years ago the outflow from the Vistula River catchment consisted of 15 to 18 tonnes, but the outflow to the Baltic Sea was only 12 tonnes (25 to 30 % of the ions was stored or accumulated by natural wetlands). This means that, about 1 000 years ago, natural losses of substances important from an agricultural point of view were 30 % less than now.

There are, in principle, two possibilities for reducing nutrient runoff from rural areas in Poland:

- reduce the natural outflow by raising the water level and rehabilitate natural wetlands or establish new constructed wetlands or
- reduce the outflow of nutrients by good agricultural practices or reduce the outflow of pollutants from point sources in rural areas.

The restoration of natural wetlands and the establishment of new water storage systems in agricultural landscape are very important in Poland. Only 5 % of the outflow from Poland is storage in reservoirs. In similar conditions, in other countries with a similar water balance, approximately 15 % of the outflow has to be stored. This part is possible to increase in the rural landscape by small water storage systems for drainage waters, construction of small ponds or special ponds for fish production or by increasing the water level in ponds and small lakes. Other solutions could be to implement protection zones against nutrient leakage or to create nutrient traps and/or wetlands. Wetlands may act as efficient purification systems for water with high nitrogen and phosphorus concentrations. In some areas many goals could be achieved by such a strategy. The cultural landscape would also be preserved as an alternative to reforestation.

Agricultural runoff, in addition to municipal sewage from urban and rural areas and industrial pollution, also contributes significantly to contamination of groundwater and surface water. In rural areas, village water quality is very low in 20 % of household water supply systems, 48 % of common wells, and 66 % of home wells. Thus, nitrate compounds and bacteria in the water supply adversely affect the health of 50 % of the village population. Rural areas are inhabited by about 16 million people, who produce over 1 000 million m^3 wastewater per year, of which only 40 million m^3 is treated in sewage treatment plants. It is estimated that only 5 % of the farms are equipped with sewage purification system. The rest of the farms use very simple systems of sewage disposal. The rural wastewater is discharged into the soil, ponds and rivers, into ditches and unused wells in a raw, i.e. untreated, condition. Overall, an estimated 65 % of Polish surface waters are considered unfit for municipal or even for industrial use.

Wetlands for ecosystems management

Ecotechnology is the use of technological methods for ecosystem management. It is based on a deep understanding of the principles on which natural ecological systems are based and on the transfer of such principles into ecosystem management in a way that minimises the costs of the measures and their harm to the global environment. There are many good reasons for adopting principles of ecotechnology in Poland. Firstly, knowledge of using ecological services is not unfamiliar among people working with landscape management. There are several examples of long traditions, e.g. the productive wastewater treatment near Łódż, Wrocław and Lublin. Secondly, the costs for introducing low technology are realistic in the light of the actual economical situation. However, treatment systems based on ecotechnology will be most beneficial in small villages and agglomerations in rural areas. Thirdly, the problems of fossil energy utilisation cannot cause further environmental deterioration; hence treatment of pollution should apply to the low-energy rules of ecotechnology. In Poland several systems based on ecotechnological solutions have been constructed. Non-government organisations work to promote ecotechnological solutions for villages and farms. Small systems (constructed wetlands) for one house, one farm or a group of farms are very popular. Most of these systems are composed of vegetation filters with common reed, cattail and willow. There are also several systems using natural wetlands.

At present about 7 000 on-site wastewater systems for individual farms based on ecotechnology concepts are in operation. About 50 constructed wetlands composed of vegetation filters with common reed or willow (with an average inflow from 5 to 200 m^3/d) and 28 hydrobotanical systems based on *Lemna* (duckweed) have been installed.

The degradation of surface waters in Poland has been assessed as so high that without ecotechnological solutions it is not possible to improve water quality. The issues concerning the choice of level of sewage treatment have not yet been solved. There is no obvious answer to the question of whether to develop central village sewage systems, i.e. concentrate sewage effluent from houses and farms, or to decentralise it by neutralisation of the effluent at the place of its origin. Since 1991 Polish standards for wastewater quality after treatment have been raised to such high levels that the conventional methods for wastewater purification used up until now have been unsuccessful in achieving the goal. This is mainly due to the introduction of new criteria for the presence of nutrient components affecting the classification of water quality. In the case of sewage discharged to lakes, the limit for phosphorus is 1 mg/l and for sewage discharged to the sea 1.5 mg/l. By the year 2000, the total phosphorus content will have to be reduced to levels not exceeding 1.5 mg/l (now 5 mg/l) and the highest BOD_5 values are not to exceed 15 mg/l (now 30 mg/l).

On the highest level, treatment plants in rural areas fulfil the following requirements:

- high technologic inertia, which means they are resistant to significant changes of hydraulic load as well as contamination load;
- ease in maintenance, saving labour and energy during exploitation, and high reliability;
- elimination of representative contamination coefficients to required levels or limitation to a level allowing self-purification in sewage receiver;
- ease in construction and low investment costs.

The economic costs of water quality degradation have been substantial. The reduction of GNP in Poland has been roughly between 5 and 7 % (Kindler, 1992; Milaszewski, 1994). This reduction however has not been met, since only 1 % of GNP in Poland corresponds to expenditures on water protection investment (Sobkow, 1994).

Irrigation with wastewater has two aspects. The first concerns the protection of water resources against pollution. The second concerns intensification of agricultural production under water-deficiency and limited amounts of mineral fertilisers. Under Polish conditions the reduction of contaminants by grassland irrigation is not only important for protection but also from an economical point of view. Agriculture that uses wastewater for irrigation takes care of its purification. High concentration of nutrient components in wastewater makes it possible to attain high yields of irrigated meadows if accurate operation and maintenance of irrigation facilities is achieved.

The ner river catchment

The entire catchment area is 1 866 km^2 or about 12 % of the Upper Warta River catchment. The length of the Ner River is 126 km. The region is characterised by a moderate climate with low precipitation (567 mm per year) and a mean annual temperature of 8.1 °C (Table 12.1).

The results of the water budget calculations gave the following water demands for grassland during the vegetation season:

- 130 mm during an average vegetation period
- 200 mm during a dry vegetation period
- 250 mm during a very dry period

Table 12.1. Indexes of water balance (P = H + S) in the Ner River catchment

Index	Year	Summer period V-X
Precipitation (P)[mm]	566.8	359.4
Outflow (H)[mm]	184.3	69.7
Losses (evaporation) (S)[mm]	382.5	289.7
Index of outflow c = H/P	0.325	0.194

The width of the valley is between 700-1 000 m and the surface area is 100 km^2 (6 % of the catchment). The area of irrigated grasslands is about 50 km^2 (50 % is valley and 70 % is agricultural land in the valley). See Figure 12.4.

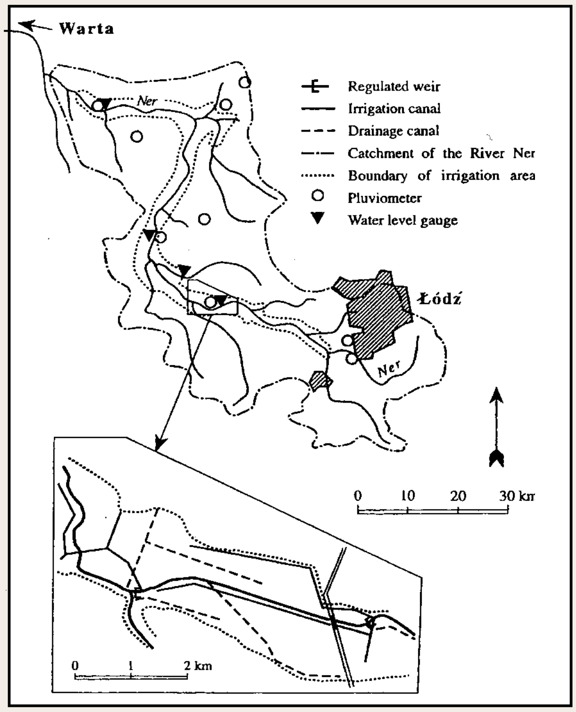


Figure 12.4. The Ner River as a macro-scale irrigation system. At the same time the river is a recipient for the city of Łodż, discharging 4 m^3/s of sewage water.

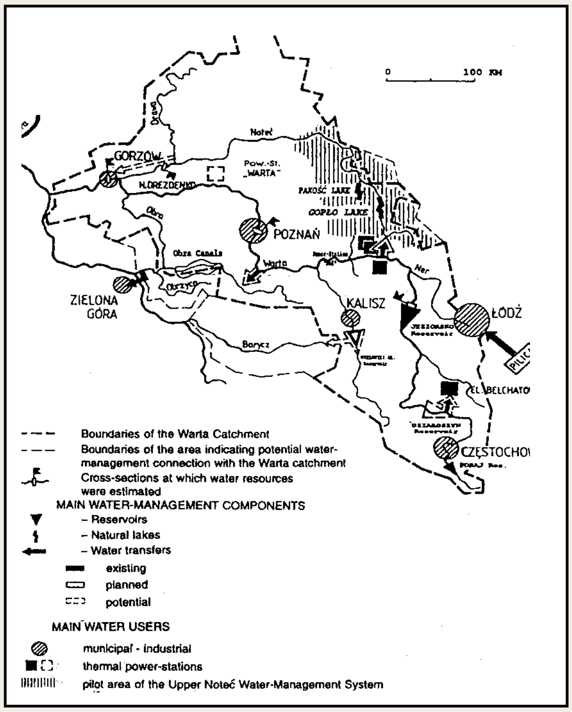


Figure 12.5. The main elements of the Warta catchment system.

Table 12.2. Nutrient value of wastewater along the course of the Ner River from 1948-1990

Distance from wastewater outlet (km)	NPK value of water (kg/m^3) 1948-50	1957-59	1964-66	1973-74	1979	1980-83	1985-90
0	-	0.121	0.087	-	0.070	-	-
12	0.108	0.071	0.086	0.064	0.056	0.075	-
18	-	-	0.064	0.060	-	0.058	-
30	0.096	0.061	0.058	0.047	0.044	0.052	0.045
50	-	0.027	-	0.041	0.031	0.041	-
60	-	-	-	0.039	-	0.037	-

The Ner-Warta catchments

Two agglomerations, one in Łódż (400 000 m^3 sewage water per day) and one in Poznań (200 000 m^3 sewage waters per day), are the largest sewage producers in the Warta River basin. These big cities have no biological treatment in their wastewater treatment plant and only a part of the sewage that is discharged to surface water has been treated with mechanical cleaning. These discharges from the Łódż Agglomeration to the Ner River contributes to 25 % of the sewage discharge volume in the Warta River basin and 42 % of total outflow from the Ner River catchment. It generates considerable danger for potable water surface-intakes in the Ner River and downstream – at the Warta River. This difficult situation is hazardous because dangerously polluted water from the Ner River is used for irrigation of many hectares of agricultural lands. Bacteriostatic and chemical pollution in water that is used for irrigation exceeds the maximum permitted standards many times over. Prolonged exposure to critical pollution concentration has brought these areas to a point of degradation, which causes danger to the health of existing human and animal populations there.

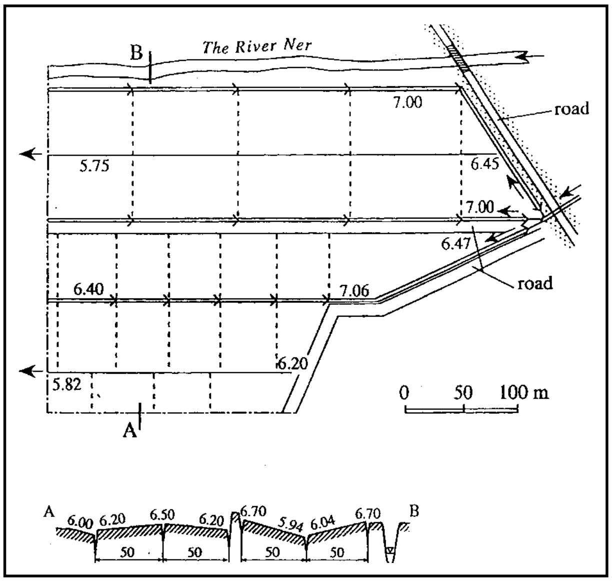


Figure 12.6. The irrigation network in the valley of the Ner River.

The Ner River is a tributary to the Warta River. The Warta River catchment is located in the western part of the Polish Plateau and is the largest tributary to the Odra River. The entire catchment area is 55 248 km^2 and constitutes about 17 % of the territory of Poland. The region is characterised by a moderate climate with relatively low precipitation (611 mm per year) and a mean annual temperature of 8.1 °C. In the year 1995, about 6.4 million people lived in the Warta River basin, of which more than one-third lived in four main agglomerations: Czêstochowa, Konin, Łódż and Poznań. The per capita fresh water supply in the entire basin was equal to 1 067 m^3/year, just above the 1 000 m^3/year benchmark used as an approximate indicator of *water scarcity* by the World Bank (Karczmarek et al., 1996).

The technical infrastructure of the Warta River water resource system is very modest (see Figure 12.5). Only two reservoirs, Poraj and Jeziorsko, are located along the river, of which only the latter has sufficient capacity to have an impact on flow redistribution. The two reservoirs control only 3.2 % of the catchment's runoff. An additional storage reservoir was built in Sulejów on the neighbouring Pilica River with the aim of supplying the Łódż agglomeration.

At present, however, most of the region's agriculture is rain-fed, with irrigated lands covering only a small percentage of the entire of basin.

Table 12.3 Average chemical composition (mg/l) of the stream water in the Ner River from 1975-1990

Elements	Distance from wastewater outlet 2 km	15 km	50 km
Total dry matter	1 055	955	739
BOD_5	170	127	68
COD	386	279	169
Ammonium nitrate	23.8	16.6	10.7
Phosphates	5.8	4.6	2.9
Sulfates	191	206	193
Chlorides	145	148	107
Zinc	1.36	0.60	0.92

Table 12.4 Effects of many-years irrigation with municipal wastewaters on properties of soil in the valley of the Ner River

No	Features investigated	Non-irrigated field	Field irrigated for 50 years
1	Humus thickness layer (cm)	0	25
2	Organic matter in % of dry matter in the layer of 5-10 cm	0.37	4.63
3	Sum of exchangeable bases in m eq. per 100 g of dry soil in the layer of 5-10 cm	1.64	20
4	Active pH in the layer of 5-10 cm	5.9	7
5	Bulk density of dry matter of soil in the layer of 5-10 cm	1.53	1.12
6	Porosity in % in the layer of 5-10 cm	42	55
7	Field water capacity (mm) in the layer of 0-60 cm at the ground water table of 1 m	63	191
8	Water capacity measured in the draught period in the layer of 0-60 cm	33	120
9	Available water - holding capacity (mm)	30	71
10	Maximum hydroscopity in % of dry matter in the layer of 5-10 cm	1.3	6.8
11	Moisture of wilting in % of dry matter in the layer of 5-10 cm	4.5	20.8
12	Hydrolic conductivity cm/s in the layer of 5-10 cm	10^{-2}	10^{-3}

Predicting future irrigation demands for the Warta River basin is a complex issue. Firstly, it is the opinion of many authors (Szpindor & Piotrowski, 1986) that the present percentage of irrigated agricultural land in Poland is far too low, even for the current climate conditions. Secondly, climate warming may necessitate an expansion of irrigated land and may also cause an increase in the water demand per unit of irrigated land, even in the case of enhanced precipitation. Finally, the increased concentration of CO_2 in the atmosphere may reduce irrigation demands owing to the anti-transpiration effect of increased stomatal resistance. For the purpose of many different prognoses connected with climate change impact (Karczmarek et al., 1996) it is assumed that in central Poland, 15 % of the arable land and 40 % of the grassland should be irrigated. These are slightly lower figures than those proposed by water resource planners and agricultural scientists (Szpindor & Piotrowski, 1986).

Irrigation system and productive wastewater treatment

The utilisation of sewage effluent in agriculture has a long tradition in Poland. There are fields that have been irrigated with wastewater for over 100 years, which, despite overloading, still meet the requirements of the second and third degree of biological treatment processes. Areas where such treatment has been carried out for many years are the Ner River Valley, Osobowice near Wrocław and the Bystrzyca Valley near Lublin. The largest irrigation system in Poland is located in the Ner River Valley, which is an example of an area where wastewater was used for fertilisation and irrigation of grasslands as early as the 19th century.

The development of the irrigation system in the Ner River, which started in the late 1800s, was connected with agricultural utilisation of wastewater from the city of Łódż. High concentration of nutrients in wastewater made high yields from irrigated meadows possible and an accurate operation and maintenance of irrigation facilities was observed.

Sewage from the city of Łódż, which has almost 1 million inhabitants and a textile industry, is discharged into the Ner River after mechanical purification. Grasslands in the area of about 5 000 hectares are irrigated by the border-strip method. The total irrigation area is divided into 22 complexes in the area of 150-300 hectares each (Figure 12.4).

The area of meadows irrigated with the border-flow system has gradually increased in area, reaching 3 200 ha in 1960 and about 5 000 ha in the 1980s along a 70 km long stretch of the river valley (Figure 12.4). A particular type of border-flow irrigation was developed in the valley, which has specific soil-water conditions (deep sandy alluvial soils and a shallow groundwater table). During the irrigation process the inflow of wastewater to an artificially formed border-check infiltrates into the soil and fills the available porosity. Excess water flows as surface runoff towards open drainage ditches. After some time the process of contamination elimination takes place

Table 12.5 Reduction coefficients (R) of BOD_5, N, P, K in the field scale

	Irrigation rates (mm)		
	40	150	300
BOD_5	0.93	0.94	0.92
N	0.90	0.80	0.75
P	0.86	0.78	0.78
K	0.91	0.90	0.86

Table 12.6 Concentration of biogens in outflow from wastewater treatment plant in Łodz

Index	Outflow from wastewater treatment plant Mechanical 1 step only 1996	Standard in 1997	Standard after 2000	Requirements for 3rd class of water in the Ner River
BOD_5 mg O_2/l	240	30	15	<12
Total Phosphorus mg P/l	11.6	5	1.5	<0.4
Ammonium nitrogen mg N - NH_4 mg/l	30	6	6	<6
Nitrate nitrogen mg N- NO_3/l	-	30	30	<15
Total Nitrogen mg N/l	35	30	30	<15

Table 12.7. Results of implementation of different ecotechnological solutions in the Ner River Valley

System	BOD (mg/dm^3)	Total-P (mg/dm^3)	Total-N (mg/dm^3)
Surface flow (SF) wetland system 340 ha			
inlet	30	5	30
outlet	15	3.6	17.2
Irrigation of grasslands 5000 ha			
inlet	-	5	30
outlet	-	3.7	20.5
SF wetland - 340 ha and irrigation and irrigation of grasslands 5000 ha			
inlet	30	5	30
outlet	15	2.3	8.8
SF wetland - 20 ha and irrigation of grasslands - 5000 ha			
inlet	30	5	30
outlet	28.5	3.4	20.5
SF wetland - 20 ha			
inlet	30.0	5	30
outlet	28.5	4.9	28.9

in the soil. The natural soil system is a dynamic medium for absorbing, treating and utilising the waste constituents. It works as a mechanical, chemical and biological filter, which is renewed through systematic agricultural use. The irrigation and drainage system consists of 22 weirs, 19 spillways, 11 bridges, networks of irrigation and drainage channels, detailed networks of irrigation ditches and drainage outlet ditches, water flow regulating structures and communication culverts. The area between the weirs constitutes a separate, independently working system of local irrigation, which covers about 200-300 ha. The Ner River is the main irrigation canal and at the same time the main outlet channel for irrigation dump and drainage waters. In this way irrigation with wastewater from the Ner River may be repeated several times along the river valley.

Artificially formed border-checks have a length of 6-15 m in the older system, which constitutes about 60 % of the total irrigated area. In the modernised and new irrigation system, which was created after 1960, the length of border-checks is about 50 m (Figure 12.6).

As a result of such irrigation, high yields of hay ranging between 10-20 t/ha were obtained from the meadows. Recently, in spite of additional fertilisation, a descending tendency in hay yields has been observed. Such an undesirable situation is caused by changes in the chemical composition of the wastewater from Łódż (see Table 12.2). The industrial wastewater contribution to the total wastewater volume was recently estimated to be 55 %.

Due to a considerable increase of the total sewage and of toxic substance in wastewater the usefulness of wastewater as fertiliser has decreased (see Table 12.3).

Influence of wastewater irrigation on soil properties and yields of hay

The basis for the estimation of irrigation efficiency in all three aspects, i.e. wetting, fertilisation and purification, is the water balance of the soil as well as the balance of mineral and organic soil substances. Investigations have proved that there is a direct relationship between irrigation and accumulation of organic substances in the soil. Irrigation with wastewater intensively affects the course of the biological processes in soil. In strongly permeable light soils a growth of organic matter in the soil profile is observed. This organic matter accumulation is a factor that initiates many positive changes in physical and chemical properties of the soils.

The influence of irrigation on yields and crop quality has been investigated in vegetation and post-vegetation periods (Mosiej et al., 1991; Somorowski et al., 1991). Field experiments made it possible to estimate treatment efficiency.

The investigations carried out on light soils in the Ner River Valley have proved that the accumulation of organic matter varies depending on the length of the irrigation period (Table 12.4). Other changes of soil properties are of a secondary character and are correlated with the organic matter content in soil. A final result of many-year irrigation with wastewater of areas in the Ner River Valley is the formation of a new anthropogenic type of soil characterised by the highest potential for plant production (Kaca, 1993).

The average yield increase under irrigation was 66 %. Irrigation with sewage water in the Ner River Valley was effective as a form of fertilisation, particularly if applied all year, giving yields over 10 t hay per ha without additional mineral fertilisers (Somorowski & al., 1991). Grassland irrigation resulted in a contamination reduction, because 75-95 % of the total content of contaminating agents remained in plant and soil (Somorowski et al., 1991). See Table 12.5.

The Ner River Valley during a transition period and in the future

At present a new wastewater treatment plant in Łódz is under construction. About 50 % of the sewage water at the new plant is treated in several mechanical and biological steps (Table 12.6). The main problem in the Ner River Valley is how to reach the 3rd class of biological treatment processes for the water in the Ner River. There are three main possibilities for improvement of the water in the Ner River:

- use the sewage water after the mechanical and biological steps for irrigation only;
- use the irrigation system and establish additionally constructed wetlands with surface flow;
- establish only constructed wetlands for purification of outflow from sewage treatment plant.

The results of implementation of different measures in the Ner River Valley are presented in Table 12.7 (Kadlec, 1994a; b; Kadlec et al., 1993).

The problem now is that it is possible to use the irrigation system in the river valley and use only 20 hectares for constructed wetland. The maximum area available for constructed wetlands (the upper part of the river, with low elevation and area, which belongs to the state) consists of 340 hectares only.

The results of calculations show that it is impossible to reach the low contamination level of the third class without connecting irrigation to constructed wetlands.

13.

MUNICIPALITIES AND WATER USE

Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta Płaza

Historical aspects and changes in priorities

The linkage between water pollution and waterborne diseases was suspected from death registers as early as in the 19th century. In 1854 an English physician, John Snow, clearly traced the outbreak of cholera epidemics in London back to the Thames River, which was heavily polluted with raw sewage. Even though the role of waterborne diseases has been recognised for a long time, dirty water is still the world's major cause of disease. More than a third of the world's population does not have safe drinking water. Waterborne diseases cause an average of 25 000 deaths per day in the world.

To control waterborne diseases it is necessary to maintain a high level of hygiene, especially in urban areas with large population densities. This is illustrated by the close relationship between the death rate from waterborne diseases and levels of water consumption in Stockholm over a long period of the 19th century (Figure 13.1). It has been shown that a particular problem is to separate sewage from the drinking water supply, which was not done efficiently in the 19th century. Waterborne diseases are still a problem in some areas of the Baltic region and to boil drinking water before consumption is recommended in many cities. On a few occasions when by technical error the wastewater leaks directly into the drinking water net for households, large groups of people have been reported severely ill.

The public water network began to be built in Sweden about a century ago. It was in the larger communities that the first stage of constructing municipal water and sewage management took place. This construction is generally regarded as having been complete around 1920, by which time most of the largest cities had sewage pipe networks. The pipes replaced earlier sewage gutter leadoff, which was used for flush-water and sometimes also for disposal of trash and excrement. The solution to the environmental problems of the time was to construct sewage pipe networks, an enterprise that involved a major economic sacrifice. Pollutants were removed from the municipalities to the nearest water area.

In 1859 the first water closet was installed in Stockholm, but it took many decades before the royal castle got this new convenience. The advantage of being spared the abhorred latrine collection soon became obvious and from the turn of the century most new houses in the big cities were provided with water closets. The closet outlet was connected to a single sewage pipe and the combined wastewater system was introduced. When the public water and sewage networks had been built, the use of water for various purposes increased significantly (Figure 13.2).

The inconvenience of the combined transport of toilet water and stormwater soon became noticeable. The treatment plants did not have the capacity to take care of the entire runoff during storms. A part of the untreated wastewater had to be led past the treatment plant and bypassed out in the recipient. In addition, flooding of basements became more common.

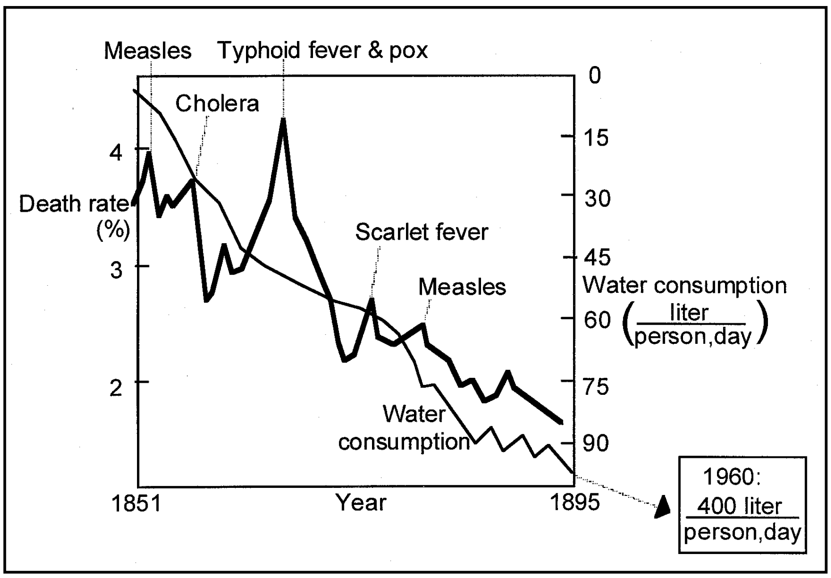


Figure 13.1. A close connection between the death rate from waterborne diseases and increased water consumption from the water network in Stockholm (Cronström, 1986).

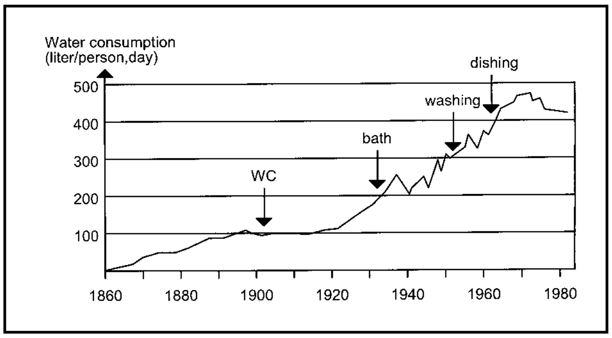


Figure 13.2. Water use in Stockholm between 1860 and 1980 (Cronström, 1986).

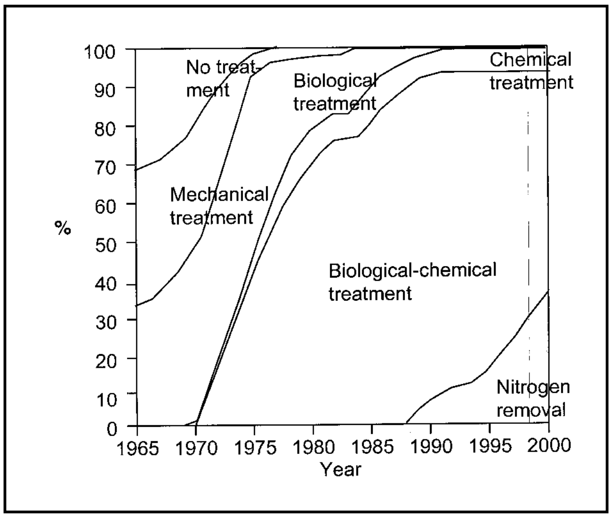


Figure 13.3. Municipal wastewater treatment in Sweden, 1965-2000 (Ministry of Foreign Affairs & SEPA, 1998).

To solve these problems a new phase of the network construction was initiated in 1955. From that time all new sewage networks were built as duplicate systems, where wastewater and stormwater were drained in separate pipes. This was done without any official recommendation.

The latest construction phase of sewage systems started with the 1969 environmental protection legislation. Due to generous governmental subsidies, an extensive network of high-grade sewage treatment works was completed in the 1970s.

There are now approximately 2 000 municipal wastewater treatment plants and plants with tertiary treatment, i.e. biological and/or chemical treatment (see Figure 13.3), which serve 95 % of the population in towns and districts with more than 200 inhabitants. As a result of improved municipal wastewater treatment, pollution discharges have been reduced substantially (Figure 13.4).

Developments in wastewater treatment systems have been strongly influenced by developments in society. Varying driving forces have changed priorities from an initial focus on hygienic aspects via gradual improvements of treatment methods to a focus – in addition to earlier requirements – on recycling resources, saving and recovering energy, public participation and interactions with other sectors in society. Developments in water and wastewater handling systems are illustrated in Table 13.1.

It is increasingly being recognised that the real causes of pollution are not the discharges that should be controlled and contained within sewage treatment, but rather the society's non-harmonised socio-economic development. In the future, the transfer of environmental control to internal elements of the economy and of general overall management will be a major task of the coming decades. This is often termed prevention, inten-

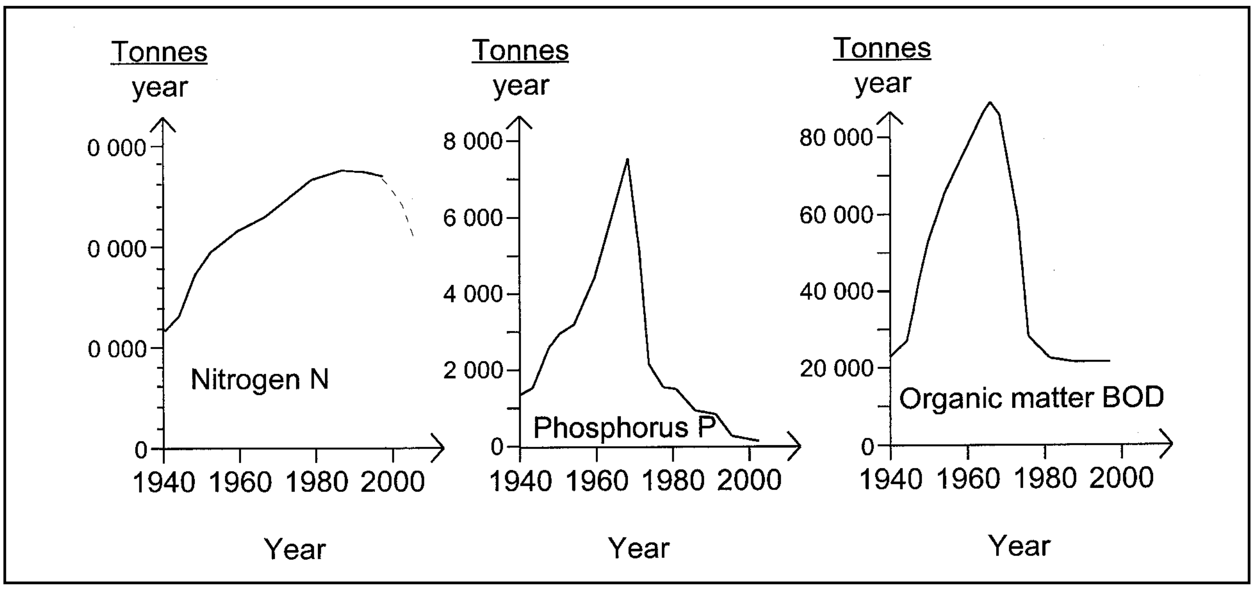


Figure 13.4. Discharges of nitrogen, phosphorus and organic matter from municipal wastewater treatment plants. The increases are attributed to an increase in the connection of households and small industries to the plants. The reductions are attributable to improved treatment. (Ministry of Foreign Affairs & SEPA, 1998).

Table 13.1. Developments in Swedish water and wastewater handling systems

Time period	Driving forces in society (examples)	Effects on environment	Remedies
Before 1930	Population growth; urbanisation	Contamination of local water sources; spread of waterborne diseases	Supply of water from an uncontaminated water source
1930 - 1990	Increasing standards in houses (WC, bath etc); increased use of different products; rapid growth of economy	Gradual building of water and wastewater handling infra-structure incl. different treatment steps; efficient control of industrial discharges	Impairment of the environment due to discharges of different substances, although compensated by different remedies
1990 -	Increased awareness of environmental issues and its relation to life style	Improved environmental quality especially on a local scale due to decreases of discharges	Development of Agenda 21; multi-disciplinary approaches to problem solutions; use of international environmental standards such as EMAS and ISO 14000

sive environmental management or sustainable development. The success of this shift will greatly depend on whether legislation and policy-making are able to live up to the complex and challenging requirements of the next century and the changing attitudes of societies.

The future framework of water pollution control will be much wider than that of today, will incorporate soft and hard elements belonging to various disciplines and sectors and should incorporate a large number of feedback mechanisms. It will cover, among other issues of non-point source management, policymaking, project evaluations, institutions and public opinion.

Table 13.2. Drinking water consumers in Sweden 1994 (VAV, 1995)

Users	Yearly use (Mm^3)	Per capita use (l/p/d)	Relative use (%)
Households	544	198	57
Industries	95	35	10
General services etc.	95	35	10
Losses and own use	219	79	23
Total	953	347	100

Table 13.3. Typical household use of water in Sweden (VAV, 1995)

Water use	Consumption (l/p/d)	Relative use (%)
Cleaning, car washing etc	20	10
Preparation of food, drinking water	10	5
Toilet flushing	40	20
Washing	30	15
Dishing	40	20
Personal hygiene	60	30
Total	200	100

Water supplied by municipalities

Water supplied by municipalities may be divided into:
- Household use
- Use by industries connected to the central network
- Public services (schools, hospitals etc.)
- Losses and own municipal use

The production of drinking water in Sweden is shown in Table 13.2. At a total household consumption of 200 l/p/d (litres per person per day), the present distribution of water use for various purposes is shown in Table 13.3.

There are many ways to reduce an area's water consumption without neglecting crucial functions of the water supply (Table 13.4):
- Reducing leakage from water distribution networks
- Making industrial process more efficient
- Making faucets and water-consuming equipment in households, schools and the like (washing machines, dishwashers, low-flushing toilets etc.) more efficient
- Artificial groundwater production (to reduce evaporation)
- More efficient irrigation (to reduce evaporation)
- Reuse and re-circulation of treated wastewater

In households in some western countries there has been a slightly increasing tendency towards reduction in water consumption per capita, brought on by more efficient faucets and other installations. Other factors could be individual water measuring and raised water prices. Cold- and hot-water consumptions are dependent on each other and measures to reduce hot water consumption may also affect cold-water consumption. Table 13.5 shows that the potential of saving water for daily household-use today ranges from 100 to 200 litres. By installing new water saving faucets, water use for cleaning and personal hygiene can be reduced by

Table 13.4. Examples of water saving methods (based on EPA, 1980)

Method	Comments
Elimination of non-functional water use	
Improve water use habits	No flushing of cigarette butts, allowing water to run during shaving, operating washing machines with partial load etc
Improved plumbing and appliance maintenance	Steadily dripping faucets and leaking toilets is a great waste of water
Non-excessive water supply pressure	
Water saving devices, fixtures and appliances	
Toilets	
Water carriage toilets	Several possibilities exist, such as dual-flush toilets and low-volume flushing toilets
Non-water carriage toilets	Such as composting toilets
Bath devices, fixtures, and appliances	Shower flow controls, mixing valves, air-assisted low-flow shower systems
Washing machines and dishwashers	
Miscellaneous	Faucets inserts and aerators, mixing valves, hot-water pipe insulation, pressure-reducing valves
Wastewater recycle/reuse systems, use rainwater	Examples are recycling of bath/laundry water for toilet flushing. These methods are at present rather expensive

Table 13.5. Household water use in litres per person and day before and after water saving measures, with percentage of water reduction (SOU, 1995)

	WC	Washing	Dish washing	Cooking drinks	Cleaning etc.	Personal hygiene	Total
Before saving (l/p/d)	40	30	40	10	20	60	200
		New water saving technology			*New faucets*		
With saving (l/p/d)	5	15	15	10	15	40	100
Reduction (%)	87.5	50	62.5	0	25	33	50

20-40 litres per person and day. The reduction for cleaning is 25 % and for personal hygiene 33 %. Faucets with separate taps for hot and cold water can be substituted with one-tap faucets where temperature and flow are regulated using the same tap. This kind of one-tap faucet makes it easier to regulate the water temperature, thus saving water that otherwise would have been turned on and "wasted" while finding the right temperature.

The highest amount of water savings, 20-35 litres per person and day (87.5 %), can be achieved by installing new low-volume-flushing toilets. A 20-year-old toilet bowl uses about 8-9 litres per flushing. A modern toilet bowl often uses 6 litres and a water-saving toilet uses less than 3 litres. The urine-separating water toilet uses about 5 to 8 litres per person and day. (However, if the toilet bowl uses too small an amount of water, problems may arise due to blockage of the small sewer pipes.) Installation of new water-saving dishwashers can reduce water use by 20-30 litres per person and day (62.5 %) and modern washing machines reduce water use by 10-20 litres per person and day (50 %).

Local water supply and treatment

Water for treatment and subsequent public consumption is normally supplied from surface water bodies (rivers, lakes and reservoirs) or from groundwater aquifers. Traditionally, surface waters have been the major sources, but groundwater sources have become more and more attractive. Groundwater is more likely to be of better quality than surface water and accordingly, treatment costs will be considerably lower.

The quality of Swedish groundwater is often so good that treatment is unnecessary. Groundwater can be abstracted from a well and pumped straight to the households for consumption. However, there are sometimes problems with groundwater quality, of which high iron (Fe) and manganese (Mn) concentrations are the most common. These compounds have negative influences on the taste, colour and stain properties of the water. Increasing the oxygen content in the groundwater reduces these negative effects. A simple way of aerating groundwater is to pump it up from the groundwater aquifer and let it undergo aeration before infiltrating it again. The aerated water then

Water use in Finland

In Figure 13.5 the activity of community waterworks is shown. Surface-waterworks usually require treatment of the water through filtering and the addition of chemicals to remove undesirable substances. In order to maintain as low a cost as possible, water treatment plants must be fairly large, which can be achieved in cities and towns. For the more sparsely populated communities it may be more economical to use groundwater since the cost of groundwater treatment is usually much lower. Since groundwater can be extracted at several points in an aquifer the cost of distribution lines will also be low. Looking at the figure it is evident that groundwater is a preferred source. Use of surface water is limited to a fairly small number of places compared to the number of groundwater sources. The situation throughout Sweden is fairly similar.

Erik Eriksson

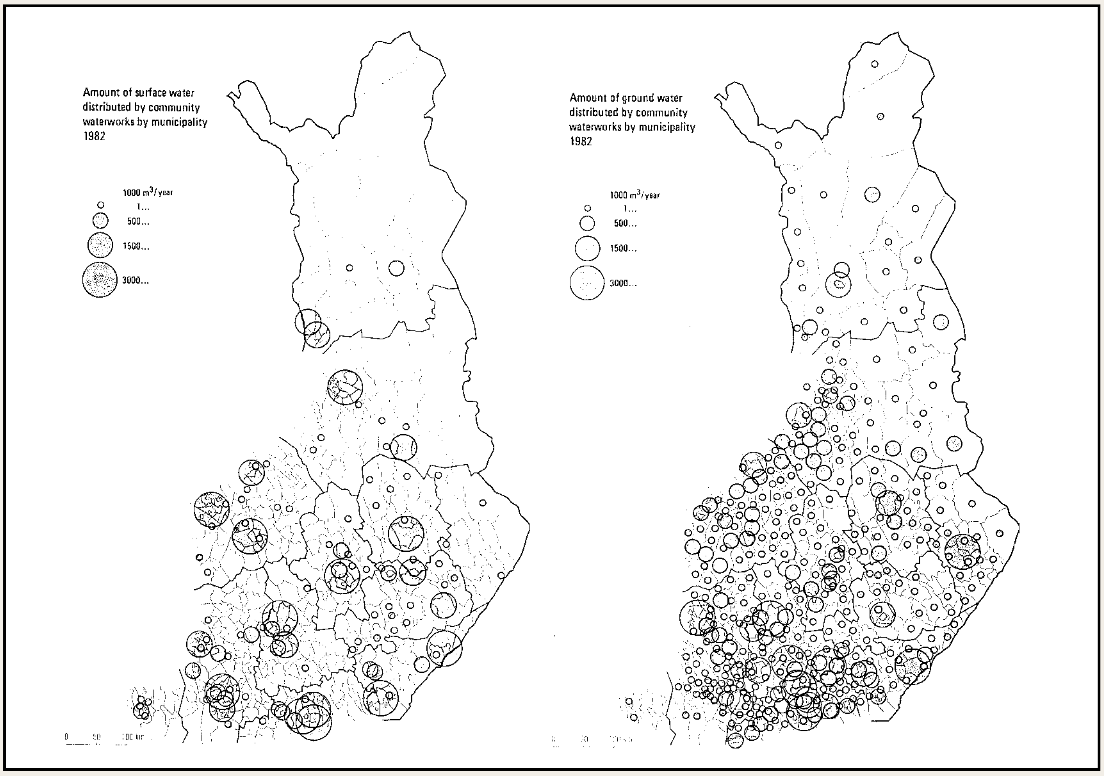


Figure 13.5. Amounts of water distributed by community waterworks for municipalities. Surface water on the left map, groundwater on the right (from National Board of Survey & Geographical Society of Finland, 1986; Atlas of Finland, folio 132, figures 21a and 21b, published under permission no 420/MAR/98).

infiltrates into the ground, but is not allowed to reach the original groundwater level before it is abstracted for consumption.

An aeration facility can be easily constructed by abstracting artesian groundwater that forms a cascade that will flow over stones placed on the ground. As explained above, the water will infiltrate into the ground after aeration but is not allowed to reach the original groundwater level before it is abstracted by abstraction wells. The distance from the artesian groundwater cascade to the abstraction wells can be fairly short, 25-30 metres.

One problem that can arise, especially in agricultural areas, is contamination of groundwater by nitrate. In Sweden, this problem is sometimes found in the southern parts of the country. If the nitrate concentration exceeds the limit (50 mg NO_3^-/l), the particular groundwater source must be abandoned since there is practically no economical possibility to treat nitrate-contaminated water.

The interest in groundwater as a raw water source has increased, not only due to its higher quality, but also because the need for consumption water has increased. One way to increase the amount of

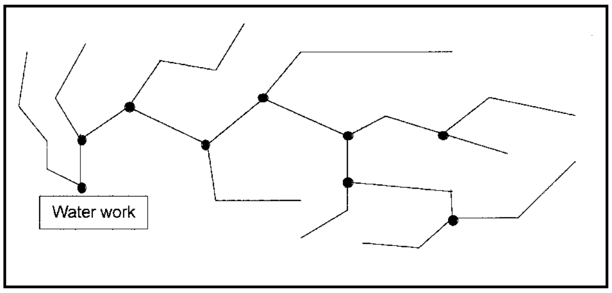


Figure 13.6. Branch water-distribution network.

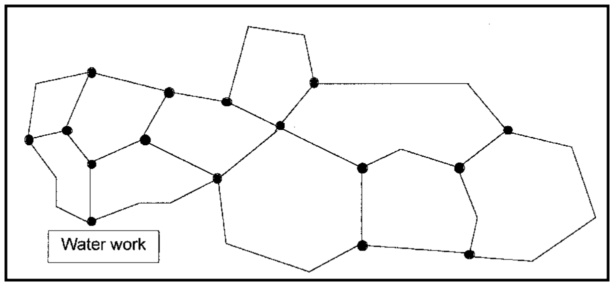


Figure 13.7. Circulation water-distribution network.

groundwater is to infiltrate surface water. This is called artificial recharge of groundwater. The method can be used to increase the amount of groundwater for a small town and can also be applied on a larger scale. Artificial infiltration is already in use in the city of Göteborg and is being studied as a possible method of handling water in Stockholm in the future.

Water transport in central systems

Water distribution network

The water distribution network should meet the criteria of good delivery security and good water circulation. Three main kinds of networks are available:

(1) *Branch networks* in which every point in the water distribution net is supplied from only one direction (Figure 13.6). The system involves fairly low investment expenses. One disadvantage is that in cases of operational stoppage a relatively high number of users may be without water supply.

(2) *Circulation networks* in which every point in the system is supplied from two or more directions (Figure 13.7). The circulation system is somewhat more costly in initial investment expenses but has a higher level of water delivery safety.

(3) *Combinations of branch and circulation networks* (Figure 13.8).

Water treatment in central systems

About 25 % of the water supplied by municipalities in Sweden comes from groundwater, while 25 % is from artificial infiltration and 50 % from surface water. If the surface water is not clean the normal procedure is to combine artificial infiltration with both pre- and post-treatment. Pre-treatment can consist of microstraining or rapid filtration, for example. Post-treatment is normally alkalinisation, which reduces corrosive properties of the water. In some cases, removal of iron and manganese is necessary. A typical treatment scheme is illustrated in Figure 13.9.

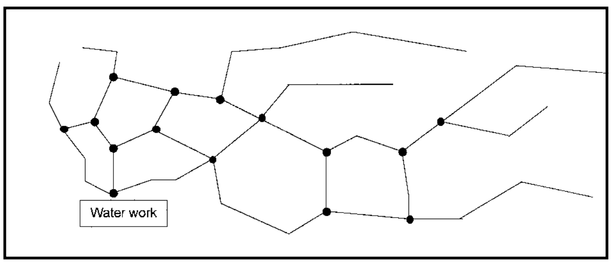


Figure 13.8. Combined branch and circulation water-distribution network.

Surface water treatment must be carried out in several steps and the lower the water quality of the water source, the more stages that are normally required. A typical water treatment plant is shown in Figure 13.10.

Surface water is normally pre-treated with screens and sometimes a pre-disinfection step is included to facilitate further disinfection. Chemicals are added to quickly coagulate impurities, and the following steps are flocculation and floc separation. Separation normally requires sedimentation or flotation, followed by rapid filtration. Disinfection agents are added to remove remaining pathogens. In the last treatment step, chemicals such as lime, sodium carbonate and/or sodium hydroxide are added to yield water with as low corrosive properties as possible. The treated water is then pumped to the distribution net.

There is an increasing interest in using slow sand filters to reduce natural organic matter (NOM) in consumption water. A slow sand filter is primarily intended for biological treatment of the water, but it must also possess physical and chemical removal capacities to work satisfactorily. The slow sand filter reduces odour and taste that are caused by organic matter.

The basic principles of a slow sand filter construction are shown in Figure 13.11. The thickness of the filter in the beginning is approximately 1 m and the particle size of the sand grains is roughly 0.30 mm. Every time the filter is cleaned, 15-25 mm of the sand layer are removed. When the filter measures only about 0.75 m, the filter material must be replaced with new material.

There are some 60 water treatment plants in Sweden employing a slow sand filter technique. In some

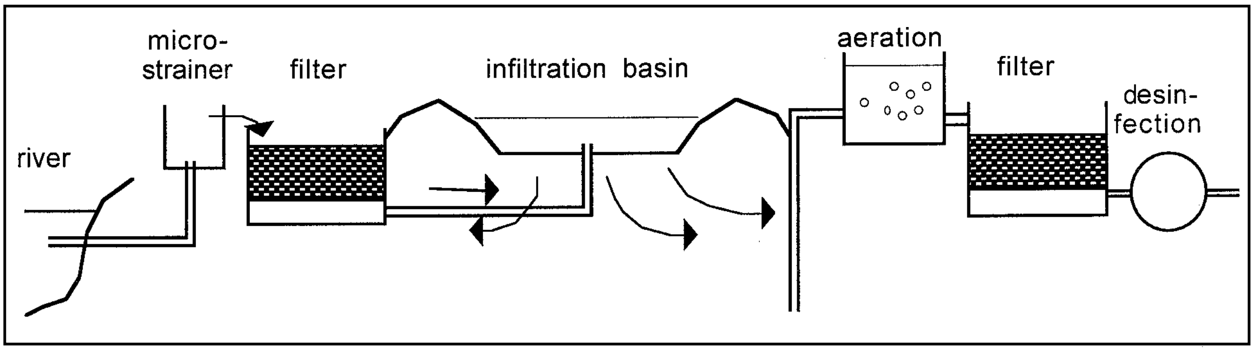


Figure 13.9. Treatment system with artificial infiltration.

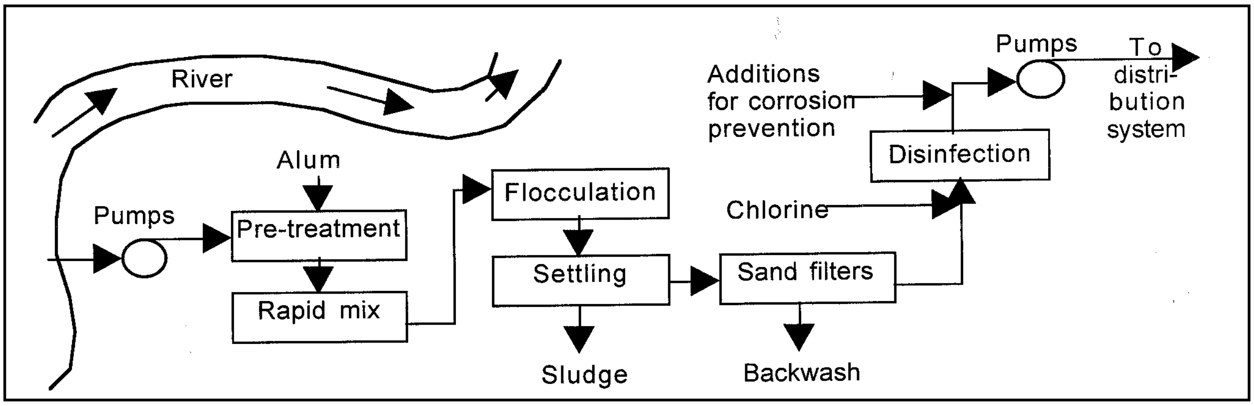


Figure 13.10. Flow sheet of a typical municipal treatment plant for a surface water supply.

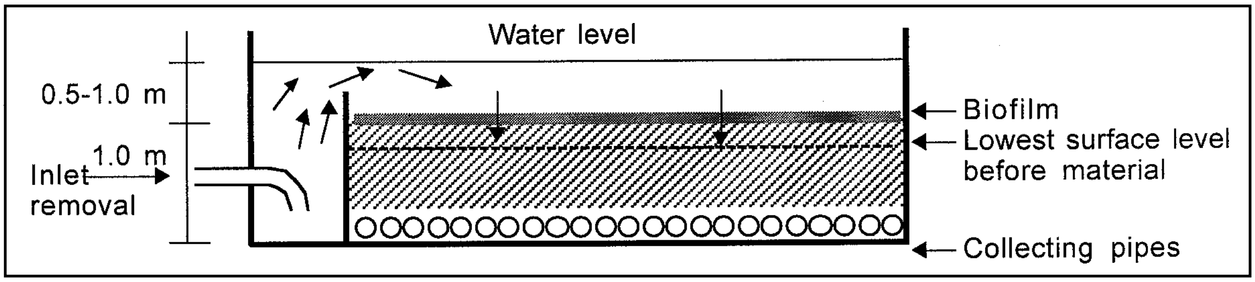


Figure 13.11. Slow sand filter.

cases, especially larger water treatment plants, the slow sand filter is preceded by a chemical pre-treatment step, but a slow sand filter can also work as the only water treatment step.

A biofilm will develop on the top of the slow sand filter after a certain period of time depending on the quality of the water being treated. This must be removed regularly, as infiltration capacity will otherwise decline. However there are no differences in water yield in slow sand filters preceded by a chemical pre-treatment step and those with only one treatment step.

Many other treatment processes can be used to supplement the treatment scheme in Figure 13.11. Active carbon may be used to remove various organic micropollutants and foul taste in the raw water. In recent years membrane technology, especially in small plants, has been introduced as an effective way of removing pollutants without having to add chemicals.

14.

Wastewater treatment technologies

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Surface and groundwater composition

Surface water is in contact with the atmosphere and is saturated with oxygen and nitrogen gases of the air. During runoff, dissolving brown-coloured humic substances pollute the water. Clay and other fine particles, bacteria and microorganisms are suspended in the water. The content of dissolved inorganic substances is generally low, since water during runoff normally does not come in close contact with soluble mineral substances.

During groundwater formation, water is filtrated and becomes clear and practically free from microorganisms. Organic substances in the water are biochemically oxidised, consuming oxygen and producing carbon dioxide. During the first phase of oxidation, humic acids are produced, which at complete oxidation are further degraded to carbon dioxide and water. The humic acids are dissolved in the water and the water becomes acid. The diffusion of oxygen is much better in air than in soil, where oxidation of organic material is inhibited in the water-saturated soil below the groundwater level. In dry soils where the groundwater level is much below the surface, almost all dissolved organic substances become biochemically oxidised during their passage through the upper soil layer. Groundwater is often oxygen-free and may then contain divalent iron and manganese compounds dissolved from soil particles. As the water infiltrates the soil, the pH-level is increased and metal ions are exchanged with metal ions from the soil particles. Table 14.1 shows the contents of urban groundwater from Gothenburg and rural groundwater from western Sweden. Differences in surface water and groundwater quality are shown in Table 14.2 (Lekander, 1991).

Table 14.1. Median, maximum and minimum contents of substances in urban groundwater at 12 places in Gothenburg and rural groundwater from 24 places in Western Sweden

	Urban			Rural		
Substance	median	max	min	median	max	min
pH	6.8	8.0	4.4	5.6	8.6	3.9
Alkalinity, mg HCO_3^-/l	447	1 511	4.9	5	1 130	-14.7
Sulphate, mg SO_4^{2-}/l	47	465	2	12	114	0.4
Nitrate, mg NO_3^-/l	7.6	226	0.1	0.4	28	0
Total hardness, mg Ca^{2+}/l	153	413	7.3	6.1	375	0.9

Table 14.2. Comparison of surface water and groundwater quality (Kiely, 1997)

Parameter	**Surface water**	**Groundwater**
Temperature	Varies with season	Relatively constant
Turbidity and suspended solids	Varies and is sometimes high	Usually low or nil
Mineral content	Varies with soil, rainfall, effluents, etc	Relatively constant at high value
Divalent iron and manganese in solution	Some	Always high
Aggressive carbon dioxide	None	Always some
Dissolved oxygen	Often near saturation, except when polluted	Usually low, requires aeration
Ammonia	Only in polluted water	Levels found to be increasing
Hydrogen sulphide	None	Usually some
Silica	Moderate levels	
Nitrate	Generally none	Levels found to be increasing due to agricultural pollution
Living organisms	May have high levels	Usually none

Table 14.3. The average values of pollutants and nutrients in Swedish domestic wastewater

	Urine (g/p/d)	Faeces (g/p/d)	Grey-water (g/p/d)	Total (g/p/d)
Dry substance	80 (46 %)	60 (34 %)	35 (20 %)	175
Suspended solids	27 (63%)		16 (37%)	43
BOD_7	20 (42%)		28 (58%)	48
Nitrogen. N	11 (82 %)	1.5 (11 %)	1.0 (7 %)	13.5
Phosphorus, P	1.0 (48 %)	0.5 (24 %)	0.6 (28 %)	2.1
Potassium, K	2.5 (63 %)	1 (25 %)	0.5 (12 %)	4.0

Wastewater composition

Wastewater is a mixture of toilet water, grey-water, industrial wastewater, drainage water, and, in a combined system, also stormwater. The composition of wastewater is a mixture of pollutants coming from the different sources.

Domestic wastewater contains grey-water from washing dishes, washing and bathing and toilet water urine and faeces. Table 14.3 shows the average values of pollutants and nutrients in Swedish domestic wastewater in gram per person and day. A major part of the nutrients originates in the urine. Grey-water contains nutrients in small amounts, with the exception of phosphorus. The average amount of grey-water is about 150 litres per person and day. The phosphorus content of grey-water depends on the use of phosphate detergents. When no phosphate detergents are used, the phosphorus content is estimated at 0.15 g/p/d. When mainly phosphate detergents are used, the content is estimated at 1.0 g/p/d.

The content of industrial wastewater can vary greatly and depends on the type of industrial process used. For instance, mercury may be released from dental practices. Source control and demand of treatment of process water have gradually decreased the pollutants originating from industrial wastewater. In Sweden, every municipality may state restrictions on what substances that may be supplied to the sewer net, for example, limiting values or prohibition of certain substances. These restrictions are valid for both connected industries and households. Industrial processes with continuous discharge are easier to trace and stop than household discharges with a more random occurrence. In general, there has been a decrease in the metal contents due to less metal use in society. Examples include a change to lead-free gasoline, a stop in the use of mercury thermometers, and a ban on cadmium in paints and in finishing. Wastewater from restaurants and offices has a composition more similar to domestic wastewater.

Drainage water is water from house foundations and groundwater leaking into the sewer pipes. The water originates from rainwater that has infiltrated the soil. Since the soil acts as retention storage, the flow variations are not as large as for the stormwater. The flow follows the variation in stormwater flow with a detention. During extreme rainfall of long duration the drain-water flow can become too high, causing spilling of untreated water and flooding of basements. The content of drain-water is the same as that of groundwater.

Stormwater composition

Stormwater originates from runoff of rainfall on roofs and streets. Pollutants in stormwater originate from surfaces such as streets and roofs that are washed with the rainwater. The variation in pollutant content is large and varies depending on the type of surface that the runoff comes from. Stormwater has generally a higher content of metals and suspended solids and a lower content of oxygen consuming substances (BOD and COD) than domestic wastewater. At high flows the pollutants are diluted by large amounts of water and the pollutant content decreases. In duplicate systems, stormwater is often led to a recipient without treatment. Depending on rainfall, stormwater has a high flow variation and dilutes the wastewater so that the pollution content decreases when the stormwater content is high. However, the first flush contains high concentrations of pollutants. The largest problem with stormwater is that the amount of water to treat increases and that the flow sometimes can be so high that untreated wastewater must be bypassed to the recipient. This water, storm sewage, is a mixture of stormwater and other wastewater. However, the pollutant content of stormwater is often less than for normal wastewater due to dilution of wastewater with large amounts of stormwater. At high stormwater flows there is also a risk for flooding of basements.

Health aspects on pollutants

The combined effects of physical, biological and social circumstances affect human health. Water is a part of the human environment; two main categories of water-associated health hazards are:

Table 14.4. Diseases associated with waterborne pathogens

Pathogen	Disease
algae	gastro-enteritis
bacteria	cholera, dysentery, typhoid, paratyphoid
parasites	malaria, tapeworm, scistosomiasis
protozoa	dysentery
viruses	infectious hepatitis, poliomyelitis, yellow fever

- Biological agents transmitted through ingestion of pathogens, through water contact or through insect vectors. Many diseases are related to waterborne pathogens (Table 14.4).
- Chemical and radioactive pollutants.

Although microbial pathogens in water will be the main pollution problem for most developing countries for some time, chemical pollution has emerged as an equally serious threat in all countries that have introduced industrialisation and chemically supported agriculture. Different pollutants found in freshwater are illustrated in Table 14.5.

Microbiological aspects of water quality and health

Microorganisms, which are transmitted by a faecal-oral route, have the potential to cause infection through the ingestion of drinking water. The fundamental principle for providing microbiologically safe drinking water is therefore to exclude excremental contamination from the water supply and to prevent subsequent contamination of the treated water.

Although this principle is accepted in Sweden, outbreaks of waterborne diseases have happened. During the period 1980-1995, a total of 90 outbreaks were reported, involving about 50 000 ill individuals and two deaths. Unknown agents, acute gastrointestinal agents, caused about 80 % of the outbreaks. *Campylobacter* was the most common identified agent followed by *Giardia lamblia* (an amoeba). Eleven campylobacteriosis outbreaks were reported between 1980 and 1995, of which three involved 1 000->3 000 ill individuals. Campylobacteriosis in humans is an acute, bacterial, enteric disease, normally accompanied by diarrhoea (H. Andersson et al., 1997).

Table 14.5. Categories of pollutants found in freshwater

Pollutant categories in freshwater
Acids and alkalis
Anions (e.g. sulphide, cyanide)
Detergents
Domestic sewage and farm manure
Food processing wastes
Gases (e.g. chlorine, ammonia)
Heat
Metals (e.g. cadmium, zinc, lead)
Nutrients (e.g. phosphates and nitrates)
Oil and oil dispersants
Organic toxic wastes (e.g. formaldehydes, phenols)
Pathogens
Pesticides
Polychlorinated biphenyls
Radionuclides

Difficulties in isolating pathogenic microorganisms from water have led to the concept of looking for indicator bacteria (as *E. coli*) that are abundant in faeces and sewage. Treatment methods may, however, be efficient to kill the indicator organism but not certain pathogens. *Giardia*, for instance, is rather tolerant of chlorine.

In order to secure safe water it is important to use different barriers against microbiological infection. Efficient wastewater treatment is an important barrier for decreasing risks for contamination of water sources. Self-purification with natural systems is another barrier. Efficient water treatment is a third barrier. Different possibilities for decreasing risks of pathogens in drinking water are shown in Table 14.6.

The infection of water related diseases follows different patterns:

Transmission by ingestion of faecally contaminated water.

Transmissions through eyes and skin (bacterial ulcers and scabies, and trachoma). Weil´s disease (leptospirosis) is transmitted through the urine of infected rats. The causative organism is able to penetrate the skin so that external contact with contaminated sewage or floodwater can spread the disease.

Transmission through pathogenic organisms, spending part of their life cycle in water or in an intermediate host. Many of these diseases are caused by worms, which infest the sufferer and produce eggs that are discharged in faeces and urine. Shistosomiasis (also called bilharzia) is probably the most important example. After the Second World War, 90-100 % of the population of certain cities of Germany was infected by worms, probably due to irrigation with sewage water on crops.

Transmission through insect vectors. Insects which breed, or feed, near water spread a number of diseases such as malaria and river blindness, so their incidence can be related to the proximity of suitable water sources.

Transmission through aerosols. Outbreaks of Legionnaires disease have been connected with the presence of *Legionella phneumophila* in domestic hot water supplies, showers heads, cooling waters and other aquatic systems that produce droplets or fine sprays. Breathing-in a contaminated spray causes the disease, which leads to pneumonia. Systematic diagnosis began in Sweden in 1978. Since then, 20-40

Table 14.6. Different methods to improve drinking water safety

Method	Motives and improvement actions
Catchment area protection	Restrictions on different activities in the catchment area as agriculture and urbanisation
Reservoir storage	Use of self-purification due to pathogen decay and sedimentation of particles
Raw water pre-disinfection	Use of raw water disinfection by chlorine or chlorine dioxide to facilitate further treatment if the water source is of poor quality
Coagulation, flocculation and separation	Efficient way to reduce the amount of microorganisms from surface waters
Slow sand filtration	Effective way to remove unwanted microorganisms including viruses and protozoa
Artificial infiltration	Effective way to improve microbiological and chemical quality of water
Residual disinfection	Reduced after-growth of bacteria and killing of pathogens although some protozoa and possibly some viruses are not affected
Maintenance of distribution system	Avoidance of leakage of polluted water into the water distribution net and formation of thick biofilms
Microbiological monitoring	Measurement of total number of bacteria and faecal indicator bacteria and in the future complementary measurements on other organisms

cases have been reported every year, although the actual number is believed to be at least ten times higher. The main growth of *Legionella* occurs between 20 and 45 ºC. To avoid *Legionella*, the temperature of the heated water must be above 60 ºC.

Chemical aspects of water quality and health

Many substances may be found in natural waters because of the solvent properties of water. In Sweden, acidification has increased the concentration of metals in certain areas. The concentrations of chemical pollutants are, however, rather low; pollutants from agriculture and urban discharges of wastes are more significant. Chemically related health effects are of two types: acute effects likely to occur due to an accident in the catchment area or in the water treatment (overdose of chemicals, no addition of disinfectants etc.) and chronic effects where continued ingestion of the contaminated water produces a long-term hazard. Lead piping and use of other unsuitable materials may cause chronic effects and much attention should be directed towards the choice of materials in water supply systems. Increased concentrations of nitrate or pesticides from agriculture are other examples of agents that may cause chronic effects. Nitrate increases in groundwater or surface waters are related to increased fertiliser usage. Different health effects of some inorganic contaminants are shown in Table 14.7.

In central water systems the water quality from the water works has a major impact on health risks. Corrosion may increase the release of metals in the water mains and service pipes. If asbestos pipes are used, much attention should be directed towards low corrosion of cement and subsequent release of asbestos fibres. Biofilms in the water-distribution net may create corrosive conditions and some natural organic materials (NOM) may form complexes with metals and increase the metal concentration in water systems.

The hardness of water may have some effect on human health. Soft water with a low concentration of calcium and magnesium ions is correlated with an increase of heart diseases. The reasons have not yet been explained, although several hypotheses have been put forward, e.g., increased corrosion of soft waters.

Some studies have indicated risks of a high aluminium concentration in water, especially if the aluminium is bound as a complex to organic materials. The possible risk of Alzheimer's syndrome caus-

Table 14.7. Health effects of some inorganic contaminants

Contaminant	Health effects
Cadmium	Damage to kidney, carcinogenic, increased risks of stroke and heart attacks
Chromium	Damages to kidney, liver, skin and digestive system
Copper	Stomach and intestinal distress; Wilson's disease
Fluoride	Skeletal and tooth damages at high concentrations
Lead	Central and peripheral nervous systems damages; kidney; highly toxic to infants and pregnant women
Mercury	Damage of kidney and nervous system
Nitrate	Methanoglobinaemia ("blue-baby syndrome")
Nitrite	Methanoglobinaemia ("blue-baby syndrome")

ing senile dementia due to aluminium in drinking water has, however, not been verified and seems to be minor.

The production of toxic and carcinogenic compounds in disinfection and especially in the dosage of chlorine has been much discussed. Chlorine reacts to some extent with organic materials, such as humic acids, in raw water to chlorinated organic compounds. The main product is chloroform, which may cause liver cancer. Although this risk is important to follow up, it is generally considered to be small.

Labour safety

Water and wastewater handling involves many labour safety risks for the operating staff. These may be divided into:

- Physical risks, including mechanical injuries, drowning in open basins or sewer nets, use of electrical equipment, fire and explosions, noise and traffic.
- Chemical risks due to breathing of dangerous gases and aerosols, swallowing of toxic substances, or skin contact with dangerous substances.
- Biological risks due to breathing, swallowing or skin contact with different biological agents.
- Physical risks due to sole works, stress etc.

In general, mechanical injuries are the most important factor for injuries at work. Risks due to sole works and stress are difficult to assess but important to consider. Specific risks in labour works at water and wastewater facilities are related to chemical and biological risks.

Much attention has been paid to the formation of toxic gases in wastewater handling. Sulphides may be supplied to the sewer net from industries and may be formed in the sewer net or in the treatment plant under conditions where no oxygen and nitrate are present. A common example is pressure pipes for transport of wastewater. Sulphides are in equilibrium with hydrogen sulphide, which may be released into the atmosphere. The main problems related with hydrogen sulphide are:

- Odour problems (rotten eggs).
- High toxicity (Table 14.8).
- Corrosiveness towards copper, iron and silver.
- Possible oxidation to sulphuric acid and subsequent corrosion of concrete and metals.

Other gases of concern include:

- Explosive gases that may be supplied to the sewer net (for instance from gasoline and solvents) and methane gas (for instance produced in anaerobic digestion).
- Low oxygen concentrations in areas with low ventilation and removal of oxygen due to biological reactions.
- Chlorine gas used in disinfection of water and wastewater.

Many chemicals used in water and wastewater treatment such as: acids, bases, sodium hypochlorite, precipitation agents and polyelectrolytes are potentially dangerous and should be handled carefully.

Biological agents may cause diseases among workers at water and wastewater handling facilities. Pathogens may be swallowed through direct contact. Aerosols from wastewater treatment contain endotoxins that may cause fever in exposed personnel. Contact with wastewater by the skin may cause diseases such as hepatitis and Weil's disease.

Table 14.8. Effects of hydrogen sulphide exposure at various concentrations (Subcommittee on Hydrogen Sulfide, 1979)

Effect	**Concentration** (ppm)
Approximate threshold for odour	0.1-0.2
Offensive odour	3-5
Threshold limit value	10
Threshold of serious eye injury	50-100
Olfactory paralysis	150-250
Pulmonary endema, imminent threat to life	300-500
Strong nervous system stimulation, apnoea	500-1 000
Immediate collapse with respiratory paralysis	1 000-2 000

Biological treatment of wastewater

Microorganisms

Microorganisms may be classified into:

- Viruses with no cell structure.
- Lower protists (all bacteria, blue-green algae) with primitive cell structures - the prokaryotic cell.
- Higher protists (fungi, algae, protozoa, rotifers, crustaceans) with highly evolved cell structures – the eukaryotic cell.
- Plants (aquatic plants, macrophytes, seed plants, ferns, mosses).
- Animals (worms, helminths).

All these microorganisms are of significance in different treatment processes. Removal of viruses is essential in drinking water production. A trickling filter has a complex ecology involving bacteria, protozoa, rotifers and worms. In wetlands the treatment efficiency is dependent on lower and higher protists, plants and animals.

Microorganisms may also be classified according to microbiological processes. Microorganisms require energy for their growth and this may be obtained from light (phototrophic organisms) or from chemical compounds (chemotrophic organisms). If the chemical compound is inorganic the organisms are called autotrophic and if it is organic they are called heterotrophic.

The organisms that need oxygen for their growth are called aerobic. Anaerobic organisms may use inorganic compounds such as nitrate, sulphate and carbonate in oxidation of energy rich compounds. Fermentation is a special case of anaerobic process in which alcohols or organic acids are formed. An anoxic process is another special case of anaerobic process in which nitrate is used in the oxidation.

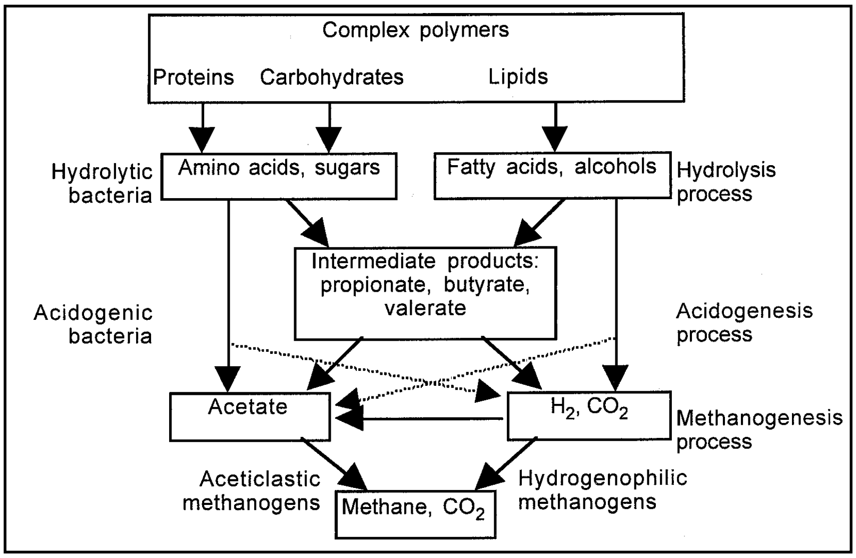


Figure 14.1. Stages in methane production from complex organic materials (Kiely, 1997).

Microbiological processes may involve different steps and groups of organisms. Stages in methane production from complex organic materials involve hydrolytic bacteria for production of low-molecular organic materials, acidogenic bacteria for production of acetic acid and methane bacteria for production of methane (Figure 14.1).

Bacterial growth

Bacteria may use light or chemical substances as energy sources in their growth. In oxidation of an energy-rich compound, electrons are produced. The energy-rich compound may then be regarded as an electron donator. The produced electrons must be taken up by another substance (such as oxygen, nitrate, sulphate, carbonate or organic materials) that is reduced and has thus the function of being an electron acceptor. Many combinations are possible for energy-rich compounds and electron acceptors that produce energy enough for bacterial growth. Different examples and applications are shown in Table 14.9.

Bacterial growth is influenced by many factors, such as:

- Concentration of energy source (oxidised compound) and electron acceptor (reduced compound).
- Presence of substances necessary for cell synthesis.
- Temperature.
- pH-value.
- Concentration of toxic substances.
- Presence of predators as protozoa that use bacteria as food.

Biological treatment units

Common ways to classify biological treatment units (biological reactors) is:

- Suspended growth reactors.
- Attached growth or fixed film reactors.
- Combined suspended and attached growth reactors.

Suspended growth means that microorganisms are in a floc matrix in the wastewater suspension. Examples are the activated sludge process, stabilisation ponds and aeration lagoons. The activated sludge process is shown in Figure 14.2. Influent wastewater

Table 14.9. Examples of different combinations of energy sources (oxidised compound) and electron acceptors (reduced compound) and examples of applications

Energy source	Electron acceptor	Group of bacteria and application examples
Organic material	O_2	Heterotrophic aerobic bacteria; treatment of wastewater and sludge handling as composting
NH_4^+, NO_2^-	O_2	Nitrification bacteria; wastewater treatment
S, H_2S	O_2	*Thiobacillus*; may cause corrosion problems for instance in sewer nets
Organic material	NO_2^-, NO_3^-	Denitrification bacteria; treatment of wastewater for nitrogen removal
Organic material	SO_4^{2-}	*Desulphovibrio*; may cause problems due to formation of hydrogen sulphide (odour, health risks, corrosion)
Organic material	Organic material	Heterotrophic anaerobic bacteria; anaerobic treatment of wastewater, anaerobic sludge digestion
H_2	CO_2	*Methanobacterium*; methane production for instance in digesters

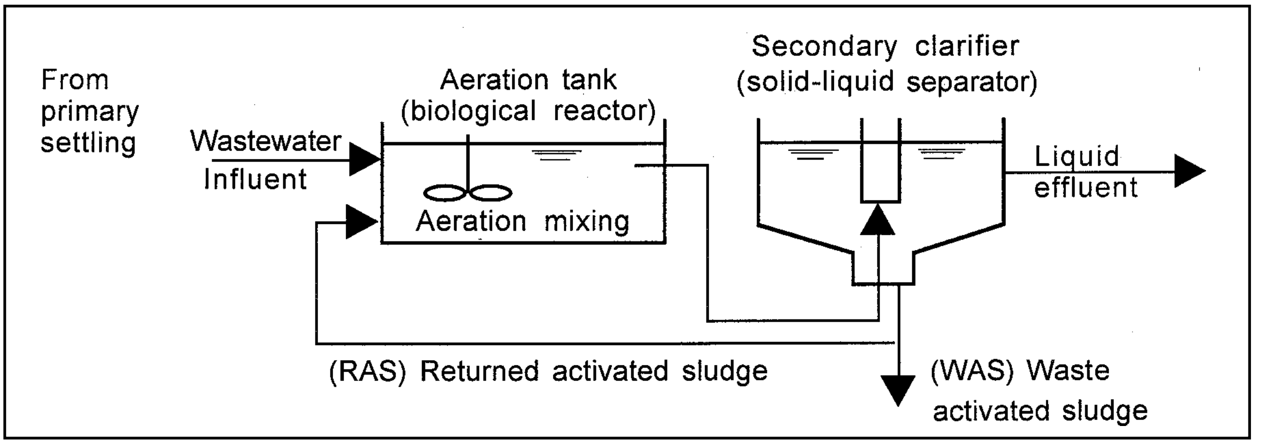


Figure 14.2. Typical layout of activated sludge process.

is supplied to an aeration basin in which organic material is oxidised to carbon dioxide and water and sludge is produced containing microorganisms and non-biodegradable suspended solids. The produced sludge is removed as excess sludge for further sludge treatment.

The activated sludge process was first introduced in Manchester in 1914. Due to development of the process it is today possible to modify it to include biological nitrogen and phosphorus removal.

In fixed film reactors microorganisms form a biofilm on a surface that may be stones or plastic materials. Organic materials, oxygen and nutrients diffuse into the biofilm. Oxygen is often a limiting factor in the biofilm and therefore it has an aerobic and an anaerobic part. The products formed are removed by diffusion into the wastewater. Produced sludge is washed away and removed in a following separation step.

The most common processes are trickling filters and rotating biological contactors. In trickling filters, wastewater distributors introduce wastewater to a tank. Air is supplied by natural ventilation or by a fan (Figure 14.3).

Rotating biological contactors have a cylindrical axis on which are mounted plastic materials (Figure 14.4). Microorganisms form a biofilm on the plastic material. The contactor rotates in a holding tank. Microorganisms are in contact with wastewater and thereafter exposed to air for degradation of the organic material.

A new development in attached growth reactors is the fluidised bed. In this system microorganisms form a biofilm on, for instance, sand particles. The sand particles are in movement due to the velocity of the supplied wastewater. This treatment unit makes it possible to use much lower residence times than for the other reactors.

Attached growth reactors may be combined to allow for biological nitrogen and phosphorus removal. The reactors may also be used for anaerobic treatment of wastewater with a high content of organic materials, such as from the food industry.

Several units for biological treatment use the combination of suspended growth and attached growth. An example is the use of submerged plastic materials in the activated sludge process.

Chemical treatment of wastewater

Chemical precipitation

Chemical precipitation is a widely used process for the removal of, for instance: (1) phosphates by the addition of iron and aluminium salts or lime, (2) metals by the addition of hydroxide, carbonate, or sulphides and (3) colloids and colour. Different examples of motives for the use of chemical precipitation are shown in Table 14.10.

In chemical precipitation three major inter-linked processes must be considered (see Figure 14.5):

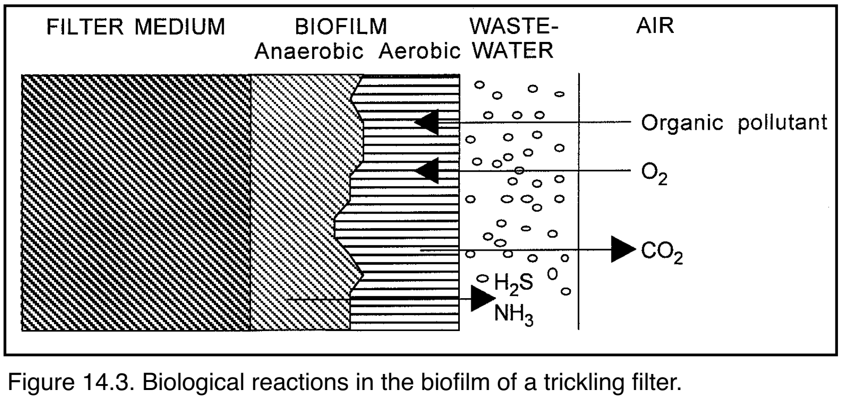


Figure 14.3. Biological reactions in the biofilm of a trickling filter.

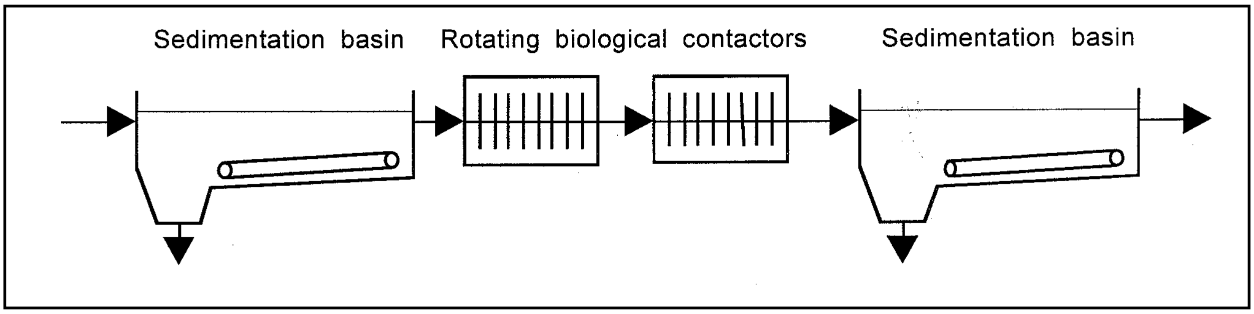


Figure 14.4. Treatment system with rotating biological contactors.

Coagulation, in which the added chemicals cause a reduction in particle charges and an enmeshment of particles. To facilitate the process chemicals are added to a rapid mixing tank.

Flocculation, in which coagulated particles form separable flocs by the use of flocculation tanks with slow stirring. It is also possible to accomplish flocculation as an integral part of the clarifier structure or in deep-bed filters. Different agents, such as polyelectrolytes, improve the flocculation process.

Floc separation, in which mainly sedimentation, flotation and/or filtration is used. In contact filtration chemicals are added before the filter and coagulation, flocculation and separation takes place in the same unit.

Disinfection

The epidemiological relation between water and disease had been suggested as early as 1854. The disinfection of water is without doubt the most potent weapon against waterborne infections in the hands of health and water authorities. In particular, the chlorination of water has led to a substantial eradication of waterborne disease at small cost in equipment, materials and personnel.

To be of practical service, water disinfectants should possess the following properties: (1) they must destroy the kinds and numbers of pathogens that may be introduced into municipal water or wastewater and do so within a practicable period of time, (2) they must not be toxic to man and his domestic animals, (3) they must be dispensable at reasonable cost, and safe and easy to store, transport, handle, and apply, (4) their strength or concentration in the treated water must be easily, quickly, and preferably automatically determinable and (5) they must persist within disinfected water in sufficient concentration to provide reasonable residual protection against its possible recontamination before use.

Disinfection describes the destruction or removal of all particular species of microorganisms at some stage of its development. Wastewater disinfection can be accomplished by several means. It includes one or a combination of the following: (1) physical treatment: storage, heat or other physical agents, (2) irradiation with ultraviolet light, (3) the addition of oxidants, such as chlorine, chlorine-ammonia, chlorine dioxide, ozone and others and (4) the use of membrane technology.

The water can be freed from infectious microorganisms through adequate treatment, i.e., producing clear water (coagulation, sedimentation and filtration) and then applying an effective disinfectant. The complete disinfection of wastewater is dependent upon optimisation of the unit processes of chemical coagulation, sedimentation and filtration to produce minimum water turbidity in order to assure maximum contact between any remaining pathogens and the disinfectant added. Activated carbon has the abil-

Table 14.10. Different rationales for chemical precipitation methods

Motives	Example
Removal of substances harmful to the recipient	Heavy metals, sulphides, fluorides, phosphates, oil, and pathogens
Removal of toxic substances before discharge to the sewer net	Heavy metals, sulphides, oil, etc.
Recovery of different substances	Metal content in precipitated sulphides, silver in precipitated silver chloride etc.
Treatment and reuse of waters	Removal of pollutants, softening of waters by precipitation of calcium carbonate, recycling of process waters after a precipitation step
Decrease of the energy consumption	Precipitation of organic material in suspended or colloidal form before an activated sludge process
Decrease of peak loads	Precipitation of pollutants before a biological step at peak loads

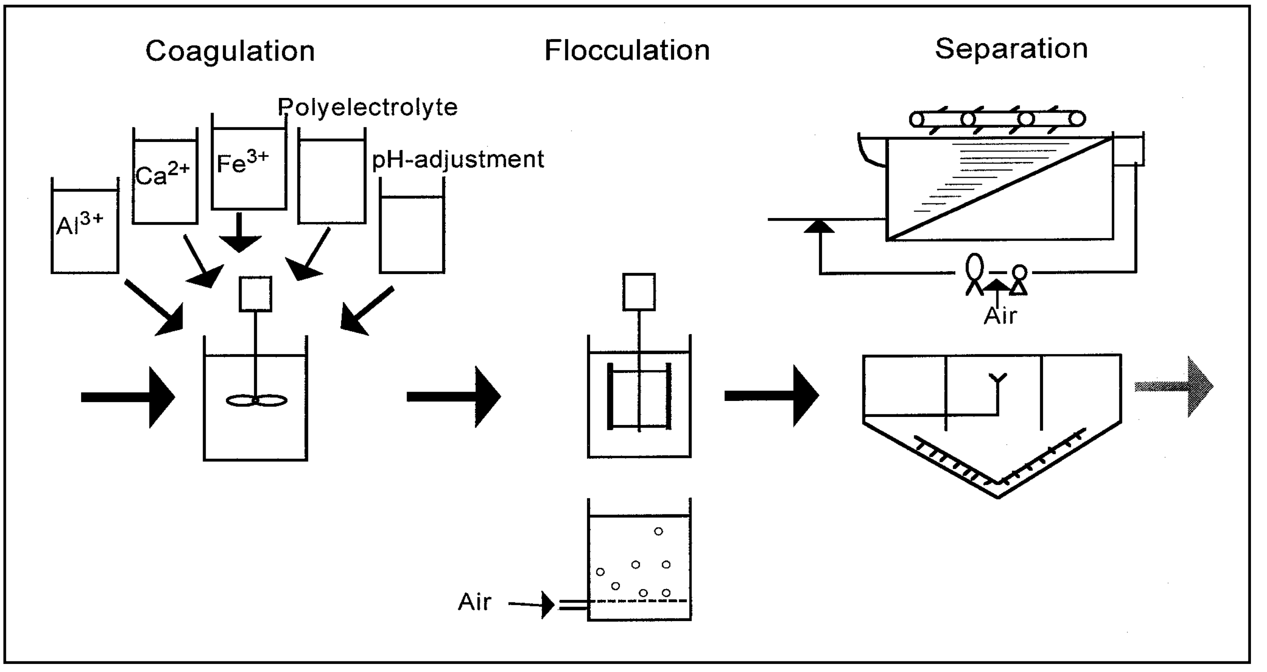


Figure 14.5. Chemical precipitation in treatment of different waters. The process includes coagulation, flocculation and floc separation.

ity to adsorb viruses from wastewater, but cannot be deactivated.

Chlorine gas is the most commonly used disinfectant. It is very soluble in water and rapidly forms hypochlorous acid, HOCl, in equilibrium with OCl^-. Both HOCl and OCl^- are effective disinfectants and are called free available chlorine in water. It is often suitable to maintain a residual of chlorine to ensure a disinfectant effect in the distribution net. A small fraction of chlorine combines with the organic material in the water to form organic chlorinated compounds that may have some long-term health effects.

Ozone is also a commonly used disinfectant that is often more efficient than chlorine at killing viruses and protozoa. To secure disinfection in water distribution nets, ozone is often combined with a low complementary chlorine dosage.

For waters of high quality, UV irradiation may be sufficient for the disinfection. Membrane technology as a disinfection method is of increasing interest and has especially been installed at small treatment plants.

Separation methods

Many separation methods are available to separate suspended solids, colloids and soluble substances from water (see Figure 14.6). For suspended solids particle sizes above about 0.1 mm, sedimentation and flotation are suitable. For particles of about 0.01-0.1 mm, conventional deep-bed filtration is suitable. For smaller particle sizes different membrane processes may be used, such as microfiltration (for sizes between about 10^{-4}-10^{-2} mm) and ultrafiltration (for sizes between about 10^{-6}-10^{-4} mm). Reverse osmosis is a membrane technology for the removal of salts, for instance in desalination. Electrodialysis is an electrically charged membrane method. Soluble organic matter may, for instance, be removed by the use of activated carbon adsorption and ions by the use of ion exchange.

Sedimentation is a process for separating suspended solids from the liquid by the use of gravity. The process is used both for separation of discrete particles and for flocculated particles obtained after a chemical coagulation and flocculation process. Sedimentation of dilute particle suspensions is often called clarifying, as the main function is to produce a clean water phase. If the purpose is directed towards production of a thickened sludge, the term thickening is used.

The form of the sedimentation basins is either rectangular or circular. Sedimentation basins are supplied with scrapers to remove the settled suspended solids. Sometimes the sedimentation basins have equipment to remove scum and floating materials.

Examples of the use of sedimentation are: (1) the removal of sand and heavy silt from water in settling basins, (2) the removal of settleable, suspended wastewater solids in settling tanks and (3) the removal from water and wastewater of non-settleable substances rendered as settleable by coagulation or precipitation.

Flotation is used to separate solid or liquid particles from water. Introducing fine air bubbles into the water brings about separation. The bubbles attach to

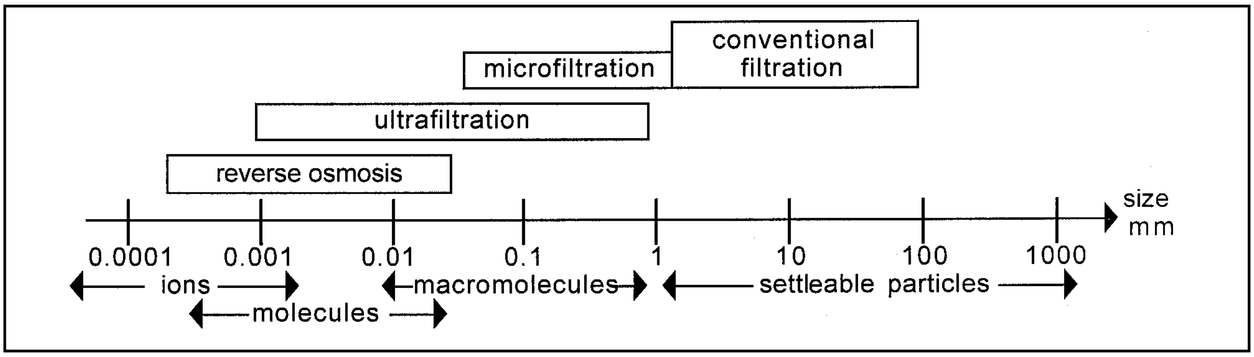


Figure 14.6. Separation range depending on size for different separation processes.

the particulate matter and cause the particles to rise to the surface. The principal advantage of flotation over sedimentation is that very small or light particles that settle slowly can be removed more completely and in less time. Examples of the use of flotation are: (1) the removal of grease and oil from wastewater with or without the benefit of aeration in skimming tanks and (2) the release of fine bubbles of air into water and wastewater for the removal of flocs or for sludge thickening.

Filtration is a key process in the production of high quality effluents from water and wastewater. A relatively deep (0.45-0.90 m) granular bed is used to remove impurities from water. Filtration combines straining, sedimentation and interfacial contact to transfer suspended solids or flocs onto grains of sand, coal, or other granular materials from which they later must be removed.

Examples of filtration processes are: (1) the filtration of water through naturally permeable formations in groundwater recharge, (2) the slow filtration of water through beds of sand and (3) the rapid filtration of water through beds of sand, coal or other granules singly or in combinations of stratified layers.

Filtration during the last few years has also found a wide application in wastewater polishing. Addition of precipitation agents before the filter improves the removal efficiency of different pollutants. Filters may also be used for denitrification, in which case organic material is added before the filter.

Characteristics of ecotechnology

In densely populated areas, conventional treatment technologies are the most common methods to treat wastewater. In rural areas, however, the conventional treatment technique has been considered inappropriate due to high costs and high energy-input. Other treatment techniques have therefore been developed. Ecological engineering, or ecotechnology, has attracted attention as a low-cost and low-tech solution to reduce the pollution load on streams, lakes and seas.

Ecotechnology has been defined in many different ways. In the beginning of the 1960s, Howard Odum defined ecological engineering as, ”those cases in which energy supplied by man is small relative to the natural sources, but sufficient to produce large effects in the resulting patterns and processes”. Later on, Odum came up with another definition: ”environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources”. The Chinese father of ecological engineering, Ma, defined ecological engineering as, ”a specially designed system of production processes in which the principles of the species symbiosis and the cycling and regeneration of substances in an ecological system are applied”. Finally, Mitch and Jørgensen defined ecological engineering as, ”the design of human society with its natural environment for the benefit of both”.

Most ecotechnological treatment systems have been established to treat municipal wastewater, but an increasing interest for treating other types of wastewater has developed. Ecotechnologically-based treatment systems are now also used to treat stormwater and leakage from mine areas. Ecological methods are also used in artificial infiltration of surface waters.

There are different natural treatment technologies: onsite infiltration systems, slow-rate land application systems, rapid infiltration land treatment systems, overland-flow treatment systems, wastewater stabilisation pond systems, floating aquatic plant systems and wetlands. Before the wastewater can be discharged into any of these facilities, it must be pre-treated. Domestic wastewater is pre-treated in a septic tank where faeces and urine are separated. Urine, and possibly also the grey-water, can then be directed to an onsite treatment facility. Stormwater should be pre-treated using a screen in the inlet to the treatment facility.

Artificial infiltration

Water from rivers and lakes may be pumped to suitable geologic formations to infiltrate and form groundwater. The reinforced groundwater supply may be obtained by direct infiltration through basins or by intentional lowering of the groundwater level, inducing infiltration from surrounding surface waters. Water may also be injected into the aquifer through wells.

Natural and artificial infiltration is basically the same processes. In artificial infiltration, the surface water used contains humic substances and microorganisms and a different flora and fauna is developed in the infiltration area. The infiltration rate is much higher in artificial than in natural infiltration.

Artificial groundwater recharge has not only proved to be a way to increase the amount of groundwater; it has also proved to be an alternative to conventional water treatment plants. The infiltrated surface water will be subject to biological, chemical and physical processes, which all reduce pollutants, on its way through the soil layers. Biological removal of pollutants will mainly take place in the infiltration basin where a biofilm develops.

During artificial infiltration, the surface water is treated and a long residence time of several days or weeks is desirable to accomplish degradation of organic materials. In this way further treatment can be simplified and the need for chemicals is reduced. During the infiltration process the temperature conditions are equalised. The flow is also equalised and the ground may be used as storage. The beneficial properties of artificial infiltration have made this method one frequently used in Sweden; about 25 % of the municipal water produced comes from artificially infiltrated water.

There are two principles for artificial groundwater recharge, the direct method and the indirect method. The latter method is also referred to as induced recharge or bank infiltration (Figure 14.7). Both these methods require geological formations that are suitable for infiltration. In Sweden, eskers are examples of geological formations that are suitable for infiltration, as well as for subsequent abstraction of water.

Onsite infiltration technologies

There are different concepts for onsite treatment of domestic wastewater. These concepts are based on separate black- and grey-water treatment (Figure 14.8). The black-water is collected in a septic tank, with the sludge collected regularly. The grey-water, on the other hand, is infiltrated into the ground in different ways. In the soil, chemical, biological and physical mechanisms remove pollutants before the infiltrated water enters into the groundwater or to a surface recipient.

Aquatic and wetland systems

Aquatic and wetland systems are characterised by continuous flooding and therefore develop an anaerobic sediment and soil layer. Facultative ponds, floating aquatic plant systems and wetlands are examples of these kinds of treatment systems.

Facultative ponds, or stabilisation ponds, can be designed as passive lagoons or as highly sophisticated systems. Common for these ponds is that they maintain a natural aerated surface layer over a deeper anaerobic layer. The typical depth of a facultative pond is 1.2-2.5 m. This treatment system is efficient with regard to BOD and, to some extent, to nitrogen. Phosphorus is only removed to a very small extent.

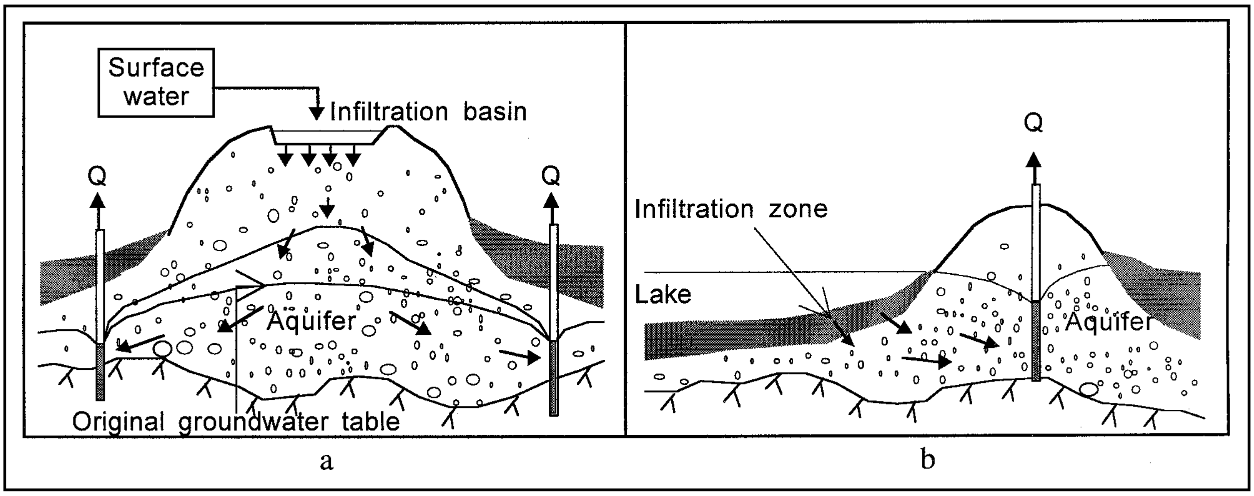


Figure 14.7. Artificial groundwater-recharge through (a) the direct method and (b) the indirect method.

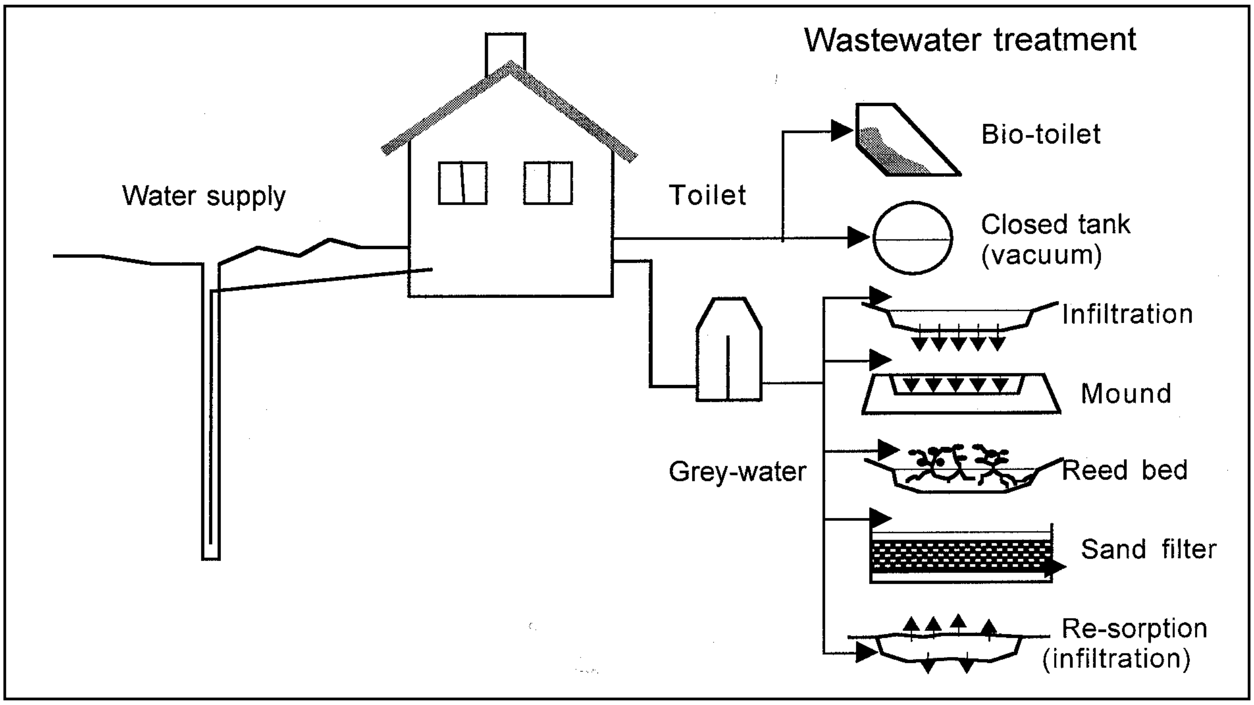


Figure 14.8. Onsite infiltration systems for wastewater treatment.

Floating aquatic systems are purposely inoculated with floating aquatic species that provide wastewater treatment. Water plants that are commonly used in these treatment systems are water hyacinths (*Eicchornea crassipes*) and duckweed species (*Lemna*, *Spirodela* and *Wolfiella*). The aquatic plants release oxygen above the water surface, effectively reducing atmospheric oxygen diffusion. This means that the major part of the water column is anaerobic, and that aerobic activity is restricted to the plant root zone.

Three mechanisms are responsible for the treatment in floating aquatic plant systems: metabolism by a mixture of facultative microbes on the plant roots, sedimentation of wastewater solids and, finally, incorporation of nutrients in living plants and subsequent harvests. BOD and total suspended solids are effectively reduced in these systems. Nitrate nitrogen is also removed, but total nitrogen and phosphorus can only be reduced if the plants are harvested regularly.

Floating aquatic plant systems have some shortcomings that have limited their widespread use. One disadvantage is that plant pest species can easily kill the plant species that colonise the pond surface. Another weakness is that the plants can be killed by

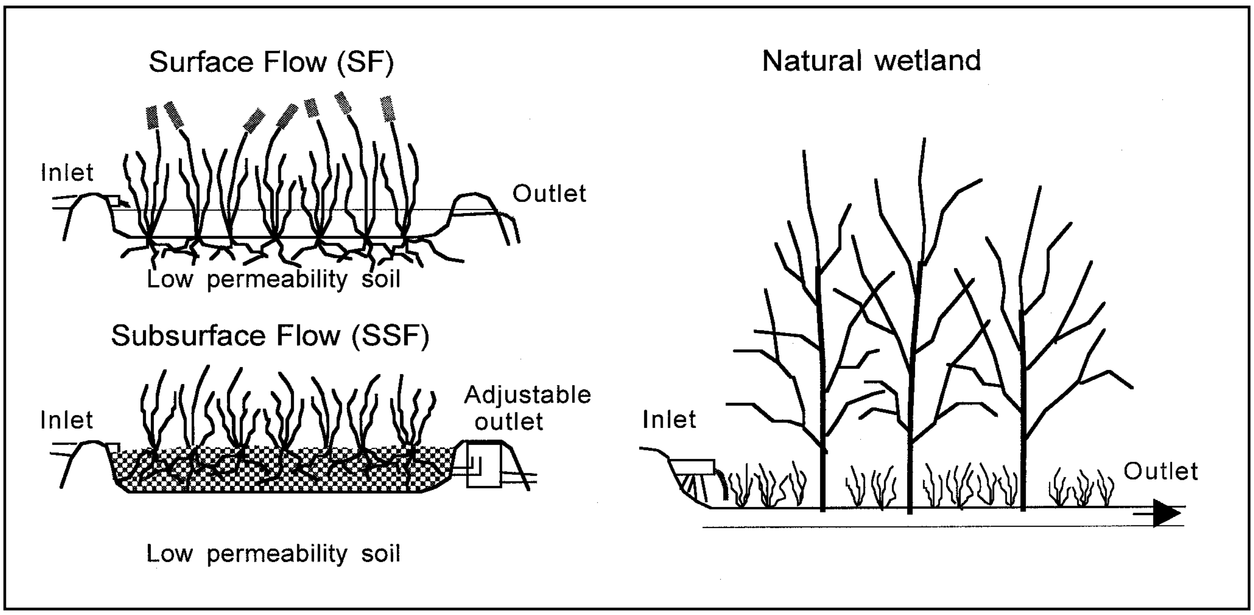


Figure 14.9. Different types of wetlands for wastewater treatment (Kadlec & Knight, 1996).

cold weather. The harvesting of the floating plants also gives rise to significant residual problems. For these reasons, floating aquatic plant systems have not come into practice in Sweden.

Wetland treatment systems use rooted plant species that can stand shallow, flooded, and saturated conditions. There are three basic types of wetland systems: natural wetlands, constructed wetlands with surface flow (SF) and constructed wetlands with subsurface flow (SSF) (Figure 14.9).

Surface-flow wetlands (natural as well as constructed) are densely vegetated by a variety of plants. The water depth is often less than 0.4 m. Open water areas might be incorporated into the design to provide for optimisation of hydraulic conditions.

Subsurface-flow wetlands use a bed of soil or gravel as a substrate for growth of rooted plants. Pretreated wastewater flows by gravity, horizontally through the bed substrate, where it contacts facultative microbes. Typical plant species in a subsurface-flow wetland are: common reeds (*Phragmites australis*), cattails (*Typha spp.*) and bulrushes (*Scirpus spp.*). Oxygen can enter the substrate layer directly by atmospheric diffusion and through the plant leaves and roots.

With wetlands it is possible to efficiently reduce BOD, suspended solids, N, P, metals, organics and pathogens. Pre-treatment of the wastewater is, however, crucial for an efficient removal of these constituents.

15.
WASTEWATER TREATMENT SYSTEMS

Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li & Elzbieta Płaza

Wastewater treatment in local systems

Subsoil infiltration systems for infiltration of wastewater, pre-treated in a septic tank, into natural soil or into buried sand filter installations are relatively simple constructions, which can handle large volumes of biologically and chemically active surfaces with long retention times. When designing such a system, considerations must be taken of the soil's particle distribution curve and of the distance to the groundwater surface.

The distribution curve of the soil's particle size determines the loading rate for the infiltration system, while the sieve analysis curve is used to determine the loading rate itself (Figure 15.1). If the sieve analysis curve falls within section B, or section A and B, the recommended loading rate is 30 l/m^2/day. If the curve falls within field A, the recommended loading rate is 60 l/m^2/day.

To avoid microbial contamination of the groundwater, Swedish safety regulations stipulate that the distance from the infiltration surface to the groundwater table is not allowed to fall below one metre. The major portion of the microorganisms in the wastewater is removed in the biofilm at the infiltration surface and in the unsaturated zone above the groundwater table. This removal capacity must, however, be regarded as just an extra safety precaution.

An important aspect in establishing an infiltration system is that the groundwater table varies during the year depending on geographical location and type of soil. In Table 15.1, the variations in groundwater level over the year and in different soil types are shown.

Table 15.1. Variations in groundwater level (in infiltration areas) during the year and in different soil types.

Type of soil	**Variation in groundwater level** (m)
Gravelly sand	<0.5
Sand	0.4 - 0.8
Silt	0.5 - 1.0
Sandy moraine	1.0 - 1.5
Sandy loam moraine	1.5 - 2.0
Silty clay moraine	2.0 - 3.0

A constructed wetland system can be designed to achieve various levels of treatment of BOD, SS, nutrients, metals, pathogens and other substances. Therefore, the characteristics of the wastewater to be treated and the desired discharge limits must be taken into consideration at an early stage of the design of a wetland system intended for wastewater treatment. Other parameters that also have to be considered at this stage are operating water depth, process loading rates, process kinetics, effects of temperature and physical configuration. The design of a constructed wetland system also includes selection of location, type of constructed wetland (surface flow wetland or subsurface flow wetland), substrata me-

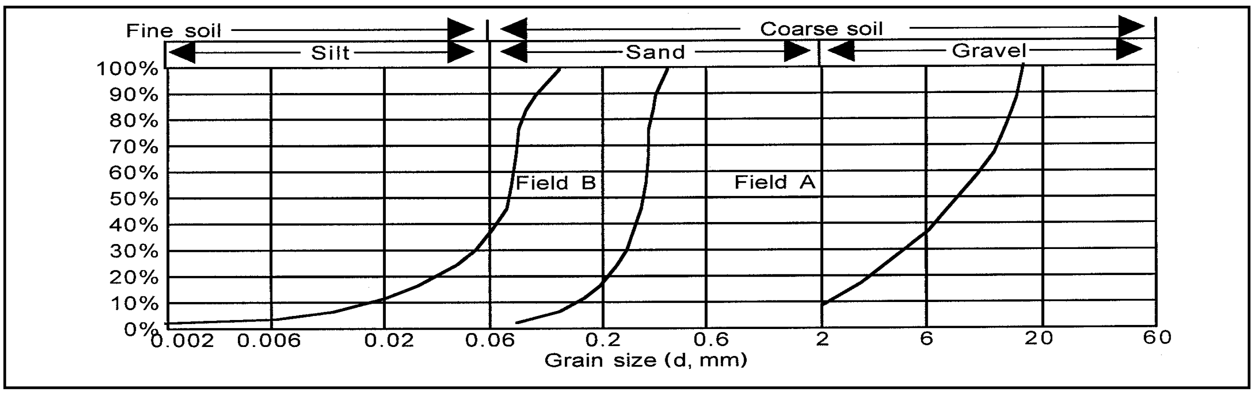


Figure 15.1. Grain size distribution diagram for determination of adsorption possibilities and sizing of the infiltration system.

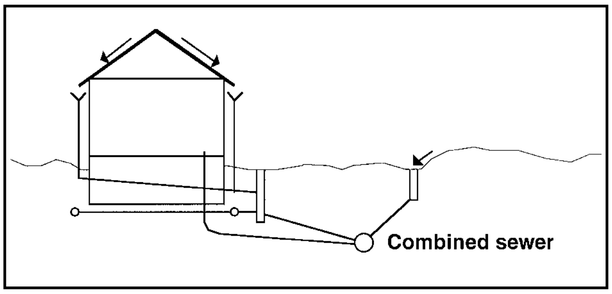


Figure 15.2. Combined system.

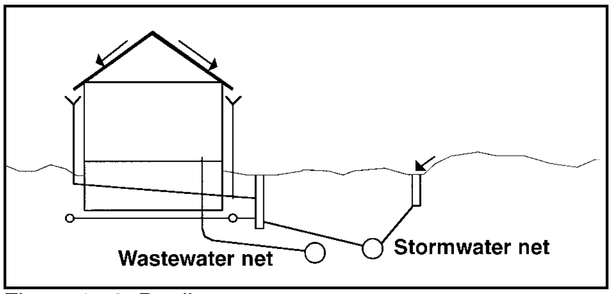


Figure 15.3. Duplicate system.

dium, vegetation, treatment units, wastewater distribution and operational scheme.

Constructed wetlands require an impermeable barrier to ensure containment of wastewater within the system. This barrier also prevents leakage of pollutants into the groundwater. The impermeable barrier can consist of in situ soils with a hydraulic conductivity of 10^{-8} m/s or less. If this type of material is not available, bentonite, asphalt or plastic membranes can be used to seal the treatment system. The barrier layer must be placed below the maximum depth of root development to avoid damage of the barrier from the roots, which would cause leakage. The bed of the wetland should have a slope of 1 % to enhance the hydraulic conductivity of the bed media.

Sewer and stormwater net

Three main systems are used for removal of wastewater and stormwater:

- The combined system, which transports wastewater, stormwater and drainage water in a common pipe. Most of the old districts in Swedish cities have combined systems (Figure 15.2).
- The separated system, which transports wastewater and often drainage water from building grounds in one pipe while stormwater is removed via gutters or open ditches. This system is commonly used in rural or sparsely populated areas where stormwater may be led into open ditches without negative effects. In more densely populated areas, stormwater may be handled locally through various methods, such as infiltration and wetlands.
- The duplicate system uses separate lines for the transport of wastewater and stormwater (Figure 15.3). This system is more complicated than the other systems because of its double street and service pipes. Drainage water may be led to either the sewer or stormwater net.

Two other systems sometimes used are a system whereby wastewater is transported by vacuum (vacuum system) and one that transports wastewater using low pressure (low-pressure system, LPS).

Wastewater treatment in central systems

The objective of wastewater treatment is to reduce the concentration of various pollutants to a level where discharge of the effluent will not adversely

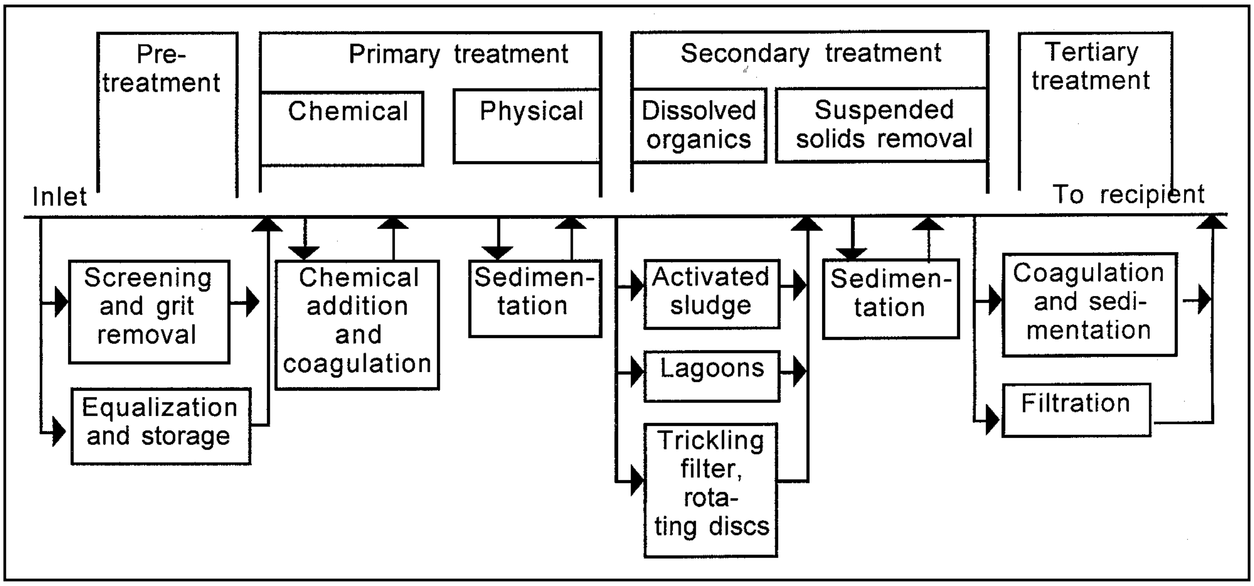


Figure 15.4. Wastewater treatment sequence with different process alternatives.

affect the environment. The treatment methods are classified as physical, chemical and biological:

Physical methods in which pollutants are removed or treated through application of physical forces like screening, mixing, sedimentation and filtration.

Chemical methods in which removal or treatment of contaminants is brought about by the addition of chemicals or by chemical reactions such as chemical precipitation and disinfection by chlorine and ozone.

Biological methods in which the removal of contaminants is brought about biologically through such means as the activated-sludge process.

Different unit operations, process and treatment systems may be used to remove a certain contaminant in wastewater. The treatment process can be combined to form process trains, i.e. treatment schemes in which the influent wastewater is treated until it reaches a specified water quality. For stringent requirements it is necessary to combine several treatment processes. Figure 15.4 shows an advanced treatment system for municipal wastewater with a technically oriented process scheme.

Six steps are important to consider in wastewater treatment:

- Pre-treatment in order to remove coarse particles and sand.
- Physical (mechanical or primary) treatment by sedimentation for the removal of suspended solids. The treatment efficiency may be improved by the addition of precipitation chemicals.
- Biological (secondary) treatment for the removal of organic substances. By modification of the biological treatment processes it is possible to remove nitrogen and/or phosphorus.
- Complementary (polishing or tertiary) treatment by use of a chemical precipitation step or a filtration step. Other possible complementary treatment methods are activated carbon, ion exchange, reverse osmosis and the use of wetland or land treatment.
- Sludge treatment with the purpose of reducing the sludge volume and stabilising the sludge.
- Sludge disposal.

Some of these steps will be discussed below.

Stormwater handling

Attention must being paid to urban runoff, or stormwater, as a source of pollution. Stormwater contains pollutants from many sources. In general it contains high concentrations of heavy metals and suspended solids (SS), but lower concentrations of BOD, COD, nitrogen and phosphorus. The first amount of urban runoff after a rainfall or an occasion of snow melting is the most polluted, making it an important task to treat this "first flush" before it enters a distribution system, wastewater treatment plant or natural recipients.

There are several methods of treating stormwater and it has been shown that methods employing natural separation processes are suitable to reduce the amount of urban runoff and associated pollutants. Stormwater is traditionally treated on-site, for instance in ponds, infiltration facilities or in percolation facilities. Lately, constructed wetland systems have been considered an appropriate technology for the treatment of urban runoff and several such systems have been put into operation in Sweden as well as in Europe and the United States.

Ponds for stormwater treatment (Figure 15.5) have double functions: they retain stormwater while cleaning it from pollutants through natural processes. These ponds should therefore have an impermeable bottom allowing water to infiltrate into the ground. Further on, the ponds should be long narrow (> 3:1) to obtain an adequate flow through the system. This will also reduce the risk of filling up the pond with weed. To further prevent this, a suitable depth must also be chosen, about 1-2 m. Since sedimentation of

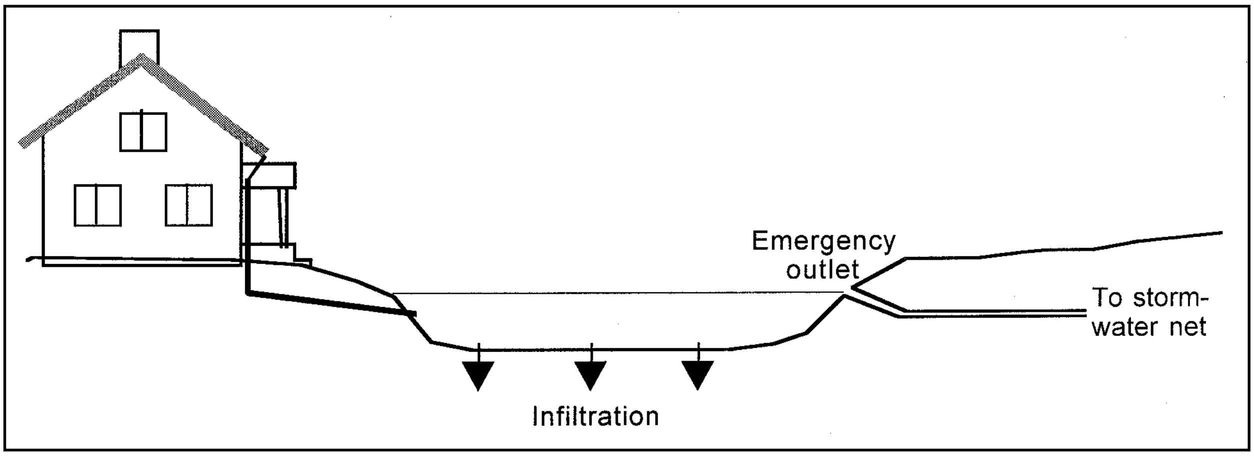


Figure 15.5. Pond with infiltration and emergency outlet.

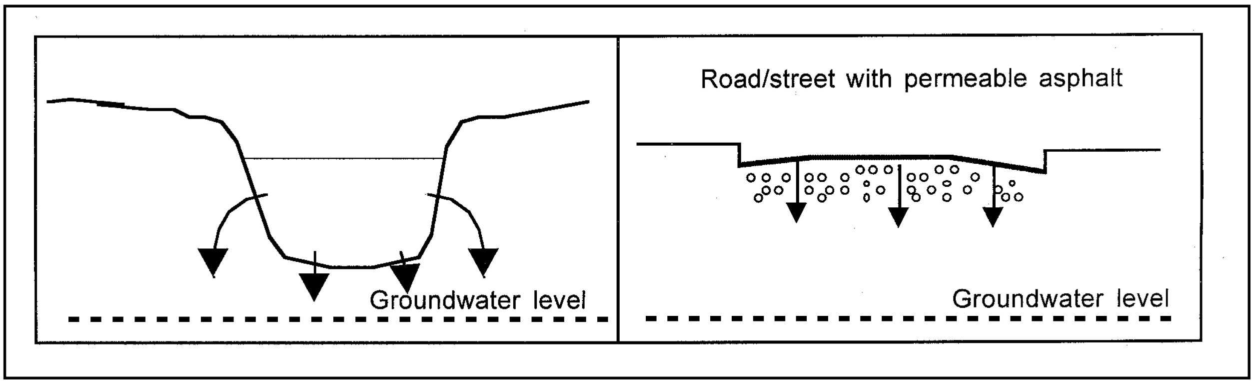


Figure 15.6. Infiltration ditch (left) and infiltration in porous pavements/roads (right) (from Larm, 1994).

heavier particles will eventually take place in the pond, a special sedimentation unit should be placed close to the inlet. Screens need to be built in both the inlet and the outlet of the pond. An emergency outlet should also be included in the construction so that excess water can overflow. The pond can with advantage be surrounded by vegetation that also reduces pollutants.

Infiltration facilities can be of different types: infiltration trenches, buffer strips, infiltration ditches or porous pavements (Figure 15.6). These systems also have a double function, in that stormwater can both infiltrate and be stored. When infiltrating into the ground, pollutants will be removed through biological, chemical and physical processes. Storage means that the flow will be regulated and detained before entering the recipient. Infiltration trenches are found in the unsaturated zone. If the soil permeability is high, stormwater can infiltrate directly into the ground. Otherwise a coarse material such as broken stones can be placed in the ground to form storage. In both cases, the distance to the groundwater table should be at least one metre. In buffer strips, stormwater can infiltrate directly into the ground.

Percolation basins (Figure 15.7) can be constructed where direct infiltration in the ground is impossible. These types of stormwater treatment facilities are primarily intended for low-polluted runoff, but can also be considered for highly polluted water. In these latter cases, the runoff must be pretreated before being discharged into the percolation basin. The percolation basin is an excavation in the ground that is filled with a coarse material, for instance broken stone. The stormwater will percolate from the sidewalls and the bottom before it finally reaches the groundwater. To optimise percolation, the basin should be long and narrow to maximise the area of the sidewalls in relation to the bottom area that will clog due to sedimentation of suspended matter.

Treatment of stormwater in constructed wetland systems has attracted a good deal of attention lately and several systems have been established in Sweden as well as abroad. The design of these systems is the same as for domestic wastewater treatment wetlands.

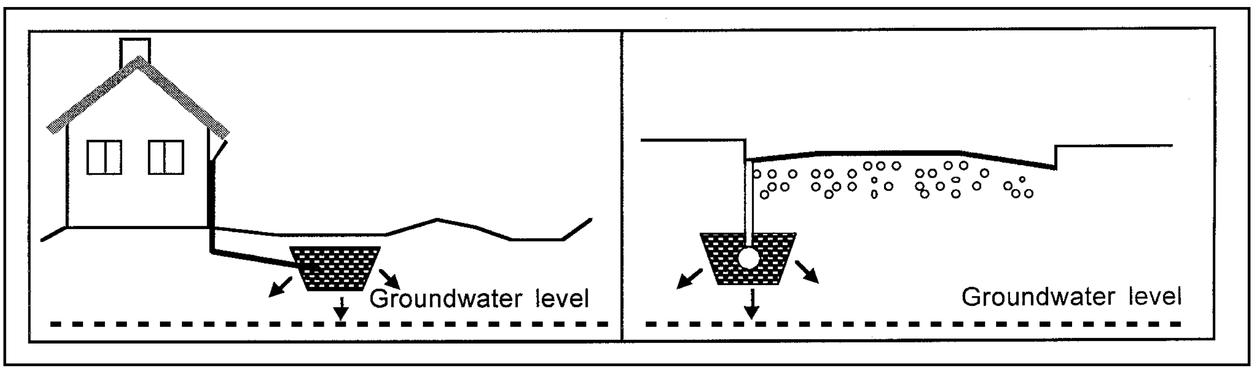


Figure 15.7. Percolation basin (left) for runoff from roofs and (right) for road runoff (from Larm, 1994).

System levels in wastewater handling

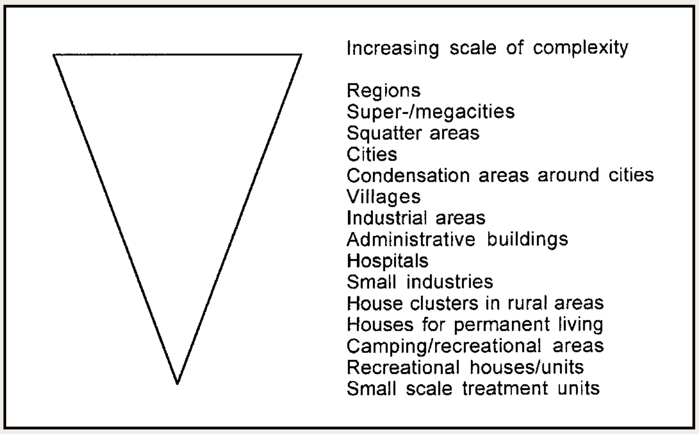
In order to facilitate the design, operation and evaluation of water and waste handling systems it is necessary to generalise and simplify the system functions and the description of system components and levels. The following requirements are important:

I The system should function in accordance with the concept of sustainable development, which means a minimisation of resource depletion and environmental degradation and a maximisation of recovery, recycling and reuse.

II The system should function logically with respect to material and energy flows in order to facilitate recovery, recycling and reuse but also to satisfy the needs of the consumers.

III The system should function in such a way as to satisfy specific goals in relation to technology, humans and society.

Water and waste handling methods might be ordered according to scale or complexity. This is illustrated in the figure below. Somewhat simplified, handling can be divided into local handling inside buildings, local handling outside buildings, central handling and regional handling. In addition, global effects of the handling must be considered. On each level many actions may be taken for improvement of the environment.



Examples of ways to improve water and waste handling at different system levels

Inside buildings	– Clean technology and waste minimisation in industries
	– Separation methods of waste inside buildings (including new toilet systems)
	– Treatment units for water and wastewater inside buildings
	– Improved labour safety
Local level	– Development of local handling systems with special emphasis on areas where centralised outside solutions are expensive (including different ecological methods)
	– Problems related to water, wastewater and waste handling in the archipelago
	– Special problems related to large industries, airports and the handling of wastes from ferries and boats
Central level	– Improved treatment efficiency and transport of water, wastewater and wastes
	– Use of rapid treatment processes to facilitate central location of water and wastewater treatment plants
	– Maintenance and repair of existing facilitates for water and wastewater handling
	– Public participation in water, wastewater and waste handling
	– Management of water, wastewater and waste handling systems
Regional level	– Improved use of the recipient for various purposes
	– Disposal of sludge and wastes with special emphasis on recycling and long-term effects
	– Role of regional planning and planning of new areas for housing and industries (including application of local Agenda 21)
Global level	– Source of control of chemicals leading to depletion of the ozone layer
	– Improved operation to reduce discharge of greenhouse gases

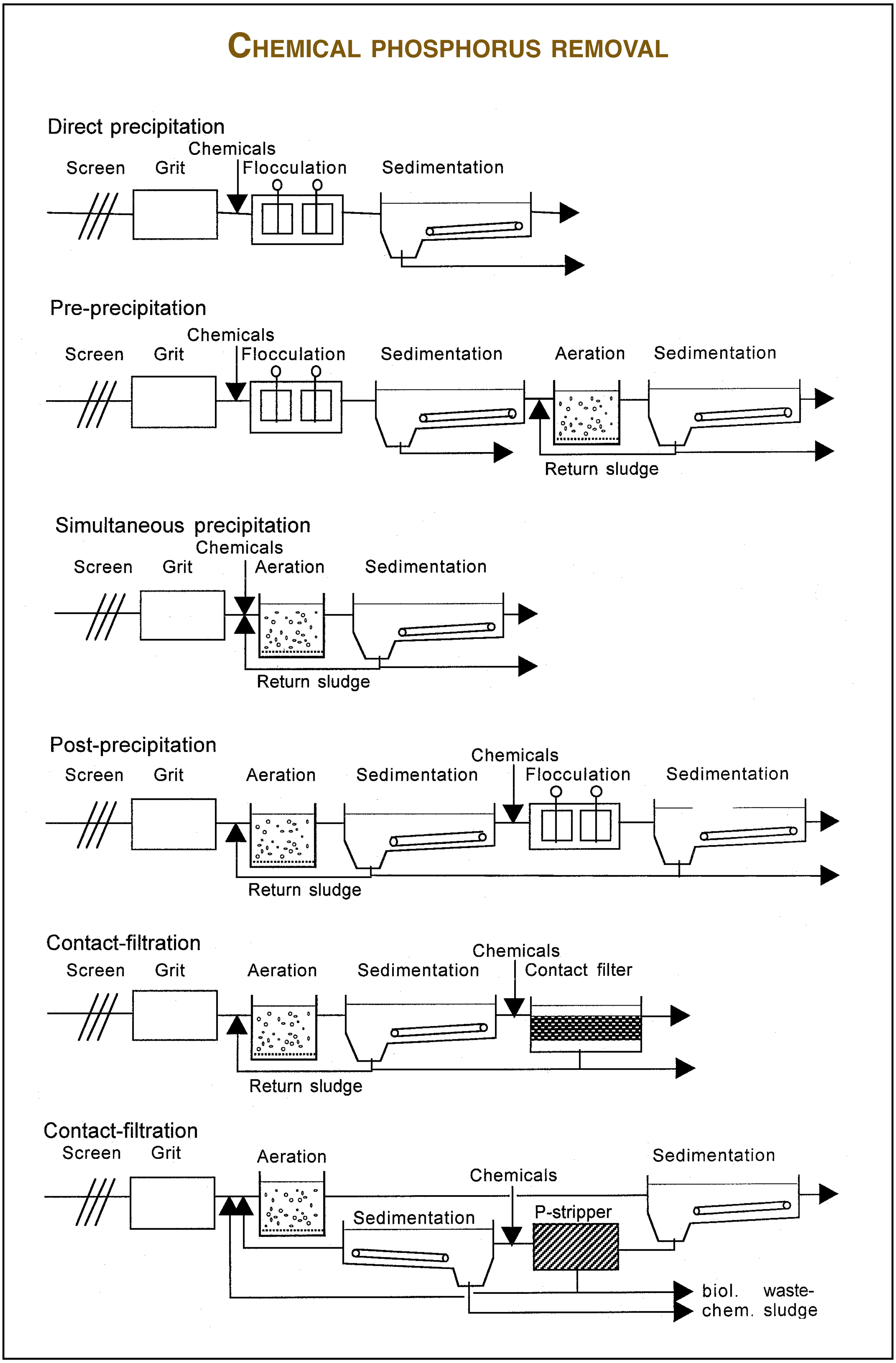


Figure 16.1. Plant configurations for chemical phosphorus removal.

16.

NUTRIENT REMOVAL AND SLUDGE HANDLING

Bengt Hultman, Erik Levlin, Lena Johansson, Nasik Al-Najjar, Puhua Li, Elzbieta Płaza & Rein Munter[1]

Eutrophication prevention and nutrients removal

Only small amounts of nitrogen and phosphorus, principally in runoff from cultivated farmland, are transported to surface waters in a simple agrarian economy. However, phosphate rock is mined and processed into fertilisers, detergents, animal feeds and other chemicals. The amounts of inorganic nitrogen and phosphorus needed to produce abundant algae and rooted aquatic weeds are relatively small. Lakes with annual mean total nitrogen and phosphorus concentrations greater than 0.8 mg/l and 0.1 mg/l, respectively, exhibit algal blooms and nuisance weed growths during most of the growing season. Reducing nutrient input through advanced treatment of wastewater can retard the rate of eutrophication of a water body. Emphasis should be placed on phosphorus removal, since phosphorus is considered the limiting nutrient, while methods are available to precipitate wastewater phosphate chemically. Nitrogen compounds are more difficult to eliminate and techniques for nitrogen removal are very costly.

Phosphorus removal

Phosphorus is present in wastewater as phosphate, both in soluble and suspended form. Only about 15 % of the total phosphorus contained in settleable particles may be removed by primary sedimentation. The principle of removing phosphorus from wastewater is therefore based on the transfer of soluble phosphorus to solid phase followed by solid-liquid separation. The phosphorus removal methods can be divided into:

- chemical treatment - chemical precipitation by the addition of lime, iron or aluminium salts
- biological treatment - assimilation in conventional plants; enhanced assimilation by process modification, algae ponds
- combined methods with chemical and biological treatment
- others, such as: ion exchange and adsorption and terrestrial treatment (irrigation; percolation; infiltration; plant treatment)

Chemical processes for phosphorus removal can be classified, according to their location in the process stream, as direct precipitation, pre-precipitation, simultaneous precipitation and post-precipitation (Figure 16.1).

Compounds of phosphorus can be removed by addition of coagulants, such as alum, lime, ferric chloride, or ferrous sulphate. With calcium salts, phosphorus can be precipitated to low residuals, depending on the pH. The precipitate is a hydroapatite, $Ca_5OH(PO_4)_3$:

$$5\,Ca^{2+} + 7\,OH^- + 3\,H_2PO_4^- \rightarrow Ca_5OH(PO_4)_3 + 6\,H_2O$$

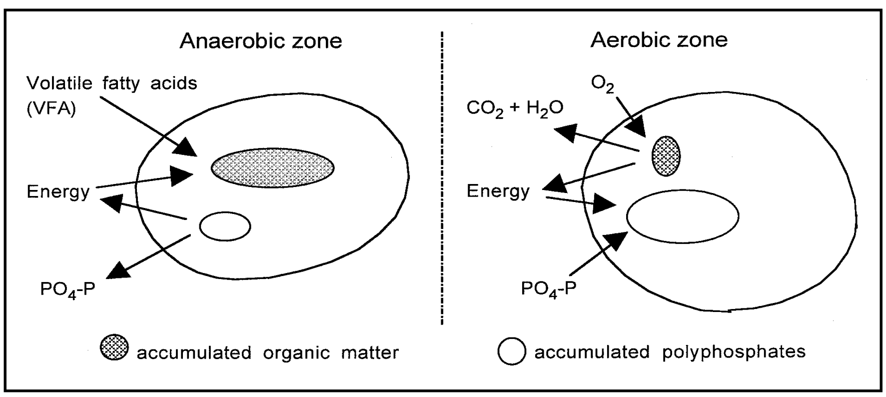


Figure 16.2. Biological phosphorus removal mechanisms in P-storing bacteria.

Optimum pH for phosphorus precipitation with lime is in the range of 11-12. The lime requirements are dictated by the hardness and alkalinity of wastewater. If using aluminium, a dosage of 1.5 to 3.0 moles of aluminium per mole of phosphorus as P is required over a pH range of 6.0 to 6.5. Iron can be added as $FeSO_4$ or $FeCl_3$.

[1] Rein Munter contributed with input to the part on nutrient removal.

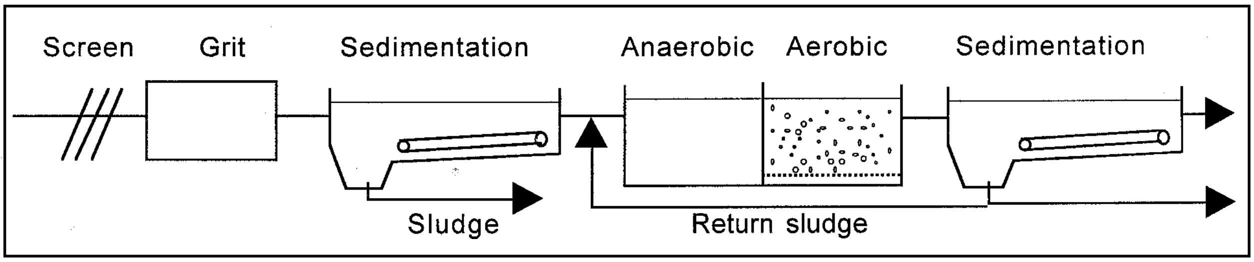


Figure 16.3. Plant configuration for biological phosphorus removal.

The iron dosage will range from 1.5 to 3.0 moles of iron (Fe^{3+}) per mole of phosphorus (as P). The optimum pH is 5.0, which is too low for conventional biological treatment.

The chemicals may be added prior to primary sedimentation, with alum and soil salts being added to the aeration tank during the activated-sludge process, or chemicals may be added in a third stage following biological treatment. Chemical precipitation, especially using lime, is sometimes practised in a third stage after biological treatment, both to remove the phosphorus and to increase the pH of the effluent in preparation for a process of ammonia-nitrogen removal.

In a biological phosphorus-removal process, polyphosphates are accumulated by bacteria and removed with the waste in the activated sludge. As a result, 10 to 30 % of the influent phosphorus is removed during the secondary biological treatment. The bacteria are exposed to alternate anaerobic and aerobic conditions. If an enhanced biological phosphorus removal is to be achieved there must also be a sufficiently high amount of readily biodegradable low-molecular organics supplied to the anaerobic zone from the influent or from anaerobically degraded complex organics. Under anaerobic conditions bacteria hydrolyse accumulated polyphosphates to use the released energy to absorb rapidly biodegradable organic material. Under aerobic conditions the stored organic material in the P-accumulating organisms is used for growth and to synthesise new polyphosphates. The basic principle of biological phosphorus removal is illustrated in Figure 16.2. Biological phosphorus removal is carried out using activated sludge technology and plant configuration is shown in Figure 16.3.

Chemical precipitation is still the dominating phosphorus removal technology of the Scandinavian countries (Table 16.1). There has been an increase in biological phosphorus removal over the last few years. This was caused mainly by economic factors, low sludge production and the fertiliser value of the bio-P sludge. Choice of technology also depends on effluent criteria (Table 16.2). The sludge containing the excess phosphorus is either wasted or removed and treated in a side stream to release the excess phosphorus (Figure 16.4). Release of phosphorus occurs under anoxic conditions.

Table 16.1. Phosphorus removal technologies applied in Scandinavian countries in % of population with P-removal (Henze, 1996)

Country	Bio-P	Pre-precipitation + direct precipitation	Simultaneous precipitation	Post-precipitation	Wetlands
Denmark	33	5	61	0	1
Sweden	1	40	25	34	0
Norway	10	75	5	10	0

Table 16.2 Expected effluent quality for phosphorus removal using various treatment methods in g TP/m^3 (Henze, 1996)

Process	Norway	Sweden	Denmark
Chemical precipitation, low dose	1.5	2	3
Chemical pre-precipitation, high dose	0.3	0.5	0.8
Biological/chemical simultaneous precipitation	0.6	0.7	1
Pre-precipitation/biological	0.6	0.7	1
Biological phosphorus removal	1.2	0.6	4
Biological + chemical phosphorus removal	0.5	0.6	1
Post-precipitation or contact filtration	0.2	0.3	0.4

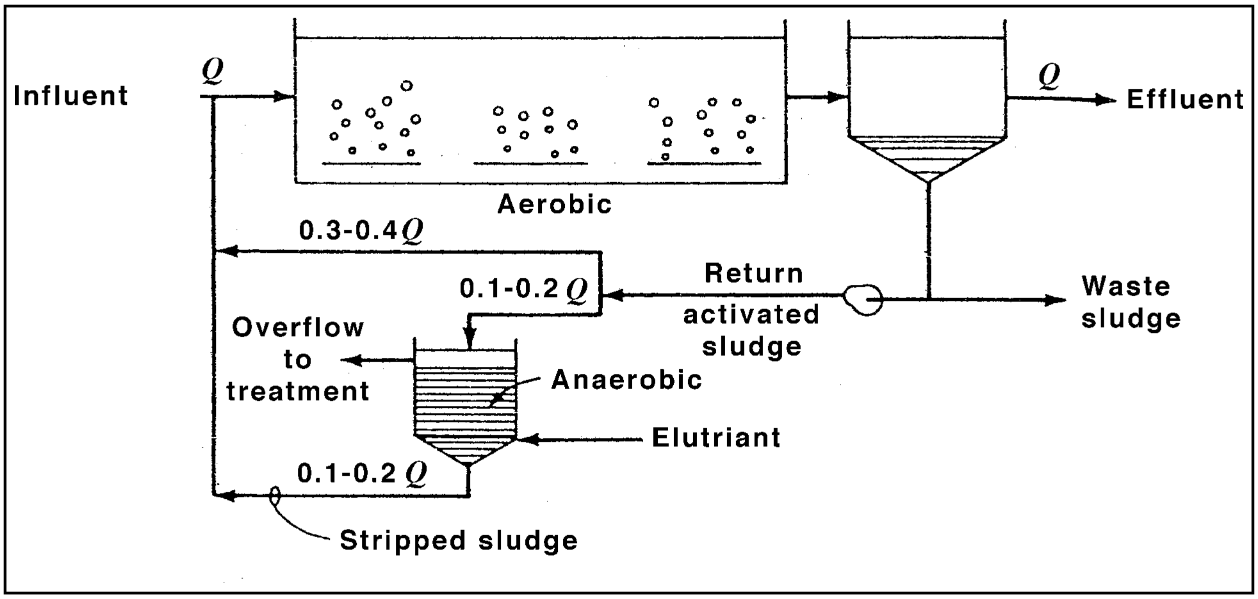


Figure 16.4. Flow diagram for biological removal of phosphorus. The Phostrip process (Linsley et al., 1992).

Nitrogen removal

In municipal wastewater nitrogen is present as ammonia and as organic nitrogen. Biological and physical-chemical processes are used for nitrogen removal. Physical-chemical alternatives include ammonia stripping, selective ion exchange and breakpoint chlorination.

In biological wastewater treatment systems nitrogen is removed by assimilation (15-20 % of total nitrogen) and by the biological nitrogen removal process, accomplished in two stages: nitrification and denitrification. In the nitrification process ammonia is oxidised to nitrate by two groups of chemoautotrophic bacteria that operate in sequence:

$$NH_4^+ + 1.5\,O_2 \xrightarrow{\textit{Nitrosomonas}} NO_2^- + 2H^+ + H_2O + \text{new cells}$$

$$NO_2^- + 0.5\,O_2 \xrightarrow{\textit{Nitrobacter}} NO_3^- + \text{new cells}$$

The energy released in these oxidations is used for the growth of the nitrifying organisms. Since the bacteria are aerobic, an oxygen supply is required for the nitrification process. Several factors influence the nitrification process, including pH, temperature, oxygen content, and toxic substances. All of these should be taken into consideration in the design of the process. Certain heavy metals, complex anions and organic compounds are toxic to nitrifiers.

The biological nitrification processes can be achieved in either a suspended growth reactor (such as in a conventional aeration basin in an activated-sludge process or in an attached-growth reactor (nitrification is accomplished by organisms attached to a growth media as in a trickling filter).

Both suspended-growth and attached-growth systems are also used for denitrification. The biological process of denitrification transforms nitrate-nitrogen into nitrogen gas. A relatively broad range of bacteria can accomplish denitrification, as many bacteria can shift rapidly between using oxygen and nitrate (or nitrite). Denitrification is achieved when heterotrophic bacteria use oxygen from nitrate and nitrite for organic carbonaceous oxidation. The process must be performed in an anoxic environment (absence of oxygen but with presence of nitrate).

Denitrification can be accomplished using an internal carbon source from sewage or by adding biologically degradable organic material (methanol, ethanol etc.).

For methanol the reaction can be written:

$$3NO_3^- + CH_3OH \rightarrow 3NO_2^- + H_2O + H_2CO_3$$

$$2NO_2^- + CH_3OH \rightarrow N_2 + CO_3^{2-} + 2H_2O$$

As for nitrification, pH and temperature influence the rate of denitrification. The most commonly used systems for biological nitrogen removal are pre-denitrification and post-denitrification. If the efficiency of the process is not enough for effluent requirements a polishing step using biofilters can be applied (Figure 16.5).

Combined phosphorus and nitrogen removal

Most plant configurations for nitrogen and phosphorus removal are based on biological processes and

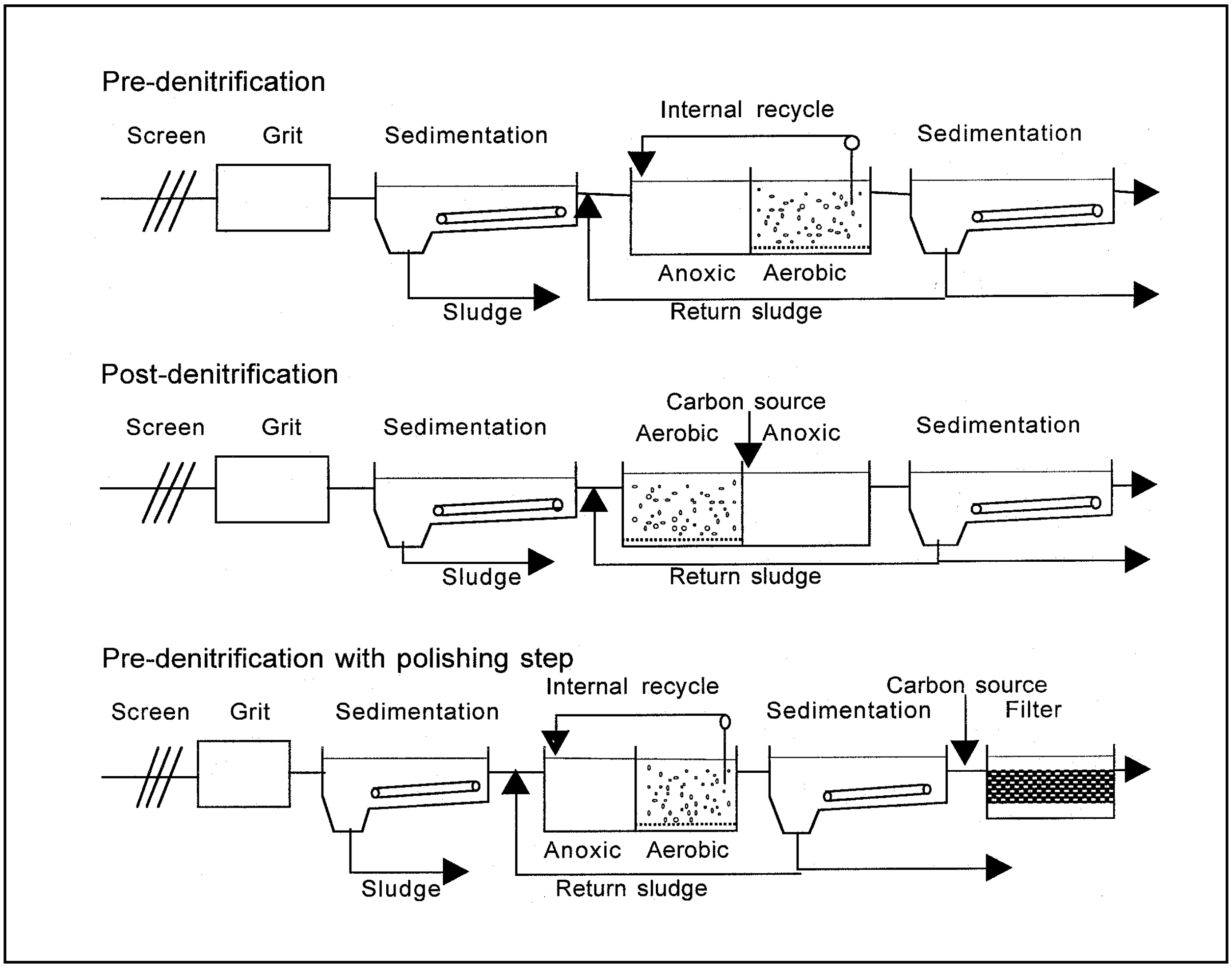


Figure 16.5 Plant configurations for biological nitrogen removal.

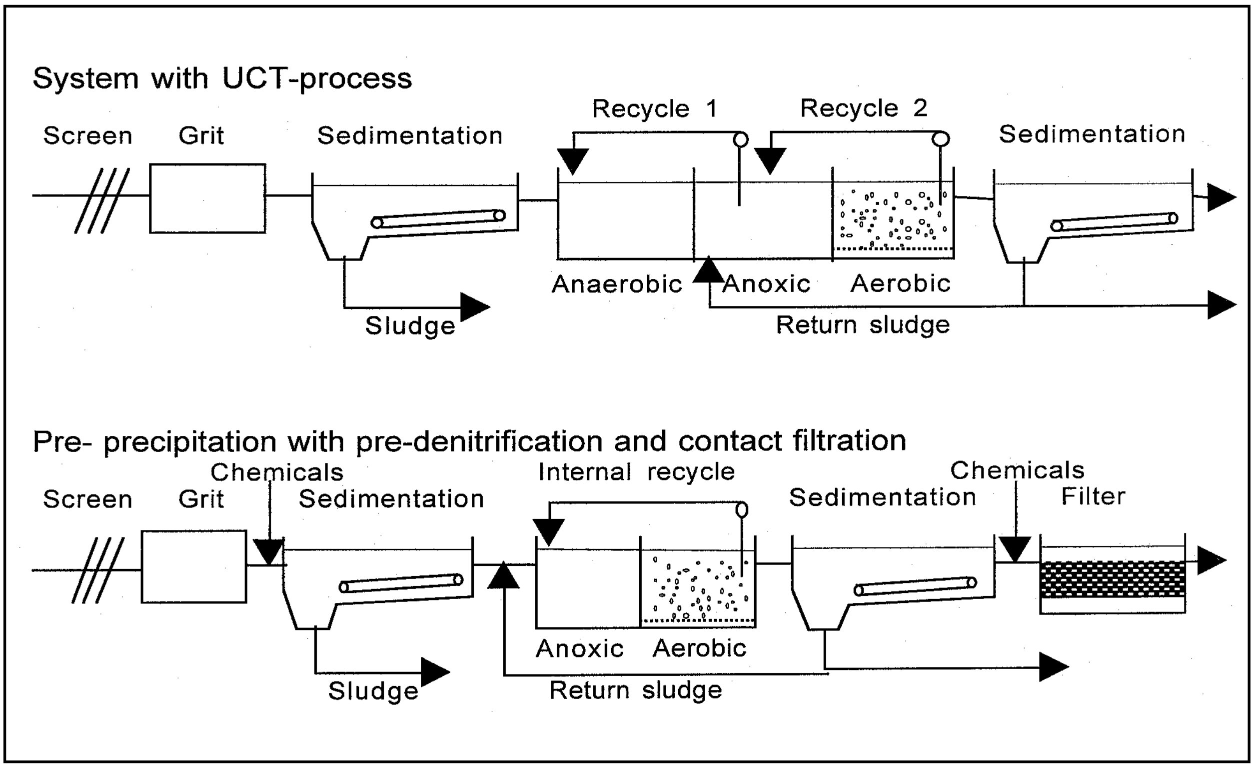


Figure 16.6 Plant configurations for combined nitrogen and phosphorus removal.

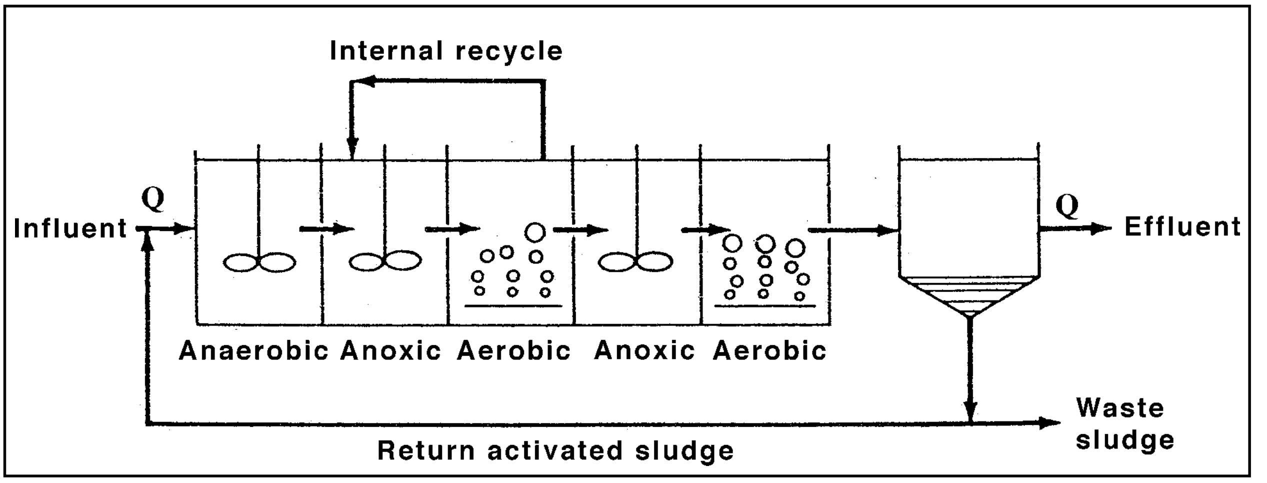


Figure 16.7. Bardenpho process for the combined removal of nitrogen and phosphorus (Linsley et al., 1992).

different combinations of anaerobic, aerobic and anoxic zones (Bardenpho, A_2O, UCT and their modifications), but a combined usage of biological and chemical methods is also applied (Figure 16.6). In the Bardenpho process (see Figure 16.7), a sequence of anaerobic, anoxic and aerobic steps are used to achieve both nitrogen and phosphorus removal. Nitrogen is removed by nitrification-denitrification. Phosphorus is removed by wasting sludge from the system. The choice of process system is dependent on factors such as effluent requirements and influent nitrogen and phosphorus concentration to the wastewater treatment plant.

Sludge handling goals

Sludge handling has two main purposes:

Stabilisation of the sludge by use of different methods such as biological (anaerobic and aerobic digestion and composting), chemical (mainly using lime) and thermal (heat drying, incineration and melting).

Volume reduction by use of thickening (gravity thickening, flotation and centrifugation), de-watering (use of centrifugation, filters and presses), drying (natural and heat drying) and incineration and melting.

Stabilisation is used to obtain a sludge that does not change with time, i.e. a stable sludge that does not cause odour problems. In addition, stabilisation may reduce the number of pathogens in the sludge, especially by use of chemical and thermal methods. Biological stabilisation removes the biodegradable part of the sludge. Heat drying and lime addition inhibits further bacterial growth. Lime-containing sludge in contact with carbon dioxide in the air is neutralised and after a certain time bacterial growth may start again. In incineration both biodegradable and non-biodegradable organic materials are removed.

Major sludge handling in Sweden is carried out for larger treatment plants: thickening, stabilisation (mainly by aerobic digestion), conditioning of the sludge before de-watering by polyelectrolytes, de-watering of the sludge (mainly using centrifuges or belt presses) and transport to final destination (mainly agriculture, landfill, land building and land reclamation).

Biological sludge stabilisation

Anaerobic digestion is a process in which organic material in the sludge is degraded without contact with air. The retention time in the digester is about 15 to 20 days. During the process, energy rich biogas is formed, consisting of about 2/3 methane-gas and 1/3 carbon dioxide. The biogas may be used for energy production for heating purposes or for producing electricity. If the carbon dioxide is removed the remaining methane gas may be used as a fuel for cars and busses (Figure 16.8).

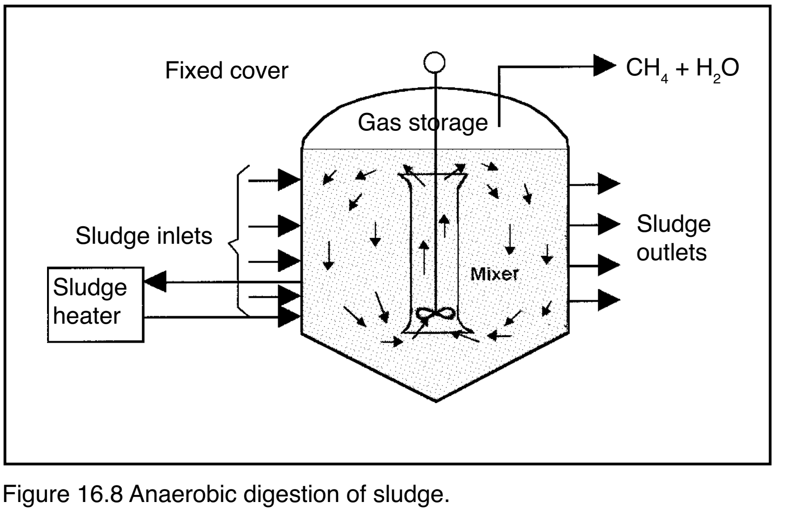


Figure 16.8 Anaerobic digestion of sludge.

In aerobic digestion the sludge is aerated for 15 to 20 days to remove biodegradable organic material in the sludge. Problems related to aerobic digestion are the energy needed for aeration and the fact that sludge cools off during the winter period. Aerobic digestion has therefore mainly come to be used at small treatment plants.

Composting is also an aerobic stabilisation process. In composting a high sludge concentration must be used, about 40-45 %. Addition of materials such as wood chips or solid wastes may help attain this. Due to high sludge concentration the heat produced during degradation of organic material increases the temperature of the sludge up to 60-80 ºC, thereby improving the hygienisation of the sludge.

Sludge volume reduction methods

Sludge from sedimentation and flotation units of water and wastewater treatment plants has a low concentration of solids and must thus be concentrated using various methods before disposal or use. Water in flocs exists as drainable water, capillary water and adsorbed and internal water, for instance in cells. Water may also be bound as crystallisation water to chemical precipitates.

Thickening methods like gravity thickening, flotation and disc centrifuges are used primarily to remove drainable water. Part of the water in capillaries can be removed by de-watering methods such as belt and filter presses and bowl centrifuges. The applied pressure during de-watering limits the amount of the capillary water that can be removed. Water in fine capillaries and adsorbed water can be removed by different drying methods, of which the most efficient is the use of heat drying. Finally, internal water and crystallisation water are removed using such methods as incineration and sludge melting.

In order to facilitate de-watering sludge is normally treated using conditioning methods. Such methods include the addition of chemicals like polyelectrolytes and metal salts or the use of heat or freezing.

Conditioning is a way of reducing the number of small particles and building up larger flocs. Metal salts and polyelectrolytes act as coagulation and/or flocculation agents. In heat treatment the structure of certain organic material such as proteins changes, resulting in sludge with very good de-watering properties. During the heating process much of the sludge material goes in solution, yielding a supernatant with a high concentration of organic material and nutrients. Subsequent freezing bursts the cells, thereby improving the de-watering properties of the sludge.

In Sweden the predominant conditioning agent is polyelectrolytes. Freezing is used in a few places with cold climate. During recent years there has been renewed interest in the use of heat conditioning for sludge. This is due to the excellent possibilities of reducing sludge production, of improving de-waterability as compared with the use of polyelectrolytes and of recovering different substances released during heat conditioning. Two commercial processes using this technology are KREPRO and Cambi.

The solids concentration of sludge is nearly doubled after thickening, which increases the solids content through partial removal of the liquid. The amount of concentration increase depends on the type of sludge, with activated sludge increasing to about 3 % solids and primary sludge to about 9 % solids. The most common methods of thickening are gravity settling and flotation. Conventional gravity thickening is also simple and inexpensive. It is essentially a sedimentation process similar to the one occurring in all settling tanks.

Gravity-settling thickening is carried out in tanks, which are usually equipped with a slow stirrer to provide gentle agitation, which enhances settling. Gravity thickening usually exhibits hindered settling phenomenon. The degree to which waste sludge can be thickened depends on many factors. Among the most important are the type of sludge being thickened and its volatile solids concentration. The initial solids concentration affects the degree of concentration that can be achieved. Hydraulic and surface loading rates are also of importance. The supernatant from the thickener is returned to the wastewater treatment process.

Flotation thickening is achieved by creating gas bubbles in the sludge. The bubbles attach themselves to the sludge particles, which gives them buoyancy and carries them up to the liquid surface. The accumulated sludge is removed from the surface by scrapers and the clarified liquid is returned to the wastewater treatment process. Air flotation thickening can be employed whenever particles tend to float rather than sink. A dissolved air flotation unit is shown in Figure 16.9.

Many methods of sludge disposal involve de-watering the sludge. The objective of this de-watering is to facilitate utilisation, disposal or further processing of the sludge. Sludge de-watering is a process whereby sufficient water from sludge is removed to give it quasi-solid characteristics by a reduction of volume and moisture content in the sludge. Sludge may be de-watered by use of drying beds, lagoons, centrifuges, filter presses and horizontal belt filters.

Dried sludge can be used as a fertiliser or soil conditioner, but the costs of drying are high. Incineration can be used as the ultimate sludge disposal method when the sludge has been de-watered to yield a solids content greater than approximately 30 %. The heat of combustion of the sludge solids is sufficient

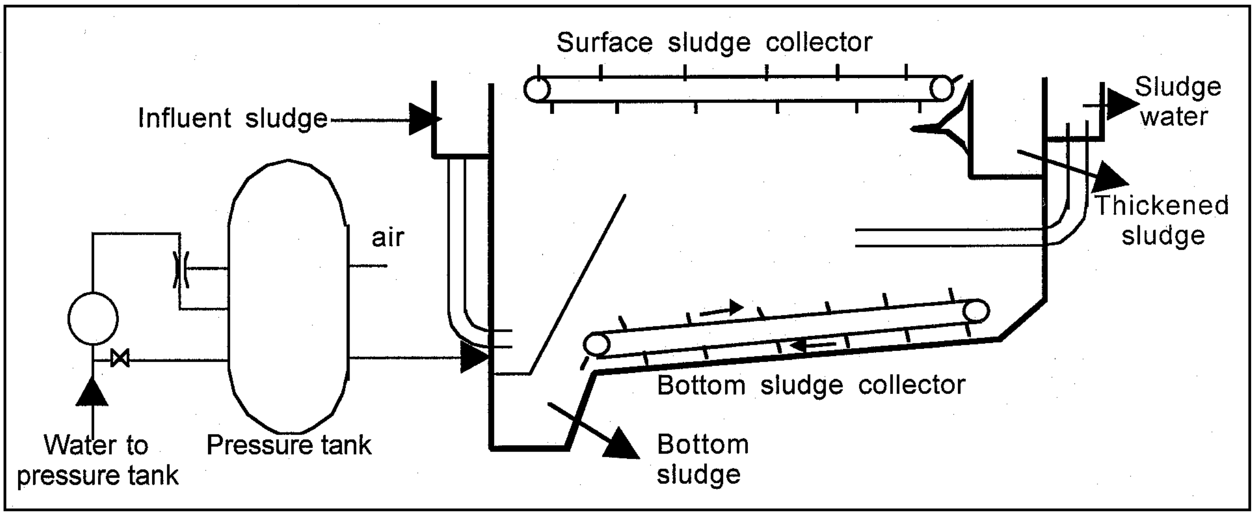


Figure 16.9. Flotation thickening of sludge.

to evaporate the residual water content. The residual ash has to be disposed by dumping on land or at sea. This ash is also useful in sludge conditioning and as a filter-aid in de-watering.

Sludge incineration, particularly for large cities, has the advantage of converting organic solids into ash, thereby reducing the weight and volume of solids. Alum, iron and lime sludge can be incinerated. Final disposal of the digested sludge can be on land or by de-watering and incineration. In large systems, sludge thickening or de-watering prior to lagooning or incineration should be considered.

Land spreading or burial in landfill may dispose of the de-watered cake, or it can be subjected to heat drying or incineration. Incineration-ash can be used as a road sub-grade stabiliser or to make concrete blocks or brick. Another alternative is to dispose of it by using it as a soil conditioner or in landfill.

Solids removed from lagoons are usually not suited to heat drying or incineration, and are thus taken directly to land spreading or landfill disposal. Sludge destined for drying beds may be thickened and is thus not suitable to heat drying or incineration. It is usually disposed of on land or in landfill. The sludge that is to be de-watered through vacuum filtration, centrifuging (solid bowl), filter pressing or horizontal-belt filtration may be disposed of by drying, incineration, land spreading or in landfill. In de-watering and drying there may be some enhancement of biological sludge containing alum.

Final destination of sludge

Agricultural use of sludge is often regarded as the best alternative if the pollutants in the sludge are below limiting and guidance values. However, lack of acceptance from food industry and consumers may make it difficult to use sludge in agriculture. Many attempts have been made to find agreements for agricultural use of sludge. A national consultation group has been formed in Sweden to stimulate the use of sludge in agriculture and reach consensus on different actions and voluntary precautionary measures to prevent unwanted chemicals and substances in the sewer net. Although this group has indeed reached some agreements, the future of agricultural use of sludge is uncertain and under debate. There is an ongoing discussion concerning the availability of phosphate to crops in the form of precipitated iron or aluminium phosphates.

Landfill use of sludge will probably be highly restricted in the future. In several countries (such as Germany) only sludge with a low content of organics is allowed for land deposit. Land deposit of sludge can contribute to the diffusive spread of such materials as phosphorus and metals due to leakage, and to the emission of materials such as methane gas (a greenhouse gas), methylated metal compounds (such as methylated mercury) and odours. In order to reduce landfill deposit of sludge Sweden has introduced a fee. The use of sludge for land building, restoration of land and use for covering of landfills may also be limited in the future due to lack of land and possible negative environmental effects.

Sludge incineration has attracted increased interest as a method for the final handling of sewage sludge. This technology has not as yet been practised to any significant extent in Sweden. The investment and operational costs are rather high and obtaining a permit to build an incineration plant may also pose a problem. Therefore, attention has been directed towards co-incineration in existing incineration plants. Co-incineration may be applied in an incineration plant for municipal solid wastes, biofuels (wood, peat etc.) or coal, or in plants producing building materials (cement, brick etc.) at high temperatures. Some experiments have been done involving

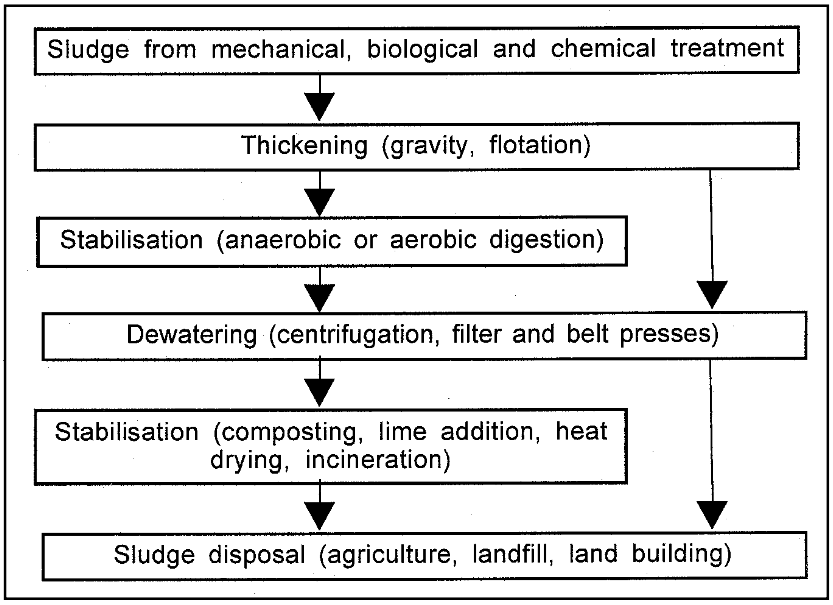


Figure 16.10. Different options for sludge handling.

co-incineration of sewage sludge, mainly together with municipal solid wastes. The experiments have in general been positive although some problems have arisen related to the sintering of ashes and increased concentrations of sulphur dioxide, nitrogen oxides and volatile metals (mercury and cadmium) in the flue gases. The need of possible complementary investments in flue gas treatment or in the handling of ashes when practising co-incineration needs to be studied further. It has also been shown that the recovery of phosphorus from ashes involves many technical problems.

During the past few years there has been increased interest in extracting products from sludge. Two main commercial systems are under consideration in Sweden, the KREPRO and Cambi processes. Both of these methods have their roots in old process technologies (such as the Zimpro and Porteous processes; US EPA, 1979). Different substances, such as acids in the KREPRO process, are dissolved from the sludge by heat and pressure treatment. The main objectives of the old technologies were to decrease the amount of sludge and condition it before de-watering, while the liquid stream with various dissolved substances was mainly regarded as a problem. The Cambi and KREPRO processes aim instead to regard the dissolved substances as resources, such as improved methane production in the digester (Cambi) or the reuse of precipitation chemicals, the production of a fertiliser and separate removal of heavy metals in a small stream (KREPRO).

System design of sludge handling

The different methods for sludge volume reduction, sludge stabilisation and final destination for sludge may be combined in different ways. Different options are illustrated in Figure 16.10.

17.

Industry and water use

Rein Munter

There is an increasing recognition in industry that the reduction of water consumption and wastewater discharge is a necessary component of good environmental practice. In reality, there has been no tradition of reducing water consumption, and existing plants were not designed with water conservation in mind. Furthermore, accounting systems are designed to determine the cost of producing chemicals and raw materials and cannot easily be adapted to measuring the true cost of using water. It is very unlikely that complete water management schemes will be introduced for existing plants, although partial schemes may be attractive. Major schemes will be limited by the cost of installing long pipe runs, storage tanks and pumps, but good payback may be achieved if product or raw materials can be recovered for recycling or for sale. The need to build new effluent treatment facilities, together with further restrictions on the discharge of specific pollutants, may justify expenditure to reduce water consumption. If existing plants are to maintain their licence to operate in the next century, the case for investment in water management schemes will inevitably become more and more attractive.

Water value and quality

As a unique natural resource, the real value of water has been underestimated in many countries. The price of water has been kept artificially low, which has not stimulated people or industries to save on it. At the same time, there is a growing awareness of the impact of pollution on water quality and a demand to tighten water quality standards. Due to modern-day sophisticated analytical methods and equipment, several rather new contaminants in drinking water have been discovered, even if in very small concentrations. The public is more aware than ever before and is demanding safe drinking water.

Water quality is not synonymous with water pollution and, similarly, water quality management should not be equated with water pollution control only. Water quality management deals with all aspects of water quality problems relating to the many beneficial uses of water, while water pollution control usually connotes adequate treatment and disposal of wastewater.

For new industrial plants, it is relatively easy to incorporate water management philosophy at the design stage, given that the technical uncertainties can be overcome. The incremental cost of modifying the process may be compared with savings in long-term operational and capital costs associated with an effluent treatment facility, as well as with an assessment of the ability of the plant to meet future environmental legislation.

For existing plants, the potential benefits of reducing water consumption may be offset by the costs associated with the installation of storage tanks and long pipe runs. Modifications to plant pipe work and supporting steelwork may be expensive and difficult to manage and there is a natural reluctance to interfere with existing plant battery units. In these circumstances, and in the absence of clear information about the direction and timing of future environmental legislation, the appeal of a stand-alone effluent treatment plant is obvious.

Water consumption

Water uses consist of intake, on-site and in-stream flow uses. Intake uses include water for domestic, agricultural and industrial purposes and uses that actually remove water from the source. On-site uses consist primarily of water consumed by swamps, wetlands, evaporation from water bodies, natural vegetation and unirrigated crops and wildlife. Finally, flow uses include water for estuaries, navigation, wastewater dilution, hydroelectric power production, and fish, wildlife and recreation purposes.

Intake water can be measured in two ways: by the amount withdrawn and the amount consumed. Projected uses for the world are presented in Figure 17.1 and real consumption in some countries in 1990 in Table 17.1.

Worldwide water consumption at the present time is estimated at 4 340 km^3/year (surface and groundwater together). More than half of this water is used in agriculture, about a quarter in industry and a quarter for use in municipalities and rural areas. The worldwide consumption however

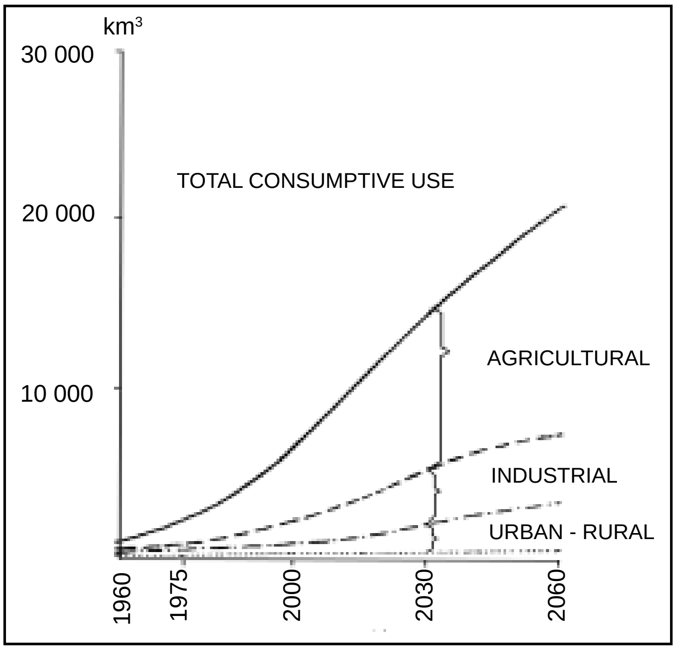


Figure 17.1. Projected uses of water in the world (Bond & Straub, 1974).

varies considerably between regions, depending on the intensity of agriculture in relation to the humidity of the climate, on the industrialisation level and on the type of industry prevailing. In the Baltic basin industrial water use dominates the consumption. This is especially true for the regions where paper and pulp industry, as well as metallurgic and other water-intensive industry, are important. Note the high percentages for Finland and Estonia in Table 17.1. Similar figures are valid for Sweden, whereas in Poland, e.g., where agriculture is important and water not as plentiful as in the northern part of the basin, industrial water use is less dominating. The figures given for USA are representative for a region with highly developed industry but with intensive agriculture under dry conditions, whereas China represents an agriculturally dominated region with less developed industry.

Water withdrawn is water diverted from its natural course for a beneficial use. Water consumed is water that is incorporated into a product or lost to the atmosphere by evapotranspiration and thus not reusable. Consumptive use is the real indicator of water demand, inasmuch as most non-consumptive water can be, or in fact is, reused. It should be noted that water reuse is not a new concept.

The investigation and management of water resources systems for water quality must include consideration and evaluation of:

- physical, chemical and biological composition of headwaters and significant groundwater discharges
- water quantity and quality requirements for all existing and potential water uses
- the manner of water withdrawal and its effect on water quality and quantity
- the existing and future water and wastewater treatment technology used to alter water quality
- the wastewater outfall configuration and effluent mixing
- the eutrophication status of the receiving waters
- the ecological changes that might be caused by wastewater discharges
- the potential effects of the discharge of heated waters

Industrial water supply

Because of the diverse nature of industrial processes, water quality requirements are industry- dependent. In addition, water quality requirements may vary for various industrial processes within a single plant and for the same process in different plants. Quality considerations are similar, depending on cost of treatment, plant age, plant operating practices and quality and quantity of the available supply.

Because of the relative low cost of water treatment as compared to the cost of total production and marketing, industries can treat almost any water to their own specifications. However, quality characteristics that exceed those given in Table 17.2 would probably not be acceptable to most industries.

Different industries view water, and hence water management, in different ways. At one extreme is the oil and refining industry, for which water is solely a utility and very little is used for process purposes. At the other extreme is the pulp and paper industry, for which water is an integral part of the process from the very introduction of the raw materials and continuing historically in copious quantities at every stage. For this industrial sec-

Table 17.1. Water consumption distribution (in %) in the world (Antilla et al., 1996)

Branch of economy	USA	China	Zambia	Finland	Estonia
Agriculture	42	87	26	3	9
Industry	46	7	11	85	84
Municipality	12	6	63	12	7

Table 17.2. Summary of specific quality characteristics of surface waters that have been used as sources for industrial water supplies (Krenkel & Novotny, 1980)

Characteristics (mg/l)	**Boiler Makeup Water**	**Textile Industry**	**Pulp and Paper Industry**	**Chemical Industry**	**Petroleum Industry**
SiO_2	150	-	50	-	85
Al	3	-	-	-	-
Fe	80	0.3	2.6	10	15
Mn	10	1.0	-	2	-
Cu	-	0.5	-	-	-
Ca	-	-	-	250	220
Mg	-	-	-	100	85
Na + K	-	-	-	-	230
NH_3	-	-	-	-	40
HCO_3	600	-	-	600	480
SO_4	1 400	-	-	850	900
Cl	19 000	-	200	500	1 600
SS	15 000	1 000	-	10 000	5 000
Hardness ($CaCO_3$)	5 000	120	475	1 000	900
Alkalinity ($CaCO_3$)	500	-	-	500	500
pH	-	6-8	4.6-9.4	5.5-9.0	6.0-9.0
Colour, units	1 200	-	360	500	25
COD	100-500	-	-	-	-
Temperature (°C)	50	-	35	-	-

tor, water management refers only to process water use and excludes utility use.

The chemical industry, for its part, encompasses both extremes. Water is both a utility and a process fluid and the industry regards water management as the integration of the two duties.

Use of water in the chemical industry

When considering water use, the chemical industry is best regarded as a collection of dissimilar but related industries. The production units involved vary from the processing of heavy organic chemicals and oil derivatives through the production of basic inorganic chemicals such as alkalis and acids and of highly complex speciality chemicals to the electrolysis of sodium chloride brine to produce chlorine. Even within specific related areas, the processes may be very different. In the production of plastics, it is essential for some processes that water is excluded if the product is to have the desired properties; for other processes, polymerisation is carried out in emulsions in water and the quality of the water is critical for product quality. Plants producing the same product may use different routes, depending on the location of the plant, the availability of raw materials of the required quality, other production processes on the same site, transport and safety considerations, the age of the plant and environmental discharge permits.

Water can enter the process with the raw materials, be added or removed at different stages in the process or be added to the final product to suit specific end uses or customer requirements. It is not uncommon to purchase speciality chemical formulations that contain in excess of 90 % water, while acids and alkalis may be sold with 50 to 70 % water content.

It is common to find several different production processes on a single site. This is due to the integrated nature of the processes and considerations of the cost and safety of transporting potentially hazardous materials between sites. Thus water use on any particular site varies widely – some plants may use water as a utility only, while other plants may use water throughout the process. For this reason, while there are general rules that must be followed, strategies for water management are unique to production sites. For the chemical industry, therefore, it is essential to concentrate on generic solutions. This means looking at the unit operations which may find application for a range of uses, i.e. looking for the building blocks that can be used to achieve a water management scheme which is economic and, above all, robust in operation.

Chemical production sites have traditionally been located where there is a plentiful supply of cheap water and where the discharge of water has been relatively unrestricted. Environmental, safety and marketing pressures are now changing this picture and this, in turn, demands more consideration of the way water is used and discharged. Coupled with the rising costs of water and an increasing awareness of the impact of water on production and product quality, the opportunities offered by water management are drawing more interest. The different ways in which water is used are described in more detail in Table 17.3.

Industrial municipal wastes

Differences between industrial and municipal wastes

The number of contaminants in industrial waste can run in a scale from zero to about 100 000 parts per million. Industrial waste varies temporally and, in the normal course of operation, is unpredictable. The strengths and volumes of municipal sewage, on the other hand, are well established and occur within the rather narrow limits of 100 to 1 000 parts per million for the contaminants that are generally measured in volumes of 50 to 150 gallons per person per day. If we take the population equivalent (PE) of domestic sewage by BOD as a unit, then the corresponding PE values for industrial effluents are in the range of about 5-1 500 depending on the branch of industry.

Industrial waste deoxygenates at rates that vary from negative values to about 5 times the rates at which normal domestic sewage deoxygenates. Some industrial wastes have no organic matter and thus no oxygenation rate or oxygen demand. Domestic sewage deoxygenates at a quite constant rate, seldom outside the range 0.07 to 0.20, and is usually discharged independently of the time of day or week.

And finally, a municipality views wastewater treatment as a service to the community, while industry view wastewater treatment as an imposed necessity.

A typical treatment scheme for municipal wastewater purification for the production of industrial process water is shown in Figure 17.2.

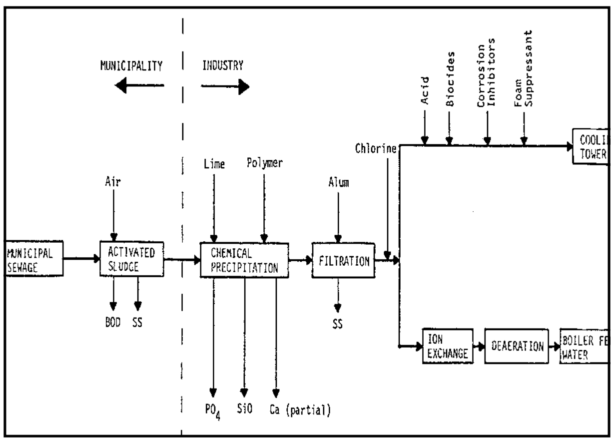


Figure 17.2. Cross-flow plate separator (from Eckenfelder, 1989).

Table 17.3. Different water uses in production processes and utilities in industry

Production processes	Utilities
In raw materials	Cooling systems
- brines	- once-through
- acids and alkalis	- open evaporative
Product washing	- closed systems
- filters	Steam raising
- centrifuges	- fossil fuel boilers
- final product	- pressure boilers
Product formulation	Water purification plant
Reaction medium	- process use
Solvent	- boiler use
	Condensate recovery
Cleaning and housekeeping	Other duties
Cleaning of batch vessels	Fire fighting

Joint treatment of municipal and industrial effluent

Combined municipal and industrial waste treatment is the most desirable arrangement and at the same time it is the most difficult to achieve. Since most of the sewage plants use some form of biological treatment, it is essential for a satisfactory operation that extremes in industrial waste characteristics can be avoided and the waste be:

- as homogeneous in composition and uniform in flow rate as possible;
- free of excessive acidity or alkalinity and not high in chemicals which precipitate on neutralisation or oxidation;
- practically free of antiseptic compounds and toxic trace metals;
- low in potential sources of high BOD, such as carbohydrates, sugar, starch, and cellulose; and
- low in oil and grease content.

Most industrial wastes contain usually only a few harmful compounds and the removal of these leaves the remaining wastes amenable to treatment along with domestic sewage. Three steps are now necessary to complete the technical solution to the problem (Nemerow & Dasgupta, 1991):

- to ascertain the capacity of the various existing treatment-plant units;
- to reduce the incoming waste load to a minimum by proper local pre-treatment of industrial wastes at each factory, and
- to re-evaluate the present plant and suggest the additions required to handle the future waste load effectively.

18.

Industrial wastewater characteristics

Rein Munter

The purposes of pollution control endeavours should be (1) to protect the assimilative capacity of surface waters; (2) to protect shellfish, finfish and wildlife; (3) to preserve or restore the aesthetic and recreational value of surface waters; (4) to protect humans from adverse water quality conditions.

The selection and design of treatment facilities is based on a study of

- the physical, chemical and biological characteristics of the wastewater
- the quality that must be maintained in the environment to which the wastewater is to be discharged or for the reuse of the wastewater
- the applicable environmental standards or discharge requirements that must be met

The main chemical characteristics of wastewater are divided into two classes, inorganic and organic. Because of their special importance, *priority pollutants* and *volatile organic compounds (VOCs)* are usually considered separately.

Physical characteristics

The principal physical characteristics of wastewater are its *solids content, colour, odour* and *temperature*.

The *total solids* in a wastewater consist of the insoluble or suspended solids and the soluble compounds dissolved in water. The *suspended solids* content is found by drying and weighing the residue removed by the filtering of the sample. When this residue is ignited the *volatile solids* are burned off. Volatile solids are presumed to be organic matter, although some organic matter will not burn and some inorganic salts break down at high temperatures. The organic matter consists mainly of proteins, carbohydrates and fats.

Between 40 and 65 % of the solids in an average wastewater are *suspended*. *Settleable solids*, expressed as millilitres per litre, are those that can be removed by sedimentation. Usually about 60 % of the suspended solids in a municipal wastewater are settleable. Solids may be classified in another way as well: those that are volatilised at a high temperature (600 °C) and those that are not. The former are known as *volatile solids*, the latter as *fixed solids*. Usually, volatile solids are organic.

Colour is a qualitative characteristic that can be used to assess the general condition of wastewater. Wastewater that is light brown in colour is less than 6 h old, while a light-to- medium grey colour is characteristic of wastewaters that have undergone some degree of decomposition or that have been in the collection system for some time. Lastly, if the colour is dark grey or black, the wastewater is typically septic, having undergone extensive bacterial decomposition under anaerobic conditions. The blackening of wastewater is often due to the formation of various sulphides, particularly, ferrous sulphide. This results when hydrogen sulphide produced under anaerobic conditions combines with divalent metal, such as iron, which may be present. Colour is measured by comparison with standards.

The determination of *odour* has become increasingly important, as the general public has become more concerned with the proper operation of wastewater treatment facilities. The odour of fresh wastewater is usually not offensive, but a variety of odorous compounds are released when wastewater is decomposed biologically under anaerobic conditions. The principal odorous compound is hydrogen sulphide (the smell of rotten eggs). Other compounds, such as indol, skatol, cadaverin and mercaptan, formed under anaerobic conditions or present in the effluents of pulp and paper mills (hydrogen sulphide, mercaptan, dimethylsulphide etc.), may also cause a rather offensive odour. Odour is measured by successive dilutions of the sample with odour-free water until the odour is no longer detectable.

The *temperature* of wastewater is commonly higher than that of the water supply because warm municipal water has been added. The measurement of temperature is important because most wastewater treatment schemes include biological processes that are temperature dependent. The temperature of wastewater will vary from season to season and also with geographic location. In cold regions the temperature will vary from about 7 to 18 °C, while in warmer regions the temperatures vary from 13 to 24 °C.

Chemical characteristics

Inorganic chemicals

The principal chemical tests include free ammonia, organic nitrogen, nitrites, nitrates, organic phosphorus and inorganic phosphorus. *Nitrogen* and *phosphorus* are important because these two nutrients are responsible for the growth of aquatic plants.

Other tests, such as chloride, sulphate, pH and alkalinity, are performed to assess the suitability of reusing treated wastewater and in controlling the various treatment processes.

Trace elements, which include some heavy metals, are not determined routinely, but trace elements may be a factor in the biological treatment of wastewater. All living organisms require varying amounts of some trace elements, such as iron, copper, zinc and cobalt, for proper growth. Heavy metals can also produce toxic effects; therefore, determination of the amounts of heavy metals is especially important where the further use of treated effluent or sludge is to be evaluated. Many of the metals are also classified as *priority pollutants* (see below).

Measurements of gases, such as hydrogen sulphide, oxygen, methane and carbon dioxide, are made to help the system to operate. The presence of hydrogen sulphide needs to be determined not only because it is an odorous gas but also because it can affect the maintenance of long sewers on flat slopes, since it can cause corrosion. Measurements of dissolved oxygen are made in order to monitor and control aerobic biological treatment processes. Methane and carbon dioxide measurements are used in connection with the operation of anaerobic digesters.

Organic chemicals

Over the years, a number of different tests have been developed to determine the organic content of wastewaters. In general, the tests may be divided into those used to measure gross concentrations of organic matter greater than about 1 mg/l and those used to measure trace concentrations in the range of 10^{-12} to 10^{-0} mg/l. Laboratory methods commonly used today to measure gross amounts of organic matter (greater than 1 mg/l) in wastewater include (1) biochemical oxygen demand (BOD), (2) chemical oxygen demand (COD) and (3) total organic carbon (TOC). Trace organics in the range of 10^{-12} to 10^{-0} mg/l are determined using instrumental methods including gas chromatography and mass spectroscopy. Specific organic compounds are determined to assess the presence of *priority pollutants*.

The BOD, COD and TOC tests are gross measures of organic content and as such do not reflect the response of the wastewater to various types of biological treatment technologies. It is therefore desirable to divide the wastewater into several categories, as shown in Figure 18.1.

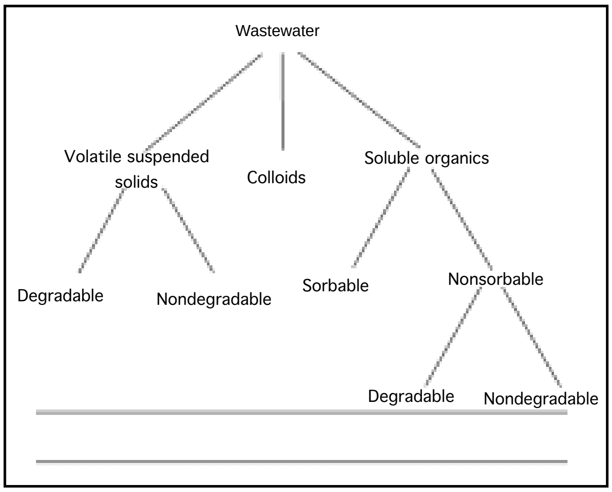


Figure 18.1. Partition of organic constituents of a wastewater (Eckenfelder, 1989).

Volatile Organic Carbons (VOC)

Volatile organic compounds (VOC) such as benzene, toluene, xylenes, dichloromethane, trichloroethane and trichloroethylene, are common soil pollutants in industrialised and commercialised areas. One of the more common sources of these contaminants is leaking underground storage tanks. Improperly discarded solvents and landfills, built before the introduction of current stringent regulations, are also significant sources of soil VOCs.

In Table 18.1 a list of typical inorganic and organic substances present in industrial effluents is presented.

Heavy metals and inorganic species

Heavy metal discharges

Several industries discharges heavy metals (Table 18.2).

It can be seen that of all of the heavy metals *chromium* is the most widely used and discharged to the environment from different sources. However, it is not the metal that is most dangerous to living organisms. Much more toxic are *cadmium*, *lead* and *mercury*.

These have a tremendous affinity for sulphur and disrupt enzyme function by forming bonds with sulphur groups in enzymes. Protein carboxylic acid ($-CO_2H$) and amino ($-NH_2$) groups are also chemically bound by heavy metals. Cadmium, copper, lead and mercury ions bind to cell membranes, hindering transport processes through the cell wall. Heavy metals may also precipitate phosphate bio-compounds or catalyse their decomposition.

Table 18.1. Substances Present in Industrial Effluents (Bond & Straub, 1974)

Substances	Present in Wastewaters from:
Acetic acid	Acetate rayon, beet root manufact.
Acids	Chem. manufact.,mines, textiles manufact.
Alkalies	Cotton and straw kiering, wool scouring
Ammonia	Gas and coke and chem. manufacture
Arsenic	Sheep dipping
Cadmium	Plating
Chromium	Plating, chrome tanning, alum anodizing
Citric acid	Soft drinks and citrus fruit processing
Copper	Copper plating, copper pickling
Cyanides	Gas manufacture, plating, metal cleaning
Fats, oils, grease	Wool scouring, laundries, textile industry
Fluorides	Scrubbing of flue gases, glass etching
Formaldehyde	Synthetic resins and penicillin manufact.
Free chlorine	Laundries, paper mills, textile bleaching
Hydrocarbons	Petrochemical and rubber factories
Mercaptans	Oil refining, pulp mills
Nickel	Plating
Nitrocompounds	Explosives and chemical works
Organic acids	Distilleries and fermentation plants
Phenols	Gas and coke manufact., chem. plants
Starch	Food processing, textile industries
Sugars	Dairies, breweries, sweet industry
Sulfides	Textile industry, tanneries, gas manufact.
Sulfites	Pulp processing, viscose film manufact.
Tannic acid	Tanning, sawmills
Tartaric acid	Dyeing, wine, leather, chem. manufacture
Zinc	Galvanizing zinc plating, rubber process.

The pollutant *cadmium* in water may arise from industrial discharges and mining wastes. Cadmium is widely used in metal plating. Chemically, cadmium is very similar to zinc, and these two metals frequently undergo geochemical processes together. Both metals are found in water in the +2 oxidation state. The effects of acute cadmium poisoning in humans are very serious. Among them are high blood pressure, kidney damage, destruction of testicular tissue, and destruction of red blood cells. Cadmium may replace zinc in some enzymes, thereby altering the stereo-structure of the enzyme and impairing its catalytic activity.

Cadmium and zinc are common water and sediment pollutants in harbours surrounded by industrial facilities. Concentrations of more than 100 ppm dry weight sediment have been found in harbour sediments.

Inorganic *lead* arising from a number of industrial and mining sources occurs in water in the +2 oxidation state. Lead from leaded gasoline used to be a major source of atmospheric and terrestrial lead, much of which eventually enters natural water systems. Despite greatly increased total use of lead by industry, evidence from hair samples and other sources indicates that body burdens of this toxic metal have decreased during recent decades. This may be the result of less lead used in plumbing and other products that commonly come in contact with food or drink. Acute lead poisoning in humans causes severe dysfunction in the kidneys, reproductive system, liver, and the brain and nervous system.

Because of its toxicity, its mobilisation as methylated forms by anaerobic bacteria, and other pollution factors, *mercury* generates a great deal of concern as a heavy-metal pollutant. Mercury is found as a trace component of many minerals, with continental rocks containing an average of around 80 ppb, or slightly less, of this element. Cinnabar, red mercuric sulphide, is the chief commercial mercury ore. Metallic mercury is used as an electrode in the electrolytic generation of chlorine gas, in laboratory vacuum apparatuses and in other applications. Organic mercury compounds used to be widely applied as pesticides, particularly fungicides. Mercury enters the environment from a large number of miscellaneous sources related to human use of the element. These include discarded laboratory chemicals, batteries, broken thermometers, lawn fungicides, amalgam tooth fillings and pharmaceutical products. Sewage effluent sometimes contains up to 10 times the level of mercury found in typical natural waters.

The toxicity of mercury was tragically illustrated in the Minamata Bay area of Japan during the period of 1953-1960. A total of 111 cases of mercury poi-

Table 18.2. Heavy Metals Found in Major Industries (Bond & Straub, 1974)

Industry	Al	As	Cd	Cr	Cu	Hg	Pb	Ni	Zn
Pulp & paper mills				x	x	x	x	x	x
Organic chem.	x	x	x	x		x	x		x
Alcalies, Chlorine		x	x	x		x	x		x
Fertilizers	x	x	x	x	x	x	x	x	x
Petroleum refin.	x	x	x	x	x		x	x	x
Steelworks		x	x	x	x	x	x	x	x
Aircraft plating, finishing	x		x	x	x	x		x	
Flat glass, cement				x					
Textile mills				x					
Tanning				x					
Power plants				x					

soning and 43 deaths were reported among people who had consumed seafood from the contaminated bay. Among the toxicological effects of mercury were neurological damage, including irritability, paralysis, blindness, insanity, chromosome breakage and birth defects. The milder symptoms of mercury poisoning, such as depression and irritability, have a psychopathological character and may escape detection. The unexpectedly high concentrations of mercury found in water and in fish tissues result from the formation of soluble monomethylmercury ion, CH_3Hg^+, and volatile dimethylmercury, $(CH_3)_2Hg$, by anaerobic bacteria in sediments. Mercury from these compounds becomes concentrated in fish lipid (fat) tissue and the concentration factor from water to fish may exceed 10^3.

Cyanide

Cyanide ion, CN^-, is probably the most important of the various inorganic species in wastewater.

Cyanide, a deadly poisonous substance, exists in water as HCN, a weak acid with the dissociation constant K_a of $6{\cdot}10^{-10}$. The cyanide ion has a strong affinity for many metal ions, forming relatively less-toxic ferro-cyanide, $Fe(CN)_6^{4-}$, with iron (II), for example. Volatile HCN is very toxic and has been used in gas chamber executions in the United States (Manahan, 1994). Cyanide is widely used in industry, especially for metal cleaning and electroplating. It is also one of the main gas and coke scrubber effluent pollutants from gas works and coke ovens. Cyanide is widely used in certain mineral-processing operations.

Ammonia

Ammonia is the initial product of the decay of nitrogenous organic wastes, and its presence frequently indicates the presence of such wastes. It is a normal constituent of some sources of groundwater and is sometimes added to drinking water to remove the taste and odour of free chlorine. Since the pK_a of the ammonium ion, NH_4^+, is 9.26, most ammonia in water is present as NH_4^+ rather than NH_3.

Other inorganic pollutants

Hydrogen sulphide, H_2S, is a product of the anaerobic decay of organic matter containing sulphur. It is also produced in the anaerobic reduction of sulphate by microorganisms and is developed as a gaseous pollutant from geothermal waters. Wastes from chemical plants, paper mills, textile mills and tanneries may also contain H_2S.

Nitrite ion, NO^{2-}, occurs in water as an intermediate oxidation state of nitrogen. Nitrite is added to some industrial processes to inhibit corrosion; it is rarely found in drinking water at levels over 0.1 mg/l.

Sulphite ion, SO_3^{2-}, is found in some industrial wastewaters. Sodium sulphite is commonly added to boiler feed-waters as an oxygen scavenger:

$$2SO_3^{2-} + O_2 \rightarrow 2\,SO_4^{2-} \qquad (1)$$

Organic pollutants

Effluent from industrial sources contains a wide variety of pollutants, including organic pollutants. Primary and secondary sewage treatment processes remove some of these pollutants, particularly oxygen-demanding substances, oil, grease and solids. Others, such as refractory (degradation-resistant) organics (organochlorides, nitro compounds etc.) and salts and heavy metals, are not efficiently removed.

Soaps, detergents and associated chemicals are potential sources of *organic pollutants*. Most of the environmental problems currently attributed to de-

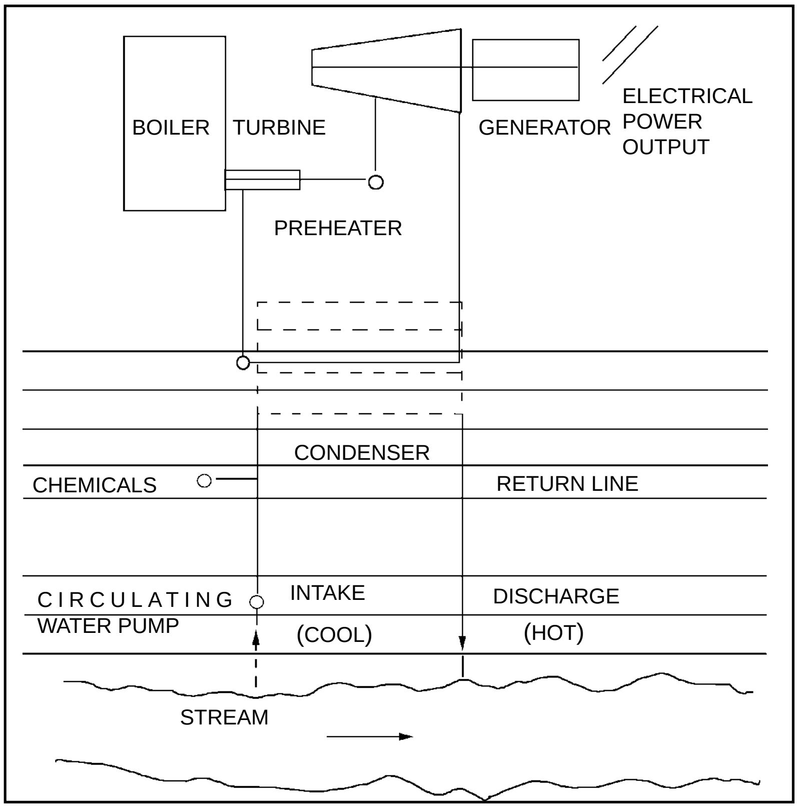


Figure 18.2. Schematic diagram of once-through cooling and steam electrical generation (Krenkel & Novotny, 1980).

Priority pollutants

The USEPA (Keith & Telliard, 1979) has defined 129 toxic chemicals as priority pollutants:

31 are purgeable organics (benzene, toluene, carbon tetrachloride, chlorobenzene, chloroform, bromoform, vinyl chloride etc.); 46 are base/neutral extractable organic compounds (nitrobenzene, naphthalene, fluorine, chry-sene, pyrene, anthracene, acenaphthene, dinitrotoluene etc.); 11 are acid extractable organic compounds (phenol, 2-and 4-nitrophenols, pentachlorophenol, 2-chlorophenol, 2,4-dimethyl-phenol etc.); 26 are pesticides/PCB's (aldrin, dieldrin, chlordane, toxaphene, heptachlor etc.); 13 are metals (antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, thallium etc.);

To this list are also included total cyanides, total phenols and asbestos

tergents do not arise from the surface-active agents, which basically improve the wetting qualities of water. The greatest concern among environmental pollutants has been caused by polyphosphates added to complex calcium, functioning as a builder.

Bio-refractory organics are poorly biodegradable substances, prominent among which are aromatic or chlorinated hydrocarbons (benzene, bornyl alcohol, bromobenzene, chloroform, camphor, dinitrotoluene, nitrobenzene, styrene etc.). Many of these compounds have also been found in drinking water. Water contaminated with these compounds must be treated using physical and chemical methods, including air stripping, solvent extraction, ozonation and carbon adsorption.

First discovered as environmental pollutants in 1966 (Manahan, 1994), *polychlorinated biphenyls* (PCB compounds) have been found throughout the world in water, sediments and bird and fish tissue. They are made by substituting between 1 and 10 Cl atoms onto the biphenyl aromatic structure. This substitution can produce 209 different compounds.

PCBs have very high chemical, thermal and biological stability, low vapour pressure and high dielectric constants. These properties have made PCBs attractive as coolant-insulation fluids in transformers and capacitors, in the impregnation of cotton and asbestos, as plasticizers and as additives to some epoxy paints.

Thermal pollution

Considerable time has elapsed since the scientific community and regulatory agencies officially recognised that the addition of large quantities of heat to a recipient possesses the potential of causing ecological harm.

The really significant heat loads result from the discharge of condenser cooling water from the ever-increasing number of steam electrical generating plants (Figure 18.2) and equivalent-sized nuclear power reactors. Large numbers of power plants currently require approximately 50 % more cooling water for a given temperature rise than that required of fossil-fuelled plants of an equal size.

The degree of thermal pollution depends on thermal efficiency, which is determined by the amount of heat rejected into the cooling water. Thermodynamically, heat should be added at the highest possible temperature and rejected at the lowest possible temperature if the greatest amount of effect is to be gained and the best thermal efficiency realised.

The current and generally accepted maximum operating conditions for conventional thermal stations are about 500 °C and 24 MPa, with a corresponding heat rate of 2.5 kWh, 1.0 kWh resulting in power production and 1.5 kWh being wasted. Plants have been designed for 680 °C and 34 MPa; however, metallurgical problems have kept operating conditions at lower levels.

Nuclear power plants operate at temperatures of from 250 to 300 °C and pressures of up to 7 MPa, resulting in a heat rate of approximately 3.1 kWh. Thus, for nuclear plants, 1.0 kWh may be used for useful production whereas 2.1 kWh is wasted.

Most steam-powered electrical generating plants are operated at varying load factors, and, consequently, the heated discharges demonstrate wide variation with time. Thus, the biota is not only subjected to increased or decreased temperature, but also to a sudden, or "shock," temperature change.

The effects of temperature on the stream self-purification process in rivers are demonstrated in Figure 18.3, which shows the variation of the rate constants k_1 (deoxygenation) and k_2 (reaeration) with respect to temperature. Examination of this relationship demonstrates that an increase in temperature causes a considerable increase in k_1. While k_2 also increases with increasing temperature, this is counteracted by the combination of lesser dissolved-oxygen content and greater rate of change of k_1 with temperature. The overall effect of the impoundment on the rate of oxygen recovery is demonstrated by the lower curve, which depicts the reaeration rate constant under existing, impounded conditions. Note that, while k_1 at a given temperature is unchanged, the value of k_2 at any temperature is significantly reduced.

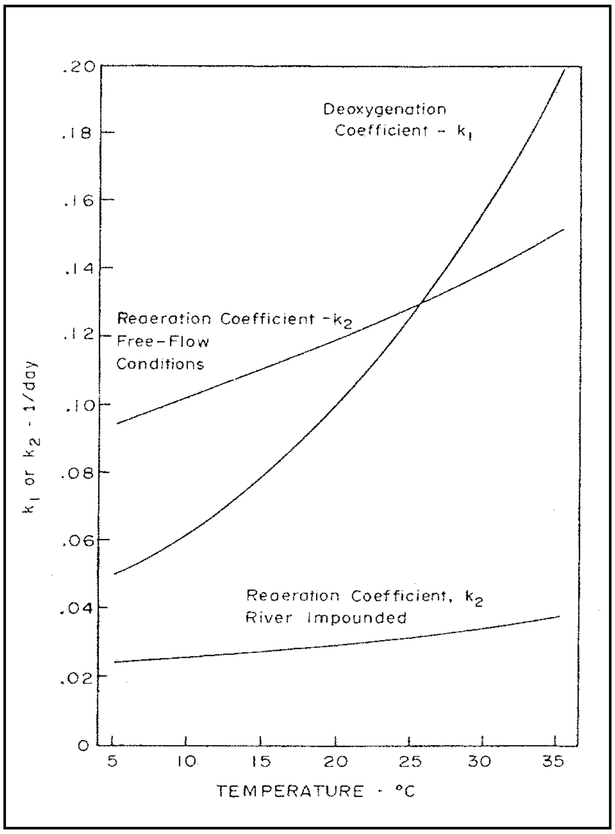


Figure 18.3. Variation of k_1 and k_2 with temperature (Krenkel & Novotny, 1980).

Increased temperature will cause remarkable reduction in the self-purification capacity of a water body. The addition of heated water to the receiving water can be considered equivalent to the addition of sewage or other organic waste material, since both pollutants may cause a reduction in the oxygen resources of the receiving waters.

In most cases, the increases in temperature are small and probably do not cause biological harm outside the mixing zone. In fact, little data exists to support the claims of extensive heat damage from power plants on the biota. Furthermore, besides entrainment problems, few substantiated fish kills have been reported as a result of power plant operations.

The possible effects of heat on fish may be summarised here:

- a Direct death from excessive temperature rise beyond the thermal death point.
- b Indirect death due to
  - less oxygen available
  - disruption of the food supply
  - decreased resistance to toxic materials
  - decreased resistance to disease
  - predation from more tolerant species
  - synergism with toxic substances
- c Increase in respiration and growth
- d Competitive replacement by more tolerant species
- e Sub-lethal effects

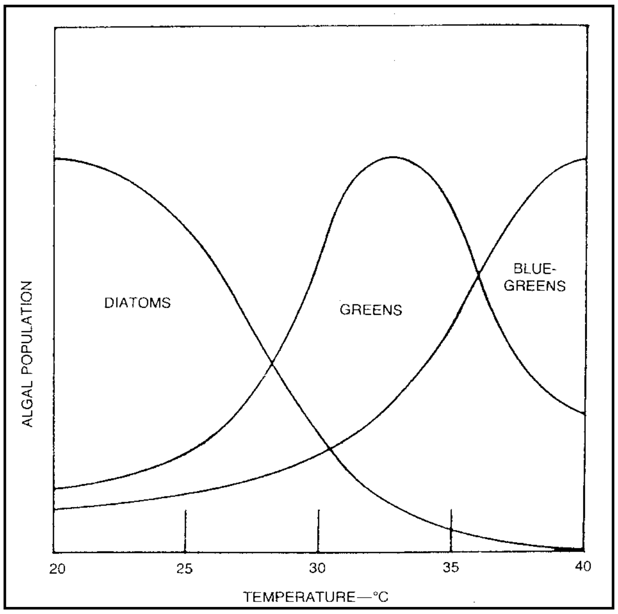


Figure 18.4. Algae population shifts with change in temperature (Krenkel & Novotny, 1980).

While each of these factors could be important at a specific location, the temperature rises typical of most power plants are usually not high enough to be of concern. It is interesting to note that field research studies on the effects of heat on the environment have been hindered, both in the United States and Europe, because of the lack of sufficient temperature elevations below existing power plants.

Figure 18.4 shows that increased temperatures cause the growth of undesirable algae. There are other negative results as well, e.g. *Escherichia coli* multiply much more rapidly at elevated temperatures.

Radioactivity and radioactive pollution

The massive production of *radionuclides (radioactive isotopes*) from weapons and nuclear reactors since World War II has been accompanied by an increasing concern about the effects of radioactivity upon health and the environment. Radionuclides are produced as fission products of heavy nuclei of elements such as uranium or plutonium. They are also produced by the reaction of neutrons with stable nuclei (Manahan, 1994):

$$^{238}_{92}U \longrightarrow ^{234}_{90}Th + \alpha_{-2}^{4} \qquad (2)$$

$$^{238}_{92}U + n_0^1 \longrightarrow ^{239}_{92}U \longrightarrow ^{239}_{93}Np + e_{-1}^{0} \qquad (3)$$

stable nuclei *unstable nuclei*

Radionuclides are formed in large quantities as waste products in nuclear power generation. Artificially produced radionuclides are also widely used in industrial and medical applications, particularly as tracers. Radionuclides differ from other nuclei in that they emit *ionising radiation* – alpha particles, beta particles and gamma rays. The levels of radionuclides found in water are typically measured in units of *picocuries/litre*, where a *curie* is $3.7 \cdot 10^{10}$ disintegrations per second.

The decay of a specific radionuclide follows first-order kinetics:

$$-dN/dt = kN \qquad (4)$$

where N is the number of radioactive nuclei present and k is the rate constant, which has units of reciprocal time. The half-life, $t_{1/2}$, is generally used instead of k to characterise a radionuclide:

$$t_{1/2} = 0.693/k \qquad (5)$$

As the term implies, a half-life is the period of time during which half of a given number of atoms, of a specific kind of radionuclide, decays. Ten half-lives are required for the loss of 99.9 % of the activity of a radionuclide.

Radiation damages living organisms by initiating harmful chemical reactions in tissues. For example, bonds are broken in the macromolecules that carry out life processes. In cases of acute radiation poisoning, bone marrow, which produces red blood cells, is destroyed and the concentration of red blood cells is diminished. Radiation-induced genetic damage is of great concern. The radionuclide of most concern in drinking water is *radium, Ra*. In all areas of the uranium-producing regions in the USA significant radium contamination of water has been observed. As the use of nuclear power has increased, the possible contamination of water by fission-product radioisotopes has become more of a cause for concern. Table 18.3 summarises the major natural and artificial radionuclides likely to be encountered in water.

Transuranic elements are of growing concern in aquatic (oceanic) environment. These alpha emitters (various isotopes of neptunium, plutonium, americium, curium) are long-lived and highly toxic.

Table 18.3. Radionuclides in water (adapted from Manahan, 1994)

Radionuclide	Half-life	Reaction, source
Natural reactions		
Carbon-14	5 730 years	^{14}N (n,p); ^{14}C
Silicon-32	300 years	^{40}Ar (p,x); ^{32}Si
Potassium-40	$1.4 \cdot 10^9$ years	0.0119 % of natural K
Naturally occurring from ^{238}U series		
Radium-226	1 620 years	Diffusion from sediments
Lead-210	21 years	^{226}Ra, 6 steps, ^{210}Pb
Thorium-230	75 200 years	^{238}U, 3 steps, ^{230}Th
Thorium-234	24 days	$^{238}U \rightarrow {}^{234}Th$ in situ
From reactor and weapons fission		
Strontium-90	28 years	Important isotopes of high biological activity
Iodine-131	8 days	
Cesium-137	30 years	
Barium-140	13 days	The isotopes from ^{140}Ba through ^{85}Kr are listed in decreasing order of fission field
Zirconium-95	65 days	
Cerium-141	33 days	
Strontium-89	51 days	
Ruthenium-103	40 days	
Krypton-85	10.3 years	
Cobalt-60	5.25 years	From nonfission reactions
Manganese-54	310 years	From nonfission reactions
Iron-55	2.7 years	^{56}Fe(n,2n), ^{55}Fe
Plutonium-239	24 300 years	^{238}U (n,γ), ^{239}Pu

Pollution load and concentration

In most industries, wastewater effluents result from the following water uses:

- sanitary wastewater (from washing, drinking and personal hygiene);
- cooling (from disposing of excess heat to the environment);
- process wastewater (including both water used for making and washing products and for removal and transport of waste and by-products); and
- cleaning (including wastewater from cleaning and maintenance of industrial areas).

Excluding the large volumes of cooling water discharged by the electric power industry, the wastewater production from urban areas is about evenly divided between industrial and municipal sources. Therefore, the use of water by industry can significantly affect the water quality of receiving waters.

The level of wastewater loading from industrial sources varies markedly with the water quality objectives enforced by the regulatory agencies. There are many possible in-plant changes, process modifications and water-saving measures through which industrial wastewater loads can be significantly reduced. Up to 90 % of recent wastewater reductions have been achieved by industries employing such methods as recirculation, operation modifications, effluent reuse or more efficient operation.

As a rule, treatment of an industrial effluent is much more expensive without water-saving measures than the total cost of in-plant modifications and residual effluent treatment.

Table 18.4. Flow and population equivalents for some typical industrial raw wastes (Krenkel & Novotny, 1980)

Industry	**Production unit**	**Flow/prod.unit**	**PE (BOD_5)**	**PE (SS)**
Slaughterhouse	1 hog (0.4 cattle unit)	600	18	6
Poultry	1 000 kg	18.3	300	130
General dairy	1 000 kg of raw milk	2.91	10	7
Cheese factory	1 000 kg of raw milk	1.66	16	6
Brewery	119.2 l of beer	1.78	19	13
Beet sugar	ton of raw beets	2.74	40	29
Paper mill	ton of paper	159	26	704
Pulp mill (kraft)	ton of pulp	260		
Tanning (Cr)	100 kg of hides	29	80	520
Laundry	100 kg of clothes	12.4	24	8
Oil refining	159 l crude oil	2.91	00.06	01.00

Industrial wastewater effluents are usually highly variable, with quantity and quality variations brought about by bath discharges, operation start-ups and shut-downs, working-hour distribution and so on. A long-term detailed survey is usually necessary before a conclusion on the pollution impact from an industry can be reached.

The population equivalent (PE) is used to compare how many people it would take to produce the same amount of pollution as produced by the industrial wastewater effluent under consideration. The following per capita (cap) loadings have been agreed upon for the population equivlent estimation:

Biochemical Oxygen Demand (BOD_5) PE
1 PE = 54 g of BOD_5/day

Suspended solids
1 PE = 90 g/day

Population equivalents for some industrial wastes can be related to production units as shown in Table 18.4. These numbers represent only very rough estimates for planning purposes. For more precise numbers, the PE estimates should always be verified by a survey and/or by consulting the plant engineer.

In Table 18.5 the values of typical concentration parameters (BOD_5, COD, suspended solids) and pH for different industrial effluents are given.

Table 18.5. Comparative Strengths of Wastewaters from Industry (Bond & Straub, 1974)

Type of waste	**BOD_5** (mg/l)	**COD** (mg/l)	**SS** (mg/l)	**pH**
Apparel				
Cotton	200-1 000	400-1 800	200	8-12
Wool scouring	2 000-5 000	2 000-5 000[a]	3 000-30 000	9-11
Wool composite	1	-	100	9-10
Tannery	1 000-2 000	2 000-4 000	2 000-3 000	11-12
Laundry	1 600	2 700	250-500	8-9
Food				
Brewery	850	1 700	90	4-8
Distillery	7	10	Low	-
Dairy	600-1 000	150-250[a]	200-400	Acid
Cannery				
citrus	2 000	-	7 000	Acid
pea	570	-	130	Acid
Slaughterhouse	1 500-2 500	200-400[a]	800	7
Potato processing	2 000	3 500	2 500	11-13
Sugar beet	450-2 000	600-3 000	800-1 500	7-8
Farm	1 000-2 000	500-1 000[a]	1 500-3 000	7.5-8.5
Poultry	500-800	600-1 050	450-800	6.5-9
Materials				
Pulp; sulfite	1 400-1 700	84-10 000	Variable	
Pulp; kraft	100-350	170-600	75-300	7-9.5
Paperboard	100-450	300-1 400	40-100	
Strawboard	950	850[a]	1 350	
Coke oven	780	1 650[a]	70	7-11
Oil refinery	100-500	150-800	130-600	2-6

[a] = *CODMn, mg* O_2*/l*

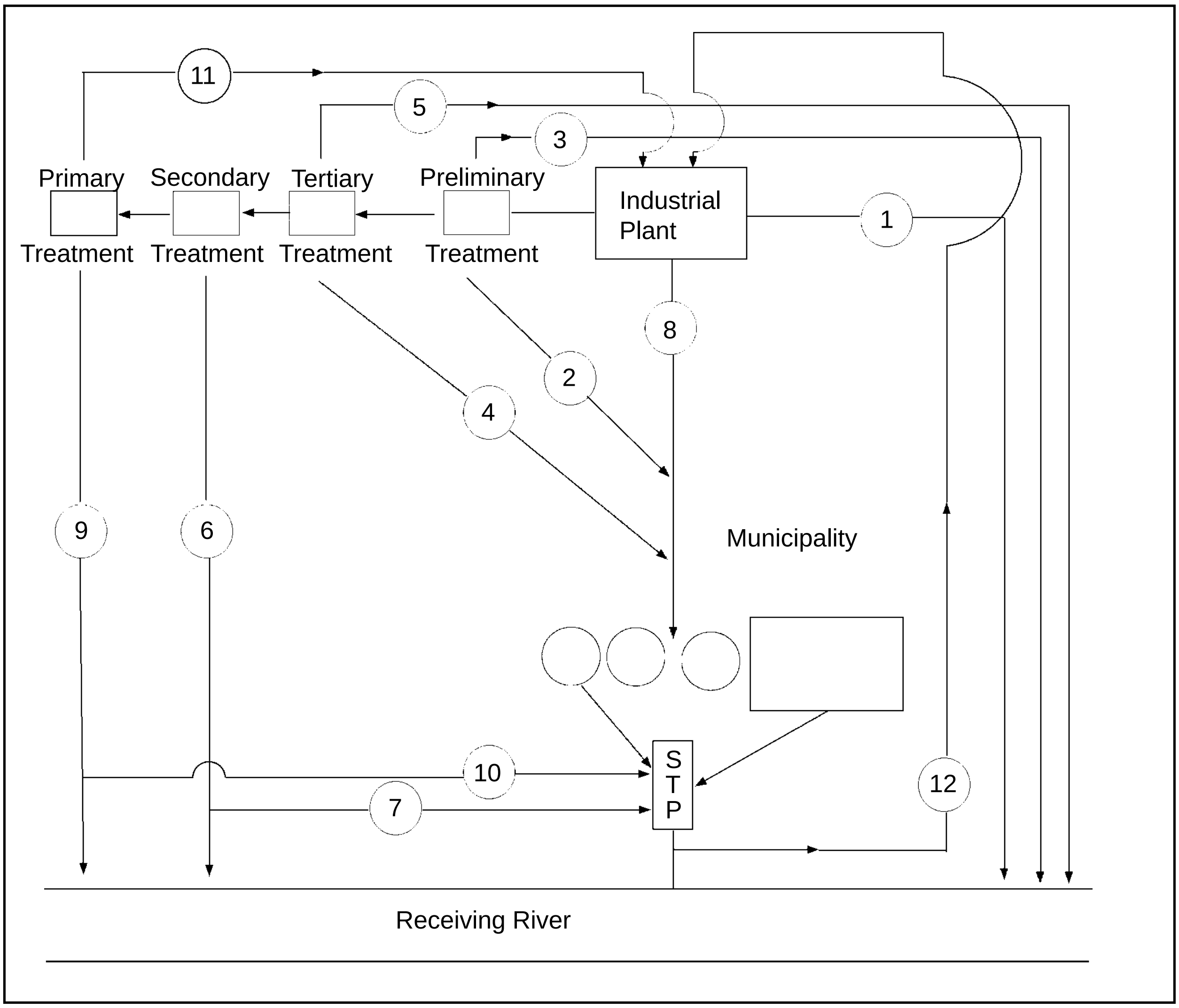


Figure 19.1. Twelve alternatives of industrial waste treatment systems (Nemerov & Dasgupta, 1991).

19.

INDUSTRIAL WASTEWATER TREATMENT

Rein Munter

Pathways of industrial effluents treatment

There are many different ways of treating industrial effluent (Figure 19.1). It is often possible and advisable for an industry to discharge its waste directly at a municipal treatment plant, where a certain portion of the pollution can be removed. A municipal sewage-treatment plant, if designed and operated properly, can handle a major part of the industrial waste, with the exception of toxic substances like cyanides, phenols in high concentrations and heavy metals. The wastewater pH should be close to neutral. Generally, the industrial effluent should be free of substances that could impair the treatment process or cause violation of water quality standards of the receiving waters. Hence, one possibility that should be given serious consideration is for industry and municipalities to co-operate in the joint construction and operation of a municipal wastewater treatment plant. In many cases, the joint treatment of industrial and municipal wastewaters can be economically and environmentally beneficial to both the industry and the municipality.

There is a fine line of distinction between a volume of wholly untreatable waste and one containing only certain components that are untreatable if combined with domestic sewage. For example, wastewater from a plating plant can probably be treated together with domestic sewage if its pH value is first stabilised at about 7.0 and the cyanides and the major part of the chromium is eliminated at a local wastewater treatment unit. The shortest pathway – discharge of untreated industrial waste directly into a nearby stream – should be permitted only after a detailed survey, by competent and certified sanitary engineers, of the existing conditions and future uses of the receiving stream. Nowadays this case should certainly be considered as an exception. Complete treatment of industrial wastes prior to direct discharge or reuse at the plant is gradually receiving more and more consideration. In fact, complete treatment (or at least, advanced, tertiary treatment) has already been implemented in many large industries, for example, textile, pulp and paper, steel and chemical industries. The methods used for wastewater treatment can be classified as *physical unit operations* and *chemical* and *biological unit processes*.

A summary of the unit operations and processes commonly used in wastewater reclamation and the principal contaminants removed are presented in Table 19.1.

Table 19.1. Unit processes and operations used in wastewater reclamation and potential for contaminant removal (adapted from Metcalf & Eddy, 1991)

	BOD	COD	TOC	Turbid.	Color	*Coli*	NH_3-N
Primary treatment	x	x	x	x	o		o
Activated sludge	+	+	+	+	x	+	+
Nitrification	+	+	+	+	x	+	+
Denitrification	o	o	o	o			x
Trickling filter	+	+	x	x	o	o	
Coag.-floc.-sed.	+	+	+	+	+	+	o
Filtration A/S	x	x	x	x	x		x
GAC adsorption	+	x	+	+	+	+	x
Ion exchange	x	x	o	o			+
Chlorination						+	+
Reverse osmosis	+	+	+	+	+		+
Ozone	o	+	x			+	

Symbols: o = 25 % removal of influent concentration, x = 25 - 50 %, + = > 50 %. Blank denotes no data

Levels of treatment

Treatment levels of wastewater are often identified as primary, secondary and tertiary (the latter also known as advanced).

Primary treatment involves separating a portion of the suspended solids from the wastewater. Screening and sedimentation usually accomplish this separation process. The effluent from primary treatment will ordinarily contain considerable organic material and will have a relatively high BOD.

Secondary treatment involves further treatment of the effluent. Biological processes generally accomplish the removal of the organic matter and the residual suspended solids. The effluent from secondary treatment usually has little BOD_5 (30 mg/l as average) and a low suspended solids value (30 mg/l as average).

Most of the readily biologically degradable organic material is removed during biological treatment, but from 40 to 100 mg/l of dissolved and biologically resistant or "refractory" organic material remains in the effluent. These materials may be end products of normal biological decomposition or artificial products, such as synthetic detergents, pesticides, oils, chlorophenols, nitro-compounds, TCE, PCE, PCB, etc.

The biodegradability of some organic compounds is characterised in Table 19.2.

Table 19.2. Biodegradability of organic hazardous waste (Leachy & Brown, 1994)

Readily degradable	Moderately degradable	Recalcitrant
Gasoline	Crude oil	TCE
Jet fuel	Lubricating oils	PCE
Diesel fuel	Coal tars	Vinylchloride
Toluene	Cresotes	PCB
Benzene	Pentachlorophenol	DDT
Isopropylalcohol	Nitrophenol	Chlordane
Methanol	Aniline	Heptachlor
Acetone	Long-chain aliphatics	
Phenol	Phthalates	
Ketone		

Unit operations

Both treatment levels, primary and secondary, have been discussed previously. The task of the present chapter is to give an overview of the third, advanced level of wastewater treatment. The united operations and processes included here (coagulation, filtration, activated carbon adsorption, electrodialysis, reverse osmosis, ozonation, advanced oxidation processes etc.) are at the same time often used for industrial effluents local treatment. A conceptual flow diagram of an advanced wastewater treatment process combination capable of producing potable water from municipal wastewater is illustrated in Figure 19.2.

Coagulation

Coagulation may be used for the clarification of industrial wastes containing colloidal and suspended solids. Paperboard wastes can be coagulated effectively with low dosages of alum. Silica or polyelectrolyte aids in the formation of a rapid-settling flock. Typical data are summarised in Table 19.3.

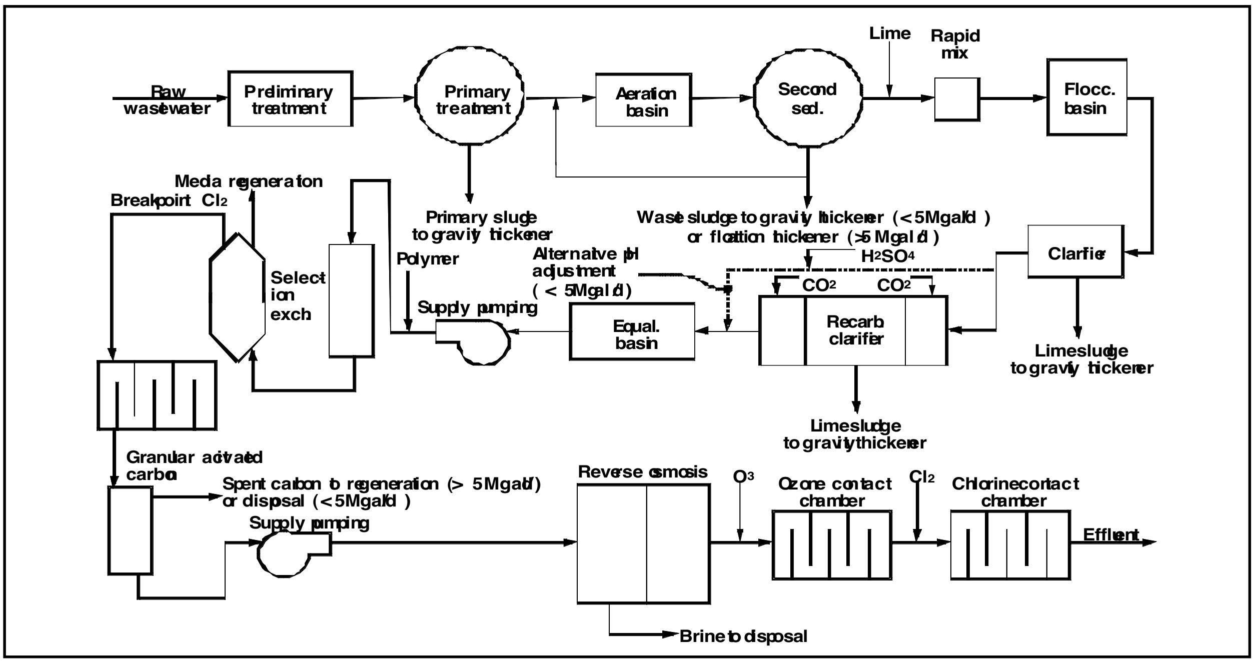


Figure 19.2. Conceptual flow diagram of advanced wastewater treatment system capable of producing potable-quality water supply (Metcalf & Eddy, 1991).

Wastes containing emulsified oils can be clarified by coagulation. The oil droplets in water are approximately 10^{-5} cm and are stabilised by adsorbed ions. Emulsifying agents include soaps and anion-active agents. The emulsion can be broken by "salting it out" with the addition of salts, such as $CaCl_2$. A lowering of the pH of the waste solution can also frequently break an emulsion. For example, polymer waste from latex manufacture has been coagulated with 500 mg/l ferric chloride and 200 mg/l lime at pH 9.6. COD and BOD reductions of 75 and 94 %, respectively, were achieved from initial values of 1 000 mg/l and 120 mg/l.

The resulting sludge contained 1.2 % solids by weight. Results from the coagulation of textile wastewaters are shown in Table 19.4 and colour removal from pulp and paper-mill effluents in Table 19.5.

It can be seen from Tables 19.4 and 19.5 that while coagulation is very efficient for industrial effluents colour reduction (the removal is normally more than 85 % and often reaches 92-95 %), it is much less effective for COD reduction (only 30-60 % removal).

Precipitation – heavy metals removal

Precipitation is employed for removal of heavy metals from industrial effluents. Heavy metals are generally precipitated as hydroxide through the addition of lime or caustic (NaOH) to a pH of minimum solu-

Table 19.3. Chemical treatment of paper and paperboard wastes (adapted from Eckenfelder, 1989)

	Influent	**Influent**	**Effluent**	**Effluent**	**Effluent**	**Coagul.**	**Coagul.**
Waste	**BOD** (ppm)	**SS** (ppm)	**BOD** (ppm)	**SS** (ppm)	**pH**	**Alum.** (ppm)	**Silica** (ppm)
Board		350-450		15-60		3	5
Board		140-420		10-40		1	-
Board		240-600		35-85		-	-
Board	127	593	68	44	6.7	10-12	10
Tissue	140	720	36	10-15	-	2	4
Tissue	208	-	33	-	6.6	-	4

Table 19.4. Coagulation of textile wastewaters (adapted from Eckenfelder, 1989)

			Colour*	**Colour***	**COD**	**COD**
Coagulant	**Dose** (mg/l)	**pH**	**Influent** (mg/l)	**Removal** (%)	**Influent** (mg/l)	**Removal** (%)
Ferrisulf.	250	7.5-11	0.25	90	584	33
Alum	300	5-9		86		39
Lime	1 200	> 11		68		30
Ferrisulf.	1 000	9-11	4.60	87	1 570	31
Alum	750	5-6		89		44
Lime	2 500	> 11		87		44

* Colour sum of absorbances at wavelengths of 450, 550, and 650 nm.

Table 19.5. Colour removal from pulp and paper-mill effluents (Eckenfelder, 1989)

Coagulant	**Dose,** (mg/l)	**pH**	**Color Influent** (units)	**Color Removal** (%)	**COD Influent** (mg/l)	**COD Removal** (%)
Ferrisulf.	500	3.5-4.5	2 250	92%	776	60%
Alum	400	4.0-5.0		92%		53%
Lime	1 500	> 11		92%		38%
Ferrisulf.	275	3.5-4.5	1 470	91%	480	53%
Alum	250	4.0-5.5		93%		48%
Lime	1 000	> 11		85%		45%

bility. The pH of minimum solubility varies with the metal in question. For example, the solubilities of chromium and zinc are minimal at pH 7.5 and 10.2, respectively.

When treating industrial wastewater that contains metals, it is necessary to pre-treat the effluents to remove substances that will interfere with the precipitation of the metals.

Cyanide and ammonia form complexes with many metals, limiting the removal of them. For many metals such as arsenic and cadmium, co-precipitation with iron or aluminium is highly effective for removal to low residual levels. In order to meet low effluent requirements, it may be necessary to provide filtration to remove flock carried over from the precipitation process. Filtration should reduce effluent concentrations to 0.5 mg/l or less.

For chromium wastes treatment hexavalent chromium must first be reduced to the trivalent state Cr^{3+} and then precipitated with lime. The reducing agents commonly used for chromium wastes are ferrous sulphate, sodium *meta*-bisulphite, or sulphur dioxide. Metals removal is summarised in Table 19.6.

Flotation (oil separation)

In oil separation, free oil is floated to the surface of a tank and then skimmed off. The design of a gravity separator is based on the removal of all free oil globules larger than 0.15 mm. The Reynolds number is less than 0.5, so Stokes' law applies. Typically, effluent oil concentrations in the order of 50 mg/l are achieved.

The hydraulic loading of a cross-flow corrugated plate separator (Figure 19.3) varies with temperature and the specific gravity of the oil. Nominal flow rates are specified for a temperature of 20 °C and a specific gravity of 0.9 for the oil. A hydraulic loading of 0.5 $m^3/m^2/h$ of actual plate area will usually result in separation of 0.06-mm droplets. Oil emulsions can be broken before separation by acidification, the addition of alum or iron salts, or the use of emulsion-breaking polymers.

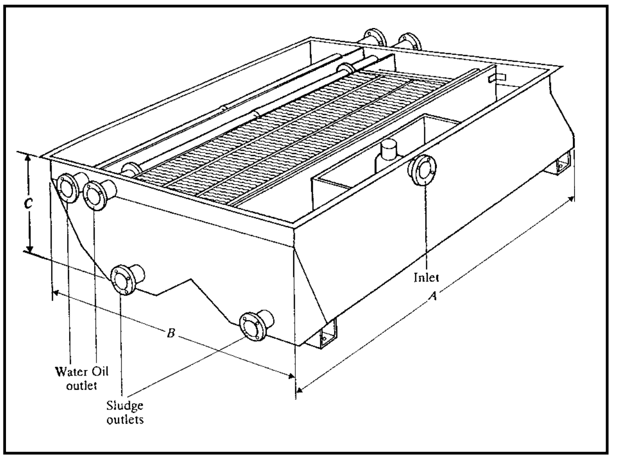


Figure 19.3. Cross-flow plate separator (from Eckenfelder, 1989).

Activated carbon adsorption

Many industrial wastes contain refractory organics, which are difficult or impossible to remove through conventional biological treatment. These materials can be removed by adsorption on activated carbon or synthetic active-solid surface. The degree to which adsorption will occur and the resulting equilibrium relationships have been correlated according to the empirical relationship of Freundlich or the theoretically derived Langmuir relationship. For practical applications more suitable Freundlich isotherm is expressed as

Table 19.6. Effluent levels achievable in heavy metal removals (adapted from Eckenfelder, 1989)

Metal	**Achievable effluent concentration,** mg/l	**Technology**
Arsenic	0.05	Sulphide precipitation with filtration
	0.06	Carbon adsorption
	0.005	Ferric hydroxide co-precipitation
Barium	0.5	Sulphate precipitation
Cadmium	0.05	Hydroxide precipitation at pH 10-11
	0.05	Co-precipitation with ferric hydroxide
	0.008	Sulphide precipitation
Copper	0.02-0.07	Hydroxide precipitation
	0.01-0.02	Sulphide precipitation
Mercury	0.01-0.02	Sulphide precipitation
	0.001-0.01	Alum co-precipitation
	0.0005-0.005	Ferric hydroxide co-precipitation
	0.001-0.005	Ion exchange
Nickel	0.12	Hydroxide precipitation at pH 10
Selenium	0.05	Sulphide precipitation
Zinc	0.1	Hydroxide precipitation at pH 11

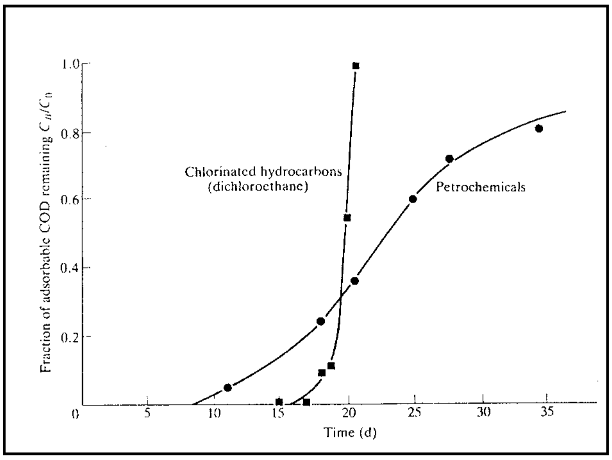


Figure 19.4. Continuous carbon column breakthrough curves (Eckenfelder, 1989).

$$X/M = kC^{1/n} \qquad (6)$$

where

X = weight of substance adsorbed

M = weight of adsorbent

C = concentration remaining in solution

k, n = constants depending on temperature, the adsorbent and the substance to be adsorbed.

The values of k for several priority pollutants (nitrobenzene, styrene, chlorobenzene, bromoform etc.) are in the range 60 - 360 mg/g and the values of 1/n = 0.12 - 0.98. In granular carbon columns, the carbon adsorption capacity at breakthrough as related to exhaustion is a function of the waste complexity, as shown in Figure 19.4. A single organic substance, such as dichloroethane, will yield a sharp breakthrough curve so that the column is more than 90 % exhausted when breakthrough occurs. By contrast, a multicomponent petrochemical wastewater shows a drawn-out breakthrough curve due to varying rates of sorption and desorption.

Depending on the nature of the wastewater several modes of carbon column design may be employed: down flow in series, moving-bed, down flow in parallel, up flow expanded in series etc. (Figure 19.5).

It is generally feasible to regenerate spent carbon for economic reasons. The modes of regeneration are thermal, steam, solvent extraction, acid or base treatment, and chemical oxidation. In most wastewater cases, however, thermal regeneration is required. Thermal regeneration entails drying, thermal desorption and high-temperature heat treatment (650-980 °C) in the presence of limited quantities of water vapour, flue gas and oxygen. Multiple-hearth furnaces or fluidised-bed furnaces can be used. The regeneration process is a compromise between burning too much carbon and leaving unburned tars that clog the pores. Depending on the type of carbon and furnace operation, weight losses of carbon during regeneration usually amount to 5-10 % by weight of the carbon regenerated. In practice, the greatest total surface area is obtained when about 3-5 % of the original carbon is burned off each time.

Lately, powdered activated carbon (PAC) has been added to the activated sludge process for enhanced performance (the PACT process). The flow sheet for this process is shown in Figure 19.6. The advantages of the PACT process are decreasing variability in effluent quality and removal by adsorption of non-degradable refractory organics and colour. PAC also has the advantage of being able to be integrated into existing biological treatment facilities at a minimum capital cost. Since the addition of PAC enhances sludge settleability, conventional secondary clarifi-

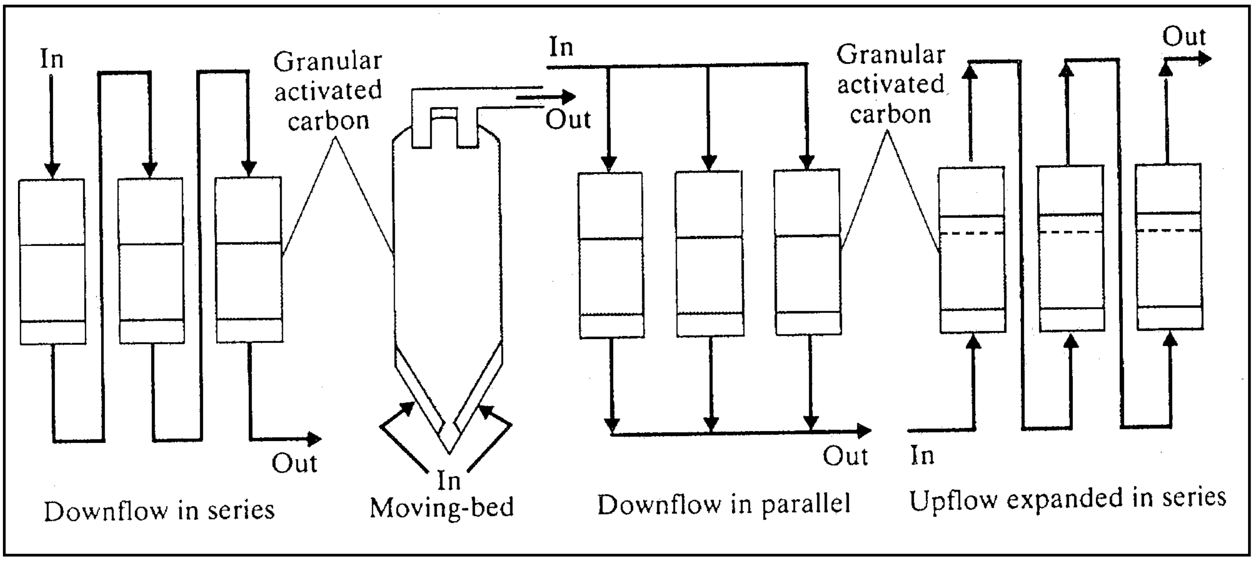


Figure 19.5. Types of granulated activated carbon (GAC) column design (Eckenfelder, 1989).

ers are often adequate, even with high carbon dosages (300-500 mg/l PAC).

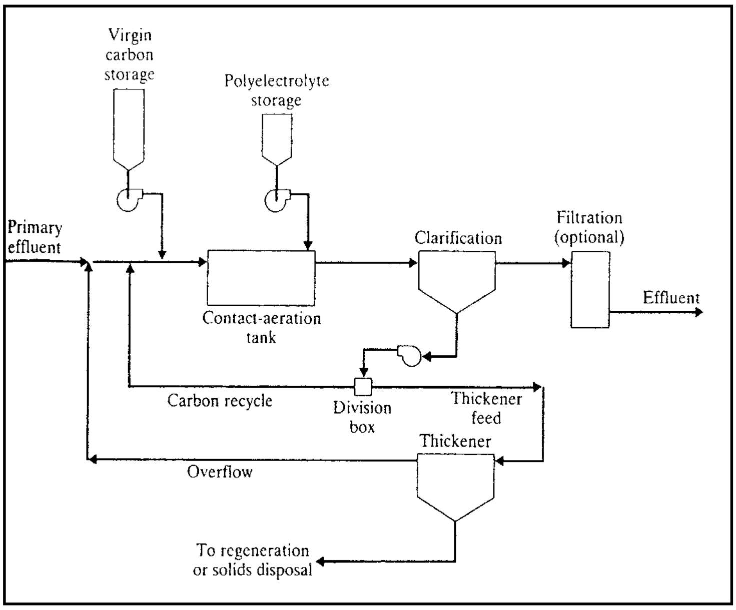


Figure 19.6. General process diagram of a powdered activated carbon (PACT) wastewater treatment system (Eckenfelder, 1989).

Ion exchange

Ion exchange can be used for the removal of undesirable anions and cations from a wastewater. Cations are exchanged for hydrogen or sodium and anions for hydroxyl ions. Ion exchange resins consist of an organic or inorganic network structure with attached functional groups. Most ion exchange resins used in wastewater treatment are synthetic resins made by the polymerisation of organic compounds into a porous three-dimensional structure.

Ion exchange resins are called *cationic* if they exchange positive ions and *anionic* if they exchange negative ions. Cation exchange resins are comprised of *acidic* functional groups, such as sulphonic groups, whereas anion exchange resins have *basic* functional groups, such as amine. The strength of the acidic or basic character depends upon the degree of ionisation of the functional groups, similar to the situation with soluble acids or bases. Thus, a resin having sulphonic acid groups would act as a strong acid cation exchange resin.

For the other types of ion exchange resins, the most common functional groups are carboxyl (-COOH) for weak acid, quaternary ammonium ($R_3N^+OH^-$) for strong base, and amine ($-NH_2$ or -RNH) for weak base.

Cation exchange of the hydrogen cycle can be illustrated by the following reactions:

$$Ca^{2+} + H_2[KAT] \rightarrow Ca[KAT] + 2H^+ \quad (7)$$

Regeneration with 2 to 10 % H_2SO_4 yields:

$$Ca[KAT] + 2H^+ \rightarrow H_2[KAT] + Ca^{2+} \quad (8)$$

Similarly, anion exchange replaces anions with hydroxyl ions:

$$SO_4^{2-} + [AN](OH)_2 \rightarrow [AN]SO_4 + 2OH^- \quad (9)$$

Regeneration with 5 to 10 % NaOH will renew the exchange sites:

$$[AN]SO_4 + 2OH^- \rightarrow [AN](OH)_2 + SO_4^{2-} \quad (10)$$

Since exchange occurs on an equivalent basis, the capacity of the bed is usually expressed as equivalents per litre of bed volume. In some cases capacity is expressed as kg $CaCO_3$ per unit bed volume or as mass of ions per unit bed volume.

Treatment of a wastewater by ion exchange involves a sequence of operating steps. The wastewater is passed through the resin until the available exchange sites are filled and the contaminant appears in the effluent. This process is defined as the *breakthrough*. At this point treatment is stopped and the bed is backwashed to remove dirt and to re-grade the resin. The bed is then regenerated. After regeneration the bed is rinsed with water to wash out residual regenerant.

The treatment and regeneration cycle is shown in Figure 19.7. In this figure, the area ABHG is the quantity of ions in the volume of solution treated before breakthrough. The area ABC is the quantity of ions leaking through the column and the area ACHG is the quantity of ions removed by the exchange resin. The resin utilisation is therefore area ACHG/K, where

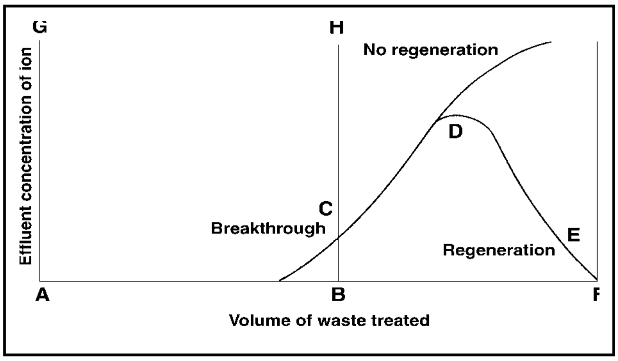


Figure 19.7. Treatment and regeneration cycle of ion exchange resin (from Eckenfelder, 1989).

K is the ultimate capacity of the resin. The area BCDEF is the quantity of ions removed from the bed during regeneration. The regeneration efficiency is therefore area BCDEF/R, where R is equal to the concentration of the regenerant times its volume.

To ensure contact of liquid with the resin and to minimise leakage, the minimum bed depth is 61 to 76 cm. The treatment flow rate can vary between 0.27 to 0.67 $m^3/(min \cdot m^3)$. The regenerant flow rate is 0.13 to 0.27 $m^3/(min \cdot m^3)$.

One of the major applications of ion exchange in industrial waste treatment has been in the plating industry, where chromium recovery and water reuse have resulted in considerable savings.

For recovery of the spent chromic acid in plating baths, the chromic acid is passed through a cation exchange resin to remove other ions (Fe^{3+}, Cr^{3+}, Al^{3+} etc.). The effluent can be returned to the plating bath or to storage. The recovered chromic acid from the spent regenerant will have an average concentration of 4 to 6 %. The spent regenerant from the cation exchanger will require neutralisation and possibly precipitation of metallic ions before it is discharged to the sewer. A flow diagram of an ion exchange process for a plating plant is shown in Figure 19.8.

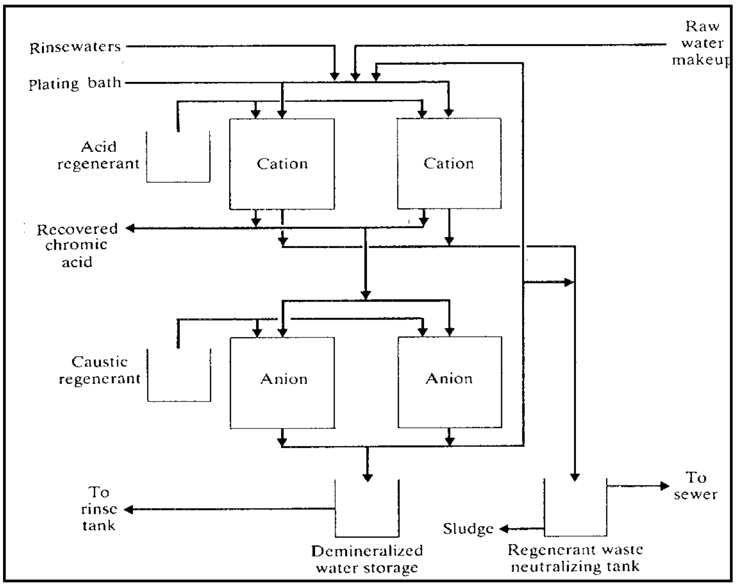


Figure 19.8. Ion exchange system for chromate removal and reuse (Eckenfelder, 1989).

Membrane processes

The membrane processes can be classified according to the size range of the separated species:

- *Reverse osmosis* is used to separate dissolved salts and small organics (size under 1 nm). Example: production of drinking water from seawater or seawater desalination.
- *Nanofiltration* is used to separate antibiotics (size under 10 nm). Example: selective demineralisation of water or concentration of organic solutions.
- *Ultrafiltration* is used to separate emulsions, colloids, macromolecules or proteins (size under 100 nm). Example: treatment of pulp and paper industry's effluents.
- *Micro-filtration* is used to separate small particles, large colloids and microbial cells (size under 10 mm). Example: removal of microorganisms from the fermentation products.
- *Gas and vapour separation* is used to isolate a gas from a mixture of gases or vapours. Example: recovery of ammonia or hydrogen from industrial gases.
- *Electrodialysis* is used to separate anions and cations by means of two charged membranes (anode and cathode). Example: production of pure water.

Reverse Osmosis

As can be seen from the list above, membrane filtration includes a broad range of separation processes, ranging from filtration and ultrafiltration to reverse osmosis. Generally, those processes defined as filtration refer to systems in which discrete holes or pores exist in the filter media, generally in the order of 102 to 104 nm or larger. The efficiency of this type of filtration depends entirely on the difference in size between the pore and the particle to be removed. The various filtration processes relative to molecular size are shown in Table 19.4.

In normal osmosis, a semipermeable membrane separates a salt solution from a pure solvent of a less concentrated solution. This membrane is permeable

Table 19.7. Membrane processes (Eckenfelder, 1989)

Material to be removed	Approximate size, nm	Process
Ion removal	1-20	Diffusion or reverse osmosis
Removal of organics in true solution	5-200	Diffusion
Removal of subcolloidalorganics	200-10 000	Pore flow
Removal of colloidal matter	75 000	Pore flow

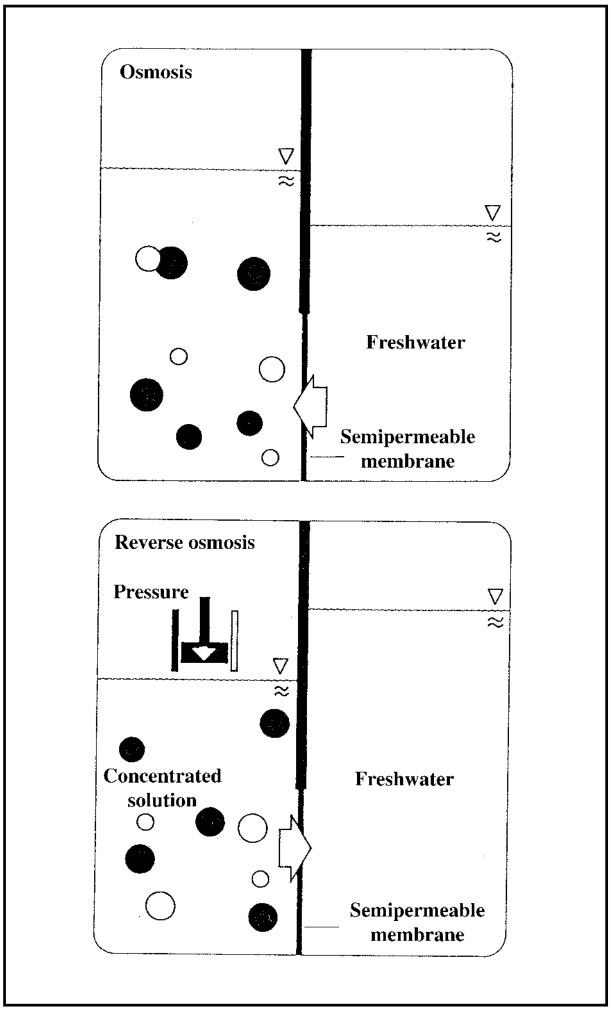


Figure 19.9. Osmosis and reverse osmosis (Eckenfelder, 1989).

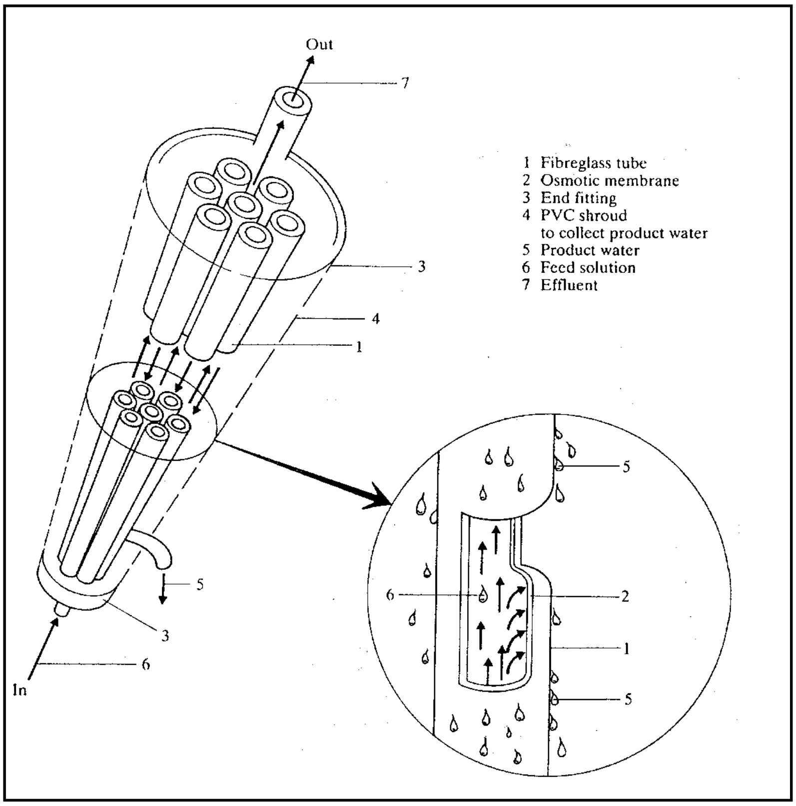


Figure 19.10. Membrane filtration system. Tubular reverse osmosis unit (Eckenfelder, 1989).

to the solvent and impermeable to the solution (Figure 19.9). The chemical potential of the pure solvent is greater than that of the solvent in solution, and therefore brings the system to equilibrium. For two solutions with different concentrations, separated by a semipermeable membrane, the osmotic phenomenon will be a water flux from the most diluted solution to the concentrated one. To stop this water flux, a pressure on the concentrated solution has to be applied. By increasing the pressure above the osmotic pressure, a water flux from the concentrated solution to the diluted one is obtained. This phenomenon is called reverse osmosis.

The equation of osmotic pressure, the so-called Van't Hoff's equation, is:

$$P = C\,RT$$

where C is the concentration of the solute, R is the gas constant and T is the temperature in K. It should be noted however that this relation should be applied to dilute solutions, i.e. to solutions under low osmotic pressures.

The permeate flux can be expressed as follows:

$$J = e \cdot d^2 \cdot \Delta P / 32 \cdot m \cdot t \cdot z$$

where e is the membrane porosity, d is the pore diameter, t is the tortuosity factor, m is the solvent viscosity, ΔP is the pressure difference across the membrane and z is the membrane thickness.

The selectivity of the membrane is defined by the solute rejection coefficient, which is given by the following expression:

$$R = 1 - C_p/C_f$$

where C_p is the solute concentration in the permeate and C_f, the solute concentration in the feed.

There are three different types of membrane structures: homogeneous, asymmetric and composite membrane. The homogeneous membrane is not used very often because of its considerably low permeate flow rate. It is only used for micro-filtration. Asymmetric membranes are made of two layers: a 1-2 mm thick top layer of finest pore size supported by a 100 mm thick, more porous matrix. With such an asymmetric structure, reasonable rates of permeate flux are obtained. Composite membranes are made of two layers as well: an extremely thin layer (1 mm) of finest pore structure deposited on a porous matrix. The thin layer can be made of inorganic materials.

Membranes are most commonly made of polymeric materials such as polyamide, polysulfone and poly-carbonate. The method of packing the membrane leads to a module design of a membrane separation unit. There are four types of modules commercially available: tubular modules, flat-sheet modules, spiral-wound modules and hollow-fibre modules.

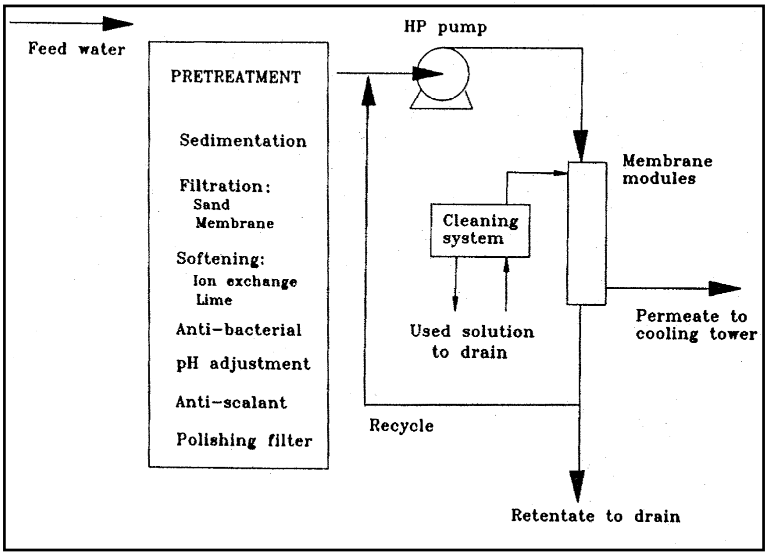


Figure 19.11. Reverse osmosis – general system (Newton & Solt, 1994).

A typical tubular membrane type is shown in Figure 19.10. Manufactured from ceramics, carbon, or porous plastics, these tubes have an inside diameter ranging from 1/8 inch (3.2 mm) up to 1 inch (2.54 cm). The membrane is typically coated on the inside of the tube, and the feed solution flows through the interior from one end to the other, with the "permeate" or "filtrate" passing through the wall. Other membrane systems used are spiral-wound hollow-fibre and plate or frame.

The water (permeate) flux is a function of the pressure differential between the applied pressure and the osmotic pressure across the membrane. Flux rates of approximately 0.1 m^3/m^2/day are typical for tubular and spiral-wound systems. The maximum pressure is generally taken to be 1 000 lb/in^2 (6 900 kPa) gage. The water flux increases with increasing feed water temperature. A standard of 21 °C is generally assumed and temperatures of up to 29 °C are acceptable.

Salt rejection depends on the type and character of the selected membrane and the salt concentration gradient. Rejection values of 85 to 99.5 % are generally obtainable, with 95 % commonly being used.

Membranes consisting of cellulose acetate are subject to hydrolysis at high and low pH values. The optimum pH is approximately 4.7, with operating ranges between 4.5 and 5.5. Generally, membranes will last up to two years with some loss in flux efficiency. The pre-treatment of water to a membrane system is vital, to maintain productivity and to obtain long membrane life. In particular, the level of fine and colloidal solids must be controlled (Figure 19.11).

An industrial standard method called the "silt density index" (SDI) is used. The SDI test entails passing the feed water through a fine-pore membrane filter (0.45 _m) under standard conditions and measuring the rate at which the flow falls through the membrane. It is recommended not to have an SDI higher than 0.3. Membrane systems are normally turned off periodically for chemical cleaning, to allow deposits to be removed. Cleaning methods include periodic depressurisations, high-velocity water flushing, backwashing, cleaning with enzyme detergents, ethylene diamine, tetraacetic acid etc. A summary of operational parameters is given in Table 19.5.

Reverse osmosis systems can operate at 90 % efficiency or better with respect to total dissolved solids. In addition to inorganic ions, the membranes also remove residual organic molecules, turbidity, bacteria and viruses.

In Figure 19.12 the application of ultrafiltration for oily wastewaters treatment is illustrated. The permeate is recycled as rinse water and the concentrate is hauled or incinerated.

Demands for lower freshwater consumption together with stringent environmental legislation within the pulp and paper industry have created a need for process water and effluent recycling, and thus totally or partly closed water circuits have become a reality. The membrane processes (ultra- and nanofiltration) are already being used in pa-

Table 19.8. Summary of system operational parameters (adapted from Eckenfelder, 1989)

Parameter	Range	Typical
Pressure (MPa gage)	3-7	4
Temperature (°C)	15-40	21
Packing density (m^2/m^3)	50-500	-
Flux $m^3/(d \cdot m^2)$	0.5-4	0.6-1.7
Recovery factor (%)	75-95	80
Rejection factor (%)	85-99.5	95
Membrane life (years)	-	2
PH	3-8	4.5-5.5
Turbidity (JTU)	-	1
Feed-water velocity (m/s)	0.01-0.75	-
Power utilization ($kW \cdot h/ 10^3$ l)	2-3.7	-

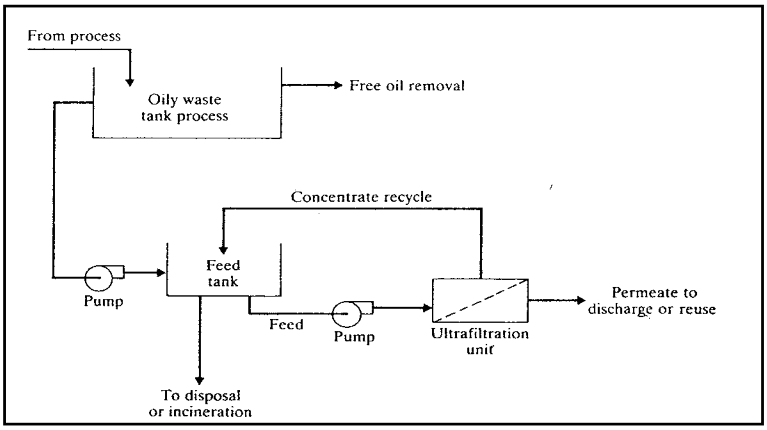


Figure 19.12. Treatment of oily wastewaters by ultrafiltration (Eckenfelder, 1989).

per machine white-water treatment and the experience has been good. The development of membrane materials like ceramics will prolong membrane lifetime and thus reduce cost. New modules are also needed, because e.g. the nanofiltration spiral-wound module needs a very heavy pre-treatment, usually by ultrafiltration. During the last decade, as a result of the development of a new filter, called the CR (cross-rotational), as well as of new membrane materials, membrane applications have proved to be competitive processes for the concentration of valuable compounds or purification of water.

Electrodialysis

The electrodialysis process uses a series of membranes made from ion-exchange resins. These membranes will selectively transfer ions. They are based on polymers of materials such as styrene or polyethylene incorporating fixed and mobile charged groups. In, for example, cation-exchange membranes, negatively charged groups are fixed and positively charged groups mobile. Then, under the influence of a driving force (an electric field or a concentration gradient), positive and negative ions are attracted to the membrane, and the membrane is permeable for positive ions while rejecting negative ions. In the electrodialysis process the transport through the membrane is promoted by an electric field across the membrane. Diffusion is negligible by comparison and ion transport is directly related to the electric current. According to Faraday's law an electric current of 26.8 Ah is needed to transport 1 gram equivalent of a salt. In practice the electric current is higher, due to inefficiencies caused by electrical resistance. Generally in electrodialysis a package of membranes is used with alternate cation and anion membranes arranged in a so-called "membrane-stack" (Figure 19.13). Membranes in an electrodialysis unit are approximately 0.5 mm thick, separated by porous spacers about 1 mm thick. Water flows through the porous spacers. Anions and cations pass through the membranes so that the original feed is desalinated and a concentrate forms on the other side of the membranes. A contact time of 10 to 20 s is required to obtain a removal efficiency of about 25-60 %. As reverse osmosis, electrodialysis also requires a high degree of pre-treatment prior to the process. Suspended solids removal is absolutely necessary, and dissolved organics should be removed to prevent fouling.

Chemical oxidation of a wastewater may be employed to oxidise pollutants to terminal end products or to intermediate products that are more readily biodegradable or more readily removable by adsorption. Common oxidants are chlorine, hypochlorous acid, potassium permanganate, hydrogen peroxide and ozone.

The strongest oxidants are hydroxyl radicals formed in various *advanced oxidation* systems, such as O_3/UV, O_3/H_2O_2, H_2O_2/UV, O_3/TiO_2, etc. (see Table 19.6).

Ozonation of wastewater compounds

Van Marum, the Dutch chemist who discovered how to lead electric current through oxygen, also discovered ozone (trioxygen) in 1785. The name "ozone" (*ozo* = "to smell" in Greek) was given to the gas by the Swiss chemist Schönbein in 1840.

Under normal pressure and temperature, ozone is a bluish gas with a characteristic intensive odour, about twice as heavy as air. Its boiling point is -112 °C and its melting point -192.7 °C at 0.1 MPa. Pure (100 %) ozone is at -112 °C a dark-blue liquid, *extremely sensitive* to the smallest organic impurities, shaking, and temperature and pressure changes, and *very explosive.*

Ozone is produced in the field of a corona discharge at voltages of 10-15 kV and frequencies of

Table 19.9. Relative oxidation power of some oxidising species (EPRI, 1996)

Oxidation species	Oxidation power*
Chlorine	1.0
Hypochlorous acid	1.10
Permanganate	1.24
Hydrogen peroxide	1.31
Ozone	1.52
Atomic oxygen	1.78
Hydroxyl radical	2.05

** Based on chlorine as reference point (=1.00)*

50-1 000 Hz. Nowadays medium frequency (400-600 Hz) is most commonly used in producing ozone.

Ozone production with reactions from air or pure oxygen can be summarised as

$$3O_2 \leftrightarrows 2O_3 + 298\ \text{kJ} \quad (11)$$

This reaction is reversible: part of the produced ozone decomposes back to oxygen, liberating 149 kJ of energy per mole of ozone decomposed. The amount of liberated energy makes ozone dangerous in high concentrations.

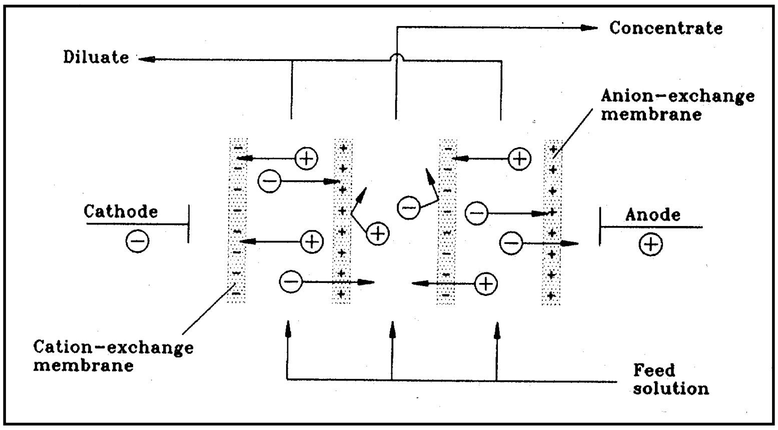


Figure 19.13. Electrodialysis stack (Newton & Solt, 1994).

In water/wastewater treatment ozone is synthesised in tube or plate generators, yielding air-ozone or oxygen-ozone mixtures with concentrations of ozone less than 20 % (by mass), which is *totally safe*.

Ozone dissolves in water better than oxygen, but not as well in chlorine. For the dissolution process Henry's law applies. Dissolved ozone decomposes in water solutions quicker the higher the pH. As a result several radicals (among of them the very active °OH-radicals) are formed. The main steps of the °OH-radicals formation are:

$$O_3 + OH^- \rightarrow {}^\circ O_2^- + {}^\circ HO_2 \quad (12)$$

$$O_3 + {}^\circ HO_2 \rightarrow 2O_2 + {}^\circ OH \quad (13)$$

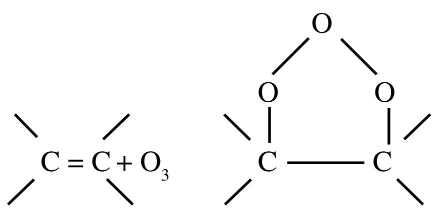
Ozone is a very strong oxidant; its normal oxidation potential at 25 °C is 2.07 V in acidic solutions and 1.24 V in basic solutions. Only fluorine and °OH-radicals have higher oxidation potential.

In its reactions with inorganic or organic compounds in water, usually one of three oxygen atoms is active, while the residual two are separated as an oxygen molecule:

$$CN^- + O_3 \rightarrow CNO^- + O_2 \quad (14)$$

$$RCH_2OH + 2O_3 \rightarrow RCOOH + 2O_2 + H_2O \quad (15)$$

However, with unsaturated hydrocarbons, ozone forms very unstable intermediates (*ozonides*) involving all three oxygen atoms:



Ozonides decompose very quickly resulting in formation of polymers or aldehydes, ketones and organic acids.

The reaction rate of molecular ozone with organic compounds depends on their oxygen saturation degree and may range from 0.1-1.0 (carboxylic acids) up to 10^6-10^8 (aniline, toluidine) $M^{-1}s^{-1}$. As a rule, chemical reactions of ozone with organic compounds are of second order; first order by both compounds concentrations.

During the ozonation process, depending on the ozone dose consumed, several intermediate oxidation products are formed. For example, ozonation of ordinary phenol (C_6H_5OH) proceeds through the steps of resorcinols formation (with 2 OH-groups) and decyclisation to muconic acid, muconic aldehyde and maleic and fumaric acids.

Higher doses of ozone (7-10 mole/mole) will lead to the formation of glyoxal (HOC-COH), formic acid (HCOOH), oxalic acid ($(COOH)_2$) and glyoxalic acid (HOCCOOH). Theoretically, all organic compounds consisting of carbon and hydrogen may be oxidised to the final inorganic products, CO_2 and H_2O, but ozone requirements in this case may exceed 15-25 mole/mole, which is not economical.

Ozone has a complex impact on water/wastewater parameters – it reduces colour, improves taste and odour, kills bacteria and viruses (even the chlorine-resistant Polio-virus), oxidises iron, manganese, cyanide, phenol, benzene, chlorophenol, atrazine, nitrobenzene and other pollutants. Ozonation is a cost-effective treatment method for many types of industrial wastewaters. From the point of view of wastewater treatment it is very important that ozone can increase the *biodegradability of* wastewater, i.e. increase the ratio BOD/COD before the activated sludge process.

Figure 19.14 (especially the scheme below) illustrates the impact of ozonation on the ratio BOD/COD. If the raw effluent is characterised by COD

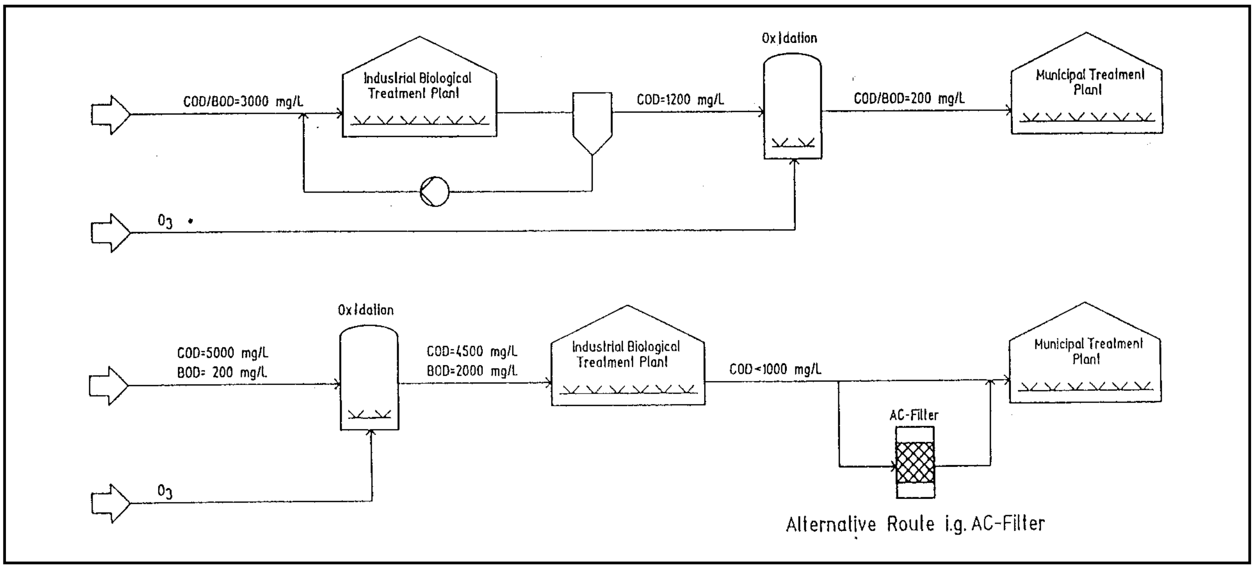


Figure 19.14. Effect of oxidation by ozone on COD/BOD content (Von der Mark et al., 1993).

= 5 000 mg/l and BOD = 200 mg/l; then, after ozonation, the corresponding values are 4 500 and 2 000 mg/l. The ratio of BOD/COD and biodegradability was increased 10 times (!) due to ozonation.

During conventional bleaching of Kraft pulp, a significant amount of organic material is dissolved in the first two bleaching stages, chlorination and alkaline extraction. Over 200 chlorinated organic compounds have been identified in bleach plant effluents. Some of them exhibit acute and chronic toxicity, while others are persistent and bio-accumulate. Studies on the oxidative treatment of bleaching effluents with ozone are being spread rapidly. Ozonation is particularly effective in removing colour. In *acidic* conditions, *direct* ozonation reactions are highly selective and only those compounds containing functional groups that are easily attacked by the electrophilic ozone become oxidised. In *alkaline* conditions, ozone decomposition leads to the formation of *°OH-radicals* and to *indirect* and *non-selective* oxidation reactions (AOPs).

The combination of radicals and molecular effects of ozone is efficient and economical. An 80 % reduction of AOX (adsorbable organic halides) and over 60 % reduction of COD and BOD can be observed. Acute toxicity and chlorophenolic derivatives disappear. A rough estimation of cost indicates that the use of ozone in treating bleaching effluents was expensive, but its combination with biological treatment is still very attractive.

Advanced oxidation processes (AOPs) are defined as near ambient temperature and pressure water treatment processes which initiate complete oxidative destruction of organics based on the generation of hydroxyl radicals, °OH. AOPs used for the treatment of process wastewater and groundwater include:

ozone at elevated pH (> 8.5)
ozone + hydrogen peroxide (H_2O_2)
ozone + granular activated carbon
photooxidation:
UV + O_3 + H_2O_2
UV + H_2O_2
photocatalysis:
UV + TiO_2.

Ozone at elevated pH. As pH rises, the decomposition rate of ozone in water increases. For example, at pH 10, the half-life of ozone in wastewater can be less than 1 minute. Oxidation of organic species may occur due to a combination of reactions with molecular ozone and reactions with °OH.

The rate of attack by °OH-radicals is typically 10^6 to 10^9 times faster than the corresponding rate for molecular ozone. The major operating cost for the ozone oxidation process is the cost of electricity for ozone generation. The energy requirement for ozonation using air ranges from 22 to 33 kWh/kg O_3, including air handling, preparation and ozone contact with water. The energy requirement for ozone production from pure oxygen is approximately half, but then the cost of the oxygen should be added.

Ozone + H_2O_2 (peroxone). Addition of H_2O_2 to ozonation processes can initiate the decomposition cycle of ozone, resulting in the formation of °OH-radicals. H_2O_2 is a relatively inexpensive, readily available chemical oxidant. H_2O_2 is produced by electrolysis of ammonium bisulphate or by oxidation of alkylhydroanthraquinones. The electrolytic process consumes approximately 7.7 kWh/kg of H_2O_2 produced.

The very interesting combination *ozone plus granular activated carbon (GAC)* for creating °OH-radicals was discovered and described only recently by the Swiss scientists Jans & Hoigne (1998). They

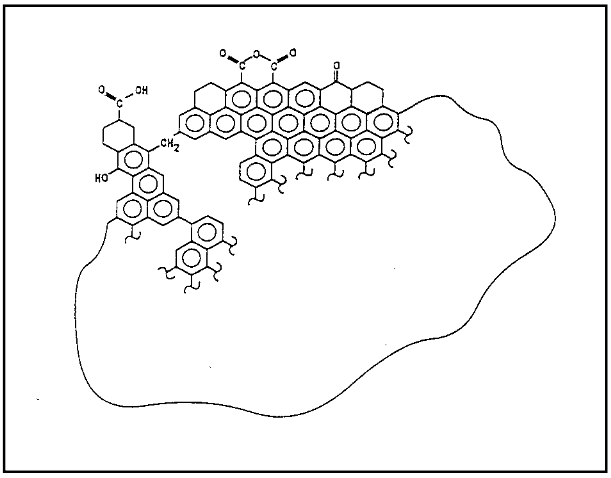


Figure 19.15. Proposed structure of activated carbon and carbon black (Sergides et al., 1987). A variety of different chemical groups can be seen on the skeletal carbon framework of AC or CB able to initiate radical-type chain reactions.

established that if a few milligrams per litre of activated carbon or carbon black was added to ozone-containing water, a suspension of the radical-type chain reactions in the aqueous phase would be initiated and there would be an acceleration in the transformation of ozone into °OH-radicals. The authors explained this phenomenon as being due to the existence of a variety of chemical groups on the skeletal carbon framework of activated carbon or carbon black (Figure 19.15).

Photooxidation. Completion of oxidation reactions, as well as oxidative destruction of compounds immune to ozone and H_2O_2 oxidation alone, can be obtained by supplementing the reaction with ultraviolet (UV) radiation. UV radiation accelerates the decomposition of ozone and hydrogen peroxide molecules. The photolysis of aqueous ozone produces H_2O_2 as an intermediate product, which then decomposes to °OH. Ozone readily absorbs UV radiation at the 254 nm wavelength. Many organic contaminants absorb UV energy as well and decompose due to direct photolysis or become excited and more reactive with chemical oxidants.

Although photochemical cleavage of H_2O_2 is conceptually the simplest method for hydroxyl radical production, the exceptionally low molecular absorptivity of H_2O_2 at 254 nm (20 $M^{-1}cm^{-1}$) limits the °OH yield in the solution (0.09 °OH-radicals are formed per photon). Photolysis of dissolved ozone (3 300 $M^{-1}cm^{-1}$) yields 2.0 °OH-radicals formed per photon. In practice the power requirement for UV lamps in ozone photolysis processes is in the watts range, as compared to the kilowatts range for hydrogen peroxide photolysis.

In *photocatalysis*, UV radiation is used to excite a solid-state metal catalyst (TiO_2), creating positive and negative charge (electron hole, e-h+ pairs) on the catalyst's surface. These positive and negative charges promote redox reactions, e.g. oxidation of organics in the solution by the photogenerated positive charges and reduction of metal ions or oxygen by the photogenerated negative charges.

TiO_2 may be introduced in the process as a slurry or fixed catalyst. In the slurry method microfiltration is a necessary post-treatment step to remove TiO_2 particles. Photocatalysis can be driven by near-UV (300-400 nm) radiation; therefore, solar energy can be used to empower the processes. Table 19.7 presents a comparison of AOPs operating costs.

Table 19.10. Comparative operating costs of advanced oxidation processes (AOPs) (EPRI, 1996)

Process	Cost of oxidant	Cost of UV
O_3/UV	High	Medium
O_3/H_2O_2	High	N/A
H_2O_2/UV	Medium	High
Photocatalysis	Very low	Medium-high

Applications of advanced oxidation processes

Up to 10 % of the oil shale mined in Estonia (about 2.5 million tonnes annually) is treated chemically at a temperature of 500-550 °C to produce oil. Phenolic effluents from crude oil separation and phenols extraction together with sewage from the local settlements (15 600 m^3/day, COD 1 570 mg/l. total phenols

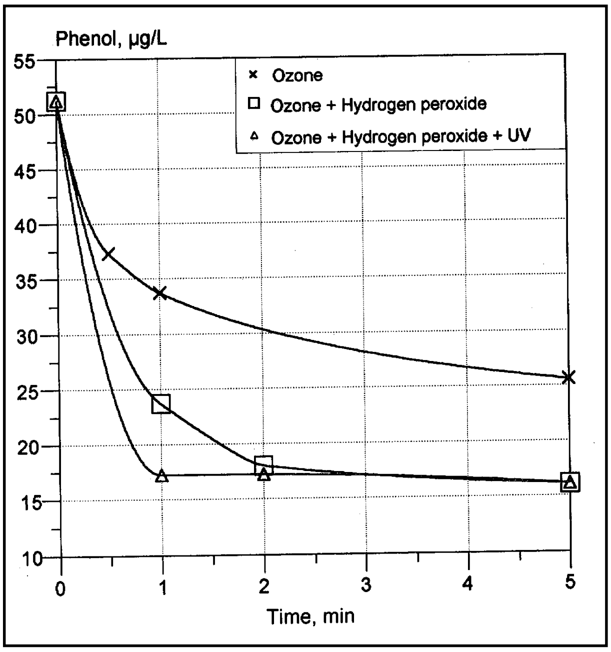


Figure 19.16. Phenol concentration reduction versus time (Preis et al., 1995).

120 mg/l) are treated biologically at the Central Wastewater Treatment Plant in Kohtla-Jarve.

A significant modern-day reduction of the capacity of oil shale semi-coking was made in 1994. Because of this, the concentration of the total phenols at the outlet of the biological treatment plant was only 3.3 mg/l (COD 100 mg/l) in April 1994 instead of 95 mg/l (COD 840 mg/l) in 1987.

Ozone and its combinations with H_2O_2 and UV were studied for post-treatment of the biologically treated phenolic effluent to achieve the MPC = 0.5 mg/l of total phenols established by the Estonian Ministry of Environment. Figure 19.16 illustrates clearly the impact of the addition of H_2O_2 and UV to ozone in simple phenol concentration reduction. Figure 19.17 shows the flow diagram for an AOP used to destroy organic compounds in contaminated water. This process utilises chemical oxidants, ozone and hydrogen peroxide, in combination with UV radiation, to achieve optimum destruction efficiency.

Wet oxidation

Wet oxidation is an attractive destruction method for the treatment of waste streams that are too dilute to incinerate but too concentrated or toxic for biological treatment. Wet air oxidation (WAO) involves liquid phase oxidation of organic or oxidisable inorganic components at elevated temperatures (125-300 °C) and pressures (0.5-20 MPa) using a gaseous source of oxygen (usually air). WAO has been demonstrated to oxidise organic compounds to CO_2 and other innocuous end products. Carbon is oxidised to CO_2, nitrogen is converted to NH_3, NO_3, or elemental nitrogen, and halogens and sulphur are converted into inorganic halides and sulphates. The lower concentration limit of organic substances for wet air oxidation is about 20 g/l COD.

Chemically, the end results of wet oxidation are similar to the end results of conventional oxidation in a furnace or incinerator. However, the mechanism of oxidation is different. Instead of taking place at atmospheric pressure at high temperature and on the dry material, wet oxidation takes place at relatively high pressures, low temperatures and in the presence of liquid water. Sometimes different metal catalysts are used as well. This is why wet air oxidation has often called "burning without a flame." The wet air oxidation process presents the following reaction-engineering problems:

- The air oxygen needed for oxidation must be dissolved in the wastewater.
- The dissolved oxygen must react with the organic compounds.

Wet oxidation reaction kinetics has been the subject of numerous studies. Most of the published results indicate that wet oxidation proceeds by a free-radical reaction mechanism. Free radicals, in the absence of initiators, are formed by the reaction of oxygen with the weakest C-H bond of the oxidised organic compound:

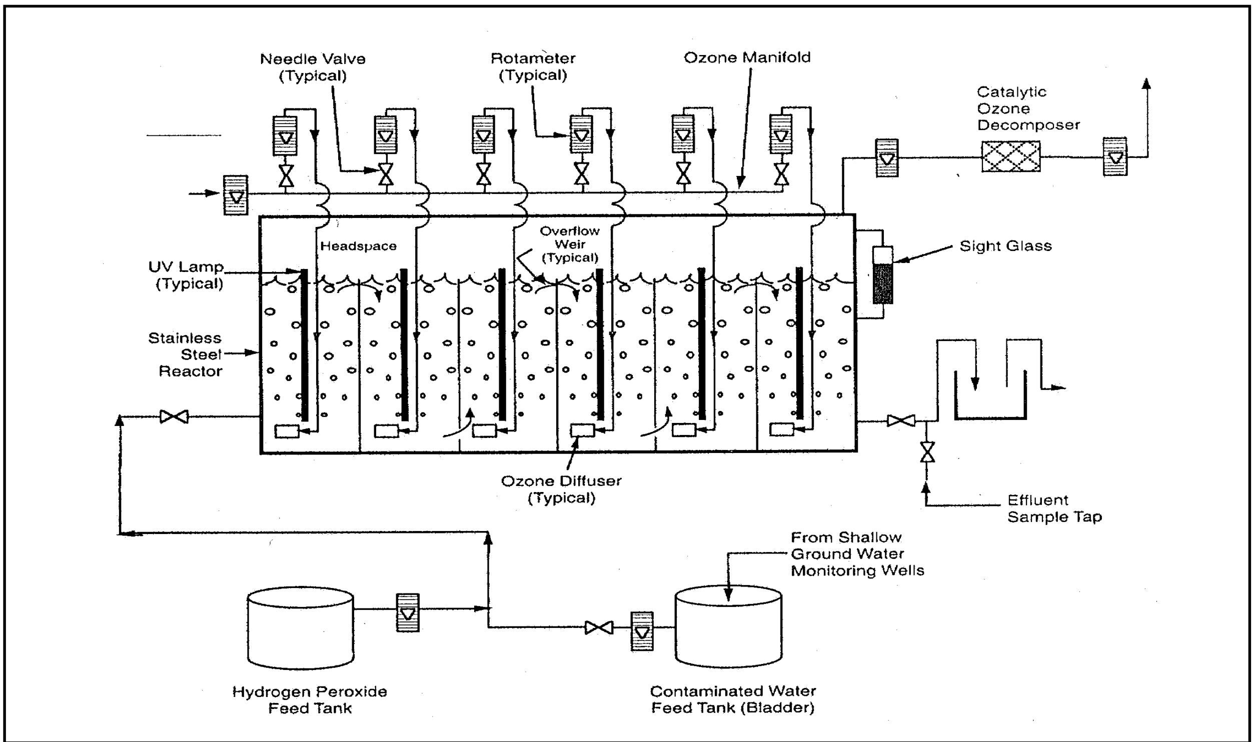


Figure 19.17. Flow diagram for an advanced oxidation process (O_3/H_2O_2/UV) to destroy organic contaminants (EPRI, 1996).

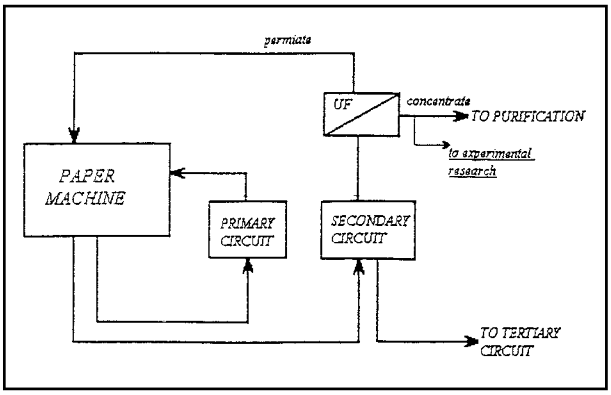


Figure 19.18. Ultrafiltration-concentrate formation in the secondary water circuit of a paper machine. Ultrafiltration concentrate contains different lipophilic extractives and has a typical COD of 4 000-8 000 mgO_2/l, solids content of 10-15 g/l, and pH of 5.0-6.5.

$$RH + O_2 \rightarrow R° + HO_2°$$

$$RH + HO_2° \rightarrow R° + H_2O_2$$

$$H_2O_2 + M \rightarrow 2°OH$$

where M can be either a homogeneous or heterogeneous species. The thermal decomposition of hydrogen peroxide at WAO temperatures is also significant:

$$H_2O_2 \rightarrow H_2O + 1/2\ O_2$$

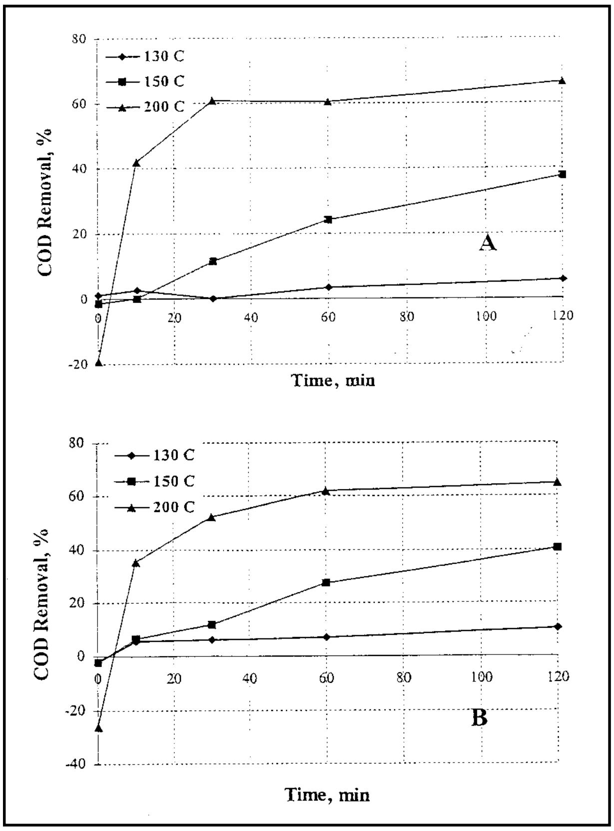


Figure 19.19. The effect of wet air oxidation (WAO) reaction temperature on the COD reduction of the membrane concentrate (A – non-filtered sample, B – filtered sample) at oxygen partial pressure of 1 MPa.

Since the °OH radical has a large electron affinity (568 kJ), it oxidises not only all organic compounds containing hydrogen, but also reacts with most halide ions to produce halide radicals.

Despite of the advantages described above, WAO has the shortcomings of requiring relatively high oxygen pressures as well as high temperatures, resulting in high capital and operating costs and incomplete or partial oxidation. In the presence of a catalyst, organic compounds are more rapidly and more thoroughly oxidised to carbon dioxide and water. The process may be operated at lower temperature, lower pressure and reduced reaction time. Practically all metals that change their valence easily and hence are suitable as redox catalysts can be used (Cu, Cu-Zn, Mn, Mn-Zn-Cr, Co, Co-Bi, Fe, Ti, Al etc.).

Wet air oxidation has been successfully applied in the treatment of sewage sludge, to convert the sludge into a sterile and biologically stable mass with good settling and dewatering characteristics. Wet air oxidation is a very promising method of treating the black liquor from pulp and paper mills, since the conventional treatment method (evaporation with incineration in furnaces) does not yield a satisfactory recovery efficiency of chemicals and energy. WAO has also been used for treatment of the paper machine effluents' membrane separation concentrates (Figure 19.18 and 19.19).

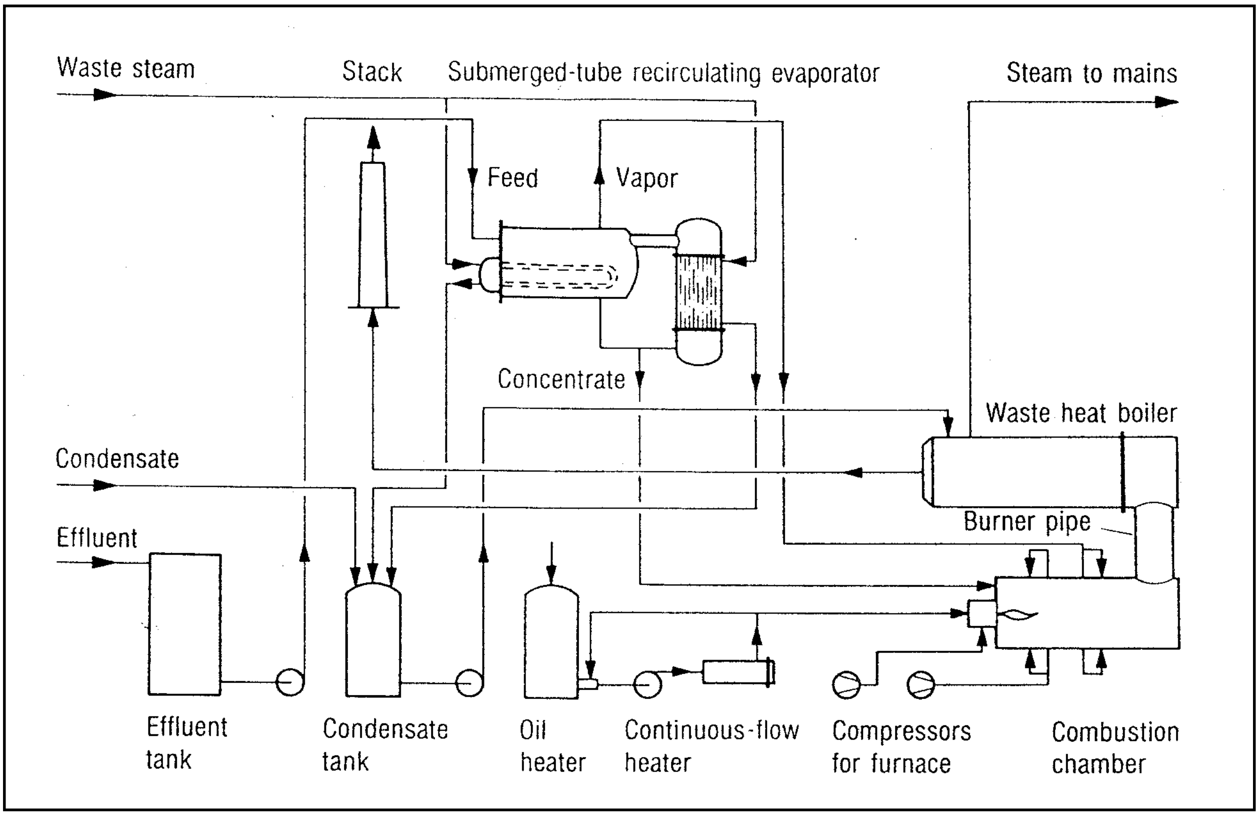


Figure 20.1. Flow chart of the Hoechst AG process for the heat treatment of industrial effluents (Billet, 1989). Plant designed by Friedrich Uhde GmbH, Dortmund.

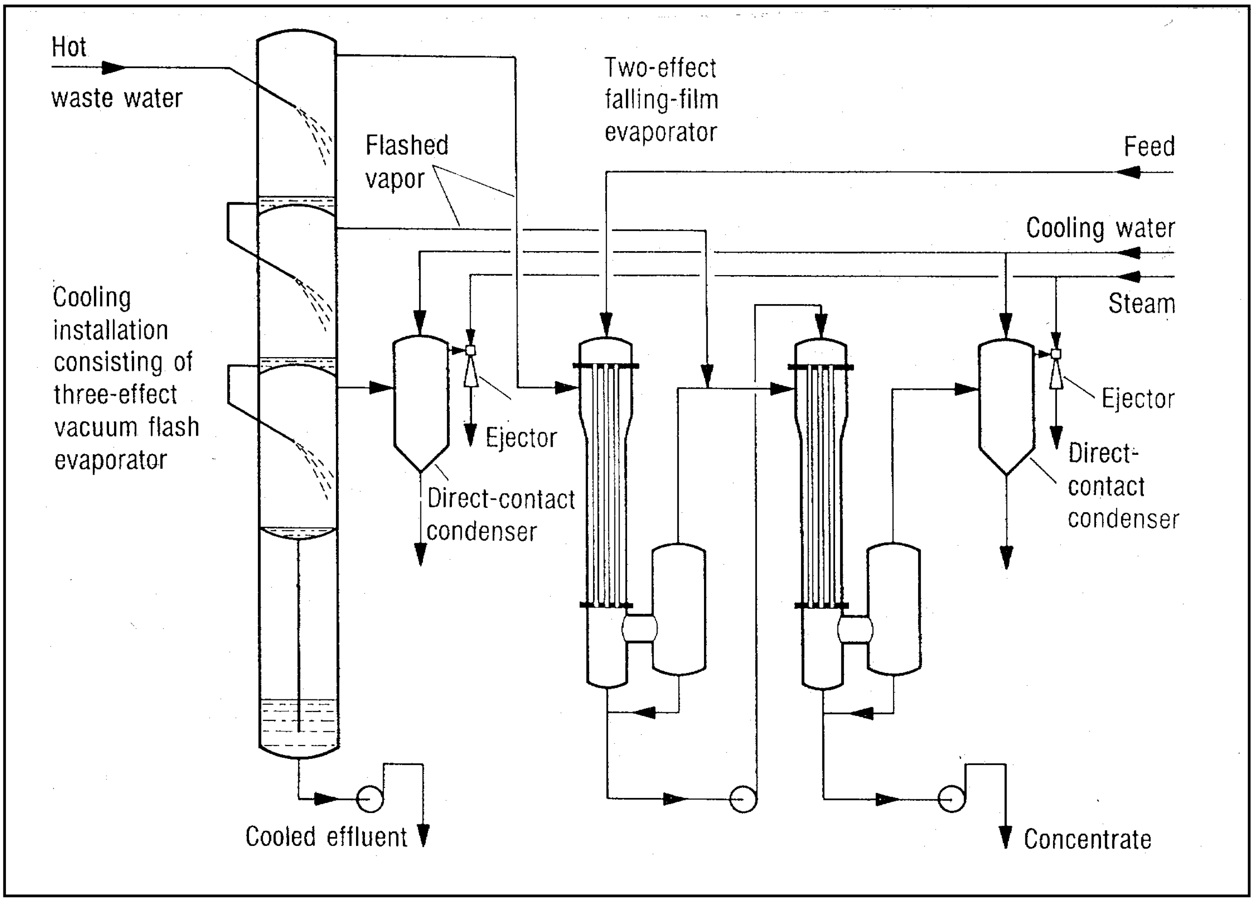


Figure 20.2. Exploitation of waste heat and recovery of condensates from hot effluents in an integrated vacuum flash/ falling-film evaporator (Billet, 1989).

20.
Industrial cooling water

Rein Munter

Thermal disposal of effluents

In many cases when industrial effluents contain high pollutant loads that defy biodegradation, recourse is taken to thermal processes in which the organic constituents are oxidised in excess air to water and carbon dioxide in a vapour phase. The heat thus obtained is utilised in raising steam.

The installations for this purpose are similar in layout to desuperheaters and consist essentially of an evaporator, a combustion chamber, a mixing tube and a waste-heat boiler. As sketched out in Figure 20.1, the evaporation stage comprises a submerge tube and a recirculating evaporator with vertical tubes connected to each other on both the water and the vapour side. About 80-100 % of the water is evaporated in it, and the saturated steam thus produced is injected through nozzles into a combustion chamber. The remaining 0-20 % is withdrawn from the evaporator stage in the form of boiling water, which is also led to the combustion chamber. In this way, the accumulation of low-volatility organic compounds is avoided. In an installation of this nature, designed to cope with effluent at a rate of 6 m^3/h, the area of the heat transfer surfaces in the submerged-tube evaporator is 90 m^2 and in the recirculating evaporator, 180 m^2. Steam is generated in the installation at 121 °C, and the boiling point in the vapour space is 104 °C.

Exploitation of waste heat

Flash evaporation in multistage vacuum coolers offers a means of recovering heat from effluents discharged at high temperatures and of recycling the water in the form of condensed vapour. In the plant shown in Figure 20.2, the effluent is flashed in a cyclone evaporator designed as a three-stage vacuum cooler. The vapour is virtually free from water droplets containing solids and is used for heating a two-effect falling-film evaporator without fouling the heater surfaces. Since the process entails small differences in temperature, falling-film evaporators are particularly effective. In one example for a plant of this nature, effluent fed at a rate of 600 m^3/h and a temperature of 80 °C is flashed to 40 °C and yields about 15 tonnes/h of steam for heating the evaporator. These examples illustrate the great scope available for treating industrial effluents in conformance with local conditions and environmental legislation. They can also be regarded as typical representatives for other accepted water treatment techniques.

Cooling tower water treatment

Cooling tower makeup water represents a significant water use for many industries. For industries such as electric power generating stations, oil refining and many other types of manufacturing plants, one-quarter to more than one-half of the total water use may be cooling tower makeup. Because a cooling tower normally operates as a closed-loop system, it can be viewed as a separate water system with its own specific set of water quality requirements, largely independent of the particular industry involved.

The basic principle of cooling tower operation is that of evaporative condensation and exchange of sensible heat. The air and water mixture releases latent heat of vaporisation.

Water exposed to the atmosphere evaporates, and as the water changes to vapour, heat is consumed that amounts to approximately 4 000 kJ per kg of water evaporated.

Under normal operating conditions, the loss of water, discharged from the cooling tower to the atmosphere as hot vapour, amounts to approximately 1.2 % for each 10 °C of cooling range. Drift, or water lost from the top of the tower to the wind, is another mechanism by which water is lost from the cooling system. A loss of about 0.05 ‰ of the recirculating water occurs in this way. To prevent the formation of precipitates in the resulting higher-concentration tower water, a portion of the concentrated cooling water is bled off and replaced with low salt makeup water to maintain a proper salt balance. The bled-off water from the cooling tower system, which is highly saline, is called blow-down.

The total makeup water flow for the cooling tower system includes all three types of water losses. The

Hazardous wastes

Hazardous-waste treatment
"If we are going to live so intimately with these chemicals – eating and drinking them, taking them into the very marrow of our bones – we had better know something about their nature and their power."
Rachel Carson, Silent Spring

Emergence of the concept

Around the beginning of the 1980s, hazardous waste became the leading environmental issue of the modern society. Now, at the end of 1990s, while at the same time science has accumulated information showing some potentially devastating problems in global ecosystems, hazardous waste still continues to attract a great deal of attention, at least in terms of money spent on environmental programs.

The problem did not emerge overnight. Environmental contamination by toxic substances from waste or other sources has a long history. It would appear that many wealthy Romans suffered from lead poisoning two millennia ago, and the decline of the Roman Empire has sometimes been attributed, at least in part, to lead-induced psychoses among the emperors.

However, it was the rapid pace of technological developments, beginning with the Industrial Revolution, that created the real roots of the problem, as we know it today. The advent of the Industrial Revolution spurred progress on many fronts. Advances in medical science and public health reduced the death rate, helping to promote a rapid growth of human population and personal consumption. Intensive agriculture supplied more goods, but with these goods came toxic substances. Sometimes these toxicants were already in the wastes generated when making the goods. Gradually, exposure to hazardous substances occurred outside the workplace via various environmental pathways. It started first with inorganic compounds such as lead and mercury, and expanded later, upon their introduction in the 20th century, with synthetic organic compounds. The long-term toxic nature of hazardous substances and the inability of the environment to assimilate them completely have done the rest.

What is hazardous waste?

The term "hazardous waste" usually means a solid waste, or a combination of solid wastes, which, because of its quality, concentration, or physical, chemical, or infectious characteristics, may cause or significantly contribute to an increase in mortality or an increase in serious irreversible illness.

Hazardous wastes include chemical, biological, flammable, explosive and radioactive substances. In practice, they may be in a solid, liquid, sludge, or gaseous state. A waste is regarded as hazardous if it is lethal, non-degradable and persistent in the environment, can be biologically magnified (as in food chains), or otherwise causes detrimental cumulative effects.

The working definition of hazardous waste, prepared under the United Nations Environment Programme in December 1985, separates the radioactive and infectious wastes from hazardous ones, stating: Hazardous wastes mean wastes (solids, sludges, liquids and containerized gases) other than radioactive and infectious wastes, which, by reason of their chemical activity or toxic, explosive, corrosive, or other characteristics, cause danger or likely will cause danger to health or the environment, whether alone or when coming into contact with other waste…

Origins of hazardous waste

Hazardous wastes can originate from a wide range of industrial, agricultural, commercial and household activities. Their major categories are:

- inorganic aqueous waste (spent sulphuric acid from galvanising, spent caustic baths from metal finishing, rinse-water from electroplating etc.),
- organic aqueous waste (rinse-water from pesticide containers, wash-water of chemical reactors etc.)
- organic liquids (spent halogenated solvents from metal degreasing and dry cleaning, distillation residues etc.)
- oils (used lubricating oils from internal combustion engines, used hydraulic and turbine oils, contaminated fuel oils etc.)
- inorganic sludge/solids (wastewater treatment sludge from chlorine-alkaline production, emission control dust from steel manufacture, waste-sand from coking operations etc.)
- organic sludge/solids (sludge from painting operations, tar residues from dyestuff intermediates production, distillation bottom tars from phenols production, soil contaminated with spilled solvents etc.).

Hazardous waste treatment

In many countries almost 90 % of all hazardous waste is hazardous wastewater. Regardless of the degree of acidity, the main method of treatment of acid wastes is neutralisation. This may be carried out by filtration of acid waste through the limestone bed or by adding lime. Oil refineries use sulphuric acid for desulphurisation, improvement of colour, refinement of lubricating oils etc. Oil refineries commonly use two processes for sulphuric-acid wastes disposal: spray-burning and indirect combustion.

Hazardous-waste treatment

Spray burning involves spraying waste acid into a hot combustion chamber (900-1 100 °C) with small amounts of excess air added to oxidise hydrocarbons to CO_2 and H_2O. The hot gases are cooled and dried, and the SO_2 is absorbed to make new sulphuric acid.

The principal reaction of the second method, indirect combustion, is the reduction of the sulphuric acid in the sludge by the hydrocarbons that are present. The granular by-product coke is recirculated through a mixer, acid sludge is added to this circulating stream, and heat is applied in the decomposing chamber.

Another example of organic liquid waste treatment concerns formaldehyde, used in numerous industries such as plastics, leather and antibiotics. It is an effective antiseptic agent, but waste treatment of a biologically inhibiting agent presents unique problems. A concentration above 130 to 175 ppm is lethal to bacteria in sewage. However, adaptation processes and selection of bacteria may increase the oxidisable concentration of formaldehyde up to 1 750 ppm.

Dickerson found that a high-rate biological trickling filter could be used to treat formaldehyde, organic oils and organic acids. In his later studies he reported on a complete treatment plant for formaldehyde wastes, involving aeration and activated sludge along with trickling filtration and with a BOD removal efficiency of approximately 90 %.

Radioactive wastes

Radioactive wastes are considered the most dangerous because they have a cumulative effect in nature and may cause irreparable damage to living tissue. Radioactive wastes may be liquid, gaseous, or solid; furthermore, they may exhibit high or low levels of activity. Since 1980 radioactive wastes have been classified in the following categories:

- high-level waste (HLW). HLW includes spent nuclear fuel from commercial nuclear reactors and the solid and liquid wastes from reprocessing spent or irradiated fuel;
- uranium mining and mill tailings. The pulverised rock and leachate from uranium mining and mill operations;
- transuranic waste (TRU). Radioactive waste that is not HLW but contains more than 3 700 Bq per gram of transuranic elements;
- by-product material. Any radioactive material, except fissile nuclides, that is produced as waste during plutonium production or fabrication;
- low-level waste (LLW). LLW includes everything that is not included in one of the other categories.

Radioactively contaminated cooling water

The primary and secondary coolants in a nuclear generating plant pick up considerable radioactive contamination through controlled leaks. Contaminants are removed from the cooling water by ion exchange. In the co-precipitation phase the insoluble precipitate acts as a "scavenger" or "carrier" to co-precipitate radioactive ions from solution. Prior to precipitation the pH is adjusted to an alkaline condition to form metal hydroxide flocs, which aid in the scavenging process.

After the supernatant settles, the sludge is removed, packaged for transportation and disposed of through burial. Co-precipitation is known to yield decontamination factors of 200 to 1 000.

Evaporation is at present the most widely used concentration process for water solutions, containing a mixture of waste of low-level activity. The wastes are boiled, the resultant vapour is condensed, and the condensate is subsequently released to the sewer.

Although evaporation is expensive, it is usually very effective and provides decontamination factors of 100 000 to 1 000 000.

Cation exchange is the principal ion-exchange process used to concentrate radioactive waste. Both synthetic resins and Montmorillonite clay serve as exchangers. This method is customarily reserved for small volumes of solutions containing low concentrations of solids and exhibiting low levels of radioactivity.

Waste disposal

It must be noted that the ultimate disposition of all liquid wastes was until recently accomplished by either burying in the earth or dumping in the ocean. It is also important to note that these two options, mined geologic disposal and sub-seabed disposal, have been investigated further. At present, mined geologic disposal is still under very thorough investigation, but sub-seabed disposal is no longer being considered. Techniques now being applied to LLW include impervious packaging, compaction, incineration and stabilisation in asphalt or a cement matrix. Compaction can achieve volume reduction of about 8:1 and incineration can reduce volumes by factors of 30 or more. Of course, incineration emissions require careful monitoring.

The concept of a facility dedicated to the full management of hazardous waste is not new. Many generators included construction and operation of their own captive facilities, referred to as on-site facilities. Other generators, not having a suitable site or not generating a sufficiently large volume of waste to justify investment in an on-site facility, transported their waste off site to specialised facilities for treatment and disposal, referred to as commercial, off-site facilities. The commercial hazardous waste management industry began developing off-site facilities in the late 60s. Some large commercial facilities now employ aqueous treatment, incineration, land disposal etc.

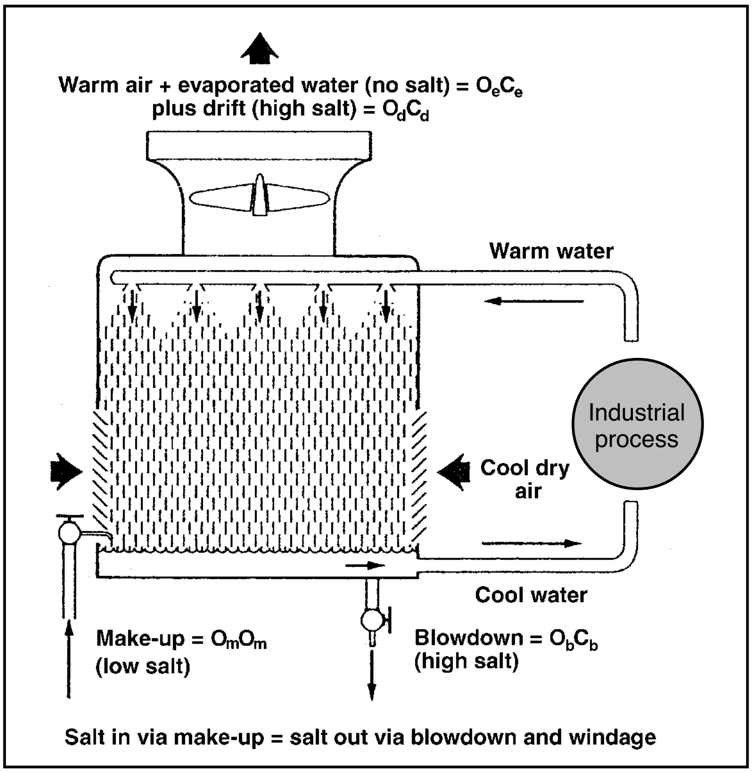


Figure 20.3. Definition sketch for salt balance in the recircu-lating, evaporating cooling tower (Metcalf & Eddy, 1991).

definition sketch for a recirculating evaporative cooling tower is shown in Figure 20.3.

Four general water quality problems are encountered in industrial cooling tower operations: (1) scaling, (2) metallic corrosion, (3) biological growths, and (4) fouling in heat exchanger and condensers (Figure 20.4). Calcium scales (calcium carbonate, calcium sulphate and calcium phosphate) are the principal causes of cooling tower scaling-problems. Magnesium scales (magnesium carbonate and phosphate) can also be a problem. A reduction of the potential for scaling in wastewater is achieved by controlling the formation of calcium phosphate, which is the first calcium salt to precipitate if phosphate is present. Other treatment methods, such as ion exchange and reverse osmosis, reduce scale formation by removing calcium and magnesium. Reverse osmosis may be linked into a cooling system in two main, distinct ways: (1) for treatment of the circulating water, and (2) for treatment of the makeup water.

Corrosion can occur when an electrical potential between dissimilar metal surfaces is created. The corrosion cell consists of an anode, where oxidation of one metal occurs, and a cathode, where reduction of another metal takes place. Contaminants such as TDS (total dissolved solids) increase the electrical conductivity of the solution and thereby accelerate the corrosion reaction. The corrosion potential of cooling water can be controlled by the addition of chemical corrosion inhibitors.

The warm, moist environment inside the cooling tower also makes an ideal environment for promoting biological growth. Nutrients, particularly N and P, and available organics further encourage the growth of microorganisms that can attach and deposit on heat exchanger surfaces, inhibiting heat transfer and water flow.

Ozone applications in cooling tower systems are relatively new, initially used in the late 1970s. Increased use and interest did not occur until ten years later, when ozone applications were used primarily as biocontrol agents but also as a stand-alone treatment replacing scale, corrosion and chemical treatments. Ozone definitely has a place in today's cooling tower system protection, and greater consideration and use will in all likelihood ensue when its mechanisms have been studied and understood better.

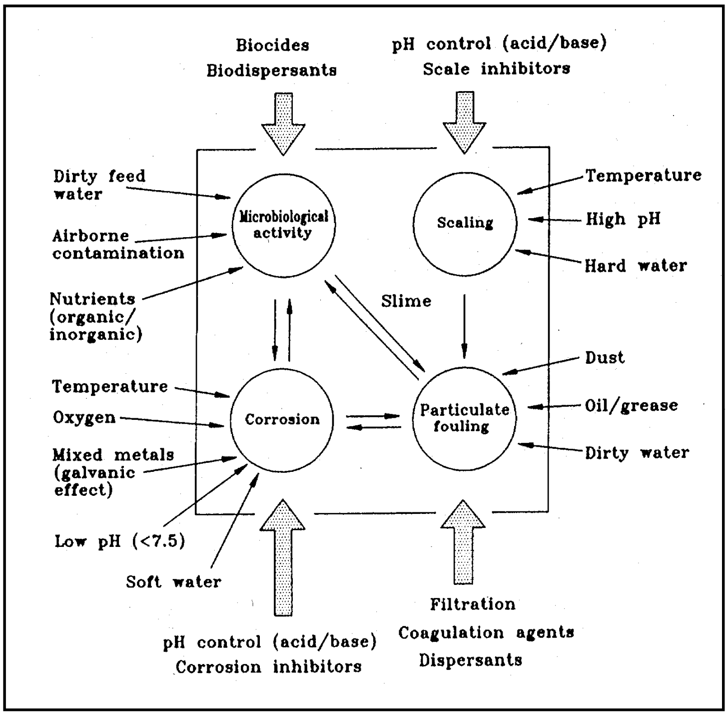


Figure 20.4. Factors affecting the performance and efficiency of cooling water and measures for their control (Newton & Solt, 1994).

21.

WATER MANAGEMENT APPROACHES

Rein Munter

Wastewater reclamation and reuse

Wastewater reclamation is the treatment of wastewater to make it reusable. Wastewater reuse involves the beneficial use of treated wastewater in applications such as irrigation, industrial cooling or as process water. Because of limited surface and groundwater resources, the use of highly treated wastewater effluent, now discharged to the environment from municipal or industrial wastewater treatment plants, is receiving more attention as an alternative source of water.

There are three possibilities for reducing wastewater:

- *Reuse*. Wastewater can be reused directly in other operations providing the level of previous contamination does not interfere with the process. Reuse can sometimes require wastewater being blended with wastewater from other operations and/or with freshwater.
- *Regeneration reuse.* Wastewater can be regenerated through partial treatment to remove the contaminants that would otherwise prevent its reuse. It can then be reused in other operations. Again, reuse after regeneration may require blending with wastewater from other operations and/or with freshwater. When water is reused after regeneration it is not re-entered into processes in which it has previously been used.
- *Regeneration recycling*. Wastewater can be regenerated to remove contaminants that have built up when the water was recycled. Here, water can re-enter processes in which it has previously been used.

It is important to distinguish between the above cases. In some instances recycling between operations can be allowed. In other cases it might not be possible, due to the build-up of contaminants not removed in the regeneration process.

Three classes of contaminants are of special concern in wastewater reclamation and reuse when the potable water supply is involved: (1) viruses, (2) organic contaminants including pesticides, and (3) heavy metals.

Integrating needs and supply

The optimum wastewater reclamation and reuse project is best achieved by integrating both wastewater treatment and water-supply needs into one plan. In the implementation of wastewater reclamation and reuse, the reuse application will usually govern the wastewater treatment needed and the degree of reliability required for the treatment processes and operations.

To determine the water supply benefit of a wastewater reclamation and reuse project in an economic analysis, the project is usually compared to the development of a new freshwater supply. In performing such an analysis, the relevant costs for comparison are the future cost of (1) constructing new freshwater facilities, and (2) operating and maintaining all the facilities needed to treat and deliver the new increment of water supply development.

Zero aqueous discharge

“Zero discharge” seems likely to become the environmental target for the future on the logic that if there is “zero discharge,” there can be no environmental impact and no pollution. This concept has been variously interpreted as “zero environmental impact discharge” and “zero aqueous discharge,” focusing on concerns that aqueous waste should be minimised instead of large quantities of solid or gaseous waste being produced as a result of energy-intensive recovery processes.

Zero aqueous discharge means no aqueous discharge from any point of the manufacturing site. This means either the total recycling of water, including treated aqueous effluent, or the evaporation of any such effluent, resulting in a solid waste for landfill. Water management is the name given to the integration and control of water systems ensuring that *both the usage and discharge of water are minimised*. This includes all areas of water use, including process and utilities such as cooling and water purification.

There are several driving forces to minimise water use that are common to all industries and geographical regions. The differences between the driving forces may be subtle, but the distinctions between them are very important to the industry involved and the attitude that industry displays towards reducing water consumption. It is common to find a combination of driving forces being used to support specific projects.

Many regions of the world suffer from a chronic shortage of raw water of suitable quality for domestic or industrial use. Variations in rainfall patterns have reduced the availability of good quality surface waters, while groundwater may become increasing saline as more water is drawn from bore holes and wells. The availability of water for human consumption takes precedence over industrial use, so industry is forced to look for alternative raw water sources that are less pure, or to recycle water – for example, from municipal effluent treatment plants, or to reduce water consumption.

Increasing demands for higher quality drinking water have led to very large capital investments by the suppliers of water to ensure removal of trace contaminants. These may be heavy metals, organic material and environmentally persistent chemicals such as pesticides, fungicides and insecticides. This increased investment has resulted in significantly higher water costs to consumers, both private and industrial, although the improvements in water quality are of little direct benefit to industrial users.

Water management

Even if discharge of aqueous effluent is permitted, this discharge is subject to increasingly stringent consent-conditions imposed by the regulatory authorities. It is likely that discharge restrictions will become even tighter in the future, requiring more investment in effluent treatment plants if industry is to maintain its "licence to operate."

Discharge limits depend on the quality and size of the receiving water, which means that inland sites on small watercourses will be imposed with many more restrictions than sites on estuaries or by the sea.

Investments in new effluent treatment plants are viewed as non-productive but essential by most industrial sectors. But the increasing costs of effluent treatment provide an added incentive to reduce the volume and contamination of wastewater.

Effluent treatment is commonly based on suspended solids removal and biological treatment, for which the basic plant design comprises large settlers and holding tanks, often allowing several days of holding capacity for wastewater. For this reason, the cost of such a plant is largely determined by the volumetric throughput. If the total volume of effluent could be reduced – for example, by reducing the demand for water – significant capital savings would result.

The steps

It is not possible to move from the present state to the ideal "zero aqueous discharge" in one step. The complexity of most water systems means that improvements have to be made progressively, starting with the cheapest and most beneficial. For the chemical and refining industries, where both process and utility uses of water are involved, the potential savings are as follows:

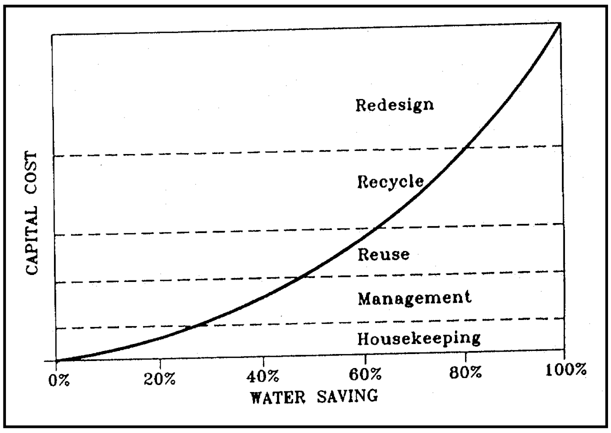


Figure 21.1. Cost implementation (Newton & Salt, 1994).

- *reductions in uncontrolled use*, for example, poor housekeeping (20-30 %)
- *improvements in control/management* of existing water systems (20-30 %)
- *reuse of water* without treatment at other points in the process (10-20 %)
- *treatment and recycling of water* for further use in the process (10-20 %)
- *improvements in process design* so that water is not required (10-20 %)

These actions represent a hierarchy of activities, from the simplest and cheapest to the most difficult and expensive. Figure 21.1 indicates the relationship between capital expenditure and potential water savings.

Water management is not technology-limited. There is a wide range of separation techniques currently available, or under development, which can be used for partial or complete removal of contaminants and/or mineral salts from water so that it can be used again.

The most difficult area is the *choice of technology* for a particular duty. Many applications require a combination of two or more unit operations, rather than just one. For most duties there is a range of equipment that could be used; understanding the technical capabilities of the processes and the capital and operating costs of the equipment is critical. For example, suspended solids removal may be achieved by a wide variety of techniques (Table 21.1).

One important consideration is the physical state of the removed components and whether they can be returned to the process. Most separation processes are designed to recover one phase rather

Table 21.1. Technologies for suspended solids removal (adapted from Newton & Solt, 1994)

Chemically-assisted	Mechanical	Membranes
Sedimentation	Centrifugal filters	Micro-filtration
Coagulation	Belt filters	Ultra-filtration
Flocculation	Sand filters	Nanofiltration
Precipitation	Multimedia filters	Reverse osmosis
Softening	Cartridge filters	
Flotation	Fibre material filters	

than both. The removed material may not be in a phase that is readily recoverable, due to a change in phase, contamination with other materials or dilution. The application of non-intrusive separation technologies such as membranes may allow cheap and easy recovery of both the water and the removed phase, thus increasing the economic viability of the process. Simple examples of this process would be:

- the recovery of paints from vessel washings;
- the recovery of dyestuffs from filter washings;
- the recovery of organic components after evaporation.

The processes

Traditionally, water treatment and effluent treatment in particular have relied on large settlers and holding tanks to even out outflows and concentrations and allow time for solids to settle. *Water management requires a move towards process engineering rather than civil engineering*. It is necessary to find solutions that can be integrated into the process, rather than applied after the process. Above all, water management requires the use of *good control technology.*

The available technologies can, with development, be used to treat a variety of problems. It is important to classify the problems and identify the potential solutions in order to make valid comparisons. Table 21.2 indicates which technologies might be used to address specific problems.

It is clear from the industries studied that, although there are problems which are specific to each industry, there are also many problems which are common to all – for example, the removal of *suspended solids, dissolved solids and heavy metals*. It is therefore possible to learn from the experiences of other industries.

Water management will in the future focus on *cleaner technologies* – for example, the use of *membranes* to remove particulate and colloidal material and dissolved salts, and the *advanced oxidation processes (AOPs)* to disinfect water and destroy organic molecules to carbon dioxide and water.

Table 21.2. Technologies for water management (Newton & Solt, 1994)

Suspended solids, oils	**Ammonia**
Gravity separation	Steam stripping
Coagulation	Nitrification
Flocculation, separation	Ion exchange
Flotation	Air stripping
Membranes	Breakpoint chlorination
Filtration	
Phenols	**Dissolved organics**
Solvent extraction	Aerobic treatment
Wet air oxidation	Anaerobic treatment
Biological oxidation	Chemical oxidation
Activated carbon	Activated carbon
Chemical oxidation	Wet air oxidation
	Incineration
Cyanide, thiocyanate	**Heavy metals**
Steam stripping	Chemical precipitation
Biological oxidation	Ion exchange
Alkaline chlorination	Activated alumina
Ion exchange	Reverse osmosis
Chemical precipitation	Electrodialysis
Dissolved solids	**Sludge**
Evaporation	Filtration
Reverse osmosis	Centrifuge
Electrodialysis	Incineration
Crystallisation	Drying
Spray drying	Stabilisation, landfill

Examples of wastewater reuse and recycling

Increasing numbers of examples of zero aqueous discharge are being reported in a variety of publications. The majority of these apply to new plants in the USA (for example, the power plants in the mid-west), where environmental legislation is particularly tight. Several examples focus on pulp and paper mills that have been active in reducing their water use – by as much as 90 % over the past 20 years – or who are actively seeking to “close down” mills in response to public concern about pollution of receiving waters. Historically such factories have had large demands on good quality river or lake waters, but there are now operating examples of zero aqueous discharge mills in Canada and New Zealand. Fewer examples of large chemical and petrochemical sites are reported.

The conclusion must be that zero aqueous discharge is technically achievable, at least for new plants in selected industries where the economic or operational driving forces are strong enough to justify the necessary investment. Several new plants have been designed with an aim of zero aqueous discharge, but it has not been possible to close the water systems due to poorer-than-design performance from the unit operations used for recovering and re-

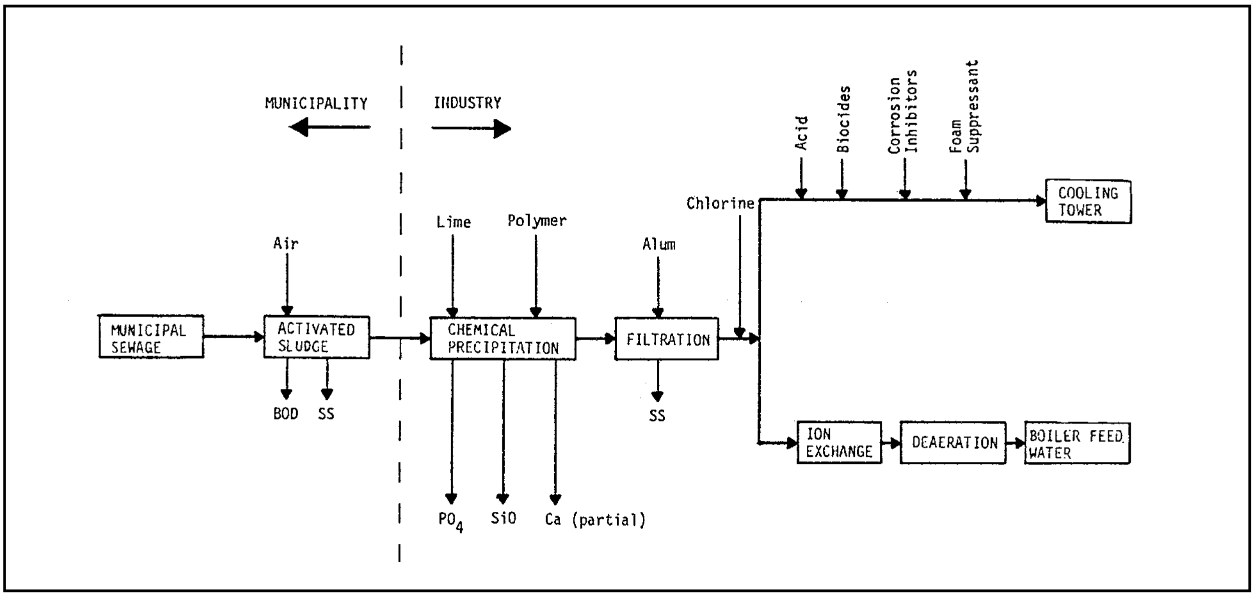


Figure 21.2. Typical treatment of municipal wastewater for industrial reuse (Cecil, 1973).

cycling water. This can have a number of causes, but is often related to a poor understanding of the impact of water chemistry on separation processes or the impact of the recycled stream on product quality or plant operation.

Two examples of industrial water reuse and recycling are discussed below. First, in Figure 21.2, the typical treatment scheme for municipal wastewater for its industrial reuse is shown. After biological treatment of the municipal effluent it is post-treated with lime and alum as coagulants and with polymer (flocculant) to remove phosphorus and suspended solids, and then disinfected with chlorine. The water may be used for cooling towers (after the addition of biocides, corrosion inhibitors and foam suppressants), or as boiler feed-water (after ion exchange and deaeration).

Second, in Figure 21.3, the general process flow diagram of potato processing wastewater recycling is shown. Incoming solids are passed over a vibrating screen, with a six-mesh-size separation. Coarse solids, such as trim and slivers, are screened off. Potato starch particles, soluble BOD_5 and other fine-sized organic pollutants in the liquid must then be treated. Primary liquid-solid separation is accomplished in a clarifier known as a Clari-Thickener. This unit has a special central compartment for thickening the sludge and biologically reducing the present colloidal material. The thickened under-flow is pumped to an Eimco Belt filter where a semidry cake is formed. The effluent from the primary clarifier is introduced into the aeration basin for treatment by activated sludge. Fixed Eimco, low speed, mechanical surface-aerators provide the necessary oxygen for aerobic treatment.

Mixed liquor suspended solids (MLSS) from the aeration basin overflow by gravity to the secondary

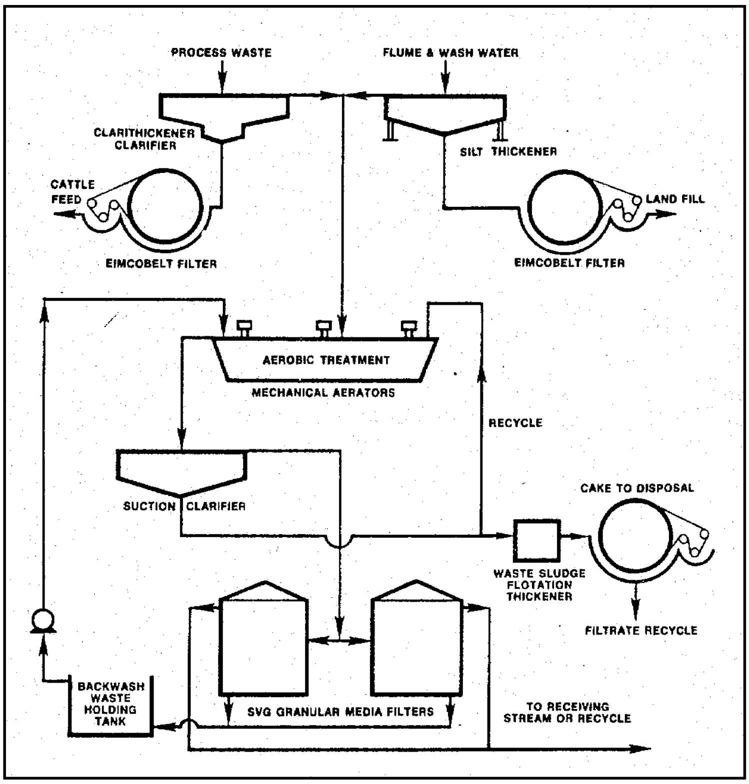


Figure 21.3. Typical potato waste treatment flowsheet (Cecil, 1973).

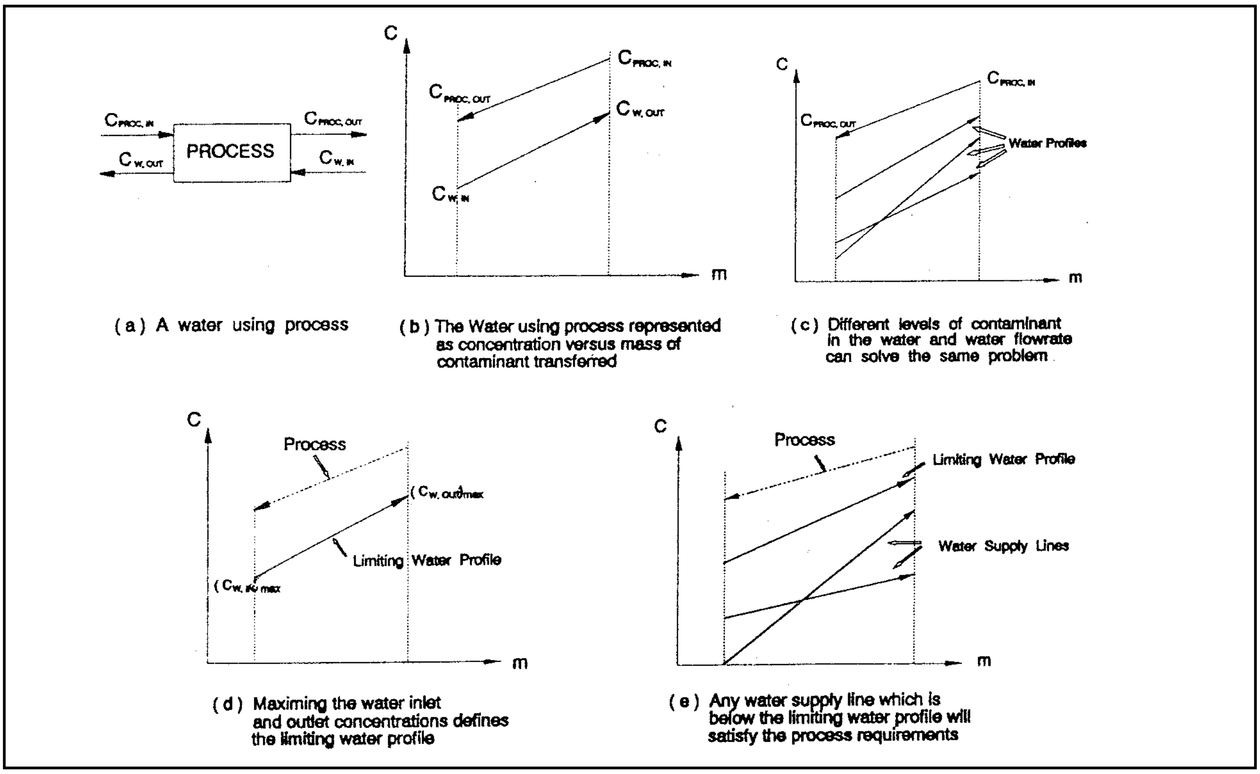


Figure 21.4. Representation of water-using processes (LaGrega et al., 1994).

clarifier, which is of suction type, concentrating the sludge and rapidly recycling it to the aeration basin. Effluent from the secondary clarifier flows to a sump. Pumps lift this stream to the feed box of the granular dual-media filters (anthracite and sand). The filter effluent is chlorinated and a major portion recycled to the processing plant.

For new plants, it is relatively easy to incorporate water management philosophy at the design stage, given that the technical uncertainties can be overcome. For existing plants, the potential benefits of reducing water consumption may be offset by the costs.

Water and wastewater minimisation

As mentioned above, there are three possibilities for reducing wastewater: *reuse, regeneration reuse* and *regeneration recycling*. If we take the example of a petroleum refinery, wastewater is generated by processes in which water comes into contact with process materials in desalting, stream stripping and many washing operations throughout the refinery. Also, wastewater is generated by the utility system from boiler feed-water treatment processes, boiler blow-down, cooling tower blow-down etc.

Using the approach of Linnhoff and Hindmarsh for heat exchanger networks, the specific method called "pinch technology" can be developed for all three above-mentioned ways of reducing wastewater. Although this methodology is illustrated with examples from petroleum refining, it can be applied to many other industries as well, including the pulp and paper, textile, dyestuffs, pigments and steel industries.

To lay some necessary foundations the water-using processes with single contaminants are considered below.

Consider the water-using operation shown in Figure 21.4a. Process material (for example, crude oil) is put in contact with water in order to reduce the level of a contaminant. The water in turn becomes contaminated. This could be, for example, a petroleum refinery desalter in which crude oil is mixed with water to extract salt from emulsified water in the oil. The oil and water are then allowed to settle with the aid of an electrical field and are separated into two phases again. Figure 21.4b shows this process in terms of concentration of contaminant vs. mass of contaminant transferred. In the example of the desalter the contaminant would be salt. Figure 21.4b shows one possible combination of inlet and outlet concentrations of water that satisfies mass transfer requirements. Specifying the inlet and outlet concentrations of water and the mass of transferred contaminant also gives a specification of the water flow rate. Clearly, different water flow rates and contaminant concentrations can solve the same problem (Figure 21.4c). In order to maximise possible reuse of water from other operations in this operation, we should specify water with the highest possible inlet concentration. Specifying the maximum possible outlet concentration then minimises the water flow rate at the maximum inlet concentration (Figure 21.4d). The water profile shown in Figure 21.4d is not necessarily the profile we will use in the final design. It simply represents a limiting case. We will therefore designate this as the *limiting water profile*. Any water supply line that is below the limiting water profile will meet the requirements of the process. Figure 21.4e shows two examples of different water supply lines that satisfy the process requirements.

The maximum inlet and outlet concentrations for the limiting profile may be determined by a number of possible considerations:

- minimum mass transfer driving force;
- maximum solubility;
- the need to avoid precipitation of material from solution;
- fouling of equipment;
- corrosion limitations;
- minimum flow rate requirements to avoid settling of solid materials etc.

Now consider a simple example involving a single contaminant. This will be used first to illustrate the basic approach of setting targets for water flow rate and later to help us develop design methods that allow the target to be achieved in design.

Table 21.3. Limiting process water data for the example (adapted from Wang & Smith, 1994)

Process number	**Mass load of contaminant** (kg/h)	C_{IN} (ppm)	C_{OUT} (ppm)	**Water flow rate** (tonnes/h)
1	2	0	100	20
2	5	50	100	100
3	30	50	800	40
4	4	400	800	10

Example

The data for this example are shown in Table 21.3. Let us emphasise that these data represent limiting data, i.e. maximum inlet and outlet concentrations of contaminant. Also, we assume that the mass transfer is a linear function of concentration. This is usually valid in dilute systems.

Figure 21.5a shows plots of the limiting water profile of each operation in Table 21.3. Also shown in the plots are the *water supply lines* for each operation, assuming that freshwater has been used in each operation and the flow rate has been minimised in each case by taking its outlet concentration to a maximum. Figure 21.6b shows the design that would correspond with freshwater use throughout. The corresponding water flow rate would be 112.5 tonnes/h.

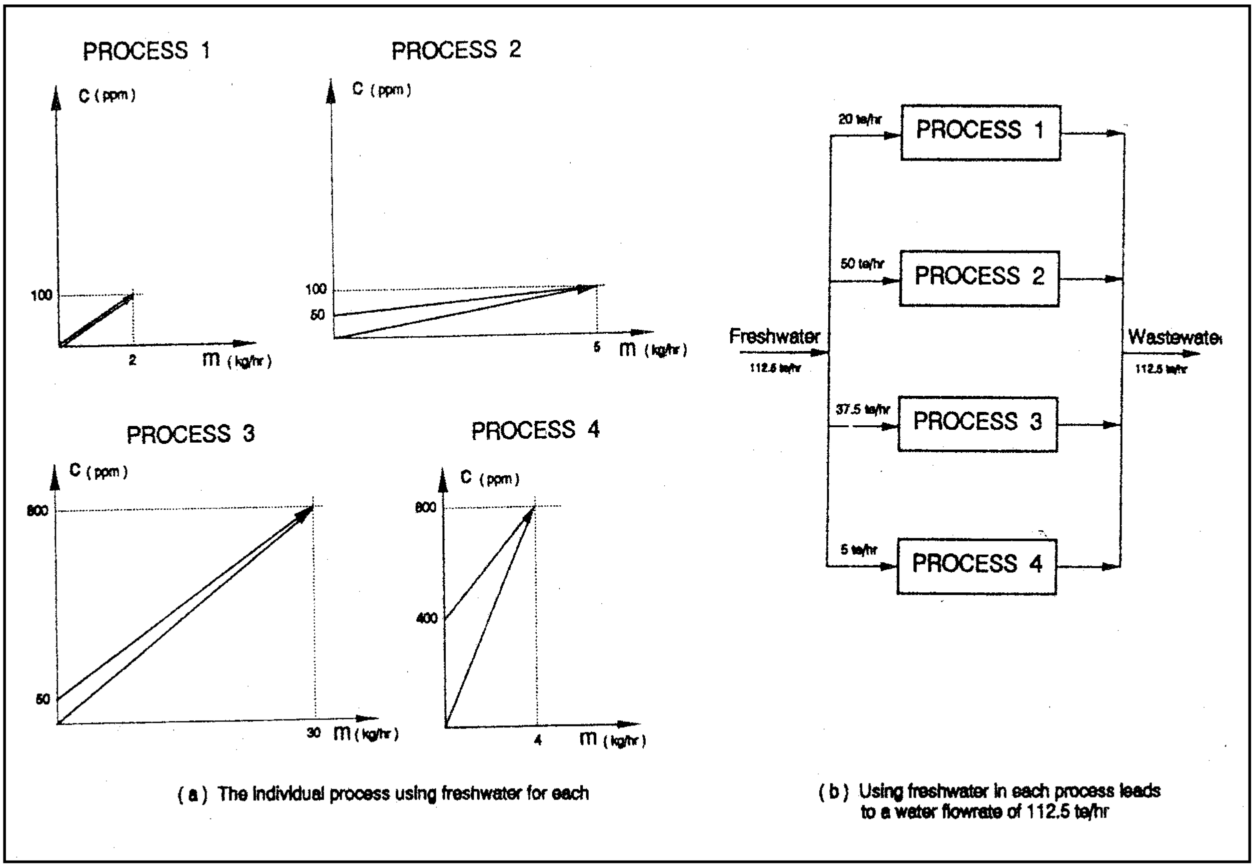


Figure 21.5. Example without water reuse (LaGrega et al., 1994).

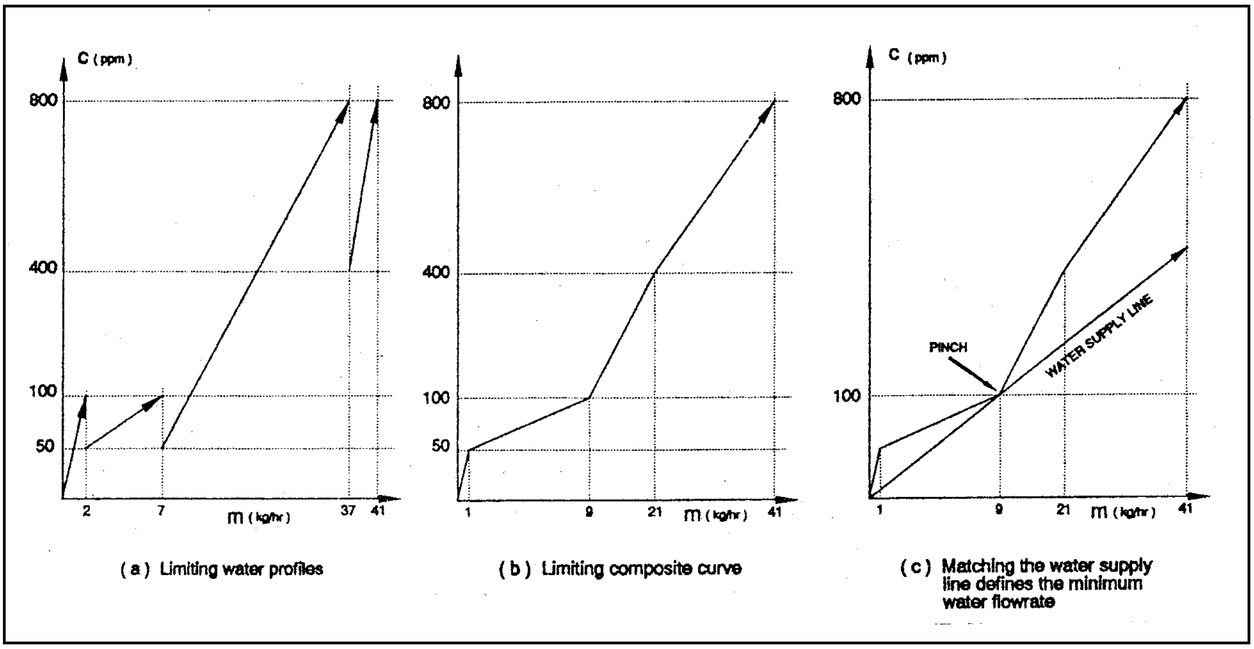


Figure 21.6. Construction of the limiting composite curve allows the minimum water flow rate, for example, to be defined (Wang & Smith, 1994).

If we are to minimise the water flow rate overall, we must analyse how the water-using processes behave in an overall sense. For this we can construct a limiting composite curve as shown in Figure 21.6. In Figure 21.6a the inlet and outlet concentrations of the processes define concentration intervals. Within each concentration interval the rate of mass transfer is constant. By combining operations within concentration intervals we obtain the limiting composite curve in Figure 21.6b. The limiting composite curve shows how the total system would behave if it were a single water-using process. The limiting composite curve incorporates the process constraints directly. Figure 21.6c shows how the water supply line is matched against the limiting composite curve. The inlet concentration of the supply line has been assumed to be zero (i.e. freshwater). *By maximising the outlet concentration of the water supply line, freshwater use and hence wastewater generation are both minimised.*

In this example, the minimum wastewater line touches the limiting water profile at both zero concentration and an intermediate point. Each point where the supply line touches the limiting water profile creates *a pinch* in the design. In general, there will be at least one pinch. Let us emphasise that, because the water supply line touches the limiting water profile, *this does not mean that we have zero mass transfer driving force at that point*. At the pinch the driving force goes to a minimum because the minimum mass transfer driving forces have been built into the data. *Figure 21.6c indicates that the minimum water flow rate for the example is 90 tonnes/h compared with the 112.5 tonnes/h in Figure 21.6b, a reduction of 20 %.*

Although comparatively new, this methodology has been successfully tested on several industrial sites. Applications have ranged from petroleum refining to speciality batch chemical operations, with water savings ranging from 30 to 60 %.

22.

INTEGRATED WATER MANAGEMENT IN THE PULP AND PAPER INDUSTRY

Lars-Göran Danielsson & Folke Ingman

Introduction

The times when pulp mills were built on sites where a small- to medium-size river could conveniently be diverted into the factory are only a few decades behind us. The procedure was for more or less all of the river water to be pumped into the mill to serve mainly as process water. After completion of the process, the water was let out into the river again downstream, usually without any or with only rudimentary purification.

Beginning in the early 1970s there was a sharpened awareness of the risks of environmental pollution and the need for purification of process waters before discharge. Different strategies to deal with the problem have developed, the best of which are based on the understanding that the most efficient way to minimise pollution is to refrain from all discharges to the environment. This became: close the process and use the same water over and over again. As we shall see, this strategy has been developed quite extensively, especially in the 1990s, and it is interesting to note that this work has in fact been profitable to the pulp and paper industry.

Increased closure is of course accompanied by a build-up of by-products and waste products in the process cycle. In order to solve these accompanying problems, increased knowledge about the process is required, and this can only be obtained by co-operation between several different branches of science and engineering. For example, there is a great need for better measurements in the process. For this end, an especially capable analytical tool has been developed called Process Analytical Chemistry (PAC). PAC combines measurements yielding large amounts of data with multivariate statistical methods that help extract relevant information from the data. In this chapter, we will present the ongoing work of closing what are called the liquor flows of the Kraft pulp mill in Sweden and give an introduction to PAC as a radical new way of holistic thinking that facilitates management of the processes.

Closing the system of the Kraft pulp mill

The pulp and paper industry in Sweden was probably one of the first branches to attempt closure and has by now come far in the goal of complete closure of plants. Intensive research is going on in this field, administrated by the Swedish Pulp and Paper Institute but involving research groups at several Swedish universities. Much of this research is directed towards a better understanding of the process, with the ultimate goal of using new knowledge for better optimisation and control. The primary motives for closing are:

- To minimise discharges of organic and inorganic matter
- To facilitate separation of substances that interfere with the processes
- To minimise dilution of energy liberated in the system

Table 22.1 shows the environmental priorities of the pulp and paper industry over the period from about 1970 up to the present. The initial focus was on decreasing the biological oxygen demand (BOD) and the chemical oxygen demand (COD) in the effluents from the mill. Later, interest shifted towards adsorbable organic halogen compounds (AOX) and the method of decreasing emissions by changing the bleaching chemicals first from chlorine to chlorine dioxide and then gradually to totally chlorine free (TCF) bleaching agents. The present emphasis is on further reduction of chemical oxygen demand, which is being achieved by increased closure of the mill.

It is evident that the use of chlorine has ceased completely while totally chlorine free bleaching has increased, as has ozone bleaching and modified cooking (Table 22.2). One of the latest developments is the introduction of pressurised hydrogen peroxide bleaching.

Table 22.1. Environmental priorities of the Swedish pulp and paper industry

1970-1985	BOD, COD	O_2, aerated lagoon
1985-1990	Lower AOX	Increased ClO_2 use
1990-1995	Minimal AOX	ECF & TCF bleaching
1995-2000	Low COD	Increased closure

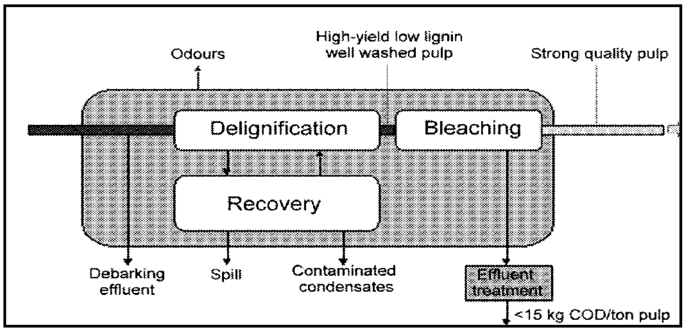


Figure 22.1. Closing the mill systems.

Table 22.2. Technical changes in Swedish pulp and paper industry between 1990 and 1997

	1990	1993	1994	1995	1997
Cl_2, kt/y	66	<5	0	0	0
AOX, kg/t pulp	1.7	0.39	0.34	<0.3	<0.3
TCF, %	0	13	21	32	45
Mod. Cook mills	4	6	8	10	10
O_3 bleach plants	0	3	3	4	5
Press. H_2O_2	0	0	2	9	>10

Figure 22.1 depicts a block diagram of the modern Kraft pulp mill and the waste discharges that still remain to be taken care of. The latter consist of odours discharged to the air (mainly sulphur compounds such as mercaptanes), debarking effluent, spill and contaminated condensates from the recovery plant for spent chemicals, and mill effluent (containing at present <15 kg COD/t pulp).

In a modern pulp mill most of the process water is already being re-circulated. As Figure 22.2 shows, 20 m^3 of process water enter the mill together with the wood (which also contains some water). Calculated per ton pulp, roughly 2 m^3 are discharged to the ambient air, 0.1 m^3 go out with the pulp and 19 m^3 are discharged to water recipients as different kinds of mill effluent. 600 m^3 of water or roughly 96 % are re-circulated in the mill.

Several elements, such as calcium, magnesium, iron and manganese, enter the mill with the wood. They do not take a direct part in the process but they may affect it in several ways. Some of these elements are beneficial (e.g. calcium and magnesium), others (iron and manganese) are detrimental to the process. As the process is being closed and the process water re-circulated, the concentrations of these elements will build up. One obvious strategy to avoid disturbances would be to collect the detrimental elements in the chemicals recovery plant and restore them to the forest in a suitable form. Beneficial elements, too, are probably beneficial only up to a certain concentration, and the surplus should be taken care of in a similar way.

A better understanding of the role of these elements and better methods for their control are necessary to develop strategies for handling them in the process. This calls for analytical methods, some of which must be capable of detecting different species of the same element. Process analytical methods are being developed for these purposes, in many cases based on analytical techniques that were virtually unknown before 1975. One such example is quantitative near infrared spectrometry.

The Kraft process

The complexity of the Kraft process is illustrated in Figures 22.3 and 22.4. Figure 22.3 depicts the so-called "fibre line" of the pulp mill. Wood chips together with white liquor are cooked at 170 °C and a correspondingly high pressure, producing pulp and black liquor. White liquor contains a mixture of sodium hydroxide and sodium sulphide and is consequently a strongly alkaline reagent that dissolves the lignin in the wood, leaving the cellulose fibres that form the pulp. The black liquor, containing lignin and spent chemicals, is separated from the pulp and goes on to evaporation and recovery. The pulp goes to washing and bleaching, and we can see that it is here that large volumes of water become involved. Most of today's research efforts are directed towards the cooking and bleaching phases, aiming at a better understanding of them in order to improve their optimisation and control.

Figure 22.4 shows a plant flow sheet for recovering chemicals in the Kraft pulp mill. It is obvious that this is to a great extent a question of re-circulating the same chemicals over and over again. Problems arise from the fact that inorganic substances entering the mill with the wood chips will become enriched with time in the cycle, and some calcium, magnesium and manganese will accompany the pulp into the bleaching plant. There, calcium and magnesium

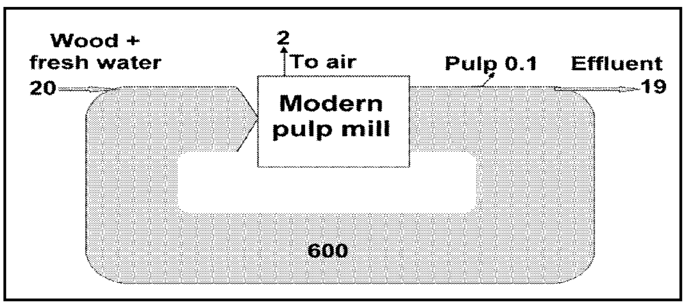


Figure 22.2. Total water balance, m³/t pulp.

are beneficial to the process, at least in rather low concentrations. However it is not known which of the Ca and Mg species are active. Free manganese, acting as a catalyst for the decomposition of hydrogen peroxide, is highly detrimental to the modern bleaching process.

Process Analytical Chemistry

Process Analytical Chemistry (PAC) has developed in recent years into a very important tool for the chemical engineer. There are several reasons for this. First, it is increasingly understood that one of the best ways to manage waste is by preventing its formation in the first place. Closing the plant system and avoiding discharge of waste products to the environment as far as possible can achieve this. Secondly, the analytical chemist has been provided with a comprehensive toolbox consisting of rapid, mainly spectrometric, non-invasive measurement techniques, combined with multivariate statistical methods to extract the relevant information from the measured data.

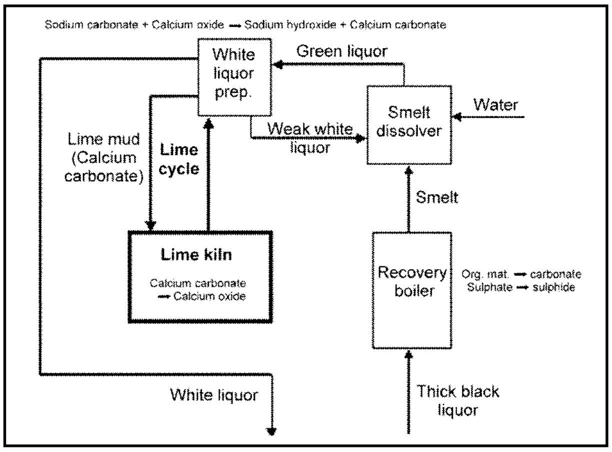


Figure 22.3. The fibre line.

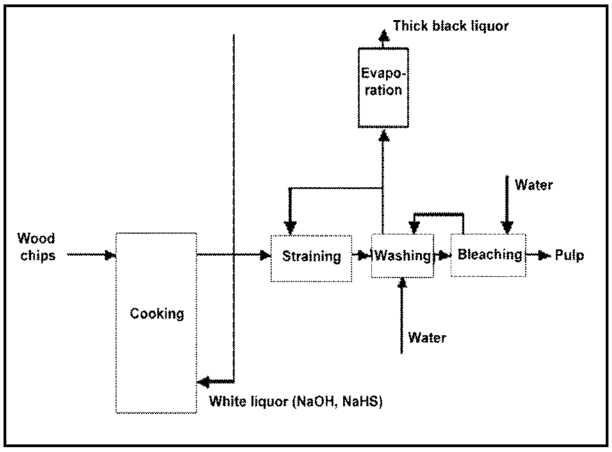
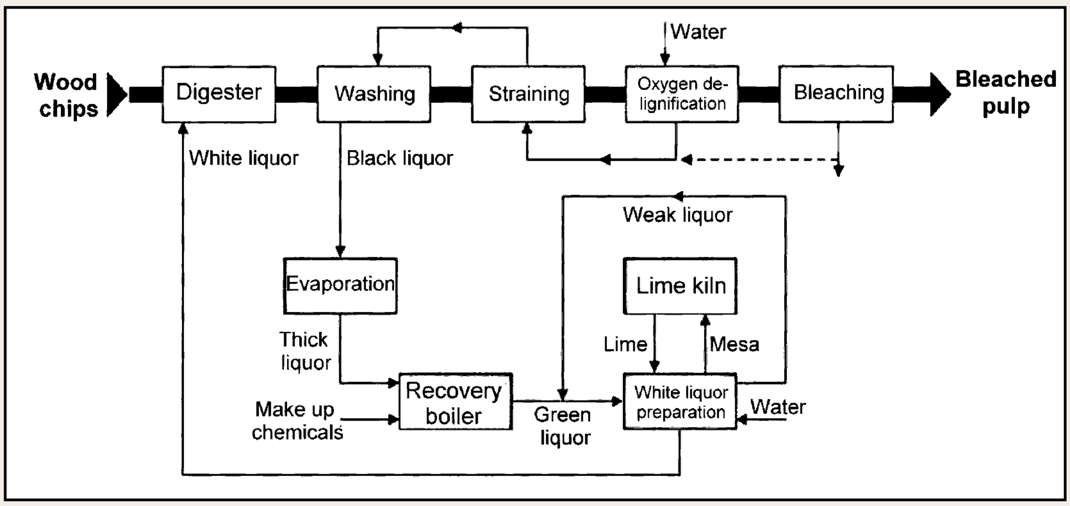


Figure 22.4. Chemical recovery.

The kraft pulping process in brief

In the Kraft pulping process, also called the “sulphate pulping process,” debarked and chipped wood is digested with a mixture of mainly sodium hydroxide and sodium sulphide (“white liquor”) at 170 °C and a correspondingly high pressure. During the process, the liquor dissolves the lignin in the wood. The residual cellulose fibres are separated from the cooking liquor, washed, bleached and dewatered to form the pulp. The spent cooking liquor containing lignin and other dissolved matter is now called “black liquor”. It is treated in a separate process to recover the chemicals. During this process, a substantial amount of energy is set free.



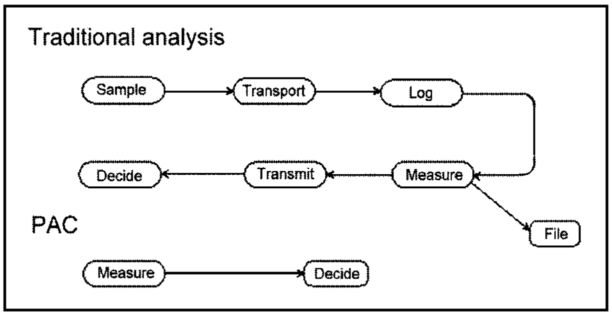


Figure 22.5. Strategies.

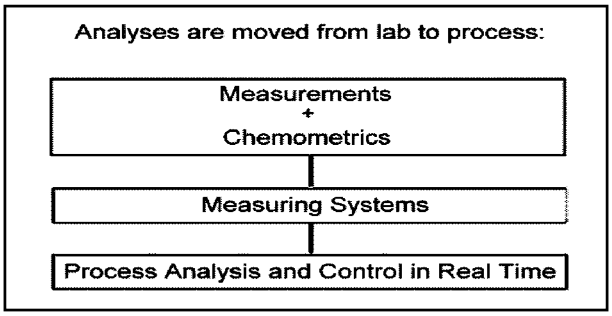


Figure 22.6. Paradigm shift.

Process Analytical Chemistry aims at playing a very active role *both* in process optimisation *and* in process control. The only effective way to improve a chemical manufacturing process is by optimising all parts of it. In order to do this, you need to understand the process, and this is where Process Analytical Chemistry can help.

In the following, we will give a general explanation of PAC and how it developed during the past decade. In addition, we will give a few examples of the role of PAC in the optimisation of the pulping process, based on our own experiences.

What is PAC and what can it do?

Traditional "end-of-pipe" analysis can be characterised as a "post mortem" kind of control. If something has gone wrong with the process we will learn about it first when it is usually too late to make any adjustments to it, and a batch may thus be lost.

The goals for Process Analytical Chemistry are to provide quantitative or qualitative information of a chemical process. This information can be used to monitor and control the process and also to optimise it regarding the use of time, energy and raw materials. This can result in higher quality and/or less environmental pollution.

Two prerequisites of PAC as we know it today are the developments of instrumental chemical analysis on the one hand and of multivariate mathematical statistics (in analytical chemistry dubbed "chemometrics") on the other. We are currently in a position where we are able to determine most analytes in almost any concentration in most sample types and where we have access to good chemometrics software and a broad understanding of the mathematics behind it.

In the upper part of Figure 22.5 the different strategies employed in traditional analysis are depicted, including all of the steps necessary before a decision can be made. The lower part, as a contrast, shows the ideal process analytical situation, where analysis is performed and decisions are taken almost simultaneously in real time.

In PAC, the problems handled are different from those in traditional analytical chemistry. Instead of determining discrete analyte concentrations, we work with classification or grouping and measure the matrix instead. The samples often contain very high concentrations, and the spectrometric measurement techniques employed in PAC generate large amounts of data, from which the *relevant information* is to be extracted. This would be virtually impossible without the chemometrics software of today. We are in fact witnessing a paradigm shift in analytical chemistry, where chemical analyses are being moved from the laboratory to the process.

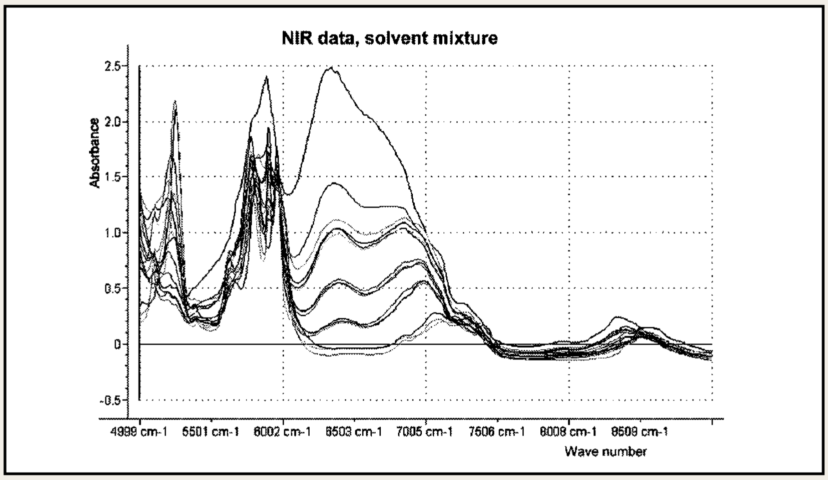
In PAC, *reliability* of the measurements is paramount, whereas quantities like sensitivity, selectivity, resolution and economy become less important.

Process analytical chemistry in the pulp and paper industry

Process analytical methods have been developed (or are being developed) that can measure sulphide and polysulphide concentrations in Kraft cook liquor during the cook. Other methods (using electrochemical sensors) aim at determining the speciation of calcium and magnesium in different parts of the bleaching plant. Spectrometric methods using fluorescence spectroscopy aim at studying manganese in the bleaching plant and in the pulp. All of these methods are at present primarily aimed at improving our understanding of the processes, but some may also be used for process control in the future.

Analytical techniques open new possibilities in process development

Until recently, analytical chemists have generally aimed at determining concentrations of discrete species in matter. A significant change in thinking during the last few years has been brought about by new instrumentation on the one hand and new mathematical-statistical data handling methods on the other. In many instances these make it possible to perform measurements of the entire sample matrix, which is revolutionising raw materials and product control in industry, among other things. Optical spectrometry in the infrared and visible wavelength ranges is non-invasive and can in many cases be applied directly to a process or a product.



The figure above shows a series of near infrared spectra recorded for a series of mixtures of four different solvents (acetone, methyl acetate, methanol and water). The concentrations of the three organic solvents vary from 0 % to 100 % and the water content varies between 0 % and 3 %. The broad, large peak in the middle is due to methanol. Evaluations by univariate methods (using measurements at one wavelength only) might be possible, but the resulting precision would be inadequate. It would certainly not be possible to determine all four compounds.

One of the problems in this case is that the spectral response of the methanol OH-group depends on its environment. Hydrogen bonds are formed in methanol/water whereby the location of the peak is shifted somewhat towards lower wave numbers (lower energy), as compared to in acetone or in methyl acetate. This is yet another reason for the failure of univariate calibration in this case.

Using multivariate calibration, utilising all data to extract the relevant information about the sample, the composition of the mixture can be determined with good results. The figure below demonstrates this, where Y is the concentration of the component in question, measured by a reference method, and X is the corresponding concentration predicted by the calibration model. This type of model can e.g. be used to control a distillation column used for recycling spent solvents.