

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 km³/yr for the year 2000 (see Table 3.3). This amount is about 12 % of the sustainable global available water (45 000 km³/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 (km³/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).

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).

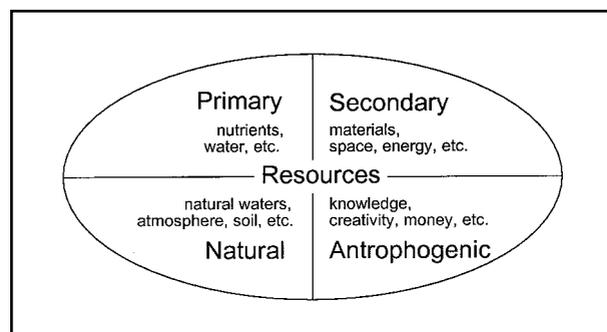


Figure 3.1. Resources in urban water management. The primary resources are the subjects of management in urban water management, secondary resources are used to carry this out. Urban water management of today is directed towards optimising natural resources and the anthropogenic resource of money (Larsen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

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), carbohy-

drates (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 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)

Level of living index	Water use (l/capita/day)								Total	Corrected for 10% loss
	Drink/ cook	Dish wash	House wash	Clothes wash	Bath/ shower	Garden	Toilet	Pool		
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	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 pa-

per 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

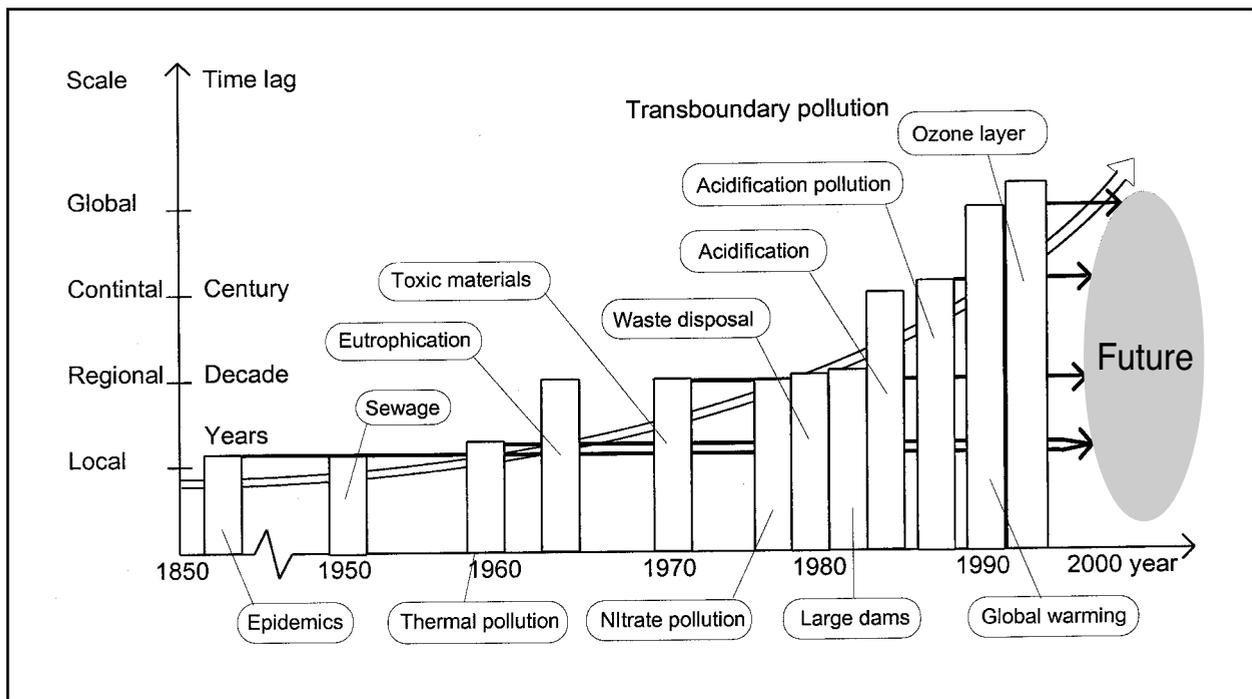


Figure 3.2. Trends in pollution problems (Somlyódy et al., 1993).

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-

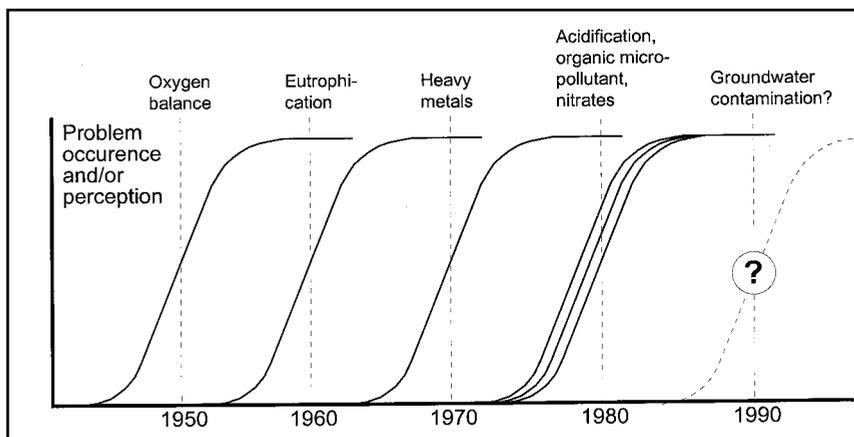


Figure 3.3. Occurrence in perception of water pollution problems in Europe (Somlyódy et al., 1993).

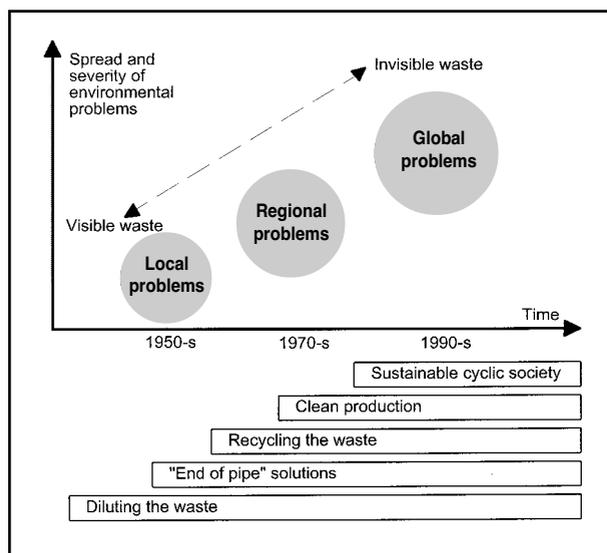


Figure 3.4. Development of environmental problems from the 1950s to today, and countermeasures (Tiberg, 1993).

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 were 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 (b) Concern about polluted areas (c) Main concern on single sources (d) Hygienic pollution	Continued concern for regional, continental and global effects, i.e.: <ul style="list-style-type: none"> • eutrophication in marine environments (Baltic Sea, etc.) • salts and nitrate in groundwater • micropollutants in marine environments and groundwater. • climate change due to greenhouse gases Increased concern about time lag effects (sediments, groundwater, etc.) Concern about combined effects of pollutants (municipalities, industries, etc.) Concern about new types of pollution (organic micropollutants, toxicity, resistant microorganism etc.) Development of measurement methods
3. Transport of drinking water	Hydraulics <ul style="list-style-type: none"> • Corrosion • Metal dissolution • Biological stability 	Water quality change in network
4. Drinking water treatment	Traditional technology <ul style="list-style-type: none"> • Disinfection • Aesthetic improvement (colour, turbidity) • Viruses and disinfection resistant microorganisms 	Organic and inorganic micropollutants <ul style="list-style-type: none"> • Disinfection by-products • Pesticides
5. Transport of wastewater	Traditional technology <ul style="list-style-type: none"> • Drainage without use of available storage 	Flow equalisation for minimisation of overflows <ul style="list-style-type: none"> • 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” <ul style="list-style-type: none"> • Centralised treatment • Large plants 	Increased application of reuse and recycling for eco-cycling and sustainability New treatment methods including: <ul style="list-style-type: none"> • 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, <ul style="list-style-type: none"> • 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: <ul style="list-style-type: none"> • 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-phenoxyacetic 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.

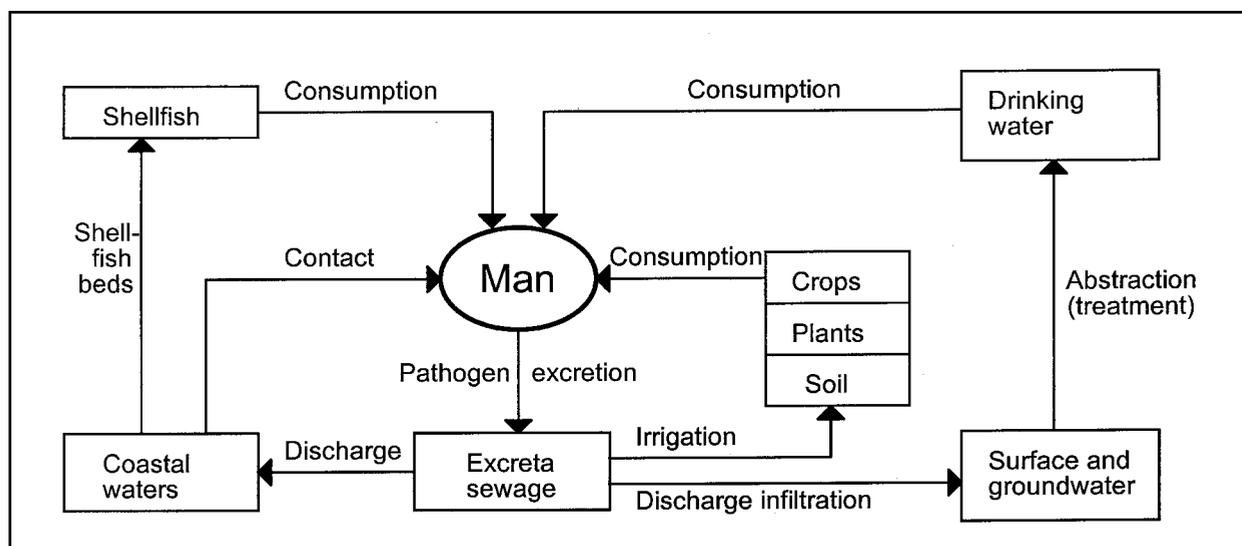


Figure 3.5. The main pathways of human exposure to pathogens in the aquatic environment (Meybeck et al., 1989).

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

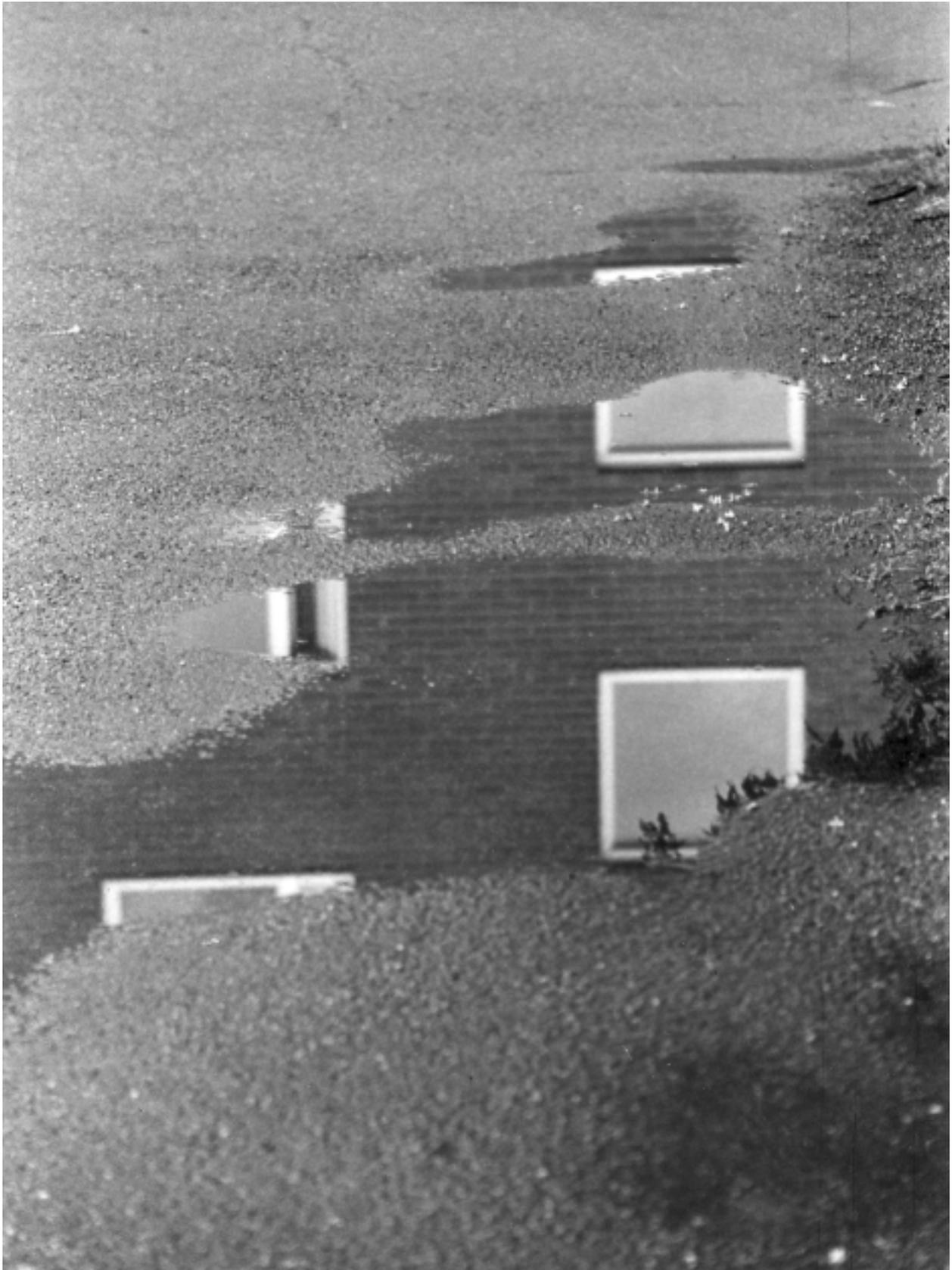
Safety and emergency planning in sanitation is a necessary condition for avoiding health effects. The number one killer of infants and children in the developing countries is diarrhoea, caused by a broad spectrum of pathogenic bacteria, viruses and protozoans of faecal origin that are spread indiscriminately 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.