Storage of surface water in The Netherlands: challenges of the future

L.W.C.A. van Breemen & J.M.J. Waals
Water Storage Corporation Brabantse Biesbosch, PO Box 61, 4250 DB Werkendam, The Netherlands

Abstract. In the next decades the use of surface water for drinking water production in The Netherlands will grow from 400 to 800 Mm^3/year. Storage of surface water is a common preliminary treatment step, because of the (self-)purification during the retention time and the possibility of bridging periods with insufficient surface water quantity or quality, but it also requires a great deal of space. Maximising the possibilities of concurrent use can overcome this disadvantage. Also environmental and financial costs have to be considered. In future the need to bridge periods with insufficient water quantity or quality may increase due to global climatic change and new legislation.

1 Introduction

In The Netherlands one-third of the total annual water consumption for domestic and industrial use of 1200 Mm^3 comes from surface water. Surface water was first used almost 125 years ago, when the city of Rotterdam started with drinking water production from the River Rhine. After World War II the use of surface water as source for drinking water production grew rapidly to 400 Mm^3/year.

The Dutch government declared in 1995 that groundwater abstraction for drinking water has reached its ceiling with 800 Mm^3/year (1). Growth of water demand will therefore increase the demand for surface water. In the next 25 years the abstraction of surface water will have to double to 800 Mm^3/year. However, surface water is a less reliable source than ground water. In the densely populated and heavily industrialised Rhine–Meuse basin high-technology treatment schemes are essential for drinking water production.

Storage of surface water as a preliminary step in the whole treatment scheme is still common, although recent advances in purification technology, such as ultra- and hyperfiltration, permit direct use of surface water for drinking water production. The major advantages of storage are:

- improvement of water quality by natural purification processes, such as sedimentation, photolysis and biological degradation, at low environmental and financial costs;
- possibility of bridging periods of:
  - unsatisfactory surface water quality, e.g. after pollution accidents;
  - water shortage.

Developing a new storage facility requires a thorough knowledge of the (dis)advantages of the different storage techniques. This paper describes the state of the art and current storage projects in The Netherlands.

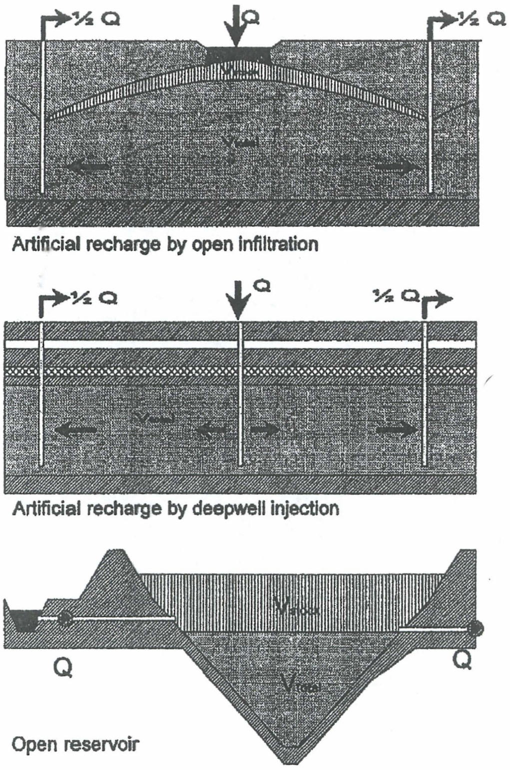

Fig. 1. Storage techniques.

2 Storage techniques

2.1 Main indicators

There are three storage techniques for surface water (Fig. 1):

- Underground storage or artificial ground-water recharge by means of:
  - open infiltration;
  - deepwell injection;
- Open storage in reservoirs.

Two indicators are important for all storage techniques:

1 the retention time (τ), defined as total storage volume (V_{tot}) divided by the supply from the storage (Q) ($\tau = V_{tot}/Q$);
2 the 'stock retention time' (τ_{stock}), defined as total stock volume (V_{stock}) divided by the supply ($\tau_{stock} = V_{stock}/Q$).

Natural self-purification by physical, chemical and biological processes depends mainly on τ. When τ decreases pollutant removal will also diminish (Fig. 2). Quality improvement during storage is the basis for further purification in the drinking water production plant. As an example, the water quality improvement in the biggest reservoir scheme in The

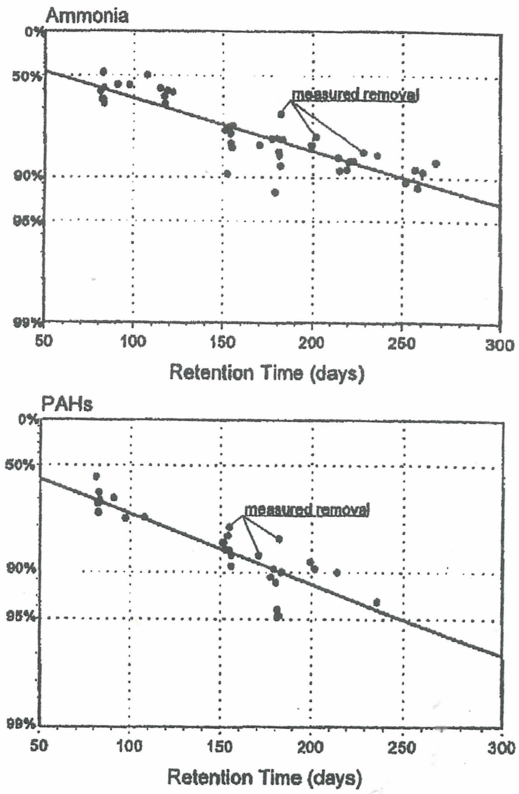

Fig. 2. Removal of ammonia and PAHs in the Biesbosch storage reservoirs as function of retention time τ (1981–95).

Netherlands (annual production capacity 215 Mm^3, τ ~ 150 d) is presented in Table 1.

The maximum period in which the storage inlet can be closed (τ_{stock}), due to accidental pollution or water shortage, is an important design criterion and depends mainly on the characteristics of the river or lake and the catchment area. The River Rhine, for instance, has a high discharge, even in summer, so the danger of water shortages is negligible. A deterioration of its water quality due to accidental pollution (e.g. the Sandoz fire in 1986) is not unusual, however. Fortunately such a pollution cloud will pass the Dutch inlet points within 3 weeks. Lake IJssel will seldom be polluted completely, but if this occurs it may take several years before the water quality is restored.

2.2 The Dutch experience

Both underground storage by infiltration and open storage in reservoirs are well-known techniques in The Netherlands (Fig. 3). In the coastal dunes the artificial ground-water recharge by surface water infiltration began 40 years ago. Open storage reservoirs were commissioned between 1960 and 1980. The negative environmental impacts of dune infiltration led to the development of the new technique of deepwell injection around 1990. At present there are some operational deepwell injection systems, but their capacity is limited (Table 2).

2.3 Differences between storage techniques

The most obvious difference between open reservoir and underground storage is the possibility of water quality problems, in particular eutrophication, in open reservoirs. Other differences include the pretreatment and the water quality after storage.

Open storage of nutrient-rich surface water without control techniques will result in eutrophication, mass developement of algae, etc. Algal blooms are known to cause serious water treatment problems (objectionable taste and odour, phytotoxins, clogging of filters, etc.). Eutrophication control techniques that have been applied successfully include influent dephosphatation, artificial mixing, food-web manipulation, hypolimnetic withdrawal and copper-sulphate treatment (2, 3).

In The Netherlands influent dephosphatation proved to be an effective technique for shallow reservoirs (4, 5). In deep reservoirs, on the other hand, artificial mixing proved to be a very effective and cheap technique to keep algal biomass at moderate levels (6–8).

Another important difference between reservoir and underground storage concerns the pretreatment (Fig. 4). If pretreatment is used for reservoirs, it is mostly for eutrophication control. Fort artificial recharge, however, it is necessary to install very sophisticated pretreatment plants. A new Dutch decree aiming to minimise the negative effects of artificial recharge, requires not only nutrients but also micropollutants (such as heavy metals, PAHs and pesticides) to be removed before surface water can be infiltrated. For deepwell injection it is necessary to remove practically all turbidity to prevent well clogging and soil pollution.

Table 1. Average quality improvements in the Biesbosch reservoirs 1991–95

Quality parameter	Unit	Inlet water	Outlet water	Removal (%)
Suspended solids	mg/l	14.2	3.2	77
Turbidity	FTU	11.4	2.3	80
Colour	mg/l Pt	14.2	7.9	44
DOC	mg/l	4.1	3.6	12
Ammonium	mg/l N	0.28	0.05	82
Total phosphorus	mg/l P	0.27	0.07	74
Chlorophyll-a	µg/l	20	5.6	72
Aluminium	µg/l	794	20	97
Iron	µg/l	728	15	98
Cadmium	µg/l	0.29	0.05	83
Lead	µg/l	4.9	0.6	88
PAH (6 of Borneff)	µg/l	0.080	0.007	91

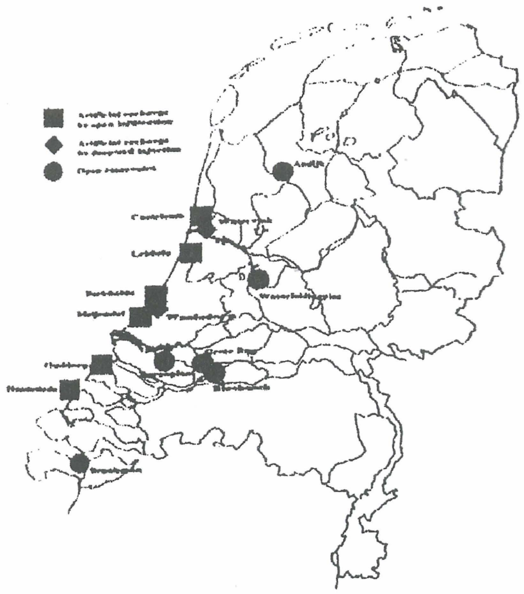

Fig. 3. Surface water storage in The Netherlands.

The main quality differences after reservoir and underground storage concern temperature, turbidity and hygienic parameters.

- After underground storage the water always has a constant temperature of about 10°C, while the temperature of reservoir water varies between 0 and 5°C in winter to 20–25°C in summer (Fig. 5).
- In reservoirs turbidity is mainly removed by sedimentation, whereas the artificial recharge pretreatment reduces turbidity by filtration. The latter is more efficient, but requires more energy and chemicals, generates more waste and is more expensive.
- After an underground passage of 20–60 days the water is hygienically safe (9). In open reservoirs the removal of enteric bacteria (Fig. 6), viruses and pathogenic protozoa such as *Cryptosporidium* and *Giardia* depends mainly on the retention time τ. The classical notion of reservoirs as hygienic barriers acquires a new dimension today with respect to pathogenic protozoa and viruses.

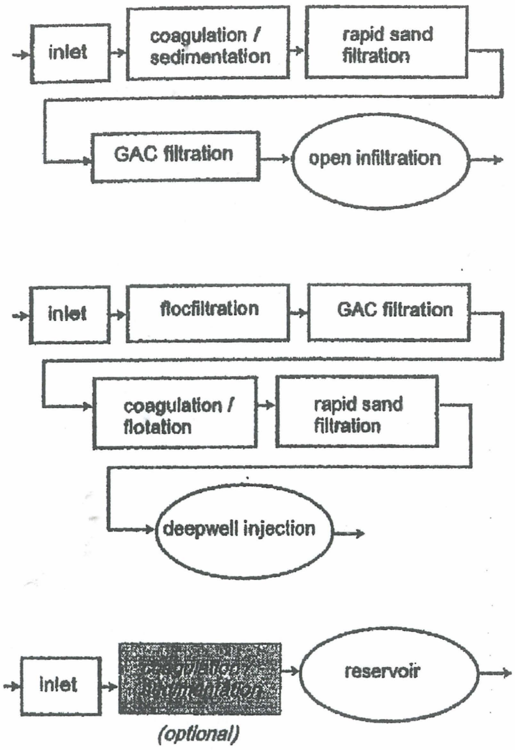

Fig. 4. Pretreatment facilities.

Table 2. Examples of storage facilities in The Netherlands

Location (water company)[1]	V Mm^3	Q_{max} Mm^3/year	τ months	τ_{stock} months	Remarks
Infiltration					
Berkheide (DZH)	5	25	2.5	2	Use of stock may cause damage to dune environment
Meijendel (DZH)	12	48	3	2	Use of stock may cause damage to dune environment
Deepwell injection					
Watervlak (PWN)	1	5	3	0	
Waalsdorp (DZH)	1	4	3	0	
Open reservoirs					
Andijk (WRK)	6	110	1.5	0	Reservoir level adjustment impossible
Biesbosch (WBB)	80	215	5	2	
Braakman (DELTA)	4	4	12	3	Industrial and emergency supply only
Grote Rug (WBE)	3	11	36	2.5	Industrial and emergency supply only
Loenderveen (GW)	8	31	3	0	Reservoir level adjustment impossible

[1] See Appendix I.

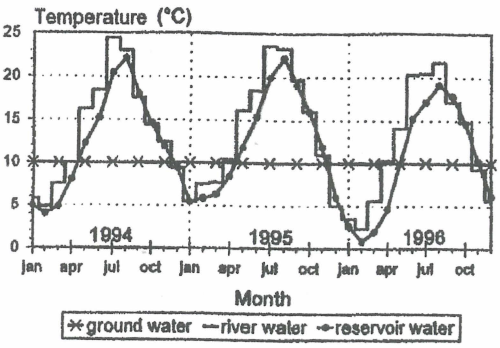

Fig. 5. Temperature of the Biesbosch reservoir scheme (1994–96).

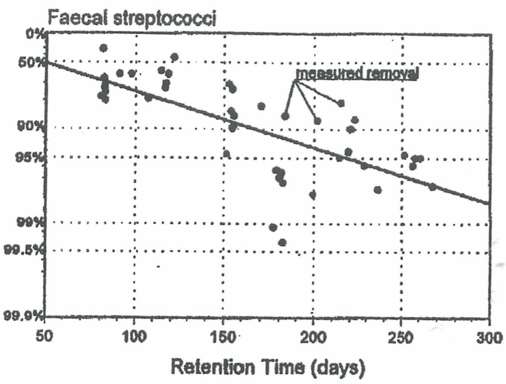

Fig. 6. Removal of faecal streptococci in the Biesbosch storage reservoirs as function of the retention time τ (1981–95).

Investigations in the Biesbosch reservoirs and the Braakman reservoirs indicate a removal efficiency for *Cryptosporidium* and *Giardia* of 97–99.9% (Table 3).

3 Storage projects in The Netherlands

3.1 Present situation

Several new storage facilities are under construction (Fig. 7, Table 4). The following developments must be taken into account in these projects.

- Space is scarce in a densely populated country such as The Netherlands; therefore the possibility to designate the storage area for concurrent use must be investigated thoroughly.
- The environmental impact of artificial recharge or open reservoirs on the surroundings must be minimised.
- Storage as integrated part of the entire treatment scheme may environmentally be more sustainable than treatment schemes without storage. An optimum for total performance (environmental and economic) has to be found.
- Global climatic change and/or new legislation may even increase the need to create new storage facilities.

3.2 Use of space

Most storage facilities consist of a small 'industrial' area for pumping stations, pretreatment plants, etc. and a comparatively large area for storage as such (Table 5). In particular, the latter poses a problem in a densely populated country such as The Netherlands (>450 inhabitants/km^2). As space is scarce, it has to be allocated prudently to different kinds of land use, such as agriculture, nature, housing and industry. This is reflected in Dutch country planning on national, regional and local scales.

The designation of storage facilities for water supply is mainly a regional affair, although municipal zoning plans are also involved. To obtain the planning consents water utilites must:

- demonstrate the necessity of a new storage facility and of any concomitant land use restrictions; and

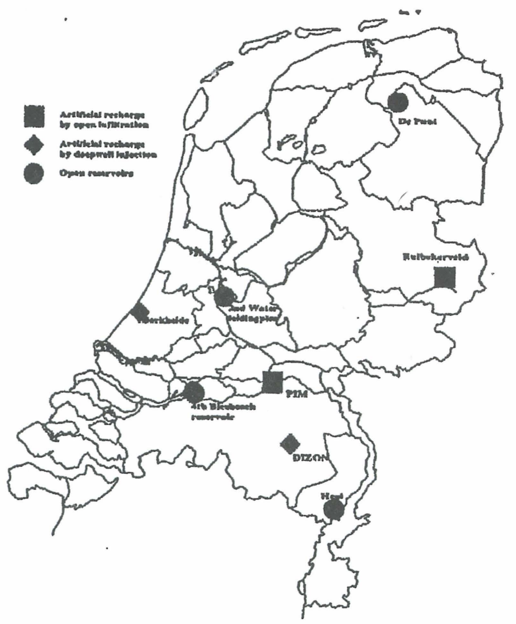

Fig. 7. Surface water storage projects in The Netherlands.

Table 3. Average quality improvements for hygienic parameters in the Biesbosch reservoirs 1991–95

Quality parameter	Unit	Inlet water	Outlet water	Removal (%)
Escherichia coli	cfu/ml	3.0	0.02	99.3
Faecal streptococci	cfu/ml	1.0	0.02	98
Cryptosporidium	oocysts/m^3	29.1*	0.34*	98.8
Giardia	cysts/m^3	100*	0.36*	99.6

* Average 1993–94, no correction for recovery.

Table 4. Storage projects in The Netherlands

Location (water company)[1]	V Mm^3	Q_{max} Mm^3/year	τ months	τ_{stock} months	Status
Infiltration					
PIM (WOB)	8	50	2	0.5	12.5 Mm^3/a to be supplied in 2000
Ruibekerveld (WOT)	1	3	4	0	To be commissioned in 2001
Berkheide (DZH)	1	4	3	0	Commissioning imminent
Deepwell injection					
DIZON (WOB/WML/NRE)	0.2	0.5	4	2	Pilot plant to investigate feasibility of deepwell injection
Leiduin (GW)	4	13	3	2.5	Design stage
Open reservoir					
4th Biesbosch reservoir (WBB)	50	200*	5	2	Design stage
Heel (WML)	20	20	12	0.5	To be commissioned in 2002
2nd Loenderveen reservoir (GW)	8	30*	3	3	Environmental Impact Assessment completed

[1] See Appendix I.
* Additional capacity of the existing reservoir scheme.

Table 5. Use of space for storage facilities of surface water

	Infiltration	Deepwell injection	Open reservoirs
Specific area requirement (ha/Mm^3/year)	20–40	~0	2–5
Concurrent land use:			
• Nature (conservation or development)	+	+	+
• Land-based recreational use (walking, biking, horse riding, etc.)	+	+	+
• Water recreation (angling, surfing, sailing, etc.)	–	+	+*
• Extensive agriculture	+	+	+*
• Other (intensive agriculture, industry, etc.)	–	+*	–

* Subject to agreement between the water utility and user about certain restrictions.

- pledge to minimise negative impacts and maximise benefits with regard to the surroundings.

Exclusive use of space in open infiltration areas is avoided by authorisation of other uses, such as nature and recreation. The designation of deepwell injection areas is no problem at all, because it requires practically no surface area. With open reservoirs it is advisable to make the reservoirs as deep as possible in order to minimise their surface area as well as to facilitate eutrophication control. If the potential for concurrent use of infiltration or reservoir sites is properly publicised, the water utility may even generate support from the authorities and the public.

3.3 Impact on surroundings

The impact of new storage facilities on the surroundings has to be assessed and minimised. Larger facilities require an Environmental Impact Assessment (EIA). Disturbances during the construction (e.g. noise, traffic, etc.) and the negative impacts after commissioning (especially ground-water fluctuations) have to be taken into account (10). In most cases it is imperative to minimise these effects. If the ground-water level is kept as constant as possible, for instance, agriculture is not impeded and cellars in houses are kept dry. In other projects, however, it may be beneficial to raise the ground-water level for wetland creation.

3.4 Environmental sustainability

Despite its many advantages, surface water storage also entails negative environmental effects, such as consumption of chemicals and energy or waste production. Although the purification efficiency of artificial recharge techniques is higher compared to open reservoirs, their adverse environmental effects are greater. In addition, recent research on these effects has indicated that hyperfiltration costs twice as much 'ecopoints' than artificial recharge by infiltration (11).

Cost–efficiency is another important factor. Table 6 shows that the indicative costs of artificial recharge, and in particular deepwell injection, are significantly higher, due to their pretreatment requirements (The quality of the water after storage, however, is superior to reservoir water.)

3.5 Future developments

The possibility to bridge periods of insufficient water quantity or quality will definitely gain importance in future. In a water-rich country such as The Netherlands it seems odd to consider water shortages. The average flow of the Rivers

Table 6. Indicative costs of surface water storage (US$/m^3)

	Infiltration	Deepwell injection	Open reservoir
Pretreatment facilities	0.43	0.57	0.00*
Storage facilities	0.07	0.07	0.15
Total costs	0.50	0.65	0.15

* Dephosphatation excluded.

Rhine and Meuse is 2000 and 300 m^3/sec, respectively, but in dry summers the flow may drop below 1000 and 25 m^3/sec. Because of other interests such as nature, shipping and agriculture, the amount of surface water available for drinking water production may fall short of demand in a dry summer, especially for the River Meuse.

Dry periods may gain importance in the future due to global climatic change. The overall trend in western Europe is that winters will be wetter and summers drier. This will certainly have effects on the discharge of Rivers Rhine and Meuse. Recent investigations in the Rhine catchment area forecast a discharge increase in winter/spring of 15% to 45% and a drop of minimum flow in summer/autumn with 15% to 45% (12). This also implies a longer period of lower minimum discharges (Fig. 8). Global climatic change may increase the evapotranspiration and water demand for agricultural (irrigation) and domestic purposes (lawn sprinkling, air conditioning, etc.). A study in south-east England predicted a 4% increase of domestic use and a 46% increase in agriculture (13).

New legislation may also increase the need for additional storage volume. The quality standards for drinking water tend to become stricter, e.g. the proposed *Cryptosporidium* standard (absent in 100 m^3). This may force water companies to prevent certain pollutants or pathogenic organisms from entering their treatment system. This may be achieved by storage facilities that allow for inlet closure during periods of high concentrations in the river.

4 Conclusions

- Surface water is an increasingly important source of drinking water supply in The Netherlands. The use of surface water will grow from 400 Mm^3/year at present to 800 Mm^3/year in the next decades.
- Water quality improvement by pretreatment and self-purification during storage is an important preliminary step in drinking water production, which is environmentally sustainable and cost-efficient.
- One of the major disadvantages of storage is the use of space. If the potential for concurrent land use is maximised, the construction of storage facilities may even become an advantage in a densely populated country such as The Netherlands, however.
- The environmental sustainability and cost-effectiveness of surface water storage for water supply must be propagated by water utilites to rally support from politicians and citizens.
- Global climatic change may alter the water balance in The Netherlands. The increased incidence of periods with insufficient water quantity is likely to enhance the importance of surface water storage.
- The present gap between surface water quality and drinking water standards is a strong argument for surface water storage.

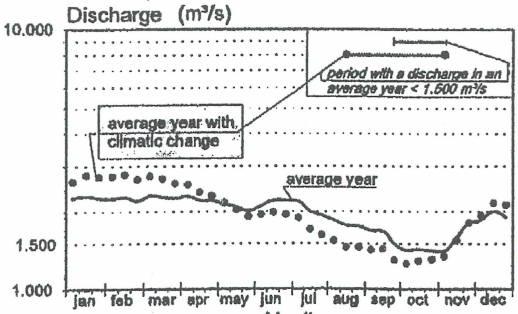

Fig. 8. Present and future discharge of the River Rhine at Lobith (German–Dutch border).

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Appendix I: List of abbreviations

DELTA	Delta Utilities
DZH	Dune Water Company South-Holland
GW	Municipal Water Company Amsterdam
NRE	Regional Utilities Eindhoven
PWN	Water Company North-Holland
WBB	Water Storage Corporation Brabantse Biesbosch
WBE	Water Company Europoort
WML	Water Company Limburg
WOB	Water Company East-Brabant
WOT	Water Company East-Twente
WRK	Water Transport Company Rhine-Kennemerland.

Reservoirs versus territory

J.A. Herreras Espino & J. de Castro Morcillo
Canal de Isabel II, Santa Engracia 125, 28003 Madrid, Spain

1 Water supply to large cities

1.1 Source of water resources

In Spain, water supply is either provided from surface or ground-water resources, except when the circumstances are extremely unfavourable — desert zones and islands — where it is necessary to resort to sea water desalination plants. Although 31% of Spain's inhabitants receive ground-water supplies, hardly any cities or large towns depend exclusively or mainly on ground water.

In climates such as Spain's, where seasons are clearly defined and rainfall is uneven, it is often necessary to store winter resources for the summer, and the water from wet years for dry periods, thereby giving rise to a need for reservoirs as the basic supply system for large cities with surface resources. The control of resources from catchment areas — where water quality is greater — and conveying it considerable distances to cities, is commonplace. Madrid, Barcelona, Bilbao, Zaragoza, etc. are well-known examples of cities that use this practice.

1.2 Future needs

The above was the case in the past, but what about the future? Will water resource availability have to be increased for cities? If so, how will these increases be obtained? Where the need for new resources is concerned, the answer seems clearly to be affirmative, because at least three reasons exist jointly or separately, to endorse this:

(a) a need to increase supply guarantees,
(b) an increase in the number of users, and
(c) an increase, in many places, of the per-capita consumption.

A justification should be given for these three reasons. Regarding the first — increased supply guarantees — the restrictions and problems caused by the most recent drought serve as a reminder that many parts of Spain require greater resource availability. With respect to the increase in the number of users, it should be remembered that it is the case of large cities that is being analysed, not the entire country population. Although overall figures for the latter are clearly tending to stabilise — and even to fall — this is not the case for metropolitan areas. It is certain that the number of inhabitants in large urban areas will increase, especially along the Mediterranean coast, which is where water supply problems are most acute. An increase in per-capita consumption is an aspect which is closely linked to both an increase in living standards and water-saving, so it will receive a greater in-depth analysis later.

Therefore, accepting that, for the aforementioned reasons, it will generally be necessary to increase the resources available, what options exist for achieving this? An analysis of the role of reservoirs in the near future is thus in order. The procedures that can now be used to obtain additional resources have been termed 'The sources of the future'. After listing these sources, the following is devoted to describing the pros and cons involved, and an attempt is made to address some associated aspects which are often considered without the objective approach that is required.

2 The sources of the future

2.1 Identification

As has already been seen, 'Sources of the future' is understood here as meaning the various procedures — in addition to the structural and management measures, and a combination of these — that can be used to generate the new water resources which the supplies require and, specifically, those of the large cities. It is more than likely that, in nearly all cases, a combination of several of these procedures must be used, depending on the local circumstances.

However, no disagreement appears to exist with respect to the following list, which contains the number of procedures now available. The order in which they are presented is in no way indicative of priority.

- Desalination of sea water.
- Re-use of waste water.
- Water-saving.
- Water markets.
- Increase in ground-water resources.
- Increase in surface resources.

2.2 Desalination

This solution is only valid for coastal towns and, especially, the islands. The high cost must be considered of both investment — over 500 Pta/m^3 — and operation, which is usually about 125 Pta/m^3, whose basic and largely uncontrollable component is the price of power.

With respect to this question and in order to explain why this type of option has not been frequent in the past, it must be remembered that in countries such as Spain, the total water percentage required for urban supply is several times lower than the demand for irrigation and that, furthermore, the best soils and climates are usually found where water is