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Overview on survey of water installations underground: underground water-conveyance and storage facilities

A. Nordmark*[,1]

ITA Working Group on Subsurface Planning, c/o The Swedish Rock Construction Committee (BK), P.O. Box 1721, SE-111 87 Stockholm, Sweden

1. Foreword

In 1997, Working Group No. 4 'Subsurface Planning' of the International Tunnelling Association (ITA), decided to make an investigation of underground water supply and storage facilities, including underground works for flood control.

Sadly enough, we have only in the last few decades experienced many times when uncontrollable amounts of rain water (or melting water) have caused major catastrophes for both nature, animals and human beings. In some of these cases, no tunnels in the world would have helped the situation. However, in areas where heavy rains are frequent, or in areas where the geological conditions are known to be insecure in the case of heavy rainfalls, and in urban areas to avoid flooding and mixing with sewage water, tunnels and storages for flood control will be of great value.

In dry regions where rain is scarce, it is vital to secure the basic need of water for both irrigation purposes in agricultural areas and in densely populated areas for drinking water supplies. It should be noted here that the water demand in the world has tripled since the middle of the 20th century. In such areas, water storages and water conveyance tunnels are of great importance.

Nine nations took active part in submitting their contributions to this study: Australia, France, Japan, Lesotho, Netherlands, Norway, Sweden, United Kingdom and USA. You will appreciate that this is a much abbreviated version of the raw data submitted by these nations (in all 300 pp.). Please feel free, therefore, to contact the Work Managers listed at the end of this overview for more details about each project.

On behalf of our Tutors for Working Group No.4, Prof. S. Pelizza (–1999), N. Bulychev (1999–2000), J.-P. Godard (2000–) and myself, I wish to thank the participating nations for their interest in this study, and in particular, I wish to thank the coordinator of this project, Dr Hidekuni Takasaki of the Japan Tunnelling Association, who has undertaken the major part of this work.

While realizing that study could be extended with more nations and cases represented, I invite you to study the introduction and the cases described on the following pages and to bring it to the attention of planners and decision makers in your country where need for similar facilities may be called for.

(*Annica Nordmark, Animateur of Working Group No.4.*)

2. Background and objects of investigation

2.1. Significance of investigation

It has always been a basic need for mankind to secure water resources. The evidence for this is that ruins of open water channels or elevated aqueducts, constructed in ancient times, still exist, and some of them are still in use. In recent years, not only have life systems in urban areas been subject to drastic change due to mass consumption, but also agricultural/industrial systems. As a consequence, chronic water insufficiency or draught due to unseasonable weather has become noticeable.

In contrast, the water-preserving faculty of the land is lowered, due to progressive surface covering in urban areas. As a consequence, rivers become susceptible to flooding with a lower intensity of rainfall than ever, resulting in frequent inundation and run-off to urban facilities, as well as making sanitary conditions worse.

Since the source of non-polluted water is located, in most cases, far from the place of water consumption, a facility of water conveyance is necessary. To minimize the fluctuation of water supply amount between the lev-

*Tel.: +46-8679-1721; fax: +46-8611-1091.
[1]Working Group Animateur.

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Table 1
Classification of collected projects from participating countries

Facilities	Water conveyance		Water storage		
Usage	Tunnel (Inc. Underground River)	Others	Reservoir & Cavern	Abandoned mine	Others (Incl. Underground dam. Natural cavern)
Water Supply	FR 1 JP 6 LS 2 SE 1 UK 1 USA 3		NO 6 UK 1		NL 1
Sewerage	FR 1 JP 2 SE 4 UK 1		FR 1 NO 3		UK 1
Industrial Water supply	JP 1				
Irrigation Water supply	AU 1 FR 2 JP 1				
Flood control	JP 3		FR 1 JP 2		

AU: Australia; FR: France; JP: Japan; LS: Lesotho; NL: Netherlands; NO: Norway; SE: Sweden; UK: United Kingdom; USA: USA.

els of draught and excess rainfall, a means of storage, in common or temporary use, is required. However, it is often difficult nowadays to construct such facilities as an open water channel or water reservoir on the surface around urban areas, because of the difficulty of site acquisition and environmental restrictions.

An underground solution, on the contrary, will offer the advantages of preventing evaporation and contamination of water, and from secondary pollution of lake or seawater from a reservoir or from the air.

2.2. Objects of research

It was the object of this research program to provide an inventory of underground facilities for water supply and water storage in urban and agricultural/industrial areas, and to offer the results of the inventory to decision-makers and planners who are involved in the urban planning and water resources planning.

3. Summary of projects

3.1. Data classification

The Table 1 shows the classification of collected projects from participating countries.

3.2. Water supply facilities

3.2.1. Water conveyance

A total of 14 projects were submitted. Although the object of this section is water conveyance facilities for city water, a case about headrace tunnels for hydraulic power generation from Lesotho is also inserted below for reference.

(1) France introduced interesting and relatively old examples:

Firstly, in Nimes and Aix-en-Provence tunnels were constructed by the ancient Romans. (Typical tunnel is 8 km in length, 4.5 m^2 in cross-section.)

Secondly, in the middle of 19th century, an 83-km aqueduct was built in Marseilles with short tunnels, and is called the 'Canal de Marseilles'.

The third is the early modern aqueducts around Paris. Although the aqueduct is longer than 120 km, the tunnels comprise very small sections (Ref. 29).

(2) Among the five cases introduced from Japan, a typical case is introduced here.

The Kasumigaura Water Conveyance Project (Tanimura, 1998) (Fig. 1) involves multiple purposes, including purification of lake water, as well as conveyance of city water, industrial water and agricultural water. The tunnel is outlined as: 45 km in total length, 4.5 m in inside diameter, and 25–35 m^3/s maximum in serviceability. Since the area is flat and urbanized, underground construction was adopted for such reasons as topographical conditions, scarcity of land on the surface, environmental protection and securing safety. The shield tunneling method was mainly employed because of the weak ground (Ref. 4).

(3) Lesotho presented two cases of headrace tunnels for hydraulic power generation in the Lesotho Highlands Water Project (Boniface, 1997). The project was carried

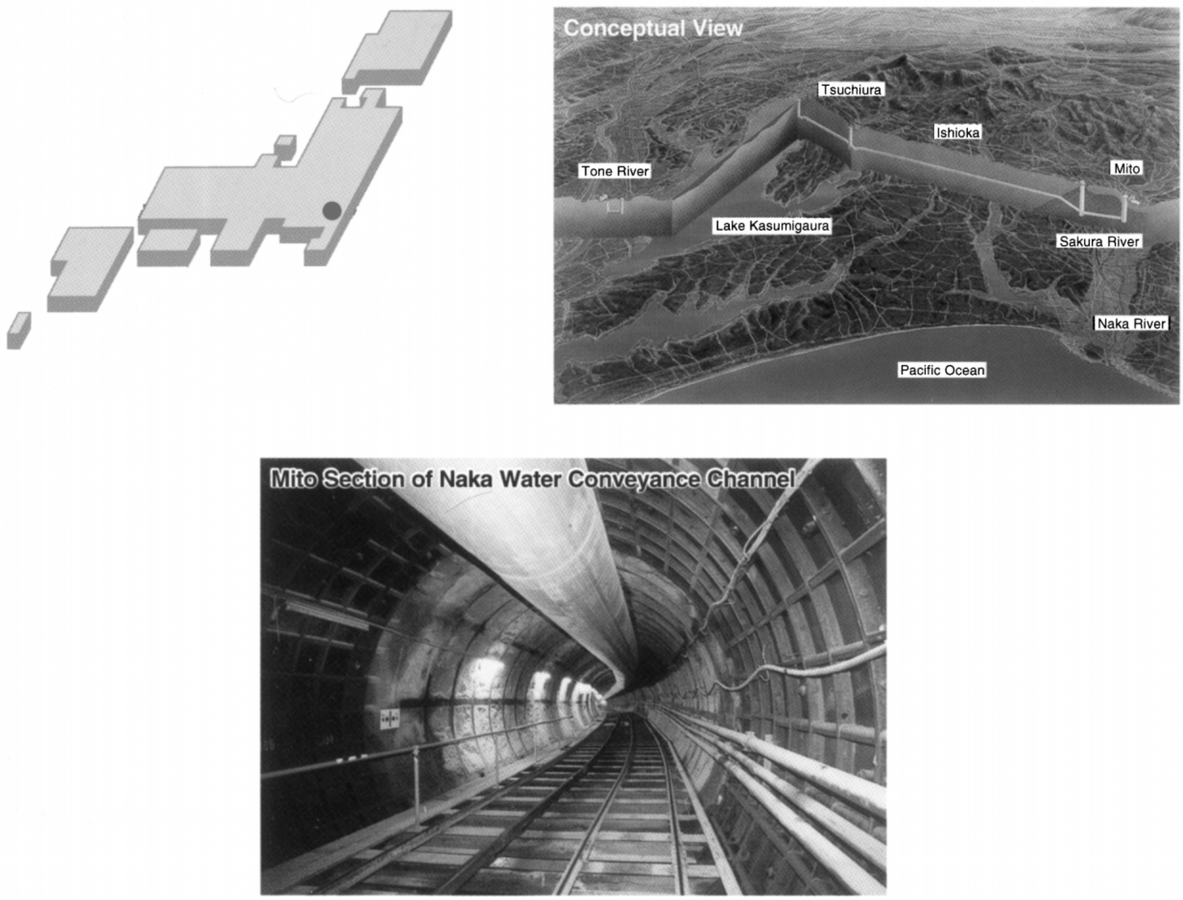


Fig. 1. The Kasumigaura water conveyance project.

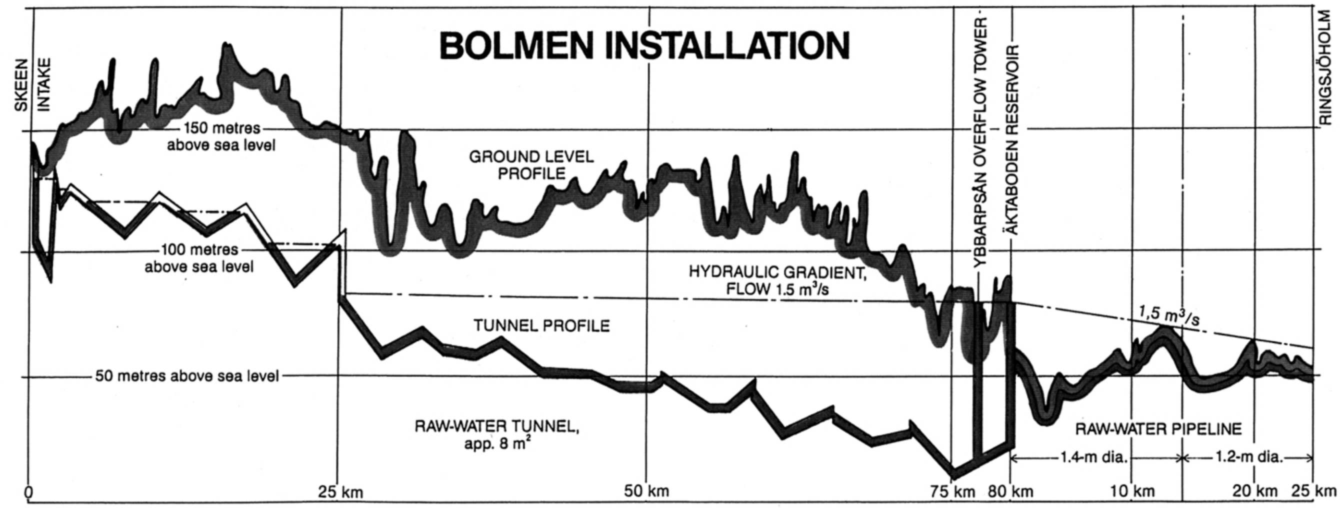
out in a mountainous area is characterized by long tunnels, 15 and 45 km, excavated by the Tunnel Boring Machine (TBM) with maximum overburdens of 500 and 1200 m. Thirty-two cubic meters per second of water are thus secured via inside diameters of approximately 4.5 m. Topographical conditions, construction cost and maintenance cost are mentioned as the reasons for adopting underground construction (Ref. 2).

(4) The Swedish Bolmen Project (Cesano et al., 2000) (Fig. 2), constructed in 1975–1985, conveys the water of Lake Bolmen via a pipeline to supply water to the southern-most region of Sweden. Inside a horseshoe-shaped tunnel, 3.5 m in maximum width, 2.5 m in height and 80 km in overall length, are pipelines having diameters of 1.2–1.4 m to supply water at 6 m^3/s maximum. The reasons for underground construction include topographical conditions, legal restrictions, construction cost and maintenance cost. To deal with hard gneiss, the blasting method was employed. Inflow water was reportedly a serious problem (Ref. 12).

(5) The London Water Ring Main Project in the UK is a water supply network comprising tunnels with an inner diameter of 2.54 m and a total extension of 83 km. Its special feature is the long service period set for 120 years. Geologically, the area is formed with London clay. Because of the maximum overburden of 140 m, the design was verified by conducting a loading test on precast concrete segments in the planning stage. To cope with the topographical conditions, underground construction and the TBM method were adopted (Ref. 24).

(6) The report from USA concerns the City Tunnel No.3 Project, New York, 1998, the largest infrastructure project in the city's history. Commenced in 1970, it is expected to be complete in 2010, with a total construction cost of US $6 billion. The total extension is 103 km with inside diameters of 4.8–7.2 m to attain a maximum serviceability of 4.9 million cubic meters per day (57 m^3/s on average). A service period of 100 years is planned. The reasons for underground construction include security and disaster prevention, followed by maintenance. Since the overburden is 81 m (and 240 m in rock) at most, state-of-the-art construction technologies were employed, using mainly the TBM and blasting method (Ref. 23).

The Metro West Water Supply Tunnel (Fig. 3), which will be completed in 2003, will increase the water delivery system's capacity by 1.7 million m^3/day. The tunnel will link MWRA's reservoirs and water treatment and



TUNNEL DATA

Volume of rock excavated	
- main tunnels	770,000 m³
- access tunnels	130,000 m³
- sidings	150,000 m³
- open cut	50,000 m³
Total	1,100,000 m³
Distance drilled	app. 3.5 million m
Explosives used	app. 2.5 million kg
Number of man-days	app. 225,000
Number of rock bolts	app. 40,000 No.
Shotcrete in per cent of the tunnel surface area	app. 17%
Pregrouting in per cent of the tunnel length	app. 25%
Pregrouting	
- number of holes	2,500 No.
- distance drilled	310,000 m
- weight of cement	10,200 t
Longest distance tunnelled in one day	20 m

Fig. 2. The Swedish Bolmen project.

storage facilities to the City Tunnel, local distribution pipes, and the people that they serve. The whole length of the tunnel is 28.3 km, and it is excavated 60–150 m below ground, utilizing state-of-the-art TBM. (Ref. 37).

3.2.2. Water storage

A total of seven project cases were submitted. Five cases were sent from Norway and one from Netherlands. These are technical reports without answering our questionnaires.

(1) In Norway, city water storage facilities have long been installed underground, with the oldest dating back to the 1950s. Many towns have later employed this method. These facilities each have a storage capacity of 1000–25 000 m³. A major reason for the popularity of such facilities is that the rock is of good quality, and no lining is needed. Among the materials submitted, three typical cases are described below.

The Kvernberget Rock Cavern Tank Project (Fig. 4) has a storage capacity of 16 000 m³ and consists of a

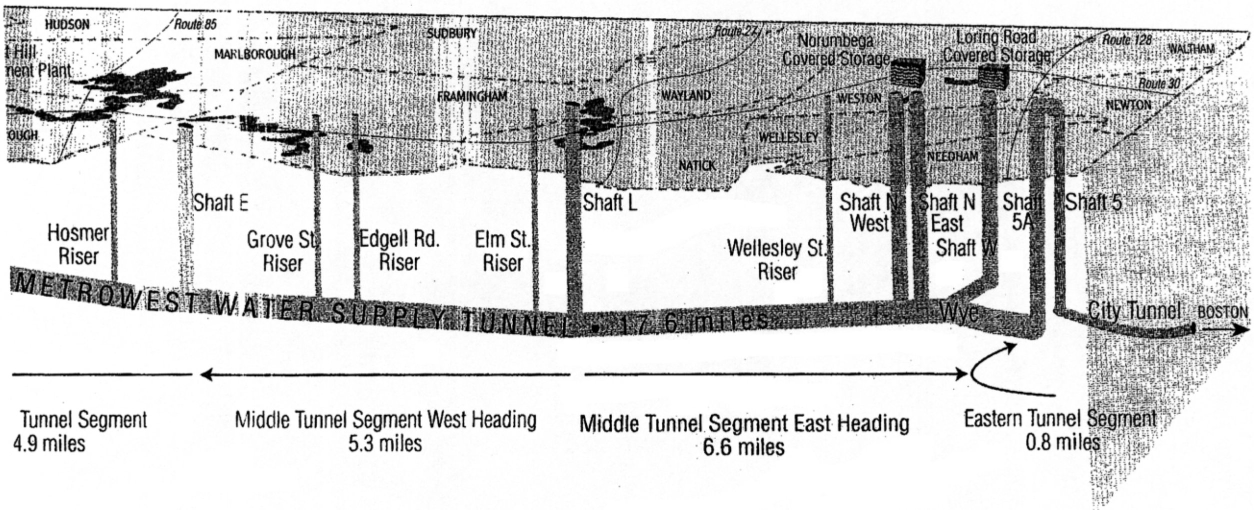


Fig. 3. The Metro West water supply tunnel (Source: Massachusetts Water Resources Authority).

twin cavern, each being 11 m wide, 7.5 m high and 120 m long. An additional cavern has also been planned. Geologically, the bedrock is composed of pre-Cambrian gneiss, which is reasonably watertight. Water is conveyed from an inland lake via a pipeline to the rock cavern (Ref. 17).

The Hogasen Underground Water Tank in Trondheim (Fig. 5) has a storage capacity of 22 000 m^3 (26 000 m^3 in quantity of excavation). It was constructed in a greenstone area close to a large fault zone. Because of that, and since the rock overburden is as small as 20–40 m, a twin tunnel system was employed, each having a small section of 8 m in excavation width and 8.5 m in height (Ref. 19).

The Skullerud Water Treatment Plant (Fig. 6) completed in 1994, has upgraded the water quality for the southern parts of Oslo city. A volume of approximately 110 000 m^3 of rock was excavated. This project includes two low level reservoirs, $2\times15\,000$ m^3 (220×12 m), and a high level reservoir 7000 m^3 (Ref. 35).

In Norway, where the geology is favorable, a no-support underground water tank is less expensive than an ordinary reinforced concrete water tank, if the storage volume exceeds 5000 m^3, and basically requires no maintenance cost (Fig. 7).

(2) From UK, the Knapp Mill Water Treatment Works Storage Reservoir Project is introduced. Partially underground, the facilities, 95.3 m wide, 51.2 m long and 6.3

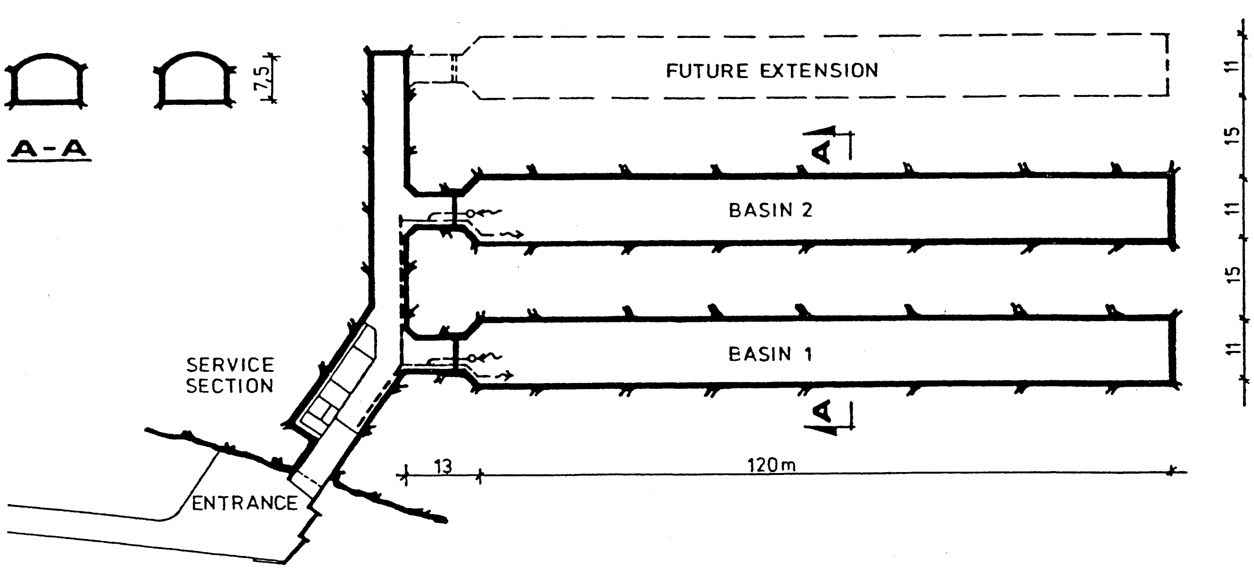


Fig. 4. The Kvernberget rock cavern tank project.

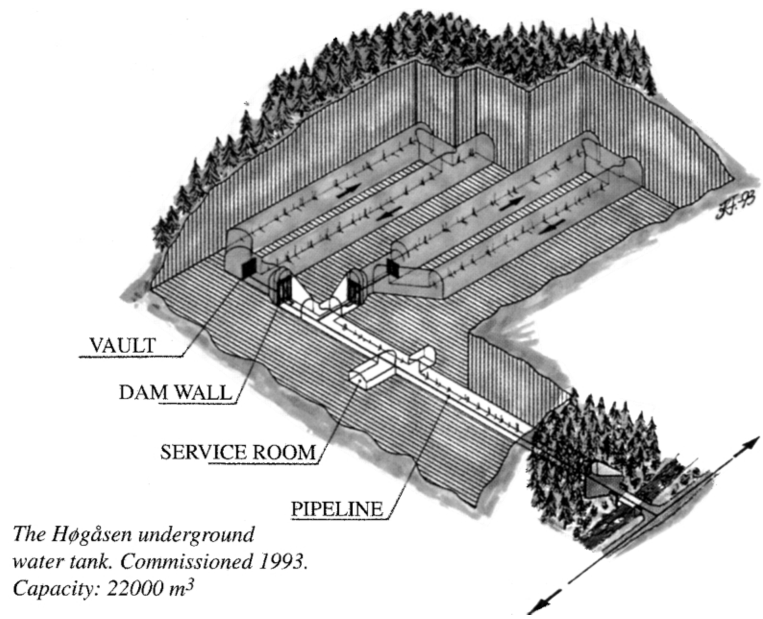


Fig. 5. The Hosagen underground water tank in Trondheim.

m high, have a storage capacity of 24 000 m^3. Underground construction was adopted for environmental protection and safety (Ref. 26).

(3) Located near the Hague in the southwestern area of the Netherlands, the DZH (Dune Waterworks of South-Holland) Project (Fig. 8) provides a system to purify, store and collect water using the sand layer of the ground there. In this area, city water had been supplied by collecting groundwater since the 1870s, but the increase in population and water demand outgrew the water supply. Thus, in 1955, a system was commercialized, whereby river water is conveyed to recharge the ground, purified by the sand layer of the ground, and collected for use as city water. This system is currently operating at 25 recharge basins in dune areas. Water is finally recharged to and collected from the sand layers using deep wells to protect the subsurface environment. After being pumped up, the water is conveyed to water

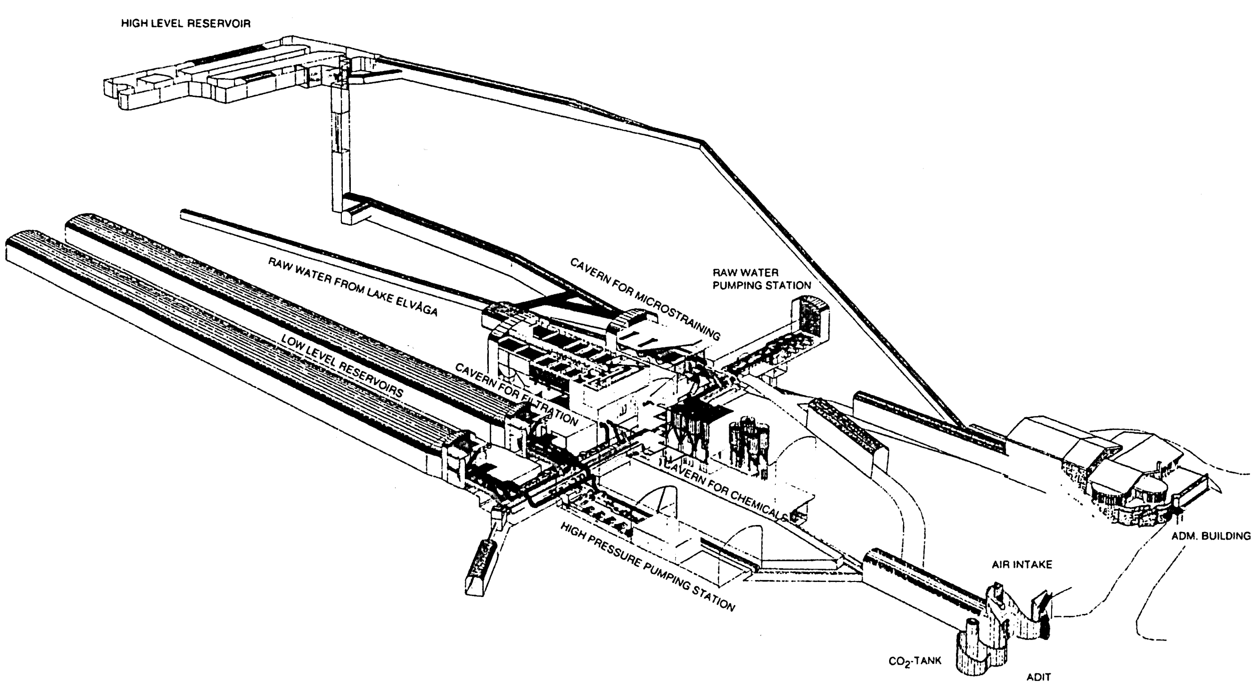


Fig. 6. The Skullerud water treatment plant.

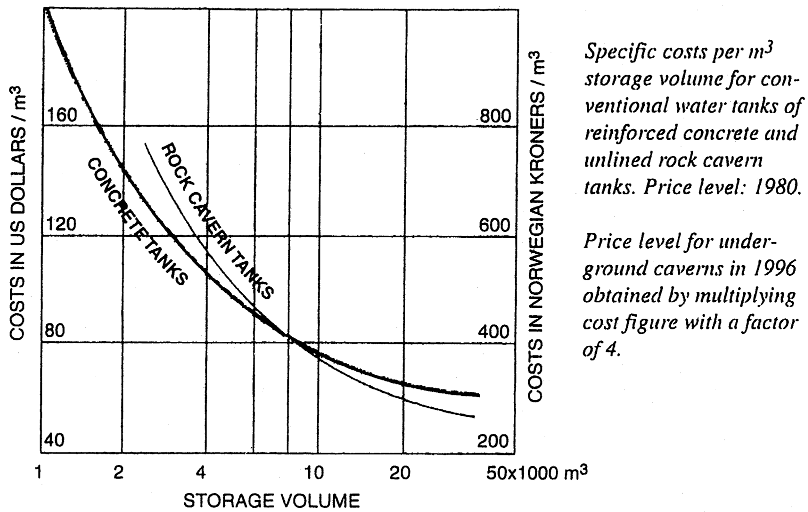


Fig. 7. The relation between costs and storage volume.

works for secondary treatment, and then supplied to urban areas (Ref. 28).

An underground dam may be cited as a similar system. This is intended to store water in a basin-shaped underground deposit layer. Many development cases have been reported in Japan and other countries.

3.3. Industrial water supply facilities (water conveyance)

Only one case has been introduced from Japan, the Kasumigaura Water Conveyance Project. In addition to industrial water, it also is intended for agricultural water and the purification of lake water. For an overview, see Section 3.2.1.

3.4. Irrigation water supply facilities (water conveyance)

Four cases were introduced from Australia, France and Japan.

1. The objects of the 'Canal de Province' are for agriculture, hydropower and tourism. A 140-km length, including 127 km underground (20 tunnels with inner diameters 2.3–5 m),was constructed from 1960 to 1990 (Ref. 32).
   The project 'Canal du Verdon' was built in 1865–1875, and could flow 4.1 m^3/s through 20 tunnels of 82 km in length (Ref. 34).
2. The case from Japan is the Kasumigaura Water Conveyance Project, which is intended for industrial water, city water, and purification of lake water, in addition to agricultural water. For the overview, see Section 3.2.1.
3. The Snowy Mountains Scheme Project carried out in southeastern Australia provides water for agriculture and hydraulic power generation. It is composed of many tunnels, extending to 134.7 km in overall length, with tunnel diameters of 3.1–8.5 m. The topographical conditions are ideally suited for this underground water conveyance and power generation scheme. The blasting method was employed for excavation (Ref. 27).

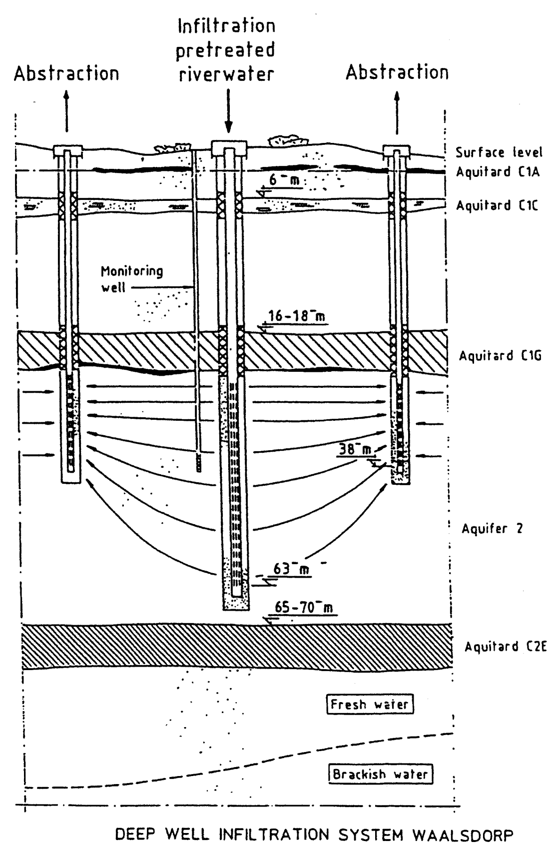


Fig. 8. DZH (Dune Waterworks of South-Holland) project.

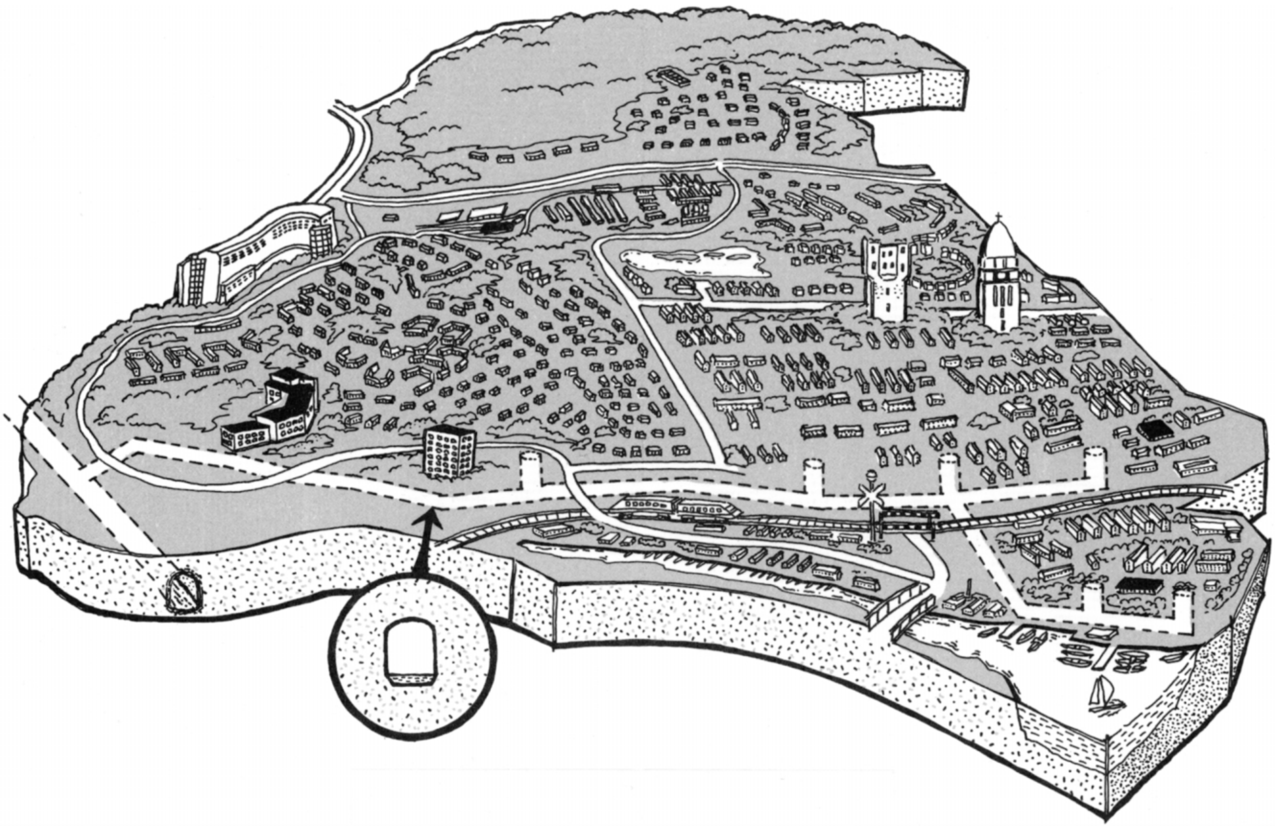
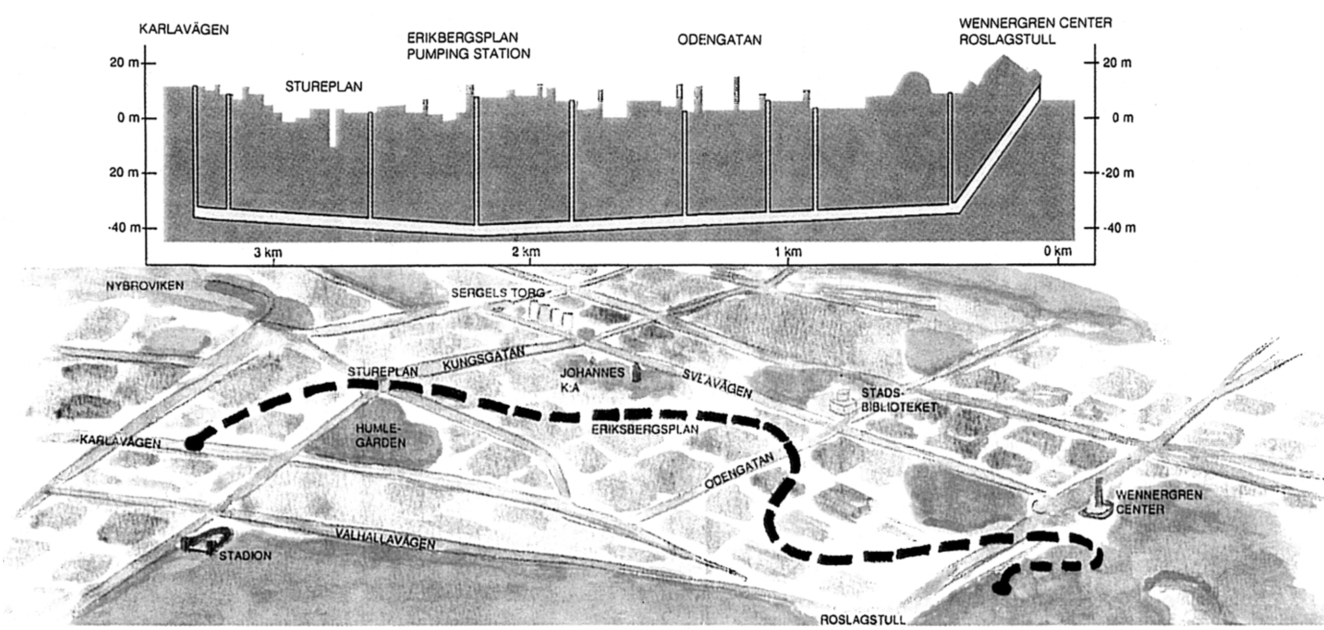


Fig. 9. The Swedish Underverket project.



Profile and view of the Stockholm "Snake Tunnel" for waste-water overflow. The tunnel has a capacity of approximately 35,000 m³.

Fig. 10. The Ormen (The Snake) project.

3.5. Sewage facilities

3.5.1. Water conveyance

Many projects were introduced from France, Japan, Sweden and UK.

(1) Examples in Paris and Marseilles were briefly introduced.

(2) Japan's Tosabori-Tsumori Sewage Tunnel, 6 m in inside diameter, has a capacity of 87 m^3/s max. Underground installation was adopted due to scarcity of land and legal restrictions. Weak soil and a thin overburden of approximately 15 m led to a special work method, the air-bubble shield tunneling method (Ref. 5).

(3) The Swedish Underverket Project (Fig. 9) constructed in 1996–1998, 3.25 km long and 15 m^2 in cross-sectional area, has a capacity of 8 m^3/s at a maximum. It includes a 25 000-m^3 storage tank. The reason for underground construction is to eliminate the risk of sewage water leaking to the ground surface. It is designed to control the leak of groundwater into the sewerage to 2 l/100 m. The overburden is 15–20 m on average, including some 1.5 m points, but the blasting method was employed, as the terrain is over the whole rock mass (Ref 1) (Hahn and Tenne, 1989).

The Regnbagen (The Rainbow) Project, constructed in 1993–1995, has a 21 000-m^3 storage tank 1895 m in length and 10.5 m^3 in cross-sectional area (3 m wide and 3.5 m high). Being located in an urban area with scarce land and a pressing need for environment preservation, this waste-storm water magazine was required to be underground. Special efforts were made to prevent vibration (Ref. 13).

The Ormen (The Snake) Project (Tollerup, 1993) (Fig. 10) constructed in 1991–1993, Stockholm, is a combined type rainwater-sewage tunnel having an overall length of 3.2 km with an excavation diameter of 3.5 m. At times of flooding, the 'surplus' water is temporarily stored until the load on the pipelines and the near-by treatment plant is reduced. It includes a storage tank of 32 000 m^3. Scarcity of land is the reason for underground construction. It was excavated at a depth of 10–40 m using tunnel boring machines. The ground, composed of granite and gneiss, was excavated at an average speed of 300 m/month (The Tunnel Boring Machine) (Ref. 14).

In the Saltsjo Tunnel Project (Fig. 11), constructed in 1986–1989, a sewage tunnel, 7.5 km in length and 3.5 m in diameter, was constructed. Formerly, water from Lake Malaren was treated for drinking purposes and the effluent returned to the lake. Today, the heat from the treated effluent is recovered at a nearby heating plant and then discharged through the Saltsjo tunnel under Stockholm city into the Baltic Sea. This will gradually improve the quality of the lake water, while keeping the amount of dissolved oxygen at a proper level, and allow safe swimming in the lake. Tunneling was employed because of a scarcity of land and the need for environment preservation, and a special specification TBM was developed for noise and vibration control to excavate hard granite and gneiss under densely populated areas (Ref. 15).

(4) The Brighton Stormwater Project, UK, is a tunnel 5.1 km in length and 6 m in excavation diameter, and serves as a storage tank with a capacity of 140 000 m^3 as it stands. The reasons for underground construction are topographical conditions and scarcity of land on the ground. The tunnel is used only during heavy rainfalls, while diluting sewage, and after the rainfall, water is pumped up for treatment and then discharged. The earth pressure balanced shield tunneling method was employed for the excavation to leave an average overburden of 35 m in a chalk layer (Ref. 21).

3.5.2. Water treatment

Four reports, one from France, two from Norway and one from the UK, were submitted.

(1) Recent projects, an earth covered treatment station in Marseilles city center, an underground cavern in Monaco and an underground treatment facilities in Toulon from France are briefly introduced (Ref. 25).

(2) Norway's Hovringen Underground Sewage Treatment Plant (Fig. 12) was constructed in hard bedrock composed of gneissous quartz diorite. The cavern required almost no support, except, locally, some rockbolts and shotcrete were used. The caverns contain a set of sewage plant facilities, including the plant equipment, and the plan includes a future extension. Presently it treats sewage for 90 000 people, or 70% of the population of the city of Trondheim. The treated water is discharged into the sea with no incident of contamination of the seawater at all (Ref. 31).

The Ladehammeren Underground Sewage Treatment Plant (Fig. 13) was constructed in greenschist layers containing quartz keratophyre. In this area, many caverns were excavated for military purposes during World War II, and during the 1970s, some of them were developed as the world's first deep underground freezer storage. This sewage plant project was commenced in 1992. As illustrated, it consists of a series of three caverns, extending to 450 m in overall length, and the total amount of underground excavation, including tunnels, is 10 000 m^3. As a secondary treatment plant, it treats the sewage of 50 000 people as well as industrial wastewater. Being located near a ship navigation simulator (SMS), the plant was excavated by the controlled blasting method to prevent vibrations. Caverns and tunnels were supported with rockbolts and shotcrete. Steelfiber shotcrete was applied, using 50-mm thick polyethylene mats to prevent leakage and fire (Ref. 22).

Due to the combination of densely populated areas and a narrow inlet of the Inner Oslofjord, the fjord has become more and more polluted and less attractive as a

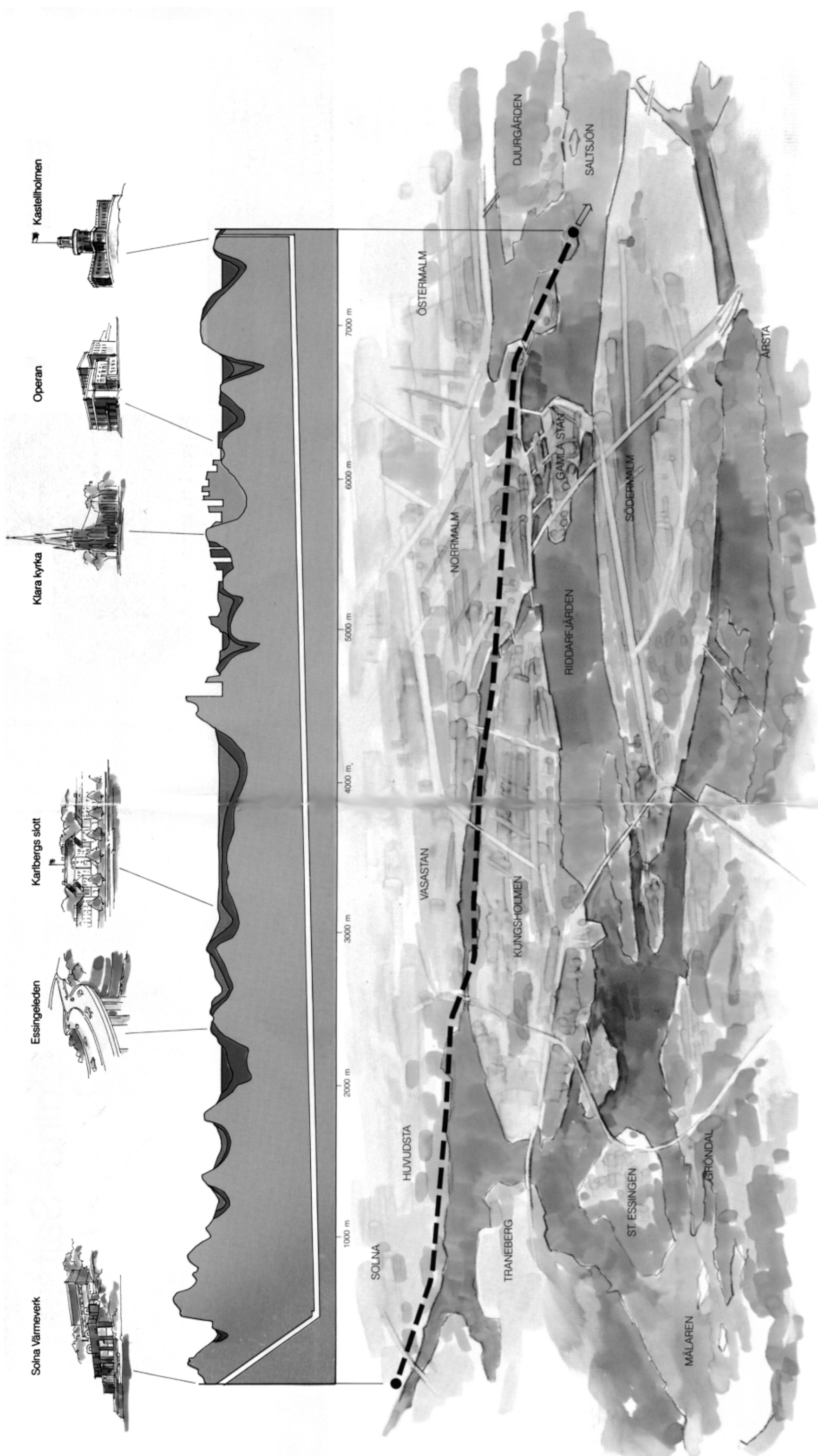


Fig. 11. The Saltsjo tunnel project.

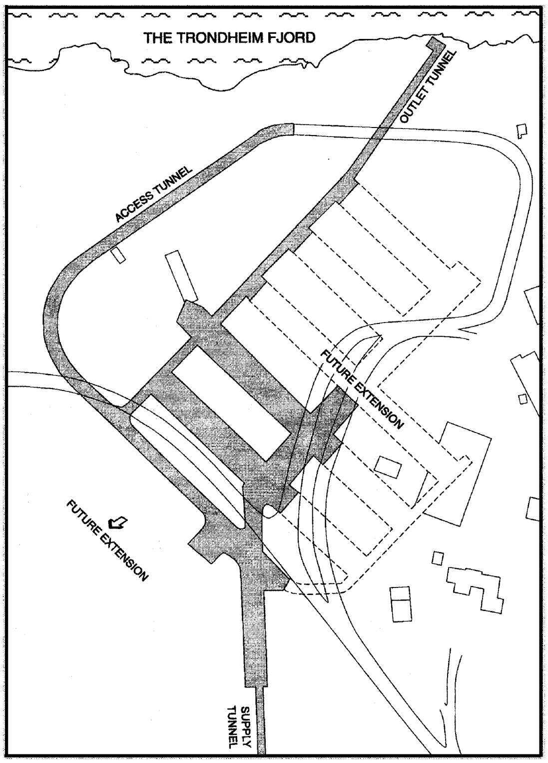


Fig. 12. The Hovringen underground sewage treatment plant.

recreation area. To improve the water quality, a sewer transportation tunnel system and an underground sewer treatment plant were constructed during the 1980s (Rohde et al.). Except for the pumping station at Frognerparken, the flow through the tunnel system is by gravitation.

To meet the new requirements to reduce outlets of phosphorous and nitrogen components, process improvements and extension to the plant were necessary. Despite heavy underground construction works, the plant has been in continuous operation with only a 10–20% reduction of capacity during the extension works.

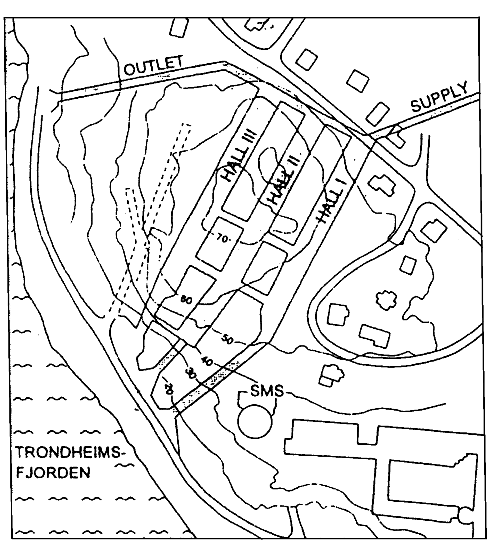


Fig. 13. The Ladehammeren underground sewage treatment plant.

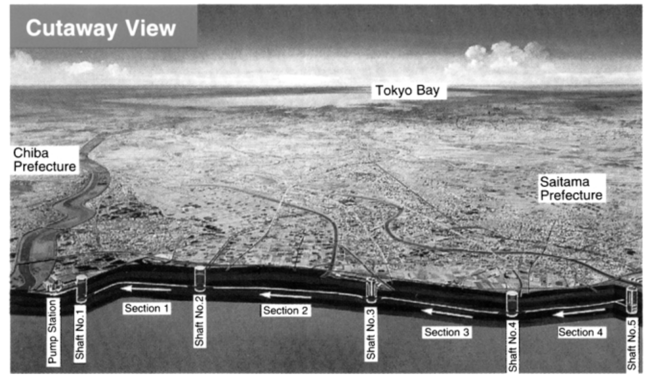


Fig. 14. The Shuto-gaikaku discharge tunnel project.

(3) The report from UK concerns the Brighton Stormwater Project. For the overview, see Section 3.5.1.

3.6. Flood control

3.6.1. Water conveyance

Japan submitted a few interesting tunnel projects which discharge excess of river water during flood.

In the Shuto-gaikaku Discharge Tunnel Project locating near Tokyo (Fig. 14) connects five rivers and channel, and pumps-up to the bigger, Edo-river. There are four shafts to collect flood water and one for pumping-up. Maximum water flow is 200 m^3/s, and will be extended to 270 m^3/s in the future. The tunnel was excavated by the shield machine, and its diameter was 11.8 m (Ref. 42).

The Tokyo Underground River Project is huge and takes a long completion term. Therefore, the construction of separable portion of the whole project is achieved and each portion used as a reservoir for floodwater.

The flood control plan designed for the small and medium sized river basins in the Tokyo Metropolis ultimately aiming at controlling 100 mm/h rainfall. This goal is to be accomplished step-by-step with the next step being to increase the presently projected control capacity of 50 mm to a 75-mm/h capacity.

The tunnel is mainly driven by shield machines, and those typical dimensions are over a 13-m diameter and 30-km length (Ref. 38).

3.6.2. Water storage

France and Japan offered some projects for underground reservoir system during flood time.

(1) Many cities in France use sport pitches for the surface storage of peak rainwater, but in the case of the new ‘Stade de France’ (the stadium built in Saint Denis, north of Paris for the 1998 World Football Cup) a huge

Table 2
Summary of operation systems of projects

	Nation	Project scheme			Design and construction				Operation	
	Ref. No.	In	Out	BOT/PFI	In	PC/CM	Bid	Nego	In	Out
Industrial water supply facilities										
Water conveyance	FR29	not answered								
	JP4	*					*		*	
	7	*					*		*	
	8	*					*		*	
	9	*					*		*	
	10	*					*		*	
	11	*					*		*	
	LS2	*					*		*	
	3	*	*				*	*	*	
	SE12	*			*			*	*	
	UK24	*					*		*	
	US23	*			*		*	*	*	
	37	*				*			*	
	38	Not answered								
Water storage	NL28	Not answered								
	NO16	Not answered								
	17	Not answered								
	18	Not answered								
	19	Not answered								
	20	Not answered								
	UK26	*			*	*	*			
	JP4′	*					*		*	
Irrigation	AU27					*				
	FR32	Not answered								
	34	Not answered								
	JP4″	*					*		*	
Sewage facilities										
Water conveyance	FR30	Not answered								
	JP5	*					*		*	
	6	*					*		*	
	SE1	*					*			
	13	*			*				*	
	14	*			*				*	
	15	*			*				*	
	YK25	*				*		*		
Water storage	FR31	Not answered								
	NO21	Not answered								
	22	Not answered								
	36	*								
	UK25′	*								
Flood										
Storage conveyance	JP39	*			*		*		*	
	40	*			*		*		*	
	41	*			*		*		*	
	FR33	Not answered								
	JP42	*			*		*		*	
	43	*			*		*		*	

storage facility has been sited under the plaining field, volume 160 000 m^3 (the supplying tunnel now being in construction).

Vitry sur Seine, a city close to Paris, has built a 55 000 m^3 underground reservoir under the City Hall Square. In addition to storage, the facility provides desilting of water, and the upper story is dedicated to car parking.

Immediately around or downstream of Paris, four res-

Table 3
Summary of reasons for building facilities underground

	Nation Ref. No.	Geography Topography	Lack of space	Environment scene	Regulations	Public accept	Construction/ mainte. cost	Safety disaster
Industrial water supply facilities								
Water conveyance	FR29	not answered						
	JP4	*	*	*			*	
	7			*				*
	8	*						
	9					*		
	10					*		
	11	*						
	LS2	*					*	
	3	*	*					
	SE12	*					*	
	UK24	*			*			
	US23						*	*
	37	*						*
	38	Not answered						
Water storage	NL28	Not answered						
	NO16	Not answered						
	17	Not answered						
	18	Not answered						
	19	Not answered						
	20	Not answered						
	UK26			*				*
	JP4′	*	*	*			*	
Irrigation	AU27	*						
	FR32	Not answered						
	34	*					*	
	JP4″	*	*	*			*	
Sewage facilities								
Water conveyance	FR30	Not answered						
	JP5		*		*			
	6	*			*			
	SE1							*
	13		*	*				
	14		*					
	15		*	*				
	YK25	*	*					
Water storage	FR31	Not answered						
	NO21	Not answered						
	22	Not answered						
	36	*		*			*	
	UK25′	*	*					
Flood								
Storage conveyance	JP39	*	*	*			*	*
	40	*	*	*			*	*
	41	*	*	*			*	*
	FR33	Not answered						
	JP42	*	*				*	*
	43	*	*	*			*	*

ervoir tunnels are now being excavated in order to store peak rainwater; their diameter is in the range 6–7 m, their length 2.2–5.1 km, providing volumes between 190 000 and 4 000 000 m^3 (Ref. 40).

(2) Capacity of the Imaigawa Underground Reservoir in Japan is 214 000 m^3 in storage volume, and bears 50–80 mm/h rainfall intensity together with the Imaigawa-river flow. The underground reservoir is 2.4 km long, 10.8 m in inner diameter and 45–85 m depth beneath ground level (Ref. 43).

Table 4
Summary of problems and measures through project

	Nation	Regulations	Phase of technical problems				Environment/disaster to		
	Ref. No.		Plan	Design	Const.	Mainte.	Residents	Users	Manager-self
Industrial water supply facilities									
Water conveyance	FR29	not answered							
	JP4						*		
	7						*		
	8						*		
	9						*		
	10						*		
	11			*			*		
	LS2							*	
	3								*
	SE12			*		*		*	*
	UK24			*	*		*		
	US23	*			*		*	*	*
	37				*		*	*	*
	38			*	*				
Water storage	NL28	Not answered							
	NO16	Not answered							
	17	Not answered							
	18	Not answered							
	19	Not answered							
	20	Not answered							
	UK26			*	*	*			
	JP4′						*		
Irrigation	AU27								
	FR32	Not answered							
	34	Not answered							
	JP4″								
Sewage facilities									
Water conveyance	FR30	Not answered							
	JP5			*	*		*		
	6			*	*		*		
	SE1			*	*		*		
	13						*	*	
	14				*		*	*	
	15				*		*	*	
	YK25				*		*		
Water storage	FR31	Not answered							
	NO21	Not answered							
	22	Not answered							
	36		*	*	*			*	
	UK25′				*		*		
Flood									
Storage conveyance	JP39				*		*		*
	40		*	*			*		*
	41	*	*		*		*		*
	FR33	Not answered							
	JP42			*	*		*		*
	43			*	*		*		*

4. Summary of special issues through projects

4.1. Operation systems of project

Questionnaire:
Type of project scheme

(1. ☐ In-house Management; 2. ☐ Out Sourcing; 3. ☐ BOT*;
4. ☐ PFI**; 5. ☐ Others__________)
Build-operation-transfer, **Private finance initiative contract
Type of design and construction

(1. ☐ In-house Engineering; 2. ☐ PM/CM***; 3. ☐ Competitive Bid;
4. ☐ Negotiation Contract; 5. ☐ Others____________)
***Project management/construction management
Type of operation method
(1. ☐ In-house; 2. ☐ Out Sourcing; 3. ☐ Others____________)
The answers are tabulated in Table 2.
Being public by nature, water-related projects are mostly executed by in-house management. Besides, competitive bids are adopted for design and construction, and in-house operation is carried out in all these projects.
With regard to design and construction, the predominance of in-house engineering in Sweden has attracted our attention. Also, examples of PM/CM contracts can be seen amongst projects in the UK and Australia.

4.2. Reasons for building facilities underground

Questionnaire:
Reasons for building facilities underground
(1. ☐ Geography/Topography; 2. ☐ Lack of space;
3. ☐ Conservation of environment and scenery; 4. ☐ Regulation;
5. ☐ Public acceptance; 6. ☐ Construction/maintenance cost;
7. ☐ Safety-control/disaster prevention; 8. ☐ Others)
The answers are tabulated in Table 3.
Although answers vary widely for reasons for building facilities underground, topographical conditions are the largest in number, followed by scarcity of land on the ground and preservation of the environment and scenic beauty. While the former two are inevitable, the latter is expected to continuously increase because of the rising consciousness of environment protection.
Maintenance cost was also mentioned in a number of cases. In many countries, but not all, underground construction cost is still considerably higher compared with construction above ground, but an increasing tendency is observed towards the evaluation of projects by life-cycle cost.
Also, because of the importance of water-related facilities, there are several cases adopting underground construction from the security and disaster prevention standpoint.

4.3. Problems and measures through project

Questionnaire:
Problems and measures through project
*Check x in the box after number
Upon whom are psychological measures implemented?
(1. ☐ Residents; 2. ☐ Users; 3. ☐ Managers of facilities)
For whom is safety control and disaster mitigation implemented?
(1. ☐ Residents; 2. ☐ Users; 3. ☐ Managers of facilities)
The answers are tabulated in Table 4.
Encounters with various problems and measures can be recognized in the design and execution stages, and because of underground installation, it is seen more often among facilities constructed in urban areas.
Environmental and anti-disaster considerations are mostly given to the inhabitants, indicating similar situations all over the world. Also, though the details are unknown, it is noticeable that quite a few cases give considerations to beneficiaries of the facilities and the facility management staff themselves.

5. Conclusion

According to the report issued by the 'World Committee on Water in the 21st Century' at the end of 1999, the 21st century will be the century of water. More than half the major rivers of the world suffer such problems as exhaustion and contamination and, in the basin areas where inhabitants depend on the rivers for agricultural, industrial and drinking water, their health and lives are threatened. Compared with the condition in the middle of the 20th century, the water demand of the world has tripled. The water demand has increased along with the increase in income, far exceeding the increase in population. In every place of the world, already supply of water cannot catch up with the demand. This situation involves an anxiety that disputes on water would frequently occur and jeopardize the stability of the world.

Coordinated and compiled by the Japan Tunnelling Association WG No.4 could prepare the Final Report obtainable to corporations from WG members and participating nations to this project. We will be very happy if the result of our study work could contribute to the whole world, and people and planners/engineers in the field of water resource.

Readers wishing to get more information on the individual project are expected to contact with the below list.

Nation	Window person	Contacts
Australia	Yoga Yogaranpan	jyogaran@zipworld.com.au
		130 rue de Rennes, 75006
France	Pierre Duffaut	Paris
		pduffaut@compuserve.com
Japan	Hidekuni Takasaki	Nihon University
		College of Industrial
	(Prof.-Dr.Eng)	Technology
		Dept. of Civil Engineering
		Tel/fax: +81-47-474-2426
		takasaki@civil.cit.nihon-u.ac.jp
Lesotho	Moroke Ntee	Lesotho Tunnelling Society
		P.O. Box 296, 100-Lesotho
		Fax: +266-31-00-50
Netherlands	Gerard Arends	Delft University of Technology
		Faculty of Civil Engineering
		and Geosciences

(Continued)

Nation	Window person	Contacts
		Dept. of Underground Space Technology Tel.: +31-15-278-5266; fax: +31-15-278-7828 ogb@ct.tudelft.nl
Norway	Einar Broch, (Prof.-Dr Ing.)	NTNU Norwegian University of Science and Technology Faculty of Applied Earth Sciences Dept. of Geology and Mineral Resources Engineering Tel.: +47-73-59-48-16; fax:+47-73-59-08-98 einar.broch@geo.ntnu.no
Sweden	Annica Nordmark (Executive Secretary)	Swedish Rock Construction Committee Tel.: +46-8-679-1721; fax:+46-8-611-1091 nordmark@bergsprangnings-kommitten.a.se
United Kingdom	Mike Gellatrey S. Battesby	London Underground Limited The Infrastructures Systems Engineer 1st floor, 30 The South Colonnade Canary Wharf, London E14 5EU United Kingdom Tel.: +44-20-7222-5600; fax: +44-20-7308-2552 gellatmi@email.lul.co.uk
USA	Susan Nelson (Executive Director)	American Underground Construction Association Tel.: +1-612-339-5403; fax: +1-612-339-3207 helsaua@postoffice.pacbell.net

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