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THEME IV

STATE OF ART PAPER

ARTIFICIAL GROUNDWATER RECHARGE

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THEME IV

STATE OF ART PAPERS

Artificial Groundwater Recharge	U. Schottler

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ARTIFICIAL GROUNDWATER RECHARGE

by
U. Schottler

ABSTRACT

This paper is based on results of the International Symposium on Artificial Groundwater Recharge in Dortmund (Federal Republic of Germany) May 14-18, 1979. During this symposium 67 reports were presented to about 550 participants from 32 nations, and as such it is not possible to summarize the multifarious results within the given volume. As such it has been tried to extract only the most interesting aspects and experiences of the multidisciplinary field of Artificial Groundwater Recharge.

For further information the total list of presented papers is given in Appendix A.

INTRODUCTION

Since the mid-1900's artificial groundwater recharge is used in Europe, whereas the development always was closely related to the use of bank filtration and the application of slow sand filters (FRANK). The step to artificial recharge within the drinking water management was induced by the especially hygienic decrease of surface water quality in the industrial regions, where the consumption of clean drinking water could not be covered sufficiently from groundwater.

In the meantime a great variety of experiences and intensive research results have shown, that the effectivity of bank filtration is often reduced by clogging and similar hydraulic defects and as well as slow sand filtration was not able to eliminate some micropollutants sufficiently.

In accordance to the decrease of raw water quality artificial groundwater recharge is increasingly being combined with other processing methods before and after treatment (Fig.).

An international comparison shows shows that the different parts of artificial groundwater recharge within the total amounts of drinking water are relatively small up to now (Table 1).

On the other hand the natural ground water resources are nearly completely used up and other origins of drinking water have to be found.

TABLE 1

Part of Artificially recharged drinking water in the international comparison (state 1977)

State	Artificially Recharged water in Mio m^3	Percentage total catchment
Fed.Rep.of Germany	449	11
Sweden	192	20
The Netherlands	142	14
Switzerland	45	4
France	44	1
Austria	2.5	0.6

REGIONAL ASPECTS OF ARTIFICIAL GROUNDWATER RECHARGE

Continuing in his overview Frank reported that in the Federal Republic of Germany more than 40% of surface water used for drinking water is artificially recharged and the amount of bank filtrated water decreases under 30% (Fig.).

The mostly used method of infiltration is still slow sand filtration combined with a prefiltration step and underground passage, often coupled with the old bank filtration catchments (Fig.)

The main advantages to insert

this system in Germany today are:

- Cheapness
- Buffering capacities against peak loads of several pollutants
- Simplicity and safety in operation
- Purification without adding-chemicals
- Storage capacity

During the slow long time decrease of surface water quality this standard system (Fig.) was tested on his efficiency.

Especially the Central part, the slow sand filter, has been the aims of various research efforts. Beside of the degradating capacity of the biological purification processes in the filter (Fig.), the chemical and physical reactions are principally equal to those working during bank filtration.

Suspended organic and inorganic matter is retained within the upper layer of the filter surface together with the algae which are growing there. This layer is a high effective reaction zone with microbial degradation, biological and mineral accumulation and absoption. The substances which cannot be destroyed are removed from the filter during filter cleaning. Very important is the remaining of the processes under acrobic conditions. Otherwise the lack of oxygen leads to NH^{4+} - and H_2S-production and several mobilizing reactions with iron and manganese. Under normal conditions this system is very effective concerning most of those parameters limiting drinking water quality, (Table 2).

TABLE 2

Quality Enhancement by Artificial Ground Water Recharge (Slow-sand-filtration and Underground-passage)

Parameter	Effect
1	2
Temperature	+++/-
Turbidity	+++
Suspended solids	+++
Conductivity	+/-
pH-Value	--
Base-capacity(CO_2)	--
Carbonate-Hardness	-
Dissolved Organic Carbon	++
Oxygen	--
Germs	+++
F.Coli	+++
Viruses	++
Chloride, Sulphate, Nitrate	-
Ammonium	+++
Iron, Manganese	+++(M)
Calcium, Manganesium	+/-
Arsenic	+
Lead	+(M)
Cadmium	+(M)
Chromium	+++
Mercury	++(M)
Selenium	+++
Beryllium	+++
Zinc	++(M)
Copper	+(M)
Nickel	++(M)
Polycyclic Aromates	+++
Desinfectants	-
Halogenated Hydrocarbons	--

Legend:
+++ Very High cleansing effect
++ High cleansing effect
+ Moderate cleansing effect
- No or low effect
-- Quality decrease
(M) Danger of mobilization.

As the installation of such artificial recharge systems is limited by the geological and hydrological conditions of the underground, Dalke et.al. presented a study of the possibilities of artificial recharge in Germany(Fig..)

Starting from a genetic classification of porous aquifers, essential hydrogeologic parameters of groundwater recharge are specified for typical aquifers. The parameters involve:

- regional distribution/prospecting.
- size and geometry
- Outer and inner structure

- Nature of elastic material
- Type and extent of utilization.

As well natural restrictions against artificial groundwater recharge, consisting of superimposed peat layers, seawater intrusions, ascent of saline groundwater, contamination, overstrain, competitive utilization, must be regarded. On the base of these negative and positive factors controlling artificial groundwater recharge, a general map has been designed (Fig.)

By means of graduate evaluation. areas have been outlined wherein artificial groundwater recharge or groundwater storage appears practicable.

As additional areas are often limited, especially regarding competitive use, new infiltration methods have to be developed.

One of the alternative solutions was suggested by Wolters. A covered seepage trench (Fig.), 5 to 6 m deep and filled with coarse sand (Fig.), has an infiltrating efficiency of 20 to 30 m3/m/day.

Airborne dust and algae growth were excluded by a light cover. First experiences show, that a cleaning of the clogged surface is necessary every 4 months.

Gerdes presented an infiltration method, expecially under the aspect of water storage, based on tunnels(Fig.)

He developed a mathematical model for calculating the infiltration rates and the surrounding flow conditions. Pilot plant experiences showed that this method may diminish the problems of colmation and incrustation.

Kotter reported experiences with pretreatment experiments to raise the efficiency of artificial groundwater recharge. In this case $FeCl_3$ was added into the inflow of a separate impounding basin to induce the precipitation of phosphates and other disturbent substances (Fig). After two and a half years the flocking agent was changed into aluminium-chloride. The basin contains 4 Mio m^3. The theoretical retention time in the impounding basin is about 20 days.

The phosphate concentration, the dissolved and particulate organic substances are reduced very effectively. The development of planctonic algae is diminished, too. After this pretreatment the water runs to infiltration basins acting as normal slow sand filter, due to the occurance of suitable sand layers.

As well as in Germany in the Netherlands artificial groundwater recharge is used intensively in dune area since 40 years. According to Van Puffelen today 175 Mio m/year of pretreated water (Rhein and Meuse) is infiltrated at different places (Fig.) The success of this infiltration method was demonstrated by a diagonal profile of the dune area (Fig.).

By the infiltration of pretreated water the saline water intrusion was pushed off as shown by the time dependent sketches of the interfaces.

Beside of this desalting effect of the aquifer, a flattening effect of quality and quantity decays succeeded. The elimination rates of micro-organisms, too (Table 3) indicate the good cleaning effect of this system.

TABLE 3

Removal of Micro-Organisms from Pretreated surface water by dune Infiltration (1977, 16 Samples, DWL, The Hague, According DRS. Hoekstha)

Bacteriological Virological	Before infiltration Max.No./ 100 ml.	After 10 m soil-passage removal in log-units.
Coliforms	120	2+
Faecal coliforms	100	2+
Colony Count (22°C)	$24 \cdot 10^6$	4
Colony Count (37°C)	$9 \cdot 10^6$	4
Coliphagus	10	2*

+ Not detectable in 100 ml.
* Not detectable in 1000 ml.

Another example from a nearby-region was given by Wildschut, who presented a deep-well injection and recovery system within the deeper sandlayers beneath the dunes, feeded by pretreated surface water (Fig.). In this special case the injected aquifer has a thickness of about 200 meters, consisting of about 50 m of fresh water and about 150 m of saltwater underneath.

It is covered by a loam layer of low permeability. Close under the brackish zone, with a thickness of 5-10 meters, the salt water layer is intersected by a semi-permeable layer. Injection and recovery takes place in the fresh water zone (Fig.   ).

Under normal circumstances injection and recovery are continuously. This causes a more or less linear cumulative spread in the underground with detention times of approx. 1 year. In this time the fluctuations of temperature, raw water quality and the content of micro-organisms are smoothed resp. diminished sufficiently.

In completion to this research Olsthoorn reported some experiences about the feasibility of recharge wells. Especially the change from the aerobic case of the infiltrated water to the anaerobic case of the groundwater induced many clogging problems in the wells. Because of the fineness of the aquifer material (d_{10} 0.15 mm, permeability K = 0.2. 10^{-3} m/s), there is a appreciable danger of clogging, too.

The tests were carried out with wells having screens of 10 to 20 m in length in bore holes of 0.2 to 0.8 m in diameter in which 10 to 60 m' of water were recharged per hour.

The wells were installed in various depth within the different aquifers (Fig.   ).

The pretreatment of the water to be recharged varied between a simple rapid sand filtration and an extensive purification to drinking water quality.

Though the well with the most extensively treated water did not clog at all during six years of continuous operation, others became blocked within several months. Some cheap and easy methods of restoration the clogged wells were tested with success, such as backpumping discontinuously using compressed air or as using chemicals like hydrochloric acid, chlorine or polyphosphates.

So in practice one has to weigh the cost of pretreatment against the frequency and method of redevelopment and to the writing off time of the recharge well.

In addition to the reported infiltration methods Hrubec informed about researches in the Netherlands to find optimum pretreatment methods. The raw water was treated according to scheme given in Fig.   by breackpoint chlorination, contact upflow filtration, ozonisation, secondary iron dosing, rapid filtration and activated carbon filtration. By means of this scheme 5 different grades of water were possible. Some of the results are given in Table 4.

TABLE 4

Data about the length of tests, recharge rates and volume of recharged water

Water Quality	A		B	C		D			E
Test hr.	I	III	IV	V*	VI*	VII*	VIII*	IX	X*
Period									
Length of recharge test(days)	525	280	520	637	443	677	677	670	471
Starting application rate (m/day)	5	5	10	10	30	10	10	10	35
Total volume of recharged water during test (m^3/m^2)	650	340	2120	5200	8200	4400	6500	4700	11000
Average recharge rate (m/day)	1.2	1.2	4.1	8	18.5	6.5	9.6	7	23.5

* Test was stopped before total clogging of the recharge surface occurred.

Not direct comparable but in some cases similar to the dune areas in the Netherlands are the Esker aquifers in Scandinevia, presented by Gustafson (Fig.). Eskers are ridge-formed glaciofluvial deposits of coarse sand and gravel. In their most typical form they are of subaqueous origin and partly covered by silt and clay. The coarse and gravel give the Eskers a high permeability and since their path normally follows the low parts of the terrain they can drain vast areas.

In many cases the Eskers are surrounded by surface water. In this case a pumpage from the Esker induces bank recharge, accompanied with changes of the chemical character of the water (Fig.).

The total hardness is increased and colour and turbidity are radically lowered. The organic content of the bank sediments normally causes oxygen free conditions and dissolution of manganese and iron (Fig.).

To remove the iron and manganese, even in humic complex forms from this groundwater Agerstrand presented the principle of re-infiltration.

By this method water is pumped into a suitable area of the aquifer where it is aerated in an overflow cascade and infiltrated to the groundwater reservoir through basins, with a filtration rate to 0.5 m/h, similar to the slow sand filters (Fig.).

When the water level raise by clogging due to voluminous iron precipitation, up to 0.5 m, 5 to 10 cm of the sand must be removed. To counteract the clogging an intermitting drying time of 6-24 hours followed by rawing the surface has proved very effective.

Martinell demonstrated the alternative method of in-situ removing of iron and manganese within the groundwater. This method based on the infiltration of oxygen into the anaerobic groundwater, which causes a precipitation of iron and manganese in the subsurface.

From United Kingdom different problems in artificial ground water recharge were described by Edworthy et.al. In the Tertiary Sands/Cretaceous Chalk aquifer systems in North London a heavy dewatering took place by overabstraction during 150 years (Fig.).

First artificial recharge experiments showed, that although direct rechsrge of the sands was not feasible, indirect recharge through the chalk was. At the start of the final recharge water moved rapidly into the lowest intervals of the sand aquifer. However, clay strata within the sands appear to have retarded continuing upward movement. When abstraction began the water levels in the sands responded in a manner characteristic of a confined aquifer. Unconfined conditions became established within three to seven days.

The general results of the investigations have shown that the very large volume of dewatered sand can be recharged artificially through the underlaying Chalk aquifer. Althrough slight groundwater quality deterioration can be expected in some localities as a result of artificial recharge, the overall significance of such changes is confidently expected to be small.

From the Lee Valley, also with Chalk and Tertiary Sand in the underground, Flavin et.al. reported the experiences with an artificial recharge pilot scheme for water recharge.

The scheme operated with six public water supply wells with adit systems (Fig.), and seven purpose drilled boreholes silted along the valley, close to an existing water supply main providing the source of recharge water. During test pumping borehole yield of 2 - 7.5 Mio 1/day were obtained, with transmissivity values ranging from 25 - 1.300 m3/day and storage coefficients from 1.4-6.5x10^{-4}. This data were the base for developing a numerical model of the aquifer, intended for use in simulation of recharge/abstractions operations for management purposes (Fig.).

A similar water management model was presented by Bibby et.al. As the groundwater resources of the Folkestone aquifer of the Lower Greensand has been utilized in conjunction with surface water abstraction from river, a lumped-parameter simulation model of the river aquifer system was developed to optimize the design at different demand levels of treatment, plant capacities and artificial recharge requirements, and to determine the overall operating policies (Fig.).

Going south to Switzerland other geological conditions, again, are destinating the methods of artificial groundwater recharge. Trueb and Schmassmann were drawing a scheme of deep eroded valleys with fillings of coarse gravel. Thus the position of the aquifer-base and the consequent thickness of groundwater may vary considerably within short distances.

As is usual in the gaining of gravel groundwater the preferential sites of the wells for pumping artificial recharged groundwater are situated above the deepest parts of the pleistocene river channels. However, the artificial recharge can also be carried out over peripheral zones of the natural groundwater or even beyond this area provided that gravel of adequate thickness and permeability occurs above the plane of groundwater surface.

Depending on these special conditions Trued defined the future aims of artificial groundwater recharge in Switzerland as following:

- the artificial recharge as emergency measure
- the underground storage of drinking water
- the optimal use of gravel filters
- the increase in sufficiency of spreading basins
  - through raised flooding
  - through clearing of sludge in the flooded phase.

As example he showed a new infiltration tank (Fig.) which was used in the Zurich area. This tank consists in a combination of raised flooding (3 m) a filterfilling of activated carbon and sand, and infiltration wells at the filterbottom.

A similar system was demonstrated by Hurnt. In Aesch, Switzerland, exists an infiltration plant since three years consisting on pretreatment by gravel filter, slow sand filter with impermeable bottom combined with infiltration wells (Fig.). The treatment efficiency of the total system was very high:

- total particulate matter	70 - 87%
- total organic carbon	30 - 40%
- dissolved organic carbon	20 - 40%
- coliforms germs	92 - 99%
- Oxygen decrease	+4 - -7%

Custodio et.al reported the experiences of 25 years artificial groundwater recharge of Barcelona region.

The recharge was there mainly carried out by infiltrations wells. Different types were in use. Small diameter tube-wells with the possibility of a back-washing of the coarse sand and gravel must be cleaned up by pumping the well and water injection through the tube-wells, once a day for 15 minutes.

Other tube-wells must be cleaned up only every two or three weeks of continuous injection for ten to twenty minutes.

A pilot plant was described which is being tested near the sea, in sea water encroached confined aquifer of coarse sand and gravel (Fig.) Treated sewage water is injected. Raw water is mainly of domestic origin, but some industrial effluents are incorporated. The recharge is feasible if a certain dose of chlorine is maintained in the injected water, and cleaning is done daily.

In Israel, too, the artificial groundwater recharge of municipal waste water effluents is often used (Shelef).

The reasons are:

- Enhancement of the quality of the effluent through filtration, sorption and retention,
- Providing of seasonal and sometimes annual storage without evaporation losses,
- Assisting in the prevention of seawater intrusion into coastal aquifers.

Another interesting water management system in Israel was mentioned by Katz among other examples, which aim was to harvest the water of four periodical winter creeks. The work comprises of:

- diversion structures for each stream,
- a 12 km - channel to convey the diverted water,
- a 2.5 Mio m' surface reservoir in the dune region where sedimentation occurs and the coliform count drops from an input figure of 10^4/100 ml to 10^2/100 ml.
- a 2 km gravity earth channel
- spreading grounds in the dune with a covering area of 50 ha, receives up to 1.3 Mio' for infiltration into the local pleistocene aquifer,

- from this aquifer the water is pumped during the dry summer period by 15 wells.

By this system with the combination of sedimentation, percolation through 5 m sand layer, retention time in the underground and mixing effects with the aquifer water improve the water quality to drinking water quality.

From South Africa Tredoux et.al. described the conjunctive exploitation of groundwater from the coastal aquifers of the cape flats and reclaimed secondary effluents.

At the moment, after extensive geohydrological surveys, the accumulated data had been incorporated into a mathematical model, on which base a pilot plant was developed.

The first stages of a 4.5 Mio/day water reclamation plant were various modes of purification and artificial recharge sequences, including the infiltration of partially reclaimed water followed by abstraction of the groundwater blend.

Among other following results were given:

- Both natural groundwater and the blended product abstracted from the aquifer can be treated by simple physical-chemical means to provide a softened product which complies the recommended standards of potable water.
- Recharge rates varying between 5 and 9 m/day are attainable provided the feedstock turbidity is maintained below 2 NTU.
- Mechanical removal of the top layer (50 mm) of the infiltration surface is the only appropriate means of restoring the recharge capacity in the event of clogging.
- The only significant change in chemical composition of the recharged water occurred under conditions of intermittent infiltration and constituted conversions between the various compounds of nitrogen.
- E.coli organisms were transmitted through the sand over distances not exceeding 27 m while artificial recharge was in progress.

SPECIAL APPLICATIONS OF ARTIFICIAL GROUNDWATER RECHARGE

One of additional applications of artificial recharge was reported by Blasy on the example of seepaging accumulated drainwater from the air terminal of Munich II. In the flat ground there is, under approx. 0.5 m thick soil layer, gravel as carrier of groundwater to a depth of about 10 m.

Underneath follows impermeable cohesive soil. The groundwater lies 1 m below ground. In those conditions a permanent groundwater lowering by means of open drainage ditches is planned above all for the central area of the air terminal. As far as possible the ccumulated drain water shall be sinked back into the underground in order to counteract the continuous groundwater supply deficiency. The infiltration will be carried out by 117 wells, each 10 m deep, with a filter pipe enlargement of 150 mm diameter. The gap between filter pipe and walls of borehole (206 mm wildcat well) will not be filled with filter gravel so that a loosening of the walls of borehole is possible at descending on the well.

Another aspect especially in semi arid zones is the possibility of *recharging surface water in coarse marginal basin sediments in the Iran*, given by Voltz.

The run-off quantities of different cross-sections in the central flow beds of fanglomerate fans, mostly representing a continuous fanglomerate seam, have been compared. After measuring the cross-sections the mean flow velocities were calculated by various irrigation formulae, considering the hydraulic radius, the hydraulic head and roughness of the flow bed.

The effective permeability coefficient is related to the entire infiltration area in the stream between the two cross-sections and allows an estimate of the discharge velocity as a comparing value for the calculation of run-off delay and artificial recharge. The investigation results on the Djahrom Basin (Iran) consisted mainly in a selection of areas suitable for groundwater recharge. The given prospecting method may be applicable in semi-arid areas with periodical rainfalls or episodic rainfalls.

SPECIAL QUALITY ASPECTS ON ARTIFICIAL GROUND WATER RECHARGE

It is an advantage of the artificial recharge (in comparison to bank filtration) that raw water can be pretreated and thus the pollution of the subsoil can be decreased.

Former the pretreatment aimed only the removal of several constituents disturbing the operation of the artificial recharge, as iron-, manganese- and ammonium-ions, paticulate matter and bacteria.

Today the removal of s pecial pollutants by artificial recharge is not sufficient.

Especially the biological non-degradable organic compounds have to be removed carefully before or after infiltration. The most acute problems arise from organic chlorine compounds because these substances partially considered cancerogenic are not or only inadequately retained during subsoil passage.

As Haberer reported, these substances even break through granulated carbon filters, if raw water quality changes.

Therefore he postulated to avoid the formation of haloforms in the treatment: This may be done by:

- The removal of organic substances before chlorinating
- The reducing the amount of chlorine (Fig.).
- By stopping the chlorination.

As example he demonstrated the efficiency of a newly developed two-step floculation, consisting of precipitation with $Ca(OH)_2$ at pH 10.5 and floculation with $FeCl_3$ at pH 6.0.

On this way more than 90% of highmolecular organic acids are removed. By this and by reducing the dosage of chlorine the formation of haloforms is decreased.

A similar way was presented by Sarfert et.al., who described a pilot plant for artificial recharge combined with special pretreatment methods like floculation with iron - and aluminium salts and floculation with anionic polyacrylamides.

The following are the fundamental requirements for this pilot plant:

- Chlorine will deliberately not be used. A possible treatment by ozone should occur later on
- Pure water loaded with as few organic substances and phospha as possible should be obtained through a suitable dosage of coagulants and coagulant aids.

First results are that non-dissolved substances are eliminated by flocculation and filtration, the water is so released from reducing compounds and micro-organisms that a chlorination of the drinking was not necessary. Other toxic substances as heavy metals, polycyclic aromatic hydrocarbons, or even viruses are prevented sufficiently.

Some other authors reported their experiences with special raw water ingredients during artificial recharge.

Schwelsfurth described the microbiological situations during aerobic and anaerobic underground passage.

Kussmaul reported a considerable decrease in concentration of the high-volatile organo-chlorine compounds directly within the infiltration area. The underground passage had only little effects on the base of concentration balance.

Similar observations by Bauep showed that pesticides and polychlorinated biphenyls reach groundwater according their sorption on filter materials in different times. Lindane is revealed as a severe contaminant of groundwater because of its solubility in water.

Volatile chlorinated hydrocarbons could eliminate by slow sand filters insignificantly in spite of cascade aeration. They are found in ground water and will be additional formed by chlorination.

Zullei remarked that use and production of disinfectants are rapidly increasing so that these substances showing up more often in surface waters. Especially phenolic components of commercial disinfectants are found in mg/1 to kg/1 values. As phenol and its derivatives may be converted by drinking water chlorination into organoleptically unpleasant chlorophenoils their presence in raw water and their behaviour during water treatment processes must be monitored.

To obtain an estimate of the pollution by these substances water samples during artificial recharge by slow sand filtration were analyzed. First results show that pentachlorophenol and 2,3,4,6 tetrachlorophenol are reduced to half of their initial concentrations by infiltration and underground passage.

After chlorination, however, their concentration rises again significantly (Fig.).

In addition to the in-situ observations, pilot plant tests were carried out and show that 2,4-dichlorophenol and 3-methyl-4-chlorophenols breakthrough the slow sand filter without any fixation on the filter material or biological degradation.

French experiences by Rizet et. al. confirm these general results of insufficient elimination capacity of artificial recharge processes against organic and inorganic micropollutants.

Remobilization effects of in former times by bank filtration eliminated heavy metals reported Schottler from the Ruhr Valley in Germany. There after quantity decrease, bank filtration was compensated by slow sand filtration and underground passage. By seasonal depending change of the biological states of the underground passage from normally aerobic to partially anaerobic the accumulated heavy metals become soluted together with iron on manganese (Fig.).

So in average of the observed time the different heavy metals were only insufficient eliminated or even increased during artificial recharge (Fig.)

Some reasons for these effects were given by pilot plant tests, described by Forstner et.al. These experimental series of heavy metals dosages combined with humic acids show that the cleansing capacity of sand filters is less determined by its material compositions (adsorption capacity, particle specific surface, percentages of hydroxous Fe/Ma-oxides, clay minerals, organic particles) than by the chemical form of the metals in the dissolved phase.

The analysis of individual organic chemical before and after soil passage, given by Piet et.al.,tough another part of artificial recharge. It could be similarly demonstrated, that particularly organo-chlorine compounds are still present in the soil and the dissolved phase even after several years. It exists a correlation between chemicals which are not completely removed by slow sand filtration and by passage of the soil. This is also essential for the possibilities of refuge disposal or dumping without groundwater quality decrease.

Therefore in 1979 the European Communities conclude mandatory limits on the protection of groundwater against pollution caused by certain dangerous substances which are nearly the same as the limits of surface water intended for the abstraction of surface water (Table 5).

In this context Harmsen presents a simulation model which describe the one-dimensional transport of interacting solutes through porous media.

The model would apply to the transport of polluted surface water upon infiltration, or of polluted groundwater (e.g. landfill leachate) through the aquifer.

The physical model considers the following phases:

- a mobile solution phase
- an immobile solution phase, which may include both the water tightly bound to the solid phase or within the reach of the electrostatic double layer, in case of changed adsorbent surfaces, and the solution in "dead end" pores or within soil aggregates.
- one or more solid phases, mineral or organic, which may include adsorbing surfaces and precipitates.

Physical processes considered in the model include:

- Transport of solutes through a mobile solution phase, by convection and hydrodynamic dispersion as well as molecular diffusion,
- diffusion of solutes between a mobile and an immobile solution phase,
- interactions between solutes in an immobile solution phase and one or more solid phases.

The mathematical description of the considered interactions (Fig. 34) were given.

Additionally Zipfel outlined the variety of sources and types of contamination and infiltration, spreading and transport of pollutants in the underground. Existing simulation models were as well presented as the lack of models evaluating and predicting quality processes in ground water flow. Possibilities of application of the existing models are given where conditions of groundwater flow and quality are relatively definite. On the other hand simulation models of the groundwater flow already exist. Thus, the possibility to simulate groundwater quality aspects by gathering additional data of quality criteria and inserting them into well-known flow systems, stepwise completing the groundwater flow model may exist.

Therefore simultaneous continuation and extension of systematic basic investigation, in particular on an original scale under controllable conditions, seems to be very important as a basis for more developed models.

With great interest the report of Hessing was accpeted by the participants of the symposium, which shared the internationally coordinated research and demonstration project on slow sand filtration developed by the WHO/International Reference Centre for Community Water Supply and Sanitation.

These activities enforces the importance of artificial groundwater recharge, which resumingly has the following main functions today:

- removal of degradable organic and inorganic substances
- removal of micro-organisms from raw water
-
- Using the biological, chemical and physical capacities of the underground for lowering persistent or precursing substances
- storage for time of quality and quantity problems with the raw water
- flattening of quality peaks and the temperature fluctuations of the surface water
- pushing off salt water intrusions.
- using the underground as reaction place for de-ironing and demanganizing by oxygen input
- preservation or recreation of groundwater levels
- using underground quality enhancement and storage as integrated parts of super-regional water management system
- preservation of natural areas

Finally artificial groundwater recharge is a cheap, simple, efficient, and modern water treatment system, well based on the experiences of former times, and able to compete with high-sophisticated chemical water treatment systems.

TABLE 5

Recommendatory Limits for Surface Water Intended for the Abstraction of Drinking Water

PARAMETERS		TREATMENT CATEGORIES A1	A2	A3
Colouration(after simple filtration)	mg/1 Pt.scale	20*	100*	200*
Temperature	°C	28*	28*	28*
Nitrates	mg/1 NO_3	50*	50*	50*
Fluorides	mg/1 F	1.8	-	-
Dissolved Iron	mg/1 Fe	0.3	2	-
Copper	mg/1 Cu	0.05*	-	-
Zinc	mg/1 Zn	3	5	5
Arsanic	mg/1 As	0.05	0.05	0.1
Cadmium	mg/1 Cd	0.005	0.005	0.005
Total Chromium	mg/1 Cr	0.05	0.05	0.05
Leed	mg/1 Pb	0.0.5	0.05	0.05
Selenium	mg/1 Se	0.01	0.01	0.01
Mercury	mg/1 Hs	0.001	0.001	0.001
Berium	mg/1 Be	0.01	1	1
Cyanide	mg/1 Cn	0.05	0.05	0.05
Sulphates	mg/1 SO_4	250	250*	250*
Phenols	mg/1 C_6H_5OH	-	-	-
Dissolved or emulalled hydro carbons	mg/1	0.05	0.2	1
Polycyclic aromatic hydrocarbon	mg/1	0.0002	0.0002	0.001
Total pasticides	mg/1	0.001	0.0028	0.005
Ammonia	mg/1 NH_4	-	1.5	4*

* May be waived under exceptional climatic or geographical conditions

Category A1 - Simple phusical treatment and disinfection, e.g. rapid infiltration and disinfection.

Category A2 - Normal physical treatment, chemical treatment, and disinfection e.g, prechlorination, coagulation, clocculation, decantation, filtration disinfection.

Category A3 - Intensive physical and chemical treatment, extended treatment and disinfection, e.g. chlorination to breakpoint, coagulation, flocculation, decantation, filtration, adsorption (activated carbon), disinfection (ozones, final chlorination).

APPENDIX A

LIST OF REPORTS

1. Frank,W.H: Historical Development and present state of artificial groundwater recharge in the Federal Republic of Germany.

2. Van Puffelen,J: Artificial Groundwater recharge in the Netherlands.

3. Bogomolow,: Artificial Groundwater recharge in the USSR.

4. Trueb, E,: Survey of the present state of artificial groundwater recharge in Switzerland.

5. Flavin,R.J., and R.J.E.Hawnt: Artificial recharge by the Thames Water Authority in the Lee Valley, North London, England.

6. Shelef, G,: Experiences with artificial ground water recharge in Israel.

7. Custodio, E.,J.Isamat and J. Miralles: Twenty five years of ground water recharge in Bercelone (Spain).

8. Kowal, A,: Infiltration practices in Poland.

9. Harnaj, V,: Experiments with artificial groundwater recharge in Rumania.

10. Katz, D,: Water quality management and quality requirements in connection with the regional planning of two facilities with different recharge systems in Israel.

11. Bauer, M,: National and International legal provisions for the application of artificial groundwater recharge.

12. Luhr, H.P. and W.Moller: Regional planning, groundwater protection and artificial groundwater recharge

13. Gustaffson, G,: Bank Recharge to an esker aquifer in Sweden.

14. Bibby, R., and S.K.Brown: Research into the conjunctive use of surface groundwater with artificial recharge in Sussex, England.

15. Tredoux, G.: The role of cape flats aquifer in the storage and abstraction of reclaimed effluents.

16. Gholamali,F: Experiences with artificial groundwater recharge at Djahrom, Southern Iran.

17. Bize, J.: Artificial recharge in the regions of Varamin and Garmsar, Iran.

18. Robert, A,: Artificial recharge of groundwater in Croissy: Systems of discharge.

19. Wildschut, R.J.: Practical applications of artificial recharge in North Holland.

20. Peters, G,: Aspects of planned artificial ground water recharge in "Fuhrberger Feld" area.

21. Hessing, E.L.P,: Tasks and present stage of the WHO project for the use of slow sandfilters in developing countries.

22. Wolters, N,: Experiments with infiltration methods in the Hessian Ried area.

23. Houdaille, F,: The groundwater of the Albien in the surroundings of Paris: New possibilities of exploitation based upon artificial recharge.

24. Frisch, H. and H.Kriele: Experiences with artificial groundwater recharge for drinking water procurement with quality equalization.

25. Blasy,L.: Infiltration of drainage water for the maintenance of the natural groundwater budget: Planning and test results in connection with the projected airport at Munich II.

26. Bize, J.: Artificial recharge of groundwater and the treatment of river water.

27. Brohl, H.K.: Research into infiltration processes in the underground Lake Tegel (Berlin-West).

28. Edworthy,K.J. and J.B.Joseph: Some effects of artificial recharge in the Lee Valley, London, England.

29. Hurni, B,: Experiences with artificial groundwater recharge via recharge wells in Switzerland.

30. Olsthoorn, T.N.: Research with experimental recharge wells in Holland.

31. Schneider, H,: Groundwater recession and re-introduction via recharge wells in protected waterworks area.

32. Haberer, K,: Special problems in infiltration water pre-treatment on the Rhine river.

33. Richard,J: Treatment of Water for use in artificial recharge.

34. Kotter,K,: Surface water pre-treatment with simple methods as preliminary stage of groundwater recharge.

35. Balke,K.D. and H.Schmidt: Possibilities of artificial groundwater recharge and storage in the Federal Republic of Germany.

36. Schmassmann,H,: Hydrogeological boundary conditions for artificial groundwater recharge in river valleys of North-west Switzerland.

37. Huppmann,C. and Kohm,J: Field tests concerning the exchange between surface water and groundwater.

38. Voltz,H.M.G,: Geotechnical reflections on artificial groundwater recharge in arid and semi-arid areas.

39. Dehrens,H., F.Neumaier and K.P. Seiler: Field experiments with fluorescent tracers to track the movement of water in unsaturated loose rock in the Bavarian Alps.

40. Matthes, G., and V.Neumayr: Radio-ecological aspects of groundwater recharge.

41. Dassonville, G,: Supply and Management of groundwater - a model study on the management of the groundwater of Moulle (Pas-de-Calais,France).

42. Harmsen,K.: A model for the transport of interacting solutes through porous media.

43. Boochs, P.W., and G.Barovic: Research into subterranean groundwater treatment by introduction of oxygen-containing water into the aquifer.

44. Landa,I., B.Skithan and O.Mazac: Geophysical stable systems controlling leakages from infiltration reservoirs.

45. Gerdes, H,: Hydraulic computation basis for seepage and infiltration galleries as regulating elements in groundwater storage management.

46. Horvath,I,: Similarity conditions for seepage flow.

47. Blazajewski, M,: Gases in the ground and their effect during artificial infiltration.

48. Zipfel,K,: Possibilities of practical application of water quality simulation models to underground passage.

49. Edworthy,K.J, and K.H.Baxter: Impact of sewage effluent recharge on groundwater in the chalk for an area in S.E.England.

50. Schweisfurth, R.: Microbiological reactions in bank filtration.

51. Agerstrand, T.: Re-infiltration, a method for removing iron and manganese and for reducing organic matters in groundwater recharged by bank infiltration.

52. Martinell, R,: Operational Experiences with iron removal in the groundwater range.

53. Roberts,P,: Experiences with micropollutants from sewage during underground passage.

54. Kussmaul,H,: Bheaviour of organohalogen compounds during underground passage.

55. Piet,G,: Behaviour of micropollutants during ground passage.

56. Bauer, U,: Organohalogen compounds and artificial groundwater recharge.

57. Zullei, N,: Disinfectants and artificial groundwater recharge.

58. Rizet,M., J.Maleevialle and R.C.Cournarie: The influence of artificial groundwater recharge by basins on the water quality.

59. Schottler,U,: Heavy metals in natural filtration systems.

60. Forstner,U., C.Nahle and U. Schottler,: Sorption of heavy metals in sand filters in the presence of himic acids.

61. Klein,G,: Behaviour and effects of biogenic organic compounds in slow sand filters for artificial groundwater recharge.

62. Schmidt,W.D.,and B.Patsch: Algae in Water catchment facilities: Possibi-

lities to prevent mass developments.

63. Hrubec,: Pilot plant sutdy of artificial recharge of pre-treated water of the river Rhine in the Veluwe Area.

64. Sarfert, F, and A.Grohmann: Groundwater recharge for drinking water procurement, using the procedural combination flocculation/filtration/underground passage (Jungfernheide pilot plant, Berlin).

65. Huisman, L,: Synopsis of the Symposium results, valuing and outlook into the future.

66. Nemecek, E,: Horizontal filter pipes.

67. Vichmann, K,: Extension of Water supply capacity on North Sea Islands.

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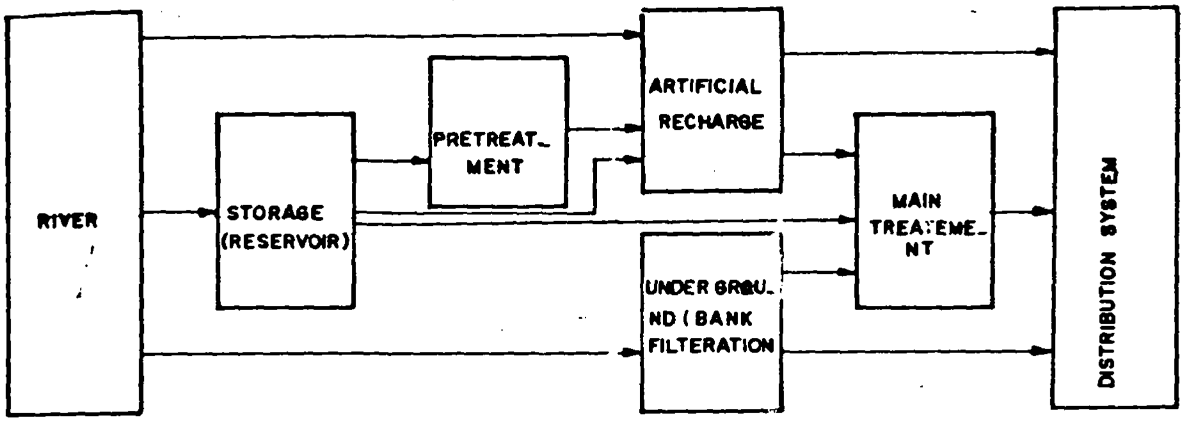


FIG.1 SCHEME OF MAIN TYPES OF DRINKING WATER CATCHMENTS USING SURFACE WATER.

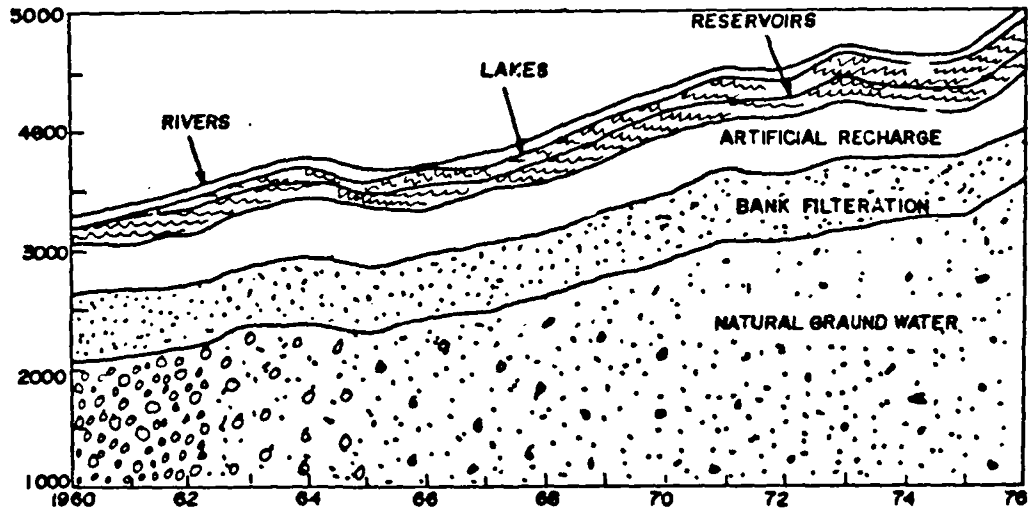


FIG.2 AMOUNT AND ORIGIN OF DRINKING WATER SUPPLY IN THE FEDERAL REPUBLIC OF GERMANY.

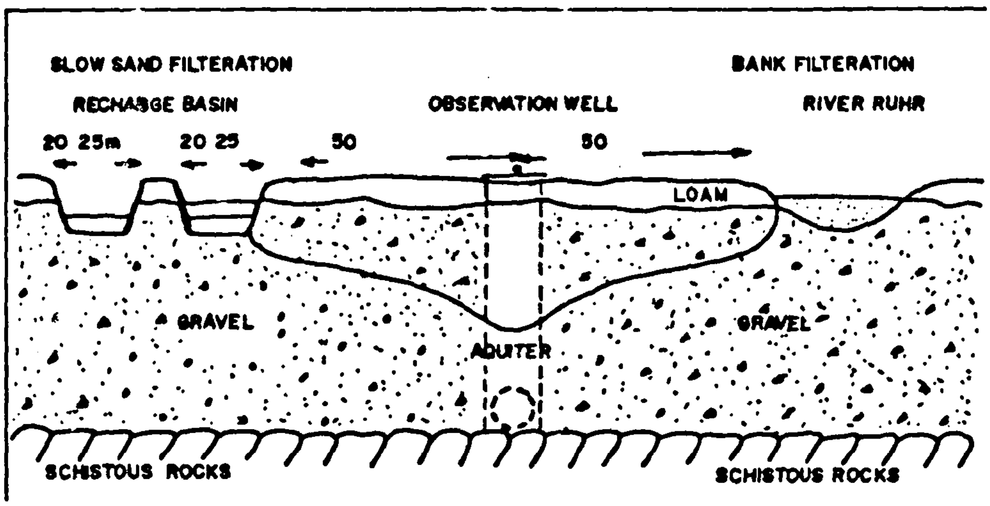


FIG.3 RECHAGE OF GROUND IN THE RUHR VALLEY

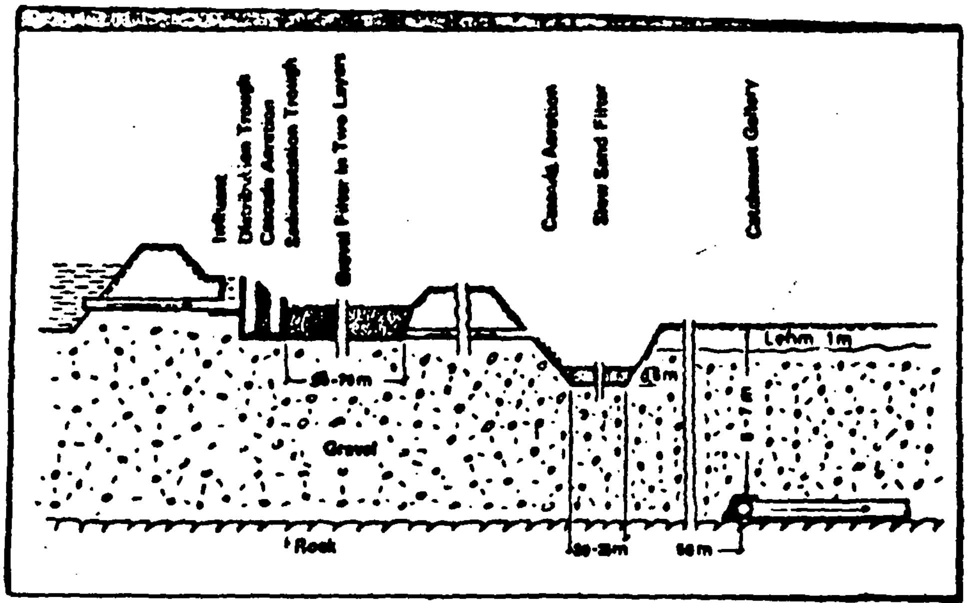


Fig.4 – Diagram of Water Treatment System for the city of Dortmund

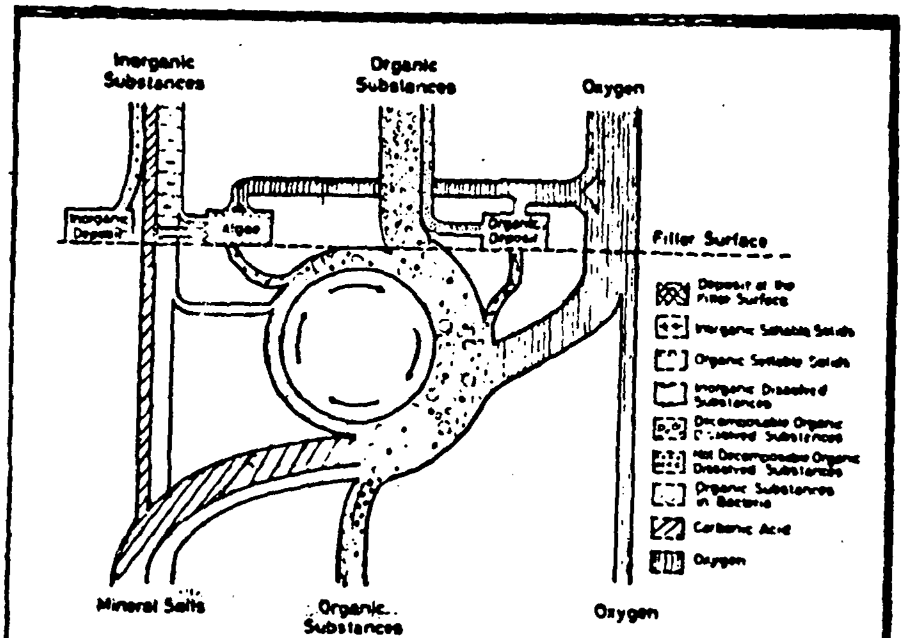


Fig. 5 — Scheme of the Purification effect of a slow sand filter

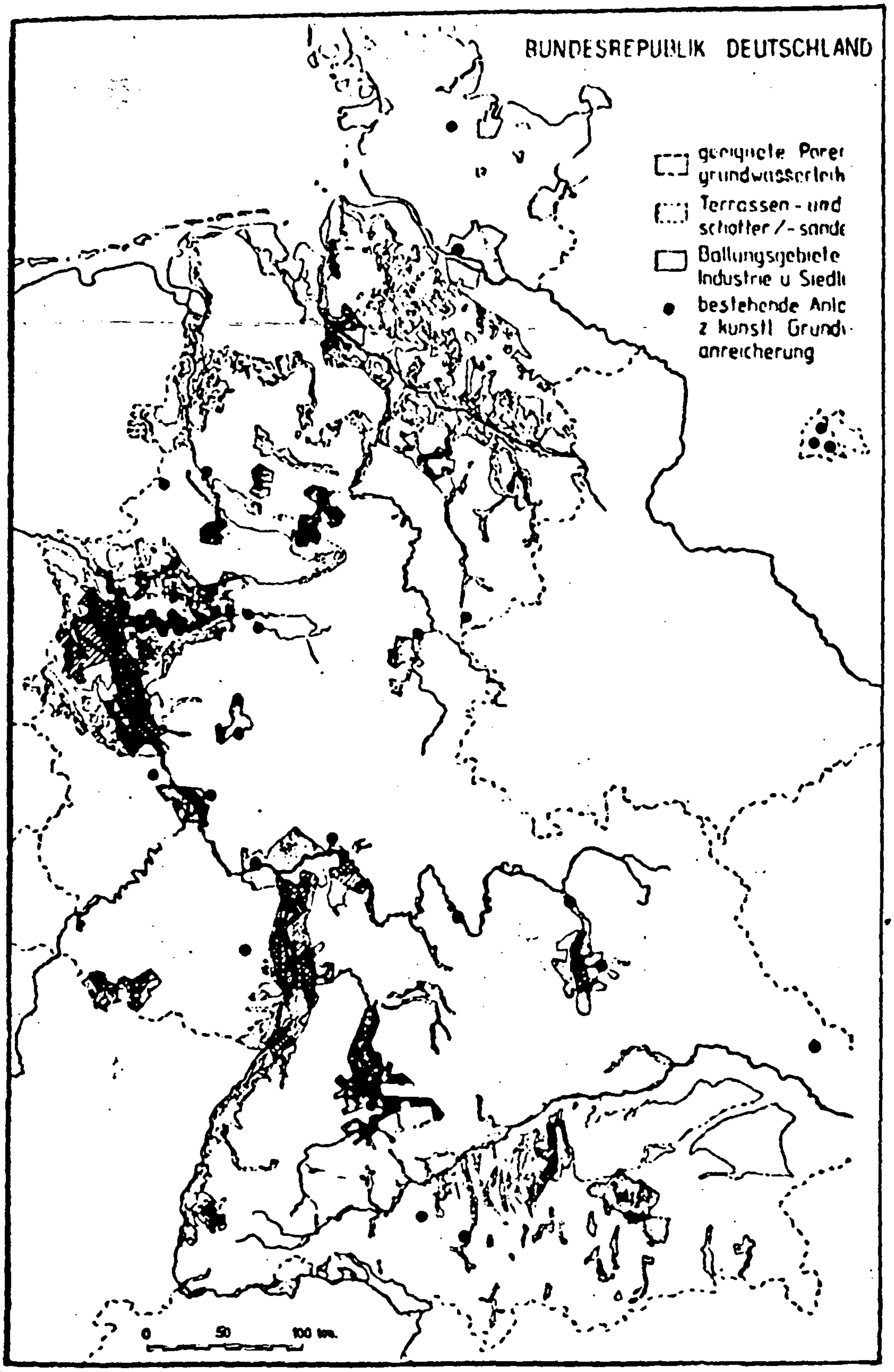


Fig.6: Possibilities for artificial groundwater recharge in the Federal Republic of Germany

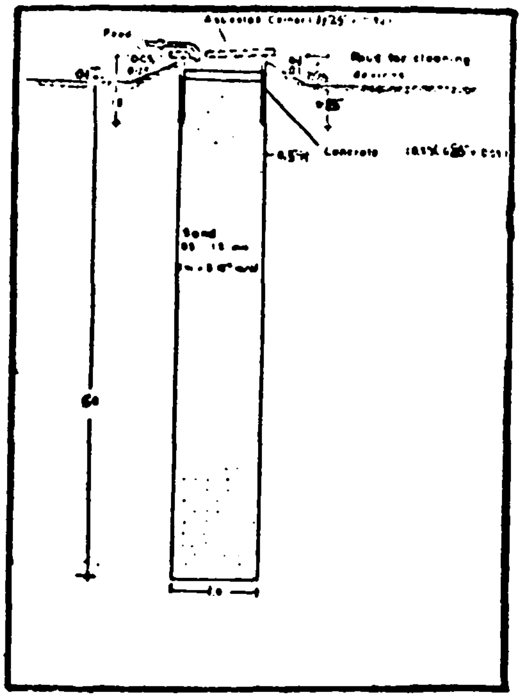


Fig.7 - Scheme figure of a seepage trench

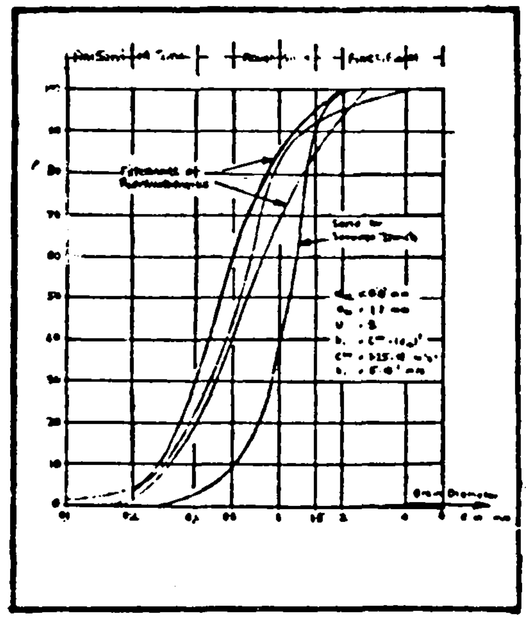


Fig.8 - Grain size curve of filter sands

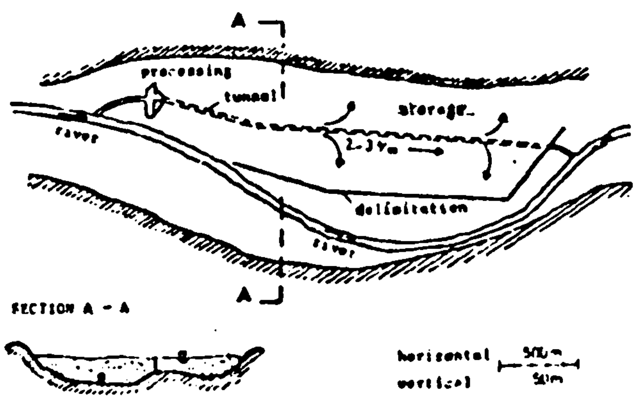


Fig.9- Scheme of infiltration tunnel

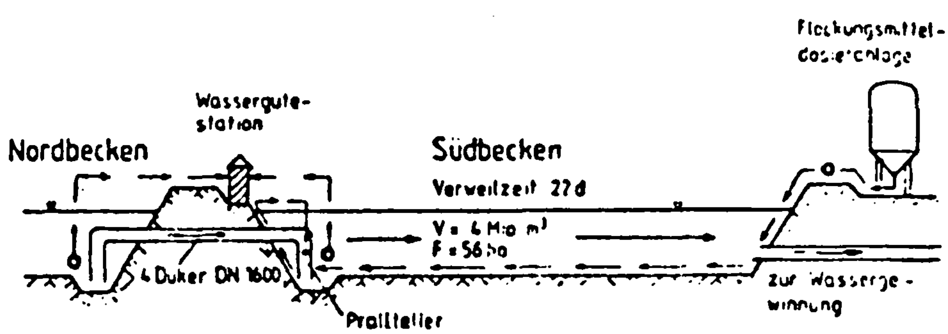


Fig.10- Dosing of floccution agents in a pre-basin

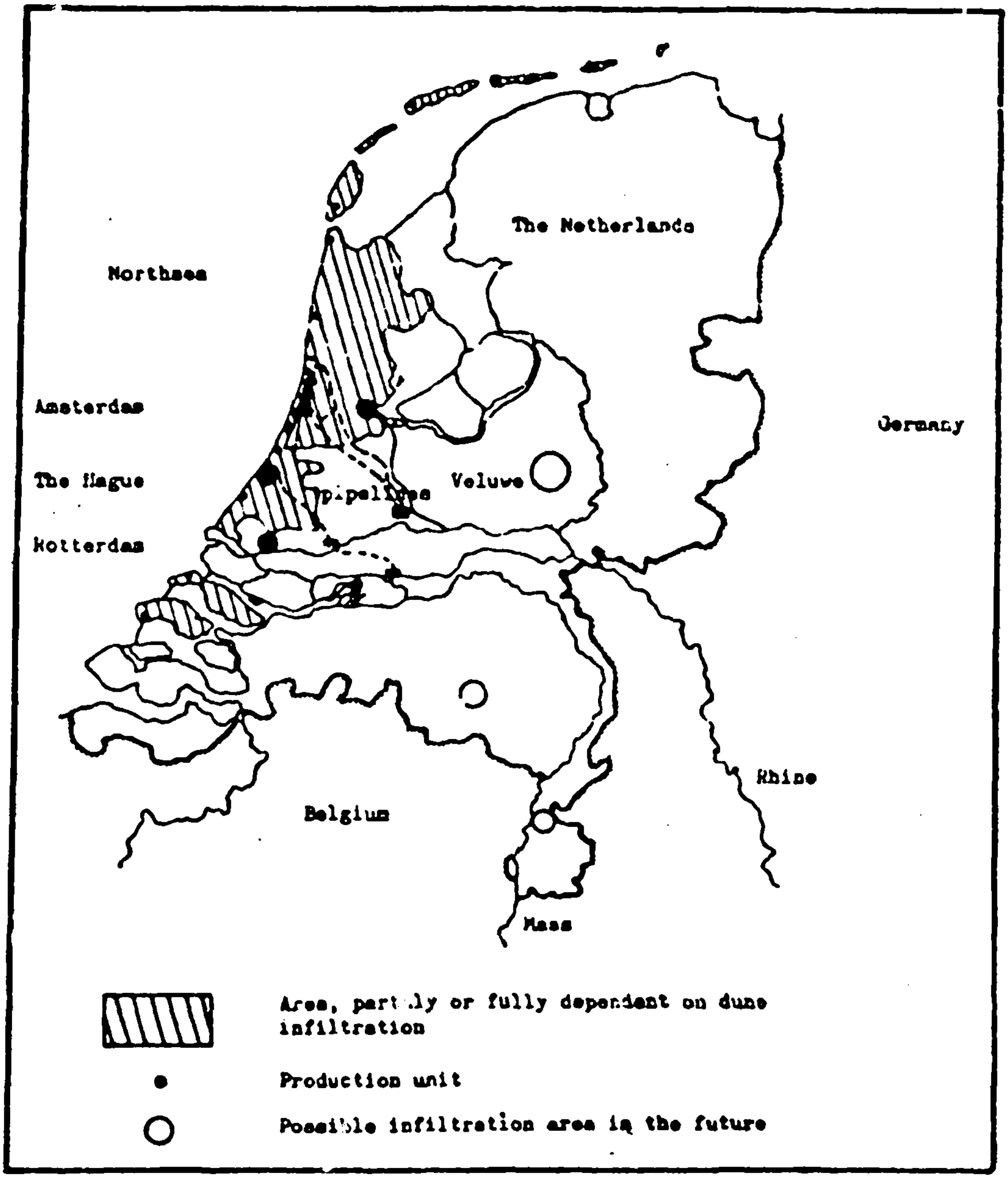


Fig.11- Map of the Netherlands with areas dependent on dune infiltration

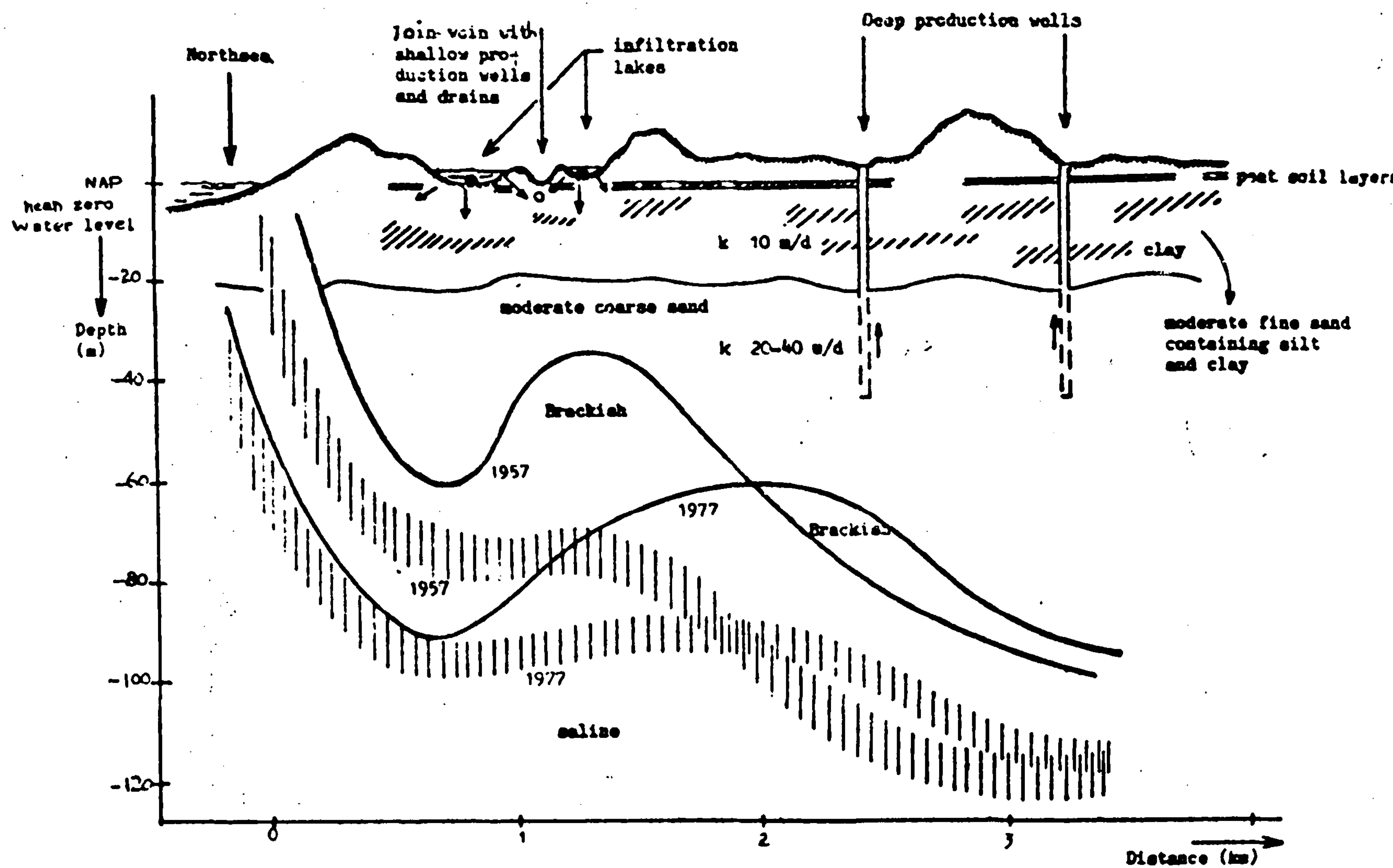
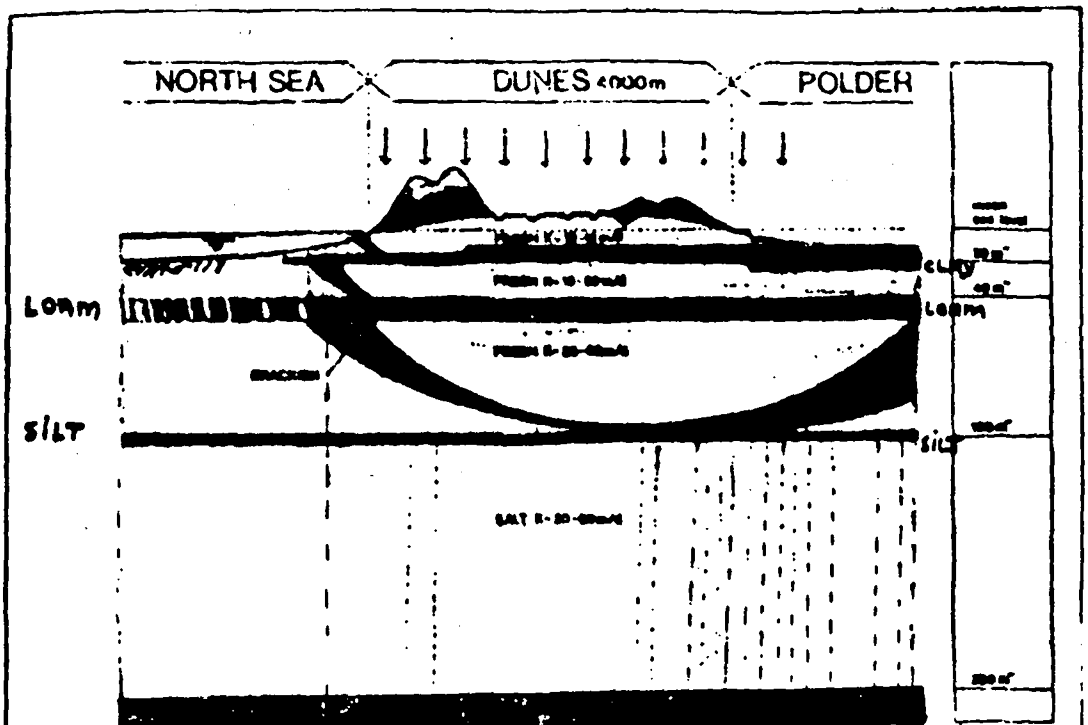
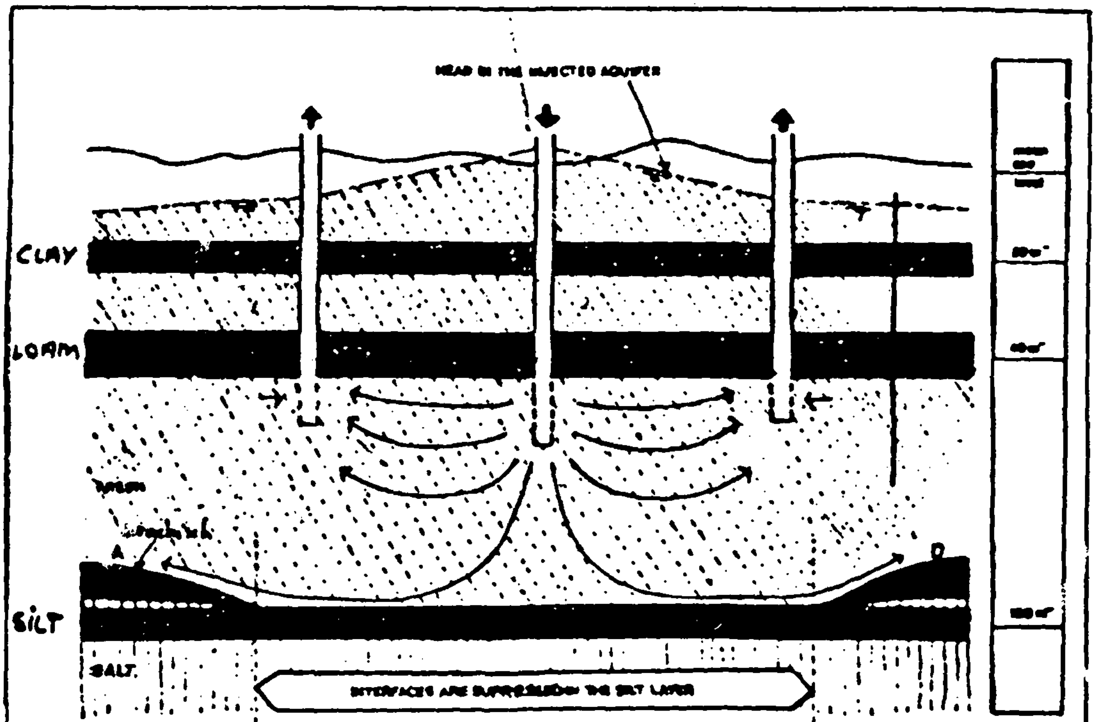


Fig.12- Diagonal profile of the northern part of the dune area of the Hague


NORTH SEA
DUNES
POLDER
LOAM
SILT
CLAY
LOAM
SILT
Fig. 13


CLAY
LOAM
SILT
A
D
Fig. 14

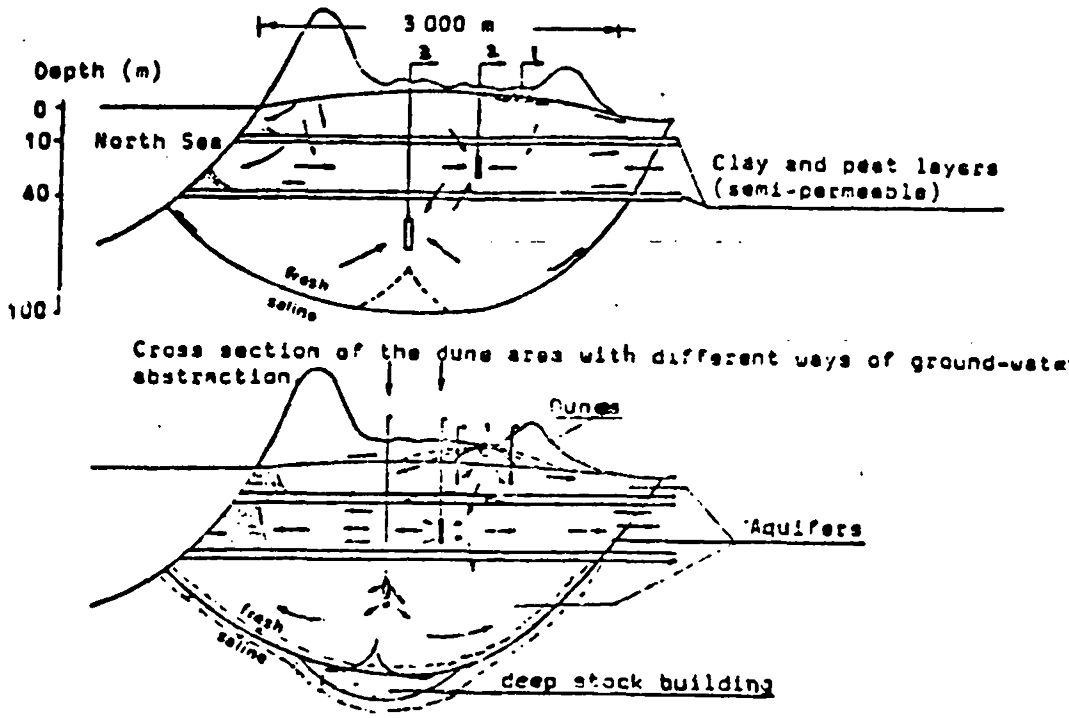


Fig.15- the applied recharge byponds and canals and the imaginable replenishment by wells in the lower aquifers

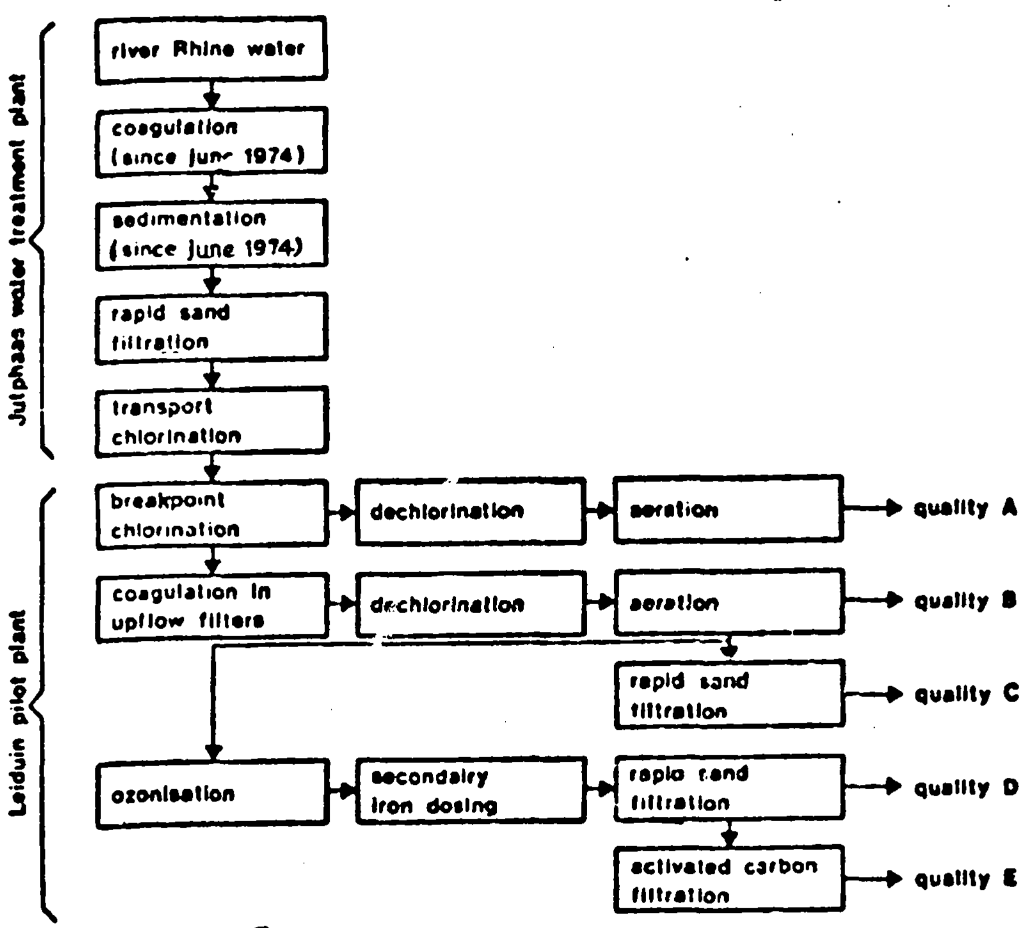


Fig –16

PRETREATMENT SCHEME OF RIVER RHINE WATER

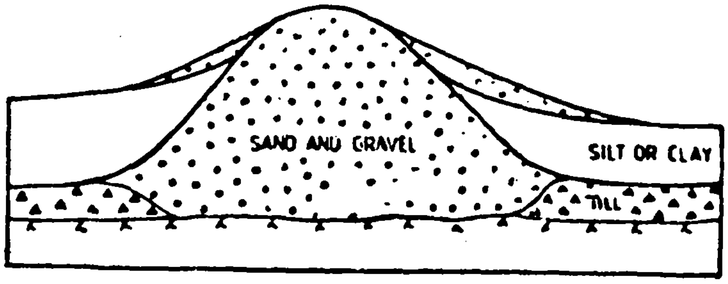


Fig.17- Typical cross section of an esker

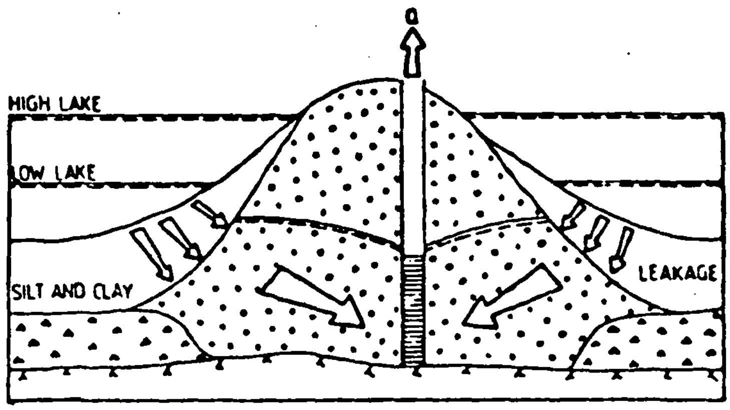


Fig.18-Bank recharge at different lake levels

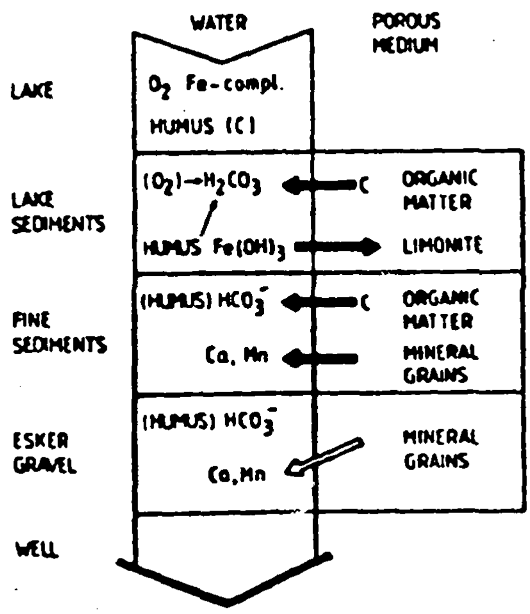
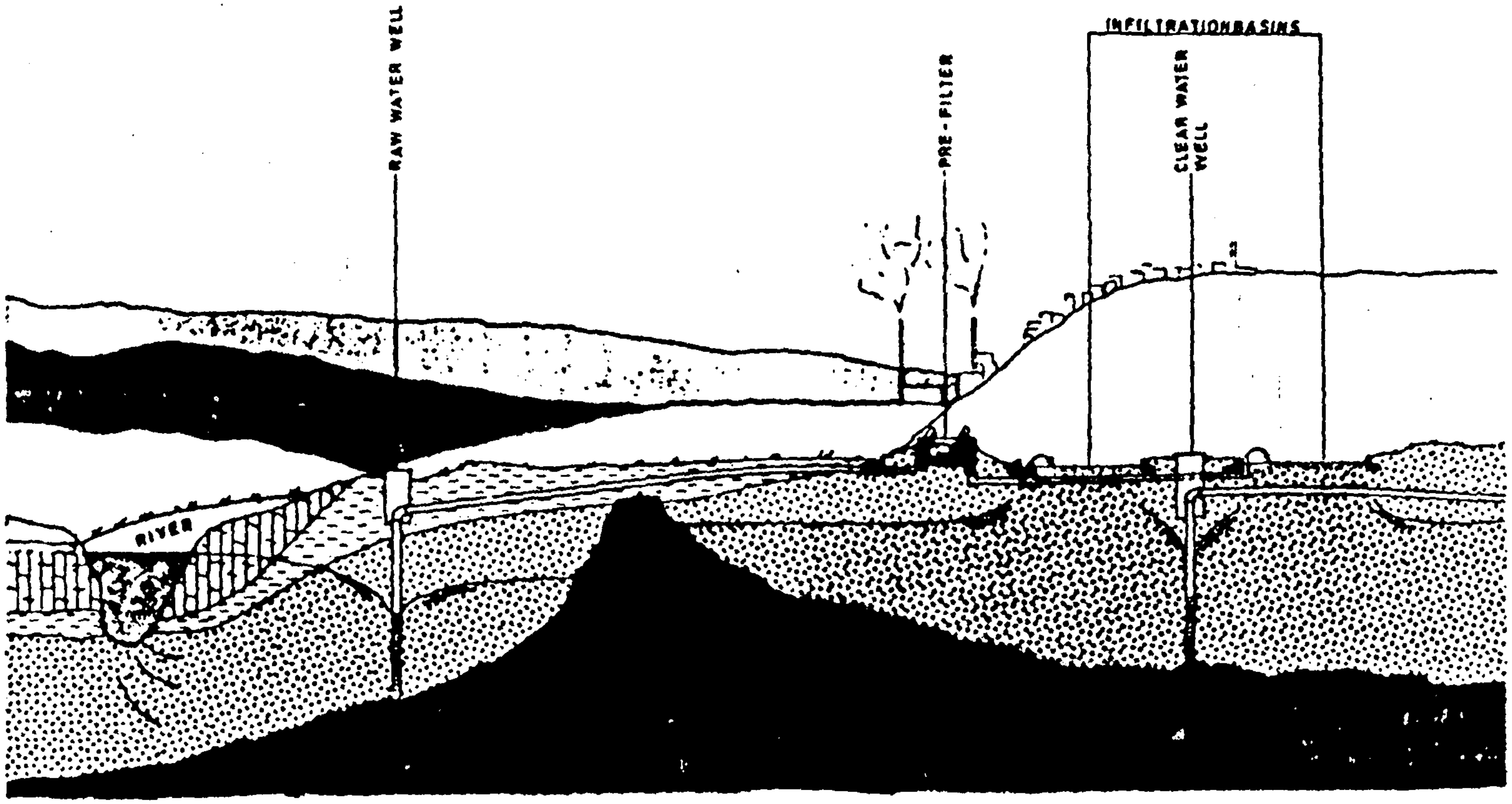


Fig.19- Chemical development during the recharge process.



LEGEND

- SEDIMENTS WITH ORGANIC MATTER
- SILT AND CLAY
- SAND AND GRAVEL
- BEDROCK

Fig.20- Sketch of water treatment by Re-infiltration of Ground Water Recharged By Bank filtration

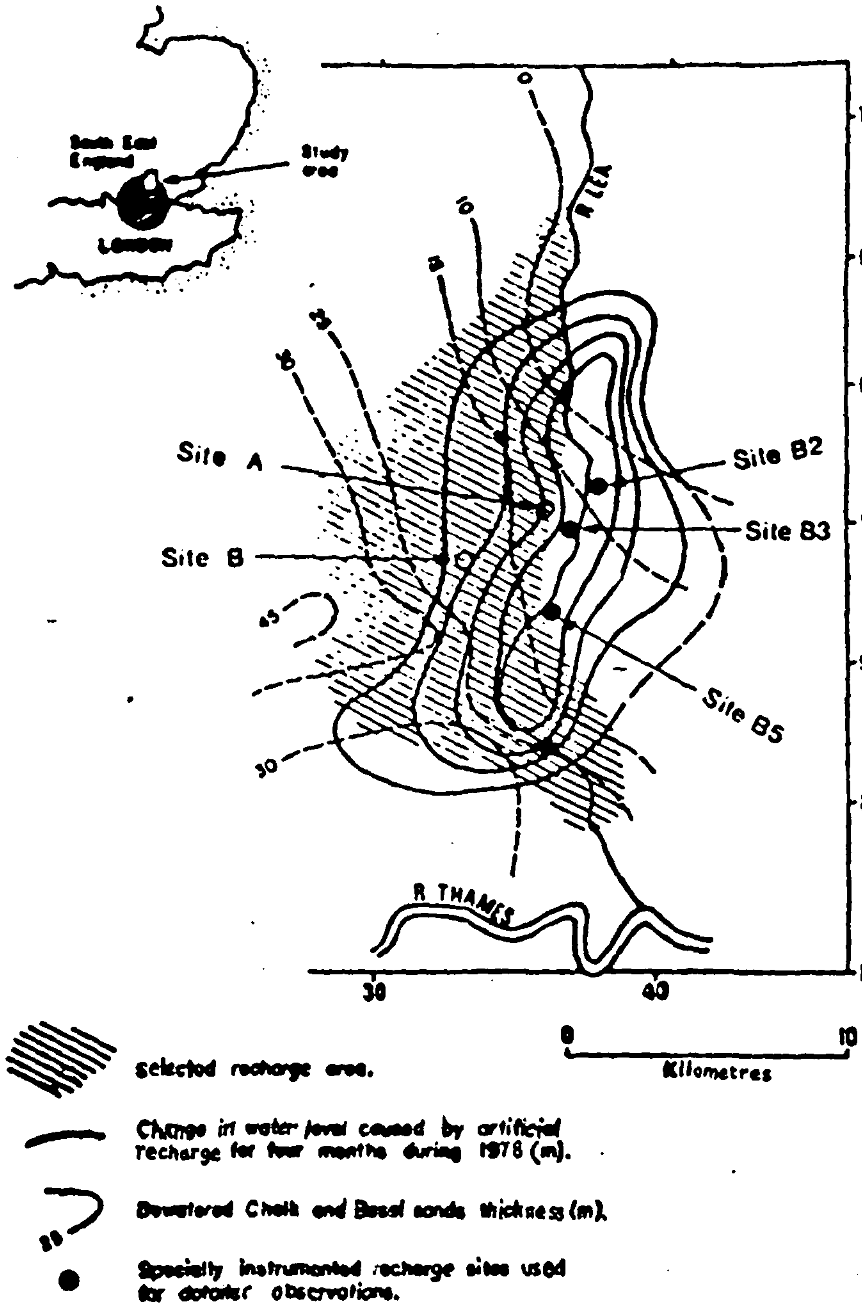


Fig.21. Location map - Lea Valley - showing recharge area and artificial recharge mound after one season.

I Regional location map

II Map showing wells, boreholes and reservoirs with superimposed contours of the rise in piezometric groundwater levels after recharge. December 1977 to April 1978.

III Geological section, showing the decline of groundwater levels since 1800.

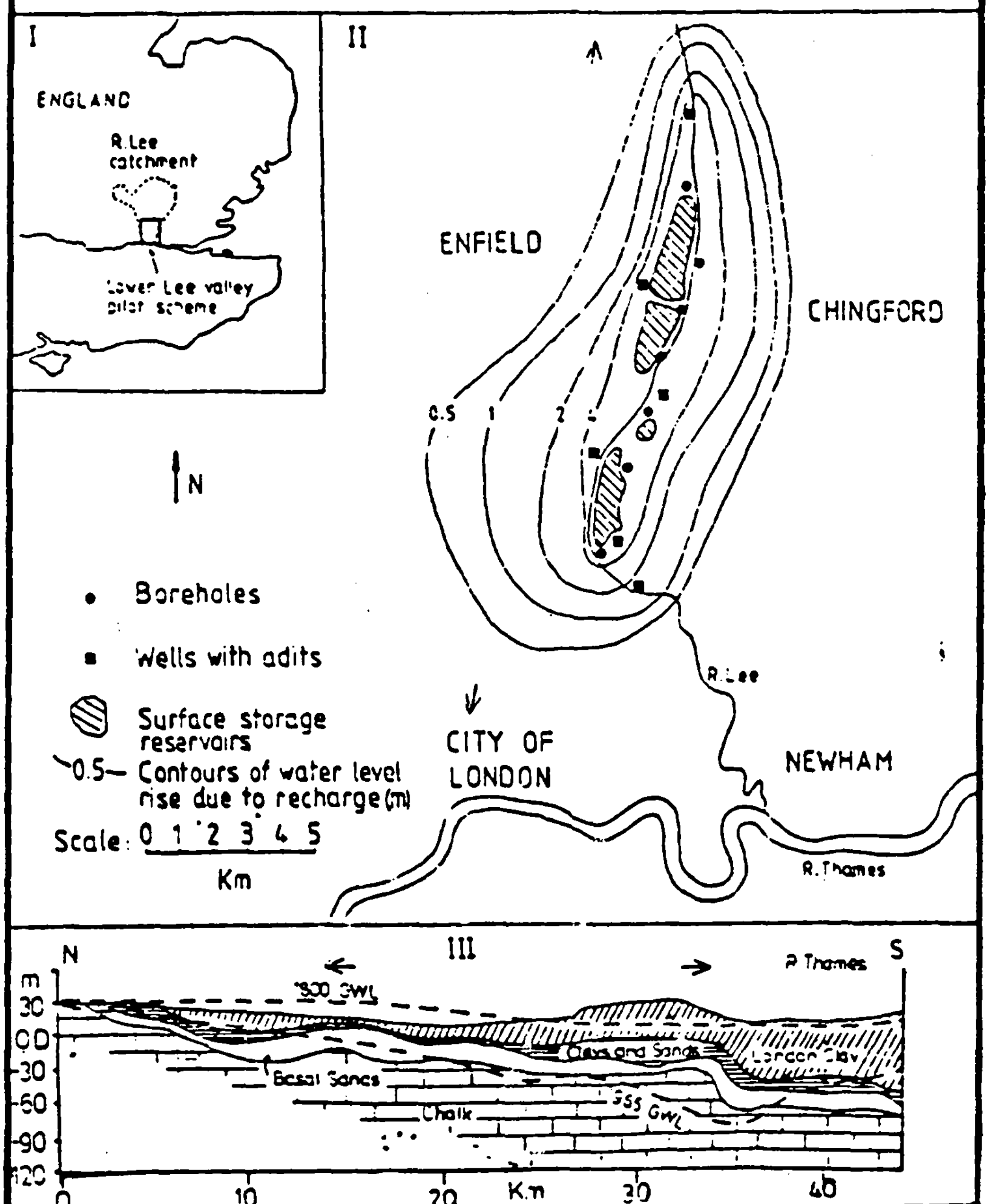


Fig. 22
Lee Valley Artificial Groundwater Recharge Pilot Scheme

SCHEMATIC DIAGRAM OF COMPONENTS OF THE THAMES / LEE RESOURCE SYSTEM RELEVANT TO THE LEE VALLEY

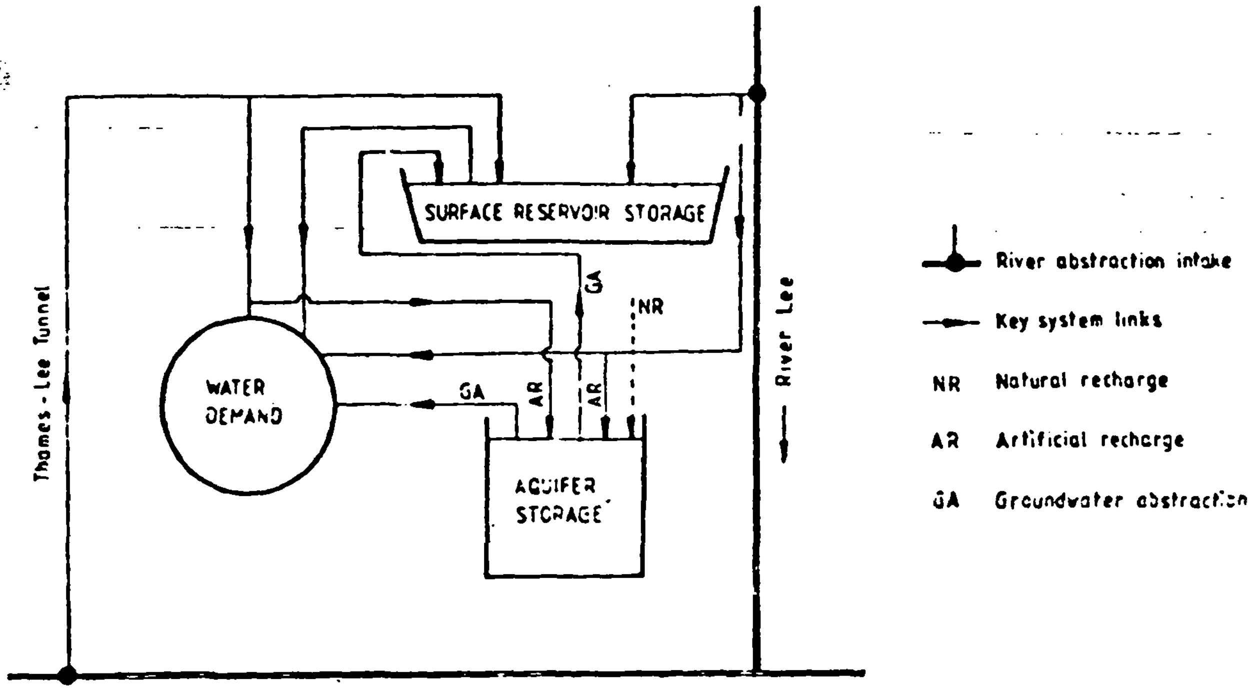


Fig. 23

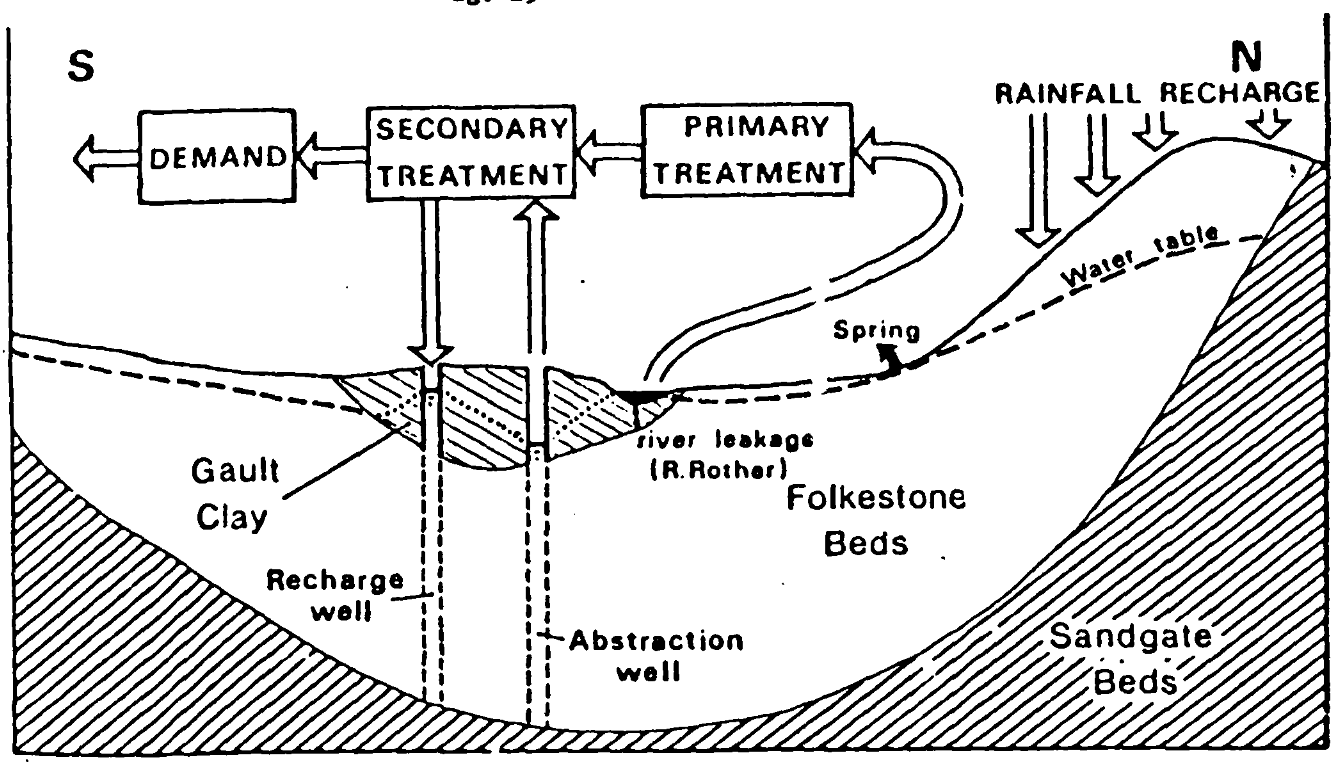


Fig. 24

Schematic of the Hardham resource area

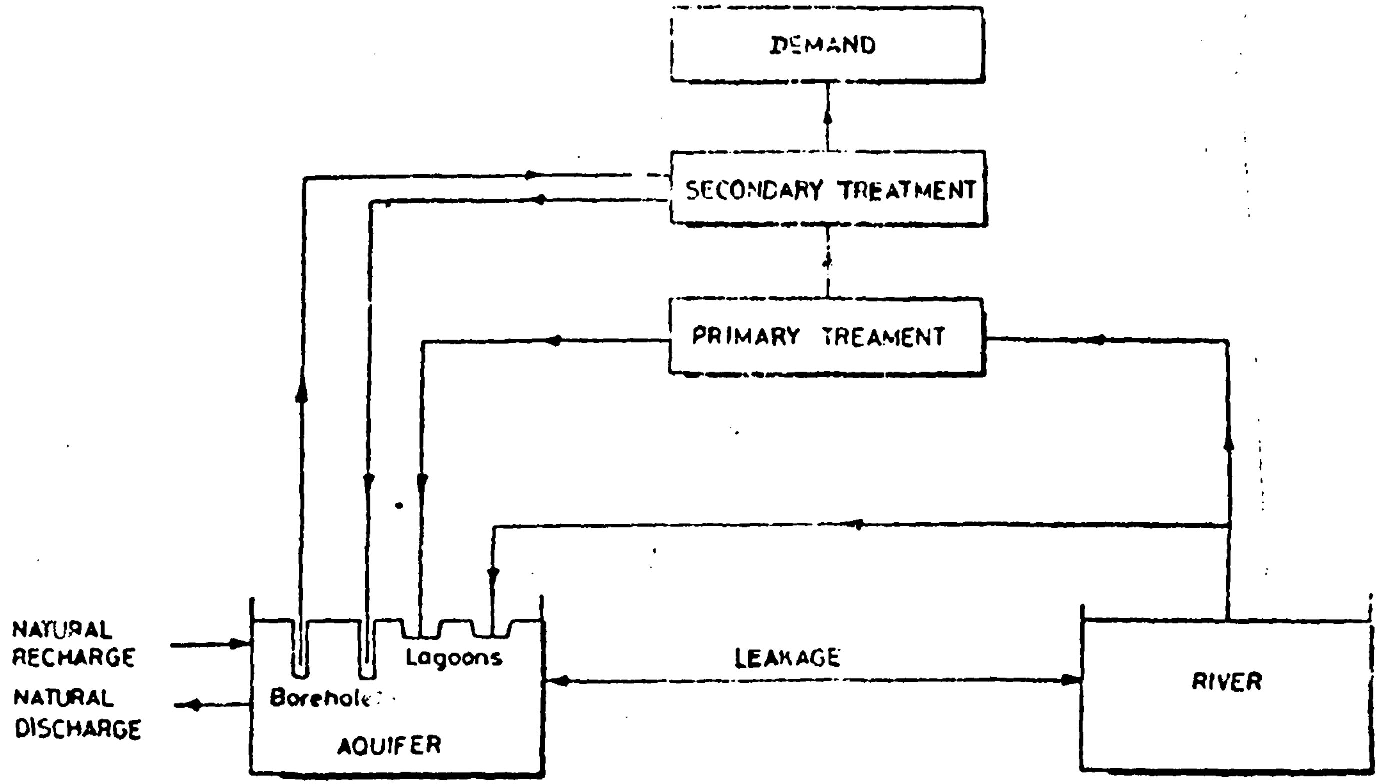


Fig. 25

Components of the resource system in the lumped-parameter model.

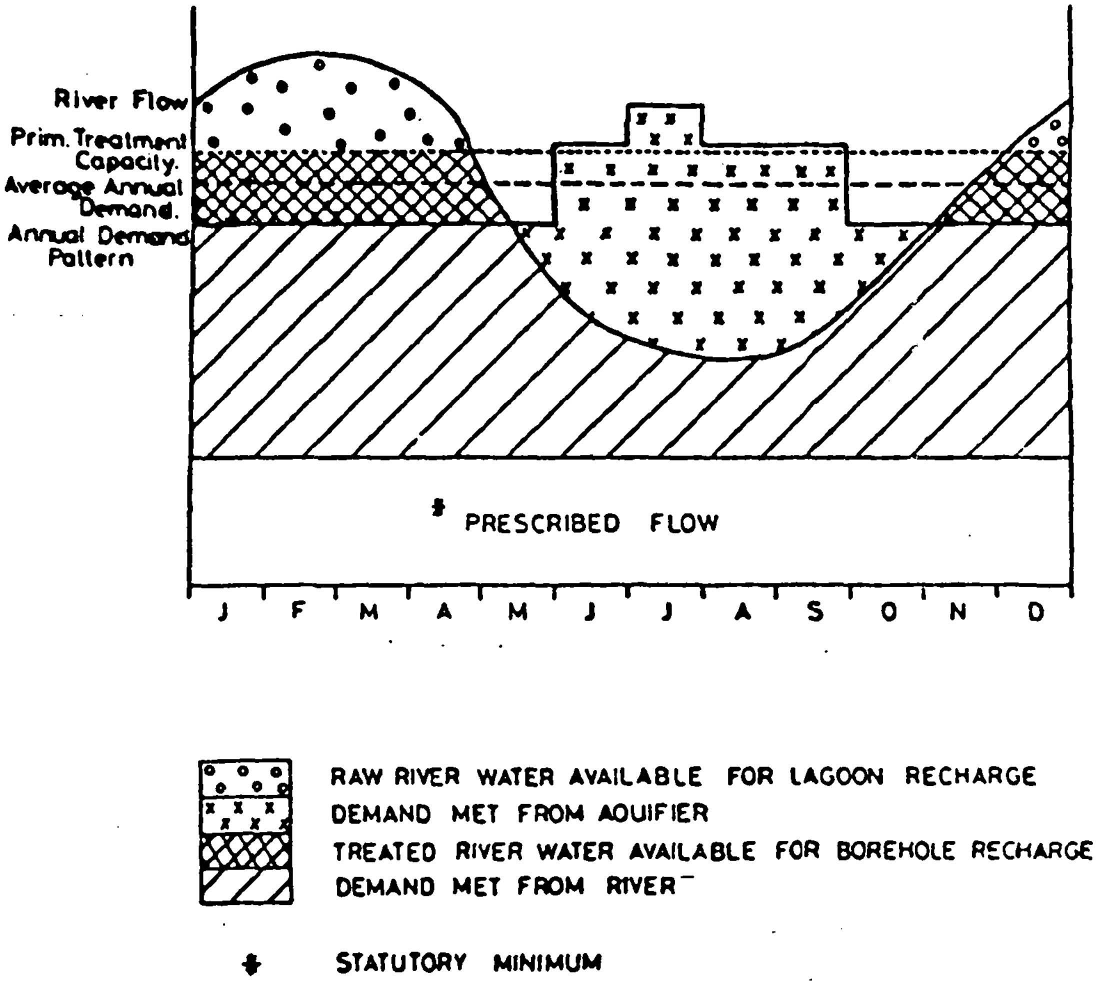
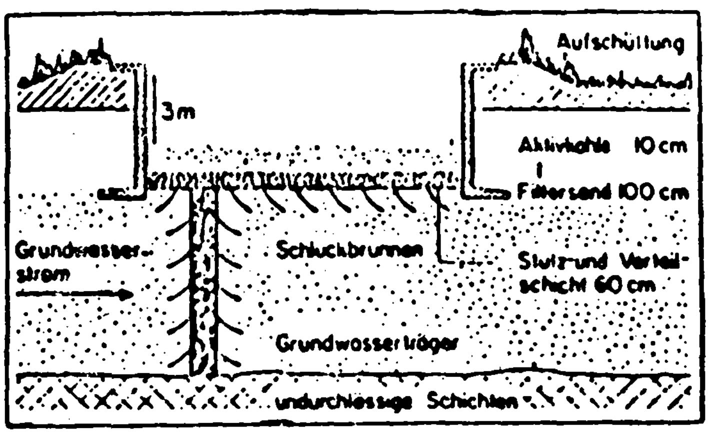


Fig. 26

Overall operating policy for the combined resource.



Recharge tank in Zürich. Combination of slow sand filter with 3 m flood and infiltration well.

Fig. 27

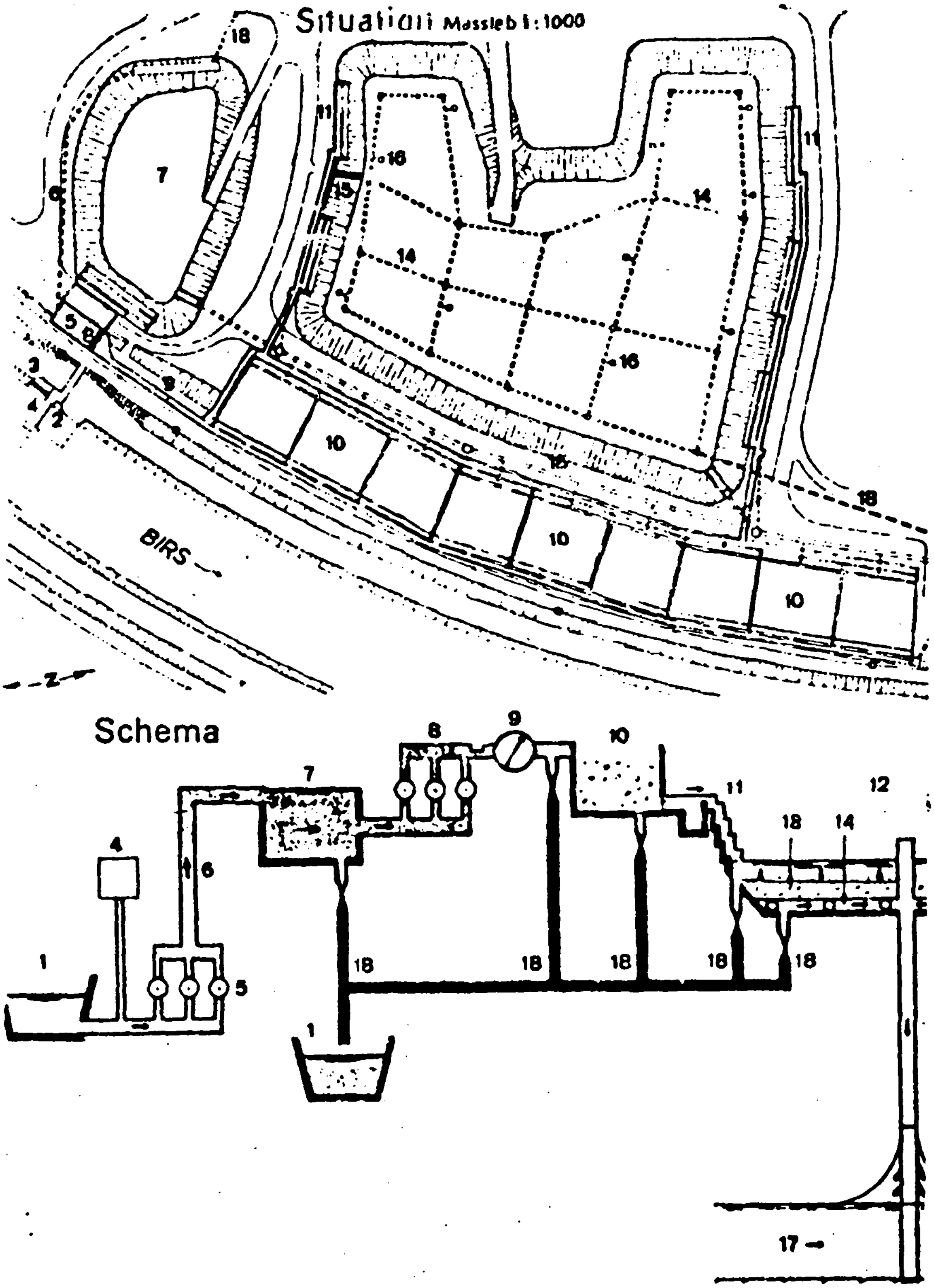
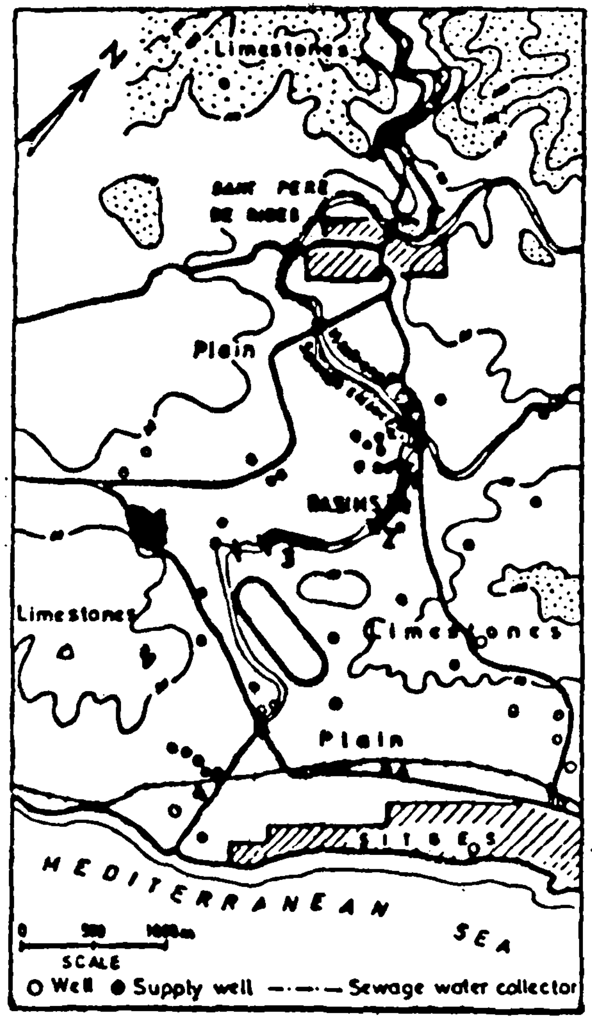


Fig.28- Scheme of the water treatment plant in Aesch (Switzerland): Combination of gravel prefilter (10), slow sand filteration (13/14), and infiltration wells (16)


N
Limestones
Plain
BASINS
Limestones
Limestones
Plain
SITGES
MEDITERRANEAN SEA
0 500 1000m
SCALE
O Well ● Supply well —·—·— Sewage water collector

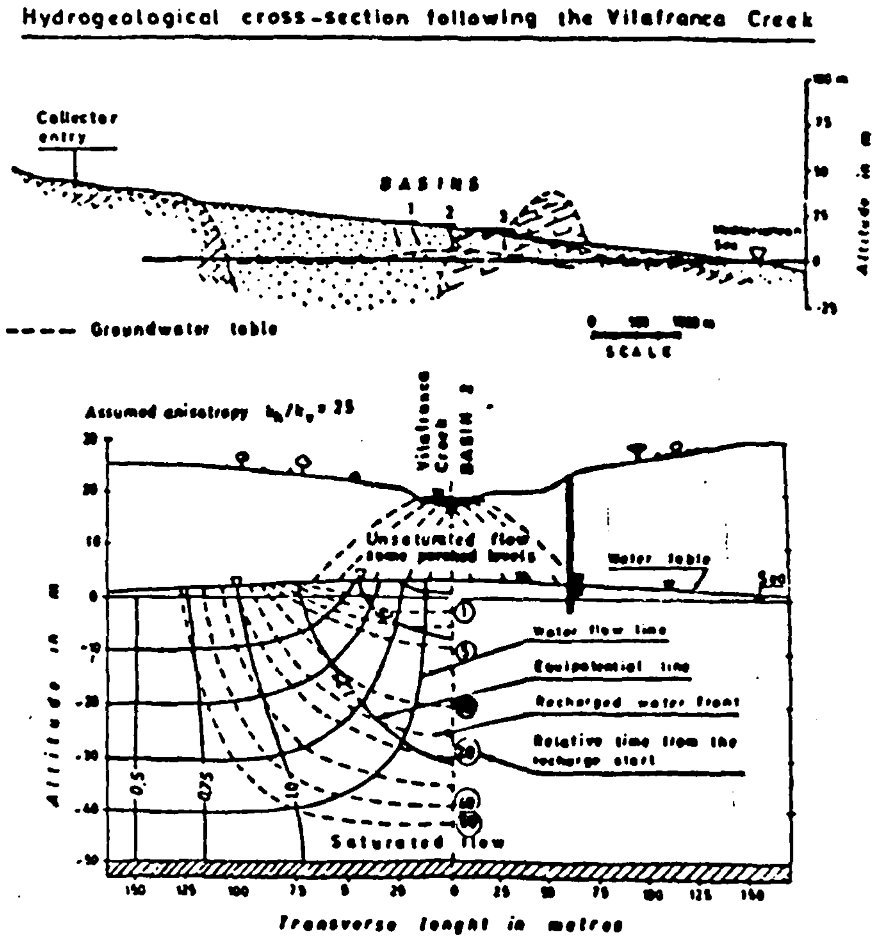

Hydrogeological cross-section following the Vilafranca Creek
Collector entry
BASINS
1 2 3
Groundwater table
SCALE
Altitude in m
Assumed anisotropy
Vilafranca Creek
BASIN 2
Unsaturated flow
Water table
Water flow line
Equipotential line
Recharged water front
Relative time from the recharge start
Saturated flow
Altitude in m
150 125 100 75 50 25 0 25 50 75 100 125 150
Transverse lenght in metres

Fig. 29

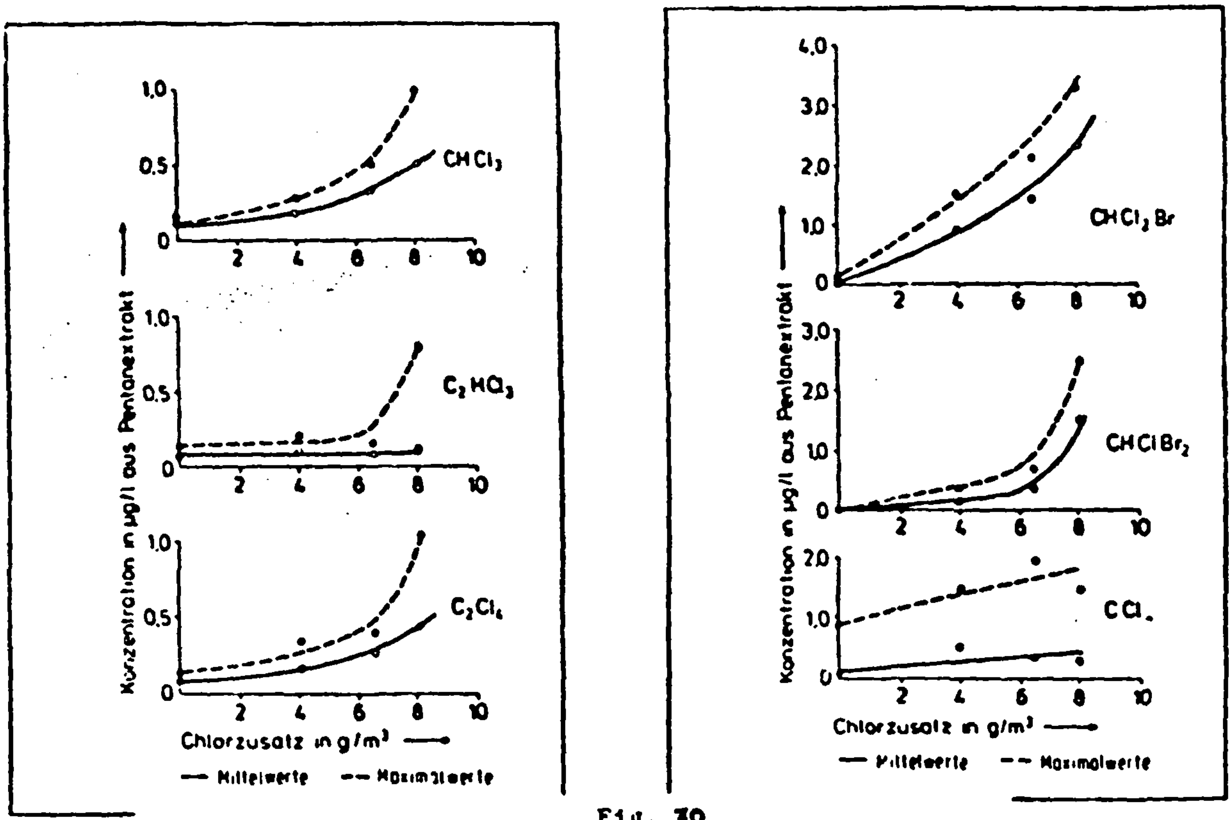


Fig. 30
Formation of low-volatile chlorinated hydrocarbons.

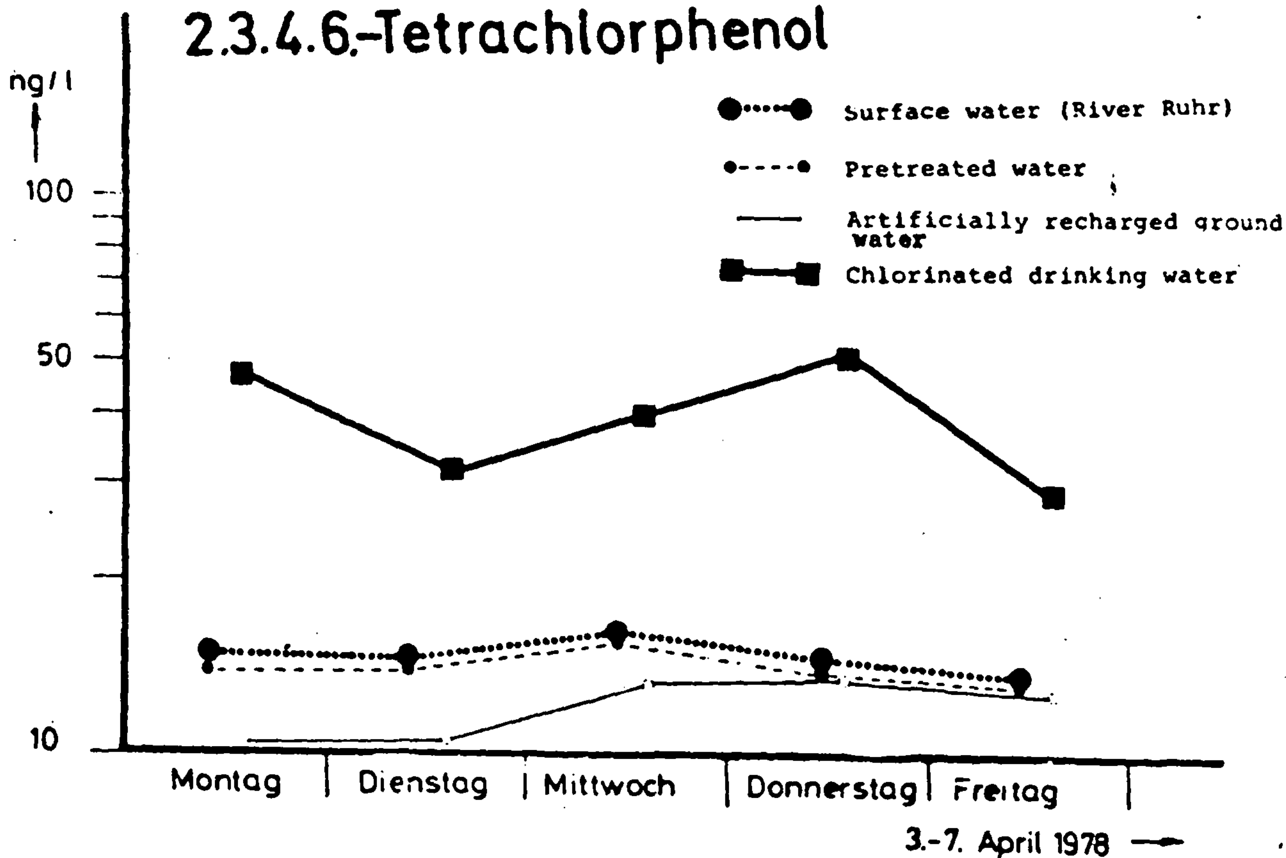


Fig. 31
Weekly formation of chloro-phenols during artificial recharge in the Ruhr Valley (Germany)

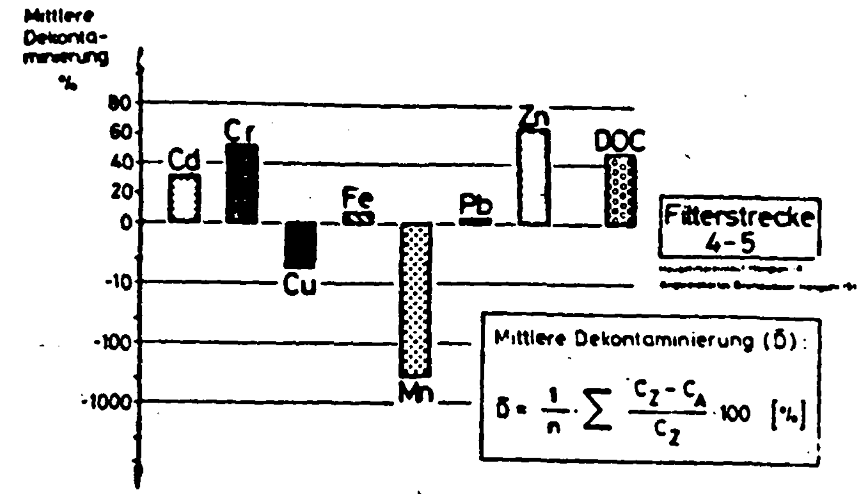


Fig. 32
Average elimination rates of heavy metals during slow sand filtration (Ruhr Valley)

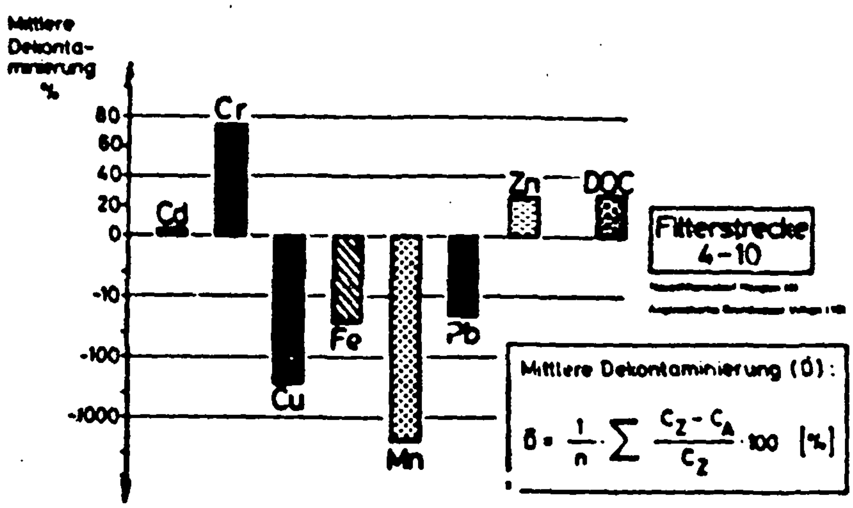


Fig. 33
Average elimination rates of heavy metals during slow sand filtration with bank filtration influence (Ruhr Valley)

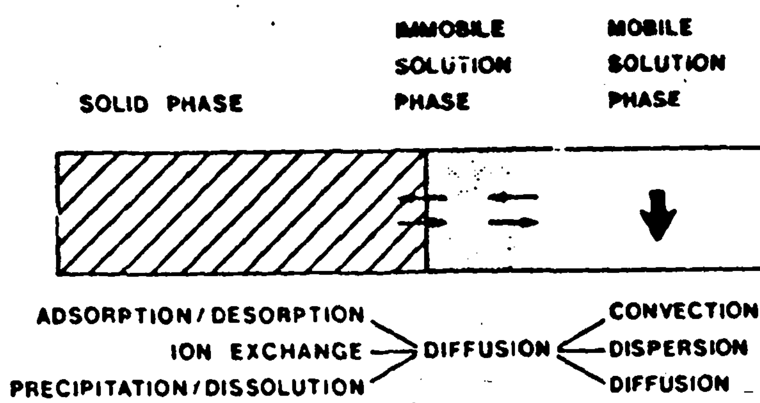


Fig. 34