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DEEP-WELL WASTE DISPOSAL IN THE FEDERAL REPUBLIC OF GERMANY - A STATE-OF-THE-ART REPORT -

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ABSTRACT

Deep-well disposal of liquid waste is practised in the Federal Republic of Germany at 31 sites. There are

- 17 disposal wells in Lower Saxony, injecting brines with polysulfide compounds from natural gas extraction;
- 1 disposal well in North Rhine-Westphalia. Injection of brine from salt solution mining has been postponed as the brine is now being chemically processed;
- 10 injection wells in the "Werra Potash District" (Hesse) for the disposal of process brine;
- 1 disposal well in the "Fulda Potash District" (Hesse), operating for the injection of surface runoff from a salt mine waste dump;
- 2 injection wells at Moosburg/Isar (Bavaria) disposing of spent hydrochloric acid.

INTRODUCTION

The injection of waste water and liquid wastes into deep wells is not new in the Federal Republic of Germany. Based on investigations by Beyschlag and Fulda (ref. 1), this technique was used for the first time by the potash industry for the injection of waste potash brines into Zechstein "Plattendolomit". Highly saline formation water has also been re-injected (ref. 2) into the subsurface for several decades by the oil and gas industry (secondary recovery). The main purpose of this practice does not fall under the term waste disposal.

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REGIONAL OVERVIEW

A preliminary regional overview, prepared mainly in teamwork by the Geological Surveys of the Fed. Rep. of Germany, is contained in (ref. 3). A revised version of this paper is presented here.

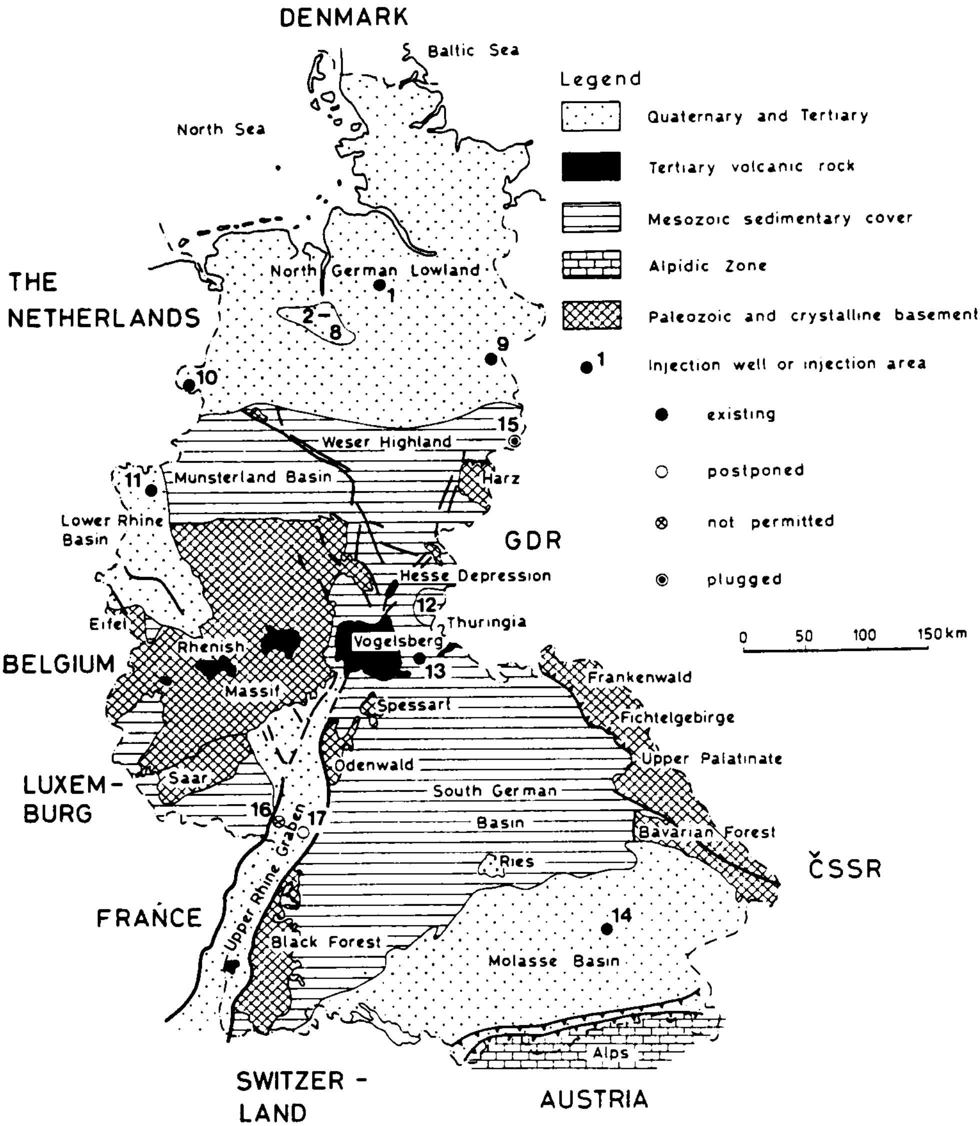

Fig. 1. Deep-well disposal of liquid waste in the Federal Republic of Germany.

Lower Saxony

Sequences of Mesozoic, Tertiary, and Quaternary sediments up to 4, 000 m thick are found in the North German Lowland. These sequences are separated by evaporite structures (pillows, domes, plugs) in north, northwest to west-striking directions. Often, the areas between the salt plugs can be used for injection of liquid waste due to the positions of the structures in these areas and because of the existence of suitable porous, fissured, or karstic rocks (sandstones or limestones).

In all cases, a several-hundred-meter-thick layer of clay, marl, sometimes also salt, covers the aquifer, which is usually 1000 m deep so that the potential for contamination of fresh water in the overlying Quaternary sequences can be excluded.

Most of the known injection wells (nos. 1-8) [+)] have been drilled as oil wells in an area of about 2500 km^2 in approximately the center of the North German Lowland. There are 2 injection wells in the eastern part of Lower Saxony (no. 9). In western Lower Saxony there is only one in Emsland (no. 10). The various salt water aquifers are listed with the geological formations in Table I.

Little data on the aquifer parameters has been published so far. A porosity of 20 % has been determined for the Valanginian sandstones in the Wietingmoor wells (no. 5), whereas a porosity of 17 % was determined for the Solling sandstones in the Brettorf well (no. 2).

The liquid wastes injected into the wells consist of gas-field brines (in part polysulfide- and ethylamine-bearing) and drilling fluids.

Table I also indicates the amounts of injection ranging from about 100 to 70, 000 m^3/year per borehole.

North Rhine-Westphalia

The only injection well in this area is near Xanten in the Lower Rhine Basin (no. 11; see ref. 4 and 5). It is planned to inject part of the brine from salt solution mining into the 10-m-thick Volpriehausen sandstone (Triassic Bunter), which has a porosity of 15 %. This layer is about 600 m deep and is confined by the Rötletten of the Upper Bunter. At present, the brine is now being chemically processed.

+) The figures in brackets indicate the well numbers given in Table I and Figure 1.

TABLE I

Injection wells in the Fed. Rep. of Germany (as of September 1980)

Well No.	injection well or area	geological formation	depth (m)	waste water or liquid waste	use of wells to date and injected amounts of waste
1	Kallmoor	Upper Cretaceous, Maastrichtian/ Campanian (Reitbrook sandstone)	1245-1298	drilling fluids, partly polysulfide-bearing	since 1964: 12,800 m^3
2	Brettorf +) Hellbusch +) (2 wells)	Lower Triassic, Bunter (Solling sandstone)	2980-2994 2872-2897	brines from natural gas extraction	since 1976: 294,500 m^3 since 1979: 125 m^3
3	Mollbergen +) (3 wells)	Upper Jurassic, (Malm, Kimmeridgian limestones)	717 - 770	brines from natural gas extraction, partly polysulfide- and ethylamine-bearing	since 1972: 84,900 m^3
4	Mellinghausen +)	Lower Cretaceous (Neocomian sandstone)	710- 745	drilling fluids, poly-sulfide-bearing	since 1979: 340 m^3
5	Wietingsmoor +) (2 wells)	Lower Cretaceous (Valanginian sandstone)	1235-1336	brines from natural gas extraction, poly-sulfide-bearing	since 1974: 301,500 m^3
6	Barenburg +)	Middle Jurassic, Dogger delta (Suderbruch sandstone)	1012-1019	brines from natural gas extraction, poly-sulfide-bearing	since 1970: 4200 m^2
7	Vogtei Siedenburg (2 wells)	Middle Jurassic, Dogger delta (Suderbruch sandstone)	1125-1165 860- 890	brines from natural gas extraction, poly-sulfide-bearing	since 1973 and 1977: 226,700 m^3

TABLE I (continued)

Well No.	injection well or area	geological formation	depth (m)	waste water or liquid waste	use of wells to date and injected amounts of waste
8	Buchhorst (2 wells)	Lower Cretaceous (Valanginian sandstone)	1011-1031	brines from natural gas extraction, partly polysulfide-bearing	since 1968: 32,600 m^3
		Middle Jurassic, Dogger delta (Suderbruch sandstone)	1233-1267		since 1970: 65,400 m^3
9	Wittingen +) (2 wells)	Middle Jurassic, Dogger delta sandstone	1533-1570 1746.5-1758.5	brines from natural gas extraction	since 1977: 68,000 m^3 since 1979: 350 m^3
10	Itterbeck-Halle	Upper Permian (Zechstein, Stassfurt carbonate)	1948.5-1959.5	workover mud from sour gas wells	since 1970: 8,800 m^3
11	Xanten	Lower Triassic, Bunter (Volpriehausen sandstone)	600	brines from salt solution mining	operation plan 1979/80 approved; at present, reprocessing of the brine but no injection
12	Werra Potash Region (10 wells)	Upper Permian (Zechstein, Plattendolomit)	325- 525	waste brine (Potash mining industry)	since 1925: 400×10^6 m^3
13	Neuhof-Ellers	Lower Permian (Grauliegend sandstone)	about 700	runoff from waste-salt dump	1971-1976: 180,000 m^3
14	Moosburg/Isar	Upper Jurassic (Malm, karstified limestone)	1100	spent hydrochloric acid (chemical industry)	since 1967: about 16×10^6 m^3

+) Note: Injection into these wells is part of secondary recovery, i.e. to maintain pressure in the oil or gas field for additional recovery of oil and/or gas.

Hesse

In Hesse, a large part of the waste water from the potash industry is injected into the Zechstein "Plattendolomit" (Werra Potash District, Hessian Depression, see no. 12 in Fig. 1 and Table I and refs. 6-8).

The area of the "Plattendolomit" presently used as reservoir covers about 250 km^2 of the Hessian part of the Werra Potash District. Since the beginning of waste water disposal in 1925 until 1976, about 600 million m^3 of waste potash brine has been injected in the Werra Potash District, i. e. in Hesse (Federal Republic of Germany) and in Thuringia (GDR). Of that amount, 402 million m^3 was injected with the Fed. Rep. of Germany. Figure 2 gives a comparison of deep-well waste disposal and discharge of waste potash brine into the Werra River for the years 1953 - 1977. The latter led to high salt concentrations which up to now are damaging the environment.

The average density of the waste water is 1. 2, whereas that of the formation water is 1. 02, so that the injected liquid wastes flow down-dip. Waste water is injected at depths between 325 and 525 m, without added pressure or up to a maximum pressure of 10 bar. A 10 % effective porosity, and in subrosion areas a 15 % porosity, was used to calculate a total storage volume of 1, 100 million m^3. Considering the storage volume already used, and possible errors, an additional storage capacity of almost 500 million m^3 can be assumed. At a maximum disposal rate of c. 20 million m^3/years the usable storage volume will be filled by around the year 2000.

The injected amount of chloride is 12, 750 t/day. Together with part of the substituted formation water, 1. 5 % of the injected chloride emerges from springs. Apart from fault zones, fractures resulting from subrosion and those in basaltic dikes serve as hydraulic connection for formation water and injected waste water to the surface. However, due to the overlying sealing clayey sequence of the Lower Bunter, a general rise in the level of the saline-fresh water boundary is not to be expected.

Runoff from a waste salt dump at the Neuhof Ellers potash mine near Fulda (no. 13) is injected into a disposal well. Injection zone: grey sandstone, top of the Lower Permian; absorption capacity: 32 m^3/h assuming an average injection pressure of 55 bar.

Bavaria

Due to the geological and hydrogeological conditions in Bavaria, it is one of the federal states where there are possibilities for the injection of waste water.

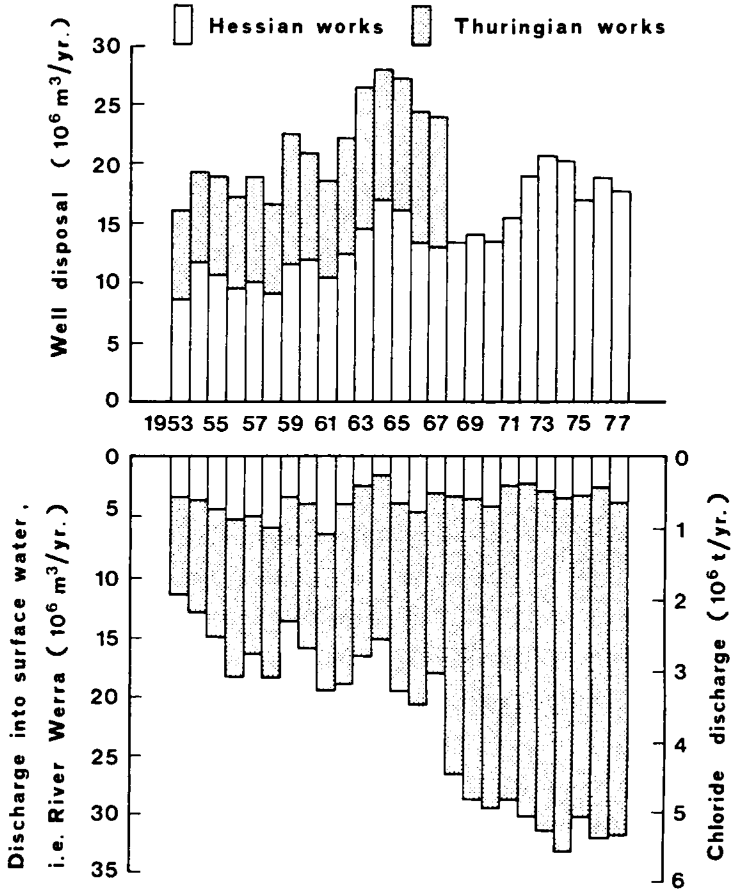

Fig. 2. Disposal of chloride-bearing waste water in deep wells and discharge into the Werra River from 1953 to 1977 (Werra Potash District), according to ref. 9.

Karstic Malm rocks in the Molasse Basin are considered suitable for the injection of liquid waste because of their regional scale capacity. These permeable rocks correspond to a surface area of more than 10,000 km^2, and they are widely covered by low permeable Tertiary sediments. In the area southwest of Regensburg, the Malm aquifer is in hydraulic connection with its base level, the Donau River. Compared with the overlying Tertiary aquitards, vertical stress decreases here in. Therefore, waste water can be injected into these Upper Jurassic rocks with almost no additional pressure. Two plants are located at Moosburg (no. 14 in Fig. 1 and Table I, see ref. 10). At this place, spent acids are injected into the 300-m-thick, karstic Malm aquifer at 1,100 m depth since 1967 and 1970. The average rates are 70 and 180 m^3/h; about 16 million m^3 have been injected.

In the Moosburg area, total dissolved solids of the Malm karst groundwater vary between 0.6 and 3.2 g/l. The water temperature is about 52° C.

The injected waste consists of spent acids from bentonite processing (about 400 t of hydrochloric acid are used per day) plus wash water from the pretreated clay. Mixing leads to a partial neutralization and dilution before injection into the aquifer. During this process the waste acid containing about 134 g/l Cl^- (at a pH of 0.5) is diluted to about 20 g/l Cl^-.

During the subsurface flow of the waste water to the regional main base level (Donau River, Fig. 3), apart from neutralization, further dilution is possible

- by dispersion in the karstic rock,
- by transmitting formation water from the up-dip Molasse sediments, and
- by mixing of the waste water with the groundwater in the Pleistocene Donau gravels.

Altogether a dilution ratio of 1 : 10,000 was estimated.

The waste water is not filtered before injection. The CO_2 from the reaction of the waste fluid with the rock carbonate remains in solution due to the pressure conditions. Therefore, the gas does not block the aquifer in the injection area.

The residence time of the karst water and thus of the diluted waste water, estimated on the basis of hydrogeological considerations and age determinations in places, is several 10,000 years (ref. 12) before it will reach the Donau River as base level. Therefore, and because of the dilution ratio, a contamination of the surface water is improbable. According to hydrogeological and geochemical interpretations (ref. 13), a contamination of overlying aquifers is excluded, because the Tertiary formation water contributes to the Malm aquifer.

CASES OF DAMAGE

The abandoned injection area of Offleben (no. 15 in Fig. 1) is located at the southern edge of the North German Lowland. From 1947 to 1949, 100,000 m^3 of waste water containing phenol from low temperature lignite carbonization were injected at about 60 m depth (ref. 3). The caprock of a Zechstein salt dome under Quaternary cover was used as an injection reservoir.

Within a period of one to two years the waste water entered the hydrological cycle and finally emerged in a spring and a well. Even in 1957, phenol concentrations of 0.3 to 295 mg/l were determined in groundwater observation wells.

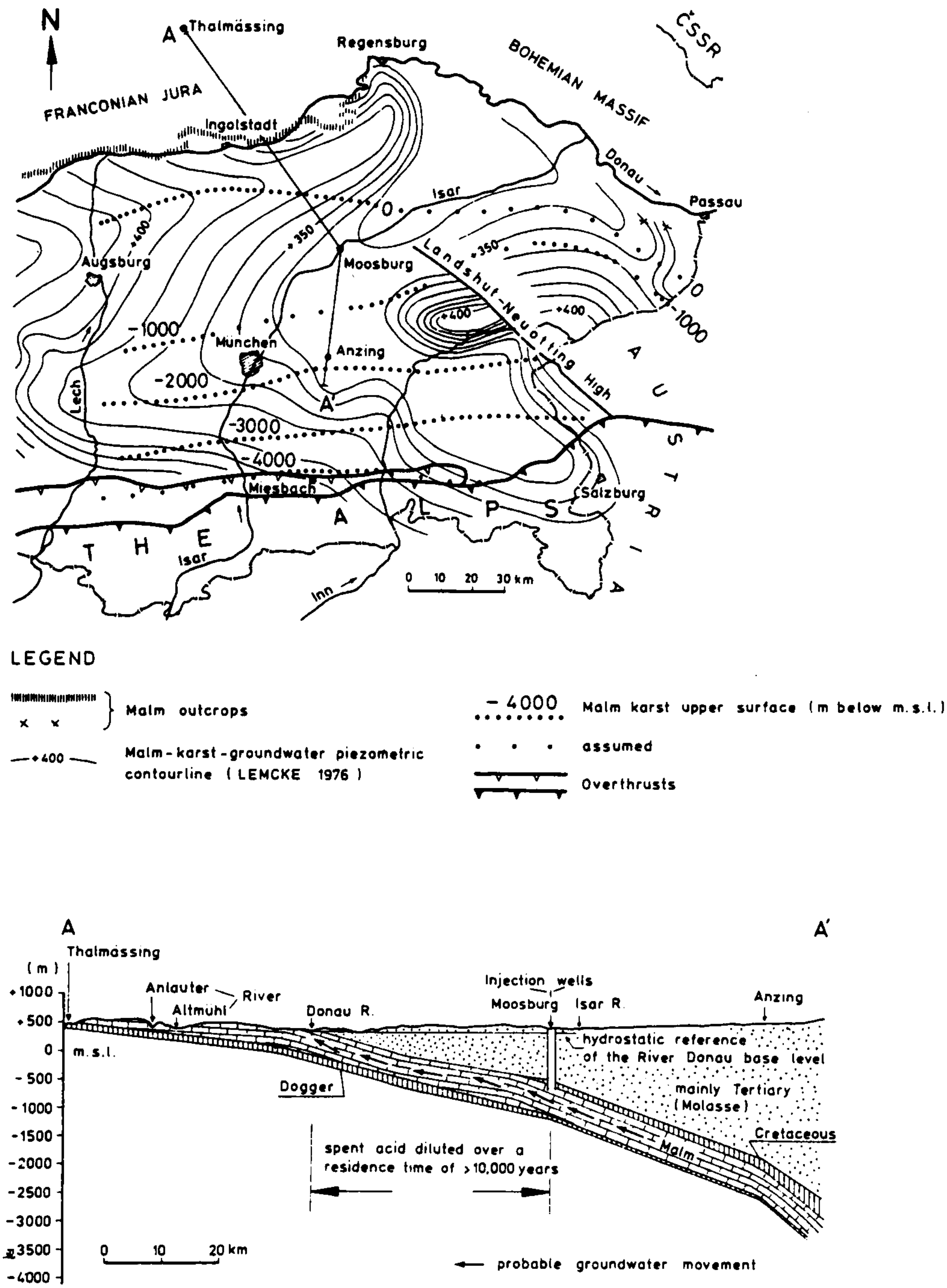

Fig. 3. Disposal of spent acid in the South Bavarian, Malm karst aquifer (geology according to ref. 11).

This injection operation demonstrates that liquid waste that is hazardous to health should not, if at all, be injected into aquifer reservoirs at minor depth. Moreover, the hydrogeological conditions in the caprock of a salt dome with its inhomogenous structure can only be established after thorough preliminary investigations. This, however, had not been done.

REJECTED INJECTION PROJECTS

Near Landau, at the western edge of the Upper Rhine Graben (no. 16 in Fig. 1), it was planned to inject liquid chlorinated hydrocarbons (dichloroethane and dichloropropane) in abandoned oil deposits ("Bunte Niederrödener Schichten" and "Cyrenenmergel" of the Tertiary) at a depth of 1,200 to 1,300 m (ref. 14). A pilot test with 1,000 m^3 of liquid waste was not carried out after the waste was classified as physiologically hazardous. Further objections were based on the fact that

- no evidence of the absolute confinement of the injection zone was produced;
- it would be impossible to monitor the waste's migration, especially of small amounts;
- this is an area of greater seismic risk, i. e. block movements are possible, especially such over longer periods of time;
- the project area is densely populated and the sometimes intensively used Quaternary aquifers (and thermal waters at other places) might be impaired;
- future projects for a possible use of the thermal anomaly at Landau might be negatively affected.

CONFLICTS IN ASSIGNING PRIORITIES

The Nuclear Research Center at Karlsruhe was commissioned to check possibilities for the injection of tritium-bearing waste water from nuclear reprocessing plants. For this purpose, an injection zone in the adjacent and abandoned Leopoldshafen oil field (no. 17 in Fig. 1) had been envisaged (ref. 15).

An 11-m-thick sand lens at about 950 m depth in the upper part of the "Cyrenenmergel" (Oligocene) was selected. An injection test with water yielded an injection rate of 8.5 m^3/h at an injection pressure of 60 - 80 bar. It would be possible to inject a total of 11,000 m^3 radioactive waste water. This project could have proved to be very useful after the regulations for radiation protection were revised (December 20, 1976), lowering the limit from 3×10^{-2} Ci/m^3 to 2×10^{-4} Ci/m^3 for tritium bearing waste water flushed into a receiving stream (in this case, the Rhine).

In the meantime, the injection project was dropped, since it was planned to produce more oil from the reservoir using new recovery techniques.

POTENTIAL FOR SUBSURFACE WASTE INJECTION

Fig. 4 gives an overview of the potential for injection of waste water and liquid waste at great depth in the Fed. Rep. of Germany on the basis of the given geological and hydrogeological conditions.

Due to the lack of comprehensive regional investigations directed towards the injection of waste water at great depth it is possible to give only approximate boundaries according to the following categories for the implementation of such projects:

hydrogeologically suitable   less suitable   unsuitable.

Therefore, it is necessary to carry out detailed investigations in each case as a preliminary phase to the actual project in order to exclude future damage and unnecessary financial risk.

Hydrogeological conditions suitable for the injection of waste water at great depth are present or probably present in the following areas of the Fed. Rep. of Germany:

- North German Basin;
- northern Lower Rhine district;
- eastern Hesse;
- Molasse Basin (South Germany).

Less suitable are the Upper Rhine Graben and the Münsterland Basin.

According to the present state of knowledge, all of the other regions have to be classified as primarily unsuitable.

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REFERENCES

1 F. Beyschlag and E. Fulda, Kali, 15(1921)363-367.
2 W. Rühl, Erdoel-Erdgas-Zeitschrift, 92(1976)311-319.

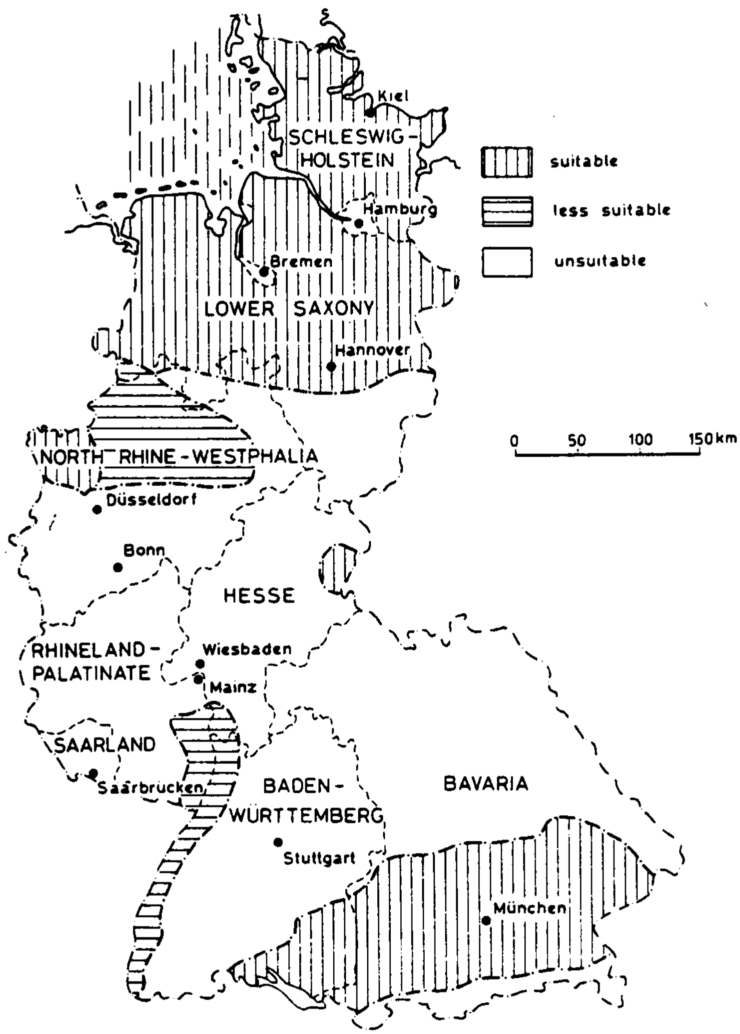

Fig. 4. Hydrogeological and geological assessment of regional possibilities for the disposal of waste water and liquid waste in deep wells in the Fed. Rep. of Germany

3 H. Aust and K. Kreysing, Geol. Jb., C20(1978)III-X, 1-224.
4 Geologisches Landesamt Nordrhein-Westfalen, Tätigkeitsbericht 1978/1979, Krefeld, 1980, pp. 32-33.
5 H.Karrenberg, Hydrogeologie der nichtverkarstungsfähigen Festgesteine, Springer, Wien - New York, 1981, p. 260.
6 A. Finkenwirth, Mem. IAH, Congr. of Hannover 1965, VII(1967)124-129.
7 A. Finkenwirth, Wasser + Abwasser, - (1968)1-7.
8 A. Finkenwirth, in W. Kumpf, K. Maas and H. Straub (Eds.), Müll- und Abfallbeseitigung, 56th edn., Ch. 8195, Deep Well Disposal, Erich Schmidt, Berlin - Bielefeld - München, 1980, pp. 1-21.

9 A. Singewald, Kali u. Steinsalz, 8(1980)2-8.
10 Bayerisches Oberbergamt, K. Fünfgelder (Ed.), Das Bayerische Oberbergamt, 2nd edn., Länderdienstverlag, Berlin, 1980, pp. 108, 109 and 174.
11 H. Hörauf and H. Wirth, Deutsche Gewässerkundliche Mitteilungen, 23(1979) 113-117.
12 F. Neumaier, oral communication, München 1977.
13 K. Lemcke, Bull. Ver. schweiz. Petrol.-Geol. u. -Ing., 42(1976)9-18.
14 H. Aust and K. Kreysing, in BRGM (Ed.), Comm. Colloque National "Protection des Eaux Souterraines Captées pour l'Alimentation Humaine", Orléans-la-Source, mars 1+2, 1977, Orléans-la-Source, 1977, part 1, pp. 11-21.
15 W. Hild, H. Krause, K. Sauer, W. Kessler and W. Fischak, in IAEA (Ed.), Proc. Symp. Management of Radioactive Wastes from Fuel Reprocessing, Paris, November 27 - December 1, 1972, Paris, 1972, part 39, pp. 1-17.