DEPARTMENT OF
~~NATIONAL RESOURCES~~
NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1978/64

THE CONTAMINATION OF GROUNDWATER BY HYDROCARBONS, WITH BRIEF NOTES ON THE HYDROGEOLOGY OF CANBERRA CITY, ACT.

by

E.G. WILSON

Record 1978/64

THE CONTAMINATION OF GROUNDWATER BY HYDROCARBONS, WITH BRIEF NOTES ON THE HYDROGEOLOGY OF CANBERRA CITY, ACT.

by

E.G. WILSON

This Record was originally issued as a BMR Engineering Geology Technical Note dated 11 March 1977. The original document was admitted as evidence in the Canberra Coroner's Enquiry into the explosion and fire at the Center Cinema, at hearings in August 1977. Minor amendments have been made to the original.

CONTENTS

Page

SUMMARY

INTRODUCTION 1

PROBLEMS ASSOCIATED WITH POLLUTION BY PETROLEUM PRODUCTS 1

SOURCES OF POLLUTION 2

Spillage 2

Waste oil 2

Leakage from underground installations 2

Corrosion in ACT soils 3

MOVEMENT OF HYDROCARBONS WITHIN THE GROUND 4

HYDROLOGICAL CHARACTERISTICS OF GEOLOGICAL FORMATIONS 5

Clay soil 5

Gravel 5

Weathered bedrock 5

THE EFFECTS OF URBAN DEVELOPMENT ON GROUNDWATER MOVEMENT 6

Sealing of ground surface 6

Construction of underground services 6

Stormwater drains 6

Sewer mains 7

Trench system 7

Building construction 7

The effect of pumping from building sumps 7

REMEDIAL ACTION AFTER CONTAMINATION HAS OCCURRED 8

Bacteriological breakdown 8

Dispersion 8

Use of chemical dispersants 9

Pumping of groundwater as a method of removal of contamination 9

CONCLUSIONS 10

REFERENCES 11

Figures

1. Gasoline/water-table relationship
2. Schematic diagram showing factors affecting hydrogeology
3. Removal of oil pollution by use of a borehole

SUMMARY

Following an explosion at the Center Cinema in Canberra City on 10 February, 1978, groundwater seepage into the building was found to be contaminated with hydrocarbons. This report discusses hydrocarbon pollution of groundwater in general and the hydrogeology of Canberra City.

Hydrocarbon pollution makes groundwater unfit for drinking, and gas may accumulate in buildings and constitute a fire hazard. Pollution may take place as leakage from underground installations, by the dumping of hydrocarbon wastes or the accidental release of refined product. Where underground installations are concerned, the age of the installation and the underground conditions that govern the onset and progress of corrosion must be considered.

Spilled or leaked hydrocarbons will soak downwards through soil until the watertable is reached where they will float as a lens within the upper surface of the groundwater.

In Canberra City heavy clay overlies clayey gravel. The gravel rests unconformably on an irregular surface of weathered siltstone and mudstone of Silurian age, at a depth of about 4.5 m. The natural groundwater regime, modified by roads, hard standing and car parks, seals much of the surface, and infiltration is negligible; however, leakage from stormwater services is a likely source of groundwater recharge, and the permeable pipe-bedding materials in underground service excavations would readily transmit fluids. Deep excavations for the construction of buildings may cut through foundation materials with diverse permeabilities, and building construction may allow the entry of groundwater into sumps for the relief of uplift pressure on the foundation. Pumping from such sumps affects the groundwater situation.

Given time and depending on the permeability of the materials, much of the hydrocarbon pollution will disperse widely and move downslope along the groundwater gradient, but will still constitute a hazard. Removal of some hydrocarbons from the upper surface of the groundwater can be achieved by a skimming device, and chemical dispersants may also be useful. Hydrocarbons absorbed on clays are difficult to remove, but bacteriological breakdown of the hydrocarbons in the aerated soil zone will take place in time. Complete removal of hydrocarbons can only be accomplished by the removal of all contaminated material.

INTRODUCTION

The Bureau of Mineral Resources (BMR) was called upon by the National Capital Development Commission (NCDC) and the City Manager's Office, Department of the Capital Territory, to investigate the geological and hydrological conditions that may have a bearing on the explosion that occurred in the lower levels of Cinema Center, Bunda Street, Canberra City on 10 February, 1977. Hydrocarbon fluids and gas were encountered in the building and this paper provides background geotechnical information relevant to the investigation. It deals with the problems of pollution by petroleum products and the sources of such pollution, discusses the movement of hydrocarbons in the ground formations, the hydrogeological conditions in the area, and the methods of hydrocarbon removal that are available, and comments on their effectiveness.

PROBLEMS ASSOCIATED WITH POLLUTION BY PETROLEUM PRODUCTS

Pollution of groundwater by refined petroleum products is not a new problem. Many cases have been investigated overseas in the last twenty to thirty years, and the number of reported cases appears to be increasing. In some instances a fire hazard was created by petrol fumes accumulating in the basement of dwelling, but, in most cases, complaints were concerned with the pollution of underground water that had become unfit for household use.

A spill or leakage of combustible liquids presents an immediate danger of fire and explosion; in dealing with the immediate risk by washing the spill into the ground, or into stormwater drains, other longer term problems may eventuate.

1. Combustible vapours may collect in sewers or basements and create a fire and explosion hazard.
2. A film of hydrocarbons may form on surface waters that is toxic to certain forms of plant and animal life and that interferes with recreational use.
3. Water may become unpalatable because it contains petroleum products in extremely low concentrations, and relatively small spills may contaminate very large volumes of groundwater.

4. The product may contaminate the soil with an oily film that is difficult to dislodge, and which slowly releases soluble contaminants via percolating rain water to aquifers, making them unusable for decades.

SOURCES OF POLLUTION

Groundwater contamination by petroleum products may be brought about by one or more spills and/or one or more leaking tanks. As groundwater flows downgradient under watertable conditions, it is most likely that the source or sources of contamination are located upgradient. Three main sources will be considered: the spillage during transfer of product from one container to another; the indiscriminate dumping of waste oil; and leakage from underground storage tanks and their piping systems. The situation is complicated where there are a number of facilities that do or may contribute to the pollution. The source of the pollution can seldom be pinpointed with sufficient certainty to determine legal responsibility.

Spillage: The most frequent cause of spillage during transfer of a product is human error; it may be due to inattention, failure to check the capacity of tanks to hold the estimated amount, opening the wrong valve or failure to make the required connections. There is a responsibility to this operation that must be laid on the operator.

Waste oil: The dumping of waste crankcase oil in a convenient ditch or stormwater drain has been a common practice in the past and is likely to continue as a source of groundwater pollution unless the re-use of waste oil is ensured by regulations and incentives aimed at providing suitable collection, storage and recycling facilities.

Leakage from underground installations: Leakage of underground storage tanks is a major source of contamination, particularly if such tanks do not have cathodic protection or a protective coating. The average life of such tanks overseas has been estimated to be 12 to 15 years at the most. In corrosive soils the life is likely to be only a fraction of the average. Leaks must be expected to occur regularly; they may develop gradually and may remain unnoticed for a long time until the losses become economically significant to the operator. By that time sufficient hydrocarbons may have leaked out to contaminate a vast aquifer.

"Statistics collected in Ontario over a four-year period show that leaking storage tanks and fuel lines were responsible for about two-thirds of the pollution problems reported. The size of product loss in known cases was reported to vary from 150 to 11,000 gallons; sixty percent of these cases involved gasoline as opposed to diesel oil. About one-third of the reported cases was caused by spills or miscellaneous and unknown causes."

(Clean Environment Commission, 1976)

Chemical analysis may establish the refinery source of a product, but identification of gasoline brand from additives may not be reliable because additives are in such small proportions that adsorption by the soil will modify the additive content.

Corrosion in ACT Soils

The only study of corrosion in the ACT was carried out by the Central Testing and Research Laboratories, Department of Construction, Melbourne, for the Googong to Campbell pipeline (Melbourne, 1975).

The problem of corrosion at any location is complex and depends on many factors. A study of the susceptibility of the area to corrosion would seem to be a prerequisite for instituting regulations concerning protective measures for underground tanks.

In the areas adjacent to the Cinema Center, underground tanks will be founded in clay soils and gravels. The water table is thought to lie near the base of the tanks; however, it will rise quickly within the gravels after rain and will make contact with the lower part of most tanks in the area.

Another factor that could accelerate corrosion in this area would be stray current from the earthing of DC electrical equipment in the area, and possibly some current leakage from underground electricity cables.

The major contributor to corrosion is time; given time, every underground tank without a protective outside coating, cathodic protection and an appropriate inner liner will leak.

MOVEMENT OF HYDROCARBONS WITHIN THE GROUND

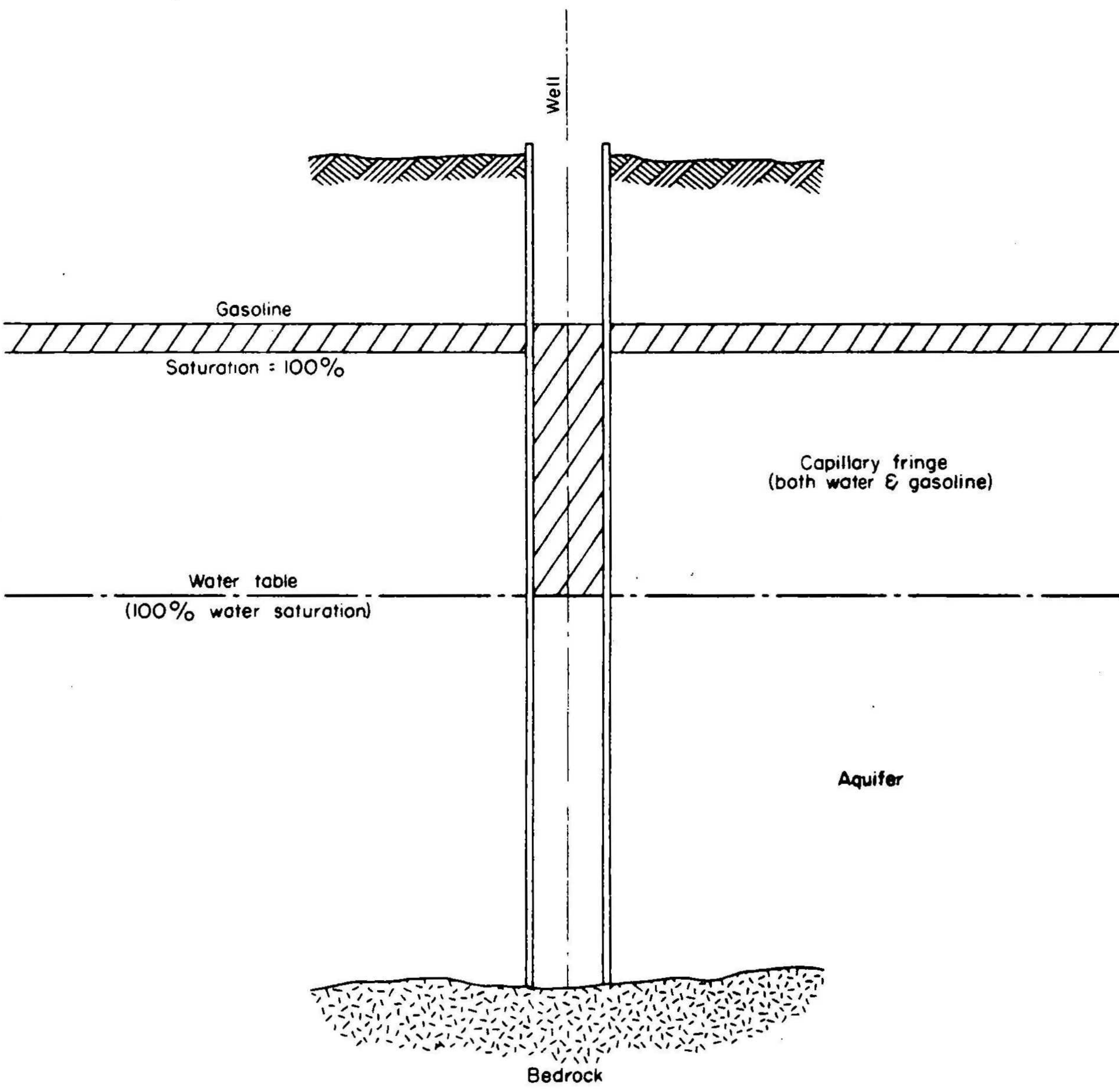
After a product is spilled or leaked, it tends to migrate downwards due to gravity, and may become adsorbed before it reaches the water table. Heavy oils do not readily penetrate the soil while lighter fractions, in particular petrol, move through soil more readily than water. The distance a spill may travel also depends on the quantity that is released; the product leaves a coating on the soil particles as it moves through successive layers, and the amount that travels on is gradually reduced until movement virtually stops. Large spills travel farther than small spills, and lighter fractions travel farther than heavier fractions.

The oil spill itself need not reach the water table in order to contaminate it. A rise in the water table following rainfall will concentrate the petroleum product on the water surface, or heavy rains may flush the pollutant down to the water table. Once the spill reaches the water table, the hydrocarbons will spread laterally on top of the groundwater because they are lighter than water. As the water table rises and falls so will the hydrocarbons on top of the water.

Figure 1 shows the petrol-water table relationship with free petrol floating directly on water in the well; however, in the surrounding ground or aquifer as it is shown on the figure, there is a three-layer relationship in which a capillary fringe containing both water and petrol separates the free petrol above from the water below. Petroleum products that become distributed through the soil as part of the capillary fringe are not readily dislodged and their recovery cannot be assured.

Another property that affects the seriousness of pollution is the solubility of the components of the product; lighter fractions have more components that are soluble in water than do heavier fractions. Soluble components in the water release vapours that may collect in sewers or basements. Fortunately, petrol vapours can readily be detected by smell at concentrations much below the level that creates any explosion hazard, and in the vast majority of cases explosions can be prevented by monitoring. However, the hazardous condition may last for a long time during which a building may remain unfit for occupancy.

Mobility of an underground pollutant depends most of all on the permeability of soil and underlying formations.



Record 1978/64

155/A16/2154

Fig 1 Gasoline-water table relationships
(Figure from Williams and Wilder, 1971)

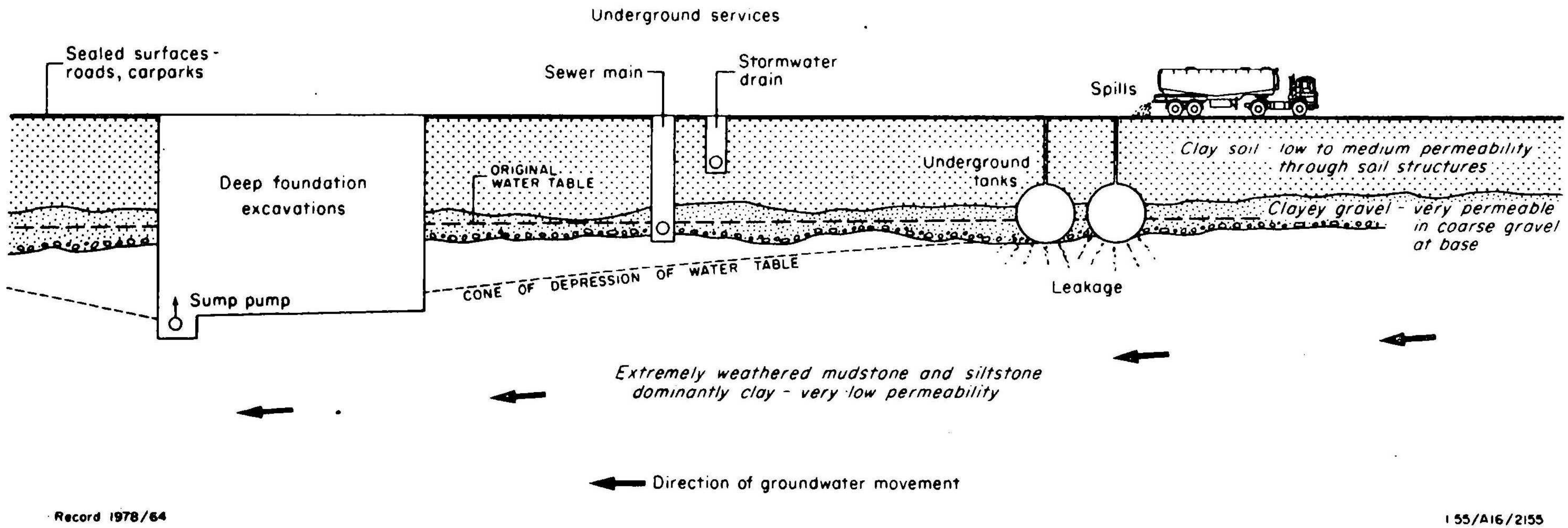


Fig. 2 Schematic diagram showing factors affecting hydrogeology

HYDROLOGICAL CHARACTERISTICS OF GEOLOGICAL FORMATIONS

In the area immediately surrounding the Cinema Center, Canberra City, a heavy clay soil extends to a depth of about three metres, and overlies clayey gravel; the clayey gravel overlies the bedrock in the area which is extremely weathered mudstone and siltstone of Silurian age (430-400 million years old) (see Figure 2).

Clay Soil

The clay soil will have some permeability through root channels and cracks that are a feature of natural soil structure. The clay material itself would be impermeable but the structure that has developed during formation of the soil will permit infiltration of both hydrocarbons and water. Reduction in permeability may take place whenever the clays adsorb water and expand thus reducing the size of voids in the soil.

Gravel

The clayey gravel ranges in thickness from about 0.5 metres to 1.5 metres; the coarseness of the gravel increases with depth and the clay content decreases with depth. The permeability in the gravel will be high in the coarse gravel allowing water to flow freely. The base of the gravels is an irregular surface, and with high permeability in the lower section of the gravel, water will flow in gravel-filled depressions in the underlying bedrock.

Weathered bedrock

The extremely weathered siltstone and mudstone of Silurian age can be described as a clay or clayey silt. Any permeability that exists in this material is through joints that are remnants of its original rock structure, but these joints will be tight and permeability will be very low.

THE EFFECTS OF URBAN DEVELOPMENT ON GROUNDWATER MOVEMENT

Modifications to the groundwater hydrology of the area have been brought about by engineering works associated with urban development.

Sealing of the ground surface

The sealing of the ground surface for hard standing, sealed roads and car parks has left practically no soil exposed at the surface, and ensures that surface infiltration from rainfall is negligible. It also ensures that the ranges in moisture content and temperature of the soil are minimal and that the permeability of the soil is not likely to be reduced by the expansion of saturated clays.

Construction of underground services

The construction of underground services such as stormwater drains and sewer lines requires the excavation of trenches gmerally within 1.5 metres of the surface for stormwater drains, and to depths ranging to 5 metres for sewer mains (depending on topography). A bed of permeable material, generally coarse sand, is laid in the base of the trench, and the pipes are laid; more sand is dumped around the pipes before backfilling the trench with the excavated material. The base of each trench is therefore a highly permeable channel of sand for the passage of fluids, and the trenches modify the groundwater regime accordingly. The backfill material is rarely compacted to the density of the original material and would also provide a path for infiltration if the surface is not sealed off by pavements.

Stormwater drains: Stormwater drains in many parts of Canberra have been laid with open joints to allow for the collection of excess soil water in swampy areas, in some cases attributable to garden watering. This practice also allows fluid to drain from a stormwater drain into the sand in the base of the trench. It is a standard engineering practice, and it should be recognised that there is no requirement for making stormwater drains watertight as there is for sewers.

Sewer mains: Sewer mains are tightly jointed and pressure tested, and would not normally contribute to fluids in the surrounding material; however, the trenches in which they lie are an important passageway for movement of underground water. They may bring water into contact with a permeable formation that would otherwise have had to depend solely on the infiltration rates of the overlying soils for its recharge.

Trench system: The trenches of stormwater drains and of sewers intersect one another to form a system of interconnected permeable channels that modify the groundwater hydrology of the area.

Building construction

The construction of buildings often requires deep excavations that cut through formations with a range of permeabilities, thereby allowing water from one formation to come into contact with another formation. Construction of a building in the excavation does not restrict the movement of such water, even when concrete is poured and vibrated in direct contact with the side walls of the excavation. Fluids will still move from one formation to another through channels where concrete has failed to fill re-entrant angles, and if pressure is build up by a rise in the water table the flow increases. A watertight seal could only be obtained by the injection of grout, a mixture of cement and water, under pressure into the zones behind the walls; this is not standard practice, nor is it necessarily a desirable practice for sound engineering reasons.

The effect of pumping from building sumps

Another modification to the groundwater regime is brought about by the installation of sump pumps in buildings. A sump pump may be installed to cope with water inflow through the floors and walls of a building, or for the removal of water that is allowed to enter the sump from outside the building. The latter procedure relieves uplift pressure on the building foundations, and thereby prevents structural damage; such an installation is regarded as a standard construction procedure.

The effect of pumping from a sump on the groundwater regime is to set up a cone of depression in the water table, akin to that established by pumping from a water bore (see Figure 2).

REMEDIAL ACTION AFTER CONTAMINATION HAS OCCURRED

Remedial action has to deal with the problem of the building owner whose basement fills up with fumes and/or whose well yields water that smells and tastes like petrol.

In a contaminated zone where groundwater exhibits only minor indications of pollution in the water, it does not necessarily mean that flushing out of the hydrocarbons has taken place. It is more likely that the smaller capillaries in the soil still retain considerable amounts of hydrocarbons and that the free flow of water takes place through the larger voids in the soil. It is virtually impossible to flush all the remaining hydrocarbons from the smaller capillaries.

There appears to be general agreement in the literature that the clean up of contaminated aquifers is not possible. With large spills some of the oil may be recovered but enough will remain in the soil either as mobile oil or as a film on soil particles to contaminate well water and to cause fire hazards in basements for many years.

There are natural process capable of removing the contaminants; these are the bacteriological breakdown of the hydrocarbons, and dispersion; both are extremely slow, if operative at all.

Bacteriological breakdown. Bacteria will break petroleum down in the aerated zone of the soil under favourable conditions; however, at greater depths petroleum will persist indefinitely.

Dispersion. The flow of groundwater will eventually remove the oil, but even in the most productive aquifers groundwater velocity is measured in centimetres per day, and at this rate contamination may persist for decades.

> "A small spill which occurred in one Manitoba community five or six years ago still contaminates nearby domestic wells. Other examples outside the province have been quoted of contamination which still persists after 20 and 70 years". Clean Environment Commission, 1976.

The concentration of petroleum product in the groundwater will not remain constant. When the water table is high after a wet period the water may pick up hydrocarbons from the oil film on soil particles, at other times

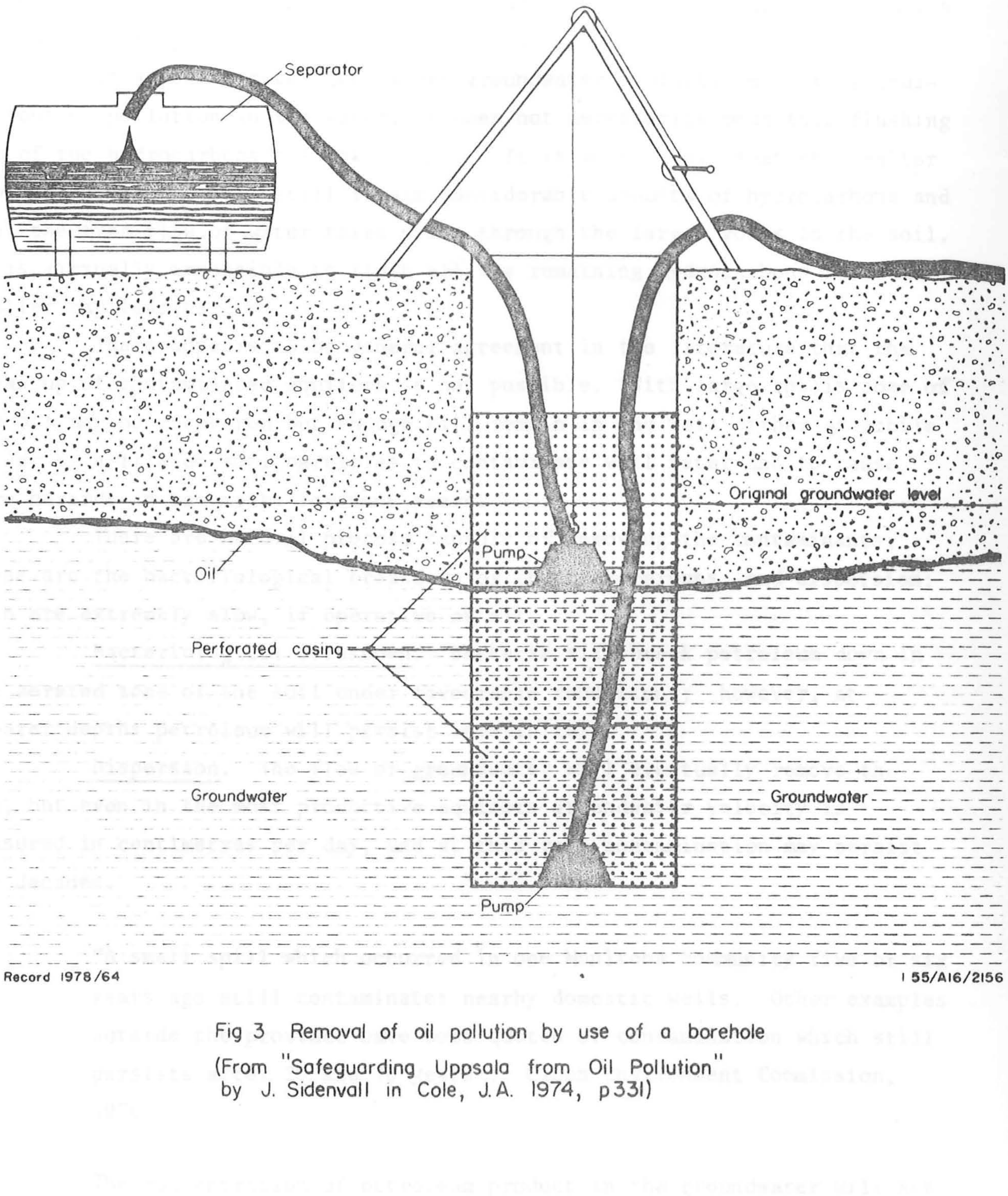


Fig 3 Removal of oil pollution by use of a borehole
(From "Safeguarding Uppsala from Oil Pollution"
by J. Sidenvall in Cole, J.A. 1974, p331)

the supply of dissolved hydrocarbons may be less. Contamination may in time spread to areas that previously were free from it; however, the process may take years because of the slowness of groundwater movement.

Use of chemical dispersants

The petroleum industry has used many compounds for flushing hydrocarbons from well fields to provide increased productivity. Similar compounds are used in the clean up of oil tanker spills at sea, and are known as chemical dispersants. It is considered likely that the controlled use of chemical dispersants could assist in the removal of hydrocarbons from the capillary fringe zone, which must be regarded as a major source of hydrocarbon fumes whilst it remains intact. Any such use should be carefully planned and carried out and the results should be closely monitored.

Pumping of groundwater as a method of removal of contamination

The principal removal techniques have included skimming techniques in which small jet pumps were placed very near the surface of the water to remove the free gasoline layer from the top of the water surface. The skimming wells pump into separator tank assemblies located in the area. These separators consist of density stratification tanks coupled to a larger baffled tank where flotation and skimming, along with aeration in the water progressively separate the gas-water mixture (see Figure 3). Whilst this technique may remove most of the free hydrocarbons until the wells no longer show any measurable hydrocarbons, residual hydrocarbons that cannot be flushed out with water still remain in the ground. The difference between the volume of the original hydrocarbon spill and the smaller amount recovered by pumping represents residual hydrocarbons in the ground.

Another pumping method for control of contamination plumes that has been proposed is that the direction of the flow of groundwater be changed by intensive pumping from wells drilled specifically for this purpose. In this way it might be possible to divert the flow of contaminants away from a particular location. There are certain unknowns about diverting a contamination plume; whilst the diversion may be successful, another area may become contaminated, and a comprehensive groundwater study should be undertaken before such measures are implemented, and their control must be assured.

Complete removal of hydrocarbons can only be achieved by removal of all the contaminated soil and rock. In some places emergency procedures are established for that purpose where it is necessary to ensure that the water supply aquifers below do not become contaminated.

CONCLUSIONS

1. The extent of ground pollution above the water table depends on the mobility of the hydrocarbons involved and the permeability of the ground formations. Light fractions travel further than heavy fractions and clays are less permeable than sands and gravels.

2. Hydrocarbon pollution will reach the water table either by a rise in the water table or by the flushing action of infiltrating water after rainfall.

3. Migration of hydrocarbons in contact with groundwater is controlled by the gradient of the water table, the permeability of the ground formations, and the modifications to the hydrological system caused by urban development, such as the construction of underground services, basement excavations and pumping installations.

4. Partial removal only of hydrocarbons can be obtained by pumping from the top of the water table, and can be expected to reduce the threat of pollution to adjoining areas.

5. Hydrocarbons retained in the capillary zone underground cannot be removed by short-term remedial action. Only flushing for long periods of time and the long term action of bacteria will reduce the extent of the contamination although it seems likely that the use of chemical dispersants may assist the flushing process in some of the more permeable aquifers.

6. The costs of remedial measures necessary to try to eliminate contamination of this nature are considered to far outweigh the relatively low costs of preventive measures for the handling and storage of hydrocarbons.

REFERENCES

CLEAN ENVIRONMENT COMMISSION, 1976 - Preliminary report on contamination of underground water sources by refined petroleum products. GROUND WATER V14, 1, p36-44.

COLE, J.A. (Editor) 1974 - Groundwater pollution in Europe, Proceedings of a conference.

HALL, P.L. and H. QUAM, 1976 - Countermeasures to control oil spills in Western Canada, GROUND WATER V14, 3, p163-169.

HEPPLE, P., 1971 - Water Pollution by Oil. Proceedings of a Seminar held at Aviemore, Scotland May 1970 (edited by P. Hepple). The Institute of Petroleum, Elsevier.

HOLZER, T.L., 1976 - Application of ground-water flow theory to a subsurface oil spill. GROUND WATER V14, 3, p138-145.

MATIS, J.R., 1971 - Petroleum contamination of ground water in Maryland. GROUND WATER, V9, 6, p57-61.

MELBOURNE, G., 1975 - Canberra Water Supply, Corrosivity survey of Googong pipe line route, ACT. Department of Construction, Central Testing and Research Laboratories Report. (Unpubl.).

OSGOOD, J.O., 1974 - Hydrocarbon dispersion in ground water: Significance and characteristics. Ground Water, V12, 6, p427-436.

SIMMONDS, M.A., 1965 - Underground corrosion. Proceedings of the Symposium on soft ground engineering, Australian National Society of Soil Mechanics and Foundation Engineering, Brisbane, 1965.

WILLIAMS, D.E. and WILDER, D.G., 1971 - Gasoline pollution of a ground-water reservoir - A case history, GROUND WATER, V9, 6, p50-54.