DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

METHODS OF OBTAINING GROUNDWATER QUALITY DATA

by

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ABSTRACT

A review of case histories of groundwater pollution investigations, mainly in the United States has highlighted some important points that must be considered when sampling groundwater and interpreting the results. Resistivity and drilling methods are most commonly used to delineate contaminated groundwater zones. Before either is utilized, a thorough appraisal of existing hydrogeological data, contaminate behaviour, and water supply locations should be made. Drilling and sampling should focus on the 3 dimensional nature of contamination zones or enclaves so as to determine the true waste migration pattern. Results should be interpreted bearing in mind cyclic changes in groundwater quality which could result from aquifer inhomogeneities or recharge effected pulses moving down to the water table. Sampling frequencies need to be logarithmic with time during single samplings and spaced at monthly to 3 monthly intervals in order to detect such changes; some existing water quality data may therefore be of limited use in this light.

Sample collection and analyses should be carried out by personnel with a background in laboratory analytical techniques.

INTRODUCTION

This report arose from a review of groundwater pollution in south eastern South Australia by members of a subcommittee of the South East Water Resources Investigation Committee (S.E.W.R.I.C.). The two authors were responsible for the geological input and in writing such, undertook a review of groundwater sampling procedures. Most articles cited in the text appear in the periodical "Groundwater", this journal being an excellent source for practical and easily readible material on the subject. The report gives some guidelines for the setting up and operation of a groundwater pollution monitoring programme and it is suggested that it, or the cited references, be consulted to ensure any such programme has been correctly planned so as to elucidate the true hydrogeological situation. Topics covered include: selection of monitoring sites, drilling techniques, drill hole completion, sampling procedures, and problems in interpretation of results. The actual handling and analysis of the samples is not covered as this is the theme of a separate report to be produced by the State Water Pollution Control Laboratories, Bolivar. It is emphasized that any pollution monitoring investigation is an interdisciplinary effort, and resources from Engineering and Water Supply, Agriculture and Fisheries, and Mines and Energy Departments should be utilized, along with those from other relevant government or educational institutions.

SELECTION OF MONITORING SITES

The most critical factor here is the means of disposal of the potential pollutant. The most common methods employed at present are: wells (eventually to be phased out except for storm runoff and some household septic waste), evaporation ponds, and land disposal of effluent through irrigation schemes. The following factors should be considered when selecting sites:

1. Pertinent features of the hydrogeological framework (mostly after Le Grand, 1965 and 1968)

   a) soil type, thickness, properties

   b) geology of unsaturated and saturated zones

   c) comparison of well hydrographs from existing records; similarity of shape (ie. response to recharge) can indicate a degree of uniformity of strata between existing wells (Pfannkuch & Labno, 1976) providing there are no discharging or recharging sites in the vicinity.

d) infiltration or recharge (both magnitude and frequency). Recharge can result in cyclic fluctuations of groundwater quality and is best monitored by using a series of closely spaced wells, each of which is screened opposite a small part of the aquifer and withdraws water from only that limited section (Pettyjohn, 1977).

e) establishment of a flow net or flow net analysis to determine flow directions on a regional and local scale, presence of anisotropy and preferred pathways (conduits, fractures etc.). In addition - consider the effect on local flow directions of large volumes discharged to the aquifer either sporadically or continually.

f) rates of flow in horizontal and vertical directions (from soil to and within aquifer).

2. <u>Characteristics of the particular contaminants as to attenuation and movement in the subsurface environment</u>

Such processes affecting attenuation include dispersion, dilution, decay, sorption, ion exchange, oxidation, miscibility, density contrast between contaminant and native groundwater (ie. more dense material eventually sinks toward base of the aquifer and lighter material may build up in the unsaturated zone), reduction, organic uptake and release, bacterial assimilation and physical filtration (see Apgar and Langmuir, 1971). These processes will all slow movement to and through the saturated zone. Of particular importance here is movement of bacteria and viruses through porous media. Romero (1970) summarizes known detail on the subject and concludes the following (see also Fig. 1):

a) bacteria and viruses travel down gradient except where pumping and local recharge may influence the hydrologic system.

b) all appear to be removed by the aquifer in the same manner as coliforms, the rate being a function of filtering proporties of the aquifer; this rate is not dependant on the rate of pollutant recharge but on distance only, and grain size.

c) aquifer materials best suited for the removal of biological contaminants are those uniformly composed of fine to very fine sand with a high clay content. For such an aquifer system, the maximum length of travel of biological pollutants with groundwater ranges between 15 and 30 m.

d) maximum lengths of travel in nonsaturated systems is only about 3 m. However, bacteria and/or virus infested pollutants might travel much further than predicted if nutrient laden waters are intercepted during the course of infiltration.

e) bacteria and viruses may survive up to 5 years under favourable conditions.

In contrast to the above, in aquifers where conduit flow prevails e.g. karstic or fractured rocks, filtration is many orders of magnitude less and distances travelled by viruses, etc., may be up to 100-200 m in a matter of days or weeks (Allen and Morrison, 1973).

If virtually no detail in 1) above is known it may be difficult to predict what attenuation might occur to contaminants beneath a particular site. In this case it is safer to assume uninterrupted movement along with rainfall or ponded water to the watertable.

3. Approximate geometry of the contaminated and uncontaminated zones

Under normal conditions (ie. with no influential discharge or recharge points) the contamination zone (plume, enclave - see Palmquist and Sendlein, 1975) is elongated in the direction of local groundwater flow (Fig. 2). Attenuation may produce bifurcation of the plume (Childs et al., 1974 and Fig. 3) but, in general, contamination masses retain their tongue shape as they move through the aquifer since laminar flow conditions persist (except in fissured rocks where flow may be turbulent) and there are generally sufficient differences in specific gravity, temperature and viscosity between them and native groundwater to prevent large scale dispersion (Pettyjohn, 1976). Provision should thus be made for more than one depth interval to be measured at some selected sites using multiple depth wells or 2 or more completed at different depths at the same site.

Surface resistivity techniques have been successfully used in delineating zones of groundwater contamination and should be considered before a drilling programme. Some groundwater samples are needed though for correlation purposes. Case histories are described in Stollar and Roux (1975), Kelly (1976a) and Berk and Yare (1977) and limitations discussed in Klefstad et al.,(1975). Ideal conditions are as follows (Stollar and Roux, op. cit.):

a) depth of groundwater generally less than 15 m or thickness of unsaturated sediments may mask any resistivity contrasts.

b) there must be significant contrast between natural groundwater and contaminated groundwater resistivity. Contrast should be at least greater than a factor of 2.

c) the geology and soil profile below the investigation site be reasonably uniform or contrasts due to lithological variation will mask contrasts due to groundwater specific conductance (equated with conductivity) variation.

d) the investigation site be relatively free of manmade obstructions - these can hinder positioning of single or multi-depth measurements

Fig. 4 shows results of an effective resistivity survey delineating contaminated groundwater beneath and down gradient from a waste disposal site. Here and at other sites drilling costs have been drastically reduced when compared to those of drilling programmes which rely on grid systems to delineate the contamination zones (Berk and Yare, 1977).

4. Manmade contingencies causing movement of contaminated water whether from pumping wells, disposal of wastes or accidents which could cause contamination.
5. The potential for advancement of a contaminated front toward existing and potential water supplies.

DRILLING PROCEDURES

Unsaturated Zone

Coring is preferred here so that laboratory determinations of physical parameters can be made. Soil and unsaturated zone moisture can be extracted and analysed. Recommended rigs are truck mounted continuous coring augers or the cable tool rig using 100 mm drive tube sampling equipment. Drive coring has been used by Young et.al. (1976) and Childs et al. (1974) for prediction of nitrate build up and sampling of variable waste migration patterns in groundwater.

For future sampling after well completion, suction lysimeters can be used (Apgar and Langmuir, 1971 and Jury et al., 1976). The former authors installed these at varying depths and up to three in each well, the intervening intervals being grouted to obtain a good seal (see Fig. 5).

In some instances techniques have been used other than drilling. For instance Foster and Crease (1974) obtained pore water from blocks of material carefully removed from trenches dug rapidly by a mechanical excavator to depths of 4 m. Pore water samples were extracted from the blocks after crushing to a paste. They note this method may not be ideal and might lead to underestimates if water is not fully recovered from the smallest pores but this is a factor common to any core sample or grab sample.

Saturated Zone

Both percussion and rotary drilling techniques have been used for such obervation wells. Percussion is preferred in Karstic areas where large cavities can produce circulation loss. Additionally, by running casing just behind the drilling bit, a preliminary idea of stratification of salinity can be gained (alternatively, a water quality profile through an aquifer can be obtained by drilling to the first sampling horizon, screening and gravel packing adjacent to that horizon and pumping - withdrawing everything and drilling on to the next sampling horizon etc. as in Yare, 1975 - see later). The first well or two should be drilled near or at the source of the contamination and to some depth to establish vertical bounds of the plume (if it exists). The 3D aspect of the plume is very important if build up rates are to be determined. The depth of subsequent wells can then be based on the findings of these initial wells.

WELL COMPLETION

General requirements are as follows;

a) wells should not allow direct access of any fluids (e.g. irrigated effluent) to the water table, ie. the well head should have a water tight seal and the annulus between casing and hole should be adequately grouted where possible to the water table (cavernous limestone may prevent this). A typical completion plan is shown on Fig. 6.

b) materials used in contruction should be chemically inert (if practicable) so that sensitive subsurface conditions are not unduly perturbed e.g. ABS casing, stainless steel screens etc.

c) the wells should have the facility to be either pumped or take an "in situ" sampling device (see later).

d) where wells are completed to sample at the water table, screens (or casing if consolidated) should coincide with the maximum height of the water table (ie. full recovery value - spring). This should allow relatively undisturbed flow (especially stratified fluid) through the well and hence into any "in situ" sampling device. This applies only to those pollutants which remain at or near the water table.

e) wells should be fully developed

f) wells should not be sited where local ponding of surface runoff (e.g. rainfall or irrigated effluent) is likely to occur unless the top of casing is left well above the expected ponding level.

g) the completed headworks, as well as being water tight, should enable easy access for both water level measurement and sampling.

Unconsolidated Material

The most common well completion practice used in pollution monitoring projects in the U.S. is to screen the interval to be tested (Pettyjohn, 1976; Yare, 1974; Everett et al., 1976). Gravel packing is often used in conjunction to ensure clean sampling and faster development. To detect any variation of water quality with depth a number of wells at one site may be completed at varying depths with 1-2 m screens and one well may be completed over the whole depth interval with a screen of appropriate length, (e.g. Kimmel and Braids, 1974 and Pettyjohn, op. cit.). This latter completion practice gives a sample representative of the whole of the aquifer interval e.g. one that would be obtained if the well were used for water supply.

Consolidated Material

If drilling conditions indicate the aquifer to be well cemented the hole may be left open from the water table. Adequate groundwater flow through the well is then possible and in situ sampling may be carried out at selected depths. Such wells should be at least 200-250 mm diameter to allow for safe withdrawal of a 100 mm diameter submersible pump (currently in use) if required for sampling.

SAMPLING TECHNIQUES

(General only - no regard given to specific pollutants)

One of the basic problems in groundwater pollution monitoring is to obtain samples representative of conditions within the aquifer, especially where stratification is suspected (as is often the case). There are many techniques for sampling wells. These and their advantages and disadvantages are discussed below. In all cases the interval sampled should be open to the aquifer, preferably screened.

a) Pumping Wells

1) with airlift techniques (eg. Trescott and Pinder, 1976). Airlifting has the advantage that small diameter wells can be sampled. Rates up to 700 kl/day (7,000 gph) can be achieved.

However, such a process may significantly alter the chemical composition of the groundwater through aeration (eg. iron) and additionally give a mixed sample of at least 10 - 30 m of aquifer. A recent modification of the airlift method is the GASLIFT SAMPLE using PROPANE as the energy source. (See Johnson Drillers Journal July-August 1976).

2) using a vacuum pump (for small diameter piezometers) - see Everett et al., 1976 and Childs et al., 1974. Here, a length of plastic tubing sufficient to extend to the water table is inserted into the well, upper end terminating in a collector flask. A second line from the flask is connected to a hand held vacuum pump. When the pump evacuates the flask and tubing water is forced into the flask. According to Everett et al., 1976, this system is capable of sampling water to a depth of 7.4 m. The small sample size and shallow operational depth may limit the use of this sampling tool in most investigations.

3) using portable submersible or centrifugal pumps (eg. McMillan and Keeley, 1968 and unit used by Dept. Mines and Energy). Again, these techniques upset equilibrium conditions in the well. Sampling at different depths may be carried out by varying the inlet depth providing the well is open to each interval opposite the inlet. In addition, centrifugal pumps are limited to depths less than 8 m and most submersible pumps are limited to well diameters greater than 125 mm.

4) drilling and sampling alternately (eg. Yare, 1975 - see earlier). In more detail, the principle involved here is to drill a well to the sampling horizon, screen and gravel pack adjacent to the horizon, pump till water level stabilizes

and then collect sample after at least 500 litres of formation water passes through the outlet. The same procedure is repeated after drilling on say another 5 m etc. This process is expensive and it can only be carried out once at each sampling level in each well. In addition, smaller scale stratification (ie. less than 5 m) cannot be detected as complete mixing over the sampling interval occurs. It should be realized however, that this technique and those outlined in 1) and 3) above give a sample representative of that which should be obtained if the wells were to be used for water productive purposes.

5) installing permanent pumping equipment eg. small diameter lineshaft Mono pumps.

b) <u>Bailing Wells</u>

This can be carried out on existing wells where a sample may be collected only at the surface. Providing the well is sealed off from surface contamination ie. cemented as outlined in well completion notes, a small bailer used very carefully could sample the top few centimeters of the water table. The zone of water table fluctuation in such wells should be screened to prevent aquifer collapse.

Where new wells are drilled samples at the water table may be collected in a similar way providing that air circulation is used down to the water table depth (ie. augering is probably the most practical technique).

It should be remembered that bailing can only be used to give samples representative of the top 0.8 m or so of the aquifer, although Kelly (1976b) sampled wells with a bailer by removing the equivalent well volume before retaining a sample for analysis.

He did recognize the inherent problems with this techniques and took the volume withdrawn and time of sampling into account.

c) Selective Depth Sampling

1) on the spot

Such a method involves use of a sampler which is lowered to the selected depth allowing free passage of water through the device, then closed at the required depth and withdrawn for decanting. Such a sampling unit is described by Tate (1973) and Foster and Crease (1974) who used an electro-magnetically operated sampler to skim the water table and for sampling at greater depth intervals in each observation well. A basic device is used at present by the Dept. of Mines. Well diameter limits the interval which can be sampled. Samplers of 130 mm diameter and 100 mm length give about 1.2 litres at a time. Again, after one sampling, the conditions in the well are disturbed and further sampling may not yield a reliable result.

2) in situ

Spalding et al., (1976) describes a device which allows sampling at any particular interval within an existing well (provided it is open at that interval - see Fig. 7). The unit is set in place at the interval required and left for about 2 to 4 weeks to allow horizontal flow through the device. At the end of this period, a messenger is sent down the supporting wire, triggering the sample trapping mechanism. When this is achieved, the sample can be with-drawn, decanted and the device returned to its position in the well. In the majority of South East aquifers, turn over time should be within one month so sampling frequency could be fortnightly. The only disadvantage this method has is that fluctuations of the water table level could give unreliable results.

Such a device of slightly larger dimensions has been constructed by E. & W.S. Mt. Gambier and should be in in use in the South East in the near future.

SAMPLING FREQUENCY

A thorough understanding of the hydrogeologic detail of each monitoring site must be achieved if correct interpretation of water quality data is required. It should be realized that variation in water quality can occur during pumping or in the interval between sampling periods - the magnitude of variation dependant upon local conditions.

a) Variations During Pumping

This may result from the following (Schmidt, 1977)

1) inhomogenity within the aquifer due to variation in permeability. Recharging or discharging boundaries will allow variable pollutant concentrations to enter the pumping well (see Fig. 8a).
2) head loss effects where the contamination is stratified within the aquifer. Initial samples may contain higher concentrations which may diminish with time. Since head loss is logarithmic with respect to time Everett et. al., 1976 suggest sampling times be also logarithmic ie. 6 secs., 1 min., 10 mins., 100 mins., after start.
3) pump rate variation. Large capacity irrigation wells yield samples more representative of regional aquifer conditions. These are more likely to show regional contamination from fertilizer application, return irrigation flow, canal recharge, etc. At the other end of the scale, small capacity pumps (eg. portable submersible pumps) give samples representative of local aquifer conditions, which may be influenced by garden watering, septic tanks, small rubbish pits and contamination with in the well column (Everett et. al., 1976).

4) changing fluid pressures in the aquifer which may thereby change partial pressures of dissolved gases and modify solute concentrations (see Kunkle and Shade, 1976).

b) Variation Between Sampling Periods

Here the idea of recharge pulses of contaminated water moving down to the saturated zone is most important and so also is the recharge mechanism which is dependent on the following factors: (Childs et. al., 1974 and Fig. 8b; Pettyjohn, 1976 and Fig. 9)

1) rainfall duration and intensity
2) surrounding land use
3) seasonal conditions
4) soil moisture
5) physical characteristics of the unsaturated zone
6) loading rate at the pollutant source
7) proximity of other waste sites
8) bank storage from streams and lakes

Sampling periods may therefore vary from one week to say three or six months, at a bare minimum in zones where active contamination is suspected.

It is easily seen that samples taken without regard to a) and b) above could give complete misunderstanding of the true situation. Some previous work may be of limited value in this light. Additionally, anomolous values previously obtained should not be disregarded as they may reveal some important clues to the behaviour of the contaminant.

After each sampling and assessment of results, a review of sampling with both (a) and (b) above in mind should be carried out to eliminate accrual of unnecessary data.

CONCLUSIONS

This review highlights the need for careful planning of any groundwater pollution monitoring programme. A thorough examination of existing knowledge of site hydrogeology and contaminate properties should be made before any geophysical or drilling investigations are undertaken. Seismic and resistivity surveys should be utilized to delineate subsurface geology and contaminant spread where practical. Drilling programmes should incorporate coring to the water table then careful groundwater sampling with depth through the aquifer. Monitoring wells should be constructed with prevention of downhole leakage the prime consideration - especially in and around waste disposal sites. Aquifer intervals should be screened or if well consolidated, left open to allow unimpeded groundwater flow through the well. Recommended sampling devices are selective depth or in situ types or submersible pumps. Bailing with conventional bailers can only give results representative of the top portion of the aquifer. Sampling practice should allow for both short and long period fluctuation caused by aquifer inhomogenity, recharge events etc. Pump samples should therefore be taken at logarithmic intervals e.g. 20 sec., 3 mins., 30 mins. etc., and sampling periods should be about 1 to 3 months apart.

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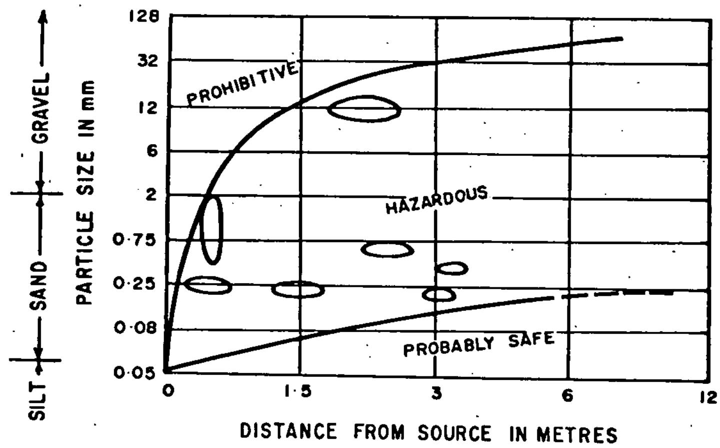
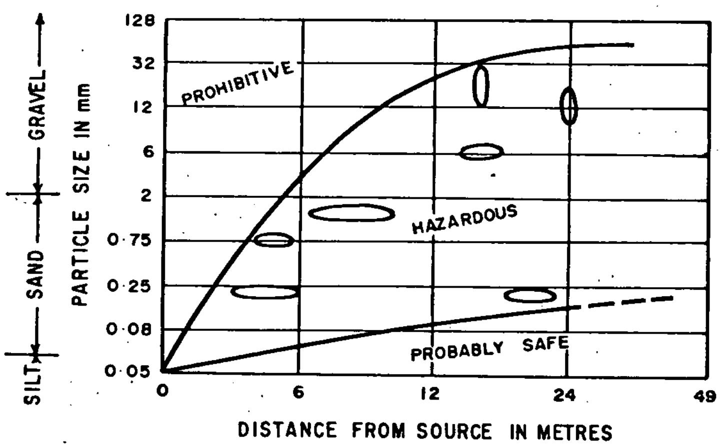


a. Biological pollution travel in non-saturated materials (after FIG. 2 of Romero, 1970.



b. Biological pollution travel with groundwater (after FIG. 3 of Romero, 1970.

ZONE DEFINITIONS (Romero, 1970 page 44)

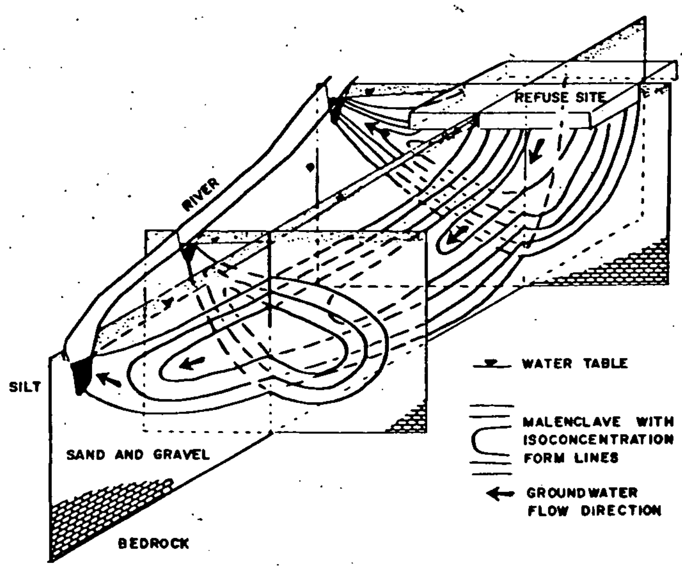
1. PROHIBITIVE ZONE - those regions of particular size with respect to distance from a source of pollution that a domestic well should not be constructed.

2. HAZARDOUS ZONE - envelopes the region for which examined case histories are well documented. It illustrates the zone or distance biological pollutants are known to have travelled in a medium of given particle size. The lowermost line of the hazarous zone are based on maximum lengths of travel.

3. PROBABLY SAFE ZONE - represents those regions of particle size with respect to distance from a source of pollution that a domestic well can probably be constructed in reasonable saftey.

FIG. 1

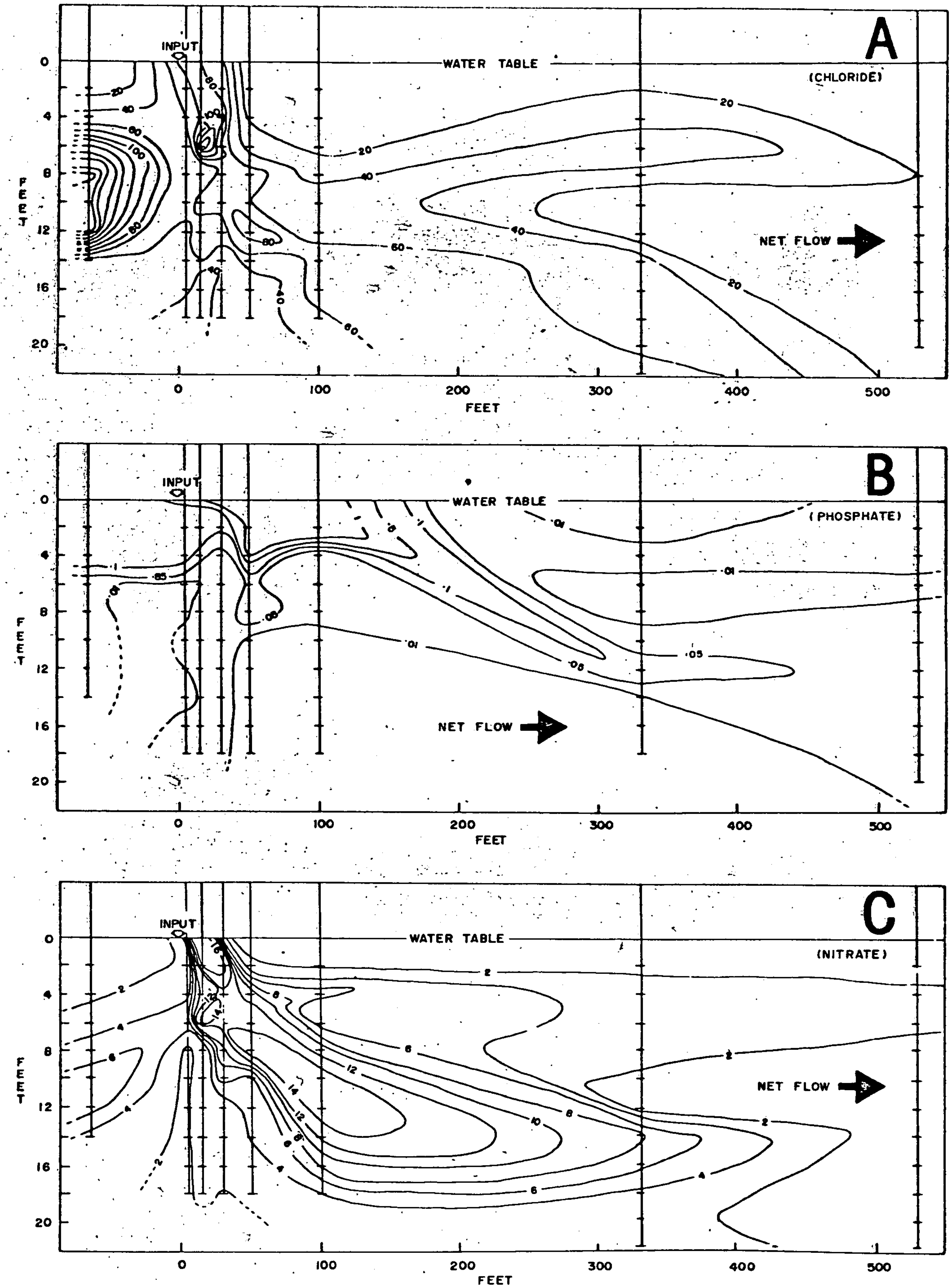
	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE:
COMPILED A.F. Williams	METHODS OF OBTAINING GROUNDWATER QUALITY DATA BIOLOGICAL POLLUTION TRAVEL IN NONSATURATED MATERIALS AND WITH GROUNDWATER	DATE: August 1978
DRN: L.P.R. CKD:		PLAN NUMBER S13492



After FIG. 9 of Palmquist and Sendlein, 1975

FIG. 2

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE:
COMPILED: A.F. Williams	IDEALIZED CONFIGURATION OF A CONTAMINATION ENCLAVE IN ALLUVIUM	DATE: August 1978
DRN: L.P.R. CKD:		PLAN NUMBER S13493

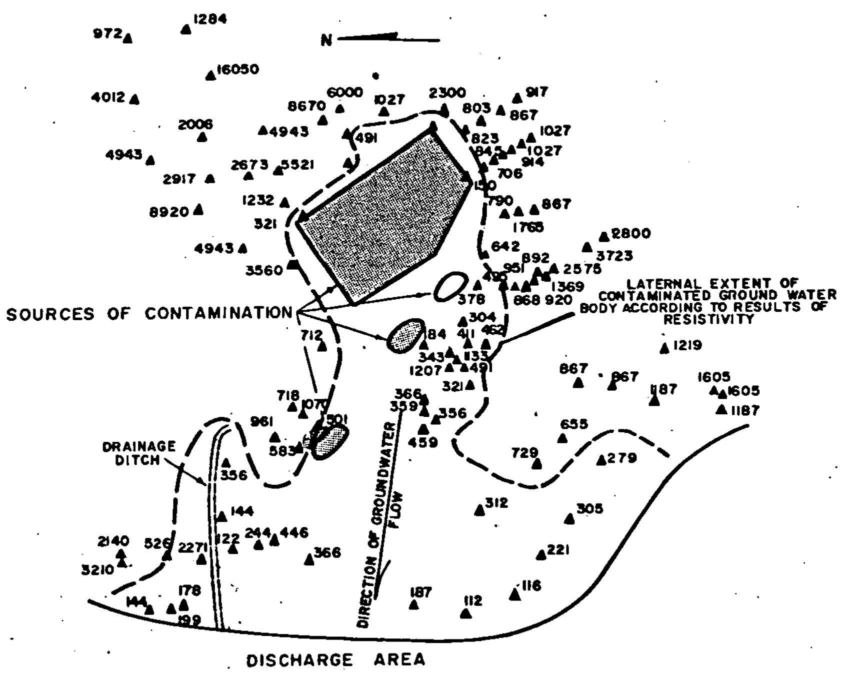


Cross sections of the waste plume at site I, about 1km. from Houghton Lake, Michigan. Contours are in parts per million. Bifurcation is obvious with all three chemical constituents. Adapted from FIG. 3 of Childs etal., 1974.

FIG. 3

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE:
COMPILED: A.F. Williams		DATE: August 1978
DRN: L.P.R. CKD:	BIFURCATION OF WASTE PLUMES	PLAN NUMBER S13494

Note - a. depth to W/T 0·3-5m.
(see text) b. specific conductance native G/W 150-400 µs/cm
specific conductance contaminated G/W 2000-6000 µs/cm
c. lithology as follows : clay in west to sand in east overlying clay from 6-12 m. in depth.
d. few man-made obstructions.

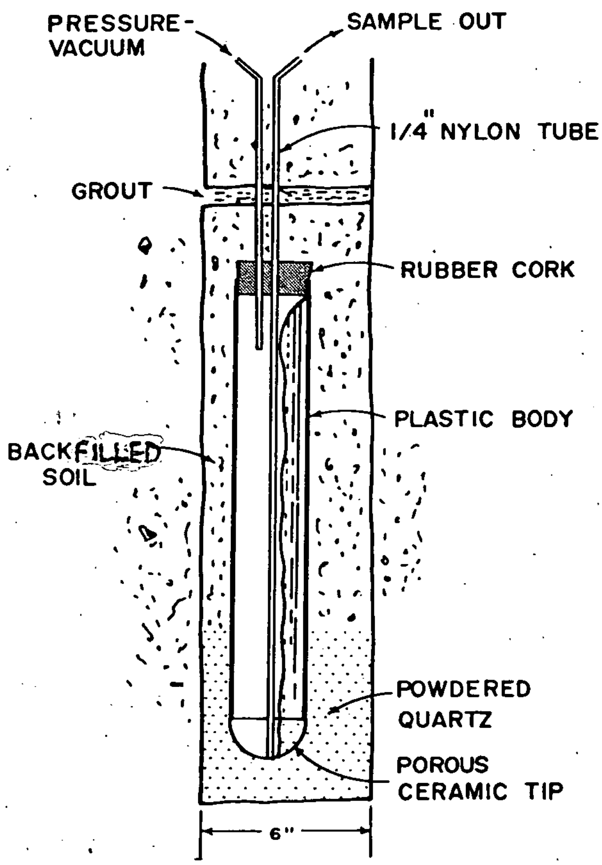


LEGEND
▲ Resistivity measurement point
Apparent resistivity in OHM - feet

Modified from FIG. I of Stollar and Roux, 1975

FIG. 4

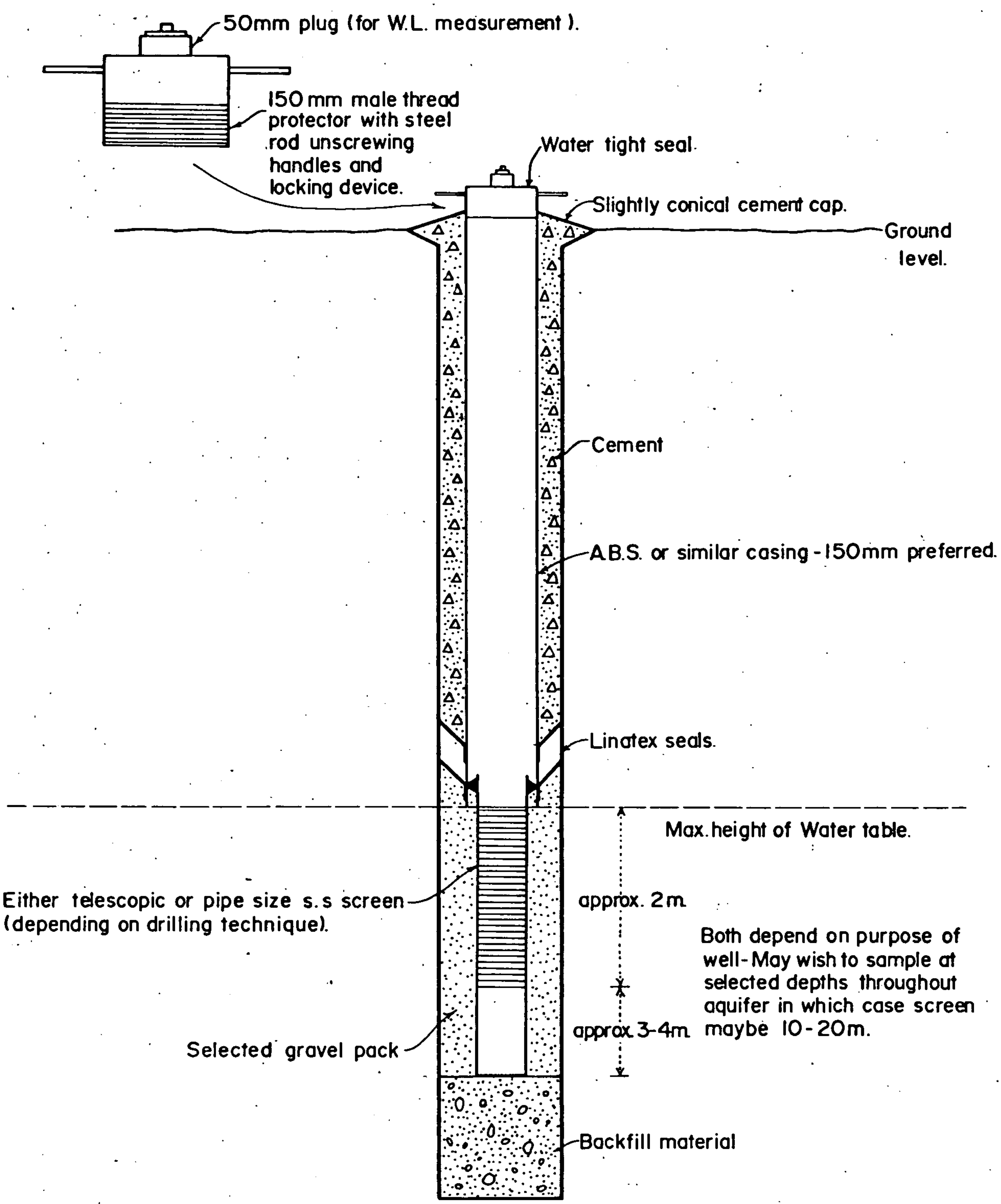
	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE: 1:1200
COMPILED: A.F. Williams	RESULTS OF A RESISTIVITY SURVEY TO DELINEATE A CONTAMINATED GROUND WATER ZONE	DATE: August 1978
DRN: L.P.R. CKD:		PLAN NUMBER S13495



Lysimeter modified after Parizek and Lane (1970)
-see Apgar and Langmuir, 1971 page 80.

FIG. 5

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE:
COMPILED: A.F. Williams	SUCTION LYSIMETER	DATE: August 1978
DRN: L.P.R. CKD:		PLAN NUMBER S13496

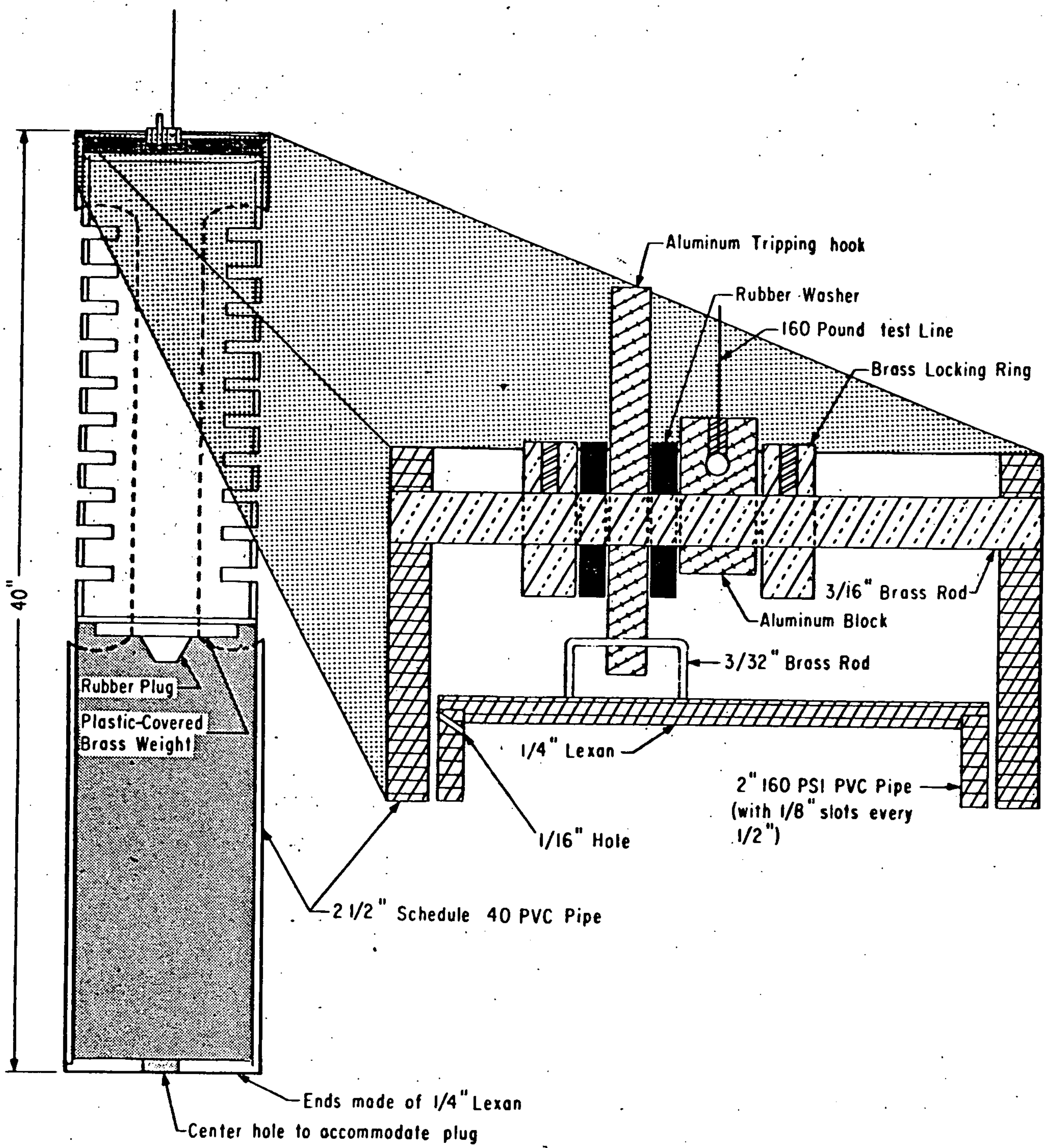


N.B. 1. Top of screen must coincide with predicted water table maximum elevation.

2. Linatex seals not applicable where hole is gravel packed.

FIG. 6

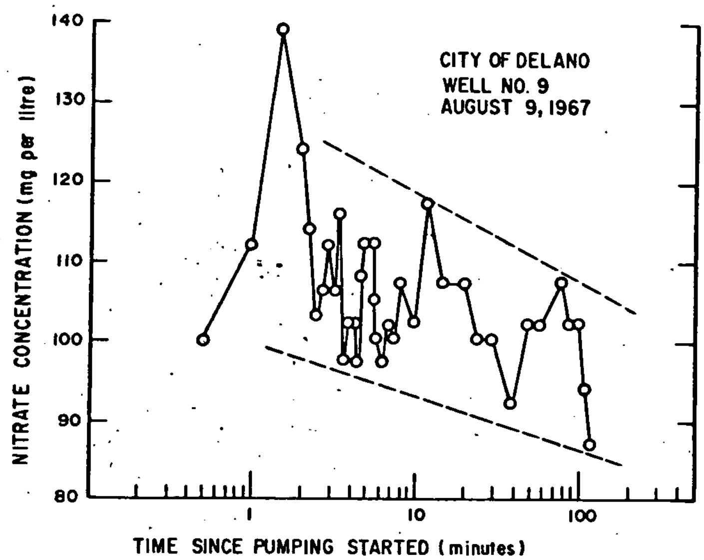
	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE: N.T.S.
COMPILED: P. Smith	LAND DISPOSAL OF EFFLUENT	DATE: July 1978
DRN: L.P.R. CKD:	PROPOSED OBSERVATION WELL COMPLETION	PLAN NUMBER S13497



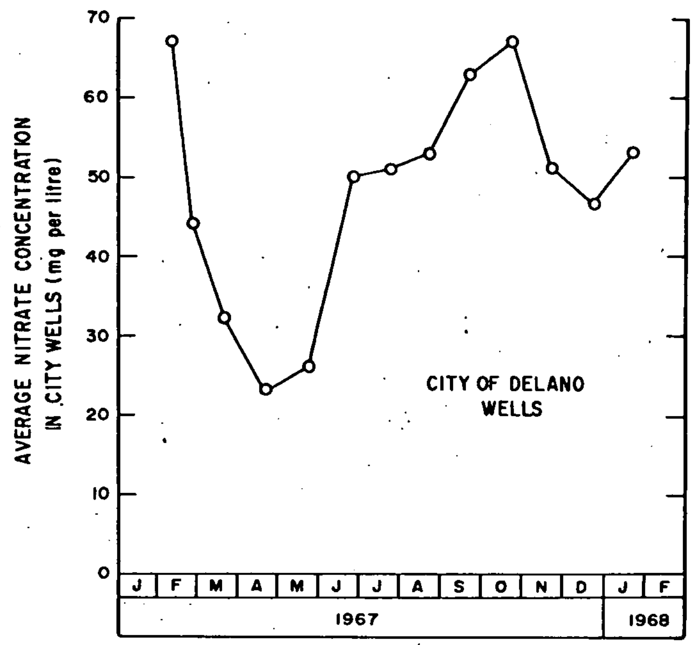
After Spaldinget, 1976. Water Resources Research Volume 12 No. 6 page 1320.

FIG. 7

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE:
COMPILED: A.F. Williams	IN SITU SAMPLING DEVICE	DATE: August 1978
DRN: L.P.R. CKD:		PLAN NUMBER S13498



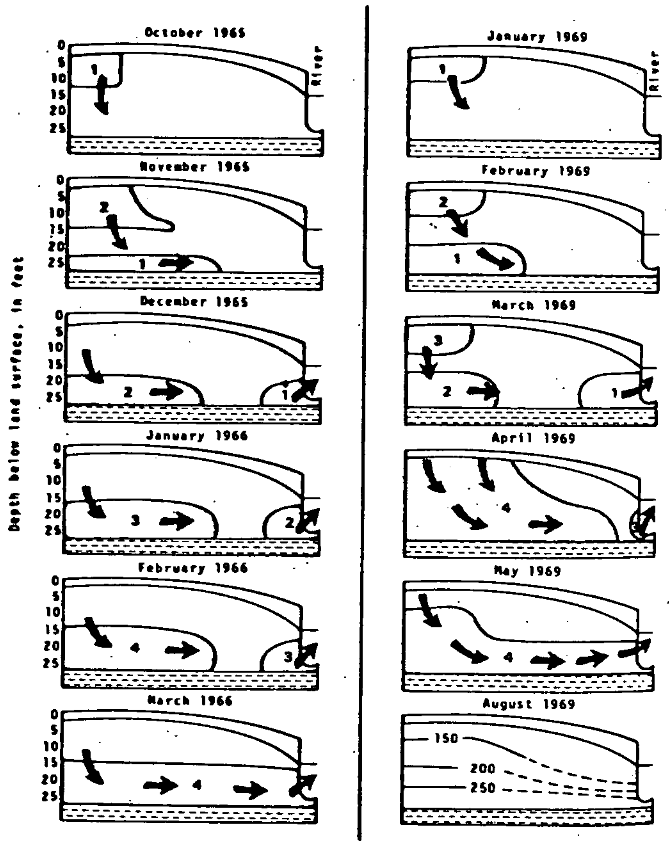
a. Nitrate contents during short-term pump test at Delano, California illustrating how say one sample taken after start of pumping could give a misleading result. After FIG. 2 in Schmidt, 1977.



b. Seasonal nitrate variations for municipal water supply wells at Delano, California. Variation thought to occur from high nitrate in water formerly above the water table being intercepted by groundwater during times of rising water levels. After FIG. 1 in Schmidt, 1977.

FIG. 8

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE:
COMPILED: A.F. Williams	WATER QUALITY VARIATION DURING PUMPING AND BETWEEN SAMPLING INTERVALS	DATE: July 1978
DRN: L.P.R. CKD:		PLAN NUMBER S13499



Schematic diagram showing the cyclic movement of masses of brine contaminated water through an aquifer during selected months in 1965, 1966 and 1969. Stippled areas for 1965-66 represent concentrations in excess of 20 000 mg/ℓ and for similiar cyclic events were recorded for 1970-75. Diagram after FIG. 7 of Pettyjohn, 1976. 1969 represent concentrations > 500mg/ℓ.

FIG. 9

	DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	SCALE:
COMPILED: A.F. Williams	CYCLIC MOVEMENT OF CONTAMINATED WATER THROUGH AN AQUIFER	DATE: August 1978
DRN: L.P.R. CKD:		PLAN NUMBER S13500