<論 文>

Environmental isotope aided studies on river water and ground water interaction in the Han River basin.

同位元素를 利用한 漢江流域의 地下水와 地表水의 연관성에 관한 연구

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Abstract

Recently river water pollution in Korea is given rise to serious problem in aspect of crop production, drinking well, water contamination and etc. Under these urgent situations, it is prime importance to protect water resources from pollutants.

An environmental isotope survey of the groundwater from the shallow alluvial and the underlying crystalline rock aquifer of the Han River Basin has been undertaken, Analysis of the data has i) confirmed the hypothesis that the groundwater from the metropolitan area is recharged from the river whereas that from the non-urbanized region of the Basin is replenished by the infiltrating precipitation; ii) shown that crystalline rock aquifers are recharged by the ground water from the overlying alluvium.

Old groundwater is a group of wells with tritium values in the range of 0 to 2 TU. These low values indicate that the water sampled was recharged much ealier, at least a few decades, than the other groundwater samples of higher tritium content. The low values in this region may, in fact, reflect the effect of the impermeable clay layers which impede infilteration from the surface.

Stable isotope evidence confirmed that a recharge in the karst area occurs at a significantly greater elevation than that to the alluvial aquifer. An analysis of the tritium level collected over an annual cycle suggests that the residence time of groundwater is probably not more than a few months. There does not appear to be any correlation between the trace level of Zn, Mn and Pb in the groundwater and the mechanism of the recharge.

要 約

近年에 이르러 國內 地表水의 오염 현상은 社會的으로 매우 심각한 문제를 야기시키고 있어 水資源의 보호문제가 매우 重要한 시점에 이르렀다.

漢江流域內에 발달 분포된 천층의 沖積 堆積層과 結晶質岩內에 저유된 지하수에 대해 同位元素를 利用한 환경조사를 시행하였으며 結果를 分析한 바 다음과 같은 가정을 확인하였다.

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1) 천층지하수의 함양원은 서울 도심지역은 하천수였고, 교외 외각의 농촌 지역은 강우의 직접 지하 침투에 의해 일어나고 있으며,

2) 충적 퇴적층으로 피복된 결정질 암은 상부충적퇴적층내에 저유된 천층 지하수가 충진원의 역활을 한다.

한강하류부의 해안 가까운 곳에 分布된 一部충적층과 그 下部의 결정질암내에 저유된 지하수는 H^3의 함량이 매우 낮은치를 나타내는데 이는 핵실험이전의 기상수가 상당히 먼곳에서 충진되었기 때문으로 시료된다.

안정동위원소 조사에 의하면 漢江上流에 分布된 석회암 대수층의 함양지역은 하류부의 충적층과는 달리 비교적 고지대였으며 석회암 대수층내에서 地下水의 체제 시간은 수개월 정도였다.

지하수의 포함된 극소량의 Pb, Mn, Zn 량과 충진메카니즘을 대비하려고 시도하였으나 명확한 관계가 나타나지 않았다.

1. INTRODUCTION

The Han River basin is the largest in south Korea with a catchment area (south of the demorcation line) of about 27 per cent of the area of South Korea. The average temperature in its down stream basin ranges from $-20°C$ in January to $+40°C$ between June and August. The mean annual rainfall is about 1230mm. The discharge from the river is about $20.9 \times 10^9 m^3$ which corresponds to a run-off coefficient of 64.8 per cent.

It is predicted that the water demand will exceed that available from the Han River by the turn of

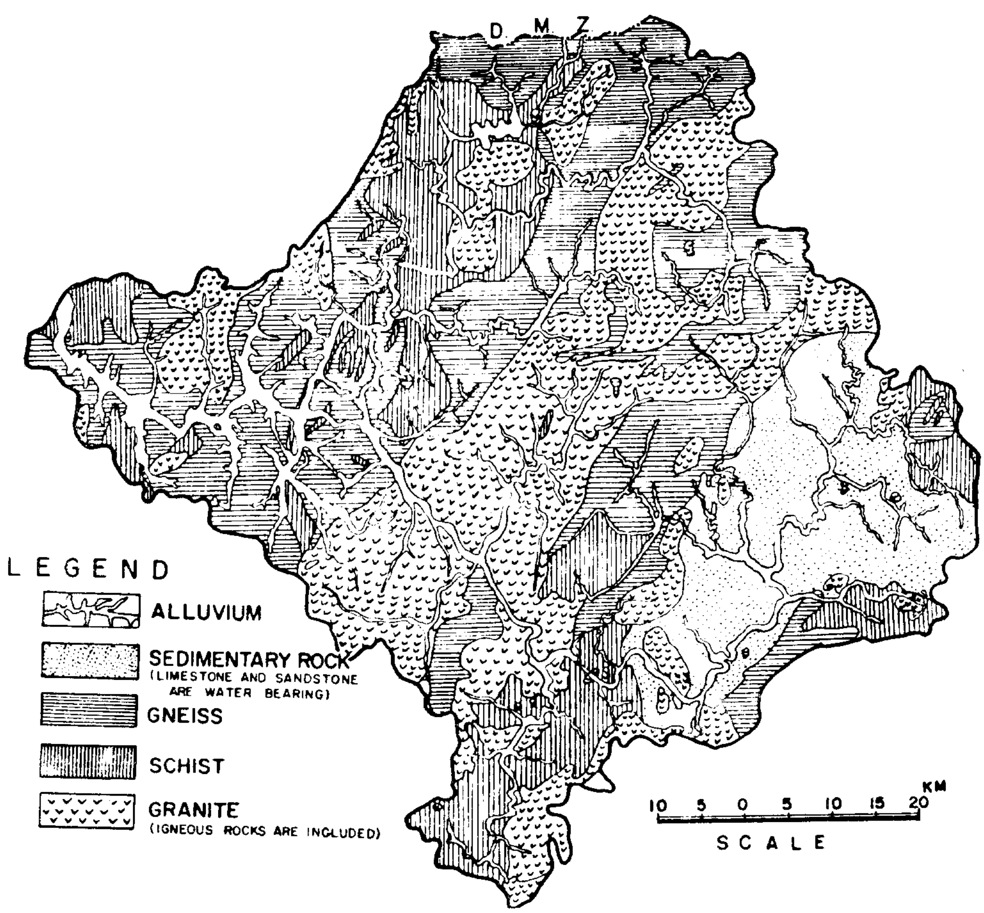

Figure 1. Generalized geologic map Han River basin Republic of Korea.

the century. By that time the groundwater demand is estimated to be $4.6 \times 10^9 m^3$ annually, which corresponds to 15 per cent of the annual rainfall on a little more than 1 per cent of the total storage (1-3). The distribution of groundwater in the various rock types of the valley is shown in Table 1 and Figure 1.

The aims of this paper are to apply environmental isotope techniques:

(i) to establish the mechanism of recharge to the shallow alluvial aquifer overlying the crystalline rock in the Han River Valley;

(ii) to investigate the interaction between the groundwater of the alluvial aquifer and of the crystalline rock;

(iii) to obtain some understanding of the dynamics of groundwater flow through the karst system

(iv) to seek evidence for a correlation between the source of groundwater and the observed levels of trace heavy metals.

The studies on Han River Valley are a part of IAEA regional co-operative program on Isotope Hydrology Project.

Analysis for deuterium were performed by AAEC, Australia (4), analysis for oxygen-18 were conducted by IAEA, Vienna, Austria (5) and tritium and chemical analysis were performed by KAERI, Seoul, Korea (6, 7).

Table 1. Groundwater in storage in rocks of the Han River Basin.

Geological classification		Area (kilometers square)	Percent of basin	Saturated thickness (meters)	Rock porosity (percent)	Storage per kilometer square ($m^3 \times 10^6$)	Volume stored by rock type ($m^3 \times 10^6$)
Crystalline rocks	Granite and other coarese-granitic intrusive rocks.	9,207	35.1	200	1	2	18,414
	Metamorphic rocks, mainly schist and gneiss	17,443	47.5	200	1	2	24,890
Sedimentary rocks	Limestone and sandstone (waterbearing), coal and other rocks (non-water bearing)	4,567	17.4	600	10	60	274,020
Total hard rocks of basin		26,219	100				
Alluvial deposits	Superimposed on all of the other bedrock types	6,822	26	8	25	2	13,644
Saprolite	Weathered rock material	19,000	72	10	40	4	76,000
Total groundwater storage in basin							406,068

2. GEOLOGICAL SETTING

Metamorphic rocks comprising schists, gneisses, quartzite and marble occupy an estimated 47.5 per cent of the basin. They extend across the basin in north-east-tending belts parallel to the trend of the major granite bodies and the major structures which control their occurrence. The rocks are fractured and weathered to depths of about 30 m. The quality of groundwater extracted from the metamorphic rocks is satisfactory for most purposes.

The sedimentary rocks comprising limestone, sandstone, and coal are of palaeozoic age. At different times in the geological past, solution topography was developed later to be buried by younger rocks. As a consequence, several of the limestone formations have cavernous and permeable zones which faciltate the storage and movement of large volumes of groundwater (Table 1). There are many high discharge springs in the area. Forty-nine have been measured with flows exceeding $1500 m^3 d^{-1}$; in one case the discharge exceeds $79000 m^3 d^{-1}$.

At different times the metamorphic and sedimentary rock have been intruded by granite and other igneous rocks and have been subject to folding and faulting. The granites cover about 35 per cent of the basin. They contain many fissures through which groundwater can circulate and are weathered to depths of as much as 30m. The weathered products make up much of the alluvium of the river valleys. That which remains in place is a permeable saprolite in which groundwater is stored (8).

3. ALLUVIAL AQUIFER—EFFECT OF URBANIZATION ON RECHARGE MECHANISM STABLF ISOTOPE RATIOS

To study the recharge mechanism, three major transects were established across the alluvial plain approximately normal to the Han River(Figure 2). Transect M intersected the metropolitan region of Seoul; transects U and D intersected largely agricultural regions upstream and downstream respectively.

Samples were collected in the spring, during the period from summer to autumn of 1980, the winter of 1981 and the summer of 1982. They were assayed for environmental tritium, stable isotope ratios and for trace heavy metals. Data have been tabulated in references (9).

The correlation between D* and 180* is adequately described by the local meteoric water line obtained from precipitation at Pohang, for many years, one of the IAEA monitoring stations (10). A frequency distribution of 180 values of all groundwater samples for spring to summer 1980, from autumn to winter, 1980/81 and summer 1982, are shown in Figures 3(a), (b) and (c) respectively. Wells in the metropolitan area are distinguished by cross-hatching; those in the agricutlural area upstream and downstream of the city are unshaded. In all cases the former are grouped and tend to be more depleted than the latter. Moreover, especially in the summer period, the stable isotope ratios in the metropolitan wells are correlated to the well with the values observed from river samples shown by partial shading. The stable isotopes in the precipitation over the valley would be expected to be more enriched than that of the river because of the elevation of the catchment.

The observations are consistent with the hypothesis that recharge to wells within the metropolitan area is dominated by the river, while that upstream and downstream of the city is largely from distributed precipitation. During the period of peak discharge in the summer the Han River flows over a very permeable sand and gravel bed some hundreds of metres in breadth. In addition, the water tables within the city would be lowered by a combination of reduced run-off and extensive pumpage. During the winter, the discharge is very low and little infiltration would occur.

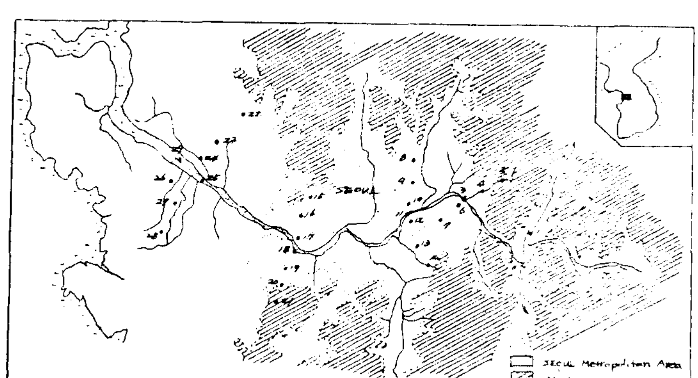

Figure 2. Location of sampling points, Han River Valley. Elevation above 100m are distinguished by line shading. The approximate boundaries of the Seoul metropolitan area are also shown.

* By definition,

$D = ((D/H)_{sample}/(D/H)_{V-SMOW} - 1) \times 1000$ permille

where V-SMOW is the Vienna-Standard Mean Ocean Water. 180 is defined similarly.

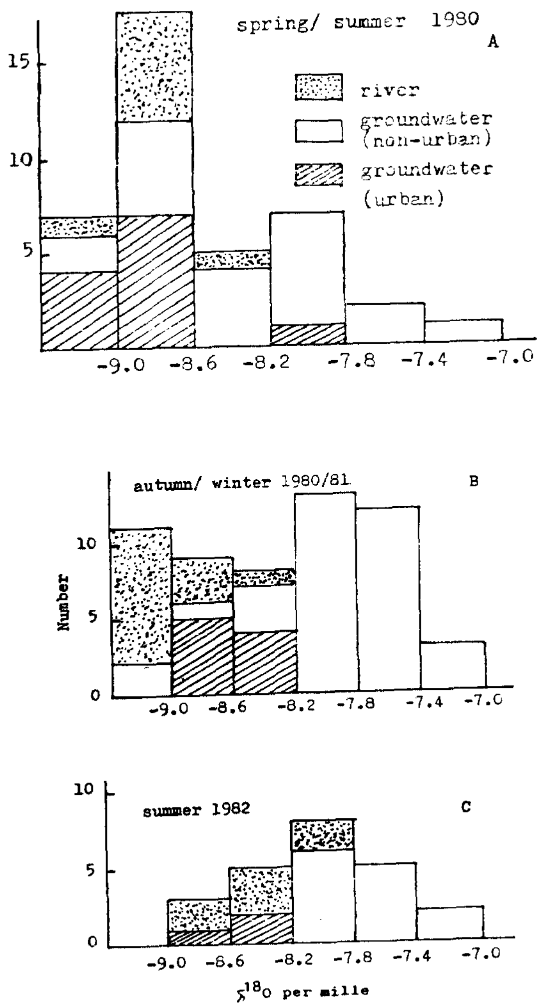

Figure 3. Frequency distribution of 180 values from groundwater and river samples. The location of the sampling points is shown in Figure 2. The three classes of samples are distinguished by shading.

Environmental Tritium

With the exception of some wells near the river coast (shown as 'old groundwater') in Figure 2, the tritium levels are generaly high. As a complete tabulation is available (9) a summary only will be presented in Table 2.

Table 2. Environmental Tritium Levels-Han River Valley[1)]

Sampling Period	Groundwater (metropolitan) (TU) [2)]	Groundwater[3)] (non-metropolitan) (TU)	River (TU)
Spring/ summer 1980	47.2±8[4)](10)[5)]	49.7±18(29)	36.5±4(12)
Autumn/ winter 1980/81	42.3±8 (9)	44.2±15(29)	36.0±5(13)
Summer 1982	40.2±10(6)	43.7±19(13)	34.4±4 (7)

(1) Sampling locations shown in Figure 2.
(2) By definition, 1 tritium unit (TU) is the ratio of one tritium atom per 10^{18} hydrogen atoms.
(3) Samples in the area of 'old groundwater' have been excluded.
(4) Standard deviation of the population.
(5) Number of samples

Two features of the tritium data deserve comment.

(i) In the are of Fig-2 the marked'Old groundwater is a group of wells with tritium values in therange of 0 to 2 TU. These low values indicate that the sampled water was recharged much ealier, at least a few decades than the other groundwater samples of higher tritium content. The low values in this region, may, in fact, reflect the effect of the clay layers which impede infiltration from the surface.

(ii) The tritium values in groundwater samples are consistently higher than those in the river water This could indicate that the sampled groundwater infiltrated some years previously when the average levels of tritium in global precipitation were somewhat higher than at present. However, some of the non-urban wells show a consistent seasonal variation (Figure 4). Such a variation would have been attenuated by dispersion if the water were a few years old. A possible explanation is associated with the fact that groundwater is generally stratified; the older groundwater of high tritium underlying the younger water of lower tritium levels. The seasonal variation could be associated with mixing accompanying the annual cycle of irrigation pumping.

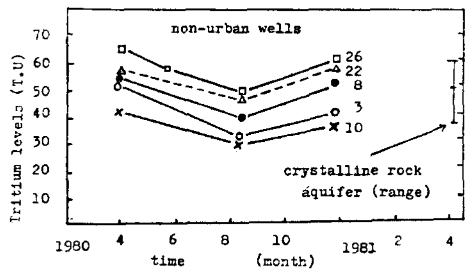

Figure 4A The variation with time of the tritium levels on the shallow alluvial ground water in the non-urban region. The range of tritium levels in the underlying crystalline rock aquifer in the equivalent non-urban region is also shown.

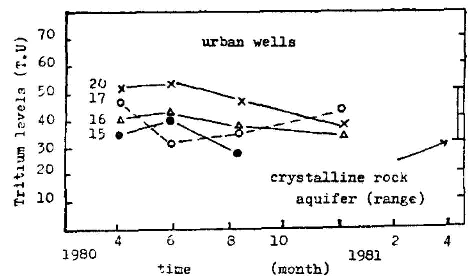

Figure 4B The variation with time of the tritium levels in the shallow alluvial groundwater in the metropolitan area, in the underlying crystallino rock aquifer, The range of tritium values in the equivalent urban area is shown. In all cases the location of the sampling points are shown in Figures 1 and 2.

4. INTERACTION BETWEEN GROUNDWATER OF THE SHALLOW ALLUVIAL AQUIFER AND THE UNDERLYINE ROCK

Sampling program. Wells shown in Figure 5, which tapped water from the crystalline rock aquifer were sampled for environmental isotopes and heavy metals during the spring, summer and autumn of 1981 and the winter of 1981/2. Evidence will be presented that the crystalline rock aquifer is recharged from the groundwater of the shallow alluvium.

Stable isotope ratios. Because of the comparatively small number of samples, and the fact that there was only a small systematic depletion of stable isotope ratios in the colder months, the total 180 data has been presented as a histogram in Figure 6. The results are entirely consistent with the above hypothesis, for the following reasons:

(i) The stable isotope ratio distributions for the two aquifers are generally similar and do not show any evidence, for instance, of an altitude effect.

(ii) Samples from wells within the metropolitan area are generally more depleted than those both upstream and down-stream of the city. This is strong evidence that both the alluvial and crystalline rock aquifers have a common source of recharge.

Environmental tritium. Further evidence for the close interconnection between the two aquifer systems is obtained from the environmental tritium data. Figures 4(a) and 4(b) illustrate that the range of values observed for the ground-water from the crystalline rock correlate well with values from the shallow aquifer.

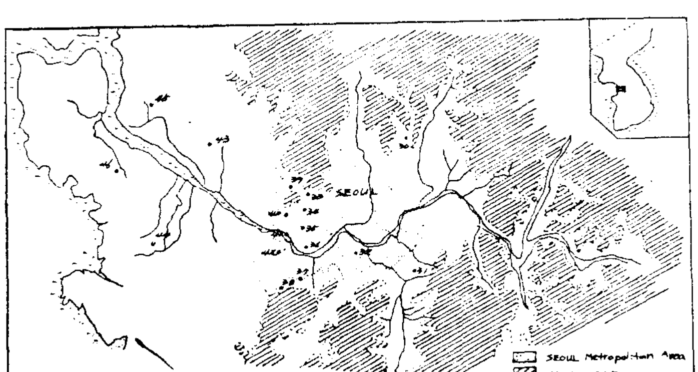

Figure 5. Location of wells tapping the crystalline rock aquifers. The extent of metropolitan Seoul is also shown.

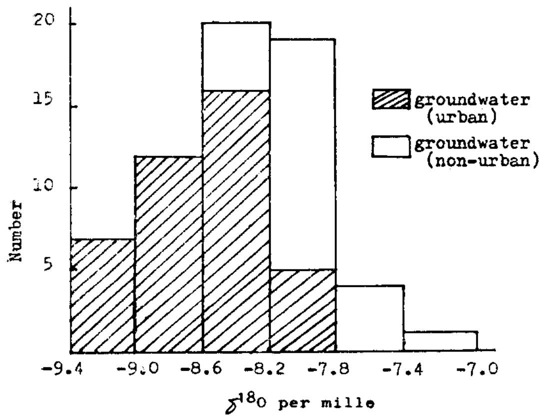

Figure 6. Frequency distribution of the 180 values of wells tapping the crystalline rock aquifer. These wells within the metropolitan boundary and distinguished by cross-hatching.

5. ISOTOPE HYDROLOGY OF THE KARST AREA

As shown in Table 1, more than half the groundwater within the Han River basin is stored by the sedimentary rocks. Some comments on the geology of the karst area are presented in section 2. Samples from selected springs and wells(Figure 5) were collected during the spring, summer, autumn and winter of 1982, and assayed for environmental isotopes and trace heavy metals. The river was also sampled at three points.

A frequency distribution of the 180 values is illustrated in Figure 7. It should be noted that:

(i) The frequence distribution of the groundwater and the river are similar.

(ii) The 180/160 ratios of the groundwater within the karst area are significantly depleted compared with those of samples from the non-urbanised region of the alluvial valley. For instance, in summer 1982 the average 180 values were -7.8 ± 0.3 and -8.9 ± 0.3 per mille respectively: The standard deviations are of the populations. The observed depletion in groundwater from karst areas is attributed to differences in altitude at recharge.

A complete suite of environmental tritium values have been assayed. The data are summarzed in Table 3.

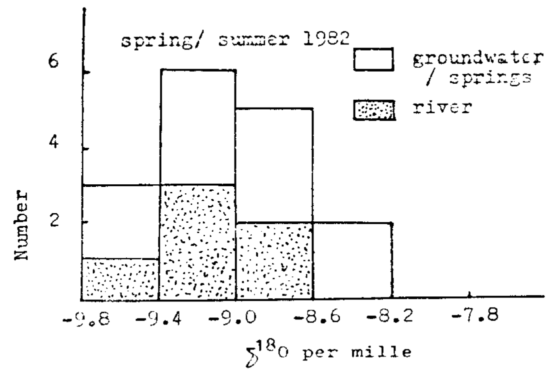

Figure 7. The frequency distribution of the δ180 values of groundwater and river samples from the karst area of the Han River basin.

Table 3. Environmental Tritium Levels in Groundwater and River Samples from the Karst Areas of The Han River Basin.

Sampling period (1982)	Groundwater	River
Spring	34.3±4* (6)+	33.0±3 (3)
Summer	34.3±4 (6)	32.0±2 (3)
Autumn	30.4±3 (8)	27.4±2 (3)
Winter	30.8±6 (8)	29.9±0.4 (3)

* The standard deviations are of the population.
\+ Number of samples in the set.

There is clearly no systematic difference between the tritium levels of the river and the groundwater. Moreover, some evidence exists for a seasonal variation in the tritium levels. The two pieces of evidence strongly suggest that the residence time of the groundwater in karst zone is very small, probably no more than a few months.

6. TRACE HEAVY METALS

One of the aims of this project is to relate the heavy metal content of the groundwater with the results of the environmental isotopic survey in order to establish (i) whether there is any evidence for the deterioration of groundwater quality associated with the release of industrial effluent to the Han River, and (ii) so, to determine the migration pathways. Special attention was paid to those areas in which river recharge predominates. As yet no correlation has been established between the levels of Zn, Pb and Mn and the recharge mechanism, distance from the river, or the electrical conductivity of the water.

7. CONCLUSIONS

1) In both the alluvial and the underlying crystalline rock aquifer, the mechanism of recharge is determined principally by the degree of urbanisation In the metropolitan area, the river is the dominant source of groundwater, whereas in the non built-up areas, recharge is principally from distributed precipitation.

2) In all but a small well-defined region of old ground-water near the coastal region, the groundwater tritium levels generally exceed those of the river. It is tentatively assumed that in the pumped samples there is a small but significant level of post-1960s water which has an intrinsically high tritium level. The seasonal variation observed in the non-urban wells is attributed to groundwater mixing associated with the annual cycle of irrigation pumpage.

3) The crystalline rock aquifer is recharged by water from the overlying alluvium.

4) In the area of Fig-2 marked'Old groundwater is a group of wells with tritium values in the range of 0 to 2 TU. These low values indicate that the water sampled was recharged much ealier, at least a few decades, than the other groundwater samples of higher tritium content. The low values in this region, may, in fact, reflect the effect of the clay layers which impede infiltration from the surface,

5) Stable isotope evidence confirmed that recharge to the karst areas occurs at a significantly greater elevatation than that to the alluvial aquifer. An analysis of the tritium levels collected over an annual cycle suggests that the residence time of groundwater is probably not more than a few months.

6) There does not appear to be any correlation between the trace levels of Zn,Mn and Pb in the groundwater and the mechanism of recharge.

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