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ENGINEERING GEOLOGICAL CONDITIONS AND HYDROGEOLOGICAL SETTING AT RIGANOKAMPOS LANDFILL SITE, ACHAIA COUNTY, GREECE

N. DEPOUNTIS[1], C. HARRIS[2] & G. KOUKIS[3]

ABSTRACT

This paper reviews the engineering geological conditions and the hydrogeological setting of the Riganokampos landfill. The site is underlain by a partially-saturated zone of alluvial fan deposits which retards leachate percolating to the underlying water table. However, leachate may still eventually migrate down gradient from the landfill site to pose a risk to the Patras groundwater supply.

KEY WORDS: leachate, waste, partially-saturated zone, migration.

1. INTRODUCTION

This paper presents an assessment of the geological environment and the potential environmental impact of the discussed Riganokampos landfill, located 5 km east-southeast of the city of Patras (Fig.1). This site is an old domestic waste tip with no lining system and no environmental monitoring for methane gas and the leachate production. The landfill acts as a dilute and disperse site in which attenuation of leachate within the body of the waste and in the unsaturated and saturated zones of the underlying strata ameliorates the impact of groundwater pollution.

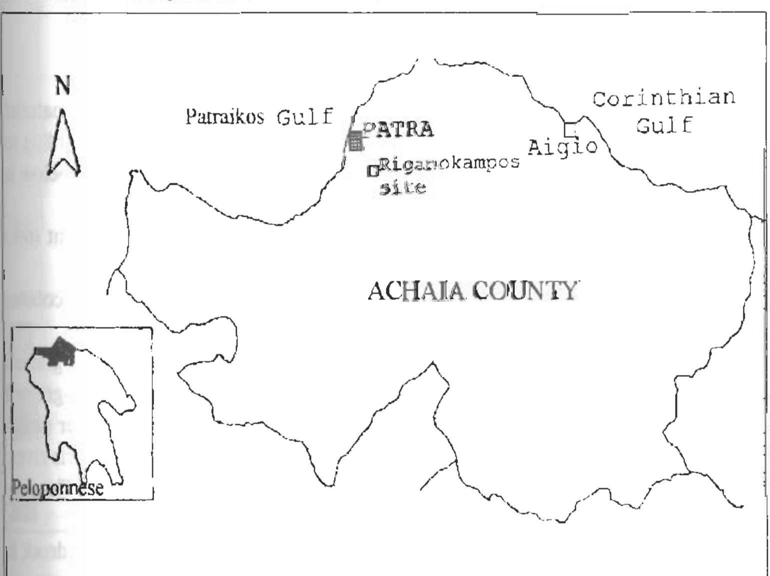

Fig.1: Location of the landfill site in relation to the city of Patras

[1] MSc, Department of Earth Sciences, University of Wales Cardiff
[2] Senior Lecturer, Department of Earth Sciences, University of Wales Cardiff
[3] Professor, Department of Geology, University of Patras, Greece

2. SITE DESCRIPTION

The old tip served the waste disposal demands of Patras during the period 1971-1993 and occupies an area of 237,000 m^2. It is estimated that approximately 800,000 tones of wastes have been deposited since 1971 with a mean compaction of 0.5 ton/m^3. The composition of the deposited wastes according to data obtained from the Municipality of Patras is as illustrated in Fig.2. The inactive component consists largely of rubble derived from derelict buildings. The landfill is developed at an elevation ranging between 100 to 220m on the channel of Elekistras stream. The stream has been diverted 500m up-slope of the site to prevent any flooding of the Southwest area of Patras. This construction diverts the surface water to the channel of the Glafkos river and interrupts surface flow towards the landfill (Fig.5). At present no restoration or remediation has been undertaken at the site except the placing of a temporary cover material.

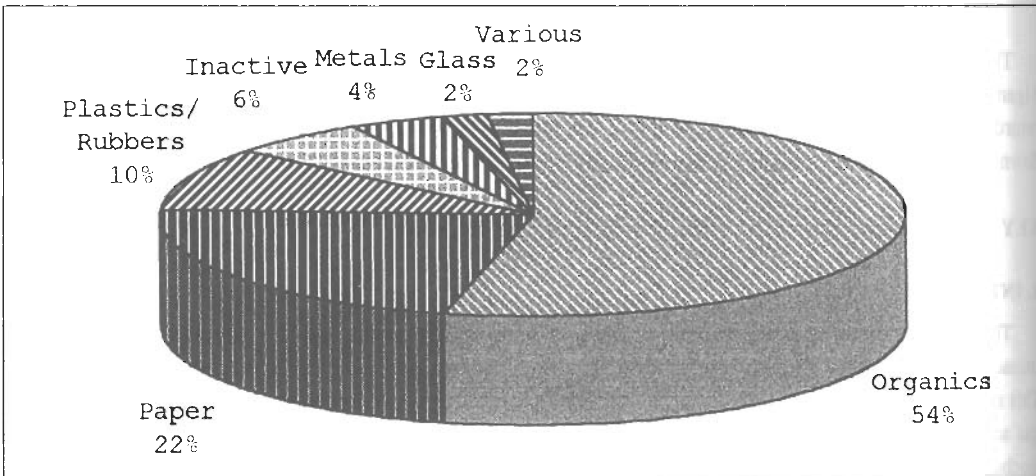

Fig.2: Composition % of wastes at Riganokampos landfill

3. ENGINEERING GEOLOGICAL CONDITIONS

The substructure, upon which the refuse and rubble have been deposited, consists of river bed material and alluvial fans. The other engineering geological formations in the area have been classified according to a previous research (Y.ΠΕ.ΧΩ.ΔΕ., 1990) and subsequent site investigation. The sequence given below is from the youngest to the oldest formation (Fig.3 and Fig.6).

i) Landfill site: Modern formation consisting of domestic wastes with the inactive component (6%) being mainly rubble materials.

ii) River bed deposits: These are recent loose coarse-grained deposits consisting of boulders, cobbles and gravels and a small percentage of sand, approximately 1-2m in thickness.

iii) Alluvial fans: The fan sediments are mixed facies of cobbles, gravels, pebbles, and fine-grained material consisting of clayey sand. According to Koukis et al. (1995), the percentage of fine-grained material is 40% by volume. These Holocenic sediments were largely deposited by the Glafkos river (south of the landfill site), but are also partly due to deposition from the Elekistras stream and Diakoniaris river. Terraces have been exposed above the river banks with the same lithological characteristics. The fan-terraces deposits have a thickness of up to 100m.

iv) Alluvial deposits: At the lower part of the investigation site the basal Plio-Pleistocene bedrock is overlain by alluvial Holocene deposits. They consist of clayey silts, well-graded sands, and loose to semicompacted gravels and cobbles. They range up to 200m in thickness at the centre of Glafkos basin and they show lateral fining towards the Patraikos gulf (Lambrakis et al., 1994). This formation forms the main aquifer of the area.

v) Weathered mantle of the Plio-Pleistocene sediments: This is a recent formation (Holocene) consisting of weathered Plio-Pleistocene sediments. It consists of weathered gritty marls with a gray-yellow colour and ranges in thickness from 2 to 5m.

vi) Diluvial formations: These Pleistocene formations occur outside the investigation area and overlie the bedrock in limited sections. They consist of poorly sorted silty gravels, cobbles, and pebbles with the cobbles and pebbles being loosely cemented by red-brown clay.

vii) Plio-Pleistocene sediments: These sediments comprise the bedrock of the enclosed area of the city of Patras. They are mainly fluviolacustrine, lacustrine, and marine sediments consisting of fine-grained facies of clayey or gritty marls and sparse lenticular intercalations of conglomerates of thickness 10cm to 1m. In many places the conglomerate thickness ranges between 3-5m. The conglomerate intercalations are discontinuous, either due to changes in depositional environment or to the strong tectonic activity of this area.

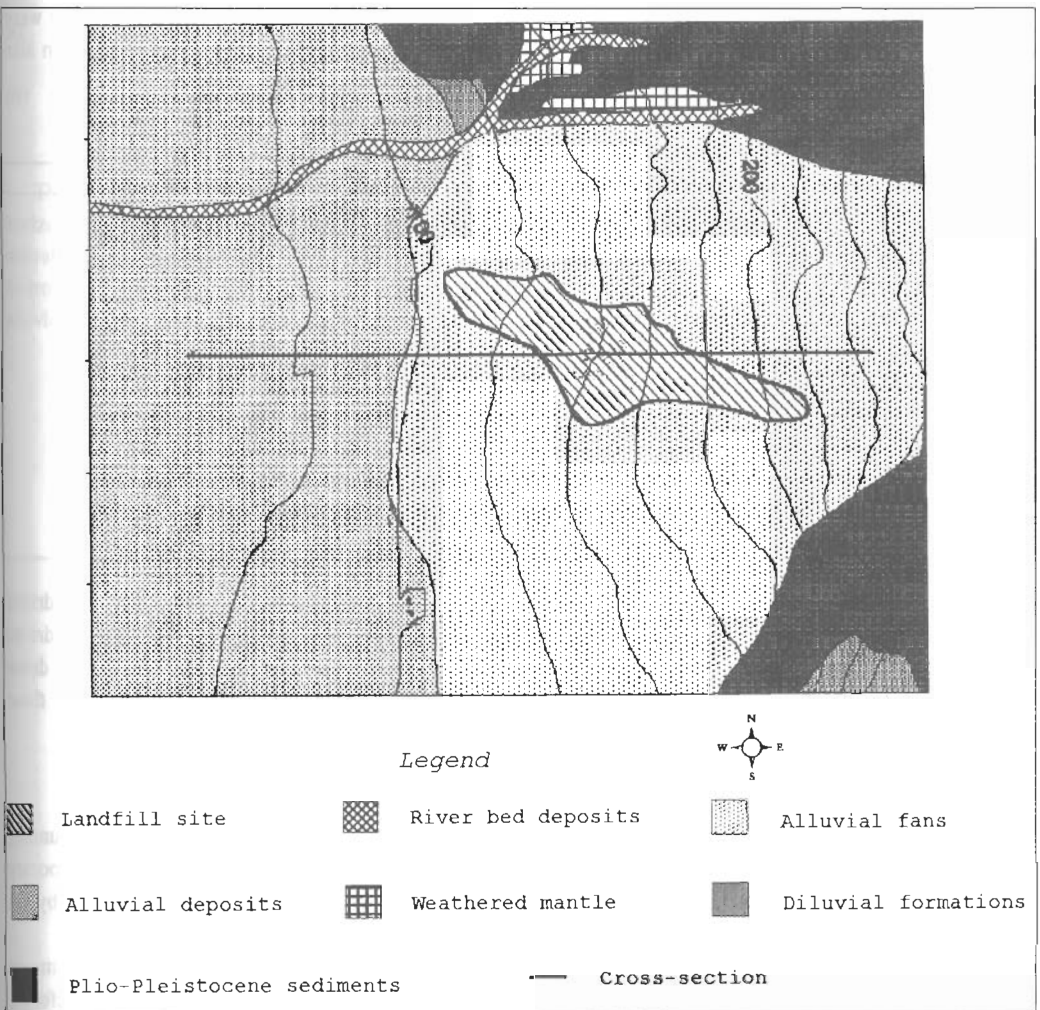

Fig.3: Engineering geological map of Riganokampos area (Scale 1: 23,000)

4. GEOTECHNICAL CONDITIONS AT THE SITE

During the investigation of the surrounding area of the landfill site for the construction of a new peripheral road for the city of Patras, 16 rotary drillings were carried out from Y.ΠΕ.ΧΩ.ΔΕ. (1990). Some of the boreholes were evaluated since they have a direct bearing on the landfill site. These are W3-W4-W5 and are located across the site (Fig.5). Their main dimensional characteristics given in the following table.

Table 1: Geotechnical drillholes at the landfill site

Drillhole No.	Depth (m)	Collar (m)	Water level (m)
W_3	20.0	145.2	-
W_4	25.2	149.3	-
W_5	25.0	146.1	-

The thickness of the drilled tip material was approximately 2m. Below the tip material there were clayey sands and gravels of low plasticity, as well as poorly graded calcareous gravels. The grain size distribution and geotechnical properties of the drilled fan materials are given in Table 2.

Table 2: Results from Laboratory Tests

Properties	Symbol	Distribution	Mean Values
Grain size distribution	Sand & Gravels	76-99%	86.3%
	Silt	1-17%	9.2%
	Clay	0-9%	4.5%
Porosity	n	28-38%	32%
Voids ratio	e		0.47
Moisture content (by weight)	w	3.4-10.9%	7.9%
Volumetric moisture content	θ_v		14.4%
Degree of saturation	Sr		45%
Air voids content	Ar		17%
Bulk Density	ρ	2.0-2.4 Mg/m^3	2.2 Mg/m^3
Specific gravity	Gs	2.65-2.72	2.71

The volumetric moisture content (θ_v) is less than porosity (n), as is expected because the drilled materials lie within an unsaturated zone. The interpretation of the laboratory results classifies the drilled materials as dense well-graded partially-saturated sands. The saturated hydraulic conductivity for dense well-graded sands is generally $K=10^{-4}$ to 10^{-5}m/sec. However, the hydraulic conductivity for these partially-saturated sands is expected to be much lower.

5. ANALYSIS OF THE TEMPORARY SOIL COVER

During the investigation of the site soil samples were taken at different positions in the surrounding area, some of them from the soil horizon of the alluvial fan deposits and some others from the temporary soil cover of the landfill site. The samples were taken from a depth of 0.5m and were analysed by the National Foundation of Agricultural Research.

Grain size distribution of the soil cover showed 70% by weight sand, 18% clay and 12% silt. This means that the capping material of the landfill site does not have the expected low permeability, and therefore is unsuitable to protect the landfill site from water infiltration. Site inspection revealed leachate seepage from several locations over the landfill surface, seepage apparently arising from perched leachate tables between the body of waste and the cover soils.

The saturated electrical conductance of the temporary soil cover is double than that of the other samples. In more [illegible] samples have values between

0.42-0.46 mS/cm/25^{0}C. Total carbonate carbon has a value of 22% in the landfill cap while it has a value of 2-3% in the surrounding area. Additionally, total organic carbon, carbon, and potassium ions are also higher in the landfill cap. Trace elements like zinc and copper have concentrations of 24.8 ppm and 9.1 ppm respectively in the landfill cap whereas the other soil samples have much lower values (0.4-0.5 ppm for zinc and 1.7-2.0 ppm for copper). This great contrast in the above values is caused by contamination of the landfill soil cover by leaking leachate.

6. HYDROGEOLOGY OF THE AREA

The engineering geological formations can be divided into three different categories according to their hydrogeological behaviour (Fig.4).

i) ***Strongly permeable formations***: These consist of alluvial fans, river bed deposits, and terraces with a high hydraulic conductivity $k=10^{-2}$m/sec to 10^{-5}m/sec which decreases at deeper horizons as they become more compacted.

ii) ***Semipermeable to permeable formations***: These consist of alluvial deposits with medium to high permeability ($k=10^{-6}$m/sec to $k=10^{-4}$m/sec) depending on grain size distribution (Rozos, 1991).

iii) ***Semipermeable formations***: These consist of Plio-Pleistocene sediments with clayey marls of permeability around 10^{-8}m/sec and conglomerates of permeability around 10^{-5}m/sec and diluvial formations with a similar range of permeability.

The circulation of water in area of the Riganokampos landfill takes place in the coarse-grained horizons of the Quaternary deposits (alluvial fans, river bed deposits and terraces). However, the alteration between fine-grained clayey materials and coarse-grained materials in these deposits causes hydrogeological variability with local significance. These deposits are hydraulically connected with the alluvial deposits which form the main aquifer of the area (Fig.6).

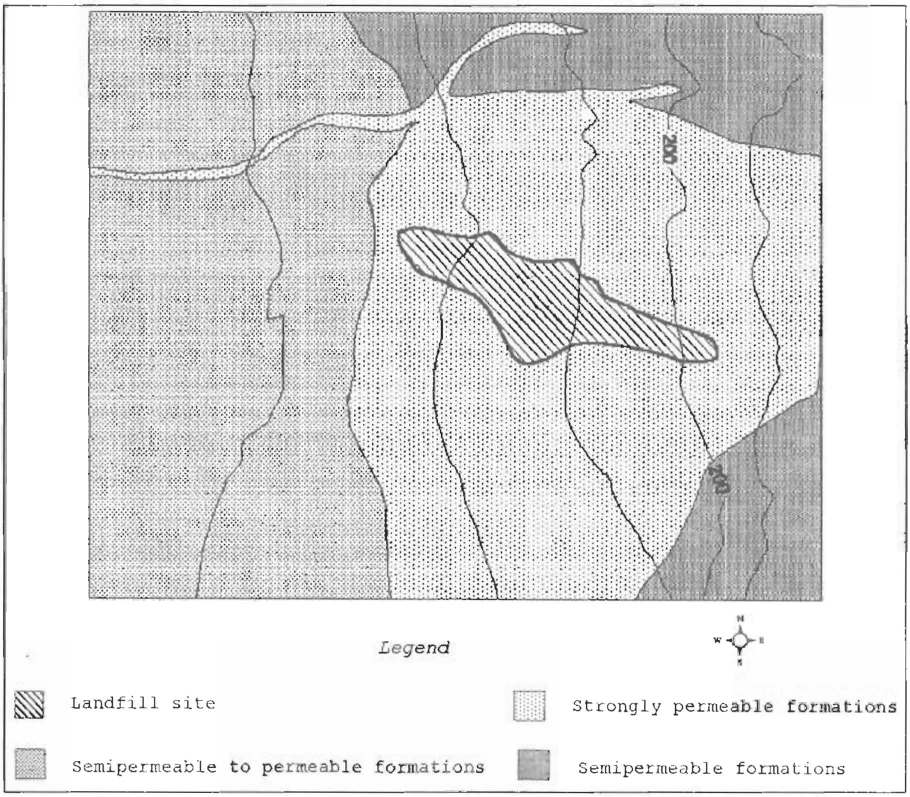

Fig.4: Hydrolithological map of Riganokampos area (Scale 1:23,000)

7. HYDRAULIC PROPERTIES OF THE AQUIFER

Figure 5 was constructed from information of well-points obtained from the Municipality of Patras (1994). The static water levels observed on 2/11/91 (see also Table 3) were used to plot the piezometric contours of the alluvial deposits aquifer. The hydraulic gradient of the aquifer is estimated to be $i=5^{0}/_{00}$ and the main direction of groundwater flow is towards the west.

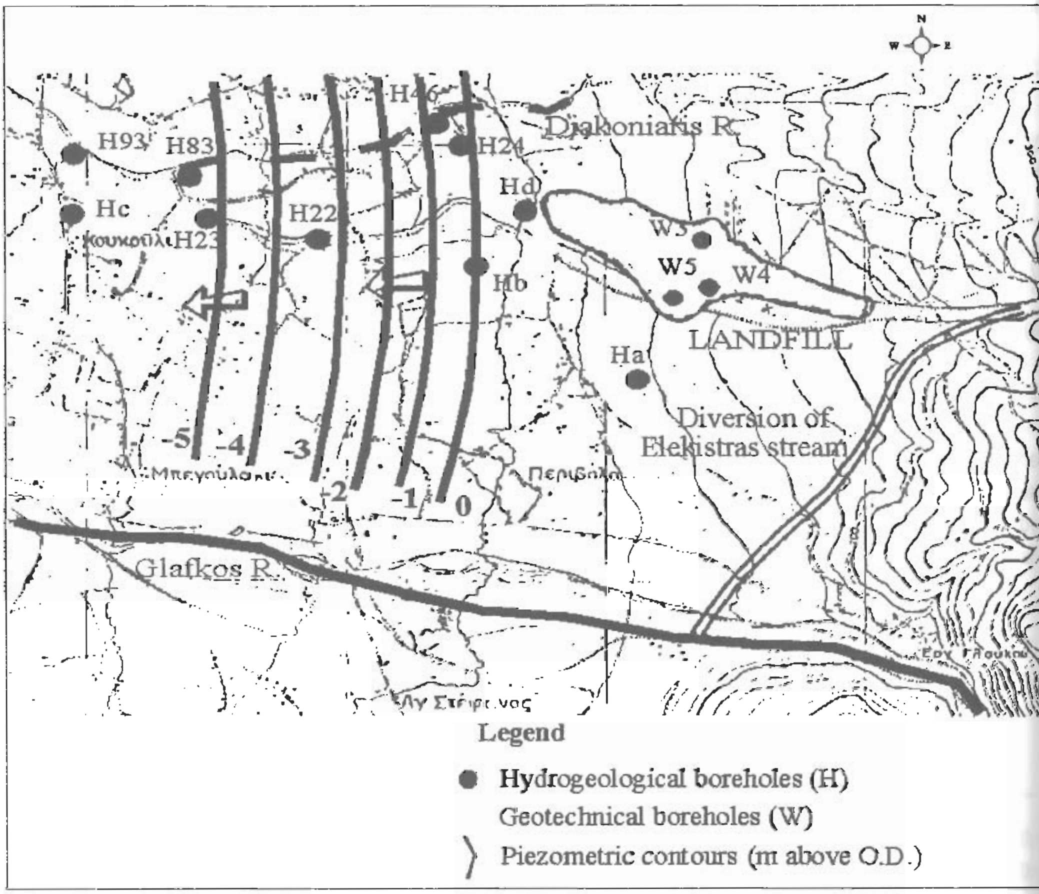

Fig. 5: Hydrological-Piezometric map of the Glafkos basin (Scale 1:28,500)

Table 3: Reported information from well-points

Boreholes	Year	Collar (m)	Depth (m)	Static water level (m)	Piezometric height (m above O.D.)
H_{22}	1985	72.0	162	75.2 (2/11/91)	-3.2
H_{23}	1989	59.1	167	64.0 (2/11/91)	-4.9
H_{24}	1991	51.3	220	51.3 (2/11/91)	0.0
H_{93}	1992	20.2	191	48.2 (5/5/92)	-28.0
H_{46}	1993	51.3	220	-	-
H_{83}	1993	51.5	220	60.3 (25/9/93)	-8.8
Ha	1978	-	170	95.0 (1978)	-
Hb	1979	-	167	67.0 (1978)	-
Hc	1979	35.1	105	39.7 (1979)	-4.6
Hd	1985	[illegible]	182	73.0 (1985)	-

The alluvial deposits are the most important aquifer for the city of Patras and their hydraulic conductivity varies depending to their grain size distribution. This aquifer is anisotropic and heterogeneous in both the vertical and horizontal directions. The main hydraulic characteristics were reported by Lambrakis et al. (1994), from pumping tests as being:

- Hydraulic conductivity, $k=2.1\times10^{-4}$ m/sec
- Transmissivity, $T=0.3$ m^2/sec
- Storativity, $S=0.10-0.12$

The above values correspond to a medium to coarse-grained sand. The level of the water table in this aquifer is at least 50m below the ground surface, so that the unsaturated zone above the aquifer is of a great thickness.

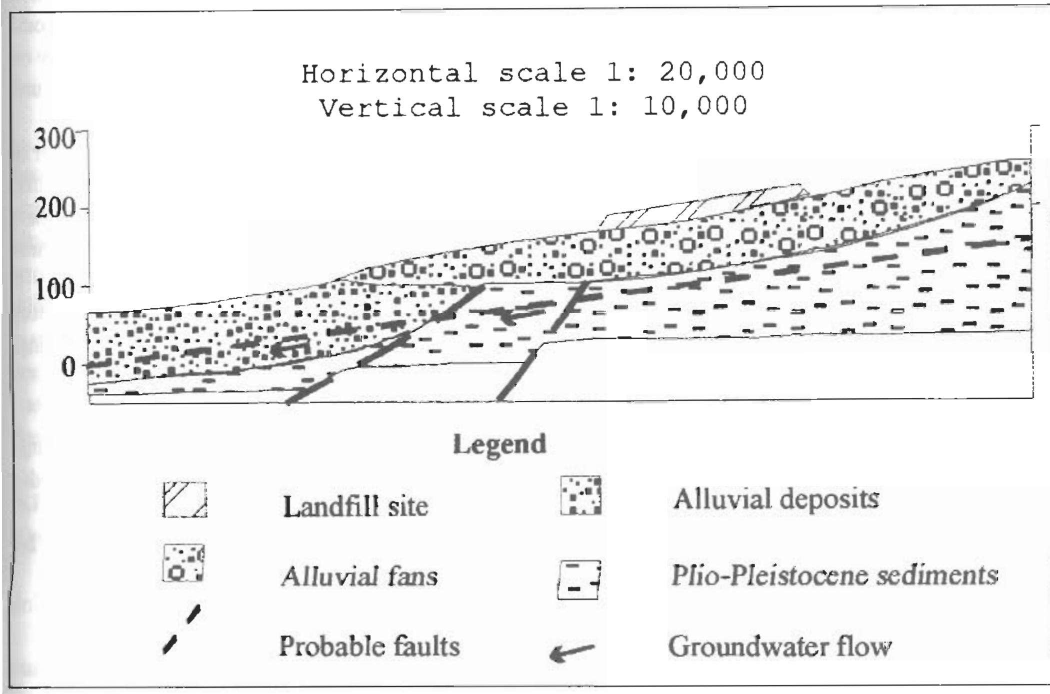

Fig. 6: Cross-section (from Fig. 3) showing the groundwater flow regime at Riganokampos landfill site

8. EVALUATION OF THE HYDROGEOLOGICAL DATA

The static water level in borehole Ha was found at 95m (1978) below the surface. Borehole Hd which is the closest to the landfill site showed a static water level at 73m (1985) and at borehole Hb the static water level was found to be 67m (1978) below the surface. Although data is not available concerning the altitude of collar of these boreholes, we assume from the topography of the area and the static water levels that the main direction of groundwater flow close to the landfill area is towards the west (Fig.6). In addition, this has already been illustrated in Figure 5 for the area downstream of the landfill site. Close to the site the thickness of the alluvial deposits decreases and there is a little recharge of this aquifer through the overlying alluvial fan deposits.

The Groundwater Quality Office of the Municipality of Patras monitors ground water quality by carrying out a series of chemical analyses in the surrounding area of interest. To date, there is no indication of groundwater pollution from the leachate plume dispersal of the landfill site, which could affect the water in boreholes H_{22}, H_{23}, H_{24}, H_{93}, H_{46} and H_{83}. These boreholes are used for supplying water to the city of Patras, so it is clear that any leachate plume migration towards them could pollute the water supplies of the city for many years.

8. CONCLUSIONS

This paper has reviewed the engineering geological conditions and the hydrogeological setting of the Riganokampos landfill. Leachate that forms from the materials deposited in the landfill percolates towards the base of the landfill and then moves downward toward the aquifer at a rate defined by the hydrogeology of the site. The soil between the landfill and aquifer consists of a partially-saturated zone of alluvial fan deposits. According to their geotechnical properties they can be characterised as dense well-graded sands. The saturated hydraulic conductivity of such a material is $k=10^{-4}$ to 10^{-5} m/sec. However, the effective unsaturated hydraulic conductivity is likely to be much lower because in the unsaturated zone, capillary forces act as barriers to the downward movement of the leachate towards the aquifer.

The hydraulic gradient within the main aquifer supplying groundwater to the city of Patras is shown to be approximately $5^0/_{00}$ and water seepage is towards the west. Thus, leachate from the landfill could migrate westwards, down gradient to pose a risk to the Patras groundwater supply. Depending partly on the time that it takes for the leachate to reach the aquifer in significant concentrations, the natural processes attenuate the undesirable components of the leachate and reduce its impact.

There is a need to define accurately the hydraulic properties of the partially-saturated zone in order to use a numerical modelling for the site to estimate the time that leachate is expected to reach the aquifer. The site conditions could be revealed by drilling one borehole inside the landfill to monitor the leachate head and one borehole down gradient of the landfill to monitor the water table and quality. These boreholes could be used to determine the hydraulic properties of the partially-saturated zone.

Scaled physical modelling at the Cardiff Geotechnical Centrifuge Centre is in progress to explore leachate behaviour in the unsturated ground, and provide an alternative approach to numerical modelling.

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