CONF-840245--9

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*Research sponsored by Low-Level Waste Licensing Branch, U.S. Nuclear Regulatory Commission under Interagency Agreement No. 40-1349-83 with the U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

THE EFFECT OF DRAINS ON THE SEEPAGE OF CONTAMINANTS FROM SUBGRADE TAILINGS DISPOSAL AREAS

by

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ABSTRACT

A numerical simulation study is performed to investigate the influence of ponded water and a bottom drain on the pathways for contaminant migration from a subgrade uranium mill tailings disposal pit. A numerical model is applied to a generic disposal pit constructed with a bottom clay liner and steep unlined sidewalls. The migration of a two-contaminant system is modeled assuming that neither contaminant decays and only one contaminant is retarded. Two dominant pathways are identified; one associated with lateral sidewall leakage and the other associated with transport through the bottom clay liner. It is found that the drain serves to reduce migration through the sidewall which, in turn, prevents the retarded contaminant from reaching the aquifer. The ponded water provides increased head which causes an accelerated vertical movement of moisture through the clay liner.

INTRODUCTION

There has been considerable recent interest among the uranium mining and milling industry as well as state and federal regulatory agencies in developing both new methods for the subgrade disposal of mill tailings and advanced techniques for evaluating the performance of new and current disposal methods. This interest is motivated by the need to isolate the mill tailings from aquifers, which exist below the tailings pit, in order to preserve the quality of the groundwater.

In some cases, clay liners have been used to impede the vertical migration of contaminants. These liners can be either flat-bottomed or saucer shaped but slope requirements and stability considerations usually make fully-lined sidewalls costly or impractical. In order to prevent the migration of contaminants through the sidewall, several bottom drain configurations have either been proposed or installed at a number of disposal facilities. Recent monitoring studies (Hoffman et al., 1982) indicate that acquifer contamination may occur in the vicinity of the disposal pit very soon after initiation of tailings disposal. This finding is contrary to predictions based upon conventional one-dimensional analysis and suggests that either the bottom liner has failed or unanticipated sidewall leakage has occurred.

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In a two-dimensional numerical simulation of a bottomed-lined subgrade disposal pit, Pin et al. (1983) have shown that rapid groundwater contamination can occur as a result of the migration of moisture across the pit sidewall with the subsequent vertical movement through a very narrow region down to the aquifer. This saturated region, called the "by-pass region", exhibits high hydraulic conductivity and thus offers a preferential pathway for the migration of both unretarded and retarded contaminants from the pit to the aquifer.

The work presented here is an extension of the study of Pin et al. (1983), and includes an examination of the effects of a botton drain extending around the perimeter of the pit and ponded water in the pit center. The model disposal area consists of an open pit excavated in a uniform geologic medium. The pit is equipped with a 0.4 m (1.25 ft) thick liner with a horizontal water table present 2.67 m (8.75 ft) below the bottom of the pit. The gradual disposal of tailings is assumed to take place over a one year period and is represented in the model by the introduction of discrete layers at regular time intervals. The contaminated wastes enter the pit as a slurry (i.e., with water in excess of that required to maintain the tailings at saturation). The migration of moisture and contaminants within this system is simulated to investigate the influences of a drain and ponded water on aquifer contamination resulting from both bottom and sidewall leakage.

PROBLEM FORMULATION

Numerical simulations are performed on the two-dimensional vertical cross-section, shown in Fig. 1, which represents a typical subgrade mill tailings disposal area possessing both a bottom drain system and a bottom clay liner. The tailings are surrounded by a homogeneous sandstone formation with a static aquifer occurring in the lower 1.125 m (3.75 ft) of the study region. For comparative purposes, the dimensions, layout, and material properties, apart from the drain, are identical to those considered by Pin et al. (1983). The hydraulic conductivity of the drain material is assumed to be independent of pressure, having a constant value of 9.1×10^{-2} cm/sec (9.5×10^{4} ft/yr), which is approximately 3 orders of magnitude greater than the saturated conductivity of the tailings. The drain material is assumed to desaturate almost instantaneously when the capillary suction pressure reaches 0.01 m (0.03 ft). In this study, all materials are assumed to have isotropic properties.

The migration of moisture and contaminants are simulated using the MIGRAT computer code (Pin et al., 1983) which numerically solves an integral form of Richards' equation and the diffusion equation on computation cells having an arbitrary number of sides. The final grid system used for the simulations performed here is the same as that used in Pin et al. (1983).

In order to include the effects of the filling process in the model simulations, tailings are added in six discrete layers with a layer of tailing added every 60 days to approximate a continuous rate of filling. It is assumed that these wet tailings are introduced into the pit by means of a sidewall discharge directed towards the center of the pit. It is also assumed that the emplaced tailings' slurry contains about 40%

more water than would be required to saturate the tailings. The excess water forms a pond in the center of the pit. This ponded water is represented in the numerical calculations by imposing a constant head boundary condition at the upper right corner of the tailings. The specified head value is taken to be the elevation of the top of the tailing within the pit and this value is increased with each addition of tailings. It is further assumed that 90% of the excess water is ultimately removed from the pit via decant line to an evaporation pond or direct evaporation from the pit. The remaining 10% leaves the pit through the drain or through bottom or sidewall leakage. During the course of the simulations, the excess water flux is computed and monitored. When the total volume of water which has entered the pit reaches the prescribed level, the constant head boundary is removed.

In order to minimize the potential for the migration of moisture from the tailings through the sidewall, a drain is located above the clay liner adjacent to the sidewall (Fig. 1). In the calculations, the drain behavior is assumed to be ideal (i.e., no clogging, no pump failure, etc). It is simulated by the selection of appropriate material properties and a constant head condition imposed at the drain cell equal to the elevation of the drain node.

Two non-decaying contaminants are considered in the simulations. Contaminant 1 is taken as a non-retarded contaminant with a constant distribution coefficient equal to 0 in all materials. This contaminant constitutes a marker for the moisture fronts created by leakage from the tailings area and a tracer for the migration of contaminated water through the unsaturated zones. Contaminant 2 is given a constant distribution coefficient of 3.0 in all materials. Equivalently, its retardation factor is about 18 (at saturation) or higher (in unsaturated state) in the clay liner. To emphasize and better show the role and consequences of both the advective transport and the non-linear retardation phenomena in unsaturated media, the constituents are assumed non-dispersive. This assumption has no effect on the pressure field or the moisture migration pattern. Its effects are on the patterns of concentration only, mainly in the frontal zones of contaminant migration, and remain small compared to the retardation phenomenon effects. In a quantitative field modeling study, this assumption in fact corresponds to the worst (undesirable), but still probable case of advective transport through channelized areas with no or little dispersive capacity. The contaminants are leaching out of the tailings with a uniform concentration C_0. No initial contamination is assumed to exist in the host material or in the saturated zone below the water table. The results are displayed in terms of the non-dimensional concentrations, C/C_0.

RESULTS

Figures 2 and 3 show percent saturation and concentration of Contaminant 1 360 days after the initiation of pit filling and 60 days after the emplacement of the last layer of tailings. At this time the pit is two-thirds full. The effect of the drain in dewatering the tailing can be seen in the plot of saturation contours (Fig 2). In the absence of the drain, the material in the pit would be at or near saturation everywhere. The presence of the drain has produced a "draw-down curve" in the pit which results in a reduced horizontal head gradient near the sidewall. It should be noted however that, although reduced, the moisture content in the pit adjacent to the sidewall is greater than that in the nearby sandstone so that some moisture is expected to migrate through the sidewall. The movement of moisture from the pit through the sidewall and through the bottom clay liner can be seen in the contours of concentration of contaminant 1 (Fig. 3). This shows that some moisture has passed through the sidewall and a concentration gradient has developed in the liner. The moisture front has advanced further in the liner below the center of the pit (the right side of the plot) as a result of the pressure produced by the ponded water. A notch exists in the contours directly below the drain since the drain prevents the vertical flow of water into the liner below. This figure also shows a small region of elevated concentrations near the corner of the pit. This feature represents the early stage of the by-pass phenomenon (Pin et al., 1983) caused by moisture migration through the sidewall producing a narrow region of saturation and an associated higher hydraulic conductivity. At this time no significant concentrations of contaminant 2 have occurred outside of the pit.

Predicted concentrations of contaminant 1 after 500 days of simulation time (100 days after the constant head/ponded water boundary condition was removed) are shown in Fig. 4. This figure shows two fronts advancing into the sandstone below the pit, one associated with the by-pass phenomenon and the other a result of water movement through the clay liner. During earlier times in the simulation, the by-pass region was developing slowly so that transport through the liner was the major pathway into the sandstone. At this time, the by-pass region is at or near saturation and has a higher hydraulic conductivity than the saturated clay liner. Furthermore, the absence of the ponded water has served to reduce the force causing migration through the liner with the net result being that the dominant transport mechanism has changed. The by-pass region front is now advancing faster than the front associated with the transport through the clay liner. After 500 days, no significant concentrations of contaminant 2 is predicted outside of the pit.

Saturation contours at 600 days (Fig 5) show continued dewatering of the tailings in the pit along with two new features. The first feature is the groundwater mound evident below the center indicating that moisture passing through the clay liner has reached the aquifer causing a local rise in the water table. The second feature is the set of detached concentric contours in the by-pass region which is evidence of the onset of desaturation of the sandstone near the pit sidewall and the edge of the clay liner. This is a result of both the decreasing moisture content in the tailing caused by the operation of the drain, and the general broadening of the by-pass region so that more water can move through the by-pass region than is migrating through the pit sidewall. Contours of concentration of contaminant 1 (Fig. 6) shows "marked" water reaching the aquifer; however, there is still very little migration of the retarded contaminant.

Saturations contours at 2000 days are shown in Fig. 7. While some excess moisture remains in the tailings, only a small region is fully saturated. Although the migration of moisture out of the pit has been waning since about day 600, as evidenced by the apparent absence of the by-pass region, considerable moisture has moved vertically during the intervening 1400 days. This has produced a uniform increase of about 0.3 m (1 ft) in the water elevation. Contaminant 1 concentrations shown in Fig. 8 reveal that the non-retarded contaminant has reached the groundwater mound below the liner and that the contamination is spreading laterally away from the mound and the by-pass region. Contaminant 2 (Fig. 9) has not yet passed through the clay liner while only a small amount appears in the upper portion of the by-pass region.

Computer simulations were terminated at day 10,000. After day 2000, small changes occurred very slowly. At 10,000 days the tailings were almost completely dewatered. The water table increased slightly over the level predicted at 2000 days. Contaminant 1 showed more lateral spreading; however, concentrations of the retarded contaminant, contaminant 2, showed no significant change from that predicted at 2000 days.

CONCLUSIONS AND RECOMMENDATIONS

The results of the simulations indicate a significantly different performance of a disposal pit as a result of the incorporation of a bottom drain. Although this study reveals that the same phenomena exist as in the case without the drain and ponded water (Pin et al., 1983), the migration of moisture and contaminants exhibit important quantitative differences.

The pressure head resulting from the ponded water increases the flux of moisture through the clay liner. However, the clay liner was an effective barrier to the [illegible]tical migration of the retarded contaminant. Far more migration thro[illegible] liner could occur if the adverse effects of the ponded water were [illegible]t least in part, offset by dewatering through the drain. The drain [illegible]so served to minimize the migration laterally through the sideall, which leads to the by-pass phenomenon, by reducing the horizontal gradient across the sidewall. It should be noted that, while the drain can greatly reduce the head gradient at the sidewall, and in this case served to prevent the retarded contaminant from reaching the aquifer, this gradient cannot be eliminated. Until the pit is comp[illegible]tely dewatered, there will always be excess moisture in the tailings which will migrate through the sidewall.

REFERENCES

Hoffman, G. L., L. H. Howlett, and S. J. Playton, "Groundwater Hydrology Neat the A-9 Pit Below Grade Tailings", Hydro-Engineering, 1982.

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BASE MAP

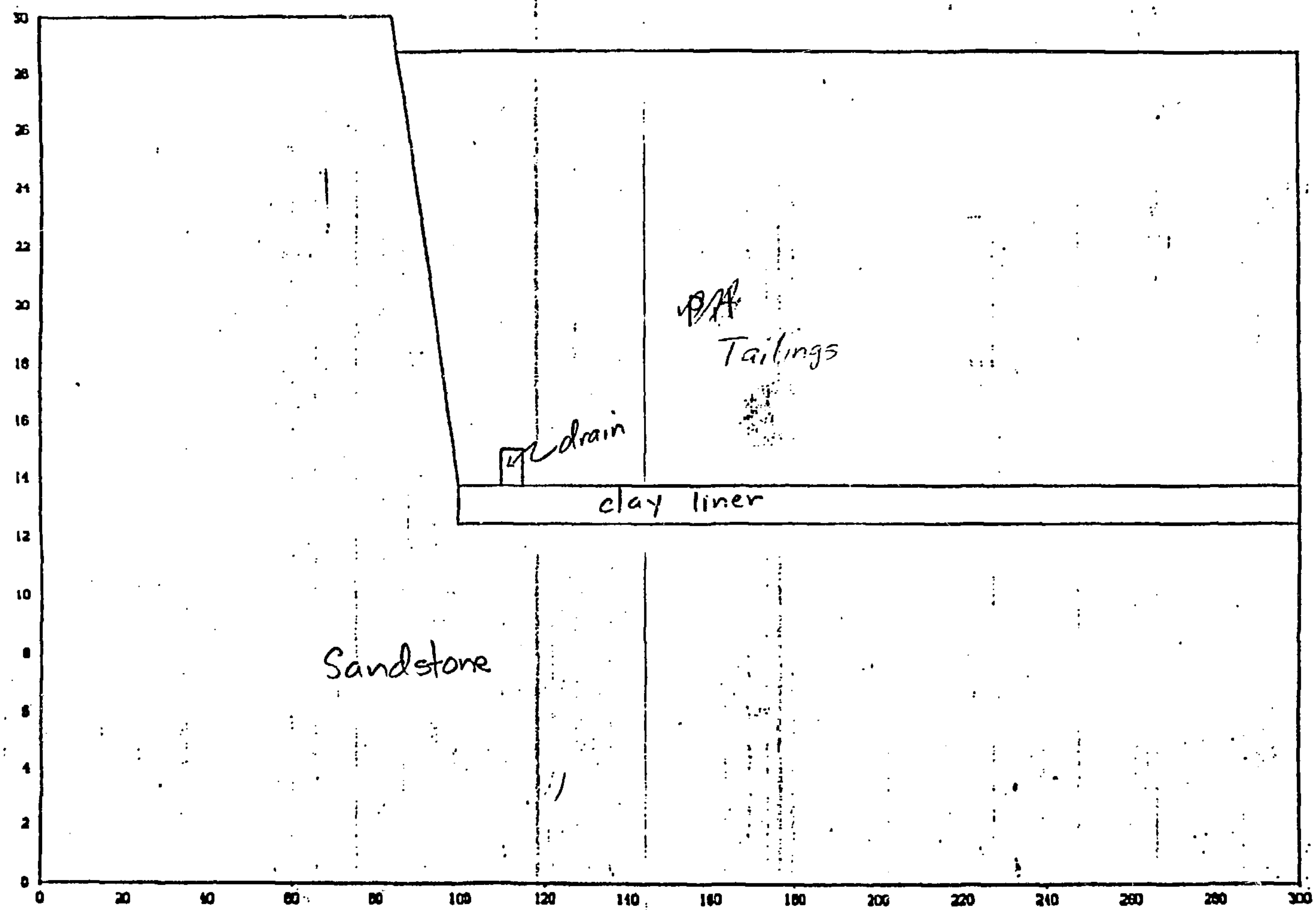

Figure 1. Base map for computer simulation study.

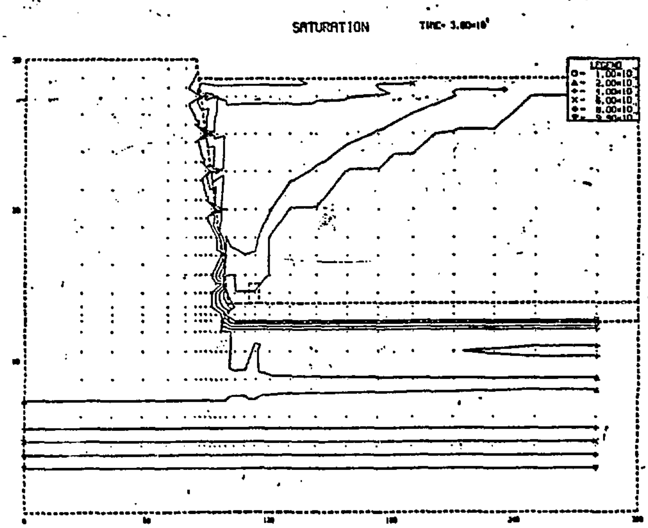

Figure 2. Contours of constant percent saturation after a simulation time of 360 days.

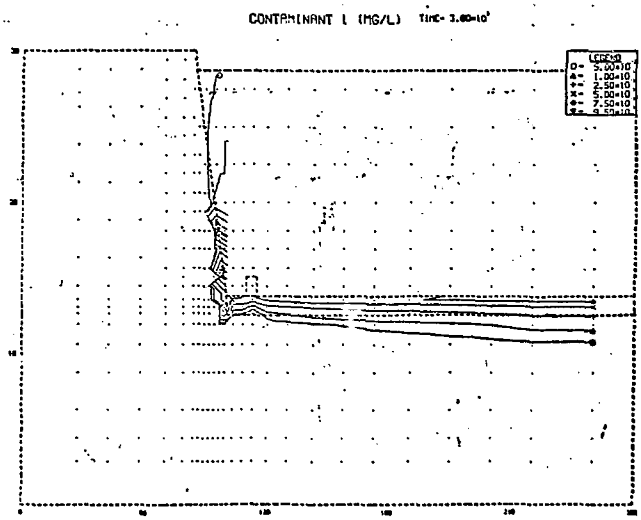

Figure 3. Contours of constant relative concentration of contaminant 1 after a simulation time of 360 days.

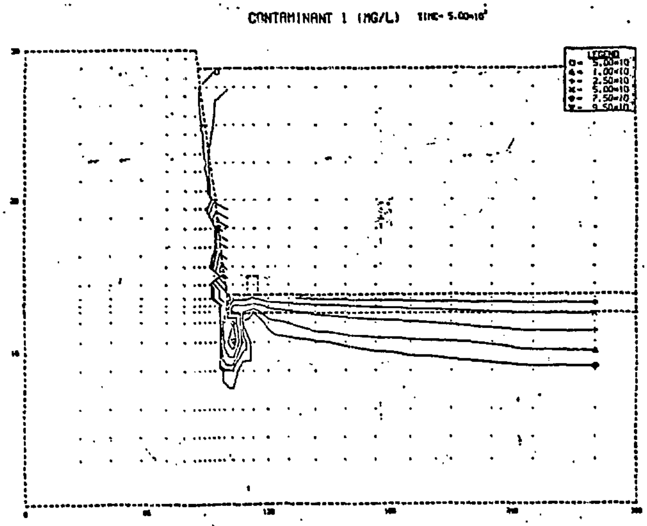

Figure 4. Contours of constant relative concentration of contaminant 1 after a simulation time of 500 days.

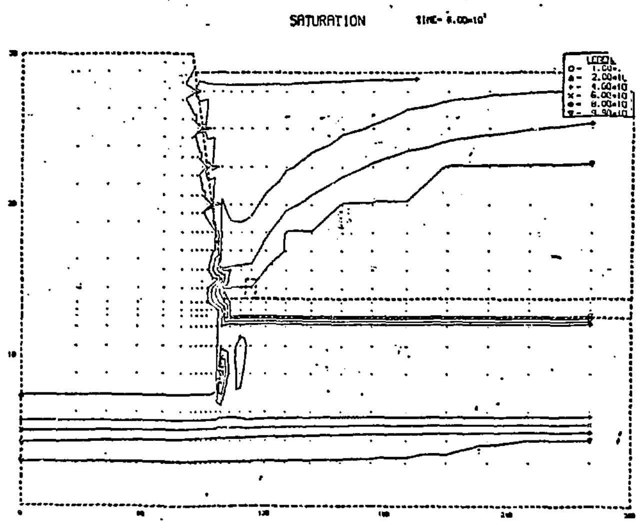

Figure 5. Contours of constant percent saturation after a simulation time of 600 days.

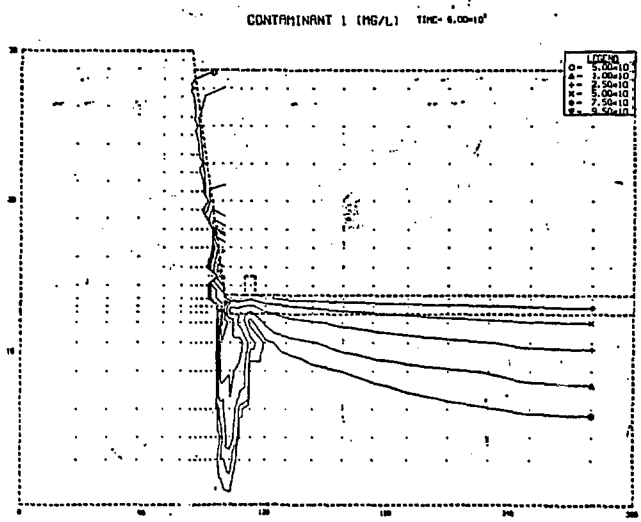

Figure 6. Contours of constant relative concentration of contaminant 1 after a simulation time of 600 days.

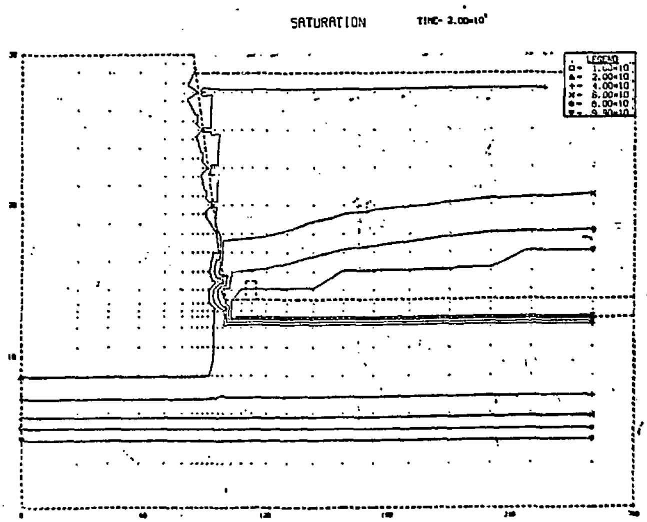

Figure 7. Contours of constant percent saturation after a simulation time of 2000 days.

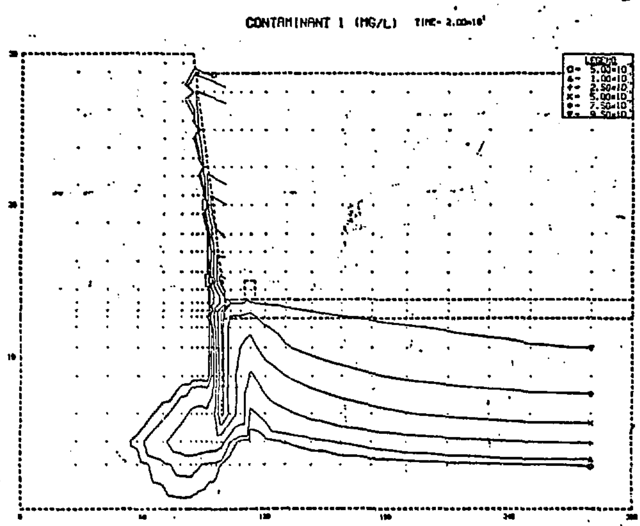

Figure 8. Contours of constant relative concentration of contaminant 1 after a simulation time of 2000 days.

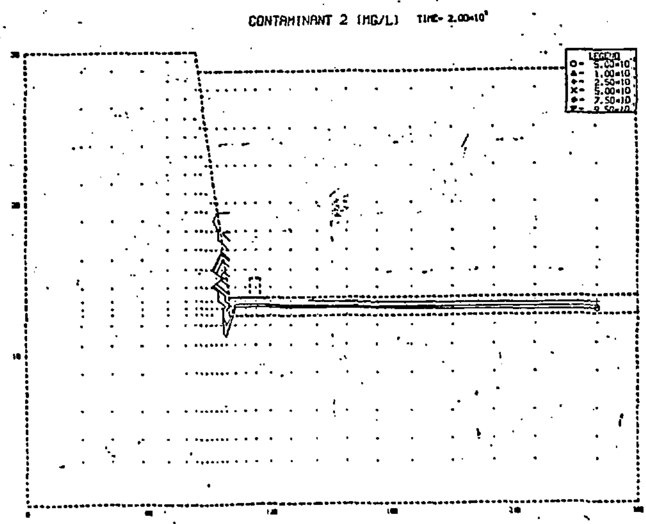

Figure 9. Contours of constant relative concentration of contaminant 2 after a simulation time of 2000 days.