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A STUDY OF METHODS TO REDUCE GROUNDWATER CONTAMINATION AROUND A LANDFILL IN KOREA

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Several alternatives were studied to prevent groundwater contamination around the Kimpo landfill site in Korea using a numerical model and hydraulic parameter measurements. The leachate flow system and pollutant transport system around the landfill were analyzed using a numerical model. Alternatives utilizing dewatering wells with radial collector well laterals had low costs but resulted in low efficiency of pollutant reduction. Installing an interception wall at the circumference of the landfill was more efficient but had a high cost. Installing an interception wall to the second layer was the most stable and most economical alternative.

INTRODUCTION

The study of groundwater flow and pollutant transport around waste landfill sites has been actively executed in many countries. The studies have included hydrogeological monitoring, 3-dimensional solute transport modeling in the subsurface, and the measurement of the distribution and biodegradation coefficients in soil around a landfill (Christensen, 1993). Predicting the concentration and range of future contamination around landfills using numerical models has developed over several years and the most suitable methods to prevent groundwater contamination have been studied (De Smedt and Bronders, 1989).

The Kimpo landfill site study area is located on a marine clay layer with a depth of 15 m. The waste weight in the landfill is causing settlement of the marine clay layer. The settlement has destroyed a considerable part of the drain facilities located in the bottom of the landfill and the area around the landfill site is being contaminated by landfill leachate. In this paper, methods to reduce the contamination around the landfill were studied. Specifically, pollutant transport around the landfill with and without the use of equipment reducing contamination was analyzed using the MT3D model (Zheng, 1988). Radial collector well laterals (RCWLs), dewatering wells, and interception walls were studied.

LOCATION AND HYDRAULIC PARAMETERS

The study location is Gyunggi-do, in the Kimpo region, and the study area is about 60 km^2 (Figure 1). To the north-east of the landfill is a mountain ridge and to the west is a coastal area of 2 percent slope in the east-west direction. The surface of study area is covered by a marine clay layer 15 m deep, and the area under the clay layer is formed of a weathered layer and a soft-rock layer. Hydraulic conductivities of the study area were measured at 51 points in the marine clay by slug tests and 2 points in the soft-rock by constant pressure injection tests (Kim, 1996). Test results are shown in Table 1.

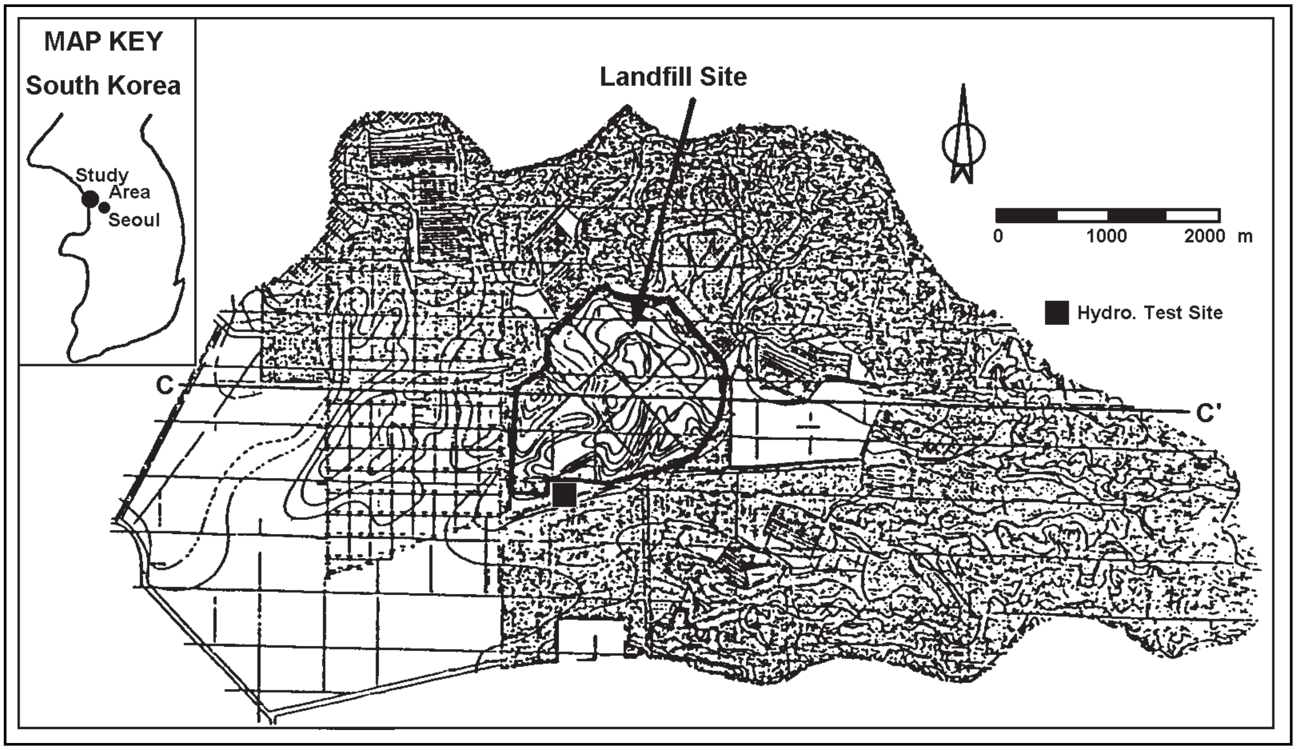

Figure 1. Location and topographic map of the Kimpo landfill site.

Table 1. Results of the Hydraulic Conductivity Tests

Layer	Hydraulic conductivity (m/sec)
upper marine clay layer	$2.04 \times 10^{-8} \sim 6.87 \times 10^{-7}$
under marine clay layer	$1.06 \times 10^{-8} \sim 6.6 \times 10^{-7}$
weathered layer	$2.45 \times 10^{-8} \sim 4.45 \times 10^{-6}$
soft-rock layer	$9.4 \times 10^{-8} \sim 8.4 \times 10^{-7}$

The longitudinal dispersivities of the marine clay around the landfill were measured by field and laboratory hydraulic dispersivity tests (Kim, 1996). Laboratory tests using columns 5 and 10 cm in length gave longitudinal dispersivities of 0.46 and 0.94 cm. A field test was performed at the point shown in Figure 1. Longitudinal dispersivity was 0.1 m. Distribution coefficients of phenol and chemical oxygen demand (COD) were measured by isothermal sorption tests, with the marine clay sampled at 8-12 m depth in an undisturbed state. Distribution coefficients of phenol and COD were 0.75 and 0.165 l/kg. The biodegradation coefficient of COD was measured by analysis of the COD concentration degraded biochemically over 10 days. The measured value was 0.022/day.

ANALYSIS OF CONTAMINATION AROUND THE LANDFILL

Analysis of the leachate flow system

The area around the Kimpo landfill was modeled using MODFLOW, a 3-dimensional finite difference groundwater flow model (McDonald and Harbaugh, 1988). The study area was divided into four layers on the basis of geology, which consist of upper marine clay, lower marine clay, weathered, and soft-rock layers. The study area of 11000 m x 5500 m, including the landfill and the surrounding area, was simulated using 100 x 60 cells per layer (Figure 2).

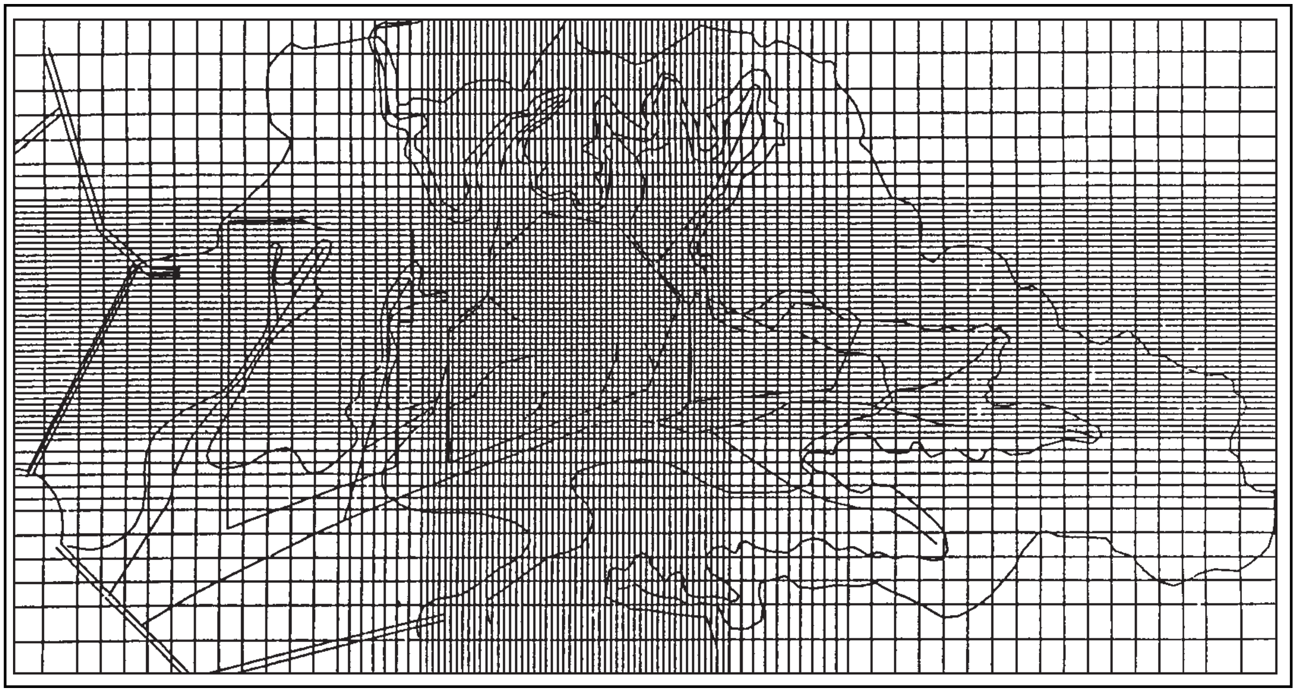

Figure 2. The finite difference net of the study area used in the MODFLOW model.

The upper boundary of the layer was the water table and the lower boundary was treated as an impermeable boundary. The hill area located to the north-east was treated as an impermeable boundary due to a groundwater divide, and the coast line in the west and the stream in the south were treated as constant heads. Hydraulic conductivities (K) were isotropic (Kx=Ky=Kz). The results of analysis of the leachate and the groundwater flow around landfill under present conditions are shown in Figure 3.

Because the drain facilities located in the bottom of landfill were destroyed by settlement of the marine clay layer and were not operating properly, the elevation of leachate in the landfill was 8-15 m higher than the water table in the area around the landfill. Thirty five percent of the leachate generated within the landfill (3000 m^3/day) flowed out to the area around the landfill (Figure 3). The leachate in the landfill first flows to streams located around the landfill and then to the coast through the stream.

Analysis of pollutant transport

The transport of pollutants in the leachate from the landfill was modeled using the MT3D (Modular Mass Transport 3-Dimensions) model. The boundary conditions used in this model are equal to those of the MODFLOW model. The governing equation of this model is:

$$R\left(\frac{\partial C}{\partial t}\right) = D\left(\frac{\partial^2 C}{\partial x^2}\right) - \mathrm{V}\left(\frac{\partial C}{\partial x}\right) - \lambda C R \tag{1}$$

where

R = retardation factor

V = linear pore water velocity

D = hydrodynamic dispersion coefficient

C = concentration of pollutants

λ = biodegradation coefficient

Modeling was conducted assuming that the leachate, containing a nonreactive pollutant material in the landfill, is injected instantaneously and its initial concentration is 1.0 mg/l. At present, assuming no cleanup, concentration distributions of pollutants in the first and second layers in the landfill after 20 years were calculated by MT3D. The calculated concentration is a concentration ratio of the initial concentration, 1.0. The mean concentration in the first layer fell from 1.0 to 0.1, and that in the second layer increased from 0.0 to 0.14 after 20 years.

Verification of numerical model analysis results

Hydraulic head and pollutant concentration distributions around the landfill were modeled by MODFLOW and MT3D. Hydraulic heads calculated by the model were verified by comparison with the observed heads shown in Figure 3, which were drawn on the basis of the values measured at a total of 78 observation holes installed around landfill. Comparison showed that errors were below a mean of 1m. Pollutant concentrations given by the model were verified by comparison with tritium concentrations measured at points KP1 and KP2 in Figure 3. Concentration ratios sampled at KP1 and KP2 with the original tritium concentration of leachate were 0.15, and at the same points, concentration ratios given by the model were 0.13.

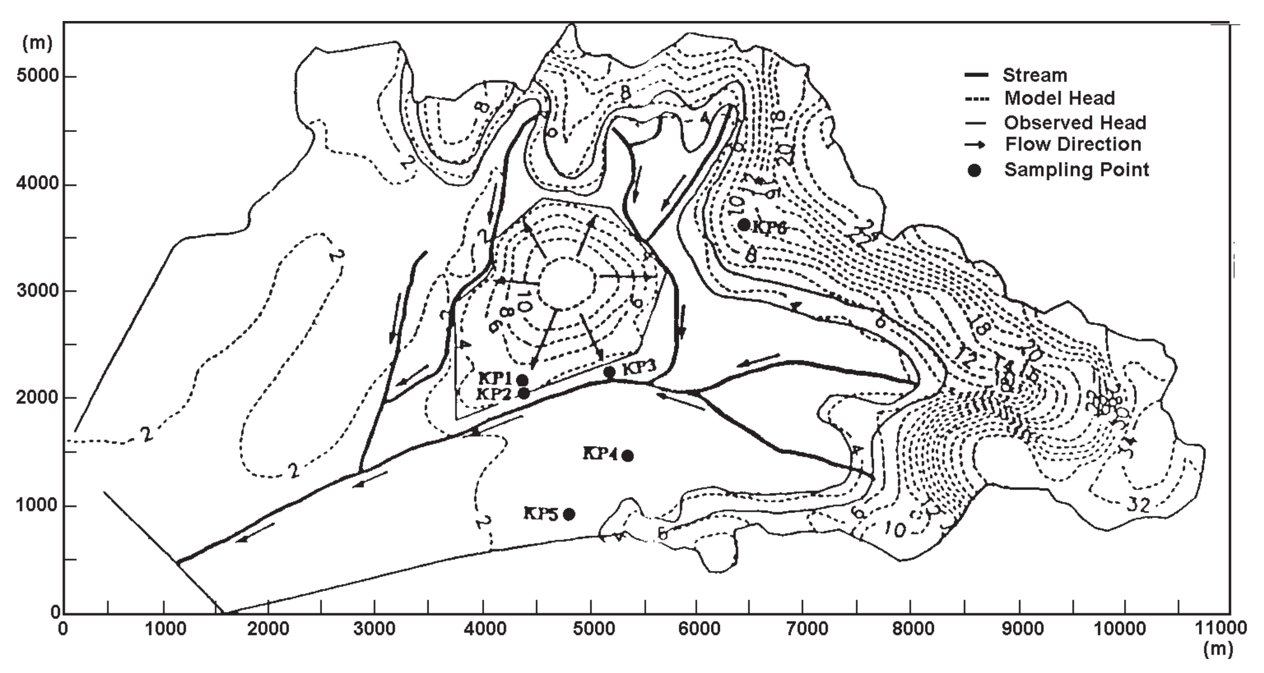

Figure 3. Hydraulic head distribution around the Kimpo landfill site.

METHODS FOR REDUCING CONTAMINATION

Installation of five sets of RCWLs

In this scenario, five sets of RCWLs were installed at an elevation of +3 m in the vicinity of the landfill center, and the rates of leachate removal in the landfill over time calculated by the model are shown in Table 2. The removal rate through the existing drain and RCWLs after 10 years is 2102 m^3/day, which is about 150 m^3/day more than at present, and is about 70 percent of the leachate rates generated within the landfill (3000 m^3/day). The results of modeling the concentration distribution of pollutants are shown in Figure 4 in the first and second layers after 20 years, which, in this case, are 0.07, and 0.12. These values are about 30 percent lower than the present state.

Table 2. Leachate Rates Eliminated by Different Scenarios (m^3/day)

Time Method	Present State	after 2 yr	after 10 yr	after 20 yr
Drain and RCWLs (5 sets of RCWLs)	1950	2428	2102	2102
Drain and wells dewatering the condensed water (30 sets of wells)		2400	2135	2135
Drain and RCWLs after establishing the wall to second layer (22 sets of RCWLs)		3205	2770	2770
Drain and RCWLs after establishing the wall to third layer (40 sets of RCWLs)		3215	2915	2915

Dewatering wells

When the leachate in the landfill was removed through 30 sets of dewatering wells, the removal rate after 10 years is constant at 2,135 m^3/day. Figure 4 shows the results of modeling the concentration distribution of pollutants in the first and second layers of the landfill after 20 years. The mean concentrations in first, and second layers in the landfill are 0.07, and 0.12, which represents values reduced by about 30 percent compared to the present.

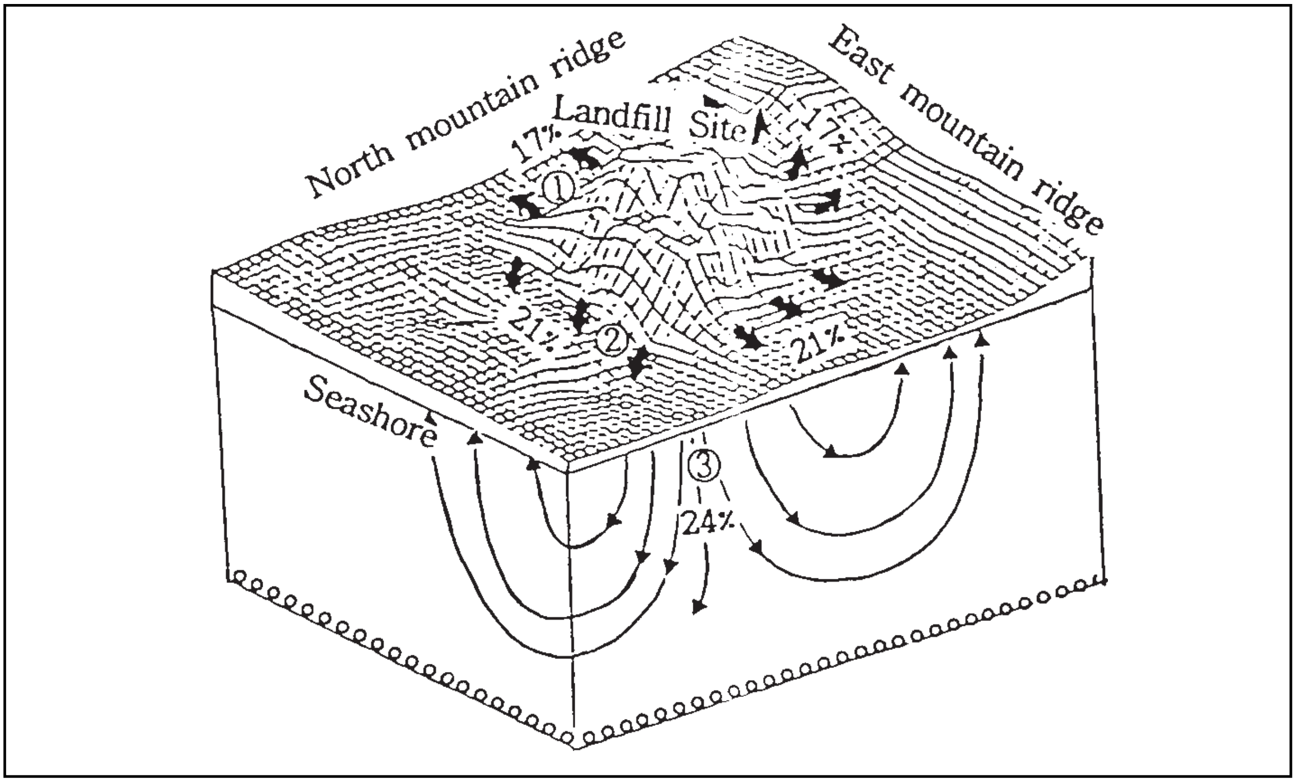

Figure 4. Concentration distributions of pollutants around the Kimpo landfill after 20 years.

Interception wall to the second layer

In this scenario, an interception wall was the installed at the circumference of the first and second layers of the landfill and the leachate was removed by 22 sets of RCWLs. The removal rates through the existing drain and the RCWLs are shown in Table 2. The removal rates through the existing drain and RCWLs after 10 years is 2,770 m^3/day, which is about 230 m^3/day less than the inflow rates to the landfill. This method eliminates about 92 percent of the inflow after 20 years.

But, because this method must install 22 sets of RCWLs and an interception wall to the second layer, a heavy economic burden is imposed. The mean concentrations in the first and second layers after 20 years are 0.06, and 0.08, which represent a 40 percent reduction compared to the present (Figure 4).

Interception wall to the third layer

An interception wall was installed at the circumference of first, second, and third layers of the landfill and the leachate was removed by 40 sets of RCWLs. The removal rates through the existing drain and RCWLs after 10 years is 2,915 m^3/day, which is about 85 m^3/day less than the rates flowing into the landfill. This method eliminates about 97 percent of the inflow. The mean concentrations in the first and second layers are 0.06 and 0.08, showing a reduction of about 40 percent (Figure 4).

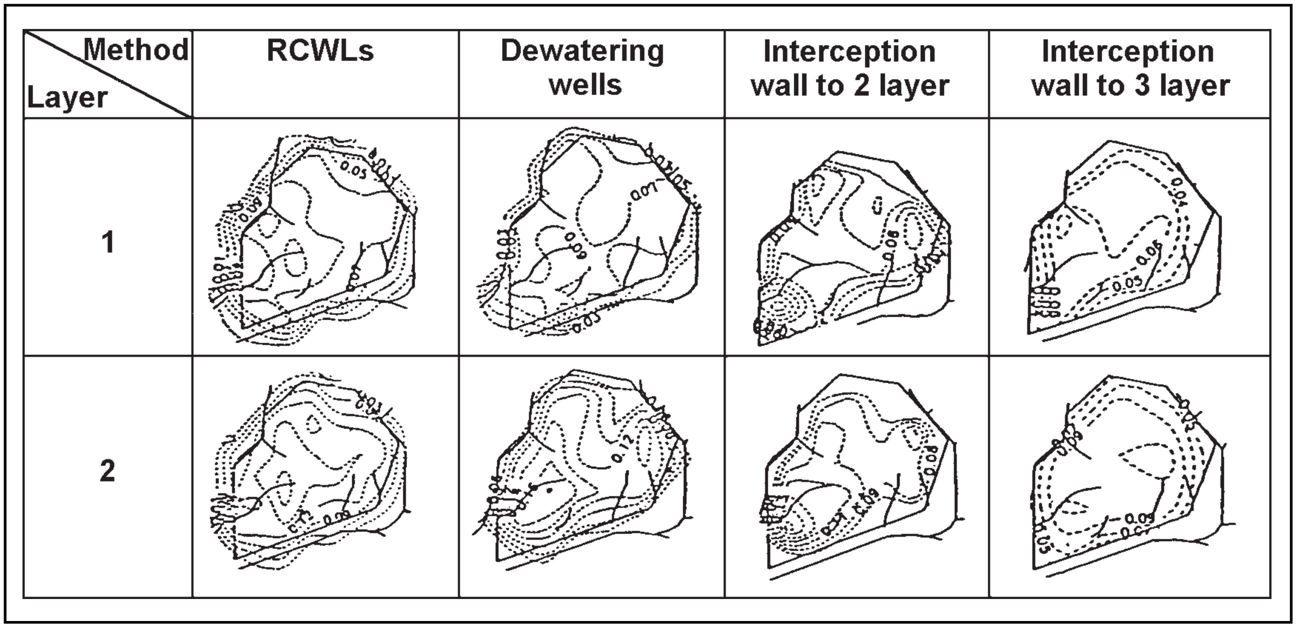

Figure 5. Measurements points of concentrations over time and percentages of leachate effluent flowed out to each direction.

MODEL ANALYSIS

Maximum effluent concentrations of Cl, phenol, and COD over time at the north point, at the coast line, and at the center point of second layer of the landfill was calculated by the MT3D model using distribution and biodegradation coefficients measured by isothermal sorption tests (Figure 5).

The establishment costs and the comparison of four cleanup scenarios are shown in Table 3.

Table 3. Synthesis Comparison for Each Method Reducing Contamination

Method Item	Present State	RCWLs	Dewatering wells	Interception wall to 2nd layer	Interception wall to 3rd layer
Elimination ratio	65 %	70 %	71 %	92 %	97 percent
Annual costs (million dollar)	-	2.3	5.6	44.0	73.1
Maximum effluent conc.(ppm)	Cl;1584 phenol:0.23 COD:0.0	Cl:1157 phenol:0.17 COD:0.0	Cl:1109 phenol:0.16 COD:0.0	Cl:0.66 phenol:8.3×10^{-5} COD:0.0	Cl:0.092 phenol:2.1×10^{-5} COD:0.0
Problems	-	High concentration		High costs	

The installation of RCWLs and utilization of the dewatering wells has a low cost but is not efficient. Installing an interception wall brought about a higher efficiency but required an excessive cost. Figure 6 presents the costs of the contamination reduction equipment for mixing leachate effluent from the landfill and groundwater to maintain water quality standards. The required cost averages about 40 million dollars.

CONCLUSIONS

The observed elevation of leachate levels in the center of the landfill center is simulated at 8 to 15 m above the surrounding water table by a numerical model. It is assumed that 35 percent of the

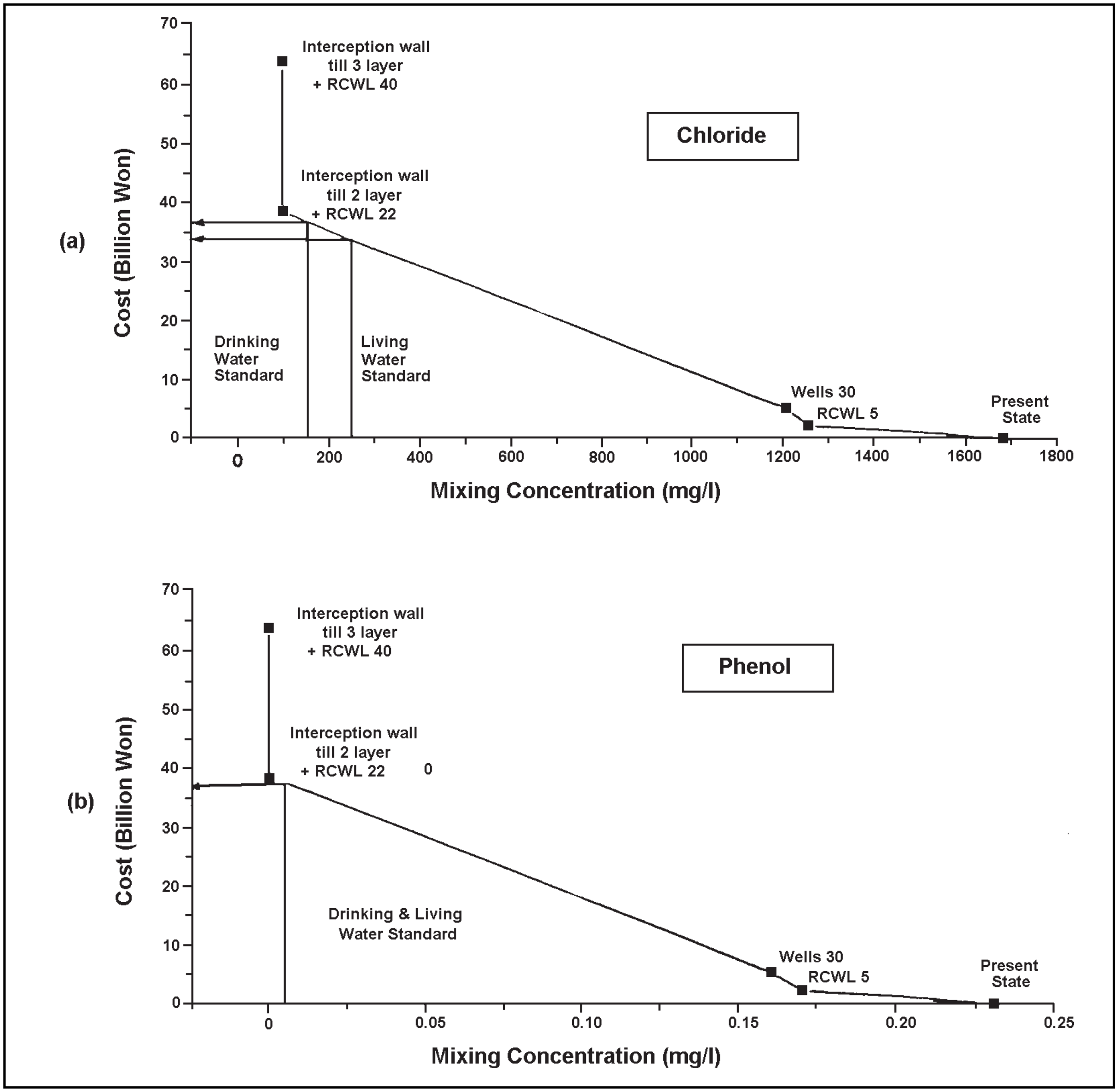

Figure 6. Required costs for mixing water to uphold water quality standard.

leachate generated within the landfill flows out to the neighboring area. Installing five RCWLs brings about a 70 percent leachate reduction, and dewatering wells bring about a 71 percent reduction. Installing 22 RCWLs and an interception wall brings about a 92 percent leachate reduction . Installing 40 RCWLs and an interception wall brings about a 97 percent leachate reduction but requires high costs. It is concluded that installing 40 RCWLs and an interception wall to the second layer is the most stable and most economical alternative.

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