AIR STRIPPER PERFORMANCE EVALUATION

KELLOGG-DEERING SITE

NORWALK, CONNECTICUT

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TABLE OF CONTENTS

1.00 INTRODUCTION

Goldberg-Zoino & Associates, Inc. (GZA) evaluated the performance of the existing packed tower air stripper purchased by the Norwalk First Taxing District (NFTD) for the Kellogg-Deering (K-D) wellfield in 1986. This air stripper was designed to reduce trichloroethylene (TCE) concentrations in the Layne 1 public supply well from 600 ppb to less than 5 ppb, and to treat the Deering 1 and Deering 2 supply wells if TCE concentrations were to increase significantly in either of these wells.

Information used in our evaluation regarding the existing K-D air stripper and wellfield was obtained from previous studies conducted at the site by NUS (refer to Feasibility Study Report, NUS Project Number S781, June 1986, and Remedial Investigation Report, NUS Project Number S781, April 1986).

2.00 GENERAL CASES FOR THE AIR STRIPPER EVALUATION

The performance of the K-D air stripper was evaluated under three general cases, assuming different TCE inlet concentrations.

Case I. Maximum TCE inlet concentration to air stripper = 820 ppb. Water flow rate = 1,750 gpm.

This case is based on a 1985 NUS model which predicted long-term maximum TCE concentrations of 820 ppb at the wellfield under worst case conditions (NUS Feasibility Study Report, Table 1-3).

Case II. Maximum TCE inlet concentration to air stripper = 2,000 ppb. Water flow rate = 1,750 gpm.

This case is based on more recent sampling data which detected TCE at higher concentrations (170 ppm) in upgradient monitoring wells than had previously been indicated from sample results prior to August 1985 (100 ppm). Assuming, for the purpose of this analysis, that a linear relationship exists between present maximum observed concentrations in upgradient monitoring wells and long-term concentrations in the K-D supply wellfield, the NUS model would predict worst case TCE concentrations to be approximately 1,400 ppb. In order to remain conservative, a safety factor of approximately 50 percent was applied, resulting in a maximum wellfield TCE concentration of 2,000 ppb.

Case III. Maximum TCE inlet concentration to air stripper = 300 ppb. Water flow rate = 1,750 gpm.

This case assumes that groundwater in the area identified by NUS as "Zone 1" is being treated separately and, as a result, TCE concentrations in this area will be significantly reduced. If it could be assumed that reducing TCE concentrations in "Zone 1" would result in a 50 percent reduction of TCE levels observed in the downgradient K-D supply wellfield, then the basis for the air stripper design would be reduced to a maximum inlet TCE concentration of 300 ppb (50 percent of the original K-D air stripper design specification).

3.00 BASIS FOR AIR STRIPPER PERFORMANCE EVALUATION

We used the "AIRSTRIP" computer model (developed by the University of Iowa Chemical Engineering Department) to evaluate the performance of the existing K-D packed tower air stripper. The equipment and packing specifications for the existing K-D air stripper, provided from the NUS Feasibility Study Report (FS), are:

Tower Size	=	11 feet diameter x 36 feet height
Depth of Packing	=	23 feet
Type of Packing	=	Jaeger Tripacks, polypropylene
Size of Packing	=	2-inch
Blower Capacity	=	23,400 cubic feet per minute (cfm)

For each case, the following parameters were used in the AIRSTRIP model:

Water Temperature	=	49°F (9.5°C)
Water Flow Rate	=	1,750 gpm
TCE Outlet Concentration	=	≤5 parts per billion (ppb)
Volumetric Air to Water Ratio (A/W)	=	70 and 95
Packing Depth	=	23 feet, 25 feet, and 28 feet

The basis for selecting these parameters is discussed in the following section.

4.00 GENERAL DESIGN CONSIDERATIONS

The performance of an air stripper is evaluated by its ability to remove contaminants from water. Two of the most important design specifications are the diameter of the air stripping tower and the depth of packing material. Tower diameter is set by the water flow rate, and should be sized to provide a hydraulic loading rate which will adequately distribute water throughout the packing material so that "channeling effects" (the tendency for water to flow along the tower walls instead of the packing) are reduced. A rule of thumb is that the ratio of the tower diameter to the packing diameter should be greater than 8.0 to minimize the channeling effects ("Unit Operations of Chemical Engineering," McCabe and Smith). This criterion is satisfactorily met in the K-D tower using 2-inch packing. Channeling effects should, therefore, be negligible.

The required packing depth for a stripping tower is determined by the mass transfer rate of contaminant(s), which is a function of Henry's Law Constant, temperature, and air flow rate. Henry's Law Constant, which is an indicator of a compound's "strippability," decreases with decreasing temperatures. Henry's Law Constant and temperature are interrelated, and are both generally considered constant for groundwater treatment applications where groundwater temperatures remain fairly constant (approximately 55°F) throughout the year.

Previous NUS hydrogeologic studies, however, have indicated that the K-D water supply wells are significantly recharged by the Norwalk River and Kellogg Pond. According to the NUS Remedial Investigation Report (RI) dated April 1986, temperatures measured in monitoring wells were "consistently in the 12°C to 13°C range with two exceptions." Higher temperatures were reported in shallow wells, and a minimum temperature of 9.5°C was observed in a monitoring well adjacent to Layne 1 from the 40-foot to the approximately 100- to 110-foot depth. Because this depth range corresponds to the wellscreen span in Layne 1, the minimum observed temperature, 9.5°C (49°F), was used in each of the K-D air stripper performance evaluations to provide a worst case analysis.

Increasing the air flow through a packed tower will typically result in higher contaminant removal efficiencies; however, the maximum air flow rate for a particular system is limited by two factors. First, for a given water flow rate through the tower, countercurrent air flow can be increased only to the point at which water can no longer flow through the tower. This corresponds to the system's "flooding velocity," and air strippers are generally designed to operate well below flooding. Using a graphical correlation for estimating flooding velocities ("Unit Operations of Chemical Engineering," McCabe and Smith), we confirmed that the maximum rated air flow of the existing blower (23,400 cfm) is approximately 40 percent of the calculated flooding velocity.

The total pressure drop through a packed tower is also used as an indicator of flooding velocity. Flooding generally occurs in packed towers at pressure drops of between 2 to 3 inches of water per foot of packing (in/ft). Pressure drops less than 0.5 in/ft are typically recommended for packed tower design. The existing K-D blower is rated for 23,400 cfm against a static pressure of 4 inches of water; therefore, the total pressure drop criterion used in the air stripper performance evaluations was 4 inches of water. This corresponds to a pressure drop of approximately 0.17 in/ft, assuming a total packing depth of 23 feet.

The other limitation on maximum air flow through a packed tower air stripper is a matter of economics. Higher air flow rates require larger blowers which result in increased energy costs. For purposes of the K-D air stripper evaluation, the maximum air flow was considered to be limited by the rated capacity of the existing blower. The blower assembly is designed for 23,400 cfm and can be manually adjusted to deliver an airflow of 17,500 cfm (NUS-FS Report, pg. C-3). These air flows correspond to air/water (A/W) ratios of approximately 99.5 and 74.4, respectively, at a water flow rate of 1,750 gpm. The K-D air stripper performance for each case, however, was evaluated at A/W ratios of 95 and 70 to provide an additional safety margin.

An alternative to higher air flow is increased packing depth and/or decreased size of packing. For some systems, increasing the packing depth can be more economical than increasing the blower size. Smaller diameter packing also effectively increases mass transfer rates, but is more prone to clogging and buildup of solids, and results in increased pressure drops through the tower.

Since the overall tower height is 36 feet, we reasonably assumed that the existing tower could accommodate an additional 2 to 5 feet of packing for a total packing depth of 25 to 28 feet. Approximately 100 cubic feet of additional packing would be required per foot of packing depth. The purchase cost for an additional two feet of 2-inch Jaeger Tripacks (at $\$15/ft^3$) is approximately $3,000; the cost for an additional five feet of packing is approximately $7,500. The purchase cost for replacing all of the existing 2-inch packing with 1-inch Jaeger Tripacks (at $\$31/ft^3$) is between approximately $70,000 and $87,000, depending on the packing depth. Because replacement of the packing is not a cost-effective alternative, evaluation of the K-D air stripper performance was conducted only with 2-inch packing.

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5.00 EVALUATION RESULTS

5.10 CASES I THROUGH III

The first step in the overall evaluation was to predict effluent concentrations of groundwater contaminants other than TCE that have been detected in study area monitoring wells, using the existing K-D air stripper packing specifications (packing depth = 23 feet, packing size = 2 inches) at 49°F and an A/W ratio equal to 70. The inlet contaminant concentrations used for this part of the evaluation were based on maximum levels observed in the study area monitoring wells during the NUS RI study. Although actual contaminant concentrations observed at the wellfield would likely be significantly lower, this first evaluation was conducted using observed maximum levels as a check on the stripper's ability to remove contaminants other than TCE.

Table 1 summarizes the results of this evaluation. The AIRSTRIP model predicts that the other groundwater contaminants present can be removed from the groundwater to meet target levels, as established by Federal drinking water standards.

Table 2 summarizes the results of the K-D air stripper performance evaluations for Cases I through III. In Case I (TCE inlet = 820 ppb), the TCE effluent standard can be attained with the existing K-D air stripper at either A/W ratio. For Case II (TCE inlet = 2,000 ppb), a packing depth of 25 feet and an A/W ratio of 95 would achieve the TCE effluent standard. For Case III (TCE inlet = 300 ppb), reduced packing depths at an A/W ratio of 70 were evaluated. For this particular case, the target TCE effluent concentration can be attained at packing depths of 18 to 20 feet. Reduced A/W ratios (decreased air flows) could also achieve the target concentration. If TCE inlet concentrations are observed to be in this range, less packing and/or a smaller blower are recommended for a more economical operation.

5.20 ESTIMATION OF MAXIMUM TCE INLET CONCENTRATIONS, CASES I-III

The AIRSTRIP model was also used to estimate maximum TCE inlet concentrations to the air stripper that would achieve target TCE levels with packing depths of 23 feet, 25 feet, and 28 feet. This data is presented in Table 3. The estimated maximum inlet TCE concentration that can be handled by the stripper under each scenario is designated in bold print. The results are summarized below:

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Flowrate	Packing Depth	Maximum TCE Inlet Conc.	TCE Outlet Conc.	A/W
1,750 ppm	23'	1,200 ppb	4.7 ppb	95
(Cases I-III)	25'	2,000 ppb	4.8 ppb	95
	28'	4,200 ppb	4.9 ppb	95

5.30 CASE IV

A final evaluation was conducted to estimate maximum TCE inlet concentration assuming three wells (Layne 1, Deering 1, and Deering 2) are simultaneously pumped to the K-D air stripper for a total flow rate of 3,850 gpm. According to the NUS reports, the Deering 1 and Deering 2 wells could be pumped to the air stripper if the TCE concentration was to significantly increase in either well. At the time of the NUS study, the TCE concentrations observed in the combined Deering 1 and 2 discharge were below 10 ppb. The NUS reports did not specify the concentrations at which Deering 1 and 2 would require treatment, or whether the three wells were intended to be pumped separately or simultaneously to the air stripper.

In this evaluation, the total flow rate was assumed to be 3,850 gpm (1,750 gpm from Layne 1 and a total of 2100 gpm from Deering 1 and 2). The corresponding A/W ratios would be approximately 45 and 30 at air flow rates of 23,400 cfm and 17,500 cfm, respectively. Because the AIRSTRIP model calculated that A/W ratios greater than 40 would exceed 4 inches of water at 3,850 gpm, this evaluation was conducted only at the A/W ratio of 30.

A summary of estimated maximum acceptable TCE inlet concentrations at different packing depths is presented below.

Flowrate	Packing Depth	Maximum TCE Inlet Conc.	TCE Outlet Conc.	A/W
3,850 ppm	23'	200 ppb	4.1 ppb	30
	25'	300 ppb	4.4 ppb	30
	28'	550 ppb	5.0 ppb	30

Figure 1 presents combinations of potential TCE inlet concentrations in Layne 1 and the Deering 1 and 2 wells, corresponding to the overall maximum TCE inlet concentrations shown above. The graph presented in Figure 1 indicates that even if TCE concentrations in Deering 1 and 2 were to increase by a factor of ten to approximately 100 ppb, the K-D air stripper could still treat water containing up to 320 ppb TCE from the Layne 1 supply well, at a packing depth of 23 feet. Similarly, at packing depths of 25 and 28 feet, the K-D air stripper could treat the Layne 1 supply well containing TCE concentrations of up to 540 and 1,090 ppb, respectively, if the TCE concentration in Deering 1 and 2 was 100 ppb.

6.00 SUMMARY AND CONCLUSIONS

We used the AIRSTRIP computer model to evaluate the performance of the existing K-D air stripper under several variations of TCE inlet concentrations, packing depths, and volumetric air to water flow ratios. Based on the results of the evaluation, we have reached the following conclusions.

1. The K-D air stripper, as presently designed, should be able to treat the Layne 1 public supply well with TCE inlet concentrations of up to approximately 1,200 ppb at an A/W equal to or greater than 95.

2. TCE inlet concentrations of up to approximately 2,000 ppb may be treated if the existing K-D air stripper can accommodate an additional 200 cubic feet of 2-inch Jaeger Tripacks packing for a total packing depth of 25 feet. The purchase cost of the additional packing is approximately $3,000. As noted above, the 2,000 ppb inlet concentration represents a worst case scenario based on detecting approximately 250 ppm TCE in one of the upgradient monitoring wells; this is 50 percent higher than the highest TCE level reported to date.

3. Assuming maximum TCE inlet concentrations are reduced to 300 ppb (50 percent of the air stripper's present design specification) due to separate groundwater treatment in Zone 1, the existing air stripper's packing depth could be decreased to 18 or 20 feet, and/or a smaller blower could be installed to attain the same performance criteria or better.

4. The maximum recommended TCE inlet concentration to the existing K-D air stripper with three wells pumping (3,850 gpm) is approximately 200 ppb. If the packing depth can be increased to 28 feet, TCE inlet concentrations of up to approximately 550 ppb may be treated to an acceptable level.

TABLES

TABLE 1
AIR STRIPPER PERFORMANCE EVALUATION OF
DETECTED CONTAMINANTS

Compound	Inlet Concentration (ppb)	Outlet Concentration (ppb)	Target Concentration (ppb)
1,1,1-Trichloroethane*	4	<1.0	200
1,1,2-Trichloroethane	630	53.7	NA
1,1-Dichloroethane	38	<1.0	NA
cis-1,2-Dichloroethylene	4,000	13.3	70
trans-1,2-Dichloroethylene	4,000	15.6	70
Dichlorobenzene*	4	<1.0	620
Chloroform	600	7.0	NA
Methylene Chloride	900	15.5	NA
Benzene	260	1.4	5
Toluene*	240	1.5	2,000
Xylene	590	4.6	440
Tetrachloroethylene	1,500	6.4	NA
Vinyl Chloride	136	<1.0	2
Ethyl Benzene*	40	<1.0	680

NOTES:

1. Basis: Temperature = 49°F
   Packing Depth = 23 feet
   Packing Size = 2 inches
   A/W Ratio = 70

2. Compound concentrations were obtained from Table 7-1, "Indicator Chemicals: Kellogg - Deering Site", Remedial Investigation report, dated April 1986. Maximum observed concentrations were used for this evaluation.

3. Target concentrations are based on federal drinking water standards.

* - Indicates these compounds are present in the study area at concentrations currently under target levels.

NA - Indicates no target levels have been established to date.

TABLE 2

SUMMARY OF PERFORMANCE EVALUATION FOR
CASE I THROUGH CASE III

CASE	TCE INLET (PPB)	WATER FLOW	PACKING DEPTH	A/W	TCE OUTLET (PPB)
I	820	1,750	23 feet	70	3.8
				95	3.2
			25 feet	70	2.4
				95	2.0
			28 feet	70	<1.0
				95	<1.0
II	2,000	1,750	23 feet	70	x
				95	x
			25 feet	70	x
				95	4.8
			28 feet	70	3.0
				95	2.4
III	300	1,750	23 feet	70	1.4
			20 feet	70	2.8
			18 feet	70	4.4

Notes:

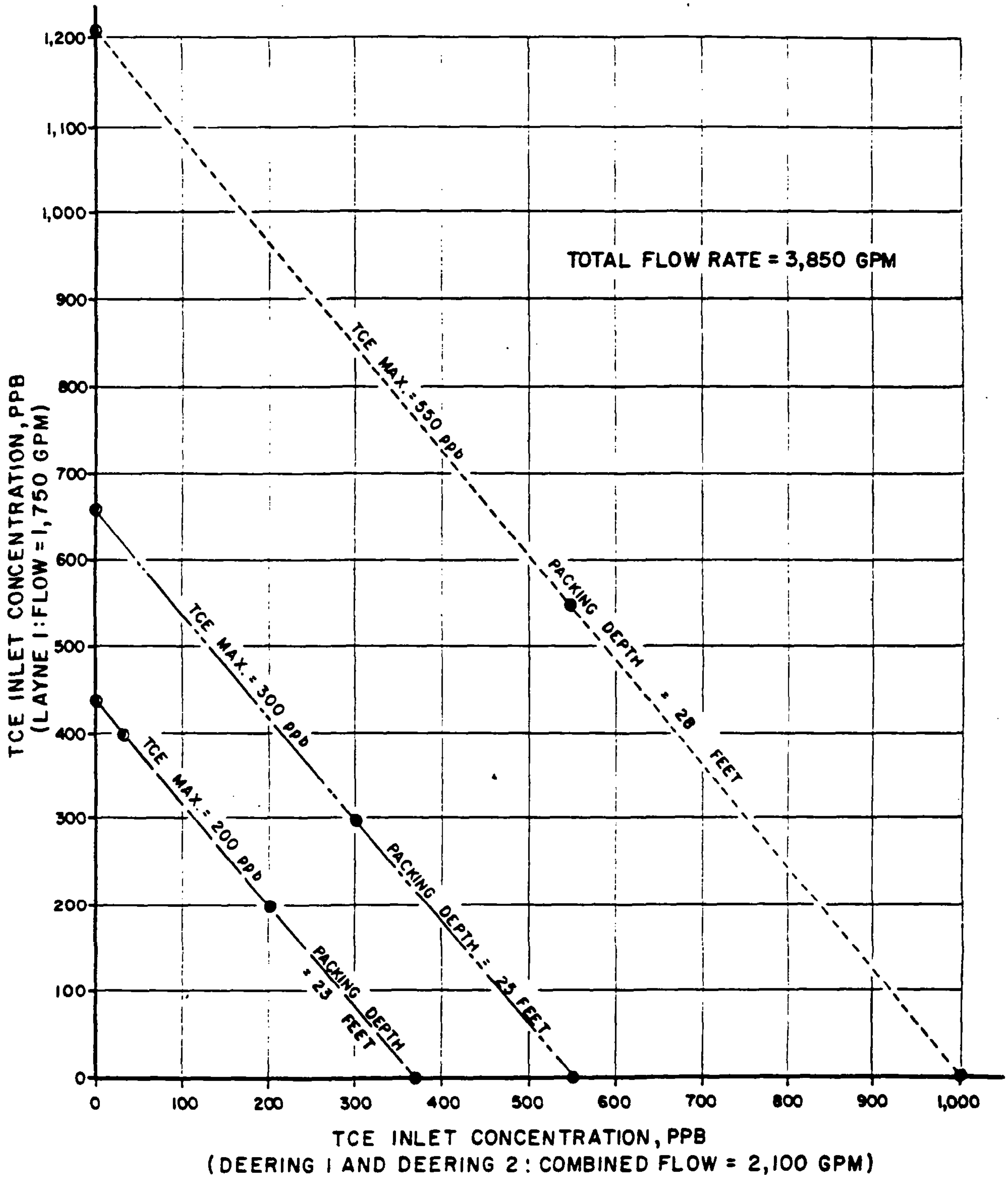
1. Water Temperature = 49°F.
2. Packing Type = 2-inch Jaeger Tripacks.
3. x = denotes greater than 5 ppb.

TABLE 3
PREDICTED MAXIMUM TCE INLET CONCENTRATIONS:
CASES I THROUGH IV

Basis: Temperature = 49°F
Packing Type = 2-inch Jaeger Tripacks

WATER FLOW (GPM)	A/W	PACKING DEPTH	TCE INLET (PPB)	TCE OUTLET (PPB)
1,750	95	23 feet	820 1,000 1,200 1,500	3.2 3.9 4.7 7.0
1,750	95	25 feet	1,500 1,800 2,000 2,200	3.6 4.3 4.8 5.3
1,750	95	28 feet	2,200 3,000 4,000 4,200 4,300	2.6 3.5 4.7 4.9 5.1

FIGURE



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KELLOGG – DEERING
WELLFIELD
NORWALK, CONN.

ALLOWABLE COMBINED CONCENTRATIONS: LAYNE 1 / DEERING 1 AND DEERING 2

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FIGURE No. 1

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