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# Airlift Recirculation Well Test Results- Southern Sector

by
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**R.M. White and R. A. Hiergesell**

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# AIRLIFT RECIRCULATION WELL
# TEST RESULTS - SOUTHERN SECTOR

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## Abstract

Chlorinated solvents used in the A and M-Areas at the Savannah River Site (SRS) from 1952 - 1982 have contaminated the groundwater under the site. A plume of groundwater contaminated with trichloroethylene (TCE) and perchloroethylene (PCE) in the Lost Lake aquifer is moving generally southward with the natural flow of groundwater. To comply with the requirements of the current SCDHEC Part B Permit, a series of wells is being installed to contain and treat the plume. Airlift Recirculation Wells (ARW) are a new and innovative technology with potential for more cost effective implementation than conventional pump and treat systems. Two Airlift Recirculation Wells have been installed and tested to quantify performance parameters needed to locate a line of these wells along the leading edge of the contaminant plume. The wells proved to be very sensitive to proper development, but after this requirement was met, performance was very good. The Zone of Capture has been estimated to be within a radius of 130 - 160 ft. around the wells. Thus a line of wells spaced at 250 ft. intervals could intercept the contaminant plume. At SSR-012, TCE was stripped from the groundwater at approximately 1.2 lb./day. The longer term effect of the recirculation wells upon the plume and the degree of recirculation within the aquifer itself will require additional data over a longer time period for an accurate review. Data collection is ongoing.

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## Introduction

Metal finishing operations at the Savannah River Site (SRS) A/M-Area utilized chlorinated solvents for degreasing and cleaning activities from the 1950's to the 1980's. From 1952 to 1982 an estimated 13 million pounds of chlorinated solvents, primarily trichloroethylene (TCE) and perchloroethylene (PCE), were used in the M-Area. Much of this solvent evaporated during use but residual solvent was discharged to a process sewer system. Approximately two million pounds are estimated to have been released to the M-Area Settling Basin. Another one and one-half million pounds may have been released to the A-014 outfall.

TCE and PCE were first identified in the local groundwater in 1981. Pump and treat technology was initiated in 1983 and continues today. Hazardous materials in the M-Area Settling Basin have been stabilized and the basin has been capped and closed. The TCE and PCE plumes in the groundwater are well characterized and continue to be monitored. The M-Area RCRA Part B permit allows implementation of innovative technologies for the characterization and treatment of DNAPL (Dense Non-Aqueous Phase Liquid) dissolved plumes and soil contamination in the A/M-Areas.

The Part B Permit for the M-Area Hazardous Waste Management Facility requires the contaminant plume to be hydraulically controlled at the 500 ppb isoconcentration location. The groundwater plume continues to develop and flow with the general groundwater movement in a south to southeasterly direction. The plume has moved downward into a confined aquifer (the Lost Lake aquifer) and is continuing generally southward into the southern part of the A/M-Area (the Southern Sector). This area is undeveloped and heavily forested. Airlift Recirculation Well (ARW) technology was chosen for use in this area because of its technical potential and because it treats the groundwater without bringing it to the surface. This eliminates the need to create and permit an outfall for the treated water discharge.

A regional groundwater flow model of the A/M-Areas (FACT) was used to estimate the location of the leading edge of the 500 ppb isoconcentration contour of the TCE plume. The 500 ppb isoconcentration contour has a concave shape with fingers protruding down gradient at each side. The two leading fingers are approximately one half mile apart. The objective of this study was to install and test recirculation wells in each of the two "fingertips" and to determine the following information:

- the feasibility of using recirculation well technology to control the contaminant plume at the 500 ppb isoconcentration line;
- operating data necessary for preparation of the revised Corrective Action Plan for this area;
- operating information necessary for the detailed design and construction of additional recirculation wells;
- the recirculation well zone of capture;
- the recirculation well zone of influence;
- the maximum well spacing for effective plume control;
- the in-well vapor stripping efficiency of the wells;
- the overall treatment efficiency of the wells relative to the contaminated plume; and
- the effect of the vacuum system on the well operation.

Two recirculation wells (SSR-001 and SSR-012) were installed in the Lost Lake aquifer in 1996. A piezometer cluster was located upgradient and downgradient of each recirculation well for observing groundwater levels and for taking groundwater samples. Each cluster consisted of one 2" PVC casing screened in the top of the Lost Lake aquifer (the "C" well) and one 2" PVC casing screened in the bottom of the Lost Lake aquifer (the "B" well). The piezometers were spaced on 10' lateral centers. The piezometer clusters at well SSR-001 were spaced equally, 20' upgradient and 20' downgradient (reference Figures 1).

The upgradient piezometer cluster at well SSR-012 was located 30' from the recirculation well and the downgradient piezometer cluster was located 20' from the recirculation well (reference Figure 2). This was simply to provide an additional point of reference for the data.

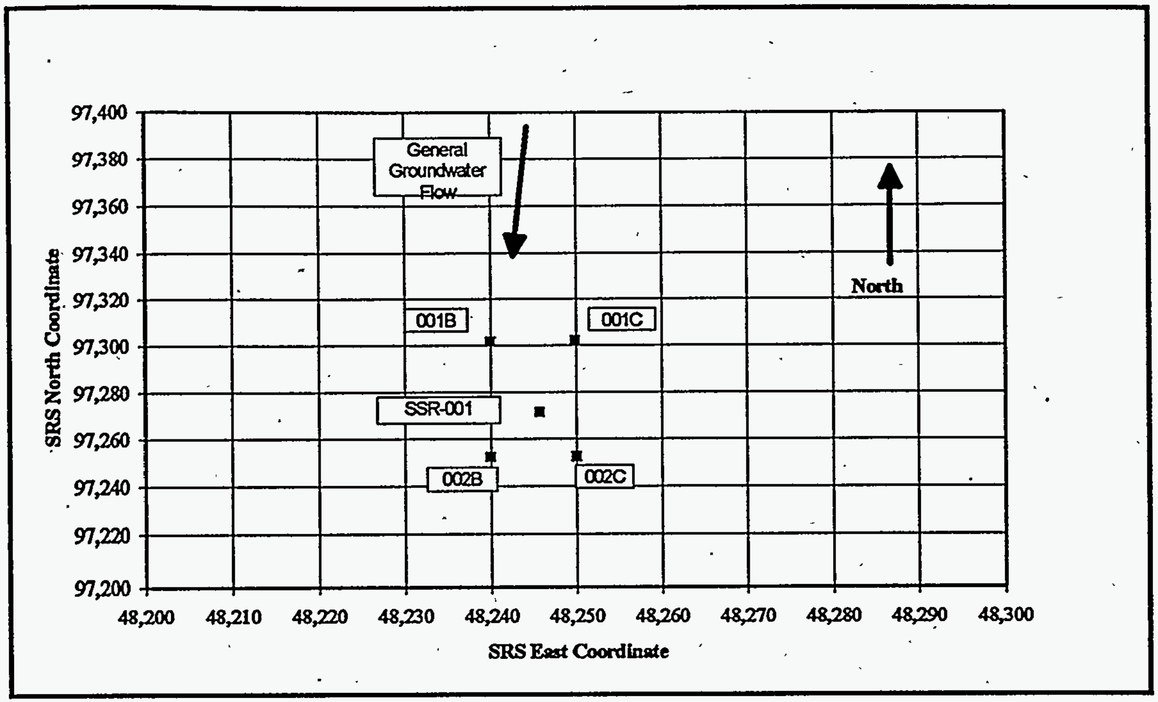

Figure 1: SSR-001 Piezometer locations

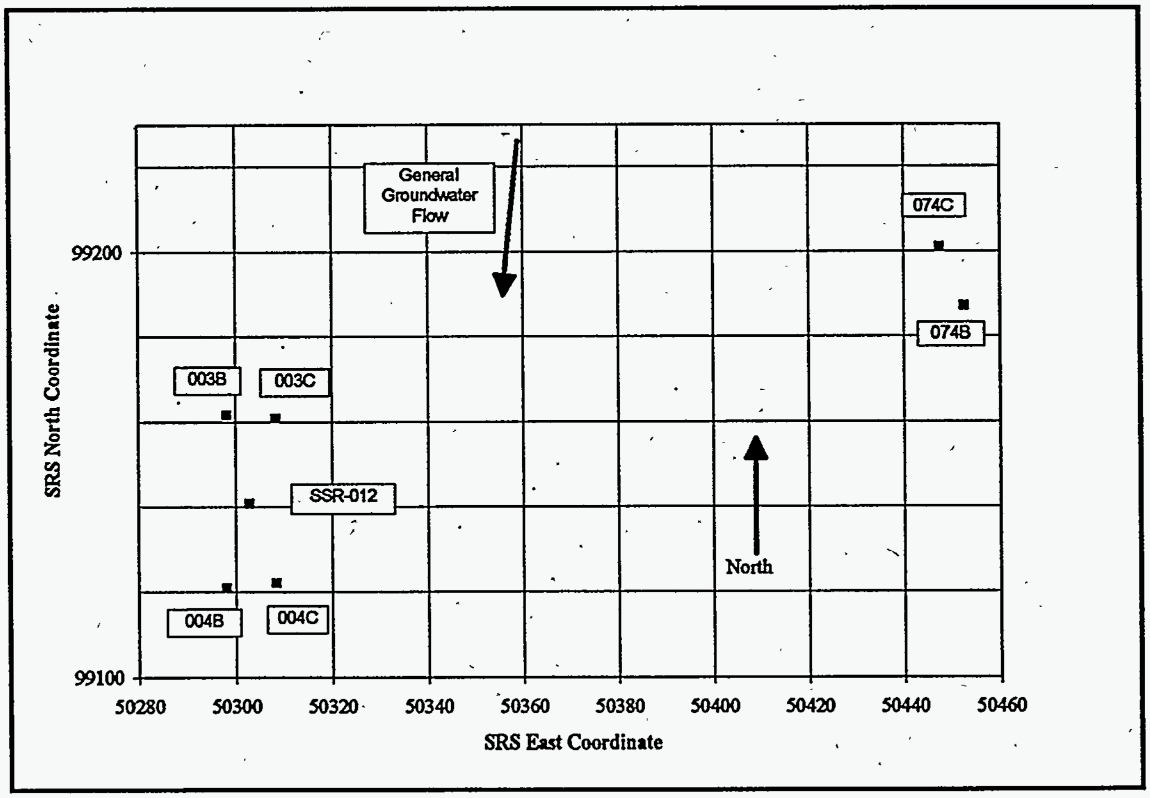

Figure 2: SSR-012 piezometer locations

The recirculation well itself consists of an 8″ schedule 80 PVC well casing with two separate ten foot screen zones; one at the top of the aquifer and one at the bottom of the aquifer (reference Figure 3). The screens are PVC with 0.020 in. machined slots. The casing was grouted in place with gravel pack at each screen and a bentonite seal between the screens. An airlift pump was constructed from 4″ schedule 40 PVC well casing and a 1″ schedule 80 PVC air line. The 4″ casing was installed inside the 8″ casing with an inflatable packer to isolate the annulus between the two 8″ screen zones. The bottom of the 4″ casing (pump inlet) was placed just above the 8″ screen at the bottom of the aquifer. A five foot long screen was placed in the 4″ casing such that the bottom of the screen was eight feet above the potentiometric head in the top of the aquifer. This is the airlift pump outlet and the discharge height was based upon results of pumping tests conducted with an airlift recirculation well at the TNX area of SRS. The 1″ airline was installed in the 4″ well casing with a discharge diffuser located seven feet above the bottom of the 4″ casing.

A duplex, oil-free air compressor package was installed at each recirculation well to provide compressed air. The compressor package was rated at 110 cfm at 125 psi. A vacuum system was also installed. The vacuum system is a commercial soil vapor extraction system and was installed for development work. Because of the remote location of the recirculation wells, there are no utilities available. To expedite testing of the wells, portable generators were installed at each well site. The generators used were surplus SRS construction generators. Although convenient and inexpensive, they proved to be unreliable. After several outages, they were replaced with rental units from a local supplier. These units ran continuously and were relatively troublefree. With one well currently in full time service, the rental generators have been replaced with a new SRS generator which has also operated reliably.

Aquifer response to the operation of the recirculation wells was observed by measuring the water level at each of the piezometer clusters and at various existing monitoring wells (e.g. MSB-074). A Grundfos sample pump was installed in each piezometer to allow water samples to be taken for analysis. Purge water taken during pumping was passed through a portable analyzer to measure dissolved oxygen, temperature, conductivity, pH and oxidation potential. Water samples were analyzed using a gas chromatograph for TCE and PCE concentrations.

Gas samples were taken from the air supply line and from the exhaust stack at each recirculation well and analyzed for TCE and PCE concentrations.

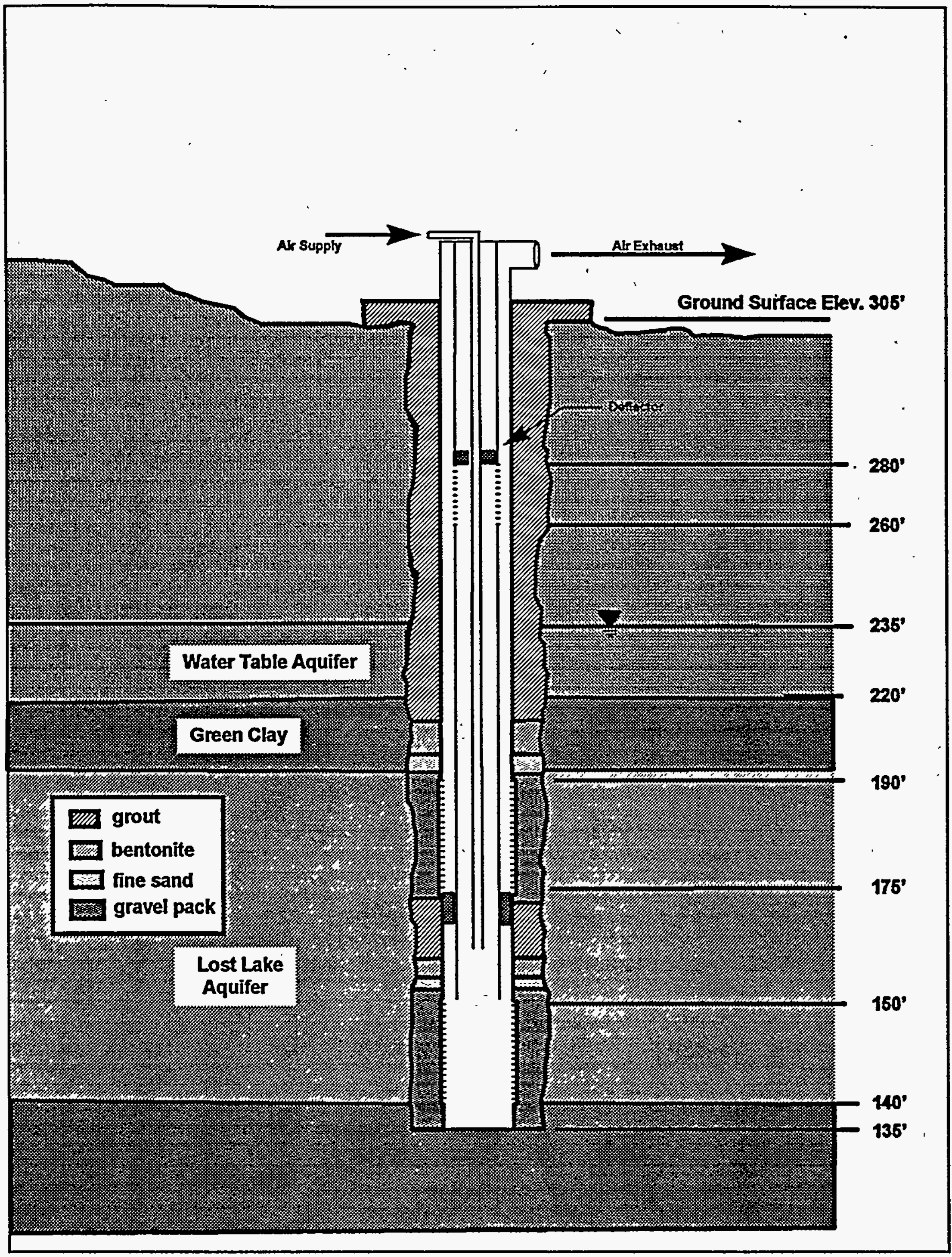

Figure 3: Recirculation well diagram

## Results & Discussion

### *Operating Results*

The two recirculation wells were started up in December, 1996. Initial results showed a modest decrease in the potentiometric head at the bottom of the aquifer and a small mound at the top of the aquifer. Unfortunately, the generators being used for power proved unsuitable for long term reliable operation. Repeated outages for one failure or another made it difficult to evaluate the data being collected. Each time the generator failed, the recirculation well would be out of service for between a few hours to a few days. Towards the end of January, 1997, these generators were replaced with rental units which proved to be much more reliable.

The data obtained in February and March of 1997, although representative of a more consistent operating regimen, did not show the same type of hydrologic response in the aquifer that the first several weeks of operation demonstrated. Significant drawdown in the bottom of the Lost Lake aquifer was not evident; nor was a significant mound present in the top of the aquifer. To investigate this lack of response a falling head test was attempted in the outer annulus of SSR-001 for comparison with a similar test performed prior to placing the well in service. The water discharged from the 4" airlift pump flowed down this annulus and out into the aquifer. During the falling head test, potable water from a tank truck is allowed to flow into the outer annulus at a constant rate. A relationship can be developed between the water level and the flow of water. This relationship is discussed in detail in the well pumping analysis section. In this particular case, the water rapidly filled the well, indicating that the upper screen was plugged. Further review of the hydrologic data indicated that the upper screen probably plugged after only a few weeks of operation. A similar test at SSR-012 confirmed that well was also plugged.

At this point a decision was made to focus on one well; SSR-012. This well was chosen because it is located in a more contaminated portion of the groundwater plume and because of its proximity to the MSB-074 monitoring well cluster which offers additional water quality sampling points.

The 4" airlift pump was removed from the well and the upper and lower screen zones were aggressively redeveloped. Both zones were swabbed and pumped until clean water was produced with turbidity values of less than 5 NTU (Nephelometric Turbidity Units). This is comparable to drinking water clarity.

When the well was returned to service, it's performance was significantly improved. A stable 15-18' drawdown was obtained at the bottom of the recirculation well. A 5-7' mound was established at the top of the well. A similar pattern was observed at the nearby piezometers and at MSB-074. The drawdown at MSB-074 B (157' away from the recirculation well) was 4" and the mound was 1" high as measured at MSB-074C (reference Figure 4 in the Appendix). This suggests that the Zone of Capture extends at least to well MSB-074 and perhaps further.

With the additional pumping efficiency of the well, the exhaust air emissions increased from 1-2 ppm of TCE to 50-60 ppm at the exhaust stack. At current rates TCE is being stripped from the groundwater at about 1.2 lb./day. This is illustrated in Figure 5 in the Appendix.

### *Groundwater Quality*

Prior to placing the wells in service, a baseline of water quality in the piezometer clusters was established. The TCE concentration around well SSR-001 was about as expected; approximately 400 ppb in the bottom of the aquifer and approximately 17 ppb at the top of the aquifer. However at well SSR-012, TCE was found in excess of 10,000 ppb in the bottom of the aquifer and approximately 4,000 ppb at the top of the aquifer. Monitoring well cluster MSB-74 is approximately 157 feet to the east of SSR-012. Routine samples taken in February, 1996 indicated TCE concentrations of 588 ppb at MSB-074B and 7 ppb at MSB-074C. Historical data indicates a decreasing TCE concentration at both wells. A possible explanation for this variance might be preferential pathways in the Lost Lake aquifer from the M-Area or from the A-014 outfall.

### *Analysis of TCE Data*

Analytical results from groundwater sampling are included in the Appendix as Figures 6-10. The data shows that the TCE concentration in the bottom of the aquifer is approximately 2.5 - 3 higher on the downgradient side of the recirculation well. The most probable explanation of this is that the contaminant plume exists in a stratified configuration as opposed to being a uniform plume fully diffused across the depth of the aquifer. The more concentrated core of this plume is flowing somewhere along the middle of the aquifer and dips downward in the area of the recirculation well. When the recirculation well is in operation it creates a relatively strong downward gradient in the aquifer. It seems reasonable to expect the plume to adjust to these changing gradients as it encounters them.

Another trend evident in the data is a small increase in the concentration of TCE at the top of the aquifer. This seems particularly evident immediately after the well is restarted or after the air flow has been increased. In the immediate vicinity of the recirculation well, the water at the top of the aquifer starts out at ambient conditions, but as water is pumped from the bottom of the aquifer and discharged into the top of the aquifer, the top of the aquifer becomes a mixture. Over time the mixture should approach the same conditions as the water being discharged from the recirculation well. Generally, the contaminant concentration in the plume is greater at the bottom of the aquifer and as this water is pumped to the top of the aquifer it may increase the average TCE concentration. As recirculating flow is established in the aquifer and contaminant mass is removed, this trend may reverse indicating that groundwater is being recycled through the recirculation well more than once.

### *Analysis of D.O. Data*

The dissolved oxygen levels of groundwater samples are included in the Appendix as Figures 11-15. The time period over which this data has been gathered is not sufficient to draw firm conclusions. However, we can generally say that the D.O. level at all wells, with the possible exception of SSM-002C, has increased over time. Now that it has been established that both wells were plugged and operating at a small fraction of their potential flow for much of the time, it is difficult to be sure that this trend is related to the recirculation well. It does appear that after SSR-001 was shut down, the D.O. level in the top of the aquifer began to decline. This also occurred at SSM-003 and 004 when SSR-012 was shutdown for redevelopment. After SSR-012 was restarted, D.O. began to rise again. If this is due to operation of the recirculation well, the D.O. level at the top of the aquifer may begin to approach that of the bottom of the aquifer over time.

### *Well Pumping Analysis*

Before the recirculation wells were placed in service, tests were completed to establish a correlation between the water level in the annulus of the well, above the upper screen in the outer casing with flow of water into the aquifer. Groundwater flow in the recirculation wells is into the bottom screen of the outer casing at the bottom of the aquifer, up the inside of the 4″ airlift pump casing (with the flow of air), out the upper 4″ screen into the top of the outer casing (above the packer), down the annulus between the 8″ outer casing and the 4″ airlift pump casing and finally out through the upper 8″ screen into the top of the aquifer. To establish a means of measuring water flow out of the upper screen, a relatively constant flow of potable water was introduced into the outer annulus and the resulting water level was monitored. At an initial flow of 5 gpm, the water level in the outer annulus stabilized at about 1.6 feet. Although the tanker ran out of water before this test could be completed at a flow rate of 17 gpm, the data indicates that (at 17 gpm) the water level would have reached about 6 feet above the static water level in the aquifer (reference Figure 16 in the Appendix).

After redeveloping SSR-012, the test procedure was modified to use a pressure transducer for water level measurement in the well annulus. In lieu of introducing water into the well, the well was operated at a high air flow rate

(>65 cfm at the inlet). When the water level appeared stable, the air was shutoff and water level was recorded as it dropped (reference Figure 17 in the Appendix). This method provided a large amount of discrete data points. These data points were used to calculate the rate of change in water level at many discrete levels as the water level dropped. By relating the rate of change in water level to a corresponding incremental change in annular volume, the flow rate could be calculated.

By establishing a similar correlation between air flow into the well and the steady state water level in the annulus, a nomograph was created for use in determining water pumping rate with air flow rate. This nomograph has been included in the Appendix as Figure 18. The results indicate an order of magnitude increase in the recirculation well water flow after redevelopment.

Air samples were taken periodically and the results are shown in Table 1.

Table 1: SSR-012 Exhaust Gas Analysis

| Date | Exhaust air flow | Air TCE Conc. (ppmv) | TCE Discharged (lb./hr) | TCE Discharged (lb./day) |
|---|---|---|---|---|
| 2/11 | 35 | 1.70 | 0.0012 | 0.03 |
| 2/25 | 50 | 1.08 | 0.0011 | 0.03 |
| 2/27 | 50 | 1.21 | 0.0012 | 0.03 |
| 4/24 | 88 | 35.54 | 0.0628 | 1.51 |
| 4/24 | 45 | 47.99 | 0.0434 | 1.04 |
| 4/24 | 28 | 53.45 | 0.0300 | 0.72 |
| 4/25 | 35 | 54.83 | 0.0385 | 0.92 |
| 4/28 | 30 | 60.51 | 0.0364 | 0.87 |
| 5/1 | 40 | 60.98 | 0.0490 | 1.18 |
| 5/5 | 46.5 | 58.78 | 0.0549 | 1.32 |
| 5/19 | 38 | 53.70 | 0.0410 | 0.98 |
| 5/20 | 45 | 54.87 | 0.0496 | 1.19 |
| 5/29 | 50 | 58.47 | 0.0587 | 1.41 |

Contaminant levels in the samples from SSR-001 were below quantifiable detection. As would be expected, the emission rates at SSR-012 are much higher than at SSR-001 due to the higher than expected TCE concentration in the groundwater. Although the emission rate is about ten times higher than expected, it is still much lower than permissible exposure limits and within the permit assumptions.

The optimal operating point for the air compressors and the recirculation well was approximately 35 cfm (exhaust flow). This stripped about 1.2 lb./day of TCE from the groundwater.

*Aquifer Analysis*

Subsequent to the redevelopment of SSR-012, water level measurements were made at MSB-074C while water was being pumped from the lower screen of the recirculation well. This data was used to calculate the horizontal conductivity and other aquifer parameters. Additional hydraulic response data gathered over the past several months was analyzed with AQTESOLVE software (a groundwater analysis tool) to obtain an estimate of the vertical conductivity. The ratio of horizontal to vertical hydraulic conductivity is referred to the anisotropic ratio. A high anisotropic ratio means that groundwater will flow much more easily in a horizontal path than in a vertical path. With a recirculation well, a high anisotropic ratio means that the zone of capture should be larger but less water will actually return to the bottom of the aquifer to be recirculated through the well. At SSR-012, the calculated anisotropic ratio is about 18. Normal practice has been to use a value of about 10 for aquifers similar to the Lost Lake aquifer, so this was a little higher than expected.

Table 2: Southern Sector Aquifer Parameters

| Parameter | Value |
|---|---|
| Aquifer thickness | 54 ft. |
| Grain size | V. fine to v. coarse sand, predominantly fine to medium |
| Sediment type | sub-mature quartz sand |
| Porosity | 0.15 - 0.25 |
| Horizontal hydraulic conductivity | 25.8 ft/day |
| Vertical hydraulic conductivity | 1.43 ft/day |
| Anisotropic ratio | 18 |
| Horizontal Darcy velocity | 0.19 ft/day |

In an attempt to quantify the zone of capture, a simple groundwater flow model was created on a spreadsheet using vector addition of components of the groundwater flow. The components depicted below were calculated individually using groundwater level measurements. Figure 19 in the Appendix illustrates the aquifer response that was observed and the potentiometric heads used to estimate Darcy velocities at various distances from the recirculation well. Darcy velocity was calculated as follows:

$$\text{Darcy velocity} = \frac{K_H}{n} \text{ X } \frac{dh}{dl} \qquad \{\text{Equation 1}\}$$

where,

$K_H$ = horizontal hydraulic conductivity

$n$ = porosity of the aquifer, and

$\frac{dh}{dl}$ = potentiometric gradient.

First, the Darcy velocity of groundwater flow under undisturbed conditions was calculated from groundwater level measurements made while the recirculation well was out of service and from the horizontal conductivity previously calculated at 25.8 ft/day. Porosity was assumed to be 0.2. Using these values, the Darcy velocity, or average pore velocity, was calculated to be 0.19 ft/day. The direction of natural groundwater flow was assumed to be directly south.

Next, the resultant groundwater velocity due to airlift pumping at SSR-012 ($V_R$) was calculated from the difference between water level measurements taken while SSR-012 was both in and out of service. The following sketch illustrates the methodology of the vector additions necessary.

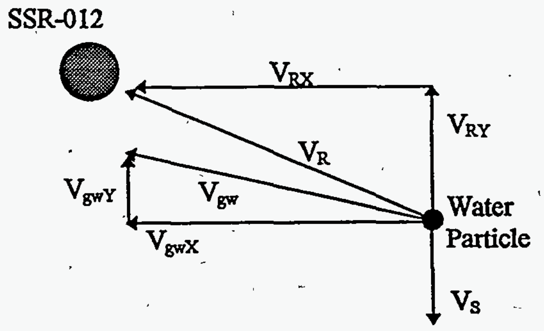

Figure 20: Particle tracking by vector analysis.

$V_R$ = the resultant groundwater velocity component due to drawdown at SSR-012 from airlift pumping

$V_{RX}$ = the groundwater velocity component due to drawdown at SSR-012 in the X direction (west is positive)

$V_{RY}$ = the groundwater velocity component due to drawdown at SSR-012 in the Y direction (south is positive)

$V_S$ = the groundwater velocity component due to natural flow (south is positive)

$V_{gw}$ = the resultant groundwater velocity

$V_{gwX}$ = the X component of the net groundwater velocity

$V_{gwY}$ = the Y component of the net groundwater velocity

where:

$V_{gw} = V_{gwX} + V_{gwY}$

$V_{gwX} = V_{RX}$

$V_{gwY} = V_{RY} + V_S$

The model was created by first developing a relative drawdown curve based upon the water levels measured in the piezometers surrounding SSR-012. Groundwater elevations were plotted vs. distance from the recirculation well to characterize the cone of depression. Additional estimated observations were then added at distances in between the actual piezometers to generate a smoother curve.

At each of these data points, dh was calculated as the difference in hydraulic head between the data point and the next data point towards the recirculation well. The radial distance to the data point, dl, was also calculated and was used to calculate the potentiometric head (dh/dl). Darcy velocity was next calculated using Equation 1. This yielded an average velocity which was assumed to act at the midpoint between the two points being evaluated. The Darcy velocity at each point was assumed to be the average of the preceding and following velocities.

A separate spreadsheet was used to calculate incremental flow paths for a hypothetical particle of water beginning at MSB-074B. The x and y components of the Darcy velocity due to the recirculation well were combined with the velocity component due to the natural groundwater flow and a travel distance was calculated in the resultant direction for an incremental period of time. Ten days was used for convenience. This step was repeated with adjustments each time to velocity vectors due to changes in position relative to the recirculation well. As the particle of water moved closer to the recirculation well it's velocity increased.

Calculations were repeated for several groundwater velocities using MSB-074B as the starting point. The results are shown in Figure 21 in the Appendix. Note that at a hypothetical groundwater velocity of 2.0 ft/day (well above the natural flow velocity at the site) the groundwater passing through MSB-074B will not be captured by the recirculation well according to this model.

This model is very simple by numerical modeling standards and ignores anisotropy. Nevertheless, it is a useful approach to help in the visualization of groundwater flow patterns in the vicinity of the recirculation well.

Much of the fundamental research performed with recirculation wells can be traced to the work of Herrling in developing the UVB well concept. As an additional step in analyzing the zone of capture, one of Herrling's charts was extrapolated to include higher anisotropic ratios. This chart is replicated in Figure 22 in the Appendix. The chart provides curves of the ratio of maximum well spacing to aquifer thickness (D/H) as a function of dimensionless parameter based upon water pumping rate, aquifer thickness and natural groundwater velocity ($Q/(H^2v)$). Herrling's chart originally included anisotropic ratios of 1,5 and 10. For our purposes an additional curve was added for an anisotropic ratio of 20. The curves for anisotropic ratios of 1,5 and 10 are spaced approximately on a logarithmic ratio. At a point near the middle of the curves a vertical line was drawn and a new point was estimated for an anisotropic ratio of 20. A line with the same general shape of the others was fitted to this point. A value for $Q/(H^2v)$ was then calculated and the corresponding D/H ratio was obtained. From this value the maximum well spacing is 259 feet.

## Conclusions

Although certainly not precise, these methods support a recirculation well spacing of approximately 250 ft. The calculated Zone of Capture is estimated at about a 160 ft. radius, although seasonal changes in groundwater flows could decrease this. The treated water discharged to the top of the aquifer, although not specifically modeled also appears to have a much more narrow range of influence. Variations in aquifer parameters at future well locations could certainly increase or decrease this number as well.

## References

Alesi, E.J., Brinnel, P., Herrling, B., Hirschberger, F., Sick, M.R. and Stamm, J., June 11 - 13, 1991, In Situ groundwater remediation of strippable contaminants by vacuum vaporizer wells (UVB): operation of the well and report about cleaned industrial sites, Third Forum on Innovative hazardous Waste Treatment Technologies: Domestic and International.

# APPENDIX

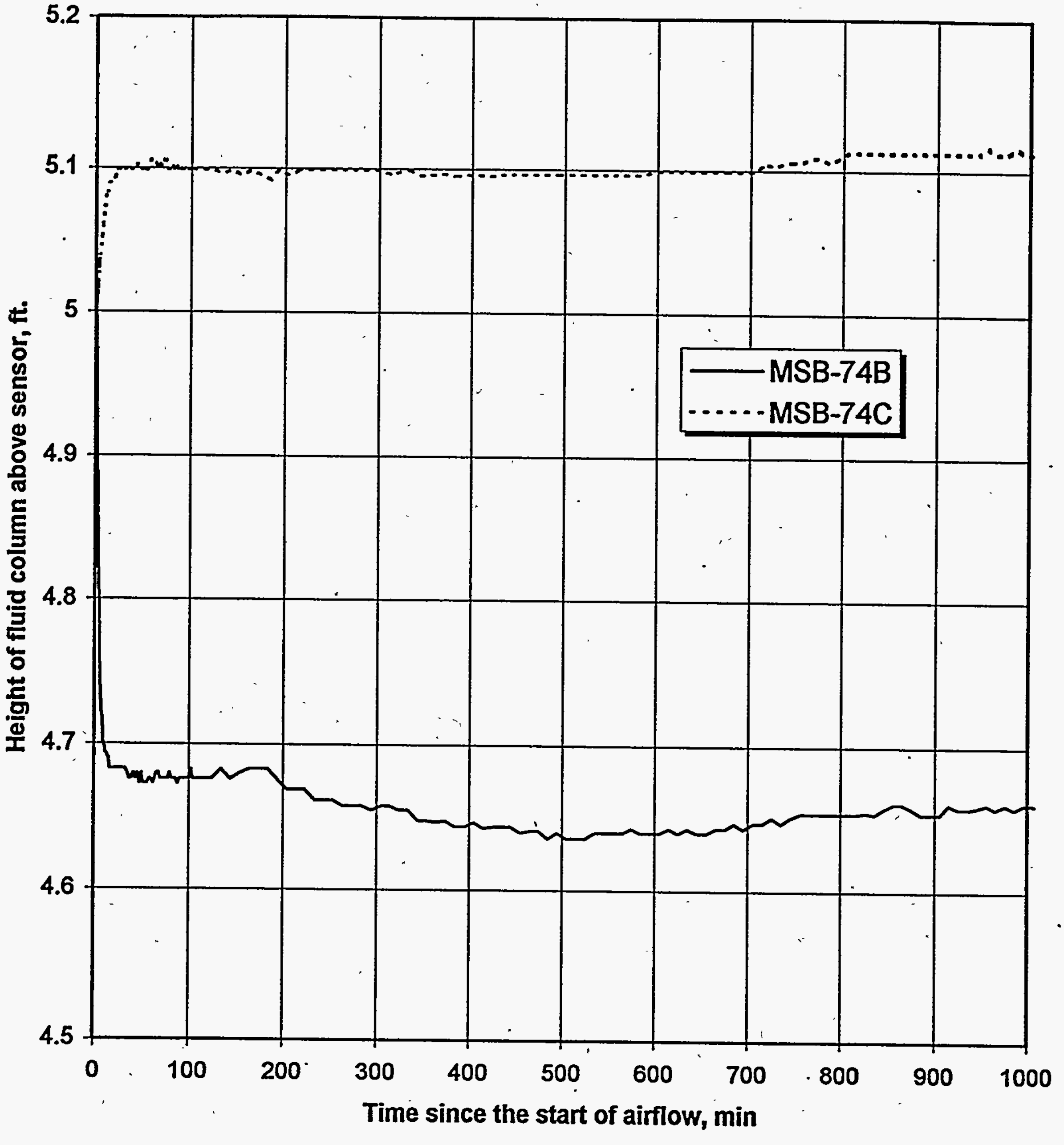

Figure 4: Hydraulic response at MSB-074B and -074C to the operation of SSR-012.

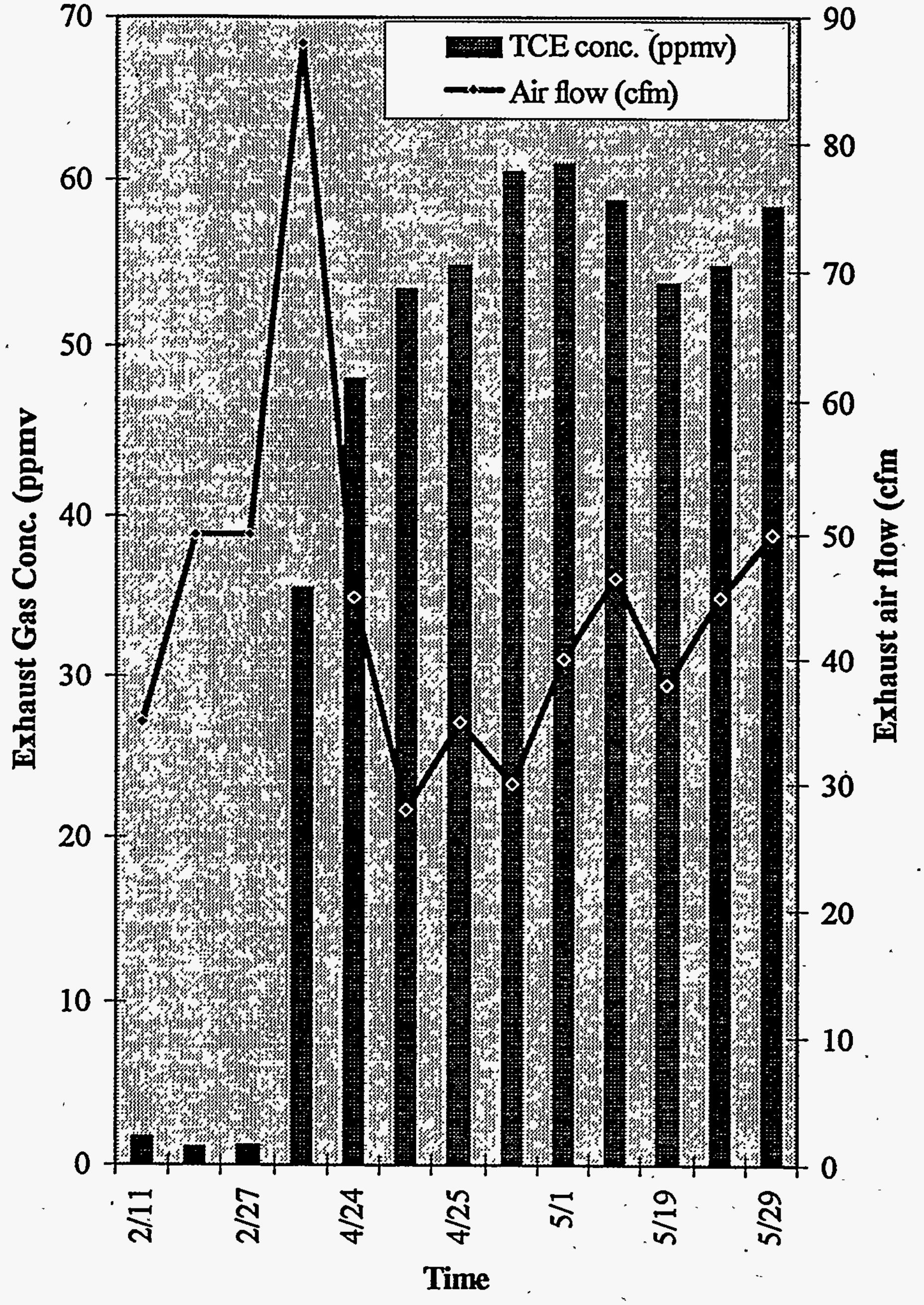

Figure 5:TCE stripped from groundwater @ SSR-012

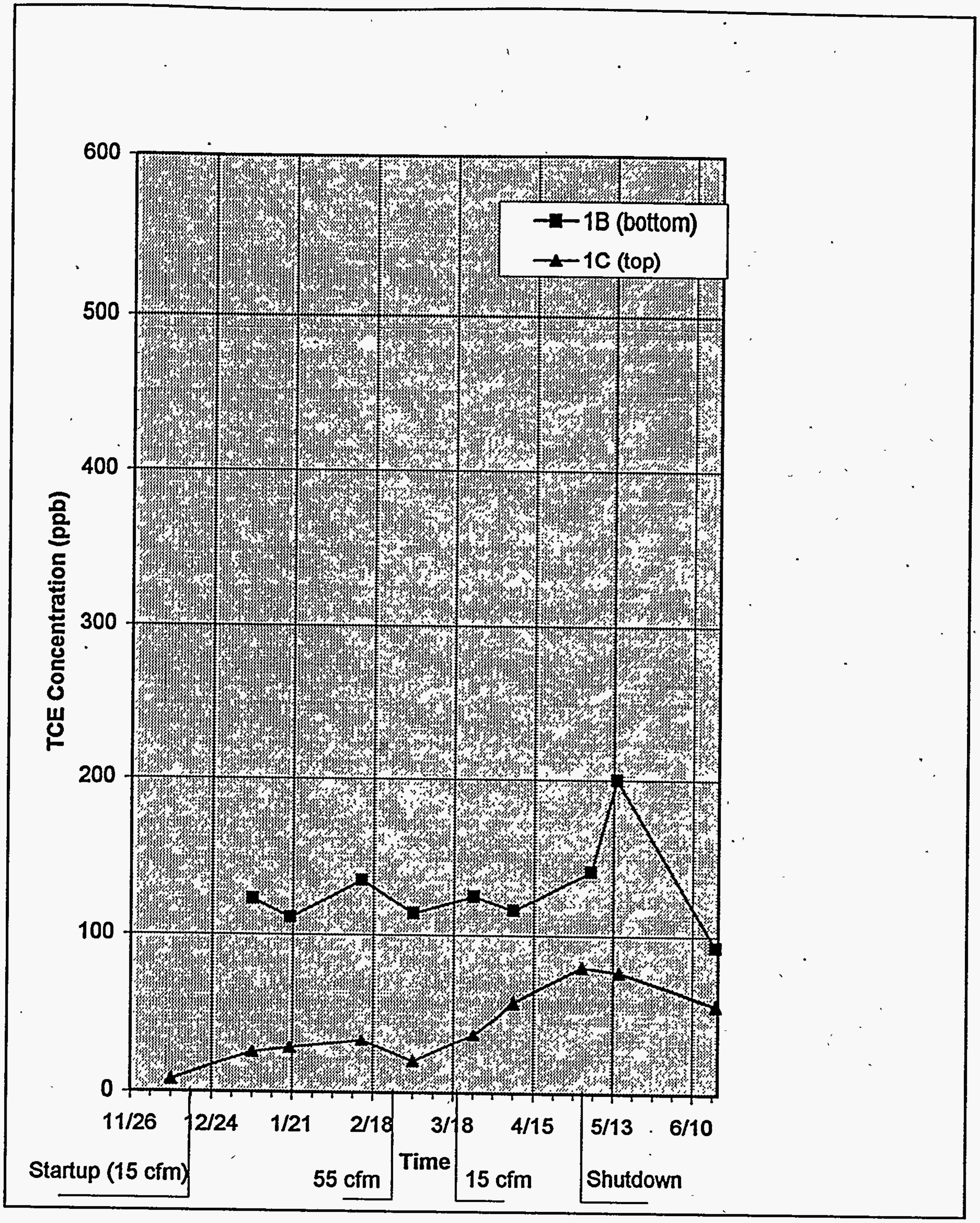

Figure 6: TCE concentration @ SSM-001B & C

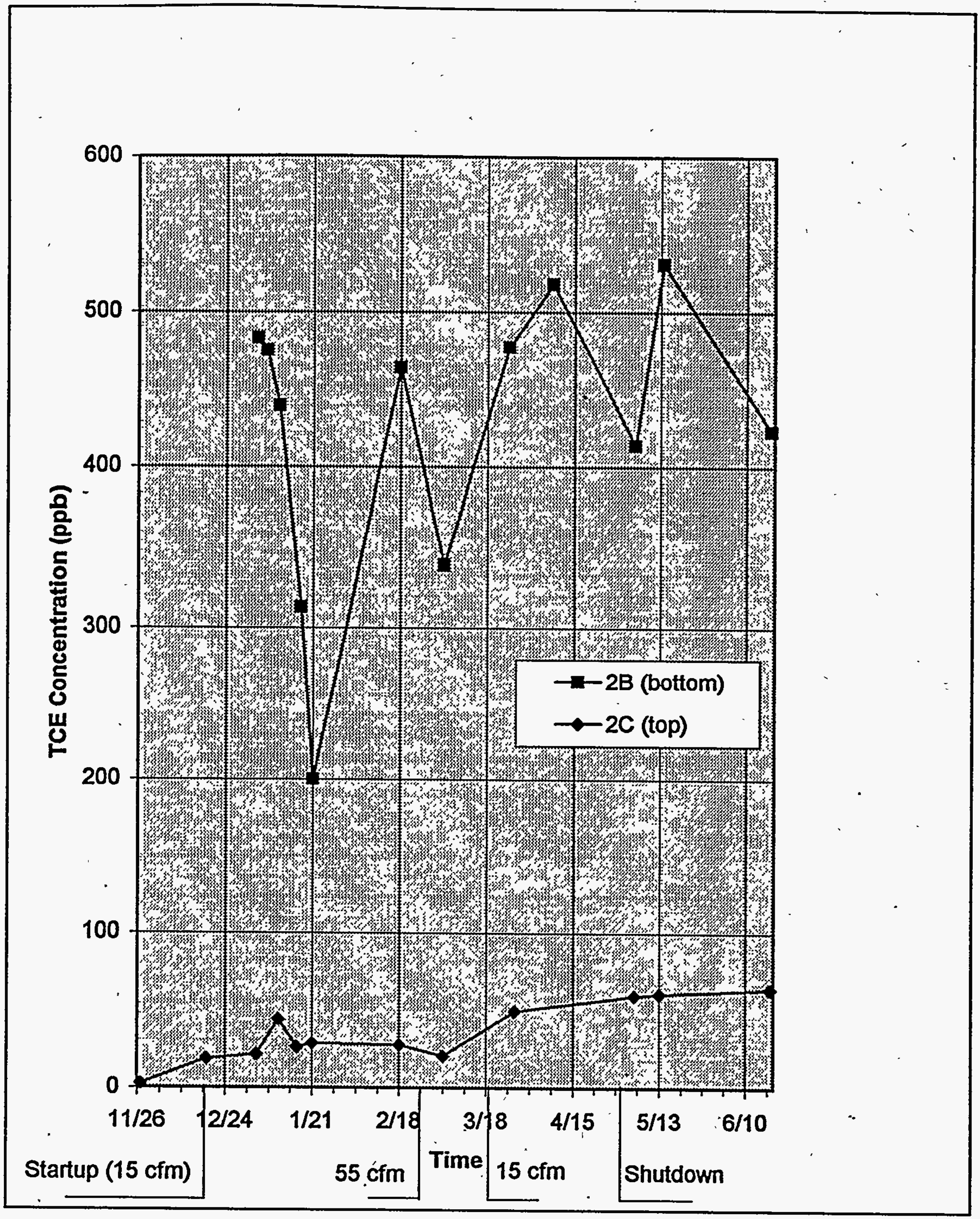

Figure 7: TCE concentration @ SSM-002B & C

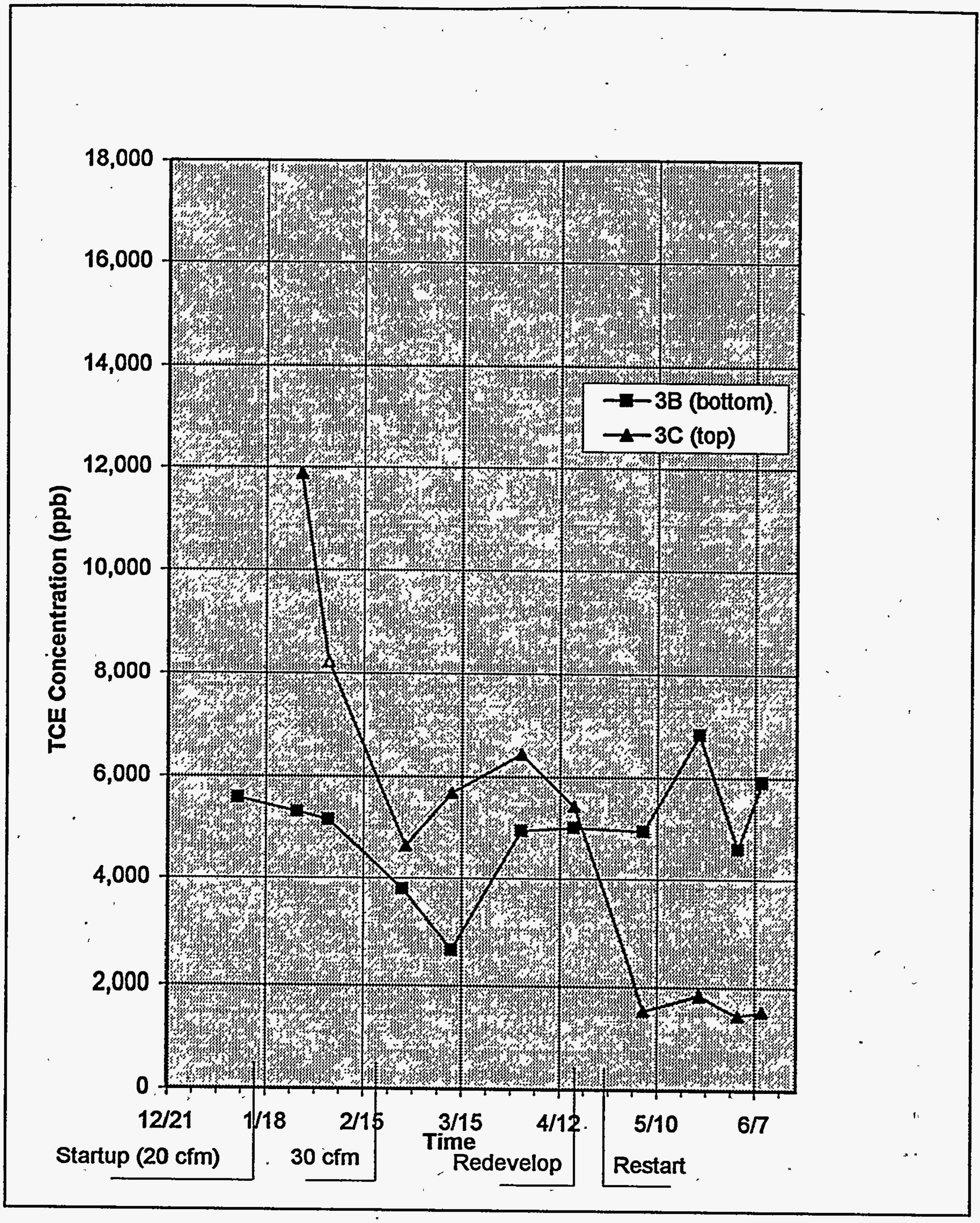

Figure 8: TCE concentration @ SSM-003B & C

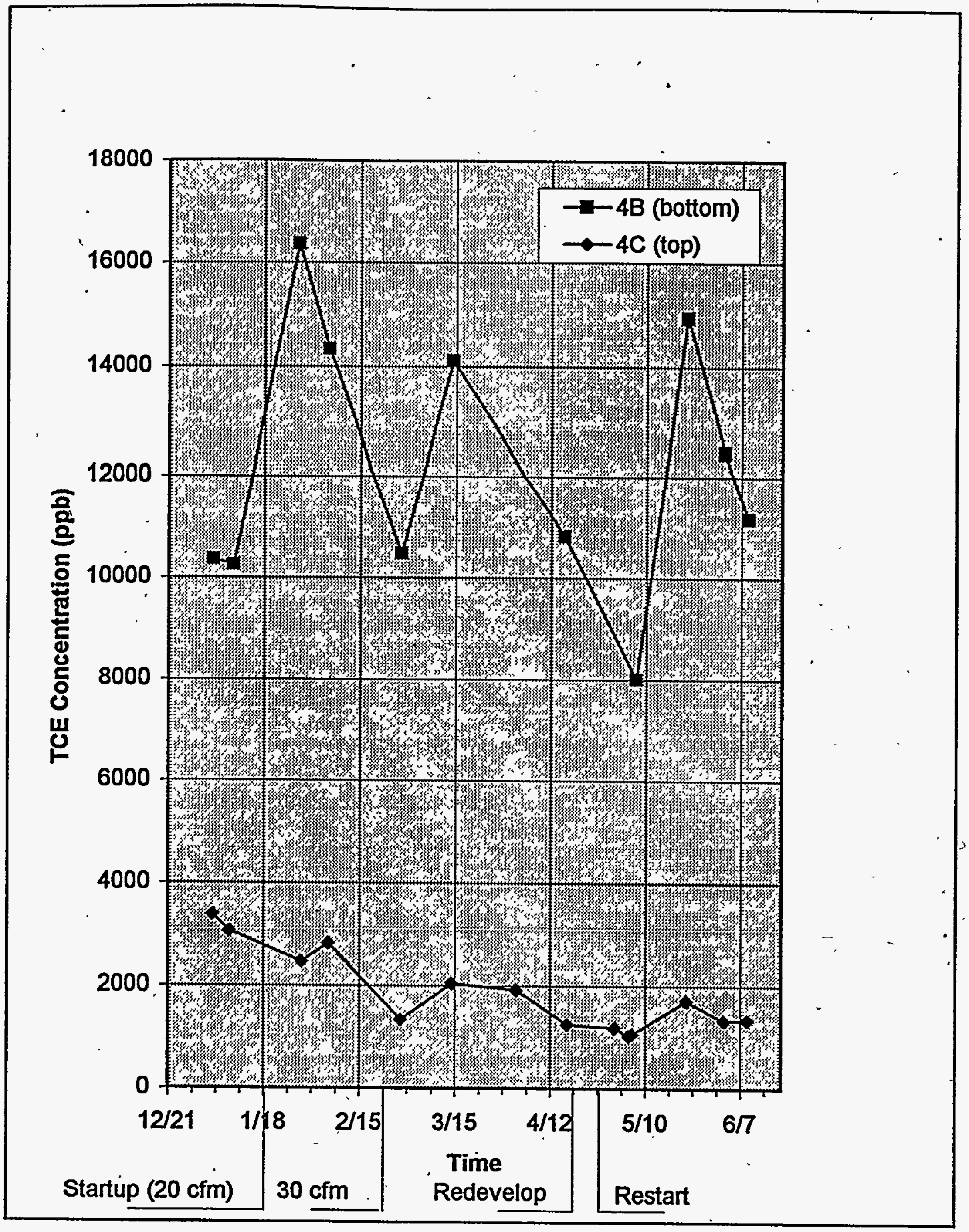

Figure 9: TCE concentration @ SSM-004B & C

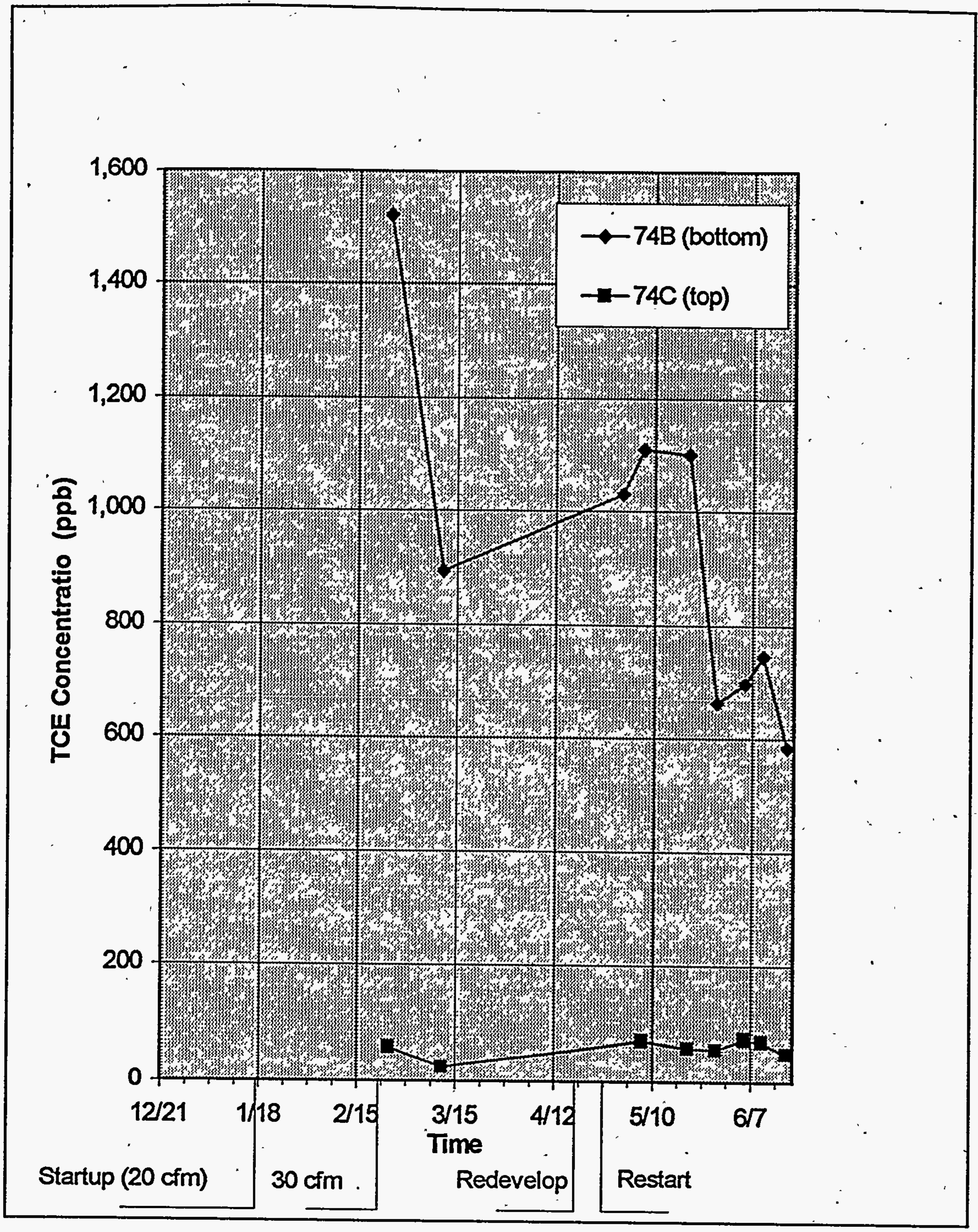

Figure 10: TCE concentration @ MSB-074B & C

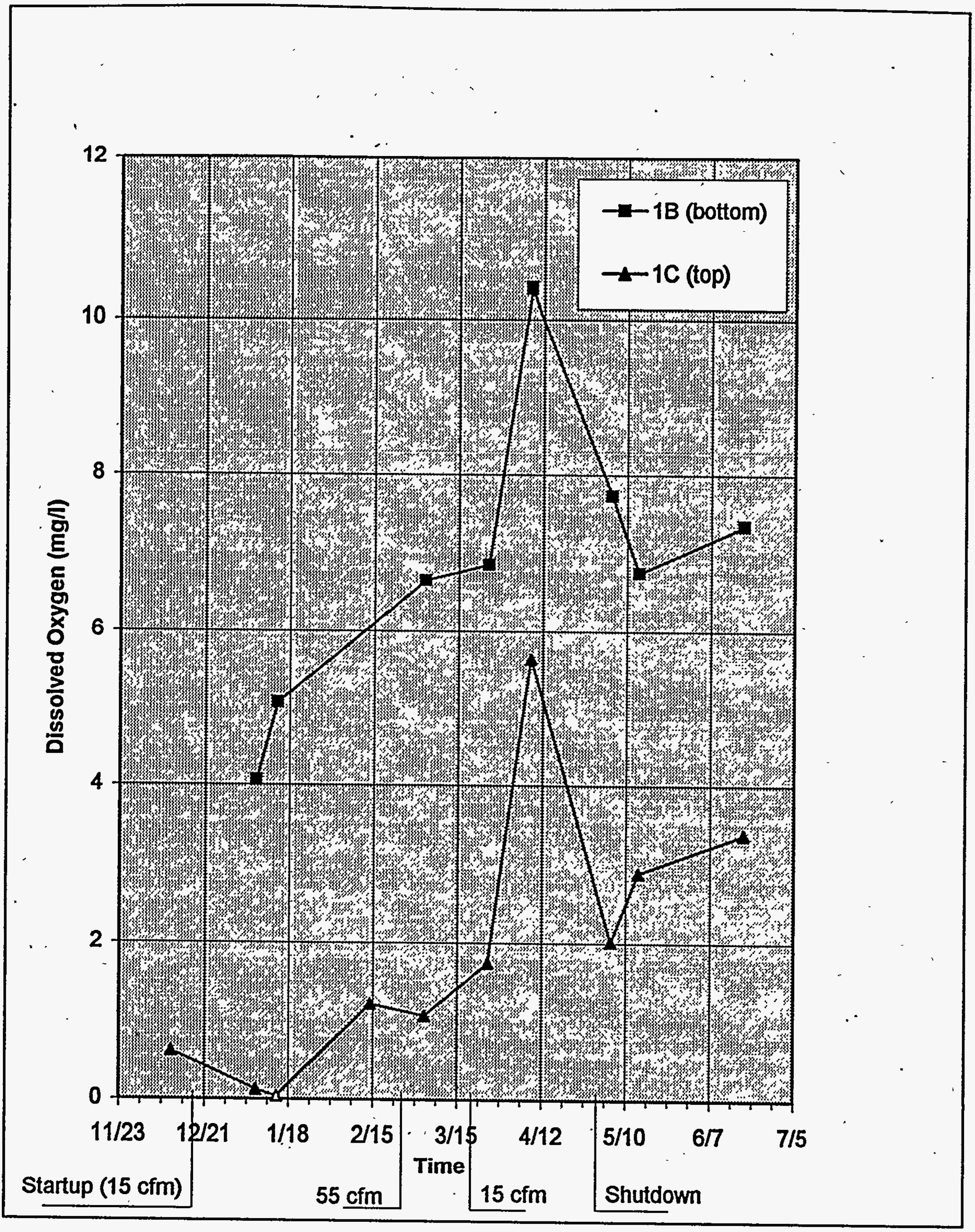

Figure 11: Dissolved oxygen concentration @ SSM-001B & C

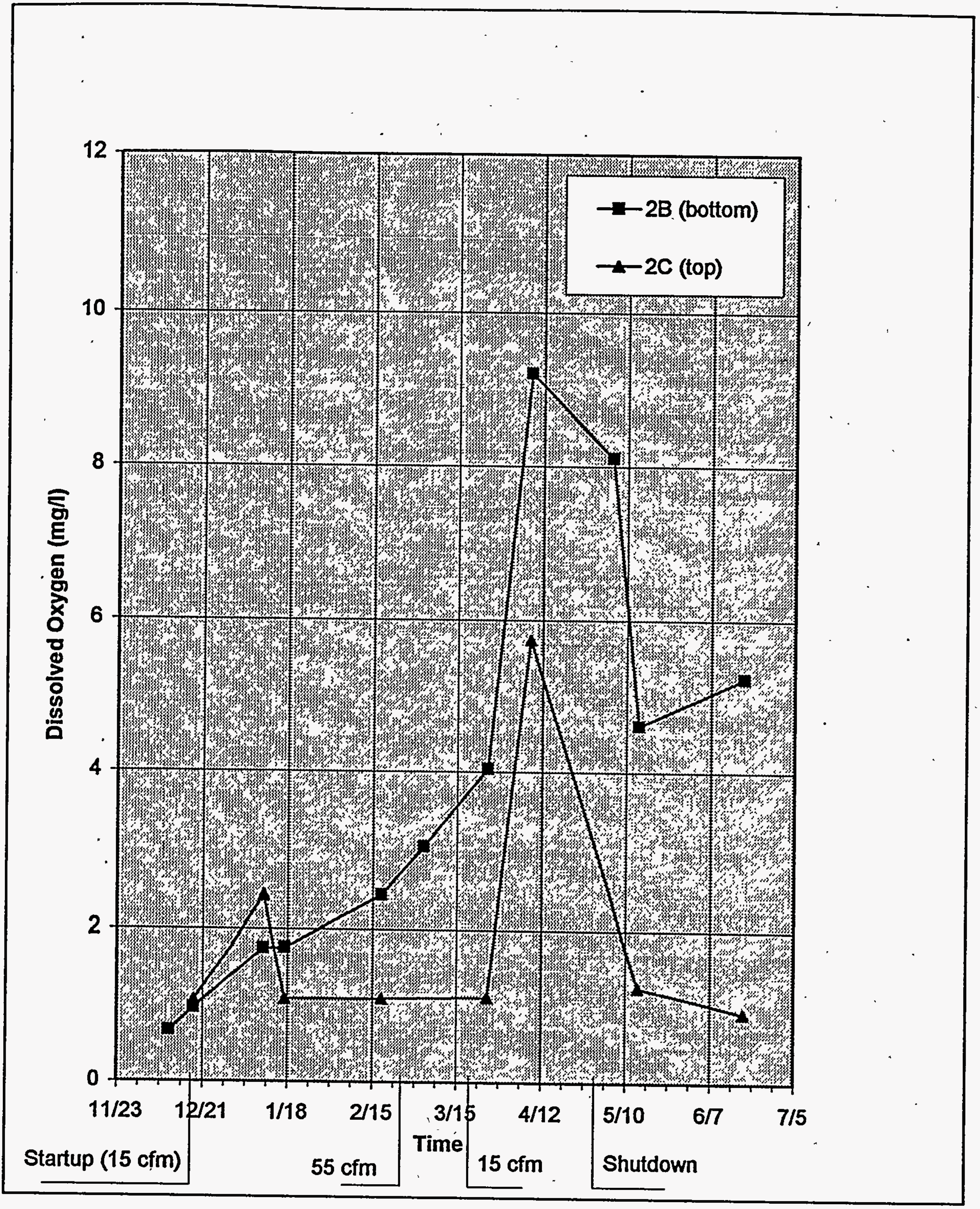

Figure 12: Dissolved oxygen concentration @ SSM-002B & C

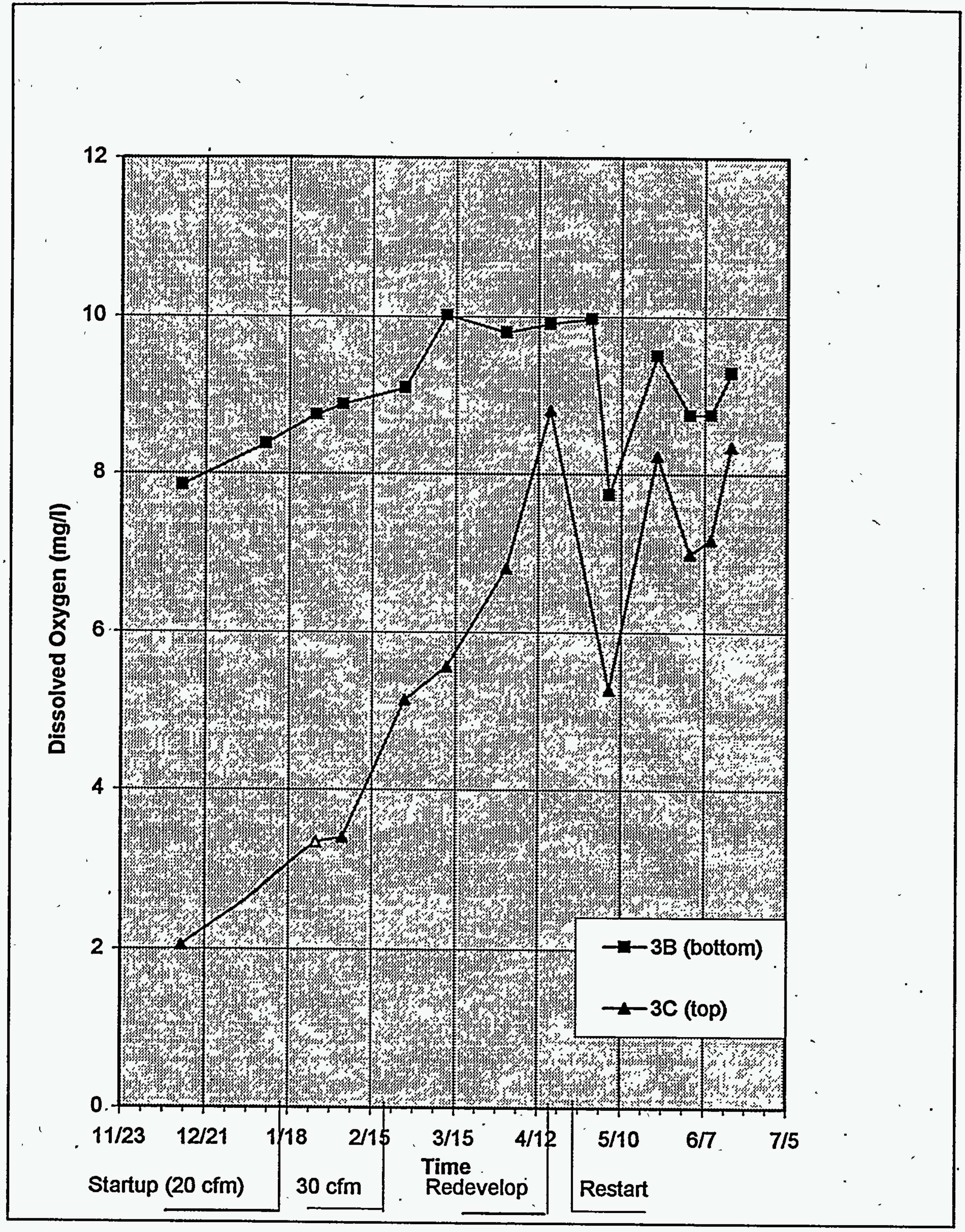

Figure 13: Dissolved oxygen concentration @ SSM-003B & C

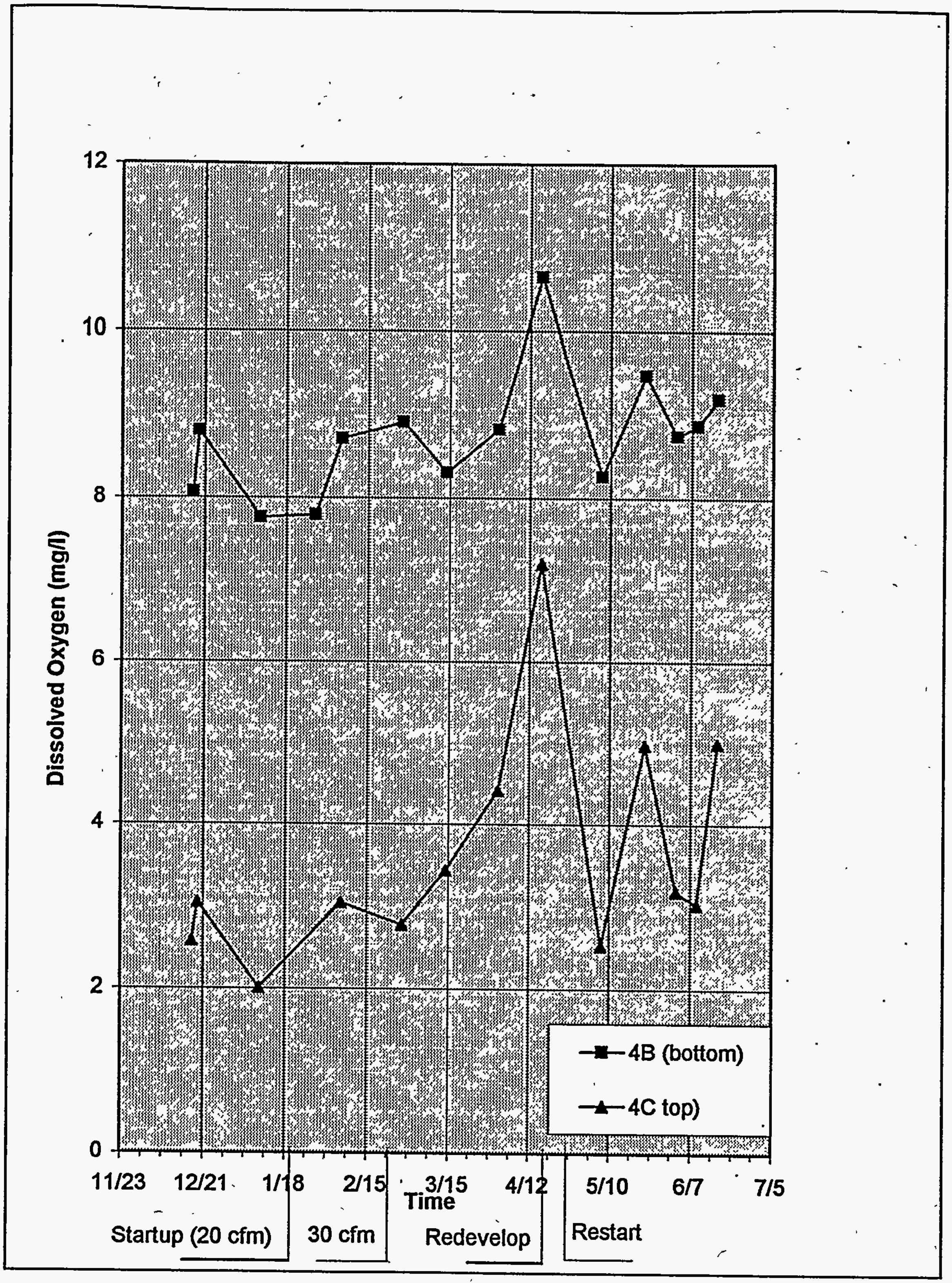

Figure 14: Dissolved oxygen concentration @ SSM-004B & C

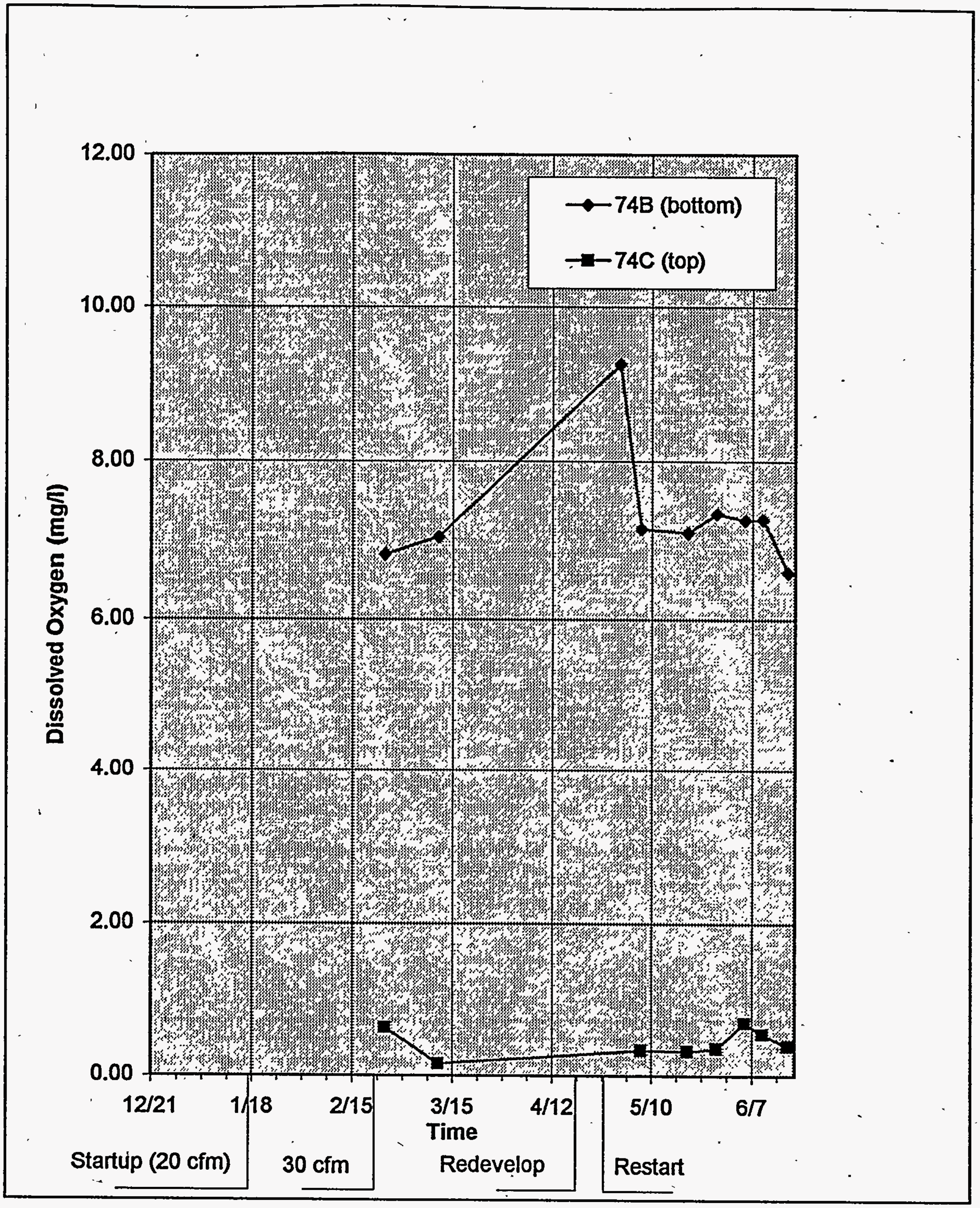

Figure 15: Dissolved oxygen concentration @ MSB-074B & C

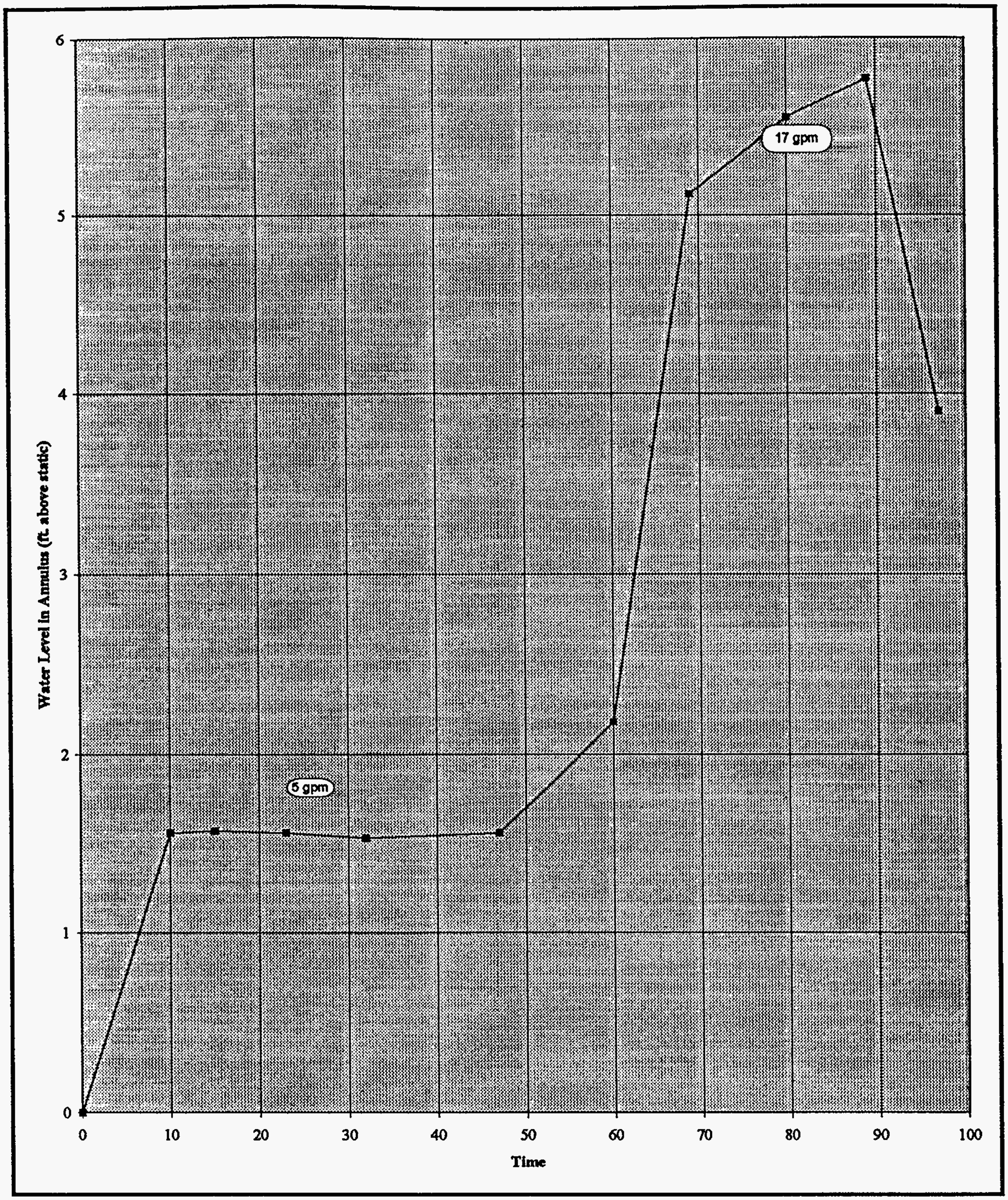

Figure 16: Initial falling head test at SSR-012

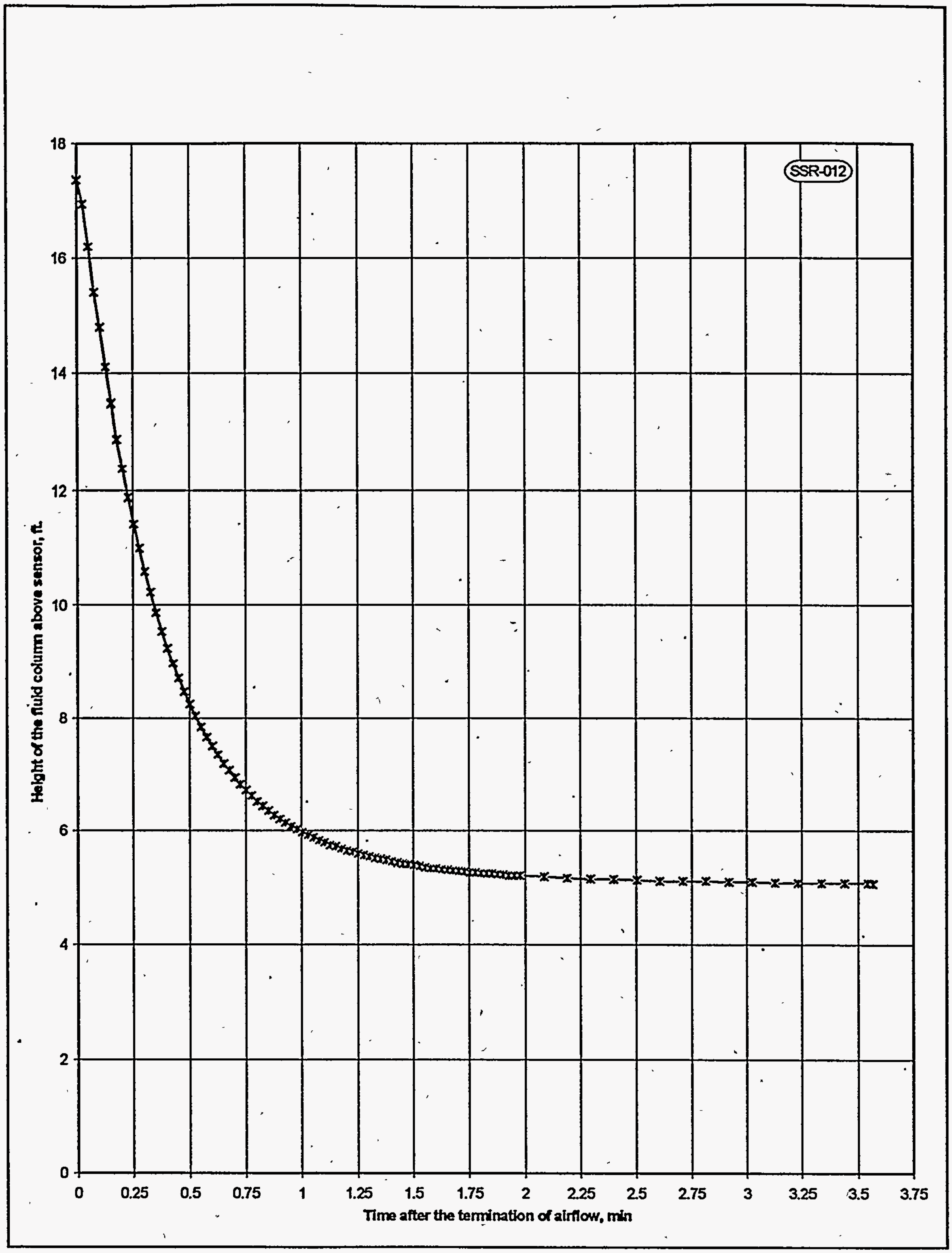

Figure 17: Falling head test at SSR-012 after redevelopment

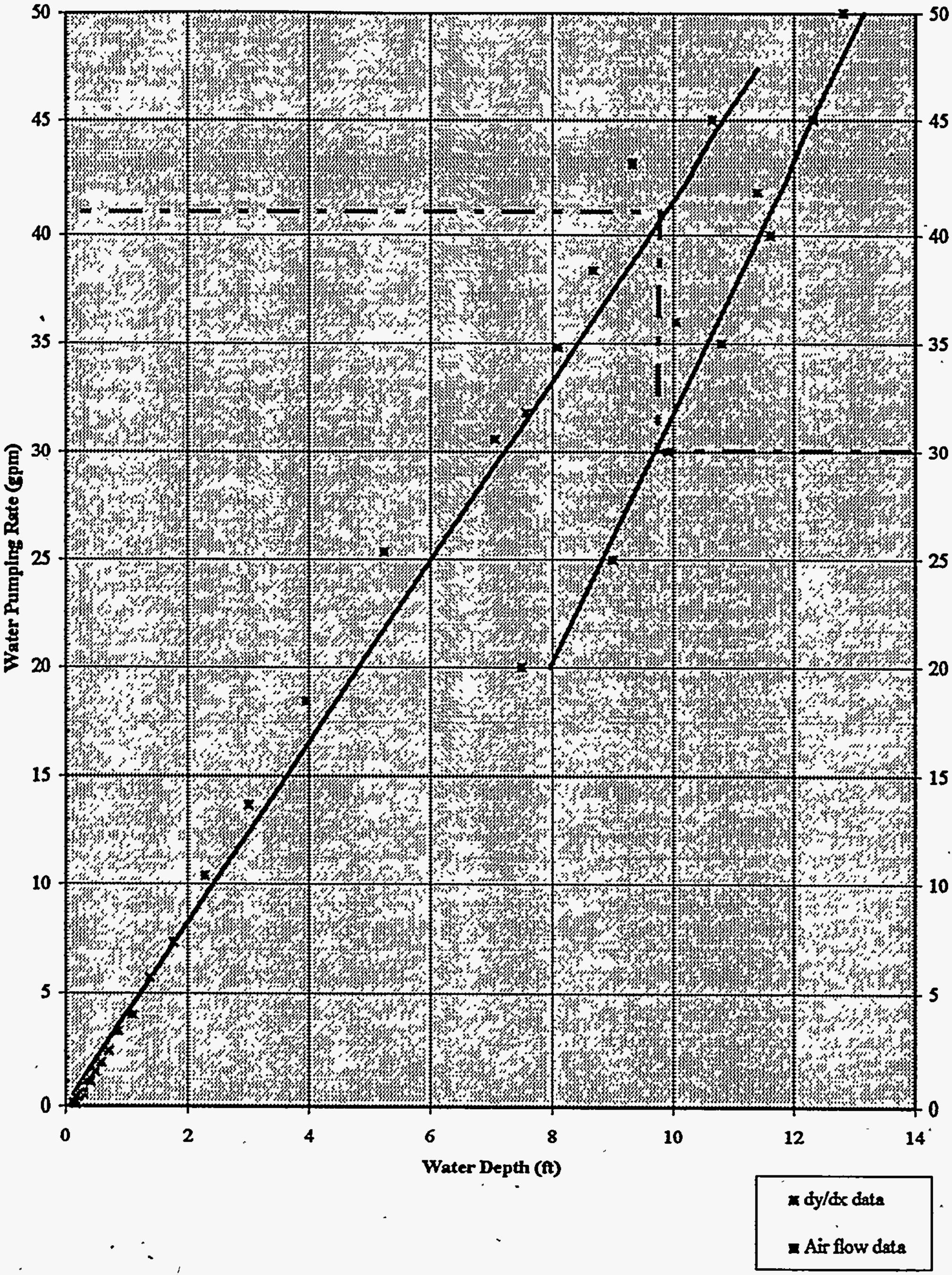

Figure 18: Water flow rate nomograph

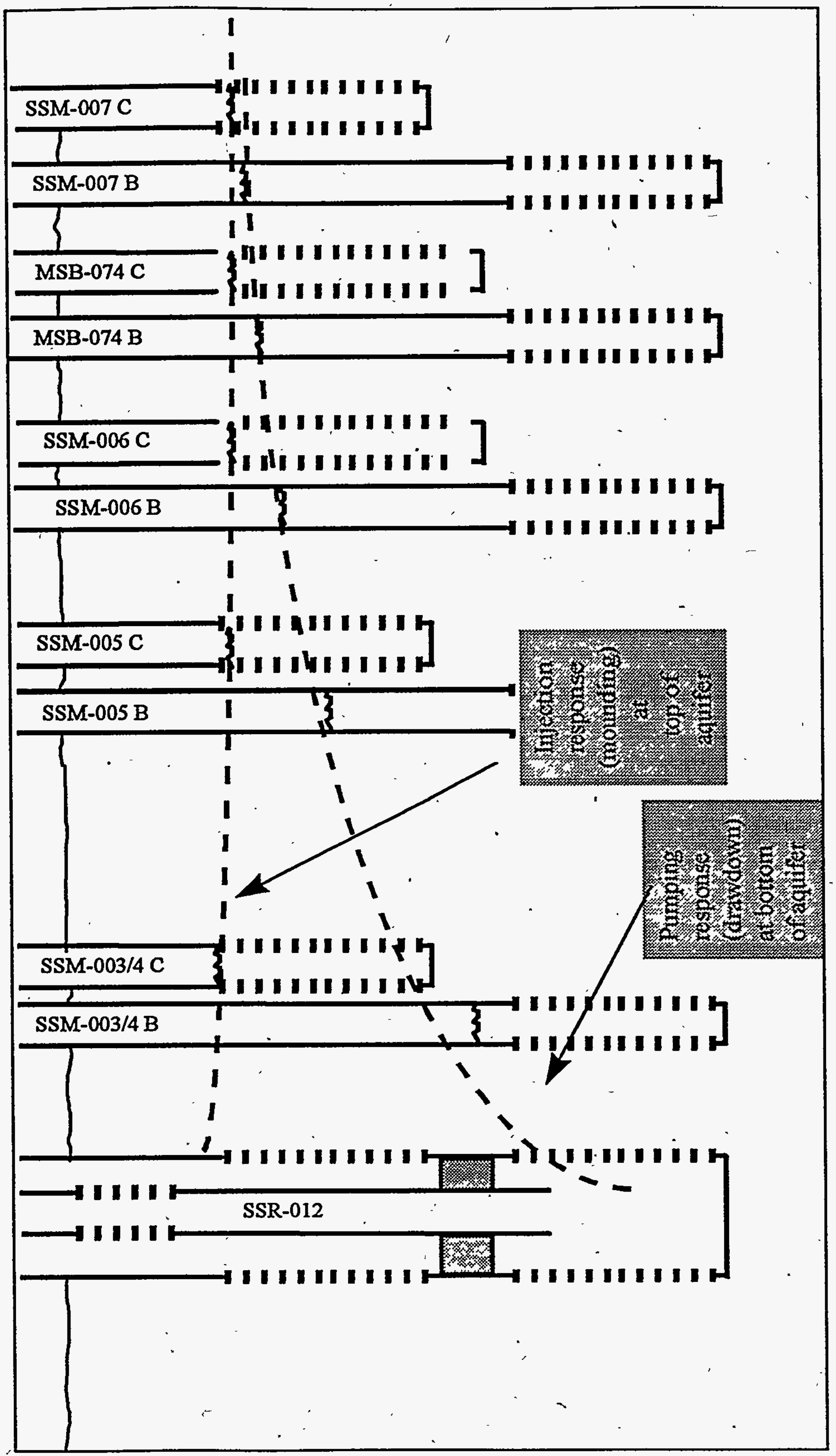

Figure 19: Typical potentiometric heads due to the recirculation well

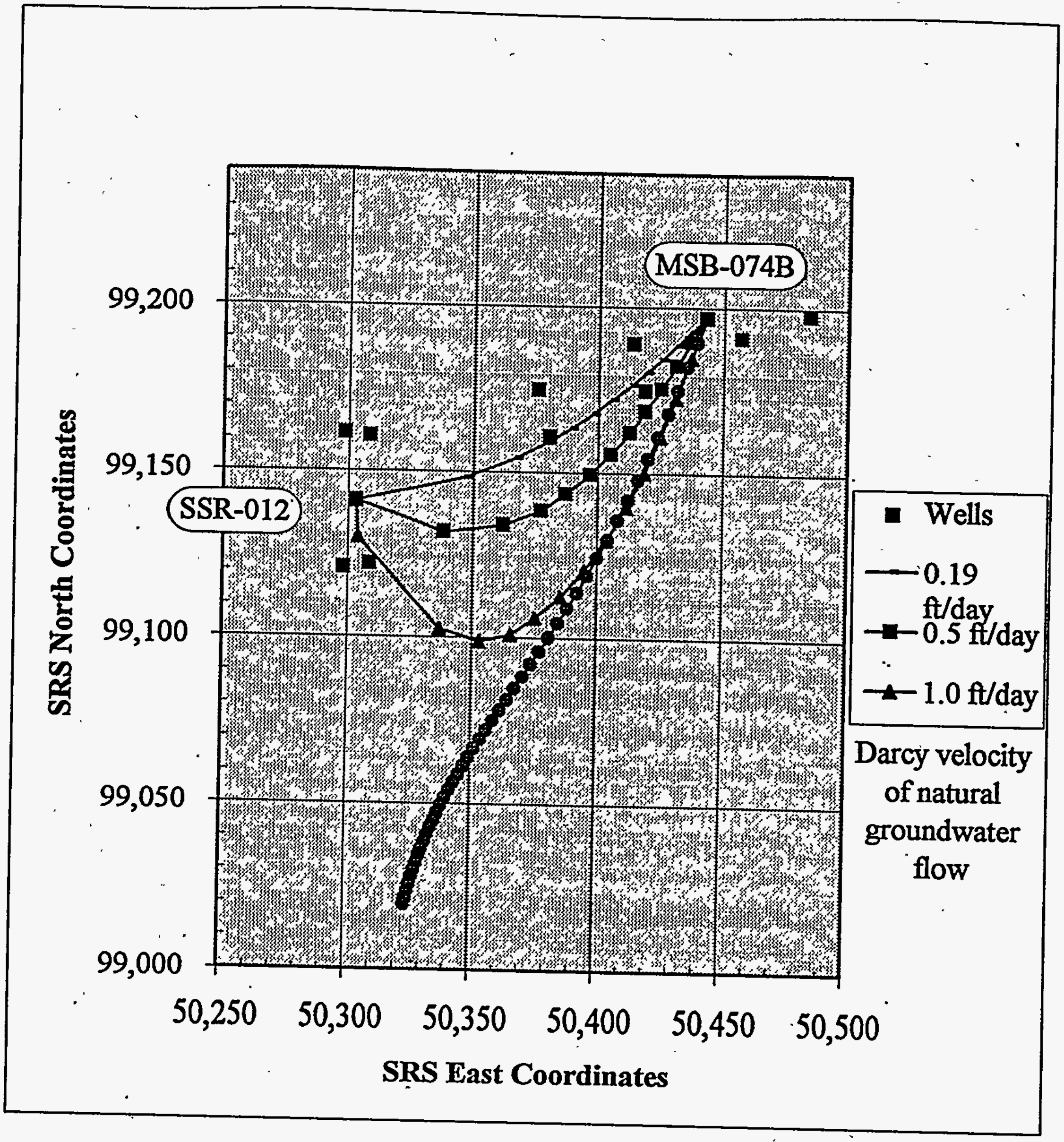

Figure 21: Results of particle tracking model

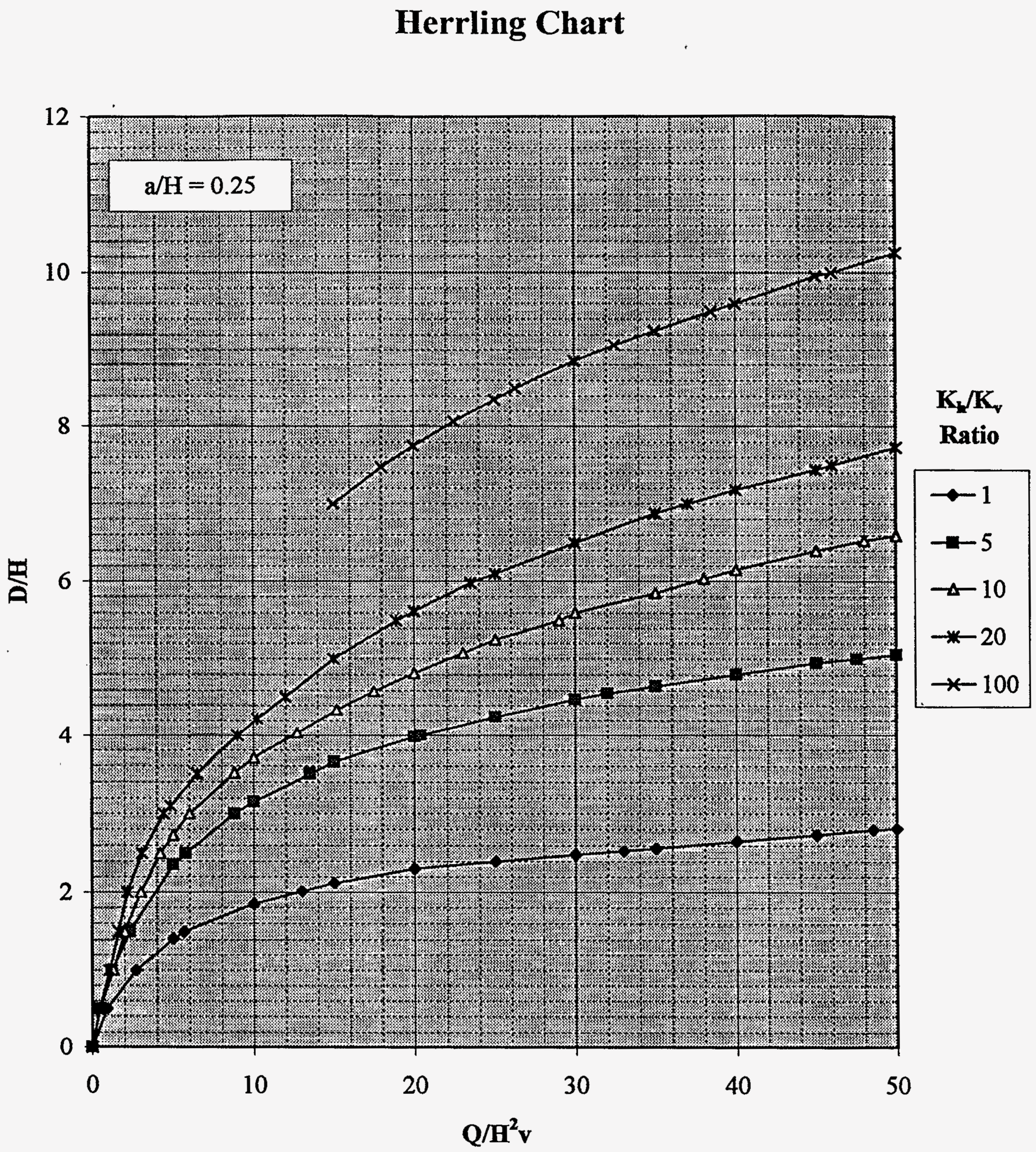

Figure 22: Herrling's well spacing chart