Slow pumping versus field filtering analysis with respect to implementation. [DNR-106] 1994

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#106

SLOW PUMPING VERSUS FIELD FILTERING ANALYSIS WITH RESPECT TO IMPLEMENTATION

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Abstract

In recent years the practice of bailing wells and filtering groundwater has been questioned. Members of the groundwater monitoring community are concerned that this practice unduly disturbs the samples. They favor the practice of pumping wells slowly, thereby eliminating the need to filter. Over the past year we compared the bailing and field filtering technique to the slow pumping method. This study compared levels of metals detected in filtered to levels in slow pumped samples. We also studied the slow pumping method with respect to implementation. The discussion emphasizes the need to balance our desire for an ideal sampling methodology with our need for a practical standard operating procedure. Our research has confirmed the general soundness of the slow pumping technique. The research also underscored some shortcomings inherent in the method. The capital intensive and time consuming nature of the slow pumping technique are sources of some concern, as is the inability of the method to retrieve a groundwater sample from wells screened in units of lower hydraulic conductivity.

Introduction

The Wisconsin Department of Natural Resources has written guidelines and developed rules over the past 10 years to assure that monitoring wells at landfills produce samples representative of groundwater quality. Our guidelines and rules have improved monitoring well construction and development and improved consistency in groundwater sample collection procedures. Despite these efforts, important questions remain concerning the degree to which groundwater samples represent groundwater quality. Many monitoring wells continue to yield turbid samples due to inadequate well development and the agitating effects of the bailer. Wisconsin requires field

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filtering of inorganic samples from these wells in order to eliminate inaccurate analyses.

In recent years the practice of bailing wells and filtering the samples prior to inorganic analysis, particularly for metals, has been questioned. Members of the groundwater monitoring community are concerned that this practice unduly disturbs the samples. They favor the practice of pumping wells at rates below two hundred mL/min. thereby eliminating the need to filter. EPA agreed with this approach and banned field filtering at Subtitle D landfills effective October 9, 1994. Wisconsin and other states are concerned about EPA's ban on field filtering because results from unfiltered samples could unnecessarily force a site into assessment monitoring under Subtitle D. Wisconsin favors lifting the ban and allowing more flexibility with regard to sampling procedures.

Currently groundwater samples at most solid waste landfills are filtered to remove turbidity from the sample. In addition to removing this artificially high level of turbidity, field filtration is likely to remove particles which are normally present in aquifer water. Kearl et al. (1992) observed particles as large as 10.0 um existing as colloids in groundwater. Since the standard pore size for groundwater sample filtration is 0.45 um, a field filtered sample will lack some of the colloidal particles normally present in the aquifer water.

Metals have a tendency to sorb to the surfaces of these colloidal particles. When samples are field filtered colloidal material can be removed and it is thought that metals concentrations will be reduced in the sample. In theory, a slow pumped water sample should contain all naturally occurring colloids without suffering the addition of material derived from the well environment. The slow pumped sample is therefore predicted to exhibit a higher level of metals contamination than a bailed and filtered sample of the same water.

Over the past year we performed a study of four sites with metals contamination comparing results from bailing and field filtering to results from the slow pumping technique. This paper presents our findings in a discussion of analytical results obtained for metals from the filtered and unfiltered samples. We also discuss the methods with respect to ease of implementation. We believe there is a need to balance what we would like to practice in terms of ideal sampling methodology with what we can practically implement in the field.

This study has addressed two issues surrounding the slow pumping versus field filtering controversy. The first issue is one of fundamental significance for those affected by groundwater monitoring: is there a significant difference between levels of metals contamination found in a well using the slow pumping method as opposed to using the bailing and field filtering method? Our criteria for significance is based on whether the magnitude of the difference would affect the enforcement status of a large number of facilities relative to the added expenditure required by the slow pumping procedure. This brings us to the second issue addressed directly by this study: to what extent would the implementation of the slow pumping method affect the ability of groundwater professionals to perform quarterly monitoring activities in a cost effective manner? Ultimately the decision to implement the slow pumping method should be based on the answers to these two questions.

Our research has confirmed the general soundness of the slow pumping technique as a sampling method. It was possible to obtain clear samples from most wells without filtering The research also underscored some shortcomings inherent in the process. The capital intensive and time consuming nature of the slow pumping technique are sources of some concern, as is the inability of the method to retrieve a groundwater sample from wells screened in units of lower hydraulic conductivity.

As a complement to our work, the results of a survey sent to organizations sampling monitoring wells in Wisconsin in 1993 are presented in Appendix A. The survey determined what types of sampling procedures have recently been most used, thereby helping to assess the impact that a ban on field filtering would have on sampling techniques typically employed at Wisconsin landfills. The survey results provide information on the methods samplers are currently using. These methods are often quite different than those used by the academic community.

Methods

Equipment

The equipment used for the study included the following: 1 positive displacement pump, 125 ft. of sampling tubing, 125 ft. of power supply cord, 1 hose reel, 1 flow through cell, 1 nephelometer, 1 pH probe and meter, 1 temperature/conductivity probe and meter, 1 dissolved oxygen probe and meter, miscellaneous equipment including pH standards, spare batteries etc., 3 six gallon carboys for DI water, 4 six gallon carboys for collection of contaminated water, 1 sample preservation kit, 1 pair of snow shoes and one huge truck.

Procedure

The wells used in this study consisted of two inch monitoring wells screened at depths ranging from ten to one hundred and fifteen feet, the screened interval being between five and fifteen feet in all cases. The study wells were all screened in unconsolidated material. For the purposes of this study wells were chosen whose hydraulic conductivities ranged widely.

The procedure was as follows:

Depth to water measurements were taken and then the pump was slowly lowered into position so that the intake of the pump was in the screened interval of the well and at least two feet off the bottom of the well. Slow pumping was then initiated with flows never higher than 600 mL/min. and in most cases less than 200 mL/min. Water pumped out of the well first entered a flow through cell containing monitoring probes for various parameters. Use of the flow through cell allows water to be monitored prior to its exposure to the atmosphere. Depending on the requirements of the individual site, the water was then released to the environment or collected for later disposal.

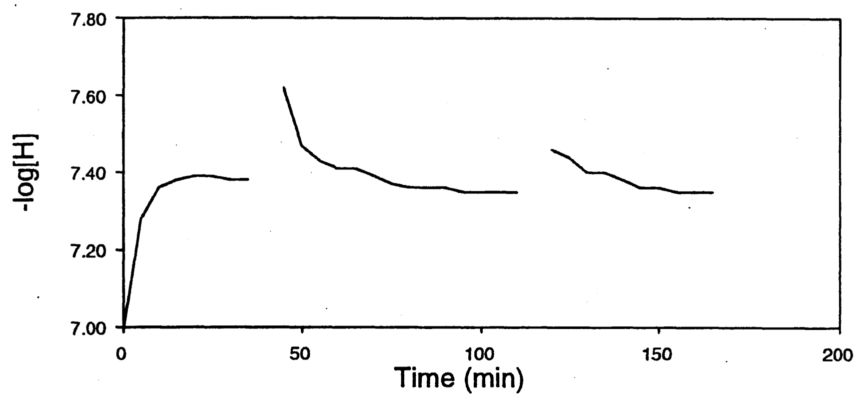

Figure 1. pH versus time for slow pump test 13. pH was a poor indicator of sample integrity. During this test pH had reached its stable value after only twenty minutes. At this point in the test the pumped water was still quite turbid as can be seen in Figure 2. Conductivity and dissolved oxygen readings often stabilized long before turbidity. The two spikes in the curve represent points where the pH meter shut down and slowly restabilized after being turned back on. These spikes are not indicative of sample pH.

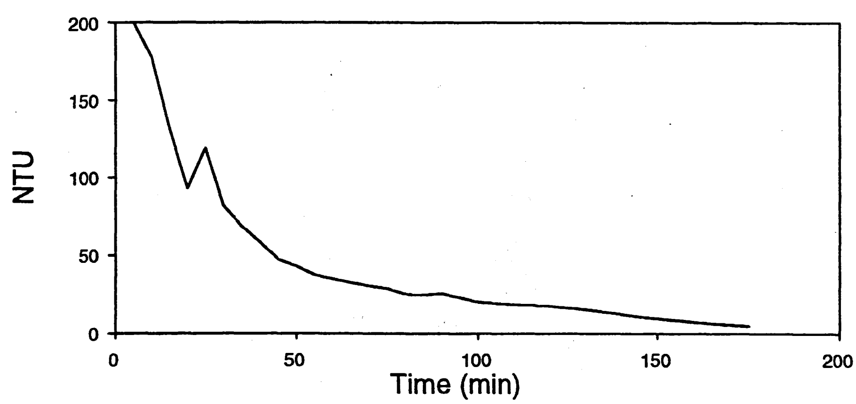

Figure 2. Turbidity versus time for slow pump test 13. This type of smooth curve was consistent throughout the turbidity data. Occasional spikes such as the one seen here at twenty-five minutes were usually caused by an interruption of the pumping process. Restarting the pump in the middle of the test had a tendency to cause an increase in turbidity in the slow pumped sample.

Several parameters were monitored in order to determine that the water taken as a sample was in fact fresh from the surrounding aquifer. These parameters were pH, temperature, conductivity, dissolved oxygen and turbidity. During some tests fewer parameters were monitored; however, complete data on turbidity over the course of the test was recorded in all cases. Backhus et al. (1993) support the position that turbidity is the most significant of the parameters to monitor in determining stabilization. This study supports their finding that other parameters tend to stabilize much sooner than does turbidity. Turbidity was used as the final determinate of chemical stability of the pumped water in all cases. Pumping was determined to be complete when no change in turbidity could be detected within the sensitivity of the nephelometer over a five minute interval. It is felt that relying on these other parameters to judge the representativness of a slow pumped sample may lead to poor results.

Figures 1 through 3 show typical data for the parameters monitored. After only twenty minutes pH had achieved its stable value (Figure 1) while turbidity at this point in the test was still nearly two orders of magnitude higher than its final, stable value, achieved over two hours later (Figure 2). Other parameters either showed similar results or behaved erratically as seen in the temperature monitoring data (Figure 3).

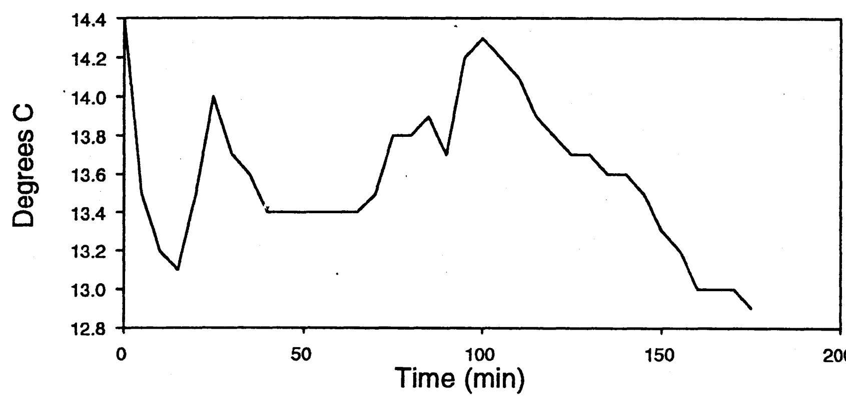

Figure 3. Temperature versus time for slow pump test 13. This type of erratic curve was often found when monitoring temperature data. Any observed trends in the temperature of the pumped water were directly the result of coincident changes in air temperature, as when the weather changed from sunny to overcast. Similarly erratic behavior was frequently seen in all parameters with the exception of turbidity.

After it was determined that stability had been reached, a 250 mL unfiltered sample was collected for metals analysis. Following this, a bailed and filtered sample was collected for comparison to the slow pumped sample. In some earlier sampling rounds bailed and field filtered data collected by consultants as part of a quarterly sampling program was used in place of our own bailed and filtered data. In these cases, our slow pumping procedure was conducted within a week of the consultants' sampling.

Samples were analyzed for specific metals as appropriate to the site. Over the course of the study analyses were performed for arsenic, cadmium, chromium, copper, iron, lead and zinc.

Slow pump tests were conducted at four sites over the course of the study. Thirteen slow pumped/bailed and field filtered sample pairs were taken. Pairs 1-4 are from site 1, pairs 5-10 are from site 3 and pairs 11-13 are from site 4. No samples were retrieved from site 2. Difficulties associated with this site and with particular wells at the other sites will be detailed below. Each sample pair was analyzed for several metals resulting in thirty-five comparable metals analyses.

Results

Metals Analysis

A laboratory analysis of samples collected using the respective methods yielded unexpected results. In thirteen sampling rounds, thirty five pairs of metals analyses were made. Out of these thirty-five sample pairs, twenty-four exhibited the expected tendency of the slow pumped sample to reflect a higher level of metals contamination than the bailed and field filtered sample. Ten of these pairs, however, showed either no difference between metal concentrations in the sample pairs or actually exhibited an effect opposite to what we expected. In eight of these samples the filtered counterpart actually exhibited higher levels of contamination than did the unfiltered, slow pumped sample. The absolute level of contamination varied widely from sample to sample and from one type of metal to another. For ease of visual comparison the results of the metals analyses have been normalized to one another using an arbitrary conversion whose value ranges from negative one to one (Figure 4). Each bar on the graph represents a slow pumped/bailed and field filtered sample pair. On this scale a value of zero indicates that analysis of the two samples found the same concentration of metal in both samples of the pair. A positive value indicates that the slow pumped sample showed a higher concentration than the bailed and field filtered sample. A negative value indicates that the filtered sample showed a higher metal concentration than the slow pumped sample.

Figure 4 is effective at allowing us to see the results of all metals analyses at one time; however, the magnitude of the bars does not correspond to the magnitude of the differences in concentration in an absolute sense. In Table 1 we see that many paired analyses exhibit rather small differences in measured levels of concentration. Over fifty percent of sample pairs showed less than a 20 ug/L difference in metal concentration. On a case by case basis this difference may or may not be large enough to push values above or below Preventative Action Limits or Enforcement Standards.

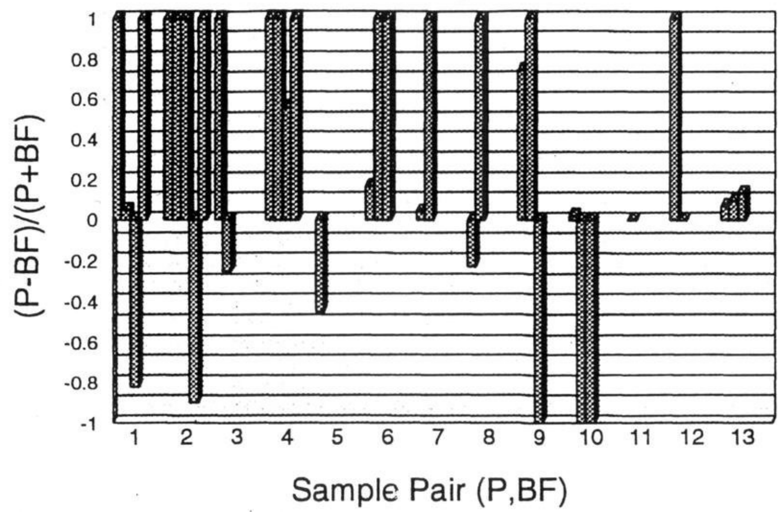

Figure 4. Normalized results of paired sample analyses. Each bar represents a sample pair. Positive values indicate that the slow pumped concentration (P) was greater than the bailed and field filtered concentration (BF) as expected. Negative values indicate the unexpected result that the bailed and filtered sample showed a higher concentration. The Y axis is not linear so that a value over 0.1 indicates a greater than 20% difference in measured concentration of metal between samples in a pair.

Table 1. Differences in metal concentrations between paired slow pumped/bailed and field filtered sample sets. Light shading indicates a difference in contaminate concentration of less than 20 ug/L. Darker shading indicates a greater than 20 ug/L difference in concentration between slow pumped/bailed and field filtered counterparts. Twenty-one of thirty five pairs exhibit less than a 20 ug/L difference in measured level of metals contamination.

	Sample Pair												
Metal	1	2	3	4	5	6	7	8	9	10	11	12	13
As		1.0										1.0	7.0
Ba											0.0	0.0	90.0
Cd	0.2	1.1		0.3									
Cr	0.3	5.0	9.0	1.2	-480	4.0	20.0	-3.0	75.0	10.0			
Cu							5.0						
Fe	-6410	-4350	-2100	50.0		80.0			240	-60.0			900
Pb	1.2												
Zn		14.0		24.0		10.0		14.0	-11.0	-29.0			

Almost twenty five percent of the sample pairs showed lower concentrations in the slow pumped sample. We have speculated as to the cause of this unexpected result. The action of the bailer stirring up sediments from the bottom of the well may have suspended large numbers of colloids derived from the sediments at the bottom of a monitoring well. If these were small enough to pass through the 0.45 um filter, the bailed and filtered sample could actually have a higher concentration of colloidal surface area than a slow pumped sample retrieved without disturbing sediments at the bottom of the monitoring well. Puls and Barcelona (1989) have considered similar possibilities.

Our study did not consistently support the theory that field filtered samples underestimate levels of metals contamination. If our explanation for the unexpected results is correct one could say that regardless of the analytical results, a slow pumped sample will still be a better representation of true aquifer water. It would be well to keep in mind, however, that our explanation is only a postulate. Our results raise questions about the relationship between a slow pumped sample and a bailed and field filtered one that could not be adequately addressed in this study.

We also found that the difference between measured levels of metals concentrations were of questionable significance in many cases. The value of concentration information collected using the slow pumping method must be evaluated in light of various complications associated with implementing the method.

Implementation of the Method

The second question addressed by our study pertains to the impact that the slow pumping method will have on the efficiency of the groundwater monitoring process. Our study was designed to test the slow pumping method under as large a variety of climatic and hydrogeologic conditions as is currently found in Wisconsin. The wells used in our study ranged in depth from ten to one hundred fifteen feet. No unusual difficulty was found in working with the deeper wells; however, in some cases shallow wells created problems. This will be elaborated upon below.

All wells used in the study are finished in unconsolidated sediments. This is a reflection of the typical Wisconsin monitoring well environment and not a reflection of a desire on our part to look at unconsolidated aquifer materials exclusively.

The hydraulic conductivity of the materials in which each well was screened varied as widely as the depth. The lowest encountered was in the fluvial sediments of site 2 where conductivity was estimated at $3.0x10^{-5}$ ft/day. This value was arrived at by comparison with similar materials (Domenico and Schwartz, 1990). The highest conductivities were also found in fluvially deposited sediments, these at site 3. Here several wells exhibited conductivities as high as $5.5x10^{-2}$ ft/day. These values were determined in pumping tests conducted by personnel of the Wisconsin Department of Natural Resources who are responsible for monitoring at the site. Difficulties concerning the implementation of the slow pumping method arose while attempting to retrieve samples from those wells of relatively low conductivity. In the case of site 2, the first well we tested was pumped dry within minutes of starting the test. In order for the slow pumping method to be a viable sampling option a well must have the ability to produce water at the rate of at least 100 mL/min. Two factors affecting the rate of flow to the well caused our inability to use the slow pumping method. The most obvious factor was certainly the low conductivity of the aquifer material. Adding to the difficulty was the shallow depth of the well. The well in question had only five feet of water in it and it was not possible to create sufficient gradient to make up for the low conductivity in achieving the necessary flow rate.

This seemingly straightforward limitation was shown later in our study to manifest itself in more subtle ways. One well we encountered was also of low hydraulic conductivity ($3.0x10^{-6}$ ft/day) but contained twenty feet of water. The conditions here were such that we were able to conduct a full slow pumping test which gave no indication that anything was wrong until seconds before a sample was to be taken. All monitored parameters had shown their characteristic response to pumping over the course of the test. Turbidity had stabilized after 120 minutes of pumping and a sample was about to be taken when air began to arrive with the sample water indicating that the well had been drawn down to the level of the pump intake in the screened interval of the well. In this case the drawdown occurred gradually over the course of the test and even though the monitored parameters had seemingly stabilized, the pumped water was still a mixture of fresh aquifer water and water derived from the stagnant water column of the well. This fact might not have been discovered and a non-representative sample might have been retrieved unknowingly had the test ended just minutes earlier. Depth to water should be monitored during the pumping test whenever the slow pumping results in any apparent draw down of the well. Static well water levels should therefore be an additional criteria required to determine that a sample is representative.

Our study was also constructed to test the method in various seasons and climatic conditions. We were concerned that cold weather might cause problems with the sampling equipment and make the process unsuitable for winter use. Difficulties such as frozen water in the pump, discharge tubing and flow through cell as well as abbreviated battery life were anticipated. During three pumping tests conducted at air temperatures solidly below freezing and lasting up to three hours no unusual difficulties arose. The equipment and method seem to be as sound at -20C as they are during the summer months. It should be noted that even though the method may be unaffected by sub–zero conditions, the long inactive periods of time spent in this type of weather can have a detrimental effect on the methodologist.

The most pronounced difference between the slow pumping method and the bailing and field filtering method is the amount of time needed to retrieve a sample from a well. In the case of the bailing and field filtering method a groundwater sampling technician could expect to retrieve a sample from a readily accessible well in as little as twenty minutes using a bailer and in significantly less time if a high volume pump is substituted for the bailer. Our Current Practices Survey revealed that 20% of those surveyed used some type of pump as an alternative to using a bailer. In contrast, our experience with the slow pumping method shows that a minimum of two hours is required by the method in order to sample one well. Because of the large amount of equipment required to pump the water and monitor the various parameters, just setting the equipment up took a minimum of forty-five minutes. The shortest amount of time we needed to spend actually pumping and waiting for monitored parameters to stabilize was fifty-five minutes for Test 5. Test 7 took only 20 minutes excluding set-up and take-down time but should be considered an anomaly in the context of this study. Even at the beginning of this test the turbidity of the water was near the limit of detection of the nephelometer, only 1.6 NTU. The process of packing up the sampling equipment after sampling was completed took a minimum of another forty-five minutes including decontamination. The times estimated above represent a series of typical cases where drive-up access to the well was available. Test 8, conducted during the winter, required the use of snowshoes to reach the well. The set up and take down times at this well, only twenty meters from the road, were each on the order of ninety minutes. Adding the length of time needed for parameter stabilization on this test brought the total length of the test to four hours.

The wells used in our study contained no contamination by VOCs which allowed the decontamination procedure to be rather uninvolved. Where VOCs are present, the required decontamination time will add significantly to the time required for sampling. The use of a slow pumping system dedicated to each well would substantially reduce the time required to sample a well. The well would have lower turbidity, decontamination would not be required and there would be less equipment to set up and take down.

A final significant difference between the slow pumping method and the bailing and field filtering method is the cost of the equipment. A non-dedicated slow pumping system costs approximately $5,000 including pump, tubing, hose real, power source, flow through cell, probes and meters. This compares with the cost of $200 for a PVC bailer and line. If a landfill owner decides to install dedicated slow pumps in each well, the up front capital cost is substantial. However, manufacturers of these pumps claim the costs are usually recoverable in a few years due to the savings on labor costs.

Current Practices Survey

As part of our evaluation of the impact of banning field filtering and/or implementing the slow pumping method, we designed a survey to send to those sampling groundwater at Wisconsin solid waste landfills. The detailed results of the survey are included as Appendix A. A brief discussion of the responses that are pertinent to this study follows.

Eighty percent of those responding to the survey use a bailer to purge wells prior to sampling while eighty-nine percent use a bailer to retrieve the sample. This information indicates that most people sampling wells at Wisconsin's solid waste landfills would have to make a significant change in their technique were they to switch to the slow pumping technique.

Sixty-one percent of those responding said that the majority (over 50%) of their wells are turbid. One of the reasons so many wells produce turbid samples is that many landfills and the monitoring wells around them are located in fine grained soils. These types of soils tend to be not only turbid but also of low hydraulic conductivity. Wells screened in these environments can in some cases be purged dry, rendering the slow pumping method impractical.

Only 7.6 percent of the landfills sampled by those responding to the survey have dedicated pump systems. The literature supporting slow pumping emphasizes the use of dedicated systems to save time through reduced initial turbulence and through elimination of the decontamination procedure. The survey results indicate that most landfill owners would have to make a substantial capital expenditure if they chose to install dedicated slow pumping systems.

Discussion

Turbidity is a better indicator that a well is producing a representative sample than the parameters more typically used such as pH, conductivity and temperature. The slow pumping method consistently delivered a sample of very low turbidity. The method was effective in retrieving a representative sample. Our study found that the expectation that filtered samples are consistently underestimating levels of contamination may be in error. With over twenty-five percent of our sample pairs exhibiting higher levels in the filtered samples it should be noted that in many cases the use of the slow pumping method may cause values that currently exceed groundwater standards to drop below these standards. The magnitude of the difference in results obtained by the two methods is significant. In all but three cases there was more than a twenty percent difference in metals concentration between the samples in a pair (Figure 4).

Implementation of the slow pumping method was problematic in some respects. Though cold weather didn't seem to affect our ability to retrieve a sample, other factors were of concern. Low hydraulic conductivity combined with shallow depths of water in a well created a situation where a dynamic equilibrium between pumped outflow and well screen inflow was unattainable. The wells in these cases were eventually pumped dry even when pumped at the low rate of one hundred milliliters per minute. It will not be possible to implement the slow pumping method under these conditions.

In addition, slow pumping greatly increases the time required for sampling. Wide based implementation of the method would result in streamlining the process through installation of dedicated equipment and other innovations; however, a minimum of pumping time is required for parameter stabilization. This will mean that the slow pumping method used in wells with non-dedicated equipment will generally be slower and cost more in terms of personnel hours.

Our findings comparing the analytical results of the two methods directly did not show a significant difference between the methods in all cases. In over half of the paired metals analyses we observed less than a twenty ug/L difference in measured metal concentration. Due to this, implementation of the slow pumping method at smaller facilities whose financial resources are limited and where metals analyses are uncommon may not be necessary. Use of the slow pumping method also may be unnecessary at facilities where the exceedance status with regard to Preventative Action Limits or Enforcement Standards is not in significant doubt.

Recommendations

1. When using the slow pumping technique use turbidity to determine when a representative sample is being obtained. Possible criteria could be below two nephelometric turbidity units (NTU) or constant NTU for three consecutive time periods.

2. When using the slow pumping technique measure water levels in the well while pumping to ensure that drawdown is not increasing when the sample is to be retrieved.

3. Do not ban field filtering. Bailing and field filtering can continue to be an appropriate method at some wells under some circumstances.

4. Consider using the slow pumping technique where costs can be justified and where exceedance status is in question.

5. If using the slow pumping technique, use a dedicated slow pumping system where possible. This will eliminate the turbulence caused by the insertion of the pump into the well thereby reducing pumping time. This will also eliminate the need for time consuming decontamination procedures.

6. Consider using a technique other than slow pumping if financial resources are limited, if exceedance status is not in question, if the well can be purged dry, if metals are not of concern or if access to the well is difficult.

Further Studies

1. Compare the sampling results for inorganics (other than metals) and VOCs when sampling using the slow pumping technique to results when bailing.

2. Investigate new more effective methods for sampling wells which can be purged dry.

3. Investigate further the cases where higher metals values were found in the bailed and field filtered samples than were found in their slow pumped counterparts.

Future Policy

1. The Department should allow landfill owners to use the slow pumping technique without filtering provided the wells are sampled using both the technique currently employed and the slow pumping technique for a minimum of two sampling rounds. The data gathered from these two sampling rounds will help determine whether the

slow pumping technique is appropriate and whether the new slow pumped data will be comparable to the existing historical data already in the database.

2. The Environmental Protection Agency should lift the ban on field filtering and instead provide a more flexible approach which allows using either the slow pumping method or the bailing and field filtering method as appropriate to the site in question.

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Appendix A

RESULTS OF WISCONSIN'S GROUNDWATER SAMPLING PROCEDURES SURVEY

1. At about how many of the following types of Wisconsin landfills do you collect groundwater samples? (e.g., If you sample at 2 municipal and 3 demolition landfills, fill in 2 in front of "municipal solid waste" and 3 in front of "demolition".)

   58% municipal solid waste — 8% demolition

   29% industrial — 5% other

2. Of the above landfills, about how many are

   31% active (taking waste) — 54% closed

3. At about how many landfills do you use the following equipment to purge the wells? (e.g., If you use a bailer at 3 landfills and a bladder pump at 2 landfills, fill in 3 in front of "bailer' and 2 in front of "bladder pump")

   80% bailer — 0.2% gas displacement pump

   12% bladder pump — 1.6% air lift pump

   0.2% centrifugal pump — 0.9% peristaltic pump

   9% submersible pump — 1.6% suction lift pump

   0.9% others (list brand name of pump if unsure of type)

4. About how many well volumes do you remove from the well when purging wells which you cannot purge dry?

   3.7 number of well volumes purged

5. About how much time elapses between the time you finish purging a well which recharges rapidly and the time that you sample it? (circle one)

   None, we have no such well 8.7%

   Less than 30 minutes 60%

   30 to 60 minutes 7.6%

1 to 2 hours 3.3%

2 to 4 hours 1.1%

4 to 6 hours 0.0%

6 to 12 hours....................................1.1%

12 to 24 hours..................................11%

25 to 48 hours..................................4.3%

49 to 72 hours..................................0.0%

6. At about how many landfills do you use the following equipment to retrieve the samples from the well?

40% bailer

49% bottom emptying bailer

11% bladder pump

1.6% centrifugal pump

6% submersible pump

0.0% gas displacement pump

0.7% peristaltic pump

0.9% suction lift pump

0.9% others (list brand name of pump if unsure of type)

7. About what percent of all monitoring wells that you sample produce turbid water (i.e., water is not clear)?

≤ 25%	25-50%	51-75%	>75%
18%	21%	27%	34%

8. Do you filter samples for inorganics? 84% yes 14% no

(e.g., Alkalinity, hardness)

If yes, is filtering done in: 66% field 18% lab

9. Do you filter samples for metals? 88% yes 12% no

If yes, is filtering done in: 71% field 17% lab

10. If field filtering, do you use:

68% a transfer container 25% an in line filter system

11. About how long is it, on the average, between the time you take a sample and the time that it is filtered? (circle one)

0 minutes (in line filtering)................. 18%

Less than 15 minutes.......................... 45%

15 to 60 minutes 16%

1 to 2 hours 6.5%

2 to 3 hours 3.3%

more than 3 hours 11%

12. About how many landfills that you sample have dedicated sampling equipment?

16% landfills with dedicated bailers (separate bailers for each well)

7.6% landfills with dedicated pump system (separate pump for each well)

13. Do you use distilled water (also includes deionized and reagent grade water) to rinse equipment between wells?

95% yes 5% no

If yes, where is it usually obtained?

22% grocery store 59% laboratory

14% other (please specify)

(most often: Culligan, or office purification equipment)

If no, what do you use?

"river water", or "just dry it off" were notable responses

Appendix B

METALS CONTAMINATION IN TESTED WELLS

All analyses were conducted at the Wisconsin State Laboratory of Hygene using the total recoverable method for acid digestion of the sample.

Slow Pumping Versus Field Filtering Study

Field No.	As	Ba	Cd	Cr	Cu	Fe	Mn	Pb	Zn	type	TEST
WSB1Rc	0		1	0.04762		-0.8228		1	0	C	1
WSB1R	<1		0.2	3.3		690		1.2	<10	P	1
WNLSB1RB	17		3.5	38		74000		32		B	1
WNLSB1RBF	<2		<0.8	3		7100		<5	<3	BF	1
WSB2Rc	1		1	1		-0.8969		0	1	C	2
WSB2R	1		1.1	5		250		<1	14	P	2
WNLSB2RB	6		<0.8	34		39000		16		B	2
WNLSB2RBF	<2		<0.8	<2		4600		<5	<3	BF	2
WS3R1c	0		0	1		-0.253		0	0	C	3
WS3R1	<10		<0.2	9		3100		<3	<10	P	3
WNLS3R1B	5		<0.8	38		44000		<5		B	3
WNLS3R1BF	<2		<0.8	<2		5200		<5	<3	BF	3
WS24Rc	0		1	1		0.55556		0	1	C	4
WS24R	<1		0.29	1.2		70		<1	24	P	4
WNLS24RB	120		9.2	450		800000		320		B	4
WNLS24RBF	<2		<0.8	<2		20		<5	<3	BF	4
WSBLANK	<1		0.06	1.1		<50		<1	<10		4
RPOP4c	0		0	-0.4528		0			0	C	5
RPOP4	<10		<0.2	290	<3	<50		<3	<10	P	5
RPOP4F	<10		<0.2	320	<3	<50		4	10	F	5
RPSCSP4B	7.4		<0.5	650		8600			33	B	5
RPSCSP4BF	<3		<0.5	770		<100			<20	BF	5
RPOP31c	0		0	0.16667		1			1	C	6
RPOP31	<10		<0.2	14	<3	80		<3	10	P	6
RPOP31F	<10		<0.2	14	<3	<50		<3	10	F	6
RPSCSP3B	37		1.3	54		68000			220	B	6
RPSCSP3BF	<3.0		<0.5	10		<100			<20	BF	6
RPJ30P42c	0		0	0.04	1	0		0	0	C	7
RPJ30P41	<10		<0.2	250	<3	<50		<3	<10	S	7
RPJ30P42	<10		<0.2	260	5	<50		<3	<10	P	7
RPJ30P4BF	<10		<0.2	240	<3	<50		<3	<10	BF	7
RPF5P313c				-0.2308					1	C	8
RPF5P3RF				8					<10	BF	8
RPF5P31				9					<10	S	8
RPF5P32				8					<10	S	8
RPF5P33				7					<10	S	8
RPF5P34				6					<10	S	8
RPF5P35				7					10	S	8
RPF5P36				6					11	S	8
RPF5P37				6					11	S	8
RPF5P38				6					16	S	8
RPF5P39				7					12	S	8
RPF5P310				5					<10	S	8
RPF5P311				5					10	S	8
RPF5P312				6					93	S	8
RPF5P313				5					14	P	8
RPF5P3BLK				<3					17		8
RPMW11M25c				0.74257		1	0		-1	C	9

Slow Pumping Versus Field Filtering Study

Field No.	As	Ba	Cd	Cr	Cu	Fe	Mn	Pb	Zn	type	TEST
RPMW11M3BF				13		<50	<40		11	BF	9
RPMW11M21				100		49000	370		94	S	9
RPMW11M22				54		2400	<40		15	S	9
RPMW11M23				72		360	<40		<10	S	9
RPMW11M24				86		240	<40		<10	S	9
RPMW11M25				88		240	<40		<10	P	9
RPMW11M25F				87		60	<40		18	F	9
RPP10M2c				0.02128		-1			-1	C	10
RPP10M3BF				230		60			29	BF	10
RPP10M2F				250		50			<10	F	10
RPP10M2				240		<50			<10	P	10
DM30MW8Ac	0	0								C	11
DM30MW8A	<10	160								P	11
DM30MW8A DUP	<10	150									11
DM30MW8AF	<10	160								F	11
DM31MW8AB	<10	190								B	11
DM31MW8ABF	<10	160								BF	11
DM317Ac	0.02564	0								C	12
DM317A	20	230								P	12
DM317AF	18	230								F	12
DM317AB	20	310								B	12
DM317ABF	19	230								BF	12
DA201Bc	0.06796	0.09677				0.13433				C	13
DA201B ABD	52	490				3600					13
DA201BF ABD	59	500				3600				F	13
DA201BX	71	530				5100				S	13
DA201BY	58	520				4300				S	13
DA201BZ	63	500				3900				S	13
DA201B	55	510				3800				P	13
DA201BF	59	510				3800				F	13
DA201BB										B	13
DA201BBF	48	420				2900				BF	13

B = bailed, unfiltered
BF = bailed, filtered
P = slow pumped, unfiltered
F = slow pumped, filtered
C = calculated: (P-BF)/(P+BF+.0000001)
S = unfiltered sample taken during pumping

Appendix B

RECORD OF PUMPING TESTS USED IN THIS STUDY

Field Filtering Versus Slow Pumping Study

Site		Waupaca Foundary	Date		30-Dec-1899
Well Number		b-1r	Air Temp.		
Depth to Water Before		20.60	Bottom Of Well		30.70
Depth to Water After			Pump Rate		200

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	7.23	70	7	16.4	8.9	73
5	7.14	342	34	16.8	69.6	64
10	7.13	428	43	16.8	64.1	61
15	7.98	489	49	15.9	55.4	61
20	7.48	520	52	15.6	49.1	63
25	7.90	550	55	15.6	43.3	69
30	7.95	562	56	15.6	39.2	67
35	7.98	571	57	15.6	35.2	54
40	7.83	575	58	15.4	31.1	54
45	7.83	579	58	15.4	28.5	51
50	7.86	580	58	15.4	26.3	48
55	7.88	583	58	15.3	23.5	54
60	7.89	588	59	15.1	21.7	58
65	7.90	588	59	15.1	18.7	55
70	7.90	589	59	15.1	16.2	56
75	7.92	592	59	15.1	13.8	52
80	7.91	592	59	15.1	12.4	49
85			0			
90	7.91	596	60	15.1	10.7	49
95	7.92	599	60	15.1	9.1	49
100	7.92	600	60	15.0	9.7	46
105	7.90	601	60	15.1	8.8	44
110	7.90	604	60	14.9	6.7	42
115	7.89	605	61	14.8	5.1	40
120	7.87	605	61	14.8	4.2	39
125	7.88	604	60	14.7	3.7	38
130	7.89	603	60	14.8	3.1	35
135	7.89	604	60	14.9	2.8	34
140	7.89	604	60	14.9	2.6	33
145	7.89	603	60	14.9	2.3	30
150	7.89	602	60	14.8	2.1	34
155	7.89	601	60	14.9	2.0	34
160	7.89	599	60	14.9	2.0	34
165			0			
170			0			
175			0			
180			0			

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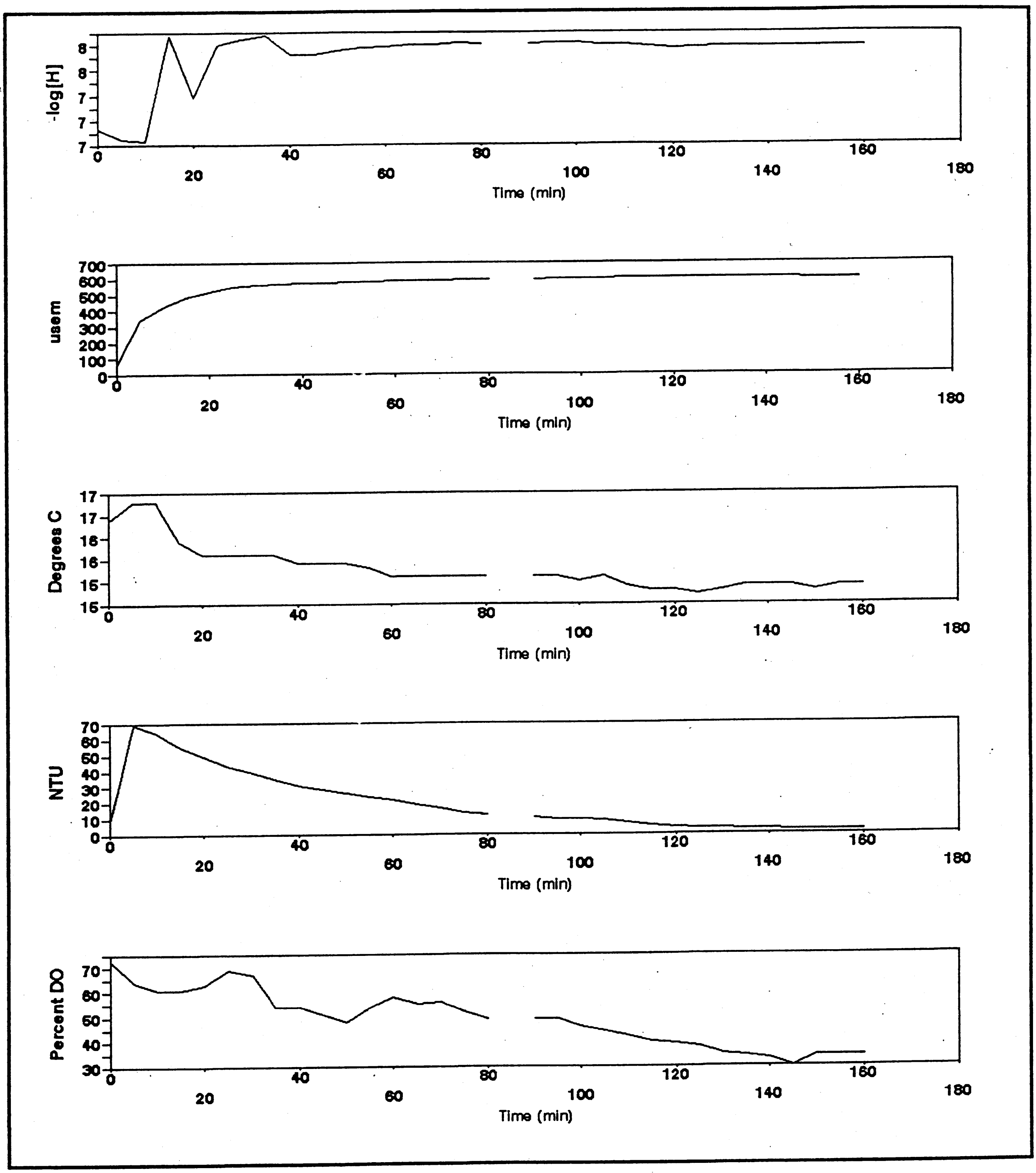
Field Filtering Versus Slow Pumping Study



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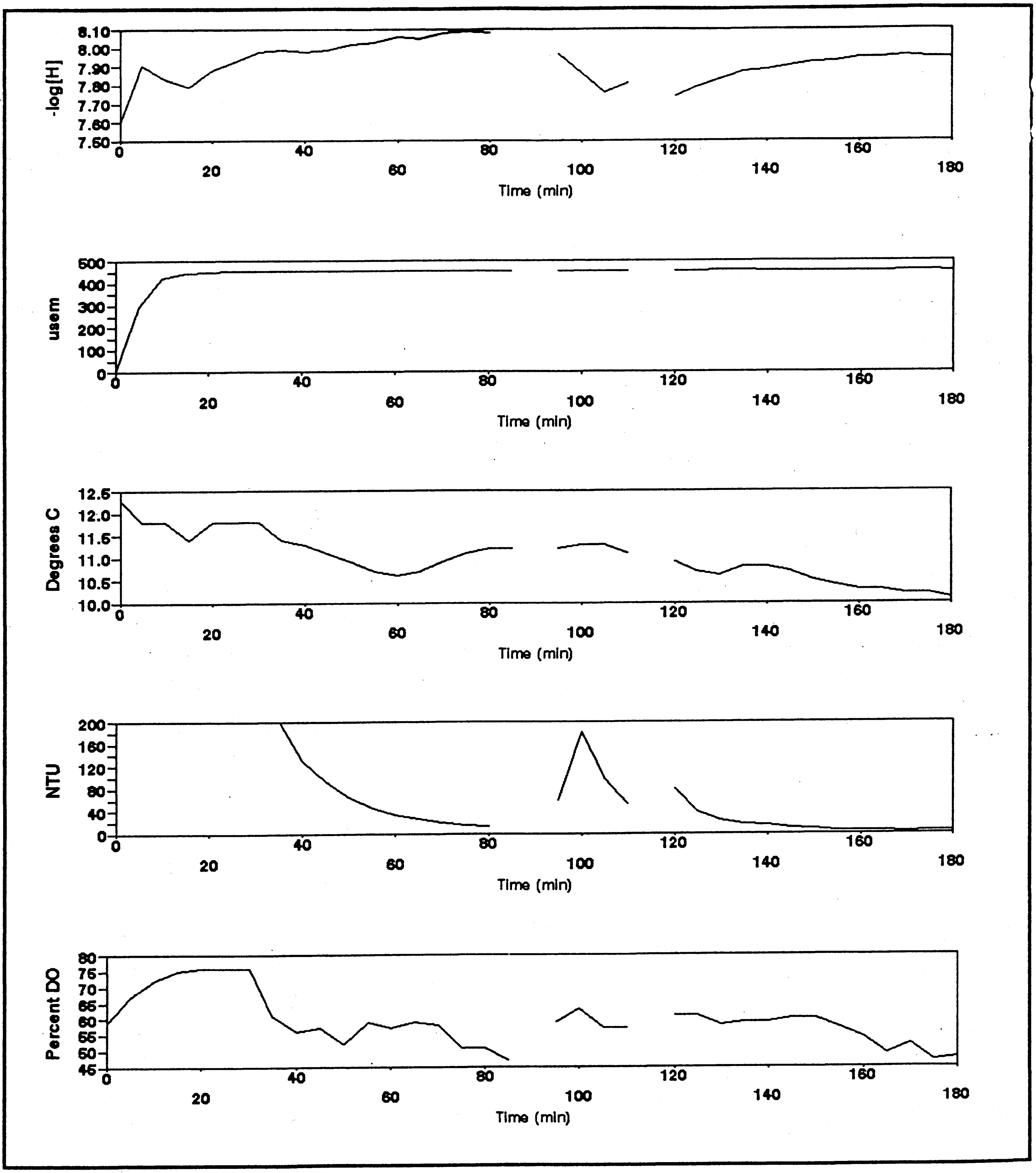
Field Filtering Versus Slow Pumping Study

Site		Waupaca Foundary	Date		30-Dec-1899
Well Number		B-2R	Air Temp.		
Depth to Water Before		19.38	Bottom Of Well		29.30
Depth to Water After			Pump Rate		600

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	7.60	5	1	12.3	200.0	59
5	7.91	295	30	11.8	200.0	67
10	7.83	423	42	11.8	200.0	72
15	7.79	445	45	11.4	200.0	75
20	7.88	452	45	11.8	200.0	76
25	7.93	455	46	11.8	200.0	76
30	7.98	455	46	11.8	200.0	76
35	7.99	455	46	11.4	200.0	61
40	7.98	455	46	11.3	131.2	56
45	7.99	455	46	11.1	93.2	57
50	8.02	455	46	10.9	64.5	52
55	8.03	455	46	10.7	45.4	59
60	8.06	455	46	10.6	33.9	57
65	8.05	456	46	10.7	26.5	59
70	8.08	456	46	10.9	20.4	58
75	8.09	456	46	11.1	15.7	51
80	8.08	455	46	11.2	13.7	51
85		455	46	11.2		47
90			0			
95	7.97	455	46	11.2	59.7	59
100	7.86	456	46	11.3	182.0	63
105	7.76	455	46	11.3	97.9	57
110	7.81	456	46	11.1	52.6	57
115			0			
120	7.74	455	46	10.9	79.9	61
125	7.79	456	46	10.7	38.8	61
130	7.83	457	46	10.6	22.9	58
135	7.87	458	46	10.8	16.9	59
140	7.88	456	46	10.8	14.1	59
145	7.90	456	46	10.7	10.6	60
150	7.92	456	46	10.5	8.1	60
155	7.93	456	46	10.4	5.6	57
160	7.95	456	46	10.3	4.4	54
165	7.95	456	46	10.3	3.8	49
170	7.96	457	46	10.2	3.2	52
175	7.95	457	46	10.2	3.9	47
180	7.95	456	46	10.1	3.9	48

Field Filtering Versus Slow Pumping Study



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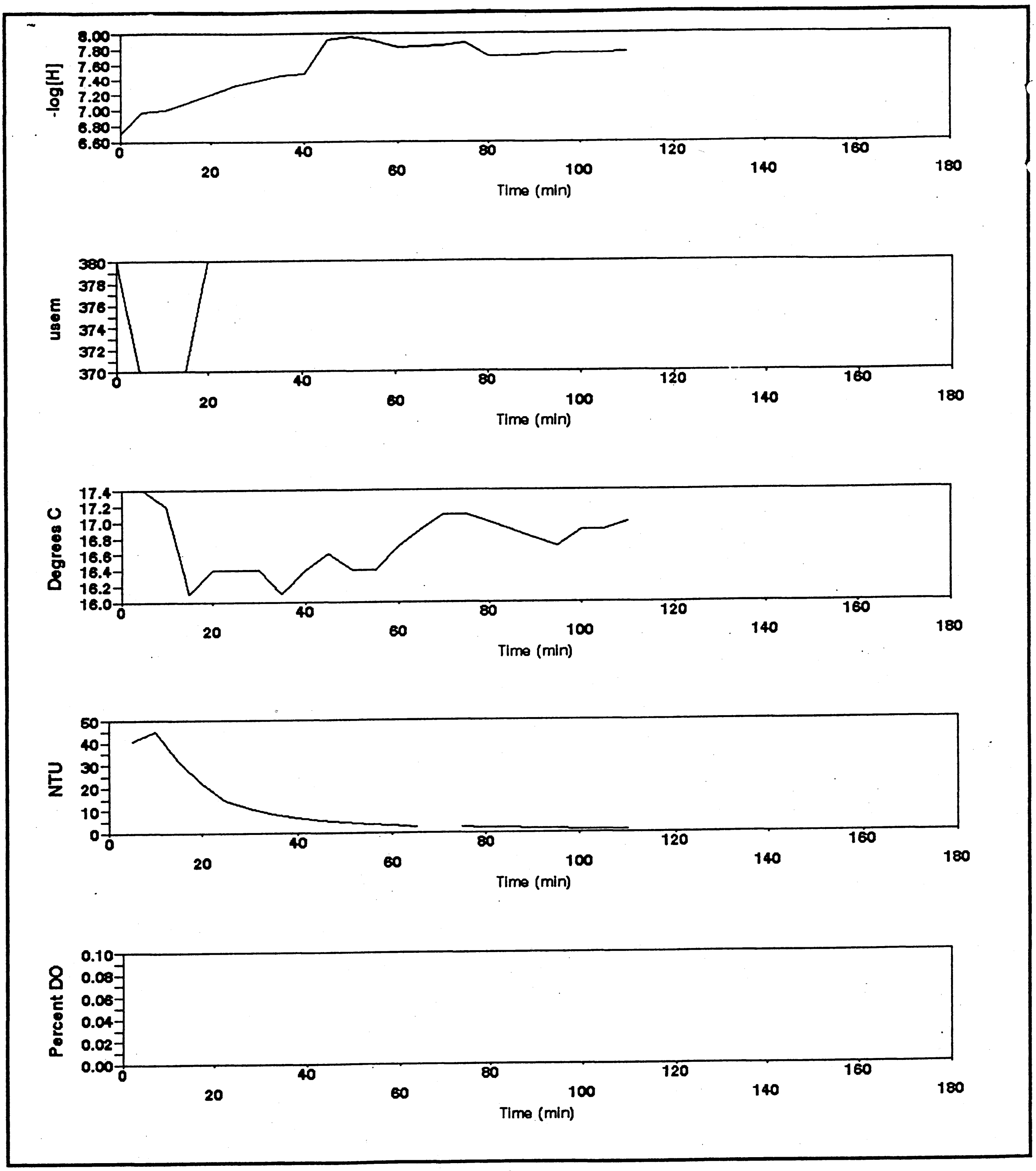
Field Filtering Versus Slow Pumping Study

Site	Waupaca Foundary	Date	08-Sep-93
Well Number	B-24R	Air Temp.	
Depth to Water Before	19.70	Bottom Of Well	
Depth to Water After		Pump Rate	

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	6.70	380	38	17.4		
5	6.98	370	37	17.4	40.9	
10	7.00	370	37	17.2	45.2	
15	7.10	370	37	16.1	32.0	
20	7.21	380	38	16.4	22.2	
25	7.31	380	38	16.4	14.5	
30	7.38	380	38	16.4	10.9	
35	7.45	380	38	16.1	8.3	
40	7.48	380	38	16.4	6.6	
45	7.92	380	38	16.6	5.2	
50	7.95	380	38	16.4	4.4	
55	7.91	380	38	16.4	3.7	
60	7.83	380	38	16.7	3.3	
65	7.84	380	38	16.9	2.7	
70	7.85	380	38	17.1		
75	7.88	380	38	17.1	2.2	
80	7.71	380	38	17.0	2.0	
85	7.71	380	38	16.9	1.9	
90	7.72	380	38	16.8	1.7	
95	7.74	380	38	16.7	1.7	
100	7.74	380	38	16.9	1.4	
105	7.74	380	38	16.9	1.4	
110	7.75	380	38	17.0	1.4	
115			0			
120			0			
125			0			
130			0			
135			0			
140			0			
145			0			
150			0			
155			0			
160			0			
165			0			
170			0			
175			0			
180			0			

Field Filtering Versus Slow Pumping Study



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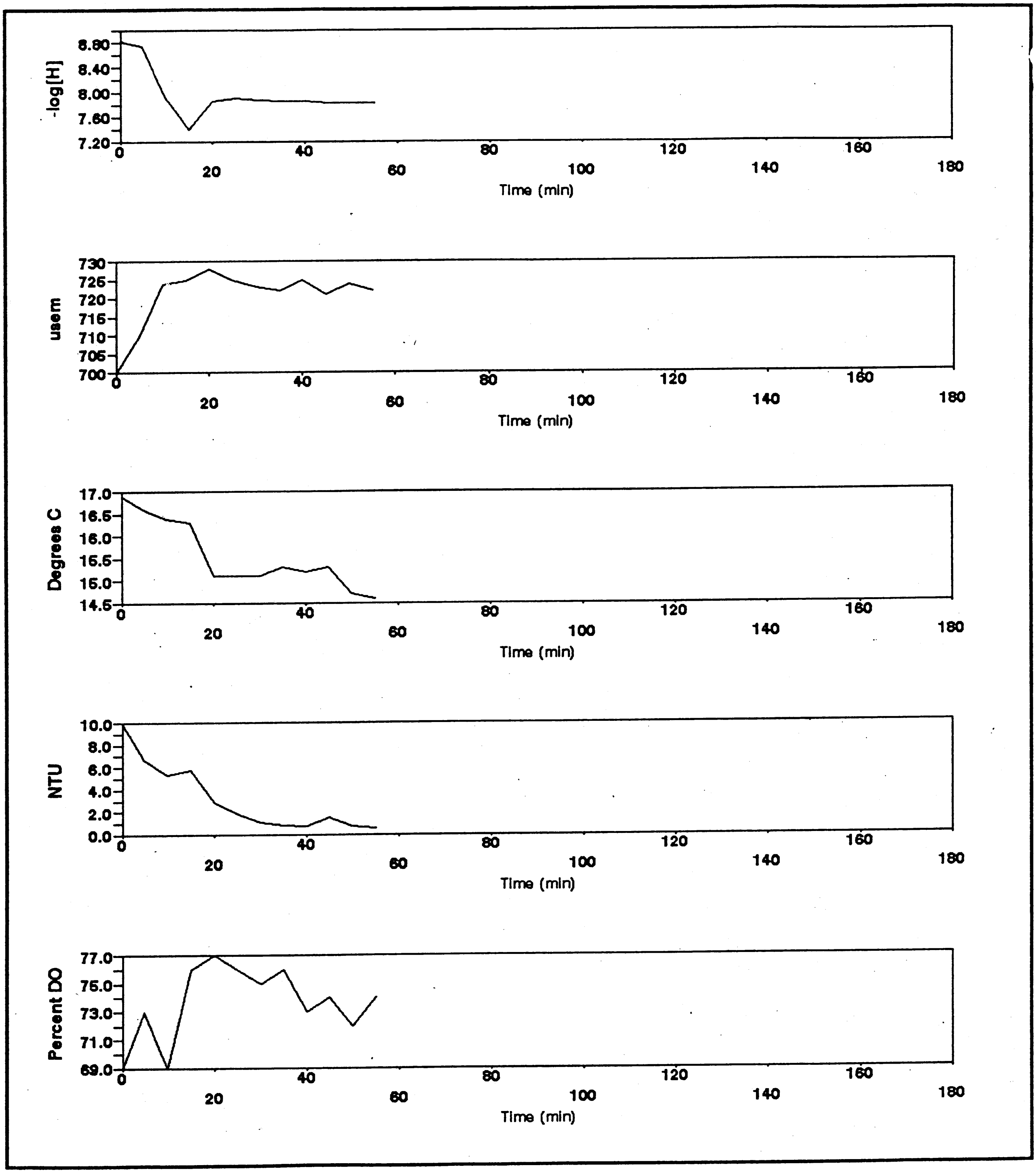
Field Filtering Versus Slow Pumping Study

	Riverside Plating	Date	08-Oct-93
Well Number	P-4	Air Temp.	
Depth to Water Before	4.24	Bottom Of Well	22.48
Depth to Water After		Pump Rate	600-800 mL/min

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	8.82	700	70	16.9	9.9	69
5	8.75	710	71	16.6	6.7	73
10	7.92	724	72	16.4	5.3	69
15	7.39	725	73	16.3	5.8	76
20	7.86	728	73	15.1	2.9	77
25	7.90	725	73	15.1	1.8	76
30	7.88	723	72	15.1	1.1	75
35	7.86	722	72	15.3	0.8	76
40	7.85	725	73	15.2	0.7	73
45	7.83	721	72	15.3	1.5	74
50	7.83	724	72	14.7	0.7	72
55	7.82	722	72	14.6	0.6	74
60			0			
65			0			
70			0			
75			0			
80			0			
85			0			
90			0			
95			0			
100			0			
105			0			
110			0			
115			0			
120			0			
125			0			
130			0			
135			0			
140			0			
145			0			
150			0			
155			0			
160			0			
165			0			
170			0			
175			0			
180			0			

Field Filtering Versus Slow Pumping Study

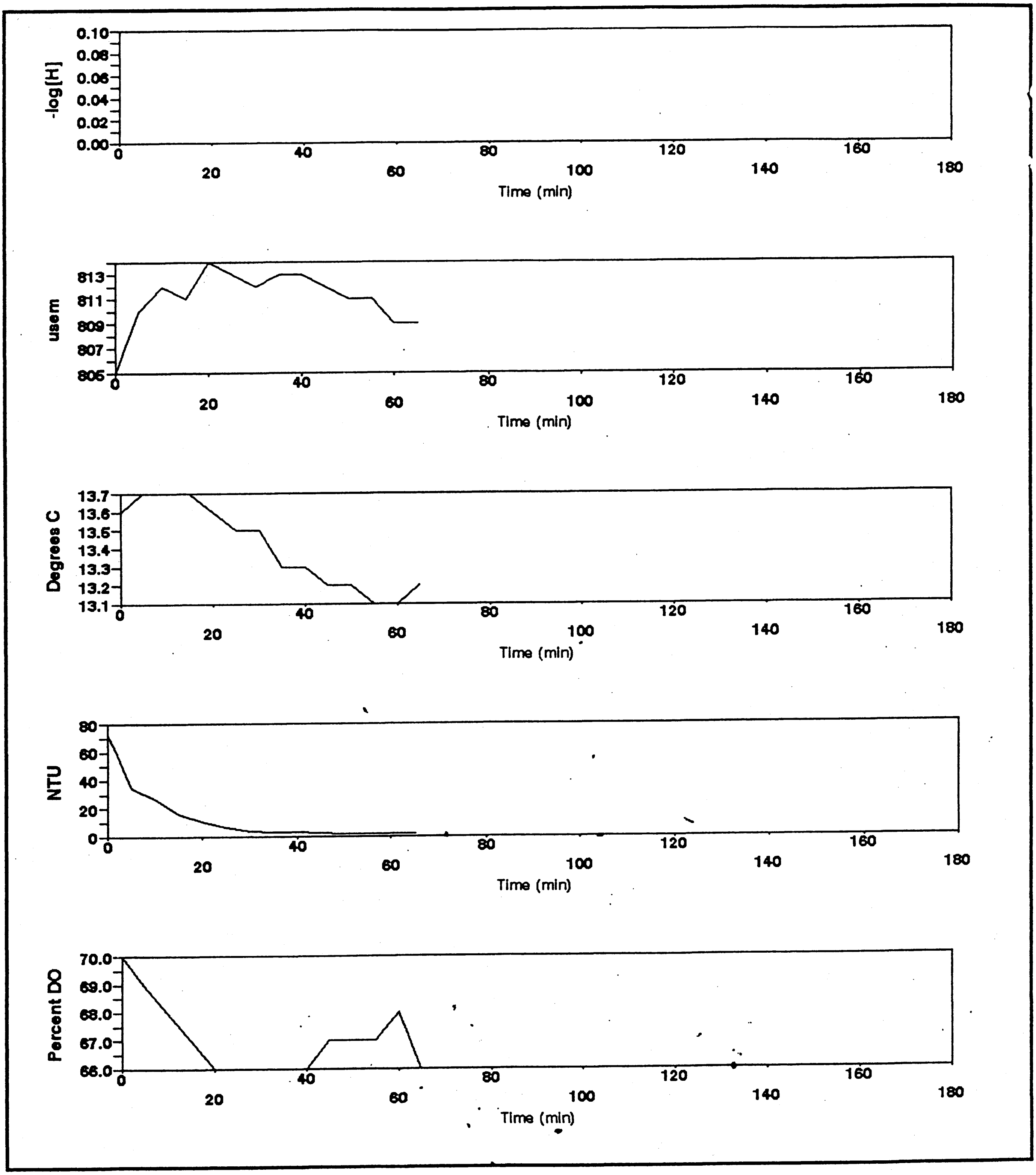


Field Filtering Versus Slow Pumping Study

Site		Riverside Plating	Date		23-Oct-93
Well Number		P-3	Air Temp.		
Depth to Water Before		5.72	Bottom Of Well		22.57
Depth to Water After		6	Pump Rate		700

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	0.00	805	81	13.6	72.5	70
5		810	81	13.7	34.4	69
10		812	81	13.7	26.8	68
15		811	81	13.7	16.2	67
20		814	81	13.6	10.3	66
25		813	81	13.5	6.8	66
30		812	81	13.5	4.3	66
35		813	81	13.3	3.4	66
40		813	81	13.3	3.1	66
45		812	81	13.2	2.5	67
50		811	81	13.2	2.2	67
55		811	81	13.1	2.0	67
60		809	81	13.1	1.8	68
65		809	81	13.2	1.9	66
70			0			
75			0			
80			0			
85			0			
90			0			
95			0			
100			0			
105			0			
110			0			
115			0			
120			0			
125			0			
130			0			
135			0			
140			0			
145			0			
150			0			
155			0			
160			0			
165			0			
170			0			
175			0			
180			0			

Field Filtering Versus Slow Pumping Study



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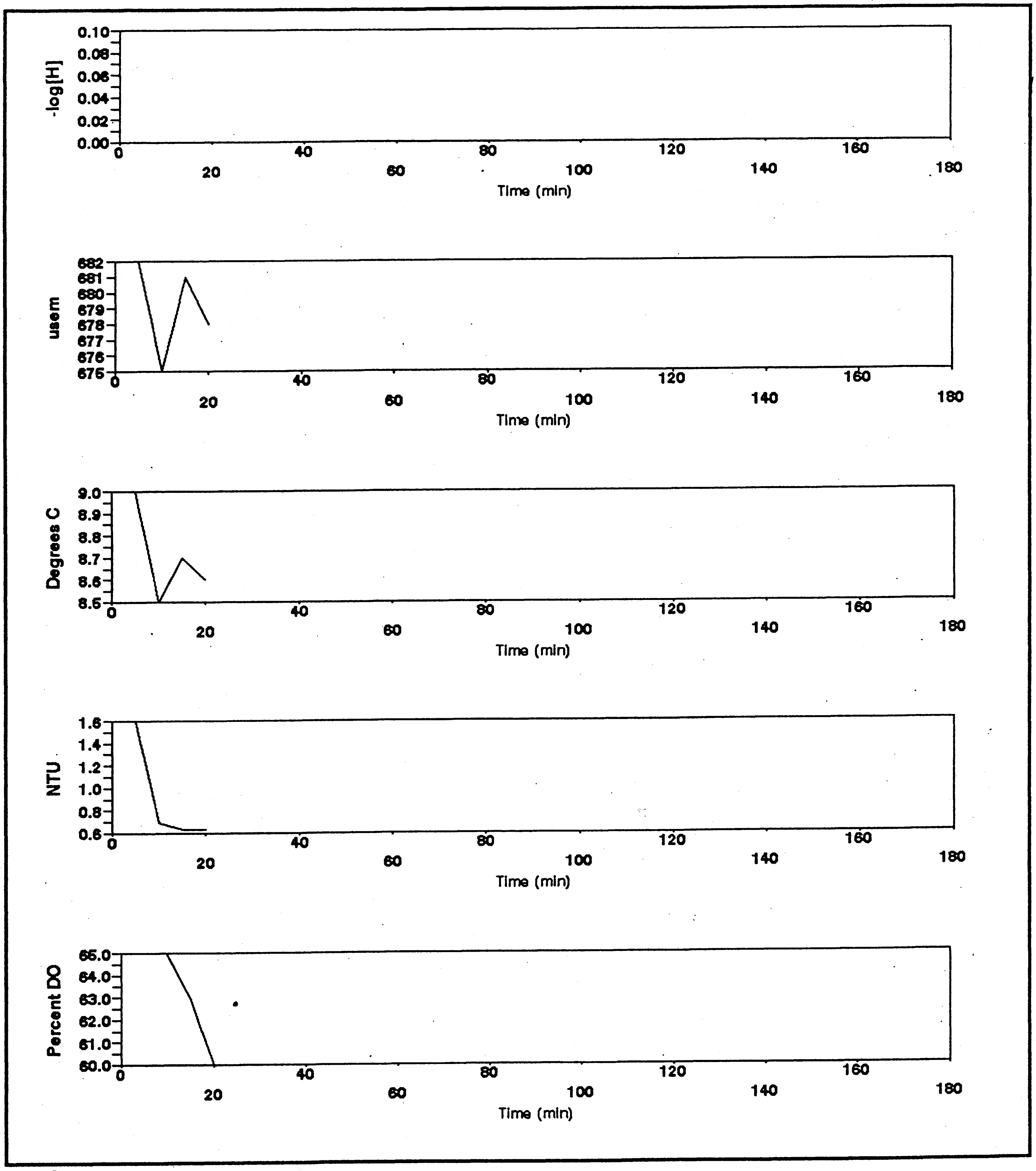
Field Filtering Versus Slow Pumping Study

Site	Riverside Plating			Date		30-Jan-94
Well Number	P-4			Air Temp.		
Depth to Water Before	5.84			Bottom Of Well		22.50
Depth to Water After				Pump Rate		
Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0			0			
5		682	68	9.0	1.6	65
10		675	68	8.5	0.7	65
15		681	68	8.7	0.6	63
20		678	68	8.6	0.6	60
25			0			
30			0			
35			0			
40			0			
45			0			
50			0			
55			0			
60			0			
65			0			
70			0			
75			0			
80			0			
85			0			
90			0			
95			0			
100			0			
105			0			
110			0			
115			0			
120			0			
125			0			
130			0			
135			0			
140			0			
145			0			
150			0			
155			0			
160			0			
165			0			
170			0			
175			0			
180			0			

Field Filtering Versus Slow Pumping Study



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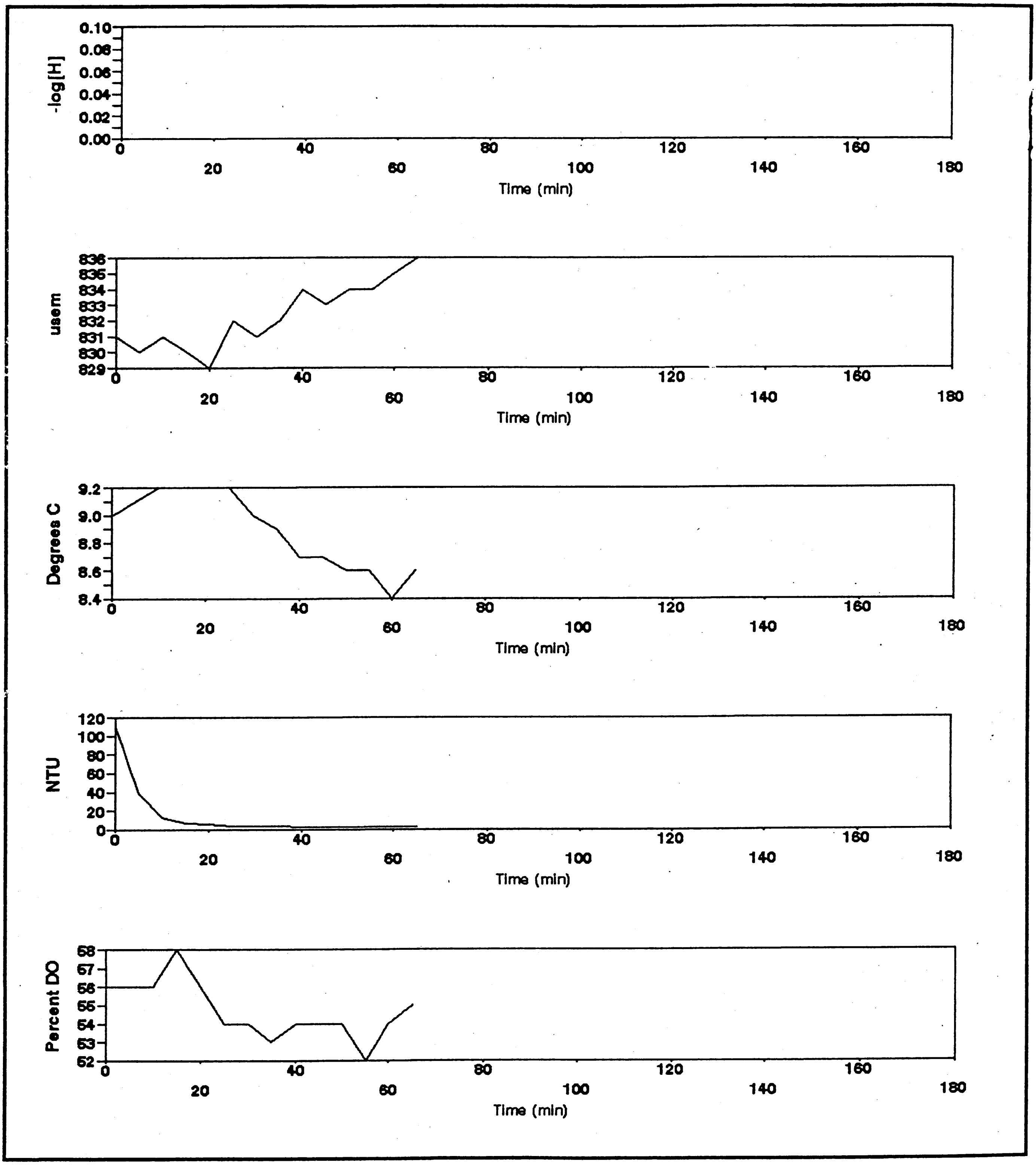
Field Filtering Versus Slow Pumping Study

Site	Riverside Plating		Date		05-Feb-94
Well Number	P-3		Air Temp.		
Depth to Water Before	6.86		Bottom Of Well		22.67
Depth to Water After			Pump Rate		

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	0.00	831	83	9.0	110.0	56
5		830	83	9.1	38.0	56
10		831	83	9.2	13.1	56
15		830	83	9.2	6.9	58
20		829	83	9.2	5.4	56
25		832	83	9.2	4.2	54
30		831	83	9.0	3.9	54
35		832	83	8.9	3.7	53
40		834	83	8.7	3.3	54
45		833	83	8.7	3.3	54
50		834	83	8.6	2.7	54
55		834	83	8.6	2.5	52
60		835	84	8.4	3.2	54
65		836	84	8.6	2.9	55
70			0			
75			0			
80			0			
85			0			
90			0			
95			0			
100			0			
105			0			
110			0			
115			0			
120			0			
125			0			
130			0			
135			0			
140			0			
145			0			
150			0			
155			0			
160			0			
165			0			
170			0			
175			0			
180			0			

ceo:rpf5p3.wq1

Field Filtering Versus Slow Pumping Study



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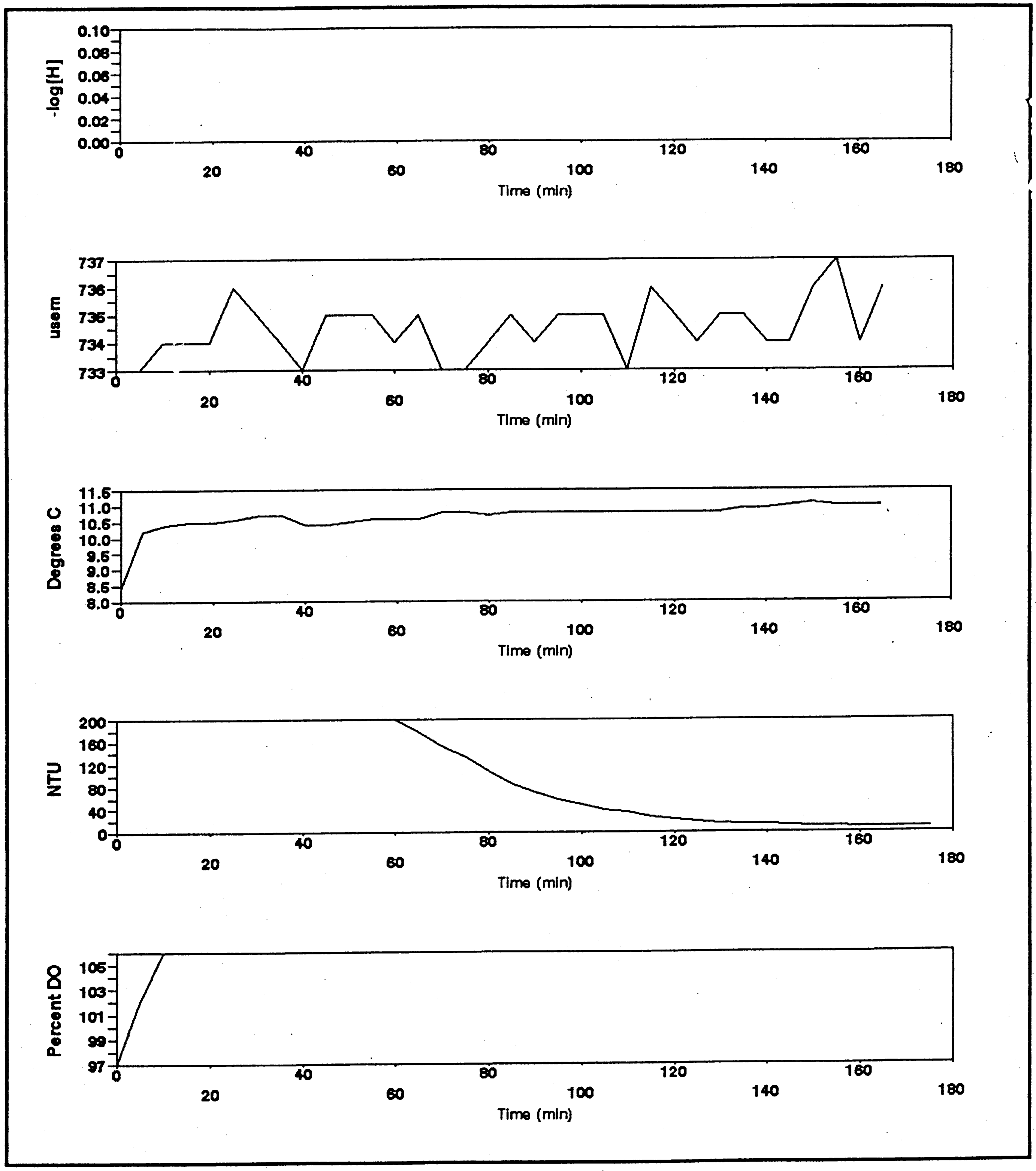
Field Filtering Versus Slow Pumping Study

Site	Riverside Plating	Date	01-Mar-94
Well Number	mw-11	Air Temp.	
Depth to Water Before	56.04	Bottom Of Well	66.73
Depth to Water After		Pump Rate	

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0		733	73	8.4	200.0	97
5		733	73	10.2	200.0	102
10		734	73	10.4	200.0	106
15		734	73	10.5	200.0	
20		734	73	10.5	200.0	
25		736	74	10.6	200.0	
30		735	74	10.7	200.0	
35		734	73	10.7	200.0	
40		733	73	10.4	200.0	
45		735	74	10.4	200.0	
50		735	74	10.5	200.0	
55		735	74	10.6	200.0	
60		734	73	10.6	200.0	
65		735	74	10.6	177.5	
70		733	73	10.8	153.5	
75		733	73	10.8	134.0	
80		734	73	10.7	109.1	
85		735	74	10.8	87.2	
90		734	73	10.8	70.9	
95		735	74	10.8	57.0	
100		735	74	10.8	48.0	
105		735	74	10.8	39.0	
110		733	73	10.8	34.7	
115		736	74	10.8	27.4	
120		735	74	10.8	21.9	
125		734	73	10.8	18.2	
130		735	74	10.8	14.9	
135		735	74	10.9	13.5	
140		734	73	10.9	12.5	
145		734	73	11.0	11.0	
150		736	74	11.1	10.0	
155		737	74	11.0	9.1	
160		734	73	11.0	8.3	
165		736	74	11.0	8.2	
170			0		7.3	
175			0		8.0	
180			0			

Field Filtering Versus Slow Pumping Study



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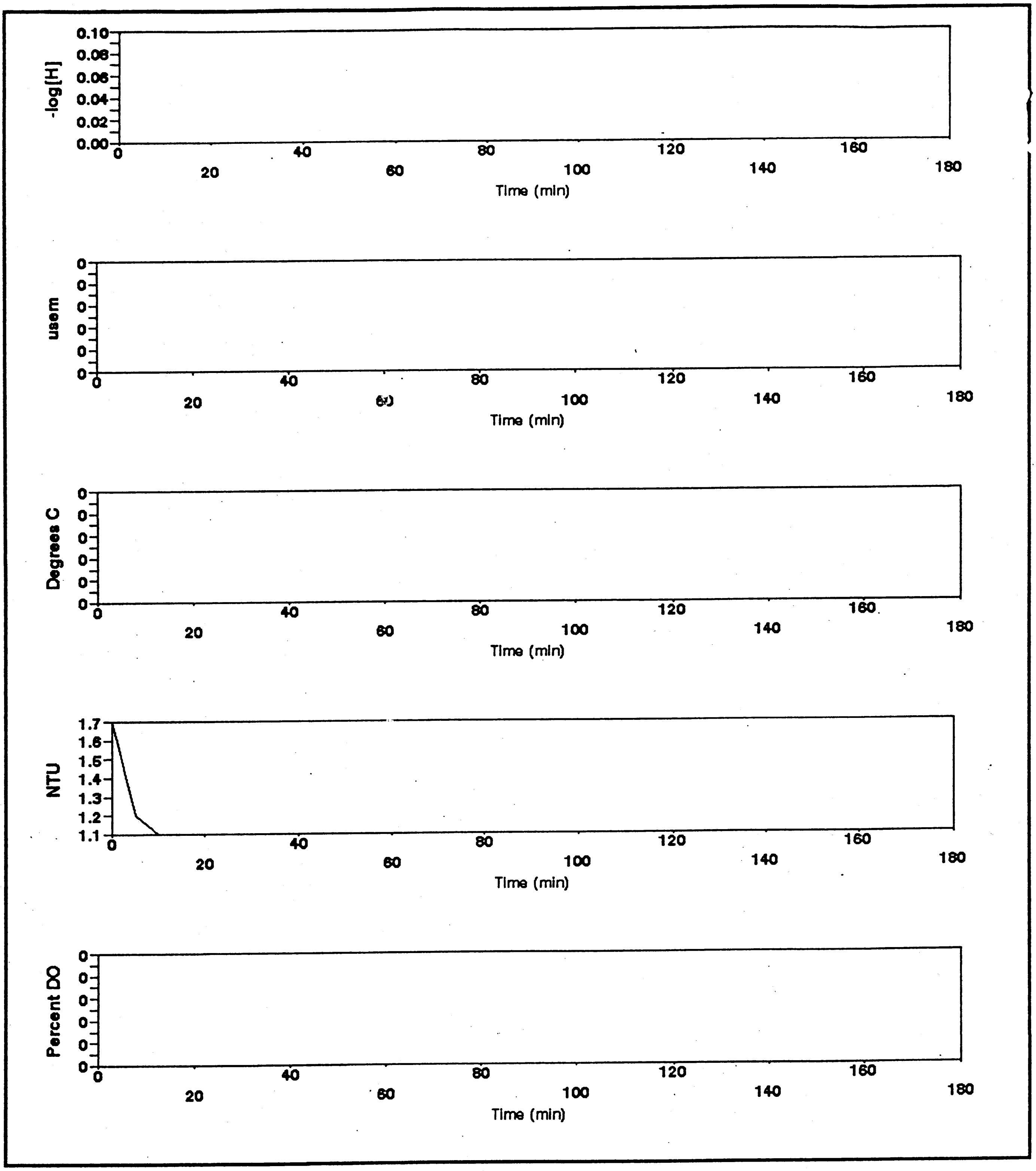
Field Filtering Versus Slow Pumping Study

Site	Riverside Plating			Date	02-Mar-94	
Well Number	P-10			Air Temp.		
Depth to Water Before	56.04			Bottom Of Well		
Depth to Water After				Pump Rate		
Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0			0		1.7	
5			0		1.2	
10			0		1.1	
15			0		1.1	
20			0			
25			0			
30			0			
35			0			
40			0			
45			0			
50			0			
55			0			
60			0			
65			0			
70			0			
75			0			
80			0			
85			0			
90			0			
95			0			
100			0			
105			0			
110			0			
115			0			
120			0			
125			0			
130			0			
135			0			
140			0			
145			0			
150			0			
155			0			
160			0			
165			0			
170			0			
175			0			
180			0			

Field Filtering Versus Slow Pumping Study



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Field Filtering Versus Slow Pumping Study

Site	Demetral	Date	03/29/90
Well Number	MW-8A (	Air Temp.	40F
Depth to Water Before	8.47	Bottom Of Well	23
Depth to Water After		Pump Rate	500 mL/min

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	8.30	650	65	10.0	186.0	5
5	8.20	595	60	9.6	185.0	3
10	9.20	666	67	9.6	200.0	4
15	8.20	774	77	9.4	164.0	3
20	9.40	841	84	9.6	132.0	2
25	8.40	859	86	9.6	112.0	1
30	8.20	884	88	9.6	83.0	1
35	8.00	904	90	9.4	54.7	1
40	9.10	919	92	9.5	39.7	0
45	8.20	929	93	9.7	40.5	0
50	8.40	937	94	9.8	31.2	1
55	7.90	939	94	9.7	19.8	0
60	8.30	946	95	9.4	13.3	0
65	7.90	948	95	9.3	8.0	0
70	7.80	950	95	9.3	6.8	0
75	8.70	951	95	9.5	9.2	0
80	8.20	953	95	9.4	5.5	1
85	7.90	954	95	9.4	6.6	1
90	8.90	954	95	9.4	3.8	1
95	8.20	954	95	9.5	3.9	1
100			0			
105			0			
110			0			
115			0			
120			0			
125			0			
130			0			
135			0			
140			0			
145			0			
150			0			
155			0			
160			0			
165			0			
170			0			
175			0			
180			0			

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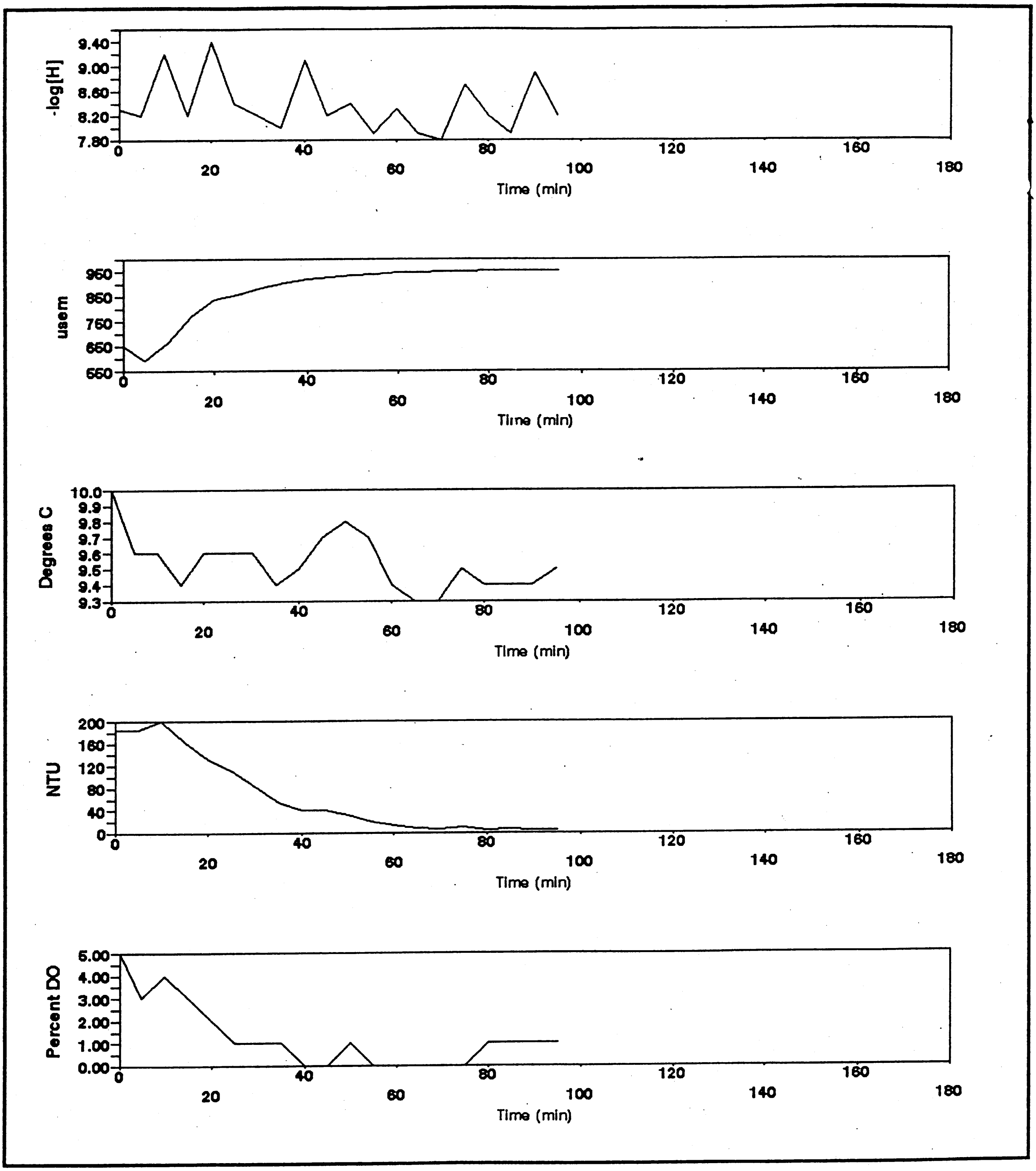
Field Filtering Versus Slow Pumping Study



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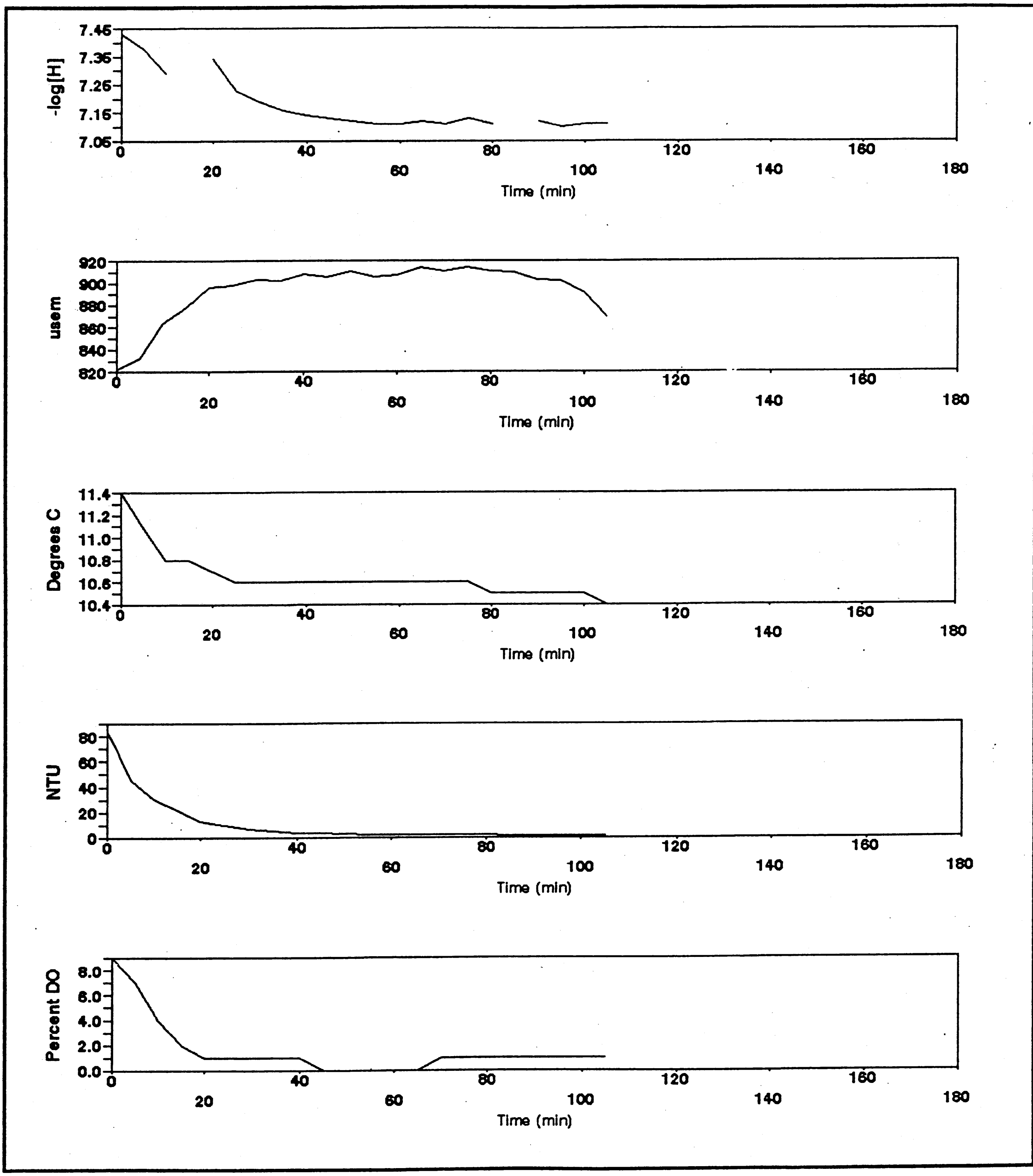
Field Filtering Versus Slow Pumping Study

Site		Demetral	Date		03/31/90
Well Number		MW7A (1	Air Temp.		55 F
Depth to Water Before		10.54	Bottom Of Well		
Depth to Water After			Pump Rate		600 mL/min

Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	7.43	822	82	11.4	83.9	9
5	7.38	832	83	11.1	45.7	7
10	7.29	864	86	10.8	30.6	4
15		878	88	10.8	21.9	2
20	7.34	896	90	10.7	13.0	1
25	7.23	898	90	10.6	9.8	1
30	7.19	903	90	10.6	6.6	1
35	7.16	902	90	10.6	5.0	1
40	7.14	908	91	10.6	3.9	1
45	7.13	906	91	10.6	3.4	0
50	7.12	911	91	10.6	2.8	0
55	7.11	906	91	10.6	2.4	0
60	7.11	907	91	10.6	2.5	0
65	7.12	914	91	10.6	2.1	0
70	7.11	911	91	10.6	2.3	1
75	7.13	914	91	10.6	2.0	1
80	7.11	911	91	10.5	1.7	1
85		910	91	10.5	1.4	1
90	7.12	903	90	10.5	1.5	1
95	7.10	902	90	10.5	1.3	1
100	7.11	891	89	10.5	1.1	1
105	7.11	870	87	10.4	1.3	1
110			0			
115			0			
120			0			
125			0			
130			0			
135			0			
140			0			
145			0			
150			0			
155			0			
160			0			
165			0			
170			0			
175			0			
180			0			

Field Filtering Versus Slow Pumping Study



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Field Filtering Versus Slow Pumping Study

Site			Demetral	Date		04/19/90
Well Number			MW1B	Air Temp.		67 F
Depth to Water Before			7.39	Bottom Of Well		107
Depth to Water After				Pump Rate		150 mL/min
Time (min)	pH	Conductivity (usem)	(usem/10	Temperature (degrees C)	Turbidity (NTU)	Dissolved Oxygen (%)
0	7.00	340	34	14.4	200.0	19
5	7.28	428	43	13.5	200.0	4
10	7.36	439	44	13.2	178.0	2
15	7.38	444	44	13.1	131.9	1
20	7.39	443	44	13.5	93.1	1
25	7.39	443	44	14.0	119.5	2
30	7.38	444	44	13.7	81.8	3
35	7.38	443	44	13.6	68.2	2
40		442	44	13.4	58.5	2
45	7.62	442	44	13.4	47.5	1
50	7.47	442	44	13.4	43.0	2
55	7.43	443	44	13.4	37.5	2
60	7.41	443	44	13.4	34.9	2
65	7.41	442	44	13.4	32.3	2
70	7.39	442	44	13.5	30.3	2
75	7.37	441	44	13.8	28.8	2
80	7.36	440	44	13.8	25.2	2
85	7.36	430	43	13.9	24.4	1
90	7.36	430	43	13.7	25.3	1
95	7.35	436	44	14.2	22.9	2
100	7.35	435	44	14.3	19.9	2
105	7.35	434	43	14.2	19.0	2
110	7.35	434	43	14.1	18.4	2
115		433	43	13.9	17.9	2
120	7.46	431	43	13.8	17.4	2
125	7.44	431	43	13.7	16.6	2
130	7.40	431	43	13.7	15.4	2
135	7.40	431	43	13.6	13.7	2
140	7.38	431	43	13.6	12.3	2
145	7.36	430	43	13.5	10.7	2
150	7.36	431	43	13.3	9.5	2
155	7.35	432	43	13.2	8.4	2
160	7.35	433	43	13.0	7.2	2
165	7.35	434	43	13.0	6.4	2
170		434	43	13.0	5.7	2
175	7.42	435	44	12.9	4.9	2
180			0			

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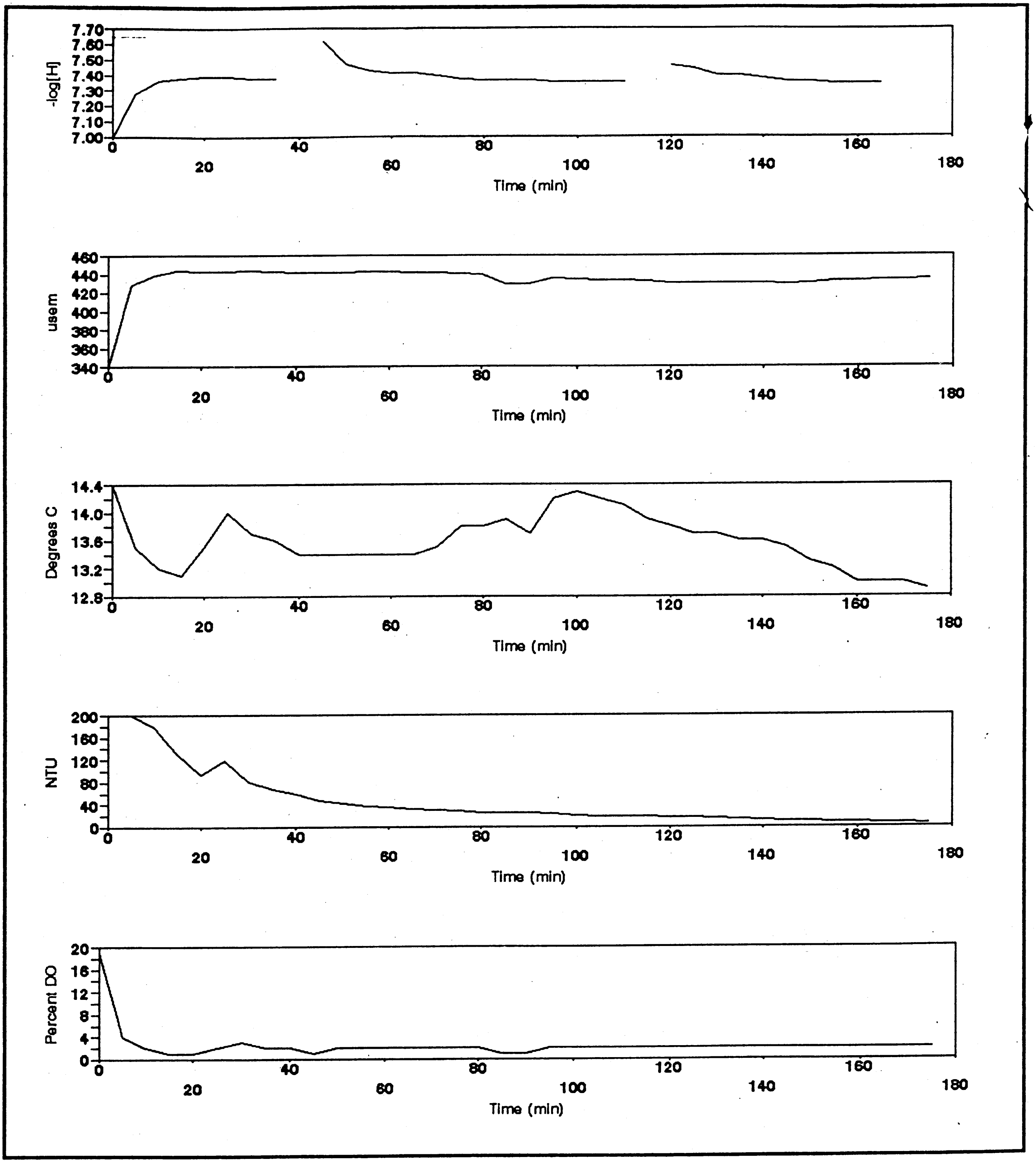
Field Filtering Versus Slow Pumping Study



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