MIAMI-DADE COUNTY NORTHWEST WELLFIELD GROUNDWATER VELOCITY INVESTIGATION

Technical Publication WS-1

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by

Steve Krupa, P.G.
Steven Hill
Cindy Bevier

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33306
(561) 686-8800
www.sfwmd.gov

EXECUTIVE SUMMARY

The Miami-Dade Water and Sewer Department's Northwest Wellfield is located just south and west of a large limestone mining region in southwest Miami-Dade County known as "the Lake Belt area." When the Lake Belt Mining Coalition proposed excavation of several new rock pits near the eastern edge of the Northwest Wellfield in 1995, concern arose about possible impacts to the public water supply. The South Florida Water Management District (District or SFWMD), along with the Miami-Dade County Department of Environmental Resources Management, initiated a cooperative effort to gather information about the surface water and groundwater regime near the Northwest Wellfield and to identify areas meriting further long-term study. The determination of groundwater flow velocities near the Northwest Wellfield was believed to provide important information relating to the aquifer's ability to filter contaminants and particles from the water.

This paper reports the results of an analysis of in situ groundwater flow velocities in four monitor well clusters located just east of the Northwest Wellfield during April 1996. Measurements of water levels were taken to establish horizontal and vertical gradients assumed to be within the cone of influence of the pumping wells. Then, groundwater flow velocities and directions were measured at different depths in each well, using a borehole flowmeter. Finally, average travel times were calculated.

The public water supply wells and monitor wells addressed in this study withdraw from the Biscayne aquifer. Horizontal gradients within this highly transmissive aquifer were quite low, in the range of 0.00018 to 0.00035. Additionally, most of the monitor well clusters had downward vertical gradients that were up to three orders of magnitude greater than the horizontal gradients. Although it rained frequently during the study, the downward vertical gradients were interpreted as being primarily caused by the influence of the pumping wells.

Groundwater flow velocities, measured with the flowmeter, ranged from 1.70 to 15.62 feet/day during the study period. Not all the groundwater flow measured was toward the pumping wells, which could mean that the flowmeter readings reflected conditions very close to the borehole, rather than regional conditions. Nonetheless, using an average velocity of 5.44 feet/day, a travel time of one year was calculated between Well NW-7 and PWS Well 9, and a travel time of 1.44 years was calculated between Well NW-6 and PWS Well 6. The travel time calculations indicated how much time it took for water quality problems, detected in specific monitor wells, to appear in specific pumping wells. This calculation subsequently provided a general idea of groundwater residence time in the vicinity of the Northwest Wellfield, which is related to the aquifer's ability to attenuate contaminants.

It is uncertain if laminar flow conditions exist close to the pumping wells, and it is possible that turbulent groundwater flow could occur in the vicinity of the monitor wells at higher wellfield pumping rates. This study recommends additional groundwater flow

measurements during times of higher pumping rates at the wellfield, additional measurements during wet and dry months to identify seasonal influences on groundwater flow, monitoring of mining lake stages during additional flow measurements, and tracer tests to verify the travel times calculated in this report.

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Robert Verrastro, formerly of Montgomery Watson and currently a Senior Hydrogeologist in the Hydrogeology Unit of the South Florida Water Management District (District or SFWMD), provided editorial comments and helpful background information gleaned from his experience with well rehabilitation at the Northwest Wellfield. Appreciation is expressed to Peter Kwiatkowski, Supervising Hydrogeologist in the Hydrogeology Unit of the SFWMD, for his helpful suggestions and editing of this manuscript. We also wish to thank Diane Bello-Smith and Janet Wise for contributing their skills in creating AutoCad drawings for this report. The authors are grateful to Felicia Berger for her editing assistance in bringing this report to publication.

INTRODUCTION

In 1995, the Lake Belt Mining Coalition of Miami-Dade County proposed excavation of several new rock pits near the eastern side of the Miami-Dade Water and Sewer Department (MDWASD) Northwest Wellfield. The possibility of public water supply wells intercepting contaminated surface water from the pits was a concern to MDWASD, the Miami-Dade County Department of Environmental Resources Management (DERM), and the South Florida Water Management District (District or SFWMD). Depending on the groundwater velocities in the area, another possible consequence of excavation was a change in the water source classification of the wellfield from groundwater to surface water. Such a change would result in substantially greater treatment costs for MDWASD, without necessarily improving the quality of the water delivered to the end user. As part of the District's efforts to evaluate the potential impacts of the proposed excavation, a Statement of Work (SOW) was prepared.

The SOW consisted of two major tasks. Task 1 involved surface water modeling, water quality evaluation, and recommendations. Task 2 included measurement of in situ groundwater velocities near the wellfield, calculation of residence times of groundwater near the wellfield, evaluation of current groundwater quality, and recommendations for future long-term studies. This technical document fulfills the Task 2 phases, except for evaluation of groundwater quality. A copy of the SOW is provided in Appendix A.

PROJECT APPROACH

A map of the Northwest Wellfield, depicting the water supply wells and nearby monitor wells, is shown in **Figure 1**. The project goals and approach were developed jointly by the District and DERM. The main focus of the project was the analysis of groundwater flow velocities near the Northwest Wellfield. DERM supplied District staff with information on the construction details of nearby monitor wells. Based on this information and the general configuration of wells, transects were selected to collect field data.

The field data acquisition portion of the project began with collection of water level information and verification of monitor well depths for those wells included in the transects. In situ borehole flowmeter measurements of groundwater velocity and direction of flow were then collected at different depths inside the well screens. MDWASD staff supplied information regarding the operation schedule and general pumping rates of the Northwest Wellfield for the period corresponding with the dates of field data collection.

After the field data were collected, horizontal and vertical groundwater gradients were calculated along the transects. Borehole flowmeter velocity measurements were corrected for hydraulic conductivity differences between the geologic formation and the internal glass bead packing in the flowmeter. Average groundwater velocities were determined. From this information, travel times and average velocities at different wellfield pumping rates were calculated.

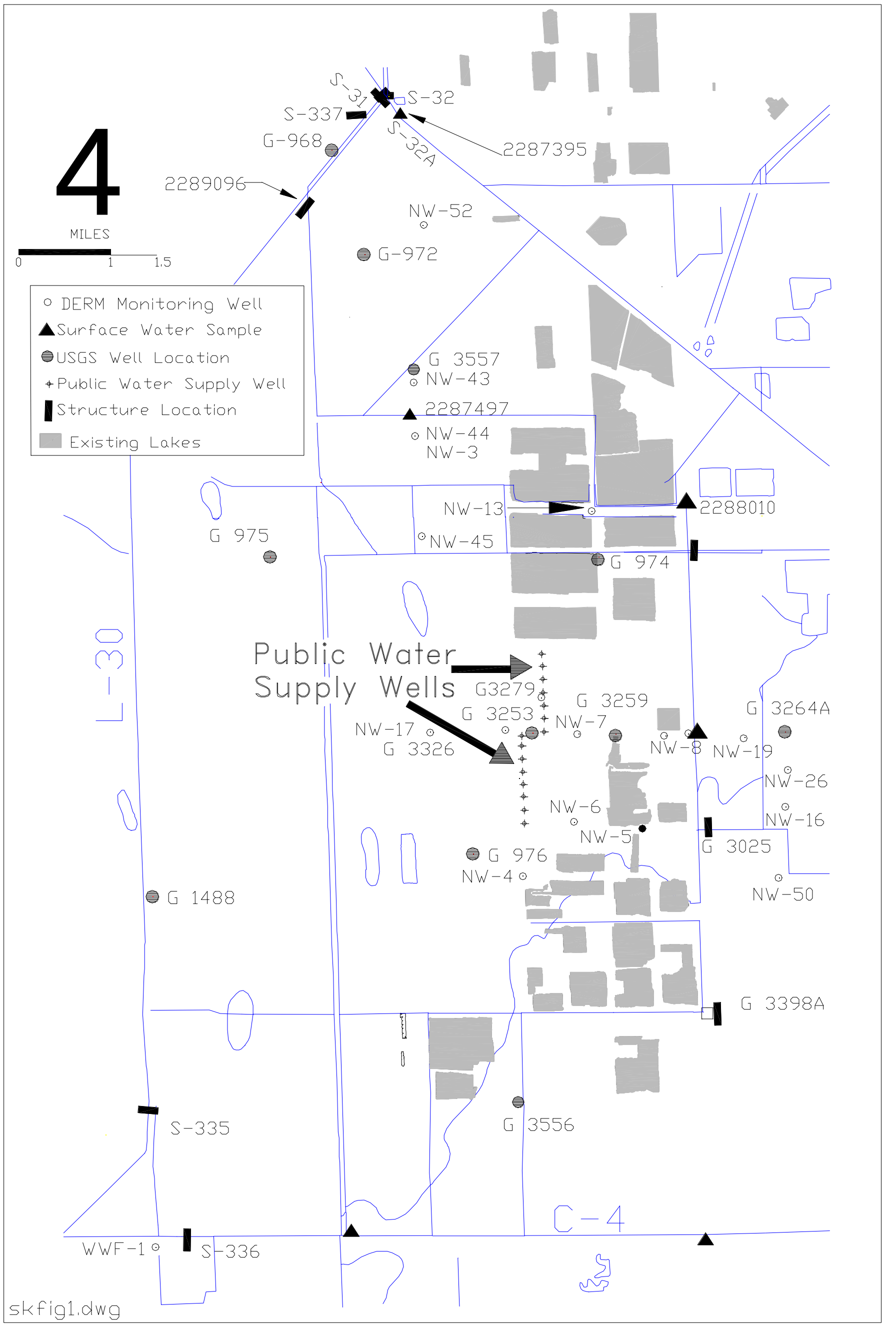


Figure 1. General Site Map of Northwest Wellfield, Miami-Dade Water and Sewer Department

DATA COLLECTION

Background and Supporting Information

The MDWASD Northwest Wellfield provides raw (untreated) water for subsequent treatment before distribution as potable water to residents in the area. A total of 15 water supply wells comprises the Northwest Wellfield. Each of these wells withdraws from the Biscayne aquifer, the source of raw water for the Northwest Wellfield. Each water supply well is constructed with 46 feet of casing and completed with open-hole intervals extending to depths of 80 to 90 feet below land surface (bls). Well construction information for each water supply well is summarized in Appendix B, Table B-1.

Hydrologic studies of Miami-Dade County, including a published document by Fish and Stewart (1991), indicate that regional groundwater flow in the Biscayne aquifer is to the east and southeast. Other factors, such as canal stages and wellfield pumpage, can locally alter the regional gradient and direction of groundwater flow. Wellfield pumpage was assumed to be the primary influence on groundwater movement in the study area. An enlarged map depicts those public water supply wells operating during the in situ groundwater velocity investigation (**Figure 2**).

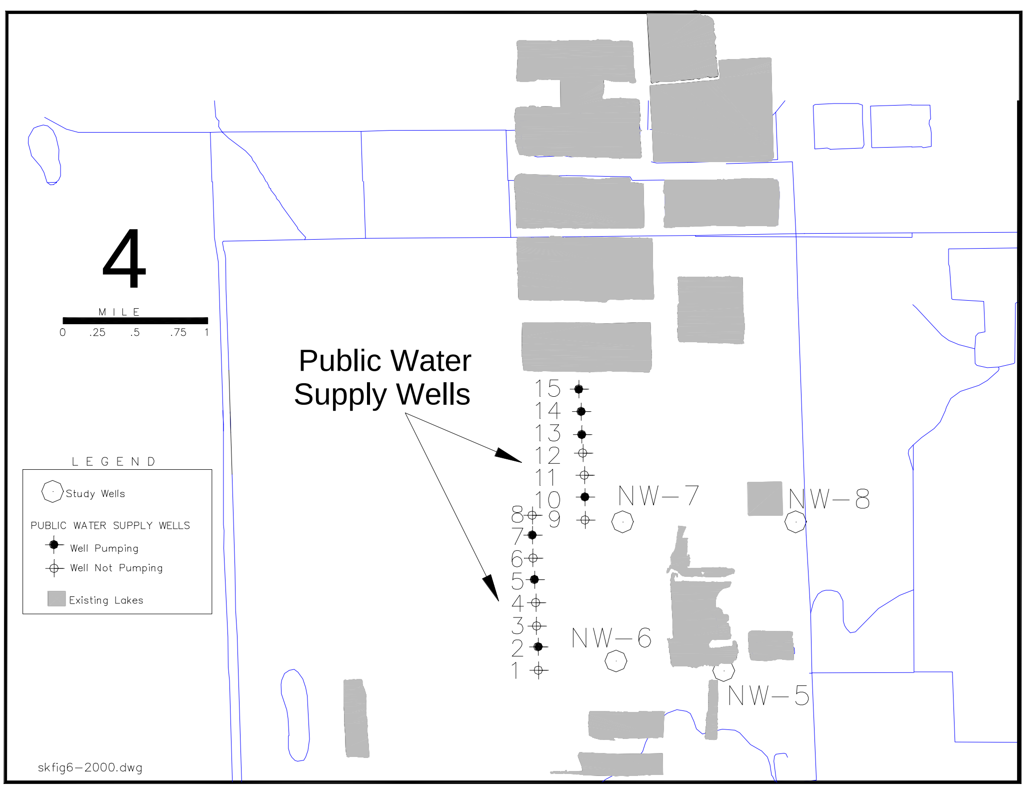
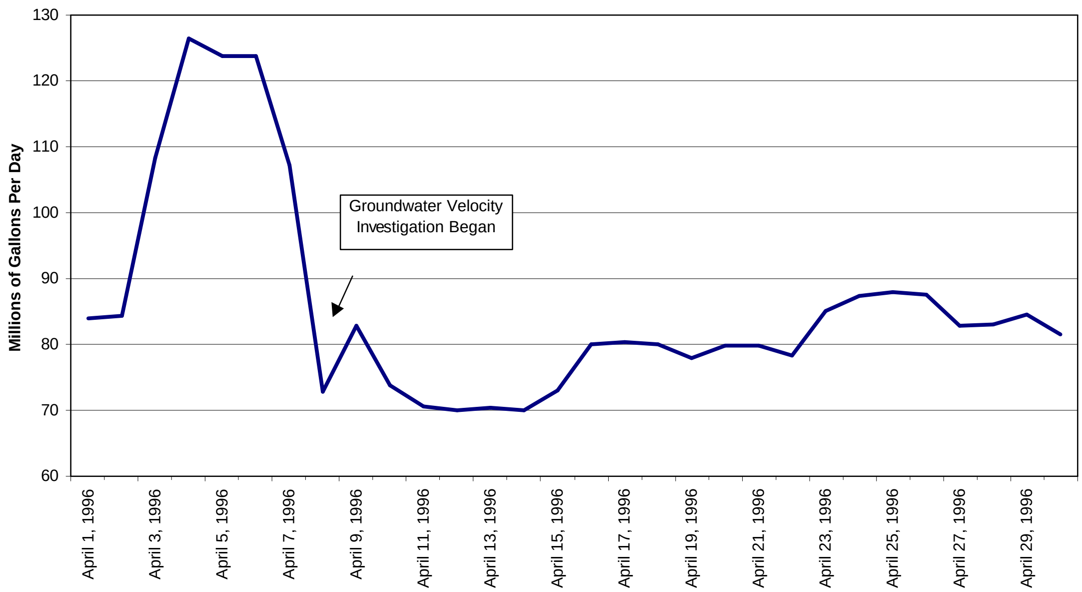


Figure 2. Public Water Supply Well Operations during Groundwater Velocity Investigation, MDWASD Northwest Wellfield

Total pumpage data for April 1996 were obtained from the MDWASD monthly report, and are presented in Appendix B, Table B-2. The daily combined pumpage rates of all the water supply wells located within the Northwest Wellfield are shown in **Figure 3**. Well operations during the field data collection portion of the study are summarized in **Table 1**.



Source: Miami-Dade Water and Sewer Dept. Monthly Reports

Figure 3. Total Daily Pumpage at MDWASD Northwest Wellfield, April 1996

Table 1. Relative Pumpage Rates during In situ Groundwater Velocity Measurements at Northwest Wellfield, Miami-Dade County

Well Number	**Pump Operations During Groundwater Velocity Measurements April 8, 1996**	**Pump Operations During Groundwater Velocity Measurements April 9, 1996**
2	Low	High
5	Low	Off
7	Low	High
10	Low	High
13	Low	High
14	Low	High
15	Low	High
Total Pumpage	7 Wells = 72.863 MGD (Actual)	6 Wells = 82.86 MGD (Actual)
Pumpage information supplied by Kevin Kotun, DERM Water Supply Section		
MGD = million gallons per day		

The supply wells are fitted with pumps that have two speed settings: "low" and "high." Low speed corresponds to 10 millions of gallons per day (MGD), while high speed corresponds to 15 MGD. The District also obtained a complete list of monitor wells (Appendix B, Table B-3) near the Northwest Wellfield from DERM. This information was useful in selecting transects for determining groundwater flow.

Selection of Transects

To facilitate the analysis of groundwater flow, selected monitor wells were grouped into transects. Four transects, each consisting of two deep and two shallow wells, were initially identified. Each transect also included at least two wells that were perpendicular, or nearly perpendicular, to the main portion of the north-south trending production wells. These four transects are shown in **Figure 4**.

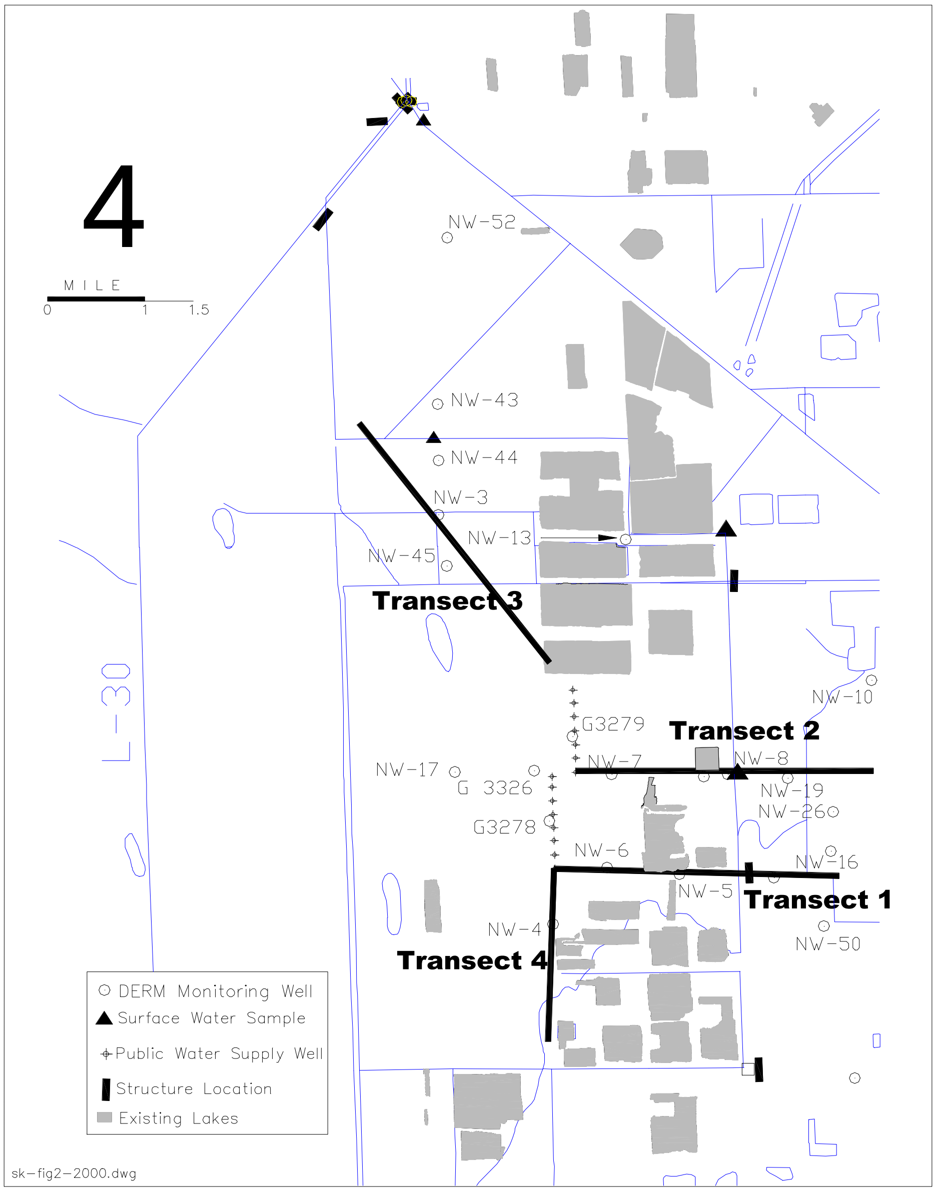


Figure 4. Original Velocity Transects Selected for MDWASD Northwest Wellfield Study, Miami-Dade County, Florida

Transect 1: This transect is composed of well clusters NW-5 and NW-6. Each cluster contains two wells. The wells are constructed of 2-inch PVC casing with stainless steel screens. These wells were evaluated as suitable for the in situ groundwater velocity investigation.

Transect 2: This transect is composed of well clusters NW-7 and NW-8. Each cluster contains two wells. The wells are constructed of 2-inch PVC casing with stainless steel screens. These wells were evaluated as suitable for the in situ groundwater velocity investigation.

Transect 3: This proposed transect was composed of NW-3, a 2-inch well. An additional well northwest of the wellfield was needed to make this transect useful. No such well existed at the time of the study, according to DERM staff. Because of this limitation, Transect 3 was removed from the investigation.

Transect 4: This proposed transect ran north-south and included well cluster NW-4. Access to these wells was not possible during the investigation. In addition, the NW-4 wells were constructed of carbon steel. Any downhole corrosion in the well casing interferes with the installation and functioning of the flowmeter. Because of these limitations, Transect 4 was not included in the investigation.

Figure 5 shows the location of the two transects that were ultimately used in the study.

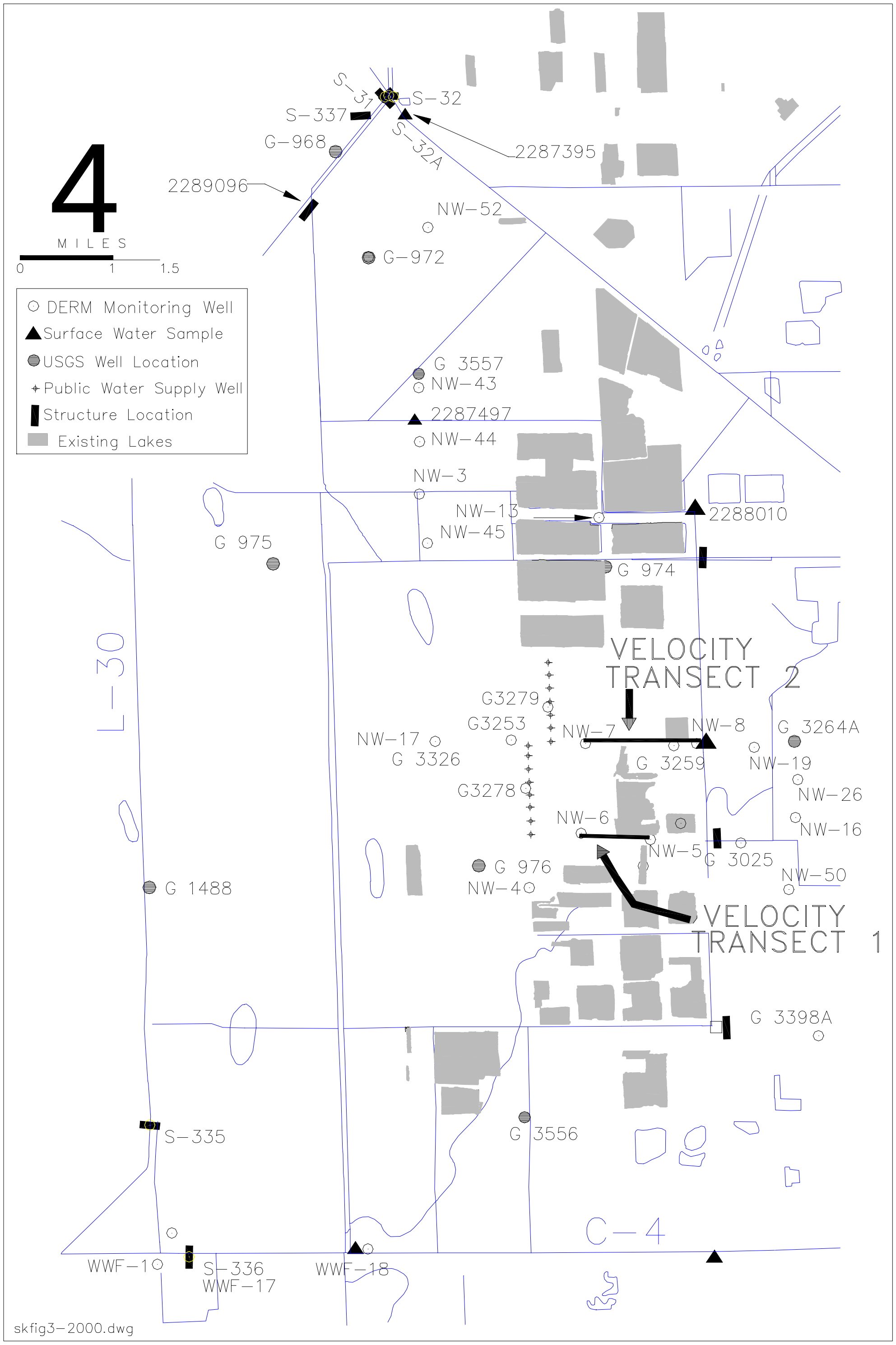


Figure 5. Wells Used in Groundwater Velocity Transects 1 and 2, MDWASD Northwest Wellfield Study, Miami-Dade County, Florida.

Field Measurements

Field measurements for the project were conducted on April 8 and 9, 1996. Each piece of equipment was cleaned and decontaminated before and after insertion into each well. The work proceeded without incident, in spite of frequent heavy rainfall.

To verify well construction information and establish water level measurements for gradient calculations, each well in the two transects was measured for total depth and static water level, using top of casing (TOC) as a reference point. The measurements are listed in **Table 2**. Well names beginning with the letter "A" are the deep wells (generally 50 to 60 feet bls). Wells beginning with the letter "B" are shallow (generally 20 to 30 feet bls).

Table 2. Total Depth and Static Water Level Measurements at Monitor Wells, MDWASD Northwest Wellfield, Miami-Dade County, Florida

Well Name	Measured Water Level from TOC (ft)	Water Levels in ft (1929 NGVD)	Measured Total Depth from TOC (ft)	Date	Time
NW-5A	5.00	2.80	55.0	April 8, 1996	13:55
NW-5B	5.06	2.82	24.8	April 8, 1996	13:35
NW-6A	4.60	3.52	59.3	April 8, 1996	15:55
NW-6B	6.60	1.65	24.6	April 8, 1996	15:55
NW-7A	3.15	2.09	59.5	April 9, 1996	10:10
NW-7B	3.15	2.55	24.7	April 9, 1996	10:10
NW-8A	1.06	4.36	59.4	April 9, 1996	13:30
NW-8B	1.09	4.59	24.7	April 9, 1996	13:30

TOC = Top of Casing

NGVD = National Geodetic Vertical Datum

Flow measurements were obtained using a heat-pulsing groundwater flowmeter manufactured by KV Associates, Inc. of Mashpee, Massachusetts. The flowmeter works by transmitting a heat pulse through a porous glass medium in the probe. Paired thermal sensors in the probe detect changes in the heat distribution, producing a linear response to flow increases (Kerfoot, 1988). The flowmeter adheres to American Society of Testing Materials (ASTM) Special Technical Publication 963 (ASTM Publication Code Number 04-963000-38) standards of design and operation. It can be used in both 2- and 4-inch diameter wells. The District and DERM agreed to measure horizontal flow only, as vertical flow measurements within cased wells are not representative of subsurface conditions. The hardware configuration of the flowmeter, as installed in a typical monitor well, is shown in **Figure 6**.

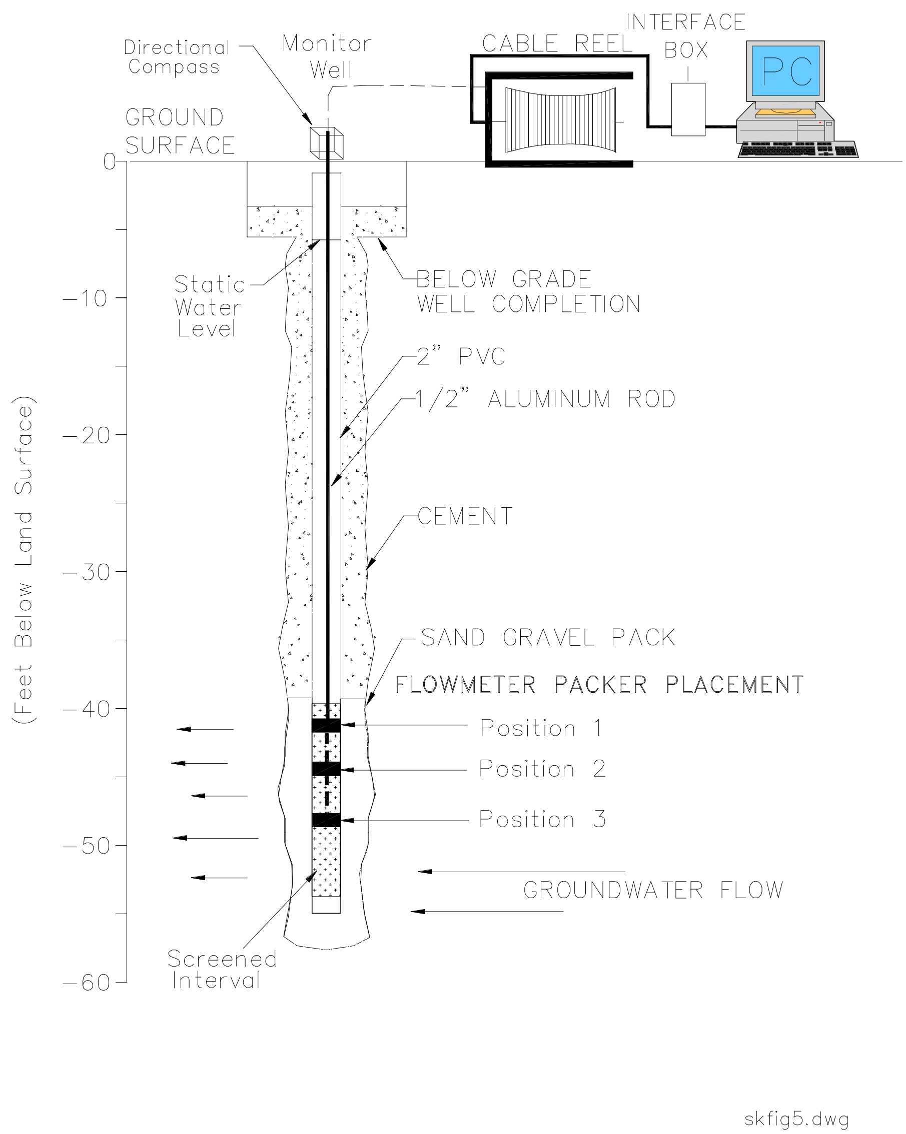


Figure 6. Idealized Cross-Section of Heat-Pulsing Groundwater Flowmeter in Borehole.

The flowmeter was initially run within the cased portions of the monitor wells to verify the equipment bias under no-flow conditions. The bias correction factor was then programmed into the computer.

The flowmeter was lowered to three different depths across the screened interval of each well. Flow measurements were taken at each depth. The flow direction (relative to north) and in situ velocity (feet/day) were recorded.

DATA ANALYSIS

Gradients

Static water level measurements obtained before the flowmeter measurements indicated that horizontal groundwater movement was generally toward the pumping wells. The shallow wells in Transect 1 (5B and 6B) showed an eastward horizontal gradient, away from the pumping wells. These shallow monitor wells may have been influenced more strongly by the nearby rock mining lakes during the measurements than by the supply wells. **Table 3** shows the horizontal gradient between pairs of monitor wells along the transects used in the study. Horizontal gradient is calculated by dividing the difference in water level between two wells by their lateral distance.

Table 3. Horizontal Gradient along Transects

Well 1	Well 2	Transect	Water Level for Well 1 (1929 ft NGVD)	Water Level for Well 2 (1929 ft NGVD)	Distance Apart (ft)	Gradient (unitless)	Flow Direction
NW-5A	NW-6A	1	2.8	3.52	3948	0.000182	West
NW-5B	NW-6B	1	2.82	1.65	3948	0.000296	East
NW-7A	NW-8A	2	2.09	4.36	6331	0.000359	West
NW-7B	NW-8B	2	2.55	4.59	6331	0.000322	West
Note: Distance between wells determined from a scaled map							

Vertical gradients between wells in the same cluster were also calculated (**Table 4**). In general, vertical gradients were steeper than horizontal gradients, and in a downward direction. This is due to the influence of the pumping wells, which pump from open intervals of 46 feet to 80 or 90 feet bls. It is not clear why an upward gradient was determined in well cluster NW-6. This finding could be inaccurate, possibly the result of surveying or recording errors (e.g., switching the measurements of 6A with 6B).

Table 4. Vertical Gradient Calculations for Wells in Same Cluster in Northwest Wellfield, Miami-Dade County, Florida

Well Name and Total Depth (ft)	Well Name and Total Depth (ft)	Vertical Distance Between Screens (ft)	Vertical Gradients Between Well Screens (unitless)
NW-5A (55)	NW-5B (24.82)	32	(2.8 - 2.82 ft)/32 ft = -0.0006 (↓)
NW-6A (59.37)	NW-6B (24.64)	44	(3.52 -1.65 ft)/44 ft = 0.0425 (↑)
NW-7A (59.49)	NW-7B (24.69)	36	(2.09 - 2.55 ft)/36 ft = -0.0128 (↓)
NW-8A (59.36)	NW-8B (24.74)	35	(-1.18 - 4.59 ft)/35 ft = -0.1649 (↓)

Flow Data

The raw velocities recorded from the flowmeter measurements were entered into a spreadsheet and corrected for porosity, aquifer/well screen hydraulic differentials, and sensor glass bead porosity using the equation below (Kerfoot, 1988):

$V_o = n_p v_i / n_a f$ (*Equation 1*)

where:

V_o = corrected transport velocity in the outside strata (l/t)

n_p = porosity of the packer beads in the flowmeter (30%, per Kerfoot, 1988)

v_i = measured velocity from the in situ groundwater flowmeter (l/t)

n_a = observed field porosity of the outside geological unit (estimated as 40%)

f = magnification factor for flow through the well screen compared with flow when the hydraulic conductivity inside the flowmeter and outside the screen are unequal.

The equation for the magnification factor f is as follows:

$f = 2K_r/(1+K_r)$ (*Equation 2*)

where:

$K_r = k_{beads}/k_{formation}$, the ratio of the hydraulic conductivity of the sensor beads to that of the formation

k_{beads} = 2,000 feet/day (Kerfoot, 1988)

$k_{formation}$ = 6,250 feet/day (estimated from Fish and Stewart, 1991, as shown below)

Calculation of $k_{formation,}$ the hydraulic conductivity of the aquifer using average transmissivity and aquifer thickness values (Fish and Stewart, 1991) is as follows:

Transmissivity of aquifer = $k_{formation}$* aquifer thickness (Fish and Stewart, 1991)

$k_{formation}$ = transmissivity of aquifer/aquifer thickness

$k_{formation}$ = 500,000 ft^2/day/80 ft = 6,250 feet/day *therefore:*

$K_r = 0.32$ or 32 percent

thus:

$f = (2*0.32)/(1+0.32)$ (*Equation 2*)

$f = 0.4848$ (unitless)

Returning to *Equation 1* and substituting in the calculated numerical factors yields:

$V_o = n_p v_i / n_a f$ (*Equation 1)*

$V_o = (.3)v_i/(.4)(.4848) = 1.55\ v_i$

The velocity results (raw and corrected) from the in situ horizontal groundwater flow measurements are listed in **Table 5**.

Table 5. Northwest Wellfield Groundwater Velocity Measurements, April 8 and 9, 1996

Well	Date	Time	Elevation of Top of Well Casing (1929 ft NGVD)	Probe Depth from Top of Casing (ft)	Probe Depth (1929 ft NGVD)	Water Level (ft, measured from top of casing)	Water Level (1929 ft NGVD)	Flow-meter Velocity (ft/day)	Flow Direction from True North (deg)	Corrected Velocity (ft/day)
NW-5A	4/8/96	1439	7.8	50	-42.2	5	2.8	10.1	102	15.62
NW-5A	4/8/96	1510	7.8	52.5	-44.7	5	2.8	7.3	62	11.29
NW-5A	4/8/96	1404	7.8	55	-47.2	5	2.8	6.5	109	10.05
NW-5B	4/8/96	1324	7.88	21	-13.12	5.06	2.82	2.5	233	3.87
NW-5B	4/8/96	1315	7.88	23	-15.12	5.06	2.82	1.5	155	2.32
NW-5B	4/8/96	1302	7.88	24	-16.12	5.06	2.82	1.3	38	2.01
NW-6A	4/8/96	1754	8.12	57	-48.88	4.6	3.52	5.7	198	8.82
NW-6A	4/8/96	1745	8.12	58	-49.88	4.6	3.52	4.2	255	6.50
NW-6B	4/8/96	1621	8.25	20	-11.75	6.6	1.65	1.3	344	2.01
NW-6B	4/8/96	1652	8.25	23	-14.75	6.6	1.65	1.5	290	2.32
NW-6B	4/8/96	1644	8.25	24	-15.75	6.6	1.65	1.6	318	2.48
NW-7A	4/9/96	1154	5.24	57.5	-52.26	3.15	2.09	1.6	215	2.48
NW-7A	4/9/96	1200	5.24	57.7	-52.46	3.15	2.09	4.2	229	6.50
NW-7A	4/9/96	1140	5.24	59	-53.76	3.15	2.09	3.1	274	4.80
NW-7B	4/9/96	1308	5.7	21.5	-15.8	3.15	2.55	2.9	181	4.49
NW-7B	4/9/96	1302	5.7	22.5	-16.8	3.15	2.55	2.4	180	3.71
NW-7B	4/9/96	1300	5.7	23.5	-17.8	3.15	2.55	2.6	177	4.02
NW-8A	4/9/96	1459	5.42	55.72	-50.3	1.06	4.36	2.9	329	4.49
NW-8A	4/9/96	1444	5.42	57	-51.58	1.06	4.36	4.2	318	6.50
NW-8A	4/9/96	1429	5.42	58	-52.58	1.06	4.36	2.6	260	4.02
NW-8B	4/9/96	1604	5.68	21.4	-15.72	1.09	4.59	3.8	357	5.88
NW-8B	4/9/96	1554	5.68	22.4	-16.72	1.09	4.59	6	186	9.28
NW-8B	4/9/96	1545	5.68	23.4	-17.72	1.09	4.59	1.1	189	1.70

Note: NGVD = National Geodetic Vertical Datum

Figures 7 through **10** represent the corrected horizontal groundwater flow velocities and directions for shallow and deep monitor wells for the two days of field investigation.

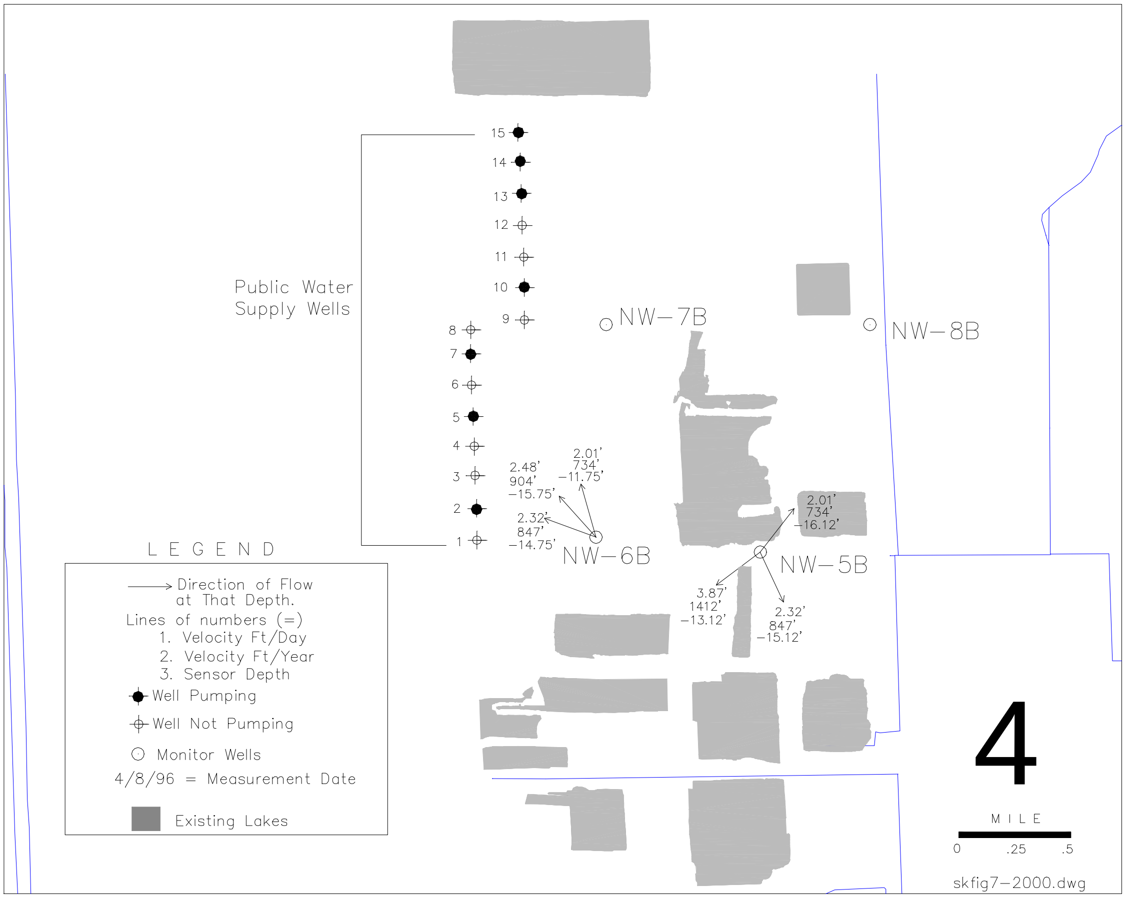


Figure 7. In situ Corrected Horizontal Groundwater Velocities in Shallow Monitor Wells at Northwest Wellfield, Miami-Dade County, Florida, April 8, 1996

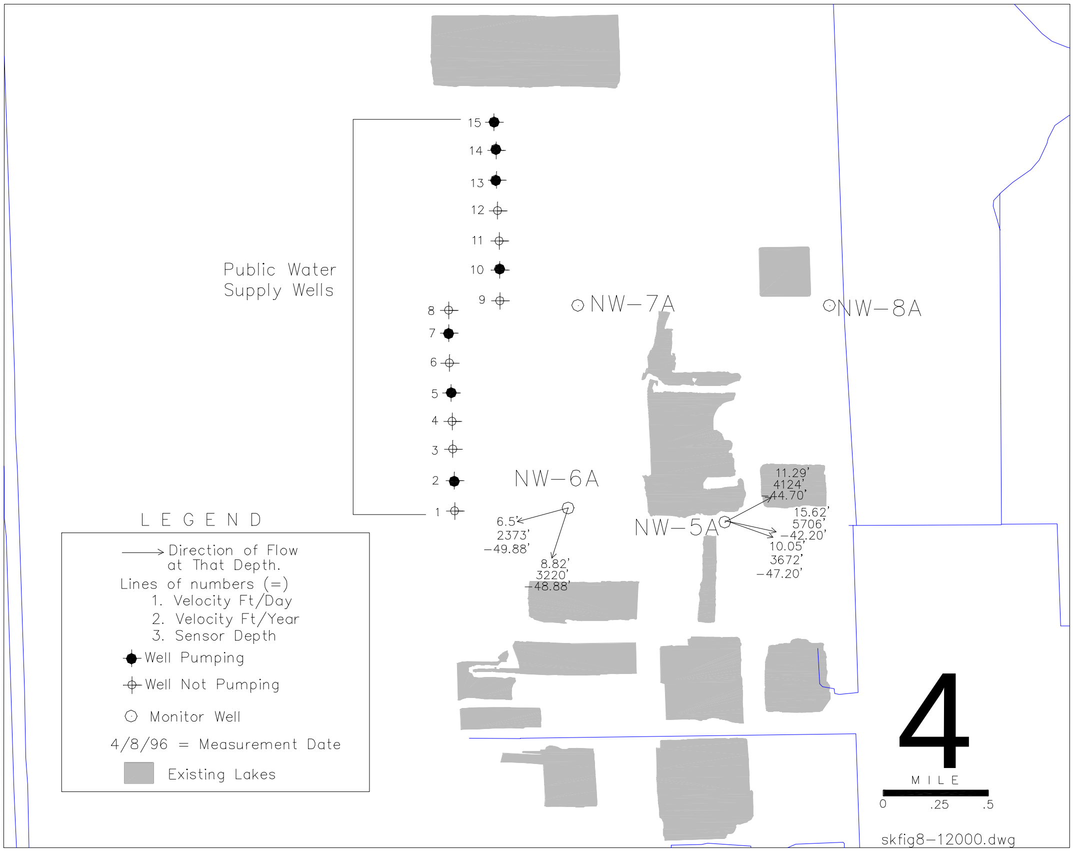


Figure 8. In situ Corrected Horizontal Groundwater Velocities in Deep Monitor Wells at Northwest Wellfield, Miami-Dade County, Florida, April 8, 1996

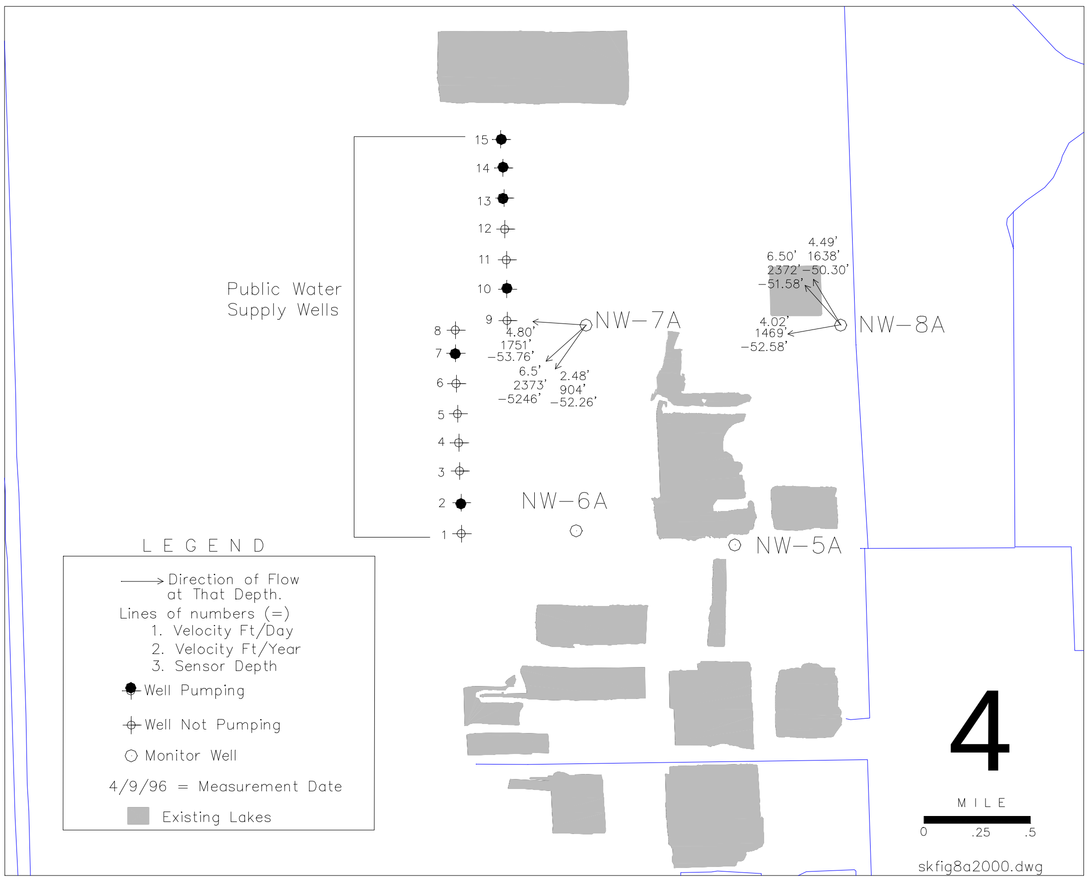


Figure 9. In situ Corrected Horizontal Groundwater Velocities in Deep Monitor Wells at Northwest Wellfield, Miami-Dade County, Florida, April 9, 1996

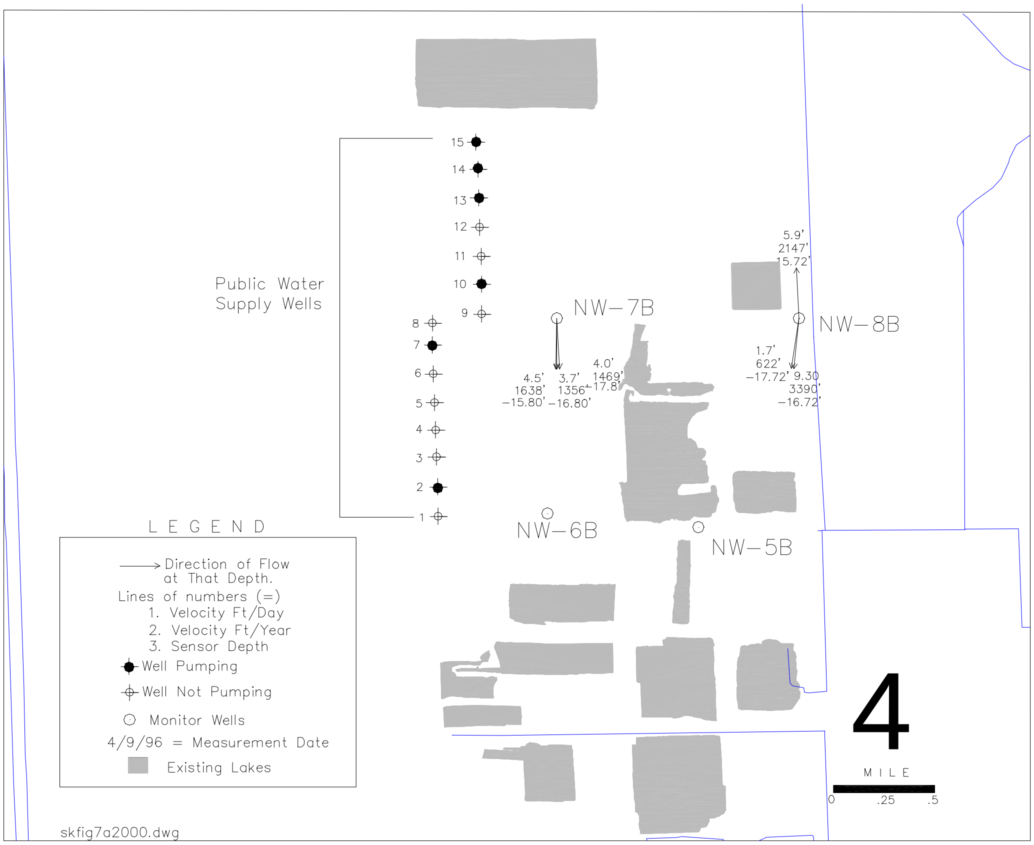


Figure 10. In situ Corrected Horizontal Groundwater Velocities in Shallow Monitor Wells at Northwest Wellfield, Miami-Dade County, Florida, April 9, 1996

Gradient Verification of Velocity

The basic equation describing groundwater flow, Darcy's law, states that the velocity between two points along a flow path equals hydraulic conductivity times hydraulic gradient. Horizontal groundwater flow in an aquifer occurs only through the actual pore space, not the entire cross-section of an aquifer. Therefore, actual horizontal groundwater velocity is calculated using the Darcy equation, shown below, divided by the porosity of the saturated medium.

$$v_1 = (k*i)/n \qquad (\textit{Equation 3})$$

where:

v_1 = the velocity of a water molecule as it moves through the aquifer

k = the hydraulic conductivity (l/t) of the aquifer

$i = (h_1-h_2)/x$

where:

h_1 is the measured head in one monitor well (l)

and h_2 is the measured head in the second monitor well (l)

and x is the horizontal distance between the wells (l).

n = the estimated porosity of the aquifer (unitless)

Using the horizontal gradients from **Table 3**, a k value of 6,250 feet/day, and an n value for the aquifer of 0.4, groundwater velocities along the transects were calculated (**Table 6**).

The average value for all the corrected flow velocities in **Table 5** is 5.44 feet per day. This value compares favorably with the calculated velocities in **Table 6**. Individual measurements at different depths within the screened intervals in the monitor wells reflect flow velocities close to the boreholes, which can be affected by: (1) tortuosity in the solutioned limestone of the aquifer, (2) well construction, and (3) deterioration of well screens.

Table 6. Groundwater Velocity along Transects Calculated with Darcy's Law

Wells in Transect	Horizontal Gradient (from Table 3)	K (ft/day)	Porosity	V_i (ft/day)
NW-5A and NW-6A	0.000182	6250	0.4	2.85
NW-5B and NW-6B	0.000296	6250	0.4	4.63
NW-7A and NW-8A	0.000359	6250	0.4	5.60
NW-7B and NW-8B	0.000322	6250	0.4	5.03

Gradient Verification of Horizontal Hydraulic Conductivity

In situ groundwater flow measurements are calculated using travel times of horizontal heat pulses arriving at individual thermistors within the flowmeter. Since v_1 (Darcy flow divided by porosity) should be equal to v_2 (velocity obtained by flowmeter), the following equations are applicable:

$$v_2 = v_1 = (k_{calc}*i)/n \qquad (\textit{Equation 4})$$

Rearranging variables and solving for k_{calc} yields *Equation 5*:

$$k_{calc} = v_2*n/i \qquad (\textit{Equation 5})$$

The term k_{calc} is the calculated hydraulic conductivity of the aquifer based on the in situ groundwater flowmeter velocity measurement. **Table 7** shows k_{calc} values derived from *Equation 5* for each of the flowmeter measurements, using the gradients calculated along the transects.

The hydraulic conductivity values calculated above compare favorably with published hydraulic conductivity values for the Biscayne aquifer in the vicinity of the Northwest Wellfield, which range from 1,000 feet/day to over 10,000 feet/day (Fish and Stewart, 1991).

Statistical Analysis

A brief statistical analysis of the corrected flowmeter velocities and the calculated hydraulic conductivity values from **Table 7** are presented in **Table 8**. These statistical values were obtained using the descriptive statistics tool in Microsoft Excel 97.

Table 7. Horizontal Hydraulic Conductivity Calculated from Flowmeter Velocity

Well	Gradient along Transect (from Table 3)	Assumed Porosity	Corrected Flow Meter Velocity (ft/day)	K actual (ft/day)
NW-5A	0.000182	0.4	15.62	34,337
			11.29	24,818
			10.05	22,088
NW-5B	0.000296	0.4	3.87	5,226
			2.32	3,136
			2.01	2,717
NW-6A	0.000182	0.4	8.82	19,378
			6.50	14,279
NW-6B	0.000296	0.4	2.01	2,717
			2.32	3,136
			2.48	3,345
NW-7A	0.000359	0.4	2.48	2,758
			4.80	5,343
			6.50	7,239
NW-7B	0.000322	0.4	4.49	5,573
			3.71	4,612
			4.02	4,996
NW-8A	0.000359	0.4	4.49	4,998
			6.50	7,239
			4.02	4,481
NW-8B	0.000322	0.4	5.88	7,302
			9.28	11,530
			1.70	2,114
		Average:	5.44	8,842

Table 8. Descriptive Statistics on Corrected Flowmeter Velocity Measurements and Calculated Hydraulic Conductivity Values from Table 7

Description	Corrected Flow Meter Velocity (ft/day)	K calc (ft/day)
Mean	5.44	8842.21
Standard Error	0.74	1773.44
Median	4.49	5225.93
Mode	6.50	3135.56
Standard Deviation	3.54	8505.12
Sample Variance	12.51	72337148.41
Kurtosis	1.72	2.74
Skewness	1.34	1.81
Range	13.92	32223.48
Minimum	1.70	2113.74
Maximum	15.62	34337.23
Sum	125.14	203370.89
Count	23.00	23.00

DISCUSSION AND CONCLUSION

The groundwater velocity measurements obtained for this study confirm that pumping at the Northwest Wellfield exerts significant influence on the groundwater velocity in the aquifer system. The magnitude of this influence is a function of location, well depth, lithologic variations, and the pumping rate at the wellfield. Groundwater velocities measured with the borehole flowmeter ranged from 1.7 feet/day (622 feet/year) to 9.28 feet/day (3,390 feet/year) in the shallow wells, and from 2.48 feet/day (904 feet/year) to 15.6 feet/year (5,706 feet/year) in the deep wells for the days on which the testing was conducted. Because the deep monitor wells are completed to a similar depth as the water supply wells, which presumably intercept the most permeable portion of the Biscayne aquifer, some of the highest velocities measured in this study were located in the deeper wells.

When groundwater velocities are low, and viscous forces rather than inertial forces prevail, groundwater flow is considered to be laminar (Roscoe Moss Company, 1989). In laminar flow, the water molecules flow in smooth streamlines. As flow velocities increase, molecular motion becomes erratic due to increased inertial forces, and flow is considered to be turbulent. Darcy’s equation establishes a linear relationship between velocity and head difference in a groundwater system. This linear relationship breaks down, however, when flow changes from laminar to turbulent. Turbulent flow conditions can occur in areas with steep hydraulic gradients induced by nearby pumping wells or in areas where the subsurface has large solution openings. Because of these factors, turbulent flow can occasionally occur in the vicinity of the Northwest Wellfield.

Horizontal groundwater gradients at the Northwest Wellfield are relatively low (0.0001-0.0003), which is typical for aquifers with high transmissivity, such as the Biscayne. Vertical groundwater gradients at the wellfield are up to three orders of magnitude higher than horizontal groundwater gradients (0.0006-0.1649). Comparable vertical groundwater gradients were measured near the District’s S-7 pump station (Broward/Palm Beach county line) during a recent field test, indicating a strong interaction between surface water stages and groundwater levels.

There were significant variations in groundwater velocities (magnitude and direction) within the same well screen, but at different depths, such as in NW-7A and NW-5B. One possible explanation is that zones of varying hydraulic head, resulting from sediments of different permeability, are affecting flow patterns close to the well screens (**Figure 11**). This explanation is supported by subsequent information obtained from test borings at the Northwest Wellfield (memorandum from Robert Verrastro, Montgomery Watson, to Vincent Flick, MDWASD, 12/15/98). The average velocity of all the readings was 5.44 feet/day (1986 feet/year) during the test period.

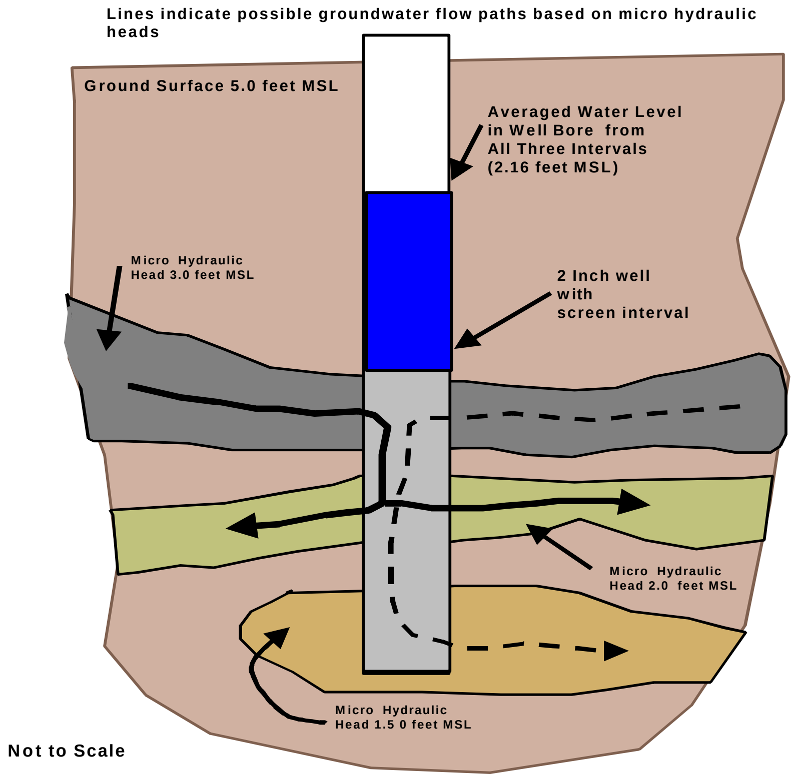


Figure 11. Idealized Cross-Section of a Well Screened in Multiple Lithologic Units with Varying Microhydraulic Heads

The flowmeter velocities measured in NW-5A were two to three times higher than the readings for the other wells included in this study. The flow regime could be influenced by the well construction, or possibly impacted by deep, active rockmining lakes located close to the well. Another finding of the study is an upward vertical gradient measured in monitor well cluster NW-6. Possible explanations could be that the well names were reversed when recording the water levels, or that the surveyed elevations are in error.

The wellfield pumpage records indicated that three days before the April field testing, the wellfield pumpage peaked for the month at 126.375 MGD (Table B-2). During the in situ flow testing, pumpage was 72.863 MGD on April 8, 1996 and 82.860 MGD on April 9, 1996. That is a difference of 53.51 and 43.52 MGD, respectively, from the maximum day pumpage in April 1996. Due to the extremely high transmissivity of the Biscayne aquifer at the site, latent effects of this sharp decrease in pumpage rates would most likely be dissipated rather quickly in the aquifer. Therefore, the groundwater flow velocities determined in this study were barely affected.

An average in situ groundwater velocity of 5.44 feet/day (1,986 feet/year) was measured during the field testing days when the average pumping rate was 77.86 MGD at the wellfield. The average velocity for the readings from all wells, with the exception of NW-5A, is 4.41 feet/day (1,610 feet/year). For travel time calculation, the value of 5.44 feet/day was used, despite uncertainty of why there were high velocities in NW-5A.

Assuming a linear increase to a maximum day pumpage of 126 MGD, a maximum average velocity of about 8.8 feet/day (3,215 feet/year) is projected. As the pumpage increases, the velocity increases could possibly become exponential rather than linear. Based on a 5.44 feet/day (1,986 feet/year) velocity and a linear distance of 1,978 feet between wells NW-7 and PWS Well 9, the travel time is calculated to be 364 days (1.00 year). The travel time from well NW-6 to PWS Well 6 (2,857 feet) is 525 days (1.44 years). This provides a general estimate of when water quality impacts detected in monitor wells can be expected to appear in the public supply wells.

RECOMMENDATIONS

The following recommendations are based on the work completed at the Northwest Wellfield to date.

1. To verify in situ groundwater velocities during higher pumping rates, additional testing should be performed during times of higher pumpage at the Northwest Wellfield.
2. Testing during both the wet and dry seasons would help identify seasonal precipitation influences on groundwater flow.
3. Additional work should include access to the public water supply pumping wells to verify water levels inside the well bores. This would enable the projection of the hydraulic gradient into the wellfield area. It would also assist in the calculations of in situ velocities close to the wells.
4. A tracer test (using commercially available, biodegradable tracer materials, such as Rhodamine WT) should be performed at the site to verify travel times calculated in this report.
5. Before the retesting, Lake Belt Coalition/Miami-Dade County should drill additional monitor wells north, west, and southwest of the wellfield. These additional wells could be used to verify groundwater velocities and assess contributions from Everglades National Park and the surrounding water conservation areas.
6. Stage levels in nearby mining lakes should be monitored during additional testing. This could help determine if flow vectors pointing away from the wellfield are due to regional flow toward the lakes or to borehole or lithologic factors.

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APPENDIX A

STATEMENT OF WORK

A Statement of Work (SOW) was prepared by the South Florida Water Management District (SFWMD) to evaluate the potential impacts of the proposed excavation of several new rock pits. These pits are located near the eastern side of the Miami-Dade Water and Sewer Department (MDWASD) Northwest Wellfield. The SOW consists of two major tasks. A copy of the SOW is included in this appendix.

RES 14

MEMORANDUM

TO:	Jim Jackson, Senior Planner, Lower East Coast Planning Division, PLD Jayantha Obeysekera, Division Director, System Wide Hydrologic Modeling Division, PLD Steve Reel, Division Director, Lower East Coast Planning Division, PLD Tommy Strowd, Supervising. Professional - Civil Engineer, Lower East Coast Planning Division, PLD
FROM:	Tim Bechtel, Supervising Professional - Environmental Scientist, Resource Assessment Division, WRE
DATE:	March 26, 1996
SUBJECT:	WRE Special Request: Approved Lake Belt Surface and Ground Water Quality Issues SOW

Steve Krupa, Richard Xue and I have developed the following Statement of Work to address water quality issues associated with the Northwest Dade County Lake Plan described in your WRE Special Request, dated December 14, 1995. We have combined, because they are closely linked in concept, your original objectives I and 11, i.e. 1. Identify water pollutant loads from existing and future land uses which may contribute to the Northwest Dade Lake Belt area and 11. Evaluate the ability of various water resource alternatives for the Lake Belt, in reducing pollutant loads to acceptable standards prior to discharge to receiving waters, into Sur-face Water Quality Tasks. In addition, pollutant load reductions to be evaluated in alternative plans will largely be derived from stormwater runoff mixed with canal water. We also believe that the quality of the water routed in alternative plans may need to be evaluated using one or more BMP methods in the BMPAM Model (Best Management Practices Assessment Model). Objective 111, Identify groundwater quality impacts to the existing Dade County West and N.W. Wellfields, is addressed in Groundwater Quality Tasks.

I. Surface Water Quality Tasks

1. Select Watershed Model

XP-SWMM:	Expert Storm and Wastewater Management Model (Software purchase price $2495 for 100 nodes, $3495 for 200 nodes, or $4995 for 500 nodes)
SRPM:	Stormwater Runoff and Pollutant Model (Need to modify, add, and test a Canal/Channel routine in the model, about 2 months)

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2. Collect Data for Watershed Modeling

Watershed/Sub-Drainage Basin Data (boundaries, acreage, slope, width of overland flow, land use, and soil data for five basins such as Cl, C2, C4, C6, and C9);

Hydrology Data for each sub-basin in -the five basins. (Precipitation, ET and Manning's roughness coefficient);

Observed Data for Model Calibration and Verification (runoff and water quality data).

3. Calibrate/Verify Runoff and Pollutant Loads from Existing Land Uses

Run the selected watershed model using observed runoff and water quality data collected by Dade County to calibrate/verify the model. Prepare report describing results.

4. Predict Runoff and Pollutant Loads from Future Land Uses

Run the calibrated/verified watershed model using land uses of the Proposed 2010 Alternative Options prepared by the Planning Department Staff. Prepare report describing results of each modeled alternative.

5. Calibrate/Verify the BMPAM Model

Collect flow and pollutant loads from a wetland and an aquifer recharge basin for model calibration and verification. Model inputs are obtained from the simulation results of watershed modeling based on future land uses. Prepare report of simulated results.

6. Describe Current Water Quality Conditions for Lake Belt Region

Use latest available water quality data from the DERM monitoring program and data collected by EPA in the Lake Belt region in 1995 and 1996 to describe the current water quality. Prepare report summarhdrig results and any Class III/OFW criteria problems.

7. Investigate Water Quality Impacts of Backpumping and Other Alternative Plans

Run the calibrated/verified BMPAM model using alternatives of surface water backpumping to intermediate surface water management systems such as Wetland Management Unit #7 and Aquifer Recharge Basins (Units 5, 6, and 8). Prepare report of simulated results.

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8. Identify Water Quality Treatment Methods

Identify logical and feasible water quality treatment methods/technologies that could be implemented in conjunction with alternative Lake Belt plans. Present results in letter report.

11. Groundwater Quality Tasks

A phased approach is recommended for the groundwater quality investigation. The initial phase includes the assessment of the current status of Dade County's Northwest Wellfield groundwater velocities based on two pumping rates. The current pumping rate is estimated at 50 MGD (March 1996). The proposed second pumping rate would be above 100 MGD and would be conducted during the current dry season (April 1996). The estimated rated capacity of the wellfield is over 150 MGD. The current pumpage of the northwest wellfield is limited to water color restrictions (Julie Baker, DERM, personal communication) and requires blending with other eastern wellfields.

Groundwater velocities would be established by sampling existing two-inch or greater PVC pipe encased groundwater wells using a KVA horizontal groundwater flow meter. Once velocities have been established in the wells, velocity flow data will be tabulated. The data will be evaluated with regards to particle travel times from existing surface water bodies (quarries and canals) to the pumping wells. This information will then be used to assess the ability (residence time) of the aquifer to treat (adsorb, settle or precipitate) undesired particles and/or contamination in the water. A comparison of surface water quality near the wellfield and the groundwater quality in the wellfield will be made to establish current groundwater treatability. The degree of treatability will be determined through consultation with the District's Planning Department and DERM staff members. In addition, a comparison of existing groundwater quality data with groundwater quality criteria will be made. If existing travel times exceed normal residence time of water in the aquifer, recommendations will be made to address this issue. If no conclusions can be drawn from the field data, recommendations will be made for longer term studies to determine the minimum "residence time" required for the adequate treatment of groundwater in the aquifer.

Phase I - Collect in-situ groundwater velocities on four transects spreading radially from the wellfield. Tabulate data, convert flow velocities to corrected flow velocities, provide map of transects and a letter report of the results and recommendations. Estimated completion date: May 10, 1996.

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Phase II - Use data collected in Phase I to evaluate travel times from large surface water bodies to well heads. Create scaled cross sections with actual velocities plotted on drawings. Provide letter report on travel times and assess residence times. Estimated completion date: June 7, 1996.

Phase III - Depending on the results of Phase I and Phase II, make recommendations for long term studies to determine the minimum "residence time" required for desired degree of treatment of groundwater in the aquifer. Conduct literature review on aquifer treatability results. Provide letter report of literature review and recommendations. Estimated completion date: July 19, 1996.

Ab

c: T. Campbell, WRE
G. Redfield, WRE
L. Wedderbum

A-6

APPENDIX B

WELL DATA

Table B- 1 summarizes well construction information for each water supply well. **Table B- 2** provides the total monthly pumpage data for April 1996. **Table B- 3** provides a complete listing of monitor wells located near the Northwest Wellfield.

Table B-1. Pumping Capacity and Depth of Supply Wells at Northwest Wellfield, Miami-Dade County, Florida

Well Number[1]	Pumping Capacity Low (MGD)[1]	Pumping Capacity High (MGD)[1]	Total Depth (ft)[1,2]	Cased Depth (ft)[1,2]	Total Open Hole (ft)[1,2]
1	10	15	81	46	35
2	10	15	80	46	34
3	10	15	90	46	44
4	10	15	90	46	44
5	10	15	80	46	34
6	10	15	78	46	32
7	10	15	62	46	16
8	10	15	80	46	34
9	10	15	83	46	37
10	10	15	90	46	44
11	10	15	90	46	44
12	10	15	90	46	44
13	10	15	90	46	44
14	10	15	90	46	44
15	10	15	80	46	34

1 Information obtained from Miami-Dade County Water Use Permit 13-00037

2 Referenced to land surface elevation (bls)

Table B-2. Daily Pumpage (MGD) at Miami-Dade Water and Sewer Department's Northwest Wellfield for April 1996

Date	1-Apr-96	2-Apr-96	3-Apr-96	4-Apr-96	5-Apr-96	6-Apr-96	7-Apr-96	8-Apr-96	9-Apr-96	10-Apr-96
NW 1 Low	0.000	0.000	4.134	10.110	9.905	10.319	7.614	0.000	0.000	0.000
NW 1 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 2 Low	0.000	0.000	4.134	10.110	9.905	10.319	9.878	10.409	0.000	10.545
NW 2 High	0.934	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.810	0.000
NW 3 Low	0.000	0.000	4.134	10.110	9.905	10.319	7.614	0.000	0.000	0.000
NW 3 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 4 Low	0.000	0.000	4.134	10.110	9.905	10.319	7.614	0.000	0.000	0.000
NW 4 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 5 Low	9.961	11.246	11.673	10.110	9.905	10.319	9.878	10.409	0.000	10.545
NW 5 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 6 Low	9.961	11.246	7.539	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 6 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 7 Low	9.961	11.246	7.539	0.000	0.000	0.000	2.264	10.409	0.000	10.545
NW 7 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.810	0.000
NW 8 Low	9.961	11.246	11.673	10.110	9.905	10.319	7.614	0.000	0.000	0.000
NW 8 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 9 Low	9.961	11.246	7.539	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 9 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 10 Low	9.961	11.246	11.673	10.110	9.905	10.319	9.878	10.409	0.000	10.545
NW 10 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.810	0.000
NW 11 Low	0.000	0.000	4.134	10.110	9.905	10.319	7.614	0.000	0.000	0.000
NW 11 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 12 Low	0.000	0.000	0.000	0.000	0.000	10.319	7.614	0.000	0.000	0.000
NW 12 High	13.386	16.869	17.520	15.165	14.857	0.000	0.000	0.000	0.000	0.000
NW 13 Low	9.961	0.000	4.136	10.110	9.905	10.319	9.878	10.409	0.000	10.545
NW 13 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.810	0.000
NW 14 Low	0.000	0.000	4.134	10.110	9.905	10.319	9.878	10.409	0.000	10.545
NW 14 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.810	0.000
NW 15 Low	0.000	0.000	4.134	10.110	9.905	10.319	9.878	10.409	0.000	10.545
NW 15 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.810	0.000
Total	84.047	84.345	108.230	126.375	123.812	123.828	107.216	72.863	82.860	73.815

April 1-10, 1996
(Sheet 1 of 3)

Table B-2. Daily Pumpage (MGD) at Miami-Dade Water and Sewer Department's Northwest Wellfield for April 1996 (Continued)

Date	11-Apr-96	12-Apr-96	13-Apr-96	14-Apr-96	15-Apr-96	16-Apr-96	17-Apr-96	18-Apr-96	19-Apr-96	20-Apr-96
NW 1 Low	0.000	0.000	0.000	0.000	0.466	0.000	0.000	0.000	0.000	0.000
NW 1 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 2 Low	10.068	9.994	10.055	9.988	11.173	9.997	10.041	9.991	8.293	9.976
NW 2 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 3 Low	0.000	0.000	0.000	0.000	0.466	0.000	0.000	0.000	0.000	0.000
NW 3 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 4 Low	0.000	0.000	0.000	0.000	0.466	0.000	0.000	0.000	0.000	0.000
NW 4 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 5 Low	10.068	9.994	10.055	9.988	11.173	9.997	10.041	9.991	9.952	9.976
NW 5 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 6 Low	0.000	0.000	0.000	0.000	0.466	0.000	0.000	0.000	0.000	0.000
NW 6 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 7 Low	10.068	9.994	10.055	9.988	11.173	9.997	10.041	9.991	9.952	9.976
NW 7 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 8 Low	0.000	0.000	0.000	0.000	0.466	0.000	0.000	0.000	0.000	0.000
NW 8 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 9 Low	0.000	0.000	0.000	0.000	0.000	9.997	10.041	9.991	9.952	9.976
NW 9 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 10 Low	10.068	9.994	10.055	9.988	0.000	0.000	0.000	0.000	0.000	0.000
NW 10 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 11 Low	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 11 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 12 Low	0.000	0.000	0.000	0.000	3.724	9.997	10.041	9.991	9.952	9.976
NW 12 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 13 Low	10.068	9.994	10.055	9.988	11.173	9.997	10.041	9.991	9.952	9.976
NW 13 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 14 Low	10.068	9.994	10.055	9.988	11.173	9.997	10.041	9.991	9.952	9.976
NW 14 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 15 Low	10.068	9.994	10.055	9.988	11.173	9.997	10.041	9.991	9.952	9.976
NW 15 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	70.476	69.958	70.385	69.916	73.092	79.976	80.328	79.928	77.957	79.808

April 11-20, 1996
(Sheet 2 of 3)

Table B-2. Daily Pumpage (MGD) at Miami-Dade Water and Sewer Department's Northwest Wellfield for April 1996 (Continued)

Date	21-Apr-96	22-Apr-96	23-Apr-96	24-Apr-96	25-Apr-96	26-Apr-96	27-Apr-96	28-Apr-96	29-Apr-96	30-Apr-96
NW 1 Low	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 1 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 2 Low	9.970	9.791	10.629	10.279	9.762	9.734	9.208	9.221	9.389	9.067
NW 2 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 3 Low	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 3 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 4 Low	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 4 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 5 Low	9.970	9.791	10.629	10.279	9.762	9.734	9.208	9.211	9.389	9.067
NW 5 High	0.000	0.000	0.000	15.419	0.000	0.000	0.000	0.000	0.000	0.000
NW 6 Low	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 6 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 7 Low	9.970	9.791	10.629	10.279	9.762	9.734	9.208	9.221	9.389	9.067
NW 7 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 8 Low	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 8 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 9 Low	9.970	9.791	10.629	10.279	9.762	9.734	9.208	9.221	9.389	9.067
NW 9 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 10 Low	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 10 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 11 Low	0.000	0.000	0.000	0.000	9.762	9.734	9.208	9.221	9.389	9.067
NW 11 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 12 Low	9.970	9.791	10.629	10.279	9.762	9.734	9.208	9.221	9.389	9.067
NW 12 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 13 Low	9.970	9.791	10.629	10.279	9.762	9.734	9.208	9.221	9.389	9.067
NW 13 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 14 Low	9.970	9.791	10.629	10.279	9.762	9.734	9.208	9.221	9.389	9.067
NW 14 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NW 15 Low	9.970	9.791	10.629	0.000	9.762	9.734	9.208	9.221	9.389	9.067
NW 15 High	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	79.760	78.328	85.032	87.372	87.858	87.606	82.872	82.979	84.501	81.603

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(Sheet 3 of 3)

Table B-3. Location and Construction Information on Monitoring Wells Near MWASD's Northwest Wellfield

NORTHWEST WELLFIELD MONITORING WELL INFORMATION								
Site ID	**Latitude**	**Longitude**	**Elev (ft)***	**Diam (in.)**	**Casing Material**	**Casing Depth (ft below Grade)**	**Total Depth (ft below Grade)**	**Comments**
NW_3A	255247	802608	7.34	2	Black Steel	83	88	Good condition, with cap
NW_3B	255247	802608	7.38	1.5	Black Steel		26	Good condition, with cap
NW_4A	254904	802503	6.22	2	Black Steel	147	149	Good condition, with cap
NW_4B	254904	802503	6.44	2	Black Steel		24	Good condition, no cap
NW_5A	254933	802350	7.8	2	Stainless Steel	50	55	Good condition, with cap
NW_5B	254933	802350	7.88	2	Stainless Steel	20	25	Good condition, with cap
NW_6A	254937	802435	8.12	2	Stainless Steel	52	54	Good condition, with cap
NW_6B	254937	802435	8.25	2	Stainless Steel	10	13	Good condition, with cap
NW_7A	255025	802424	5.24	2	Stainless Steel	57	60	Good condition, with cap
NW_7B	255025	802424	5.7	2	Stainless Steel	17	20	Good condition, with cap
NW_8A	255025	802339	5.42	2	Stainless Steel	52	55	Good condition, with cap
NW_8B	255025	802339	5.68	2	Stainless Steel	20	23	Good condition, with cap
NW_9A	255117.5	802123	6.52	1.5	Black Steel/PVC		45	Good condition, locked
NW_9B	255117.5	802123	6.52	1.5	Black Steel		23	Good condition, locked
NW_10A	255117.5	802147	5.71	1.5	Black Steel/PVC		50	Good condition, with cap
NW_10B	255117.5	802147	6.01	1.5	Black Steel/PVC		28	Good condition, with cap
NW_13A	255236	802415.5	7.91	1.5	Black Steel/PVC		51	Good condition, with cap
NW_13B	255236	802415.5	7.97	2.5	Black Steel/PVC		21	Top PVC pipe broken, no cap
NW_15A	254947	802121	5.26	1.5	Black Steel		60	Bad condition, no cap, bent top
NW_15B	254947	802121	5	2	Stainless Steel	20	23	Good condition, no cap
NW_16A	254948.5	802212	8.83	3	Black Steel	58	60	Good condition, with cap
NW_16B	254948.5	802212	6.32	3	Black Steel	18	20	Good condition, with cap
NW_17A	255028	802601	6.42	1.5	Black Steel		135	Destroyed
NW_17B	255028	802601	6.12	1.5	Black Steel		24	Minor damage, no cover
NW_19A	255026	802234	3.66	1.5	Black Steel		50	Need cover repair, w/ cap
NW_19B	255026	802234	3.66	1.5	Black Steel		23	Need cover repair, w/ cap
NW_26A	255003	802214	3.572	2	Stainless Steel	50	52	Good
NW_26B	255003	802214	4.308	2	Stainless Steel	21	23	Good
*1929 NGVD								