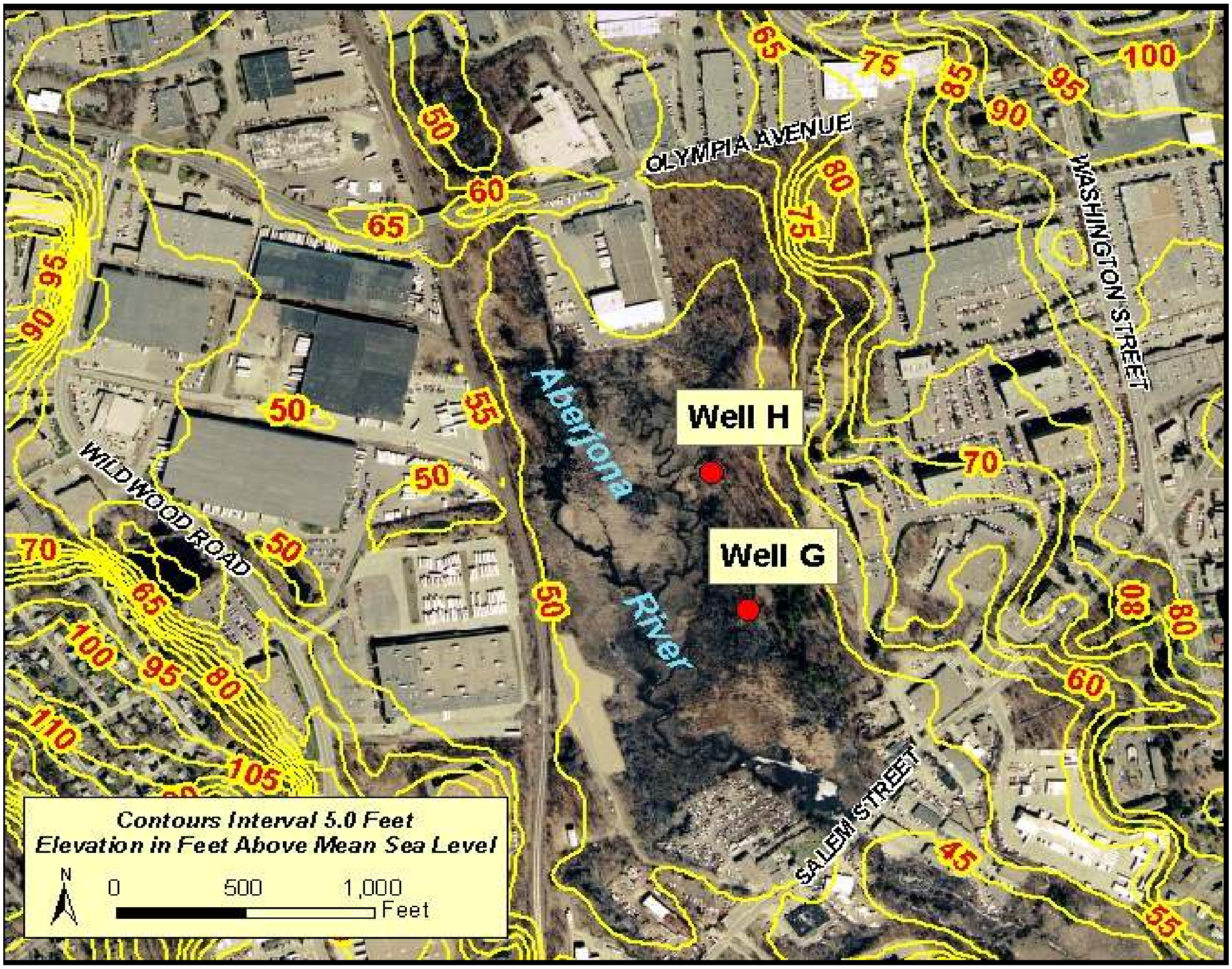
CONSTRUCTING POTENTIOMETRIC SURFACES
WELLS G & H SUPERFUND SITE, WOBURN, MASSACHUSETTS



Land surface elevation in area surrounding Wells G & H Superfund Site, Woburn, Massachusetts (courtesy of Paul Spahr; image data courtesy of Office of Geographic and Environmental Information (MassGIS), Common wealth of Massachusetts Executive Office of Environmental Affairs.

Introduction

On the morning of December 4, 1985, a set of hydraulic head measurements was made in a network of monitoring wells completed in the glacial materials underlying the Aberjona River valley at Woburn, Massachusetts. The data were used to reconstruct the pre-1967 and post-1979 steady-state flow conditions in the aquifer when former municipal wells G and H were not pumping. The potentiometric surface maps made using these data became important exhibits during the Woburn toxic trial portrayed in the book and movie *A Civil Action*.

Later that day, wells G and H were turned on and pumped at their average production rates: 700 gpm for well G and 400 gpm for well H. These production rates were maintained for 30 days, until January 3, 1986. At that time, water levels throughout most of the aquifer were approaching a new steady-state configuration with respect to the pumping stress imposed by wells G and H. On January 3, 1986, another synoptic set of water-level measurements was taken in the monitoring wells. These water levels were used to reconstruct typical flow conditions between 1967 and 1979 when both wells were operational and supplying water to local residences. The December 4, 1985 measurements are shown on the "*Dec 4 '85 P-map*" worksheet (Figure 1), whereas the January 3, 1986 measurements are shown on the "*Jan 3 '86 P-map*" worksheet (Figure 2).

Instructions

The water-level data presented on the two maps represent information at discrete locations in the aquifer. Contouring these data requires interpolation between the known data points to produce a continuous potentiometric surface. Using the guidelines given in the *Reference Book*, construct potentiometric surface maps for both sets of reconstructed steady-state conditions. One rule of thumb to remember while contouring is that in shallow aquifers, water levels often mimic the topography of the land surface. So consult the topographic map of the area provided at the beginning of this description to help guide your contouring, especially in the areas remote from the influence of the wells G and H.

Print out several copies of Figures 1 and 2 to use as practice maps until you develop a feel for the orientation and spacing of the equipotential lines. Often the distance between known data points is equal. Some students find it beneficial to plot where the contours will pass between two known data points before drawing the contour line. Focusing on drawing one contour line for the entire map may help avoid confusion and mistakes. Use a two-foot contour interval to create each map. This will require some locations on the maps to have very closely spaced equipotential lines. Label the equipotential lines.

Once contours are drawn, the maps can be used to infer differences in the groundwater flow conditions and river/aquifer interactions when the actual wells were periodically used to supply water to parts of Woburn between 1967 and 1979. The well operated by the Riley Tannery (southwest corner of the map) was operational throughout this 13-year period and during the 30-day period in December 1985 and January 1986, thus a cone of depression will exist around this well in both potentiometric surface maps.

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Questions (6 Total)

Question #1. The spacing between equipotential lines on Figure 1 (December 4, 1985 - wells G and H not pumping) varies across the site and represents the configuration of the potentiometric surface prior to 1967. Figure 2 (January 3, 1986 - wells G and H pumping) represents the potentiometric surface configuration between 1967 and 1979. Using the scales along the borders of the maps to the nearest 25 feet, compute the hydraulic gradient in each of the areas described below by completing the table (see equation 1-2 in *Reference Book*). These areas have been highlighted on the maps with the water levels underlined**.**

In which designated area is the hydraulic gradient the steepest in each map? In which designated area is it flattest in each map? What implications does the variability in the hydraulic gradient have on the velocity of groundwater flowing across the site?

	Location	**Water Level Well 1 (ft)**	**Water Level Well 2 (ft)**	**Difference in Hydraulic Head (ft)**	**Distance Between Wells (ft)**	**Hydraulic Gradient (ft/ft)**
Figure 1	*Northeast Quad*	71.3	59.3			
	Southwest Quad	45.1	41.8			
	Near G & H	44.1	43.9			
Figure 2	*Northeast Quad*	71.6	59.2			
	Southwest Quad	44.2	41.7			
	Near G & H	38.5	21.5			

Question #2. On your completed potentiometric surface maps, Figures 1 and 2, draw flow lines (include arrowheads) indicating the direction of groundwater flow from the Cryovac Plant (A), the UniFirst Properties (B), and the Riley Tannery (C) to their respective discharge points at the river or pumping wells. Remember to maintain the 90-degree rule at the intersections of the flow lines with the equipotential lines and take the shortest path between the equipotential lines.

Question #3. With respect to the Cryovac Plant (A), does the possibility exist for groundwater to flow to either well G or well H under pre-1967 conditions (Figure 1)? What about with respect to pumping conditions between 1967 and 1979 (Figure 2)? Explain.

Question #4. With respect to the UniFirst Property (B), does the possibility exist for groundwater to flow to either well G or well H under pre-1967 conditions (Figure 1), with respect to 1964 to 1979 conditions (Figure 2)? Explain.

Question #5. With respect to the Riley Tannery (C), does the possibility exist for groundwater to flow to

Question #5. With respect to the Riley Tannery (C), does the possibility exist for groundwater to flow to either well G or well H under pre-1967 conditions (Figure 1), with respect to 1967 to 1979 conditions (Figure 2)? Explain.

Question #6. Compute the travel time of groundwater moving from the centers of points A, B, and C to well G or well H using the following information. The aquifer material has an average hydraulic conductivity of 250 ft/day and an average porosity of 0.25 (25 percent). Use the hydraulic heads from the 1967 to 1979 conditions illustrated in Figure 2 to calculate the hydraulic gradients and flow line lengths. [Show all work]

Length of flow line A to the nearest 25 ft:
Change in head along flow line A to the nearest tenth of a foot:
Average hydraulic gradient along flow line A to three significant digits (see equation 1-2):

Calculate the groundwater velocity to the nearest one ft/day (see equation 1-3):

Calculate the travel time to the nearest day (see equation 1-5):

Length of flow line B to the nearest 25 ft:
Change in head along flow line B to the nearest tenth of a foot:
Average hydraulic gradient along flow line B to three significant digits (see equation 1-2):

Calculate the groundwater velocity to the nearest one ft/day (see equation 1-3):

Calculate the travel time to the nearest day (see equation 1-5):

Length of flow line C to the nearest 25 ft: ft

Length of flow line C to the nearest 25 ft: __________ ft
Change in head along flow line C to the nearest tenth of a foot: __________ ft
Average hydraulic gradient along flow line C to three significant digits (see equation 1-2): __________ ft

Calculate the groundwater velocity to the nearest one ft/day (see equation 1-3):

Calculate the travel time to the nearest day (see equation 1-5):

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WELLS G & H SUPERFUND SITE, WOBURN, MASSACHUSETTS

Questions (6 Total)

Question #1. The spacing between equipotential lines on Figure 1 (December 4, 1985 - wells G and H not pumping) varies across the site and represents the configuration of the potentiometric surface prior to 1967. Figure 2 (January 3, 1986 - wells G and H pumping) represents the potentiometric surface configuration between 1967 and 1979. Using the scales along the borders of the maps to the nearest 25 feet, compute the hydraulic gradient in each of the areas described below by completing the table (see equation 1-2 in *Reference Book*). These areas have been highlighted on the maps with the water levels underlined**.**

In which designated area is the hydraulic gradient the steepest in each map? In which designated area is it flattest in each map? What implications does the variability in the hydraulic gradient have on the velocity of groundwater flowing across the site?

	Location	**Water Level Well 1 (ft)**	**Water Level Well 2 (ft)**	**Difference in Hydraulic Head (ft)**	**Distance Between Wells (ft)**	**Hydraulic Gradient (ft/ft)**
Figure 1	*Northeast Quad*	71.3	59.3	12.0	550	0.022
	Southwest Quad	45.1	41.8	3.3	625	0.005
	Near G & H	44.1	43.9	0.2	375	0.001
Figure 2	*Northeast Quad*	71.6	59.2	12.4	550	0.023
	Southwest Quad	44.2	41.7	2.5	625	0.004
	Near G & H	38.5	21.5	17.0	375	0.045

Answer: In Figure 1, the hydraulic gradient is steepest in the northeast quadrant of the map near W.R. Grace and UniFirst (gradient = 0.022). In Figure 2, the hydraulic gradient is steepest near wells G and H with a gradient of 0.045. The flattest hydraulic gradient in Figure 1 is near wells G and H at 0.001. This area, near the Aberjona River, prior to pumping wells G and H is the bottom of the valley where there is little topographic relief. In Figure 2, the hydraulic gradient is flattest in the southwest quadrant near the Riley well (gradient = 0.004). The area southeast of wells G and H along the Aberjona River also has a flat gradient but measurements were not made there.

The hydraulic gradient is directly proportional to the velocity of the groundwater flow. If we (falsely)

The hydraulic gradient is directly proportional to the velocity of the groundwater flow. If we (falsely) assume a uniform hydraulic conductivity and porosity, then steeper gradients indicate more rapid groundwater flow. Thus, the steeper gradient in the northeast quadrant prior to pumping well G and H suggests more rapid groundwater flow in that area relative to the areas near the river where the gradient is relatively flat. In reality, the porosity and hydraulic conductivity are not uniform across the site, as demonstrated in the geologic cross section in Chapter 1 - Problem 1, and have a significant impact on the variability of groundwater flow velocities.

Question #2. On your completed potentiometric surface maps, Figures 1 and 2, draw flow lines (include arrowheads) indicating the direction of groundwater flow from the Cryovac Plant (A), the UniFirst Properties (B), and the Riley Tannery (C) to their respective discharge points at the river or pumping wells. Remember to maintain the 90-degree rule at the intersections of the flow lines with the equipotential lines and take the shortest path between the equipotential lines.

Answer: Flow lines should be drawn on potentiometric surface map illustrating the approximate direction of groundwater flow. Flow is toward the central axis of the buried valley and then downgradient to the south. See answer maps "*Dec 4 '85 P-map answer*" and "*Jan 3 '85 P-map answer*" worksheets. These flow lines will vary depending on the construction of the equipotential contour lines.

Question #3. With respect to the Cryovac Plant (A), does the possibility exist for groundwater to flow to either well G or well H under pre-1967 conditions (Figure 1)? What about with respect to pumping conditions between 1967 and 1979 (Figure 2)? Explain.

Answer: Pre-1967 conditions (Figure 1): Depending on the construction of contour lines, flow from the Cryovac Plant will discharge to the Aberjona River since wells G and H were not pumping.

1967 to 1979 conditions (Figure 2): It is likely, depending on the contour line construction, that flow from the Cryovac Plant will be captured by well H.

Question #4. With respect to the UniFirst Property (B), does the possibility exist for groundwater to flow to either well G or well H under pre-1967 conditions (Figure 1), with respect to 1964 to 1979 conditions (Figure 2)? Explain.

Answer: Pre-1967 conditions (Figure 1): Depending on contour line construction, flow from the UniFirst Property will discharge to the Aberjona River since well G and H were not pumping.

1967 to 1979 conditions (Figure 2): It is likely, depending on the contour line construction, that flow from the UniFirst Property will be captured by well H.

Question #5. With respect to the Riley Tannery (C), does the possibility exist for groundwater to flow to

Question #5. With respect to the Riley Tannery (C), does the possibility exist for groundwater to flow to either well G or well H under pre-1967 conditions (Figure 1), with respect to 1967 to 1979 conditions (Figure 2)? Explain.

Answer: Pre-1964 conditions (Figure 1): Dependent on contour line construction, flow from the Riley Tannery property will be captured by the Riley well or will discharge to the Aberjona River. The 2-foot contour interval and the scant data are not sufficient to determine an accurate flow direction.
1967 to 1979 conditions (Figure 2): It is likely, depending on the contour line construction, that flow from the Riley Tannery property will be captured by well G.

Question #6. Compute the travel time of groundwater moving from the centers of points A, B, and C to well G or well H using the following information. The aquifer material has an average hydraulic conductivity of 250 ft/day and an average porosity of 0.25 (25 percent). Use the hydraulic heads from the 1967 to 1979 conditions illustrated in Figure 2 to calculate the hydraulic gradients and flow line lengths. [Show all work]

Length of flow line A to the nearest 25 ft: 2400 ft
Change in head along flow line A to the nearest tenth of a foot: 88 ft - 27.4 ft = 60.6 ft
Average hydraulic gradient along flow line A to three significant digits (see equation 1-2):
60.6 ft / 2400 ft = 0.025 ft/ft
Calculate the groundwater velocity to the nearest one ft/day (see equation 1-3): To well H, the average linear flow velocity = 250 ft/day * 0.025 ft/ft /0.25 = 25 ft/day
Calculate the travel time to the nearest day (see equation 1-5): Travel time = distance/velocity = travel time = 2400 ft / 25 ft/day = 96 days
Answer: There may be slight variations in the change in head and flow path length depending on the potentiometric surface construction.

Length of flow line B to the nearest 25 ft: 2200 ft
Change in head along flow line B to the nearest tenth of a foot: 68 ft - 27.4 ft = 40.6 ft
Average hydraulic gradient along flow line B to three significant digits (see equation 1-2): 40.6 ft / 2200 ft = 0.018 ft/ft
Calculate the groundwater velocity to the nearest one ft/day (see equation 1-3): To well H, the average linear flow velocity = 250 ft/day * 0.018 ft/ft /0.25 = 18 ft/day
Calculate the travel time to the nearest day (see equation 1-5): Travel time = distance/velocity = travel time = 2200 ft / 18 ft/day = 120 days
Answer: There may be slight variations in the change in head and flow path length depending on the potentiometric surface construction.

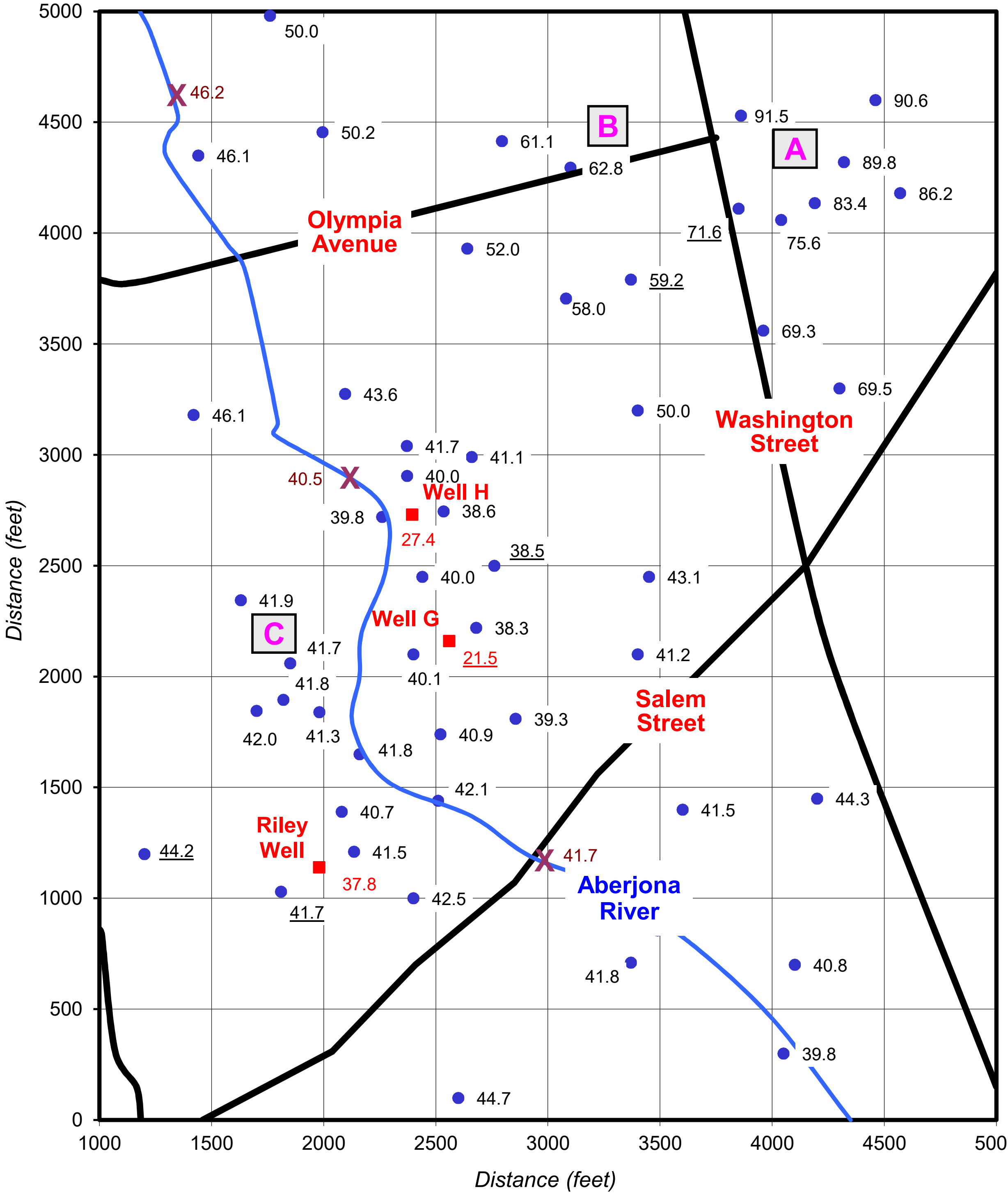
Length of flow line C to the nearest 25 ft: 700 ft

Length of flow line C to the nearest 25 ft: 700 ft
Change in head along flow line C to the nearest tenth of a foot: 41.7 ft - 21.5 ft = 20.2 ft
Average hydraulic gradient along flow line C to three significant digits (see equation 1-2 in *Reference Book*): 20.2 ft / 700 ft = 0.029 ft/ft
Calculate the groundwater velocity to the nearest one ft/day (see equation 1-3): To well G, the average linear flow velocity = 250 ft/day * 0.029 ft/ft /0.25 = 28.9 ft/day
Calculate the travel time to the nearest day (see equation 1-5): Travel time = distance/velocity = travel time = 1000 ft / 28.9 ft/day = 24 days
Answer: There may be slight variations in the change in head and flow path length depending on the potentiometric surface construction.

Name _______________ Figure 1 **Chapter 1 - Problem 2**

Dec 4 '85 P-map

POTENTIOMETRIC SURFACE
January 3, 1986 - Wells G and H Pumping
1967 to 1979 Conditions



N

EXPLANATION

🟥 Pumping well
● Monitoring well
X Streambed piezometer
Contours Interval = 2 ft

A = W.R. Grace - Cryovac Plant
B = UniFirst
C = Riley Tannery property

Name ____________________ *Figure 2* **Chapter 1 - Problem 2**

Jan 3 '86 P-map

Name ____________________ *Figure 2* **Chapter 1 - Problem 2**

Jan 3 '86 P-map

Name ____________________ *Figure 2* ***Chapter 1 - Problem 2***

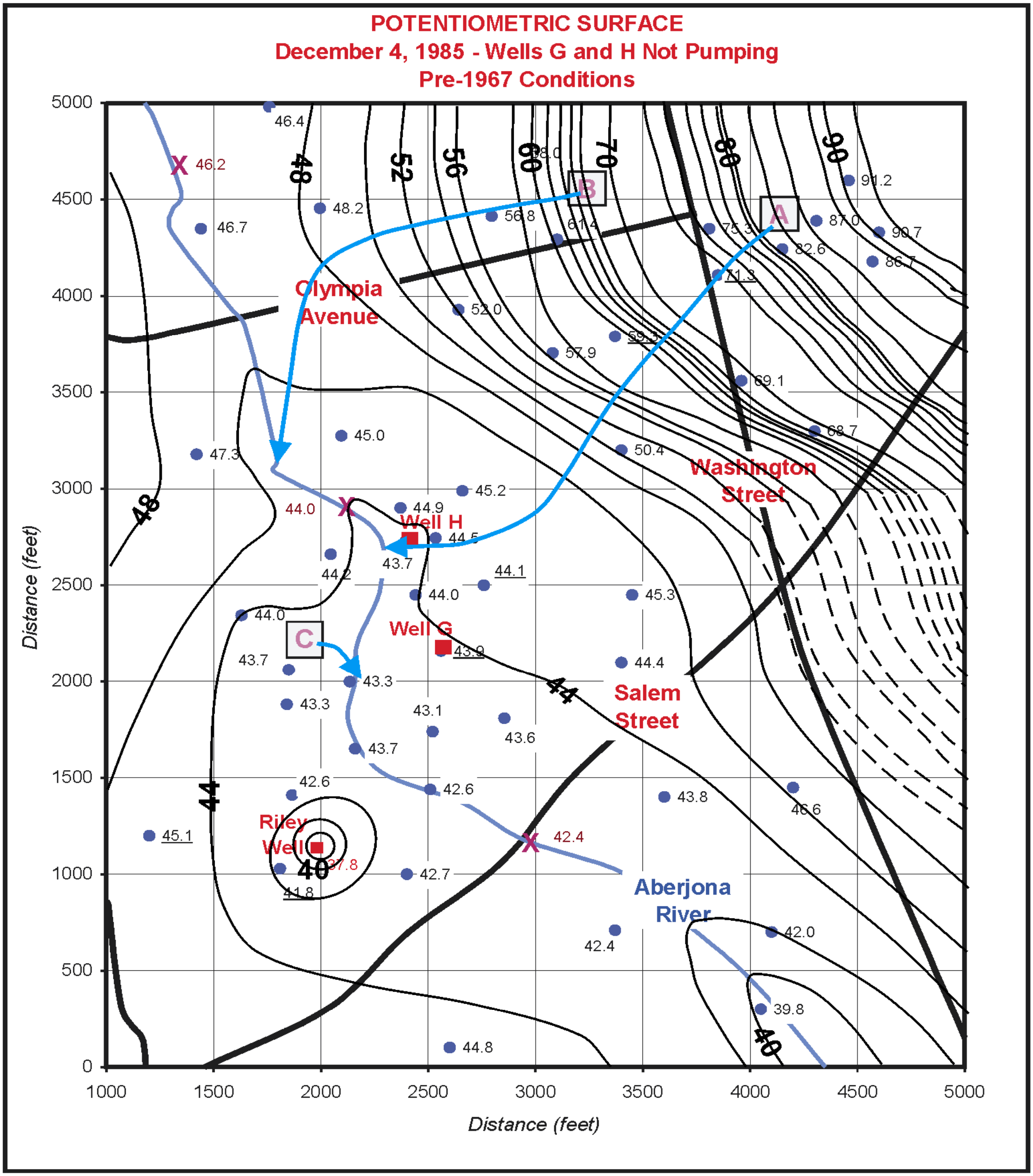
Jan 3 '86 P-map

Name ____________________ *Figure 2* **Chapter 1 - Problem 2**

Jan 3 '86 P-map

Name ____________________ *Figure 2* ***Chapter 1 - Problem 2***

Jan 3 '86 P-map



POTENTIOMETRIC SURFACE
December 4, 1985 - Wells G and H Not Pumping
Pre-1967 Conditions

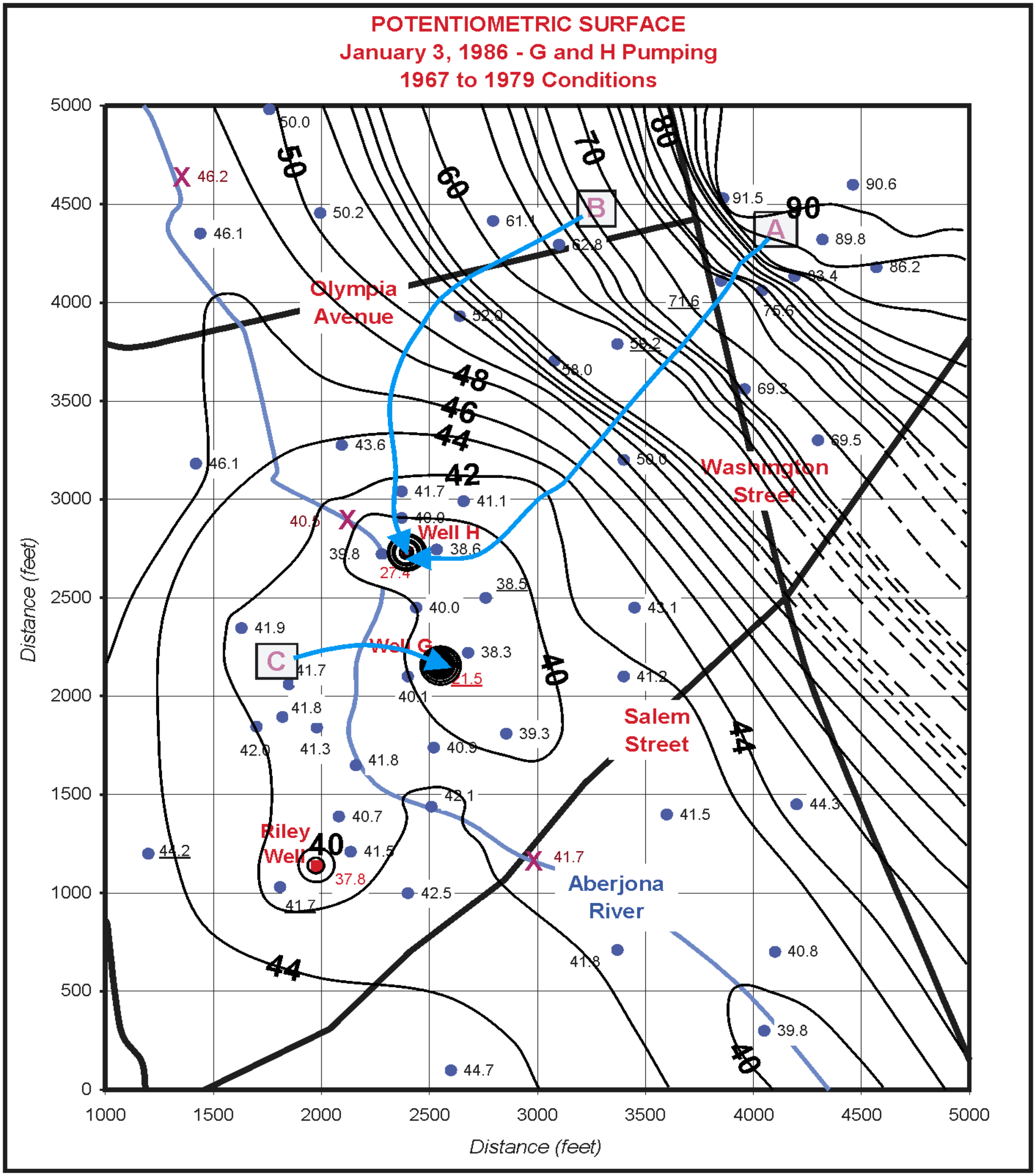
N

Figure 1

EXPLANATION

🟥 Pumping well
● Monitoring well
X Streambed piezometer
Contours Interval = 2 ft

A = W.R. Grace - Cryovac Plant
B = UniFirst
C = Riley Tannery property



POTENTIOMETRIC SURFACE
January 3, 1986 - G and H Pumping
1967 to 1979 Conditions

EXPLANATION

- 🟥 Pumping well
- ● Monitoring well
- X Streambed piezometer
- Contours Interval = 2 ft

A = W.R. Grace - Cryovac Plant
B = UniFirst
C = Riley Tannery property

N

Figure 2

Name ____________________ *Figure 2* ***Chapter 1 - Problem 2***

Jan 3 '86 P-map answer

Name ____________________ *Figure 2* ***Chapter 1 - Problem 2***

Jan 3 '86 P-map answer