Using Computational Thinking and Models to Investigate Groundwater Contamination in Tucson, Arizona

Module 2
Shape of the Water Table

Kristin L. Gunckel, University of Arizona
Garrett Love, North Carolina School of Science & Mathematics
Judy Cooper-Wagoner, University of Arizona
Beth A. Covitt, University of Montana
Alan Berkowitz, Cary Institute of Ecosystem Studies
John C. Moore, Colorado State University
Randall Boone, Colorado State University

This material is based upon work supported by the National Science Foundation DRL – 1543228 Comp Hydro: Integrating data computation and visualization to build model-based water literacy. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Table of Contents

Module 2: Shape of the Water Table

Driving Question: What is the shape of the water table under the Sunnyside/ south Tucson area?

Overview:

Lesson 1: Physical Piezometer Model of Water Table (OPTIONAL)

Purpose: To develop an understanding of how well data are collected and used to model the 3-D shape of the water table.

Lesson 2: Physical Model Contouring Water Table Elevations

Purpose: To contour the water table
To provide practice drawing and interpreting contour lines
To explore issues of uncertainty and discretization in data and modeling

Lesson 3: Net Logo Regional Water Table in 2D and 3D

Purpose: To use contour maps of the regional water table to model the water table in three dimensions.
To further develop interpretation of plan view and cross-section views.
To explore issues of uncertainty in data and modeling, trade-offs in discretization of cell size in a model, and boundary effects.

Learning Goals:

Hydrologic (H)	Data (D)	Computational (C)
1. **Water Tables and Aquifers:** Students will be able to describe (slope and aspect) the regional water table as a surface located in a 3-dimensional space underground. 2. **Groundwater-Surface Water Relationships:** Students will be able to describe the relationship of surface water to groundwater systems. 3. **Groundwater Flow Drivers**: Students will be able to interpret direction of groundwater flow in an unconfined aquifer from high gravimetric potential (head) to low gravimetric potential using a variety of representations and models.	1. **Interpolation of Data:** Students will be able to interpolate data in order to contour contamination concentrations and water table elevations. 2. **Visualization:** Students will be able to interpret 3D shape of water table from plan and cross-section views of contour maps. 3. **Uncertainty:** Students will be able to recognize where missing data contribute to uncertainty. 4. **Noise and Complexity:** Students will be able to look for trends in noisy data and recognize that more data often leads to more complexity.	1. **Discretization**: Students will be able to discuss how size of discrete intervals (cell size or contour interval) affects models and representations. 2. **Parameterization:** Students will be able to divide the problem-space into discrete cells and assign variables to those cells based on properties of the system. 3. **Iteration:** Students will be able to explain that computers repeat a sequence of commands many times (iterate) to complete a task. 4. **Models as Best Approximations or Estimates (uncertainty)**: Students will be able to explain that computer models are best estimates based on the data available

Lesson 1: Physical Piezometer Model of Water Table (OPTIONAL)

Learning Goals: H1, H2, H3, D1, D2, (D3, D4)

In the last module students realized that the contamination was flowing underground. To understand the processes that move the contamination, students need to be able to visualize the water table.

Activity #	Activity Label	Activity Function	Activity Procedures	Materials Needed
1	What is the shape of the water table?	Establish Question	1. Show students the Groundwater tank flow model. Using a dry erase marker, draw a line on the tank that shows the water table (interface between saturated and unsaturated zone). Define the water table as the top of the aquifer where water fills the spaces between the sand and gravel (saturated zone). **2. Introduce the driving question: What is the shape of the water table in the south Tucson area?**	1. Groundwater flow tank model for reference 2. Dry erase marker
2	Piezometer model	Explore & Model	3. Explain to students that hydrologists figure out how deep the water table is by measuring the depth to water in a well called a piezometer (a piezometer is just a well with no pump used to measure water table elevation). 4. Draw or project the diagram of the piezometer on the board. 5. Explain how the elevation of the water table is measured. Distinguish between the depth to water (relative to the ground surface or well top) and the water table elevation (absolute). 6. Demonstrate how students will measure the water table depth and calculate the water table elevation. 7. Assign students to teams to measure the groundwater level in 10 piezometers arranged outside. Have students measure the well water depth and calculate the elevation of the water in the wells. Have students mark the water level in the well with blue tape.	1. 10 Piezometers with stands 2. Tape measures, rulers, or yard sticks (English units) 3. Sponge and string measuring strings and/or water detectors. 4. Blue tape 5. Calculators 6. Paper towels 7. Piezometer Setup Measurements handout 8. Piezometer Setup Map handout 9. Student Task 2-1

Activity #	Activity Label	Activity Function	Activity Procedures	Materials Needed
3	Understanding the model	Explain and Reflect	8. Use blue string to outline the water surface (marked by blue tape). Use brown string to outline the ground surface too. 9. If time permits, measure out several contour lines (see optional section on pages 6 & 7). Note that water would flow perpendicular to the contours. 10. Use Discussion and Argument Questions (page 7) to point out the following features represented the model. a. Water table b. Slope of the water table c. Relationship between surface and water table, including rivers d. Depth of water table (where it is deepest & shallowest) e. Direction of water movement in aquifer 11. Use the Discussion and Argument Questions to discuss a. Orientation of contour lines b. Uncertainty and complexity	1. 10 Piezometers with stands 2. 2 rolls of string, different colors 3. Tape measures, rulers, or yard sticks (English units) 4. 10’ lengths of white string (for contour lines)

Piezometer Model (OPTIONAL)

Module 2, Lesson 1; Task 1

Materials

1. 10 Piezometers with stands
2. Tape measures, rulers, or yard sticks (English units)
3. Sponge and string measuring strings and/or water detectors.
4. Blue tape
5. 2 rolls of string, different colors
6. 10' lengths of white string
7. Calculators
8. Water table calculation sheets
9. Paper towels

Piezometer Set-up

1. Find a large open space, preferably outside, to set up the model.
2. Locate the north direction.
3. Fill the piezometers with water according to the Piezometer SetUp Measurements (page 9)
4. Arrange the piezometers according to the Piezometer Setup Map (page 10), paying attention to where North is. Use the grid on the map to aid in relative placement of piezometers.

Methods of Measuring and Marking Water Level

1. Attach a small piece of cellulose sponge to a string.
2. Drop sponge into top of piezometer. With care, you will be able to tell when the string feels slightly unweighted.
3. Pinch the string where it comes out of the top of the piezometer.
4. Without letting go of the pinch point, pull the string out of the piezometer.
5. Measure the distance from the top of the sponge to the pinch point in inches.
6. Repeat at least three times to get consistent measurements.
7. Record the most consistent measurement on your handout.
8. Place a piece of blue tape on the outside of the piezometer to mark water level at this point.
9. Use the data you recorded on your handout to find the water table elevation.

Marking Ground Surface and Water Table

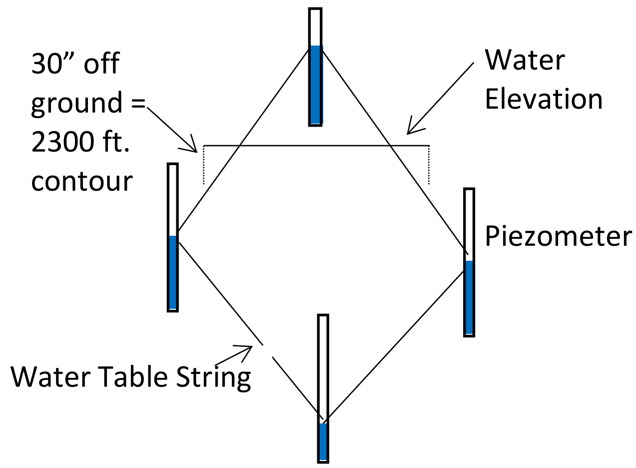
1. Use string to connect all ground surface elevations on piezometers. Connect piezometers to make a continuous line around the outside of the array. This line outlines the ground surface.
2. Use a blue string to connect to connect all blue tape marks on piezometers. Connect piezometers to make a continuous line around the outside of the array. This line outlines the water table.

Marking Contours (optional)

1. Decide on an elevation for a contour line. For example, begin with the 2300 ft contour, which would be 30 inches off the ground.
2. Use a tape measure or meter stick to measure where the water elevation string is 30" off the floor on each side of the array.
3. Use a piece of string that is longer than the piezometer array is wide. Stretch the string across the piezometer array, with one student holding the string at each end. Have students hold the

string so that it touches the water table string at the point where the water table string is 30" off the ground or floor. The horizontal string now represents the 2300 foot elevation line.

4. Repeat with several strings to mark several contour lines. Decide on an interval contour lines so that each is the same vertical interval. For example, the 2400 foot elevation line would be 40" off the ground and the 2200 foot elevation line would be 20 inches off the ground.



Questions for Discussion and Argument

Hydrology Questions

1. What is the general shape of the ground (land) surface? Which direction does it slope?
   Students can walk around the outside of the model and look at it from all directions. We want student to recognize that they are looking at a representation of the land groundwater in cross-section (from the sides). Students should see that the land surface slopes gently towards north northwest.

2. What is the general shape of the water table? Which direction does it slope?
   Students should see that the water table also slopes gently north and is also tilted a little to the west towards the direction of the Santa Cruz River.

3. What does the water table represent?
   The water table represents the top of the saturated zone. All the pore spaces below the water table are filled with water. The blue string outlines the top of this saturated zone.

4. How does the shape of the water table relate to the shape of the ground surface? Where is the water table deeper? Where is it shallower?
   The water table slopes a little more steeply than the land surface. The water table is shallower on the southern end and deeper on the northern end.

5. Groundwater moves underground. Based just on elevation differences, which direction would the water likely be flowing?
   Groundwater flows from high potential energy to low potential energy. In unconfined aquifers, this means it generally moves from highest elevation to lowest elevation.

6. What would cause the elevation of the groundwater to change?
   If water infiltrates into the ground from the surface, the groundwater is recharged and the water table would rise. When groundwater flows out of the ground or is pumped

from the ground, the water table would fall. There is some recharge of groundwater from storms during the monsoon, especially along the mountain edges. However, there is more water being pumped from the groundwater than is being recharged and the water table is steadily dropping. Students can slide the blue water table string up and down the piezometers to represent changes in the water table elevation

7. What would we see on the land if the water table elevation was the same as the ground surface elevation?

    Students can slide the blue water table string up and down the piezometers to the point that the water table is even with the ground surface. At this point, the water would be on the surface of the land and would collect or flow on the surface. This situation represents a spring and if there is enough water, a stream will form. This happens in the mountains around Tucson.

8. Why does the land surface and water table dip down slightly in the far southwest corner?

    We don't have enough data from this set to really know the reason for this shape. One possible explanation for this dip is that the Santa Cruz river is not far from this well location.

Data Questions

1. What is the orientation of the contour lines relative to the orientation of the water table?

    Students should notice that the contour lines run across the slope of the water table (or ground surface). Help students visualize this orientation. Students may contour these lines on a map. Also help students see that the flow direction is perpendicular to the contours. A large arrow drawn on a piece of paper and placed across the contours could help make this point.

2. Where would you like to have more data? Where would you drill an additional well to increase confidence in the model?

    Students may point out that the piezometers are not evenly spaced. They may want to see more data on the west and north sides especially. Students should be able to give a reason for where they want more data and what it might help them better understand.

3. How would data from more wells change this model?

    Students might say that more data would increase confidence, but it might also increase the complexity. Larger data sets can be noisy and one has to look for overall trends across many data points. Therefore, more data might make it more difficult to find the overall trends, but the trends that they do find they might feel more confident in.

Piezometer Water Table Model

Materials

PVC
50 ft of 1 in diameter PVC , schedule 160 or 200 light weight
12 1" PVC caps

Wood stands
3 pine or fir 1X8X8 boards (base)
3 pine or fir 2X2X8 vertical supports
3 pine or fir 1X2X8 base boards

Clips
9 Tool hanging clips comes with screws (ACE hardware)

Screws
24 1 ½ in deck screws for the support posts
24 ¾ in deck screws for the support base board

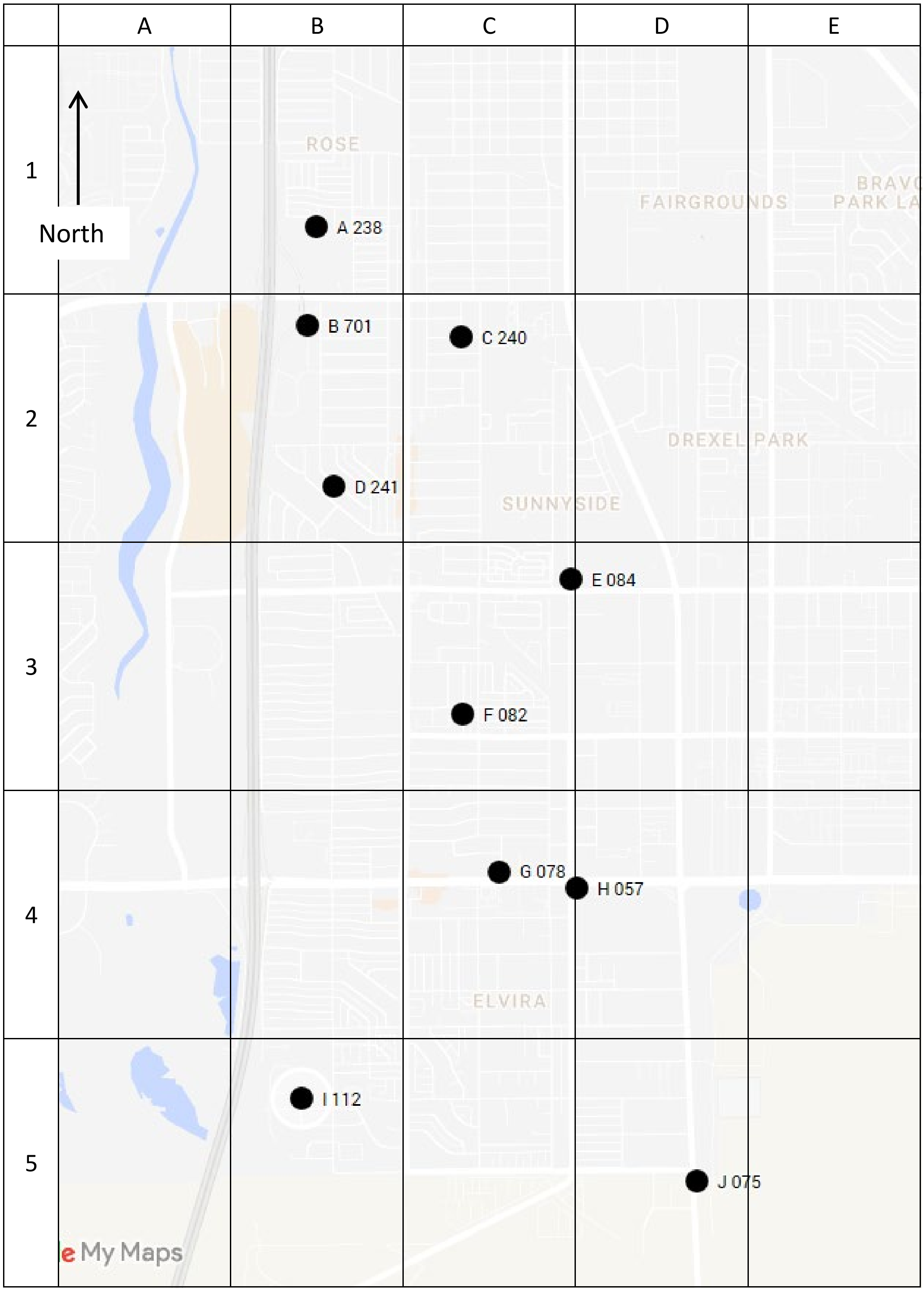
Drill bit
1 ½ wood bit to make stand hole, drilled about ¼ in into the base

Other
Blue paint masking tape
Blue yarn
Graduated Cylinders (1 liter)
Bucket

Piezometer Setup Measurements

Piezometer code	Piezometer height (in)	Elevation top piezometer (ft)	Surface elevation (ft)	Water table elevation (ft)	Depth to water (ft)	Surface in inches below PZ top	Depth to water from surface (in)	Depth to water from top of PZ (in)	height of water column (in)	water volume (ml)
A 238	52	2520	2446	2286	160	7.36	16.05	23.41	28.59	395
B 701	52	2520	2453	2294	159	6.70	15.92	22.62	29.38	400
C 240	54	2540	2473	2344	128	6.74	12.85	19.59	34.42	475
D 241	54	2540	2464	2306	158	7.65	15.77	23.42	30.58	520
E 084	54	2540	2503	2402	101	3.66	10.12	13.78	40.22	555
F 082	58	2580	2497	2411	87	8.27	8.66	16.93	41.07	565
G 078	58	2580	2513	2441	72	6.73	7.17	13.90	44.10	610
H 057	60	2600	2525	2438	87	7.47	8.73	16.20	43.80	600
I 112	58	2580	2500	2438	62	8.00	6.20	14.20	43.80	600
J 075	60	2600	2555	2486	69	4.53	6.87	11.40	48.60	670

Piezometer Set-up Map



Grid size is relative to aid in placement of piezometers.

<u>Piezometer Code</u>

A 238

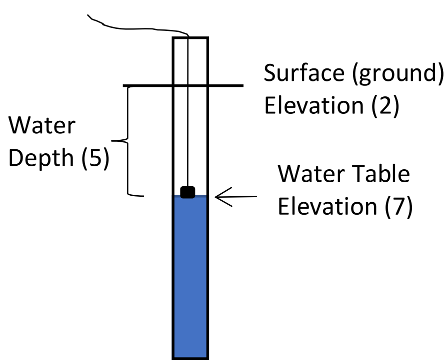
Well Code

Piezometer Label

Student Task 2-1: Piezometer Data and Water Table Elevation Calculations

Name:

Driving question: What is the shape of the water table in the south Tucson area?



Directions

1. Piezometer label (written on tube)
2. Surface elevation (written on tube)
3. Measure the distance from the top of the tube to the surface elevation line (in inches). Write in decimal form ex: 1¼ inches = 1.25 inches .
4. Drop the sponge and string into the tube. Stop when the string will no longer go down. Pinch the string at the top of the tube. Remove the string (without letting go of the pinch). Measure the distance from the sponge to the pinch (in inches).
5. Subtract #3 from #4 to determine the depth to the water from surface.
6. Change scale. 1" = 10 feet. Multiply #5 X 10
   Ex: (20.25 inches) X (10 ft/inch) =
7. Subtract #6 from #2 to determine the elevation of the water table. Round to the nearest foot.

1. Piezometer Label	**2. Surface Elevation (ft)**	**3. Top of tube to surface elevation (in)**	**4. Distance from top of tube to water (in)**	**5. Depth to water (in) - #4 minus #3**	**6. Change scale to ft. 1"=10' -- #5X10**	**Elevation of water table (ft) - #2 minus #6**
Example	2480 ft	3 3/8 in = **3.38 in**	13 6/8 = **13.75 in**	13.75-3.38 = **10.37 in**	10.37X10 = **103.7 ft**	2480-103.7 = 2376.3 ft Rounded to **2376 ft**

<u>Fraction to decimal conversions</u>

1/16 = 0.06	5/16 = 0.31	9/16 = 0.56	13/16 = 0.81
2/16 (1/8) = 0.13	6/16 (3/8) = 0.38	10/16 (5/8) = 0.63	14/16 (7/8) = 0.88
3/16 = 0.19	7/16 = 0.44	11/16 = 0.69	15/16 = 0.94
4/16 (1/4) = 0.25	8/16 (1/2)= 0.50	12/16 (3/4) = 0.75	

Lesson 2: Contouring Water Table Elevations

Learning Goals: H1, (H2), H3, D1, D2, D3, C1

Activity #	Activity Label	Activity Function	Activity Procedures	Materials Needed
1	How can contours represent the shape of the water table?	Establish Question	1. Review the previous day's activities with the piezometer model. **2. Establish the driving question: How can we use contours to represent the shape of the water table on a map?**	
2	Contouring water table elevation	Model and Explore	3. Introduce the table-top piezometer model. 4. Demonstrate how to use the string to outline the water table (outlining the ground surface is optional). 5. Working in pairs, have students outline the water table on their models using string. 6. Demonstrate how to contour the water table using rulers and straws or pipe cleaners. Point out the water table elevations are already drawn on the map. Remind students that these are the same water table elevations that they measured in the previous lesson. Draw an example contour line on the map. Emphasize that the contour line connects points of equal elevation; that is, the water table is the same elevation everywhere along the line. 7. Working in pairs, have students contour their models. You may choose to have some pairs use a 50 ft contour interval and other groups use the 25 ft contour interval.	For each pair: 1. Table Piezometer Model 2. Rulers 3. Vis a vis or dry erase markers 4. Pipe cleaners or straws 5. 2 string (one for water table; 1 for ground – ground is optional) 6. Student Task 2-2: Contouring Water Table Evaluation

Activity #	Activity Label	Activity Function	Activity Procedures	Materials Needed
3	Analysis and Discussion	Explain and Reflect	8. Have students compare maps drawn with 25 ft contours and 25 ft contours. 9. Discuss with students affordances and limitations of different contour intervals (see discussion questions page 13). 10. Discuss the flow of groundwater and the movement of the contamination plume (see discussion questions page 13). You may refer to EPA map of contamination plume (page 14). 11. A key is provided for reference (page 15). You may choose to project it during the discussion.	1. Key to Contoured Water Elevations 2. EPA Map of Contamination Plume for reference.

Discussion Points and Argument Questions

1. How do the contour maps with different contour intervals compare? Which maps are best? Consider ease of reading, amount of information conveyed, and relationship to the data.

   Important points to draw out in this conversation are:

   - Certainty and confidence increase where there is more data. One cannot confidently draw contour lines that extend very far beyond the wells because there is no data available for guidance.
   - Very large contour intervals may not provide enough detail for some purposes, but very small contour intervals may be too complex to other purposes. Surfaces drawn with very small contour intervals may also not be valid because there is not enough data to draw the contours confidently at a small interval.

2. Which way does the groundwater flow?

   Points to emphasize:

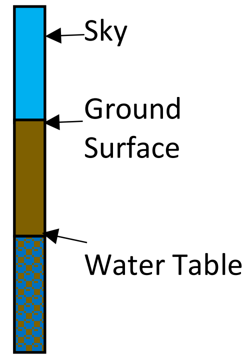
   - Groundwater flows from highest potential energy to lowest potential energy. In unconfined aquifers, the highest potential energy is where the water table is highest in elevation and the lowest potential energy is where the water table is lowest in elevation.
   - The flow direction is perpendicular to the water table contours.
   - Notice that the water table contours and contamination plume contours are perpendicular to each other and that the flow of groundwater is in the same direction as the contamination plume seems to be moving. The contamination follows the flow of groundwater from high elevation to low elevation.

Word did not find any entries for your table of contents.

Water Table Model Directions

Materials:

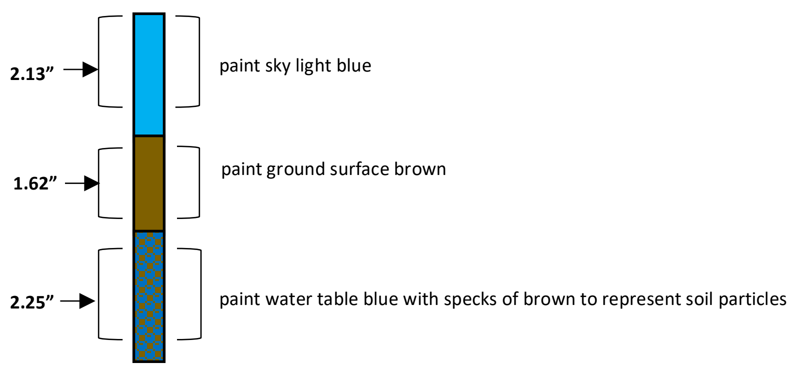
1. Particle board (¾"x 8 ½"x 11 ½")
2. Wooden dowels, 6" length (10 per model) https://www.dollartree.com/crafters-square-wood-dowels-12ct-packs/291114
3. Light blue paint
4. Brown paint
5. Black sharpie marker
6. Copy of well map
7. Copy of ruler
8. Masking tape
9. Laminating film
10. String
11. Chenille stems
12. Expo markers (thin-tipped)
13. Drill press
14. Laminator



Assembly

1. Dowels represents wells A-I. Label each dowel end with a letter.
2. Paint wooden dowels

Dowel A (Well 238)



Dowel B (Well 701)
sky – 2"
ground surface – 1.56"
water table – 2.44"

Dowel C (Well 240)
sky – 1.71"
ground surface – 1.33"
water table – 2.96"

Dowel D (Well 241)

sky – 1.96”
ground surface – 1.58”
water table – 2.46”

Dowel E (Well 084)
sky – 1.5”
ground surface – 1”
water table – 3.5”

Dowel F (082)
sky – 1.5”
ground surface – .5”
water table – 4”

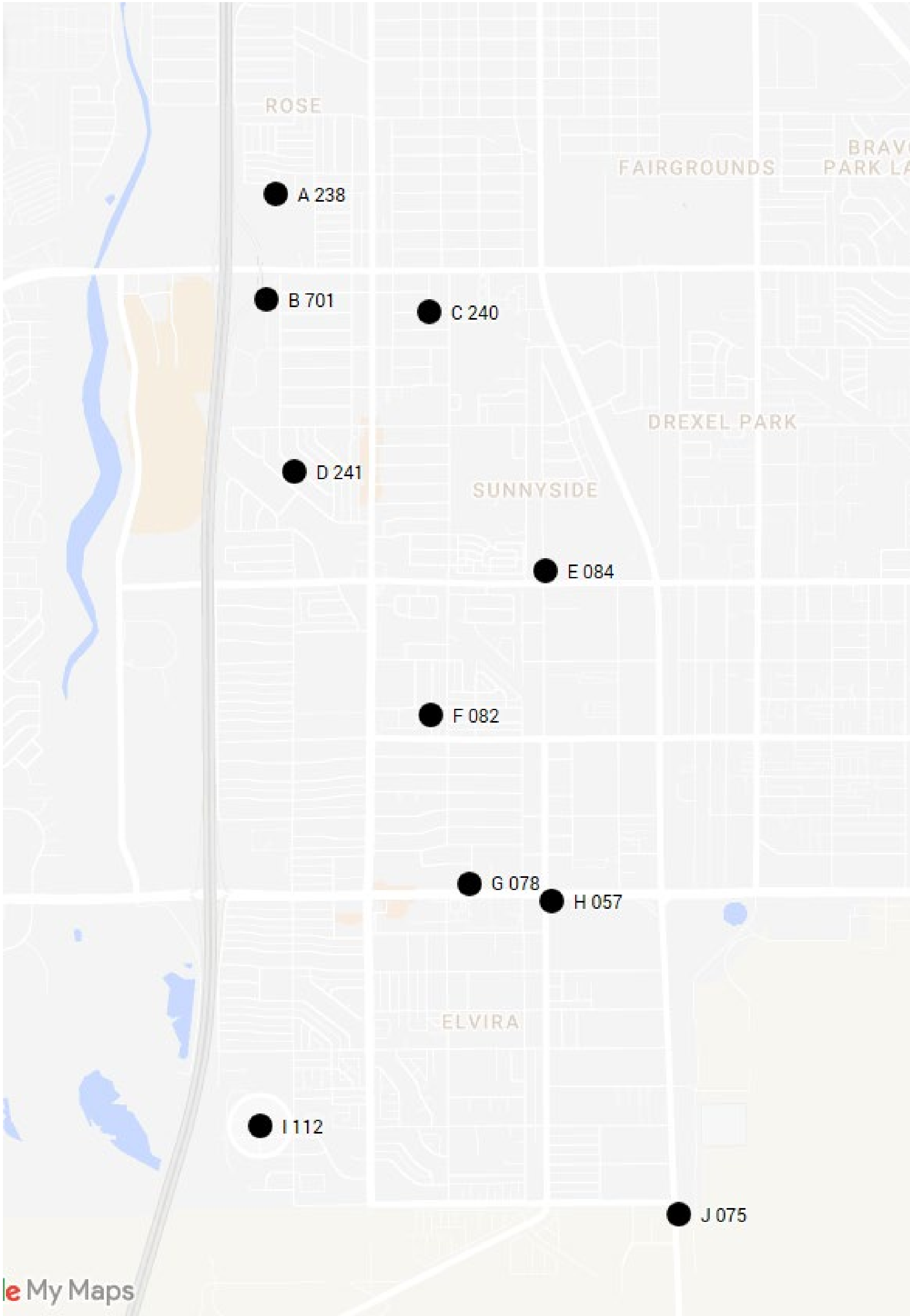
Dowel G (Well 078)
sky – 1.5”
ground surface – .69”
water table –3.81”

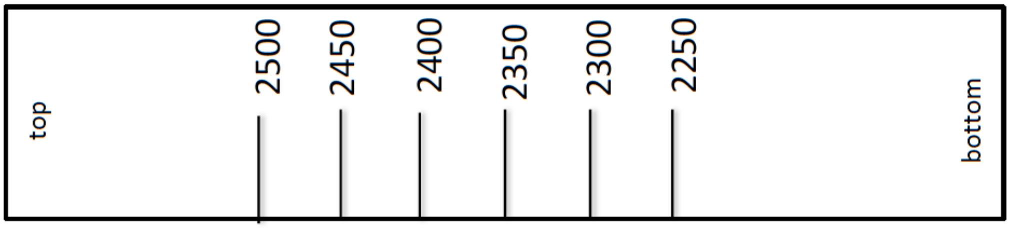
Dowel H (Well 057)
sky – 1.19”
ground surface – 1”
water table – 3.81”

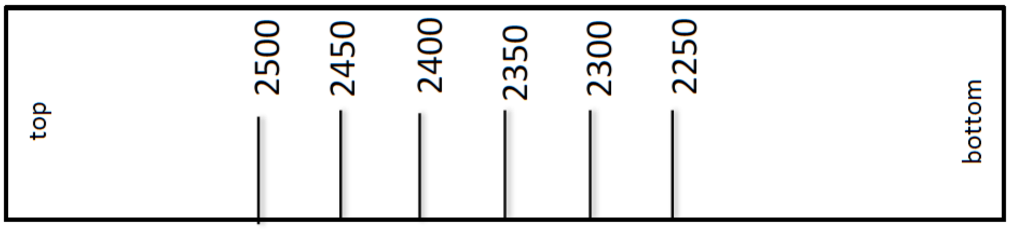
Dowel I (Well 112)
sky – 1.5”
ground surface – .69”
water table – 3.81”

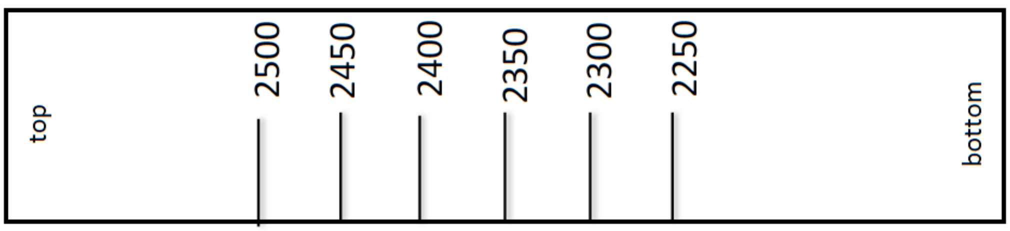
Dowel J (Well 075)
sky – 1”
ground surface – .5”
water table – 4.5”

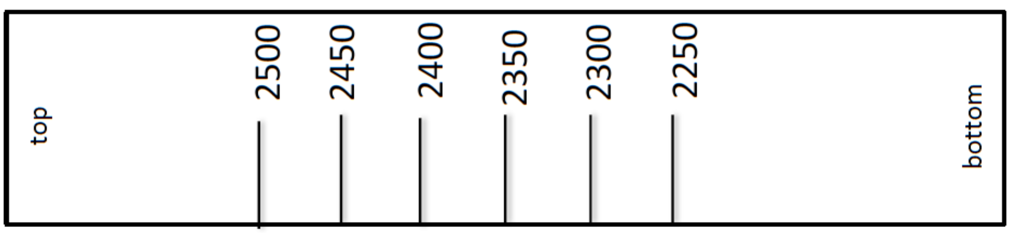
3. Print and laminate copy of well map.
4. Tape well map to particle board to secure for next step.
5. Drill press ¼ diameter holes into particle board with well map on top. Align drill press with black circles on the map. Wooden dowels will fit snuggly into the holes.
6. Print rulers and laminate (1 ruler per model).
7. Cut string into 36” length (1 string per model).
8. Cut chenille stem in half (1 per model).

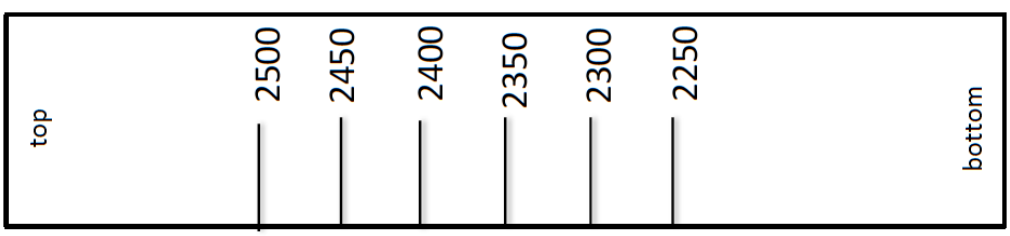

ROSE
FAIRGROUNDS
BRAVO PARK LA
A 238
B 701
C 240
DREXEL PARK
D 241
SUNNYSIDE
E 084
F 082
G 078
H 057
ELVIRA
I 112
J 075
My Maps

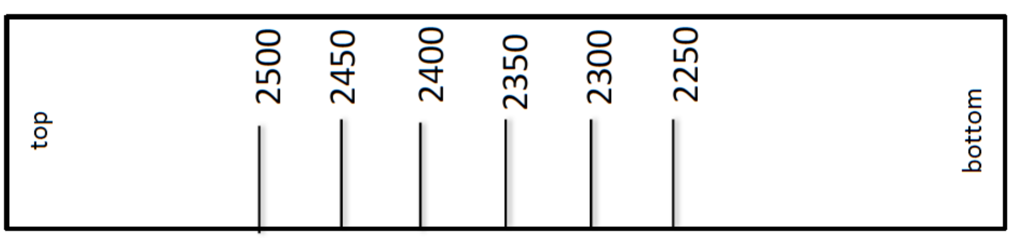

top
2500
2450
2400
2350
2300
2250
bottom


top
2500
2450
2400
2350
2300
2250
bottom

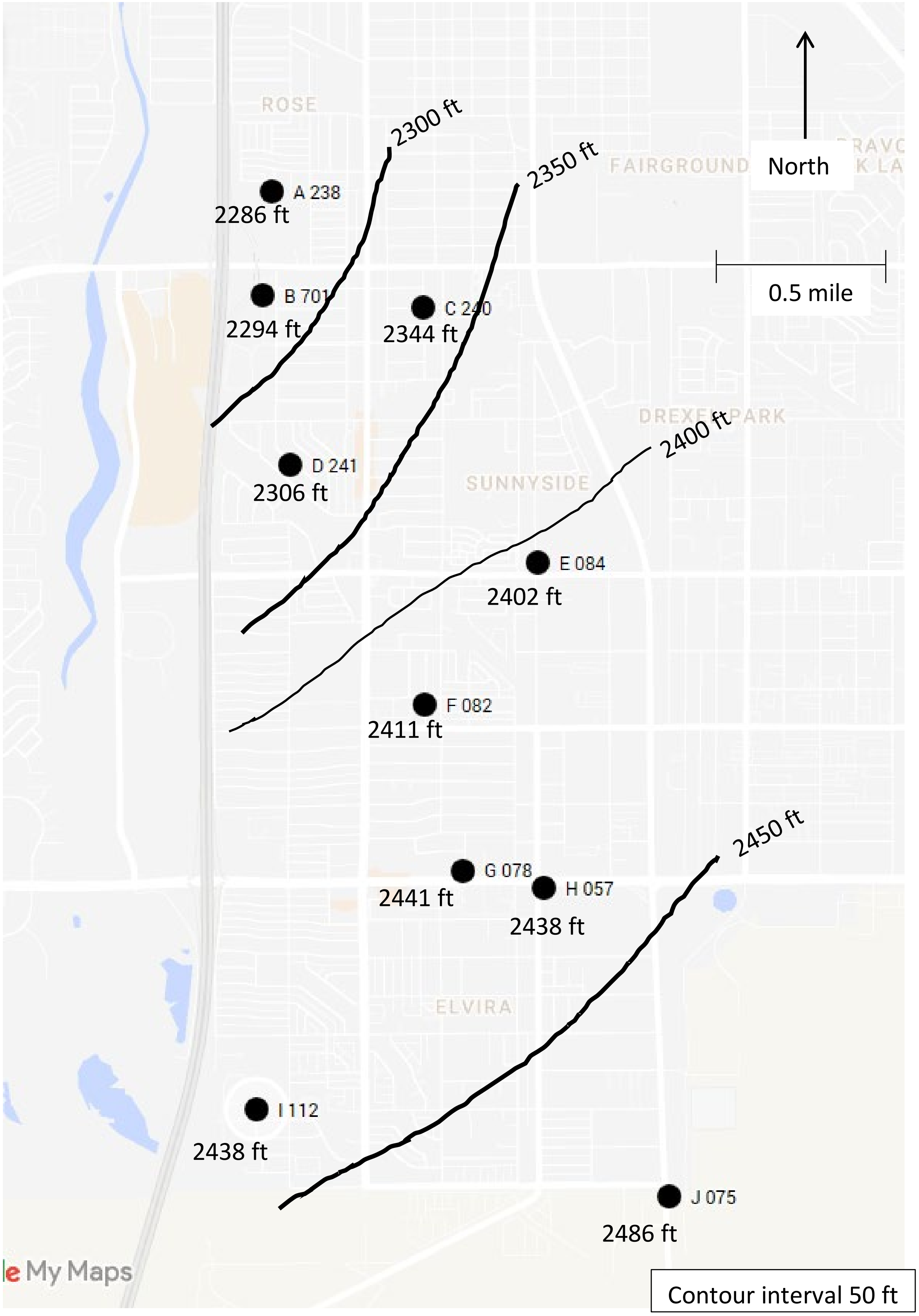

top
2500
2450
2400
2350
2300
2250
bottom


top
2500
2450
2400
2350
2300
2250
bottom

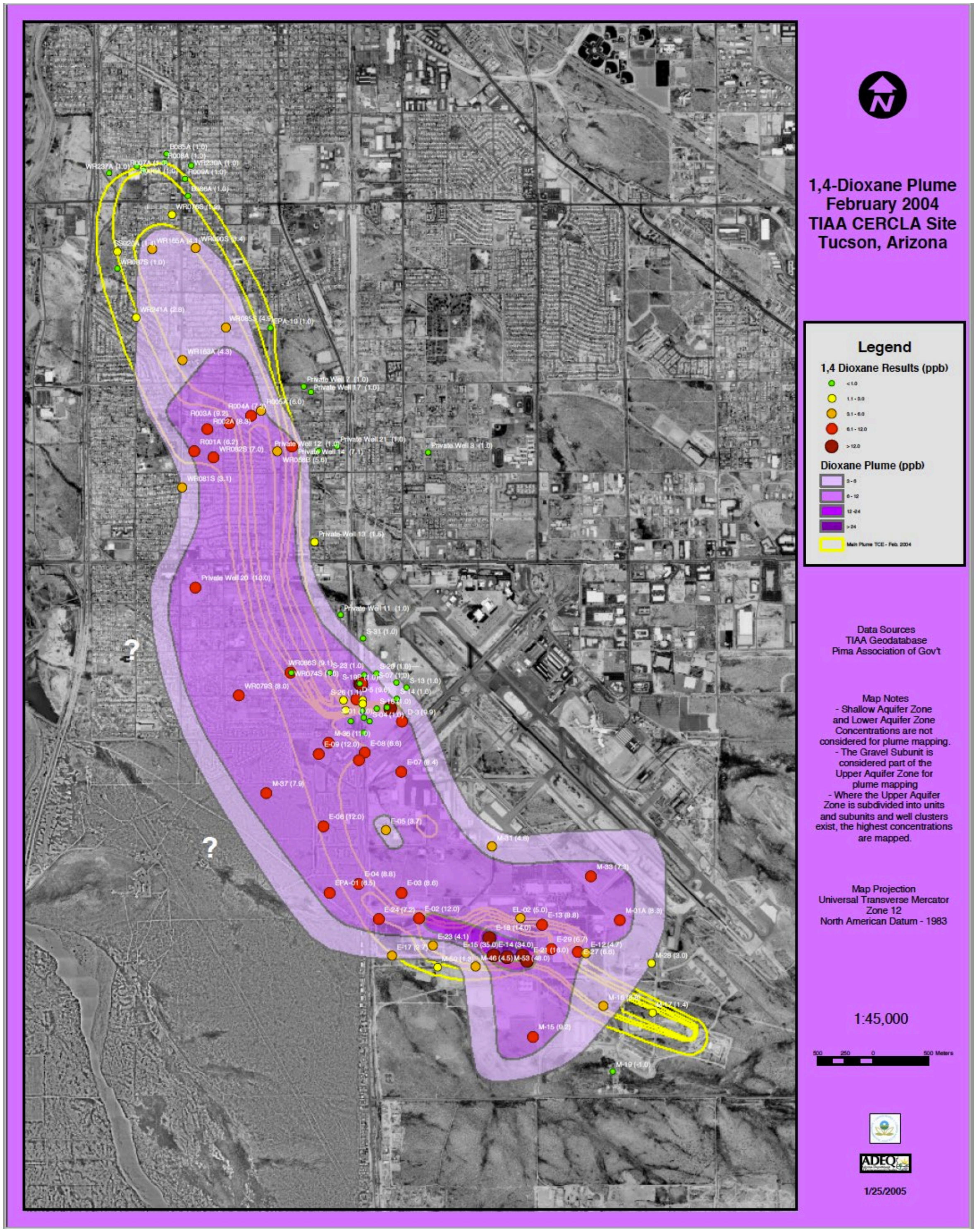

top
2500
2450
2400
2350
2300
2250
bottom


top
2500
2450
2400
2350
2300
2250
bottom

Contoured Water Table Elevations Key
(approximate key)



Arizona Department of Environmental Quality Map of Contamination Plume



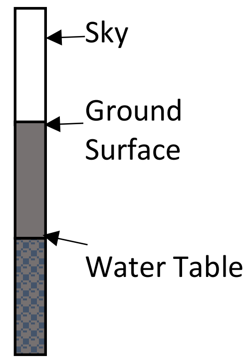
Arizona Department of Environmental Quality (Cartographer). (2004). 1,4-Dioxane Plume, TIAA CERCLA Site, Tucson, Arizona.

Student Task 2-2: Contouring Water Table Elevation

Name:

Driving Question: How can we use contours to represent the shape of the water table on a map?

Set Up Your Water Table Model



1. Make sure the dowels are inserted into the correct well holes on the model.
2. Using one string, connect the top of the water table on each well. It is easiest to connect in a circular pattern around the outside, but be sure to include all of the wells.
3. Using the other string, connect the top of the ground surface on each well (optional).
4. Answer these questions:
    a. Where is the water table highest in elevation?
    b. What is the general shape of the water table?
    c. Where is the water table deepest (greatest distance between the ground surface and the water table?
    d. Which direction would the groundwater flow? Why?

Contour Your Water Table Map

The red numbers on the map are the elevation of the water table at each well. These are the elevations you measured in the piezometer tubes. Contour lines connect points of equal elevation. They can represent the three-dimensional shape of the water table.

1. On your model, place a pipe cleaner or straw across the strings so that the pipe cleaner looks like it is level. The pipe cleaner or straw is showing you where the elevation of the water table (the strings) is the same on both sides of the model.
2. Now move the pipe cleaner so that it is along the 2450 ft. elevation point. To figure out where this point is, place the ruler vertically next to string near well J with the 1 end down. Move the ruler along the string towards well I until the string is at 2450 ft on the ruler. This point represents where the water table is 2450 ft. in elevation.
3. Use the marker to place a dot on the map at that point.
4. Repeat steps 3 & 4 beginning near well J and moving towards well H.

5. Place your pipe cleaner across the water table string above the two marks you made on the map. Your pipe cleaner should be level. The water table is 2450 ft. in elevation everywhere along the pipe cleaner.
6. On the map, use the marker to draw a line that connects the two dots. This line should be under the pipe cleaner. Mark this like 2450 ft. This is your 2450 ft. contour line. All points on the water table along this line are 2450 ft in elevation.

Comparing Contour Intervals

The contour interval is the vertical elevation difference between adjacent contour lines. Different maps have different contour intervals, depending on what fits the data the best.

1. Draw the water table elevation contour lines with an interval of either 50 ft or 25 ft. Use the steps above and the information in the table below to draw the contour lines. Be sure to write the elevation of each contour line you draw on the map.

50 Foot Contour Interval	
Water Table Elevation	Mark the map where the string is this high off the map.
2400 ft	3.5 inches
2350 ft	3.0 inches
2300 ft	2.5 inches

25 Foot Contour Interval	
Water Table Elevation	Mark the map where the string is this high off the map.
2425 ft	3.75 inches
2400 ft	3.5 inches
2375 ft	3.25 inches
2350 ft	3.0 inches
2325 ft	2.75 inches
2300 ft	2.5 inches

2. Write the contour interval somewhere on the map.
3. Groundwater flows from highest elevation (potential energy) to lowest elevation (potential energy). Draw an arrow on the map that shows the direction that water will flow. Your arrows should be perpendicular to the contour lines.
4. Compare your map with the map of the other people at your table. Discuss the advantages and disadvantages of each map. Consider how much information it shows, how much data is needed to draw the contours, and how much work is involved.

Which contour interval would be best for this map?

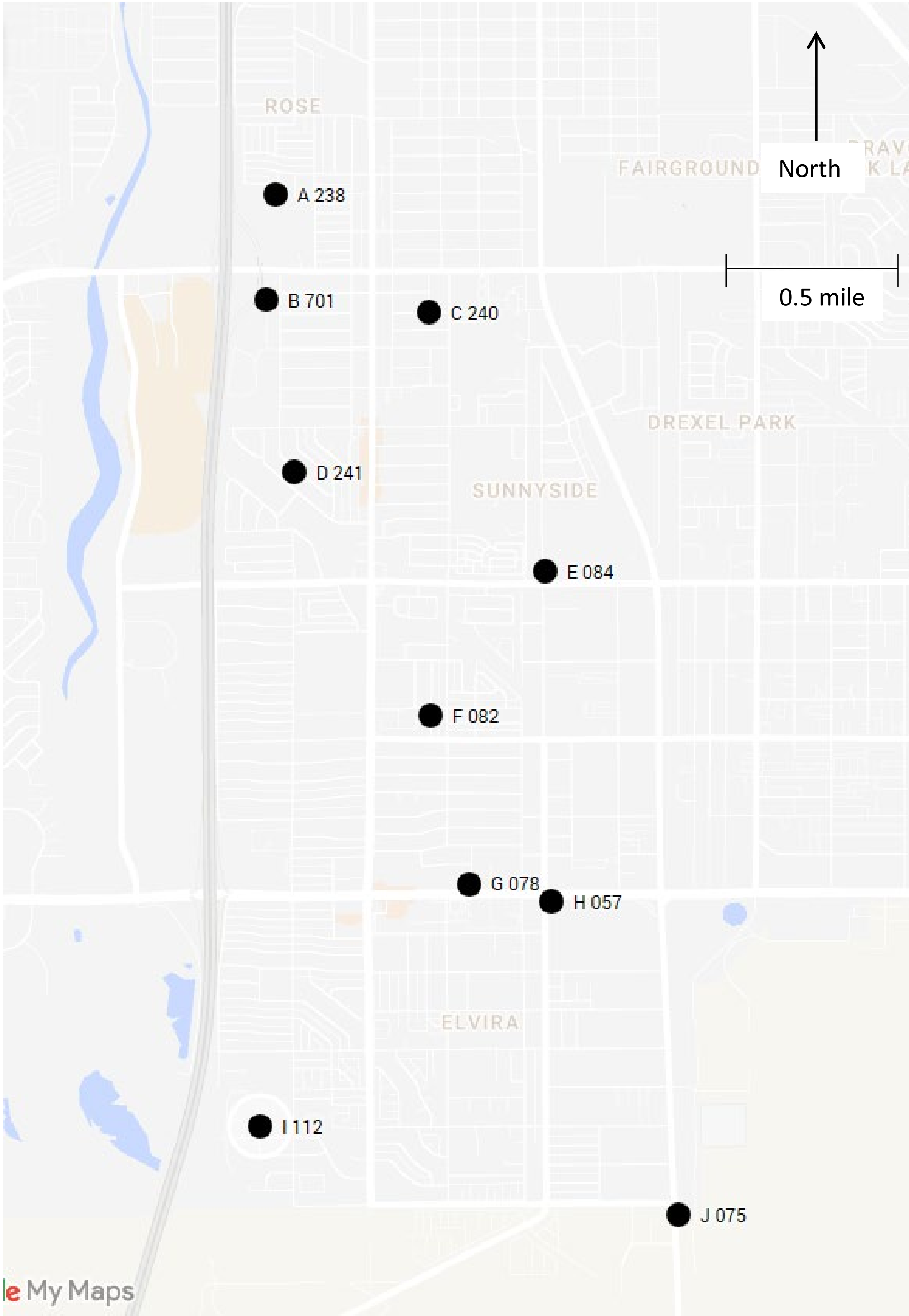
a. 100 ft
b. 50 ft
c. 25 ft
d. 10 ft

Explain the reasons for your choice.

Clean up your Model

1. Carefully take the string off the model. Wrap it into a neat ball.
2. Use a damp paper towel to wipe off all your marks on the map.

Water Table Elevations



Lesson 3: Regional Water Table in 2D and 3D

Learning Goals: H1, H2, H3, D1, D2, D3, D4, C1, C2, C3, C4

Activity #	Activity Label	Activity Function	Activity Procedures	Materials Needed
1	What does the regional water table look like?	Establish Question	1. **Establish the driving question: How does the shape of this water table relate to the water table in the overall region?**	
2	Explore colored contour map of regional water table	Model and Explore	2. Show the Regional Water Table document (detailed directions on page 20).	1. Regional Water Table document 2.
3	Net Logo 3-D model of regional water table	Model and Explore	3. Lead students through creating and comparing the 4X4, 5X5, and 10X10 3D Net Logo models of the regional water table. (Detailed directions on page 20).	1. 3D Net Logo models 4X4 , 5X5, 10X10. https://ecoapps.nrel.colostate.edu/netlogo/ 2. 10Z10AZeg-tabl (on Net Logo remote server) for demo (optional) 3. Student Task 2-3
4	Analysis and Discussion	Explain & Reflect	4. Discuss issues of discretization and parameterization. 5. Relate the modeled area to the larger regional water table and the small area near the TARP Superfund Site.	

Regional Water Table Contour Maps and 3D Net Logo Model

Module 2, Lesson 3; Task 3

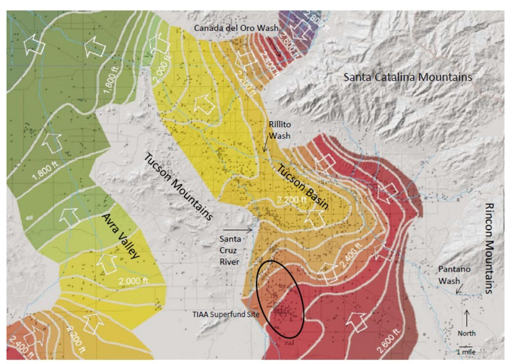
In this activity students will use what they know about water tables and reading contours to interpret a map of the regional water table. They will have an opportunity to use the computer model to move between two-dimensional and three-dimensional representations of the water table.

Driving Question: How does the shape of this water table relate to the water table in the overall region?

Show the Regional Water Table

1. Present the Regional Water Table document
2. Orient students to the map. Notice the major landmarks, including the mountain ranges and the major washes/rivers. The oval represents the area of the TARP Superfund Site. The small dots are well locations.
3. Use the following question to guide students in reading the map.
    a. What does the colored area show? What do the large arrows show?
    b. What is the contour interval?
    c. Where is the water table highest? Where is it lowest?
    d. Where is the water table steepest? Where is it flattest?

Regional Water Table Map



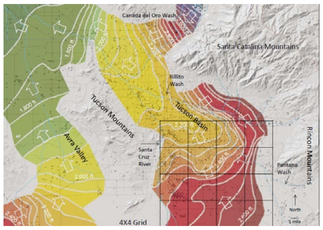
Translating the image into three dimensions using Net Logo.

You may choose to introduce students to this process by showing them a finished version located on the Net Log remote server, such as elev10x10AZeg-tabl.nlogo3d (water table) or elev10x10AZeg-surf.nlogo3d (surface topography). This will help them see what they are doing as they move through the process of translating a 2D image into a 3D representation.

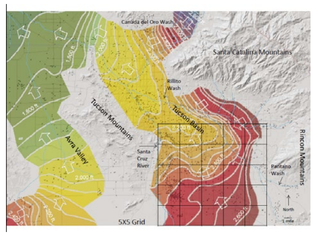
The process of translating the 2D image to 3D involves discretization – dividing up a continuous parameter (slope) into discrete chunks that the computer can handle. In this process, students will see how the size of the discrete chunks affects a) the quality of the resulting representation and b) the work involved in making the representation.

1. Assign each group to one of three grid sizes from the Regional Water Table document
    a. Slide 2 4X4 grid
    b. Slide 3 5X5 grid

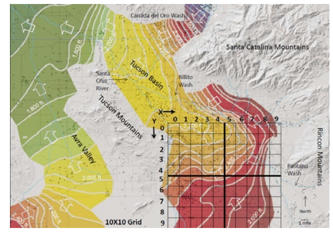
c. Slide 4 10X10 grid



4X4 Grid



5X5 Grid



10X10 Grid

2. Based on the map, each group will assign one color to each cell in their grids. Students will have to decide on what basis they will assign colors (e.g., color that covers the most area or color at the center of the cell). Students can write the colors on their Student Task Sheet.
3. Students open the appropriate Net Logo tool (Elevations4X4.nlogo3d, elevations5X5.nlogo3d, elevation10X10.nlogo3d) and click the "Set-up" button.
4. Students use the pull-down menus for each cell to assign colors in Net Logo based on the table they completed on their Student Task Sheet 2-3.
5. Each color on the map represents an elevation interval of 50 feet. The table below shows the elevation intervals represented by each color on the map. In order to have Net Logo model this slope, however, each color needs a single value. This step is the process of discretizing a continuous parameter. Point out that there is also a consistent interval between the discrete elevation values (50 ft).

Color	Elevation (ft) interval represented	Discrete elevation (ft) for model
Light Yellow	2050-2100	2075
Yellow	2100-2150	2125
Dark Yellow	2150-2200	2175
Light Orange	2200-2250	2225
Orange	2250-2300	2275
Dark Orange	2300-2350	2325
Light Red	2350-2400	2375
Red	2400-2450	2425
Dark Red	2450-2500	2475
Light Brown	2500-2550	2525
Brown	2550-2600	2575
Dark Brown	2600-2650	2625

6. Students now enter the values in the table into the Net Logo model. More than one member of the team can enter their values at the same time.
7. In the 3D space, students can rotate the block to see the three-dimensional shape of the water table.
8. There are pre-set versions of both surface elevations (elev10X10AZeg-surf.nlogo3d) and water table elevations (elev10X10AZeg-tabl.nelogo3d). You can use these for comparison and discussion purposes.

Investigations

1. Manipulate the 3D model to look at the array of columns from different angles.
2. Use the "Slice-X" and "Slice-Y" sliders to get cross-section slice view through the models.
3. Compare the 4X4, 5X5, and 10X10 grids.

Computational and Hydrologic Questions for Discussion and Argument

1. How would you describe the overall shape of the water table in the region modeled? Where does the area of TARP fit in?

    The water table is shaped kind of like a 3-sided bowl open and sloping (dipping) to the north northwest. The water table is steepest nearest the Rincon Mountains. This is where water flowing off the mountains recharges the aquifer. The water table under the TARP Superfund site is part of the west side of the bowl in the area modeled.

2. What is the purpose of dividing the area into cells to make a computer model?

    The cells allow you to divide up a continuous slope into discrete blocks that are all the same elevation to enter into the computer model.

3. How do the 4X4, 5X5, and 10X10 grids compare?
    a. Which grid gives the most detail?

        10X10 gives the most detail because each cell covers the smallest area.

    b. Which grid uses the most data?

        10X10 uses the most data because it divides the area up into the most cells.

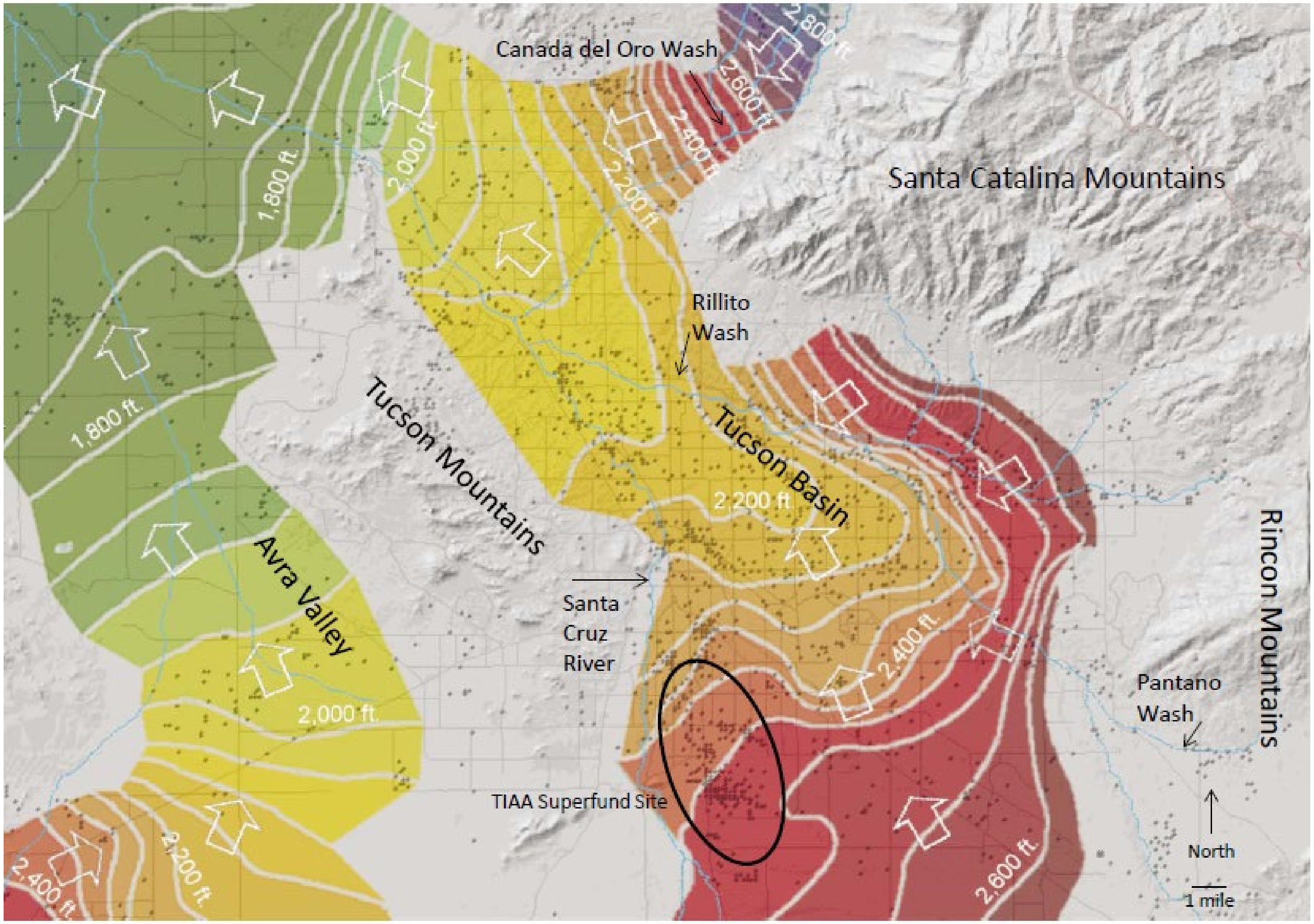
    c. Which grid takes the least amount of time or work to model?

        4X4 takes the least amount of time because there is the least amount of data to work with.

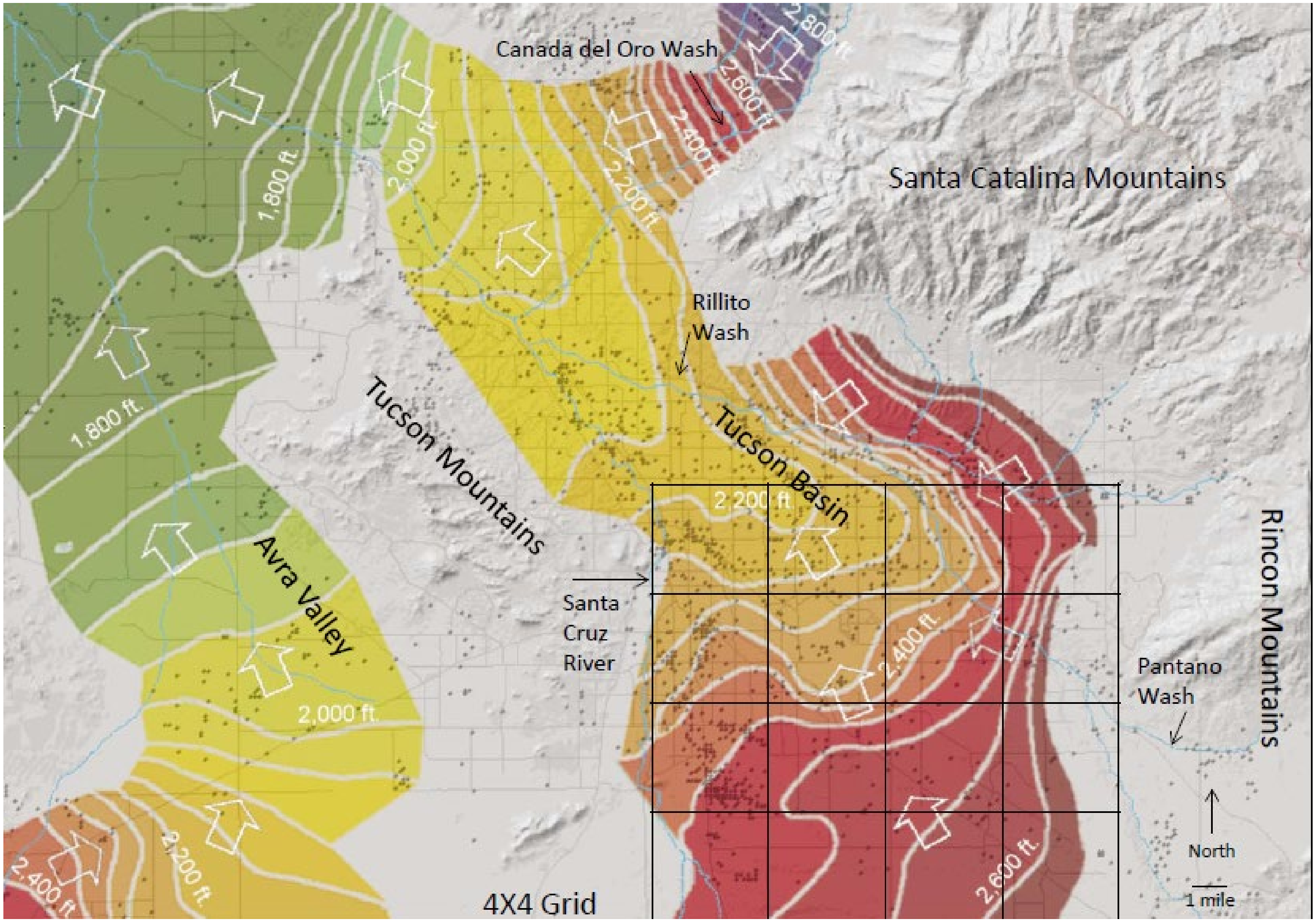
    d. Which grid do you think is best to make the model? Why?

        This answer depends on trade-offs. Smaller cells give more detail but require more data and more work.

Regional Water Table

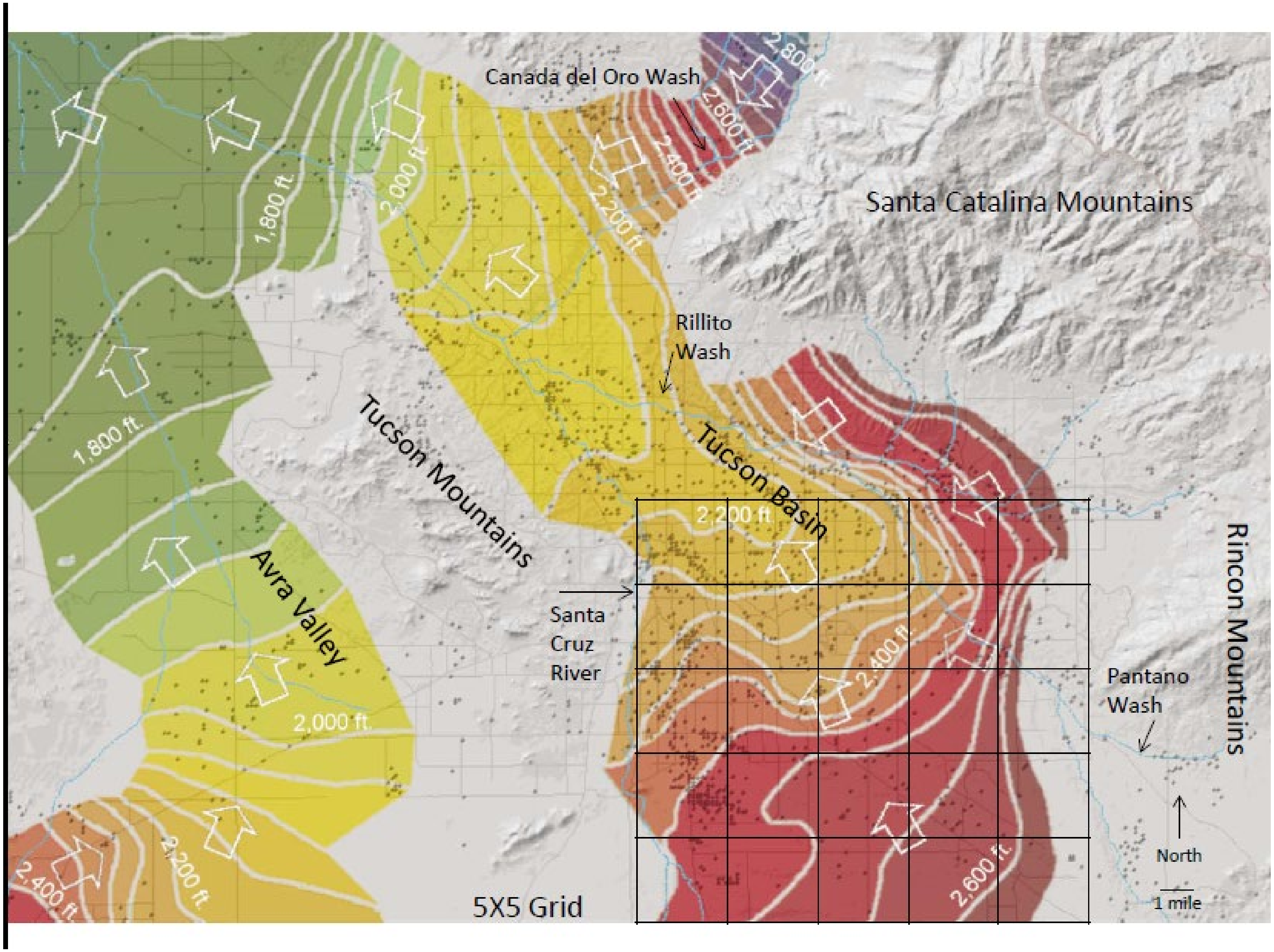


4X4 Grid

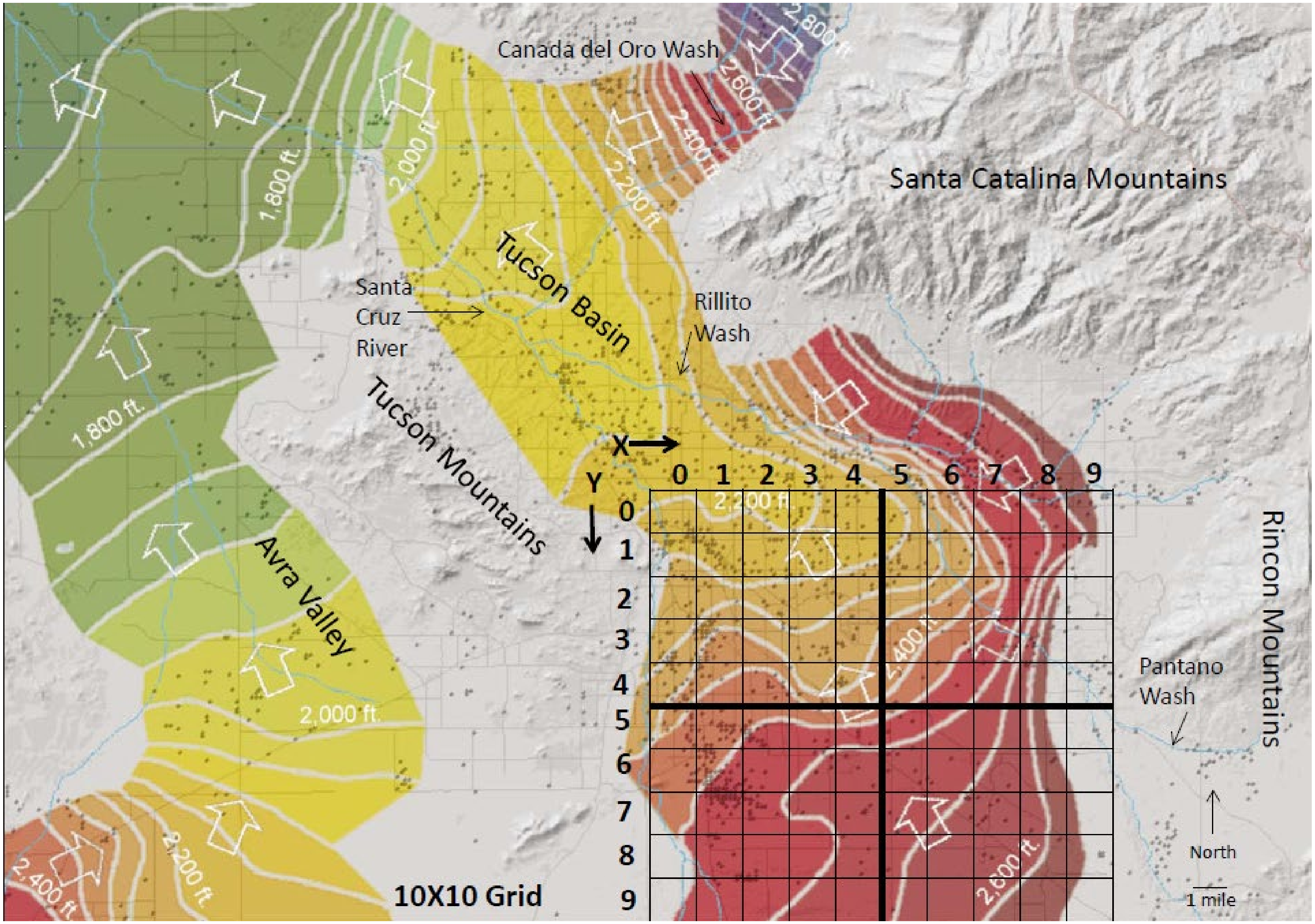


Canada del Oro Wash
2,800 ft.
2,600 ft.
2,400 ft.
2,200 ft.
2,000 ft.
1,800 ft.
Santa Catalina Mountains
Rillito
Wash
Tucson Mountains
Tucson Basin
1,800 ft.
2,200 ft.
Avra Valley
Santa
Cruz
River
2,400 ft.
Rincon Mountains
Pantano
Wash
2,000 ft.
North
1 mile
2,200 ft.
2,400 ft.
4X4 Grid
2,600 ft.

5X5 Grid


Canada del Oro Wash
2,800 ft
2,600 ft
2,400 ft
2,200 ft
2,000 ft
1,800 ft
Santa Catalina Mountains
Rillito Wash
1,800 ft
Tucson Mountains
Tucson Basin
2,200 ft
Avra Valley
Santa Cruz River
2,400 ft
Pantano Wash
Rincon Mountains
2,000 ft
North
2,200 ft
2,400 ft
5X5 Grid
2,600 ft
1 mile

10X10 Grid


Canada del Oro Wash
2,800 ft.
2,600 ft.
2,400 ft.
2,200 ft.
2,000 ft.
1,800 ft.
Santa Catalina Mountains
Tucson Basin
Santa Cruz River
Rillito Wash
Tucson Mountains
1,800 ft.
X
Y
0 1 2 3 4 5 6 7 8 9
2,200 ft.
Avra Valley
2,400 ft.
2,000 ft.
Pantano Wash
Rincon Mountains
North
2,400 ft.
2,200 ft.
2,600 ft.
10X10 Grid
1 mile

Student Task 2-3: Regional Water Table Contour in 2D and 3D

Name:

Team Members:

Driving Question: How can we use the computer to show the three-dimensional shape of the water table?

To translate a 2D image (colored map) to a 3D representation, you have to **discretize** the image by dividing it into chunks that you can then tell the computer to use to make the 3D representation. To do this, follow these directions.

1. Orient yourself to the Regional Water Table map. Notice the major landmarks, including the mountain ranges and the major washes/rivers. The oval represents the area of the TARP Superfund Site. The small dots are well locations.
    a. What does the colored area show? What do the large arrows show?
    b. What is the contour interval?
    c. Where is the water table highest? Where is it lowest?
    d. Where is the water table steepest? Where is it flattest?
2. Place a grid over the image. This is what you will use to divide up the area into discrete cells. This step is done for you in the document. Check off the grid size you have been assigned to use:
    - ☐ 4X4
    - ☐ 5X5
    - ☐ 10X10
3. Assign colors to each cell.
   The colors represent the average elevation of the area in that cell. There are two ways to decide which color to assign. Choose one way and stick to it. Circle the method your team will use:
    a. Assign colors based on the color that covers the most area in the cell
    b. Assign colors based on the color at the center of the cell.

   Each team member will write the color of the cell in the appropriate grid on the next pages.
    a. Team member #1: Upper left cells
    b. Team member #2: Upper right cells
    c. Team member #3: Lower left cells
    d. Team member #4: Lower right cells

X →
Y ↓

4X4 Grid

	0	1	2	3
0	Team member 1	Team member 1	Team member 2	Team member 2
1	Team member 1	Team member 1	Team member 2	Team member 2
2	Team member 3	Team member 3	Team member 4	Team member 4
3	Team member 3	Team member 3	Team member 4	Team member 4

X →
Y ↓

5X5 Grid

	0	1	2	3	4
0	Team member 1	Team member 1	Team member 1	Team member 2	Team member 2
1	Team member 1	Team member 1	Team member 1	Team member 2	Team member 2
2	Team member 3	Team member 3	Team member 4	Team member 2	Team member 2
3	Team member 3	Team member 3	Team member 4	Team member 4	Team member 4
4	Team member 3	Team member 3	Team member 4	Team member 4	Team member 4

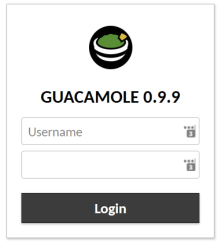
X →

Y ↓

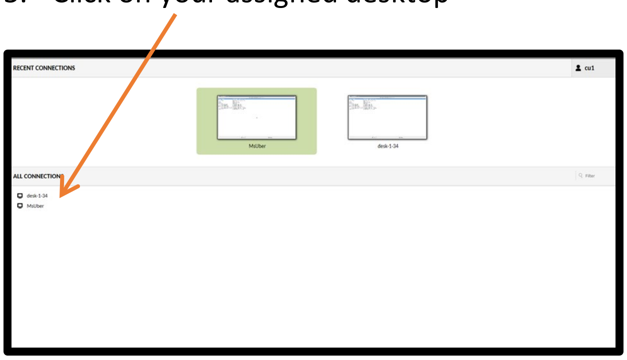
10X10 Grid

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	Team member 1	Team member 1	Team member 1	Team member 1	Team member 1	Team member 2	Team member 2	Team member 2	Team member 2	Team member 2
1	Team member 1	Team member 1	Team member 1	Team member 1	Team member 1	Team member 2	Team member 2	Team member 2	Team member 2	Team member 2
2	Team member 1	Team member 1	Team member 1	Team member 1	Team member 1	Team member 2	Team member 2	Team member 2	Team member 2	Team member 2
3	Team member 1	Team member 1	Team member 1	Team member 1	Team member 1	Team member 2	Team member 2	Team member 2	Team member 2	Team member 2
4	Team member 1	Team member 1	Team member 1	Team member 1	Team member 1	Team member 2	Team member 2	Team member 2	Team member 2	Team member 2
5	Team member 3	Team member 3	Team member 3	Team member 3	Team member 3	Team member 4	Team member 4	Team member 4	Team member 4	Team member 4
6	Team member 3	Team member 3	Team member 3	Team member 3	Team member 3	Team member 4	Team member 4	Team member 4	Team member 4	Team member 4
7	Team member 3	Team member 3	Team member 3	Team member 3	Team member 3	Team member 4	Team member 4	Team member 4	Team member 4	Team member 4
8	Team member 3	Team member 3	Team member 3	Team member 3	Team member 3	Team member 4	Team member 4	Team member 4	Team member 4	Team member 4
9	Team member 3	Team member 3	Team member 3	Team member 3	Team member 3	Team member 4	Team member 4	Team member 4	Team member 4	Team member 4

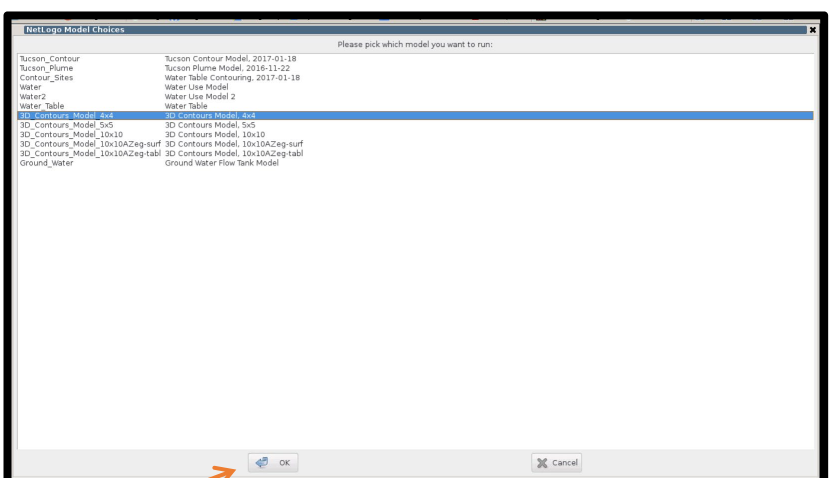
4. Go to the Net Logo Remote Server https://ecoapps.nrel.colostate.edu/netlogo/
Your teacher will assign you a Username and Password. Enter the username and password into the Guacamole box and click "Login."



5. Click on your assigned desktop

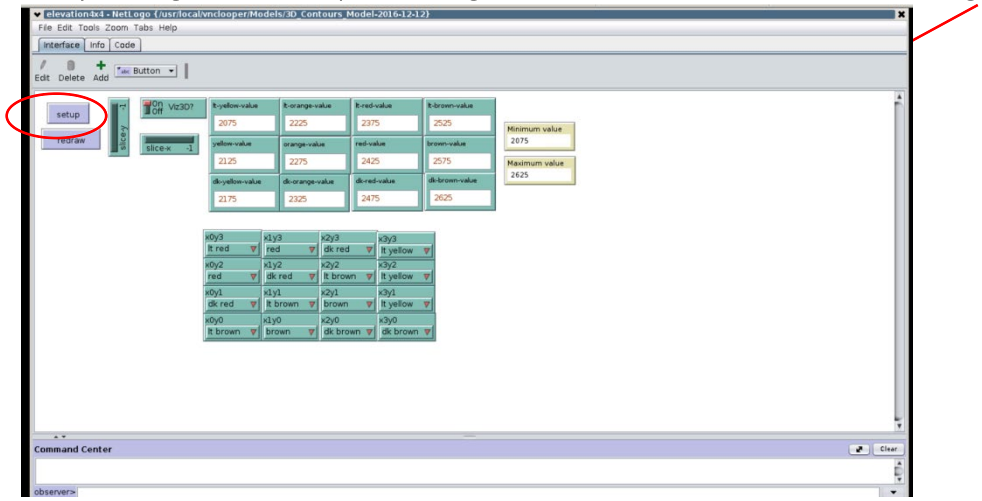


6. Open Net Logo 3D model
    a. If you have been assigned to a 4X4 grid, open: 3D_Contours_Model_4X4
    b. If you have been assigned to a 5X5 grid, open : 3D_Contours_Model_5X5
    c. If you have been assigned to a 10X10 grid, open: 3D_Contours_Model_10X10



Click the OK button at the bottom of the page.

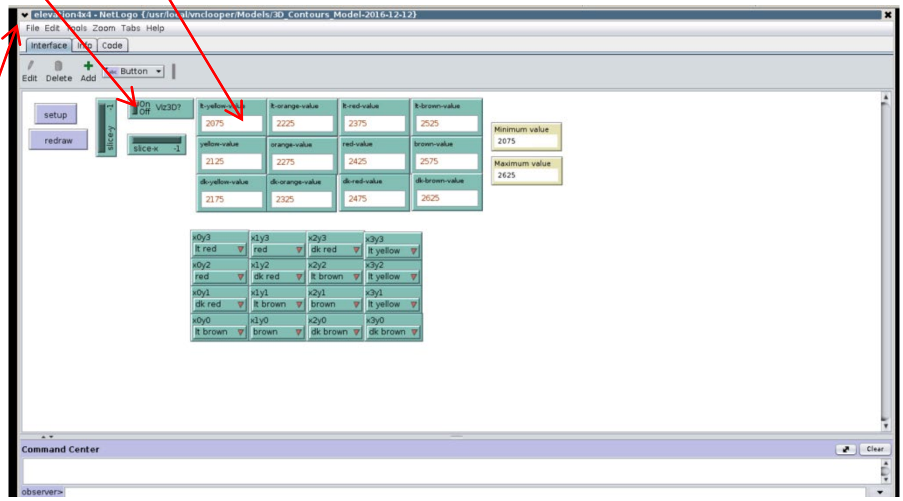
7. Click the "Set-Up" Button on the upper left corner
8. Use the completed grid from step 4 to assign the colors to each cell in the Net Logo model.



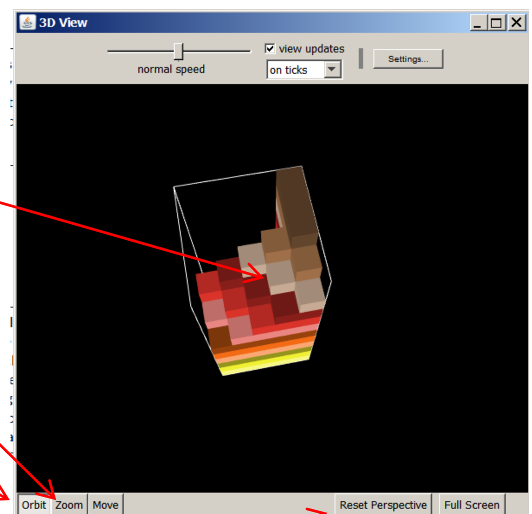
9. Each color on the map represents an elevation interval of 50 feet. The table below shows the elevation intervals represented by each color on the map. In order to have Net Logo model this slope, however, each color needs a single value. This step is the process of discretizing a continuous parameter. This process was started for you. Complete this table but assigning a discrete elevation for the remainder of the colors using a 50-ft contour interval (difference between each discrete elevation).

Color	Elevation (ft) interval represented	Discrete elevation (ft) for model
Light Yellow	2050-2100	2075
Yellow	2100-2150	2125
Dark Yellow	2150-2200	2175
Light Orange	2200-2250	
Orange	2250-2300	
Dark Orange	2300-2350	
Light Red	2350-2400	
Red	2400-2450	
Dark Red	2450-2500	
Light Brown	2500-2550	
Brown	2550-2600	
Dark Brown	2600-2650	

10. Enter these values into Net Logo.
11. Make sure the "Viz3D" button is "on."
12. Click the black down arrow on the top left and then click on 3D to move to the 3D version. To return to the interface, click the 3D and then click on the "elevations link."



13. Now you can rotate, zoom, and move the 3D diagram around to see different perspectives. Hover your mouse over the diagram, click and hold, then move your mouse to move the diagram.



If the labels on the buttons are not visible, just use the diagram to the right to identify the buttons. The buttons will still work.

Zoom: Lets you zoom in and out.

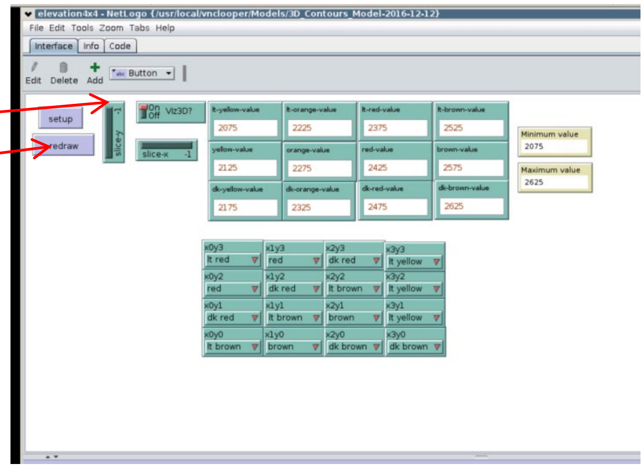
Orbit: Lets you rotate the model

Move: Lets you move the block.

If you forget where you started, click "Reset

14. Use the “Slice X” and “Slice Y” sliders to slice through the block at various points to get a cross-sectional view at that point. Be sure to click “

    Redraw” every time you change a slider.



Investigations

1. Manipulate the 3D model to look at the array of columns from different angles.
2. Use the “Slice-X” and “Slice-Y” sliders to get cross-section slice view through the models.
3. Compare the 4X4, 5X5, and 10X10 grids.

Computational and Hydrologic Questions for Discussion and Argument

1. How would you describe the overall shape of the water table in the region modeled? Where does the area of TARP fit in?

2. What is the purpose of dividing the area into cells to make the computer model?

3. How do the 4X4, 5X5, and 10X10 grids compare?
    a. Which grid gives the most detail?

    b. Which grid uses the most data?

    c. Which grid takes the least amount of time or work to model?

    d. Which grid do you think is best to make the model? Why?