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

Module 1
Contamination

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                To consider issues of uncertainty in interpreting data.
                To compare representations of the same phenomenon.
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                To explore benefits and drawbacks of computer contouring models
                To understand contour interval and fit to data.
                To consider issues of uncertainty in interpreting data.

Learning Goals:

Hydrologic (H)	Data (D)	Computational (C)
1. **Contamination Plumes**: Students will be able to describe the shape and direction of flow of the contamination plume and identify possible contamination sources.	1. **Plotting Data:** Students will be able to plot sample location and contamination data on a map and interpret contamination plume shape and direction of movement. 2. **Interpolation of Data:** Students will be able to interpolate data in order to contour contamination concentrations. 3. **Comparing Models to Observations:** Students will be able to perform and adjust several runs of a model to falsify models and work toward modeled and observed agreement. 4. **Uncertainty:** Students will be able to recognize where missing data contribute to uncertainty. 5. **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. **Trade-offs:** Students will be able to identify and describe benefits and challenges of using computers to analyze data. 2. **Discretization**: Students will be able to discuss how size of discrete intervals (cell size or contour interval) affects models and representations. 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: Paper Maps: Locating Wells

Learning Goals: D1

Activity #	Activity Label	Activity Function	Activity Description	Materials Needed
1	Where is the contamination?	Establish Question	1. Create a google.sheets file using the data on Wells for Student Maps. Set share settings so that students can access the link. 2. Building from the previous day's introduction to Tucson International Airport Area (TIAA)/Tucson Airport Remediation Project (TARP) situation, **class asks the driving question: Where is the contamination located? How do we find out?** 3. Students share initial ideas about how to find out.	1. Wells for Student Maps.
2	Locate wells	Explore	4. Have students follow the directions on Student Task 1-1 to locate some of the major landmarks and wells in the project site on My Maps (Google). 5. Students save their maps on google.	1. Student Task 1-1: Locating Wells 2. My Maps (Google) 3. Wells for Student Maps

3	Class discussion	Reflect	6. As a whole group or in small groups, have students talk about the following questions. These questions are also on Student Task 1-1.
			   a. Where else would you locate a well? Why?
			   b. Why isn't there a well at every house?
			   c. What questions does this map raise for you?
			7. Following the discussion, students may write their answers on the task sheet.	

Student Task 1-1: Locating Wells

Name:

**Driving Question:** Where is the contamination located? How do we find out?

In order to answer the driving question, we need data from sampling wells located throughout the area. In this activity you will plot the location of these wells and the concentration of 1,4 dioxane in the water from these wells. These wells are water sampling wells and not drinking water wells.

1. **Begin a new map**
    a. Go to My Maps
        i.   https://www.google.com/maps/about/mymaps/
        ii. Click "Get Started"
    b. Click the red button that says "CREATE A NEW MAP"

2. **Add some location markers**
    a. Tucson International Airport
        i.   In the Search Box, type "Tucson International Airport"
        ii. Click the blue search button
        iii. Click the "+" sign that says "Add to map"
   iv. You should now see Tucson International Airport listed in the white legend box on the left
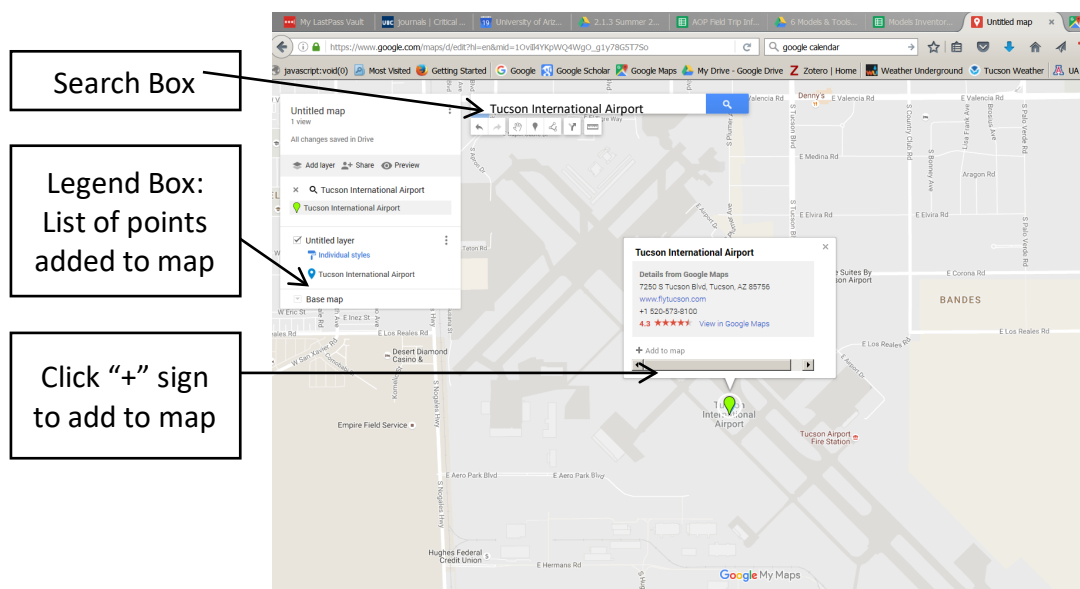
    b. Sunnyside or Desert View High School
        i. In the Search Box, type "Sunnyside High School, Tucson"(or "Desert View High School, Tucson"
        ii. Click the blue search   🔍   button
        iii. Click the "+" sign that says "Add to map"
    c. Your address (Optional)
        i. In the Search Box, type in   your home address.
        ii. Click the blue search   🔍   button
        iii. Click the "+" sign that says "Add to map"

3. Add the location of the water sampling wells
An easy way to add many locations at once is to upload a file. The file has the following data in it for 14 wells.

Well Number	Latitude	Longitude	1,4 Dioxane (ppb)

    a. Click on the "Add layer button" in the white box on the left of your map.
    b. Click on the icon that says "Import"
    c. Look at the data in the document "Wells for Student Maps"
        i. Click on the blue "Select" button
    d. Choose the columns to position your placemarkers
        i. Be sure "Latitude" and "Longitude" are checked. If not, check them.
        ii. Click the blue "Continue" button
    e. Choose a column to title your markers
        i. Check "Well Number"
        ii. Click the blue "Finish" button
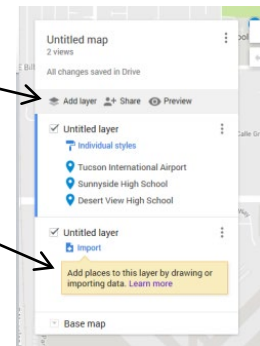
    f. Change the color or shape of the icon for your wells (Optional)
        i. Hover your mouse over "All Items" in the white legend box
        ii. Click on the little paint can icon.
        iii. Choose a color and symbol for the wells

4. Read your map
    a. Change to satellite view
        i. Click on the words "Base map" at the bottom of the white legend box.
        ii. Click on the Satellite version of the map.
    b. Get information about each well plotted on the map

i.   Click on any well icon

ii. A box will appear with the well name, latitude, longitude, and contamination level (ppb means parts per billion).
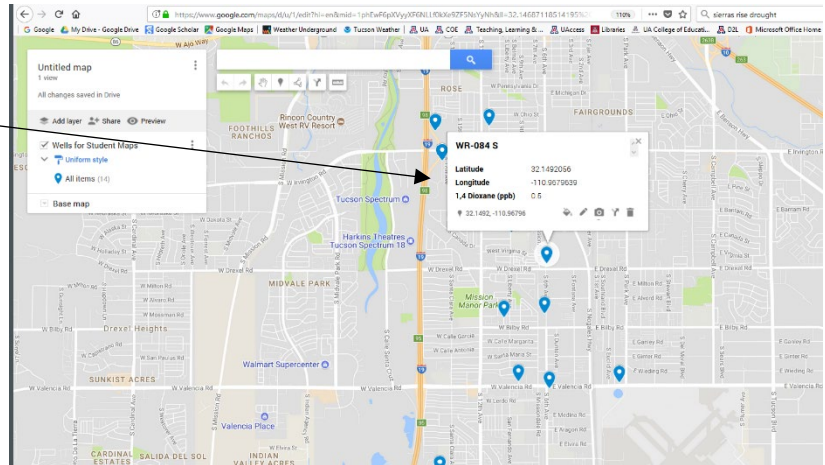
5. **Questions for Discussion and Argument**
    a. Where else would you locate a well? Why?

    b. Why isn't there a well at every house?

    c. What questions does this map raise for you?

6. **Save your map**
    a. Click on the words "Untitled Map" at the top left.
    b. Enter the title "Sample Well Location" and your name.
    c. Add a description that explains what the map shows.
    d. Click the blue "Save" button.
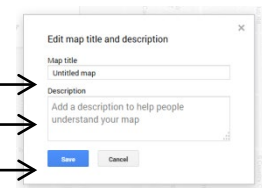
Wells for Student Maps

Well Number	Latitude	Longitude	1,4 Dioxane (ppb)
WR-237 A	32.1656694	-110.98435	0.5
WR-239 A	32.166275	-110.9764722	0.5
WR-701 A	32.161944	-110.9834116	2.2
WR-240 A	32.1613389	-110.9743333	3.6
WR-241 A	32.1538861	-110.9817944	0.5
WR-085 S	32.1530639	-110.97315	5.7
WR-084 S	32.1492056	-110.9679639	0.5
WR-058 B	32.1429944	-110.9682694	5.9
WR-078 S	32.1345694	-110.9721194	3.5
WR-057 A	32.1337222	-110.9675694	6.3
WR-055 B	32.1344167	-110.9573083	0.5
WR-082 S	32.1424722	-110.9742889	5.5
M-112	32.1231944	-110.9837222	0.5
WR-075 S	32.119045	-110.960519	7.1

Lesson 2: Paper Maps: Contouring the Contamination Plume

Learning Goals: H1, D1, D2, D3, D4

| Activity #	Activity Label	Activity Function	Activity Description	Materials Needed
1	Where is the contamination?	Establish Question	1. **Return to the driving question: Where is the contamination?** 2. Ask how we might represent what the contamination might be under places where there is not a well.	
2	Contouring contamination	Explore	3. Provide students with Student Task 1-2 Contouring Concentration 4. Projecting on the overhead, model how to hand draw the isoconcentration contours using interpolation. You may need to model the entire contour line for 1.0 or 3.0 5. Have students complete the other isoconcentration contour lines for the 1.0, 3.0, 5.0 and 7.0 ppb. Students will need some instruction and scaffolding in drawing contours.	1. Hydrology and Data Discussion Points and Argument Questions 2. Student Task 1-2: Contouring Concentration map 3. 1,4 Dioxane Concentration-Contour Completed Map
3	Compare to existing maps.	Explain	1. Students compare their maps to each other. 2. Teacher may show EPA map for students to include in comparisons.	Arizona DEQ Map of 1,4-Dioxane Contamination Plume
4	Class discussion	Reflect	3. As a whole group or in small groups, talk with students about the following questions. Help students read the maps, think about interpolation, uncertainty, and variability. Question and discussion points are listed on the next page. 4. Following the discussion, students may write their answers on the task sheet.	

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Hydrology and Data Discussion Points and Argument Questions

1. What does this map suggest to you about where the contamination is coming from? Be sure to explain why.

    The plume is generally shaped so that the lower concentrations are on the edges (north, west, east) and higher concentrations are towards the center of the plume and towards the southern edge. This might suggest that the plume is moving to the north and/or that the source of contamination is in the south, possibly near the airport.

2. Where are you most uncertain about where you drew your lines? Why?

    Students may say that they were more uncertain around the edges. Explore with the students that contour lines are interpretations and that there is variability in interpretations, but that interpretations must also be supported by the data. Where there is less data, there is more uncertainty.

3. What would happen if you had data from more wells? How would it make drawing the map easier or harder or both?

    Eventually we want students to recognize that more data is both beneficial and challenging. It can increase the complexity and make interpretation more challenging, but it can also increase confidence in interpretations. Real data are not perfect and will have lots of variability. Scientists have to try to find the overarching trends in the noise in the data.

4. How is your map similar to or different from the EPA map?

    Students should see that their map has the same general shape as the EPA map, but the EPA may be more detailed. Notice that the EPA map shows both the 1,4 dioxane plume (purple shading) and the TCE plume (yellow isoconcentration lines).

5. What are some reasons for this variability?

    The EPA map used more data. More data means more complexity but also less uncertainty. However, there is still uncertainty in the EPA map as well, especially near the boundaries and between wells.

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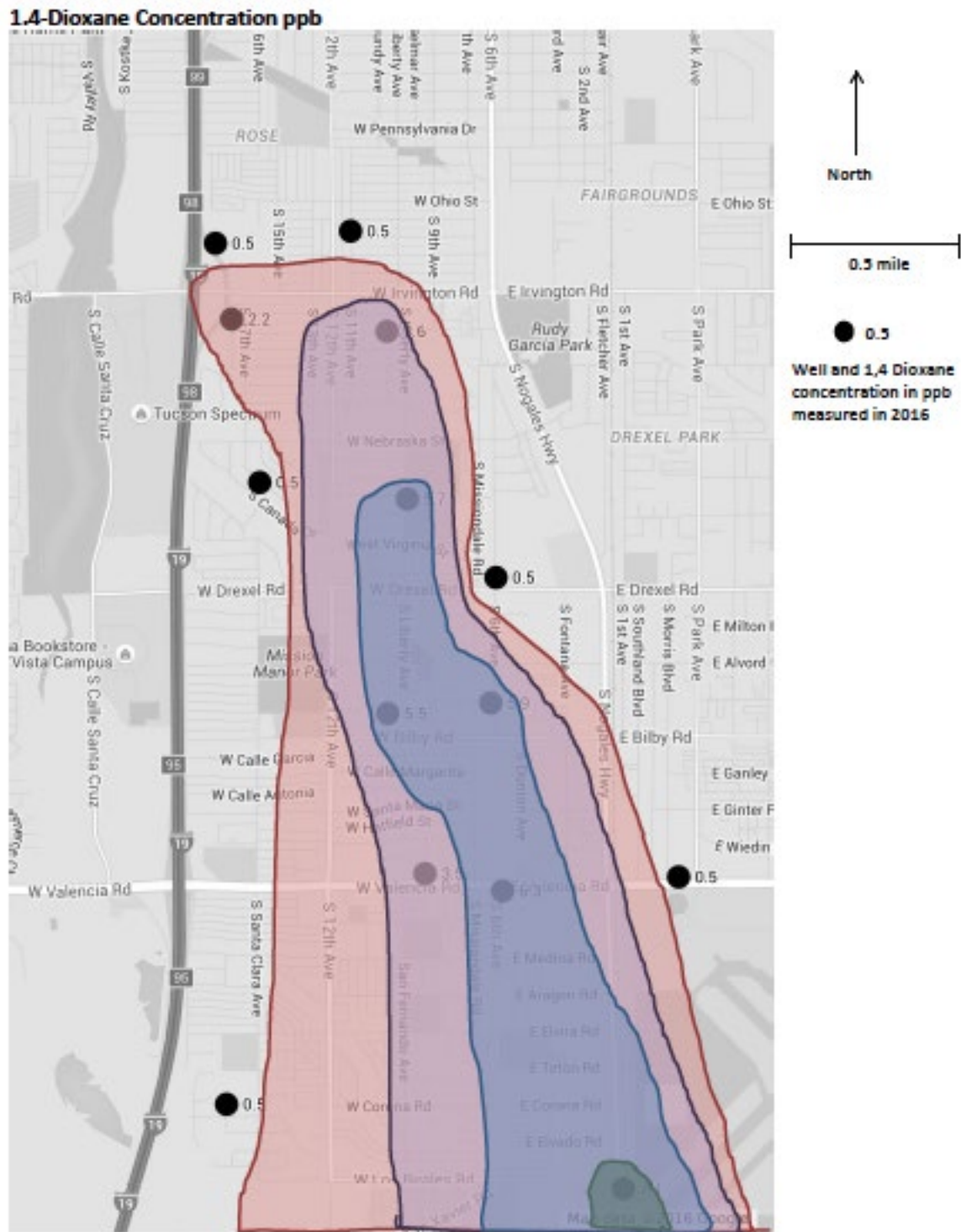
Arizona Department of Environmental Quality Map of Contamination Plume
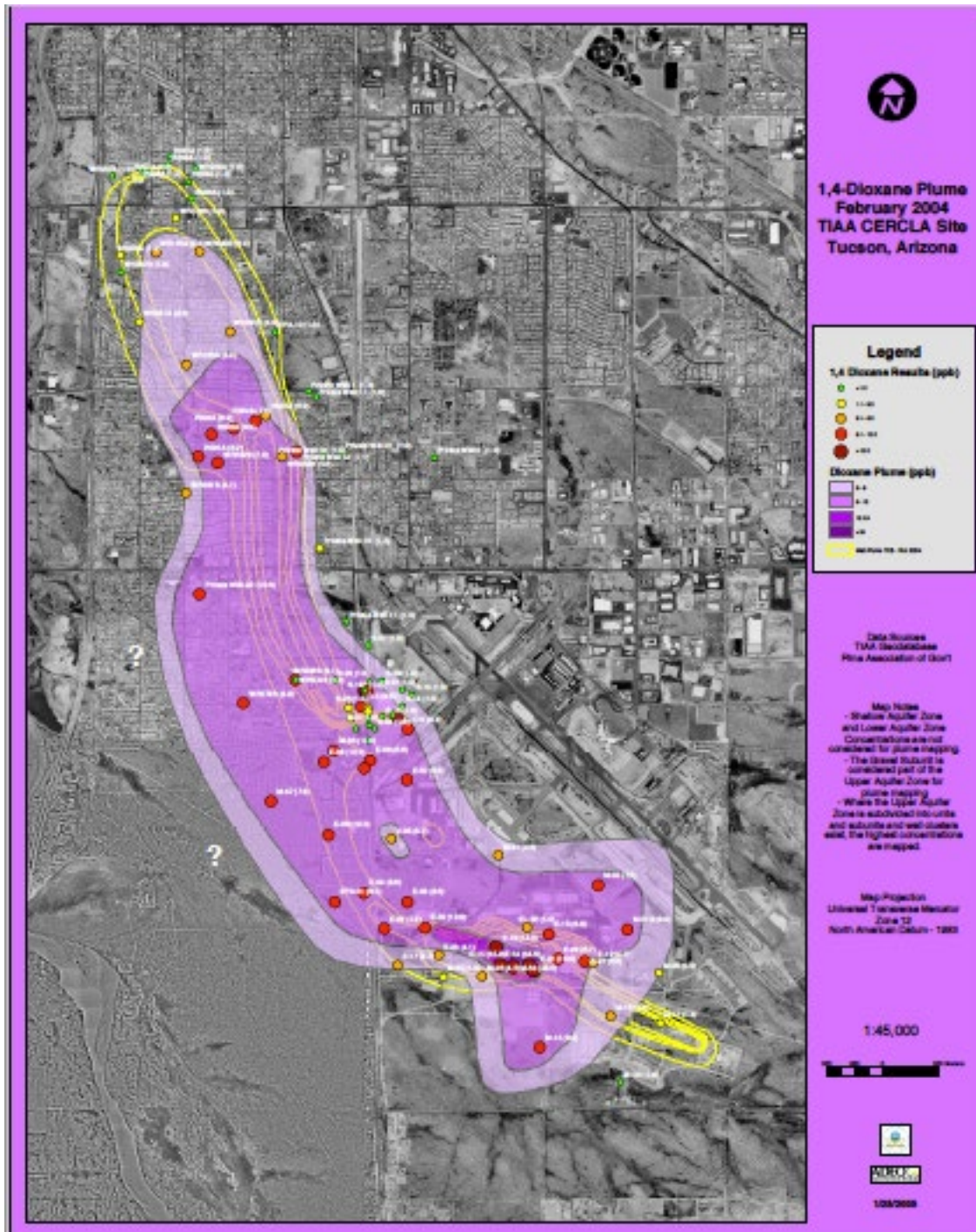
Arizona Department of Environmental Quality (Cartographer). (2004). 1,4-Dioxane Plume, TIAA CERCLA Site, Tucson, Arizona.

Student Task 1-2: Contouring Contamination Plume

Name:

**Driving Question:** Where is the contamination?

<u>Contour lines connect points of equal value.</u> They are commonly used to show elevation and topography (shape of the land), but they can also be used to contour other phenomena, such as temperature, concentration of a contaminant, or water depth.

On the map provided, the location of 14 wells are plotted (black dot). Next to each well is the concentration of 1,4-Dioxane (in parts per billion (ppb)). Use these data to draw contour lines for the concentration. Every point along a contour line has the same concentration of 1,4-Dioxane. Draw contour lines for the following concentrations: 1.0 ppb, 3.0 ppb, 5.0 ppb, 7.0 ppb

The process of estimating where the contour line should go is called **interpolation**.

Here are some tips and rules for drawing contours.
1. Contour lines never cross.
2. Contour lines will only go through a well if the well is exactly the value of the line (e.g., 1.0 ppb).
3. Begin near the top of the map and draw in the line for 1.0. Everywhere on this line the concentration is 1.0 ppb.
   a. Locate 2 adjacent wells, decide whether the 1.0ppb line will go between those or around those wells.
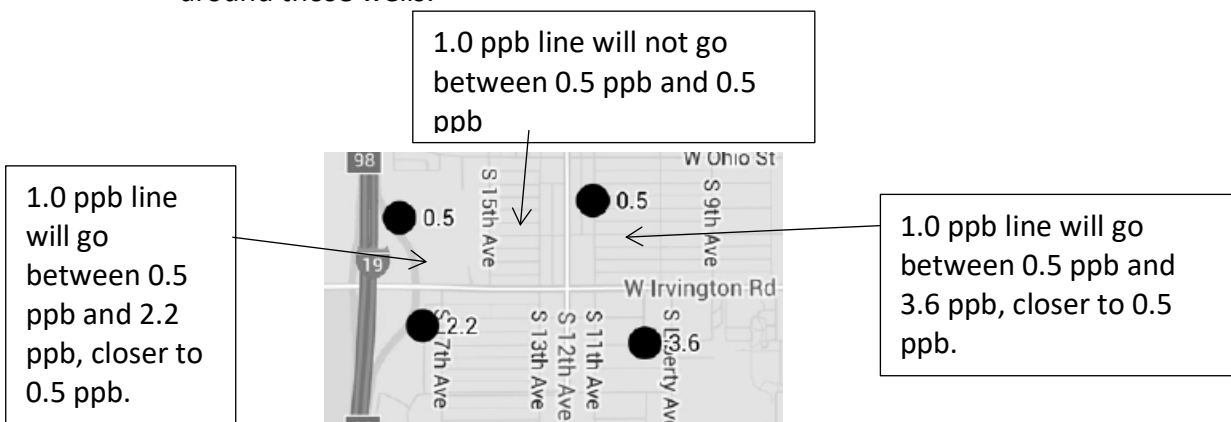
4. Sketch in the contour line based on your interpolation. Everywhere on this line the concentration is the same.
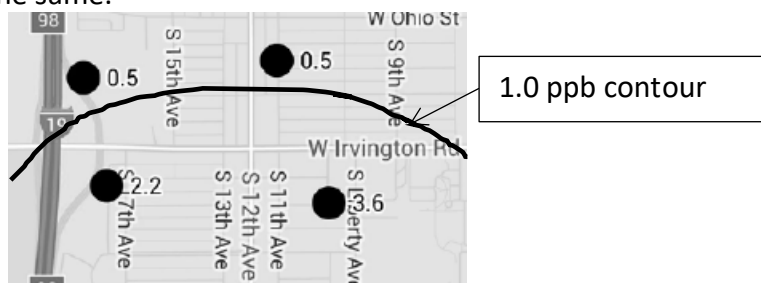
5. Continue the process for all of the lines and data points.

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Discussion and Argument Questions:

After you have contoured your map, compare your map with classmates' maps. Use the maps discuss and argue about the following questions. Be sure to include <u>evidence</u> and <u>reasoning</u> for your claims.

1. What does this map suggest to you about where the contamination is coming from? Be sure to explain why.

2. Where are you most uncertain about where you drew your lines? Why?

3. What would happen if you had data from more wells? How would it make drawing the map easier or harder or both?

Now compare your map to the map made by the Environmental Protection Agency (EPA).

4. How is your map similar to or different from the EPA map?

5. What are some reasons for this variability?

1.4-Dioxane Concentration Contouring Map

North

0.5 mile

● 0.5

Well and 1,4 Dioxane concentration in ppb measured in 2016

Lesson 3: Computer Models: Modeling Plume Shape

Learning Goals: H1, D1, D2, D3, D4, D5, C1, C2, C3, C4

Activity #	Activity Label	Activity Function	Activity Procedures	Materials Needed
1	How has the contamination plume changed over time?	Establish Question	1. Building from the previous day, **establish the driving question for the day: How has the contamination plume changed over time?** 2. Point out that hand contouring maps for each year would be time consuming. Introduce the idea that a computer model could be helpful for generating maps quickly for comparison.	
2	Net Logo Modeling	Explore	3. Have students follow the directions on Student Task 1-3 to use Net Logo to model the plume shape. One advantage of the model is that the computer will quickly contour lots of data points. 4. If time permits, use the TARP Plume Change Series 2006-2016 (pages 23-33) to show a quick time series of changes in plume shape. Help students see that the contamination is flowing from south to north.	1. Net Logo Concentration Contouring Model on ecoapps https://ecoapps.nrel.colostate.edu/netlogo/ 2. Options for Using Net Logo in Teams handout 3. Student Task 1-3: Using Net Logo to Contour 1,4 Dioxane-Contamination 4. TARP Plume Change Series 2006-20016

4	Interpretation of contouring representations	Explain & Reflect	5. To conclude this module, help students use the maps to understand the following principles:
			   a. All maps are interpretations of the data.
			   b. More data makes maps more accurate but also more complicated.
			   c. Contour intervals must match the data.
			   a. Maps are more uncertain along the edges (boundaries) where there are fewer data.	

Options for Using Net Logo in Teams

There are several options for using Student Task 1-3 in teams.

1. Student Task 1-3 distributes the work across four team members so that each team member is responsible for manipulating the model.
    a. All team members log in to the EcoApps website (steps 1-3)
    b. Team member #1 runs the model the first time (steps 4-10)
    c. Team member #2 changes the contour interval and runs the model a second time (step 13).
    d. Team member #3 changes the year and runs the model again (step 15).
    e. Team member #4 changes the year a second time and runs the model again (step 16).
2. You can have all students share one Student Task 1-3 work sheet and include everyone's name or you could have each student be responsible for their own Student Task 1-3 work sheet.
    a. If teams turn in one Student Task 1-3 worksheet as a team, the team member responsible for running the model would enter screen shots and group answers for their assigned steps.
    b. If each team member turns in their own Student Task 1-3 worksheet, each team member takes their own screen shots and writes group answers after each model run. All team members see the same image on their computers.

Class Discussion and Argument Questions:

Use these questions as a guide for whole class or small group conversations. Students do not write the answers to these questions.

1. What do these maps tell you? What patterns do you notice? What might be some possible hypotheses to test that would explain these patterns?
    > Elicit student interpretations. They will likely notice similar patterns to the patterns on their own contour maps and the EPA maps.

2. Where do you think the contamination sites are located? What is your evidence?
    > Elicit student interpretations. Ask for evidence. Ask students to consider how they would test their hypotheses.

3. Where do you predict that the contamination plume would go next? Why do you think this?
    > The highest concentrations were in the southeast near the airport in 2006 and are more towards the middle and northeast in 2016. This suggests the plume is moving from southeast to northwest. In the future it will probably continue to move in that direction.

4. What are some advantages and disadvantages of using computers to model the contamination data?
    > Computer models can model the data faster to generate maps quickly. This allows us to see how the plume has changed over time and possibly predict where the plume may go in the future. However, computer models are only as good as the data and the rules programmed in.

5. Why are the contour interval and year used in each map important to pay attention to?
    > If the contour interval chosen should match the scale of the data. If the contour interval chosen is too large, important details are missed. If it is too small, the contours are meaningless. The year is important to pay attention to because there is different data for each year. In comparing maps, you have to know which year is used.

6. Where on the maps are you most certain that the map is correct? Where on the map is there the most uncertainty that the map is correct? Why?

7. What is the effect of having more data? What are the trade-offs in uncertainty vs. complexity?

    By now students may be recognizing that real data can be complex and noisy. They may increase confidence (certainty), but they also increase messiness that must be filtered.

8. How do you know if the computer is "right"? Where are you more confident about the model and less confident? How can you increase your confidence in what the computer model produces? How can you identify error?

    As with question #3, students can discuss the benefits and drawbacks of interpreting computational models. Students should be developing a skepticism of all interpretations and asking whether the representations make sense based on the data. Depending on how students set minimum-to-draw sliders and contour intervals, students may get more or less complex representations. Explore with students the benefits and drawbacks of the more complex representations. Likely, the representations with smaller contour intervals show more detail than is actually supported by the data.

9. What happens along the edges of the map? What assumptions do you have to make about how to handle the areas on the edges of the data (boundaries)?

    Students may notice that the edges of the Net Logo contoured images are fuzzy and not well defined. Depending on how they set the minimum-to-draw slider and contour intervals, students-generated Net Logo representations may fill the entire image with color. Have students question if there is data to support this interpretation. Eventually, students should begin to realize that the edges (boundaries) are the least certain areas because of the lack of data. Computers, however, have to do something with these areas and it is up to the user to either program in (code) or set conditions that tell the computer what assumptions to make at the boundaries.

Student Task 1-3: Computer Models: Modeling Plume Shape

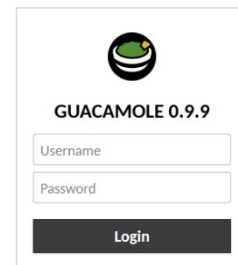**Name:**

Team Members:

Driving Question: How has the contamination plume changed over time?

Today you will look at a computer model of the 1,4 Dioxane contamination and compare it to your contour map. You can also look at how the map for different years from 2006 to 2016.
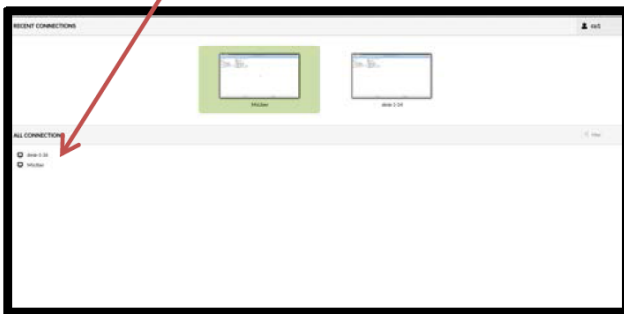
1. Go to the Net Logo Remote Server
   https://ecoapps.nrel.colostate.edu/netlogo/
   Your teacher will assign you to a Username and Password.
   Enter the username and password into the Guacamole box
   and click "Login."

2. Click on your assigned desk

3. Choose "Tucson Contour" from the list. Click the OK button at the bottom of the page
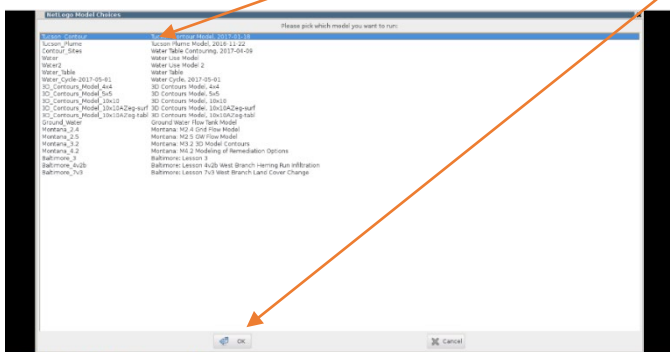
Team member #1:

4. Move the speed slide to the right towards "faster."

5. Click the "Setup" Button.

6. Select the year you wish to model. For the first time, choose 2016.

7. Click "Add all wells."

8. Set the other scales
   a. Interval: 2.0 ppb
   b. Base Contour: 1.0 ppb
   c. Minimum Concentration to Map: 1.0 ppb

9. Run the model by clicking the "Contour Concentrations" button. You may have to wait a few seconds for the model to generate your map.

10. Once the map is generated, you may see the map with or without the wells by clicking the "Wells" button at the bottom of the page.
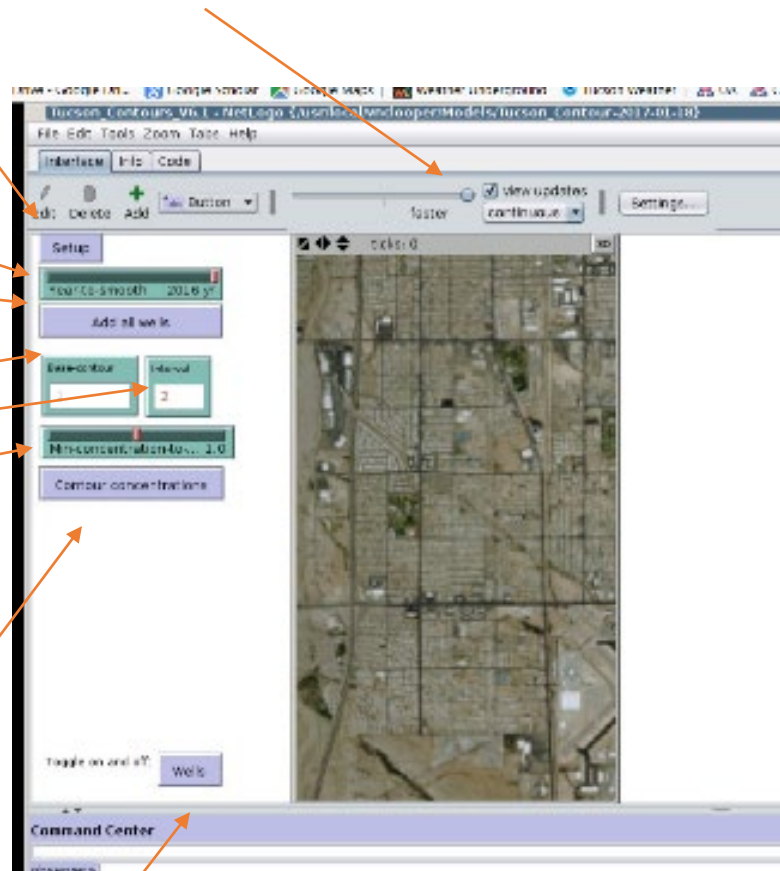
11. Take a screen shot of your map and insert it here:
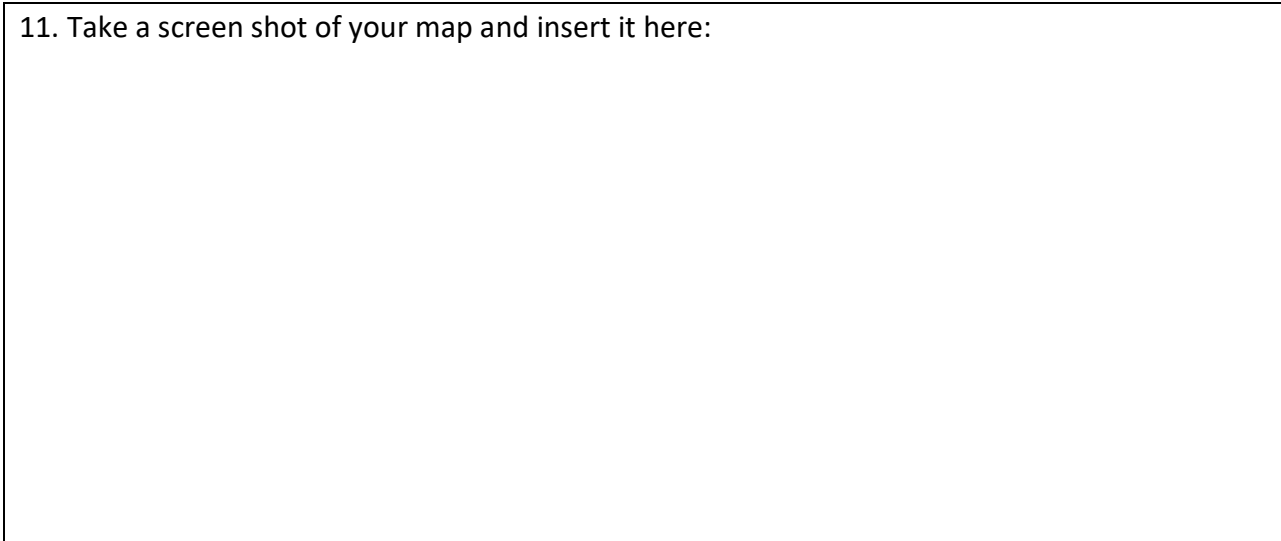
12. How does the computer-generated contour map compare to the contour map you drew? What is similar? What is different? Why?

Team member #2

13. **Change the contour interval**
The contour interval is the difference between two contour lines. On a map of concentration of contamination it is the difference in concentration between two contour lines. The map you drew and that the computer just modeled has a contour interval of 2 ppb (parts per billion). Now try making a map with the contour interval of 1.0 ppb.
    a. Click "Setup"
    b. Set Year-to-smooth: 2016
    c. Click "add all wells"
    d. Set base-contour: 1.0 ppb
    e. Set Interval: 0.5 ppb (this is the contour interval).
    f. Set min-concentrations-to-smooth: 1.0 ppb
    g. Click "Contour Concentrations"
    h. Insert a screenshot of your map here:

Contour Interval 0.5 ppb

14. Which map is more accurate (contour interval of 2.0 ppb or contour interval of 0.5 ppb)? Why?

Team member #3

15. Change the year

This model has well 1,4 dioxane concentration data for years 2006 to 2016. Choose a different year to model to see how it compares to 2016.

    a. Click "Setup"

    b. Set Year-to-smooth: Choose a year between 2006 and 2016

    c. Click "add all wells"

    d. Set base-contour: 1.0 ppb

    e. Set Interval: 2 ppb (this is the contour interval).

    f. Set min-concentrations-to-smooth: 1.0

    g. Click "Contour Concentrations"

    h. Insert a screenshot of your map here:

What year is your map?_____

Team member #4

16. Repeat step #15 with another year (if you have time)

What year is your map?_____

17. What do your maps tell you about how the 1,4 dioxane plume is changing or moving?

TARP Plume Change Series 2006-2016

2006
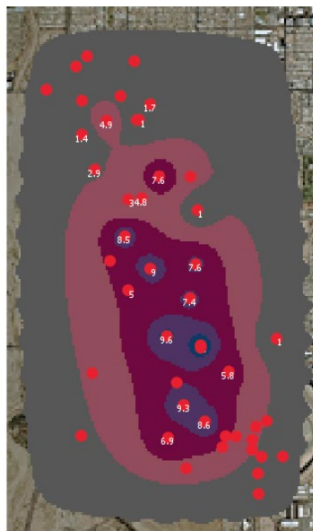
Base contour – 1.0
Contour interval – 2.0
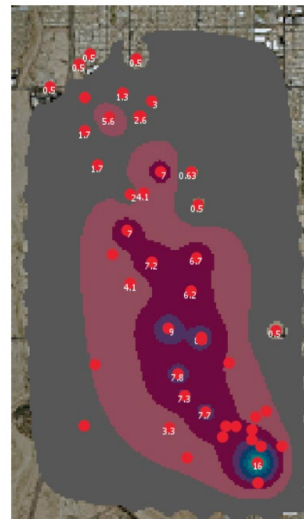Min Concentration to map - 1.0

2007
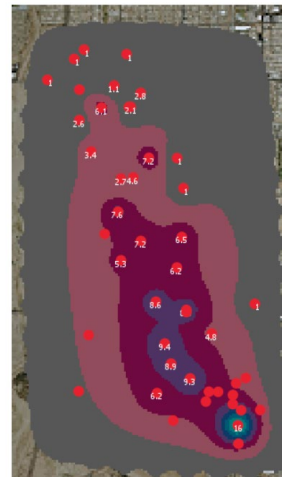
Base contour – 1.0
Contour interval – 2.0
Min Concentration to map - 1.0

2008
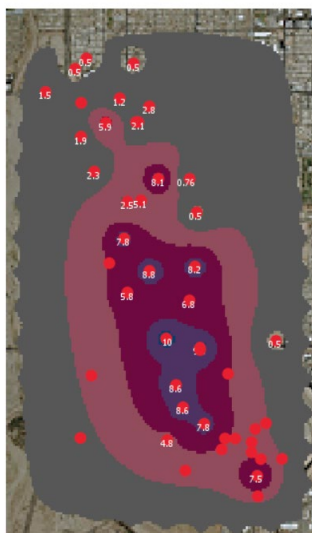
Base contour – 1.0
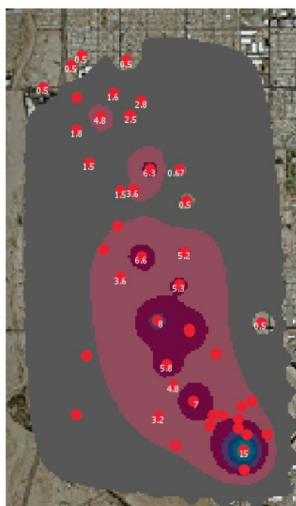Contour interval – 2.0
Min Concentration to map - 1.0

2009

Base contour – 1.0
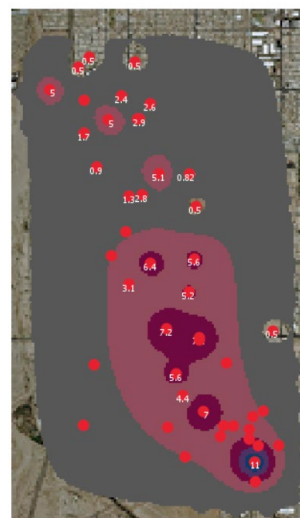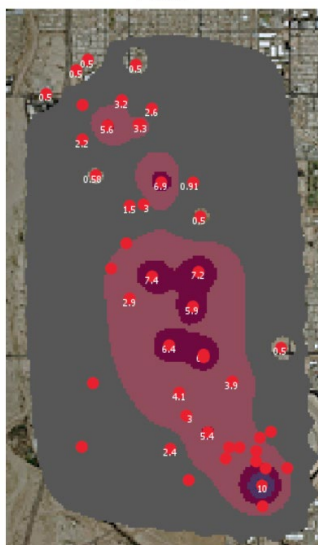Contour interval – 2.0
Min Concentration to map - 1.0

2010

2011

Base contour – 1.0
Contour interval – 2.0
Min Concentration to map - 1.0

Base contour – 1.0
Contour interval – 2.0
Min Concentration to map - 1.0

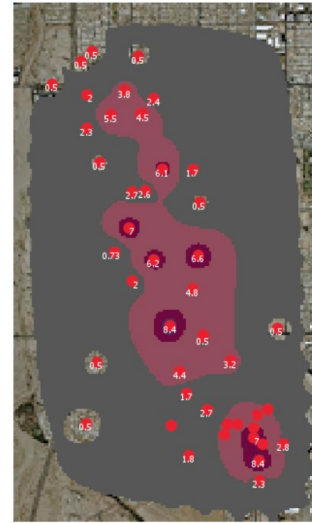**2012**

2013

Base contour – 1.0
Contour interval – 2.0
Min Concentration to map - 1.0

Base contour – 1.0
Contour interval – 2.0
Min Concentration to map - 1.0

2014

Base contour – 1.0
Contour interval – 2.0
Min Concentration to
map - 1.0

2015

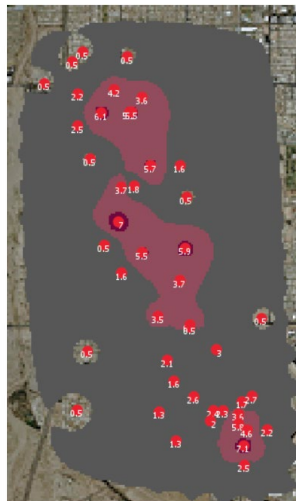Base contour – 1.0
Contour interval – 2.0
Min Concentration to
map - 1.0

2016

Base contour – 1.0
Contour interval – 2.0
Min Concentration to
map - 1.0