Raining on Tiny Town

Lesson Summary

Students use spray bottles to simulate a rain event in a physical model. They measure precipitation collected in “rain gauges” and apply computational thinking to learn about variability, estimation, interpolation, extrapolation and discretization of their data. Using these approaches and their rain gauge data, students are able to create a contour map of their simulated rain event across the extent of their basin.

Purpose/Objectives

- To create a physical model that simulates rainfall.
- To measure accumulated “rainfall” and relate depth and volume as measurements for precipitation.
- To gain familiarity with the benefits and limitations of sampling rainfall with rain gauges.
- To use geometric techniques to construct an isopleth map (also known as a contour plot) from a set of spatially distributed values.
- To estimate spatial values from a contour plot, while discerning whether values are interpolated or extrapolated.
- To create a raster grid (a discrete representation of spatially distributed physical data) that can be used in a computational model.

Comp Hydro Learning Goals Alignment

C1 C2 C5

H2-4 D2-4

Next Generation Science Standards Alignment

HS-ESS2-4 HS-ESS3-5

Materials Needed

For each research group of 3-6 students:

- Raining on Tiny Town – Student Pages
- 8-10 empty film canisters or similar small cylinders with flat bottoms
- Spray bottle with mist option and a measured fill line (e.g. 500 mL)
- Graduated cylinders (1 mL, 0.1mL gradations)
- Small ruler (centimeters)
- Graph paper (~1 cm grids)
- Flat clear plastic tub or basin, at least 3” deep and approximately 8.5 x 11 inches
- Clay, glue dots or other material to help anchor canisters to bottom of basin
- Funnel
- Towels
- Crayons/colored pencils
- Data sheet for each student (or access to data sheet in Excel)
- Creating a Contour Plot PowerPoint

Optional:

- Printout of graphic file Watershed-raingaugeEg.pdf 1
- Video Creating a contour map using isolines (34:22)
-
- Video Raster data in a spreadsheet (6:55)
- Transparency/thin graph paper OR photocopies of the completed contour Google sheets (corresponds to directions below) or Excel spreadsheet
- Video Creating raster data from contour plots (17:29)
- Markers
- Rubber bands

Agenda

Activity #	*Activity Label*	*Timing*	*Activity Description*
1	Precipitation simulation in small groups	50 minutes	Students simulate a rainfall event and collect data from 8-10 “rain gauges.” Students learn about variability and estimation.
2	Isopleth mapping (creating a spatial contour plot)	50 minutes	Students draw contours, interpolate and extrapolate data to create a rainfall contour map and estimate precipitation over unmeasured areas.
3	Computational Interpolation (Rasterizing)	20 minutes	Students convert their contour map to a raster grid and learn about spatial discretization.

Safety Concerns:

- Ensure that students using spray bottles follow protocol and limit spraying outside the bin.
- Floors and surfaces may become wet and slippery.

Activity One: Precipitation Simulation in Small Groups

Activity Summary

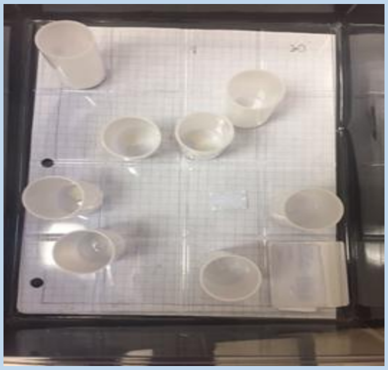
Students learn how rainfall is measured by simulating a rain event in Tiny Town. Students measure rainfall collected in “rain gauges” and observe variability in rain totals across their model.

Key Vocabulary

Basin
Rain Gauge
Accumulation
Estimation
Watershed
Variability

Advanced Preparation

This lesson can get messy! Make sure you have paper towels ready. Place graph paper inside a clear protective covering to protect it from getting wet.



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- Clay, glue dots or other material to help anchor canisters to bottom of basin
- Funnel
- Towels
- Crayons/colored pencils
- Data sheet for each student (or access to data sheet in Excel)

Activity Sequence

1. Introduce the lesson. Recall that flooding results when a large amount of water falls (precipitation) on an area in a short amount of time and runs off to a given location. In this lesson students model one of the ways rainfall is measured in real life. Distribute materials for the Raining in Tiny Town simulation and an activity page to each student group (3-6 students). Follow the procedure outlined on the activity page.

2. Measure and record the length and width dimensions of the basin. Note that most basins will typically be a bit wider at the top, but that this wider dimension is the appropriate one to measure. (Can you see why?) Measure and record (on the data sheet) the diameter of each rain gauge, which may be the same if your gauges are a consistent size. Calculate the area of each rain gauge in square cm.

3. Using a sheet of graph paper and a PENCIL, draw an x,y axis on the paper, then “map” the pattern of your rain gauges on a sheet of graph paper and record a number label for each gauge (#s 1-10). Slide the graph paper underneath the basin. If *the basin is the same* size or smaller than the graph paper, place a protective cover (like a transparency sheet) over the graph paper to keep it from getting wet. Distribute the 8-10 film canisters as “rain gauges” by placing them open-side-up inside the flat plastic basin (see photo on left), one for each location on your graph. Secure the canisters to the bottom of the bin using clay or glue dots.

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Continued: Precipitation Simulation in Small Groups

4. Simulate the "Tiny Town" storm. Fill the spray bottle with a measured amount of water (at least 500 mL). Record this Initial Volume on the datasheet. Set the spray nozzle to a 'strong mist' setting so that squeezing the trigger creates a mist of fine droplets and not a strong, directed squirt. Use the spray bottle trigger to create a mist that falls vertically downward into the basin. The goal is to ensure that the majority of sprayed water lands IN the basin and that some of it lands in the rain gauges without being directly targeted at the gauges. Repeated sprays from a consistent location and angle are best. Consider how you might best simulate accumulation from a natural rainstorm, but on a very small scale.

5. Spray until at least 500mL of water has been emptied from the spray bottle. Note that larger amounts of water will take longer to spray, but will lead to easier measurements and more interesting data patterns. STOP before any of the rain gauges overflow. You will also want to avoid knocking over any rain gauges. Measure and record the amount of water remaining in the spray bottle when the storm simulation is complete. Record this End Volume on the datasheet. Subtract the End Volume from the Initial Volume and record this Estimated Total Rainfall.

6. Measure rainfall. Detach a rain gauge from the bottom of the basin, being careful to retain the water accumulated inside. Tap it lightly inside the basin so that water on the outside of the gauge falls back into the basin. Place gauge flat on a surface and using the ruler, measure the depth of the water inside the rain gauge as precisely as possible. Record this value on your data sheet in the row corresponding to the gauge number. Use the funnel to transfer the gauge water to the small graduated cylinder and measure and record the volume of the water as precisely as possible.

7. Repeat for each of the other 9 gauges. DO NOT POUR WATER FROM THE GAUGES BACK INTO THE BASIN. Pour the water remaining in the basin through a large funnel and measure using the larger graduated cylinder. (Note that you may need to take multiple measurements). Record this volume of water.

8. Distribute Raining on [Tiny Town Calculations and Discussion Student Worksheet].
   a. (#1) Total volume of water is the sum of the water in all the gauges plus the volume measured by pouring out the basin.
   b. (#2) Percentage in the basin is the ratio of the previous total volume and the "Estimated Total Rainfall" sprayed from the bottle. (#3) It should be evident that some of the water misses the basin and ends up on the table or in the air or even stuck to the sides of the basin, making the percentage less than 100%.
   c. (#4) Dividing volume (3-D) by area (2-D) yields a length. In this case that length would be the depth of the water if it evenly filled the basin (#5). Note however, that the individual rain gauges likely vary from that depth, and that this value is a (weighted) average depth. If students can grasp this total -> average relationship, they will hopefully be able to reverse the process to then generate a total rainfall estimate that follows.
   d. (#6) Multiply depth by gauge area to get volume ($V = A*d$). This would be a good time to reinforce that 1 mL is the same as 1 cubic centimeter.
   e. (#7) Find a mean depth by averaging all of the gauge depths and then multiply this value by the area of the entire basin. Again $V=A*d$ but where the Area is for the entire basin and d is an estimated mean depth, also for the entire basin.
   f. (#8) Fewer samples should make us less confident in the estimate (conversely "More accuracy = more work"). However, direct comparison to the measured value (that included the poured water) might actually demonstrate that the 5 selected points generate a better value. Such observations can prompt further discussion about statistical variation, randomness, outliers and in particular, bias (if they had a specific agenda in 'choosing' their 5 points). Similarly, the next question (#9) can prompt some thought about sampling and accuracy.

Lesson 2
Activity 1

Raining on Tiny Town

Calculations and Discussion

Note: These calculations are from the Sample Data Sheet excel file

Name:_________________________________ Date:___________________

1. Calculate the total volume of water that accumulated in the basin. Show your calculations: 120.5 (total water in gauges) + 315 (total water in rest of basin) = 435.5mL

V tot =__435.5mL_______

2. What percentage of water that fell actually ended up in the basin (basin + rain gauge amounts)? Show your calculation:

((550mL-435.5mL)/550mL) x 100 = 20.8% was not captured.

100% - 20.9% = 79.2% was captured

3. Why is this percentage less than 100%?

Much of water that was sprayed landed outside the basin or stuck to the sides of the basin and rain gauges.

4. Take the volume that fell on the basin (V tot , from above) and divide it by the Area of the basin, which you should be able to calculate from the measured dimensions.
Show your calculation:

435.5mL/610.5cm^2 = 0.71mL/cm^2

5. What is this value that you just calculated? What does it represent? (Hint: include your units in the division and if you cancel them correctly, it will indicate what type of quantity the value represents)

I calculated how much water in mL fell per cm^2 in the basin.

Note that if you were measuring rainfall in a real system, you would likely only have information from the rain gauges and would not be able to measure the remaining water, like you did when you poured it from the basin. Now see if you can estimate the total volume of water that accumulated in the basin using only the measurements from the rain gauges.

6. Select a rain gauge. Note that we measured both the depth and the volume of the water in each gauge, but we did not need to measure both. Use the depth of water from one gauge sample to calculate the volume of that sample. Show your calculation. How well did the calculated volume compare to the measured volume?

For gauge 1: 1.20cm x 7.07 cm2 = 8.5 cm3
- In this case, the calculated volume matched the measured volume exactly

7. Show a calculation that uses all of the gauge depths, but only the gauge depths, to estimate the volume for the entire basin.

1.2 +.7+1.6+1.2+1.9+2.7+1.2+3+1.9+1.5 = 16.91cm

16.91cm/10 = 1.69 average depth of the rain gauges
1.69cm x 610.5 cm2 = 1031.7cm3

8. Recalculate the volume of the entire basin, but use only the data for 5 of your 10 gauges. Show your calculations. Do you think this is a better or worse estimate of the total volume? Why?

1.2 +.7+1.6+1.2+1.9 = 6.61cm
6.61cm/5 = 1.32 average depth of 5 rain gauges
1.32x 610.5 cm2 = 805.86 cm3

This calculation is likely less accurate because we are using less data to inform our estimation over the same size basin as the prior calculation using 10 data points.

9. How many gauges do you think would be ‘enough’ to get an accurate measure of rainfall volume in the Tiny Town basin? Why?

I suggest using 15-20 rain gauges. More data = more accuracy.

Activity Two: Isopleth Mapping (creating a spatial contour plot)

Activity Summary

Students use spatial rain gauge data to create a spatial contour plot. They then discuss ideas for estimating values outside of the measured gauges.

Key Vocabulary

Contour
Interpolation
Extrapolation
Isoline

Advanced Preparation

This activity can be challenging for students. You can simplify the activity by:

- Having students round their rain gauge values to the nearest whole number or .5 value.
- Photocopying one graph paper from the class and distributing for each student to use.
- Preparing a completed contour map.
- Allowing students to contour independently for several minutes, but then use the completed contour map for activity three.

Materials Needed

- Creating a Contour Plot PowerPoint
- Data sheet with completed data from activity 1
- Clean Graph paper (~1 grids) or if graph paper remained dry from Activity 1, it may be used for Activity 2
- Straight edge
- Crayons/colored pencils

Optional:

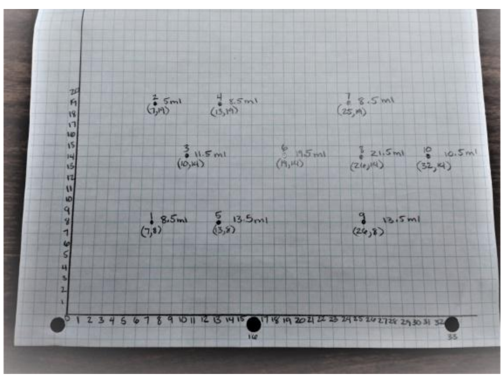
- Rubber bands
- Printout of graphic file Watershed-raingaugeEg.pdf 1
- Video Creating a contour map using isolines (34:22)
- Video Raster data in a spreadsheet (6:55)
- Transparency/thin graph paper OR photocopies of the completed contour Google sheets (corresponds to directions below) or Excel spreadsheet
- Video Creating raster data from contour plots (17:29)
- NetLogo Contour Model

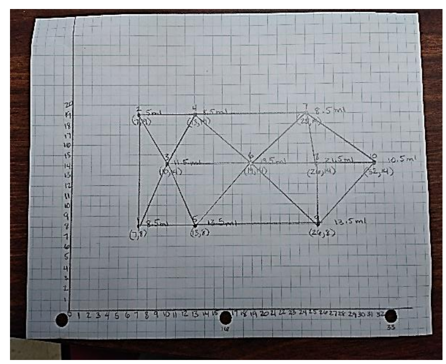
Activity Sequence:

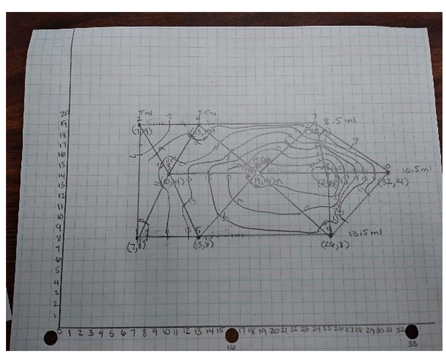
1. If desired, the teacher may view in advance, the "Creating a Contour Map Using Isolines" video. Have the pdf file "Watershed-rainguageEg" available to help you replicate the example. Note: This video is over 30 minutes long and is not recommended for students.
2. As you move through the lesson sequence, show the slides from the Creating a Contour Plot PowerPoint to provide a visual aid for the different parts of the activity.
3. Use the graph paper from the previous activity to complete the rainfall contouring. The graph paper should already have a Cartesian grid with the locations of the 10 rain gauges plotted. If the graph paper is wet, have students recreate their Cartesian grid and data points on a dry piece of graph paper. Record the depth (or volume) value next to each gauge location on the graph paper. Students can erase all other values from the graph at this point.
4. Use the rain gauge data to create a spatial contour plot. The method is demonstrated in the video "Creating a Contour Map Using Isolines" and includes the following steps:
   a. Determine the maximum and minimum gauge values and the range of values. Then determine an interval size that will allow for 5-10 convenient values inside this range. (eg. gauge values with a range from 2.3 to 4.2 could contain 6-7 intervals of 0.3 units).
   b. Select values for each isoline that fall within the range of the gauge data. (eg. 2.4, 2.7, 3.0, 3.3, 3.6, 3.9, 4.2).
   c. Triangulate the data by drawing straight lines between neighboring data points (lines should never cross).
   d. Select one sketched line segment. Determine which isoline values fit within the range of the two endpoints of this segment. (eg. isolines 2.7, 3.0 and 3.3 would fit between endpoints 2.4 and 3.5).

Continued: Isopleth Mapping (creating a spatial contour plot)

   e. Interpolate along the segment to determine locations for each of the isolines, which should be equally spaced along the segment, although with some smaller intervals near each endpoint. This can be done accurately by measuring the physical length between the endpoints (e.g. 8cm) and determining a ratio between gauge value and length (e.g. 3.53-2.43 = 1.1, so there is 1.1 units per 8 cm or approx. 1.4 units per cm which means a 0.3 unit interval spans nearly 2.2 cm on the map). Optional: Mark a rubber band with evenly spaced increments representing the interval size. The marked rubber band can be stretched between any two gauge values to help locate the internal intervals. Be careful not to confuse the gauge units (which will be in lengths like cm or inches) and the map units (also lengths).
   f. Repeat the interpolation for other segments.
   g. Connect isolines between like values of neighboring segments by drawing a slightly curved line between like points.
5. Discuss ideas for appropriate contouring outside of the measured gauges. Recognize that rain did fall in those areas and encourage discussion on the best methods to extrapolate to this area. Note that most methods would be the equivalent of assigning some values to parts of the boundary (of the page) and interpolating to there, but the question is what values and where? Allow learners to make their own choice, but note the added uncertainty!
6. OPTIONAL: Color the contour intervals (area between two adjacent isolines). Discuss the meaning of being in an area of a certain color.
7. OPTIONAL: Use the [NetLogo Contour Model] to reinforce what a completed contour map looks like.







Activity Three: Computational Interpolation (Rasterizing)

Activity Summary

Students convert their contour map into a raster grid. Once completed students compare and contrast the raster and contour representations of rainfall distribution over Tiny Town. Student discuss strategies for improving accuracy.

Key Vocabulary

Raster
Contour plots
Dimension
Spatial discretization

Advanced Preparation

If students struggled with the prior activity, have a photocopy of a completed contour map for students to use.

Materials Needed

- Completed contour plot from Activity 2
- Transparency/thin graph paper OR photocopies of the completed contour
- Marker
- Google sheets (corresponds to directions below) or Excel spreadsheet

Optional:

- Video Raster data in a spreadsheet (6:55)
- Video Creating raster data from contour plots (17:29)

***Activity Sequence**:*

1. If desired, the teacher should prepare in advance by viewing the videos "Creating raster data from contour plots" and "Raster data in a spreadsheet." These videos are not recommended for viewing during class time.
2. Overlay the contour graph with a transparency or thin piece of graph paper. Use the existing graph lines to create a larger resolution grid of squares, on top of the contour graph. Start with a 5x5 grid for standard graph paper this will likely mean 5-8 graph squares per grid unit. Alternately the grid can be drawn directly onto a copy of the contour graph.
3. Label the columns of the new graph with letters across the top and the numbers down the side.
4. Create a raster of contour data in the Google spreadsheet:
    a. Open a new spreadsheet in Google sheets. Resize 15 columns (through letter O) to create square grids. This can be done with a click-and-drag of the vertical line between the labels of columns O and P.
    b. For each of the large grid squares on the transparency, record a rainfall depth value for each square. Discuss possible strategies for selecting what this value is. Some suggestions ("More accuracy = more work!"):
        i. Mark the center of each grid square and use the closest isoline
        ii. Mark the center of the grid square and use the average of the isolines on either side of it.
        iii. Mark the center of the grid square and interpolate a value that is between the two closest isolines.
        iv. Use the value of the isoline with the longest portion cutting through the grid.
        v. Select the area between two isolines that occupies the largest fraction of the grid. Use the average of the isolines that border this area.
        vi. Estimate a value for each small square within the grid and average all of these values.
    c. Enter the value determined from each grid in the corresponding location (indicated by row and column) on the spreadsheet.
    d. Click-and-hold in cell A1 and then drag to cell O15 and release to select all 225 cells from A1 to O15 (indicated as A1:O15 on the sheet).

Continued: Computational Interpolation (Rasterizing)

e. Find "Format" in the menu and select "Conditional Formatting"

f. In the "Conditional format rules" menu that appears, click on "Color Scale" and select a scale. Then click "Done". This should color all of the cells in your selection that have values in them.

	A	B	C	D	E
1	1.2	1.4	1.6	1.8	1.6
2	1	1.4	1.8	2	1.8
3	0.8	2.2	2.4	2	1.8
4	1	2.4	2.6	2.4	2
5	2	2	2.8	2.4	2

5. Discuss how well this raster compares to the contour in representing the rainfall. Discuss strategies for improving accuracy.

6. Optional: Divide each transparency grid in quarter (half in each dimension). Repeat the process on a second spreadsheet. Note that this should produce better visibility of the contours but at the cost of 2x2 = 4 times as many values that need to be determined and input. ("More accuracy = more work!")

7. Introduce the term spatial discretization (dividing continuous space into discrete parts).

8. Discuss: how can discretization help us think about real landscapes and real rainfall events?

Teacher Resources

1. How is precipitation measured?
   a. https://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/Prelim_2018_ed/8_I_6_en_MR_clean.pdf
2. What is a rain gauge?
   a. https://www.sciencedirect.com/topics/engineering/rain-gauge
   b. https://www.youtube.com/watch?v=WyMabcRzUcw
3. Raining in Tiny Town Sample Data Sheet:

Name: ______________________________

Date: __________________

Basin Dimensions: Length (cm)__33_____ Width (cm)__18.5__________ equals 610.5cm^2

Spray Initial Volume (mL):__750______________ Spray End Vol (mL):___200_______

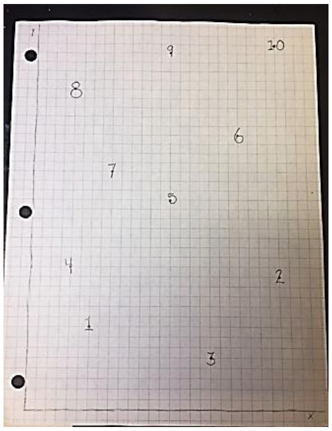
Estimated Total Rainfall (mL): (Initial volume - End volume)_550____________

Rain Gauge Data

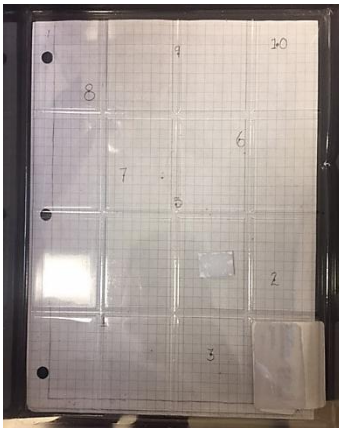
Gauge	X -coordinate	Y - coordinate	diameter	area	Measured rain depth	Measured rain volume
			cm	cm2	cm	cm3
1	7	8	3	7.07	1.20	8.5
2	7	19	3	7.07	0.70	5
3	10	14	3	7.07	1.60	11.5
4	13	19	3	7.07	1.20	8.5
5	13	8	3	7.07	1.90	13.5
6	19	14	3	7.07	2.70	19.5
7	25	19	3	7.07	1.20	8.5
8	26	14	3	7.07	3.00	21.5
9	26	8	3	7.07	1.90	13.5
10	33	14	3	7.07	1.50	10.5

4. Sample images of the steps in Raining in Tiny Town:

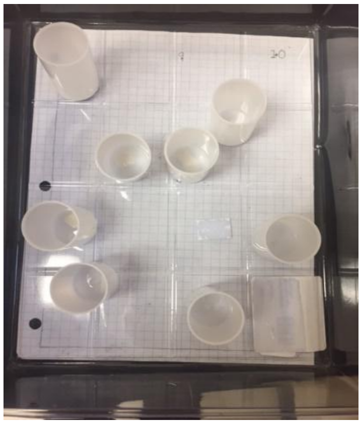
"Map" the pattern of your rain gauges on a sheet of graph paper and record a number label for each gauge



Slide the graph paper underneath the basin.



Distribute the 8-10 film canisters as "rain gauges" by placing them open-side-up inside the flat plastic basin, one for each location



Now you are ready to simulate the "Tiny Town" storm