Extreme Events: What Do the Data Say?

Objectives:

Students will be able to:
- compare a typical and extreme weather event using precipitation and streamflow data
- use descriptive statistics (measures of central tendency & measures of spread) to investigate variability in precipitation
- use a graph to interpret patterns in precipitation and streamflow

Author:

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Time:

50 minute class period

Grade Level:

6-12

Standards:

AZ Science Strands

Inquiry, Nature of Science, Personal and Social Perspectives, Water, Earth's Processes

NGSS - Core Ideas

Earth systems, Weather and climate, Biogeology, Natural hazards, Human impacts, Forces and motion

Practices - Analyzing and interpretting data; Using mathematics and computaional thinking; and more

Crosscutting Concepts - Cause and effect, more

Specific AZ, Common Core, and NGSS standards on page 3.

Background:

Are all summer monsoon storms the same? We know that some areas of the Phoenix Metropolitan Area might get a lot of rain and other parts only a little during the summer monsoons. What happens to runoff from these storms as they move through an urban area? Can we measure these differences and impacts?

Specifically, in this lesson, we will examine six precipitation (i.e. rain) gauges and one streamflow gauge in Indian Bend Wash, an 82 square mile watershed in urban Phoenix, AZ (see map). We will focus on two summer monsoon storms that fell on 8/18-8/20 and 9/8-9/9 in 2014. The first storm was a typical localized North American Monsoon, http://www.wrh.noaa.gov/twc/monsoon/monsoon_NA.php, whereas the second received a "boost" of tropical moisture from Hurricane Norbert. This resulted in an extreme event that produced 8.38 cm (3.3 inches) of rain at Sky Harbor airport, which was the most rain on a calendar day ever recorded in a 115-year period of record.

Vocabulary:

variability - refers to the extent to which data points differ from each other; common measures of variability include range, mean, variance and standard deviation

interquartile range – measure of variability based on dividing rank-ordered data sets into quartiles (4 equal parts)

spatial variability – occurs when a quantity that is measured at different spatial locations exhibit values that differ across the locations

coefficient of variation – is a standardized measure of spread that describes the amount of variability relative to the mean

streamflow – the flow of water in a stream or river

precipitation gauge – an instrument used to measure the amount of liquid precipitation over a set time period

stream gauge – is a location used by environmental scientists to monitor water flow in streams; it typically includes both a measure of stream height and a measure of discharge (quantity of water passing a location along a stream)

Advanced Preparation:

Students should have some familiarity with weather patterns, watershed, and descriptive statistics. Determine best video for engagement section, prepare video and slideshow for viewing. Prepare Figures and Worksheet handouts, ensure calculators have scientific functions if standard deviation calculations will be done.

Materials:

- Slideshow
- Map of Indian Bend Wash showing preciptation and stream guages
- Student Worksheet 1 and 3, Student Worksheet 2 for high school,
- Figures 2 and 3 handouts,

▪calculators

Recommended Procedure:

Part 1

Engagement:

1) Slides 1-3: Introduce the topic. Show video of monsoon storm (possible options:,https://vimeo.com/121842625 https://www.youtube.com/watch?v=-RnjYRvN0bM, https://www.youtube.com/watch?v=BU1vAJMkgLM, and an 8 minute version: https://vimeo.com/106827999)

2) Slide 4: Think back to a typical monsoon storm, which usually falls in July, August, and early September. How long did it last for? Did your house get rain but not your best friend's house or vice versa? Can you remember the record-shattering storm in September 2014, which flooded the I-10 highway and made national news. How long did it last? Was there flooding in lawns and parking lots?

3) What does the term 'average rainfall' mean? What are other ways you have learned to describe data (mean, median, mode, range)? Why might home prices for a neighborhood or region be described as "median home price" instead of an "average"? What does this tell us about how variable home prices are (i.e. some can very low, while other can be very high, while most fall within a smaller range)?

4) Slide 5: Discuss the ice cream sundae example, and subsequent slides 6-10 explaining visualizations of variation.

5) Slide 11: Explain that Indian Bend Wash was designed to direct the flow of surface water away from homes and roadways during rain events. The water running through this man-made wash during heavy rainstorms flows into the Salt River. The Maricopa County Flood Control Districts monitors both the rainfall and the streamflow with two kinds of gauges: 1) precipitation gauges measure the volume of rainfall in various locations along the wash, and 2) stream gauges measure how much surface water flows through a designated section of the wash over a certain amount of time.

Exploration

6) Slide 11: For Part 1 of this lesson we'll only look at data from 6 Indian Bend Wash precipitation gauges.

7) Slide 12: Have students review the graphics on prompt 2 of Student Worksheet 1.

8) Slide 13: Using the data provided, students calculate the interquartile range for each storm.

9) Slide 14: Using the data and graphics provided, have students respond to prompt 3, 'Which storm had greater spatial variability?'

High school level:

10) Slides 15 and 16: Explain standard deviation and coefficient of variation. Explain how knowing the ratio of the standard deviation to the mean helps us better understand what the variability looks like in comparison to the average or typical monsoon storm Distribute Worksheet #2 and review the data provided.

11) Slide 17: Have students find the mean, standard deviation, and coefficient of variation for each storm.

12) Slide 18: Compare these answers to the boxplots and interquartile range calculations

13) Slide 19: Have students respond to prompt 5.

Explanation/Expansion:

Part 2

14) Slide 20: Show images of flash flooding from slides

15) Slide 21: Think about the dry washes around the valley. When does streamflow occur in these areas? Does the flow occur at the same time or after precipitation? Does the flow only occur where the precipitation occurred? Do different types of storms result in different flow?

16) Slides 22 and 23: Show Map of Indian Bend Wash indicating location of 'Stream gauge', and the photos of the actual stream gauge.

17) Slide 24 and 25: Do you think the stream gauge is measuring stream flow in photo 1 of McKellips Lake Park? What about photo 2? How can we describe 'streamflow'?

18) Slides 26 and 27: Distribute Figures 2 and 3 handout to students and have students review that data shown graphically for the two storm dates.

19) Slide 28: Distribute Student Worksheet 3 and have students respond to prompt 1.

20) Slides 29 and 30: Discuss responses, then have students respond to prompts 2-4.

21) Have students respond to prompt 5, and bonus prompt.

Evaluation:
Students complete all worksheets

Extension:
Students view slides 31-34, and complete part 3, worksheet 5, on 'back of the envelope calculations' to learn how reasonable estimates of known values are sometimes used to find an unknown value.

Standards

Arizona Science Standards

Strand 1, Inquiry Process, Concept 3: Analysis, Conclusions, and Refinements
7 - PO 5. Formulate a conclusion based on data analysis.
PO 5. Explain how evidence supports the validity and reliability of a conclusion.
HS-PO1. Interpret data that show a variety of possible relationships between variables
HS- PO6. Use descriptive statistics to analyze data

Strand 2, History and Nature of Science, Concept 2: Nature of Scientific Knowledge
7/8 - PO 3/1. Apply scientific processes to other problem solving or decision making situations
HS -PO4. Describe how scientists continue to investigate and critically analyze aspects of theories

Strand 3, Science in Personal and Social Perspectives, Concept 1: Changes in Environments
7/8 - PO 1. Analyze environmental risks caused by human interaction with biological or geological systems.
HS -PO1. Evaluate how the processes of natural ecosystems affect, and are affected by, humans.
HS -PO 2. Describe the environmental effects of the following natural and/or human-caused hazards
HS -PO 3. Assess how human activities (e.g., clear cutting, water management, tree thinning) can affect the potential for hazards.

Strand 5: Physical Science, Concept 2: Motions and Forces
8 - PO 4. Describe forces as interactions between bodies
HS -PO 1. Determine the rate of change of a quantity
Strand 5: Physical Science, Concept 5: Interactions of Energy and Matter
HS -PO 1. Describe various ways in which matter and energy interact

Strand 6: Earth and Space Science, Concept 1: Geochemical Cycles
PO 1. Identify ways materials are cycled within the Earth system
PO 2. Demonstrate how dynamic processes such as weathering, erosion, sedimentation, metamorphism, and orogenesis relate to redistribution of materials within the Earth system.
PO 5. Describe factors that impact current and future water quantity and quality including surface, ground, and local water issues.

NGSS Core Ideas

ESS2.A: Earth materials and systems
ESS2.D: Weather and climate
ESS2.E: Biogeology
ESS3.A: Natural resources
ESS3.B: Natural hazards
ESS3.C: Human impacts on Earth systems
PS2.A: Forces and motion

NGSS Practices

Asking questions
Analyzing and interpreting data
Using mathematics and computational thinking
Constructing explanations
Obtaining, evaluating, and communicating information

NGSS Crosscutting Concepts

Patterns
Cause and effect
Scale, proportion and quantity
Systems and system models
Energy and matter; Flows, cycles, and conservation
Stability and Change

AZCCRS/ELA Literacy

RST7: Integration of knowledge and Ideas
WHTS1: Write Arguments

AZCCRS/Mathematics

Domains: Number and Quantity, Measurement and Data
Math Practices:
4. Model with mathematics.
8. Look for and express regularity in repeated reasoning.

Acknowledgment

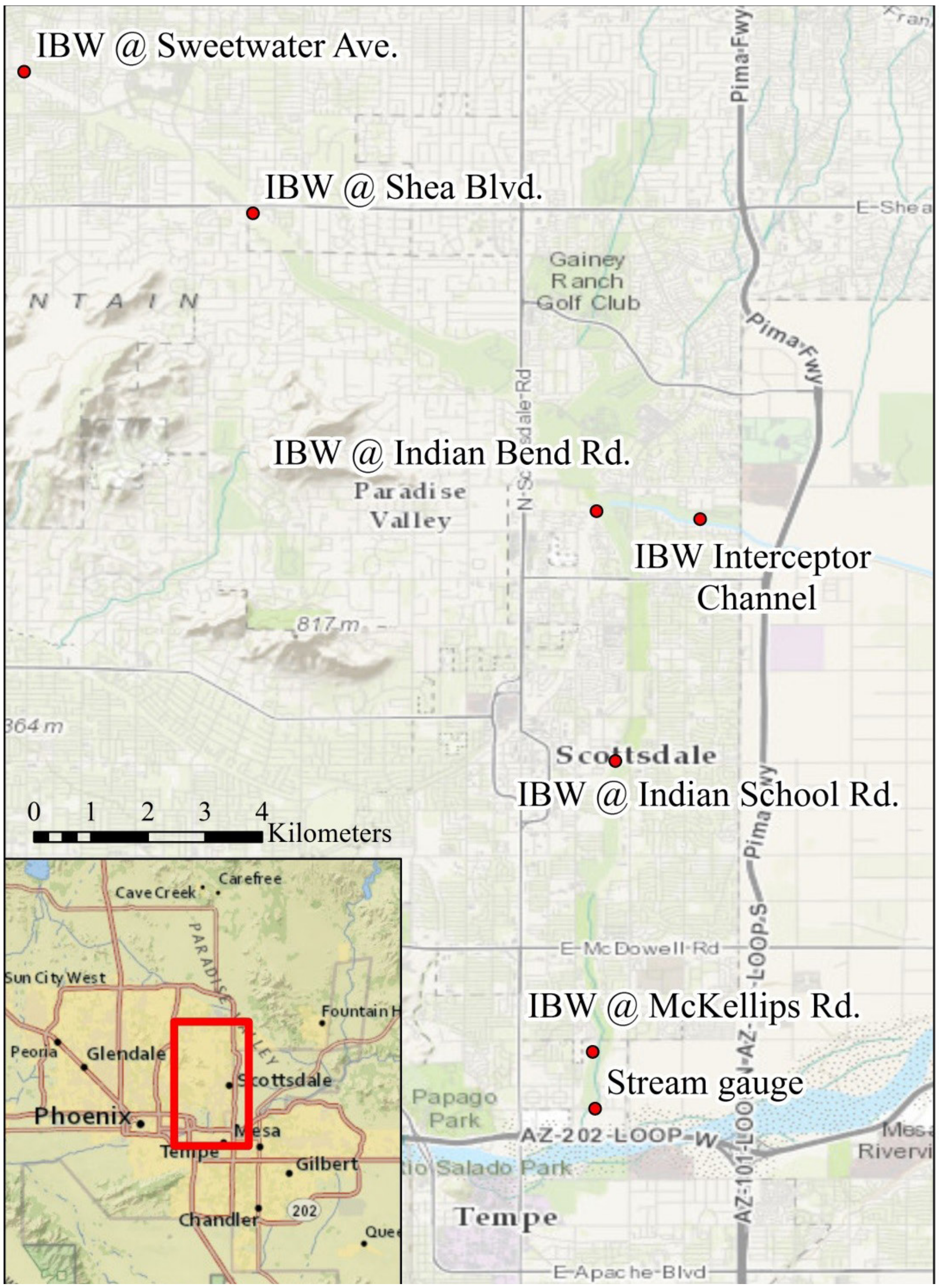
J. Guo was supported byan ASU/NASA space grant.

CAP LTER is supported by the National Science Foundation

Extreme Weather in Phoenix
How extreme is it?

Are all summer monsoon storms the same? We know that some areas of the Phoenix Metropolitan Area might get a lot of rain and other parts only a little during the summer monsoons. What happens to runoff from these storms as they move through an urban area? Can we measure these differences and impacts?

Specifically, in this lesson, we will examine six precipitation (i.e. rain) gauges and one streamflow gauge in Indian Bend Wash, an 82 square mile watershed in urban Phoenix, AZ (below). We will focus on two summer monsoon storms that fell on 8/18-8/20 and 9/8-9/9 in 2014. The first storm was a typical localized monsoon storm, whereas the second got a "boost" of tropical moisture from Hurricane Norbert. This resulted in an extreme event that produced 8.38 cm of rain at Sky Harbor airport, which was the most rain on a calendar day ever recorded in a 115-year period of record.



Student Worksheet #1
Extreme Weather Events

Part 1. Comparing spatial variability using coefficient of variation

1) Different kinds of monsoon storms may differ in their spatial variability. You can think of spatial variability as patchiness: rain falling in one place, but not in another location close by. One measure of variability is the interquartile range, which is the difference between the 1st and 3rd quartiles of the data. Quartiles divide rank-ordered data into four equal parts, and the values that divide each part are called the 1st, 2nd, and 3rd quartiles. The 2nd quartile is simply another way of referring to the median!

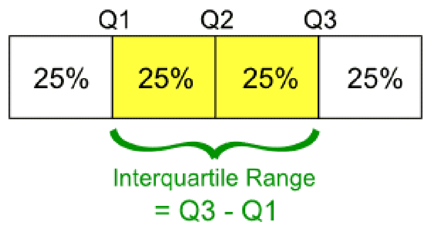


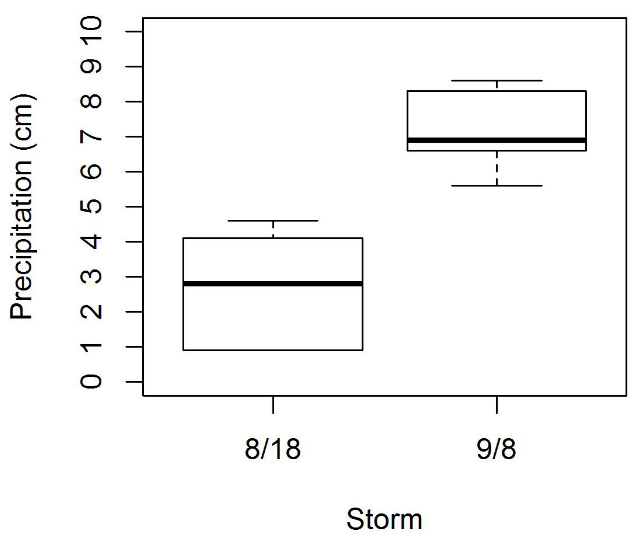
Figure 1 shows boxplots of precipitation for each storm. The bottom and top edges of the box represent the first and third quartiles, respectively. Thus, the difference between those 2 values is the interquartile range. The thick black line inside the box is the median or 2nd quartile.

Find the Interquartile Range for each storm:

August : __________________

September: ________________

Figure 1: Box Plots of August and September Storms



3) Which storm had a greater interquartile range and therefore greater spatial variability?

4) **(For High School Students)** A more precise measure of variability is to calculate the coefficient of variation, or CV. Since this statistic normalizes (divides) standard deviation (σ) by the mean (μ), we can use it to compare storms of different sizes. Tables 1 and 2 show how much rain fell at 6 different locations in Indian Bend Wash during each storm. Use the formulas provided to find the CV of each storms, either with a calculator or in Excel. (Hint: since we calculating the CV across six gauges, n=6.)

Table 1. Total rainfall during 8/18/14 to 8/20/14 monsoon storm

Gauge	Total (cm)
McKellips	4.6
Indian School	0.9
Indian Bend	4.1
Interceptor Channel	0.9
Shea	2.8
Sweetwater	2.8

$$\mu = \frac{\sum \chi_i}{n}$$

$$\sigma = \sqrt{\frac{\sum (\chi_i - \mu)^2}{n}}$$

$$CV = \frac{\sigma}{\mu}$$

Table 2. Total rainfall during 9/8/14 to 9/9/14 frontal storm

Gauge	Total (cm)
McKellips	8.6
Indian School	8.3
Indian Bend	6.6
Interceptor Channel	5.6
Shea	6.6
Sweetwater	7.2

8/18/2014 storm		**9/8/2014 storm**	
Mean (μ):		Mean (μ):	
Standard deviation (σ):		Standard deviation (σ):	
CV:		CV:	

5) Which storm had the larger coefficent of variation(CV)? How did this compare to your answer just using the box plots?

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Part 2. Precipitation and streamflow

Figures 2 and 3 depict precipitation and streamflow simultaneously. The left axis of precipitation corresponds to the multi-colored points, which represent different precipitation gauges. Precipitation data is plotted at half-hourly increments. The right axis of streamflow corresponds to the black line, which shows the rate of water moving through the stream. Note that the scales are different in each figure.

1.) To compare the two storms, let's estimate some quantitative information from each graph:

Quantity	8/18 storm	9/8 storm
Maximum precipitation (cm/30min)		
Maximum streamflow (m^3/s)		
Time from max ppt to max streamflow (hours)		
Duration of precipitation (hours)		
Duration of streamflow (hours)		
Mode* of precipitation (cm)		

*Mode is the most common value

2) How does the precipitation differ between each storm?

3) How does streamflow differ between each storm?

4) How does the relationship between precipitation and streamflow differ between each storm?

5) Using at least 4 sets of values from the table on worksheet 3, write a paragraph that compares and contrasts precipitation and streamflow for these two storms. Incorporate three additional values into your paragraph. I will get you started:

The maximum precipitation was much higher in the 8/18 storm (__ cm) than in the 9/8 storm (__ cm). Similarly,

Bonus: Based on the graphs, how would you find the total volume of water that passed through the stream gauge?

Extension: Back-of-the-envelope calculations

Student Worksheet #5 (Extension)
Extreme Weather Events

Back-of-the-envelope (BOTE) calculations are a rough way to find an unknown value by using reasonable estimates of known values. Often, these calculations involve making important assumptions and converting units. Unit conversions are provided in the Reference sheet.

1) Let's pretend that we don't know the streamflow on Indian Bend Wash (maybe the gauge just happens to break on the day a large storm occurs). But we do know the mode of precipitation (see table above) and the size of the watershed (82 square miles). Since precipitation is a length (cm) and watershed size is an area (miles^2), we can multiply the two to estimate the volume of water that falls in the watershed. Some unit conversions are needed to yield a result in cubic meters.

Unit conversions:

1 mile = 1609 meters   1 meter = 100 cm   1 minute = 60 seconds

$$\underline{\hspace{1cm}}\, mi^2 \left(\frac{\underline{\hspace{1cm}}\, m}{mi}\right)\left(\frac{\underline{\hspace{1cm}}\, m}{mi}\right)\underline{\hspace{1cm}}\, cm \left(\frac{m}{\underline{\hspace{1cm}}\, cm}\right) = \underline{\hspace{1.5cm}}\, m^3$$

$$\underline{\hspace{1cm}}\, mi^2 \left(\frac{\underline{\hspace{1cm}}\, m}{mi}\right)\left(\frac{\underline{\hspace{1cm}}\, m}{mi}\right)\underline{\hspace{1cm}}\, cm \left(\frac{m}{\underline{\hspace{1cm}}\, cm}\right) = \underline{\hspace{1.5cm}}\, m^3$$

2) We also know that the precipitation is reported every 30 minutes, so we can divide the volume by 30 minutes to obtain a rate. Some unit conversions are needed to yield a result in cubic meters per second.

$$\frac{\underline{\hspace{1.2cm}}\, m^3}{\underline{\hspace{0.8cm}}\, \min}\left(\frac{\min}{\underline{\hspace{0.8cm}}\, s}\right) = \underline{\hspace{1.2cm}}\, \frac{m^3}{s}$$

$$\frac{\underline{\hspace{1.2cm}}\, m^3}{\underline{\hspace{0.8cm}}\, \min}\left(\frac{\min}{\underline{\hspace{0.8cm}}\, s}\right) = \underline{\hspace{1.2cm}}\, \frac{m^3}{s}$$

3) So how close are we? Since we actually **do** know the streamflow in Indian Bend wash, we can compare our estimate to the actual values. Typically, we want our BOTE calculations to be the same order magnitude as the actual value. This means that the two numbers should have the same number of digits. For example, 52 and 79 are within one order of magnitude, but 52 and 790 differ by one order of magnitude, and 52 and 7920 differ by two orders of magnitude.

8/18 storm		9/8 storm	
BOTE estimated stream-flow:		BOTE estimated stream-flow:	
Actual maximum stream-flow:		Actual maximum stream-flow:	

4) Is the BOTE estimate the same magnitude of the actual maximum streamflow for each storm?

Figure 2. Time series of precipitation and streamflow during the 8/18 to 8/20 storm

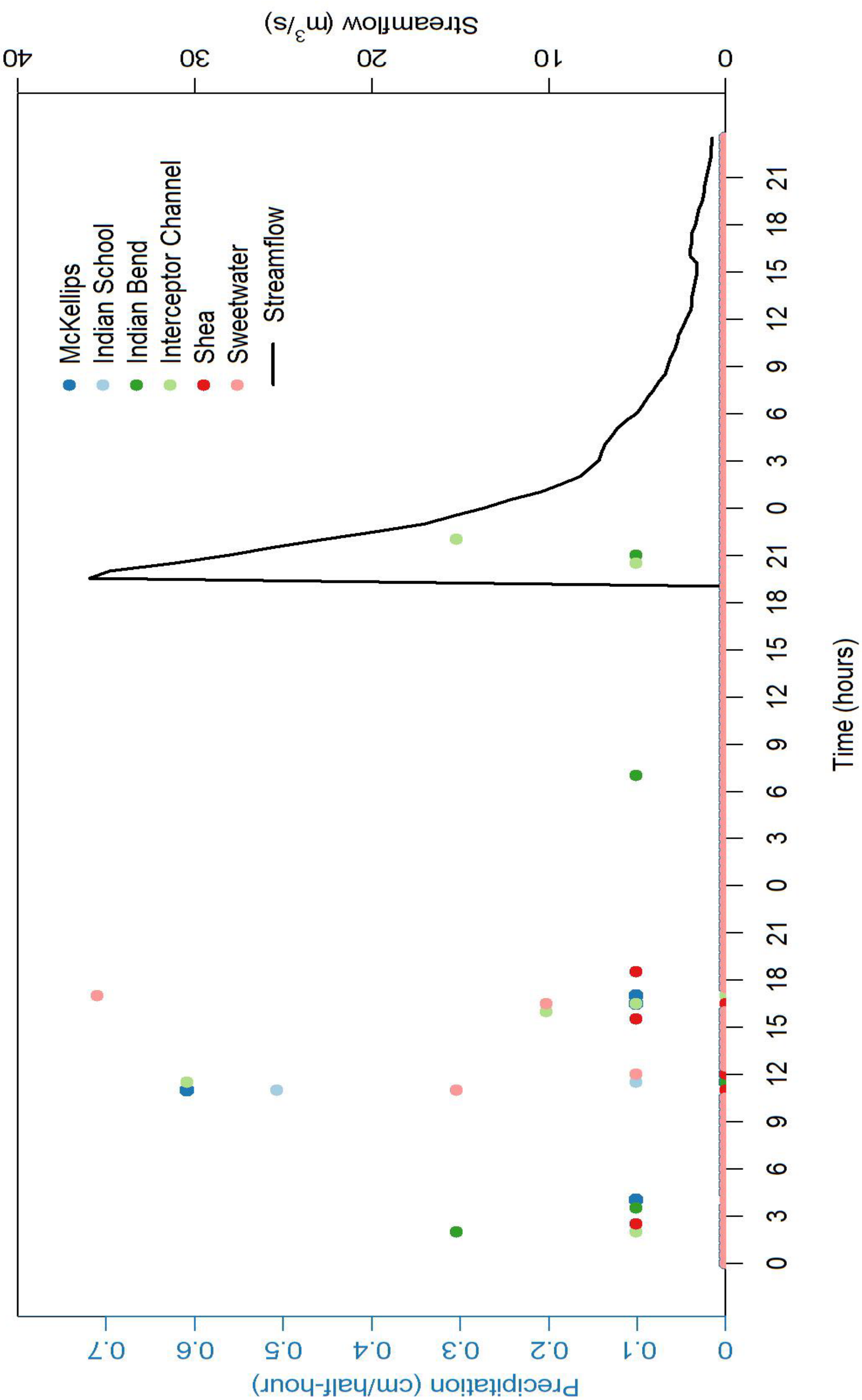
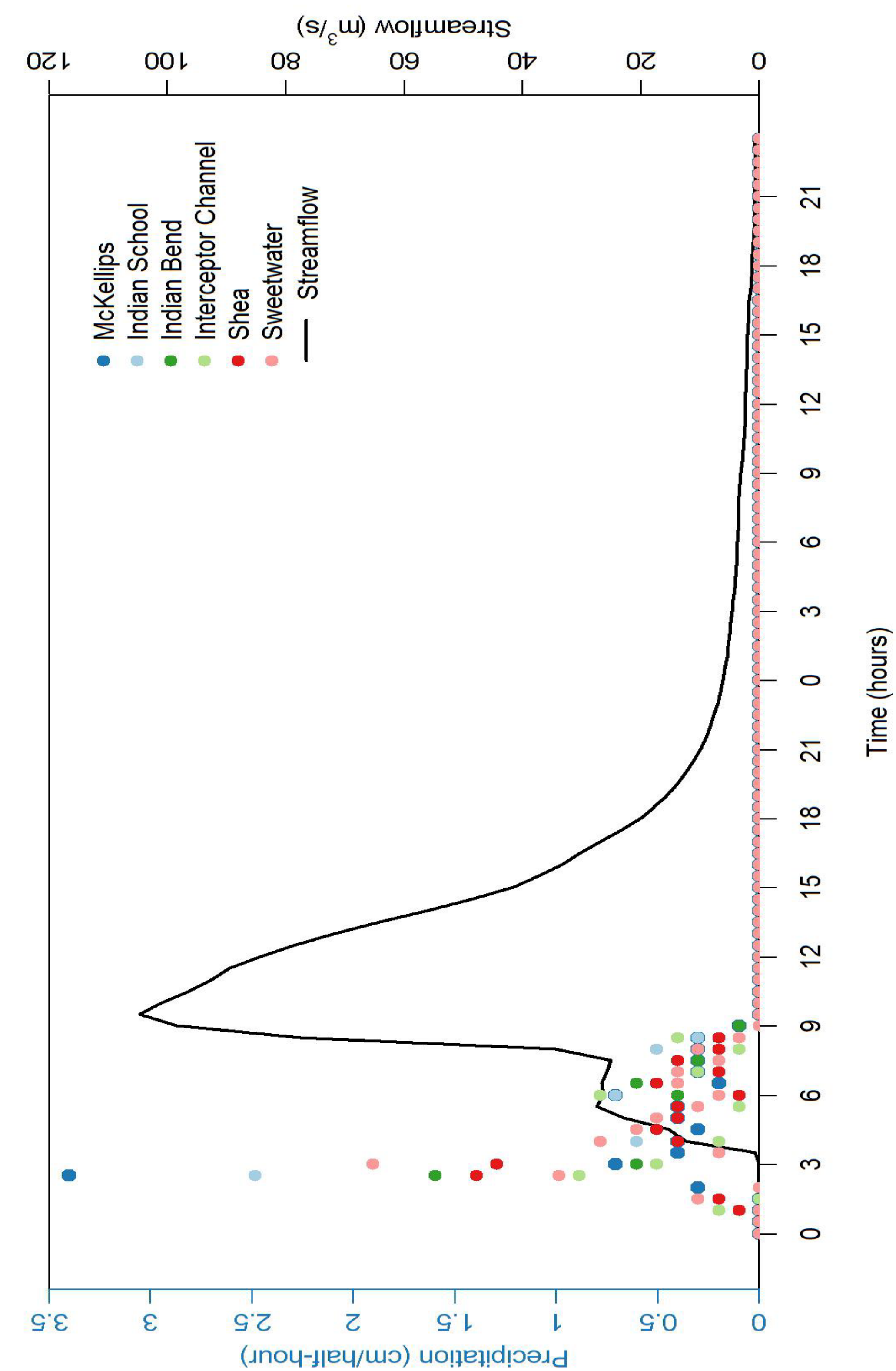


Figure 3. Time series of precipitation and streamflow during the 9/8 to 9/9 storm



Extreme weather events: What do the data say?

Slides to accompany lesson

Part 1, Question 1

What are some characteristics of a typical monsoon storm?

Part 1 – spatial variability

- Typical versus extreme monsoon storms have different characteristics
- One difference is in the “patchiness” of the rainfall, also known as spatial variability
- Monsoon video

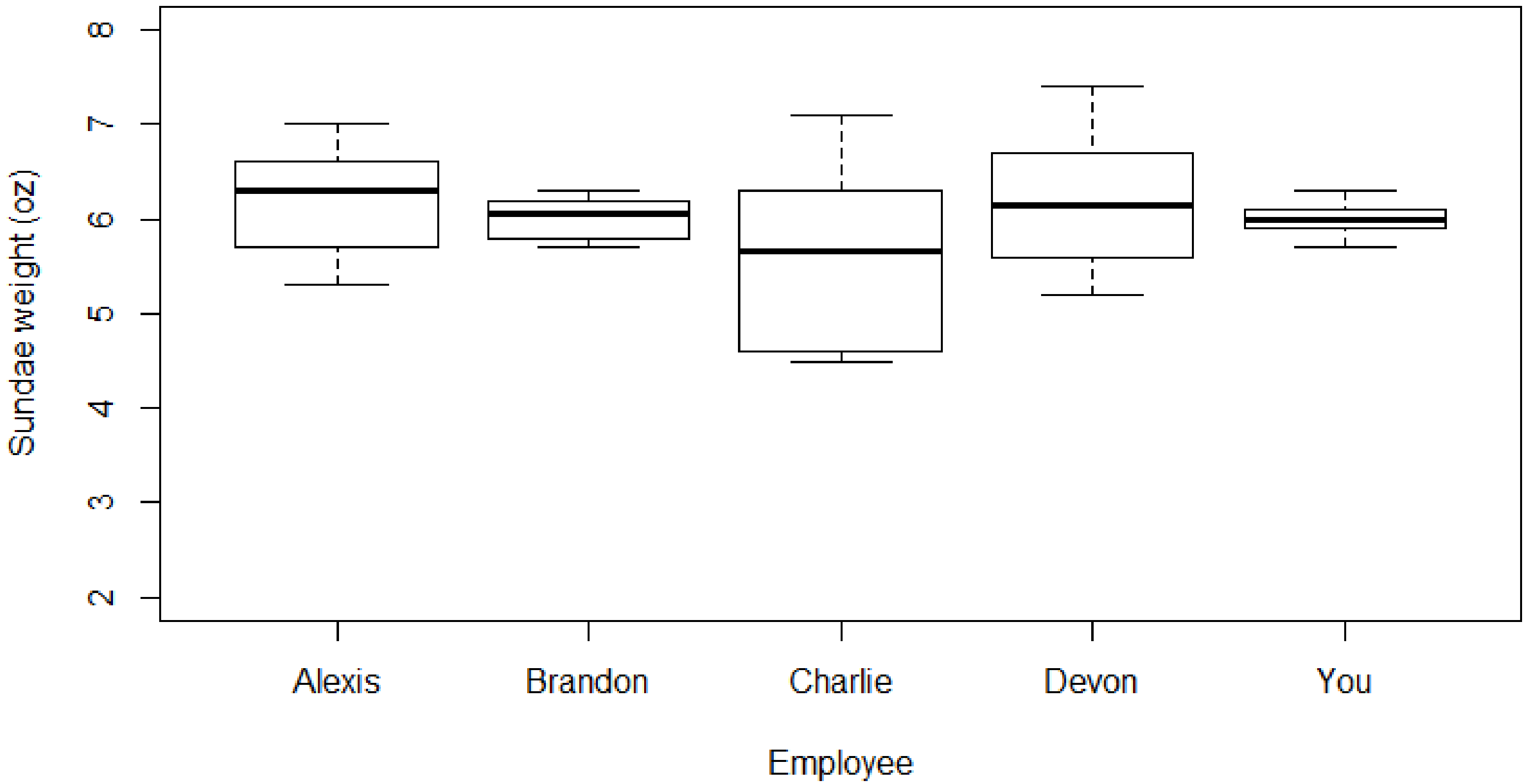
Understanding variability

- Often, we see averages or medians reported, e.g. average precipitation per year, median home price
  - These are measures of central tendency
- Scientists are also interested in measures of spread, or the variability of the data

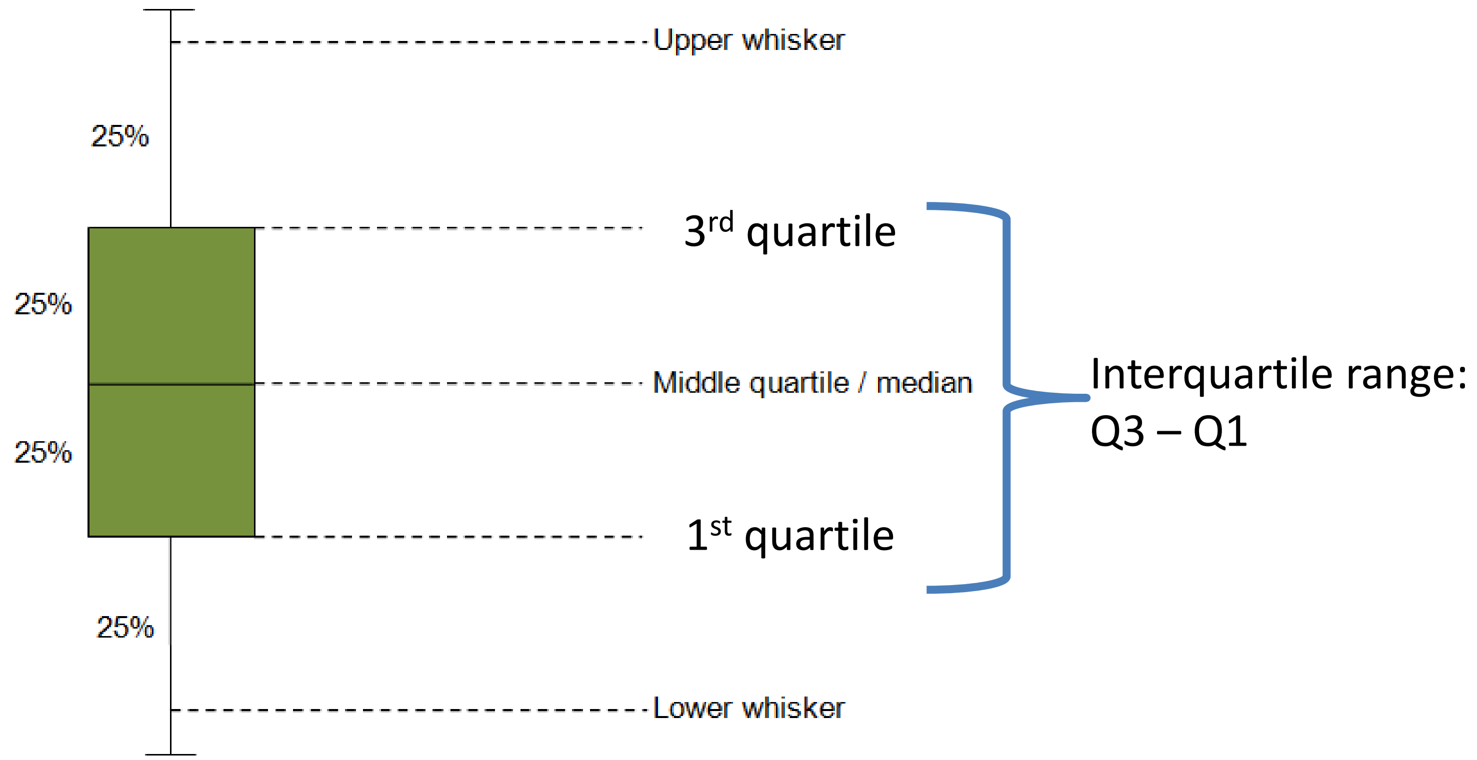
Variability in ice cream sundaes

- Your summer job is making ice cream sundaes for a local dessert emporium
- Monthly prizes are awarded to the employee who makes the most consistent sundaes, which should weigh 6 ounces each.

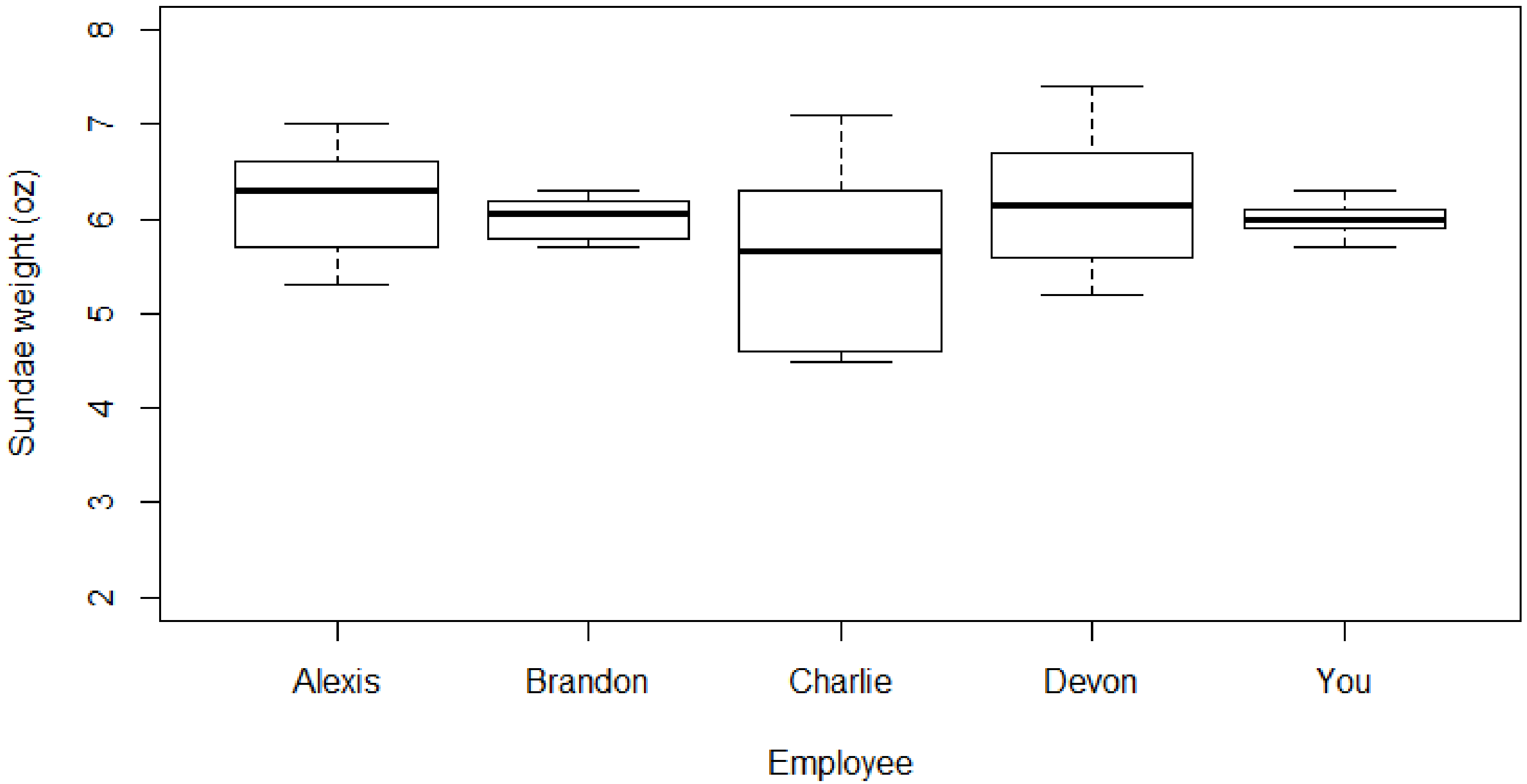
Which employee wins? Why?



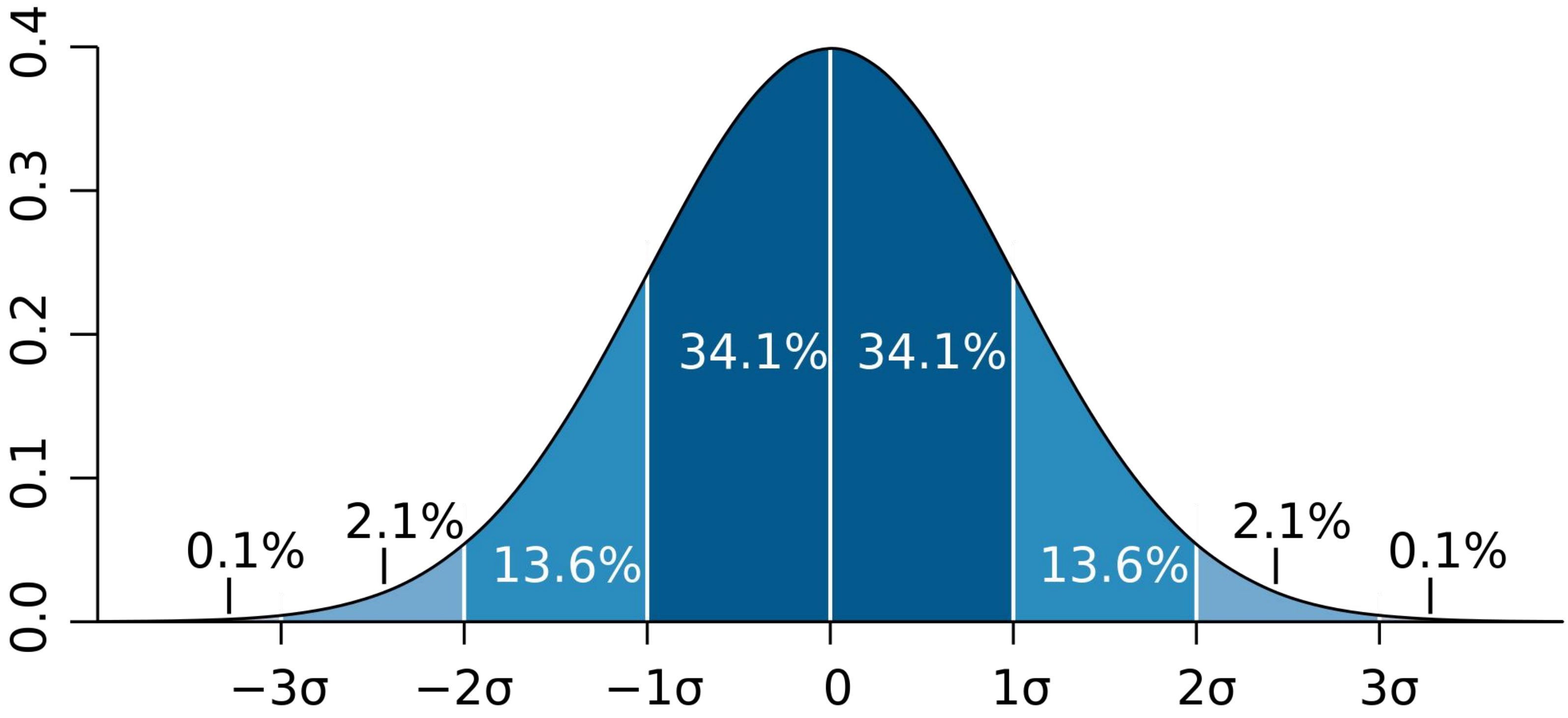
Box and whisker plots



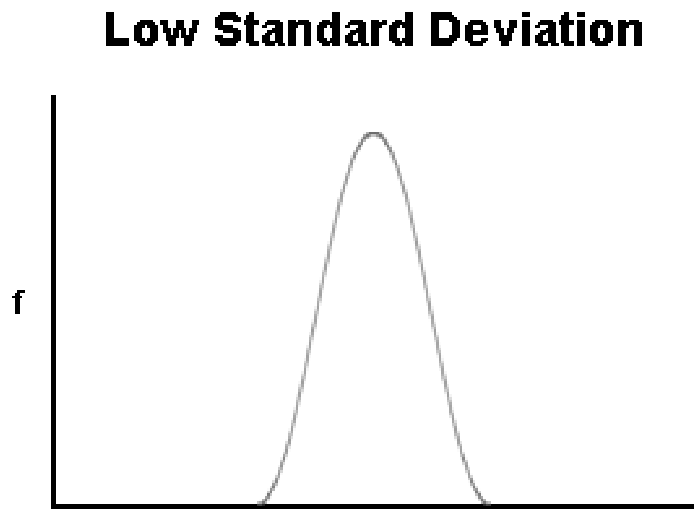
Which employee wins? Why?

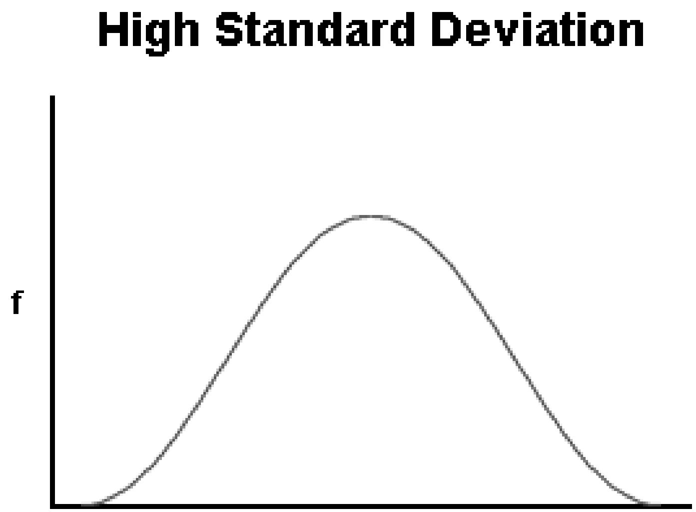


Standard deviation of a normal distribution

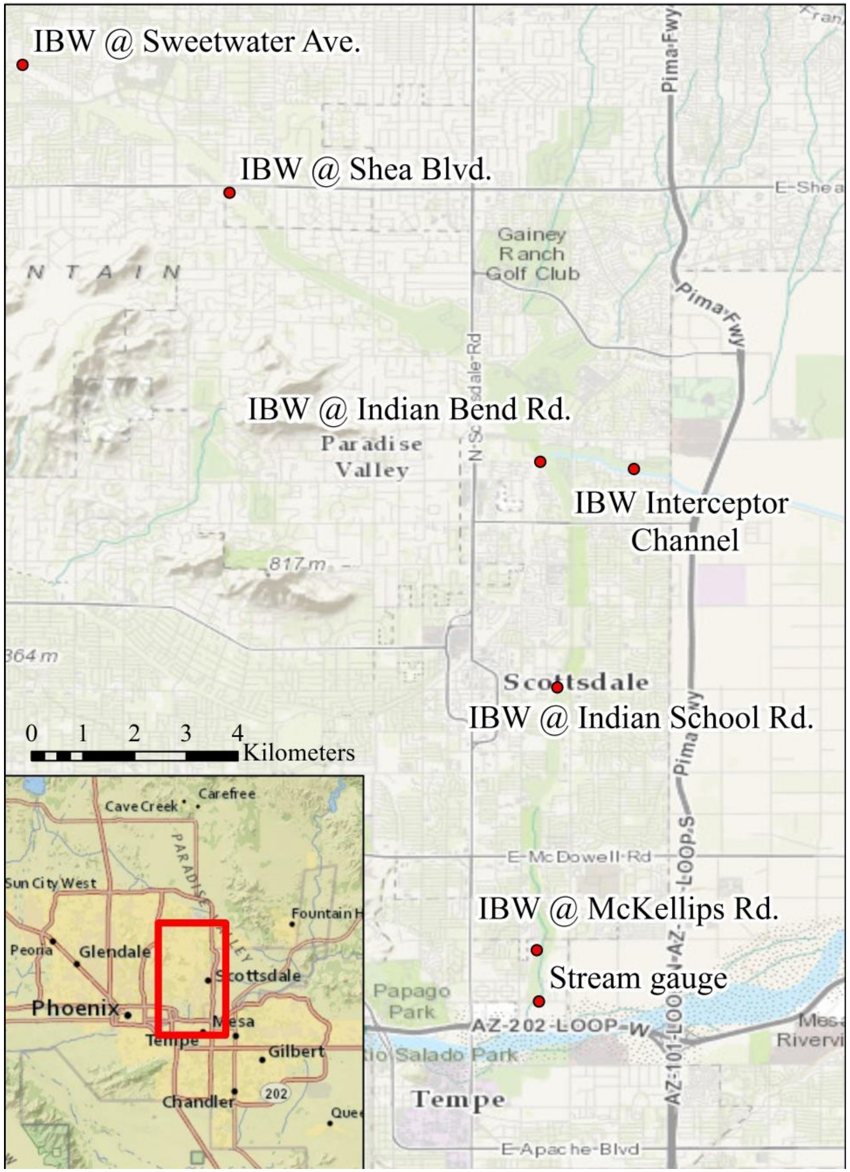


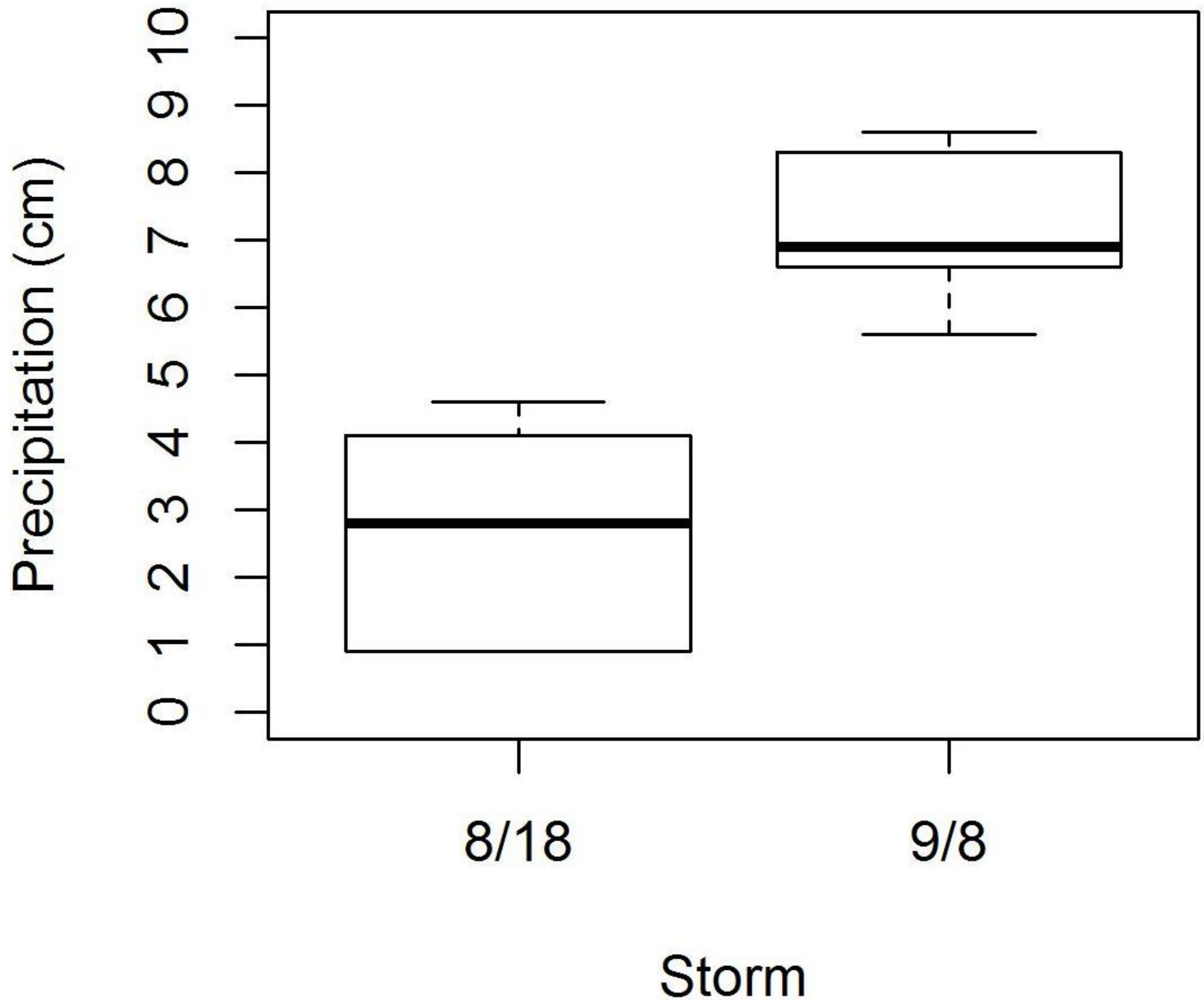
Can we compare standard deviations?





Indian Bend Wash





Precipitation (cm)
0
1
2
3
4
5
6
7
8
9
10
8/18
9/8
Storm

Part 1, Question 2

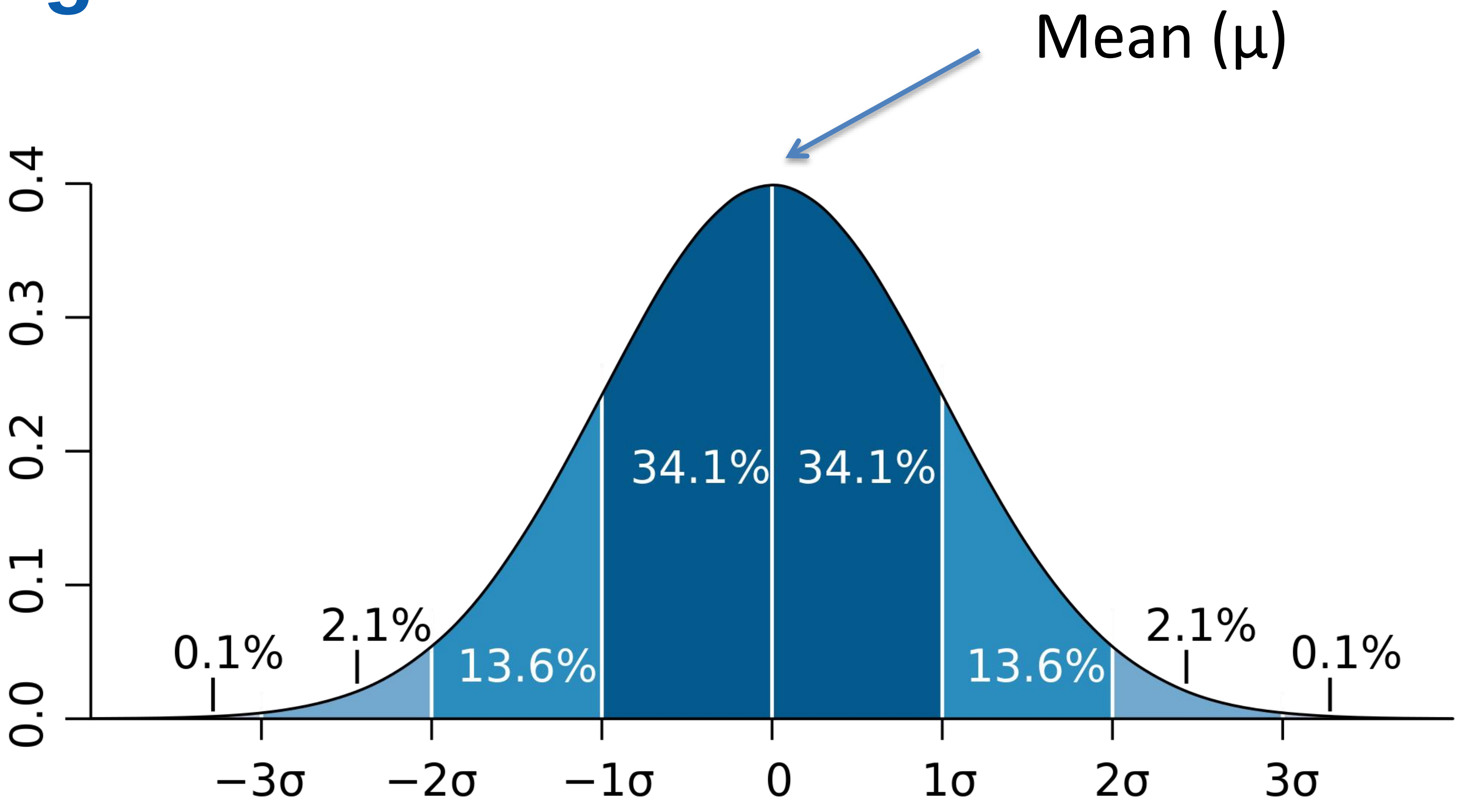
Find the interquartile range for each storm:

8/18 storm		9/8 storm	
Interquartile range:	4.1-0.9 = 3.2	Interquartile range:	8.3-6.6 = 1.7

Part 1, Question 3

Which storm had greater spatial variability, the typical monsoon from 8/18 or the extreme monsoon from 9/8?

High school extension



Larger μ may result in larger σ

- So, to compare variation between datasets with very different means, we can normalize (divide) the standard deviation by the mean

$$CV = \frac{\sigma}{\mu}$$

- CV or coefficient of variation is the percent of the mean that is the standard deviation

Part 1, Question 4

Find the mean, standard deviation, and CVs for each storm.

Part 1, Question 4 answers

8/18 storm		9/8 storm	
Mean (μ):	2.68	Mean (μ):	7.15
Standard deviation (σ):	1.42	Standard deviation (σ):	1.04
CV:	0.53	CV:	0.14

Part 1, Question 5

Which storm had the larger CV? How did this compare to your answer using boxplots and IQR?

Flash floods

Rapid flooding of low-lying areas is called a flash flood

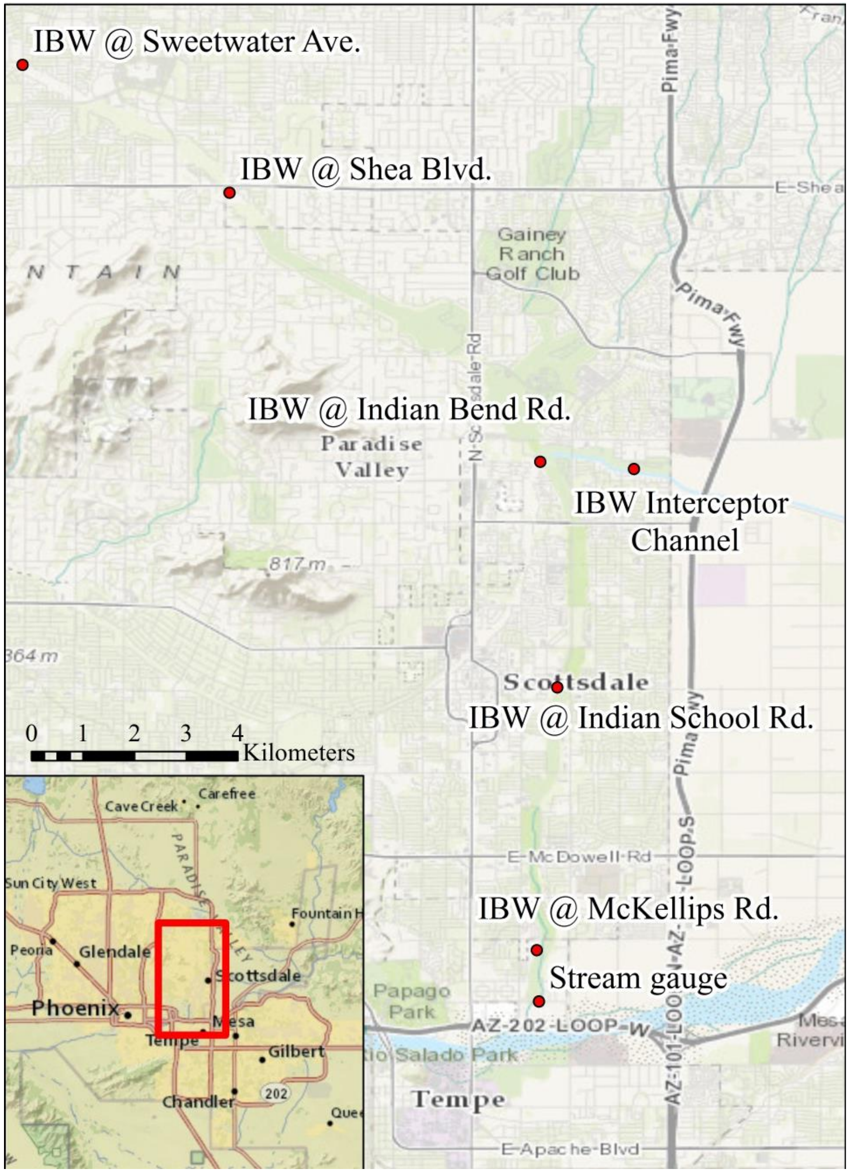
azgolfhomes.com

ABC15

Part 2 – precipitation and streamflow

- In many of Phoenix’s dry washes, streamflow only occurs after it rains
- How does the relationship between precipitation and streamflow differ between typical and extreme monsoon storms?

Indian Bend Wash



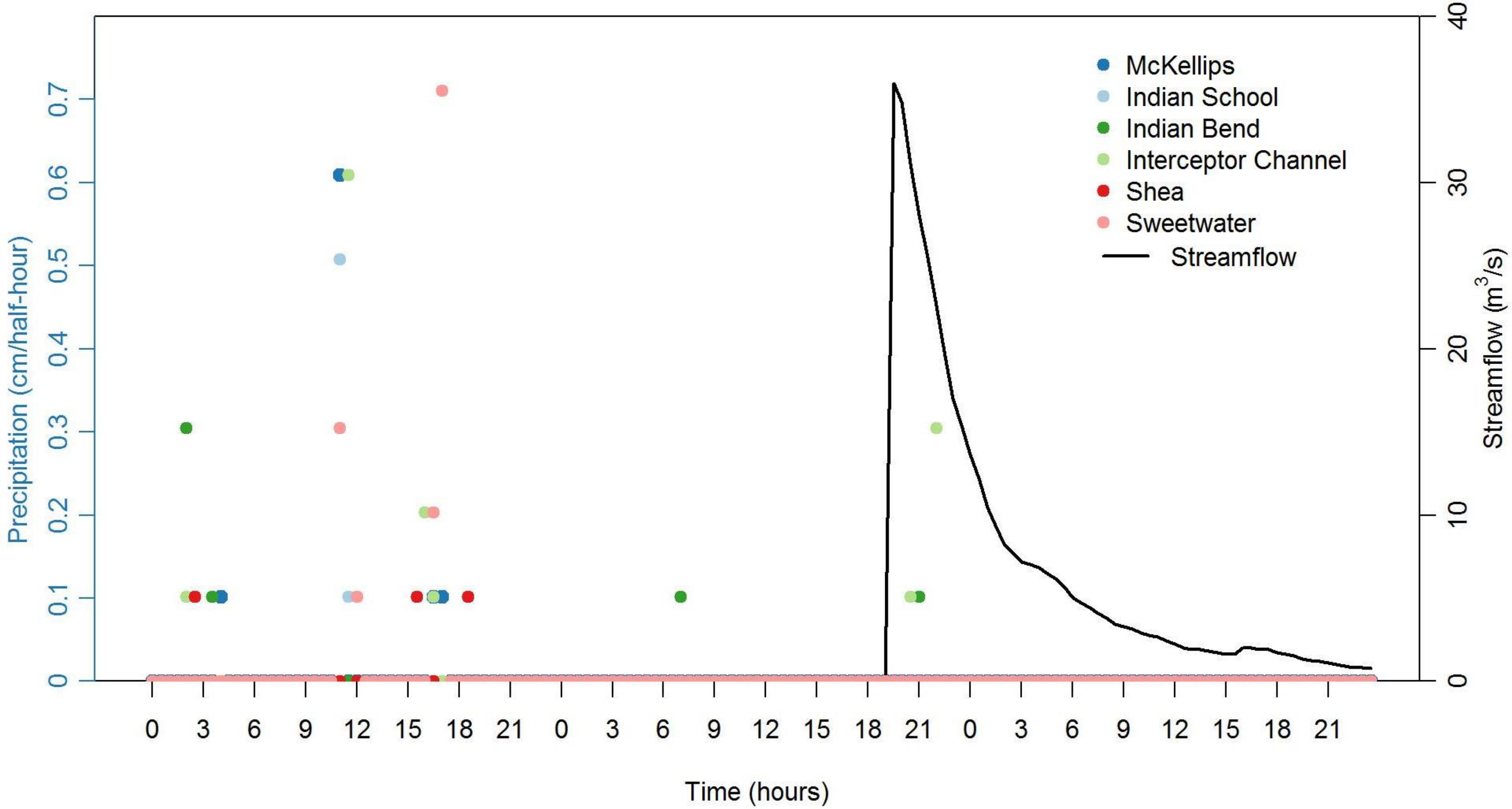
Stream flow gauge along Indian Bend Wash

Is the stream gauge recording flow right now?

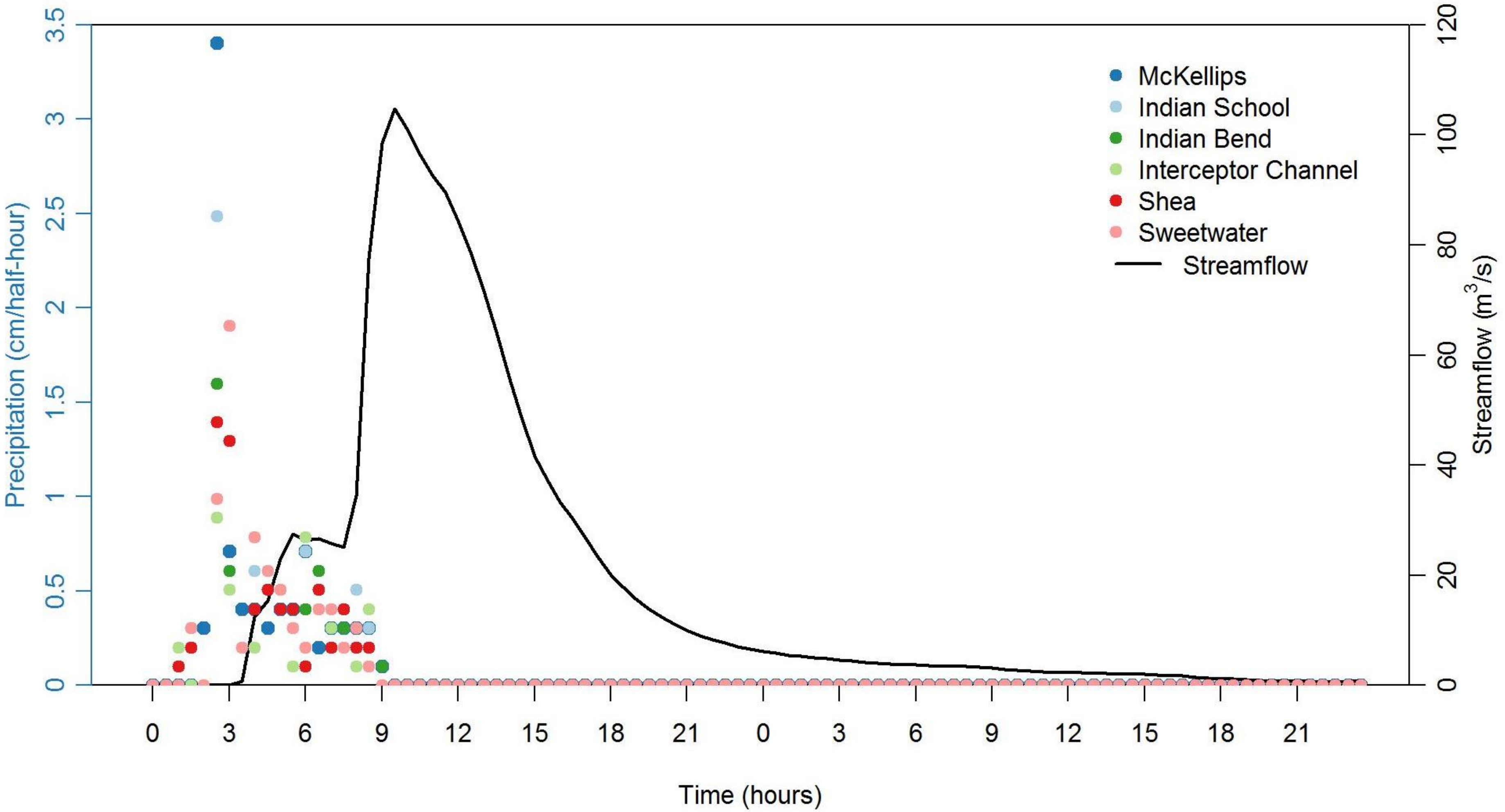
aroundguides.com


How about now?
Dave Seibert/The Republic

8/18 storm


McKellips
Indian School
Indian Bend
Interceptor Channel
Shea
Sweetwater
Streamflow
Precipitation (cm/half-hour)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Streamflow (m3/s)
0
10
20
30
40
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21
Time (hours)

9/8 storm



Precipitation (cm/half-hour)
0
0.5
1
1.5
2
2.5
3
3.5
Streamflow (m^3/s)
0
20
40
60
80
100
120
McKellips
Indian School
Indian Bend
Interceptor Channel
Shea
Sweetwater
Streamflow
0
3
6
9
12
15
18
21
0
3
6
9
12
15
18
21
Time (hours)

Part 2, Question 1

Estimate 6 quantities from the graph of precipitation and streamflow from each storm

Part 2, Question 1 answers

Quantity	8/18 storm	9/8 storm
Maximum precipitation (cm)	0.7	3.4
Maximum streamflow (m^3/s)	35	100
Time from max ppt to max streamflow (hours)	27	8
Duration of precipitation (hours)	45	9
Duration of streamflow (hours)	26	45
Mode* of precipitation (cm)	0.1	0.4

Part 2, Questions 2, 3, & 4

2) How does precipitation differ between each storm?
3) How does streamflow differ between each storm?
4) How does the relationship between precipitation and streamflow differ between each storm?

Part 3 extension: BOTE calculations

Back of the envelope (BOTE) calculations allow us to estimate a value from known values using simplifying assumptions and unit conversions

For example, let's assume that the streamflow gauge broke just before a large storm. Could we estimate streamflow from just the precipitation?

Estimation premise

We know the area of the watershed and the mode of the precipitation height, which means we can multiply the two to estimate the volume of water produced in one 30-minute increment.

What are the two major assumptions we have to make to use this method of estimation?

Simplifying assumptions (that we know to be untrue, but are useful anyway)

1. All rainfall ends up in the stream.

   Is this true?

   If not, will our BOTE be an over- or under-estimate of the true streamflow?

2. Rain falls evenly over the watershed.

   Is this true?

   If not, will the accuracy of this estimation method depend on the type of storm?

Thank you for listening!

And a huge thanks to Monica Elser, Lisa Herrmann, Melissa Wagner, and Joanna Merson for their help and feedback on this activity.

Do you have any questions for me?

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