Analyzing Floods: Understanding Past Flood Events and Considering Future Flood Events in a Changing Climate — High School Sample Classroom Assessment

Introduction

In the first half of 1993, a "perfect storm" of climatic and weather events sent a record amount of water flooding through the Upper Mississippi River Drainage Basin. Climate models predict that as the global climate changes, it is likely that there will be larger and more frequent storms, which will lead to larger flood events like the flood of 1993. In this task, students use recurrence intervals from the Mississippi River to estimate the expected size and frequency of 100-year and 500-year floods for historical data (1943 to 1992) and an imaginary future scenario where large floods are more frequent (1943 to 2021). They compare the recurrence interval versus discharge on semi-log scatterplots and consider data from global climate models to make evidence based-claims about how changing climate in a warming world will influence river discharge and flood events.

This task is adapted from:

- *McConnell, D., Steer, D., Knight, C., Owens, K., & Park, L. (2008).* The good earth: Introduction to earth Science, *p. 536. New York: McGraw Hill Higher Education.*
- *Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., and Kanae, S. (2013). Global flood risk under climate change.* Nature Climate Change, *3, 816–821.*
- *The Weather Channel. The Mississippi River Flood of 1993. Available at: www.weather.com/encyclopedia/flood/miss93.html. Last accessed: October 18, 2013.*

Standards Bundle

(Standards completely highlighted in bold are fully assessed by the task; where all parts of the standard are not assessed by the task, bolding represents the parts assessed.)

CCSS-M

MP.2	**Reason abstractly and quantitatively.**
MP.3	**Construct viable arguments** and critique reasoning of others.
MP.4	**Model with mathematics.**
HSN.Q.A.1	**Use units as a way to understand problems** and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and **interpret scale and the origin in graphs and data displays.**
HSN.Q.A.3	**Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.**
HSS.ID.B.6	**Represent data on two quantitative variables on a scatter plot, and describe how the variables are related.**
HSS.ID.B.6a	**(Algebra 2 Option) Fit a function to the data; use functions fitted to data to solve problems in the context of the data.**
HSF.IF.C.7e	**(Algebra 2 Option) Graph** exponential and **logarithmic functions, showing intercepts and end behavior,** and trigonometric functions, showing period, midline,

and amplitude.

HSA.CED.2a **(Algebra 2 Option) Create equations in two or more variables to represent relationships between quantities;** graph equations on coordinate axes with labels and scales.

NGSS

HS-ESS2-2 **Analyze geoscience data to make the claim that one change to Earth's surface can** create feedbacks that **cause changes to other Earth systems.**

HS-ESS3-1 Construct an explanation **based on evidence for how the** availability of natural resources, **occurrence of natural hazards,** and changes in climate **have influenced human activity.**

HS-ESS3-5 **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.**

CCSS-ELA/Literacy

W.11-12.1 **Write arguments to support claims in an analysis of substantive topics** or texts, **using valid reasoning and relevant and sufficient evidence.**

WHST.11-12.1 **Write arguments focused on discipline-specific content.**

W.11-12.1.a and WHST.11-12.1.a

Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, **and create an organization that logically sequences claim(s),** counterclaims, **reasons, and evidence.**

W.11-12.1.b **Develop claim(s)** and counterclaims **fairly and thoroughly, supplying the most relevant evidence** for each **while pointing out the strengths and limitations** of both in a manner that anticipates the audience's knowledge level, concerns, values, and possible biases.

WHST.11-12.1.b **Develop claim(s)** and counterclaims **fairly and thoroughly, supplying the most relevant data and evidence** for each **while pointing out the strengths and limitations of** both **claim(s)** and counterclaims **in a discipline-appropriate form** that anticipates the audience's knowledge level, concerns, values, and possible biases.

Information for Classroom Use

Connections to Instruction

This task is aimed at students who have taken Algebra 1, but it includes additional options that expand the plotting components for students who have taken Algebra 2. This assessment task could fit within a science instructional unit on rivers, natural hazards, and/or climate change, such as in an environmental science course. Task Components A and C, including the additional options, would fit well within an Algebra 2 course as a real-world example of logarithmic relationships.

Overall, the entire task can be used as a summative assessment in a unit where students have strong command of the plotting components and the science content underpinning the task, as listed in the assumptions. Task Components A through C could be used as formative assessment with Task Component D and/or E as a summative assessment. Because the plotting tasks are similar, Task

Component A could be used as a formative assessment followed by Task Component C as a summative assessment. Task Components A and C could be formative assessments with Task Components B and D as summative assessments, respectively, following the plotting.

This task requires students to use evidence and reasoning to make, support, and evaluate forecasts, which function as claims in writing argument in ELA/Literacy. Students can be formatively assessed on writing argument in Task Components B, D, and E, or teachers can use Task Components B and D as formative assessments and Task Component E as a summative assessment. *Students can also be assessed on writing argument in the option for Task Component A.* This task has been aligned to the ELA/Literacy standards for writing argument for the 11–12 grade band. Teachers using this task in 9th or 10th grade should refer to the comparable CCSS for the 9–10 grade band.

Approximate Duration for the Task

The entire assessment task likely will take 3–6 class periods (45–50 minutes each) spread out over the course of an instructional unit, with the divisions listed below:
Task Component A: 1–2 class periods
Task Component B: 1–2 class periods, depending on whether done as homework
Task Component C: 1–2 class periods
Task Component D: 1–2 class periods, depending on whether done as homework
Task Component E: up to 1 class period

Assumptions

Instructors and students should have a working understanding of stream discharge, the factors that affect flooding, what is meant by a 100-year and 500-year storms, the concept of recurrence intervals for floods, the basics of global climate change, and how to use a semi-log graph to plot and interpret logarithmic data.

Materials Needed

All materials needed to complete this task are provided as attachments. If the teacher decides to allow students to use a spreadsheet/plotting program or graphing calculators, then the students need access to such programs and need to understand how to use them. Although not necessary to complete the task, teachers may choose to read about or include alternative or additional data from the article by Hirabayashi et al. (2013), in which case teachers would need access to the article (cited in the introduction) in the journal *Nature Climate Change.*

Supplementary Resources

- Teaching the Quantitative Concepts in Floods and Flooding by Dr. Eric Baer: http://serc.carleton.edu/quantskills/methods/quantlit/floods.html. This resource outlines concepts that students typically struggle with and has many examples and explanations.
- Additional information about the 1993 Mississippi River flood can be found at Prof. Charles L. Smart's website: www.kean.edu/~csmart/Observing/13.%20Streams%20and%20floods.pdf
- Information about rivers and flooding can be reviewed through Science Courseware's Virtual River Flooding, found at Geology Labs On-line: www.sciencecourseware.org/VirtualRiver.

Accommodations for Instruction and Assessment Tasks

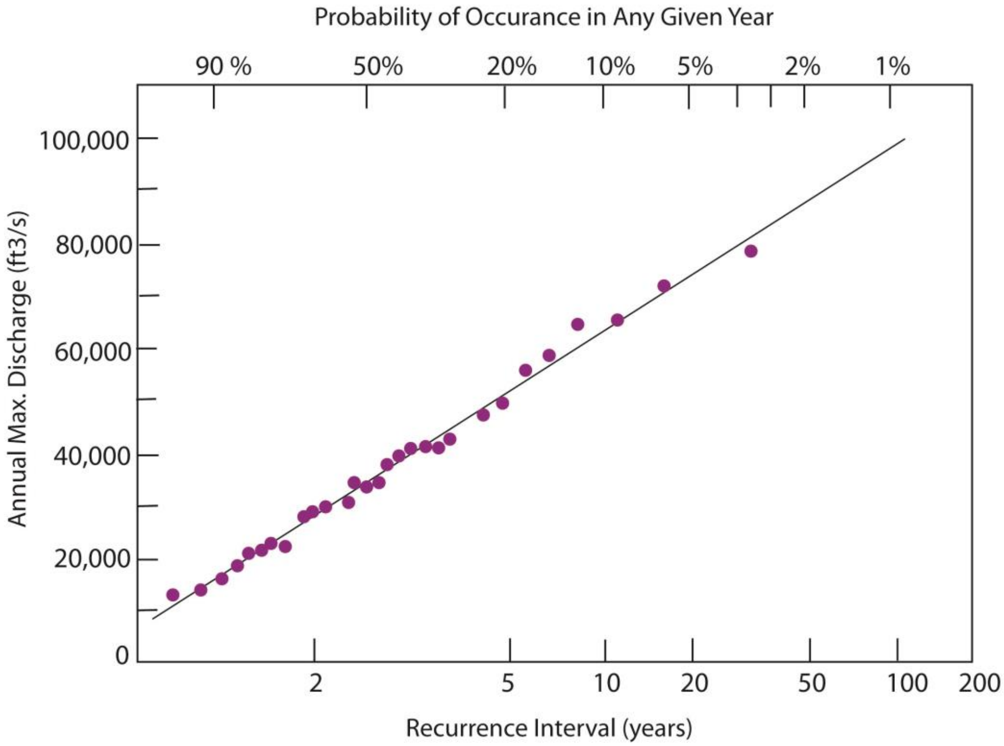
To accurately measure three dimensional learning of the NGSS along with CCSS for mathematics, modifications and/or accommodations should be provided during instruction and assessment for students with disabilities, English language learners, and students who are speakers of social or regional varieties of English that are generally referred to as "non-Standard English".

Assessment Task

<u>Context</u>

In the first half of 1993, a perfect storm of climatic and weather events sent a record amount of water flooding through the Upper Mississippi River Drainage Basin. From January through July of that year, record amounts of snow fell on several upper Midwest states. Second, heavy storms added large amounts of rainfall all at once in parts of the basin. This higher-than-normal precipitation filled storage reservoirs and saturated the ground, leading to the spatially largest flood in U.S. history, one that covered 44,000 square kilometers (17,000 square miles) in nine states (McConnell et al., p. 310). Over 70,000 people were displaced by the floods. Nearly 50,000 homes were damaged or destroyed, and 52 people died. More than 12,000 square miles of productive farmland were rendered useless. Damage costs were estimated between $15 billion and $20 billion (The Weather Channel).

Scientists compare floods like the one that occurred on the Mississippi River in 1993 with other floods that occurred on the same river in other years by calculating the flood's recurrence interval over a specific period of time in the past. First, the flood events that occurred in a specific time range are ranked in order of greatest to least discharge (i.e., the amount of water flowing in the stream at any given second). For each flood event, the rank is used to calculate recurrence interval: RI = (N+1)/rank, where N = the total number of years within the chosen time range. The recurrence interval (calculated from past events) is used to gauge the future probability of an event by calculating the percent chance that a similar flood will occur again in any given year (Baer, SERC website). The percent probability (P) of an event with recurrence interval (RI) is P = (1/RI)*100. When the recurrence interval is plotted on a semi-log scatterplot with discharge, the logarithmic trend line (line of best fit) can be used to predict the probability of a flood of any discharge occurring in a given year, including the 100-year and 500-year flood values used on building flood zone maps. *(Note: Because of the abundance of data points with low RI values, trendlines may be more easily calculated with datasets that exclude RI values less than 2.)*



The trend line (line of best fit) on the semi-log scatterplot of recurrence interval versus the amount of flood water (a stream's discharge) like the one above can be used to predict the size of floods during 100-year (recurrence interval of 100) and 500-year flood events (recurrence interval of 500). Image is derived from: http://web.mst.edu/~rogersda/umrcourses/ge301/what%20is%20a%20100%20year%20flood.htm Last accessed: February 8, 2014

Climate models predict that as the global climate changes, weather patterns also will change. In some areas, it is likely that there will be larger and more frequent storms and unusual weather conditions like those that led to the flood of 1993. This has implications for what we understand the discharge of a 100-year storm to be. Because the RI is calculated from the flood data over a specific time range, a dataset with a larger number of severe flood events could change the recurrence intervals, the trend line (line of best fit) on the scatterplot, and the predicted size of the 100-year and 500-year floods.

In this task, you will use streamflow data from the Mississippi River spanning the years from 1943 to 1992 to calculate the recurrence interval for each ranked flood event and the percent chance of the flood happening in a given year. You will plot that data on a semi-log graph to determine the recurrence interval of a flood the size of the 1993 flood and make predictions about the size of a 100-year and 500-year flood. You will then consider the effect that the 1993 flood and seven very large, imaginary flood events occurring in the near future (up to 2021) will have on the calculated data and flood predictions. Finally, you will review results from global climate models that make the same type of comparison between past flooding conditions and future projections of flooding around the world.

Task Components

A. Calculate the recurrence interval and percent probability for flood events on the Mississippi River at Keokuk, IA, for the time range of 1941–92, a 49-year range (Attachment 1). This dataset ends the year prior to the 1993 Mississippi River flood and represents historical data (McConnell et al., p. 313). Plot the discharge versus recurrence interval (RI) on the semi-log grid provided in Attachment 3. Draw a straight line through the plotted points with RI values of 2 or more and use that line to estimate the size of 100-year and 500-year floods for this river measuring station at Keokuk (McConnell et al., p. 313). Describe why your graphical representation of the flood events can be used to estimate the size of 100-year and 500-year floods for this measuring station.

Additional Option for Students Taking Algebra 2:
In addition to plotting the discharge versus RI on the semi-log grid provided, plot the discharge versus RI on traditional graph paper and use that equation to calculate the 100-year and 500-year flood values. Calculate the trendline (line of best fit) equation for each scatterplot either using paper and pencil calculations or using graphing technology, such as a spreadsheet program or a graphing calculator. Compare and contrast the equations that were calculated. Consider whether one scatterplot is more accurate or easier to calculate. Using your scatterplots as evidence, construct an argument for which, if either, scatterplot allows for easier estimation of the size of floods for this river.

B. The amount of discharge of a 100-year flood is used by the public to predict whether a home is at risk of flooding (i.e., within the area affected by a 100-year flood) or not at risk of flooding (i.e., outside of the area affected by a 100-year flood). The discharge of the 1993 Mississippi flood at Keokuk, IA, was 446,000 cubic feet/second. Consider the recurrence interval and percent probability of the 1993 flood. Using observations based on your scatterplot, construct an argument for how this natural hazard event is likely to have changed how homeowners decide whether their homes are in danger of flood damage and where builders may decide to construct new homes in the future.

C. Attachment 2 imagines a future where large floods like the 1993 flood on the Mississippi River are more common. Calculate the recurrence interval and percent probability for the past flood events and the seven imaginary future flooding events on the Mississippi River at Keokuk, Iowa for the time range of 1941-2021, an 80-year time range (Attachment 1). Plot the discharge versus recurrence interval (RI) on the semi-log grid provided. Draw a straight line through the plotted points with RI values of 2 or more and use that line to estimate the new size of 100-year and 500-year floods in this imaginary future scenario. Describe why this this line can be used to estimate the 100- and 500-year floods in the future scenario.

Additional Option for Students Taking Algebra 2:
Determine an equation for the future trend line (line of best fit) and use that equation to calculate the 100-year and 500-year flood values. On one semi-log graph, plot the equations for both of the trend lines, and consider the differences between the current trend (from Task Component A) and the possible future trend (from Task Component C). Student also will use this scatterplot for Task Component D.

D. Compare the historical and future semi-log scatterplots and use your observations of the data and trend lines to create an evidence-based prediction for the effect a changing climate could have on the size and frequency of flooding events on Mississippi River at Keokuk, IA, if weather conditions like those that lead to the 1993 become more common. As part of your forecast, make a claim about the rate of climate change in this imaginary future scenario. Describe how the evidence supports your forecast.

E. Climate scientists used historical flood data to calculate the current predicted 100-year flood discharge values for areas all around the world just like you did in Task Component A. They also created global climate models to imagine where flood events are most likely to happen, how large they would be and how often they might occur in the next 100 years as the climate warms. They use these models to calculate a future 100-year discharge value just like you did in Task Component C. Scientists compared the historic and future world 100-year flood data values as you did when you compared your two scatterplots, and the results of the comparison model are shown in Attachment 4.

Use the model results to make an evidence-based forecast about the effects a changing climate could have on the size and frequency of flooding events in different parts of the world. As part of your forecast, make a statement about the rate of climate change predicted by the model (considering the time range chosen for the calculations). Describe how the evidence supports your forecast. In your description, compare your global forecast to the forecast you made for the Mississippi River (considering types of effects and the rate of climate change), and discuss which is more useful in predicting the effects of climate change: data from a single area somewhere in the world (regional data) or global model results.

Alignment and Connections of Task Components to the Standards Bundle

Task Components A and C ask students to calculate flood recurrence interval values for historical annual peak discharge data and for annual peak discharge data of a potential future time range, to plot these data on a semi-log scatterplot, and to estimate the size of 100-year and 500-year floods for historical and future data. Together these partially assess parts (individual practice bullets from Appendix F) of the NGSS practices of **Analyzing and Interpreting Data** and **Using Mathematics and Computational Thinking;** parts (bullets from Appendix G) of the NGSS crosscutting concepts of **Stability and Change** and **Patterns;** and the CCSS-M practices **MP.2** and **MP.4.** By plotting values on a semi-log scatterplot, students are partially assessed on the CCSS-M content standard of **HSS.ID.6,** and by using those scatterplots to estimate the size of a 100-year and 500-year flood, the students are partially assessed on the CCSS-M content standards of **HSN.Q.A.1** and **HSN.Q.A.3.** Plotting and interpreting data in these task components enhance the assessment of the science practices and crosscutting concepts, whereas the scientific context of modeling discharge events enhances assessment of the math standards. *In the Additional Option for Students Taking Algebra 2, students are asked to determine trend line (line of best fit) equations for the data and to compare the data on a semi-log scatterplot with a regular scatterplot, which partially assesses the CCSS-M standards of* ***HSA.CED.2*** *and* ***HSS.ID.B.6a.*** *The advanced option also asks students to plot the trend line equations on a semi-log scatterplot, which partially assesses the CCSS-M standard of* ***HSF.IF.C7.e.***

Task Component B asks students to use the scatterplot they made for the historical data as evidence to construct an explanation for how the 1993 flooding event affected human behavior. This partially assesses the NGSS performance expectation **HS-ESS3-1** by partially assessing parts (bullets from Appendix E) of the associated disciplinary core idea of **Natural Hazards (ESS3.B as it relates to HS-ESS3-1)** and part of the associated crosscutting concept **Cause and Effect.** The task requires the students to consider where the 1993 flood fits within the historical data when making their explanation, which partially assesses parts of the NGSS practices of **Engaging in Argument from Evidence** and **Analyzing and Interpreting Data, Using Mathematical and Computational Thinking,** and the CCSS-M practices of **MP.1** and **MP.3.** By requiring students to use their observations and reasoning to construct an evidence-based scenario, this task partially assesses the ELA/ Literacy standards **W.11-12.1, W.11-12.1.a, WHST.11-12.1**, and **WHST.11-12.1.a**, writing argument.

Task Component D asks students to make an evidence-based forecast for how a changing climate will affect river systems like the Mississippi River. This partially assesses the NGSS performance expectation of **HS-ESS2-2** by partially assessing parts of the practice of **Analyzing and Interpreting Data (as it relates to HS-ESS2-2)** and the disciplinary core idea of **Weather and Climate (ESS2.D as it relates to HS-ESS2-2).** This also partially assesses parts of the NGSS crosscutting concepts of **Stability and Change** and **Cause and Effect.** By using information from data tables and semi-log scatterplots as evidence to support their claim, students are partially assessed on parts of the NGSS practices of **Using Mathematical and Computational Thinking** and **Engaging in Argument from Evidence** and the CCSS-M practices of **MP.1** and **MP.3.** By requiring students to compare scatter plots and use their observations to construct an evidence-based forecast and support their claim, this task partially assesses the ELA/ Literacy standards **W.11-12.1, W.11-12.1.a, W.11-12.1.b, WHST.11-12.1**, **WHST.11-12.1.a**, and **WHST.11-12.1.b**, writing argument.

Task Component E asks students to interpret climate model results to make an evidence-based forecast about the effects climate change will have on river discharge around the world and to compare this forecast with the local forecast they made for the Mississippi River using the data plots, including a comparison of the rate of climate change. This partially assesses the NGSS performance expectation of

HS-ESS3-5 by partially assessing part of the associated practice of **Analyzing and Interpreting Data (as it relates to HS-ESS3-5),** part of the disciplinary core idea of **Global Climate Change (ESS3.D as it relates to HS-ESS3-5),** and part of the crosscutting concept of **Stability and Change (as it relates to HS-ESS3-5).** This also partially assesses parts of the NGSS crosscutting concepts of **Scale, Proportion, and Quantity** and **Cause and Effect;** parts of the NGSS practices of **Developing and Using Models, Analyzing and Interpreting Data,** and **Engaging in Argument from Evidence;** and the CCSS-M practices of **MP.1** and **MP.3.** By requiring students to use model results to construct and support an evidence-based forecast and make informed statements and comparisons about forecasts, this task partially assesses the ELA/ Literacy standards **W.11-12.1, W.11-12.1.a, W.11-12.1.b, WHST.11-12.1**, **WHST.11-12.1.a**, and **WHST.11-12.1.d**, writing argument.

Together, **Task Components A, C, D and E** partially assess the NGSS performance expectation of **HS-ESS3-5.** Through the use of graphical displays of flood data, the interpretation of patterns in the frequency and size of flood events, and development of forecasts for the effect of climate change on flood events using data and model results, the task components are assessing part of the disciplinary core idea of **ESS3.D: Global Climate Change,** and part of the crosscutting concept of **Stability and Change** through part of the practice of **Analyzing and Interpreting Data (as they relate to this performance expectation).** By comparing the forecasts (derived from the data), including a comparison of rates of climate change and the types of change in flood size and frequency, and by considering the effectiveness of regional data versus climate models in understanding the effects of climate change, students completing the task components are integrating the disciplinary core idea with the crosscutting concept and the practice.

Evidence Statements

Task Component A

- Students calculate the recurrence interval and percent probability for the historic flood events on the Mississippi River.
- Students plot the historic discharge and recurrence interval data on the semi-log graph, and draw an increasing, straight trend line (line of best fit) through the data points.
- Students use the trend line to estimate the discharge amount for 100-year and 500-year flood events for the historic data.
- Students describe that the mathematical representations of the discharge and recurrence interval illustrate a pattern of change, which allowed them to estimate the value at the measuring station.
- *Additional Option for Students Taking Algebra 2 (includes all of the following):*
    - *Students plot the historic discharge and recurrence interval data on the traditional graph paper (non-log scatterplot), and draw a nonlinear trend line (line of best fit) through the data points.*
    - *Students derive an equation that models the nonlinear trend line on the non-log scatterplot.*
    - *Students derive an equation that models the straight trend line (line of best fit) on the semi-log plot.*
    - *Students use the trend line equation(s) to calculate discharge amounts for the 100-year and 500-year floods.*
    - *Students construct an argument, including a claim as to which scatterplot (non-log versus semi-log) allows for easier estimation of the size of floods for this river*

- *Students identify and describe interpretations of the scatterplots as evidence for the claim.*
- *In their argument, students include a line of reasoning that compares the data presentation and equations of the two scatterplots*
- *In their argument, students evaluate the data presentation and equations of the two scatterplots for their relevance and sufficiency to support their claim.*

Task Component B

- Students use the trend line to estimate the recurrence interval and percent probability for a flood with discharge of 446,000 cubic feet/second.
- Students make a specific claim or claims for how the 1993 flood is likely to have had effects on how homeowners and builders make decisions regarding 1) whether existing homes are in danger, and 2) where new buildings should be constructed in the future.
- In support of their claim, students identify and describe evidence from the scatterplots, including that the 1993 flood had a greater discharge than the historic 100-year flood.
- Students describe the utility of the historical 100-year flood map in predicting flood damage given the 1993 flood
- Students evaluate the utility of both the historical 100-year flood map and the 1993 flood data in determining flood risk
- Students make a connection between the size of the flood and the area of land affected by the flood (i.e., the larger the discharge value, the greater the area of land affected)
- Students synthesize the evidence and evaluation to argue, with logical reasoning, that the 1993 flood likely changed homeowners' and builders' attitudes towards using the historical 100-year map for predicting damage likelihood and building sites.

Task Component C

- Students calculate the new recurrence interval and percent probability for the past and imaginary flood events on the Mississippi River.
- Students plot the "future" discharge and recurrence interval data on the semi-log graph, and draw an increasing, straight trend line (line of best fit) through the data points.
- Students use the trendline to estimate the discharge amount for 100-year and 500-year flood events for the future data.
- Students use algebraic thinking to describe why the trendline predicts the discharge amount for the future data.
- *Additional Option for Students Taking Algebra 2 (includes all of the following):*
    - *Students derive an equation that models the straight trend line (line of best fit) on the semi-log plot.*
    - *Students use the future trend line equation to calculate discharge amounts for the 100-year and 500-year floods.*
    - *Students plot the historic and future trend line equations on one semi-log graph.*

Task Component D

- Students create a forecast that makes a prediction for how the size (discharge) and frequency (recurrence interval) of flood events along the Mississippi River will change in response to a changing climate.
- In their forecast, students include a statement about the rate of climate change in the imaginary future scenario that relates the rate to those observed in the scatterplots.
- Students describe evidence that supports the forecast, citing and justifying at least one of the

following as supporting evidence of the prediction:
  - A comparison of the historical and future trend lines, describing what those trendlines mean in terms of climate change and predicted patterns
  - The difference in the size (discharge) of a flood with a specific recurrence interval (e.g., the 100-year flood) between the historical and future scatterplots
  - The difference in the recurrence interval (or percent probability) for a flood of a specific size (one discharge value) between the historical and future scatterplot
- Students reason that the evidence from the flood data and scatterplots illustrate patterns, caused by changing climate, that can be extrapolated to predict the likelihood of future events in their forecast.
- Students show reasoning (written or oral) that as the rates of climate change increase or decrease, flood event frequency will reliably change accordingly.

Task Component E

- Students create a forecast that makes a prediction for how the size and frequency of flooding around the world will change in response to the changing climate described in the models.
- In their forecast, students identify at least one increase and at least one decrease in size and frequency of flooding as effects of the changing climate described in the models.
- In their forecast, students include a statement about the rate of climate change predicted by the model.
- As evidence for their forecast, students cite patterns in the model results for the difference in the actual amount of discharge for a 100-year flood or the percent increase or decrease in the size of a 100-year flood in a warming climate.
- Students make a statement about the difference in the rate of climate change between the Mississippi River forecast and the global forecast.
- Students make a statement about the difference in the nature of flooding between the Mississippi River forecast and the global forecast.
- Students make an evidence-based statement about the usefulness of regional data in comparison to global model results for predicting the effects of climate change.

Attachment 1. Historical Flood Data Chart

RI = (N+1)/rank, where N = number of years; P = (1/RI)*100

Rank	Year	Discharge (ft^3/s)	Recurrence Interval (RI)	% probability (P) of a flood of this magnitude occurring within any given year
1	1973	344,000	50	2.00
2	1965	327,000	25	4.00
3	1960	289,500	17	5.99
4	1986	268,000		
5	1951	265,100		
6	1974	260,000		
7	1979	257,000		
8	1944	256,000		
9	1952	253,800		
10	1969	253,000		
11	1975	252,000		
12	1947	245,700		
13	1986	241,000		
14	1948	233,600		
15	1982	225,000		
16	1962	224,100		
17	1983	224,000		
18	1946	223,300		
19	1967	221,200		
20	1976	214,000		
25	1972	192,000		
30	1954	181,400		
40	1970	140,000		
49	1977	79,800		

Attachment 2. Hypothetical Future Flood Data Chart

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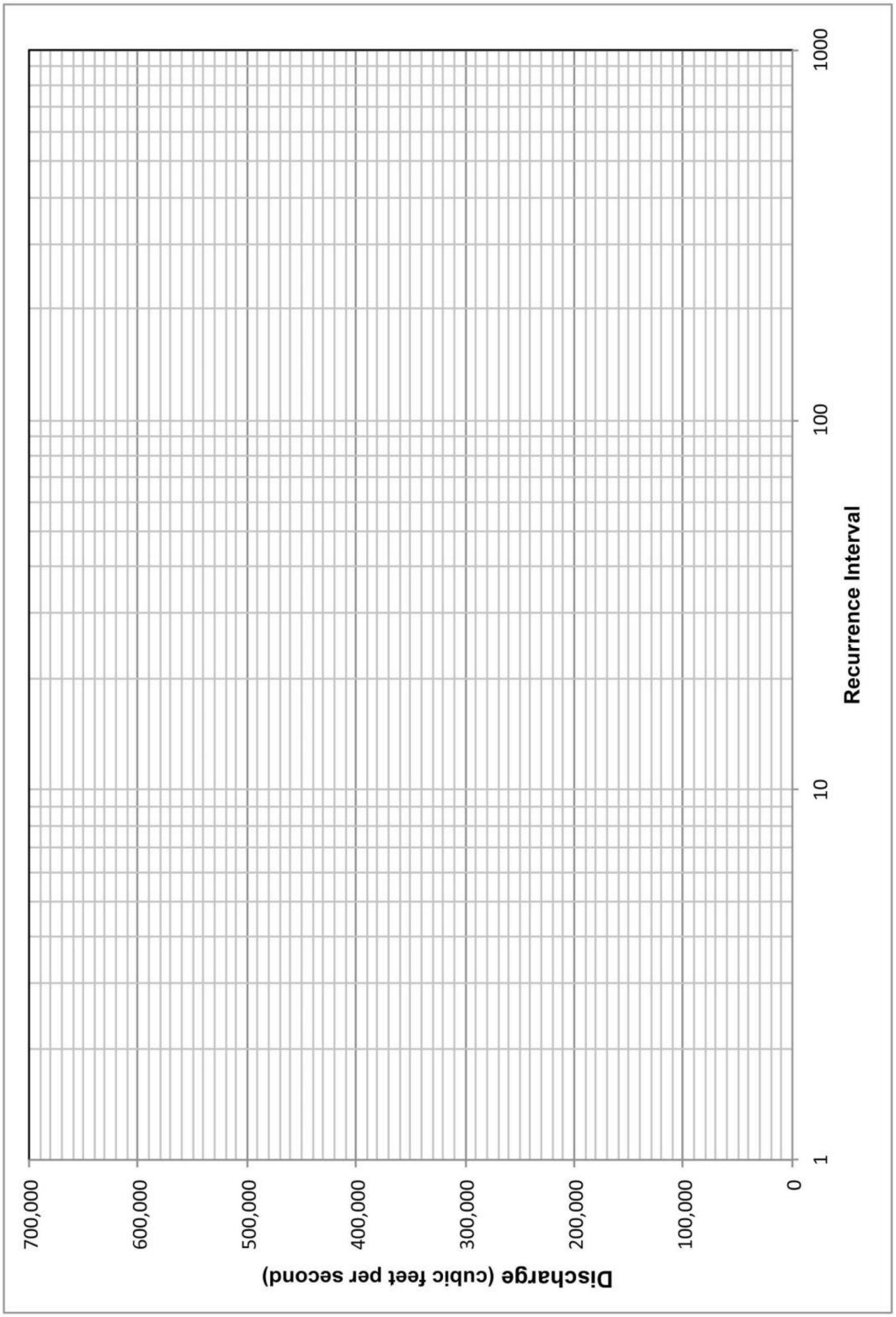
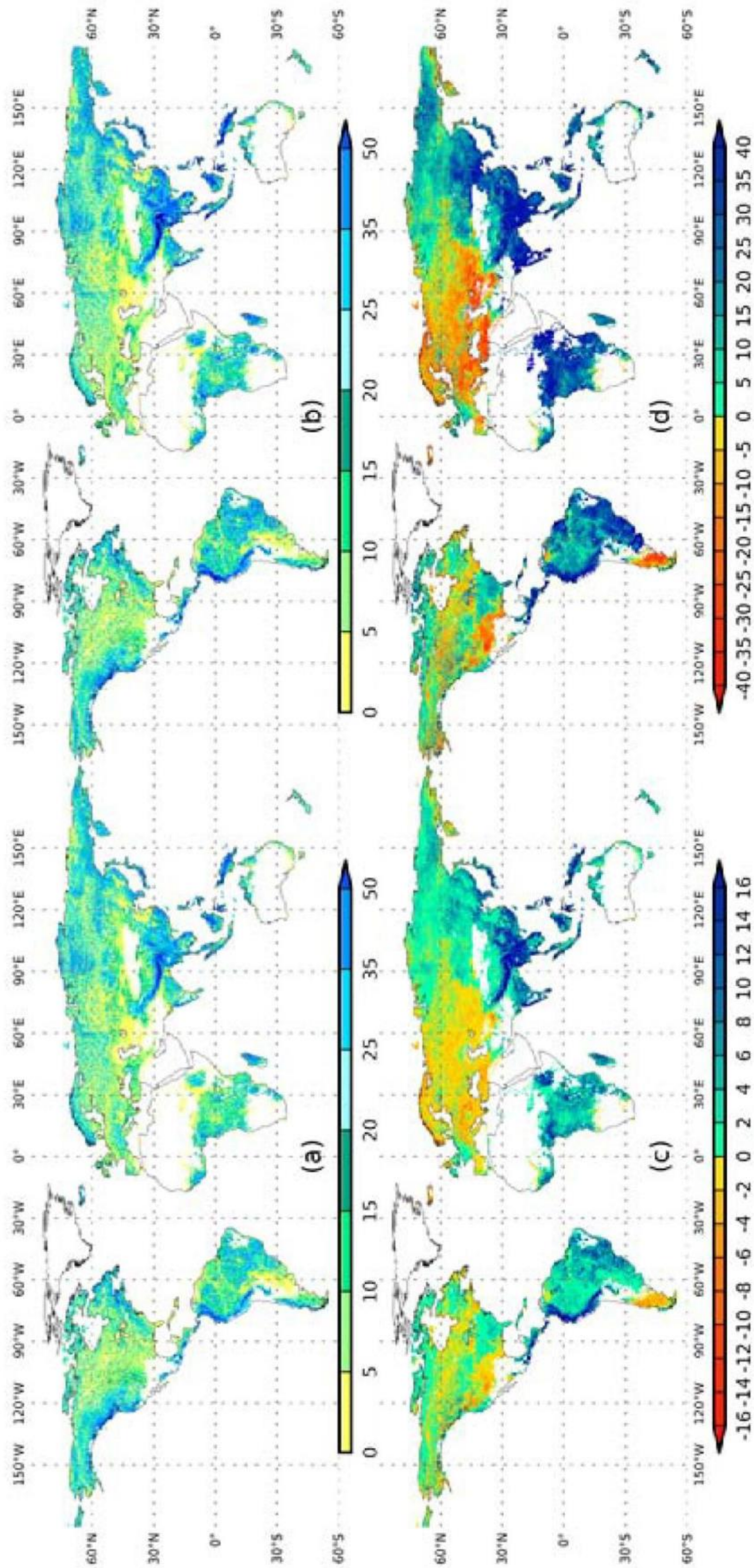
Rank	Year	Discharge (ft^3/s)	Recurrence Interval (RI)	% probability of a flood of this magnitude occurring within any given year
1	1993	446,000	81.0	1.2
2	Future Severe Storm	400,600	40.5	2.5
3	Future Severe Storm	369,000	27.0	3.7
4	Future Severe Storm	351,000		
5	1973	344,000		
6	1965	327,000		
7	Future Severe Storm	316,000		
8	Future Severe Storm	300,500		
9	Future Severe Storm	291,000		
10	1960	289,500		
11	Future Severe Storm	275,000		
12	1986	268,000		
13	1951	265,100		
14	1974	260,000		
15	1979	257,000		
16	1944	256,000		
17	1952	253,800		
18	1969	253,000		
19	1975	252,000		
20	1947	245,700		
21	1986	241,000		
22	1948	233,600		

23	1982	225,000		
24	1962	224,100		
25	1983	224,000		
26	1946	223,300		
27	1967	221,200		
28	1976	214,000		
30	1972	192,000		
48	1954	181,400		
49	1970	140,000		
78	1977	79,800		

Attachment 3. Semi-log Graph

Note: Teachers may choose to have their students design their own plots rather than be given the plot below.





Attachment 4. Global Climate Model Results

Model results show:

(a) the amount of discharge (mm/day) associated with a 100-year flood for historical data (1971–2000), and

(b) the amount of discharge (mm/day) associated with a 100-year flood for future model data (2071–2100).

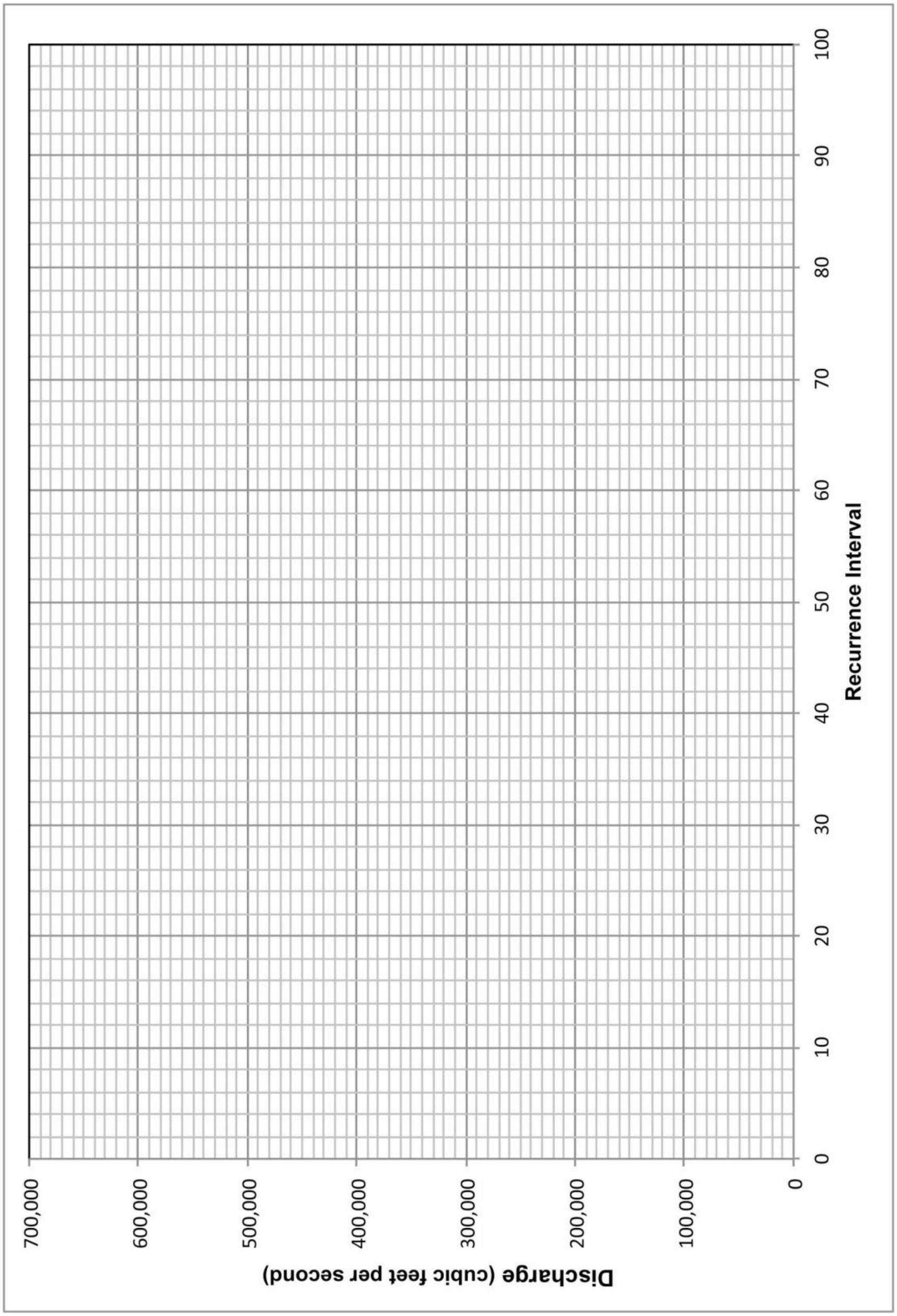
Comparison of the two models show:

(c) the difference in the actual amount of discharge for a 100-year flood (mm/day), and

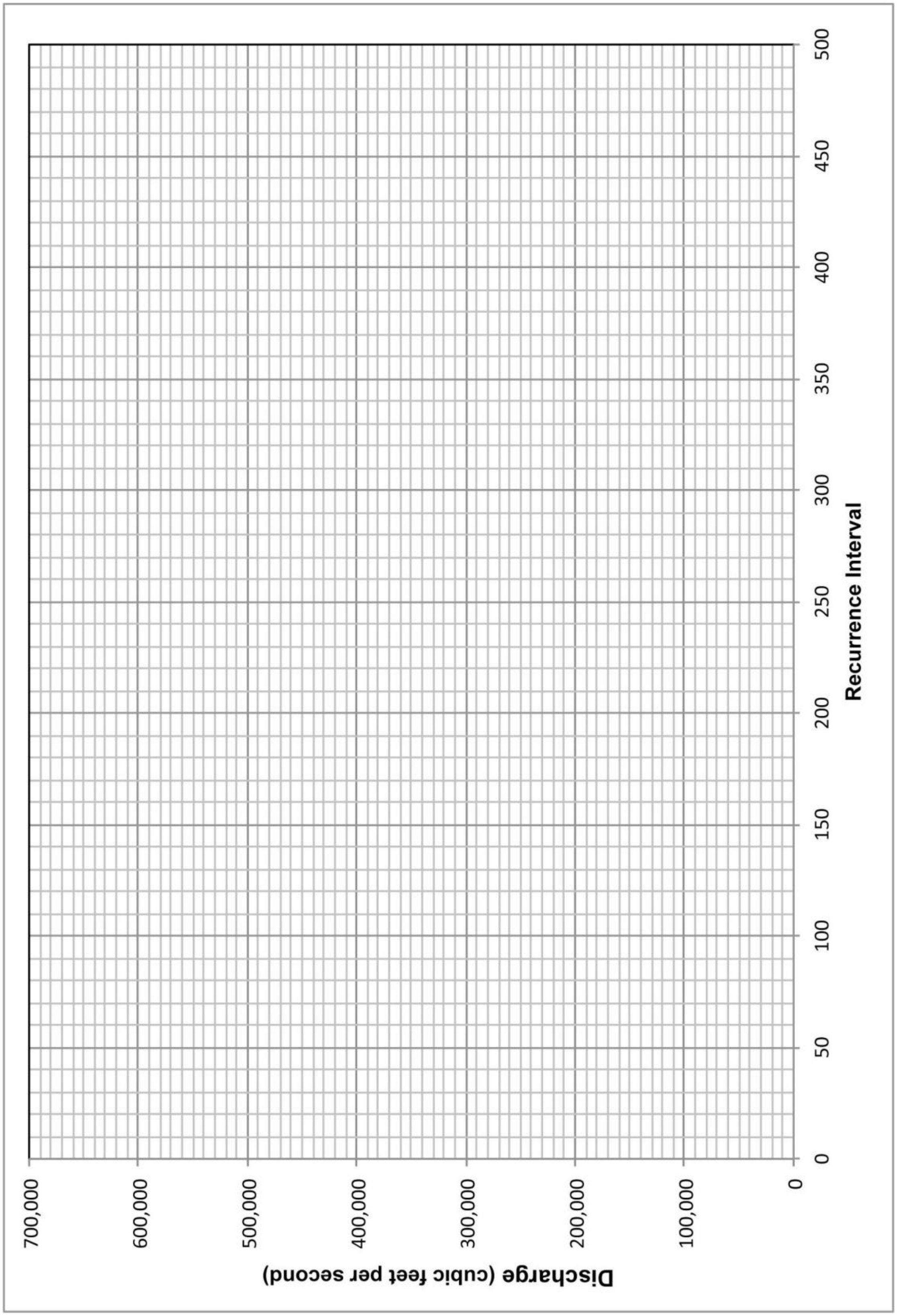
(d) the percent increase or decrease in the size of a 100-year flood in a warming climate.

This image is Figure S4 from the supplementary material for the following paper:
Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., and Kanae, S. (2013). Global flood risk under climate change. Nature Climate Change, *3, 816–821. The image is used with permission from the authors.*

Attachment 5. Graphs for Additional Option for Students Taking Algebra 2

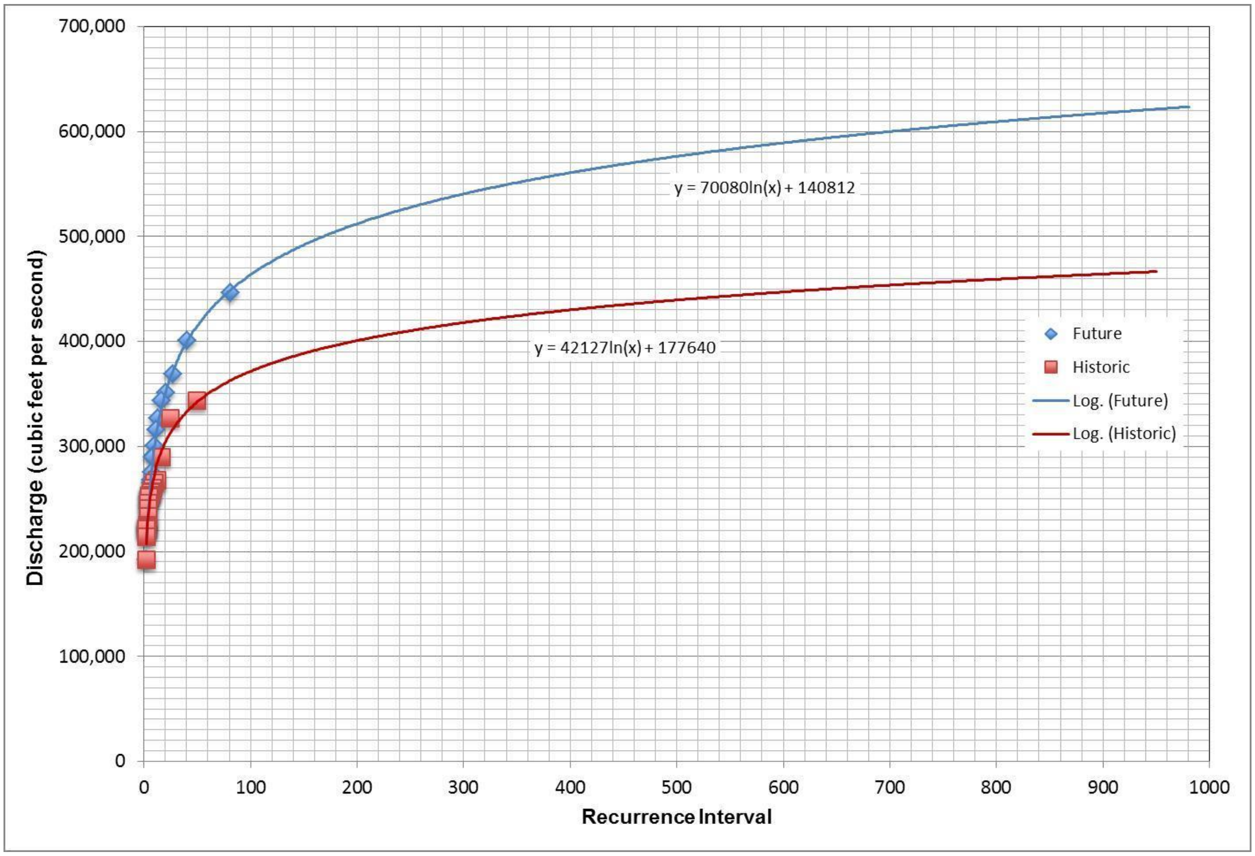


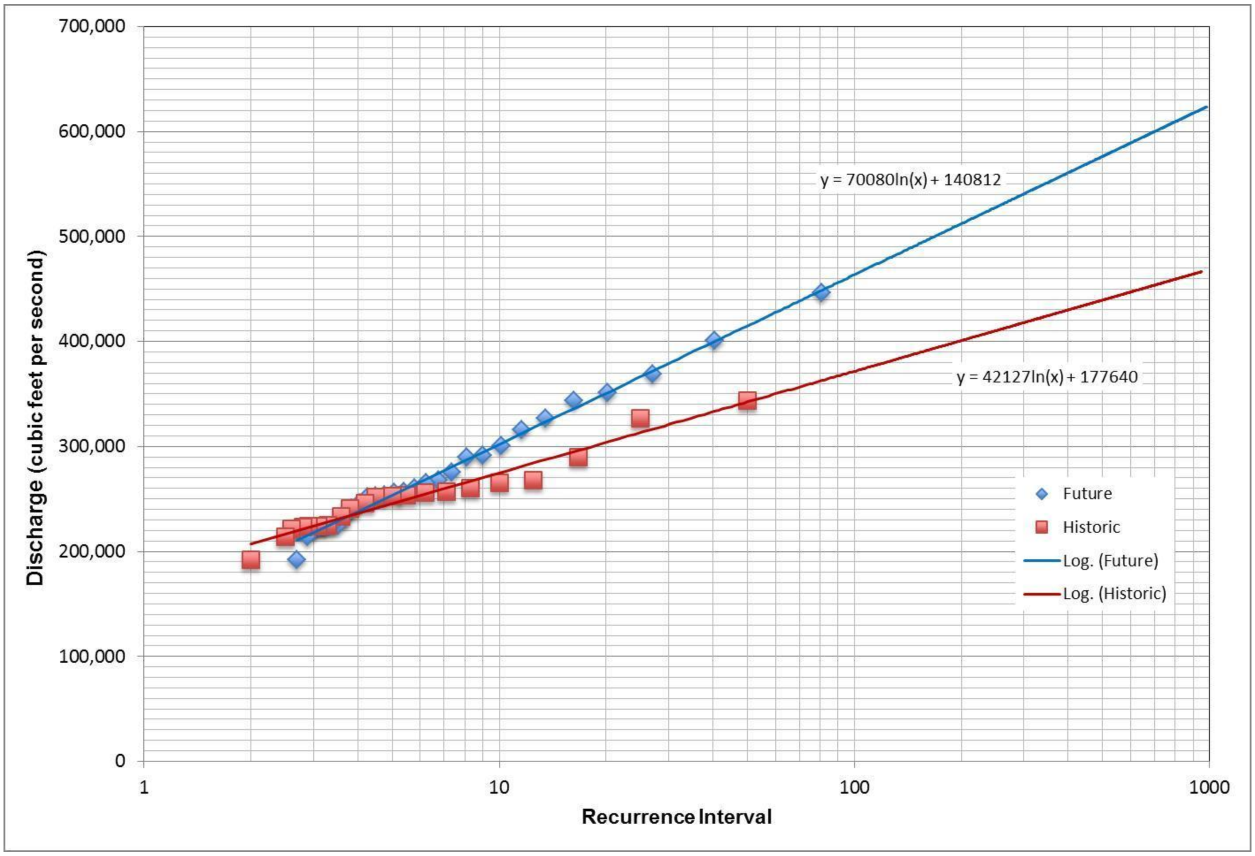
Note: Teachers may choose to have their students design their own plots rather than be given the plot.



Note: Teachers may choose to have their students design their own plots rather than be given the plot.

Sample Answer Scatterplots




700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Discharge (cubic feet per second)
1
10
100
1000
Recurrence Interval
y = 70080ln(x) + 140812
y = 42127ln(x) + 177640
Future
Historic
Log. (Future)
Log. (Historic)