

Mathematics for Sustainability

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Penn State

JMM

Jan 19, 2019



John Roe

Oct 6, 1959 – Mar 9, 2018

Penn State's General Education Objectives

In Quantification (GQ) fields, students practice and master basic mathematical and statistical skills of **lifelong value** in solving **real world problems**.

–Penn State's Updated Learning Objectives

- *Mathematical Mindsets*, interview with Jo Boaler



Steven Strogatz

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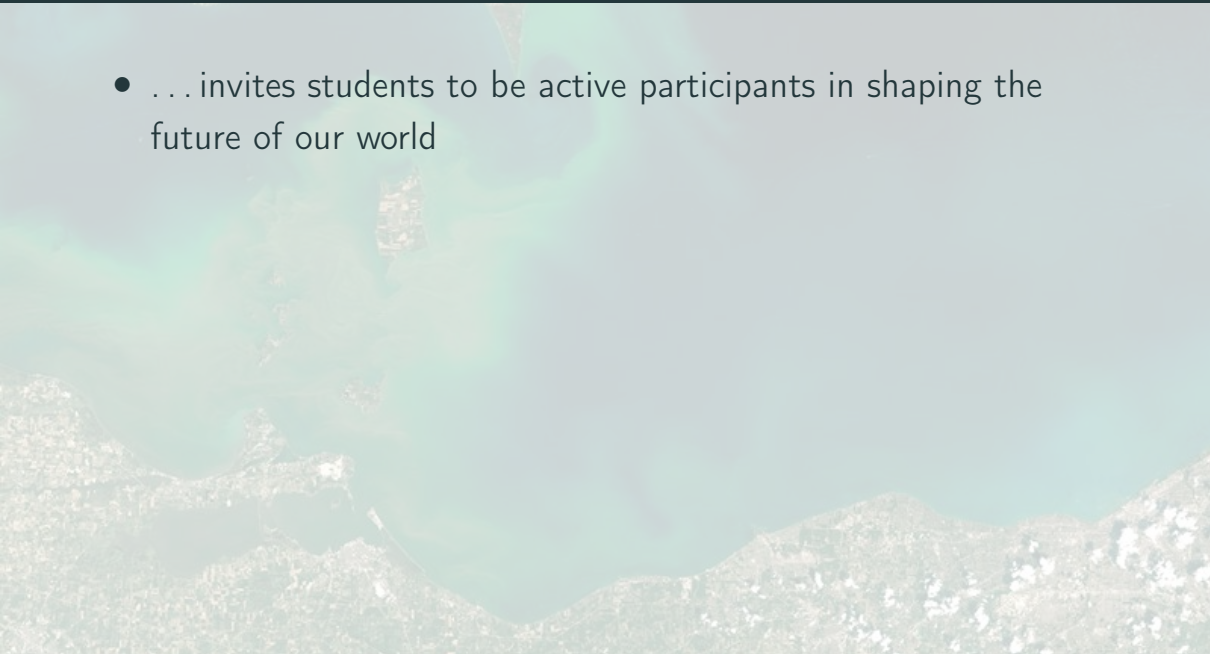
- *Mathematical Mindsets*, interview with Jo Boaler
- “Think about how many people hate mathematics.”
- Many students are not well served.
- “We need a math revolution.”



Steven Strogatz

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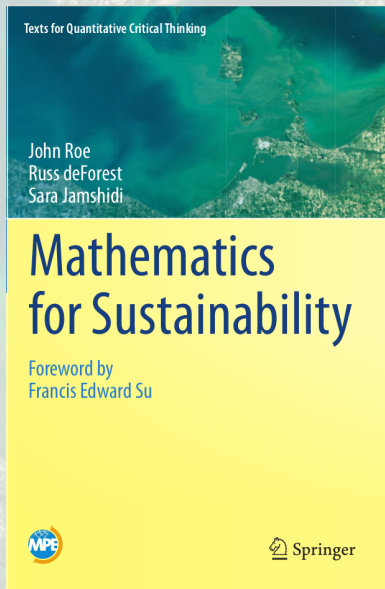
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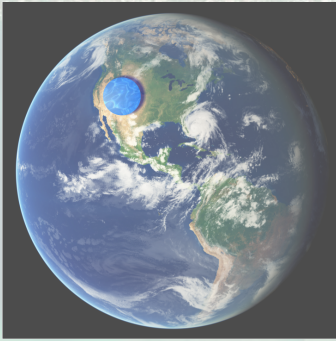
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- ...develops quantitative skills that can help students be more effective advocates for the things they care about



- **Mathematics for Sustainability**, Springer (May, 2018)
- Also available electronically through SpringerLink

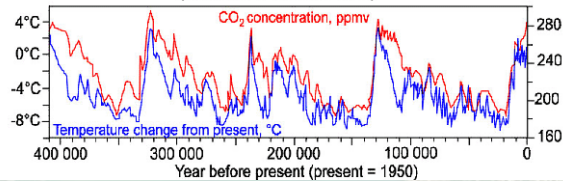


Water



Energy

Temperature and CO₂ levels in the atmosphere over the past 400 000 years
(from the Vostok ice core)



Climate

- Oct, 2015 landslide



- Oct, 2015 landslide
- 180 million tonnes of debris



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- That's about "90 million midsize SUVs".
- Question: How would you put the size of this landslide in familiar terms?



One Solution



- Niagara Falls flow rate:

One Solution



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- 2800 tonnes/sec

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- How long for a similar mass of water to go over Niagara Falls?

One Solution



- Niagara Falls flow rate:
- 2800 tonnes/sec
- Landslide lasted 1 min
- How long for a similar mass of water to go over Niagara Falls?
- About 18 hours.

- 180 million metric tons of debris
- 600 foot high wave
- Fourth largest tsunami recorded in the past 100 years



Unit-Factor Method

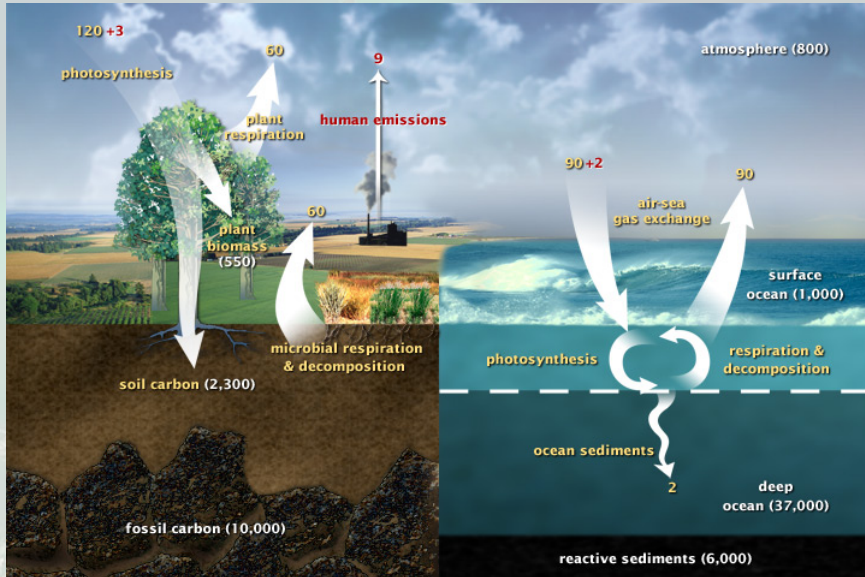
Estimate total carbon-dioxide emissions from round-trip travel to a Penn State football game.

$$100,000 \frac{\text{people}}{\text{game}} \times \frac{1 \cancel{\text{vehicle}}}{4 \text{ people}} \times \frac{300 \cancel{\text{miles}}}{1 \cancel{\text{vehicle}}} \times \frac{1 \cancel{\text{gallon}}}{15 \text{ miles}} \times \frac{20 \cancel{\text{lbs}}}{1 \cancel{\text{gallon}}} \times \frac{1 \text{ ton}}{2000 \cancel{\text{lbs}}}$$
$$= \frac{100,000 \times 300 \times 20}{4 \times 15 \times 2000} \frac{\text{tons}}{\text{game}} \approx 5000 \frac{\text{tons}}{\text{game}}$$

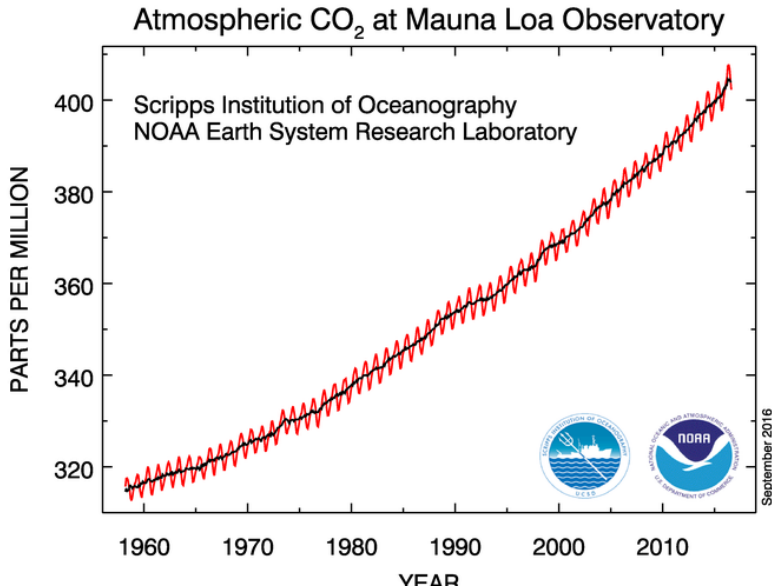
Making Effective Comparisons

- 5000 tons of carbon-dioxide emissions
- Avoided emissions from 1 wind turbine running one year
- Avoided emissions from switching 150,000 incandescent bulbs to LEDs (annual).
- Avoided emission from recycling 1700 tons of waste
- Carbon sequestered by 5000 acres of forest in one year.
- See the [EPA Greenhouse Gas Equivalencies calculator](#)

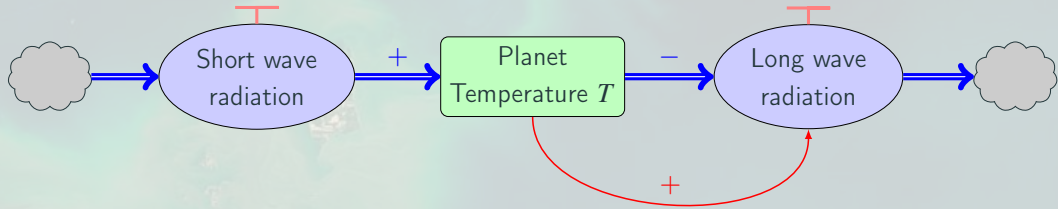
Dynamic Equilibrium



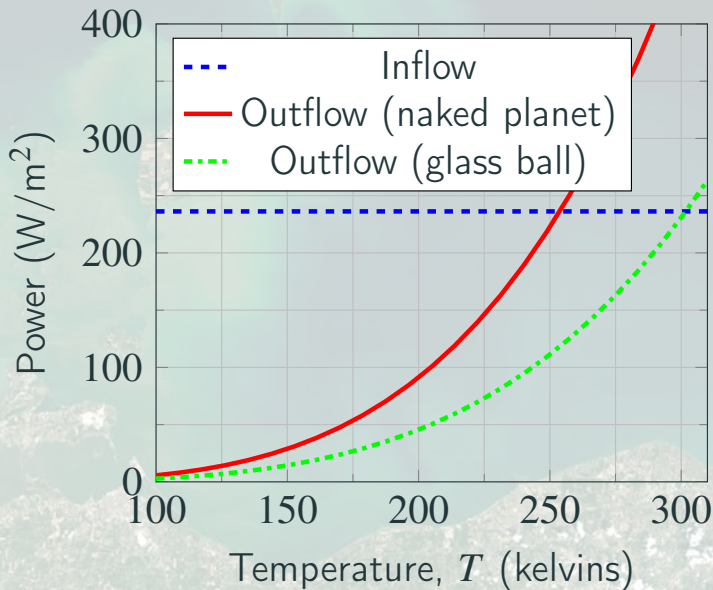
Out of Equilibrium



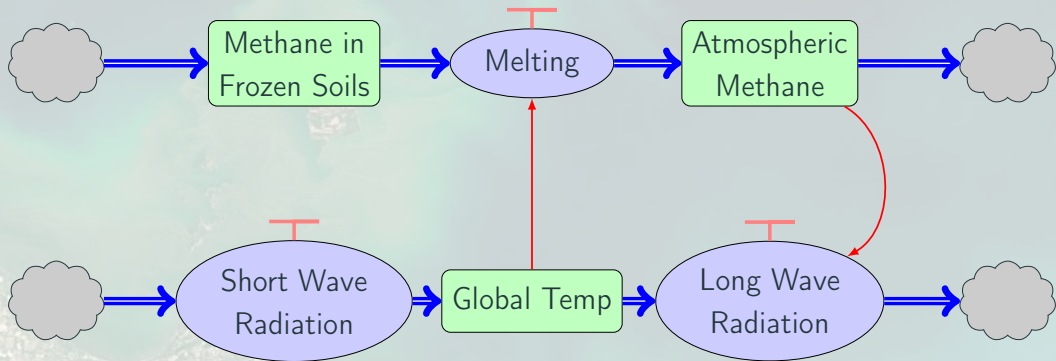
Earth's Energy Balance



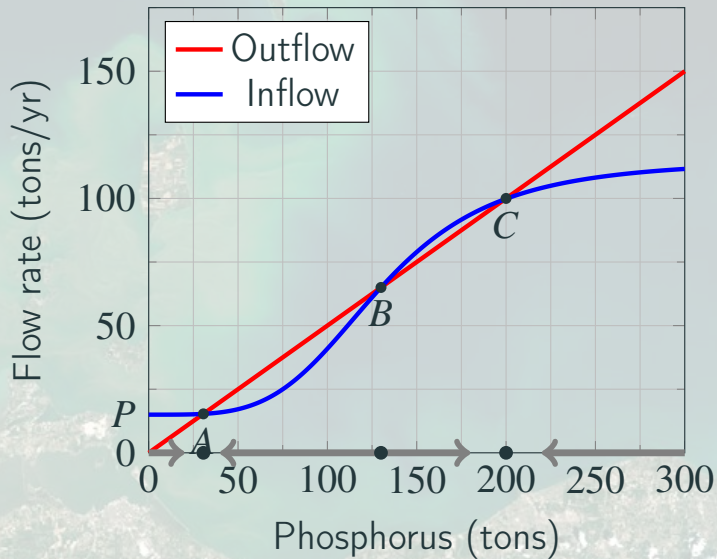
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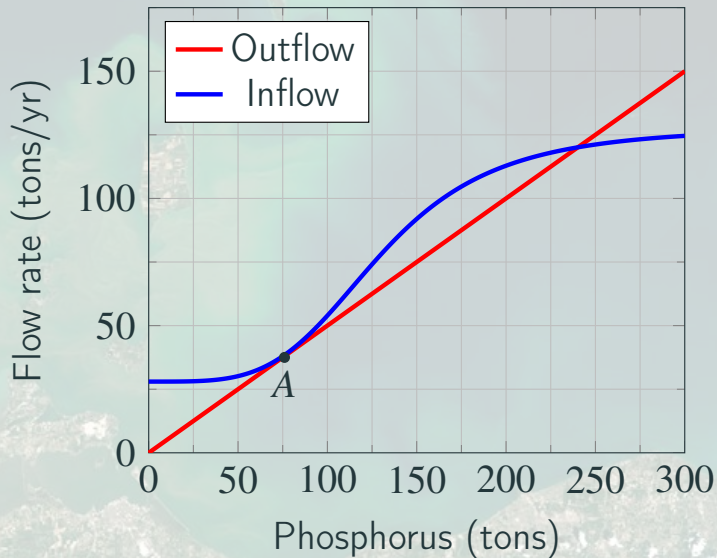
Feedbacks



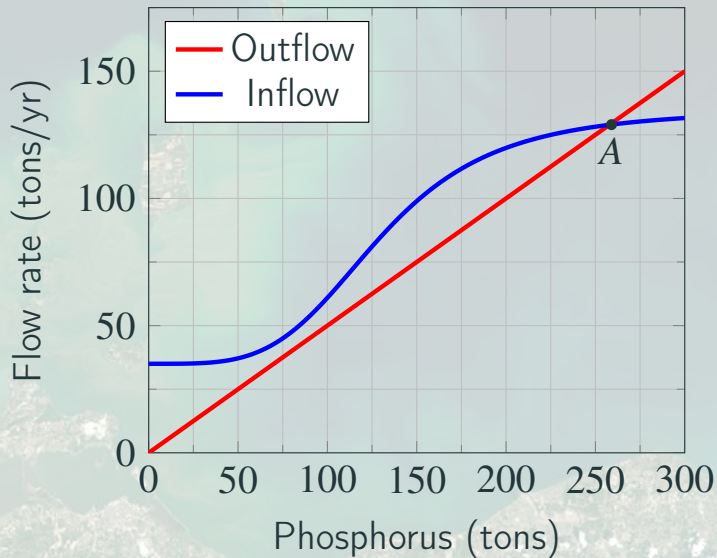
Stability of equilibria



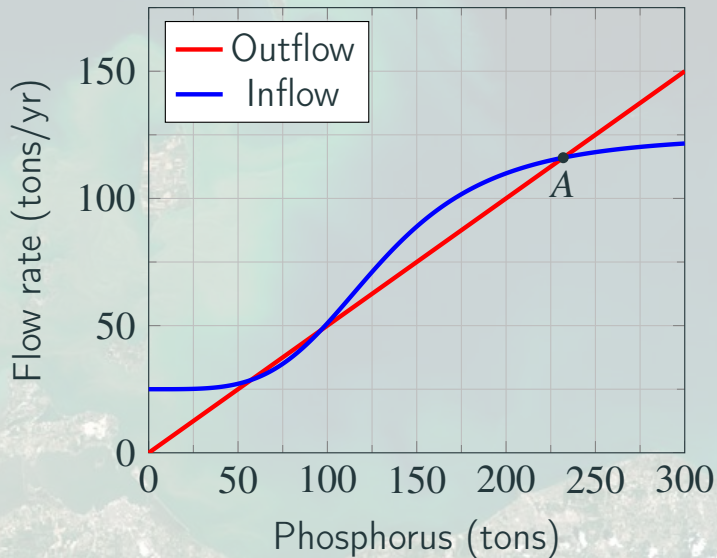
Tipping points and hysteresis



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Tipping points and hysteresis



Homophily in Networks

Group	Percentage Response			
Level of Concern	None	Low	Medium	High
Overall sample	2%	10%	36%	53%

Concern among Friends				
Friends' Concern				
Own Concern	None	Low	Medium	High
None	5%	11%	37%	47%
Low	2%	12%	36%	50%
Medium	1%	8%	34%	57%
High	1%	5%	27%	67%

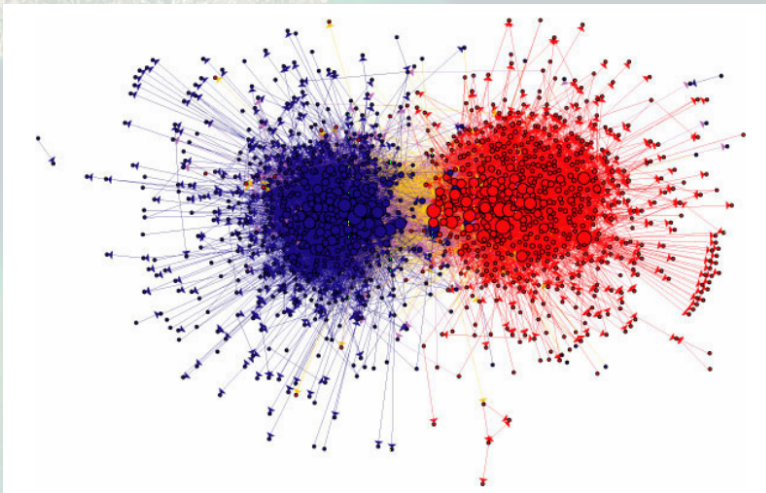
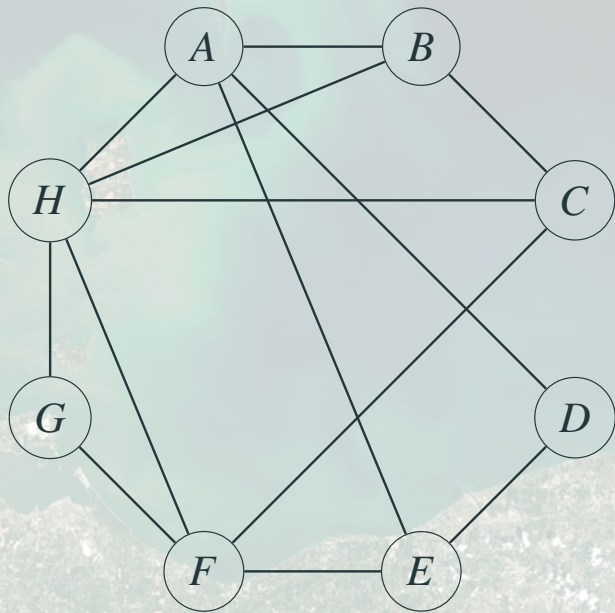
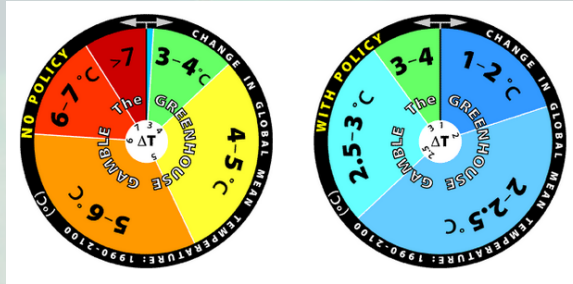


Figure 1: Links between political web pages prior to 2004 U.S. Presidential election.

Information cascade



Uncertainty and Risk

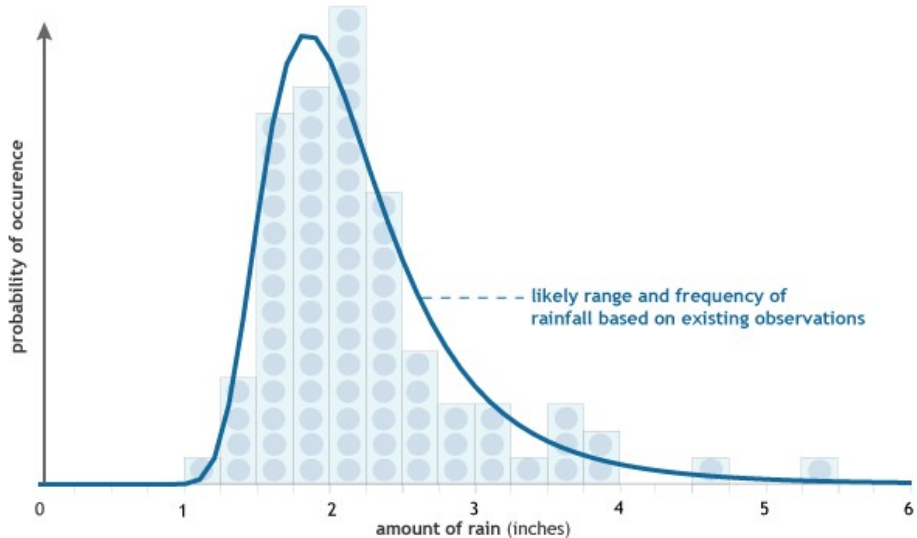


Temperature anomaly	under 3 °C	3-4 °C	4-5 °C	5-6 °C	6-7 °C	7 °C+
Probability (no policy)	0.01	0.12		0.34	0.15	0.09

Temperature anomaly	under 2 °C	2-2.5 °C	2.5-3 °C	3 °C+
Probability (with policy)		0.43	0.27	0.10

What is a 1,000 year storm?

What would 1-day rainfall extremes look like if we had a longer observational record?

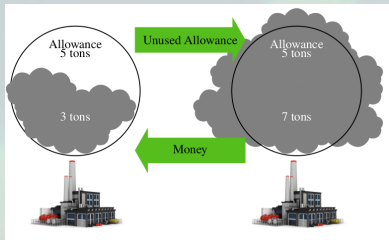


The Stern Review



- The Stern Review: The Economics of Climate Change
- Controversy on discount rates used in assessing future costs of climate change
- Discounting applied over long time horizons involves making an ethical choice

The Tragedy of the Commons



- Game Theory
- Resolving the Tragedy of the Commons
- Cap and Trade
- Revenue Neutral Carbon Taxes

Course Details

- Active learning environment
- Students work in groups, facilitated by undergraduate teaching assistants:
 - Alexa Derago
 - Bethany Barkley
 - Jason Wang

Writing Assignments

- **In the News:** Blog posts connecting current events or news with themes of course
- **Make an Estimate:** Personal estimates of water use, energy use, greenhouse gas emissions
- **Critical Response:** refuting or supporting others' arguments with quantitative evidence.
- **Write and Respond Project:** Advocacy or analysis writing piece related to the course, supported by quantitative arguments
- **Reflective writing assignment**

Instructor Resources

- *Mathematics for Sustainability*, Springer
- Rubrics, assignments, exercises, quizzes, slides available by request
- deforest@math.psu.edu

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- “The writing assignments helped us pick topics we were personally interested in and it helped to make it more fun and intriguing.”
- “This is a wonderful course that made me appreciate math and what its impact is on the "real world"
- “I was confused with why there were so many writing assignments for this math course... This is a Gen Ed math course... Only math majors should be writing papers about math.”

Student Feedback

- “I chose this class because I thought it would be an easier math class for me to take because I was not good at quantification, that was the wrong idea. There was nothing easy about this class but in the end, I do feel more confident in my quantitative skills.”

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- “I always feel engaged in the discussions, as well as am excited to think critically on the issues presented in the course.”
- “I never realized I would learn so many interesting topics in a math class ”

An aerial photograph of a large, irregularly shaped lake, possibly a reservoir, surrounded by a mix of green forested land and brownish, cleared areas. The entire image is covered with a semi-transparent teal or light blue overlay, which serves as a background for the text.

Thank You!