Estimating Climate Change Impacts on Water Temperatures for Philadelphia's Water Supply

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March 29, 2022

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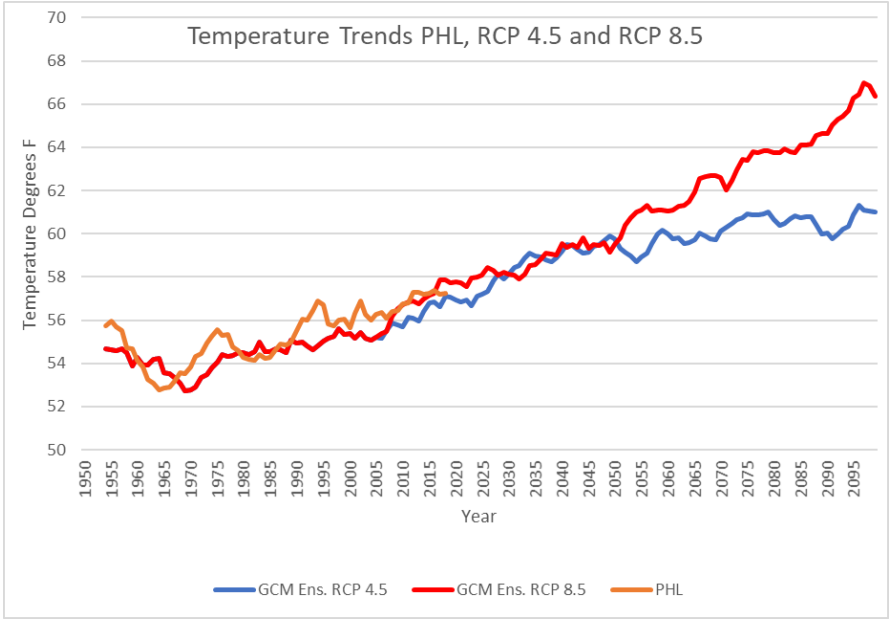
Water Temperature: Some Issues

- Ecological impacts
  - Dissolved oxygen
  - Biodiversity changes
  - Algae blooms
- Water supply impacts
  - Harmful algae bloom
  - Changes to chemical dosing and reaction rates
  - Aesthetic complaints from customers

Climate Change and Water Temperature

- Global Climate Model (GCM) temperature, 1950 - 2099
- Philadelphia Airport, 1950-2020
- End-of-century increase of 4 to 10^{o} Fahrenheit (F)

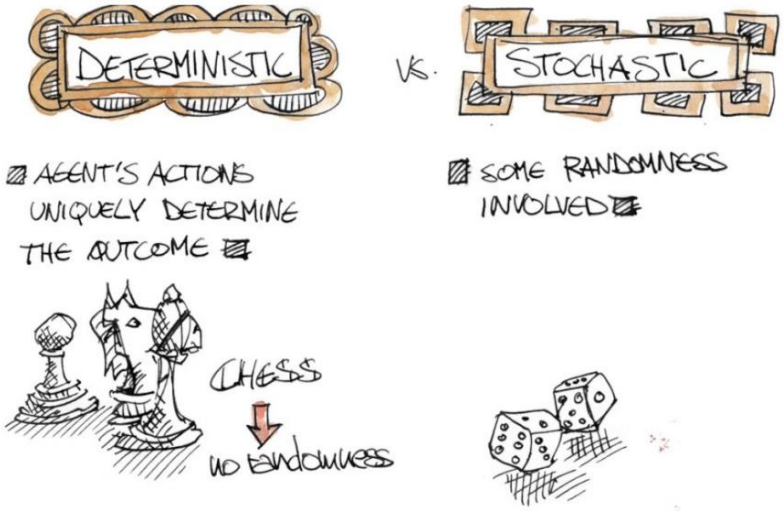
Note: *Temperatures tracking with RCP8.5!*



Air – Water Temperature Modeling

Three types in use:

1. Deterministic models (energy budget approach)
2. Stochastic models
3. Regression models (relies mainly on air temperature data)



Because of the complexity of the complete heat transfer equation, simple regression methods have been the dominant method.

Air – Water Linear Regression Approach

A most widely applied approach to relate air temperature to stream temperature is based on air/stream temperature correlations.

The equation in its simplest form:

$$Ts(t) = A + BTa(t)$$

- **Ts** is the estimated stream temperature in degrees Celsius (C) or F
- **Ta** is the air temperature in degrees C or F
- **A** is a constant in degrees C or F
- **B** is a dimensionless constant
- Can be done on a monthly or daily basis (with or without lag)

Data Sources and Period of Record

- **Three sets of data in the analysis period:** Oct. 1, 2018 – June 8, 2021
- **Water Temperature Data:** USGS Fairmount Dam (degrees Celsius)
- **Flow Data**: USGS Fairmount Dam (cfs)
- **Air Temperature Data:** Philadelphia Airport (degrees Celsius)

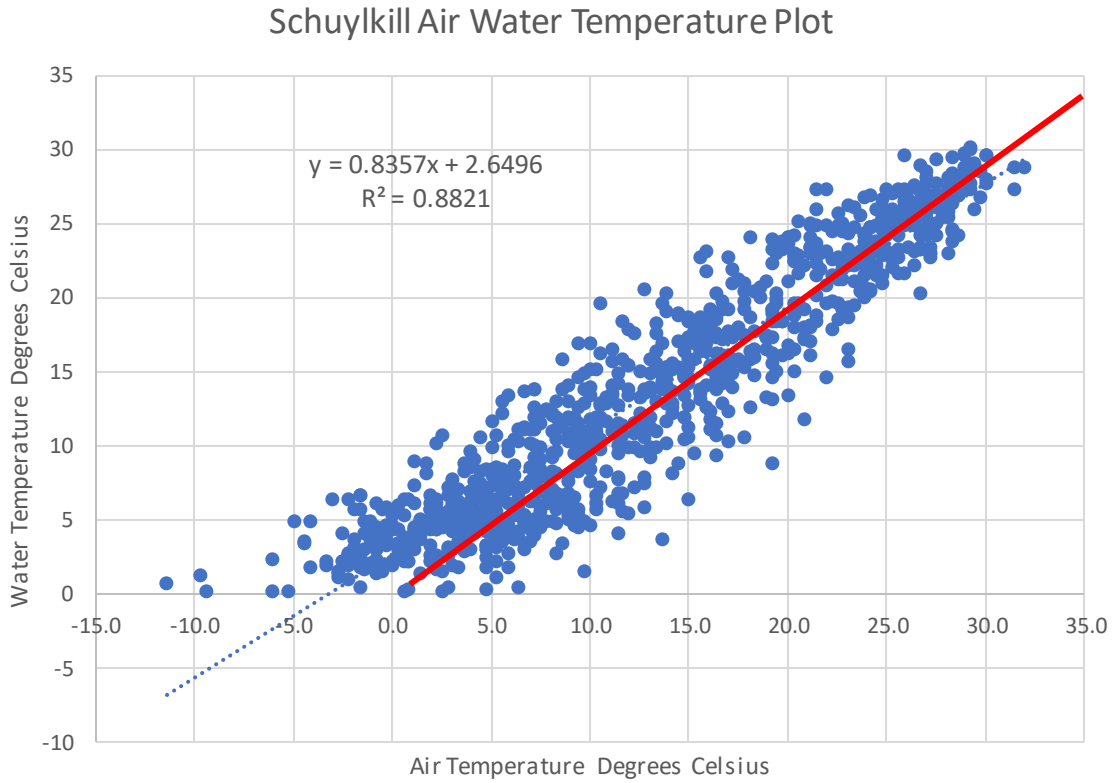
Three Approaches Tested

- Single variable regression of air temperature to water temperature
- Single variable regression of air temperature to water temperature with one-day lag
- Multi-variable regression of air temperature plus flow to water temperature with air temperature below freezing set to 0º Celsius

Regression Statistics	
Multiple R	0.94349
R Square	0.890173
Adjusted R Square	0.889946
Standard Error	2.737926
Observations	970

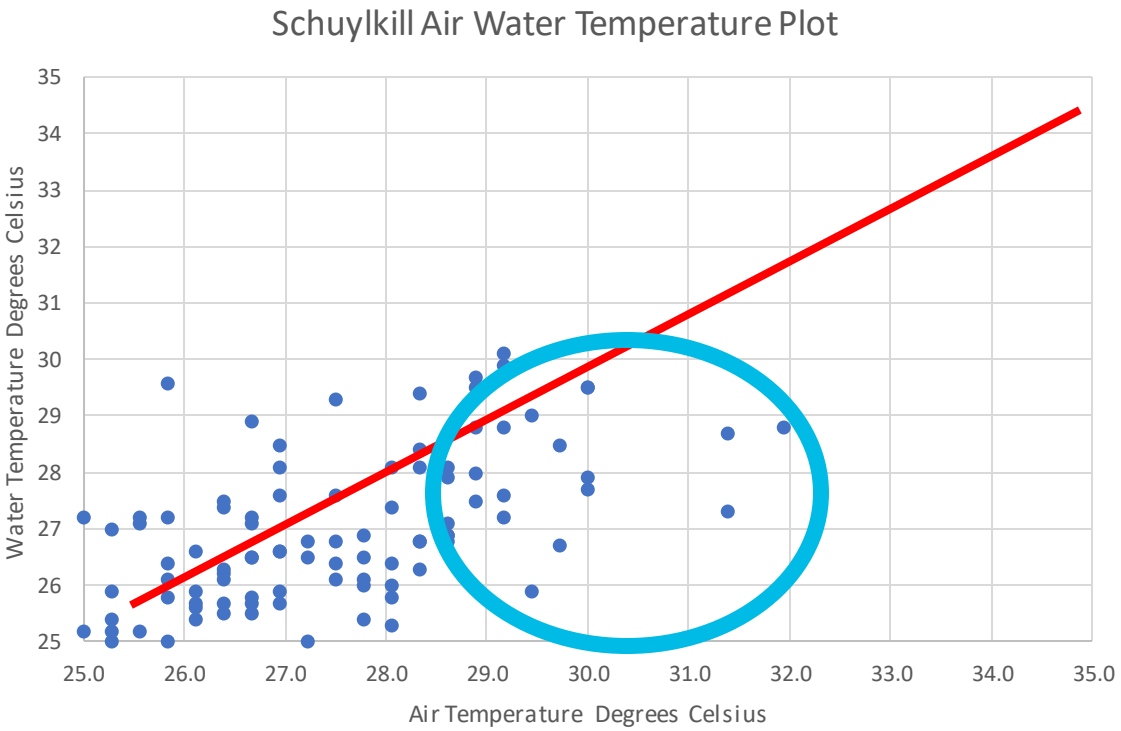
Air-Water Temperature Plot

- 56% of the days, the water temperature is above the air temperature
- 44% of the days, it is below the air temperature
- Linear regression is clearly applicable



Higher Air-Water Temperature Plot

- At higher temperatures, evaporation can suppress water temperature
- Possible effect seen here



Regression Results for Three Approaches

Data Used: USGS Fairmount Dam Water Temp. and Flow Data; PHL Airport Air Temperature Data	Temperature in degrees Celsius						Air or Air/Flow To Water Temperature		Fairmount Dam to Regressed Water	
Regression Tests Runs	Max Air	Max Water	Min Air	Min Water	Mean Air	Mean Water	Correlation R	R^2	Correlation R	RMSE
All Queen Lane Data with anomalies removed	33.6	33.8	-13.1	0.0	13.7	14.9	0.91	0.83	0.91	3.6
Fairmount Dam Data regressed to PHL Air Temp.	31.9	30.1	-11.4	0.1	12.9	13.4	0.94	0.88	0.94	2.8
Fairmount Dam Data regressed to PHL Air Temp. with 1-day lag	31.9	0.9	-11.4	0.1	12.9	13.4	0.92	0.84	0.92	3.3
Fairmount Dam Data regressed to PHL Air Temp (sub-zero adjusted to zero) plus Fairmount Dam Flow Data	31.9	30.1	0.0	0.1	13.1	13.5	0.94	0.89	0.94	2.7

From Data Regression to Projections

- The recommended regression equation using PHL air temperature data and Fairmount Dam water temperature data is:

$$Y = 0.8357 * X + 2.65$$

  - **Y** is Schuylkill River water temperature at Fairmount Dam in degrees Celsius
  - **X** is daily average air temperature in degrees Celsius from PHL Airport

- This equation can use Global Climate Model projections of air temperature to project water temperatures

Temperature Projections Using RCP8.5

Projected water temperature:

- 1995-2014 (base period)
- 2050 – 2069
  (mid-century projection)
- 2080 – 2099
  (end-of-century projection)

Some statistics:

- Mean yearly temperature
- Mean monthly temperature
- Number of days above 80°, 85°, and 90°
- Graph of 20-year water for three periods

Projected Monthly Temperature Increases

- Significant increases in the summer
- Temperature increase of 8° F by end of century

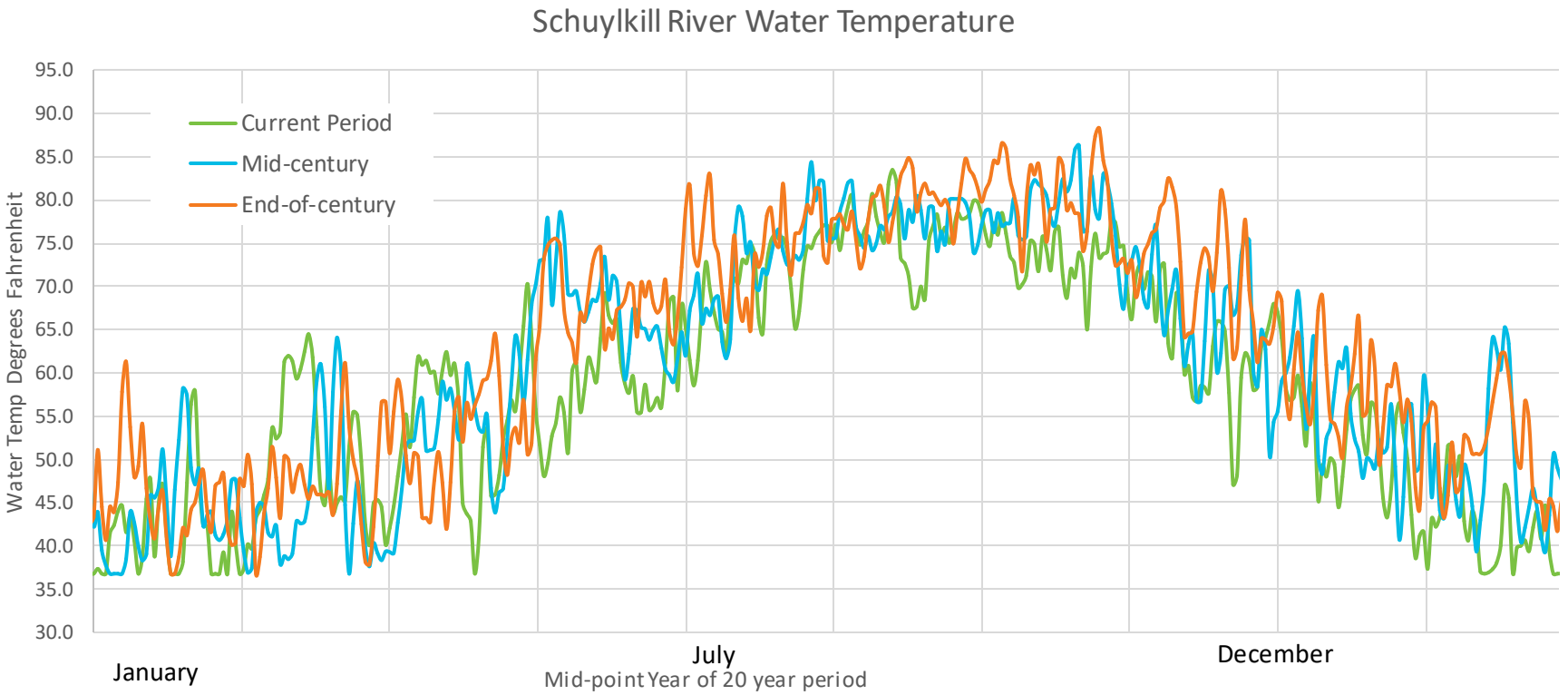
Schuylkill Water Temp (F)			
Parameter	Current	Mid-Century	End-of-Century
Annual Avg.	57.4	60.6	63.2
Jan.	40.6	42.2	44.4
Feb.	42.1	42.9	44.4
Mar.	47.5	49.4	50.9
Apr.	54.7	58.5	59.8
May	62.4	65.7	69.6
Jun.	70.9	75.3	77.6
Jul.	75.8	80.1	83.1
Aug.	74.3	78.2	82.4
Sep.	67.9	72.0	75.7
Oct.	59.0	62.0	65.4
Nov.	50.2	54.7	55.8
Dec.	42.2	45.7	48.6

Extreme Water Temperature Days

- Warm water temperatures by end of century might exceed three weeks
- Potential impacts to water quality presently under review by PWD

Water Temp. (F)	Number of Days per Year Above Temp. Threshold period		
	Current	Mid-Century	End-of-Century
85	0.6	6.1	21.5
90	0	0.4	2.7
95	0	0.05	0.1

Annual Temperature Patterns



Conclusions

- Single Variable Linear Regression highly successful in estimating water temperatures
- Projections using Global Climate Model daily temperature projections though 2100 indicate
  - Up to 8^{o} F summer water temperature increases
  - Significant periods of water temperatures above 80^{o} F
  - Potential impacts to:
    - Treatment chemical use
    - Dissolved oxygen levels
    - Algae blooms and taste and odor concerns