CEVE 101: Project 03

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We begin by loading the required packages.

```
using Revise
using RainwaterHarvesting
```

Line 1

Revise allows us to update code without restarting Julia.

Line 2

We load the RainwaterHarvesting package that contains our simulation tools.

Setting the file path

Next, we specify the path to the rainfall data file and read it in.

```
filepath = "data/14.txt"
rainfall_data = RainfallData(filepath)
```

Line 1

This is the path to the rainfall data file for the station of interest.

Line 2

This creates a RainfallData object containing the rainfall data for the specified station.

```
RainfallData for station: ARARIPE
  Location: -7.2108888888889, -40.136111111111
  Years of data: 44
  Total days: 16066
```

If we dig under the hood a bit, we can see that there are two main pieces of information:

- station_info: a dictionary containing information about the station, such as its name and location.
- annual_data: a dictionary mapping years to AnnualRainfallData objects, each containing the date and precipitation data for a given year.

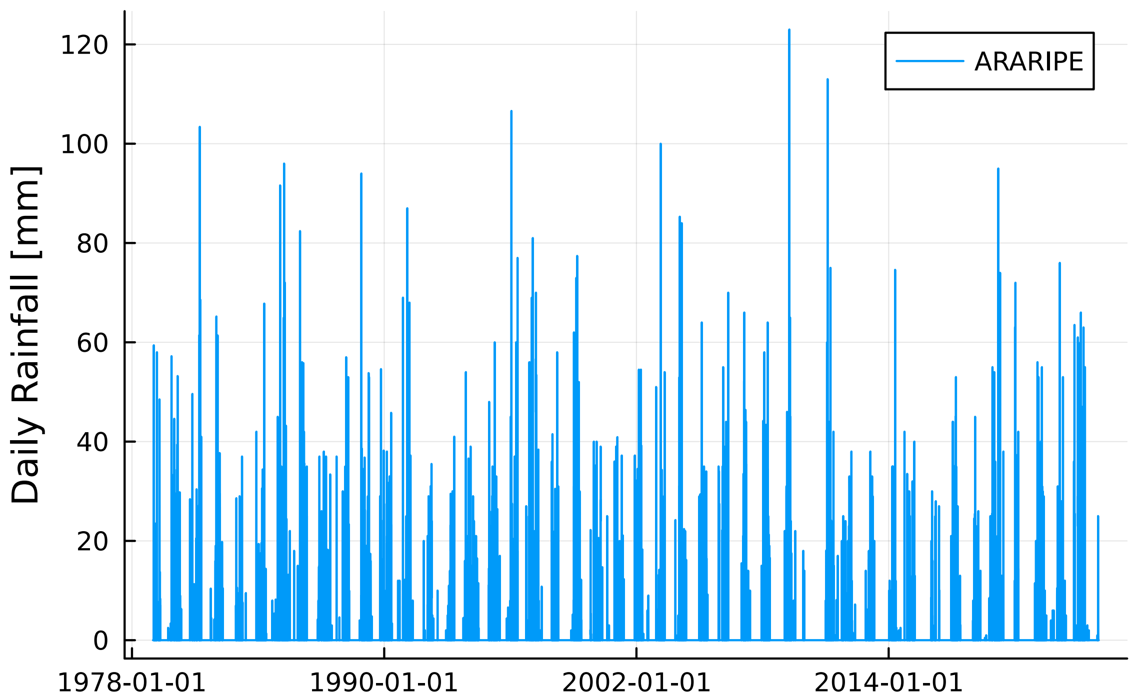
Plotting the Data

We can plot the data for one or all of the years to verify that it looks correct.

```
plot(rainfall_data)
```

Line 1

This `plot` function is defined in viz.jl and is a thin wrapper around the Plots.jl package.



Discussion

Select a different station (not 1.txt) from the data folder. Update the filepath variable to point to your chosen station. Repeat the steps provided to load and plot the data for your station. Identify which years are kept after data cleaning. Discuss whether the available data is sufficient for meaningful risk assessments. Research the years of major droughts in Ceará, Brazil. Determine if your data includes these years. Discuss the implications of missing data during drought years on your analysis. Use the provided Discussion section.

1. Identify which years are kept after data cleaning. 44 years are kept after data cleaning.
2. Discuss whether the available data is sufficient for meaningful risk assessments. The available data is sufficient for meanginful risk assessments. It includes over four decades of data, which should provide valuable insights into how rainfall changed over years in that region of Brazil.
3. Research the years of major droughts in Ceará, Brazil. The state of Ceará, Brazil has historically dealt with droughts. The most serious droughts occurred in the 1800s after which water

infrastruture has been improving. Some notable droughts that have occurred were through 2012-2016,

Sources: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023WR036411 https://piahs.copernicus.org/articles/385/225/2024/ 4. Determine if your data includes these years. My data includes the years 1980 until around 2020. 5. Discuss the implications of missing data during drought years on your analysis. Use the provided Discussion section. Missing data from the 1800s could cause an underrepresentation of the extremity of droughts that occur in the Ceará region. It can also prove to be a challenge for calibrating models to predict rainfall and simulate how impactful future droughts will be. Having data for drought years would also help with contextualizing the current state of water infrastructure and water security in Ceará, Brazil. ## Understanding the Theoretical Model

Let's explore the model that simulates the rainwater harvesting system.

Mass Balance Equation

The mass balance model for the rainwater tank is given by:

$$V_{t+1} = V_t + Q_t - C_t \mid 0 \leq V_t \leq V_{\max}$$

- V_t: the volume of water in the tank at time t
- Q_t is the volume of water added to the tank at time t
- C_t is the volume of water consumed at time t
- $V_{\max}$: the maximum volume of the tank

Inflow (Q_t)

Inflow is calculated as

$$Q_t = \eta \times A \times \max(P_t - F, 0).$$

- η: the runoff coefficient, which accounts for losses due to evaporation, spilling, etc.
- A: the area of the roof (we will use square meters)
- P_t: the precipitation at time t (we will use millimeters per day)
- F: the first flush volume (we will use millimeters). The first flush volume is often discarded, so that each time it rains the first bit of water (which is usually dirty) is not used (see here for more details).

Consumption

Consumption is modeled as:

$$C_t = \begin{cases} 74.1 & \text{day of year} > 150 \\ 0 & \text{day of year} \leq 150 \end{cases}$$

This makes two major assumptiuons. First, the household begins using water from the tank after the 150th day of the year. This is based on the idea that the rainy season lasts for about the first 150 days of the year, and so they may have other sources of water before then. The second assumption is that each household consumes 74.1 liters per day during the dry season. How does this compare to your household's water usage?

Discussion Responses

Step 1> Discuss limiting assumptions and approximations in the model outlined. Some of the limiting assumptions include: There is a fixed consumption amount of around 74 liters per day per household. Household sizes may vary, and individual practices might also vary so an average household might not actually use 74 liters per day of water during the dry season. Considering changing climates and seasons, one might have to use less or more water per day during certain periods of future years that would also differ from 74.1 L/day. The same flush volume is used. However, the flush volume may be different – stormwater may be more diluted when more rain falls, and perhaps one would change one's flush volume on an individual/household level. The runoff coefficient is also held constant, although climactice conditions and daily weather (for example) might change the amount of runoff off roofs or other surfaces of homes. Again, considering climactic changes and weather changes, it may not be accurate to assume that the rainy season lasts 150 days. Some rainy seasons might have more or less rain, which could alter water use and where people source water from.

Step 2 > Discuss how you might modify the model to relax these assumptions. Provide mathematical equations, but you don't need to implement them in code.

To relax these assumptions, you could incorporate more factors into various values/ The runoff coefficient could be written instead as n_t =n_0 -k(Temperature) and adjust for evaporation. The household consumption quantity C_t could be dependent on temperature/heat index for that day, and how big the household is. For example, Ct = C0 + a(# of members) + b(Temperature) where a and b are constants. One should also consider changing the 150 day hard cutoff for use of rainwater, and instead base the cutoff on a minimum eg. limiting value for preciptation in a week to determine when the 'dry season' has come.

Model Implementation and Testing

Defining the Model Parameters

We can define the model parameters with sensible default values. You will have the opportunity to change these values later.

```
param = ModelParameters(
    runoff_coefficient=0.80,
    roof_area_m2=45.0,
    first_flush_mm=2.8,
    tank_capacity_L=16000.0
)
```

Line 1

This creates a `ModelParameters` object with the specified parameters.

Line 2

The runoff coefficient (η) is a measure of how much of the rain that falls on the roof ends up in the tank.

Line 3

The roof area (A) is the area of the roof that the rain falls on.

Line 4

The first flush volume (V_f) is the volume of rain that is discarded because it is dirty.

Line 5

The tank capacity ($V_{\max}$) is the maximum volume of the tank.

Running the Simulation for One Year

Let's run the model for the year 1981.

```
rainfall_1981 = rainfall_data.annual_data[1981]
results_1981 = run_timesteps(rainfall_1981, param)
p1 = plot(results_1981)
```

Line 1

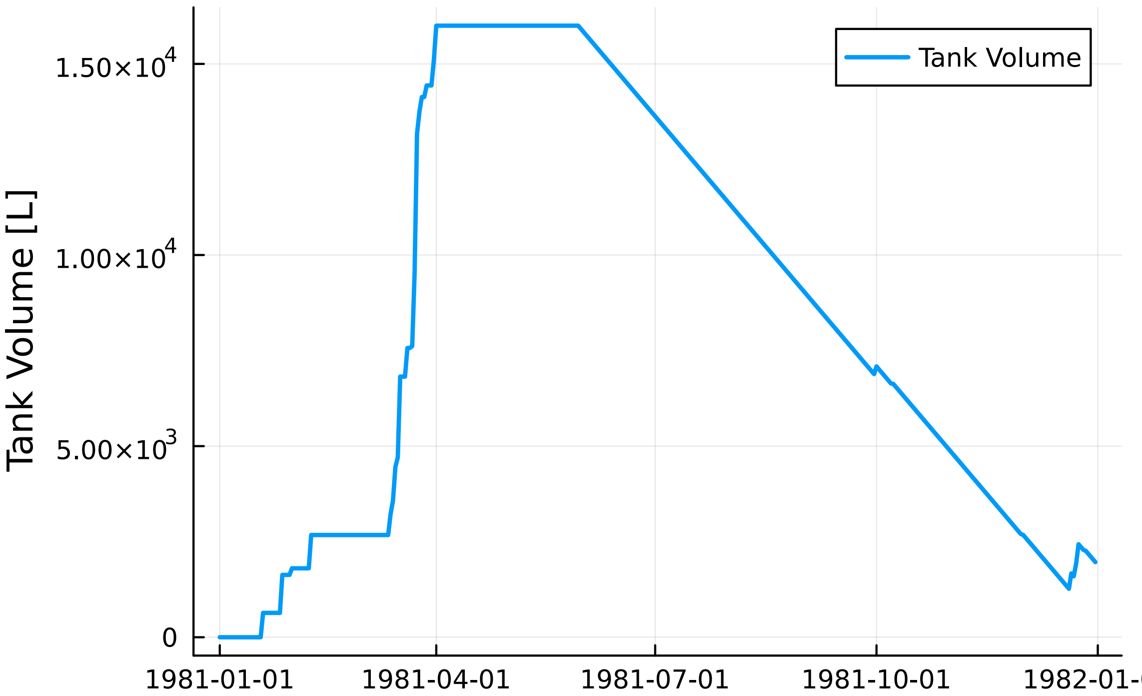
We select the annual rainfall data for the year 1981.

Line 2

We run the simulation for the year 1981.

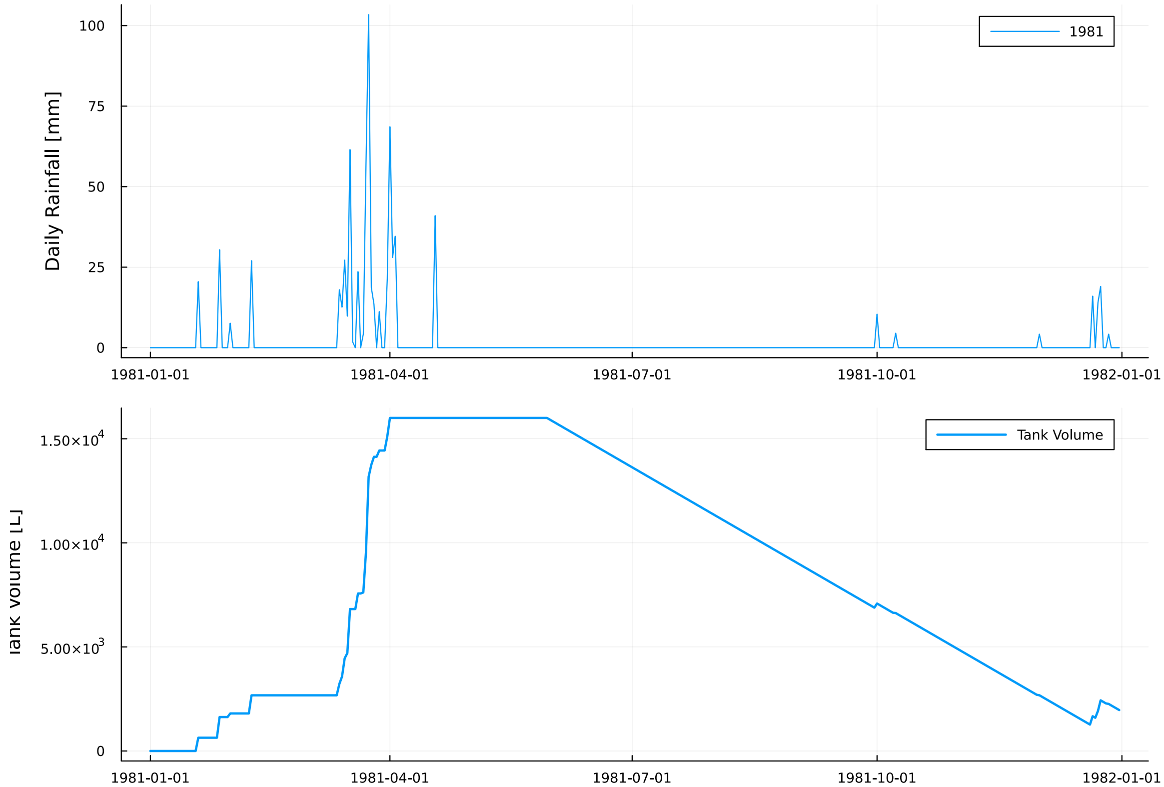
Line 3

We plot the results, again using a `plot` function defined in viz.jl.



To compare rainfall and tank volume:

```
p2 = plot(rainfall_1981)
plot(p2, p1, layout=(2, 1), size=(1000, 700), link=:x)
```



Observe how the tank's water level responds to rainfall events. Note any periods when the tank runs dry or overflows.

Modify Model Parameters

Adjust parameters like roof_area_m2 or tank_capacity_L in the param object. I adjusted the parameters; 1 - first flush 2 - runoff coefficient Rerun the simulation with your new parameters. I reran the simulation with the new parameters. Plot the results to visualize the impact. I plotted the results to visualize impact. (?) Explain why you chose to modify these parameters. I chose to modify the parameters because: Flush: infrequent rain or unpredictable dry/wet seasons might force households to use a larger first flush. I added 0.8 to the parameter value. Runoff coefficient: Roof infrastructure may not be consistent throughout all of the region, so I think it may be necessary to decrease the runoff coefficient to account for things like gutter efficiency, roofs of differently porous materials, rapid evaporation during heat waves and roof slope and design. I decreased the parameter value by 0.05.

Discuss how the changes affect the simulation outcomes.

Reliability Analysis

We can run simulations for all years, one at a time, and then check how many times the tank runs dry. You can run simulations for all years at once with the following code:

```
all_years = sort(collect(keys(rainfall_data.annual_data)))
all_results = [run_timesteps(rainfall_data.annual_data[year], param) for year
in all_years]
any_failures = [!isempty(result.failure_dates) for result in all_results]
println("Number of years with failures: ", sum(any_failures), " out of ",
length(all_years))
```

Line 1

We get all the years in order.

Line 2

We run the simulation for each year.

Line 3

We check if any failures occurred.

Line 4

We print the number of years with failures and the total number of years.

```
Number of years with failures: 18 out of 44
```

Discussion: Perform Reliability Analysis

1. Calculate the number of years where the system failed to meet the demand. According to the output, 18 out of 44 years failed to meed the demand.

2. Determine the system's reliability percentage. The reliabilty percetnage = (years without failure / total years) * 100 = 18/44 * 100 = 59.1%

3. Discuss and interpret your findings. The system failed 18 out of 44 at a failure rate of around 41 percent, which is quite significant. This indicates that the current system generally might not be robust enough to sustain demand with the new parameters. The system is 59 percentage or less than 2/3 of the time reliable, somoe quantity over half of the years. Improvements can be certainly incorporated to increase the system's reliability because it would be ideal to be able to sustain a growing population and growing demand in Ceará, Brazil. The implications of this result is that the current system of water supply during the dry season might be vulnerable to fluctuations that will only increase as the climate changes and weather patterns shift. Droughts could become more common, for one, and so the tank might not be sufficient to actually handle the invariability in water supply. To improve on the current system, planners should consider changing the tank size, incorporating other water conservation practices, and using other resources including forecasting and broadcasting (information serviced rapidly to the public). /Users/jessicaxu/Documents/GitHub/ceve-101-f24-project03/template.qmd Discussion: Identify a Gap in the Methods

4. Find one limitation in the current model (e.g., data quality, assumptions). Explain why it's a limitation. One limitation to using the current model is the assumption that the historical rain-

fall data represent current as well as conditions. If this data doesn't account for the likely shifts in weather patterns due to climate change, the model might not be effective for predicting system failures, for one. For example, increasingly common droughts and longer droughts could certainly cause more severe and longlasting failures than those outlined in past years. It is risky to assume that historical datasets can fully contextualize future events.

5. Suggest how to address the identified gap. To address this gap, the model could be enhanced by incorporating current rainfall data that already to some degree takes climate changes into account. For example, one can integrate the predicted changes in rainfall patterns due to climate change with data sourced from regional climate projections or even IPCC reports. One could then run the simulation under different climate scenarios scenarios ranging from moderate to very severe in terms of effect. With details from the simulation, one could better understand the uncertainty in future rainfall patterns.

6. Discuss how this would enhance the analysis. (Note: You don't need to implement the change—just propose it.) Incorporating climate projections into the rainfall data would make the analysis more helpful to government or other local authorities managing resource availability by increasing the accuracy in the model's assessment of the system's overall reliability. For one, you can better estimate how likely failures will be in the future based on future rainfall patterns rather than relying solely on historical data. In the long-term, having more information would foster better understanding of the risks climate change poses to the people in Ceará (eg. whether they will be impacted by droughts or floods or other events in any given year). Stakeholders such as local authorities and individual households could then hopefully make more informed decisions about how to modify rainwater collection systems to reduce risk of failure. Ultimately, being able to use outcomes from a model like this could help us identify the vulnerabilities in the water resourcing system and suggest/implement improvements that increase resilience against climate change.