

# Examining Treatment Strategies for Cholera Incorporating Spatial Dynamics

Group: Plague Doctors

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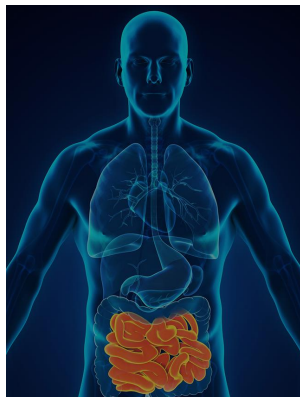
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- Treatments have not always gone as planned in history
- Cholera

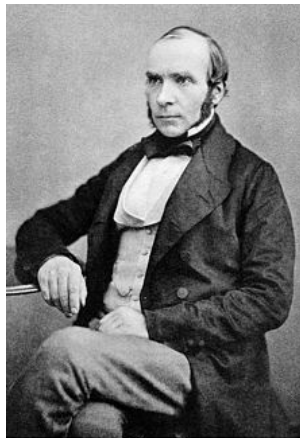
# Some Biology on Cholera

- *Vibrio cholerae*
- Colonizes the small intestine
- 10 percent of infected individuals develop symptoms
- Causes severe dehydration



# Outbreaks in London (19<sup>th</sup> Century)

- 1832, 1849, 1854, 1866
- Miasma Theory
- John Snow



*John Snow*

# Developing a Single-Patch Model

- Entire population ( $N$ ) included
- 3 Compartments : S, I, R
- Compartment values are proportional
- Water compartment for Cholera

# SIRW Model Assumptions

- Birth Rate = Natural Death Rate and is constant
- Population equally susceptible to infection
- No waning immunity
- No latency period
- Only infected individuals can infect the water sources
- Water sources can infect individuals

# SIRW Model



- Using the method of Next Generation Matrix (van den Driessche and Watmough, 2002)

$$F = \begin{pmatrix} \beta_i & \beta_w \\ 0 & 0 \end{pmatrix}$$
$$V = \begin{pmatrix} \frac{1}{\gamma + \mu} & 0 \\ \frac{1}{\gamma + \mu} & \frac{1}{\sigma} \end{pmatrix}$$

- $R_0$  is computed as the spectral radius of  $FV^{-1}$ :

$$\begin{aligned} \mathcal{R}_0 &= \rho(FV^{-1}) \\ &= \frac{\beta_i + \beta_w}{\gamma + \mu} \approx 1.1 - 2.7 \end{aligned}$$



- Two equilibria:

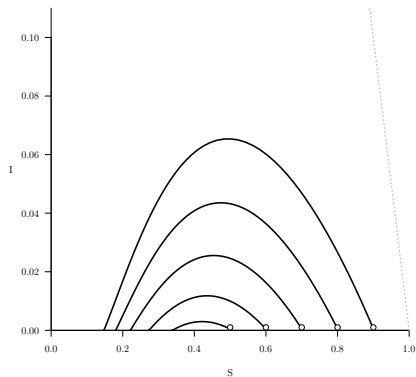
① DFE:  $(S, I, R) = (1, 0, 0)$

② EE:  $(S^*, I^*, R^*) = (\frac{1}{R_0}, \frac{\mu}{\gamma + \mu}(1 - S^*), I^*)$

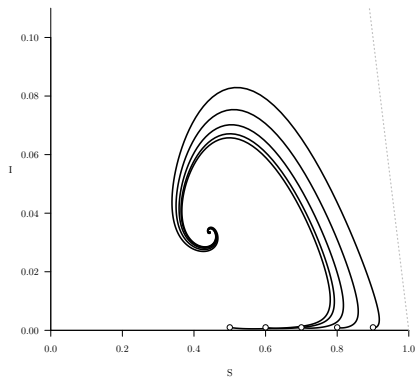
- The DFE is stable when  $\mathcal{R}_0 < 1$ .
- The EE is globally stable when  $\mathcal{R}_0 > 1$  (Tien and Earn, 2010).

# SIWR Model Phase Portrait

Base Model Without Vital Dynamics  $\mathcal{R}_0 = 2.4$

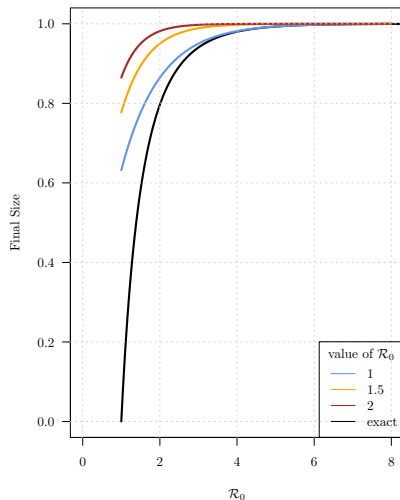


Base Model With Vital Dynamics  $\mathcal{R}_0 = 2.25$



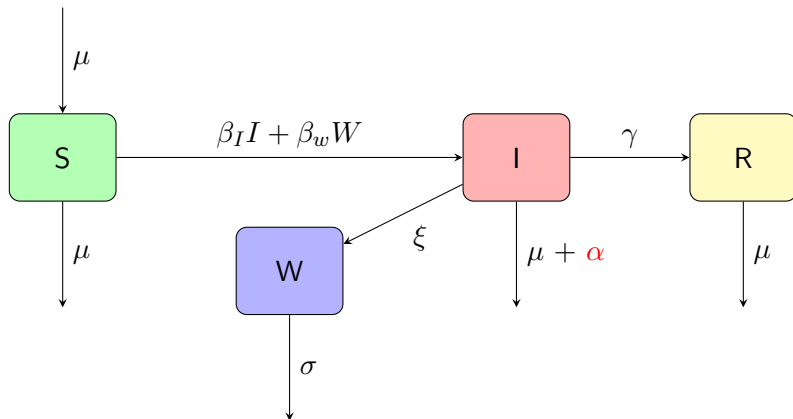
# Final Size

- Assuming  $\mu = 0$  and  $\mathcal{R}_0 > 1$ , final size formula\* still holds:
- $$Z = 1 - \exp\left(-\mathcal{R}_0 Z - \frac{\beta_w}{\sigma} w_0\right)$$

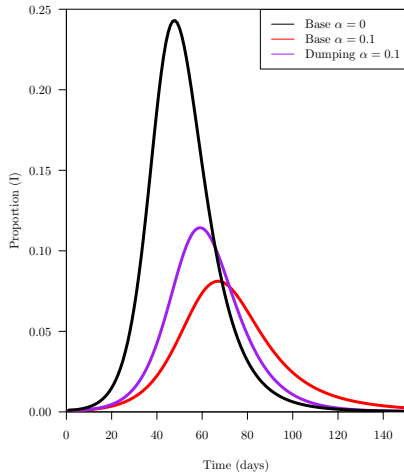


# Effects of the 19th Century Treatments

- Added parameter for death rate from Cholera: ( $\alpha$ )



# Effects of the 19th Century Treatments

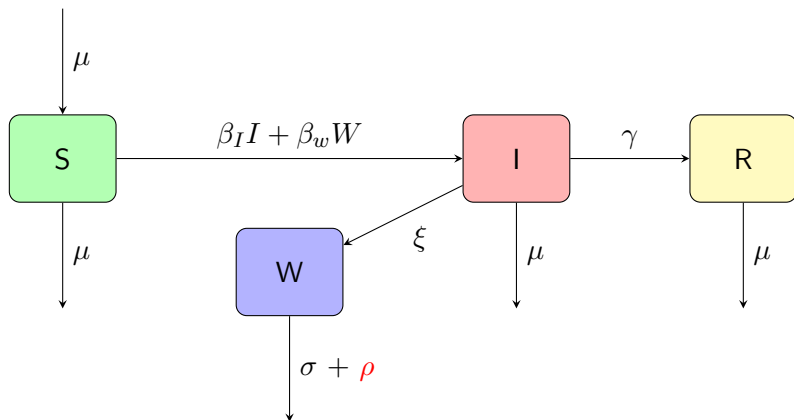


- Estimated death rate from cholera in the 19th century estimated to be up to 50%
- Including disease induced death is “beneficial” if death rate by cholera is high (Why?)
- Improper sanitation increases peak prevalence

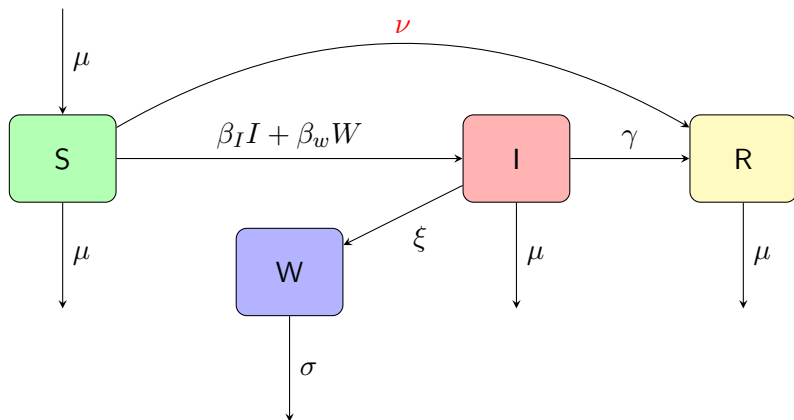
# Treatment Strategies For Cholera

- 1 Sanitation of Water
- 2 Vaccinations
- 3 Antibiotics

# Sanitation of Water

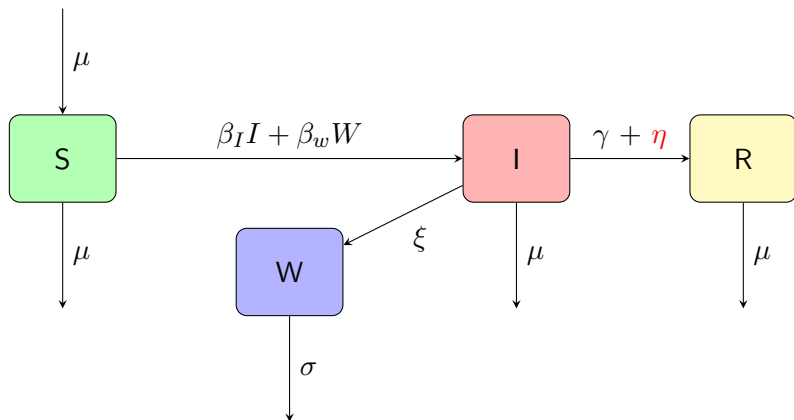


# Vaccinations

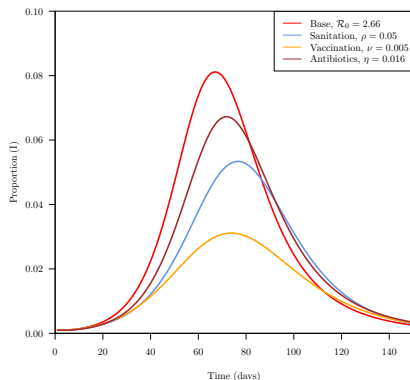




# Antibiotics



# Comparing the Treatment Strategies



- Parameters chosen from literature
- Lowest peak prevalence for vaccination treatment

$$\frac{dS_i}{dt} = \mu N - \mu S_i - \beta_i S_i I_i - \beta_w S_i W_i + r(S)$$

$$\frac{dI_i}{dt} = \beta_i S_i I_i + \beta_w S_i W_i - I_i(\gamma + \mu + \alpha)$$

$$\frac{dR_i}{dt} = \gamma I_i - \mu R_i + r(R)$$

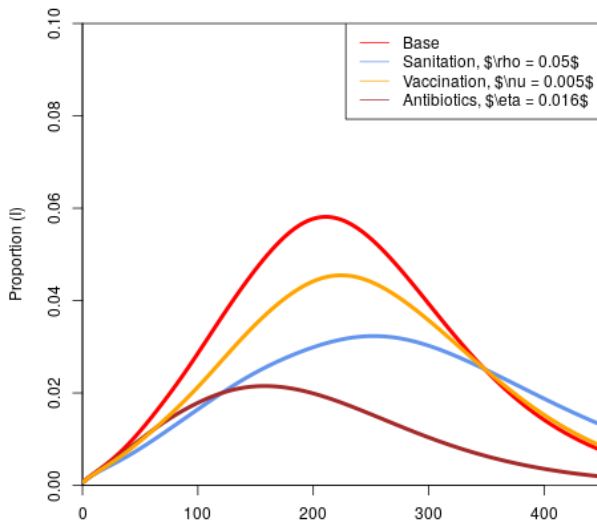
$$\frac{dW_i}{dt} = \xi I_i - \sigma W_i + r(W)$$

# Multi-Patch Model Assumptions

- No dispersal of infected individuals
- All patches have the same set of parameter values

Base Sanitation Antibiotics Vaccination

# Comparing the Treatment Strategies In Multipatch Model



# Conclusions and Further Research

- 19th century outbreaks poorly handled without antibiotics/vaccines
- Different Treatments have different costs and outcomes
- Further research on improving water sanitation effectiveness to reduce reliance on vaccines/antibiotics

Thank you!



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