Mathematical Model of West Nile Virus Dynamics: Study of Passive Immunity and Vertical Transmission

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Introduction

- West Nile Virus (WNV)
  - Flaviviridae
  - *Flavivirus*
  - Single stranded, positive-sense RNA virus
- Maintain in mosquito-bird cycle
  - Infects humans, birds, mosquitoes, horses, and other mammals

Introduction

- 1937: Uganda, first isolated
- 1950: Egypt, ecology studied
- 1999: New York City; 62 cases; 7 deaths
  - First appearance of WNV in western hemisphere
- Infects over 250 species of birds
- No vaccine; can be prevented with adulticide and larvicide

SEIR Model Formulation

$$\frac{dL_S}{dt} = b(M_S + M_E) - mL_S - \delta_L L_S$$

$$\frac{dL_L}{dt} = bM_I - mL_I - \delta_L L_I$$

$$\frac{dM_S}{dt} = mL_S - \frac{\alpha_M \beta M_S B_I}{N_{Total}} - \delta_M M_S - T(t)M_S$$

$$\frac{dM_E}{dt} = \frac{\alpha_M \beta M_S B_I}{N_{Total}} - \eta M_E - \delta_M M_E - T(t)M_E$$

$$\frac{dM_I}{dt} = mL_I + \eta M_E - \delta_M M_I - T(t)M_I$$

$$\frac{dE_S}{dt} = \phi_S(B_S + B_I) + (1-\mu)\phi_R B_R - \theta E_S - \psi E_S$$

$$\frac{dE_R}{dt} = \mu\phi_R B_R - \theta E_R - \psi E_R$$

$$\frac{dB_S}{dt} = \Lambda - \frac{\alpha_B \beta M_I B_S}{N_{Total}} + p_S B_M + \psi E_S - \tau B_S$$

$$\frac{dB_I}{dt} = \frac{\alpha_B \beta M_I B_S}{N_{Total}} - \delta_B B_I - \tau B_I$$

$$\frac{dB_R}{dt} = (1-\sigma)\delta_B B_I + p_R B_M - \tau B_R$$

$$\frac{dB_M}{dt} = \psi E_R - (p_S + p_R)B_M - \tau B_M$$

$$\frac{dB_D}{dt} = \sigma\delta_B B_I$$

$$\frac{dH_S}{dt} = -\frac{\alpha_H \beta M_I B_S}{N_{Total}}$$

$$\frac{dH_E}{dt} = \frac{\alpha_H \beta M_I B_S}{N_{Total}} - \delta_E H_E$$

$$\frac{dH_F}{dt} = (1-\gamma_H - \kappa_H)\delta_E H_E - \delta_F H_F$$

$$\frac{dH_N}{dt} = \kappa_H \delta_E H_E - \delta_N H_N$$

$$\frac{dH_R}{dt} = \delta_F H_F + (1-\omega_H)\delta_N H_N + \gamma_H \delta_E H_E$$

$$\frac{dH_D}{dt} = \omega_H \delta_N H_N$$

$$\frac{dQ_S}{dt} = -\frac{\alpha_Q \beta M_I B_S}{N_{Total}}$$

$$\frac{dQ_E}{dt} = \frac{\alpha_Q \beta M_I B_S}{N_{Total}} - \delta_C Q_E$$

$$\frac{dQ_W}{dt} = \left(1 - \gamma_Q - \kappa_Q\right)\delta_C Q_E - \delta_W Q_W$$

$$\frac{dQ_P}{dt} = \kappa_Q \delta_C Q_E - \delta_P Q_P$$

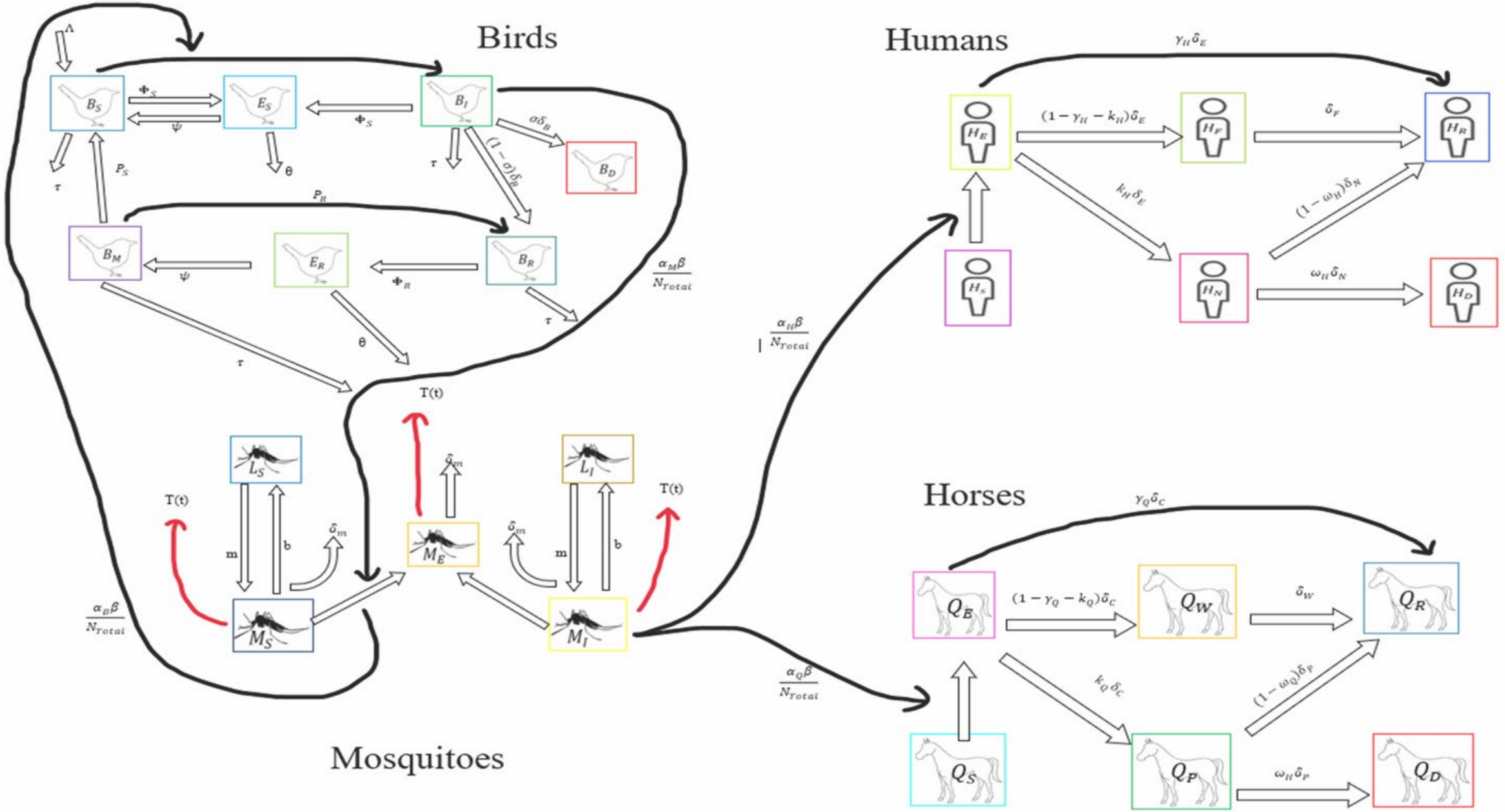
$$\frac{dQ_R}{dt} = \delta_W Q_W + (1-\omega_Q)\delta_N Q_N + \gamma_Q \delta_C Q_E$$

$$\frac{dQ_D}{dt} = \omega_Q \delta_P Q_W$$

SEIR Model Formulation - continued

$$\frac{dL_S}{dt} = b(M_S + M_E) - mL_S - \delta_L L_S$$

- $\frac{dL_S}{dt}$: Rate of change of susceptible larval number with respect to time
- b: Mosquito birth rate
- m: Mosquito maturation rate
- δ_L: Natural larval death rate
- M_S: Number of susceptible mosquito
- M_E: Number of exposed mosquito
- L_S: Number of susceptible larval



Schematic of WNV Model

Passive Immunity

Vertical Transmission

Passive Immunity

- Occurs naturally
  - From person to person
  - Mother to infant
- Immediate protection, not permanent

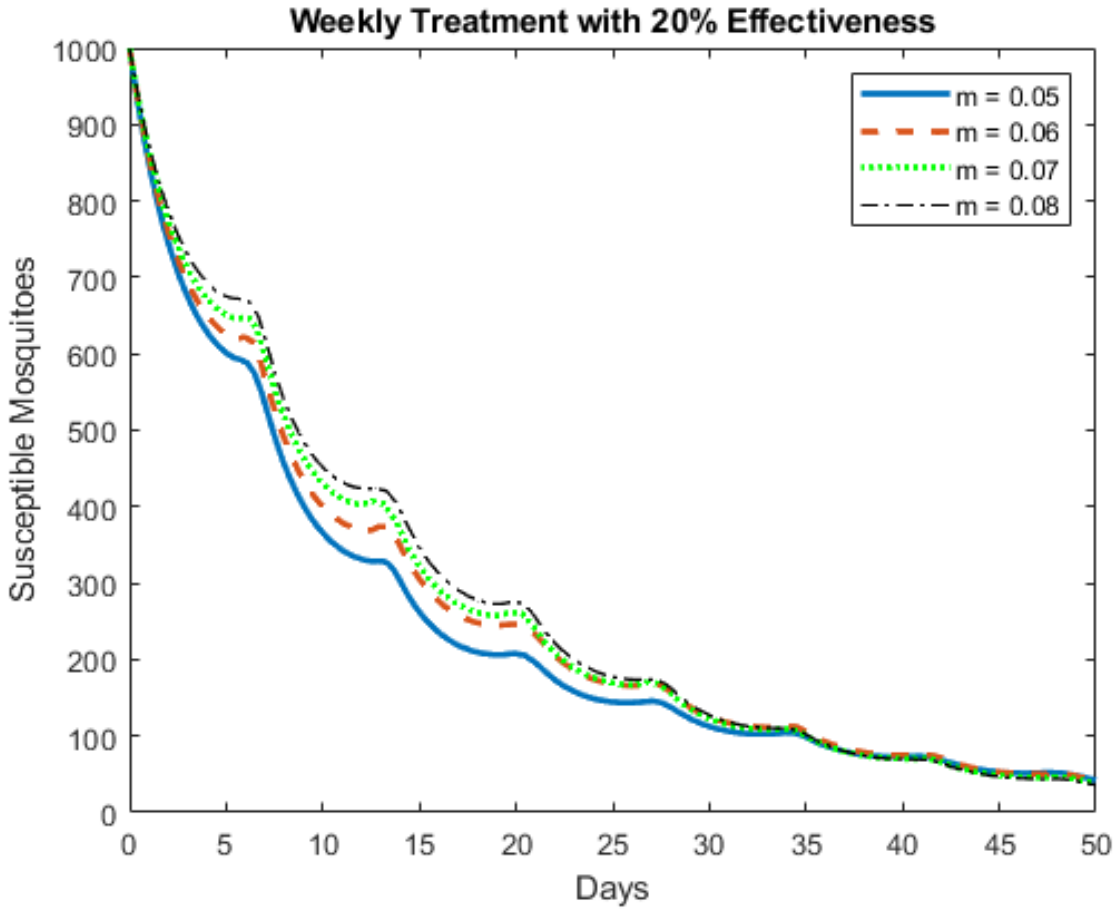
Passive Immunity

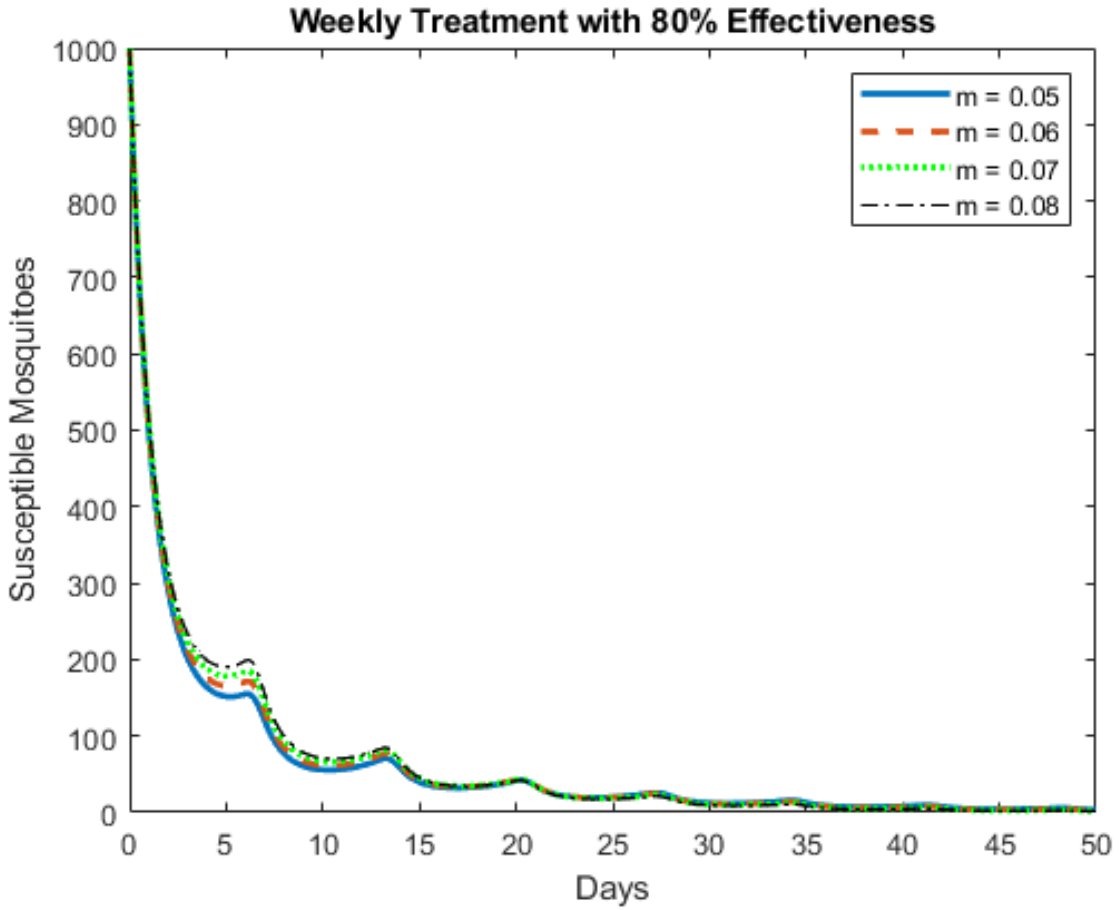
Vertical Transmission

- Occurs naturally
  - Maternal to offspring
- Arbovirus adopted for survival

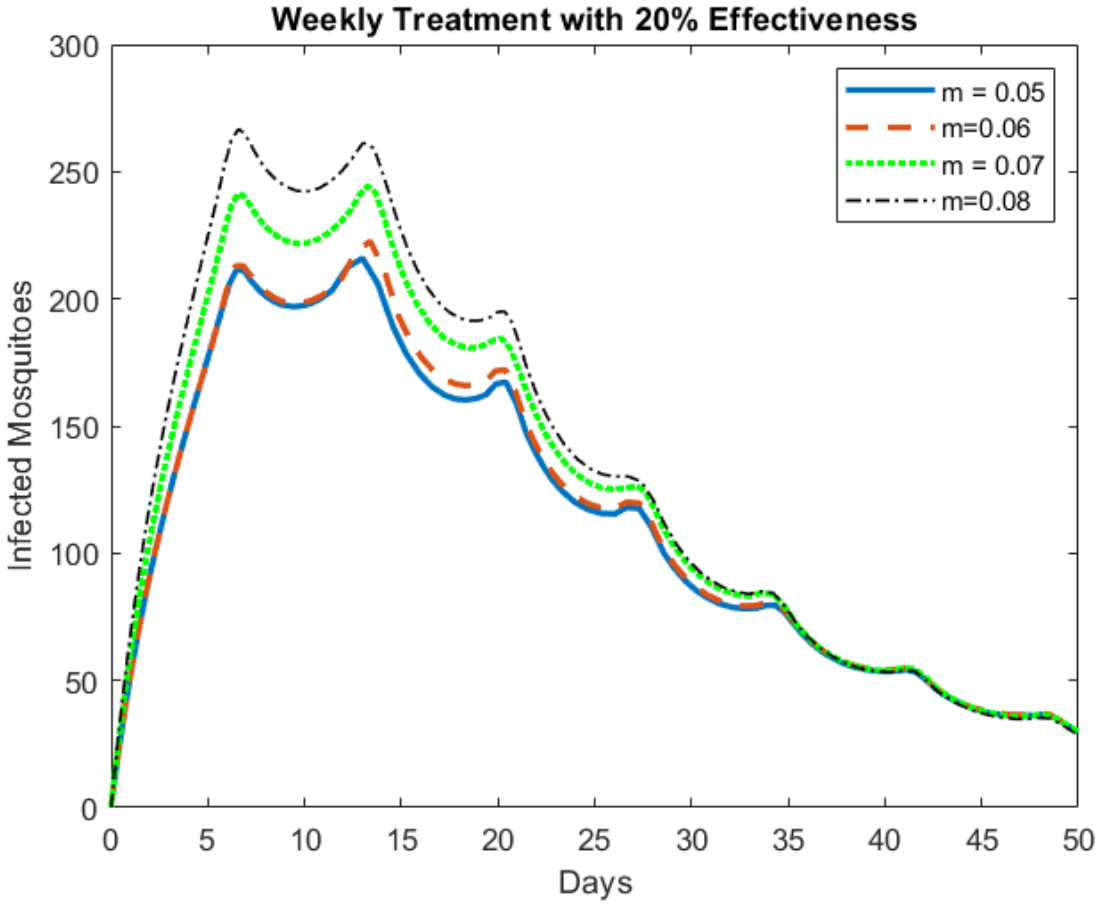
Vertical Transmission

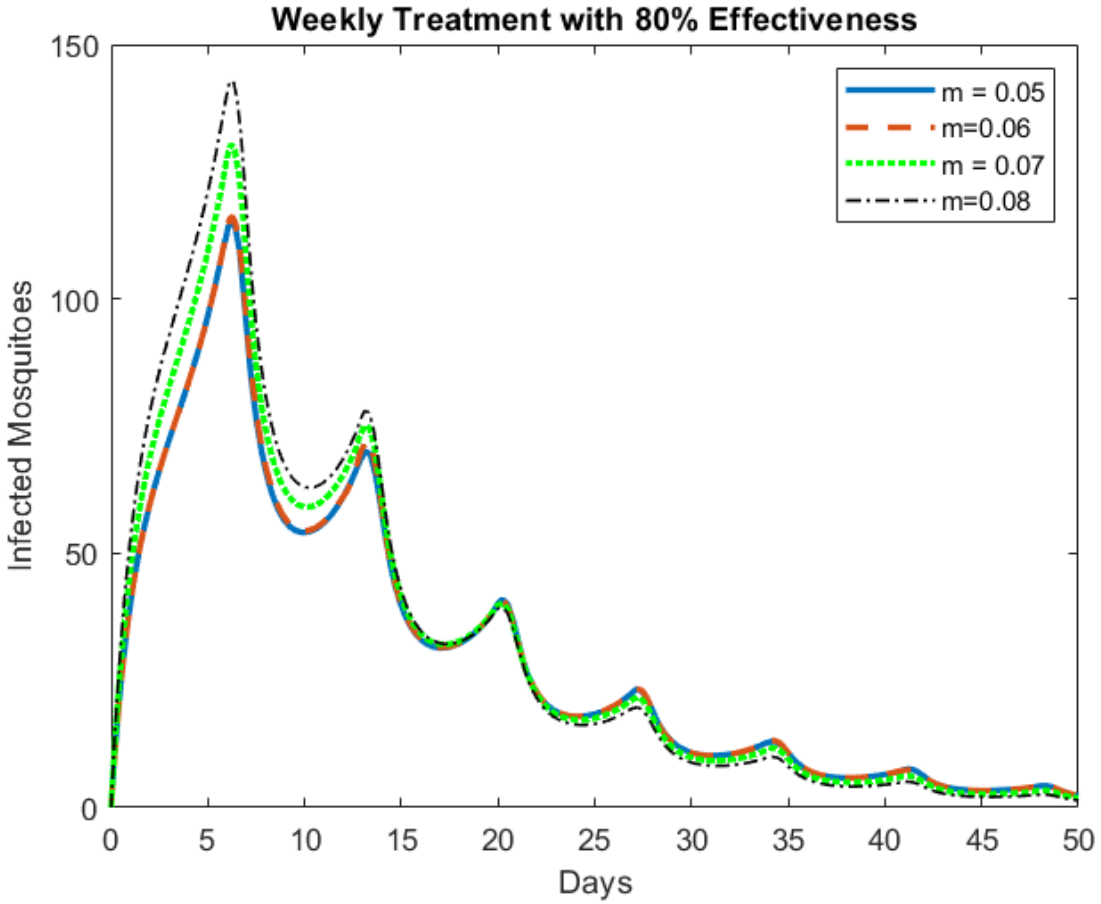
Vertical Transmission



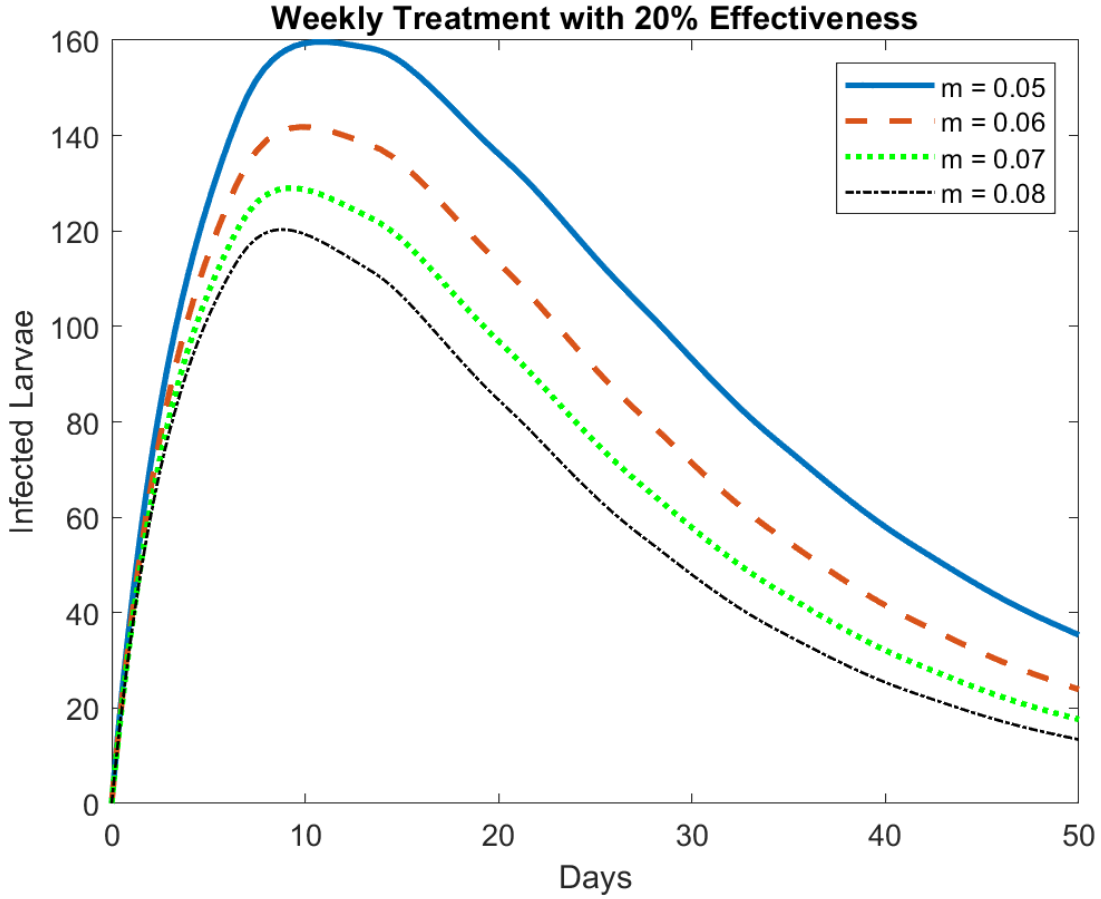


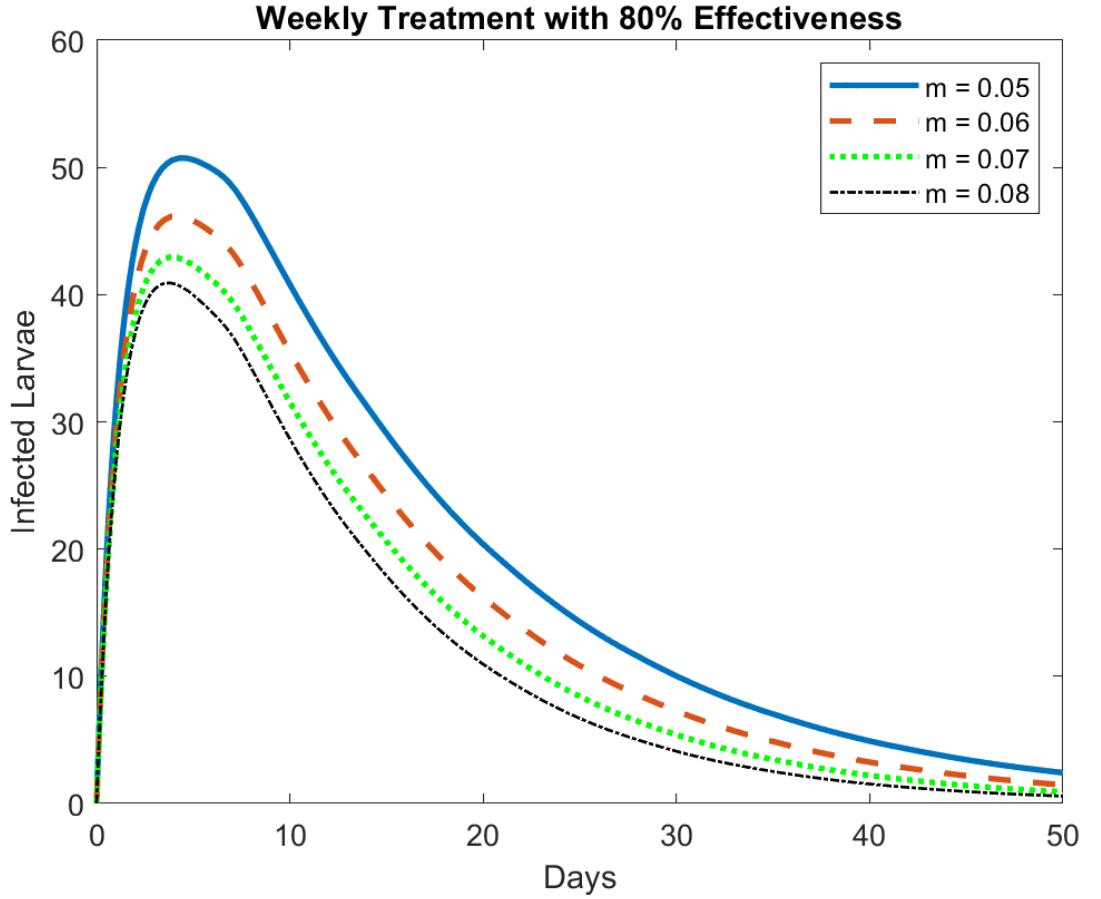
Vertical Transmission



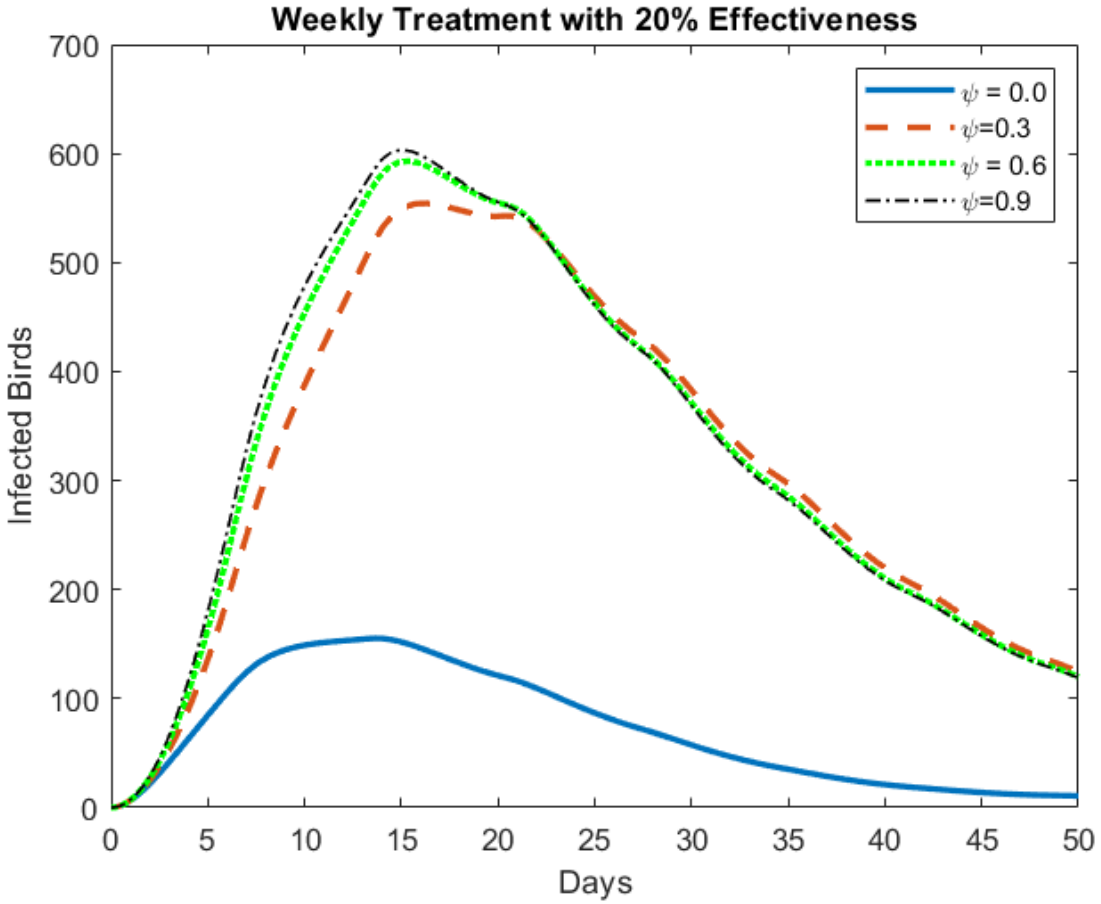


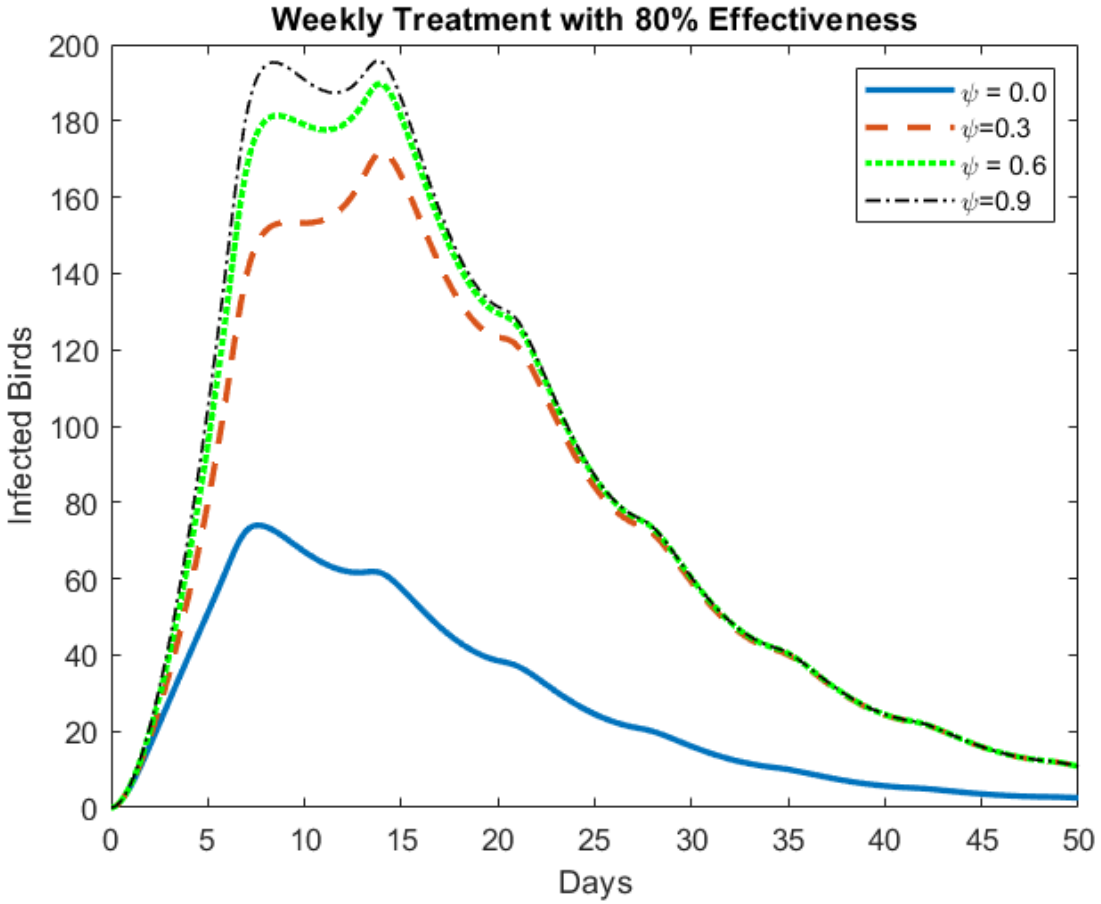
Vertical Transmission



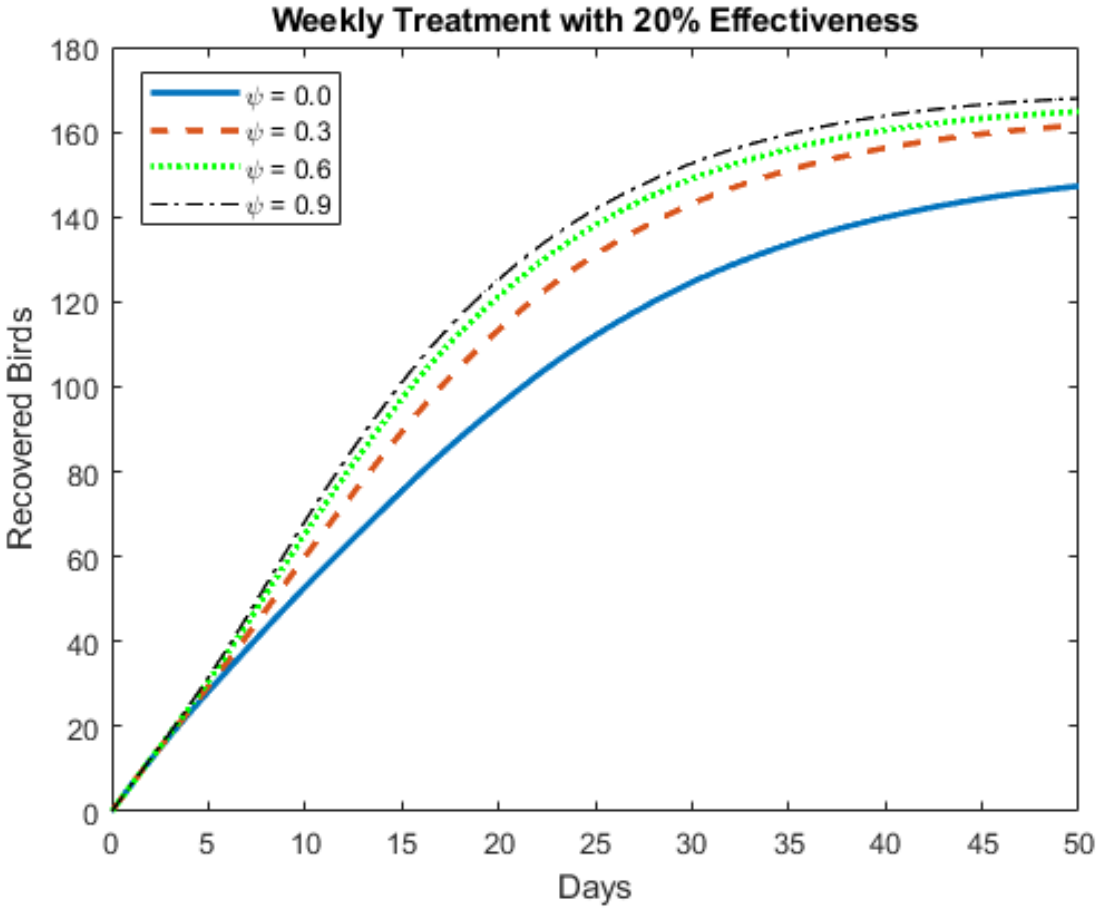


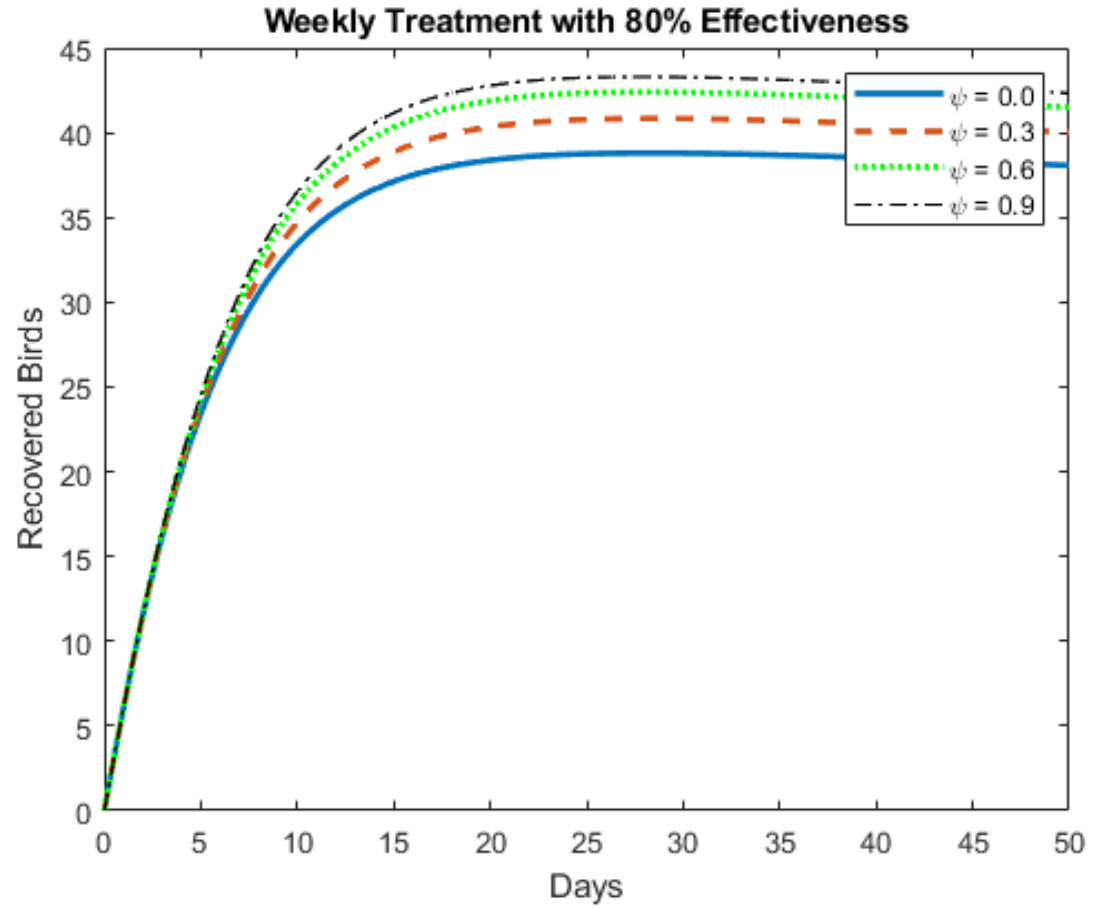
Passive Immunity



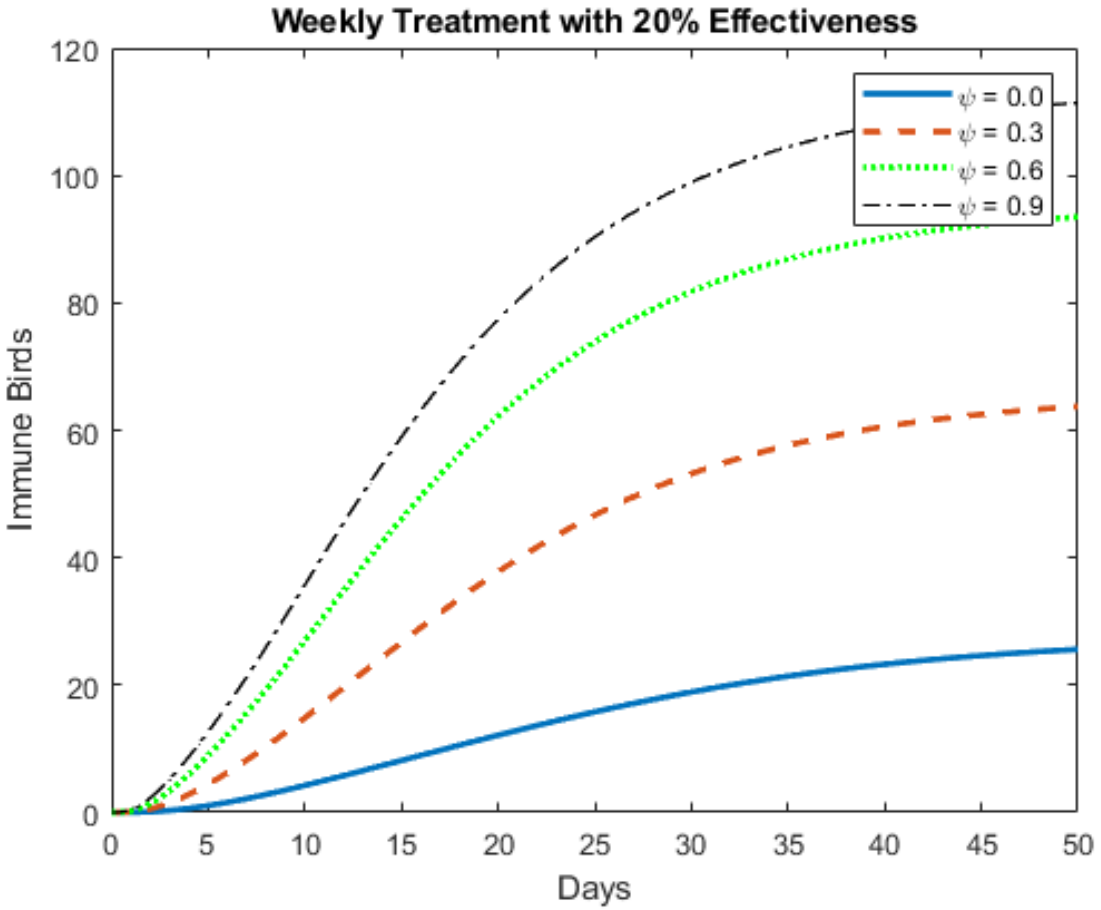


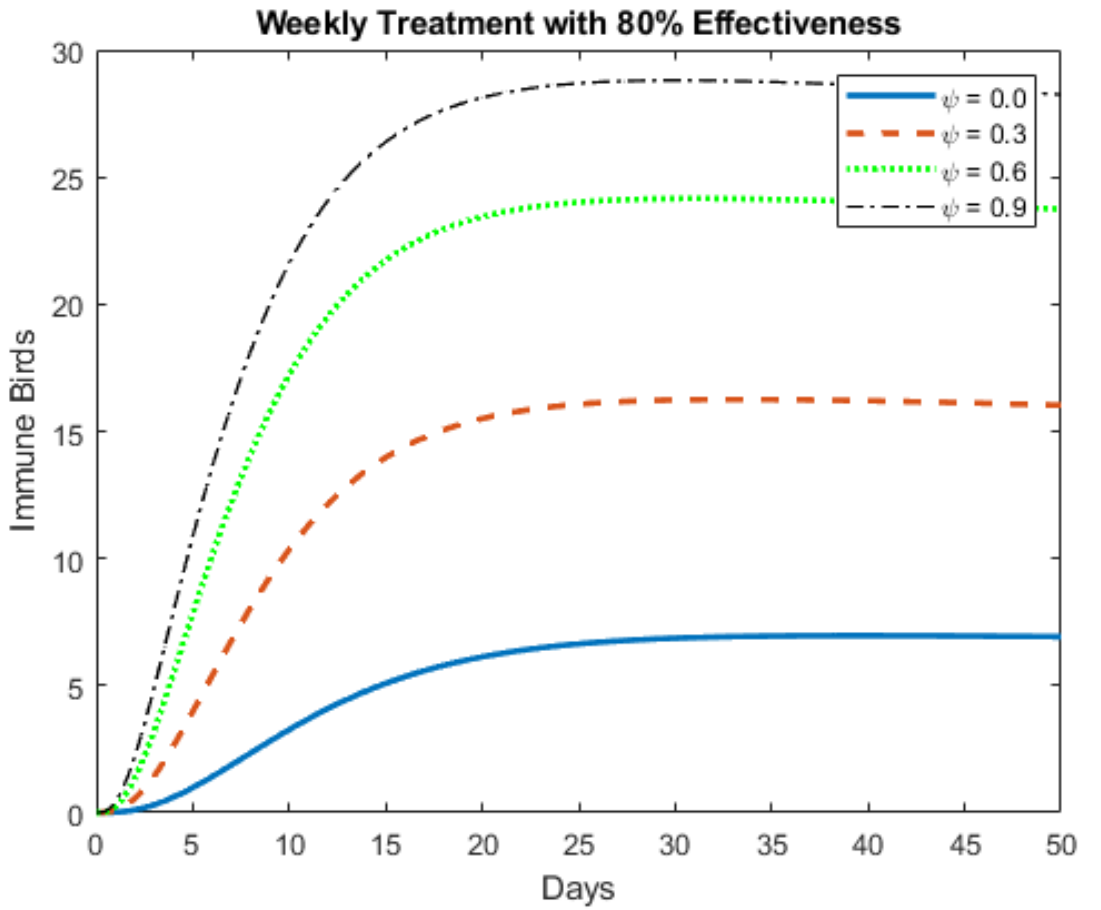
Passive Immunity





Passive Immunity





Concluding Remarks

- The SEIR model also makes several simplifying assumptions about the population.
- Model enables us to make predictions.
- No model can perfectly predict the future.

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Thank You

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