Section III: Results

Deterministic simulations of the five-equation model revealed distinct population dynamics under each treatment condition. In the absence of antibiotic treatment (Figure 1), bacterial populations increased and stabilized at a steady-state equilibrium, with resistant bacteria persisting at lower levels due to a lower initial concentration and lower growth rates. No population crashes or oscillations were observed, indicating stable growth under baseline conditions.

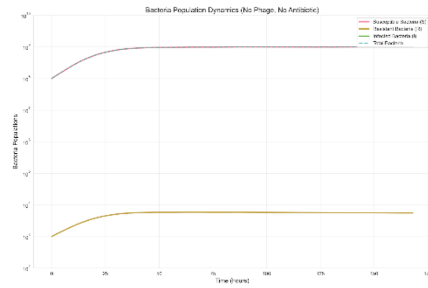

Figure 1A: Simulation with only resistant and susceptible bacteria. Bacteria initially grow before stabilizing around the carrying capacity.

When bacteriophages were introduced without antibiotics (Figure 2), susceptible and resistant bacterial populations declined sharply following rapid phage amplification. Infected bacteria persisted for longer periods due to a time delay between infection and lysis, but they eventually collapse as well. Total bacterial concentrations decreased by several orders of magnitude compared to initial concentrations, and were almost completely eradicated. Phage levels remained elevated after bacterial suppression, although signs of decay due to a lack of bacteria are present in the later stages of the simulation.

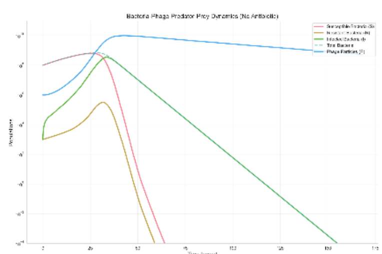

Figure 2: Simulation containing only bacteria and phages. Susceptible and resistant bacteria populations crash instantly, while infected bacteria concentrations persist for a little longer until crashing as well. Phage concentrations surge before decaying.

Under antibiotic treatment alone (Figure 3), susceptible bacteria declined initially, while resistant bacteria steadily increased. As antibiotic concentration decayed over time, susceptible and resistant bacteria populations stabilized, with resistant bacteria dominating total bacterial concentrations.

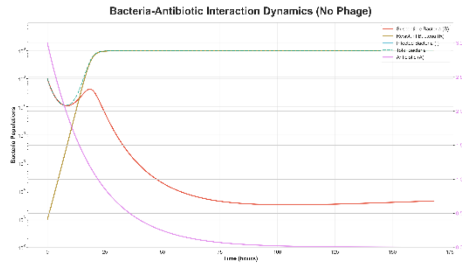

Figure 3: Simulation with antibiotics and bacteria. Resistant bacteria steadily grow while susceptible bacteria concentrations crash before stabilizing.

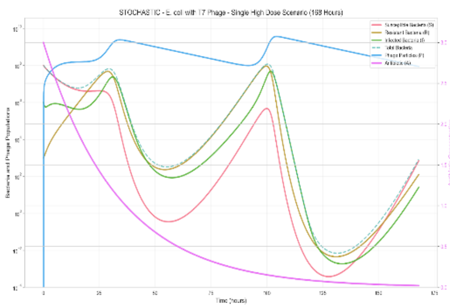

Figure 4: Simulation with bacteria, phages, and antibiotics. Bacteria populations sharply decline to antibiotics before oscillating along with phage concentrations.

Combined phage and antibiotic treatment (Figure 4) produced the most unstable dynamics of all treatment cases. Antibiotics initially kill off many susceptible bacteria, slowing down phage replication. After antibiotics have substantially decayed, phage and bacterial populations oscillate, with periods of very high and very low bacterial concentrations and less extreme growth/decay cycles for the phages. This treatment strategy is more effective than bacteria-antibiotic treatment due to periods of bacterial concentration of decline, but is counterintuitively less effective than phages alone due to a combination of antibiotic killing and a lack of phage resistance among bacterial populations.

To further evaluate treatment optimization, a parameter sweep was conducted across a range of initial phage concentrations (Figure 5). Results demonstrated a nonlinear relationship between

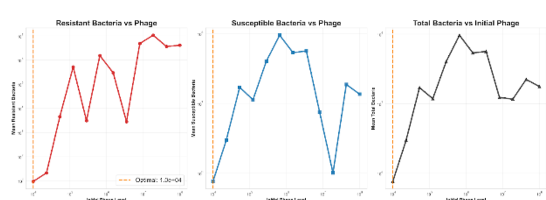

Figure 5: Simulation comparing inital phage concentrations and final bacteria concentrations. Moderate phage concentrations are best at bacterial clearance.

initial phage levels and final bacterial concentrations. Low phage concentrations resulted in insufficient bacterial suppression, while excessively high phages led to increased resistant bacterial populations due to phage-mediated transduction of antibiotic-resistant genes. Moderate phage concentrations were best at minimizing resistant bacteria concentrations and total bacteria load. These findings suggest the existence of an intermediate phage concentration that balances bacterial clearance and resistance limitation.