Feasibility of a Bioaerosol Sampling Network to Measure Resuspended Spores

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Introduction

- EPA has the responsibility for protecting human health and the environment following the release of biological material in an urban area.
- Accurate measurements of residual contamination are needed to make informed decisions on recovery activities following initial remediation.
- EPA’s toolbox includes approaches for surface, soil, and water sample collection.
- The outdoor environment is a challenging environment for sample collection because of contaminant movement between media, including from surfaces to air (i.e., resuspension).
- This research assessed filter-based air sampling methods for *Bacillus anthracis* following a wide area contamination.

Objective

- Research Objectives
  - Evaluate the performance of different filter-based air sampling strategies.
  - Assess the cost-effectiveness of the strategies.
  - Identify operational gaps.

- Presentation Objectives
  - Define the modeling approach and associated assumptions for measuring the performance of the bioaerosol sampling network.
  - Discuss the factors that affect the bioaerosol concentration produced by resuspension and subsequent impact on network design.
  - Present network designs that consider detection efficacy and costs.

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- **Bad**: Bioaerosol concentration is too low. Detection limit of best real-time systems is 100 ACPLA (or 1E+5 CFU/m^3), orders of magnitude higher than the expected resuspended concentration.

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- **Ugly**:

Approach for Evaluating Air Sampling Strategies

- Developed a system performance model in MATLAB to evaluate different air sampling strategies.
- Model components
  - Spore air concentration
    - Scenario definition
    - Spore emission rate caused by resuspension
    - Spore dispersion
    - Daily average spore concentration in the x,y plane at multiple heights
  - Air sampling strategies
    - Air sampler technical specifications: low flow (10 Lpm) and high flow (300 Lpm) systems
    - Air sample costs: equipment, labor, and supply sample costs
  - Network evaluation
    - Number and location of samplers that collect 1 spore
    - Unitized cost per sample per strategy

System Performance Model Framework

Scenario Definition
- Release size and length
- City
- Years
- Area monitored

Spore Emission Rate
- Surface loading with decay functions
- Vehicle and pedestrian activity
- Resuspension fraction with decay function

R-Line
- Spore emission rate outputs
- Meteorology: surface and upper atmosphere

Strategies
- Low flow & cost systems
- High flow & cost systems
- Native Samples
- Hybrid

Vary number and spacing

Cost Calculations
- Capital costs
- Operation costs

Network Evaluation
- Sampler density
- Network effectiveness
- Cost per day
- Parameter sensitivity

Outputs

Number and location of samplers

Normalized cost per sample

Data Sources and Assumptions

- Data Sources
  - Used publicly available peer-reviewed data when available.
  - Non-peer reviewed but publicly available data used when necessary.

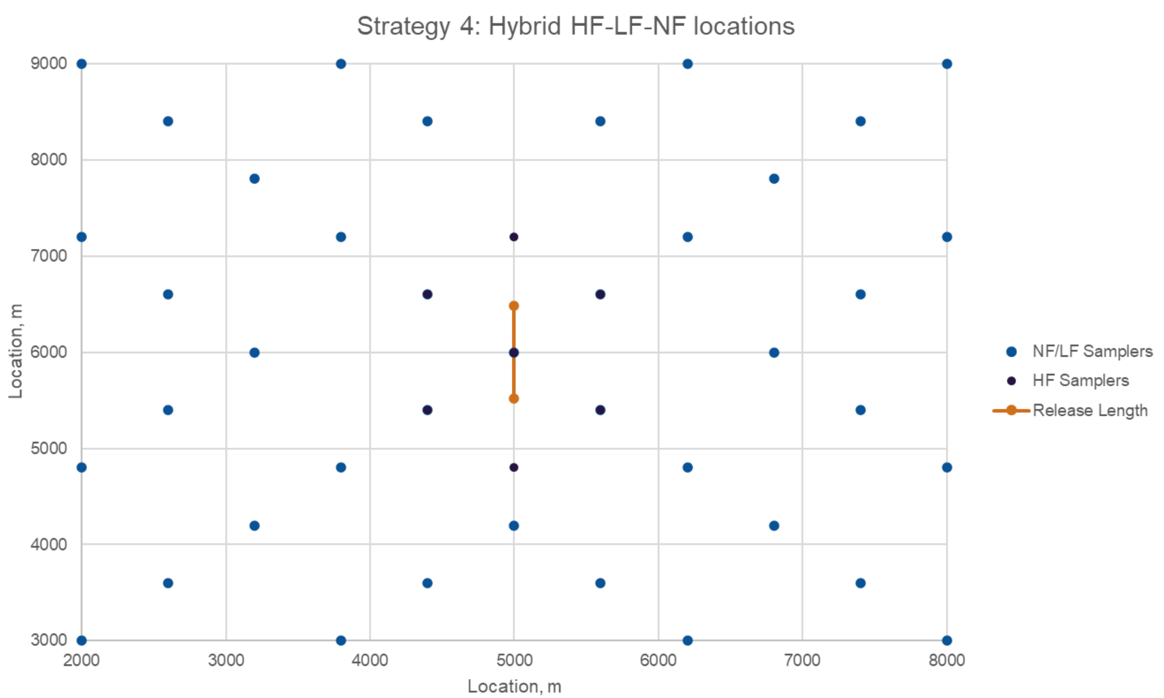
- Key Assumptions
  - Decay function to relate resuspension fraction to surface loading
    - Easily resuspended particles are aerosolized first.
    - Decreasing resuspension fraction over time.
  - Did not include rain or mitigation influences on surface loading.

Scenarios Modeled

- National Planning Scenario #2.
- New York City and Denver, CO with uniform road grid covering 36 km^2.
- 12 time periods from Oct. 2001 to Aug. 2002.
  - 6 fall, 4 spring, 1 winter, and 1 summer.
  - A period is 28 days, with decon @ day 15.
- Input variables constant or allowed to fluctuate.
  - Activity patterns tied to the day of the week.
  - Initial resuspension fraction.
  - Surface loading.
- Assume the public conducts normal activities after release.
- Sampler heights of 2, 4, 10, 20, 30, 40 and 50 m.

Network Designs and Strategies Evaluated

Network Designs	Strategies Evaluated
Design 1: 121 samplers, 3.4 per km^2	Low flow and High flow strategies
Design 2: 81 samplers, 2.4 per km^2	Low flow and High flow strategies
Design 3: 45 samplers with, 1.5 per km^2	Low flow, High flow, and Native sampler strategies
Design 4: 7 high flow samplers around line of release (8.8 per km^2), 24-hour sample collection. 17 low flow (24-hour collection) and 17 native (144-hour collection) samplers, each at ~1.5 per km^2, further from the line of release.	Hybrid – combination of low, high and native samplers



General Results & Observations

- Selectively choosing results can be misleading and generate wrong conclusions.

- Easy to identify statistically significant or insignificant differences in the bioaerosol concentration.
  - Emission rate caused by resuspension decreases each day because of source depletion.
  - Meteorology influences on wind speed & direction, boundary layer thickness.
  - Distance of the sampler from the initial release location.
  - Height of the sampler above the ground.

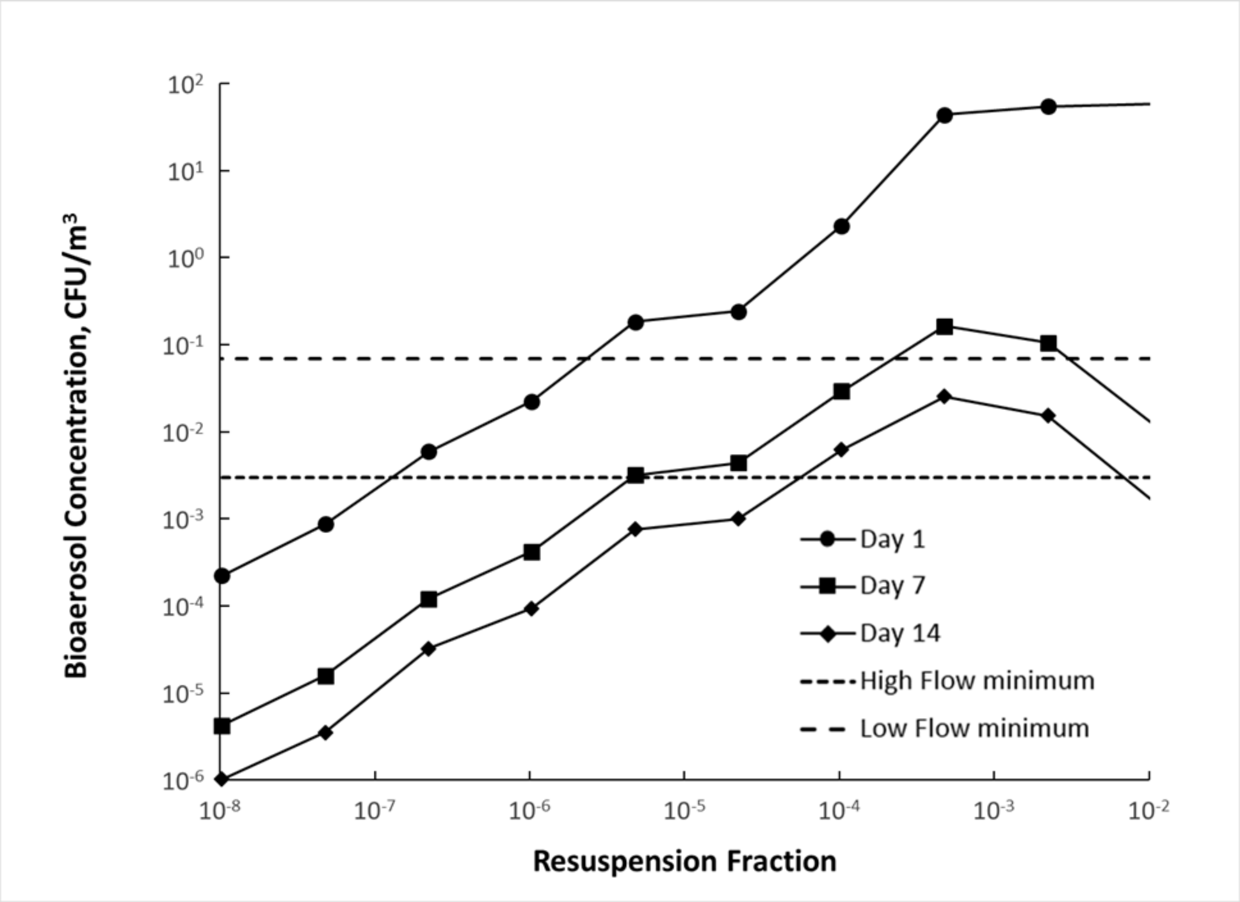
- **Need to consider all 3.4 million bioaerosol concentrations produced during this modeled scenario when evaluating the performance of a sampler network.**

Influences on Daily Average Bioaerosol Concentration

- Statistical model was a general linear model with sampler location as a categorical variable and all other variables as continuous.

- Results
  - Resuspension fraction: p-value < 0.0001
  - Location: p-value < 0.0001
  - Sampler height: p-value < 0.0001
  - Sampler location (x,y plane): p-value < 0.0001
  - Initial surface loading: p-value < 0.004
  - Meteorology: p-value $= 0.328$

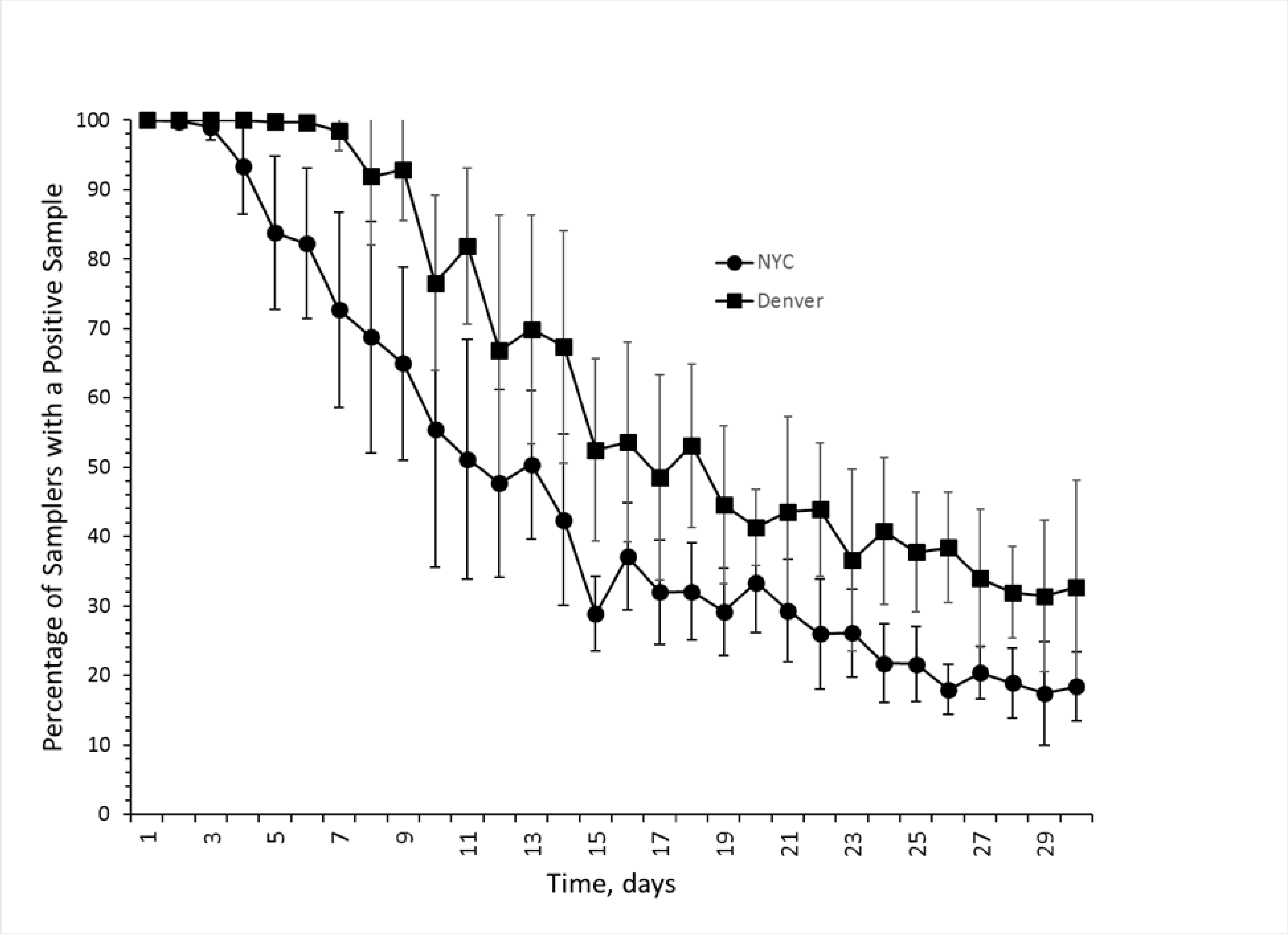
Resuspension Fraction Influences



- All inputs constant except for resuspension fraction.
- 12 scenarios modeled.
- Average concentration across the 36 km^2 area.

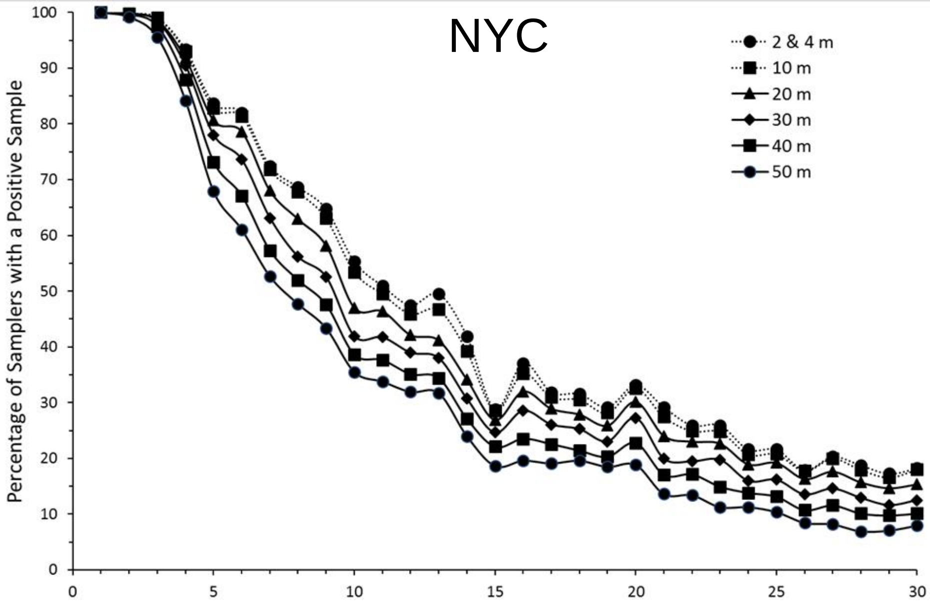
- Bioaerosol concentration decreases over time because of source depletion.
- Constant or decreasing concentration when resuspension > 0.005 because of source depletion.

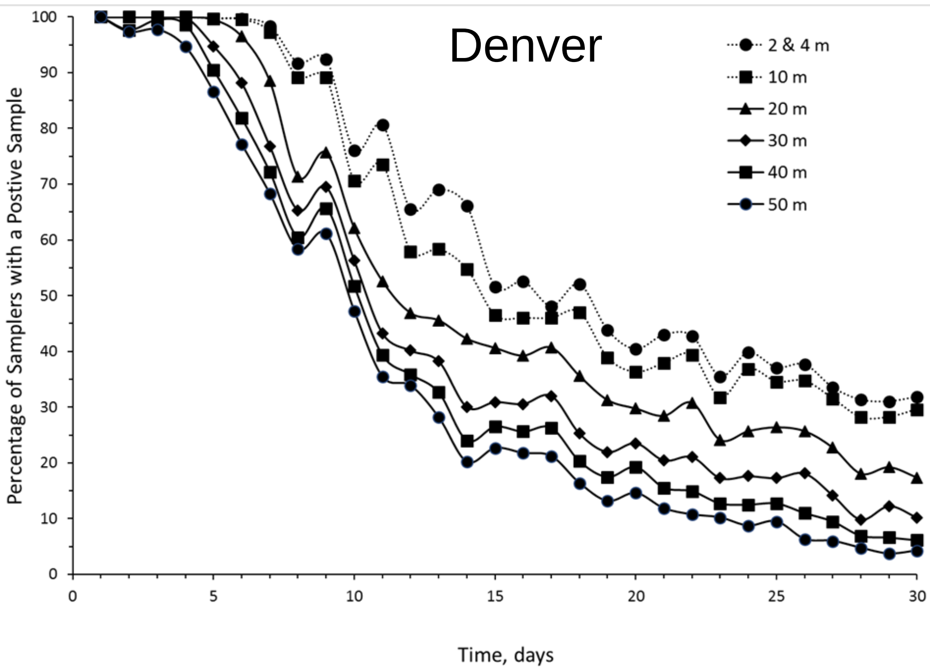
City Influences on Detection Efficiency



- High flow network of 121 samplers (3.4 per km^2).
- Meteorology drives the standard deviation.
- NYC < Denver because urban canyons reduce lateral dispersion.

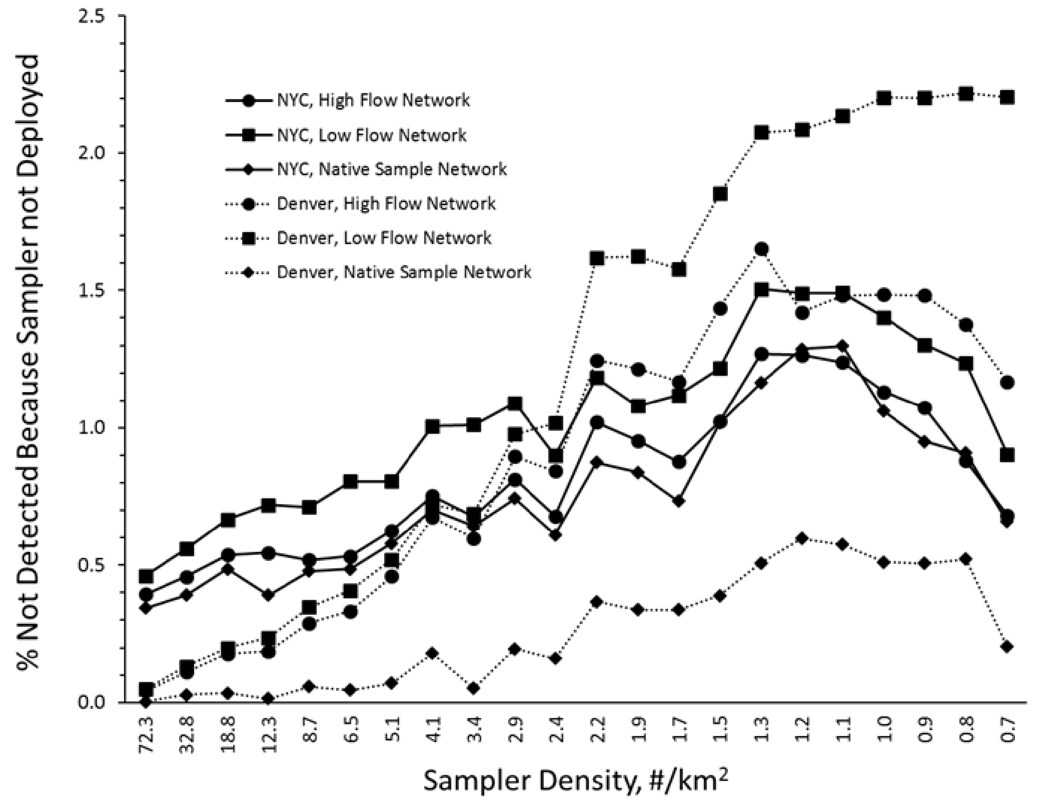
Sampler Height Influences on Detection Efficiency





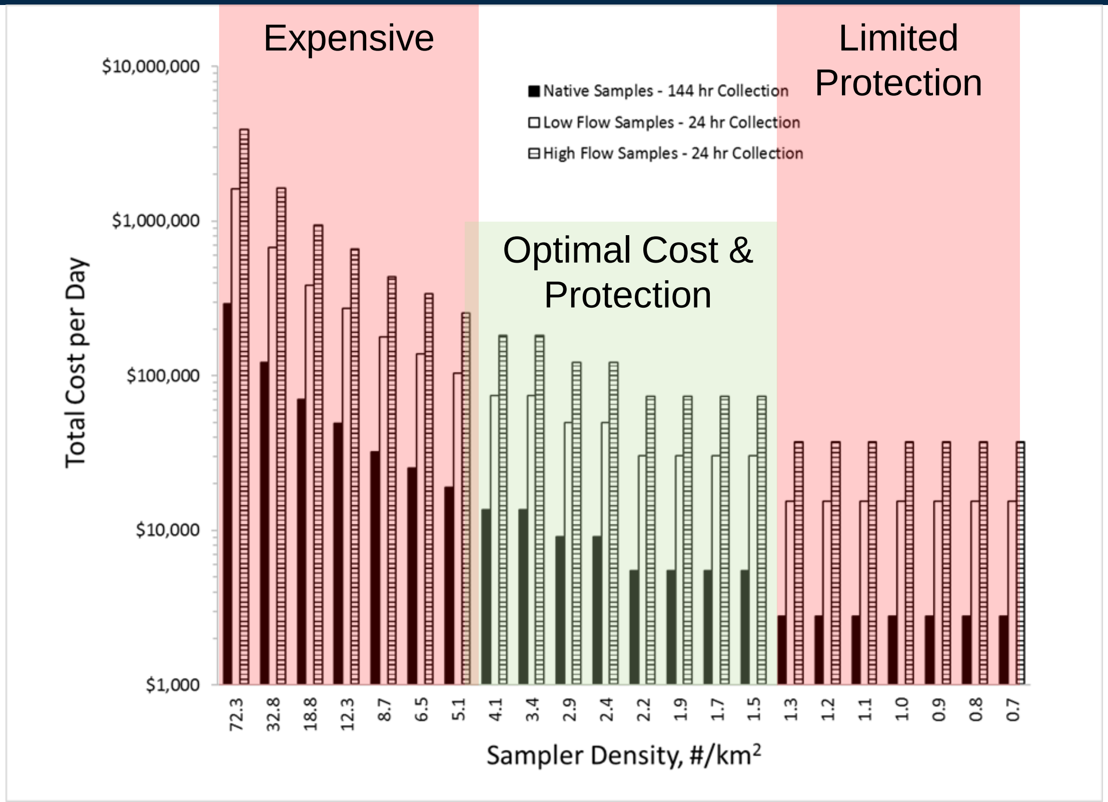
- Urban canyons in NYC promote vertical mixing.
- Small spread in detection efficiency as a function of height

Network Effectiveness



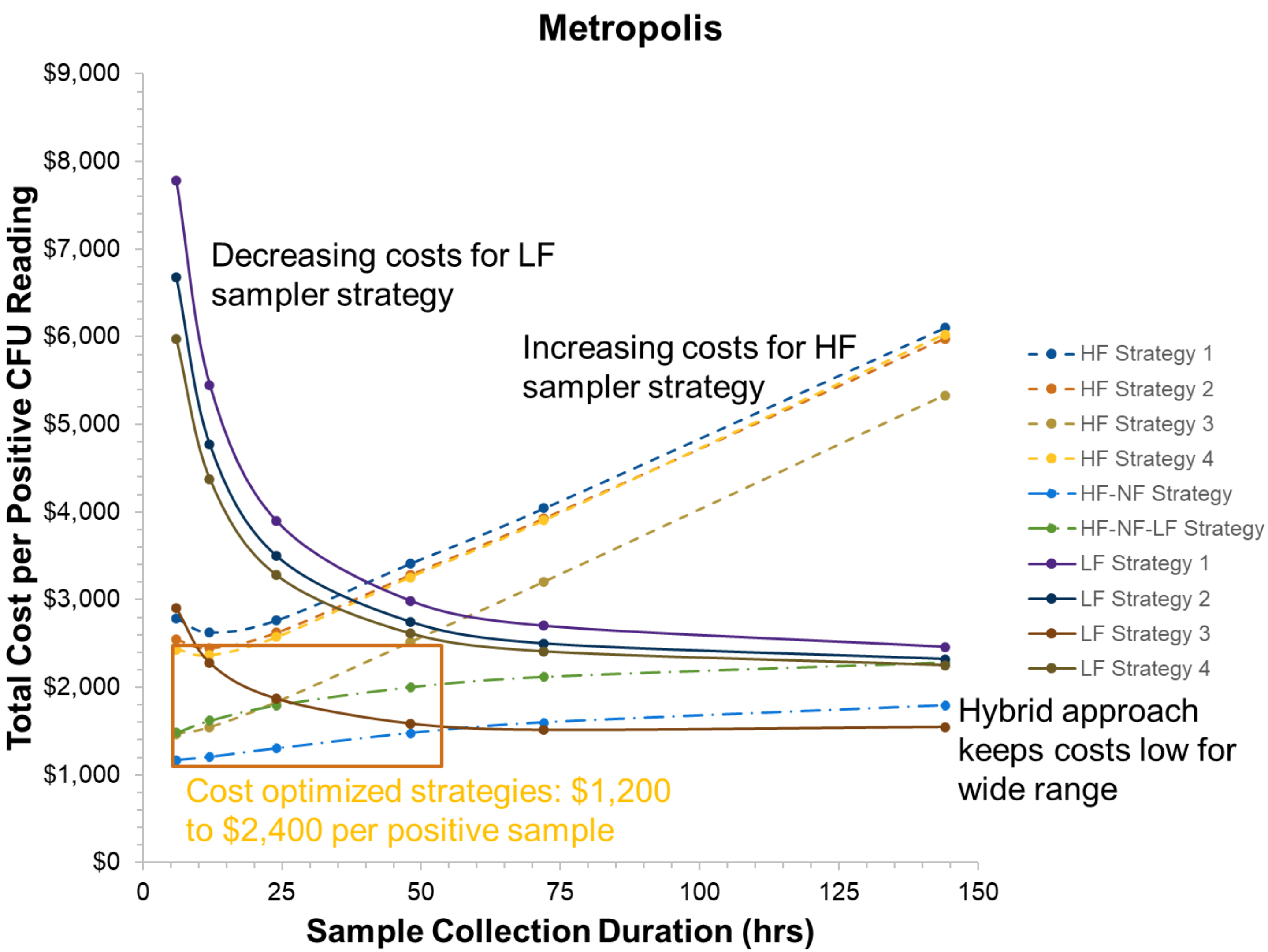
- 7,600 to 10,176 locations assessed across the 36 km^2.
- 0% to 2.2% of the locations failed to detect a positive because a sampler was not deployed.
- Trend: Native > High Flow > Low Flow
- Sampler density determines whether NYC or Denver network more effective.

Network Cost



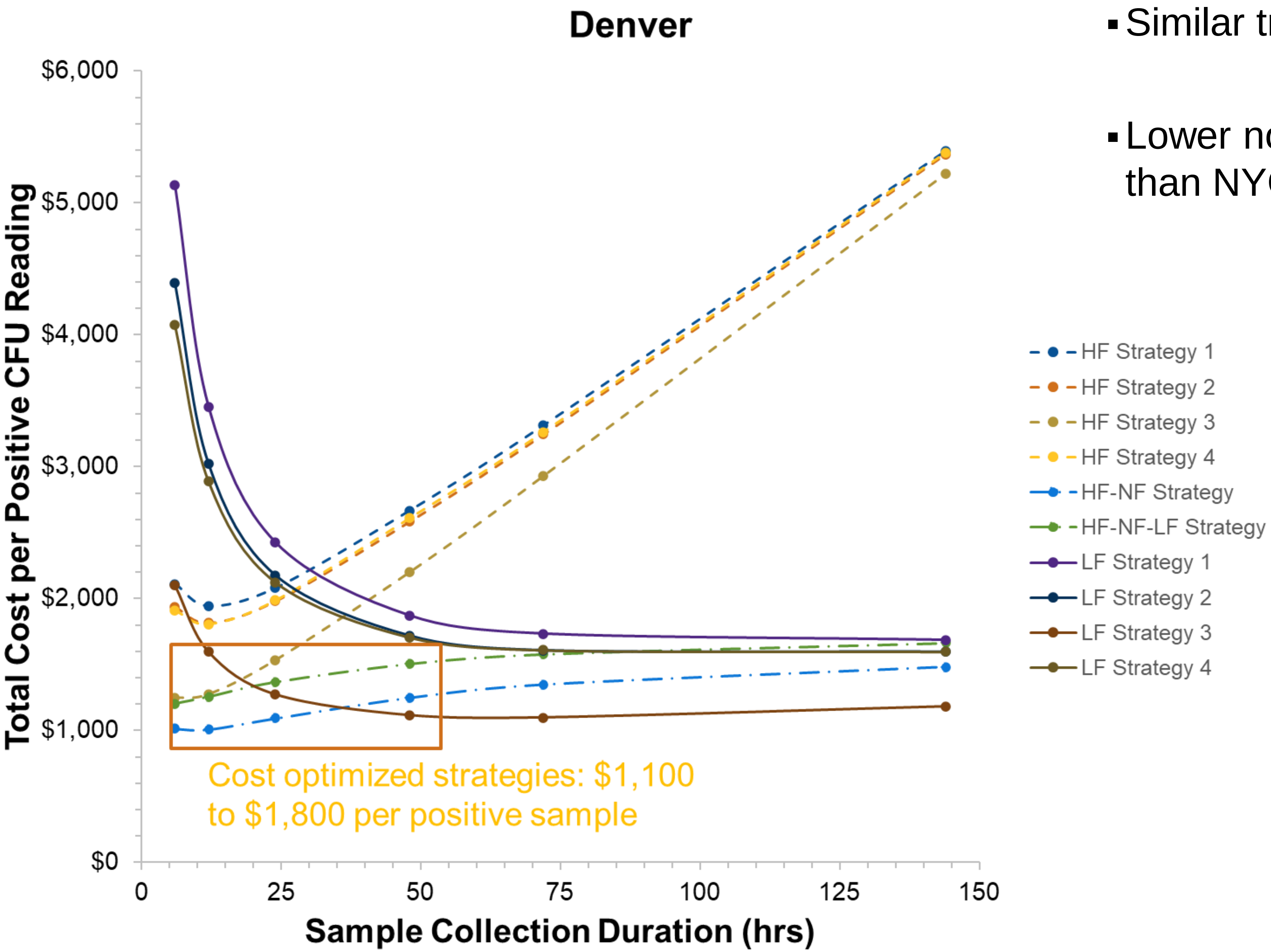
- High flow network costs determined by equipment purchase
- Low and native sampler network costs determined by labor
- A hybrid design with sampler densities from 1.5 to 4.1 per km^2 may be best

Network Optimization: NYC



- High flow samplers increase the normalized cost as sample duration increases
- Low flow samplers decrease the normalized cost
- Hybrid approach keeps costs low
- Minimize sample duration to maximum public health protection

Network Optimization: Denver



- Similar trends as NYC
- Lower normalized cost than NYC

Economics Summary

- Optimal Design: $813,000 for 30 days of operation
  - Hybrid Strategy: 7 high flow samplers around the point of release, 17 low flow and 17 HVAC air intake filters further from the release point

Costs for deployment of 45 samplers for 30 days

- High Flow = $2,400,000
- Low Flow = $907,000
- HVAC Filters = $165,000

Summary

- A filter based bioaerosol sampling network could be a cost-effective option for long term monitoring of resuspended spores.
- Resuspended bioaerosol concentration is a function of:
  - Resuspension fraction
  - Number of days since release
  - Sampler location and height
- Network spatial density and the mix of sampler types should consider location specific influences on resuspended spore dispersion:
  - Urban density, Topography, Meteorology
- This analysis suggests:
  - It is possible to develop a priori a bioaerosol sampler network that specifies the types, number, and location of the samplers for an approximated 36 km^2 area.
  - A uniformly distributed network in all cardinal directions is necessary because of daily variability in meteorology.
  - The number of samplers could be reduced over time by removing those farthest from the point of release; therefore further reducing costs.

Limitations

- How the resuspension fraction changes as surface loading is depleted and environmental conditions vary is unknown.
  - Assumed an equation for depletion rate equation.
  - Rain or mitigation influences on surface loading were not considered.

- Potentially important operational aspects were not considered.
  - Number and availability of trained personnel to deploy the network.
  - Access to the large number of bioaerosol samplers required.
  - Location and power access.

- A more comprehensive network design tool is needed to rapidly design a bioaerosol network for an impacted location.

Disclaimer

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Extra/Back-up Slides

Definitions and Conversions

- 1 CFU/m^3 = 1E-3 ACPLA
  - Or 100 ACPLA = 1E+5 CFU/m^3, lowest possible detection limit for real-time instrumentation
- Low Flow Sampler = 10 Lpm (SKC Leland Pump)
  - ~0.07 CFU/m^3 to collect 1 spore in 24 hours
- High Flow Sampler = 300 Lpm (XMX, etc.)
  - ~0.003 CFU/m^3 to collect 1 spore in 24 hours