To Green or Not to Green: *Modeling Incentive-based Programs for Green Infrastructure Investment on Private Properties*

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Simulation of Economic Incentive Frameworks for an Urban Stormwater Program Using an Agent-based Modeling Platform

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Overview

- Background/Motivation
- Initial Modeling
- Ongoing/Future Work

Background

- What’s the problem?
- What is green stormwater infrastructure?
- Where should we invest?
- Why incentivize?

“Only Major Growing Source of Water Pollution” – U.S. EPA

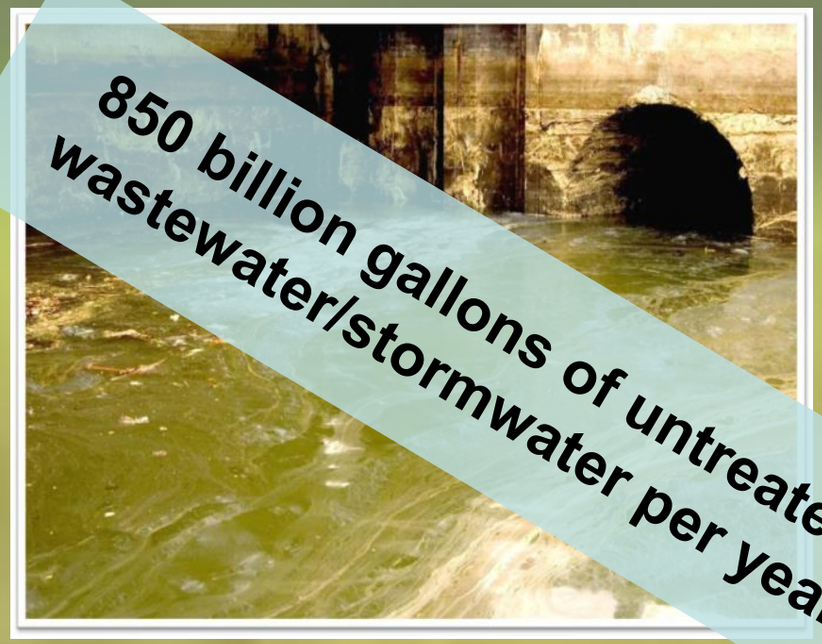
40-80%of sediment in Chesapeake Bay is from eroded urban streams

Forestsforwatersheds.org, 2014

300-900% increase in nusiance flooding in Eastern U.S. coastal cities over last 50 years

Boston Globe, 2013

Water Quality Impairments	Flooding
Urban Stormwater Runoff	
Combined Sewer Overflows	Ecological Impacts



850 billion gallons of untreated wastewater/stormwater per year

NRDC, 2013

2014 had 8th worst dead zone in Chesapeake Bay – 1 mi^3

Nic 2014

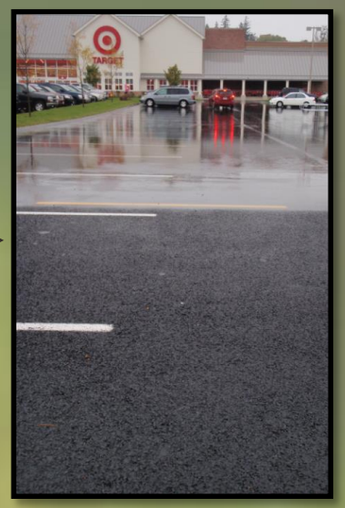
Traditional Stormwater Management

Collect

Convey

Detain

Green Stormwater Infrastructure



Infiltrate

Retain

Public vs. Private Retrofits

<u>Public ROW is limited</u>

- **Philadelphia, PA**
  - 10,000 impervious acres to be retrofitted - CSO
- **District of Columbia**
  - 415 impervious acres to be retrofitted – MS4
  - $100M of GI pledged in CSS areas - CSO
- **Prince George's County, MD**
  - 15,000 impervious acres to be retrofitted – MS4
- **Montgomery County, MD**
  - 4,300 impervious acres to be retrofitted – MS4

*Considering that new development <1% of existing development – more retrofits expected in the future for other programs

Rise of Incentives

GSI Incentive Programs

- **Philadelphia, PA**
  - Credit/rebate of up to 80% provided for onsite retention
  - Aggressive grant programs (based upon $/ac treated)
    - Promotes the aggregation of projects
- **District of Columbia**
  - Stormwater Retention Credit (SRC) trading program
  - Allows for 50% off-site mitigation for retention
  - Trading program established, run by Dept. of Env. (DDOE)

GSI Investment Dynamics

<u>"Hand of God"</u>

- Top-down
- Mandated
- Bureaucratic
- Piecemeal

<u>Organic Growth</u>

- Bottom-up
- Incentivized
- Efficient
- Aggregated

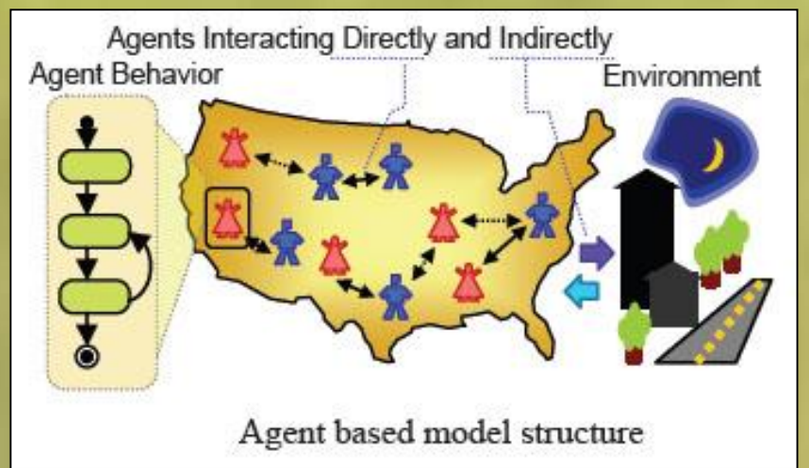
Initial Modeling

Taken From:

Brown, S. and Ferreira, C. (2013). "**Agent-Based Modeling of Urban Tropical Green Infrastructure Investment.**" Alam Cipta: International Journal of Sustainable Tropical Design Research and Practice, 6(2), December, 2013.

Agent-Based Modeling

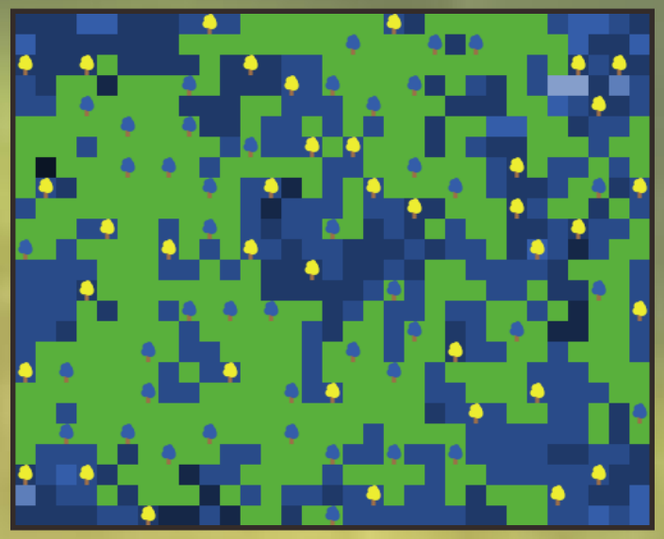
- Framework consisting of **agents** in an **environment** (interaction rules)
- Explores complex **emergent** system behavior (macro vs. micro)
- Irrational, imperfect knowledge, heterogeneous population
- Spatially and temporally dynamic



Modeling: Greening Cities

“Real” Urban Development

Ideal Urban Development



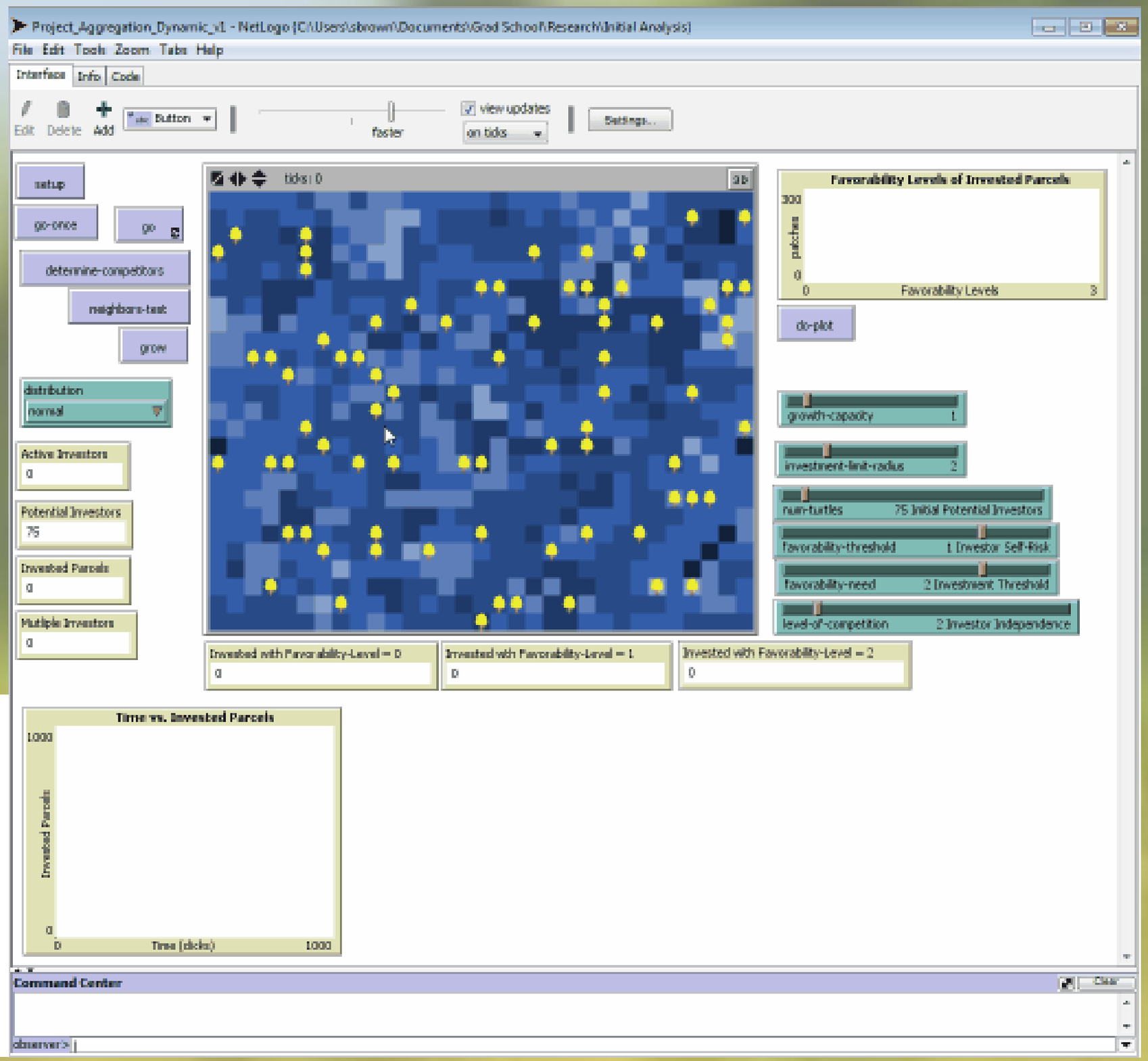
Stylized Urban Development

Research Effort

GSI Investment Model

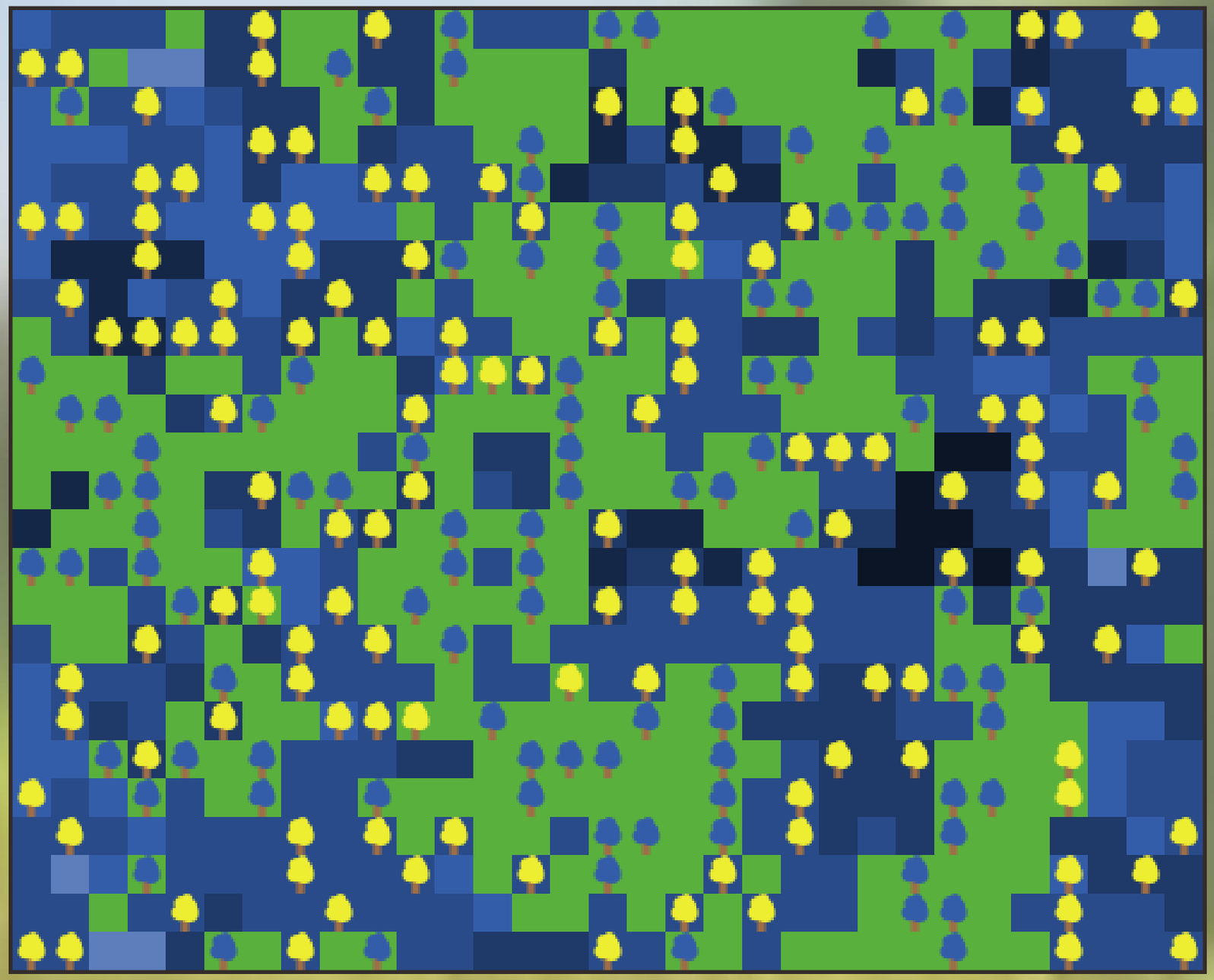
- Model developed using Netlogo
  - Investment of GSI retrofits on urban parcels
- Representation space:
  - Environment = parcels (ability to “green”)
  - Agents = Investors (Risk, Aggressiveness)
  - Behavior = synthetic data / assumptions
    - Investor risk, competition, growth

GSI Investment Model



Brown and Ferreira, 2013

Results - Patterns



<u>Observations:</u>

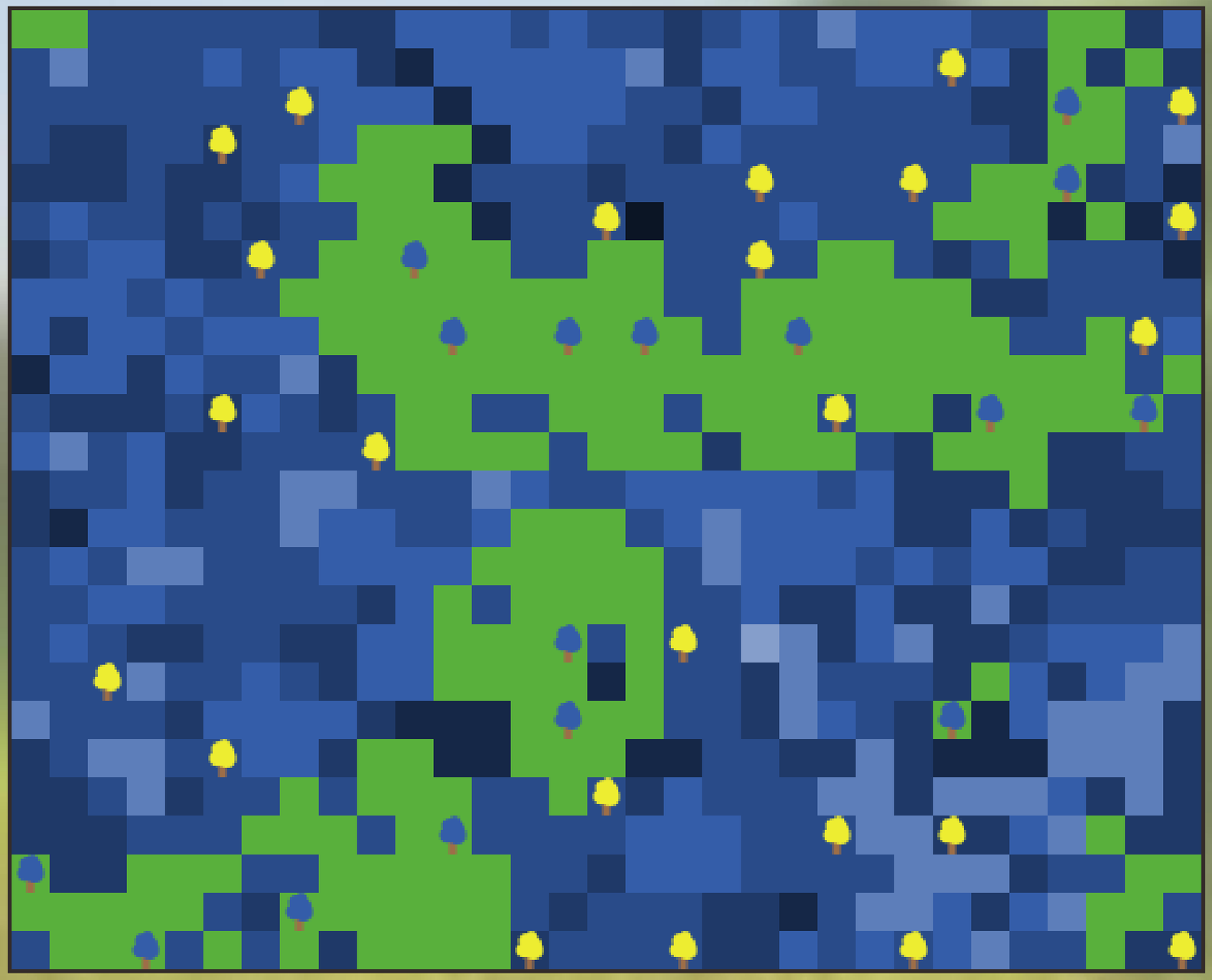
- High investment
- High connectivity
- Initial investors ~ invested parcels
- ~40% of invested parcels are occupied by investors
- ~55% of invested parcels have multiple investors
- Inefficient policies

Risk-averse, unaggressive investors

Initial Conditions: GC = 3, <u>IR = 1</u>, TU = 300, FT = 1, <u>FN = 3</u>, LoC = 4

Results: 329 invested parcels, 180 multiple investors, 115 active investors

Results - Patterns



Observations:

- High/moderate investment
- Moderate/well connected
- Invested parcels ~25% of total parcels
- ~8% of invested parcels are occupied by investors
- ~5% of invested parcels have multiple investors
- Ideal policy conditions

Risky, aggressive investors

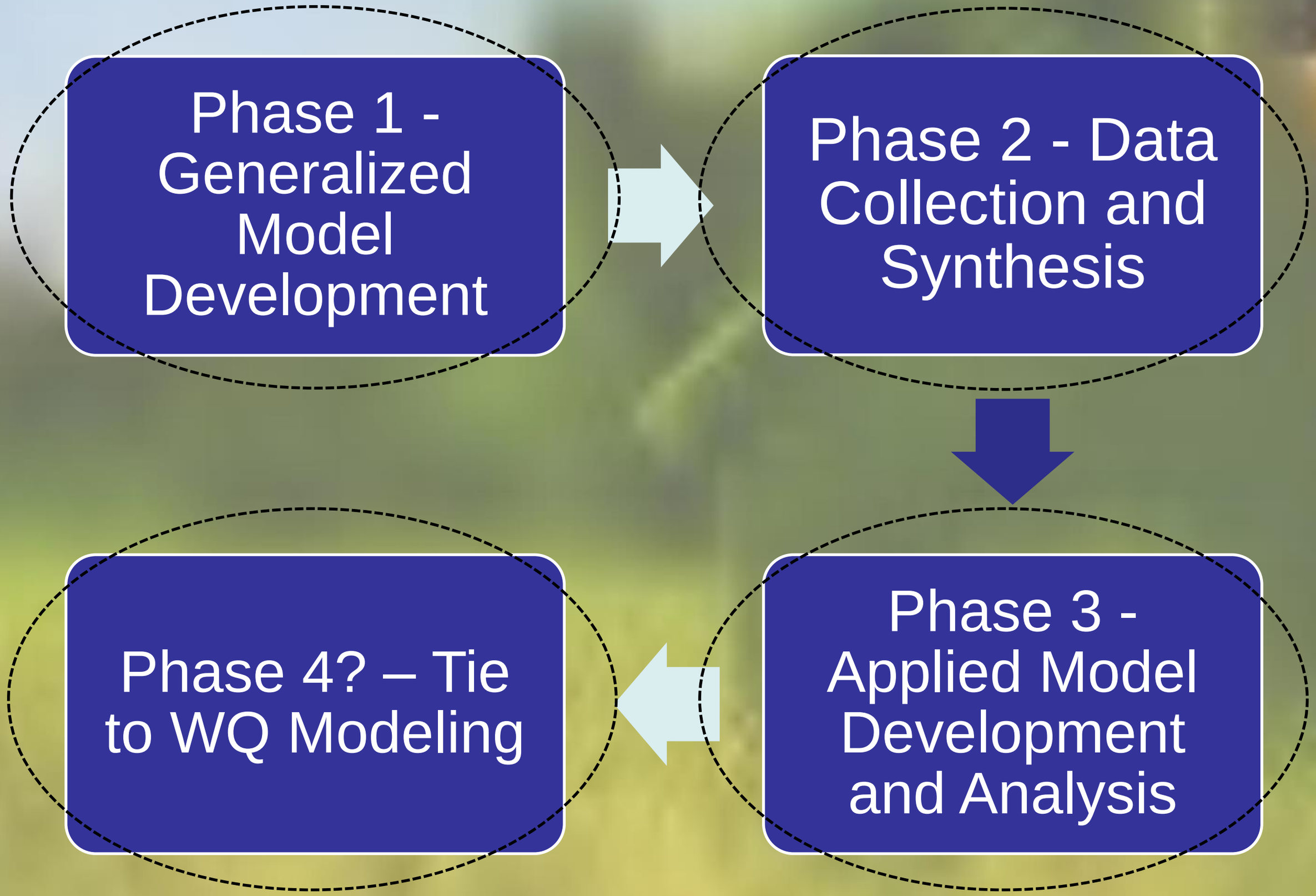
Initial Conditions: GC = 2, IR = 2, TU = 50, FT = 1, FN = 2, LoC = 1

Results: 199 invested parcels, 9 multiple investors, 16 active investors

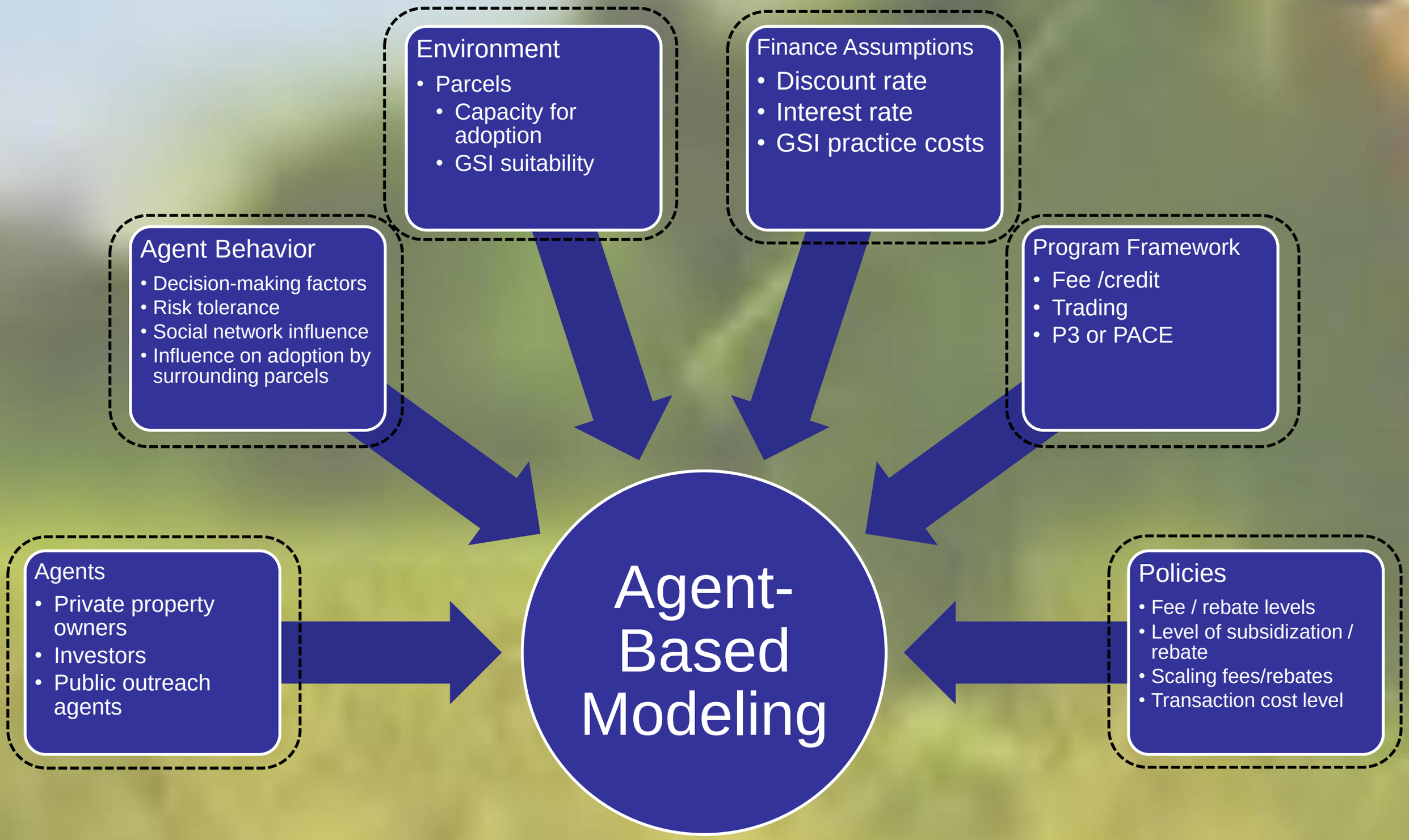
Ongoing/Future Work

- Use non-synthetic (“real”) behavioral data
  - Risk, motivations, innovativeness, etc.
- Move from stylized to real-world setting
- Social influence on information dissemination
- Investigate various incentive-based programs
- Investigate water quality/quantity benefits

Research Phases



Phase 1 – Generalized ABM Architecture

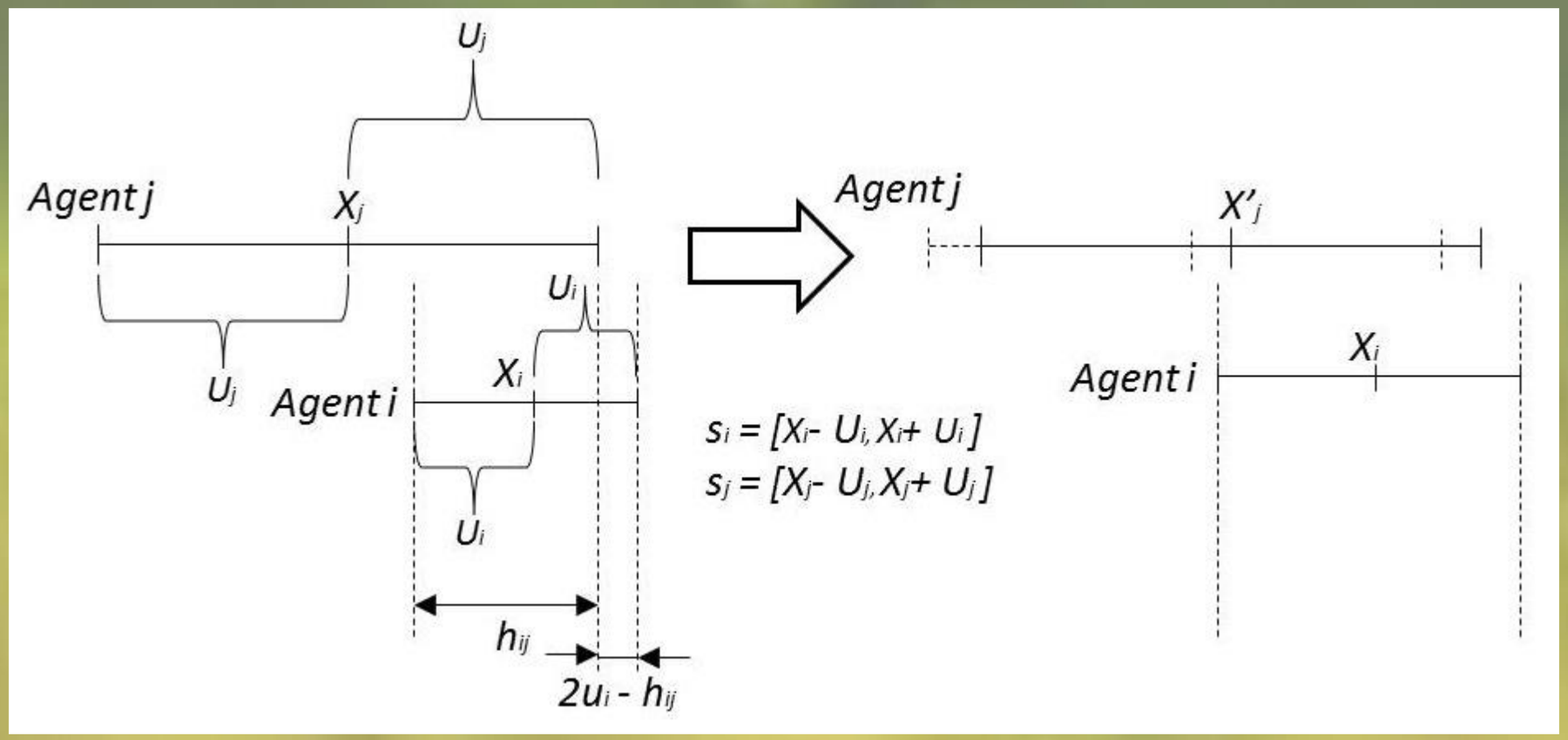


Social Influence

Relative Agreement Algorithm:

1. Agent *i* with opinion x_i and uncertainty u_i influences agent *j* with opinion x_j and uncertainty u_j

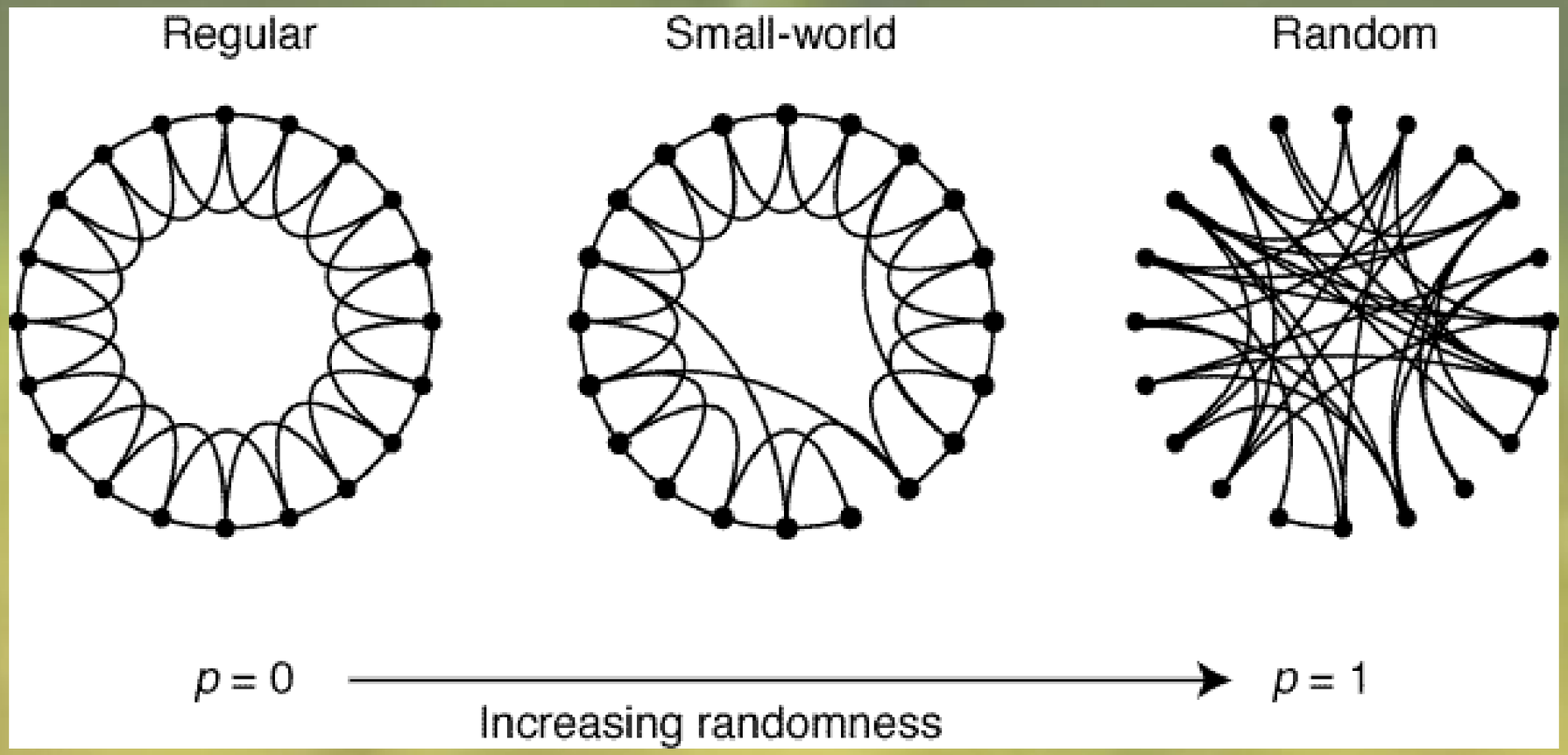
2. Agreement is determined and opinion of agent j is adjusted

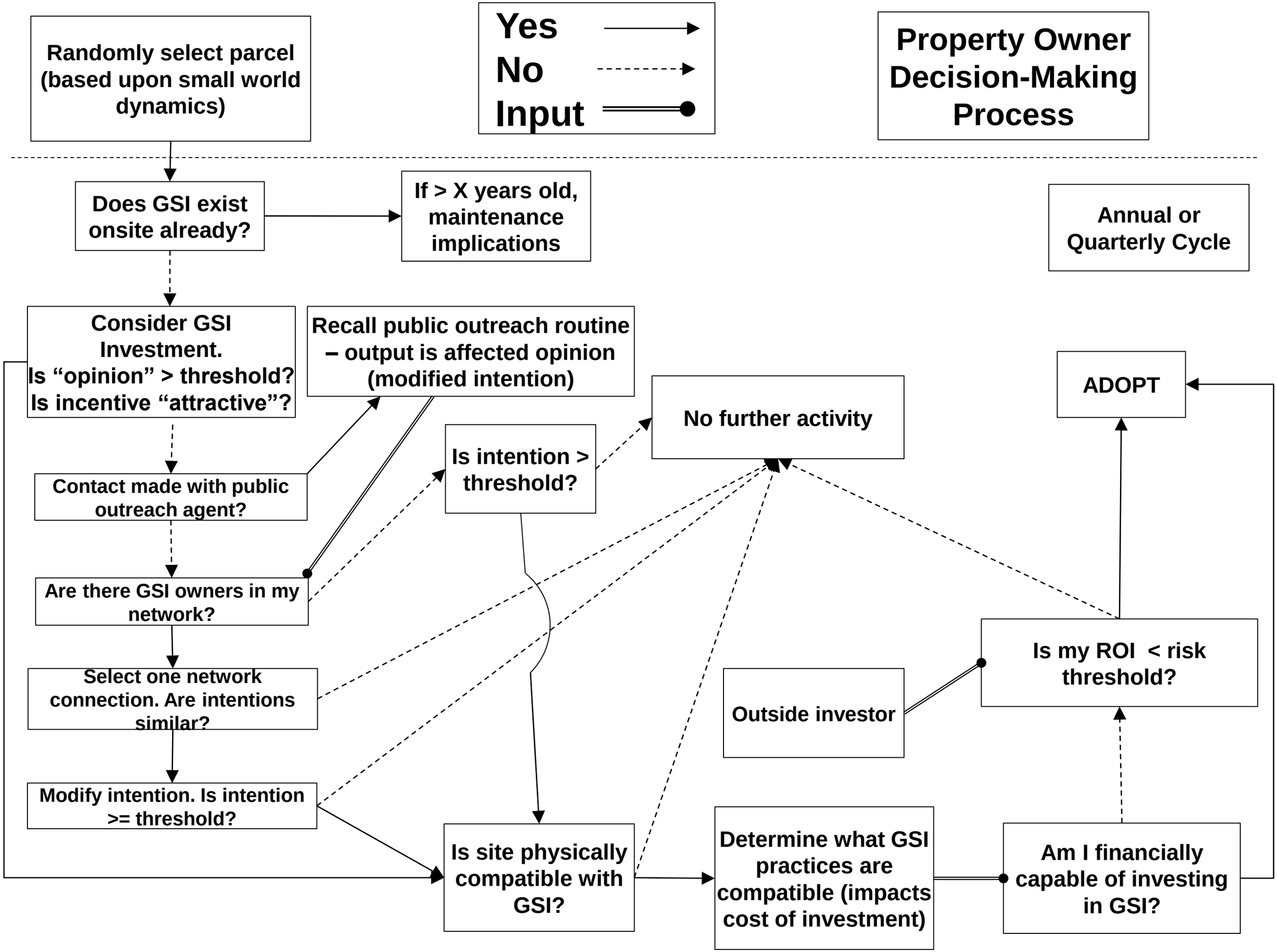


Social Influence

Small World network dynamics

- If P=0, info only gained from immediate neighbor
- If P=1, info gained randomly from anyone
- “Realistic” or “typical” social networks have a $0.01 < P < 0.1$




Yes
No
Input
Property Owner Decision-Making Process
Randomly select parcel (based upon small world dynamics)
Does GSI exist onsite already?
If > X years old, maintenance implications
Annual or Quarterly Cycle
Consider GSI Investment. Is "opinion" > threshold? Is incentive "attractive"?
Recall public outreach routine – output is affected opinion (modified intention)
ADOPT
No further activity
Is intention > threshold?
Contact made with public outreach agent?
Are there GSI owners in my network?
Is my ROI < risk threshold?
Select one network connection. Are intentions similar?
Outside investor
Modify intention. Is intention >= threshold?
Is site physically compatible with GSI?
Determine what GSI practices are compatible (impacts cost of investment)
Am I financially capable of investing in GSI?

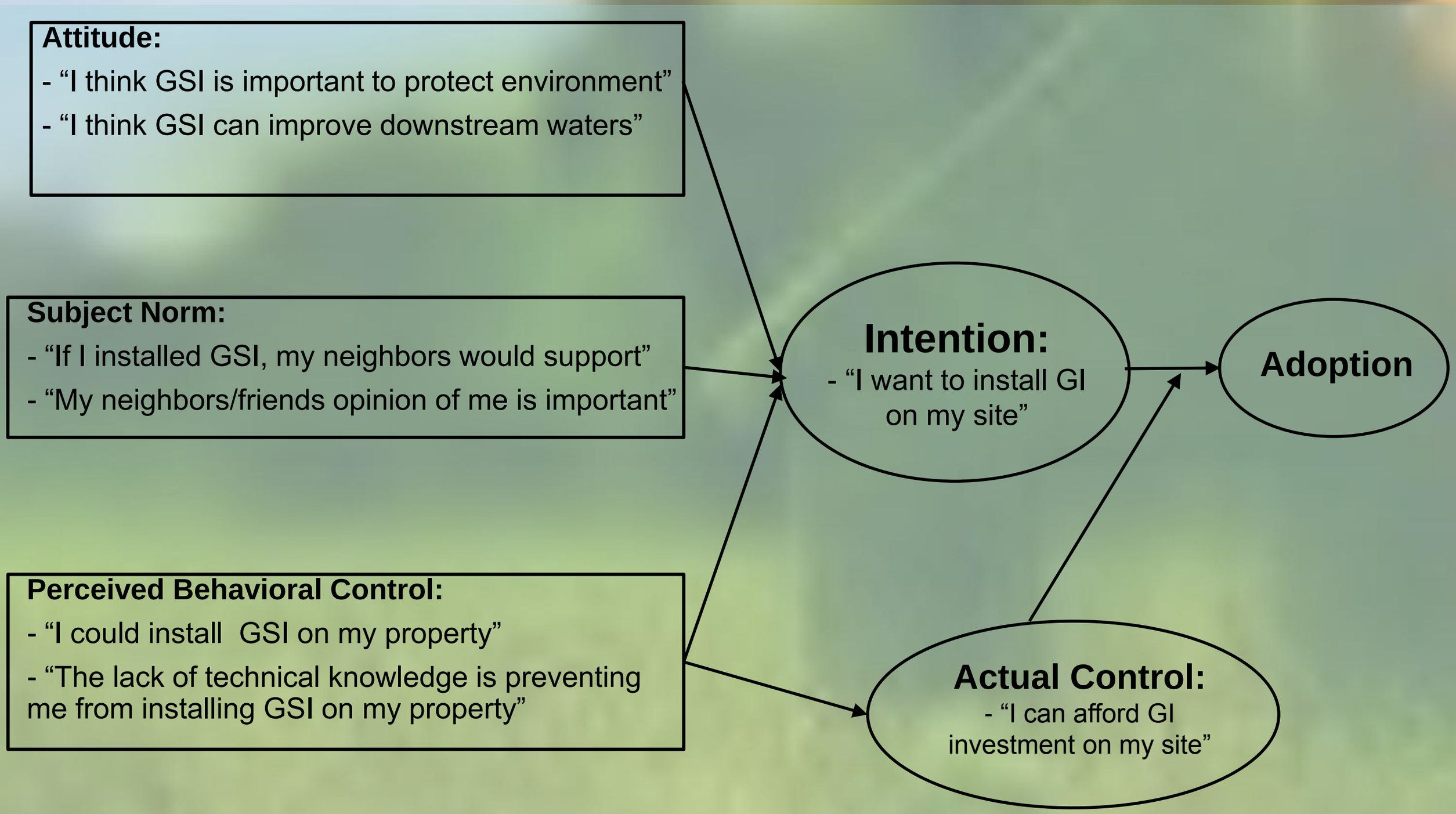
Phase 2 – Data Collection

- Survey / interview [agent]
  - TPB, Innovativeness, Risk
  - Statistical analysis
  - Model parameter development
- GIS data [environment, agent]
- GSI cost data

Theory of Planned Behavior

- Factor is based upon the strength of <u>belief</u> (*b, n, c* below) and the <u>evaluation</u> (*e, m, p* below) of belief in each case
- Mathematical Form is:
  - $A \propto \sum_i^n (b_i e_i) = \boldsymbol{Attitude}$
  - $SN \propto \sum_i^n (n_i m_i) = \boldsymbol{Social\ Norm}$
  - $PBC \propto \sum_i^n (c_i p_i) = \boldsymbol{Perceived\ Behavior\ Control}$
- $BI \propto (A) + (SN) + (PBC)$
- $BI = W_1(A) + W_2(SN) + W_3(PBC)$
  - W1, W2, W3 determined through regression with *BI* as criterion

Theory of Planned Behavior



Phase 3 - Research Analysis

Applied Model

Agent-Based Modeling

- Policies (incentives, programmatic, framework)
- Modeling parameters (financial, behavioral)

Emergent Behavior

- Diffusion of innovation (rate)
- Level of investment (amount)
- Distribution of adoption (spatial)

Policy Recommendations

- Incentive level (rebate level, subsidization level)
- Programmatic (fee rates & schedule, level of outreach & education, framework)

Conclusions

- GSI retrofits on private property = needed, challenge
- Initial modeling has fleshed out concepts
  - Proof of concept
- Future work
  - Incentive programs
  - Decision-making dynamics
  - Social influence
  - Actual costs and spatial data

Questions?

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