Potential Diffusion Trajectories of Low Impact Development (LID) solutions for Urban Storm Water Management in Built-Up Areas

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Practitioner Application

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Problem

The presented application utilizes a system dynamics model for exploring potential diffusion trajectories of **Low Impact Development (LID) solutions** to manage urban stormwater in built-up areas. The case of **Grefsen-Kjelsås** in the city of **Oslo, Norway** is used.

The application is a part of **Work Package 3: Integrated Assessment of Urban Water Management** of the **New Water Ways project** (https://newwaterways.no).

The City of Oslo has relied on a grey infrastructure (pipelines and treatment plants) to manage urban stormwater. However, growing population, increased impervious surfaces, ageing infrastructure and pollution affecting receiving waters, alongside climate change with more intense and frequent rainfall events has pushed the existing grey infrastructure to the limit.

The Municipality of Oslo has identified LIDs as a part of the storm water management strategy. LID refers to systems and practices that mimic decentralized natural processes that infiltrate and retain storm water on site and thereby delay or prevent stormwater to reach the sewer system. LID includes green roofs, rain gardens, vegetated swales, trees, constructed wetlands and rain barrels.

Problem

The sewer system in **Grefsen-Kjelsås** was built in 1955, and today the total length of the pipes is 10 000 m. The system is composed of a combined sewer system (60%) and a separated sewer system (40%). The combined sewer carry sewer from buildings and stormwater in the same pipes.

This system is designed with a **Combined Sewer Overflow (CSO)**, named AK52, acting like a relief valve allowing untreated wastewater discharge into the receiving river **Akerselva**. The separated sewer system, on the other hand, has an independent system for sewage from buildings and another for stormwater.

The separated sewer system reduces the pollution problems at **AK52**, but flush accumulated pollutants from streets and pavements (e.g., chemicals from vehicles and fertilizer from gardens) into **Akerselva**. The sewer contains mainly grey cast iron pipes. Investigation of the pipes has identified a total of 36 fractures and 755 drillings.

The majority of the drinking water pipes in this area also have poor conditions with fractures. Consequently, subscribers might lose water. In addition, there is a risk for contamination of the drinking water through suction due to drop in pressure at the fracture.

Problem

About 6000 people are living in **Grefsen-Kjelsås**. The standard of living is high, and the majority of the houses is private owned. A survey conducted in 2018 of people living at Grefsen plateau identified a higher educational level and a higher income level than the median average of Oslo.

A number of the householders had experienced flooding of their basements. The population has knowledge about the problems related to stormwater and the pollution problems downstream Akerselva.

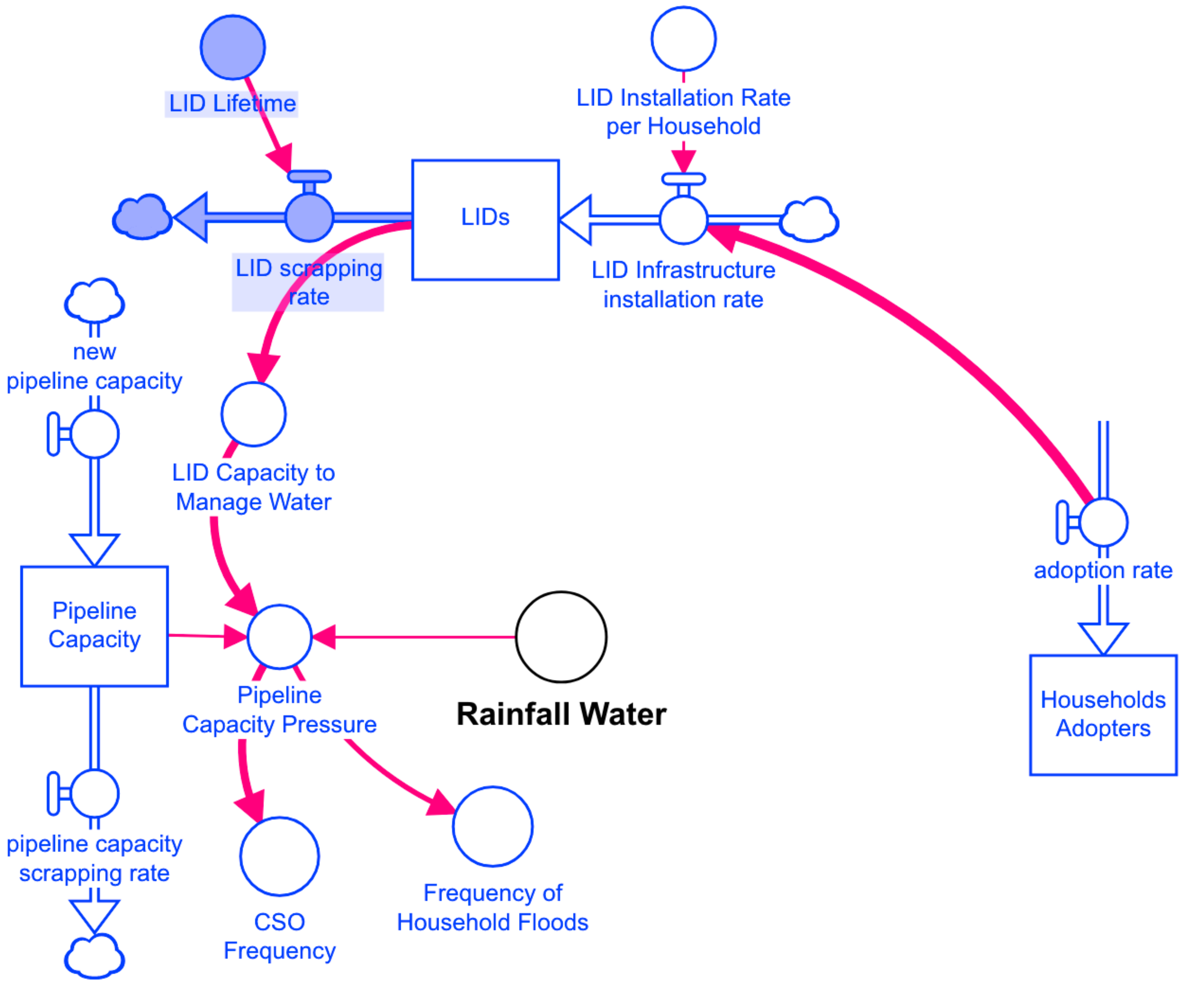
The municipality of Oslo demands that storm-water is managed on the property for new buildings. However, for already built-up areas there is no obligatory regulation for storm water management. Thus, LID might be a solution to improving the situation in **Grefsen-Kjelsås** but requires the participation of the residents.

Other studies within the NWW identified that there is some level of motivation among the residents of the area to implement LIDs. In particular, both actual and fictive reverse auctions were conducted to identify the willingness to pay for LIDs on the side of the residents.

Model/Framework

- The system dynamics model is designed to:
    - represent/formalize “social” aspect of the issue: adoption, human behavior
    - integrate hydrological and “social” sub-systems
    - integrate the results of reverse auctions studies conducted within the NWW project
    - explore possibilities of utilizing intrinsic value that the residents of a built-up area might place on LIDs and potential “co-joint” effects of policies
    - flexible enough to simulate a variety of assumptions behind the adoption potential
    - simple in representation to be explained to various stakeholders
- For simplicity, only one LID measure is modeled: rain beds/rain gardens.
- A very simplified version of the model’s structure is portrayed on the following slides.

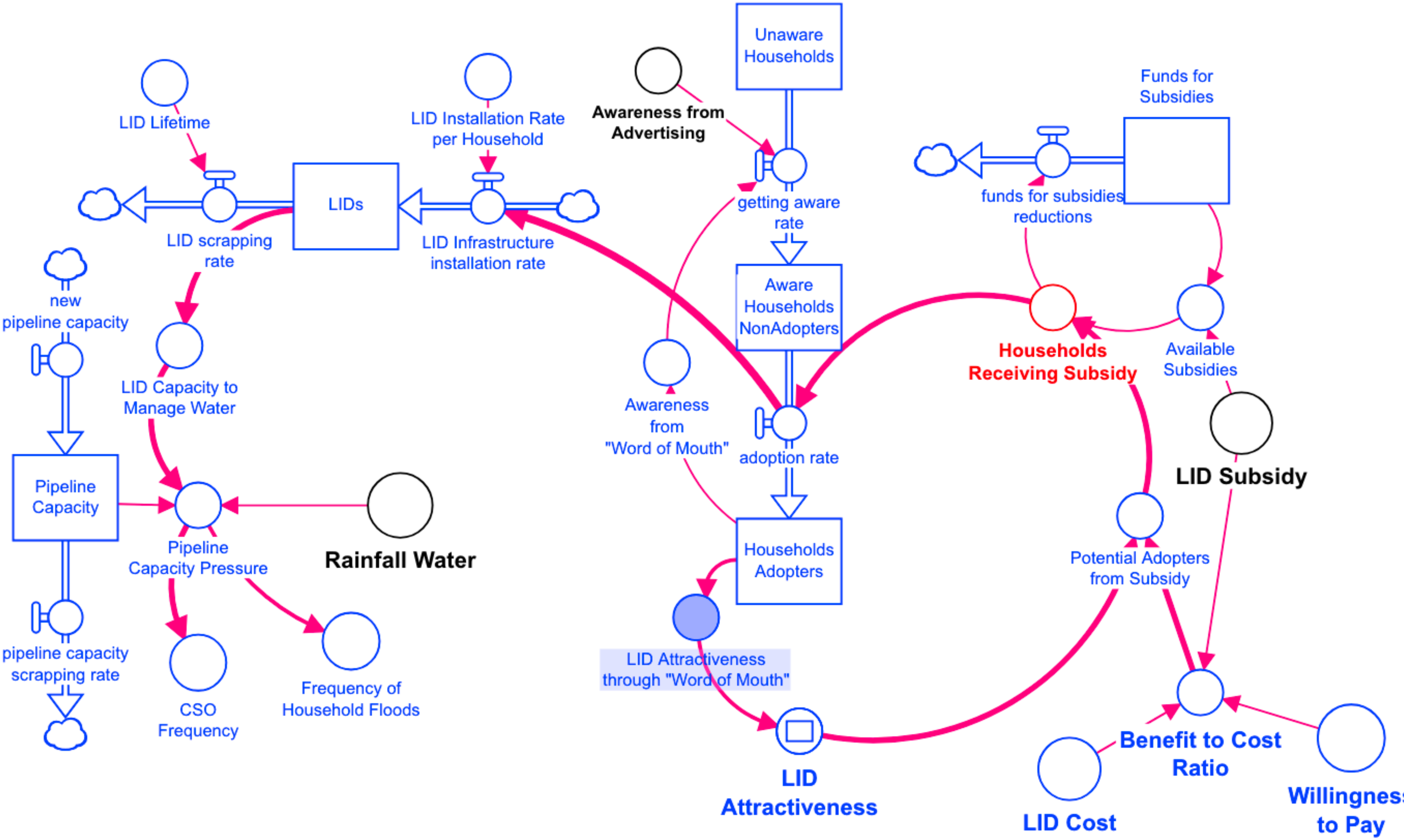
Hydrological sub-system



Integrative Model: nature/technology sub-system

- A note on fast/slow dynamics:
  - slow dynamics: investments in storm water management capacities with long lifetimes
  - fast dynamics: rainfall and water runoff dynamics leading to floods unfolds within minutes/hours
- The model runs on a yearly basis, since the primary focus is on the “slower” dynamics of investments/installations in the context of longer-term adaptation to climate change
- The “faster” dynamics is crucial, however, and is incorporated in the model via two structures:
  - an annual precipitation profile: an array of rainfall events of varying intensity typical for the area is specified with water levels and return periods (frequency: 1/3/5 etc - year rain) assigned to each intensity type; current pipeline capacity is formulated in terms of a water level that can be adequately managed and set to match a 3-year rain
  - a table function that relates the discrepancy between capacity to manage storm water and a water level of a particular rainfall event to a probability of a flood event (separately for combined sewer overflow and household-related floods); the probabilities could be interpreted as annual frequencies of the flood events
  - The table function is formulated based on the results from a hydrological model developed for NWW project: this detailed high resolution model simulates flood dynamics for various precipitation and storm water management capacities given the physical characteristics of the area (permeability, landscape, etc.)
- This conceptualization allows for an operational representation of LIDs: “green solutions” effectively enhance the existing “grey” capacity to manage storm water

“Social” sub-system



Integrative Model: “social” sub-system

- LIDs installations are the consequence (co-flow) of diffusion dynamics, modeled as a variant of Bass-diffusion model

- The central premise is that there is an intrinsic value that some of the area’s residents (measure in households) place on LIDs. This premise is operationalized via:

  - LID Attractiveness = formulated as a fraction of the households in the area that would install LID if LID cost matches Willingness to Pay (intrinsic value)

  - If Willingness to Pay only partially offsets LID Cost, a fraction of LID Attractiveness will be used to determine potential adopters.

  - This representation enables to integrate, at least at conceptual level, the results of reverse auctions conducted for the area within the NWW project and aimed at informing the residents about LID and revealing the monetary value they would place on “green solutions”.

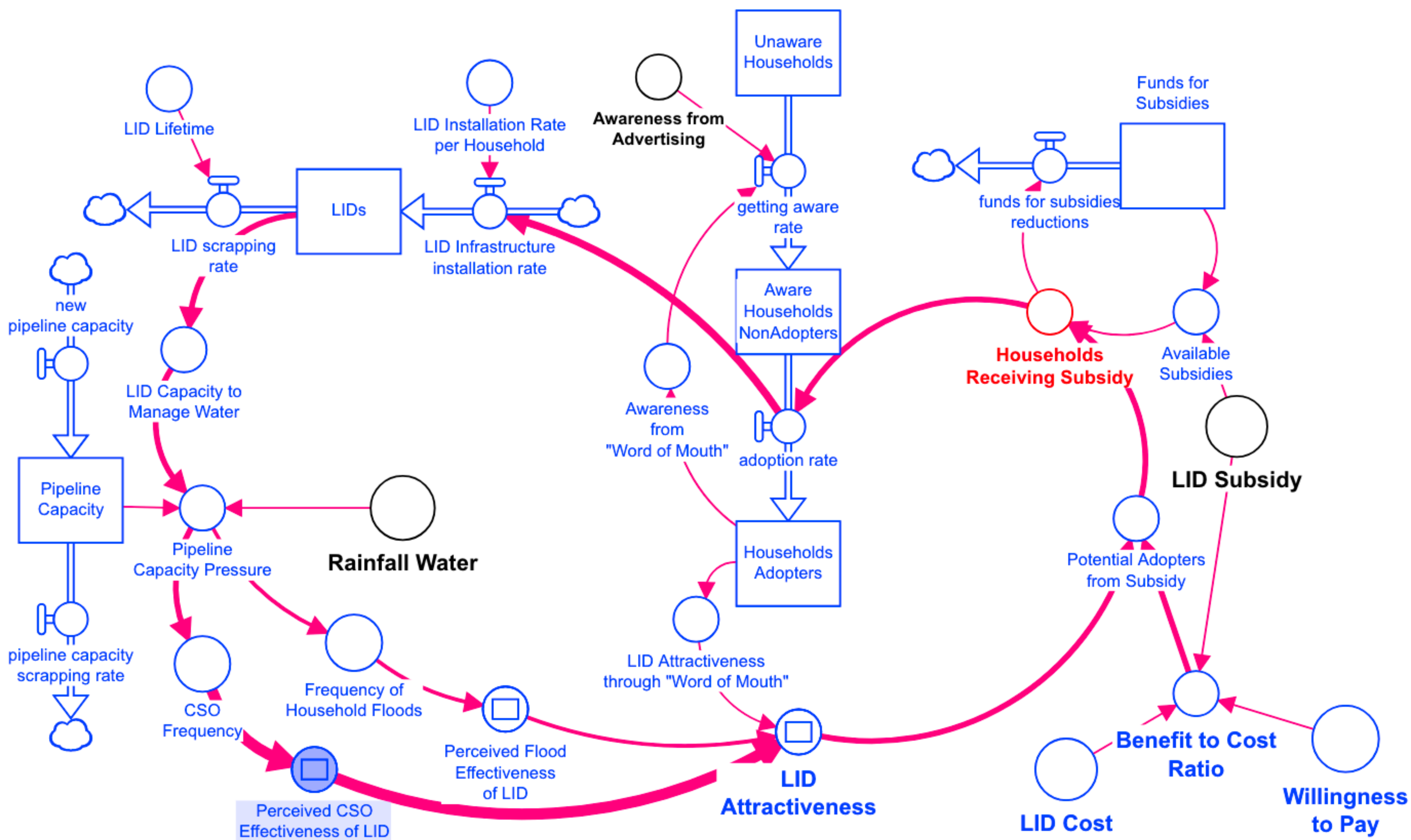
- For actual adoption rate to realize fully the potential for adoption, there have to be enough households that are aware of LIDs. Thus, the structure allows for explicit representation of LID advertising campaigns.

- The structure is designed such that a variety of incentive policies could be simulated. Some of the policies reduce effective cost of LID (subsidies) and other policies increase benefits associated with LIDs (storm water management fee; see later).

- If the stock of aware non-adopters and resources for resource-constrained policies (such as funds for subsidies) are available, the potential of diffusion from given LID Attractiveness and effective Benefit-to-Cost ratio is being realized fully over time.

- Two “word of mouth” effects could be specified: one affecting “awareness” and the other affecting LID Attractiveness itself and, thus, providing the first endogenous source for potential change in initial potential for LID diffusion.

Major Feedbacks

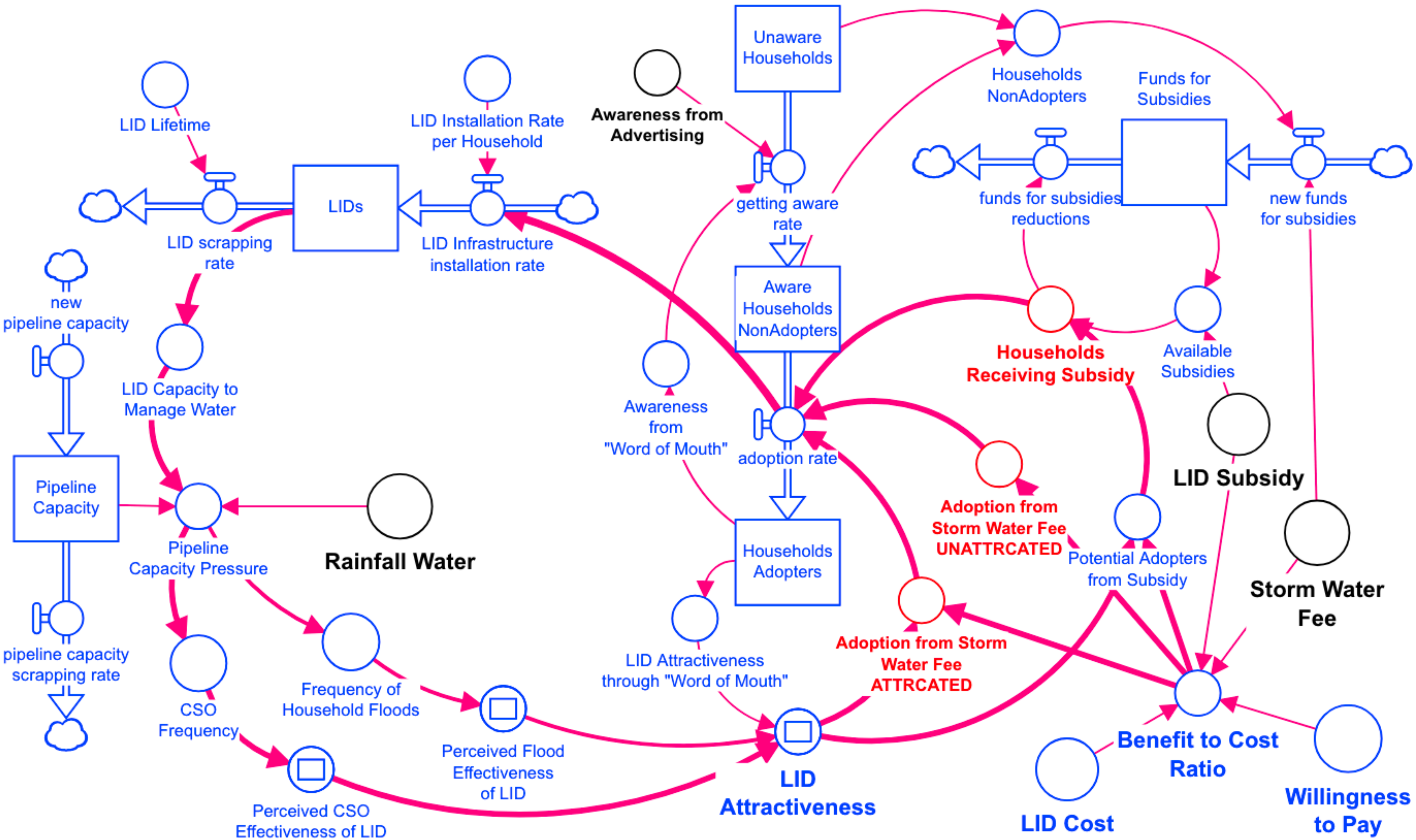


Major Feedbacks

- The main endogenous mechanisms that can potentially increase LID Attractiveness operate through the decrease in the frequency of flood events as LID installations unfold and the system's capacity to manage storm water is being enhanced - reinforcing feedbacks

- These feedback mechanisms are potentially powerful but are likely to manifest over longer rather than shorter term: it takes time for LID installations to reach the scale that would enable flood reductions and it takes time for the residents in the area to perceive these improvements, incorporate them in the decision-making and, ultimately, act on them by installing more LIDs.

Policies



Unaware Households
Households NonAdopters
Funds for Subsidies
LID Lifetime
LID Installation Rate per Household
Awareness from Advertising
LIDs
getting aware rate
funds for subsidies reductions
new funds for subsidies
LID scrapping rate
LID Infrastructure installation rate
new pipeline capacity
Aware Households NonAdopters
Households Receiving Subsidy
Available Subsidies
LID Capacity to Manage Water
Awareness from "Word of Mouth"
adoption rate
LID Subsidy
Pipeline Capacity
Adoption from Storm Water Fee UNATTRCATED
Potential Adopters from Subsidy
Pipeline Capacity Pressure
Rainfall Water
Households Adopters
Storm Water Fee
pipeline capacity scrapping rate
Frequency of Household Floods
LID Attractiveness through "Word of Mouth"
Adoption from Storm Water Fee ATTRCATED
CSO Frequency
Perceived Flood Effectiveness of LID
Benefit to Cost Ratio
Perceived CSO Effectiveness of LID
LID Attractiveness
LID Cost
Willingness to Pay

Policies

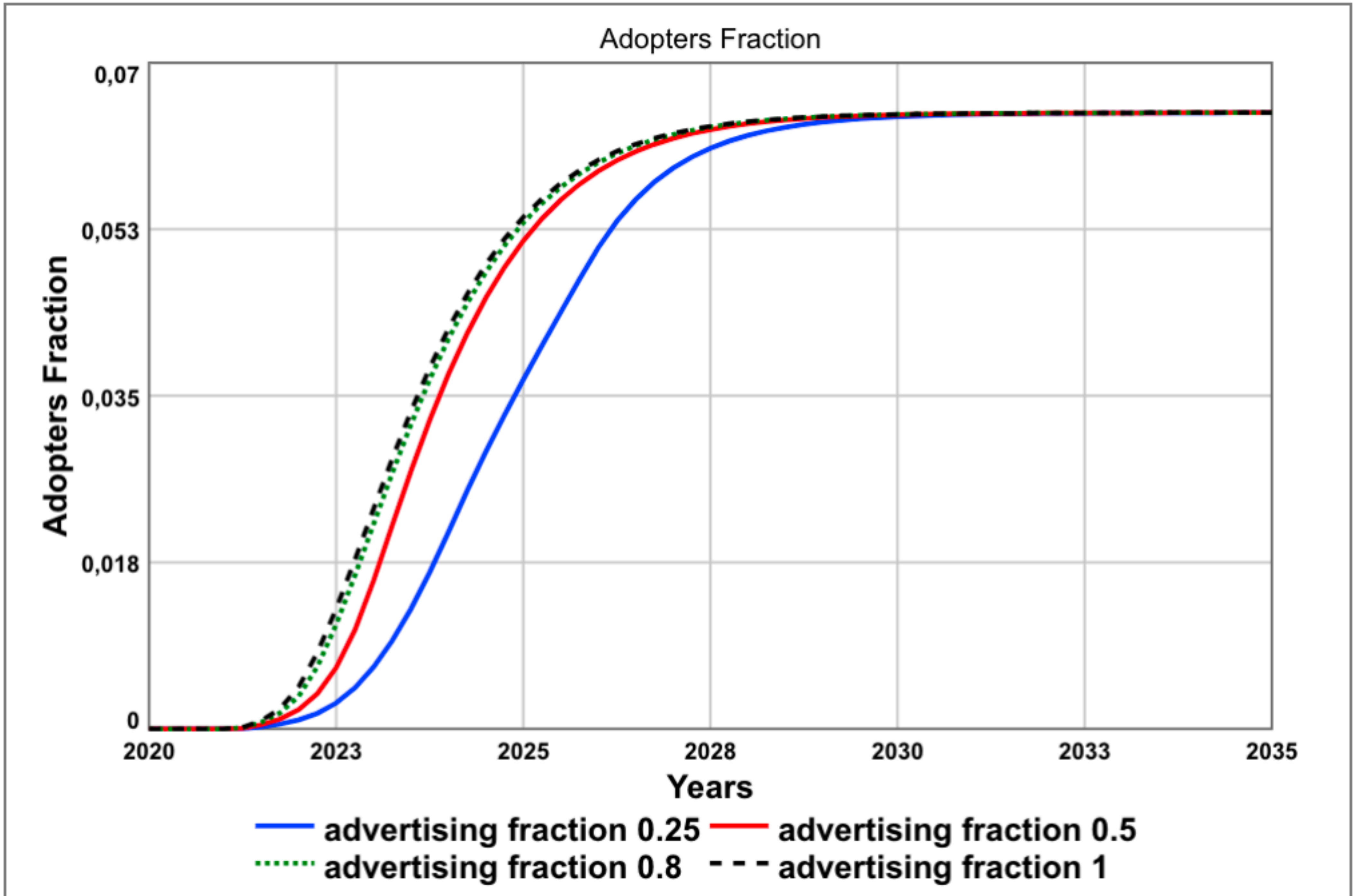
- The model allows for simulating two policies aimed at incentivizing LID adoption:
  - Subsidies for LIDs from Municipality = formulated as a fraction of LID Cost covered by a subsidy
  - Storm Water fee = an annual fee charged as a separate item on a water bill to be payed by a household.
- There is an ongoing research (also within NWW project) on the size and the design specifics of such a fee. The model operates with a baseline 700 NOK/Year/Household fee - which is roughly in the range of discussed values. For comparison, in the numerical context of the model, a fee of 3600 NOK/Year/Household would cover the full cost of LID annualized over its lifetime
- Subsidies could be simulated in an “unlimited mode” (no financial constraints) or as being payed out from the storm water fee receipts. The latter design of subsidy policy was a suggestion by some stakeholders in the NWW project.

Results/Recommendations

- Two conceptual insights have been obtained throughout the process of interviews and conversations with various stakeholders and knowledge experts within the NWW project about the model:
  - The role of LIDs was explicitly defined as providing contribution to the capacity of urban water infrastructure to manage storm water
  - Due to the need for the model to calibrate “positive” impact of LIDs on urban start water management capacity, an explicit target of 25% of households adopting LID solutions (which should be enough to provide adequate capacity to handle a 3-year rain) was elicited.
- The subsequent result section focuses on diffusion dynamics of LIDs in terms of adoption fraction as a fraction of total households in the area

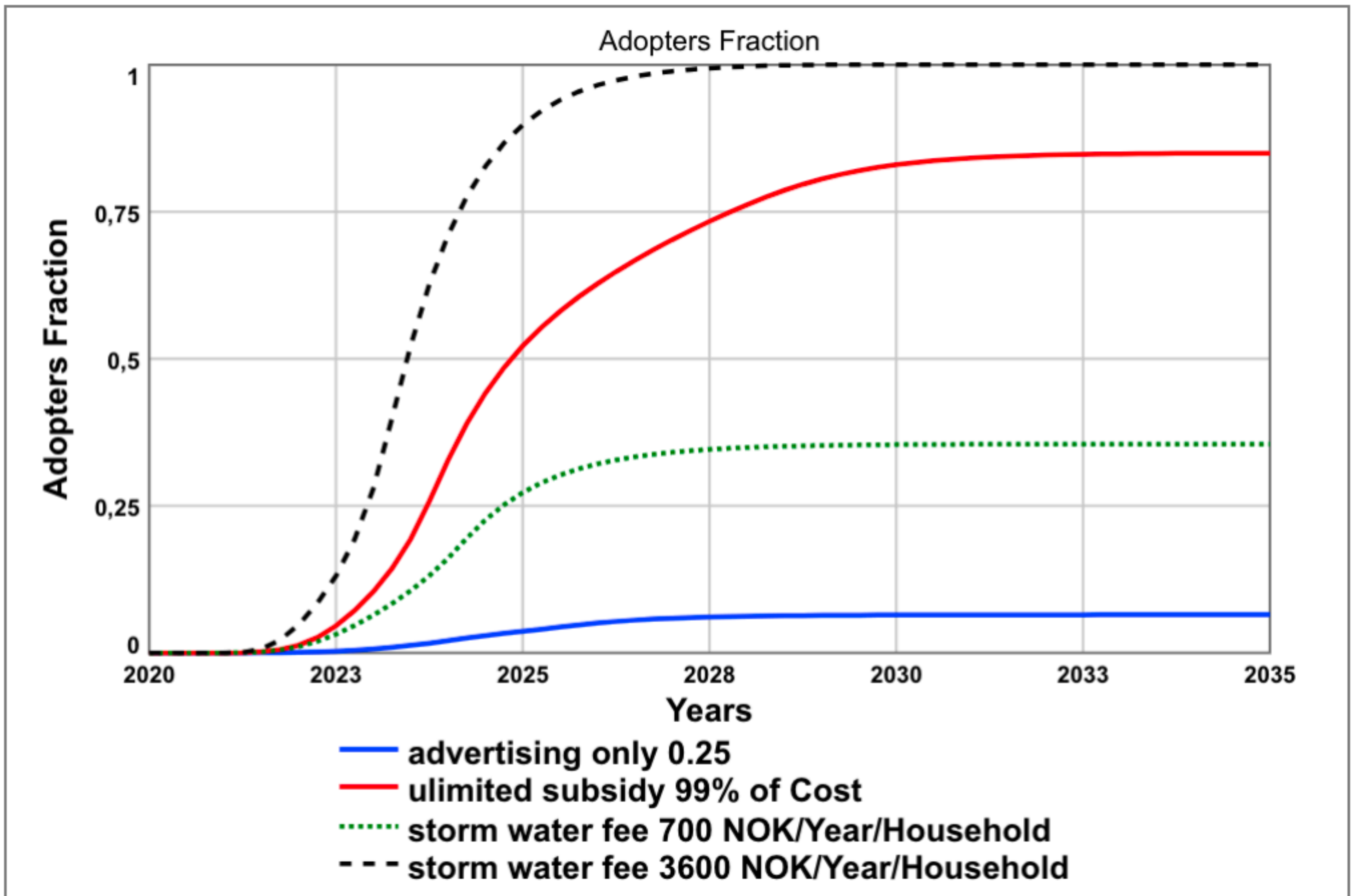
1. Advertising is important, but impacts the speed of diffusion rather than the ultimate adoption

2. Ultimate adoption depends largely on assumptions about initial intrinsic interest and the potential for its improvement due to LID's performance - though, this is a long-term feedback loop and might be questionable in the face of climate change



3. The simulations demonstrate a crucial difference between subsidies and storm water fee as incentive policies:

while subsidies at most can only realize maximum LID adoption potential from LID attractiveness assumed in the model, storm water fee can incentivize LID among the households who are not interested in LID at all and, therefore, significantly higher adoption fractions could be achieved even at fee well below the fee of 3600 NOK/Year per Household (the one that covers full annualized cost of LID).

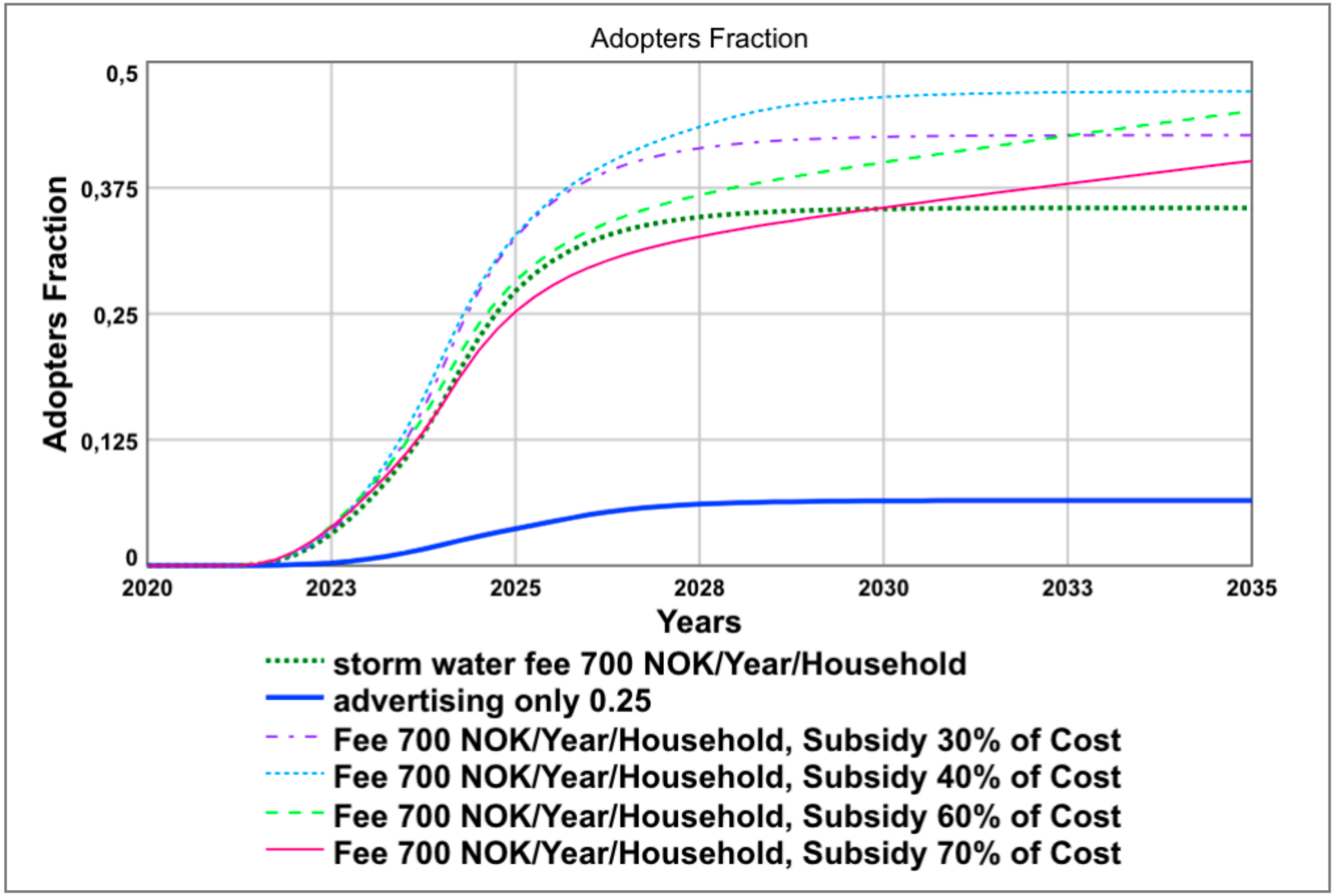


4. Some reasonable combinations of storm water fee and storm water fee-financed subsidies might provide meaningful cumulative LID adoptions

moderate subsidies might be preferred to more "aggressive" ones, as they capitalize on the storm water fee revenues from yet "non-adopters" in the short run

the transition is much slower in the "aggressive" case which might be crucial since LIDs are likely to be most effective in the near-term

aggressive subsidies will draw the "easier" adopters first leaving the "harder-to-get" ones to storm water fee, while less "aggressive" subsidies will let storm water fee "do its work" first, while keeping subsidies for households with lower willingness to pay (the risk of subsidizing households who could be motivated simply by storm water fee)



Discussion/Limitations

- As of now, the model does not contain the effect of climate change on precipitation profile. It is a strong expectation that with climate change precipitation in the area will increase: rainfall events that have a higher return period will become more common.

- In this context, “green solutions” of the type modeled are likely to have little visible effect in the longer run. These, however, are important measures in the shorter run.

- This aspect might have an impact on diffusion dynamics depending on the information that the residents receive while being motivated to install LIDs: incentives that downplay the likely decrease in the visible of LIDs in the longer run might impact re-purchase decisions on the households.

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