# Exploring Win-Win Strategies for Urban Stormwater Management: A Case Study in Philadelphia's Combined Sewer Area

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**ABSTRACT**

Focusing on the neighborhood where the Village of Arts and Humanities is, we have developed, evaluated, and tested a method for incorporating community input regarding ancillary green infrastructure (GI) benefits into a multi-objective GI optimization model. The model adapts the Stormwater Investment Strategy Evaluation (StormWISE) model for use in urban settings where the community interests are expressed using additive utility functions with weights elicited from community workshops. The ancillary benefits quantified in the case study are the highest priority benefits identified by the GreenPhilly Community Advisory Research Board (GCARB) though exercises created for the workshops. Four weighting methods are compared to assess consistency and sensitivity of the results.

## INTRODUCTION

Green Infrastructure (GI) is an increasingly popular tool in urban stormwater management, partly for the ancillary benefits it provides (e.g., street beautification) (Wise et al., 2010; Baptiste et al., 2015; Heckert & Rosan, 2015), and partly for the opportunity for politicians to use GI for community development. Documented ancillary benefits include reductions in floods, heat stress, air and noise pollution, stormwater fees, and use of energy and road salt; improved property values; and enhanced aesthetics, safety, cohesion, and health of communities (Tzoulas et al. 2007; Wise et al., 2010; Gómez-Baggethun et al., 2013; Demuzere et al., 2014; Wolch et al., 2014).

It is worth noting that ancillary benefits accrue at various geographic scales, while GI planning for stormwater management generally applies at the city or regional scale. For example, energy, water, and stormwater fee savings apply to households, property values, aesthetics, safety, and community cohesion improvement apply to communities, while floods, heat stress, and air pollution reductions are managed, at least in part, at a city/ regional scale. The appropriate sizing of GI planning zones is

still debated, but there is a tendency to considering ancillary benefits on the neighborhood or community scales (Schilling and Logan, 2008; Collier et al., 2013; Lovell and Taylor, 2013). Since not everyone values the benefits the same, we argue that GI planning can be most successful when communities are involved in the planning process so that GI can more effectively enhance the quality of life for local communities.

Therefore, this paper proposes a methodology for community GI investment planning for exploring "win-win" strategies that meet stormwater management goals and maximize preferred ancillary benefits for local communities. This method includes holding workshops to identify important benefits, elicit preferences, and a multi-objective optimization model. To evaluate the method's usefulness, we invited community leaders, local experts, and government officers to join our research team as the GreenPhilly Community Advisory Research Board (GCARB) for comments and advice on the method, who also offered us an opportunity to test it.

The GCARB identified and ranked categories of ancillary benefits in the first two meetings, as documented in McGarity et al. (2015), so this paper presents the results in the third and fourth meetings which emphasize prioritization of those benefits. The study area is the neighborhood of the Village of Arts and Humanities, a Registered Community Organization (RCO) in North Philadelphia. The optimization model is an expansion of the Stormwater Investment Strategy Evaluation (StormWISE) model (McGarity, 2012) to include GI ancillary benefits. StormWISE is a multiobjective programming model that generates alternative Pareto efficient plans.

## IDENTIFICATION OF IMPORTANT BENEFITS

The literature indicates that causal linkages between GI practices and some categories of ancillary benefits remain highly uncertain (Tzoulas et al. 2007; Lyytimäki & Sipilä, 2009; Demuzere et al., 2014), yet those benefits still play an important role in people's perceptions of GI. To understand the community's perception of the ancillary benefits, we developed a plus/minus-based exercise for the participants to indicate positive/negative relationships between particular GI practices and various categories of benefits. The exercise was tested in the third GCARB meeting using a form similar to Table 1, where the columns are the 8 common GI practices and the rows are 14 high-rank GI benefits identified in McGarity et al. (2015). Meeting participants were divided into five groups of 3 or 4, and were asked to imagine themselves to be residents in the study area when discussing the causal relationships. Table 1 shows the results of aesthetic and amenity from all five groups, with the number of symbols indicating the number of groups identifying the associated causal relationship. For example, rain gardens and aesthetics have three "+", meaning that three groups think rain gardens have that benefit. Note that amenity is defined as open space created by GI installation that improves community cohesion and stimulates the residents' physical activity. The results from the plus/minus exercise can help reduce the effort needed for benefit quantification by focusing subsequent efforts on the benefits that are most likely to be affected by GI.

**Table 1. Example results of plus/minus exercise (amenity and aesthetics benefits)**

| GI Benefit | Wet/Dry Ponds | Rain Gardens | Trees | Green Roofs | Stormwater Planters | Impervious removal | Permeable Pavement | Cisterns |
|---|---|---|---|---|---|---|---|---|
| Amenity | | ++ | + | | | + | - | |
| Aesthetics | ++ | +++ | | + | + | ++ | ++ | -- |

To quantify fourteen benefits is difficult, so we focused on the most important benefits. We developed the second exercise to identify the highest priority concerns of the stakeholders. It involved asking the groups to decide how one million dollars should be invested among eight GI practices (the columns in Table 1), given a map of the study area and data on how much each GI practice cost. To prime the participants, they were asked to list and rank five goals (benefits) they would most like to achieve.

Table 2 shows the benefit categories that received endorsements from at least 3 groups. Aesthetics and amenity both received 5 votes, while green jobs obtained 4. Although flood reduction, heat stress reduction, and safety concerns all have 3 votes, flood reduction and safety concerns, in general, received lower rankings from the groups than heat stress reduction. Water quality and runoff reduction each got 1 only vote because the participants thought the government would take care of those benefits, which do not directly accrue to the local community. The groups also suggested that those categories should be considered separately from ancillary benefits.

**Table 2. Benefits having at least 3 votes from the top-5 goal lists**

| GI Benefit | Aesthetics | Amenities | Green Jobs | Flood Reduction | Heat stress Reduction | Safety concerns |
|---|---|---|---|---|---|---|
| Votes | 5 | 5 | 4 | 3 | 3 | 3 |

Table 3 shows the average budget allocations that the participants gave the GI practices. Rain gardens and permeable pavement have the highest average allocations (about $220K), followed by trees and green roofs. Permeable pavement is popular because it creates public space and is expected to be part of community facilities, such as playgrounds and parks. Rain gardens are favored for the aesthetics and amenity benefits they provide. Trees can provide aesthetic benefits and shade that help save energy for households. Green roofs also provide aesthetic benefits and insulation for buildings and could be installed on the roofs of school and other public buildings. Impervious surface removal was recommended because it can provide a basis for other practices, while rain barrels are cheap and can be implemented immediately. Stormwater planters are advantageous because they can be installed in commercial and residential areas. Finally, wet/dry ponds can become community parks, if properly designed. Note that two groups created an additional maintenance category, giving it $100K, while one group also allocated $150K of the budget to education.

**Table 3. Average allocations of GI investment among five groups (unit: $USD)**

| GI Category | Wet/Dry Ponds | Rain Gardens | Trees | Green Roofs | Planters |
|---|---|---|---|---|---|
| Allocation | $30,000 | $224,000 | $170,000 | $124,000 | $39,000 |
| GI Category | Impervious removal | Permeable Pavement | Cisterns | Maintenance | Education |
| Allocation | $71,000 | $220,000 | $52,000 | $40,000 | $30,000 |

## ANCILLARY BENEFIT QUANTIFICATION

Based on the results of the exercises, we chose to limit the quantification of preferences concerning ancillary benefits to benefits with higher votes (i.e., community amenity, aesthetics, green jobs, and heat stress) along with maintenance costs, which were mentioned repeatedly in the group discussions. We also added stormwater fee savings as an additional benefit to evaluate in order to assess whether people care about out-of-pocket maintenance costs or the savings in fees. We quantified the benefits of each GI measure using a variety of scales, as explained below. Though the numbers might not be precise, they provide a basis for comparing the GIs and quantifying stakeholder preferences for tradeoffs among the benefits.

A. **Aesthetics evaluations** would ideally be done asking participants to rate fabricated photos that show how each GI looks after installation. However, for demonstration purposes, the aesthetic scores are assigned to a typical installation of each GI based on vegetation and the results from the plus-minus exercise on a scale of 0-10, and then summed the aesthetic values of all installations in the study area within a given plan in order to quantify the aesthetic value of that plan. Although the aesthetic values of GI depend on the particular design and other factors, such detailed evaluation is impractical at this screening stage of planning.

**B. Amenity value** is evaluated similarly to aesthetics, but, instead of separately evaluating the eight GI practices, we considered "GI bundles" that combine GI practices with community facilities. For example, permeable pavement can be turned into either a playground with slides, and seesaws or tennis courts with nets and fencing. Similarly, a series of rain gardens and stormwater basins can be the basis for a community park. We therefore assigned an amenity value to GI bundles (i.e., playgrounds, sports fields, and parks) assuming that small GI bundles (playgrounds and sports fields) provide more amenity than GI bundles with large areas (parks). The amenity value of a GI investment plan is calculated by aggregating all the GI installations in the plan that can be transformed into playgrounds, sports fields or parks.

**C. Green job** quantification is based on employment multipliers found in the literature (see McGarity et al., 2015). Because estimates for different GI measures are from different sources whose methods may be inconsistent, they should be interpreted cautiously. The job multipliers are assigned to GI practices based on two criteria: rooftop/ground installation and costs. We assumed that rooftop installation creates more jobs than ground installation, and vegetated practices create more jobs than non-vegetated ones. The job multipliers were altered according to those criteria and our own judgement. The unit of green job is job-years per $1 million spending.

**D. Heat Stress Reduction** is not directly measured. Therefore, we use tree cover and green roof cover (called it green canopy; in hectare) as a proxy. The literature indicates that trees and green roofs can reduce heat stress and urban heat island effects (Wise et al., 2010; Gómez-Baggethun et al., 2013; Demuzere et al., 2014).

**E. Maintenance cost**, in $/year, is estimated based on feedback from expert members of our research team.

**F. Stormwater fee savings**, expressed in $/yr savings, are based upon the stormwater fee rate in Philadelphia, 2013 ($4.5/month/500ft$^2$ impervious area).

## PREFERENCE ELICITATION

People's preferences toward GI are quantified using multiattribute utility functions. We applied the additive form to combine GI benefits because of its simplicity and interpretability. The expression for the additive utility function is:

$$U(x_1, x_2, \ldots, x_n) = \sum_{i\in\{1,2,\ldots,6\}} w_i * x_i \quad (1)$$

where $w_i$ and $x_i$ represent the weight and scale for attribute *i*, respectively. $i$ =1,…,6 is the index for the attributes and $U$(x) is the overall utility. A common practice is to normalize the weights so that $\sum_{i\in\{1,2,\ldots,6\}} w_i = 1$. The attributes in GI planning are the benefits. The weights are subjective values that represent the relative importance of the attributes to the person. For example, if green jobs (unit: job-yr) and runoff reduction (unit: $m^3$/yr) are given weights of 0.2 and 0.8, respectively, it would mean that one $m^3$ of runoff reduction is as important as four green jobs.

We applied four weighting methods in the fourth GCARB meeting, as described below: direct weighting (DW), swing weighting (SW) (Clemen & Reilly, 2001), and two versions of a variant of swing weighting that we call pair-wise swing weighting. In the first version (PSW), each participant compared two alternatives at a time, with redundant assessments allowing for consistency checks. An analysis of the first five pairs of PSW questions yielded the fourth set of weightings (PSW-5), since only five questions are needed to assess six weights if their sum is set to 1.

**A. Direct Weighting (DW).** Here, a participant allocates 100 points among the attributes, given their ranges.

**B. Swing Weighting (SW).** The participant is asked to imagine an alternative with the worst values of all attributes, and is then asked to choose just one attribute to "swing" from its worst value to its best value. That attribute automatically gets a weight of 100. Then the participant is asked to choose a second attribute to swing up from the worst to the best value, assuming the first attribute is not available. This is the second most important attribute, and its weight is directly stated by the participant based on how desirable the alternative is relative to two other alternatives: one with all attributes at their worst value, rating 0, and the other with the most important attribute at its best value (rating 100) and the other attributes at their worst values. This process is repeated until all the attributes are weighted. We then normalized the weights by dividing each by the sum of the weights.

**C. Pairwise Swing Weighting (PSW).** Here we propose a new weighting method that asks people to compare alternatives in pairs using SW, given the reference point of 0 for the alternative with all attributes at their worst value. Within a comparison, the preferred alternative is given a score of 100, and the other is given a lower score between 0 and 100. Table 4 is an example of a comparison. In this case, Alternative B has 0.6 of the value of Alternative A. Then, given these ratios for several pairs of alternatives, we can use multiple regression to find the attribute weights.

**Table 4. Pairwise Swing Weighting question – an example**

| Outcome | Aesthetics Score | Amenity Score | Green Canopy(%) | Job Creation (job-year) | Maintenance Cost ($/year) | Stormwater Fee Saving ($/year) | Rating |
|---|---|---|---|---|---|---|---|
| Worst Case | **0** | **0** | **15%** | **15** | **230,000** | **3,000** | **0** |
| Alternative A | 10 | 8 | 32% | 70 | 230,000 | 42,000 | 100 |
| Alternative B | 4 | 10 | 15% | 75 | 100,000 | 18,000 | 60 |

*Shaded cells are participant's inputs.

This method, unlike DW, asks the participants to compare alternatives instead of individual benefit categories. The participants have to consider all the attributes at the same time to give ratings to the alternatives. Also, it compares plausible alternatives, unlike SW which compares extreme and hypothetical ones. We asked 15 questions (involving every possible pair of the 6 attributes).

**D. Pairwise Swing Weighting with Least Pairs of Questions (PSW-5).** PSW asked more than 5 questions, with the extra questions in theory improving the reliability of the statistical estimates. However, participants tired of the questions fairly quickly, so that the answers to later questions may be less trustworthy. Therefore, we applied a version of PSW in which we used only the first five pairs of questions to calculate the weights for six attributes.

We now compare the results from the four methods. Fig. 1 shows the average weightings from the four methods. DW shows that green jobs, aesthetics and amenity are the most important benefits. SW shows a more uniformly distributed weightings, though still emphasizing the same benefits (contrary to Clemen and Reilly 2001's and Hobbs and Meier 2000's suggestion that DW should yield artificially "flat" or similar weights). PSW and PSW-5 both emphasize amenity and green jobs, however, PSW regards them almost equally important while PSW-5 weights green jobs 65% higher than amenity.

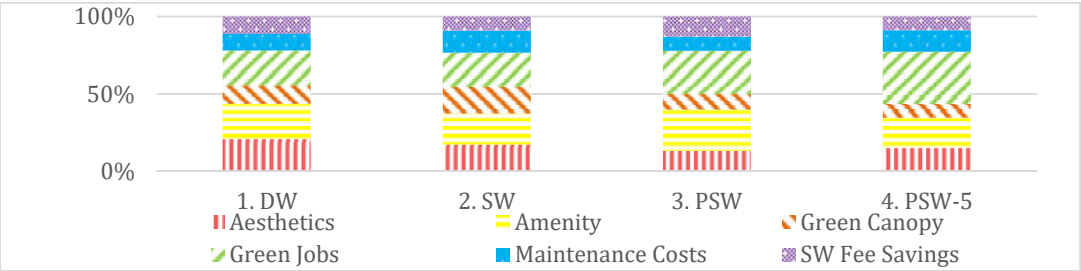



**Fig. 1. Average weights generated from the four weighting methods**

Table 5 shows the ranges of weights chosen. As maintenance costs and stormwater fee savings both have weights ranging from 0.09 to 0.14, it is likely that when people talk about maintenance, they are thinking about both maintenance levels and fees.

**Table 5. Ranges of weights**

| | **Aesthetics** | **Amenity** | **Green Canopy** | **Green Jobs** | **Maintenance Costs** | **Stormwater Fee Savings** |
|---|---|---|---|---|---|---|
| **Range** | 0.13-0.21 | 0.2-0.27 | 0.09-0.12 | 0.22-0.34 | 0.09-0.14 | 0.09-0.14 |

The correlations between two sets of weights chosen by the same person with different methods (Fig. 2) can help identify inconsistent answers. A correlation of 1 means the weightings in two methods are linearly and positively related, and low or negative correlation values mean the weightings appreciably diverge. "M12" means "between method 1.DW and 2.SW", while "M13" means "between method 1.DW and 3. PSW", and so forth. R1 to R12 represent the participants. Fig. 2 shows that the weights of R1, R6 and R12 are inconsistent (negative correlations) among four weighting methods. Inconsistencies can be resolved by further individual interviews (Hobbs and Meier, 2000), and are of the most concern if correlations among methods are of a similar or smaller magnitude than the average correlation among different people using the same method. For example, the average between-person correlation for method 1 and 2 (0.19 and 0.42, respectively; Fig. 3) are well below the average between method correlation of M12 in Fig. 2 (0.71), which shows that disagreements among people are more important the effect of choice between method 1 and 2.

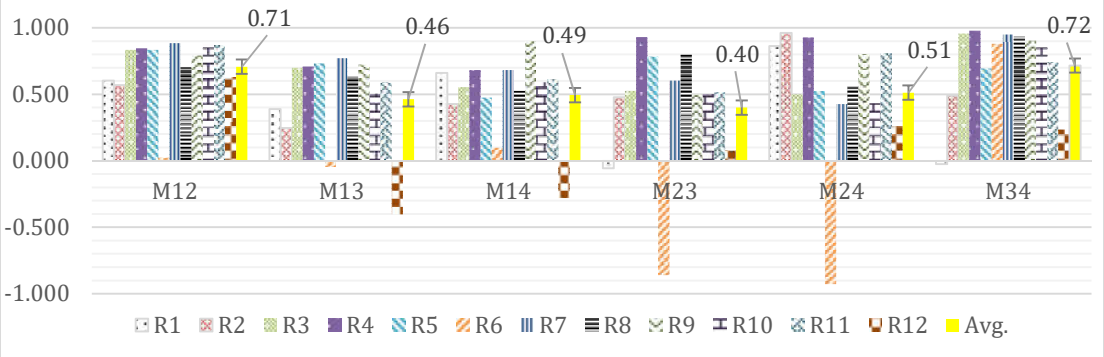



**Fig. 2. Correlations between methods (1. DW, 2. SW, 3. PSW, and 4. PSW-5) for all 12 participants (R1, R2,…, R12) and the average in each group**

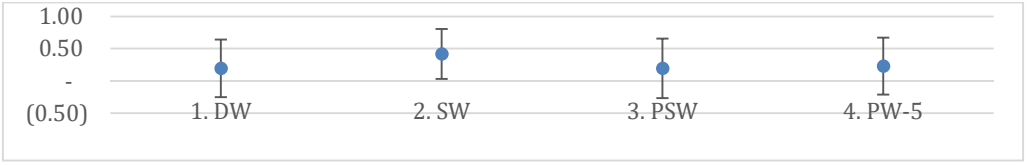



**Fig. 3. Average between-person correlations and the standard errors of the weights generated from the four weighting methods**

## COMMUNITY STORMWISE MODEL

We adapt McGarity's StormWISE (2012) model to accommodate ancillary benefits. This version reports the six ancillary benefits as well as two stormwater benefits: runoff and sediment reduction. We assume that the stormwater benefits make no difference to the community as long as they reach some goals (i.e., 75 million gallons/year runoff reduction and 100 tons/year sediment reduction in the following example). The objective is to maximize the utility function (with the average weights elicited from each of the four methods and weights of 0 for runoff and sediment reductions; Fig. 1) with the constraints for available lands for GI practices, budget, minimum

runoff and sediment reductions, and total available area for roof-top and ground installations.

We discuss an example for demonstration purposes assuming a total budget of $10 million. The optimal investment strategies given the assumed weightings are shown in Fig. 4. None of the solutions suggest any investment in green roofs, impervious removal, and cisterns, because they are either too expansive (green roofs) or providing little community benefits (impervious removal and cisterns). Although the weightings of DW and PSW-5 are not exactly the same (Fig. 1), they are similar enough to reach the same optimal solution in Fig. 4. All the solutions suggest a investment of $1M in dry/wet ponds (which is the assumed investment limit) because it is the most cost-efficient GI in terms of aesthetics and amenity based on our assumptions. The solutions of DW and PSW suggest somewhat similar allocations except the latter allocates $1.8M to permeable pavement instead of investing $2M in stormwater planters. This is because permeable pavement is part of GI boundles that provide amemity which has higher weight in PSW's weighting, while stormwater planters is not but it yields higher aesthetics value which is a more favorable attribute in DW's.

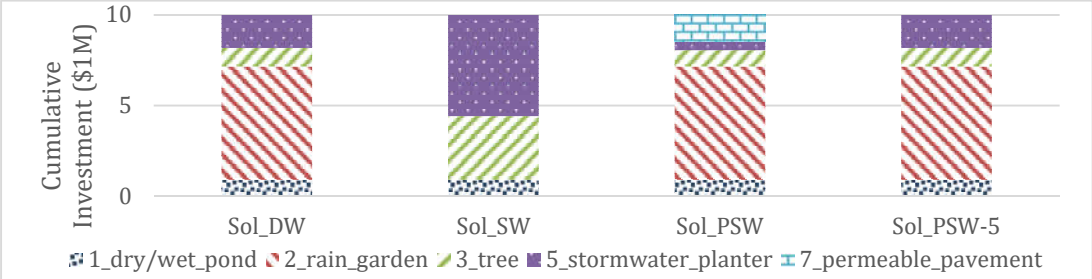



**Fig. 4. The optimal solutions generating from StormWISE model using average weights from the four methods**

The solution of SW suggests a very distinct strategy that has about $5.5M investment in stormwater planters and $3.5M in trees, which is the result of a higher weight for green canopy. Planting trees is the cheapest option that contributes to green canopy, but a investment of $3.5M in trees would use up all the available surface area for ground-based GIs, precluding further investment in rain gardens, permeable pavement, and impervious surface removal. Thus, the remaining budget has to go into GIs that collecting rain water from roof-tops (i.e., stormwater planters, green roofs, and cisterns), among which stormwater planters are preferred because of the lower cost and various benefits they provide.

Fig. 5 shows the expected benefit in each of the benefit categories yielded by implementing the four solutions. All the benefits are normalized to a 0 to 1 scale, with 1 meaning the best outcome and 0 the worst. The DW and PSW solutions share the same solutions and therefore the same outcomes. The solution of DW/PSW-5 has higher values in each benefit category than PSW's solution except in amenity. Overall, the two solutions provide the same level of community benefits and stormwater benefits. The solution of SW has higher values in runoff and sediment reduction, green canopy, maintenance cost, and stormwater fee savings due to the vast area of tree planting in that solution. Trees and stormwater planters can provide some jobs, some

aesthetics, and little amenity but not as much as rain gardens, which results in lower values in aesthetics and green jobs and much lower in amenity.

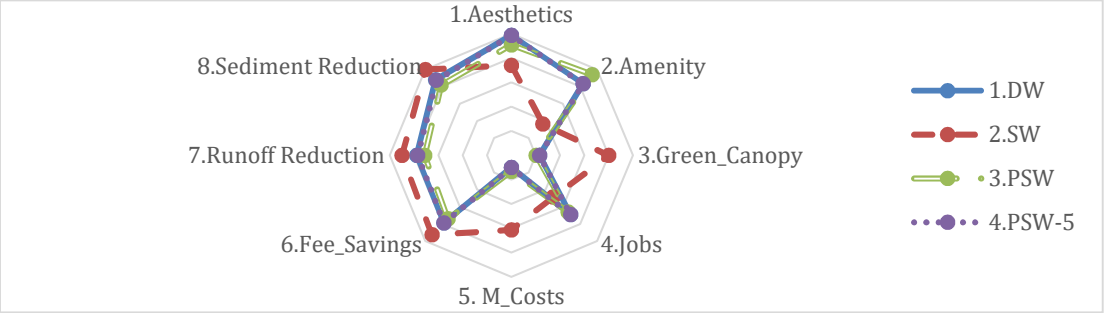



**Fig. 5. Benefit outcomes of the four solutions normalized in 0 to 1 scale.**

## DISCUSSION & CONCLUSION

This paper has developed a planning method to include community benefits in GI investment planning. The method involves the community in benefits identification and quantification and preference elicitation, and these are integrated in a new version of the StormWISE model. Although the causal relationships between GI and ancillary benefits are uncertain and the subject of active research, this paper has shown that our approximations of those benefits can help preference elicitation and optimization.

The results from Community StormWISE model show that the weightings can help identify "win-win strategies" for GI investment planning by achieving stormwater management goals (runoff and sediment reductions) and maximizing the community benefits based on local people's preferences. The model can be expanded to include more categories of benefits at the expense of increased effort to quantify benefits and preferences and larger model size.

However, we advise the reader that the uncertainties associated with benefit quantification and weighting mean that the results should be interpreted cautiously. This method can serve as a guiding tool for GI investment with consideration of community benefits but the solutions represent just an initial screening and would need to be refined in later, more detailed design stages. Another caveat is that, conventionally, the weighting methods use numbers and tables to represent alternatives which many participants in our meeting said they found to be alienating. They suggested using visual representations of the GI plans instead of tables of benefit values, an approach that we will consider in our future work.

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