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Allocating Urban Agricultural Reuse Strategies to Inventoried Vacant and Underutilized Land

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ABSTRACT. Community groups have a growing desire to use vacant and underutilized land for urban food production purposes; however, there are limited community-based tools available to assess the suitability of sites or location-allocation decisions. The purpose of this research is to provide decision support to community groups via a scientific software product developed in Microsoft Excel ® that will aid users in identifying and inventorying the location and condition of vacant and underutilized land, determining the relative site suitability of the inventoried land, and allocating urban agricultural reuse strategies across the urban landscape. This paper describes an augmented capacity to the prototype community-based decision support tool (C-SAP) developed by Kirnbauer and Baetz (2011). C-SAP includes two existing tools that employ a binary scoring methodology for the vacant and underutilized land inventory process (VULI) and the analytic hierarchy process for the calculation of a set of site suitability indices (SSI). The additional capacity introduced herein, known as LOCAL, employs a multi-objective binary integer program formulation for the location-allocation of reuse strategies at a neighborhood, community or potentially city-wide planning level. The application of the prototype decision support tool to twenty one sites identified as potential future sites for urban agriculture is summarized and discussed. This tool has the potential to assist groups in clarifying both community needs and constraints, while producing outputs that provide a scoped, informed direction to users for the allocation of reuse strategies. This paper describes a methodology for engaging community groups in making well-informed decisions related to effectively and efficiently bringing vacant and underutilized land back into productive reuse in a way that complements city-wide land use planning initiatives related to sustainable growth.

Keywords: urban food production, food urbanism, decision support, analytic hierarchy process, land inventory, site suitability

1. Introduction

Land-use planning authorities in many jurisdictions across the globe are challenged by a rising need to formulate and implement effective policies that forecast, plan for, and deliver urban growth (or shrinkage) plans that alleviate the social, environmental, and economic pressures created as a result of historical policies that facilitated the ever-present patterns of urban sprawl and urban decline. Coupled with the challenge of urban growth is the provision for adequate, accessible, and equitable, complementary productive public spaces, which will be critical in sustaining residential and employment populations. For example, unprecedented policies in the Province of Ontario, Canada have placed requirements for municipalities to accommodate up to 40% of new residential growth in already built-up areas, through intensification projects directed largely to vacant and underutilized land parcels (OMPIR, 2006). Existing vacant and underutilized land parcels, including publicly or privately held residential, industrial, commercial, institutional, agricultural, utility, parks and open space, or remnant lands that are not currently being used to their full potential or not fulfilling their intended purpose, hold untapped opportunities for productive reuse, which may act to enhance, anchor or stabilize declining neighborhoods.

There is a growing movement at the community-level across many jurisdictions, both in growing and shrinking cities, towards vacant and underutilized land reuse for urban agricultural purposes. An established philosophy that is gaining new momentum among urban planners, architects, community advocates, and city officials is the development and retrofitting efforts of communities to integrate a typology of productive uses into the urban landscape (Cleveland Land Lab, 2008, 2009; Friedman, 2007; Grimm, 2009; Hohenschau, 2005; Langdon, 2008; Viljoen et al., 2005). In recent years, there is mounting interest in movements such as 'the 100-mile-diet' (Smith and McKinnon, 2007), 'zero-mile-diet' (MacDonald, 2010), 'slow food movement' (Patrini and Waters, 2007), and organic farming on the urban fringe (Beauchesne and Bryant, 1999) as a way to transition from our dependence on cheap oil to more resilient, locally-focused communities. These efforts are complemented by a growing body of literature that seeks to answer many of the lingering questions surrounding how to reuse vacant and underutilized land effectively and safely, in ways that are compatible with the urban environment and city

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planning policies, and at the same time yield high value or utility for a community (de Zeeuw, 2004; Heinegg et al., 2002; Kirnbauer and Baetz, 2011; Rideout, 2010). Further driving this movement forward is the issue of community food security (Brown and Carter, 2003), with a particular focus on vulnerable, at-risk populations (HFS, 2010). Defined typologies for urban agricultural, including recommended minimum and maximum area, appropriate location (e.g. intra-urban vs. extra-urban), and service radii have been presented in recent works (Cleveland Land Lab, 2008 and 2009; Duany Plater-Zyberk, cited in Langdon, 2008; Grimm, 2009; Hohenschau, 2005; Mendes et al., 2008).

Recent work completed on two Pacific Northwest cities demonstrated that land inventories can be used to integrate urban agriculture into planning and policy-making processes (Mendes et al., 2008). Both Portland, Oregon and Vancouver, British Columbia have developed inventories on city-owned land to determine the overall suitability for community gardens and other urban agriculture uses, using high-resolution aerial photos to assess attributes including tree canopy, the presence of buildings and parking (Mendes et al., 2008). Kirnbauer and Baetz (2011) present a prototype community-based decision support tool, known as C-SAP, to assist community groups in completing a vacant and underutilized land inventory based on six umbrella criteria: neighborhood quality, developability potential, visual quality (of the site), compatibility with the urban environment, modal options, and vulnerable population characteristics. The prototype tool allows the user to evaluate up to fifteen community-based reuse strategies for vacant and underutilized land, five of which are related to urban food production, and provides the user with a set of relative site suitability indices for each strategy across all inventoried sites (Kirnbauer and Baetz, 2011).

The following paper introduces an additional capacity, hereafter referred to as LOCAL, to the community-based prototype decision support tool, known as C-SAP (Kirnbauer and Baetz, 2011), that allows the user to carry out location-allocation modeling using a multi-objective binary integer programming approach and a set of user-specified constraints. While the augmentation has the potential to evaluate all fifteen strategies in the location-allocation model, only the urban agricultural uses are employed in the application discussed herein. The tool was applied to twenty one sites that were identified by the Hamilton Community Garden Network (HCGN) as being currently underutilized and potential urban food production locations across the City of Hamilton, Ontario. A range of allocation scenarios were generated (eight in total) using LOCAL to assess the sensitivity of the model to changes in community requirements and constraints. While applied to a municipality in Ontario, Canada, this tool is not limited to this municipal jurisdiction; with reasonable modifications, including the replacement of built-in parcel and census data, C-SAP could be applied to jurisdictions across the globe.

It is important to note that the integrity of all data inputs, and therefore the integrity of the LOCAL outputs, is dependent on the user adhering to the specific data input (eg. latitudinal and longitudinal coordinates must be represented in decimal degrees) and spreadsheet formatting requirements (eg. column position/headings must coincide with the templates provided), as identified in the instructions provided in C-SAP. Furthermore, the accuracy of all geo-coded data inputs should be verified to ensure the integrity of the spatial data utilized in C-SAP. An overview of C-SAP, including the additional capacity, is described below.

2. Description of C-SAP's Existing and Augmented Capacity

The location-allocation model discussed within this manuscript is an additional module, developed to augment the existing decision support tool created by Kirnbauer and Baetz (2011). Figure 1 depicts a simplified flow diagram for the existing tool with the augmented capacity. Prior to the module development, the tool could be used to inventory the location, condition, and other relevant attributes of vacant and underutilized urban land. The inventoried data is subsequently assigned a binary score and normalized. The user is then required to complete a series of judgment statements relating to the importance of each criterion, using the Analytic Hierarchy Process (AHP). This process can be completed for a suite of fifteen reuse strategies, or a user-specified sub-set of these strategies, that contribute to a city's green infrastructure capacity: community gardens, neighbourhood farms, commercial farms, orchards, farmers' markets, tot-lots, parkettes, urban plazas, neighbourhood parks, community parks, fields/courts, tree/plant nurseries, renaturalization, bioretention, and circulation enhancement.

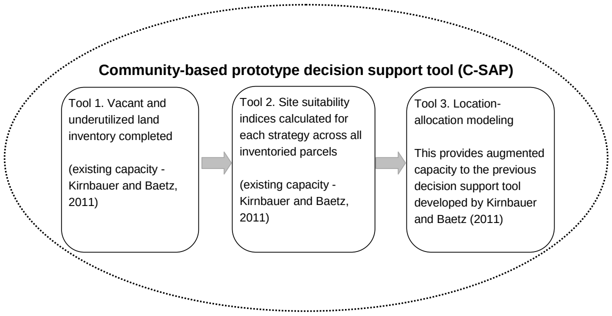
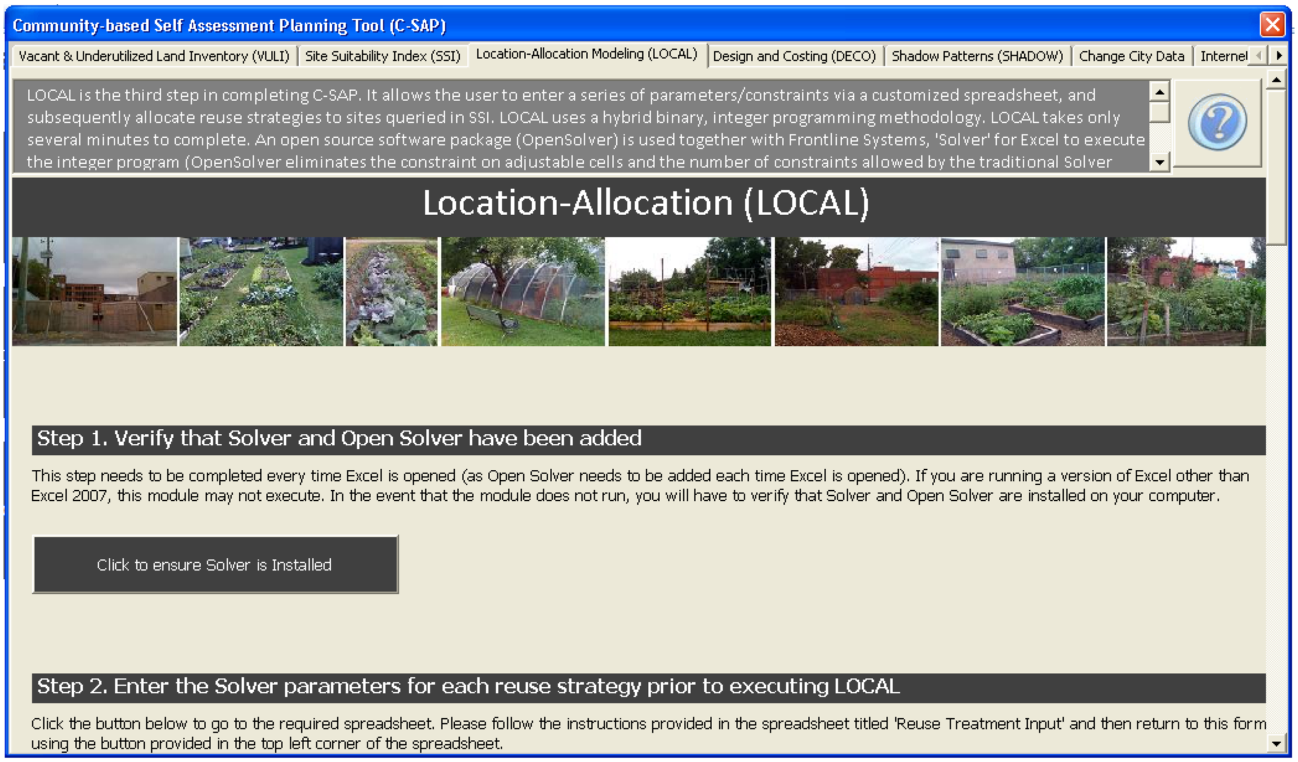


Figure 1. Overview of prototype decision support tool, known as C-SAP.

AHP is used to calculate the weights of each of the six umbrella criteria (i.e. a priority vector) based on the user-specified judgment statements (Saaty, 1990). The product of the weights and matrix of relative scores is calculated and provided to the user in the form of a site suitability matrix. This process produces a suitability index for each reuse strategy at each site, based on the best performing site for each criterion. The matrix of suitability indices can then be reviewed by the user and statements with respect to the suitability of a particular use across the evaluated sites can be made. This process is described in detail in Kirnbauer and Baetz (2011).

The additional capacity to the existing decision support tool involves the application of a multi-objective program that



LOCAL is the third step in completing C-SAP. It allows the user to enter a series of parameters/constraints via a customized spreadsheet, and subsequently allocate reuse strategies to sites queried in SSI. LOCAL uses a hybrid binary, integer programming methodology. LOCAL takes only several minutes to complete. An open source software package (OpenSolver) is used together with Frontline Systems, 'Solver' for Excel to execute the integer program (OpenSolver eliminates the constraint on adjustable cells and the number of constraints allowed by the traditional Solver

Location-Allocation (LOCAL)

Step 1. Verify that Solver and Open Solver have been added

This step needs to be completed every time Excel is opened (as Open Solver needs to be added each time Excel is opened). If you are running a version of Excel other than Excel 2007, this module may not execute. In the event that the module does not run, you will have to verify that Solver and Open Solver are installed on your computer.

Step 2. Enter the Solver parameters for each reuse strategy prior to executing LOCAL

Click the button below to go to the required spreadsheet. Please follow the instructions provided in the spreadsheet titled 'Reuse Treatment Input' and then return to this form using the button provided in the top left corner of the spreadsheet.

Figure 2. Screenshot of the customized GUI used to complete LOCAL.

utilizes the site suitability matrix as the decision variable coefficients in a binary integer location-allocation model (LOCAL), for a user-specified set of the inventoried sites and associated constraints. Each constraint in the model can be altered by the user to perform a series of "what-if" scenarios and sensitivity analyses to assist the user in better articulating the potential trade-offs of heavily constraining the binary integer programming model or fully relaxing the model constraints. By performing "what-if" analyses, the user is provided with a series of output files that identify potential alternative location-allocation solutions, which can be useful for initiating well-informed discussions related to suitable locations for vacant and underutilized land reuse. The model is further described below.

3. Methodology

3.1 Overview of the Location-Allocation (LOCAL) Model

LOCAL is based on a binary integer programming formulation and is solved via customized code modules written in the Visual Basic for Applications (VBA) programming language, provided in the Microsoft Excel® developer's environment. A screenshot of the customized graphical user interface (GUI), used to complete LOCAL, is shown in Figure 2. The program requires the Solver add-in, which is typically included on the Microsoft Excel® installation CD's. OpenSolver, an Excel VBA add-in, is also required to extend Excel's built-in Solver with a more powerful Linear Programming solver (Mason, 2011). OpenSolver removes the artificial limits, imposed by the traditional Solver package, on the size of problem that can be solved in Excel (i.e. variable and constraint limitations). OpenSolver can be used to solve large linear and integer programming optimization problems, and is available for public download at opensolver.org. LOCAL uses Excel's traditional Solver add-in to build the model and subsequently, OpenSolver uses a separate engine to solve the programming model.

The steps required to complete LOCAL are depicted in Figure 3. Prior to completing LOCAL, an inventory of vacant and underutilized land needs to be completed for the minimum planning scale of a neighourhood, and the site suitability matrix calculated for the evaluated sites. Following these steps, the user can query the inventoried sites for 3 different scales of analysis: a single neighourhood, a series of neighborhoods, or an entire city. The user is then required to enter a set of mandatory and optional constraints. These constraints include:

- the minimum contiguous area required for each strategy to be viable at a particular location;
- the maximum area desired at one location for each strategy (may be a combination of several fragmented areas that also meet the minimum contiguous area requirement);
- the maximum number of reuse strategies allocated across the area under analysis;
- the service radius for each strategy and the corresponding minimum population density required within this radius;
- the minimum separation distance required between strategies of the same type;
- the minimum width or length requirements for the area for reuse, and
- the sunlight conditions at the site.

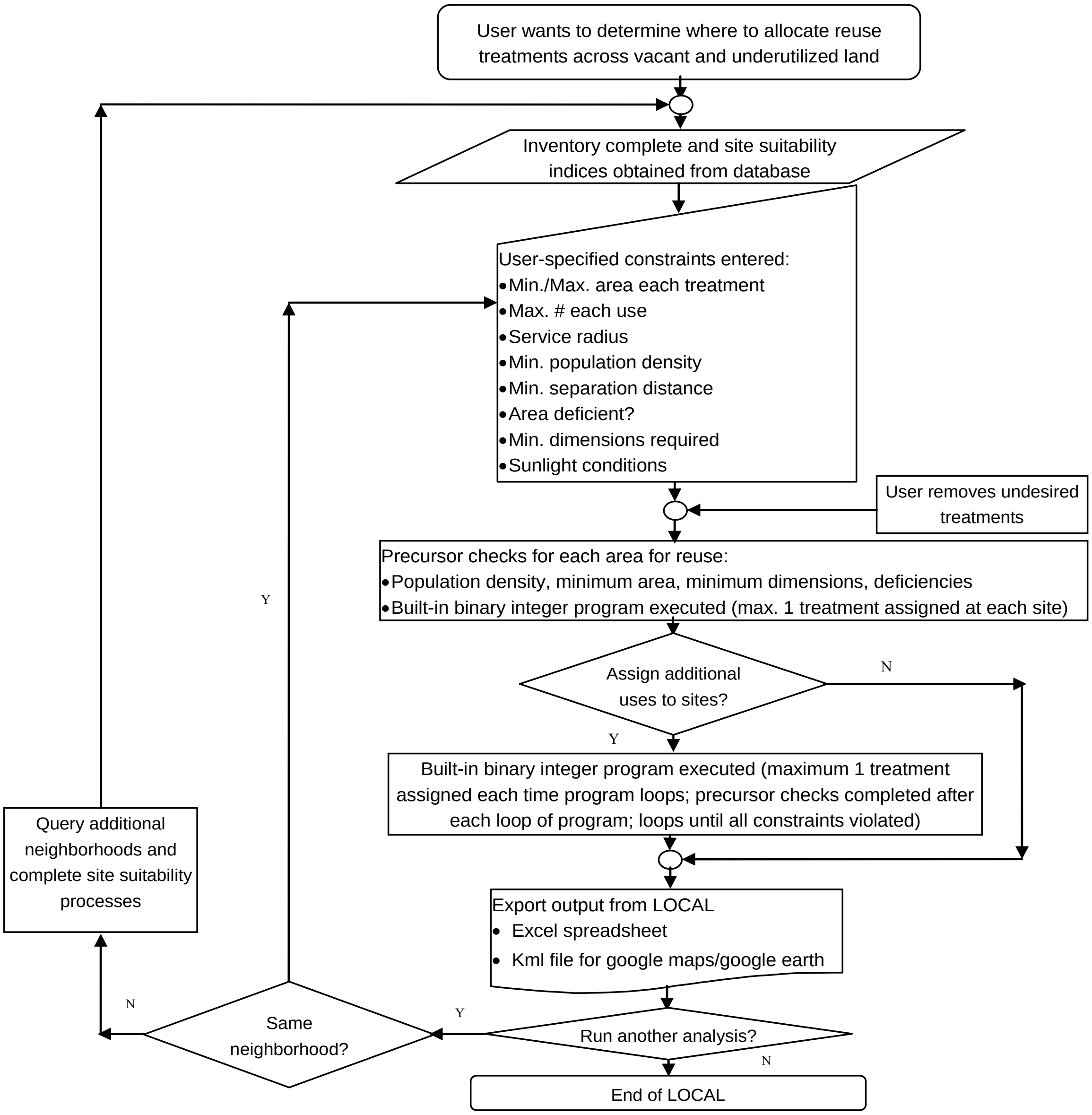


Figure 3. Flow diagram for LOCAL.

The user is also required to identify whether the area is deficient in a particular use. Pop-up comments are provided for the user to assist them in completing this input.

Once the binary program builder button is selected on the graphical user interface (GUI), the model is built and executed automatically for the user, so there is no interfacing required between the user and the traditional Solver dialogue box. The model formulation is described below.

3.2 Model Formulation

Prior to running the model, a series of precursor conditions need to be satisfied. First, a check is carried out to determine if the area under analysis is deficient in terms of the particular reuse strategy (e.g. acres of strategy *j* per 1000 persons); if the spatial area under analysis is not deemed deficient in a particular reuse strategy, the use is removed from the model. Next a check is completed to determine if the minimum area is met at each site for each strategy. Similar subsequent checks are completed for minimum dimension requirements (if any) and finally minimum population density requirements. Sites that do not meet the minimum specified requirements are removed from the analysis by setting their site suitability scores to 0. Following the validation of the precursor conditions, the model is automatically built and executed as follows:

Objective Function: *Maximize the cumulative sum of the site suitability scores across the allocated sites*:

$$\text{Max} \quad \left\{\sum_{j=1}^{m}\sum_{i=1}^{n} SSI_i^j \cdot X_i^j\right\} \qquad (1)$$

where:

SSI_i^j = Site Suitability Index (coefficient) for strategy j at site i;

X_i^j = binary decision variable (equal to1 if the strategy j is allocated to site i; 0 if the strategy j is not allocated to site i);

$j = 1, 2, \ldots, m$ ($m_{max} = 15$);

$i = 1, 2, \ldots, n$ (n sites for potential reuse).

Subject to the following constraints:

Constraint 1. *Decision variables must be binary*:

$$X_i^j \in \{0, 1\} \tag{2}$$

Constraint 2. *The sum of each reuse strategy allocated across the area under analysis must be less than or equal to the user-specified maximum number desired for each strategy*:

$$\sum\nolimits_{i=1}^{n} X_i^j \le X^{\max j} \quad \text{for each } j,\ j = 1 \text{ to } m \tag{3}$$

Constraint 3. *The distance between reuse strategies of the same type (e.g. community gardens) must be greater than or equal to the minimum, user-specified separation distance for each strategy. C-SAP will calculate the distance between all potential areas for reuse and ensure that a maximum of one allocation can be made when the minimum distance separation criterion is violated (this ensures a broader spatial distribution of each reuse strategy)*:

If $D_{i,k} \le D^j_{\min.sep}$ for *any site i and adjacent site k (i ≠ k), for i = 1, 2, ..., n and k = 1, 2, ..., n:*

$$\sum_{i=1}^{n-1} \sum_{k=i+1}^{n} X_i^j + X_k^j \le 1 \quad \text{for each } j,\ j = 1 \text{ to } m \tag{4}$$

where:

$D_{i,k}$ = geodesic (i.e. straight line) distance between site i and site k

$D^j_{\min.sep}$ = minimum separation distance required for reuse strategy, j

X_i^j and X_k^j = binary decision variable for reuse strategy j at sites i and k, respectively.

Constraint 4. *The number of reuse strategies assigned at each site must be less than or equal to 1 (for each run of the solver model)*:

$$\sum\nolimits_{j=1}^{m} X_i^j \le 1 \text{ for each } i;\ i = 1 \text{ to } n \tag{5}$$

Post calculation. *The maximum, user-specified area is allocated to each site identified by the model. The potential area for reuse at each site is subsequently re-calculated (previous area minus area allocated; the remaining area is used in subsequentt strategy allocations, if any).*

Precursor checks prior to additional (optional) strategy allocations. *The same precursor conditions must be satisfied for each reuse strategy prior to including it in the analysis. Each reuse strategy allocated in the previous step is identified and eliminated from subsequent runs of the model (i.e. to avoid assigning the same use at a site)*

Model loops (optional). *The solver model will loop, assigning additional uses to each site, where possible, until no viable options to assign additional strategies exist at any site.*

Several limitations with respect to the formulation of the model warrant further discussion. Firstly, Solver and OpenSolver do not have the capacity to dynamically adjust the remaining area available at each site once a reuse strategy has been allocated, and subsequently iterate within the OpenSolver engine to allocate additional uses. In other words, only one strategy can be allocated to each site via each run of the model. As such, a hybrid approach was developed whereby a programming routine, outside of the Solver model, is used to perform a series of model adjustments and subsequently iterate and initiate the Solver model, creating a looping sequence, until no additional strategies can be assigned without violating the model constraints. It is important to note that while this tool is useful in assisting a user in solving combinatorial location-allocation optimization problems relating to vacant and underutilized land reuse, it provides a heuristic approach for the generation of 'good', near-optimal solutions, but not necessarily 'the optimal' solution.

4. Decision Support Tool Output

This tool is helpful in allocating reuse strategies to vacant and underutilized land, based on a series of user-specified constraints. It provides output to the user in two different formats: a tabular format and a spatial format. The first output option is a Microsoft Excel® spreadsheet, which includes a summary of all inventoried site and neighborhood characteristics, umbrella criteria scores, relative scoring, site suitability indices, model output for strategy allocations, and finally the areas allocated for each strategy across the evaluated landscape. The second output option involves the creation of a keyhole markup language (.kml) file, that ties tabulated allocation data stored in the prototype decision support tool to the geographic coordinates of the inventoried parcel, and is presented in electronic map format for sharing/viewing on the web or in Google Earth. This is carried out by linking key elements of the output to a mapping tool provided on a publicly accessible geo-coding website (BatchGeo, 2011). The model can be reset and the queried data restored for additional analyses of the neighborhood(s), or the user can query a new neighborhood(s), repeating this process as many times as desired.

4.1. A Note on the Branch and Bound Method

The binary integer programming approach described herein resolves a binary vector x for each inventoried site that maximizes the objective function described above, subject to a set of linear constraints. This is done using a linear programming-based branch-and-bound method (Frontline Systems Inc., 2011). Integer programs make a model "non-convex", where there may be a large number of local minima and maxima (Frontline Systems Inc., 2011). Problems of this nature often require longer computing times and extensive memory requirements, and in problems involving just a few hundred variables, it is possible that the solution will never converge on the global maximum (Frontline Systems Inc., 2010). As such, the application of global optimization techniques is required to guarantee convergence in finite time to the optimal solution. With well-formulated models, however, these problems can sometimes be resolved.

The branch and bound algorithm searches for an optimal solution to the binary integer programming problem by solving a standard linear programming (relaxed) problem, in which the binary integer requirement on the variables is replaced by the relaxed constraint $0 \leq x \leq 1$ (Frontline Systems Inc., 2010). If the solution contains one or more non-integer values, the algorithm branches, creating two new sub-problems at the node representing the first decision variable. Two constraints are added at each node to create two new branches: $x_i = 1$ and $x_i = 0$. For each new branch, a relaxed linear program (i.e. 'a regular Solver LP') is solved to determine if a better solution exists; this process continues, eliminating sets of sub-problems that are either infeasible or cannot be better than a solution already obtained, until all decision variables have integer values and all constraints are satisfied (Frontline Systems Inc., 2010).

5. Application of LOCAL and Discussion of Key Findings

The developed decision support system was applied to a series of sites identified in Hamilton, Ontario as potential/desirable sites for future community gardening projects. A non-profit organization, known as The Hamilton Community Garden Network (HCGN), supports and promotes individuals and communities in developing and maintaining community gardens in Hamilton, Ontario from the perspective of improving food security and increasing community involvement (Personal Communication, C. Wagner, July 19, 2011). Following a public meeting held by the HCGN, a report produced by Mayo (2008) was prepared, providing a summary of key meeting discussion topics, a literature review of best practices and municipal policies in other cities across Canada, and strategic future directions for the HCGN to best ensure the growth of community gardens to combat social alienation and ensure a path towards a food secure city. While Hamilton is an agricultural city, with over 50 agricultural operations in the outer wards and peri-urban locations, finding suitable land in inner wards was identified as a key issue in Hamilton (Mayo, 2008). As one of the key actions put forth in the HCGN report was educating community garden leaders through the development of a toolkit (Mayo, 2008), it is believed that LOCAL could be an integral part of this toolkit and assist leaders in making well-informed decisions related to the primary issue of allocating agricultural uses to suitable urban locations. At the community meeting, a mapping process was carried out whereby attendees were asked to identify parcels of land across the city that were believed to be suitable locations for urban agriculture. Throughout this process, thirty one sites were identified on both private and public lands, of which twenty one were used in the application of LOCAL, spanning seventeen distinct neighborhoods across the city. Ten of the thirty one identified sites have since been developed for gardens, other land uses, or could not be identified, and as such were not included in the application. The remaining twenty one sites were inventoried in C-SAP to evaluate the suitability of each site for urban food production uses and allocate a suite of strategies across the evaluated neighborhoods. As part of the inventory process, the spatial and physical attributes of each site were collected, scored, normalized, and presented as a matrix of site suitability indices for reuse strategy.

The typology of urban agricultural reuse strategies available for application in the decision support tool includes community gardens, neighborhood farms/co-ops, commercial farms, orchards and farmers' markets. Community gardens/allotments provide opportunities for individuals to grow their own food for personal consumption. Neighborhood farms/co-ops provide opportunities to work as part of a group on a communal plot(s) for the benefit of the growers. Commercial farms are commercially run growing operations, typically operated by one person for sale to markets or grocers. Orchards provide opportunities for growing fruiting crops for community consumption and commercial sale. Farmers markets provide opportunities for selling locally grown produce outdoors. All of these uses were selected as potential uses for each of the inventoried sites. Upon completion of the land inventory for the twenty one sites, fifteen pair-wise comparisons of the umbrella criteria (judgment statements) for each reuse strategy were completed. These statements were used to evaluate the weight of each of the umbrella criteria used in the inventory process, using the Analytic Hierarchy Process (Kirnbauer and Baetz, 2011). Three sets of judgment statements were used in the application described herein: a set for community gardens and neighborhood farms, a set for commercial farms and orchards, and a set for farmers' markets. This was done as the relative importance of the umbrella criteria within each grouping was deemed similar based on the intended use. The resulting weights for each criterion are summarized in Table 1, while the calculated site suitability indices are summarized in Table 2 (the product of the weights and the inventory scores)

Table 1. Normalized Weights for Umbrella Criteria, Derived from User-Specified Judgment Statements

Umbrella Criteria	CGNF*	CFO	FM
Neighborhood Quality	8	7	10
Developability Potential	33	45	31
Visual Quality of Site	18	15	18
Compatibility w/ Urban Environment	18	15	12
Modal Options	7	5	21
Vulnerable Populations	16	13	8

*CGNF: Community Gardens & Neighborhood Farm; CFO: Commercial Farms & Orchards, FM: Farmers Markets

The umbrella criteria weights for each applied set of judgment statements demonstrate shifts in priorities for each use, and assist in articulating the importance of the various neighborhood and on-site characteristics inventoried prior to applying the statements. Developability potential, which reflects the overall material and labour requirements necessary to develop the site for the intended use, is deemed significant for all uses (weight of 1/3 to 1/2 of the aggregated site suitability score). Visual quality of the site, compatibility with the urban environment and proximity to vulnerable populations weigh significantly high for community gardens and neighborhood farm uses. Commercial farms and orchards have lower transportation, neighborhood quality and vulnerable population criteria weights. This reflects the assumption that individuals will not be traveling as frequently to these sites as it is anticipated that they will operate at a predominantly commercial-level, with fewer participants, and potentially fewer direct sales to neighboring residents. Farmers' markets were given higher transportation, neighborhood quality and visual quality criteria weights, as it is important to provide sufficient access to these sites for citizens as well as maintaining a strong visual presence.

Table 2. Normalized Site Suitability Indices for Each Strategy across Twenty One Sites

Site ID	CGNF*	CF	Orchards	FM
A	75	76	72	75
B	62	60	59	71
C	66	65	64	68
D	64	72	65	76
E	83	85	85	90
F	51	56	55	47
G	66	58	59	67
H	41	46	45	43
I	79	76	81	75
J	70	73	71	71
K	57	61	63	53
L	68	73	71	63
M	38	52	47	47
N	40	43	44	52
O	69	72	78	87
P	63	64	60	71
Q	61	55	60	68
R	78	76	73	84
S	49	57	57	49
T	63	67	66	71
U	51	54	54	51

*CGNF: Community Gardens & Neighborhood Farms; CF: Commercial Farm; FM: Farmers Markets

▣ Largest site suitability index for each strategy

□ 2nd Largest site suitability index for each strategy

⬚ 3rd Largest site suitability index for each strategy

Table 2 shows the site suitability indices for each reuse strategy across all evaluated sites, with the largest, 2nd largest and 3rd largest site suitability index for each strategy distinctly outlined. Suitability indices have been normalized and are presented out of a maximum score of 100. Community gardens and neighborhood farms are presented together in Table 2, as they scored identically due to the application of common criteria weights and common inventoried attributes (note: not all attributes were relevant for the remaining three uses and as such did not need to be inventoried, resulting in different scores).

As described in Kirnbauer and Baetz (2011), the user can customize the inventory questions for each strategy, prior to initiating the neighborhood inventory process. These questions are then held constant for the entire neighborhood(s) analysis. In this instance, the same questions were selected for community gardens and neighborhood farms, reflecting the equal importance of all inventoried attributes for both strategies (resulting in all sites being scored the same for both strategies). Several sites scored consistently high for many of the agricultural uses including Sites A, E, I, O, and R, four of which are active city-operated parks (e.g. fields, diamonds, play structures) and one which is adjacent to a recreational trail, with Site E (Corktown Park) scoring the highest for all urban agricultural uses (> 80 for all uses). This is a logical outcome as parks have been allocated across the city in an attempt to service residential neighborhoods at specified levels of service. It stands to reason then that these sites will likely be ideal candidates for agricultural uses based on population density, overall accessibility, and overall compatibility with the urban environment, particularly sensitivity to abutting uses. Several other options that appear quite reasonable other than the highest ranked suitability index are apparent in Table 2. Community gardens and neighborhood farms, commercial farms, orchards, and farmers' markets had suitability indices greater than 70 for five, eight, seven, and ten sites, respectively. While the scoring methodology used in the prototype decision support tool does not have a distinct site suitability threshold whereby scores above are accepted and scores below are rejected, it provides the user with a set of options that may facilitate the location-allocation decision-making process. A user may choose to exit the decision support tool after calculating the site suitability indices; however, LOCAL was developed to use the output shown in Table 2 along with a set of user-specified constraints to further articulate where to best allocate uses across the urban fabric. An example of the type of analyses that a user could complete is described below.

For the twenty one sites inventoried, eight different constraint scenarios (A1 ~ A8) were evaluated to observe the sensitivity of changes to the user constraints and their effect on allocation patterns and overall objective function values. To conserve space, inputs for the first of eight constraint scenarios are summarized in Table 3. LOCAL converged to a feasible solution for all evaluated constraint scenarios. The efficient run time in LOCAL is largely due to the binary integer programming formulation and imposed constraints, which effectively "prune out" infeasible options.

The following constraints were adjusted: the maximum number of each strategy desired across the community, the minimum population density required for each strategy, the minimum contiguous area required, and the minimum dimensions

Table 3. User-Specified Constraints (Input) for the First of Eight Applications (A1)

Reuse Strategy	Community Garden	Neighborhood Farm	Commercial Farm	Orchards	Farmer's Market
Minimum Area (m^2)[1]	300	300	1200	300	300
Maximum Area (m^2)[2]	2023	4046	4046	4046	2023
Max. # strategies desired[3] (# allocated)	4 (3)	4 (1)	4 (2)	4 (4)	4 (0)
Service radius for each reuse strategy (m)	400	800	1000	1000	1000
Minimum population density (upa)[4]	25	50	50	50	50
Minimum separation distance (m)[5]	400	800	1000	1000	1000
Is the area currently deficient ?(y/n)[6]	Y	Y	Y	Y	Y
Minimum width (m)[7]	10	10	10	20	5
Minimum length (m)[7]	30	30	120	15	60
Sunlight conditions	Full Sun	Full Sun	Full Sun	Full Sun	Any

[1] Minimum contiguous area required for each strategy at a given site.
[2] Maximum area desired at a given site for each strategy.
[3] Maximum number of strategies desired across the entire area under evaluation (actual # strategies allocated using LOCAL).
[4] Minimum population density required within the service radius for each strategy to be considered viable (units/hectare).
[5] Minimum separation distance between strategies of the same type.
[6] Is the area currently deficient in the corresponding strategy? If no, the strategy is not considered in the analysis.
[7] Minimum width and length of the site to make it useable for the corresponding reuse strategy.

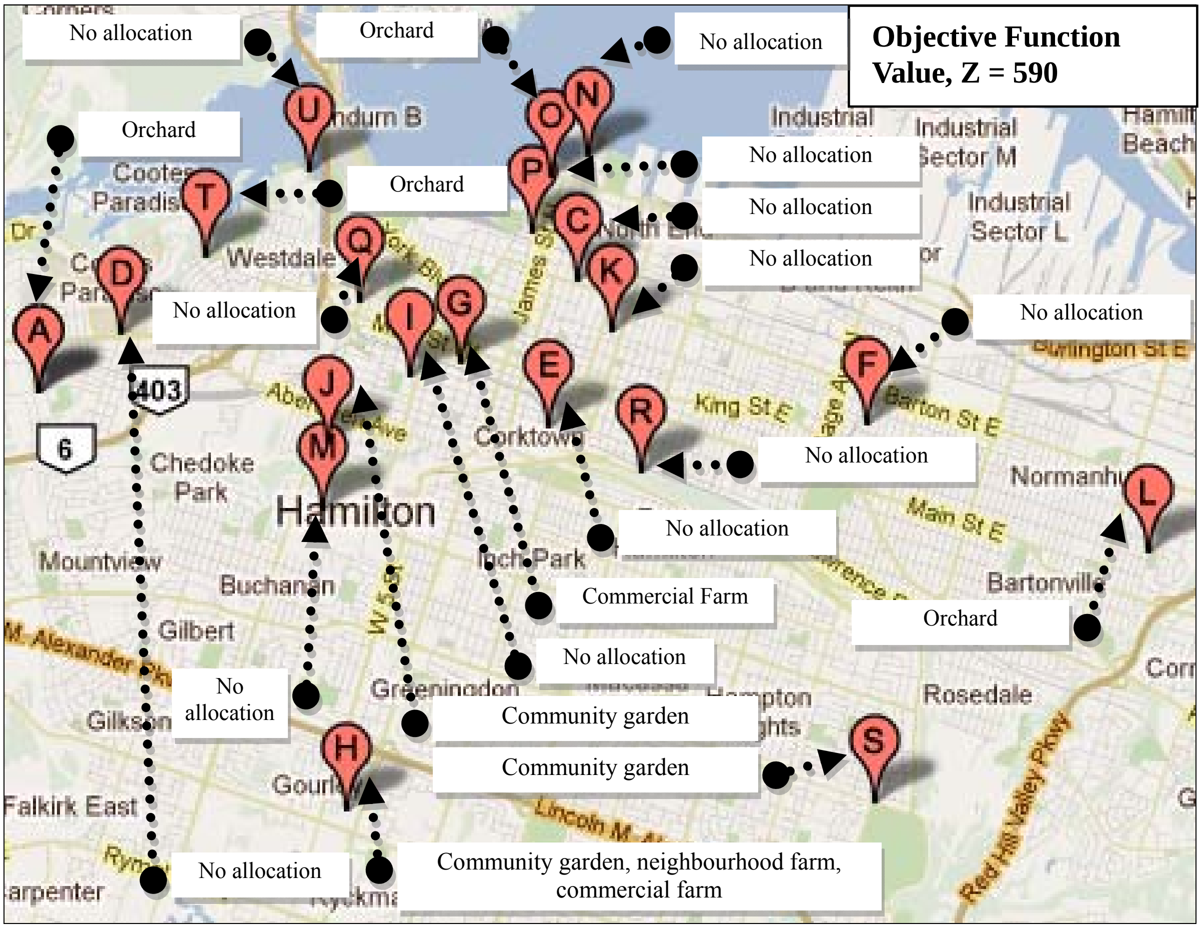


Figure 4. Simplified depiction of LOCAL output for application 1 (most constrained).

required to ensure a site is useable for a particular strategy. Applications A1 and A5 were constrained by all four parameters; applications A2 and A6 were constrained by the minimum dimension requirements, the maximum number of strategies desired, and the minimum area. Applications A3 and A7 were constrained by the maximum number of strategies desired and the minimum area, while applications A4 and A8 were constrained by the maximum number of strategies desired. Minimum and

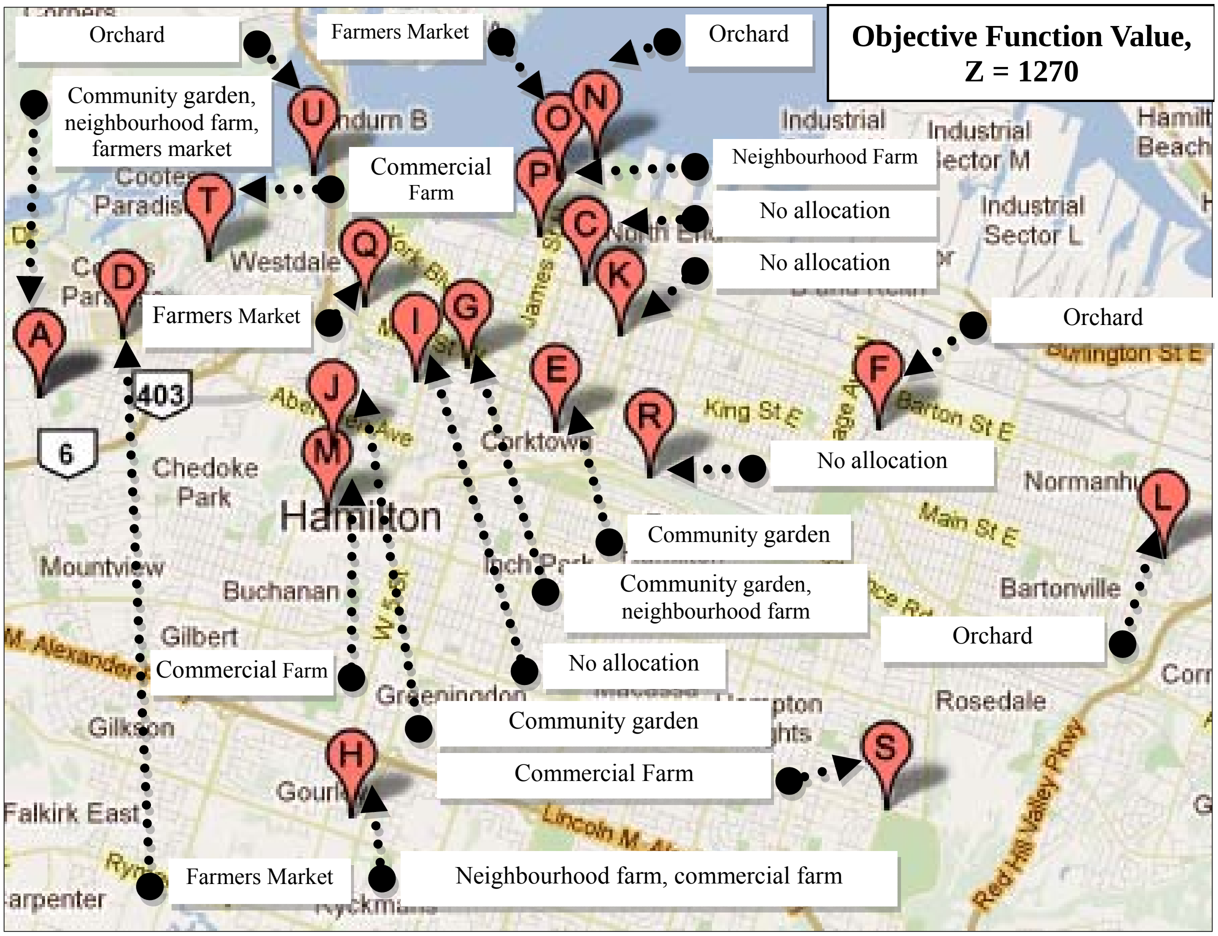


Figure 5. Simplified depiction of LOCAL output for application 4 (least constrained).

maximum areas for each strategy were derived from a variety of sources on urban agriculture typologies (Cleveland Land Lab, 2008 and 2009; Duany Plater-Zyberk, cited in Langdon, 2008; Grimm, 2009; Hohenschau, 2005; Mendes et al., 2008).

A simplified spatial summary of the location-allocation model results is depicted in Figures 4 and 5 for applications A1 and A4, respectively. Due to the size of the accompanying tabular data output, excerpts have not been included within this manuscript. Across all eight applications, Sites B, E, F, I, K, P and R did not have a large number of strategies allocated to them. This is explained by the fact that they did not meet the minimum contiguous area requirement in the majority of the applications or minimum density requirements. The objective of applications A1 through A4 was to allocate four of each urban agriculture strategy (community garden, neighborhood farm, commercial farm, orchard, farmers' market) across the twenty one inventoried sites. Application A1, the most constrained of applications A1 through A4, was effective in allocating 100% of the desired orchards, but fell short in all other strategy categories, largely due to the density requirement (only Sites E, H, J, R, and S met this requirement for community gardens and Sites H and J for neighborhood farms). This application had a resulting objective function value of 590 (the product of the site suitability indices multiplied by the decision variables). Application A2 was effective in allocating 100% of the desired community gardens, neighborhood farms, orchards and farmers' markets but only found one out of four locations for a commercial farm. This application achieved an objective function value of 1070, sizably larger than the first application, largely explained by the fact that the density requirement was relaxed. Application 3 further relaxed the constraints by removing the minimum dimension requirement. In doing so, 100% of the desired community gardens, neighborhood farms, orchards and farmers' markets and three out of four locations for commercial farms were allocated. The objective function value for this application increased to 1190. Finally, Application 4 was further relaxed by reducing the minimum contiguous area from 300 m^2 to 200 m^2 for all uses with the exception of commercial farms (which were held at 1200 m^2). All of the desired uses were allocated and an objective function value of 1270 was achieved.

The objective of applications A5 through A8 was to allocate 8 community gardens, 5 neighourhood farms, 2 commercial farms, 2 orchards and 4 farmers' markets across the twenty one inventoried sites. These applications followed the same sequence with respect to relaxing the constraints and achieved similar success rates in terms of allocations, with objective function values ranging from 460 to 1350.

The output from LOCAL reveals that as the constraints are relaxed, a set of eight viable allocation scenarios are generated, with each relaxation resulting in an increase in the number of reuse strategy allocations and therefore an increase in the objective function value. It is recognized; however, that resolving a completely relaxed problem may not capture the needs and values of the user, thereby limiting the usefulness of the output. It is very likely, on the other hand, that the user may need to impose constraints, such as those applied in the eight applications discussed herein, to achieve the desired goals for delivering equitable access to productive public spaces. It is recommended that the user generate a variety of scenarios similar to the methodology presented in this manuscript, as this process may assist in generating meaningful discussion, potentially leading to improved decision-making.

6. Conclusions

This paper describes an augmentation to a prototype decision support tool for identifying and inventorying the location and condition of vacant and underutilized land and determining the relative suitability of each identified site for a suite of parks and open space, urban agriculture, and stormwater management uses (Kirnbauer and Baetz, 2011). The augmented decision support capacity allocates reuse strategies across the urban environment, subject to a set of user-specified constraints. The prototype decision support tool was subsequently applied to a case study of inventoried data for twenty one sites identified by the Hamilton Community Garden Network as potential future urban agricultural locations (Mayo, 2008). A variety of constraint scenarios were applied to the twenty one sites and the output was summarized and discussed herein. As expected, the highly constrained model was not successful in meeting the user needs, while the least constrained scenario was successful in meeting 100% of the user needs for the total number of allocations desired. The decision support tool is able to generate scenarios quickly, with the binary integer programming model converging to a solution in a matter of seconds in all applied scenarios. This output provides the user with 'good', near-optimal solutions and may assist in making well-informed decisions related to location-allocation problems for the temporary reuse of vacant and underutilized land.

The decision support tool, including LOCAL, and accompanying files are available for download off of the McMaster University Sustainable Communities Research Group website, located at www.eng.mcmaster.ca/civil/sustain/downloads.html.

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