The Inclusion of Large-Scale Tree Planting in a State Implementation Plan

A Feasibility Study





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Prepared for

The National Tree Trust

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Cover photo: Map from the EPA's Green Book showing the attainment status of US areas with respect to the 8-hr ozone standard. (EPA 2005a)

Table of Contents

Executive	Summary	iv
Acknowle	dgments	vi
1.0 Introd	uction	1
1.1	Background	1
1.2	Scope	4
2.0 Challe	nges	5
2.1	Challenges: Mortality	5
	Background	5
	Discussion	6
	Feasibility	7
2.2	Challenges: Species Selection	10
	Background	10
	Discussion	10
	Feasibility	14
2.3	Challenges: Stock Size and Form	16
	Background	16
	Discussion	17
	Feasibility	19
2.4	Challenges: Planting Methods	21
	Background	21
	Discussion	21
	Feasibility	24
2.5	Challenges: Site Selection	26
	Background	26
	Discussion	26
	Feasibility	29
2.6	Challenges: Costs	31
	Background	31
	Discussion	32
	Feasibility	34
2.7	Challenges: Personnel	37
	Background	
	Discussion	
	Feasibility	
2.8	Challenges: Verification	40
	Background	40
	Discussion	41
	Feasibility	
3.0 Conclu	usions, Recommendations, and Resources	46
3.1	Conclusions	46
3.2	Recommendations	46
3.3	Resources	
4.0 Refere	ences	49

Figures

Figure 1. Complex Processes of Ozone Formation and Deposition	.2
Figure 2. Interaction of Tree Mortality and Cumulative Survival	.6
Figure 3. Mortality of Newly Planted Yard Trees in Sacramento, CA, 1994-2004	.7
Figure 4. Three sections of the US National Arboretum's Plant Hardiness Zone map1	11
Figure 5. Plant Production of VOCs1	12
Figure 6. Ginkgos Planted in a Difficult Site in Washington, D.C	15
Figure 7. One Alternative Strategy of Species Selection for Difficult Sites1	16
Figure 8. Conceptual Representation of the Relationship Among Size, Cost, and	
Survivorship of Urban Trees2	20
Figure 9. Tree Planter Being Set Up for a Run2	22
Figure 10. Tree Auger on a Dolly2	25
Figure 11. Image showing Use of Random Point Tool2	28
Figure 12. Brownfields in a Downtown Area With Planting Potential	30
Figure 13. Correlation Between Number of Trees Planted and the Total Cost per Tree by	/
the Sacramento Tree Foundation, 1991-20043	34
Figure 14. A Volunteer Checks the Rootball for Girdling Roots Before Planting	37
Figure 15. Crown Volume Modeled for 9 Common Municipal Tree Species in	
Longview, WA4	12
Figure 16. Example of Tree Growth Reduced by Urban Conditions4	13

Tables

Table 1. Suggested Mortality Rates for Urban Trees During the Establishment Period8
Table 2. Suggested Mortality Rates for Urban Trees after Establishment
Table 3. Suggested Cumulative Survival Rates after 30 Years9
Table 4. Advantages and Disadvantages of Different Stock Forms
Table 5. Advantages and Disadvantages of Different Stock Sizes
Table 6. Overview of Common Planting Mistakes in Urban Forestry 23
Table 7. Review of Post-Planting Care Options
Table 8. 1990-2004 Tree Planting Costs for the Sacramento Tree Foundation
Table 9. Approximate Costs of a Large Tree-Planting Project in Kelowna, Manitoba 33
Table 10. Approximate 2005 Cost Range of Different Stock Sizes
Table 11. Approximate 2005 Cost Range for Large Numbers of Planted Trees35
Table 12. Total 2005 Program Cost Range For Example Program
Table 13. Advantages and Challenges of Volunteers in SIP Tree-Planting Projects38
Table 14. Examples of Volunteer Sources for a SIP Tree-Planting Program
Table 15. Verification targets with increasing levels of precision41
Table 16. Guidance for Sampling Protocols in Verification Procedures
Table 17. Possible Timing of Verification for the Three Critical Measurements

Appendix

Overview of Young Urban Tree Mortality Studies	
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Executive Summary

The objective of this study was to provide a pragmatic framework for the discussion of including large-scale tree planting in a State Implementation Plan (SIP). Specific goals toward attaining that objective included:

- Identifying the challenges of implementing a large-scale planting
- Researching these challenges and the limiting factors associated with them

Recommending procedures to surmount them

The following points summarize the findings of this study:

- The <u>scale</u> of tree-planting programs required to meet the increased canopy levels suggested by modelers is about two orders of magnitude (10 to 100 times) greater than most urban tree-planting programs. Assumptions and procedures from those programs will likely not be applicable.
- The primary **<u>objective</u>** of a SIP tree-planting program is fundamentally different from most other very large programs targeting numbers planted, since survival and growth constitute the actual measures of success.
- Young urban tree **mortality** presents a significant problem to attaining the required canopy cover, since it can be shown that a group of trees planted at the same time (a cohort) can be expected to lose about half its members over a 30-year span even at relatively low mortality rates—unless they are seedlings, when the numbers will be much higher.
- The <u>species diversity</u> of the urban forest will tend to decrease as the number to be planted rises, since availability depends on market demand. The implication of this trend is that the very large SIP cohorts will be dominated by a small number of species unless careful advance planning is conducted.
- High <u>VOC emitters</u> will need to be restricted in the species pool, but in some regions establishing a cap (say, 20%) might prove the better strategy so that long-lived and low-maintenance species could provide higher overall benefits.
- There will be a <u>restricted ability</u> to match species to site because of the sheer lack of sufficient time to deal with such large numbers. Since that match is critical to long-term health and survival, special procedures will need to be developed to accomplish this task without requiring standard site assessment for each tree.
- The <u>stock size</u> will probably drop as the cohort number rises, not so much because of availability as because of cost control and restrictions imposed by other facets of planting (technique, labor, etc.). The use of such smaller stock size is unusual in urban forestry, but more common in rural planting programs.

- The balance between cost and survivability for very large SIP cohorts seems to come with the use of <u>2-yr branched liners</u>. These will probably have to be contract grown, if sufficient numbers and species mix are to be obtained, and special procedures may be required to permit such an arrangement.
- The very large SIP cohorts will probably require some form of <u>mechanized planting</u> in order to execute the work within limits of time and budget. Attractive options include the tree auger, the careful use of which can meet demands for speed, cost, and survivorship.
- As the size of the cohort increases, the temporal and spatial coordination of personnel, equipment, and plant materials (**logistics**) becomes more complicated, time-consuming, and expensive. To carry out this complicated work successfully, careful planning will be required.
- The work of **planting site acquisition** will be substantial, with the time spent per site rising with cohort size as private individual sites are increasing needed. For this reason, strategies to carry out the work will need to be developed well ahead of time, and appropriate funds and personnel made available.
- State air quality personnel may be unfamiliar with tree benefits <u>models</u> and may not understand the range of benefits currently calculated for the urban tree resource. Foresters, likewise, know little about air quality models. Communication between air quality and tree benefit modelers should be fostered through workshops, educational materials, and personal contact.
- The <u>costs</u> will vary enormously depending on stock size, species, vendor, planting method, labor source, and management/administration options. A cost estimator spreadsheet has been developed to facilitate planning and is available for download: http://www.treescleanair.org/policymakers/factsheets/CostEstimator.xls
- The <u>likely cost range</u> for each 1,000,000 trees is \$25M-\$100M. In particular jurisdictions some of these costs may be offset by funding strategies, displaced to other budgets, or even considered irrelevant.
- The involvement of <u>volunteers</u> and other non-professionals that is likely due to the large number of trees involved, brings many benefits and challenges. Because such groups differ greatly from the typical workforce in urban forestry, the recommendation is made to engage an experienced and successful agency and to put in place good quality assurance and quality control procedures.
- It will be necessary to include some form of <u>verification</u> procedures with any submission of tree planting within a SIP. Targets of any such procedure are installation, survival, and growth, depending on the desired level of precision. The exact procedures adopted will depend on the required level of precision needed.

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The following cooperators participated in this project:

Lisa Tilney, Project Manager	Gary Allen, Executive Director
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Drafts of factsheets on each challenge were created and sent to reviewers around the country. The revised documents were then posted on the project website for use. Those documents have now been revised and rewritten for inclusion in this feasibility study.

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1.0 Introduction

1.1 Background

Urban foresters and environmentalists have long suggested that trees and other vegetation in urban areas convey multiple beneficial impacts to the environment and quality of life in cities and urban areas. Research scientists with the United States Department of Agriculture Forest Service (Dwyer et al, 1992; McPherson, 1992; Nowak and Crane 2000) and others have substantiated these beneficial effects. As a result of these research efforts, interest has increased in managing urban vegetation cover to improve urban environments, particularly air quality (Taha, 1996; Luley, 1998; Nowak et al, 2000; Luley and Bond, 2002; Hitchcock, 2004; Taha, 2005).

Although air quality in the United States has generally improved, ground-level ozone (O_3) continues to be a difficult pollutant to manage nationwide. In fact, the number of cities that are out of compliance with the newly established 8-hour ozone standard of 85 parts per billion (ppb) is significant (see Cover Map), and has risen substantially from that associated with the former 1-hour standard of 120 ppb.

The major constituent of smog, ground-level ozone can damage vegetation and ecosystems. However, elevated ozone is more than an environmental problem, as it seriously affects human health for half the U.S. population that lives in cities affected by non-attainment status.

The reactivity of O_3 causes health problems because it damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants. Scientific evidence indicates that ambient levels of O_3 not only affect people with impaired respiratory systems, such as asthmatics, but healthy adults and children as well. Exposure to O_3 for several hours at relatively low concentrations has been found to significantly reduce lung function and induce respiratory inflammation in normal, healthy people during exercise. This decrease in lung function generally is accompanied by symptoms such as chest pain, coughing, sneezing, and pulmonary congestion (EPA, 2005).

Measures to reduce ground-level ozone have become increasingly expensive and less effective. Many states have exhausted the viability of common management practices typically used to gain federally required ozone reductions (EPA, 2004). For this reason, the United States Environmental Protection Agency (EPA) is now actively considering new and innovative measures that can be used by states in their efforts to attain regulatory compliance with the revised ozone standard.

In September 2004, the EPA released guidelines that allowed the use of fundamentally different measures into a State Implementation Plan, or SIP (EPA, 2004). The instigation for this action came from more than a decade of research on methods to attain national ambient air quality standards that focused on measures other than traditional emission reduction. The new policy is designed to encourage the consideration of measures that have not typically been considered or approved in a SIP.

Two measure categories have been established with strict definitions: "A <u>voluntary</u> measure is a measure or strategy that is not enforceable against an individual source," while "an <u>emerging</u> measure is a measure or strategy that does not have the same high level of certainty as traditional measures for quantification purposes" (EPA, 2004). A measure can be both voluntary and emerging, *e.g.*, steps taken by a community (voluntary) to reduce the heat island effect (emerging). When considered along with the ability to bundle measures together (EPA 2005b), these new categories (limited by the EPA to 6% of the total amount of emission reductions required) offer a flexible regulatory framework for the incorporation of tree planting into a SIP.

The primary examples of the role for tree planting with a SIP are surface modifications to reduce the "heat island" effect, and urban tree canopy modification. These topics have been the subject of intense research efforts over the last decade (Cardelino and Chameides, 1990; McPherson and Nowak, 1994; Taha, 1996; McPherson, 1998; Luley, 1998; Luley and Bond, 2002; Nowak, 2005; Taha, 2005). Notable corrections to earlier modeling have been made with respect to vertical mixing (Hudischewsky et al, 2001), BVOC emission rates (Donovan et al, 2005), and ambient humidity (Byun et al, 2005).



Figure 1. Complex Processes of Ozone Formation and Deposition

Source: Stockholm Environment Institute (http://www.york.ac.uk/inst/sei/APS/a-proj.htm)

Because the interaction of the factors affecting ozone formation is exceedingly complex (Figure 1), researchers rely on one or more of the following models to investigate the effects of manipulating current values:

- Meteorological models
 - Used to incorporate atmospheric physical laws and measured observations to predict weather conditions at certain times in particular locations
 - o Examples
 - MM5, a limited-area terrain-following model designed to simulate or predict mid-scale atmospheric circulation (home page: http://www.mmm.ucar.edu/mm5/)

- WRF, a mid-scale weather prediction system "designed to serve both operational forecasting and atmospheric research needs" (home page: http://www.wrf-model.org/)
- Photochemical models
 - Used to assess how pollutant concentrations change with differing pollution emissions, meteorological conditions, and atmospheric conditions
 - o Examples
 - CAMx, "a publicly available open-source computer modeling system for the integrated assessment of gaseous and particulate air pollution" (home page: http://www.camx.com/)
 - CMAQ, modeling software with a unique framework and science design that enables scientists and regulators to build their own modeling system to suit their needs (homepage: http://www.epa.gov/asmdnerl/CMAQ/)
- Urban forestry models
 - Used to calculate structural and functional information from sample tree data merged with local weather and air pollution concentration data
 - o Examples
 - UFORE, a computer model that calculates the structure, environmental effects, and values of urban forests (home page: http://www.i-Treetools.org)
 - STRATUM, a street tree management and analysis tool that uses tree inventory data to quantify annual environmental and aesthetic benefits, and calculate a dollar value for them (home page: http://www.i-Treetools.org)

Models such as these are applied to historical data for high ozone pollution events. Modeling of Atlanta ozone levels on June 4, 1984, for instance, suggested that a reduction of tree cover by 20 percent would have increased maximum ozone concentrations by about 14%, mostly because of the rise in temperature (Cardelino and Chameides 1990). The incident in the New York City region forming the basis of modeling with different levels of tree cover (Civerolo et al, 2001) occurred July 12-15, 1995, while the extraordinary Los Angeles event investigated recently from a related perspective (Taha 2005) took place August 3-7, 1997. By altering aspects of the tree canopy at the time of the event, such as extent of cover or species composition, researchers are able to model the likely effects of canopy changes upon concentration and extent of pollution.

Studies of US regions that are currently non-compliant with EPA standards, including the New York City and the Los Angeles/Central Valley areas (Luley and Bond 2002, Taha 2005), have concluded that planting 8-10 million trees in the larger areas (such as New York or Los Angeles) would be required to reduce ozone levels on the order of a few parts per billion. Similar work has been carried on abroad. One recent study of Birmingham, England showed comparable improvement in atmospheric quality when 10% of the available planting space was filled with low-VOC emitter species (Donovan et al, 2005).

Work such as this has piqued the current interest in exploring the inclusion of largescale tree planting in a SIP. These studies and modeling efforts are the necessary first step in developing reliable data to demonstrate that managing urban tree cover can reduce ground-level ozone.

1.2 Scope

This feasibility study examines the implications of adopting large-scale tree-planting measures, and focuses on the challenges that such measures would meet. It provides a pragmatic framework for the discussion of including large-scale tree planting in a SIP. It recognizes that achieving ozone reductions through tree planting will require expanding current planting rates by one to two orders of magnitude (10 to 100 times).

The planning, execution, and verification of tree-planting goals are serious issues for groups implicated in the actual process of incorporating tree planting into a SIP. Since the SIP is a legally binding document with strong consequences for noncompliance, it seems critical that the proposal to include tree planting be examined carefully before any commitments are made.

Finally, the narrow focus of this study on the potential interaction between altering the quantity of tree canopy and increasing air quality does not intend to dismiss the importance of other means to affect ozone levels through vegetation (Hitchcock, 2004). This study restricts itself to one method of affecting the *net* changes in tree canopy recommended by the EPA (2004), which pointed to total tree population management factors such as canopy growth, canopy loss, or canopy protection.

The net changes in tree canopy can be summarized thus (adapted from Luley and Bond, 2002):

$$\mathbf{C}_T = \mathbf{C}_0 + \mathbf{C}_G - \mathbf{C}_L$$

where $C_T =$ future canopy at time T

 C_0 = canopy at time zero

 C_{G} = canopy growth

 $C_L = canopy loss$

Using this notation, one can describe the scope of this study as limited to the major anthropogenic component of C_G . It ignores the other large anthropogenic factor, canopy loss, for which a companion study is sorely needed. It also ignores proposals for "urban surface modification" that would include increases in surface albedo along with vegetative cover (Taha, 2005). All such related areas of inquiry may hopefully be furthered by this close, pragmatic look at large-scale tree planting that has been repeatedly proposed (already Nowak, 1993) and modeled.

2.0 Challenges

The feasibility of a multi-year large-scale planting project, and of realizing the airquality benefits that have been modeled to flow from it, depends on overcoming a host of practical challenges. Though not insurmountable, these challenges are formidable, and need to receive appropriate evaluation and planning if a large-scale SIP tree-planting project is to succeed in the long run. This second section examines the challenges individually, spelling out the important questions and making conclusions about feasible solutions to each.

2.1 Challenges: Mortality

Background

SIP planting programs would differ from others because the achievement of their objective would be measured against a future state of the forest. To ensure compliance, that survival—and the air quality benefits calculated from

Rather than targeting tree planting, a SIP program must target tree survival.

it—should be calculated as accurately as possible.

The argument for careful estimation of urban tree mortality within SIP planning runs thus:

- 1) Air quality and urban forest modeling have shown that tree canopy can reduce ozone concentrations, as well as bring other benefits such as carbon sequestration, temperature reduction, and indirect reduction of emissions (Nowak, 2005)
- 2) The benefits demonstrated in this modeling depend on the projected size of the urban tree canopy at a given future point
- 3) The projected canopy size from planting relies on assumptions about growth and mortality of existing and new trees
- 4) The future size of the canopy can be affected significantly by large-scale planting
- 5) Compliance for SIP purposes will depend on the accuracy of these projections

Growth and mortality rates are thus critical to the question of including urban tree planting within a SIP. Figure 2 (p. 6) illustrates an example of how mortality rate affects cumulative survival, where the upper curve represents the cumulative survival rate and the lower curve the annual mortality rate.





While the growth of young urban trees is highly visible, has been well measured (see Thompson et al, 2004), and has strong industry investment, their mortality is relatively unseen, insufficiently measured, and easily overlooked. Its importance in rural forestry is well established, but the forces responsible for its prominence (competition for light, limited nutrients) are much reduced in urban forestry. Also, urban tree managers have been slow to keep accurate records (Miller, 1997).

Urban young tree mortality has a large human component whose significance is often ignored in tree planting projects. Beyond tree-to-site matching, urban tree growth is largely outside practical influence for large populations such as those considered for inclusion in a SIP, since it is driven by genetic growth traits interacting with local environmental factors. Urban young tree mortality, on the other hand, has a large human component

whose significance is often ignored in tree planting projects (Ip, 1996). Because of this, the question of young tree mortality impacts modelers, policy makers, planners, local tree managers, and even the persons doing the actual planting.

Discussion

Annual young urban tree mortality is relatively high during the establishment period of roughly four years, with roughly half the loss coming in the first year after planting (Miller, 1997). The most common causes for this early mortality are well-known (Watson and Himelick, 1997):

- Water stress (too little, too much)
- Incorrect planting depth (too low, too high)

- Physical damage (lawn care wounds, vandalism)
- Stress-related problems (borers, cankers, etc.)

A lack of community involvement has also been identified (Sklar and Ames, 1985; Austin, 2002). Unfortunately for planning purposes, the mortality rates also vary greatly among studies—and even within studies--as can be seen from the overview in Appendix. This variation comes from the many differences among the planting programs studied:

- Climate and soil factors
- Planting agents (contractors, professional staff, volunteers)
- Planting sites (yard, institution, street)

One clear example of how mortality rates behave when all factors except climate are held reasonably constant comes from the quality assurance data on the large numbers of trees planted through the cooperation of the Sacramento Municipal Utility District and the Sacramento Tree Foundation (Sommer et al, 1994). After 19 consecutive semi-annual inspections of a 2% random selection of recently planted trees (SMUD 2004), the short-term mortality rate for 1996-2004 averaged 10.5% (SE 5.7%)—with the removal of one anomalous outlier (see Figure 3), the average drops to 9.4% (SE 3.2%). If one can assume that half the establishment period loss comes during the first year (Miller, 1997), these figures imply a robust estimate of the cumulative mortality rate for the establishment period of about 20%.



Figure 3. Mortality of Newly Planted Yard Trees in Sacramento, CA, 1994-2004 (Reworked from data in SMUD 2004)

Feasibility

The high and uncertain mortality rate of young urban trees has major effects upon SIP planning:

1) Literature review suggests the mortality rates in Table 1 can usually be expected for newly planted urban trees (modified from McPherson and Simpson, 1999), though very high rates exceptionally arise.

 If young tree mortality is not taken into account, canopy projections could be overly optimistic, anticipated levels of air quality benefits too high, and jurisdictions non-compliant. Projections of air quality benefits from urban forestry programs are very sensitive to tree survival rates (McPherson and Simpson, 1999). A three-step process can estimate needed planting numbers, once the final target canopy is known:

If young tree mortality is not taken into account, canopy projections could be overly optimistic, anticipated levels of air quality benefits too high, and jurisdictions noncompliant.

- i) Decide on the stock, planting methods and personnel, and sites.
- ii) Select suitable mortality rates for the project, and calculate its effect on their target. If the project divides into very different methods, adjust mortality rates accordingly.
- iii) Ensure that enough additional trees will be planted to supply the desired target canopy based on steps i and ii.

Establishment Period (approximately 1-4 years after planting)			
Annual Mortality Rate		Factors for Selecting Rate	
High	7-9%	Hot and dry climate, untrained volunteer planting, unmonitored planting, unsuitable or low-quality stock, high stress planting sites, lack of post-planting care, no community involvement	
Average	5-7%		
Low	3-5%	Temperate and moist climate, trained volunteers, monitoring of planting, high-quality stock, low-stress planting sites, post-planting care, community involvement	

Table 1. Suggested Mortality Rates for Urban Trees During the Establishment Period

Table 2. Suggested Mortality Rates for Urban Trees after Establishment

Post-Establishment Period (4-30 years after planting)			
Annual Mortality Rate		Factors for Selecting Rate	
High	2%	Hot and dry climate, poor match between sites and species, poor stock quality, lack of training and supervision at planting, many high stress planting sites, no community involvement	
Average	1%		
Low	0.5%	Temperate and moist climate, good match between sites and species, stock with appropriate root structure, training and supervision at planting, many low-stress planting sites, community involvement	

Cumulative Survival Rates after 30 years				
Establishment Mortality Rate		Post-Establishment Mortality Rate		Cumulative Survival Rate (rounded to nearest multiple of 5)
		High	2%	40%
High	7-9%	Average	1%	55%
		Low	0.5%	65%
		High	2%	45%
Average	5-7%	Average	1%	60%
		Low	0.5%	70%
	3-5%	High	2%	50%
Low		Average	1%	65%
		Low	0.5%	75%

Table 3. Suggested Cumulative Survival Rates after 30 Years

<u>Disclaimer</u>. The mortality rates given here are based on averages from data that are limited in quantity and geographical distribution. Mortality estimates should be updated as better data become available, but obtainable data provide the best guess of future populations given the current limitations. Note also that the probability of disastrous loss has been ignored.

- 3. Reasonable and cost-effective steps should be taken to mitigate tree loss during the establishment period (details in Gilman [2005]):
 - Reduce water stress
 - o Weed suppression
 - o Mulch
 - Community involvement
 - Avoid incorrect planting techniques
 - o Education
 - o Contract specifications
 - o Monitoring
 - Minimize post-planting physical damage
 - o Community involvement
 - o Protection
- 4) Some kind of random sampling to monitor actual survivorship rates ought to be instituted. This topic is treated in more detail in the discussion of verification later in this document.

2.2 Challenges: Species Selection

Background

A very large SIP tree-planting program will need to identify species suitable to its long-term needs. That identification is critical, because tree survival and growth the critical results needed from planting programs within a SIP—depend in the long run on a good fit between species and site. Also, some species appear to be better suited biologically than others for promoting air quality. Finally, the introduction of a substantial number of trees into an existing population should be approached with caution, because it could affect local species diversity, population susceptibility to pests, and other biological and management issues associated with measurable shifts in diversity.

Discussion

The important species factors to consider within a general tree-planting framework have been well described in the arboricultural literature (Watson and Himelick, 1997).

- 1. The species must have an appropriate hardiness—*i.e.*, tolerance for the average minimum temperature range—for the area.
- 2. It must be tolerant of the particular site conditions where it will be planted.
- 3. Its status as an emitter of ozone precursors should be taken into account, since some species are known to contribute large amounts into the atmosphere.
- 4. Pest resistance can be important where regionally destructive pests are active or overplanting of a species has created local imbalances leading to pest outbreaks.
- 5. Its status as a native and its invasive tendencies should be evaluated.

Failure to consider factors such as these would have much broader implications, and would jeopardize the success of the program as a whole.

1. Information about the hardiness or low temperature tolerance of most tree species can be found in standard horticultural works (such as Dirr, 1998) and in the USDA's Plants database (http://plants.usda.gov/, native and naturalized trees only). In addition, existing suitable tree lists based on hardiness exist for most states within the Cooperative Extension system. That information can be compared with the USDA's most recent map of average minimum temperature ranges in the United States (Figure 4) to judge the hardiness of a species (The Sunset Climate Zone Map is often consulted on the West Coast because of its detailed view of climate differences there).

2. Trees must also be genetically adapted to tolerate particular site characteristics. Planting sites that have adequate growing space (above and below ground), drainage, pH, nutrition, sunshine, and other elements will support good growth and development for many different species. However, as these site factors becoming limiting individually or collectively, the number of species that can be suitably planted in them becomes increasingly smaller. Site analysis techniques (*e.g.*, Bassuk, et al., 2003; Gilman, 2005) have been developed to promote the critical fit between species and site. For sites where the air is highly polluted, lists have been constructed of tolerant species (Watson and Himelick, 1997; Nowak, 2000). Similar lists exist for other site problems. The use of such materials will greatly facilitate locating "the right tree in the right place" and lead to a functional canopy.



Figure 4. Three sections of the US National Arboretum's Plant Hardiness Zone map. Source: http://www.usna.usda.gov/Hardzone/ushzmap.html

3. Some species produce high levels of ozone precursors called volatile organic compounds (VOCs), which include isoprenes and monoterpenes (Figure 5). They are part of plants' natural defense system, but they also react with nitrogen oxides (NO_x) in the presence of sunshine to contribute to ozone formation. Higher temperatures increase the rate of VOC release and ozone formation; thus, peak ozone levels in the northern hemisphere usually occur in summer months, especially during the afternoons, though regional and temporal differences are known.

Some tree genera produce much higher rates of VOCs than others. High VOC emitters include oaks, poplars, spruces, and willows (Geron et al, 1994).

Nine genera that have the highest standardized isoprene emission rate and, therefore, the greatest relative effect among genera on increasing ozone are: beefwood (*Casuarina* spp.), *Eucalyptus* spp., sweetgum (*Liquidambar* spp.), black gum (*Nyssa* spp.), sycamore (*Platanus* spp.), poplar (*Populus* spp.), oak (*Quercus* spp.), black locust (*Robinia* spp.), and willow (*Salix* spp.). However, due to the high degree of uncertainty in atmospheric modeling, results are currently inconclusive as to whether these genera will contribute to an overall net formation of ozone in cities (*i.e.*, ozone formation from VOC emissions are greater than ozone removal). ((Nowak 2005)

Species	Chemical Structure	Primary Natural Sources	Annual Global Emission (x10 ¹² g C)	Reactivity (atmospheric lifetime in days)
Methane	CH4	Wetlands, rice paddies	319-412	4000
Isoprene		Plants	175-503	0.2
Monoterpenes	$ \nabla $	Plants	127-480	0.1-0.2
Ethylene		Plants, soils, oceans	8-25	1.9
Other reactive VOCs	СНО	Plants	~260	<1
Other less reactive VOCs	сн₃он	Plants	~260	>1

The Major Biogenic VOCs



Work proceeds on this topic. Authors of a recent study (Donovan et al, 2005), for instance, derived an urban tree air quality score (UTAQ) for common English urban trees based on field data collection and various model scenarios, in order to rank species for their air quality effects. In the worst category were once again members of the genera poplar, willow, and oak, while the best category included maples, hawthorns, and pines. In their simulations, increasing canopy cover by planting high VOC-emitting species slightly <u>increased</u> ambient ozone levels.

It seems shortsighted to ban otherwise useful species because of their VOC potential. The test case may be the oak genus, whose many species are widespread and successful in this country, from both an environmental and a horticultural perspective. There are a number of arguments for keeping oaks on a SIP planting list:

- VOC emission levels vary among oak species by a factor of 3 or so in recent studies (Geron, et al, 2001; Karlik, et al, 2002), and to ban the entire genus would be to exclude investigating the potential of interspecific differences
- Atmospheric modeling tends to account poorly for species composition (Donovan, et al, 2005), leaving the *overall* effect of the selection of individual species or genera in doubt
- Long-lived and drought-tolerant oaks have the potential to cool the urban environment much longer than other species in regions that are hot and dry, and lowering ambient air temperature improves air quality (Cardelino and Chameides, 1990; Nowak, 2005)
- In areas such as California and Texas, the existence of many endemic and indigenous oaks demonstrates they are well adapted to local environment

• Longer-lived species may be generally more beneficial to air quality, because they reduce the secondary emissions of machinery used for tree removal, replanting, and maintenance (Nowak et al, 2002)

For these reasons, an optimal strategy would seem to be to limit, but not exclude, oaks from the species pool. Accepting the results of Geron et al (2001), for instance, one might establish a valid limit using models that are sensitive to species composition by examining the effect of including members of the lowest group of oak emitters such as live oak (*Quercus virginiana*), canyon live oak (*Q. chrysolepsis*), or chestnut oak (*Q. prinus*).

In lieu of research on what a reasonable limit might be in a particular domain, high emitters could be treated collectively as a genus and submitted to the 10-20-30 (percent species-genus-family) diversity guidelines (Santamour, 1990). Under this approach, no more than 20% of the actual trees to be planted would be permitted to fall into the strong emitter category as defined by current scientific research. In a cohort of 1,000,000 trees, for instance, the following scenario would result:

<u>Group</u>	Number	VOC emission level*
Low emitters	800,000	$< 1.0 \ \mu g \ C \ g^{-1} \ h^{-1}$
High emitters	200,000	~ 100 μg C g ⁻¹ h ⁻¹
Cohort average VOC emission level: ~20 μg C g ⁻¹ h ⁻¹ *Source: Geron et al, 2001, emission measured against leaf dry weight		

Until the effects of such an ambient BVOC level have been modeled for local meteorological values, it will remain difficult to draw definitive conclusions about the inclusion of a limited percentage of high emitters. But it may well be that, whatever the negative effects from the perspective of ozone formation, it would be balanced or even outweighed by the positive effects of including species that are longer lived and require lower maintenance.

4. Species selected for SIP planting must be resistant to destructive pests that can kill trees within a few years. In the northeastern U.S., for instance, it would be unwise to plant maples in regions where the lethal Asian longhorned beetle has yet to be contained. Likewise, in Michigan and adjoining states where the emerald ash borer is threatening hundreds of thousands of ash trees in rural and urban forests, ashes should be excluded from planting lists for this area. Clearly, the presence and importance of insect and disease pests varies considerably depending on the area of the country, and even of a State. Local personnel, State government, and University pest management experts should be consulted to determine what pest management issues might affect species selection in an area.

5. Species native to the specific region should be strongly considered for parks, woodlands, wetlands, and other semi-wild sites. Native species are often better adapted to regional weather (see for instance Duryea, 1998), and can show greater survival and growth where harsh conditions prevail. In the urban environment, more narrowly understood, a different approach should probably prevail. Some exotic

species (such as ginkgo, *Ginkgo biloba*) make excellent long-lived urban trees, tolerating harsh conditions that few native trees can, and it would be shortsighted to eliminate them from the available species pool. Moreover, the term "native" itself is open to question, since there is no standard definition of its spatial or temporal criteria. Plants, like people, immigrate and become naturalized, and they can also emigrate or die out over time. Thus in urban areas it would be difficult to justify the exclusion of selected exotic species.

Related to the question of origin is that of invasiveness. An "invasive species" has been officially defined as a species that is 1) non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Exec. Order 13,112 1999). Unwanted invasiveness could be a serious problem, especially when an exotic species's success leads to the destruction of habitats.

Invasiveness is a property that is tied to specific regions and sites, and both native and exotic trees can be invasive under suitable conditions. Species known to be invasive in specific regions (such as tamarisk in the West, Norway maple in the East, or Australian pine in Florida) should be avoided there. On the other hand, the invasive tendencies of some native trees could be managed as an ally in the effort to increase urban canopy, since a single tree planted on a suitable site and with appropriate management could quickly produce multiple offspring through vegetative reproduction—the common use of willows for stream bank stabilization is a good example of putting this trait to work. Clearly, careful attention to the invasive properties of tree species is called for during selection for SIP planting, since inattention could result in the ecological solution being worse than the atmospheric problem.

Feasibility

The large number of trees to be planted for a SIP use raises two fundamental problems in species selection—matching species to site, and maintaining species diversity. Approaches must be sought that will solve these problems that are critical to survival and growth at the individual and population levels.

Matching species to site will be difficult in a large-scale SIP planting, since detailed site analysis may be impossible given the sheer size of the planting project. There will be large planting sites with room for many trees, of course, and there a single analysis will often serve an entire group of trees. In some cases where planting is occurring outside city or urban boundaries, soils maps that are readily available by county for most of the country could be coupled with limited site analysis for guiding site selection and planting decisions.

Selecting species for small sites is hampered by the infeasibility of conducting individual site analyses. Selecting species for small sites will be hampered by the infeasibility of conducting individual site analyses. As the number projected to be planted increases, it is likely that small individual private sites will become increasingly needed. This problem renders suitable species choice difficult, and threatens to lower the long-term substantially and survivability of the SIP population.

Alternative species selection strategies will probably be required (Figure 7, page 16). The actual work of species selection could be restricted to identifying the truly difficult sites that would limit survival and/or growth on most species: brownfields, urban rubble, compacted wasteland, floodplains, etc. Here site analysis can probably not be avoided. Sites that lack such obviously difficult traits can be populated with a general mix of species without specific site analysis, if need be, and planners can still expect a reasonable rate of survival and growth from them.



Figure 6. Ginkgos Planted in a Difficult Site in Washington, D.C. Source: http://www.xs4all.nl/~kwanten/americanorth.htm

Also, many species used in urban planting tolerate a large range of conditions. Some urban hybrids, such as London plane (*Platanus x acerifolia*), are well known for this ability, as are species such as ginkgo (*Ginkgo biloba*) or Norway spruce (*Picea abies*). Species with unusual genetic plasticity in their tolerance for variable site conditions could be used where sites appear questionable when site analysis is not possible. Such species can be identified from existing published resources (*e.g.*, Dirr 2003, Bassuk, et al, 2003 for Northeastern US), electronic media (such as Horticopia, 2003) and online guides (*e.g.*, SelecTree for California, online at http://selectree.calpoly.edu/attribute_search.lasso).

Maintaining species diversity is extremely important, as has been clearly shown, but it becomes harder with large-scale planting projects. The guidelines for species diversity (Santamour, 1990) should guide, but not determine, the construction of species lists. At the same time, the large number of trees needed for SIP planting will tend to limit diversity simply because large quantities will probably only be available for certain highly marketable species. Without careful planning, the stock for a particular project may be dominated by a few common species—such as green ash (*Fraxinus pennsylvanica*), honeylocust (*Gleditsia triacanthos* var. *inermis*), Norway maple (*Acer platanoides*), or red maple (*Acer rubrum*)—that are widely grown by the industry and are already overplanted in urban areas.



Figure 7. One Alternative Strategy of Species Selection for Difficult Sites

To ensure species diversity in very large SIP planting, it may be necessary to set up growing contracts. Once planners have set the number, species, stock size, and form needed, regional growers could be contracted to supply the required materials at a specific time in the future. As long as sufficient seed or other propagation source was available, growers could supply required stock that not only would maintain species diversity, but would also be reasonably priced. Special arrangements may be necessary in some jurisdictions to comply with existing restrictions concerning the bid process.

2.3 Challenges: Stock Size and Form

Background

A very large tree-planting program will need to make an early decision on the size and form of the trees it is going to plant. This necessity results from the fact that size and form link tightly with questions of selection, equipment, costs, mortality, and personnel. Because there are so many interlocking factors, it will be important to settle as many questions as possible at the beginning of the project.

Typically, urban tree managers prefer stock 2-3" in caliper for planting in their urban forest, primarily because of the instant tree presence and because vandalism tends to be reduced on larger caliper trees. But in a SIP planting, a budget adequate for large stock is unlikely.

It is probable that in any single SIP planting project, a combination of tree sizes and planting stock types will be used. The decision to use any tree size and stock type

can be driven by a range of factors, including, but not limited to, site, tree species, nursery availability, cost, location and access, and equipment.

To begin with, trees are sized by trunk diameter, and small deciduous trees are standardly measured 6" above grade (ANLA 2004). Four size-classes of planting stock can be described:

- Seedling: recently sprouted tree, typically less than 0.5" caliper
- Small: less than 1.5" caliper
- Medium: 1.5-3" caliper
- Large: more than 3" caliper

The "Small" size-class actually includes multiple forms: whips, liners, and small ornamental trees, such as crabapples and hawthorns. Since the word "liner" is somewhat unfamiliar to non-professionals and since it is a strong candidate for SIP planting, here is a careful definition:

In nursery production, a "liner" refers to a small plant that is transplanted and grown on to become a larger plant. Tree liners are often referred to as "whips." They are small trees, branched or unbranched, typically 4-ft. to 8-ft. tall and 1/2-in. to 3/4-in. in caliper. Liner shoots are one or two growing seasons old. Their root systems may be three- to six-years old, depending on the species and whether they have been grafted or budded (Mathers et al. [N. d.]).

In addition to stock size, stock form also varies greatly. Three different categories can be singled out:

- Containerized
- Bare-root
- Ball-in-burlap (B & B)

These categories, however, contain many important variations. Containers can be plastic or fiber, round or square (boxed), shallow or deep, and ridged or smooth. Bare-root trees typically cover whips, liners, and medium-sized trees. B & B trees are usually wrapped in burlap, but there may or may not be a wire basket present, and the burlap may be synthetic. These variations will influence the cost and survivorship of SIP tree-planting programs.

Discussion

In choosing planting stock size and form, it often helps to start with the factor perceived locally as the most limiting. For instance, if available labor is restricted, then the choice might fall on small sizes or bare-root stock so that the volunteers could be

Many factors influence stock selection, and no single size or form will be suitable for all planting involved. In contrast, stressful downtown areas with a high pedestrian rate may be better suited to larger B&B trees for best performance over the long run.

Many factors influence stock selection, and no single size or form will be suitable for all planting sites, personnel or timeframes. By aiming for size and form diversity, the planting program will have the greatest flexibility and resilience. To that end, the following tables of comparisons may be of aid.

Туре	Advantages	Disadvantages
Containerized	 Easy to handle Available/useable anytime Different container types obtainable Large quantities available 	 Root defects common Light medium may fall apart Easily water-stressed Species selection somewhat limited
Bare-root	 Less costly than same-sized container or B&B Tend to have larger root mass Can be easily handled 	 Subject to drying out Only available early spring and fall Species and quantity limited Not applicable to all regions Some species not adaptable
B & B	 Roots protected by soil before planting Large sizes available Stress-tolerant during establishment Often largest species selection 	 Heavy (mechanical equipment needed) Root flare not always visible High root loss during harvesting if not root pruned regularly in nursery

 Table 4. Advantages and Disadvantages of Different Stock Forms

Table 5. Advantages and Disadvantages of Different Stock Sizes

Size	Advantages	Disadvantages
Small	Least costlyLarge numbers usually obtainableQuick establishment	 Highest mortality rate Subject to predation, vandalism, and suppression by weeds
Medium	Often good cost-benefit ratioWidely available for most species	 Subject to vandalism on some sites Root structural problems common in some stock forms
Large	Lowest vandalism rateInstant tree presence	Longer establishment periodMost expensive size

Various descriptions of desirable stock traits have been published. These range from the standards (ANLA 2004) known as the *American Standard for Nursery Stock* (*ANSI Z60.1-2004*), to a great host of professional and educational documents made available to urban forest managers (*e.g.*, Urban Tree Foundation, 2005). Most municipalities or agencies that have tree-planting programs have used these various documents to develop their own planting specifications.

From a SIP perspective, the critical consideration during stock selection must be the quality of the root system. Root problems are responsible for the vast majority of urban tree longterm failures (Watson and Himelick, 1997; Harris, et al.,

From a SIP perspective, the critical consideration during stock selection must be the quality of the root system.

2004). Root system quality depends on the root structure of the purchased stock and the fit between species and site that strongly controls growth and health.

The quality of the roots can be maximized at the time of purchase by selecting stock grown with techniques developed to reduce defects, particularly those associated with containerized trees. Root control bags use various means to reduce root circling or exiting. Above-ground production and air root-pruning also reduce root problems, and are preferable for that reason to conventional production means, probably especially for plate-rooted species like maples (Gilman et al, 2003). A minimal means of control would be to add a specification in the bid request, such as the following standard component of many recent tree purchase specification templates:

"The trunk, root collar (root crown), and large roots shall be free of circling and/or kinked roots."

For normal urban forest purposes, the best way to obtain high-quality root structure is to actually see it. In the context of a very large SIP planting, the most that can probably done is to encourage planting organizations to place specifications in the bid request that describe the accepted frequency of root defects, and the consequences for significant diversion from that value. Whether any actual sampling occurred to determine whether that frequency is being met will depend on the local context.

Feasibility

Because of its large scale, a SIP planting will be not only quantitatively, but also qualitatively different from typical installation programs to which urban tree managers are accustomed. One example of this is that as the number of trees to be planted rises, the average stock size will tend to drop, partly due to efforts to control costs and partly because of larger stock limitations for less common species. Because smaller sizes are unfamiliar to many urban forest managers, moreover, it becomes all the more important that research results be used for determining the methods of selecting, transporting, storing, and planting stock.

The most cost-effective size for large-scale urban planting may be the branched liner (Schneider, 2005). It can be specified as a two-year-old bare-root liner or as a 2- or 3-gallon tree; in either case, it typically stands 4-8' tall with a caliper of half to threequarters of an inch. It is much cheaper than a 2-3" caliper tree, yet its survival rate is typically much higher than seedlings. In this sense, it lies at a crossover point between cost and survivorship, as Figure 8 illustrates in a conceptual manner.

At the same time, a mix of stock sizes will likely be required. Branched liners will suit the majority of sites, but not all. Seedlings may be more appropriate in terms of time and cost for open,

A mix of stock sizes will likely be required.

unpopulated areas, while B&B can be reserved for harsh downtown sites where factors such as cost and time are superseded by considerations such as environmental justice or local meteorological effect. Choices will need to negotiate the competing factors of cost, survivability and size (Figure 8) in a manner commensurate with local needs and desires.



Figure 8. Conceptual Representation of the Relationship Among Size, Cost, and Survivorship of Urban Trees

No production method will work for all species and all regions. What matters most, as stated earlier, is that the highest quality root system be sought for the species, size, and stock form. For plate-rooted species, probably at least 80% of many urban forests given the predominance of maples, a shallow wide bag may be best. But the same production system may not produce the best red oaks, generally a heart-rooted species (Gasson and Cutler, 1990).

Finally, the more common the species is in the trade, the more likely it will be available in large size stock and numbers. In general, availability of common species should not be a problem for stock > 2" in caliper (Schneider, 2005), though multiple sources and a middleman or broker may well be required.

Large numbers of smaller stock, on the other hand, will probably be unavailable except for the most common rural and urban species. The most economical and convenient arrangement will be to arrange for contract growing—best done at a regional nursery, so that the stock will be well adjusted to local conditions. Such an arrangement will ensure both species mix and stock availability, and supply large numbers at a reasonable price.

2.4 Challenges: Planting Methods

Background

Any very large tree-planting program needs to decide on its planting methods early in the planning process. This requirement emerges from the fact that other important aspects of tree planting interlock with it: cost, stock, mortality, and oversight. Each of these aspects is complicated enough by itself, but evaluating them as a cluster requires early decisions so that the project is manageable.

The often-repeated fact that it will be difficult to plant high numbers of trees in a short time and keep the survival rate reasonably high, influences all choices for SIP planting, including that of planting method. In making the actual choice, planners will have to balance three requirements that compete with each other:

- <u>Tree survival and growth</u>: these goals form the top priority for any SIP treeplanting program, and strongly affect the choice of planting method
- <u>Task scheduling</u>: putting a very large number of trees into the ground requires substantial time, but biological requirements restrict the planting window
- <u>Labor and budget</u>: it will be costly to plant a large number of trees, but attempts to limit the expense must be balanced with SIP objectives

There are many solutions to achieving this balance, and care must be exercised in making decisions. For high survival, for instance, one might think of machine-aided planting by careful—and carefully monitored—professionals. But the job would probably be expensive, and might not fit well into the SIP project as a primary planting method. For low cost, one might think of hand planting by volunteers. That combination, however, would probably bring with it high mortality rates and complicated management.

Discussion

Three topics form the focus of this section: installation methods, installation errors, and post-installation care. Once the complete picture has been reviewed, the question of appropriate choices for SIP planting can be broached.

Installation Methods

Although many variations are known, installation means can be separated broadly into three groups: hand planting, machine-aided planting, and mechanical planting.

<u>Hand techniques</u> have a long history in urban and community forestry, and for just cause. They are easily mastered, and minimal equipment is required--*e.g.*. a shovel or similar hand tool. Furthermore, the method need not be as expensive or as slow as generally reported. It has been noted, for instance, that experienced personnel can plant 1,000 or more seedlings per day on a single site, though inexperienced personnel only a quarter to a third of that rate (Wisconsin DNR, 2005). In an urban setting, the method is especially suited to sloped ground or planting by volunteers on individual small sites, where it is not fast at all, but it has been used for large-scale projects with success (Wilson, 2005a).

<u>Machine-aided planting</u> is a common municipal and landscaping approach that will probably be the first thought of tree professionals as they begin to plan for a SIP tree-planting program. The range of machines is quite large:

- Power auger
- Backhoe
- Skidsteer
- Tree planter
- Tree spade

Typically, saplings or young trees are used with such equipment, although experienced professionals also use a tree spade to move very large trees—a procedure that obviously has a very limited role here.

<u>Mechanical planting</u> might also be suitable for community forestry planting in the context of a SIP. The tree planter is well established as a viable method in rural forestry for certain purposes (*e.g.*, windbreaks) and under appropriate conditions (soil relatively level, not wet or rocky), and could be applied where those conditions exist in more populated environments (*e.g.*, transportation corridors). Key procedures for high survivability have been worked out in rural forestry (adapted from Federal Standards 2003):

- A three- or four-person crew should be used. In addition to the driver, one person follows the machine to straighten and pack poorly planted trees. Another keeps seedlings protected, separated, and ready to load into planting machine trays.
- Seedlings should be kept covered and moist at all times, from leaving the nursery to being placed in the ground. If roots are exposed to the sun and wind, the trees may be dead before they are planted.
- The machine should be set deep enough to allow the roots to hang straight in planting slit. Typical depth is 8 to 10 inches.
- Seedlings should be planted at the same depth or just slightly deeper than they grew in the nursery seedbed.



Figure 9. Tree Planter Being Set Up for a Run

Source: http://www/fnr.purdue.edu/inwood/tree%20planting.htm

Such machines have been particularly effective on level ground where same-sized seedlings are planted in rows, and have demonstrated particularly good success with

conifers (South and Mitchell, 1999). However, follow-up weed management becomes essential if large-scale mechanical installation of seedling is adopted.

Installation Error

A second critical planting discussion topic concerns common errors in planting technique. Such errors account for the majority of young tree deaths during the establishment period, the first 3-5 years after transplanting (Miller, 1997). The more such errors can be avoided, the better the survivorship—and that brings lower immediate costs and greater eventual air benefits.

The common planting mistakes and their fatal consequences are well known (Watson and Himelick, 1997). Table 6 summarizes the essential points.

Planting Mistake	Consequences	Mitigation	Procedures
Allowing pre-planting stress	Roots dry out during transportation, storage, and staging	Cover stock during transportation and storage, and keep shaded and moist during staging and planting	Write specs, set penalties, and spot check
Planting too deep	Roots below grade, especially on clay or wet soils, suffocate and die	Plant stock on undisturbed base with primary lateral roots at grade (but above grade on wet sites)	Train, set penalties for contractors, accompany crews at beginning, spot check
Leaving ties, wires, synthetic bags, or circling roots	Stem girdling leads to root death	Cut any restriction to root growth before planting	Train, set penalties for contractors, spot check
Failing to make proper soil-root contact	Roots quickly die when exposed to air	Tamp soil around plant, water in well	Train, accompany crews at beginning, spot check

Table 6. Overview of Common Planting Mistakes in Urban Forestry

If appropriate procedures are established to reduce these planting errors, the beneficial results will make a great difference over 30 years and across a large SIP population.

Post-Installation Care

A related topic concerns post-installation care. Research has shown that it can be highly beneficial to young tree survival, especially on difficult sites (Watson and Himelick, 1997). Yet because of the enormous scale of SIP tree planting, such care may prove impractical, except perhaps for certain sub-populations planted in a particularly stressful environment.

Table 7 reviews (using conclusions in Watson and Himelick, 1997 and Harris, et al, 2004) commonly recommended post-planting care from the perspective of a very large SIP population. This review suggests that most post-planting care, though

obviously desirable from a biological perspective, will be costly and perhaps even impossible from a pragmatic perspective unless limited to at-risk species and highstress sites.

Post-Planting Care	Advantages	Disadvantages	Alternatives
Water	Promotes establishment in first year, particularly on droughty sites	Costly and perhaps not even possible at the required frequency	Select drought- tolerant species, increase stock size, plant at beginning of rainy season, mulch, consider a hydrogel
Stakes	Supports the tree and protects the site. Ties and stakes should be degradable.	Costly, time consuming, and unnecessary for many sites. Can disfigure and kill tree if not removed.	Reserve for windy sites with tall stock, or where high population pressure.
Shelters	Protects stock from predation, promotes stock height	Trees often unable to support selves, shelter must be removed if not degradable, benefits are species-dependent	Reserve for sites with animal problems and for species with demonstrated benefit
Fertilizers and biostimulants	Can promote young tree growth above and below ground	Requires weed control to be effective; unnecessary on sites with decent soil	Reserve for difficult sites. Use mulch, weed control, larger stock.
Mulch	4" depth provides many benefits	Organic mulch breaks down over time	NA
Weed control	Removes competition for water and nutrients	Costly, time- consuming, short-term effect, possible local restriction to herbicide use, damage from string trimmers	Reserve for small stock, mulch, or use a recommended ground cover

Table 7. Review of Post-Planting Care Options

Feasibility

Most SIP planting programs will probably need to use a mix of installation methods in order to get the large number of trees into the ground with a reasonable survival rate. The choice will need to be matched to stock size, species, site and available personnel.

Planting very large numbers in a short time will require non-traditional approaches, especially if branched liners are used, with which most urban tree managers have little experience. Large-scale planting procedures, such as the use of tree planters, will only be successful, however, if the careful techniques that have been demonstrated to provide high survivorship are followed.

A 24" diameter power auger with a depth control is an attractive option for SIP planting, and suits the needs of dealing efficiently with a large number of branched liners. Augers come in many forms: hand-held, wheeled (Figure 10), and mounted on a tractor, skidsteer, or similar machine. Planting on a single site with them can be fast (2,000/day) and result in high survival rates (Heitzman and Grell, 2003).



Figure 10. Tree Auger on a Dolly Source: http://www.christmas-tree-equipment.com/

Like all tools, they have potential disadvantages. They require a trained operator and a small (2- to3-person) ground crew. Also, the tool can glaze the sides of a hole when used in moist clay soil. There is a tendency to drill the holes too deep unless a depth control (proper depth will depend on the stock) is present, but the ground crew will need to pay close attention in any case. Further, buried utilities have to be identified and avoided.

Installation errors cannot be eliminated, but they can be reduced. QA/QC procedures, like the ones indicated in Table 6, will need to be put in place, and oversight (especially of volunteers and contractors) will be required. Species, site, stock size, and form will have a strong influence on the type of QA/QC procedures necessary. For example, checking on girdling roots will be important for containerized stock but less so for bare-root plants, while planting depth will be an important issue on clay soils but less on sandy soils.

Even limited postinstallation care on the whole SIP population may not be feasible. Even limited post-installation care on the whole SIP population may not be feasible when planting is carried out on a top-down basis. Despite adequate monies, there probably will not be sufficient time and labor available to provide care to hundreds of thousands of trees even once, much less repeatedly. One of the best reasons for involving volunteers, in fact, might be that such a large and distributed labor group might significantly raise the possibility of the trees receiving post-installation care.

2.5 Challenges: Site Selection

Background

A very large tree-planting program will logically need to locate a very large number of suitable sites in a timely, accurate, and cost-effective manner. Site availability strongly affects the degree to which tree planting can be incorporated into a SIP because planting space for trees must be both available and accessible. At some point in the planning phase, both the potential for and the quality of sites need to be assessed.

Discussion

The lengthy and complicated effort of locating and evaluating planting sites for a very large number of trees can be divided into top-down and bottom-up approaches. The top-down approach can be broken down into discrete steps:

- 1. <u>Estimate</u> available planting space in the target area so that the modeling of air quality benefits will be based on the actual situation
- 2. <u>Locate</u> that space in order to categorize it and organize its recruitment for SIP planting
- 3. <u>Prioritize</u> the available space in terms of labor and cost in order to maximize return
- 4. <u>Determine ownership</u> of high-return spaces so that permission can be obtained as necessary
- 5. <u>Adopt special techniques</u> when selecting poor-quality sites in order to attain reasonable survival rates

Although executing these steps will entail a significant amount of time and effort, their positive effect on the SIP objective—installation, survival, and growth of a large number of new trees—makes the process highly valuable for planners.

Estimating Available Planting Space

There are a number of valid ways to estimate available planting space. Plantable space can be defined as a land area that is currently grassy, agricultural, or barren, and that has adequate space below and above ground for healthy tree development. The trick is to identify planting spaces easily and accurately in order to produce a reliable number for modeling and policymaking, and yet avoid a costly and time-consuming process.

Remote estimation can be carried out using one of two GIS-based methods that have been worked out at the USDA Forest Service's Research Station in Syracuse, NY. These techniques can be described succinctly in the following steps (Walton and Nowak, 2005):

Photo Interpretation

- 1. Use Digital Orthophoto Quadrangles (USGS 2002) or other digital aerial photography
- 2. Download the "Random Point" and "Photo Interpretation" programs from the Research Station website: http://www.fs.fed.us/ne/syracuse/Tools/tools.htm.
- 3. Install these programs into ESRI's ArcView[®] 3.2 as extensions. [Note: this software has been discontinued by the vendor.]
- 4. Define the target domain (area considered for planting) inside the GIS
- 5. Drop random points (Figure 11) inside the domain using the Random Point extension tool
- 6. Identify whether the area under the point is potentially plantable using the Photo Interpretation extension tool
- 7. Follow standard protocols for scaling up the results to yield a total estimate of plantable space

Land Cover Data Use

- Obtain National Land Cover Dataset (known as "NLCD 2001") files for the target area of planting from the EPA website (http://www.epa.gov/ mrlc/nlcd.html)
- 2. Use the "tree" and "impervious" layers of the dataset to identify potential plantable space
- 3. Note that each pixel carries a value from 1 to 100 for each layer
- 4. Sum the "tree" and "impervious cover" values for each non-water pixel
- 5. Subtract that total from 100% to yield an estimate of plantable space
- 6. The resulting "plantable space" layer can be used to pinpoint areas to investigate

Details on these procedures can be obtained by contacting the USDA FS Research Unit in Syracuse, NY.

Other estimation procedures exist, either manually working with photographs or using paper maps of different scales (Swiecki and Bernhardt, 2001). For both random selection procedures, ground verification maybe necessary to verify estimates of potential planting space. Clearly, ground survey as a means to quantify potential planting space is impractical for anything but small domains or areas or when dealing with exceptionally large and open planting areas.



Figure 11. Image showing Use of Random Point Tool

Locating Available Planting Space

Prioritizing sites and their acquisition in some logical manner will provide a cost-effective approach to this difficult task, and will make the best use of centralized resources. Making remote estimates is one thing; actually locating planting sites on the ground is another. A good start can be made by categorizing planting locations by the number of actual tree sites that can be obtained from a single contact with the responsible person. As a convenience, this study refers to all locations where the contact can offer less than ten tree sites as "small planting locations," and those offering more than ten will be "large planting locations." The division is arbitrary, but useful.

Large planting locations are cost-effective to pursue from a central office, because the cost of contacting the responsible person is spread over the number of trees planted, and because the cost of planting per tree goes down when multiple trees are installed at the same location. Large planting sites include:

- Transportation corridors
- Vacant open space
- Parks of all sizes and jurisdictions
- Golf courses and other private or public "non-park" recreational lands
- Commercial landscapes, such as those around large stores, corporate buildings, etc.
- Institutional campuses, such as colleges and universities, hospitals, etc.
- Large private residential land inside an urban area

Such locations can be found through NLCD cover maps. They can also be readily identified on local land-use or tax parcel maps for use in a GIS.. Large planting locations such as these can supply a large number of planting sites with a relatively low rate of time per tree.

Smaller planting spaces can be cost-intensive to identify, because the cost per tree for contact, planting, and follow-up monitoring or replanting is typically very high. For public property, such as street right-of-ways, the work required will depend on the tools available. Communities with high-quality and up-to-date street tree inventory data and software can run reports on available space-*-if* the inventory actually records planting sites (whether occupied or not) and not just trees. Online street planting site information, such as that for New York (OASIS: NYC Open Accessible Space Information System) and Washington, D.C. (Casey Trees Endowment Fund), could be utilized as well where it exists.

The solicitation of smaller planting sites on private land will be labor-intensive, and attempting to find a large number for a SIP planting program would probably exceed the resources of most governmental offices. Many non-forprofit organizations have extensive

The solicitation of smaller planting sites on private land will be labor-intensive.

experience in that area, however, and are familiar with the needs and techniques of the process. Examples of such organizations include TreePeople (Los Angeles), Trees Atlanta, TreesNY, and TreeTrust (Minneapolis-St. Paul). Working with organizations like these in the search of small private planting sites would be highly beneficial.

It might prove cost-effective to prioritize planting sites for a large-scale SIP planting project according to the following criteria:

- 1. <u>Large planting sites with high ratios (10:1 or greater) of tree spaces per site</u> such sites require the least amount of effort per tree
- 2. <u>Ownership</u>—overall, public spaces will be easier to access, plant, and manage
- 3. <u>Site quality</u>—on sites with decent soil and drainage, the same cost and effort put into planting will tend to produce higher survival rates and greater canopy gain
- 4. <u>Community support</u>—locations and sites with community support should be preferentially planted because the initial survivorship rate will be higher and the long-term costs lower (Sklar and Ames, 1985)

Prioritizing sites and their acquisition in such a way will provide the best costeffective approach, and make the best use of centralized resources.

Feasibility

Because so many planting sites would be needed for a very large SIP planting project, it might be most effective to institute a two-pronged strategy: top-down and bottomup. Each has its strengths and weaknesses, and the combination would offer a great deal of flexibility to the search for planting sites. The top-down approach would be run from centralized urban forestry offices at the state and local levels using remote sensing, aerial photography or local maps to identify potential planting sites. Possible steps include:

- Create a GIS-based data management system for categorizing and managing planting sites
- Locate large planting spaces
- Separate public spaces from private
- Set up suitable quality assurance and quality control procedures
- Solicit public spaces through standard channels
- Establish a target size to be sought and a minimum of planting sites
- Solicit private spaces through a targeted outreach program
- Consider incentives for private participation

Bottom-up approaches work by reversing the process. In response to a publicity campaign, individuals and organizations notify some centralized office that they are willing to have trees planted on their sites. One effective form of this approach would rely on proven techniques used by the larger tree-planting volunteer organizations (adapted from Lynch and McCurley, 1999).

- Identify regional organizations with demonstrated expertise in volunteer tree planting
- Establish suggested target number of planting sites to be sought by each organization, depending on its size, experience, and resources
- Approach the organizations for discussions about participation and target number, offering in return financial support and other resources as available
- Work with the organizations on appropriate means of publicity
- Set up suitable quality assurance and quality control procedures
- Monitor progress and procedures
- Individual organizations will have their own methods for proceeding with such work, so flexibility in means chosen to attain the target will be necessary.



Figure 12. Brownfields in a Downtown Area With Planting Potential Source: http://www.irvington.net/Redevelopment/Brownfield%20Development%20Area.gif

A special word should be added about the feasibility of using poor-quality sites, since they are usually available for planting (Figure 12). Almost any site can support growth for some species of tree, and special techniques have been worked out for common types such as brownfields (*e.g.*, Giblin and Gillman, 2004), clay tailings (*e.g.*, Mislevy, et al., 1989), surface-mined lands (Skousen, [n.d.]) and wetlands (*e.g.*, Garber and Morehead, 1999). When predictably poor-quality sites are being selected for SIP planting, special care must be taken to consider appropriate research on successful projects. On average, poor-quality sites will have higher mortality rates, and they will be more expensive because of the labor-intensive techniques and added material costs that will be required for acceptable tree survival and growth.

Inner-city sites are often the most challenging for tree survival, and special steps must be taken if success is to be achieved (Rodbell, 2005). Sites composed primarily of urban rubble with a shallow layer of dirt are unlikely to support long-term tree growth unless techniques similar to those developed for restoration and reclamation can be

Inner-city sites are often the most challenging for tree survival, and special steps must be taken if success is to be achieved.

used. And in some urban neighborhoods, the challenges to tree planting are as much social as biological or environmental, and unusual techniques are required if the planting projects are to succeed (Austin, 2002). Reasons to plant in such areas include not only the wish for environmental justice, but also the hope to maximize environmental benefits by planting trees into the hottest areas.

Finally, it should be recognized that the work of estimating and locating planting sites will probably require substantial time and effort. It will need to be started early in the project, since it will influence many other areas—species selection, stock size, labor force, etc. The work will likely need to be situated within urban forest management, since many decisions will depend on an understanding of the interactions among trees, sites, and community.

2.6 Challenges: Costs

Background

Estimating the costs of large-scale SIP tree planting is difficult. One issue is that urban forest managers have not had experience with such large plantings. Generally, large-scale urban tree planting peaks at about ten thousand trees, with the vast majority of communities putting many fewer than that into the ground on an annual basis. Few large programs have reported data, and what exists often ignores the substantial indirect costs involved.

Another complication in making such estimates is that cost factors vary greatly from community to community. Examples include stock size and planting agent and

method. Items such as labor, equipment, transportation, and overhead may vary by dollar amount or by whether they are even considered cost items at all. The result of such uncertainty is that any discussion of the costs for a large-scale SIP planting must be limited to general ranges that can, nonetheless, provide guidance to planners.

Discussion

Useful information can be gained from the limited cost data for past large urban treeplanting projects, even though the actual number of trees planted is much lower than that projected as necessary by most modelers to affect air quality. The Sacramento Tree Foudation (STF) provides a good and possibly unique example of a large-scale urban planting program that could help to estimate the potential costs of SIP treeplanting proposals. The STF has been working in cooperation with the Sacramento Municipal Utility District (SMUD) since 1990 to provide trees free of charge to SMUD customers as a means of reducing the demand for residential air conditioning (SMUD, 1995). Table 8 shows the all-inclusive1990-2004 program costs (covered by SMUD) for that project, which include stock, planting accessories, site visit, and post-planting inspection (Tretheway, 2005).

Year	Trees Planted	Total Costs*	Total Cost/Tree
1990	3,000	\$289,000	\$99
1991	24,443	\$1,378,000	\$56
1992	32,629	\$1,620,000	\$50
1993	41,815	\$1,904,000	\$46
1994	50,829	\$2,047,000	\$40
1995	38,786	\$2,034,000	\$52
1996	22,730	\$1,831,000	\$81
1997	17,294	\$1,594,000	\$92
1998	17,908	\$1,495,000	\$83
1999	23,783	\$1,500,000	\$63
2000	19,990	\$1,506,000	\$75
2001	19,885	\$1,560,000	\$76
2002	19,175	\$1,600,000	\$83
2003	16,679	\$1,482,000	\$84
2004	17,242	\$1,500,000	\$82
Totals	366,188	\$23,340,000	
Average	21,540		\$66.38
Median			\$76

Table 8. 1990-2004 Tree Planting Costs for the Sacramento Tree Foundation

*Inconstant dollars

The stock being planted for this project consists of containerized 0.75-1" liners, at a cost of about \$15 a piece (Tretheway, 2005). When this stock cost is compared to the average cost/tree above, it gives a ratio of about 3:1. This means that it has cost the program an average of about \$3 per tree in programmatic costs for every \$1 spent on the stock itself. Detailed program information can be found on the following websites:

- Sacramento Tree Foundation (http://www.sactree.com)
- SMUD (http://www.smud.org/residential/saving/trees/index.html)

A very different example is provided by the city of Kelowna in Manitoba, Canada, which in 2004 planted 135,000 conifer seedlings in a single day, using volunteer residents (Wilson, 2005a). This case of an urban seedling planting is helpful, since most tree seedling planting occurs in a rural forestry or agricultural (e.g., apple or pecan orchards) context. The limited data available from this project produce these approximate costs (Wilson, 2005b):

Item	Approximate Cost (\$US)	Comments
Stock	\$25,000	135,000 1-yr-old contract-grown conifer seedlings
Equipment	\$17,000	Hand trowels for volunteers
Transportation	\$17,000	Manager estimate
Administration	\$8,500	Manager estimate

Table 9. Approximate Costs of a Large Tree-PlantingProject in Kelowna, Manitoba

In this case, the ratio of program to stock costs is about 2:1. Since no costs were included for planning, site selection, or verification, the actual ratio for the use of seedlings in a large-scale SIP planting would probably be somewhat higher. This accords well with the author's informal survey of representative 2005 professional rates for rural seedling planting, which typically range from 2:1 to 4:1.

Many indirect costs associated with a largescale planting are routinely passed over in silence. In traditional urban forestry, the anecdotal costs of planting larger stock vary enormously from community to community. In some communities, planting bareroot stock with volunteers produces a stock to program cost ratio below 1:1, though administrative and

logistical costs are typically ignored. Communities using contractors with a one-year guarantee, on the other hand, cite costs closer to 3:1. Many indirect costs associated with a large-scale planting are again often not included.

That this discussion has so far ignored the effects of scale. In part that silence is due to the fact that the planting numbers used by modelers are one to two orders of magnitude greater than those of documented urban programs. Actual cost figures for comparative urban projects simply do not exist. A second reason for this omission is that the scale will presumably affect costs in ways that are hard to predict. Stock costs will clearly tend to drop as the number rises, for instance, as long as supply is

not limited. Likewise, costs of general planning and administration may sink on a per-tree basis. But those savings may well be somewhat offset by the flat or rising costs in other areas, such as by increased effort to find sites (Sarkovich, 2006), more complicated planting management, more complex logistics for dispersed planting sites, etc. For these reasons, the effects of scale are generally ignored in this discussion of costs.

However, the robust STF data provide some basis for taking scale into account during planning. Analysis of the number of trees planted with total program cost per tree (with first-year data removed to eliminate start-up effects) demonstrates a strong negative correlation, as shown in Figure 13.



Figure 13. Correlation Between Number of Trees Planted and the Total Cost per Tree by the Sacramento Tree Foundation, 1991-2004

This trend indicates that as more trees were planted per year, the total cost per tree decreased. It is hard to extrapolate from these results, since they reflect specific choices about stock and program in a specific region. But the general conclusion that total program costs per tree drop significantly *across this number range* (roughly 10,000-60,000 trees) may well apply to other choices of stock and program. What happens as the number of trees planted continues to increase, however, is unknown. The regression in Figure 13 suggests that the costs may flatten out, but non-stock costs might increase again as the number of trees planted per year continues to rise, driving the costs ratio back up.

Feasibility

The observations made in the discussion above based on actual planting costs provide a *relative* framework for estimating the costs for a large-scale SIP planting. Reasonable ranges can be established for the different small stock types discussed earlier using sample stock costs based loosely on representative 2005 prices (Schneider, 2005).

Stock Type	Non-stock Cost Factor	Approximate 2005 Range of Stock Cost/Tree	Range of Non- stock Cost/Tree	Range of Total Cost per Planted Tree
Seedling	2-4 times stock cost	\$0.15 - \$0.40	\$0.30 - \$1.60	\$0.45 - \$2
1-yr plant	2-4 times stock cost	\$2 - \$10	\$4 - \$40	\$6 - \$50
2-yr liner/whip	2-4 times stock cost	\$8 - \$35	\$16 - \$140	\$24 - \$175
1-1.5" BR	1-3 times stock cost	\$12 - \$35	\$12 - \$105	\$24 - \$140
1" container	1-3 times stock cost	\$25 - \$50	\$25 - \$100	\$50 - \$150

Table 10. Approximate 2005 Cost Range of Different Stock Sizes

This range ignores the effect on overall project costs created by varying mortality rates of the different stock types. Also, larger stock types have been omitted because it seems likely that they will constitute a tiny fraction of the SIP population.

If a given project were to choose to plant only one stock type, and if the costs are assumed to rise at a constant rate with planted tree numbers, then total cost ranges *per planted tree* could be estimated as follows for smaller sized stock:

	Table 11. Approximate	2005 Cost Range f	for Large Numbers	of Planted Trees
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Stock Type	Total Cost Range	Total Cost Range	Total Cost Range
	per 10,000 Trees	per 100,000	per 1,000,000
	Planted	Trees Planted	Trees Planted
Seedling	\$4,500 - \$20,000	\$45,000 - \$200,000	\$450,000 - \$2,000,000
1-yr plant	\$60,000 -	\$600,000 -	\$6,000,000 -
	\$500,000	\$2,000,000	\$20,000,000
2-yr liner/whip	\$240,000 -	\$2,400,000 -	\$24,000,000 -
	\$1,400,000	\$14,000,000	\$140,000,000
1-1.5" BR	\$240,000 -	\$2,400,000 -	\$24,000,000 -
	\$1,050,000	\$10,500,000	\$105,000,000
1"	\$500,000 -	\$5,000,000 -	\$50,000,000 -
container/B&B	\$1,500,000	\$15,000,000	\$150,000,000

Once again, it needs to be stressed that cost ranges for planted trees must not be equated with total stock costs for a particular SIP tree-planting project. Because stock type mortality rates vary widely, the actual number of trees required to attain a given population size also varies. Higher mortality rates require a higher number of trees to be planted initially. No actual project will plant a single stock type. Available sites vary enormously, and it would make little sense to use one type across an entire area. To estimate actual project costs, planners can make use of a Cost Estimator that has been developed and posted on the project website at:

http://www.treescleanair.org/policymakers/factsheets/CostEstimator.xls

By way of practical illustration, let us assume that a group of planners has reached the following decisions:

- Total number of trees desired: 1,000,000
- Length of program: 1 year
- Equal numbers of surviving stock types in 3 years (200,000 each)
- 3-yr mortality rates: seedlings, 90%; 1-yr plants, 30%; 2-yr plants, 20%; 1-1.5" BR, 15%; and 1" container plants, 10%.

Using the ranges suggested above, the estimated total cost range for the project would look like this:

Stock type	Total Number (incl. mortality)	Total Program Cost Range
Seedling	2,000,000	\$0.9M - \$4M
1-yr plant	286,000	\$1.7M – \$5.7M
2-yr liner/whip	250,000	\$6M – \$35M
1-1.5" BR	235,000	\$5.6M - \$25M
1" container	222,000	\$11.1M – \$33.3
Totals	2,993,000	\$25.3M – \$103M

 Table 12. Total 2005 Program Cost Range For Example Program

A mid-range estimate of total program cost required to have 1 million trees surviving after 3 years, given the particular decisions about distribution of stock sizes and mortality rates, would be in the neighborhood of \$64,000,000.

To see what this might mean within the framework of this feasibility report, we can apply these numbers to the results of the modeled impact of increased tree canopy on the ozone levels from an historical non-compliant episode in the New York City area (Civerolo, et al, 2001), where the overall domain effect of planting 10 million trees was a drop of 4 ppb (about 3% of the peak level).

Acknowledging all the uncertainties involved in the numbers, this cost estimate suggests that the average total cost after 10 years of planting (under the selection of stock sizes and with assumptions of mortality rates outlined above) would be something like \$150,000,000 for each 1 ppb of ozone reduction. The feasibility of

such a large financial commitment can finally only be judged within a particular jurisdiction.

2.7 Challenges: Personnel

Background

As with so many of the factors investigated so far, that of planting personnel has bearing on many other aspects of a very-large SIP project. In fact, the choice of personnel will affect costs, planting methods, mortality rates, and management.

The involvement of volunteers, in particular, constitutes a significant aspect of most large planting programs. Volunteers will likely play an important role in many States, as bottom-up planting methods look attractive for the many small planting sites that will probably be necessary for large-scale planting. Yet their participation within a SIP context requires careful planning and execution, since so much is at stake.

Significant volunteer tree planting already occurs in both urban and rural contexts, and volunteers have proven instrumental in urban and community programs across the country. Since SIP tree planting will be measured for success against survival and growth, suitable quality assurance and quality control procedures must be implemented that are uncommon in many existing programs.

This section will focus on volunteers, but the use of contractors also raises serious issues. It will be important to exercise many of the same QA/QC procedures for contractors as for volunteers.



Figure 14. A Volunteer Checks the Rootball for Girdling Roots Before Planting Source: Tree Trust (Minneapolis MN)

Discussion

There are advantages and challenges to involving volunteers in any project (Hager and Brudney, 2004). The most significant advantage for SIP planting is the sheer size of the potential labor force, something very attractive for a project with a unique combination of large numbers of trees to plant and an extensive area in which to plant them. The most important challenge will probably lie in the area of work quality, since volunteers typically lack the training and experience of professionals. Table 13 provides an overview of the potential advantages and challenges of using volunteers in a SIP tree-planting project. The two factors are grouped by the "reference" of their effect, because an advantage from one perspective could easily be a challenge from another.

Reference	Advantages	Challenges
Community	 Volunteer labor is usually widely available and somewhat less costly Volunteers bring skills and resources otherwise unavailable to the project Volunteers can use their own networks to locate resources Planting trees promotes community advocacy 	 An adequate budget must be provided for volunteer coordinator and staff The project must be made fun and meaningful for volunteers to participate Volunteers must be carefully selected, trained, monitored, and recognized Recruiting and managing volunteers requires special skills, and is time-consuming
Volunteer	 Participating in urban tree planting gives a sense of community identity Involvement promotes the feeling of urban forest ownership 	 Correct techniques are critical to the project's success Volunteers need to meet commitments despite problems that may arise
Urban tree resource	 Volunteers learn about trees and tree care, and become advocates for urban forestry Volunteers can provide post-planting care to the trees they plant that otherwise may not be feasible Tree survival is higher when the local community is involved 	 Volunteer planters have uneven levels of knowledge, motivation and ability Volunteers can only do hand planting, limiting stock size and planting speed

Table 13. Advantages and Challenges ofVolunteers in SIP Tree-Planting Projects

Feasibility

The work of finding and managing volunteers is demanding. It will probably be easiest to collaborate with existing well-run volunteer organizations that have experience with planting projects. Inviting such organizations to participate in a SIP tree-planting project will necessitate both serious funding and extensive support, since the size and scope of the project far exceeds any experience the organization will have faced.

Once careful consideration has led to the decision to involve volunteers, there remain the tasks of finding volunteers and/or volunteer organizations, and evaluating them. Table 14 indicates some possible sources.

Level	Examples	
International	SERVEnetT, ActionWithoutBorders, VolunteerMatch	
National	The Alliance for Community Trees, National Arbor Day Foundation Plant-It 2020	
State	Urban Forestry Coordinators	
Community	Sacramento Tree Foundation, TreePeople, Trees Forever, TreeFolks, TreemendousMiami, Trees Atlanta, TreesNY, Openlands Project, TreeTrust, The Park People	
Local—Institutions	Chesapeake Bay Foundation, Allegheny Park, Dade County Schools	
Local—Organizations	Master Gardeners, Garden Clubs, Wilderness Volunteers, Volunteers in the U.S. National Forests, Volunteers in Parks, The Youth Conservation Corps (YCC), California Conservation Corps	

Table 14. Examples of Volunteer Sources for a SIP Tree-Planting Program

When contacting appropriate volunteer agencies, it will be vital to communicate the project's mission and stress its significance (Lynch and McCurley, 1999). It will also be profitable to explain the expectations of this tree-survival program (Bloniarz and Ryan, 1996). Once the project's target planting number and quality requirements have been described, then the organization will need to be offered salary, training, and IT support before any expectation of collaboration can be realized.

Quality assurance and quality control procedures are critical for a SIP treeplanting project. Quality assurance and quality control procedures are critical for a SIP tree-planting project. These procedures will need to be applied to volunteers and their organizations, as they will be to contractors or anyone planting under project auspices. Because SIP tree planting is a large project with statewide significance, only experienced and successful volunteer organizations should be solicited to join the project. Volunteer organizations can be evaluated within five categories that have been identified as critical (Lynch and McCurley, 1999):

- Planning and organization
- Recruitment and selection
- Orientation and training
- Supervision and education
- Recognition and motivation

An organization lacking demonstrable recognition of and achievement in these categories will not likely be a successful partner in a SIP tree-planting project. Categories such as training and supervision are so critical to the enterprise that planners would be well advised to examine them particularly closely, offering aid where appropriate.

Finally, quality assurance and quality control of planting personnel will require a substantial input of time and funding. Training will have to be arranged for all volunteer personnel who have not already had it, and random inspections of work by all personnel should be carried out from the very beginning so that mistakes can be corrected constructively or, where repeated problems emerge, the responsible persons can be removed from the project if necessary.

2.8 Challenges: Verification

Background

The scientific basis for including tree planting in a SIP stems from models of air-quality benefits expected from urban tree canopies. For these model projections, a future forest condition is assumed (e.g., increase in tree cover by 10%), and then the impact of the forest change is modeled to determine its impact on air quality. To verify the modeling projections, planners are required to use the best available science (EPA, 2004). This requirement implies both using the best models available, and verifying that the canopy changes modeled are actually attained. For SIP tree-planting programs, three properties form probable targets of verification because they significantly influence model projections:

- Installation—number, location, and species of trees actually planted
- Survival—number of installed trees that survive through time
- Growth—surviving tree growth rates

For large populations, measuring all three properties in a rigorous and statistically valid manner would constitute a significant amount of time, effort, and expense, and is thus unlikely with the SIP context. If tree planting is being included as an emerging or a voluntary measure, however, the EPA explicitly requires some sort of verification:

In the SIP submittal, the State needs to develop and include specific program evaluation procedures for the measure. The State should carefully consider what approach could provide the most effective means to accurately evaluate the measure. (EPA, 2004)

Clearly, tree planting is different from traditional SIP measures. Since maximum canopy impacts will take decades to achieve, increasing through time as the trees grow, no short-term measurements will verify the benefits being claimed from the tree resource. The EPA has attempted to acknowledge that difficulty by specifying that the benefits "should reflect the schedule on which the measures are being put in place and [tree] growth rates over time" (EPA, 2004).

Finally, the measurement of the tree properties might require revision of the modeled benefits, if tree planting leads to results that differ from the parameters used for modeling.

The primary purpose of program evaluation is to quantify the amount of actual reductions realized through the program, and to serve as a basis for adjustments to the amount of emission reductions available if the original estimates of emission reductions are not being achieved. (EPA, 2004)

In other words, survival and growth will have to meet planning expectations, or the State will probably be required to enact adjustments to offset any increased mortality or decreased growth. Therefore, reliable and well-founded procedures to verify the status of the SIP tree population will be an unavoidable component of any SIP that includes tree planting.

Discussion

Different jurisdictions will probably make different choices on the type and degree of verification proposed for any tree-planting measures adopted in a SIP. Although verification and evaluation have been

Different jurisdictions will probably make different choices on the type and degree of verification.

prescribed by EPA guidance on the inclusion of tree planting within a SIP, the level of precision with respect to final canopy size and composition has not. Three precision levels, based upon the measurement and evaluation of different parameters, are described in Table 15.

Table 15. Verification targets with increasing levels of precision.

Precision	Target of verification	Metrics
Low	Installation	Number and species of trees planted
Medium	Survival	Rate after establishment period
High	Growth	Species-specific rates

<u>Installation.</u> It is common for large-scale planting programs (*e.g.*, Maathai, 2003) to verify that trees were actually planted, and planted correctly. This verification is done for various reasons, including quality control, contractor oversight, and cost containment. Within a SIP, such verification becomes paramount. If a state submits a claim for pollution mitigation from new canopy, that measure must be evaluated. Unless the right tree number and species (e.g., limited VOC emitters) are actually being planted, subsequent benefit calculations may be threatened. Procedures to verify the number and species of trees planted will probably have to be included in the SIP.

<u>Survival.</u> Well-established programs that have been planting urban trees on a large scale report survivorship routinely as a means of measuring the return on planting and cost effectiveness (*e.g.*, SMUD, 2004). Research on young urban tree mortality—overview in Appendix—has demonstrated that a

The <u>variability</u> of the mortality rate, not its level, suggests the need for verification.

substantial number of trees planted will not survive. The survival rate can be estimated for modeling purposes, but it cannot be known exactly without field verification of survivorship, because too many unpredictable factors influence mortality rates. The <u>variability</u> of the mortality rate, not its level, suggests the need for verification.



Figure 15. Crown Volume Modeled for 9 Common Municipal Tree Species in Longview, WA. These Data Have Been Used to Calculate Annual Air Benefits in the Pacific Northwest (simplified from McPherson et al. 2002)

<u>Growth.</u> Surviving new trees must grow at or above the predicted rate to realize the modeled air quality benefits. All models extrapolate from field data (as in Figure 15) to produce generalized growth curves/equations for various species. These curves,

and the species they represent, derive from tree growth and species mix for specific regions. Different climate, species mix and geography of other regions using these curves, however, will alter the actual air quality benefits achieved (as in Figure 16).



Figure 16. Example of Tree Growth Reduced by Urban Conditions.

Decrease in Average Canopy Size of American Sycamores in Northern Florida as Surrounding Rooting Volume Decreases (Grabosky 2005)

To verify that the actual growth rates in a given jurisdiction match those used in the modeling, it would be necessary to monitor the growth of the SIP tree population over time. It should be noted that the results of this high-precision verification could actually be helpful to the attainment of air quality standards if local growth rates exceed those used in the original modeling.

Finally, it could be argued that a significant deviation from good canopy condition across the population would reduce the actual air quality benefits obtained. Established protocols exist to evaluate tree condition, such as the crown evaluation parameters devised for rural forestry (FIA, 2003) or the numeric scale used for landscape trees (CTLA, 2002). Yet growth measurements can serve as a proxy for crown condition because significant sub-par condition across the population would show up as reduced growth rates for most species (Kozlowski and Pallardy, 1997), and those reduced rates would propagate through the urban forest benefit models used by air quality modelers, lowering the projected benefit levels.

Feasibility

Both the process and the outcome of verification will be improved if data appropriate to the level of precision have been collected. A reasonable database would probably contain the following data:

- Unique identifiers for distinct tree groups (common area, date, or planting agents)
- Species data (common and botanical names, percentages)
- Location data
- Stock data (form, size,)
- Planting data (date planted, soil type, land use)

The design and maintenance of a database for tracking the large SIP tree population is no minor task. (Note that a national database, where all states' data would have the same structure and type, might eliminate this task as well as facilitate comparative analyses). The associated time and cost will need to be taken into account during the planning phase, along with that required to execute verification procedures.

Where large tree populations are involved, a sampling scheme is typically employed (Husch et al, 2003). Its design will depend on the State's tolerance for error, the tree resource's distribution, and the EPA's requirements. In many cases, simple random sampling may suffice, though sampling by "strata" or subgroups may be preferable in some situations. For example, if a large proportion of the planting sites can be suspected of limited growth potential—measured in rural forestry as a low "site index"—then verification might be stratified according to planting site type. Stratified sampling improves precision, or lowers sampling size, in comparison to simple random sampling when the strata have different means or variances from that of the general population (Thompson, 2002). Table 16 provides some general guidance to designing a sampling protocol and interpreting its results.

Item	Low Precision		Medium Precision	High Precision
Critical datum	Planted	High VOC	Alive	Annual trunk or crown increase
Critical datum type	Y/N	Y/N	Y/N	Continuous
Critical datum variance	Low	Low	Low to Medium	Medium to High
Targets for testing	Critical datum by planting group	Critical datum by tree group	Critical datum by species, site type, and stock form	Critical datum mean and standard deviation by species
Null hypothesis	All groups equal	Rate below target	No differences among species, soil types, or stock forms	Growth same as species norms used in modeling
Sampling design	Simple Random	Simple Random	Stratified Random	Stratified Random

Table 16. Guidance for Sampling Protocols in Verification Procedures

In addition to wanting sound verification procedures to be included with a treeplanting measure in the SIP, EPA requires that planners set up a verification schedule (EPA, 2004). The State is enjoined to "enforceably commit to complete an initial evaluation of the effectiveness of each measure no later than 18 months after putting the measure in place. Where possible, this evaluation should be done sooner" (EPA, 2004). This schedule is only practical for tree installation, as the time horizon for verifying survival and growth goes well beyond this limitation. However, the EPA also addresses the additional time required for the measure to take effect: Some emerging measures may also take a substantial period of time to fully implement. Tree planting and protection programs, for instance, may take decades to fully realize potentially beneficial impacts. Estimates of pollutant reductions should reflect the schedule on which the measures are being put in place and growth rates over time as well as loss of trees due to disease or removal. (EPA, 2004)

In this case, the 18-month deadline could be used to verify tree installation. The further EPA recommendation that the measure be reviewed at least every three years might be adapted by using the first interval to determine initial survival rate, and the subsequent intervals to monitor growth rates and survival. Table 16 provides a possible verification schedule.

Time From Planting	Target of Verification			
	Installation/Species	Survival	Growth	
3-6 months	Х			
12-18 months		Х		
Every 3 years		Х	Х	

Table 17. Possible Timing of Verification for the Three Critical Measurements

Some discussion with the EPA will likely be necessary to allow adjustment of the verification requirement to the extended benefit schedule of this particular measure.

<u>Disclaimer.</u> The guidance given here represents one set of possible verification procedures for large-scale tree planting as a SIP measure. It is based on general factors that may not take into account the needs of a particular jurisdiction.

3.0 Conclusions, Recommendations, and Resources

Each of the discussions of particular challenges to the inclusion of large-scale tree planting within a SIP has generated its own set of conclusions, recommendations, and resources. This final section looks at the broad implications of these discussions for the feasibility ("the determination whether a plan is technologically possible and practical within a given situation") of the proposal as a whole.

3.1 Conclusions

- It is important to recognize that large-scale SIP planting is not a case of "same old, same old." Current well-established practices of urban tree planting will have limited application.
- Planting very large numbers of trees—ten to one hundred times typical large urban forest rates—to achieve SIP credits presents formidable practical challenges that need to be recognized and addressed.
- Because of the change in scale and the concomitant challenges, the planning component will be large. Given that a minimum of two years will be required to propagate sufficient quantities of suitable stock with a range of species, the ramp-up time will be at least three years.
- The complexity of a large-scale SIP planting suggests that technical competence, procedural training, and QA/QC protocols will be critical to planting success. As with any SIP control measure, failure to produce estimated results may place a jurisdiction out of compliance.
- The uncertainty of adopting large-scale urban tree planting in a SIP as a means of ozone reduction is higher than that of more traditional measures. First, biological organisms are susceptible to disastrous failures that could nullify the measure. Also, the models calculating their benefits are still evolving—as seen in the case of the indeterminate suitability for SIP planting of a limited percentage of oak species (*Quercus* spp.).
- The feasibility of including large-scale tree planting within a SIP can finally only be determined by local jurisdictions. The lack of comparative data for cohorts larger than 100,000 trees per year within an urban context, the host of pragmatic issues to settle at the local level, and the substantial commitment of resources required—these factors present challenges that must be evaluated within specific contexts.

3.2 Recommendations

• Work to establish understanding and cooperation among stakeholder agencies, departments and groups, both inside and outside government. This effort needs to occur at the national, regional and state levels, and should bring together Air

Quality, Forestry and EPA personnel. Early involvement of local planting organizations will also be critical.

- Ramp up to the final desired planting level over a reasonable time period. Select a relatively small number (e.g., 10,000 trees) for the first year while program details and logistics are being worked out, and then expand an order of magnitude (e.g., 100,000 trees) the second year before attempting larger numbers.
- Establish QA/QC procedures for contractors and collaborators that are suitable to and feasible for a large-scale project, and monitor compliance.
- Supply participants of each pilot stage with an easy-to-use feedback mechanism, and finish each ramp-up stage with a detailed evaluation that forms the basis of the progression to the next stage.

3.3 Resources

Two resource collections have been made available through this Project to aid persons wishing to pursue the question of including large-scale tree planting in a SIP.

The first is formed by the 100 or so items listed under "References" in this study. Those printed and electronic materials have been carefully selected and can be consulted with profit. Furthermore, the references that they themselves cite provide a further resource.

The second resource collection consists of the texts, applications, and links assembled on the Project website: http://www.treescleanair.org. These electronic resources can be explored by anyone who knows how to use a web browser, and through the connections to other websites the user enjoys a nearly endless set of materials through which these important questions may be further researched.

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Overview of Young Urban Tree Mortality Studies

Study	Туре	Annual Mortality Rate	Study Period	Location	Comments
Sklar and Ames 1985	Street	7%	6 yrs	Oakland CA	Inner city trees with community participation
	Street	20%			Inner city trees without community participation
Gilbertson and Bradshaw 1990	Street	8%	3 yrs	Liverpool, England	401 trees across 6 sites, rate varied greatly by site
Nowak et al 1990	Street	19%	2 yrs	Oakland CA	Rate varies by adjacent housing type
Miller and Miller 1991	Street	6%	4 yrs	Wisconsin	3 communities with well- established programs
lp 1996	Mix	7%	3 yrs	Northwest Canada	8.5 million trees on 347 sites, rates vary by planters' knowledge/supervision
White 2001	Street	3%	4 yrs	Cleveland, OH	1996 planting of 7,969 trees
SMUD 2004	Yard	9%	9 yrs	Sacramento CA	Average of 19 semi- annual inspections 3 months after planting (1 outlier removed)
Nowak et al 2004	Mix	9%	2 yrs	Baltimore MD	Trees < 7.5cm/3in DBH anywhere in city limits
Thompson et al 2004	Mix	6%	4 yrs	lowa	20 large and small communities, sites included street, park and schoolyard