ECONOMIC MODELING FOR LARGE-SCALE URBAN TREE PLANTINGS

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Large-scale urban tree planting is advocated to conserve energy and improve environmental quality, yet little data exist to evaluate its economic and ecologic implications. This paper describes an economic-ecologic model applied to the Trees for Tucson/Global ReLeaf reforestation program. The program proposes planting 500,000 desert-adapted trees before 1996. The computer simulation accounts for planting locations, planting rates, growth rates, and mortality rates when projecting average annual benefits and costs. Projected net benefits are $236.5 million for the 40-year planning horizon. The benefit-cost ratio and internal rate of return for all trees is 2.6 and 7.11, respectively. Trees planted in parks are projected to provide the highest benefit-cost ratio (2.7) and trees along residential streets the lowest (2.2). Tree removal costs are the most important management expense and air conditioning energy savings provide the greatest benefits. Average annual cooling energy benefits per tree are projected to be 227 kWh ($16.34) for evapotranspirational cooling and 61 kWh ($4.39) for direct shade. Ninety-seven percent (464 lb) of the total carbon conserved annually per mature tree is attributed to reduced power plant emissions.

INTRODUCTION

Citizens in communities throughout the United States are beginning to plan and implement large-scale reforestation efforts. The goal of the American Forestry Association's Global ReLeaf program is to plant 100 million trees in U.S. cities. The momentum generated by this campaign is expected to be accelerated by President Bush's America the Beautiful - Community Trees Program. Tree plantings are advocated as a means to conserve energy and improve environmental quality. However, relatively little data exist to evaluate the economic and ecologic implications of different investment strategies. This paper describes an economic-ecologic modeling approach applied to the Trees for Tucson/Global ReLeaf reforestation program, which proposes planting 500,000 desert-adapted trees before 1996. The model may be adapted for other communities and used to evaluate the short- and long-term cost effectiveness of tree planting proposals.

Urban forest valuation techniques emphasize the current capital asset value of the stock of standing biomass without including management costs (Franks and Reeves 1988, Neely 1988). However, to evaluate the economic and ecologic impacts of different planting scenarios over time, one must account for changes in tree management costs as well as benefits over the projected planning horizon. Miller (1988) modeled the costs and benefits of street trees using a computer program, wherein specified management actions directly impact the condition of trees and their value. This study presents a model that incorporates specific urban forest benefits associated with non-street as well as street trees. It assumes that urban trees can substitute for technology in cities by providing equivalent functions, such as air cooling, carbon dioxide reduction, and rainfall and dust interception (Merriam 1981, Coughlin and Strong 1983, Rowntree 1986). The objective of this study is to develop a slightly more complex economic-ecologic model to estimate selected urban forest benefits and costs that can be used to evaluate the value of a proposed investment in tree planting.

PROCEDURES

Tucson, Arizona (156 sq miles) is a rapidly urbanizing city with 404,000 residents. It is located within the hot arid Sonoran Desert and receives an average of 11 inches of rain a year. Vegetation cover has diminished in recent years because of city-wide efforts to conserve water (McPherson and Haip 1989). Although desert landscapes reduce water use, the overall reduction in vegetation reduces community attractiveness and may accentuate urban warming and other environmental problems. To improve environmental quality and conserve natural resources, the community-based Trees for Tucson/Global ReLeaf (TFT/GR) program helps citizens reforest neighborhoods with desert-adapted trees. It is estimated that planting 500,000 trees by 1996 will increase tree numbers from 1.25 million to 1.75 million and tree canopy cover from 20% to 30%.

Tree planting and management costs, growth rates, and benefits from this planting will vary, depending on where trees are planted within Tucson. Benefits-costs are simulated for three tree locations. It is assumed that 25% of the trees will be planted in areas that receive professional care, such as parks, schools and commercial landscapes. The highest survival and growth rates are expected for these trees, hereafter referred to as park trees.

The second location is in residential yards. Because TFT/GR encourages homeowners to plant their own shade trees, 60% of all trees are assumed to be planted in yards. Yard trees are expected to receive less intensive maintenance than park trees.

TFT/GR is also working with neighborhoods to plant trees along residential streets. Hence, 15% of all trees are assumed to be for roadsides. Slowest growth rates and highest mortality are anticipated for these trees because the city currently prohibits irrigation systems along roadsides and requires adjacent residents to maintain street trees.

Modeling Approach

A microcomputer spreadsheet program is used to project average annual benefits and costs for five-year time periods that span a 40-year planning period (1990-2030). Hence, benefits and costs arecalculated for the midpoint of each five-year period and assumed to be uniform throughout each period. All trees are to be planted during the first five years, with no replacements.

The three major components of the model developed for this study are: tree population, tree size, and benefit-cost analysis. Tree population calculates the number of trees at each location during each time period based on planting rates and expected tree mortality. The tree size component calculates total leaf area for each location and time period using data on tree population and projected growth rates. The third component projects benefits and costs on a per unit leaf area and per stem basis. The following sections describe methods used to simulate tree populations and sizes.

Tree Type and Leaf Area. All planted trees are assumed to be similar to the "typical tree" modeled. The "typical tree" is a native velvet mesquite (*Prosopis velutina*), a popular tree because of its rapid growth, drought tolerance, and moderately dense shade. Mature crown size is assumed to be 25 ft tall and wide. A leaf area index (LAI) of 3 is assumed based on preliminary research data from an open-grown mesquite tree in a Tucson park. Leaf area (LA) is calculated using a ground projection (GP) term, where GP is the area under the tree crown dripline:

$$LA = LAI \times GP \qquad (1)$$

A unique aspect of this study is linking benefits and costs to leaf area because many benefits and costs increase as leaf surface area increases. The dollar value of each benefit and cost for a mature mesquite tree is divided by the total leaf area (1,473 sq ft) to derive values per sq ft. Benefits and costs are assumed to be linearly related to leaf area, which may not always be true (e.g., removal costs may increase non-linearly when more expensive equipment is required to remove larger trees).

Growth Rates and Irrigation Water Costs. Growth rates are calculated for trees in each location depending upon differing estimated irrigation rates. Potential evapotranspiration rates (PET) for low water use plants are modified to account for the anticipated effects of deficit irrigation (Sacamano undated). Although desert trees such as mesquite require ample irrigation during their first years, they can perform reasonably well with little supplemental irrigation after establishment. However, growth rates will slow as drought stress increases.

Reductions in water use from PET rates are assumed to be least for park trees, which are irrigated regularly. Reductions are assumed to be greatest for street trees because most will be infrequently watered with hoses by neighborhood residents. The situation for yard trees is intermediate. Trees receiving ample irrigation (100% of PET) are assumed to grow 3 ft per year in both the horizontal and vertical dimensions, while trees receiving 50% and 15% of PET are projected to have annual growth rates of 2 ft and 1 ft, respectively. Assumed irrigation rates and tree sizes are shown for each location and time period in Table 1.

Annual water use and cost are projected using crown diameter, irrigation rate, and local water price ($0.002/gal) data with a model previously developed at the University of Arizona (1976).

Mortality Rates. Vandalism, damage from vehicles, improper planting and maintenance, and storm damage are examples of factors likely to influence life span and loss rates for trees in Tucson. Therefore, the assumed life span of the mesquite has been reduced from over 100 years in the desert to 60 years in the city.

Three types of mortality are projected for trees at each location: Type A--establishment-related losses for young trees; Type B--age-independent losses due to weather, site modifications, etc. and are considered constant over time; Type C--senescence-related losses associated with aging (see Table 1, Richards 1979).

Table 1. Projected Average Annual Irrigation Rates, Tree Crown Sizes, and Mortality Rates for Each 5-Year Time Period

Years	1990-94	95-99	00-04	05-09	10-14	15-19	20-24	25-29
Park								
% PET	100	40	20	20	20	20	20	20
Size (ft)	12	24	25	25	25	25	25	25
% Mortality A	1.0							
% Type B	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
% Type C							0.5	1.0
% Loss Rate	1.5	0.5	0.5	0.5	0.5	0.5	1.0	1.5
Yard								
% PET	75	26	15	15	15	15	15	15
Size (ft)	11	20	25	25	25	25	25	25
% Mortality A	1.0							
% Type B	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
% Type C						0.5	1.0	2.0
% Loss Rate	1.6	0.6	0.6	0.6	0.6	1.1	1.6	2.6
Street								
% PET	50	15	15	15	15	15	15	15
Size (ft)	10	16	21	25	25	25	25	25
% Mortality A	4.0							
% Type B	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
% Type C					0.5	1.0	2.0	3.0
% Loss Rate	5.0	1.0	1.0	1.0	1.5	2.0	3.0	4.0

Planting and Management Costs

Planting, pruning, and removal costs are estimated for trees in each location based on information obtained from local landscape professionals. Costs for disease and pest control are not included because most desert-adapted trees are resistant to these problems. Similarly, other tree care costs are omitted because of infrequent use and limited cost. Although some liability and public health costs (e.g., property damage and allergies from pollen) accrue as a result of tree planting, these types of expenditures are difficult to quantify and, therefore, are not considered.

Planting Costs. This model assumes that 500,000 trees in 5-gallon containers are planted between 1990 and 1996. Average planting costs per tree range from $12 to $20 depending on location (Table 2). It is assumed that all yard and street trees are planted by residents.

Pruning Costs. Pruning costs are estimated for each location based on the anticipated pruning frequency and estimated pruning costs for a mature mesquite. Pruning frequency refers to the percentage of trees expected to be pruned once by a paid professional during the 40-year planning period. Half of all park trees are assumed to be pruned by a professional arborist at an average cost of $250 for a mature mesquite (Table 2). Pruning frequencies are assumed to be less for yard and street trees. Pruning costs are assumed to be greater for yard and street trees due to a higher probability of location-related conflicts with vehicles, powerlines, and buildings.

Removal Costs. Removal costs are estimated based on mortality rates and the estimated costs of removal of mature mesquites in different locations. Mature tree removal costs reflect anticipated location-related conflicts (Table 2).

Quantifiable Local Benefits

Numerous benefits are claimed for urban trees. Some of these can be quantified, others cannot. Some benefits accrue onsite to the land owner; others accrue to the local community; other benefits are global in nature (McPherson and Woodard 1989). If a local policy maker is deciding whether to endorse urban reforestation, then arguably only local, quantifiable benefits should be compared with local, quantifiable costs. Thus, benefits such as reduced global atmospheric carbon dioxide and reduced water consumed at offsite power plants are not considered because they are non-local. Improved aesthetics, increased urban wildlife habitat, reduced human stress, and increased leasability of commercial property are not considered because of valuation problems. Effects of trees on property values and the value of sales of trees by local nurseries also are not considered because of problems of double-counting. Therefore, dollar value benefits are estimated for cooling energy savings due to shade on buildings and reduced air temperatures, and avoided costs for dust and stormwater runoff control.

Air Conditioning Energy Savings. Estimates of air conditioning (AC) energy savings incorporate the

Table 2. Location Specific Assumptions for Modeling Costs and Benefits

Planting Location	Planting Cost $/tree	Pruning Cost $/tree	Pruning Frequency %	Removal Cost $/tree	% Bldgs w/ AC (PAC)	% Shade Effic. (PSE)
Park	20	250	50	450	100	25
Yard	12	350	25	550	50	66
Street	15	300	15	350	50	25

direct effects of tree shade on buildings and the indirect effects of evapotranspirational (ET) cooling from trees on air temperatures (Huang et al. 1987). Direct cooling savings are projected by estimating the potential AC energy savings from a mature mesquite tree, and then applying reduction factors to account for less than maximum shading and for shading buildings with and without AC. The potential annual AC savings from a mature mesquite shading the west wall of a well-insulated Tucson home is calculated as 250 kWh (about 5% of total AC costs) based on previous computer simulation results (McPherson, in press). Assumed reduction factors for the percentage of homes with air-conditioning (PAC) and percentage shading efficiency (PSE) are shown in Table 2. Direct energy savings are calculated using the 1988 electricity sales price to residential customers of $0.072/kWh.

Indirect effects of ET cooling are calculated by first identifying the amount of Tucson Electric Power's (TEP) 1988 electricity sales by end use sectors to: residential (2,000 GWh), small commercial (1,193 GWh), and large users (1,678 GWh) (TEP 1989). The fractions of total electricity sales used for air conditioning are estimated to be 17%, 35%, and 17% for each end use sector, respectively (pers. comm., Jon Guenther, TEP, Oct. 9, 1989). The potential effect of lowered air temperatures from 500,000 trees on AC energy use are then identified and applied to calculate the potential AC savings for each end use sector. This calculation requires estimating the impact of trees on drybulb temperature depression.

Tucson's afternoon summertime temperatures appear to be increasing at a rate that is typical for many U.S. cities, about 1°F per decade (Balling and Brazel 1987). Other studies indicate that increasing tree canopy cover by 10% reduces drybulb temperatures by as much as 4 to 6°F (Myrup 1969, McGinn 1982). Planting 500,000 trees will increase the Tucson canopy cover by approximately 10%, which is assumed to reduce urban heat island warming by 3°F. Computer simulations for typical residential buildings in Tucson indicate that this temperature reduction may lower annual cooling costs from 21% to 25% (847-1,263 kWh) compared to a no-planting scenario. Thus, a potential AC energy savings of 20% is assumed for the residential sector, and values of 12% and 5% are applied for small commercial and large users (Akbari et al. 1988). Using these figures, the maximum potential indirect AC energy savings from 500,000 trees is calculated by sector to be 68 GWh, 50 GWh, and 14 GWh for residential, small commercial, and large users, respectively.

Avoided Costs for Reducing Airborne Particulates. Programs aimed at reducing airborne particulates in the Tucson area include paving dirt roads and switching from diesel to compressed natural gas (CNG) buses. Paving one million square yards of unpaved roads within the city limits will cost about $0.78 per sq yd per year, when paving and maintenance costs are amortized over the 40-year planning period (pers. comm., Mary Lou Arbaugh, City of Tucson Transportation Dept., Dec. 11, 1989). However, paving roads generates benefits other than dust control; assigning 80% of the paving costs to dust suppression gives an annualized paving cost of $0.63 per sq yd. Annual dust control costs through paving are $0.12 per lb because each square yard of unpaved road produces about 5.2 lb of particulates (PAG 1988).

The annual mass of particulates that trees remove from the air is estimated to be between 42 lb and 400 lb per tree (Johnson and Baker 1990). Data on particulate removal by mature desert trees have yet to be developed, so a conservative annual removal rate of 40 lb per mature mesquite tree is adopted.

Avoided Costs for Reducing Stormwater Runoff. Urbanization increases the land area that is covered with impermeable surfaces, which increases the incidence and severity of flooding. One means of controlling storm water runoff is to construct basins that detain runoff and thus reduce stream flows and flooding potential. The county in which Tucson is located requires construction of on-site detention basins for new development to insure that off-site flow does not exceed pre-development rates. It costs about $67,000 to purchase land, construct, and landscape a basin to store one acre-foot of runoff (pers. comm., Tom Nunn, Pima County Dept. of Transportation and Flood Control, Sept. 28, 1989). The annualized cost of detention basins is $0.0025 per gal when construction and maintenance costs are amortized over 40 years. The canopy of a mature mesquite tree can store about 3 gal of rainwater, which ultimately evaporates (Aston 1979). More significantly, trees planted in accordance with principles of rainwater harvesting provide miniature catchment basins. Trees planted in 8-ft basins four inches deep with runoff directed into them provide about 125 gal of storage. Basins of 8-ft, 6-ft, and 4-ft width are assumed for park, yard, and street trees, respectively.

Non-Community Benefits

Urban trees can reduce atmospheric carbon dioxide directly through assimilation when photosynthesis occurs, and indirectly due to reduced carbon dioxide emissions from power plants (Akbari et al. 1988). It is estimated that mature mesquite trees sequester 13 lb of carbon per year. TEP power plants produce about 0.9 lb of carbon in the form of carbon dioxide per kWh of power produced. Hence, total conserved carbon is calculated as the sum of avoided power plant emissions and carbon dioxide sequestered in tree biomass.

Approximately 0.6 gal of water are used at TEP power plants to produce 1 kWh of electricity (pers. comm., Jon Guenther, TEP, Oct. 9, 1989). Trees that reduce power production indirectly reduce water consumption. However, TEP's marginal power supply is generated in plants in northern Arizona and New Mexico, making the water savings insignificant to the local community. Nonetheless, the extent to which this conserved water offsets the water consumed by evapotranspiration is of interest.

Benefit-Cost Analysis

Several types of benefit-cost analysis are used to evaluate the proposed planting project. Net benefits are calculated for the entire 40-year planning period. Benefit-cost ratios are calculated for each location and time period to compare the temporal and spatial aspects of the proposed investment. For instance, many of the tree planting and management costs are incurred early on, while the benefits grow with the trees. Because benefit-cost ratios do not incorporate the time value of money, an internal rate of return (IRR) is calculated for the community investment in trees planted at each location. The IRR is the interest rate that equates the present value of the cash flow series to the initial investment. Net present values are not calculated because selecting a discount rate is problematic when public, private, and corporate entities are involved.

RESULTS

Projected Tree Numbers and Leaf Area

Tree numbers are projected to increase rapidly but never reach 500,000 due to establishment-related losses of about 10% per year (Figure 1). Tree numbers decline at a slow and steady rate from 1995 to 2020 because no replacement planting is assumed. Loss rates increase during the fourth decade due to increased age-related mortality. Forty-three percent (215,041 trees) of the 500,000 trees planted are projected to die by the year 2030. Total leaf area is projected to increase more slowly than tree numbers because 10-15 years are required for trees to reach full-size. Once all trees reach mature size, leaf area gradually decreases due to mortality.

Projected Management Costs

Planting costs annualized over the 40-year period range from $0.30 to 0.50 per tree per year (Figure 2). Pruning and water costs range from about $1 to $3 per tree per year. The projected average annual water use is estimated to be 1,071 gallons per tree, or $2.14. This is about the same amount of water used inside the home by a single person for ten days. Projected water and pruning expenses for the more intensively managed park trees are nearly twice as great as projected expenses for the street trees maintained by adjacent homeowners. Tree removal is the most significant expense, with annualized costs ranging from $3.11 to $6.63 per tree. Per tree removal costs are greater for yard and street trees than park trees due to higher mortality rates for full-sized trees.

Average annual costs for each five-year time period depict how the demand for management resources are expected to vary with time (Figure 3). Average annual expenses during the first five years are projected to be about $3.5 million, primarily due to large one-time planting costs. Total average annual expenses drop to about $3 million for the next

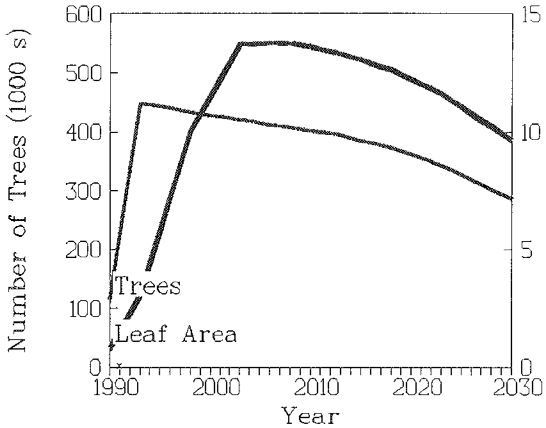

Figure 1. Number and Leaf Area of Trees

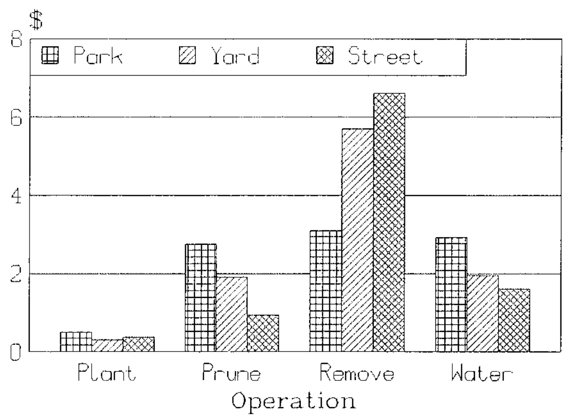

Figure 2. Projected Annualized Costs Per Tree

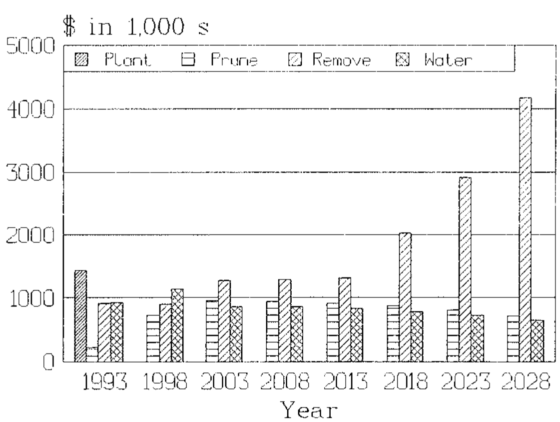

Figure 3. Projected Annual Costs for All Trees

20 years, but are projected to increase rapidly to over $5 million annually by the year 2028 due to increased removal costs.

Because pruning costs are assumed to be directly linked to leaf area, projected expenses (Figure 3) mirror the leaf area curve shown in Figure 1. Removal costs gradually increase with time as trees grow larger. Increased mortality of mature trees accounts for higher projected expenditures for removal during the last 15 years. Water costs follow a pattern similar to that projected for pruning, except initial costs are higher. High irrigation rates are projected for the establishment period, and offset the effect of small tree size on total water demand. Although irrigation rates will diminish from 1995-1999, rapid increases in tree size are projected to increase total water costs compared to the previous five-year period. Water costs will gradually decrease during the remaining 30 years as leaf area diminishes and irrigation rates remain constant.

Temporal and locational differences in projected average annual tree management costs are shown in Figure 4. Annual management costs for park trees range from $8 to $10 per tree during the first 20 years, and are greater than costs for yard or street trees due to substantial expenses for pruning and water. Relatively greater mortality rates for

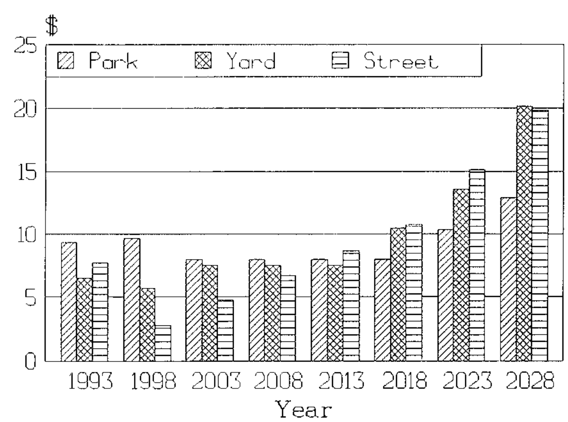

Figure 4. Projected Annual Costs Per Tree

mature yard and street trees during the last 20 years result in annual management costs as high as $20 per tree.

These data reflect the modeling assumption that funds spent initially to promote tree establishment, rapid growth, and strong crown structure can prolong the serviceable life of a tree and restrain senescence-related cost escalation. Annual management costs averaged for the entire 40-year period are smallest for park trees ($9.28) and greatest for yard trees ($9.87), with an overall average of $9.61 per tree (Table 3).

Projected Energy Savings and Environmental Benefits

Average annual cooling energy savings from direct shade for all trees is 61 kWh per tree, and annualized benefits are projected to range from $1.74 to $5.07 per tree depending on location (Figure 5). Yard trees provide the most shade to buildings and hence the greatest savings. The greatest cooling energy benefits result from evapotranspirational cooling effects, and average 227 kWh per year per tree. ET cooling benefits ranged from $15 to $17 and are about three times greater than direct energy savings from shade. This finding agrees with results from another computer simulation study for a single family residence in Phoenix (Huang et al. 1987). In that study, 80% of the total cooling energy savings are attributed to ET cooling. Park trees provide the greatest ET cooling benefits due to high irrigation rates and rapid growth. Total average annual cooling energy savings for all trees is projected to be 288 kWh ($20.74) per tree, with yard and park trees providing annualized benefits exceeding $21 per tree.

Projected annualized particulate control benefits range from $3.81 to $4.35 per tree and stormwater control benefits range from $0.06 to $0.29 per tree (Figure 5). For all trees, the average annual avoided-cost savings for dust and stormwater control is $4.16 (34.7 lb) and $0.18 (73 gal) per tree. Annualized avoided-costs for dust and stormwater runoff control vary little across locations.

Carbon savings averaged 408 lb annually per tree. Mature trees are estimated to each conserve 477 lb of source carbon per year. Hence, 97% (464 lb) of the total carbon conserved by a mature mesquite tree is attributed to reduced power plant emissions resulting from tree shade and ET cooling. Water conserved at the power plant due to reduced electricity demand is calculated to average 171 gal annually per tree, or 16% of each tree's average annual water consumption.

The stream of savings associated with each functional benefit (Figure 6) follows the trend of rapidly increasing and then gradually decreasing leaf area shown in Figure 2. Total annual benefits are projected to exceed $10 million from the years 2000 to 2025.

Table 3. Projected Benefits and Costs

Location	Costs ($) Ann/ Tree	Costs ($) 40 Yr Tot (mil.)	Benefits ($) Ann/ Tree	Benefits ($) 40 Yr Tot (millions)	Net ($) Benefits (millions)	B/C	IRR %
Park	9.28	38.9	25.68	106.3	67.4	2.74	5.47
Yard	9.87	91.4	25.69	241.9	150.6	2.65	14.43
Street	9.54	15.7	20.59	34.3	18.6	2.18	2.00
All Trees	9.61	145.9	25.09	382.5	236.6	2.62	7.11

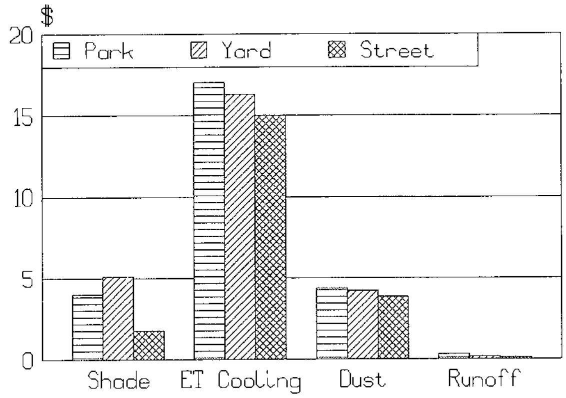

Figure 5. Projected Annualized Benefits Per Tree

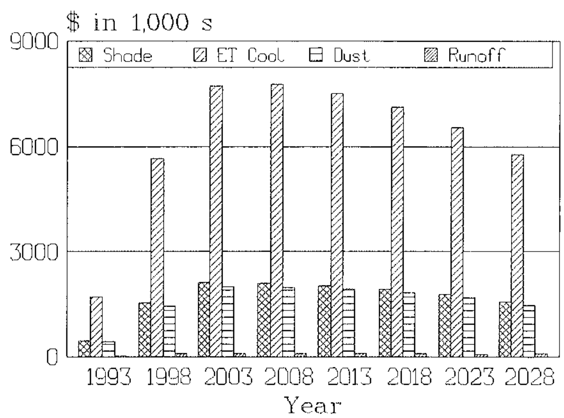

Figure 6. Projected Annual Benefits for All Trees

Projected annual benefits per tree range from $4.22 for young street trees to $30 for mature yard trees (Figure 7). Rapid growing park trees provide the greatest benefits during the first decade. Once trees mature, greater savings are projected from yard trees because of increased building shade and air conditioning energy savings. Street trees provide less benefits than yard or park trees initially because deficit irrigation is assumed to result in slower growth rates and less leaf area. Annual monetary benefits from mature street trees are projected to average $26.25 per tree. This figure is less than for mature yard and park trees because of assumed locational differences in direct shade on buildings. When annual benefits are averaged on a per tree basis over the entire 40-year period, yard and park trees provide the largest benefits ($25.69, $25.68),

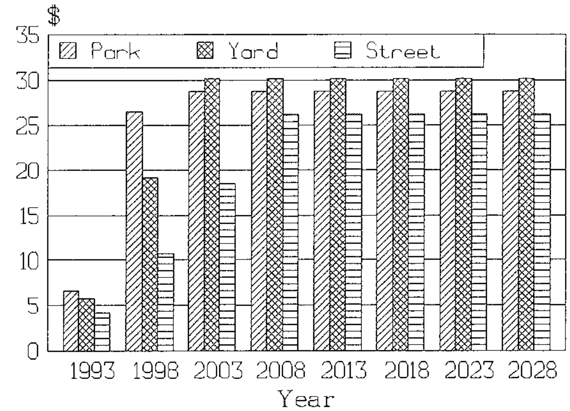

Figure 7. Projected Annual Benefits Per Tree

street trees provide the least benefits ($20.59), with an overall average benefit of $25.09 per tree (Table 3).

Projected Benefits and Costs

Projected total benefits exceed total costs by $236.5 million for the 40-year period (Table 3). Sixty-four percent ($150.6 million) of net benefits are projected for trees in yards, where 60% of all trees are assumed to be planted. The ratio of benefits to costs for all trees is 2.62, indicating that benefits are over two and a half times greater than costs. The benefit-cost ratio is largest for park trees (2.74) and smallest for street trees (2.18).

An internal rate of return (IRR) of 7.1% is calculated for all trees (Table 3). The IRR for yard trees is 14.4%, largely because of the relatively small initial investment in planting costs on a per tree basis ($12). The IRR for street trees is only 2% because high establishment-related mortality and slow growth rates yield small functional benefits, despite relatively large initial expenditures for planting and management.

The projected annual stream of benefits and costs shows that costs exceed benefits during the first five years, largely due to one-time planting expenses (Figure 8). However, for the next 25 years, projected benefits are three or more times greater than costs. During the last decade, costs begin to catch up with benefits as the end of the serviceable life of the trees grows near. If one extrapolates this trend for the next decade, costs will begin to exceed benefits.

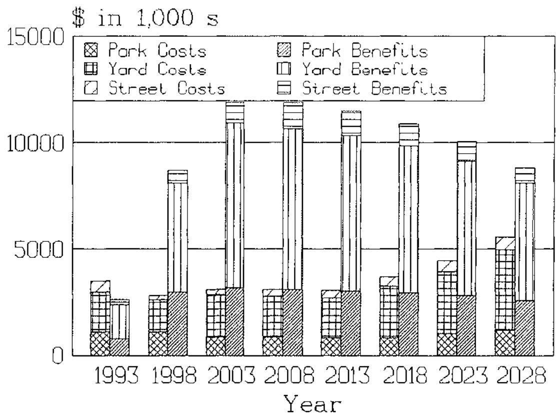

Figure 8. Projected Annual Benefits and Costs

CONCLUSIONS

Modeling of selected benefits and costs associated with the Trees for Tucson/Global ReLeaf program suggests that energy savings, dust control, and storm runoff detention benefits may outweigh tree planting and maintenance costs. Although the homeowner can obtain substantial cooling energy savings from direct building shade, greater benefits accrue to the community as a whole due to the aggregate effect of trees on urban climate. Public sector investment in tree planting may be warranted because economic, health, and aesthetic benefits extend beyond the site where individual trees are planted. Greatest net benefits can be expected from trees planted in parks and yards. Finally, substantial global benefits accrue as the trees reduce atmospheric carbon dioxide directly through the tree biomass and indirectly by reducing fossil fuel consumption. The estimated indirect effects are over 30 times the direct effects. Thus, despite the expense of planting trees in urban areas, such trees may be highly effective at reducing atmospheric carbon dioxide.

Modeling results are only as reliable as the data used to generate the findings. The research basis for this type of economic-ecologic modeling is paltry. Modeling limitations can be reduced through research in the following areas.

1. Develop rapid and accurate means to estimate leaf area of trees and explore relations between leaf area and functional benefits.
2. Obtain more data on tree mortality rates and how these vary with location.
3. Develop better tree growth models that account for site conditions, consumptive water use, actual irrigation practices, and other factors.
4. Develop more accurate estimates of relations between local climate, vegetation structure, and building cooling energy and landscape water use.
5. Measure dust, solar radiation, and rainfall interception rates for commonly used landscape plants.
6. Consider incorporating other important costs (e.g., liability and increased winter shade) and benefits (e.g., effects on property values, peak energy use, and water demand effects) into the model.
7. Incorporate benefits and costs for existing trees and replacement plantings into the model.

Despite the lack of a well-researched database for modeling, the approach described here offers decision-makers a timely and relatively sophisticated tool for evaluating the economic and environmental implications of proposed tree plantings. To improve this tool, studies should begin to monitor the effects of new tree plantings so that validation and verification can be accomplished.

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