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The environmental and economic costs of sprawling parking lots in the United States

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ABSTRACT

Urban sprawl is considered by most environmental scientists and urban planners to be a serious environmental problem. However, public perception about parking availability often forces planning offices to recommend parking lot sizes that exceed daily demands. The recent trend of increasing the size of stores, churches and even schools comes with increasing the size of parking lots that service these buildings. The objective of this paper is to analyze space allocation of parking lots in a typical midwestern county and to estimate the supply of parking spaces to potential demand. We also estimate the loss of ecosystem services represented by the area of parking lots in this county. We found that parking lots cover 5.65 km^2 (1 397 acres) of Tippecanoe County, Indiana which implies that 0.44% of the county area is devoted to parking lots. Our results show that there are approximately 2.2 parking spaces per registered vehicle, that parking lots make up more than 6.57% of the total urban footprint in this county, that the area of parking lots exceeded the area of parks in the city limits by a factor of three and that parking lot runoff and pollutants are significant compared to runoff and pollutants from these areas prior to their conversion to parking lots. As other authors have done before us we lament the poor use of land in urban regions of the United States, and encourage planners to think creatively about the use of land for parking.

Introduction

America's love affair with the automobile is well known (Alvord, 2000). However, little is reported on the amount of space devoted to parking our vehicles as we shop, work, worship, or attend school. Paved parking surfaces, also known as parking lots, are an insidious partner of increased urbanization particularly in regions experiencing rapid development. The national estimate of urban coverage is between 2% and 5%, and it is increasing rapidly (Jin and Zhang, 2002; Imhoff et al., 2000). Frequently cited culprits of urban sprawl have been residential development and shopping malls (Squires, 2002), but the proportion of the urban landscape dedicated solely to parking lots has not been systematically documented.

Parking lots are considered unattractive and hostile (Gibbons, 1999); they can increase congestion and lower land values (Wilson, 1995), undermine walkability, are generally oversupplied (Mukhija and Shoup, 2006) and are a subtle subsidy to the automotive industry. Indeed we spend an inordinate amount of money and land to park our cars (Manville and Shoup, 2005) at the expense of the environment, and the expansion of public transportation.

Several decision making factors contribute toward large parking lots. First, most businesses when applying for a building permit determine the number of spaces they will need for the day of peak demand such as the day after thanksgiving for shops, day of Christmas service for some churches, school events where all parents and teachers need to be present, etc. (Shoup, 2005). Thus parking lot size can be considered excessive since it remains mostly empty for the remainder of the year. This is especially true in open environments like the suburbs, and it further exacerbates inefficient and unpractical public transportation. On the other hand, finding a parking space in large cities can be difficult or costly, but one may ask whether a commodity with such negative and wide reaching environmental effects should not carry its associated cost and be strictly regulated? A second factor contributing to large parking lots is brought on by urban planners who generally believe that parking is a problem only when there is a shortage of it (Shoup, 2005), and therefore tend to overestimate the amount of necessary parking in an effort to avoid such shortages. Shoup (2005) states that, "because planners and politicians want to avoid criticism for allowing development that later creates parking spillover,

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cities require an oversupply of parking spaces". Shoup (2005) recommends eliminating parking lot requirements entirely so that people pay market prices for parking instead of perceiving that parking is free, despite the hidden costs of systematically providing (or over-providing) parking. Finally, the public is often critical of the lack of adequate parking by their faulty perceptions of parking space availability. For example, Wilson (1995) argues that the notion of a shortage of parking is a result of viewpoint. He states that during peak parking demand, the reason a parking lot looks full is because "the most visible spaces are the first to be occupied" (Wilson, 1995).

Aside from the land they occupy parking lots also have several different environmental costs. They increase storm runoff and contaminant loads to freshwater systems, therefore increasing both pollution and flood risks. They also contribute to the urban heat island effect and have a biodiversity value of zero, i.e. are essentially biologically inert in that they do not support any biological organisms. Jakle and Sculle (2005) state that, "Expanses of open asphalt impact hydrology and climate across city space." Such hydrological impacts could include increased flooding of downstream locations, increased water flow which could lead to increased sedimentation in streams and rivers, and larger non-point pollution loads (Jakle and Sculle, 2005).

Parking lot sealants, which are applied to pavement every 3–5 years to protect it from weather and chemicals, have also been recognized as polluters of urban streams. In a field study performed in Austin, Texas researchers found that polycyclic aromatic hydrocarbons (PAHs) coming from parking lot coal-tar based pavement sealants ended up in sediments and were the most likely cause of decreased community health of benthic macroinvertebrates (Scoggins et al., 2007). The researchers also reported that macroinvertebrate densities were two times lower in streams downstream from the surveyed parking lots and that community structure was changed to favor species for which the polycyclic aromatic hydrocarbons are less toxic.

Because the environmental consequences of paved surface lots are seemingly considerable, it is important to quantify the amount of parking within our urban landscape from a land use perspective. Our paper addresses the question: "What is the areal footprint and the ensuing economic and environmental consequences of parking lots?" Our study attempts to quantify, in spatial terms, the total coverage of parking lots in Tippecanoe County, Indiana. We use high resolution aerial photography and a Geographic Information System (GIS) to estimate the areal footprint of parking lots in relationship to: (1) the total area coverage of parking lots; (2) the number of available parking spaces vs. the potential demand for parking in the county; (3) the ratio of area in parking lots to area in parks and wetlands, which we call social value tradeoff metrics; (4) several perspective metrics, which relate the parking lot area to more meaningful comparative (or easily relatable) values; (5) impact of parking lots to the distribution of parking spaces by land use category for a high density urban cover portion of the study area, and (6) estimate the impact of parking lots in the county to ecological services and the amount of runoff produced by the imperviousness of the parking lots. Finally our discussion attempts to describe economic ramifications of excessive numbers of parking spaces and discusses how planning impacts parking lot size.

Measuring parking lots and calculating parking spaces

We used geographical information systems (GIS) to delineate parking lots from high resolution aerial photography for Tippecanoe County, which is located in western Indiana (Fig. 1). This county contains the cities of Lafayette and West Lafayette. The aerial photography had a spatial resolution of 6 in. and a minimum 30% adjacent flight line overlap.

We digitized paved areas that were clearly parking lots, in that we could visually identify on the aerial photography more than three cars parked in an organized fashion or we could distinguish parking lot delineations as stripes, or concrete bumpers. Areas necessary for the maneuvering of the vehicle in and out of parking spaces as well as handicap spaces (which are larger than regular parking spaces) and small islands of landscaping were included in the various parking lot polygons. If the islands in the parking lot were larger than one parking space we would break up the parking lot and exclude the landscaping. Access roads to the parking lots, truck storage areas, junkyards, or gravel lots were not included. Digitizing for the highly urban centers which consisted mostly of West Lafayette and Lafayette was done at the 1:1000 scale, in the rural areas of the county we scanned through the aerial photography at 1:3500 scale. This means that smaller parking lots in the rural areas of the county may have not been digitized, but because of their low concentration and smaller size, we expect their contribution to be negligible.

Our estimate of the number of parking spaces can be conservative because of the following two factors. First, we counted eight parking garages in the county but we used only the surface area of the top level as estimates of parking lot area. Most of these garages contain at least four levels for parking. Second, we neither counted parking spaces in downtown areas that occur along streets, including residential streets, nor did we include paved areas at single-family residences, which generally consist of a widened driveway. Future work to estimate the area occupied by such parking is being pursued.

We conducted two additional analyses in the county. The first is what we refer to as the "mall area study" that focused on (a) calculating the size of the parking lots as a function of the size of the buildings they service; and (b) the occupancy (i.e., whether a vehicle was parked in a space) at the time the photo was taken. Only a small region ($\sim$4 km^2) of the county was examined for this purpose because of the large amount of time required to digitize and count parking spaces, as well as site visits to classify buildings and parking lots which were necessary to maintain accuracy.

The second analysis focused on estimating the number of parking spaces as a function of parking lot size. We randomly selected 100 parking lots and counted the number of parking spaces from the aerial photograph. We developed a linear regression model of parking lot size (in m^2), to the number of spaces:

$$\text{number of spaces} = 0.036 \times \text{parking lot size} \quad (1)$$

which provides the number of spaces as a function of area (R^2 = 0.98, F = 4823.40, P = 0.00). We used this equation to calculate the number of parking spaces as a function of parking lot area.

Spatial footprint metrics

Research in risk perception and communication (Fischhoff, 1985a,b; Griffin, 1999; Greenwood and Riordan, 2001) has found that communicating scientific results to the public and decision makers often requires translating scientific facts into meaningful terms. For example, calculating the total size of parking lot coverage in an area may need to be related to more common measures that are simpler to comprehend. These kinds of metrics, sometimes referred to as perspective metrics, are considered useful when scientific information is difficult to perceive.

County census data were obtained for the year 2000 from the following: total resident population, number of individuals of driv-

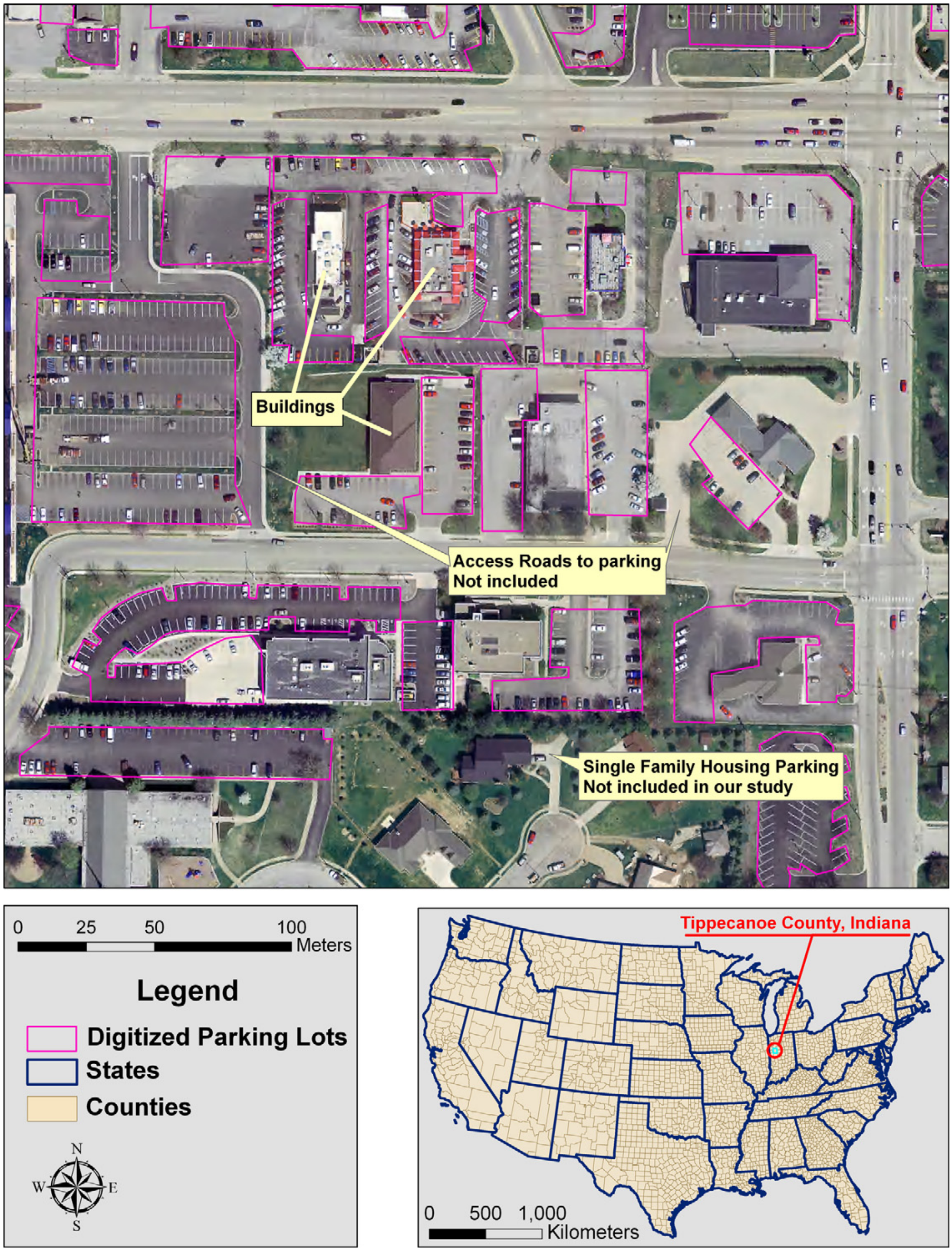

Fig. 1. Close up of orthophoto from Tippecanoe County, Indiana, detailing the digitizing of parking lots and areas which were not digitized in this study.

ing age, and the number of households. We also obtained from the Bureau of Motor Vehicles, the number of registered passenger vehicles in Tippecanoe County. We used these statistics to generate the following supply/demand metrics: the number of parking spaces in the county per person of driving age, per household and per registered vehicle. In addition, we tabulated the total area of parks to compare the amount of area devoted to parking compared to natural areas set aside as parks, both county wide and solely contained within city limits of Lafayette and West Lafayette. It should be noted that Tippecanoe County is home to Purdue University and its, approximately 40,000 students which are not included in the census, but six of the eight multilevel parking garages which were not counted in the parking lot footprints (except for the top floor, which were counted) are on the Purdue University campus.

We translated the total area of parking lots into two different perspective metrics that help to communicate the areal extent of this urban land use. We calculated (1) the number of regulation sized American football fields that would fit in the same space as

Table 1
Parking lot footprint metrics. (1) calculated only for a subset of Tippecanoe County, e.g. "Mall area study".

Metric group	Metrics	Value
Areal coverage	Total area	5.65 km^2
	% of total land in county	0.44
	% of urban land use	6.57
Perspective size	# of American football fields	1075
	Extrapolated to states	If scaled to conterminous states, equal size of NJ, CT, and RI
Supply	Spaces per registered vehicle	2.2 (92,987 registered vehicles)
	Spaces per household	3.7 (55,226 households)
	Spaces per person of driving age	1.7 (202,714 spaces and 117,755 people >16 yrs)
Social value tradeoffs	Urban PL area to urban parks area ratio	3
	PL area to buildings area ratio[1]	1.2
Ecological services	Increase in runoff volume	917%
	Increase in P, N concentrations	200%
	Increase in ESV if PL converted to wetlands	38.4%

all parking lots in the county; (2) the area of states occupied by parking lots if scaled to the conterminous United States.

Several researchers (e.g., Kreuter et al., 2001) have used Costanza et al. (1997) ecosystem economic valuations by biome type (e.g., grassland, temperature forests) as a means to value the loss of ecosystem services to urbanization. We used total value per hectare of biomes (e.g., forest, grassland or wetland) reported by (Costanza et al., 1997) and the total area of each land cover class that are proxies for each biome following Kreuter et al. (2001) to estimate the ecosystems service value (ESV) lost because of the presence of parking lots in the county:

$$\mathrm{ESV} = \sum (A_k C_k) \qquad (2)$$

Where A_k represents area of the kth land cover class that is replaced by parking lots and C_k is ecosystem value from Costanza et al. (1997). Since we lacked data on what land cover classes were replaced by parking lots, we examined the ESV for two conditions: (1) we assumed that parking lots replaced land cover classes in proportion to that of areas outside of current urban land uses and (2) replaced the class that had the highest ESV (e.g., wetlands). We compare these values to the amount of lost revenue from growing a typical crop (e.g., corn) in the same amount of space. This is a reasonable assumption/comparison since urbanization, especially in sprawling environments tends to expand into neighboring agricultural fields. We adjusted Costanza's 1997 values to 2007 values using annual price index for both years reported by the U.S. Census Bureau 1997 = 86.1 and 2007 = 177.7 (multiplier is 177.7/86.1 = 2.06).

To assess the amount of runoff and contaminant loads produced from parking lots in the county, we ran the Long-Term Hydrologic Impact Assessment (L-THIA) model (Harbor, 1994; Tang et al., 2005) for two scenarios: (1) land area occupied by parking lots and (2) runoff of the same land area that was assigned ecosystem classes (e.g., wetlands, forests, agriculture and grassland) in the proportion existing in the non-urban areas of the county.

Results

We found that parking lots cover 5.65 km^2 (1 397 acres) in Tippecanoe County, Indiana (Table 1). The total area of the county is 1 302 km^2. The urban area in the county (NLCD, 2001) totals 86 km^2, or 6.40% of the total area of the county. Thus, parking lots occupy 0.44% of the county area and 6.57% of the urban cover of Tippecanoe County. Comparatively, in Tippecanoe County there is 14.4 km^2 of parks, and 1.3 km^2 of those are within the boundaries of the cities of Lafayette and West Lafayette. Parking lots that are within the same city boundaries total 3.9 km^2 of land coverage. So the ratio of parking lots to parks in the entire county is 0.4/1.0 and in the urban setting is 3/1.0. The total area of wetlands in the county is 7.36 km^2 which means that the ratio of parking lot area to wetlands is 0.77/1.0.

Using Eq. (1), we estimated the number of parking spaces in Tippecanoe County to be 202,714 (Table 1). Based on the 2000 census, the number of adults (ages 16 and older) was 117,755, thus there are approximately 1.7 parking spaces per person of driving age in the county. The number of families in Tippecanoe County is 32,403, which yields 6.3 parking spaces per family in the county. Similarly there are 2.2 parking spaces per registered passenger vehicle in the county.

In the "mall study area", five types of parking lot uses were identified (Table 2). These uses were commercial, industrial, residential, educational (schools), and hospital/medical. When comparing the sum of the area of parking lots and building footprints, 55% of the land is occupied by parking lots, while 45% of the area is occupied by buildings. We also found that the total occupancy parking space rate was 28% (Table 2). The largest ratio (56%) of parking space occupancy is for industrial parking lots, which would be expected since the flights over Tippecanoe County were conducted during the workweek, i.e. on April 4th and 14th 2005 (a Monday and Thursday, respectively).

The total ESV of non-urban, non-agricultural land covers in the county adjusted to 2007 values was \$58.6 million. If all of the county's parking lots were replaced by wetlands, the ESV of this area would be \$22.5 million; thus there would be an increase of 38.4% of the county's ESV if parking lots were replaced with wetlands.

Table 2
Areal occupancy percentage of the parking lots associated with the different building-use classes. The last column displays the ratio of occupied vs. total number of spaces for each Parking lot category.

Parking lot use	Percent total area	Ratio of occupancy vs. number of spaces
Residential	8.63	19.00
Commercial	73.67	30.86
Transportation (transportation, communication, and utilities)	0.00	0.00
Industrial	7.70	56.16
Educational (schools)	8.65	54.30
Dormitories	0.00	0.00
Hospital and miscellaneous medical	1.36	31.65
Total	100	

Table 3
Average annual runoff and NPS pollutants for pre-development and post-development with parking lots.

	Pre-development	With parking lots
Total annual volume (acre-ft)	207.20	1898.11
Nitrogen (lbs)	1993	6930
Phosphorus (lbs)	562	1654
Suspended solids (lbs)	46373	287,030
Lead (lbs)	1.31	67
Copper (lbs)	1.648	74
Zinc (lbs)	6.794	930
Cadmium (lbs)	0.564	4
Chromium (lbs)	4.993	51
Nickel (lbs)	0	61
BOD (lbs)	1794	118,949
COD (lbs)	0	599,919
Oil and grease (lbs)	0	46,545

The impervious areas of parking lots alter runoff and allow pollutants to accumulate before being transported to nearby water bodies by runoff. L-THIA (Table 3) indicates that average annual runoff from the parking lots in the county is nearly 1900 acre-ft (2,340,000 m^3 = 618,162,603 gallon). This is an increase in runoff of more than 900% compared to runoff from the land before it became parking lots. In addition to significant increases in runoff, non-point source pollutants increase as well. For example, nitrogen and phosphorus losses in runoff increase by approximately 200% while heavy metals and other pollutants increase substantially more.

Discussion

Parking lot footprint

A large proportion, over 6.5%, of the urban footprint, is allocated to parking lots in Tippecanoe County, Indiana. We estimated that this is the same size as 1075 American football fields. In our mall study area, we found that parking lots exceeded the footprint of buildings they service by 20%.

There are many more spaces than registered vehicles (1.7×), households (6.3×) or people living in the county of driving age (2.2×). This implies that if all of the vehicles in the county were removed from garages, driveways, and all of the roads and residential streets and they were parked in parking lots at the same time, there would still be 83,000 unused spaces throughout the county. Annual ecological services value of these parking area represents over $22 M if they are all replaced by wetlands.

If the percentage of parking lot area in the county (0.44%) is scaled to the area occupied by the conterminous United States, the entire states of Connecticut, and Massachusetts (12,550 + 20,305 = 32,855 km^2) would be paved over with parking lots. In a independent estimation, Shoup (2005) calculated that to park all the motor vehicles in the U.S. in 2002 assuming that each car required three parking spaces and that each parking space was 18.58 m^2 (200 ft^2), the area needed would be 12,820 km^2 (4950 $mile^2$) which is approximately the area occupied by the state of Connecticut. This is 2.6 times more land area than we estimate. He points out that his estimation does not include the area needed for maneuvering in and out of parking spaces. Our values do include access alleys, which we can derive from Eq. (1) as occupying 33% of a typical parking lot so that Shoup's estimate would be increased to 17051 km^2 or approximately the area occupied by Connecticut and Delaware (12,550 + 5060 = 32,855 km^2). The remaining discrepancy can be explained by the fact that we hypothesize that 0.44% of the land in the United States is devoted to parking lots based on this study, but we realize that this number is on the higher end of estimates of parking lot footprints because land in Tippecanoe County is cheap compared to more dense urban areas that are found on the East and West coasts of the United States.

However, we conjecture that the total coverage for parking in our study underestimates the total areal extent of parking in general. We excluded parking along residential streets, parking associated with personal homes and parking spaces in multi-level garages. Many large parking lots also require co-locating retention ponds to control runoff. If the size of these runoff remediation efforts is added, the area of the parking lot footprint increases even more. A larger scale study of the area devoted to parking lots in the United States is already underway and will permit a refinement of the values estimated above.

Parking lots and planning

Planning requirements for parking lot size vary considerably (Table 4). In Fort Wayne, Indiana (Fort Wayne city code, 1997), for example, the minimum parking requirement for a high school is one space per employee and six per classroom, whereas in Middleton, Wisconsin (Middleton city code, 2007), it is one space for each 10 students plus one additional space for each two classrooms. For industrial uses in Fort Wayne one parking space must be provided for every two employees during the largest shift, or one parking space per 800 ft^2 (whichever is less) and one space per company owned vehicle stored on site. While in Middleton a minimum of, whichever is greater: one space for each full time employee during largest shift, or one visitor parking space for each 500 ft^2 of office space or sales floor area open to the public. It is clear that city planners should closely monitor parking needs and regulate minimum as well as maximum parking space requirements.

There are many municipalities that are addressing parking lot sprawl creatively. For example, to help compensate for the possibility of over estimates for needed parking, some cities are allowing developers to make smaller parking lots with the stipulation that additional land is set aside for later development if necessary (Shoup, 2005). In other cities, the minimum parking requirement is relaxed if certain conditions which increase the use of alternative modes of transportation are enacted. In areas where the land is expensive, such options become very attractive to developers. In the city of Pasadena, California, an ordinance was passed which stipulates that projects that exceed 25,000 ft^2 must have at least

Table 4
Minimum parking and landscaping requirements for two cities in the study area.

	Fort Wayne, IN	Middleton, WI
High school	One space/employee and six/classroom	One space/10 students +one/classroom
Industrial	One space/two employee during largest shift or 1/800 ft^2, whichever is less and one space/company vehicle which is stored onsite	One space/full time employee during largest shift, or one visitor parking/500 ft^2 of office/retail space open to the public (whichever is greater)
landscaping	One tree/4000, 5000 and 7000 ft^2 of parking area for residential, commercial and industrial	One tree/12 parking lot spaces for lots with >6 spaces
Population	257,000	18,000

10% of their employee parking designated for carpool and vanpool vehicles, have bicycle parking near the employee entrance, and have public transportation information prominently displayed (Knepper, 2007). If the project is greater than 100,000 ft^2, then carpool and vanpool loading areas must be added to the above requirements as well as connecting sidewalks. For newly constructed retail, one LEED (leadership in energy and environmental design) certification point can be obtained by promoting car-share programs (USGBC, 2007). The contract with the car-share company must be for a minimum of 2 years. Employees must be given the option to enroll in the car-share program onsite, preferred parking is provided, and the program must accommodate 5% of the employees. In Schaumburg, Illinois, zoning ordinances (cf. EPA, 2006) were developed to promote a bike friendly community with minimum bike parking requirements placed near building entrances, in highly visible places and separate from automobile parking. Milwaukee, Wisconsin relaxed parking requirements if shared parking, transit-oriented development and/or on-street parking were developed instead. Parking garages rather than surface lots were heavily encouraged and 50% of the ground floor of the garage needed to be used for retail. This was viewed as a major contributor toward the city having one of the lowest parking ratios of the country (*note*: a parking ratio is the number of spaces per square footage of the building(s) it services). Lastly, in downtown Indianapolis, Indiana, shared parking between retail, business, and entertainment allowed for a decrease in parking spaces built from 6000 to 2815 and an associated decrease in building costs of $30 million overall as well as a saving of $1 million per year of operation costs. Mixed-used parking also promoted a pedestrian friendly design for downtown Indianapolis (EPA, 2006).

Mukhija and Shoup (2006) recommend adding more and bigger trees to parking lots, placing them behind buildings to hide them from the street view, building parking garages that are architecturally similar to regular buildings, and having them be multipurpose, i.e. the first few floors be stores and the other floors be parking. They argue that if parking design, i.e. quality was more closely regulated it would improve the urban landscape, the community feel of an area and the safety and pedestrian quality of a neighborhood.

Economic tradeoffs between public transportation and public parking structure investments

The economic costs of parking are no doubt complex; with many being hidden. Shoup (2005) recommends that the public be charged for parking in areas where the supply to demand ratio of parking is small. These funds could be directed toward public transportation initiatives. There are many varied examples of cities which have specifically targeted decreases in land devoted to parking spaces. For instance, the City of Portland, Oregon, enacted measures which aimed to make transit more accessible and easier to develop further in the future. They also eliminated free commuter parking and free on-street parking, installed parking meters and developed a parking meter revenue sharing plan, developed aggressive maximum parking ratios, restricted future development of surface parking lots, and added restrictions on parking near light rail stations. The changes described above allowed for the transit share to increase to 41% in 2005 from 21% in 1997, for decreased parking ratios from 3.5 spaces per 1000 ft^2 to 1.95 spaces per 1000 ft^2, and helped in developing the area and decreasing the number of commuters. The savings in parking development costs were estimated to be over $35 million (Knepper, 2007). Similarly, the University of Washington, Seattle, decreased parking spaces on campus while their campus population grew by 8000 students, by subsidizing public transportation which prevented building 3600 parking space; this saved them an estimated $100 million. In Boulder, Colorado, discounted annual transit passes can be bought by employees of certain firms, residential associations, and city employees. The various interested groups buy the passes in bulk at a discounted rate and then provide them to their constituents. This in turn creates an incentive for use of public transportation and a decrease in parking space requirements.

Green technologies and parking lots

Alternative technologies and design options have emerged in recent years in an effort to reduce impervious surface runoff and increases in temperature due to heat islands created by paved lots. Note that asphalt (black) or concrete (light grey) have different albedos and thus different effects on heat retention and release but this effect is not discussed here. Some of many design options to mitigate the negative environmental effects of parking lots include the increased use of one-way aisles, the creation of more covered multilevel parking lots or underground parking lots, and the sharing of parking facilities among businesses (McPherson, 2001; Noguera, 2005). All these target the actual areal footprint of the parking lot. Other possible solutions include the use of technologies such as permeable pavements, and/or photovoltaic canopies (Golden et al., 2007; Mukhija and Shoup, 2006) associated with green roofs, i.e. vegetated roofs. Most of the research pertaining to vegetated roofs and photovoltaic systems has been completed on building roofs but their applicability to parking lots is obvious. A one storey parking lot could be covered with vegetation thus supporting benefits such as reduced storm water runoff and mitigation of extreme surface temperatures. Van Woert et al. (2005) reported that vegetated roofs retained 82.8% of water on average compared to 48.7% for gravel roofs. Their experiments also showed that less sloped roofs with thicker media retained precipitation the most and for the longest time. Green roofs can theoretically reduce the urban heat island effects due to the vegetation's low solar absorbance and insulation properties (Saiz et al., 2006). Similarly, photovoltaic canopies have been shown to decrease temperature at the surface of a parking lot in Phoenix, Arizona (Golden et al., 2007). In general, employing more 'green' technologies in parking lot development could improve the quality of life for citizens and reduce the harmful impacts placed on the environment (Evans and Schiller, 1996).

Summary

Urban sprawl is considered by most environmental scientists and planners to be a serious environmental problem. However, public perception about parking availability often forces planning offices to recommend parking lots that exceed daily demands. The purpose of this paper was to analyze space allocations of parking lots in a typical Midwestern county and to estimate the supply of parking spaces to potential demand. Our results show that parking lots take up considerable space, are costly, reduce ecosystem services, and contribute toward runoff and pollutants.

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References

Alvord, K.T., 2000. Divorce Your Car! Ending the Love Affair with the Automobile. New Society Publishers, Gabriola Island, B.C.

Costanza, R., dArge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., vandenBelt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Evans, J.M., Schiller, S.D., 1996. Application of microclimate studies in town planning: a new capital city, an existing urban district and urban river front development. Atmospheric Environment 30, 361–364.

Fischhoff, B., 1985a. Managing risk perception. Issues in Science and Technology 2, 3–96.

Fishchhoff, B., 1985b. Protocols for environmental reporting: what to ask the experts. The Journalist (winter), 11–15.

Fort Wayne city code, 1997. (http://www.cityoffortwayne.org/index.php/content/view/216/315/, last visited 12/21/07).

Gibbons, C.J., 1999. Parking Lots. University of Connecticut, Haddam, CT, pp. 1–6.

Golden, J.S., Carlson, J., Kaloush, K.E., Phelan, P., 2007. A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures. Solar Energy 81, 872–883.

Greenwood, M.R.C., Riordan, D.G., 2001. Civic scientist/civic duty. Science Communication 23 (1), 28–40.

Griffin, R.J., 1999. Using systematic thinking to choose and evaluate evidence. In: Friedman, S.M., Dunwoody, S., Rogers, C.L. (Eds.), Communicating Uncertainty: Media Coverage of New and Controversial Science. Lawrence Erlbaum, Mahwah, NJ, pp. 225–248.

Harbor, J.M., 1994. A Practical method for estimating the impact of land-use change on surface runoff, groundwater recharge and wetland hydrology. Journal of the American Planning Association 60, 95–108.

Imhoff, M.L., Tucker, C.J., Lawrence, W.T., Stutzer, D.C., 2000. The use of multisource satellite and geospatial data to study the effect of urbanization on primary productivity in the United States. Ieee Transactions on Geoscience and Remote Sensing 38, 2549–2556.

Jakle, J.A., Sculle, K.A., 2005. Lots of Parking: Land Use in a Car Culture. University of Virginia Press, Charlottesville, North Carolina.

Jin, M., Zhang, D.L., 2002. Observed variations of leaf area index and its relationship with surface temperatures during warm seasons. Meteorology and Atmospheric Physics 80, 117–129.

Knepper, V., 2007. Developing parking policies to support smart growth in local jurisdictions: best practices. Metropolitan Transportation Commission for San Francisco Bay Area, CA (http://www.mtc.ca.gov/planning/smart_growth/parking_seminar/BestPractices.pdf).

Kreuter, U.P., Harris, H.G., Matlock, M.D., Lacey, R.E., 2001. Change in ecosystem service values in the San Antonio area. Texas Ecological Economics 39, 333–346.

Manville, M., Shoup, D., 2005. Parking, people, and cities. Journal of Urban Planning and Development-ASCE 131, 233–245.

McPherson, E.G., 2001. Sacramento's parking lot shading ordinance: environmental and economic costs of compliance. Landscape and Urban Planning 57, 105–123.

Middleton city code, 2007. (http://www.ci.middleton.wi.us/ordinances/Parking_Ordinance.pdf, last visited 12/21/07).

Mukhija, V., Shoup, D., 2006. Quantity versus quality in off-street parking requirements. Journal of the American Planning Association 72, 296–308.

Noguera, J., 2005. Parking lots, store chains and spatial agglomeration. Papers in Regional Science 84, 145–158.

Saiz, S., Kennedy, C., Bass, B., Pressnail, K., 2006. Comparative life cycle assessment of standard and green roofs. Environmental Science & Technology.

Scoggins, M., McClintock, N.L., Gosselink, L., Bryer, P., 2007. Occurrence of polycyclic aromatic hydrocarbons below coal-tar-sealed parking lots and effects on stream benthic macroinvertebrate communities. Journal of the North American Benthological Society 26, 694–707.

Shoup, D.C., 2005. The High Cost of Free Parking. Planners Press, American Planning Association, Chicago.

Squires, G.D., 2002. Urban sprawl causes, consequences & policy responses. The Urban Institute Press, Washington, DC.

Tang, Z., Engel, B.A., Pijanowski, B.C., Lim, K.J., 2005. Forecasting land use change and its environmental impact at a watershed scale. Journal of Environmental Management 76, 35–45.

U.S. Environmental Protection Agency, Development, Community and Environment Division, 2006. Parking spaces/community places. Finding the balance through smart growth solutions. Washington, DC: EPA 231-K-06-001.

USGBC, 2007. Green building rating System. LEED for retail–new constructions and major renovations. Available at http://www.usgbc.org/ShowFile.aspx?DocumentID=2611.

VanWoert, N.D., Rowe, D.B., Andresen, J.A., Rugh, C.L., Fernandez, R.T., Xiao, L., 2005. Green roof stormwater retention: Effects of roof surface, slope, and media depth. Journal of Environmental Quality 34, 1036–1044.

Wilson, R., 1995. Suburban parking requirements: a tacit policy for automobile use and sprawl. Journal of the American Planning Association 61, 29–42.