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Changing Landscapes in the Twin Cities Metropolitan Area

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Cover Photo: *Tamarack Village Shopping Center and nearby residential development, Woodbury, Minnesota. (Photo © The Regents of the University of Minnesota, 2006. Used with permission of the Metropolitan Design Center.)*

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Changing Landscapes in the Twin Cities Metropolitan Area

by Steven Manson and Marvin Bauer

Humans have long altered the land by clearing forests, farming, and building settlements. It is increasingly apparent, however, that these transformations have serious social and environmental implications. This is evident in the Twin Cities metropolitan area, a 7,700 square-kilometer seven-county region home to roughly 2.8 million people. The metro area population is forecast to top 3.5 million in 2020, continuing a trend of the region being one of the fastest-growing metropolitan areas in the nation. Urbanization in the Twin Cities and elsewhere in the United States is characterized in large part by suburbanization, or decentralized, low-density residential land use.

Increasingly, the public, researchers, and policy makers recognize that urbanization must be examined and understood at small spatial scales, on the order of individual lots or parcels of land. The severity and nature of the impacts of urban growth are related to the extent to which urbanization occurs through a leapfrog process that intersperses housing with open spaces such as agriculture lands or woodlands. Although the total *amount* of land converted to urban uses is important to determining the impacts of urbanization, its *spatial configuration* also matters a great deal. Decentralized urbanization offers some important benefits, such as freedom of choice and affordable housing; however, it also has negative implications for traffic, atmospheric chemistry, natural habitat, water resources, infrastructure efficiencies, and inner-city viability. A dispersed pattern of urban development makes it more expensive to provide infrastructure such as roads or sewers, for example, because these networks must be spread out and extended to reach every house or business. Similarly, ecosystem functions such as providing natural habitat and water purification require undisturbed expanses of open space, forests, and wetlands. Decentralized development creates a fragmented landscape, one that is a crazy quilt of human and natural land covers. Much of the current research on urbanization examines changes in aggregate measures of urbanization, such as variations in housing density or commuting times among counties. Although this broad view is important to understanding urbanization, it does not capture the patterns and processes of land conversion at fine temporal and spatial scales.

Single-family residential development in Woodbury. Development tends to occur near existing developed land, expanding outward from current urban areas—the so-called "birds of a feather" principle of urban development.

Our research integrates several different approaches to describe and understand the processes of urbanization in the Twin Cities. We started by creating maps of the changing landscape based on satellite imagery, an approach that offers a streamlined method for inventory, monitoring, and analysis of land, vegetation, and water resources. We were interested in two particular kinds of information about the Earth's surface: the kind of land cover found in a given location (e.g., urban, agricultural, or forest) and the percentage of impervious surfaces (such as roads or parking lots) that do not allow water to penetrate into the underlying soil. We can learn much about urbanization in the Twin Cities metro area from these satellite images. We also combined these maps of land cover and impervious surfaces with other data—such as U.S. Census data and physical characteristics of the land—in a geographic information system (GIS), a computer system used to manipulate and analyze spatial data. We used these combined data sets to create computer models to explore the underlying causes of land change and how this change varies from place to place across the Twin Cities.

The research on which this article is based was supported in part through a grant from CURA's Faculty Interactive Research Program, with additional support from the Minnesota Pollution Control Agency and from the University of Minnesota's Agricultural Experiment Station, College of Liberal Arts, McKnight Land-Grant Professor Program, and Minnesota Population Center. This research contributes to the larger body of knowledge on urbanization and can help policy makers and various publics make better decisions.

Land-Cover Classification and Change Mapping

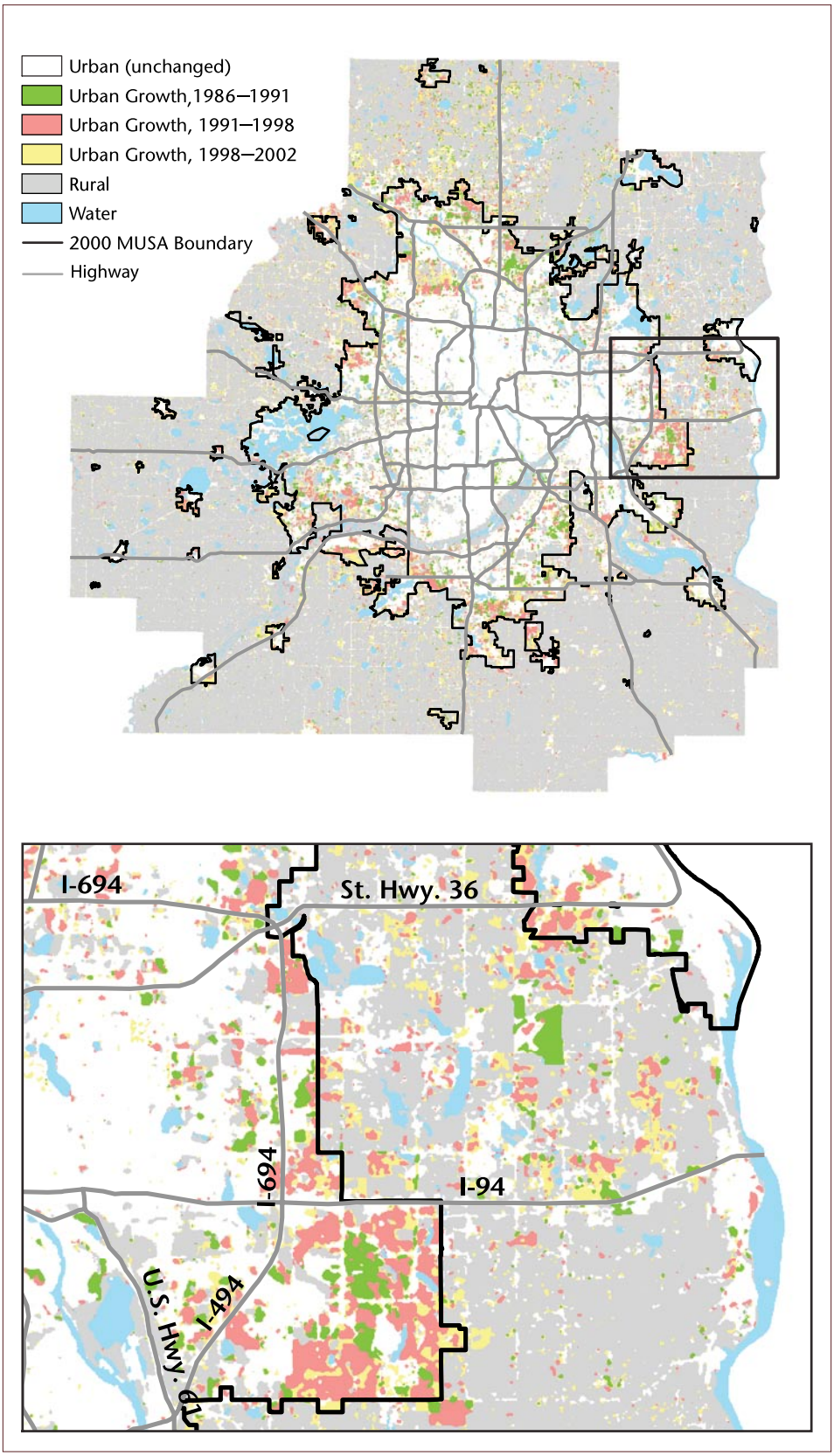
Historically, aerial photography has been an important source of information on land cover (the physical surface and vegetation) and land use (human occupation and applications). The cost of aerial photography acquisition and interpretation of cover types, however, is prohibitively expensive for geographic areas larger than a small city or township. An alternative is to acquire the needed information from digital images of the Earth taken from satellites. This approach has several advantages. First, the broad view of a satellite provides coverage of large, multi-county geographic areas. Second, by comparison with printed photos, the digital form of the data lends itself to more efficient analysis using computers, and the classified data can be used in geographic information systems. Finally, land-cover maps can be generated at considerably less cost than by other methods, such as ground surveys or aerial photography interpretation, which usually require a good deal of human expert knowledge and time.

We used data from a satellite called the Landsat Thematic Mapper (TM) to develop maps of both land cover and impervious surfaces in the Twin Cities metro area for 1986, 1991, 1998, and 2002. The Landsat images resemble those taken with a digital camera, but the satellite senses both visible light (the colors that humans see) and infrared light (wavelengths longer than those our eyes are sensitive to). Each image is composed of millions of picture elements, or *pixels,* each equivalent to a 30-by-30-meter area on the ground, or about one-quarter acre.

Land-Cover Classification. The most common use of remotely sensed imagery is to convert what the satellite sees (visible colors and infrared) into categories of land on the ground. Our land-cover classification system has seven classes: agriculture, forest, grass, urban, water, wetlands, and extraction (i.e., gravel mining). In addition to using the Landsat TM remotely sensed imagery, we collected samples of each land-cover class on the ground to understand what each class looked like from space and to test how well the classification system maps land cover in the real world. We then used specialized statistical methods to classify each pixel in the imagery according to one of the land-cover classes. After classifying imagery for individual years, we mapped changes in land cover for the periods 1986 to 1991, 1991 to 1998, 1998 to 2002, and 1986 to 2002.

Overall, this approach produced very good results. For the four individual years, 94 out of every 100 pixels were classified correctly (94% classification accuracy). We also used high-resolution aerial photography to double-check the maps created from remotely sensed

Figure 1. Urban Growth in the Twin Cities Metropolitan Area, 1986 to 2002



imagery against what was actually on the ground. With few exceptions, the areas identified as having changed from agriculture or rural to urban were identified correctly. It should be noted that we have classified land *cover,* not land *use*. Although they are related and often similar, there are semantic and practical differences between land use and land cover. A single land use such as "urban," for example, can include multiple land-cover types, including buildings, streets, grass, and trees.

We used the classified imagery to create a map of the major land-cover types in the metro area (Figure 1). Between 1986 and 2002, the amount of urban land increased from 23.7% to 32.8% of the total area, whereas rural cover types such as agriculture, forest, and wetland decreased from 69.6% to 60.5%. The majority of these changes are at the periphery of Minneapolis and St. Paul and their first-ring suburbs. Figure 1 illustrates one of the major advantages of satellite data classification: We can produce a map of where land-cover change has occurred.

We used the change map to calculate change statistics across land-cover classes for the four years (Table 1). From 1986 to 2002, urban area increased by 173,000 acres (9.1%), whereas agricultural area decreased 136,000 acres (7.1%), forest area decreased 22,000 acres (1.1%), and wetland area decreased 17,000 acres (1.0%). In relative terms, the amount of urban area in the Twin Cities metro area increased 38.5% from 1986 to 2002, with the greatest increase occurring from 1991 to 1998. During the same period, agriculture, forest, and wetland decreased, respectively, by 15.0%, 7.9%, and 12.4%.

Impervious Surface. In addition to considering changes in different kinds of land cover, it is useful to examine variations within specific classes. One increasingly critical case is the amount of impervious surfaces in the landscape. Impervious surfaces are those that water cannot infiltrate and are primarily associated with building rooftops and transportation infrastructure such as streets, highways, parking lots, and sidewalks.

Our approach to estimating and mapping impervious surface area is based on a strong relationship between the amount of impervious surface in a given area and the amount of "greenness" in satellite images of that area. Greenness is determined largely by the amount of green vegetation on the ground and is therefore inversely related to the amount of impervious surface. We modeled the relationship between greenness and percentage of impervious area using statistical methods to estimate the amount of impervious area in each Landsat TM pixel. In an urban area, there are three major land-cover types: vegetation, impervious surfaces, and water. Each kind of cover looks different to the satellite, enabling accurate estimation of the proportion of each pixel that is impervious. The resulting classification gave us a map that portrays a continuous range of impervious area from 0% to 100% for the entire Twin Cities metro area (Figure 2).

The next step in our investigation was to examine changes in the amount of impervious surface during the period 1986 to 2002. For the entire seven-county metro area, the percentage of impervious area increased from 9.0% in 1986 to 13.0% in 2002 (Figure 3). In general, increases in impervious area were primarily at the periphery of already developed areas. The greatest changes occurred in Anoka and Carver Counties, where the impervious area more than doubled. Conversely, in Ramsey County, the most densely populated county in the state, impervious area increased only slightly after 1991.

An additional advantage of the digital maps available from the Landsat TM classifications is the ability to generate maps and area statistics for smaller areas such as cities or townships. Figure 4 shows the City of Woodbury, a suburb east of St. Paul and one of the most rapidly growing areas in the state during the 1990s, which saw an increase from roughly 8% to 22% impervious surface.

In summary, information from satellite remote sensing can play a useful role in understanding the nature of land change and where it is occurring. Classification of the Landsat TM data also provides a means to map and quantify the degree of impervious surface area, an indicator of environmental quality, for large geographic areas and over time at modest cost. Both kinds of information are essential to planning for development and preserving our natural resources and environment, and are useful to urban planners and citizens. Further information, including maps and statistics from our research, are available at www.land.umn.edu.

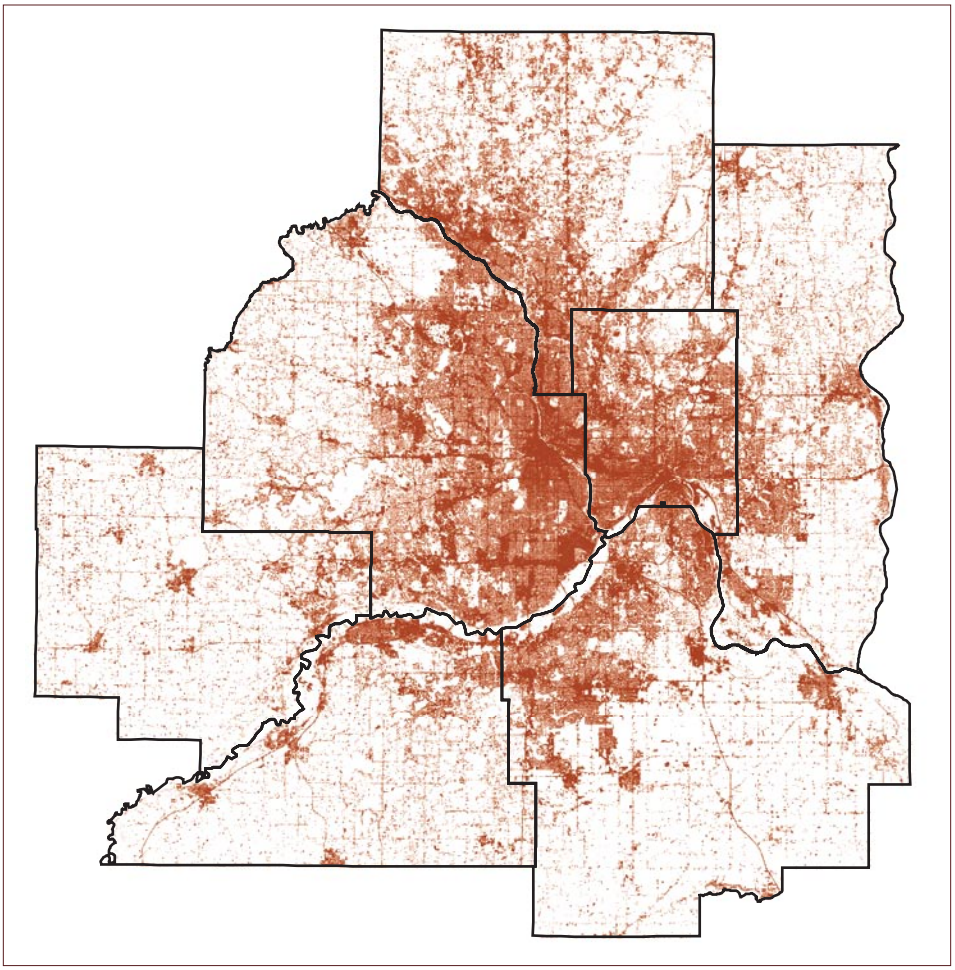
Modeling Changing Urban Landscapes

Our ability to measure, understand, and conceptualize urbanization at very fine spatial scales is evolving with our increasing ability to combine land-change maps from remotely sensed imagery with other kinds of geographic data, such as U.S. Census information. We can combine these various forms of geographic data with computer models to gain insight into the factors that influence urbanization. A perennial challenge for city planners, for example, is determining

Table 1. Summary of Landsat TM Classification Area Statistics for the Twin Cities Metropolitan Area, 1986, 1991, 1998, and 2002

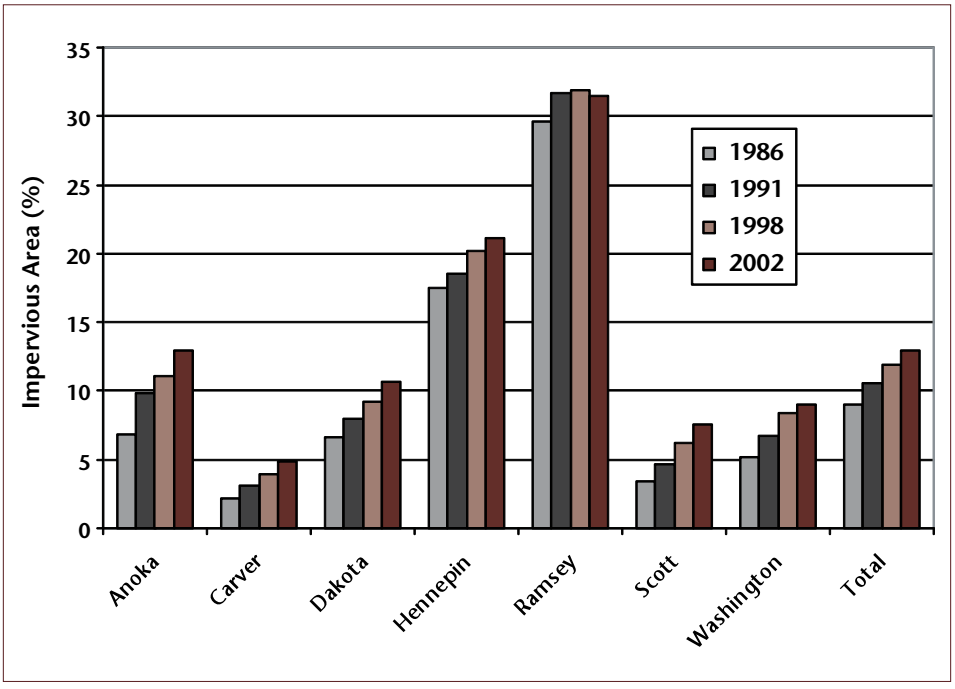
Land-Cover Class	1986		1991		1998		2002		Relative Pct. Change 1986–2002
	Area (acres)	Pct. (%)	Area (acres)	Pct. (%)	Area (acres)	Pct. (%)	Area (acres)	Pct. (%)	
Agriculture	902,000	47.4	838,000	44.1	781,000	41.1	766,000	40.3	–15.0
Urban	452,000	23.7	494,000	26.0	588,000	30.9	625,000	32.8	+38.5
Forest	279,000	14.6	274,000	14.4	262,000	13.7	257,000	13.5	–7.9
Wetland	143,000	7.6	158,000	8.3	136,000	7.1	126,000	6.6	–12.4
Water	104,000	5.5	114,000	6.0	111,000	5.9	106,000	5.6	+3.5
Grass	18,000	1.0	19,000	1.0	17,000	0.9	16,000	0.9	–9.7
Extraction	4,000	0.2	6,000	0.3	7,000	0.4	6,000	0.3	+42.6

Figure 2. Impervious Surface Area Classification for the Seven-County Twin Cities Metropolitan Area, 2002



Note: Impervious surface area is mapped as a continuous variable from 0% to 100%, with darker color denoting a higher degree of impervious surface area.

Figure 3. Changes in the Percentage of Impervious Surface Area from 1986 to 2002, by County



where and how much urban development will occur in the future. Although local and state governments control development in a broad sense through zoning and incentives, individual landowners have much latitude in where and how much property to develop.

We created two stylized models of where (location) and how much (quantity) development is likely to occur in the Twin Cities metro area. We used two related modeling methods, statistical spatial regression and cellular modeling, to explore urbanization in the metro area from 1986 to 1998 to better understand the urban development process and create tools that can be used to predict future land use.

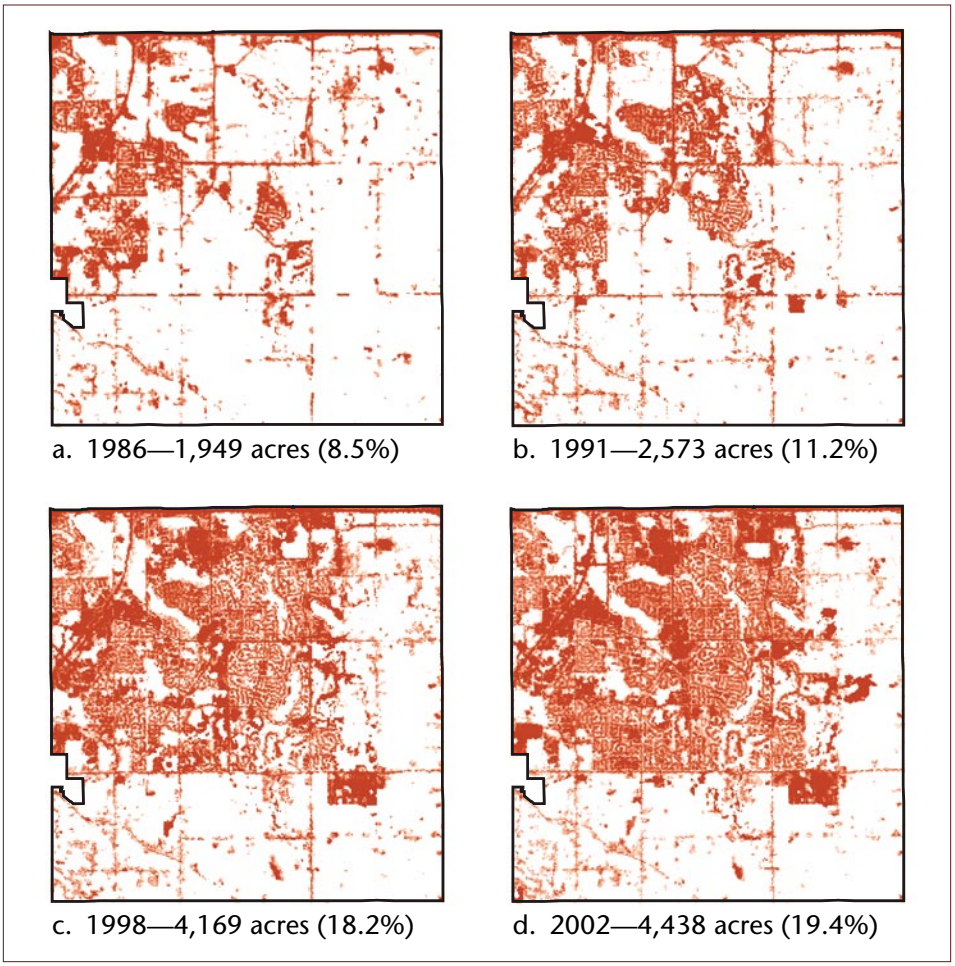
Modeling urbanization is very difficult because it is a complicated process that is contingent on a host of social, political, cultural, economic, and ecological influences. That said, urbanization in the Twin Cities metro area can be conceived of as a "bow wave"[1] of development pushing outward from existing urban areas. This bow wave operates according to two general principles: (1) development expands outward from current urban areas and (2) urbanization is more likely in some places than others depending on a range of social and ecological factors.

The first principle can be termed the "birds of a feather" rule, in that new development tends to occur near existing developed land. Building new properties adjacent to currently developed areas is generally less expensive because infrastructure such as roads and utilities is easier to extend from current infrastructure than it is to build as a stand-alone system. The desirability of a house in a given location is also a function of nearby amenities—such as roads, schools, infrastructure, and shopping—that require a critical mass of people in close proximity. Perhaps most important, many of the factors that influence the siting of development in a given place are usually still in force in adjacent areas, which leads to the second general rule.

The second principle governing the bow wave of development posits that the likelihood of any given parcel of land being developed is a function of socioeconomic and environmental characteristics that vary over the landscape. These include inherent features of a plot of land, such as its size or the

[1] This term originated with Fraser Hart, professor of geography at the University of Minnesota.

Figure 4. Impervious Surface Classification Maps for the City of Woodbury, 1986 to 2002



Note: Impervious surface area is mapped as a continuous variable from 0% to 100%, with darker color denoting a higher degree of impervious surface area.

ease with which it may be cleared and leveled for erecting buildings. These characteristics also relate to external factors controlled by the location of the land parcel in the broader spatial organization of the landscape, such as the school district or the distance to important market and employment centers. Therefore, although the bow wave of development flows outward from areas of current development across the landscape, all other things being equal, it occurs earlier in a desirable school district and later in areas with fewer amenities.

Of course, there are exceptions to these two general rules. Counteracting the birds of a feather effect, for example, is the fact that people are willing to pay more for properties that are not hemmed in by development. Similarly, urbanization can fall victim to its own success—for example, when so many homeowners are attracted to an area with less crowding and traffic that they create the crowding and traffic they sought to avoid in the first place. Development also can leapfrog over certain areas entirely, for reasons ranging from restrictive zoning to market speculation, personal situation, or happenstance.

Despite these exceptions, these two general principles serve as a useful way to conceptualize urbanization in the Twin Cities metro area. They also suggest two different, yet related, modeling strategies for understanding urbanization, spatial regression, and cellular modeling. Cellular modeling relies on the first principle, that development expands outward from existing urban areas, whereas spatial regression modeling relies on the second, that development is more likely in some places as a function of a range of social and ecological factors.

Spatial Regression Modeling. We used statistical spatial regression to assess the relationship between urbanization in a location (measured by land cover or impervious surfaces) as a function of social and environmental factors for that location. Although certain factors that influence urbanization—such as "this is a nice neighborhood"—are intangible, we can measure proxies, such as distance to the nearest lake or access to schools that perform well on standardized tests. More important, GIS allows us, for every single location (or every pixel, in this case) in the metro area, to analyze the relationship between the urban land use and various explanatory factors. Spatial regression is designed to use, and deal with the challenges imposed by, geographically referenced data. In aggregate, we can develop an overall view of the importance of these various factors in explaining the incidence of urbanization.

Regression analysis creates a mathematical model of the relationship between some measure, called the *dependent* variable, and a series of *independent* variables. We measured the dependent variable of urbanization in two ways: either by percentage of impervious surface or by the incidence of the urban land class derived from the remotely sensed imagery. We can determine the strength of the apparent relationship between the percentage of impervious surface and the occurrence of urban land as a function of certain factors (the independent variables in our model) that vary across the Twin Cities metro. We identified a number of factors important to urbanization by examining the research literature and speaking with households, policy makers, and developers in the region (Table 2). This list is by no means complete, but instead represents an array of factors that range from whether a particular location falls within an area enrolled in agricultural land protection programs to the test scores of its school district. Furthermore, it is important to bear in mind that this form of analysis determines *correlation,* not *causation,* and these relationships only make sense within a broader discussion of the larger social, economic, and policy contexts of urbanization. Some relationships between urban development and social and environmental factors are seemingly obvious, whereas others are indeterminate.

As expected, there are strong relationships between urban development and areas in the Twin Cities metro targeted by land-use policies. This is evident in the strong negative relationship between urban land use and areas excluded from development by local,

state or federal laws (– – –) or areas with high levels of enrollment in state or federal agricultural protection programs (– –). These forms of land protection are explicitly designed to prevent development and they generally work well in the metro area. Conversely, there is a strong positive relationship (+ + +) between development and location within the Metropolitan Urban Services Area (MUSA). The regional planning authority, the Metropolitan Council, implemented MUSA in the 1970s to encourage efficient growth and use of roads, sewers, and transit in the region. As intended, it is difficult to develop land outside of the MUSA because providing essential services such as sewage treatment is expensive.

We found that development varies by county in the metro area. Location in Anoka and Scott Counties has a positive (+ +) or weakly positive (+) relationship with both impervious surfaces and urban land cover, which indicates development was more likely in these regions. Location in Carver, Dakota, and Washington Counties also has a positive, although somewhat weaker, relationship with development. Location in Hennepin County has no apparent relationship with development (•). Ramsey County is the only location with a negative relationship with new development (– –). Although these differences among counties likely relate to a number of features—such as variation in land-use policies or taxes—the key determinant is likely the availability of land. Ultimately, however, the spatial regression analysis only points to further avenues of inquiry, such as considering counties one-by-one in terms of their taxation regime or incentives available to land developers.

In addition to policy considerations as such, we also examined median income as a proxy for socioeconomic variation over the landscape. Income has a strong negative relationship (– – –) with impervious surfaces and a positive relationship with development. Although it is not advisable to generalize too much with such a gross socioeconomic indicator as median income or to generalize across entire cities, residents in the metro area at lower income levels are found primarily in the cities of Minneapolis and St. Paul. Despite the Twin Cities being a very tree-rich region, these heavily developed areas have a greater proportion of land devoted to transportation, commercial, and industrial uses associated with impervious surfaces. Conversely, higher-income residents can generally be found in areas with larger, more vegetated parcels common to the suburbs. The same income dynamic is at play in the positive relationship between urban land use and development (+ +), given that the bulk of new development is occurring outside the core Twin Cities.

The relationship between urban land use and proximity to the nearest of either Minneapolis or St. Paul is strongly positive (+ + +), which suggests that the likelihood of development increases as a location is closer to either of the Twin Cities. This is in keeping with the expectation that urban land cover is more likely near large market centers, as they are hubs for employment and amenities such as sporting events and the arts. A similar logic holds true for proximity to the nearest water body (+) or to parkland, which shows a strong positive (+ + +) relationship with urban land use and positive (+ +) relationship with impervious surfaces. People like to live near water and parks, and land developers are happy to oblige. It is important to note, however, that in the case of parks, the reverse can also hold true in that we are more likely to situate parks where people live. This highlights once again the caveat that correlation does not necessarily imply causation.

Soil quality and slope are two other, more subtle, environmental features that affect development, although far less in the Twin Cities metro area than in other locales given the relative uniformity of the landscape here. There is a weak negative (–) relationship between slope and impervious surfaces, and no discernable relationship with urban land use. Slope of land is a tricky factor to interpret because although some builders seek out areas with greater slope for their potential

Table 2. Relationship between Impervious Surface Area or Development State and Selected Social and Environmental Factors in the Twin Cities Metro Area, 2000

Relationship to. . .		Factor and description
Impervious surface area	Development state	
– – –	– – –	**Excluded areas.** Is the location excluded from development by local, state, or federal law?
– –	– –	**Agricultural protection.** Does the location fall within an area enrolled in an agricultural protection program designed to reduce development?
+ + +	+ +	**MUSA.** Does the location fall within the Metropolitan Urban Services Area?
		County. In which county does the location fall?
+ +	+	Anoka
+	+	Carver
+	+	Dakota
•	•	Hennepin
– –	– –	Ramsey
+ +	+ +	Scott
+	+	Washington
– – –	+ +	**Income.** Median household income in dollars for the location.
+ + +	+ + +	**Twin Cities.** Proximity to the nearest of Minneapolis or St. Paul.
+	+	**Water.** Proximity to the nearest water body greater than three acres in size.
+ +	+ + +	**Park.** Proximity to the nearest park.
+ +	+	**Soil.** Quality of soil for agriculture in the location.
–	•	**Slope.** Slope of the land in that location

Note: Relationships vary from strongly positive (+ + +) to no apparent relationship (•) to strongly negative (– – –). A positive relationship means that the factor is correlated with greater impervious surface or development, whereas a negative relationship means that the factor is correlated with less impervious surface or development.

to provide scenic views, these areas are also difficult locations on which to build infrastructure given the ruggedness of the terrain. There is a positive (+) relationship between agricultural soil quality and urban development, as these soils are comparatively easy locations on which to build, especially if they have been farmed.

Cellular Modeling. A *cellular model* divides the Earth's surface into very small *cells* or units of land (in our case, pixels from remotely sensed imagery). The purpose of the model is to examine the current land cover in a cell and predict its land cover at a later time. Future land cover is modeled according to two conditions: the land cover that presently exists within the cell and the land cover of neighboring cells. Each of the different land-cover classes determined by classifying the Landsat TM imagery has its own set of rules based on these two conditions.

The first condition, existing land cover, is very important. A cell with water is essentially guaranteed to remain water from one year to the next. A cell that is urban this year is very likely to remain developed next year given the permanence of housing, although there is a very small chance it will revert to undeveloped land through abandonment or reversion to natural uses. In comparison, a cell with forest, extraction, grass, or wetland is less likely to remain the same next year because it can be developed fairly easily. Agricultural cells are the most likely to convert to urban land cover from one year to the next. Finally, there is a remote possibility that a non-urban cover such as agriculture or forest can switch over to another non-urban cover.

The second condition, surrounding land use, takes into account the extent to which a cell is influenced by what is going on around it. All other things being equal, an agricultural cell that is surrounded by other agricultural cells is more likely to remain in its current state than one that is surrounded on all sides by urban land cover. The same holds true to a lesser degree for forest, grass, wetlands, and extraction. Water, as per the first rule, is fairly immune to change as a function of surrounding land cover.

The model we used extracted these rules by examining transitions between different land-cover classes in the Twin Cities for the period from 1986 to 1991. The model then projected forward the process of development to the year 1998. In other words, the model used past experience to predict where (location) and how much (quantity) development would occur in the future.

We determined how well this approach performs by comparing the actual Twin Cites landscape in 1998, as derived from the Landsat TM imagery, to the model projection of the landscape in 1998. It is important to note that the model only had access to land-cover maps from 1986 and 1991 as a basis for predicting what future land cover would look like. Figure 5 shows where the model projected land cover correctly and, more important, incorrectly. The white areas are where the model projected urban cover correctly and the gray areas are where it predicted non-urban land cover correctly (that is to say, agriculture, extraction, forest, grass, water, and wetlands). Overall, the model predicted the majority of urban versus non-urban land cover fairly well, although it makes two kinds of errors. First, the areas in blue are those where the model assumed there would be urban land cover in 1998 when in fact there was no such development. Second, the areas in red are those the model predicted would remain undeveloped when they were actually developed by 1998. The model is far more prone to the second kind of error because it missed the explosive growth of the Twin Cites in the 1990s, which was fueled by population expansion and an increase in house lot sizes compared to development in the earlier 1986 to 1991 period on which the model was based.

The model performed far better when we knew how much growth to expect, but not where to expect it (Figure 6). This situation is analogous to a planner estimating the quantity of future development and having the model predict where this development will likely occur. Here the model used the same rules as before to determine *where* development is likely to occur in 1998, but we knew *how much* land was developed based on our knowledge of actual land cover in 1998. Figure 6 shows that this model predicted with great accuracy where

Figure 5. Comparison of Cellular Model of Twin Cities Urbanization with Actual Urbanization from Landsat TM Imagery based on Estimated Quantity of Urbanization, 1986 to 1998

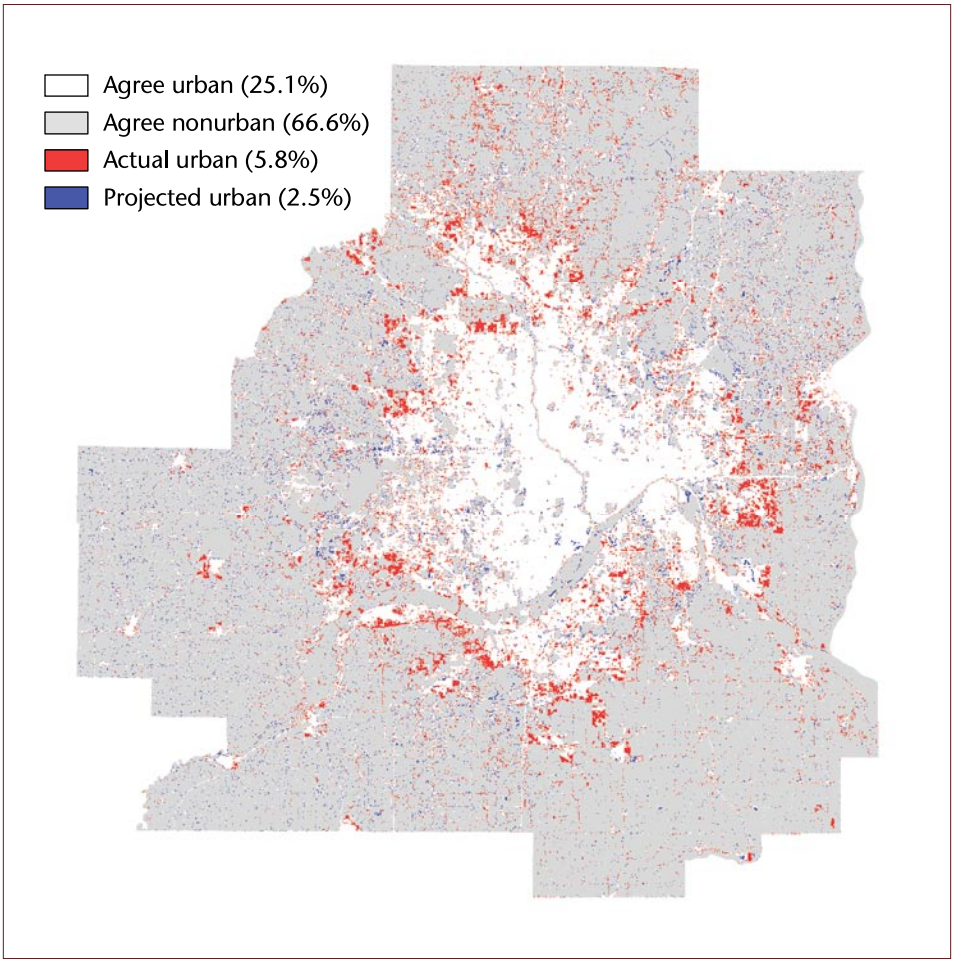
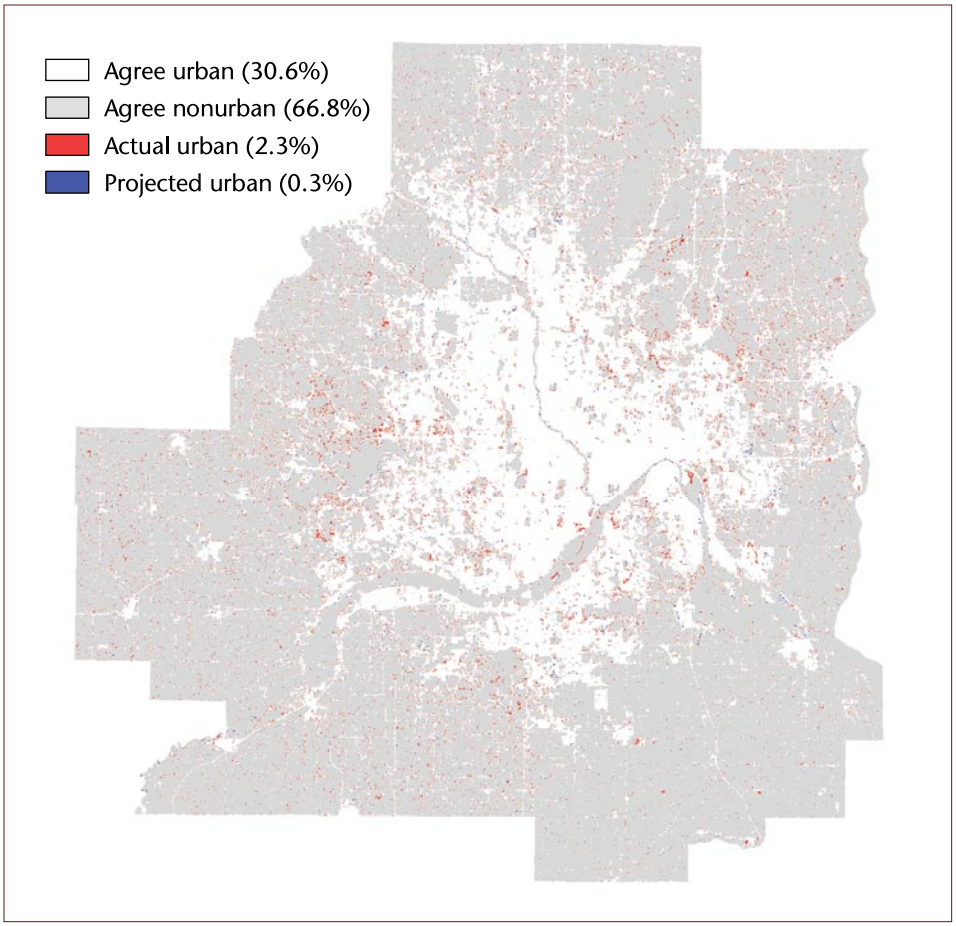


Figure 6. Comparison of Cellular Model of Twin Cities Urbanization with Actual Urbanization from Landsat TM Imagery based on Actual Quantity of Urbanization, 1986 to 1998



development actually occurred in 1998. The incidence of either kind of error (predicting urban areas where there are none, or non-urban areas where there are in fact urban areas) is far lower when we know how much urban development to expect.

Policy Implications

The use of remote sensing, geographic information science, and modeling illustrate the policy implications of land use. Of the various lessons drawn from this research, four in particular stand out for the Twin Cities metro area. First, the region is seeing significant changes in both the quality and quantity of urban and rural land covers. Second, and related to the first, the amount of impervious surface in the metro region is also on the rise in particular sub-areas. Changes in both land cover and impervious surfaces have attendant social and ecological impacts. Third, land and resource policies play a key role in the trajectory of land-cover change. Finally, although it is important to understand the spatial nature of land change, to predict this change it is very important to develop strong estimates of future population growth.

First, based on the results from the classification procedure, the landscape of the Twin Cities metro is increasingly urban at the cost of agricultural land and forest cover. As noted above, urban land cover increased from less than one-quarter to more than one-third of the metro area at the expense of agriculture, forest, and wetlands. In other words, 1 out of 10 rural or natural areas was lost to urbanization in less than two decades, and the rate at which this conversion occurred increased over time. Perhaps more important, in addition to there being significant conversion of agriculture and forest cover to urban land uses (which is an almost necessary precondition to continued growth and vitality of the Twin Cities metro area), the remaining non-urban land cover is increasingly fragmented. We found that although landscape diversity (the number of different types of land cover in a given area, such as a zip code) has remained relatively constant since 1986, fragmentation of this land cover has increased, especially for agricultural land and forest cover. In other words, most areas have the same mix of land cover over time, but the average size of agricultural and forest tracts is decreasing as development chops them up into smaller and smaller pieces. This land-cover fragmentation has a host of socioeconomic and ecological impacts, leading to increased traffic and infrastructure costs, for example, while impairing ecosystem functions such as providing natural habitat and water purification.

Second, impervious surfaces are increasing along with the increase in urban land cover. Imperviousness directly affects the amount of runoff to streams and lakes, and is related to nonpoint source pollution and the water quality of surrounding lakes and streams. It is also related to energy balances and urban heat island effects, where the sun's heat is trapped within a city and then released at night. It also affects the aesthetics of landscapes and leads to habitat degradation and fragmentation. The increasing amount of impervious surface area is directly related to conversion of rural landscapes to urban and suburban land uses, but the linkage is not always clear, as some forms of development produce less impervious surfaces than others.

Residents, developers, and governments must remain mindful of the amount of impervious surface assocated with various kinds of urban land cover. Impervious surface area maps provide one of the best measures of the potential for imperviousness impacts and are useful inputs to urban planning and management activities. A key advantage of the method we used is that although a majority of pixels in urban areas are mixtures of two or more classes (e.g., different housing densities), by using a range from 0% to 100%, we avoid the errors associated with assigning a mixed pixel to one class in a set of discrete classes (e.g., having to distinguish between low- and medium-density housing). Another advantage, and a key difference between our classifications and maps produced in most other ways, is that by mapping impervious area on a scale of 0% to 100%, we have the ability to display the results in various combinations and for other purposes. To describe the relationship between amount of impervious area and environmental quality of watersheds, for example, we could devise a system that

identifies protected (0–10% impervious surface), impacted (10–25% impervious surface), and degraded (25–50% impervious surface) watersheds.

Third, policy exerts considerable influence on the trajectory of land-cover change. The spatial regression analysis showed that of the various factors that can influence urbanization, among the most powerful are policy instruments that guide development. Conservation easements and agricultural protection programs provide a strong restraint on urban development. Similarly, the Twin Cities metro area is one of the few large metropolitan regions in the United States with a strong regional planning body, the Metropolitan Council. By controlling the provision of key infrastructure such as sewer service and public transportation, the Metropolitan Council can exert a good deal of pressure on urban form.

More broadly, spatial regression is useful for policy development because it offers a means to unify differing kinds of spatial data with the social and environmental characteristics of the landscape that bear on development. In addition, because it is based on standard statistical methodology, spatial regression gives us a vehicle to test our understanding of various development factors and identify relationships that require further investigation. Spatial regression sheds light on how the importance of these factors can vary over space, in essence adding context to the bow wave conceptualization of urbanization by highlighting how social and environmental forces play out, and again pointing out areas for further investigation.

Finally, although it is important to understand the spatial nature of land change, to predict this change it is very important to develop good estimates of future population growth. Knowing *where* change will occur is important, but so is knowing *how much* change will occur. Cellular modeling illustrates this need well. Although this approach is useful because it requires very little data (two land-cover maps are all that is needed), the model does far better with realistic estimates of the quantity of change. This model does not incorporate much of what is known about urbanization, such as the importance of policy initiatives or economic forces, but it does incorporate spatial relationships by assessing the relationships between neighboring land-cover types and the chances that land will be transformed from one kind of cover to another. It is therefore a straightforward interpretation of a key aspect of the bow wave conceptualization of urbanization—namely the role of incremental growth outward from existing urban areas—but it works best with accurate population estimates.

Conclusions

Our research has a number of immediate policy implications, and it has further ties to the policy community through ongoing consultation with staff at the Metropolitan Council. We have been working with the Metropolitan Council and the Minnesota Pollution Control Agency, as these agencies find the maps of land cover and impervious surfaces to be useful inputs to hydrology and runoff models and planning future development. Satellite remote sensing provides a cost-effective alternative for obtaining such information when the costs of traditional mapping approaches are increasing and budgets are declining. By working with staff at the Metropolitan Council and with past and present documentation produced by the council, we also can identify likely scenarios for future growth, tied to population and socioeconomic forecasts and paying particular attention to the role of policy instruments such as zoning, transportation, and infrastructure provision. We also can identify the scenarios of interest to stakeholders represented by the Metropolitan Council and, similarly, the data and growth models of greatest use to them.

The severity and nature of the impacts of urbanization are intimately related to the pace and spatial configuration of how urban land is developed from rural and natural land cover. Our current form of urbanization, with its emphasis on decentralized land use and development, offers key benefits to the region but with social and ecological costs. The combination of remote sensing, geographic information systems, and spatial modeling offers a powerful and efficient way to describe and understand the processes of urbanization in the Twin Cities. These range from maps of land cover and impervious surfaces to computer models that allow us to explore the underlying causes of land change in the metro area. This research adds to our knowledge of urbanization and, perhaps more important, can help various publics and policy makers find ways to ensure that the Twin Cities metropolitan area remains a sustainable and enjoyable place to live, work, and play.

Steven Manson is assistant professor in the Department of Geography at the University of Minnesota. His research focuses on geographic information science, modeling land change in rural and urban environments, global climate change, socioeconomic vulnerability, and understanding complex systems. **Marvin Bauer** is professor in the Department of Forest Resources at the University of Minnesota. He is a recognized leader in remote sensing and has long conducted groundbreaking research on using digital remote sensing to inventory, monitor, and analyze land, vegetation, and water resources in Minnesota.

This study was supported by a grant from CURA's Faculty Interactive Research Program. The program was created to encourage University faculty to carry out research projects that involve significant issues of public policy for the state and that include interaction with community groups, agencies, or organizations in Minnesota. These grants are available to regular faculty members at the University of Minnesota and are awarded annually on a competitive basis. Additional funding for this research was provided by the Minnesota Pollution Control Agency and by the University of Minnesota's Agricultural Experiment Station, College of Liberal Arts, McKnight Land-Grant Professor Program, and Minnesota Population Center.

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University of Minnesota Launches Consortium for Metropolitan Studies

The University of Minnesota recently established the Consortium for Metropolitan Studies, an effort to link the various centers, programs, institutes, faculty, and staff at the University engaged in teaching, research, and outreach efforts related to understanding metropolitan change and development. According to a May 2006 report by the consortium's Interim Steering Committee, the mission of the consortium is "to strengthen the University's overall contribution to understanding metropolitan-urban-suburban issues by enhancing and extending the work of our existing programs and strengthening the University's connections to those individuals, communities, and activities in Minnesota, the region, and nationally, who are working with those issues on a daily basis."

The report details a broad range of consortium activities, including increasing the level of engagement between University activities and public- and private-sector efforts in Minnesota; emphasizing interdisciplinary and collaborative approaches; supporting research and educational activities; and sponsoring workshops, conferences, and other public events to engage with and facilitate the broader public discussion in Minnesota on metropolitan, urban, and suburban issues.

CURA director Tom Scott, who chaired the Interim Steering Committee, stated, "Those of us who were on the Interim Steering Committee are very optimistic about the potential the consortium has for strengthening the research, teaching, and outreach work of our separate institutes, centers, and programs, and for greatly enhancing the University's role in urban and metropolitan issues in this community and elsewhere."

A call for nominations was issued in July for a faculty director to lead the consortium. The consortium will also be advised by an executive committee and a consortium advisory council. The director, executive committee, and advisory council will be appointed by Senior Vice President for System Academic Administration Robert Jones this fall.

For more information about this initiative, visit the consortium website at www.academic.umn.edu/system/projects/cms.html.

New Publication

***Politics and Freeways: Building the Twin Cities Interstate System*. By Patricia Cavanaugh. Minneapolis: CURA and the Center for Transportation Studies (CTS), 2006. CURA Publication No. 06-2.**

CURA is pleased to announce the availability of *Politics and Freeways,* a new publication that reports on a study of the changing politics and participants in Twin Cities–area interstate decision making since the 1950s. The project was jointly sponsored by CURA and the Center for Transportation Studies (CTS), and was advised by an expert committee including former Minnesota Department of Transportation (MnDOT) commissioner and CTS director Richard Braun and former MnDOT officials Peter Fausch and Jim Newland. The report was written by Patricia Cavanaugh, a Ph.D. candidate in the Department of Political Science and a research assistant at CURA.

"Transportation systems cannot be planned, developed, or implemented without contending with the politics in which they are always embedded," Cavanaugh noted during a presentation of her findings at the CTS Seventeenth Annual Transportation Research Conference, held May 24–25 in St. Paul. Cavanaugh examined local cases representing different eras in the history of the interstate program. The era that launched the interstate in the 1950s was a period of great optimism and public support, she said, including backing by Minnesotans for gas tax increases. The protest era of the 1960s and 1970s, in contrast, saw the rise of citizen opposition and environmental advocacy. Citizen advisory committees and other groups emerged to fight freeway expansion, skeptical because of the visible effects of the interstate in other urban communities. The Minnesota Legislature also became more involved in major transportation project decisions during this time. The next—and current—era is known by many as the "era of falling behind."

Cavanaugh focused on seven case studies spanning five decades, from which she identified three areas of political tension. First is the timeframe: Major projects take decades, but citizens and elected officials operate under a shorter outlook. Second, state departments of transportation look at a broader geographic area than do cities and neighborhoods. Although both views are appropriate, Cavanaugh said, the divergence leads to conflict. The third area—problem definition—is the one with the most potential to be resolved through political means. Citizens may define a problem in terms of social or moral aspects—Interstate 35W expansion in the late 1980s, for example—whereas the Minnesota Department of Transportation (MnDOT) defines it in terms of reducing congestion. "When you're trying to solve different problems," Cavanaugh noted, "you're not even in the same policy debate." These types of differences were prevalent in all seven cases.

Cavanaugh also touched briefly on historical changes in leadership and funding. In 1981, the surface transportation bill had fewer than 10 earmarks, but recent bills have had several thousand.

Politics and Freeways: Building the Twin Cities Interstate System was jointly published by CURA and CTS. The report is available at www.cura.umn.edu/publications/Freeways.pdf. A limited number of hard-copies are also available from CURA.

This article is reprinted and adapted here with permission from the Center for Transportation Studies (CTS) at the University of Minnesota. A version of this article previously appeared in the July 2006 CTS Report, *available online at www.cts.umn.edu/publications/newsletters/index.html.*

Changing How Minnesota History Is Told: A Program Evaluation for Historic Murphy's Landing

by Jamie Peterson

Historic Murphy's Landing (HML) is an 88-acre living history museum owned and operated by Three Rivers Park District that depicts life in the Minnesota River Valley during the 1800s. Costumed interpretive staff at HML recreate history by sharing stories of the hardships settlers endured and guiding visitors through a village populated by historic buildings originally constructed in the 1800s (Figure 1). Field trips for school and childcare groups fuse the academic study of U.S. and Minnesota history with real experiences of life in the 1800s for children of all ages. These field trips provide an opportunity for teachers to complement their history curriculum and spark interest among children in learning history.

During the winter and spring of 2005, HML created new programs for children's groups that focused on four main areas of Minnesota and U.S. history: Children and Family Life, Fur Trade, Immigrant Journeys, and Village Trades. Each program included historical content that museum interpreters relayed to students through a combination of lecture, discussion, role-playing, songs, and hands-on activities. In addition, each program provided an opportunity for students to complete a craft project symbolic of some element of the program in which they participated.

Before the spring 2005 season of children's programming began, Kathy Dummer, site supervisor at HML, sought help from CURA's Community Assistantship Program (CAP) to find an outside evaluator for the programs. I was hired as a research assistant through CAP in June of that year to conduct a participant-oriented evaluation. The primary goals of the evaluation were to assess program implementation, understand how children experienced HML, examine how well HML programs met teachers' and chaperones' expectations, and offer recommendations to improve the programs. This article discusses both the evaluation process and the recommendations that resulted from the project.

Photo courtesy of Jamie Peterson

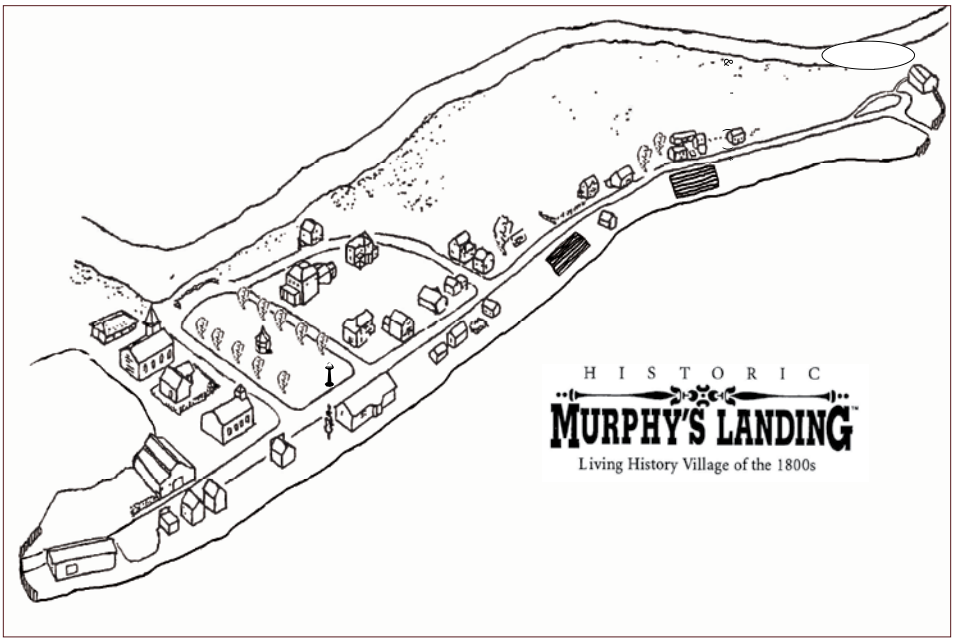
A school group participating in the Immigrant Journeys program at Historic Murphy's Landing takes part in a demonstration of how a log cabin was built in the 1800s.

After several initial meetings with staff, I formulated an evaluation plan that included a variety of activities, such as reviewing lesson plans and promotional materials, observing programs, talking with children and chaperones/teachers, developing and piloting evaluations for children and chaperones/teachers, and revising and administering the evaluations. The plan also included several formal and informal meetings with site supervisor Kathy Dummer, her assistant, and HML interpreters.

In undertaking the program evaluation, one of HML's goals was to increase the number of visitors and expand its programming, and staff requested preliminary results midway through the summer to more promptly improve their programming. Consequently, the evaluation proceeded in a more applied fashion, instead of adhering strictly to the schedule of a typical evaluation program, in which programs are held constant throughout the evaluation process. Based on preliminary results, staff discussed issues raised by the evaluations and interpreters broke into smaller groups to focus on a specific program, brainstorm solutions to these issues, and propose changes. If a solution to an issue was deemed feasible, the change was implemented right away. With this flexible evaluation approach, staff at HML were able to respond to evaluation results immediately, thereby improving the museum's programs and increasing the likelihood that visitors would have a positive experience and recommend HML to others.

After completing the summer evaluation process, I developed additional recommendations for improvements to

Figure 1. A Sketch Map of Historic Murphy's Landing



Map courtesy of Historic Murphy's Landing, Three Rivers Park District

HML programs. However, the summer evaluation reflected only the experiences of children visiting as part of childcare groups, not the experiences of children visiting with school groups. Because these groups have different expectations and because the programs offered during summer differ in some respects from those offered throughout the rest of the year, HML decided to continue the evaluation process into the fall.

After the fall evaluation process was completed, I provided final conclusions and recommendations. The results of the evaluation provided valuable insights to staff regarding how the programs were implemented, whether visitors' experiences met their expectations, and how the programs could be improved to increase visitor satisfaction. One of the major findings was that children and chaperones who visit in the summer with childcare groups and children and teachers who visit during the academic year with school groups have very different expectations and experiences at HML. Children in childcare groups expected more entertainment and were less engaged in the historical content of the programs. Chaperones with the childcare groups had fewer classroom management skills and expected a greater focus on educating children about history. Based on my own experience working in summer daycare programs, I was aware of the pressure chaperones in such programs typically experience. Chaperones often perform a delicate balancing act, trying to meet childrens' desires to be entertained while meeting parents' desires to educate their children. In contrast, children in school groups were less demanding of staff in terms of their expectations for entertainment and the children engaged more readily in the historical content of the programs. Teachers with school groups were more skilled in managing their children's behavior, and were less focused on children learning about history during their visit. This finding may seem counterintuitive; however, teachers seemed to view HML as either a reward for students who had already studied Minnesota history (in which case, the program was reinforcing knowledge) or as a way to pique children's interest in Minnesota history for subsequent lessons in school. The teachers did not expect HML to educate the children about history, they expected HML to make history come alive and give students a better perspective on life in the 1800s. In this respect, the programs at HML were more suited to school groups than childcare groups.

Accordingly, my recommendations included offering different programs to childcare and school groups and providing interpreters with training in classroom management skills. Many of the interpreters at HML displayed a wonderful depth of knowledge about history in the 1800s, but did not necessarily know how to teach young children or manage behavior issues. It appeared that it was assumed interpreters had, or would automatically acquire, these skills; they were not taught or developed. One program recommendation, therefore, was to train interpreters to manage students while onsite.

Another recommendation regarding programming was to revise lesson plans to include goals and objectives. Interpreters often have their own style of recreating history for students; however, the programs were often widely inconsistent across interpreters due to variation in personal styles. By creating objectives and goals to guide the programs and lessons, interpreters would have more stringent guidelines to follow regarding program content, but they would also have some flexibility to meet those goals and objectives using their preferred interpretive style. Additional program recommendations included modifying the programs to accommodate the mixed-age groups who frequently visited during the summer. Interpreters were often challenged to work with kindergarteners and sixth graders in the same group. Therefore, I recommended program revisions such as providing "easy" and "hard" tasks for younger and older children, respectively. Also, I recommended that children in these mixed-age groups be reminded that in the 1800s, older children were often responsible for younger children, and that older children be instructed to assist younger children if they finished a task quickly. Small program changes such as these can contribute to keeping older children engaged while still involving younger children in the activities.

One significant finding from the evaluation was that roughly three-fourths of the chaperones/teachers and nearly half of the children surveyed expressed dissatisfaction with the number of buildings the group visited. Although HML has more than 40 buildings on-site, within the village square area where most programs occur, there are only about 20 buildings. Because each program is structured around specific historical content and not simply a general tour of the HML site, groups typically visit only two to three buildings during a program. If groups were to tour the entire HML site, the children would have to walk nearly two miles and the program would be more of a long walking tour than an experience of life in the 1800s. Although this information was in the pre-visit information packet that groups received, children, chaperones, and teachers

often arrived at HML expecting to tour many more buildings than they actually did. Therefore, two major recommendations were to revise programs to include visits to more buildings and to improve communication prior to arrival regarding the number of buildings a group would visit during the program.

One issue with which interpretive staff consistently struggled was finding a balance between breadth and depth of content in HML programs. If the number of buildings a group visits during a program is increased, the depth of content would need to be reduced. A creative solution was implemented this past spring to address this issue. Visitors can now attend an "open day," held once every week. During this open day, groups may arrive early and tour the HML site independently, without participating in one of the structured programs. Groups are able to enter as many buildings as they wish and talk with interpreters in each building as long as they desire. This change is intended to address the issue of visiting "enough" buildings and covering "enough" content by letting chaperones and teachers determine how much the children see and learn.

Finally, one change to how programs are implemented arose after I observed an interpreter give an especially successful program to a childcare group. Midway through the program, the interpreter "checked-in" with the lead chaperone to ask how the program was progressing. Based on this short conversation, the interpreter was able to make slight modifications to the last half of the program to better meet the children's and chaperone's expectations. This midpoint check-in was included as a recommendation for all interpreters, as chaperones and teachers often made nominal requests and were pleased when they received a program more tailored to their desires, even if this involved only slight changes in the program.

As a result of the evaluation process, Kathy Dummer reports that programs at HML are now designed intentionally, based on actual feedback from visitors, instead of being designed by default, based on what staff think visitors want. In addition, interpreters now view themselves as professionals who are committed to continually revising programs to provide the best possible experience for visitors.

For more information on Historic Murphy's Landing and its programs, visit www.threeriversparkdistrict.org /outdoor_ed/murphys_landing/.

Photo courtesy of Jamie Peterson

During the Village Trades program, children practice a variety of trades typical of a nineteenth-century Minnesota town, including weaving, printing, blacksmithing, laundering, and running a general store.

Jamie Peterson is a doctoral student in the Department of Educational Psychology at the University of Minnesota. Her research interests include evaluating educational programs, as well as how informal and formal interactions between teachers and students can influence student learning.

This project was supported by CURA's Community Assistantship Program (CAP), which provides student research assistance to community organizations and government agencies in Greater Minnesota.

2006–2007 Faculty Interactive Research Program Awards

The Center for Urban and Regional Affairs is pleased to announce the recipients of CURA's 2006–2007 Faculty Interactive Research Program grants. The program was created to encourage University faculty to carry out research projects that involve significant issues of public policy for the state and that include interaction with community groups, agencies, or organizations in Minnesota. Grants are available to regular faculty members at the University of Minnesota, and are awarded annually on a competitive basis. This year, CURA received more than 40 applications and awarded grants to five proposals.

■ **David M. Levinson (Department of Civil Engineering), Job-Housing Mismatch: An Affinity Model of Worker-Job Matching.** Traditionally, travel surveys based on 1% of the population are used to understand travel behavior. Recently, much more complete data has become available to researchers and policy makers, allowing them to better understand job-housing mismatch in a region. The Longitudinal Employer–Household Dynamics dataset, available from the Minnesota Department of Labor, includes residence and employment location information for each employed individual in the Twin Cities metropolitan area (excluding self-employed and selected sales personnel). Using these data, as well as data from other sources, this project will analyze the relationship between people's choices of residence relative to their employment locations in the Twin Cities region.

This project will extend travel behavior research to help understand the characteristics of people's choices of residence relative to their employment locations. The central research hypothesis is that although travel time and income are important factors in where people live and work, other factors may help shape the commuting patterns observed in metropolitan areas. Certain residential neighborhoods produce more workers for a given employment district and in a given industrial classification than can be explained by travel time and income alone. By better identifying the causal factors in travel location, travel demand modelers, transportation planners, and engineers will be better able to address job-housing mismatches and imbalances between demand skills and worker skill sets.

■ **Susy S. Ziegler (Department of Geography), Land-Use Policy to Conserve Resources in Southeastern Minnesota.** Local, state, federal, and international organizations have made significant progress in recent decades to preserve open space and protect undeveloped land in Minnesota. However, conservation organizations, often working with limited resources, do not always have a plan for managing these properties. One environmentally sensitive area without a comprehensive management plan is the Zumbro River and Weaver Dunes area in the Upper Mississippi River Valley in southeastern Minnesota. Wetlands, tributaries to the Mississippi River, terraces, and upland sand dunes in the area contribute to a complex landscape that provides critical habitat for rare, threatened, and endangered species.

As part of a larger project to help inform planning decisions for long-term restoration and maintenance of this area, this project will use geographic information systems (GIS) to define, delineate, and catalog the functions of landscape elements in Wabasha County; analyze current land-use policies of selected towns on the Mississippi, Zumbro, and Whitewater Rivers; and propose land-use policy changes that incorporate an understanding of the dynamic nature of the various functions of the landscape. The long-term goal of this research is to help The Nature Conservancy, the Minnesota Department of Natural Resources, the U.S. Army Corps of Engineers, and other stakeholders make planning decisions to conserve the environmentally sensitive blufflands in the Upper Mississippi River watershed.

■ **Randall E. Hicks (Department of Biology, University of Minnesota at Duluth), Assessing the Impact of Microbially Influenced Corrosion on the Accelerated Loss of Port Transportation Infrastructure.** Shipping through the Duluth-Superior Harbor, the largest port in the Great Lakes, has a $200 million annual impact on Minnesota's economy. Steel sheet piling used for docks, bridges, and bulkheads in the port is corroding at an accelerated rate not seen at other ports within the Great Lakes. Replacing a 20-kilometer stretch of these structures may cost more than $100 million if the cause and possible remedies for the corrosion cannot be identified. An expert panel convened in fall of 2004 to examine the corrosion issue recommended further analysis to check for microbially influenced corrosion in the harbor.

Working with the Duluth Seaway Port Authority and the U.S. Army Corps of Engineers, this research project will attempt to confirm or eliminate the involvement of microbial consortia in the accelerated corrosion process taking place in the Duluth-Superior Harbor. The hypothesis that will guide the research is that species of iron-oxidizing and sulfate-reducing bacteria are present in greater abundance at accelerated corrosion sites in the harbor than at nearby sites in the St. Louis River and Lake Superior that show little or no corrosion. Information about the structure, composition, and activity of microbial communities in the Duluth-Superior Harbor will not only help identify the cause of accelerated corrosion, but also will be useful for designing, testing, and implementing mitigation efforts to reduce the loss of the harbor's transportation infrastructure.

■ **Patricia Avery, Benjamin Jacobs, and Mistilina Sato (Department of Curriculum and Instruction), Preparing Minnesota Teachers for Diverse Contexts.** Minnesota demographics are changing rapidly, as urban, suburban, and rural areas alike become increasingly diverse. During the past decade, more than half the total population growth in the state has occurred among Asian, African American, Latino, and American Indian populations. As a result, Minnesota schools are more

ethnically and culturally diverse than ever. At the same time, the teaching force in Minnesota remains predominantly White, creating a potential mismatch between teachers' expectations and experiences and students' cultural backgrounds and learning styles. Minnesota's teacher preparation programs are becoming more sensitive to the changing needs of diverse school populations and seek to better prepare teachers by heightening awareness of cultural issues and providing for culturally-responsive pedagogy.

As part of a collaborative effort among the University of Minnesota, Minnesota State University at Mankato, and the College of St. Catherine (representatives of the three institutional systems that provide teacher preparation in Minnesota), this research project will examine the critical teacher preparations experiences that contribute to the standards-based instructional practices of first-year teachers who are graduates of the three institutions. Using surveys, interviews, classroom observations, and document analysis, the project will seek to determine the relationships among teacher preparation program elements, new teacher learning, teacher support structures, and classroom performance in ethnically and culturally diverse school and classroom contexts. Findings of this study will influence teacher preparation program design throughout Minnesota and nationally, suggest recommendations for policy related to new teacher support and retention, and improve learning opportunities for students in Minnesota schools.

■ **Ann S. Masten (Institute of Child Development), Academic Risk and Resilience among Homeless and Highly Mobile Children.** The achievement of homeless and highly mobile children in urban schools has profound significance for regional and national policies and programs aimed at closing achievement gaps among school children and fostering positive development and success for all children. Many of the children at risk for academic and related problems in urban districts are highly mobile. Data recently reported by the Minneapolis Public Schools indicates large gaps between homeless and high-mobility students and other students in the district on attendance and achievement scores. And in the Twin Cities, as elsewhere, homeless and highly mobile children are disproportionately from minority cultural and ethnic groups. Addressing the large achievement gap between low-income and other children in the Minneapolis school district is unlikely until the issue of school success among homeless and high-mobility children is addressed.

A collaborative team of University of Minnesota and Minneapolis Public School researchers, working with shelter providers, will analyze predictors and patterns of achievement and attendance among homeless and high-mobility students. Using state-of-the-art longitudinal analyses and three years of data across all grades in the district, the team will examine patterns of academic difficulties and resilience over time. Data will show how key factors are related to changes over time in achievement, including attendance. Additionally, the team will collect more detailed data about a group of 5- and 6-year-olds living in a homeless shelter to examine more closely the risks and protective factors for successful school transitions. Findings will inform district initiatives to address achievement gaps and mobility issues, and also broader community efforts to promote success among homeless and high-mobility children.

22nd Annual Conference on Policy Analysis, October 18

The 22nd Annual Conference on Policy Analysis will be held Wednesday, October 18, 2006, at the Continuing Education and Conference Center on the University of Minnesota's St. Paul campus. The theme of this year's conference is "Visions for Minnesota's Future." The conference is intended to provide an opportunity for analysts and policy makers to gain insight into current trends and changes in the policy-making environment, explore emerging policy issues, and share ideas with policy analysts from around Minnesota.

This year's keynote speaker is Al Quie, former Minnesota governor and congressman, who will share his thoughts on the impacts of the politicization of the judiciary. A second keynote session will feature a discussion by a panel of experts on the issue of universal healthcare. The conference will also feature concurrent sessions on property tax reform, the impacts of immigration on public policy in Minnesota, wind energy, housing costs and affordability, public education financing, politics and the media, and socio-economic disparities in Minnesota's child protection system.

The conference is sponsored by the Economic Resource Group (ERG), a State of Minnesota consortium to promote the sharing of policy information, and the University of Minnesota's College of Continuing Education; and cosponsored by the Citizens League and the University of Minnesota's Humphrey Institute of Public Affairs. The registration fee is $125 if postmarked by October 4, or $140 if postmarked after October 4. Full-time students may register for $25 with a current class enrollment statement. For more information, visit www.cce.umn.edu/policyanalysis, e-mail conferences5@cce.umn.edu, or call Electra Sylva at 612-624-3708.

Municipal Wastewater Treatment: A Novel Opportunity to Slow the Proliferation of Antibiotic-Resistant Bacteria?

by Timothy M. LaPara, Sara J. Firl, Leslie J. Onan, Sudeshna Ghosh, Tao Yan, and Michael J. Sadowsky

Located on the Mississippi River in St. Paul, the Metropolitan Wastewater Treatment Facility is the largest treatment plant in Minnesota, averaging 180 million gallons of wastewater daily from 62 communities and 800 industries.

The discovery of antibiotics and their subsequent application to clinical medicine is one of the outstanding scientific achievements of the twentieth century. The tale of how antibiotics were discovered is one of scientific legend: Sir Alexander Fleming astutely recognized that a contaminated Petri dish actually contained a bacteria-killing mold. For his discovery of penicillin, Fleming shared the 1945 Nobel Prize in physiology/medicine with Sir Howard Florey and Ernst B. Chain.

The unique feature of penicillin (and other antibiotics) is not merely that it kills bacteria—there are many compounds that have such a capability—but that it specifically affects bacteria. This key feature is absolutely critical for the medical application of antibiotic therapy. Antibiotics administered to humans are lethal to disease-causing bacteria but do not impact the patient. This is possible because antibiotics act on features of the bacterial cell that are absent in humans. For example, penicillin prevents the formation of new bacterial wall materials; human cells do not even contain a cell wall.

During the last half-century, antibiotics have become pervasive in human medicine. Since the discovery of penicillin, a plethora of new antibiotics, semi-synthetic antibiotics, and synthetic antibiotics (antibacterials) have been discovered or developed (Table 1). These new drugs target different features of bacterial physiology, thus expanding the range of bacterial species that can be successfully treated with antibiotics. Antibiotics are also used extensively in agriculture and for other non-medical purposes. Low doses of antibiotics are often included in animal feed to promote growth and increase weight gain, as well as prevent the onset of

Table 1. Major Classes of Antibiotics and Antibacterials, and Representative Drugs in Each Class

Class	Representative Drug(s)
β-lactams	Penicillin, Amoxicillin, Methicillin
Aminoglycosides	Streptomycin, Neomycin, Kanamycin, Gentamicin
Macrolides	Tylosin, Erythromycin
Ketolides	Telithromycin
Tetracycline	Tetracycline, Oxytetracycline
Lincosamides	Clindamycin
Ansamycins	Rifampin
Glycopeptides	Vancomycin
Quinolones/fluoroquinolones	Nalidixic acid, Ciprofloxacin
Sulfonamides	Sulfamethoxazole

disease. Although reliable estimates are difficult to obtain, most scientists believe that approximately 70% of all antibiotics are used for agricultural purposes.

In this article, we report on a research project that investigated the role of municipal wastewater treatment facilities in the spread or control of antibiotic-resistant bacteria. The project was supported by a grant from CURA's Faculty Interactive Research Program, as well as grants from the Undergraduate Research Opportunity Program at the University of Minnesota. We hypothesized that the disinfection processes most treatment facilities use would adequately inactivate antibiotic-resistant bacteria in wastewater. However, our research suggests that treatment facilities, which are primarily designed to protect water quality, do not adequately prevent resistant bacteria from being released into the environment. We conclude that relatively simple changes in the design, operation, and regulation of municipal wastewater treatment facilities could substantially reduce the release of these bacteria and, we hope, slow the proliferation of antibiotic resistance among bacteria appearing in clinical patients.

A Brief History of Antibiotic Resistance

Antibiotic-resistant bacteria were discovered soon after the medical use of penicillin began. At the time, the development of resistant bacteria was largely viewed as inconsequential. If a patient had an infection that a resistant bacterium caused, then an alternative antibiotic was always available for effective treatment. However, some foresighted scientists warned of the pending problem of antibiotic resistance. In his Nobel acceptance speech, Alexander Fleming himself cautioned doctors about the danger of giving an "underdosage" of penicillin, noting: "It is not difficult to make microbes resistant to penicillin in the laboratory by exposing them to concentrations not sufficient to kill them, and the same thing has occasionally happened in the body . . . Moral: If you use penicillin, use enough."

The pioneering work of Stuart Levy in the 1970s was also informative. Levy was concerned that antibiotic use in agriculture at subtherapeutic concentrations could lead to the proliferation of antibiotic resistance. His research demonstrated that tetracycline-resistant bacteria were present in the droppings of chickens within one week after tetracycline was included in their feed. More alarming, however, the bacteria in chickens that were fed only tetracycline became resistant to multiple antibiotics within two weeks. Finally, multiple-antibiotic-resistant bacteria dominated the fecal material of farmers working with these chickens within five months, even though the farmers had received no antibiotics during the study.

It was not until the 1980s, however, when a multiple-drug-resistant form of tuberculosis emerged, that scientists became concerned about antibiotic resistance. Multiple-drug resistance soon appeared among other pathogens, particularly among nosocomial (hospital-acquired) infections. Today, 40% to 60% of nosocomial *Staphylococcus aureus* infections are methicillin resistant. The problem of antibiotic-resistant bacteria is particularly significant for immunodeficient patients, who are susceptible to a broader array of pathogens, many of which are multiple-drug resistant.

Many believe that the problem is linked to excessive antibiotic use in hospitals, making them a "hot spot" for resistant bacteria. Unfortunately, mounting evidence refutes this perspective. Community-acquired methicillin-resistant *Staphylococcus aureus* is becoming far more prevalent, particularly at public gymnasiums, where insufficiently sanitized towels are prevalent.

The Development of Antibiotic Resistance in Bacteria

The simplest method by which bacteria become resistant to antibiotics is via a *point mutation* of the deoxyribonucleic acid (DNA) within their genome. Point mutations are typically lethal to the bacterium or have no effect, but on rare occasions these mutations are beneficial (from the bacterium's perspective) and allow the organism to become resistant to antibiotics. Point mutations, however, are not the major concern with respect to antibiotic resistance. This form of bacterial evolution is slow and random, and it is unlikely that bacteria could rapidly achieve resistance to multiple antibiotics via point mutations alone.

Ultimately, the proliferation of antibiotic resistance is caused by the propagation of specific genes that allow bacteria to defy the lethal effects of antibiotics. These *antibiotic resistance genes* are probably not new, but likely result from millions of years of evolution, during which time bacteria have developed many mechanisms to survive the dangers that the world thrusts upon them. Certainly, many of these genes were specifically developed to counteract antibiotics, which are, after all, naturally occurring compounds. Many antibiotic resistance genes, however, likely are subtle adaptations of genes that provide protection against other toxic compounds. For example, there is a strong correlation between genes that encode for resistance to heavy metals and antibiotic resistance genes.

The existence of antibiotic resistance genes, however, is insufficient to explain the global proliferation of resistance. Bacteria also harbor other genes that are specifically designed to help bacteria rapidly evolve—genes designated as *evolution genes* by 1978 Nobel Prize winner Werner Arber. Evolution genes allow bacteria to rapidly develop new genes (usually by manipulating preexisting genes) and to spread them

throughout the bacteria population. The evolution genes that allow *lateral gene transfer* are perhaps the most important class of evolution genes with respect to antibiotic resistance. Lateral gene transfer is the exchange of genetic material between different bacteria; it allows bacteria to share their abilities to resist antibiotics. This is believed to be the principal mechanism by which similar resistance genes are found throughout the world among many different species of bacteria.

During the last 20 years, scientists have also recognized the importance of *integrons*, another type of evolution gene. Integrons are responsible for integrating resistance genes into the genomes of bacteria, and then controlling the expression of these resistance genes. Because of this unique ability, integrons can be viewed as a genetic "luggage rack" in which different genes can be kept until they are needed. Integrons are a key component in the development of multiple-antibiotic-resistant bacteria because they allow bacteria to easily accumulate numerous genes.

Responding to Antibiotic Resistance

Although scientists have known about antibiotic-resistant bacteria for almost as long as they have known about antibiotics, the assumption was that new antibiotics would be discovered or developed faster than bacteria could become resistant. The discovery of new antibiotics, however, has slowed substantially since the 1960s. In fact, most "new" antibiotics are merely subtle modifications of previously existing ones and have little impact on bacteria that are already resistant.

During the last decade, therefore, there has been a considerable effort to restrict antibiotic use to only those applications where antibiotics are appropriate. Physicians are now reminded to avoid prescribing antibiotics for viral infections such as influenza and the common cold. Likewise, patients are carefully instructed to follow prescription guidelines so that enough of the drug is administered to limit the development of resistant bacteria. There is also increasing pressure to limit or eliminate non-medical use of antibiotics and antibacterials. As noted above, a substantial fraction of all antibiotics are used in agriculture at subtherapeutic concentrations. Although the United States appears to be far from prohibiting this practice, the European Union is banning subtherapeutic antibiotic use in agriculture in 2006. Although more controversial, many scientists—led by the Alliance for the Prudent Use of Antibiotics—are recommending the elimination of triclosan and other antibacterials from liquid hand soap, toothpaste, and other common household items.

A New Paradigm: Resistance Control?

The current situation with respect to antibiotic resistance is bad and the future is bleak. The discovery of new drugs has slowed to a trickle—a problem that will only worsen as pharmaceutical companies devote a greater fraction of their research and development budgets to less essential drugs (e.g., Botox, Viagra). Simultaneously, the ever-increasing use and misuse of antibacterials in common household products can only exacerbate the problem.

From our perspective, current efforts to reduce the spread of antibiotic resistance are an excellent first step. Certainly, our historically indiscriminate use of antibiotics needs to end. The more important issue is to identify novel approaches to limit the spread of antibiotic resistance. Our intention in undertaking this research, therefore, was to take a different approach to solving the problem of antibiotic resistance. We started by asking some simple yet fundamental questions about the proliferation of antibiotic-resistant bacteria.

First, where do the majority of antibiotic-resistant bacteria originate? Certainly, many bacteria are naturally resistant, but the majority of antibiotic-resistant bacteria result from antibiotic use. Therefore, people and animals taking antibiotics are most likely the primary source of antibiotic-resistant bacteria.

Second, how do resistant bacteria spread throughout the world after they originate inside a person? Humans actually contain about 10 times more bacterial cells in their bodies than they do human cells. The overwhelming majority of these bacterial cells reside in our gastrointestinal tracts, and most are released from the body during defecation.

Having asked and answered these two simple questions, we then inferred that municipal wastewater treatment plants, which handle virtually all human toilet waste in large municipalities (in rural areas, septic systems are more commonly used), would be critical in reducing the spread of antibiotic resistance. We hypothesized that municipal wastewater treatment facilities could adequately control the release of antibiotic-resistant bacteria to the world.

Municipal Wastewater Treatment Facilities: How Do They Work?

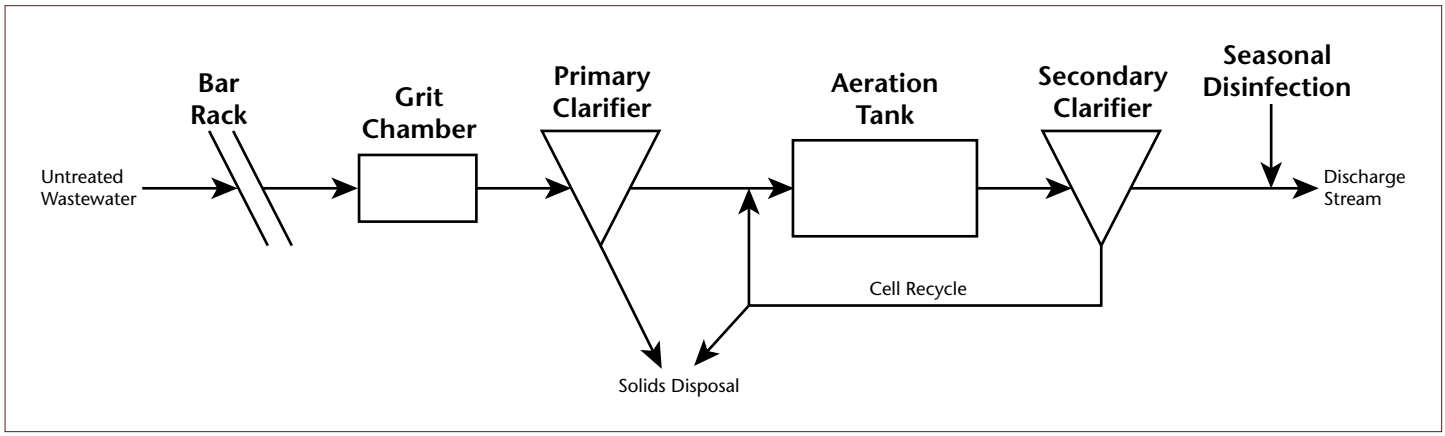
Municipal wastewater treatment facilities are primarily designed and operated to protect the environment. Municipal wastewater treatment facilities remove readily biodegradable compounds from sewage. Although there is relatively little in human sewage that is toxic, these biodegradable compounds are of environmental concern because if they were released untreated, they would biodegrade in the environment, resulting in oxygen depletion leading to septic conditions. Municipal wastewater treatment facilities, therefore, allow surface waters to maintain high dissolved oxygen levels, improving their aesthetic and recreational use value, as well as their ability to support healthy populations of fish and other aquatic fauna.

Although all municipal wastewater treatment facilities are unique, most are similar in design and involve a common series of unit operations (Figure 1). The first few unit operations, called primary treatment, are designed to remove particles from the wastewater. The bar rack removes large particles (greater than 1 inch), whereas the grit chamber removes sand and other dense, rapid-settling particles. The primary clarifier is a quiescent settling zone that allows organic particles to settle or float so that they can be removed. These primary treatment operations account for about 50% of the treatment that occurs.

The next unit operation, the aeration tank, is designed to remove dissolved organic compounds (which are readily biodegradable) from the wastewater by creating conditions favorable for the growth of bacteria. The tank works by bubbling air through the wastewater, allowing bacteria to metabolize pollutants that are present. Because these bacteria grow in excessive quantities, they must be removed from the wastewater. This is accomplished by the next unit operation, which is a quiescent settling chamber called the secondary clarifier. The combination of the aeration tank and the secondary clarifier is called the activated sludge process, which is the most common technology for the secondary treatment of wastewater.

Following primary and secondary treatment, the quality of municipal wastewater is quite good—not yet potable (i.e., safe to drink), but often

Figure 1. Schematic Diagram of a Conventional Municipal Wastewater Treatment Process



Note: Individual unit operations are labeled in bold lettering.

as good as or better than the quality of many lakes and rivers. This treated wastewater, however, still contains pathogenic bacteria that could make people sick if they accidentally ingested the water. Municipal wastewater treatment facilities, therefore, perform a final treatment step in which the treated wastewater is disinfected to help reduce the number of disease-causing microbes. Disinfection is required only when recreational use of the receiving stream is a reasonable expectation. In Minnesota, for example, wastewater treatment facilities usually disinfect their wastewater only from April to November.

In addition to treating the wastewater, municipal wastewater treatment facilities must deal with the solid residues that the primary and secondary clarifiers collect. These solid residues are readily biodegradable organic materials that are most commonly treated by a process called *anaerobic digestion*. The conventional anaerobic digestion process, which largely mimics our gastrointestinal tracts (hence the "digestion" nomenclature), is kept free of oxygen and operated at 98.6°F. Following digestion,

Photo courtesy of Timothy LaPara

An aeration tank at a municipal wastewater treatment plant. The tank removes dissolved organic compounds by bubbling air through the wastewater, creating favorable conditions for the growth of bacteria that are capable of metabolizing pollutants.

the treated wastewater solids are either applied to farmland as a fertilizer and soil conditioner, or sent to a landfill for disposal. The former alternative is preferred as a "sustainable" practice, whereas landfill space is finite.

Because anaerobic digestors operate at conditions similar to the human body, they are not particularly good at eliminating human pathogens. Numerous alternative treatment technologies, therefore, have been developed to better treat wastewater solids. All of these alternative treatment technologies are more expensive, however, and thus municipalities do not frequently use them. Perhaps the most attractive treatment alternative is thermophilic anaerobic digestion, which operates almost identically to conventional anaerobic digestion, except that it operates at sufficiently high temperatures (greater than 110°F) to kill most human pathogens.

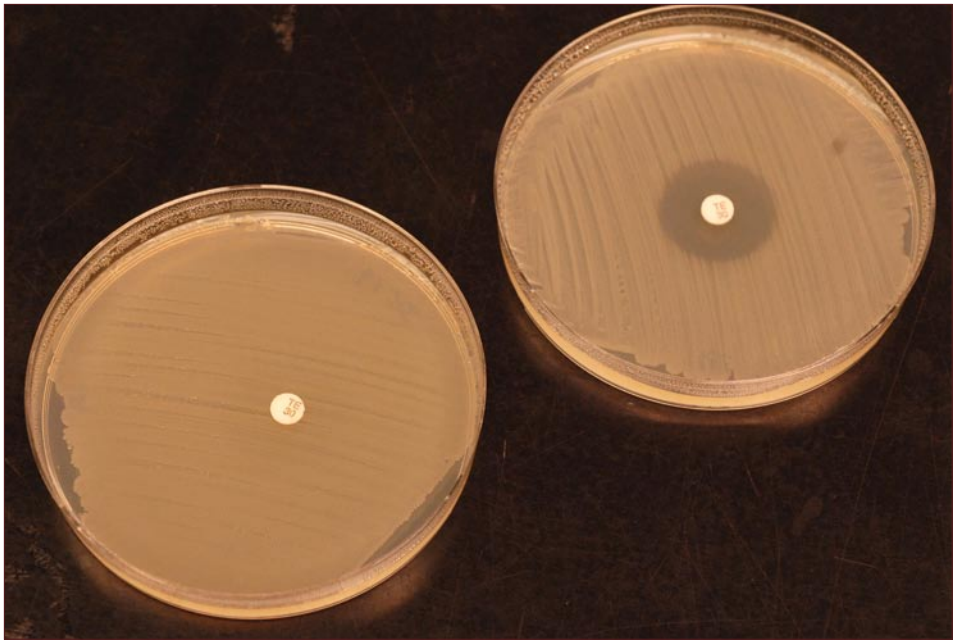


Photo © Steve Schneider, 2006

Bacteria growing on petri dishes that include disks treated with the antibiotic tetracycline. The bacteria growing on the left petri dish were obtained from treated wastewater and are resistant to tetracycline, as shown by the ability of the microbes to grow near the white disk. The bacteria growing on the right petri dish are a tetracycline-sensitive strain of* E. coli*. The circular ring around the disk shows that these microbes cannot grow in the presence of tetracycline.

Methodology and Analysis

The first goal of our project was to determine the extent to which municipal wastewater treatment facilities prevent the release of antibiotic-resistant bacteria. There are two potential paths by which antibiotic-resistant bacteria can escape a municipal wastewater treatment facility. The most obvious is in the treated wastewater. Our research, therefore, investigated the importance of secondary clarification and disinfection in preventing the release of antibiotic-resistant bacteria from the aeration tank. Resistant bacteria could also be released in the solids collected during primary treatment and from the secondary clarifier. Our research, therefore, compared the effectiveness of two variations of conventional anaerobic digestion and thermophilic anaerobic digestion at destroying resistant bacteria.

We investigated the efficacy of wastewater disinfection at the Metropolitan Wastewater Treatment Facility in St. Paul. This facility is very large, treating an average of 180 million gallons of sewage each day. Typically, the quality of treatment from the Metropolitan plant is top-notch, and the facility regularly wins state and national awards for operational excellence. Throughout the year, we quantified about 100,000 (10^5) tetracycline-resistant bacteria per milliliter of water in the aeration tanks at the Metropolitan plant. From the treated wastewater, we quantified about 300 tetracycline-resistant bacteria per milliliter in the winter (i.e., when disinfection was not performed) and about 30 tetracycline-resistant bacteria per milliliter during the summer (i.e., during the disinfection period). That is, about 99.6% and 99.97% of the resistant bacteria in the aeration tanks are removed in the winter and summer, respectively. Although this removal efficiency might seem sufficient, 30 bacteria per milliliter translates to more than 10 trillion (10^{13}) tetracycline-resistant bacteria released each day from this treatment facility into our waterways.

We also investigated the efficacy of anaerobic digestion at the Western Lake Superior Sanitary District (thermophilic process) and the Empire Wastewater Treatment Facility (conventional process), which are located in Duluth and Farmington, respectively. Both of these plants have also earned awards for operational excellence. We again detected about 100,000 (10^5) tetracycline-resistant bacteria per milliliter in the waste stream entering the anaerobic digestors at each of these treatment facilities. However, we were unable to detect any tetracycline-resistant bacteria in the waste stream leaving the anaerobic digestors at these two treatment facilities, in part because the research method we used is unable to detect levels of tetracycline-resistant bacteria below 1,000 (10^3) per milliliter of sludge solids. However, this suggests that both anaerobic digestion processes were able to inactivate at least 99% of antibiotic-resistant bacteria. We are currently attempting to develop an alternative technique to measure the efficiencies by which these anaerobic digestors inactivate antibiotic-resistant bacteria.

The second goal of our research was to characterize the antibiotic-resistant bacteria in sewage. From the three treatment facilities, we isolated and identified 173 bacterial strains that were resistant to tetracycline. All of these bacterial strains were pathogenic (disease-causing—e.g., *Shigella* or *Klebsiella* spp.), possibly pathogenic (e.g., *Escherichia coli*), or non-pathogenic but related to pathogens (e.g., *Citrobacter* spp.). In more than 50% of these bacteria, we also detected at least one gene encoding for tetracycline resistance.

Based on these initial data, we then studied 14 different tetracycline-resistant bacterial strains in more detail. All 14 of these strains contained an integron and were resistant to at least three different antibiotics (we tested resistance to amoxicillin, ampicillin, chlortetracycline, enrofloxacin, erythromycin, sulfamethoxazole, trimethoprim, and tylosin). We also tested these bacteria for lateral gene transfer. Although this work is still ongoing, many of these bacterial strains are capable of

exchanging with other bacteria a gene encoding for tetracycline resistance.

Following our work on tetracycline-resistant bacteria, we isolated an additional 65 different bacteria that were resistant to ciprofloxacin. Ciprofloxacin is a relatively new antibiotic and there is not much known about bacterial resistance to it. Once again, we found that all of these bacterial strains were pathogenic, possibly pathogenic, or related to pathogens. We then focused our efforts on 11 of these strains, all of which were resistant to at least four different antibiotics. About half of these strains contained an integron or a gene encoding for resistance to tetracycline. Although this work is also ongoing, our analysis revealed that several of these strains were capable of laterally exchanging genes encoding for resistance to ciprofloxacin.

Conclusion and Policy Recommendations

Our research has demonstrated that extremely high numbers of antibiotic-resistant bacteria are released from municipal wastewater treatment plants, even when disinfection is performed. Our original hypothesis was that disinfection would adequately inactivate antibiotic-resistant bacteria in treated municipal wastewater, and that an outcome of our work would be to encourage the implementation of year-round disinfection. Instead, we learned that although a 99% inactivation looks encouraging, 1% of a very large number (10^{15}, or 1 quadrillion) still represents a very large number (10^{13}, or 10 trillion) of antibiotic-resistant bacteria that are released from the Metropolitan Wastewater Treatment Facility each day.

The bacteria that we studied were all pathogens or related to pathogens and all were resistant to multiple antibiotics. A substantial fraction of these bacteria (greater than 50%) harbored genes encoding for tetracycline resistance. These bacteria frequently harbored integrons (genes that allow bacteria to accumulate multiple genes for antibiotic resistance) and some of them were capable of transferring their resistance to other bacteria. The frequency of lateral gene transfer of ciprofloxacin resistance, which occurred in more than 40% of the strains we studied, is particularly worrisome because this trait is typically very rare (less than 1%) among clinical strains of ciprofloxacin-resistant *E. coli*. Simply put, the bacteria that we detected in municipal wastewater are some of the most resistant bacteria ever studied. There is a substantial need, therefore, to prevent these organisms from reaching the environment.

At first glance, the most obvious solution to the problem of antibiotic-resistant bacteria in treated municipal wastewater would be to require more stringent disinfection. The majority of municipal wastewater is disinfected using chlorine, which poses a security risk (chlorine gas is very dangerous) and generates disinfection by-products that are known or suspected carcinogens. Although we recommend a policy shift to include year-round wastewater disinfection, we do not recommend that more stringent disinfection regulations be imposed because of these unwanted consequences.

Instead, we recommend that wastewater effluents be passed through a sand filter prior to disinfection. Sand filters can physically remove antibiotic-resistant bacteria from treated wastewater, but without the use of potentially dangerous chemicals. At the present time, sand filters are rarely used in wastewater treatment, but they are commonly used at drinking water treatment facilities, so the technology is well-developed and well-understood. Additional research is needed, however, to optimize the removal/inactivation of antibiotic-resistant bacteria by our proposed combination of sand filtration and effluent disinfection.

Although our research on the fate of antibiotic-resistant bacteria in anaerobic digestors was inconclusive due to the limitations of our research method, we suspect that our ongoing research will demonstrate that thermophilic anaerobic digestors achieve substantially better inactivation efficiencies than conventional technologies. This ongoing research is particularly pertinent because of a recent shift in policy that emphasizes the application of treated wastewater solids to land rather than putting these residues into landfills—that is, the "environmental friendly" practice of applying wastewater solids to land may have unexpected and undesirable consequences in terms of the proliferation of antibiotic-resistant bacteria.

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Project Funding Available from CURA

The Center for Urban and Regional Affairs supports community-based research projects through several different programs. If you represent a community organization or agency and are unsure which program listed below is most suitable for your project proposal, simply complete a general Community Program Application Form at www.cura.umn.edu/Programs/curaappform.html and we will route your request to the appropriate program.

■ The **Communiversity Program** funds quarter-time graduate student assistantships for one semester to help community-based nonprofit organizations or government agencies with a specific project. The application deadline for spring semester 2007 assistantships is October 30, 2006. For more information, contact Jeff Corn at 612-625-0744 or curacbr@umn.edu, or visit www.cura.umn.edu/communiversity.php.

■ The **Community Assistantship Program (CAP)** matches community-based nonprofit organizations, citizen groups, and government agencies in Greater Minnesota with students who can provide research assistance. Eligible organizations define a research project, submit an application, and if accepted, are matched with a qualified student to carry out the research. The deadline for applications for spring 2007 support (mid-January through May) is October 30, 2006. For more information, to discuss potential projects, or for assistance with applications, contact CAP coordinator Will Craig at 612-625-3321 or wcraig@umn.edu, or visit www.cura.umn.edu/cap.php.

■ **Neighborhood Planning for Community Revitalization (NPCR)** provides student research assistance to community organizations in Minneapolis, St. Paul, and metro area suburbs that are involved in community-based revitalization. Projects may include any issue relevant to a neighborhood's or community's needs and interests, including planning, program development, or program evaluation. Priority is given to projects that support and involve residents of color. Applications from organizations collaborating on a project are encouraged. Applications for spring 2007 support (January through May) are due October 30, 2006. For more information, visit www.cura.umn.edu/npcr.php or contact NPCR program director Kris Nelson at 612-625-1020 or ksn@umn.edu.

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