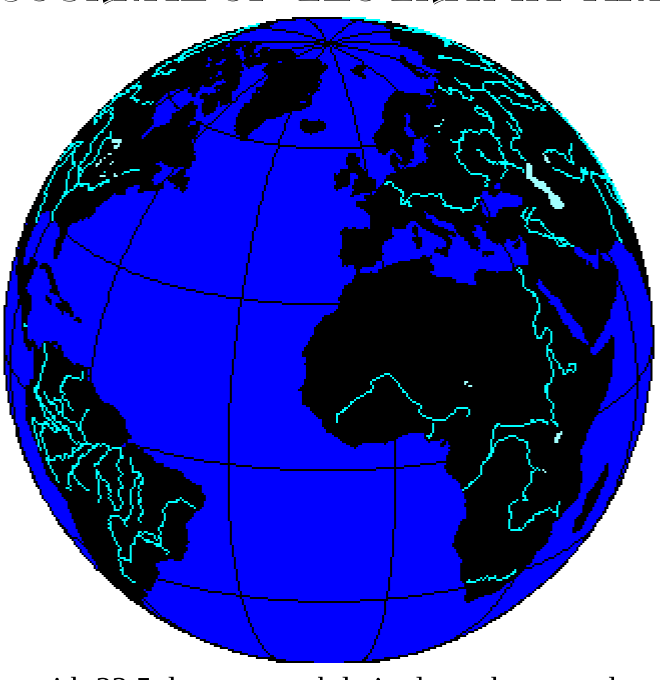
SOLSTICE:

AN ELECTRONIC JOURNAL OF GEOGRAPHY AND MATHEMATICS



Earth: with 23.5 degrees north latitude as the central parallel.

VOLUME XII
NUMBER 1
JUNE, 2001

INSTITUTE OF MATHEMATICAL GEOGRAPHY

SOLSTICE: AN ELECTRONIC JOURNAL OF GEOGRAPHY AND MATHEMATICS

http://www.imagenet.org

SUMMER, 2001

VOLUME XII, NUMBER 1

ANN ARBOR, MICHIGAN

WebSite: http://www.imagenet.org

Electronic address: sarhaus@umich.edu

MISSION STATEMENT

The purpose of Solstice is to promote interaction between geography and mathematics. Articles in which elements of one discipline are used to shed light on the other are particularly sought. Also welcome are original contributions that are purely geographical or purely mathematical. These may be prefaced (by editor or author) with commentary suggesting directions that might lead toward the desired interactions. Individuals wishing to submit articles or other material should contact an editor, or send e-mail directly to sarhaus@umich.edu.

SOLSTICE ARCHIVES

Back issues of Solstice are available on the WebSite of the Institute of Mathematical Geography, http://www.imagenet.org and at various sites that can be found by searching under "Solstice" on the World Wide Web. Thanks to Bruce Long (Arizona State University, Department of Mathematics) for taking an early initiative in archiving Solstice using GOPHER.

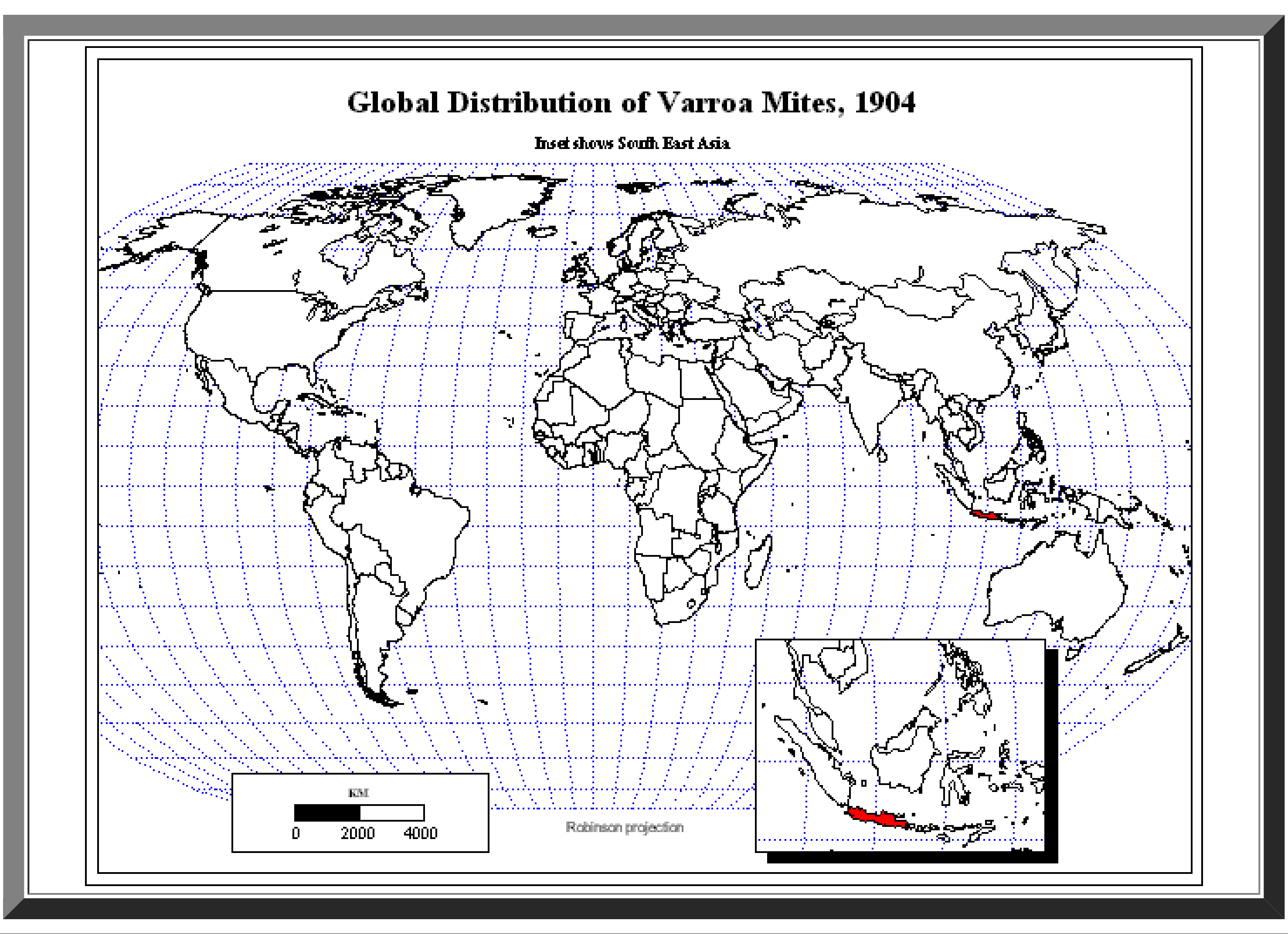
PUBLICATION INFORMATION

The electronic files are issued yearly as copyrighted hardcopy in the Monograph Series of the Institute of Mathematical Geography. This material will appear in a Volume in that series, ISBN to be announced. To order hardcopy, and to obtain current price lists, write to the Editor-in-Chief of Solstice at 1964 Boulder Drive, Ann Arbor, MI 48104, or call 734-975-0246.

Suggested form for citation: cite the hardcopy. To cite the electronic copy, note the exact time of transmission from Ann Arbor, and cite all the transmission matter as facts of publication. Any copy that does not superimpose precisely upon the original as transmitted from Ann Arbor should be presumed to be an altered, bogus copy of Solstice. The oriental rug, with errors, serves as the model for creating this weaving of words and graphics.

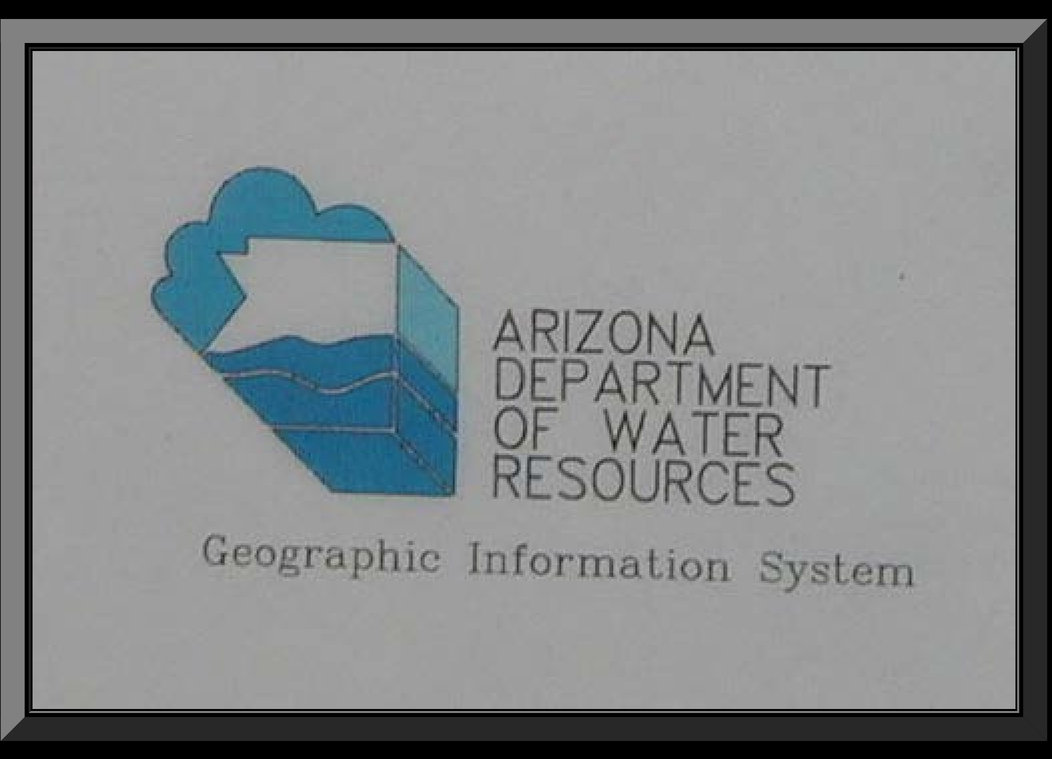
Updated Varroa Mite Map
of Data of Diana Sammataro.

One advantage of on-line publication is the capability to easily update files that depend on temporal data. *Solstice* author Diana Sammataro has been sending IMaGe current data for her Varroa Mite Map on a regular basis, since it first appeared in Volume IX, Number 1, 1998. The current form of the map is shown below.



Map by Sandra L. Arlinghaus and John D. Nystuen.

DETECTING ARIZONA WATER RUSTLERS



Water Rustlers in Arizona:
Detecting Possible Illegal Water Use in Arid Lands using Remote Sensing and GIS Methods

John D. Nystuen
Emeritus Professor of Geography and Urban Planning

Maps courtesy of the Arizona Department of Water Resources.

Outline

*** Purpose**

Describe an example of an operational use of remote sensing and GIS by the Arizona Department of Water Resouces

*** Problem**

The problem: water sources, water use, and water law in the Phoenix and Tuscon regions of south-central Arizona combined in a water management effort to sustain adequate ground and surface water resources

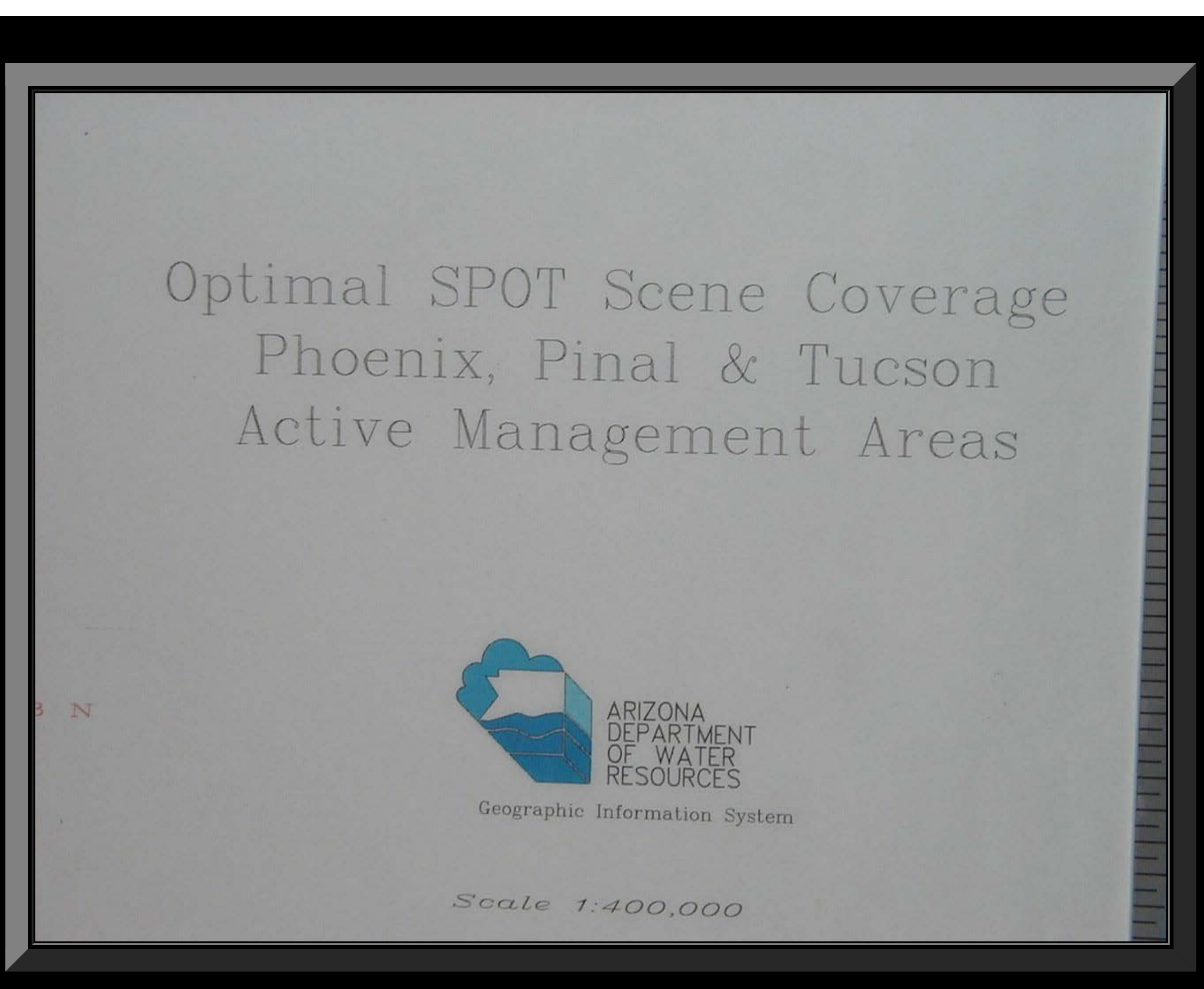
*** Monitoring Program**

The monitoring program: Use of multispectral SPOT color images and ArcInfo land ownership (parcel) maps and water rights records in appropriate time frame, spatial resolution and extent

*** Institutional Issues**

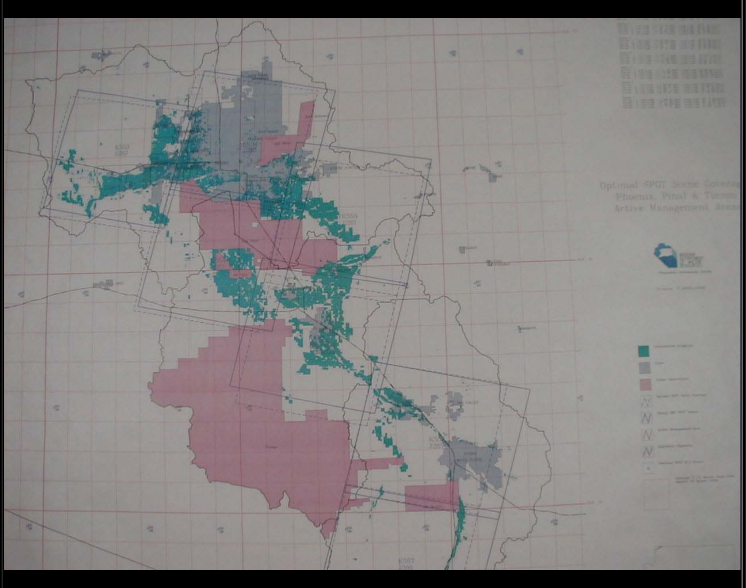
Institutional issues: Data management, multiple-purpose uses, departmental cost sharing, political issues and sustainable programs

Page 2.

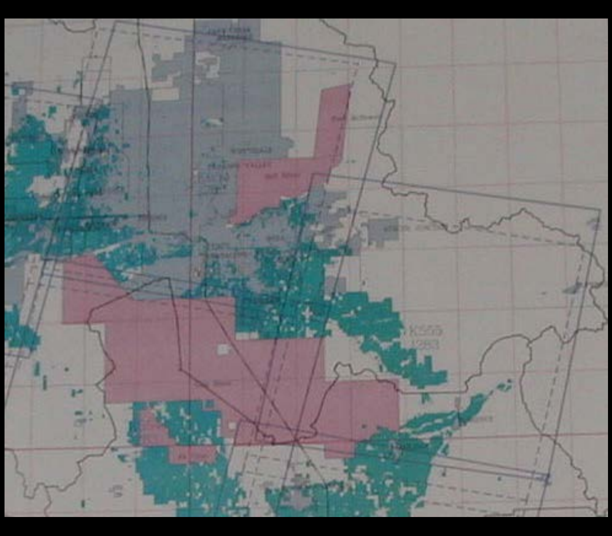

Optimal SPOT Scene Coverage
Phoenix, Pinal & Tucson
Active Management Areas
ARIZONA
DEPARTMENT
OF WATER
RESOURCES
Geographic Information System
Scale 1:400,000

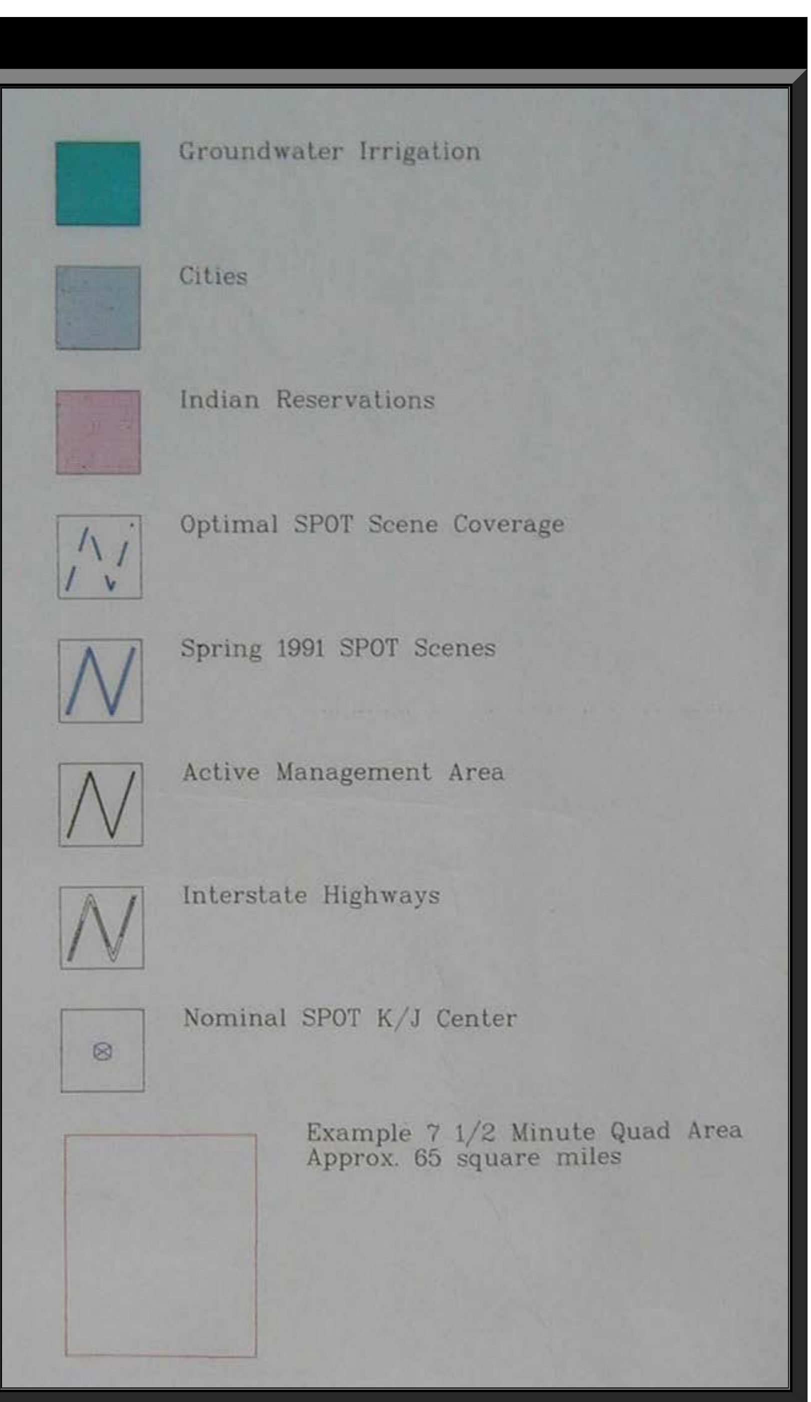
Page 3.

CENTRAL ARIZONA WATER MANAGEMENT REGION



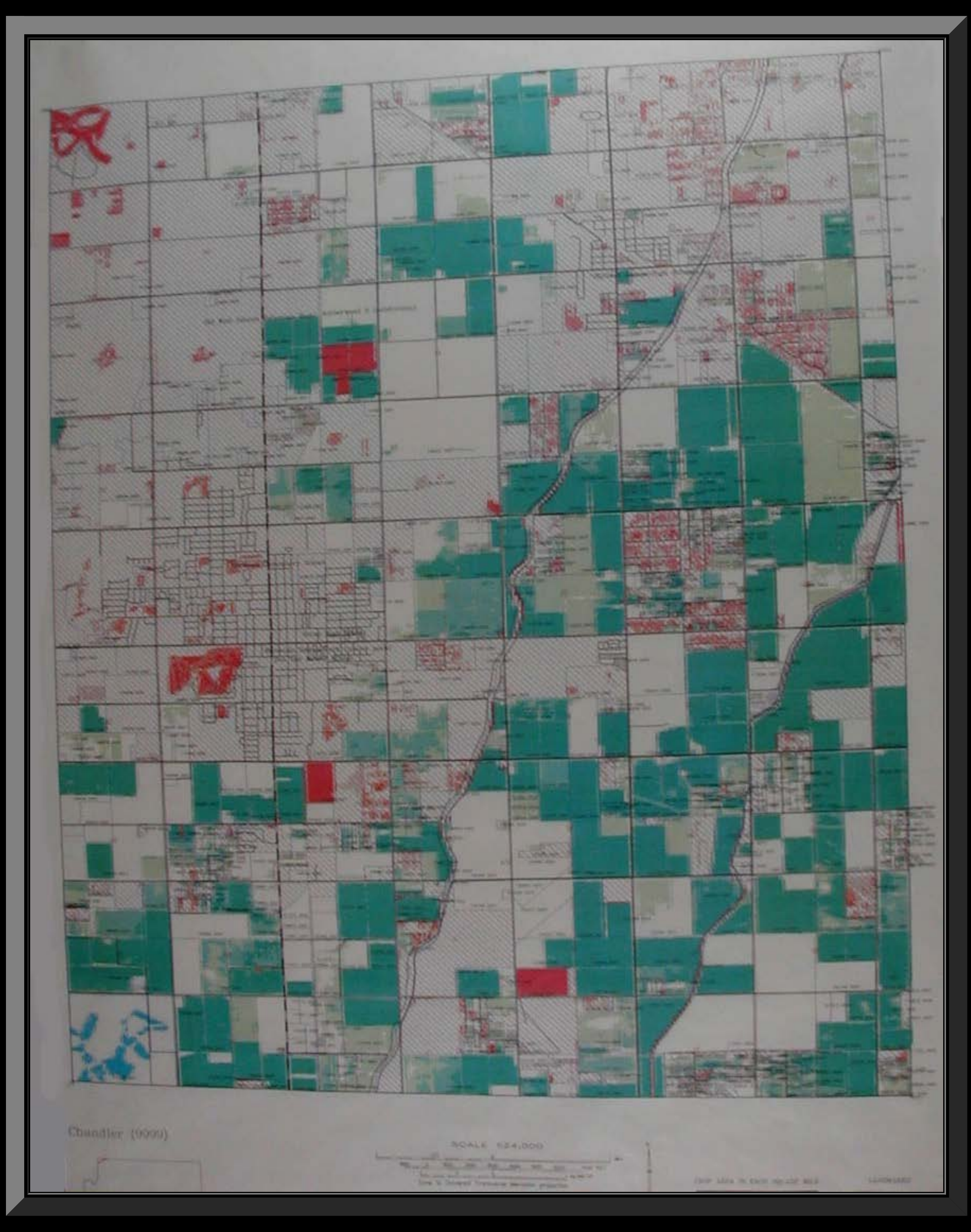
SPOT IMAGE OF PHOENIX AREA:
IMAGE REQUESTED (BOXES MADE OF DASHED LINES)
AND IMAGE DELIVERED (BOXES MADE OF SOLID LINES)

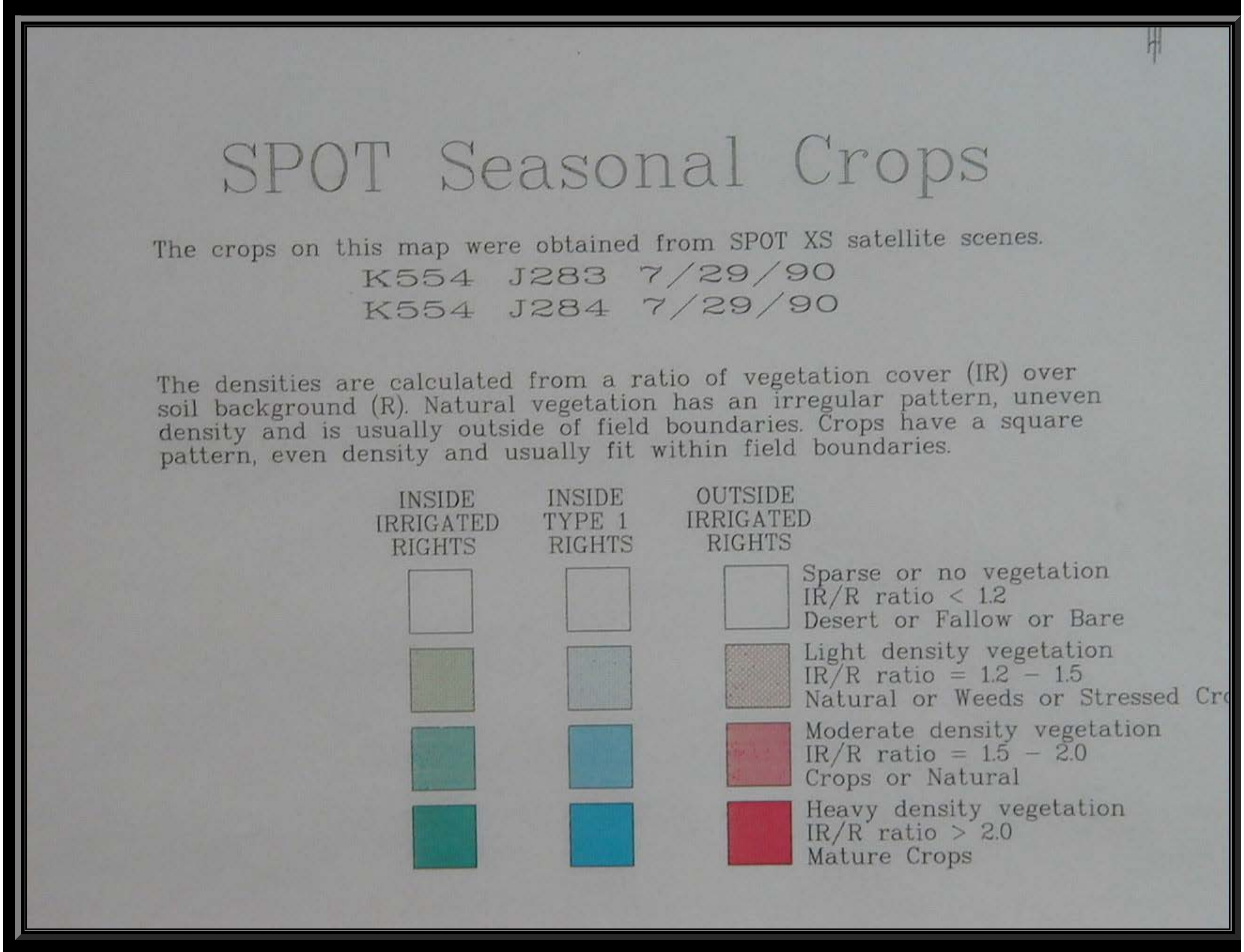




Page 4

Using GIS to combine SPOT image with parcel map. USGS topographic sheet backdrop. The ribbon-shaped land use parcels at the upper and lower left corners are golf courses. Read the legend below for further detail.





Page 5.

Links to Related Articles:

S. Arlinghaus, W. Drake, J. Nystuen, A. Laug, K. Oswalt, D. Sammataro, Animaps.

K. Sims, The Fiji Islands and the Concept of Spatial Hierarchy.

The Neglected Relation

Sandra L. Arlinghaus, The University of Michigan
William C. Arlinghaus, Lawrence Technological University

Link to original: Java applets may cause a browser crash on load.

Mathematics, like musical composition and other fine arts, is purely a human creation. Without us, does it exist? This sort of "meta" question has long interested scholars with multidisciplinary interests (readers are referred to the references section at the end for a few of the numerous references to ideas of this sort that have appeared in the literature over centuries). Indeed, does the societal culture in which the predominant mathematics is developed and embedded in a particular historical epoch influence the kind of mathematics that is developed? Again, this question has been studied in many ways: we consider one case here--that of the mathematical relation and selected real-world interpretations. These are displayed in a number of visual formats not merely as curiosities but more significantly for the suggestion they might offer as to why or why not certain types of formal structures get created. It is important to attempt to understand deeper processes such as these: the mathematics we use in the real-world often influences the decisions we make.

Municipal authorities might use demographic forecasts based on curve fitting to guide the direction of urban land use planning. A City Administrator might use a rank-ordered set of priorities to decide how valuable taxpayer funds will be allocated over a period of years to develop (or not develop) infrastructure. The way in which the mathematics is used will influence the outcome of the analysis and, therefore quite likely, the policy that is set in place. We also invite feedback, using the capability of the internet, so that readers might share other cases with each other (near the end of this document).

One-to-many transformations between two mathematical sets are an often neglected class of relationships. Much of modern mathematics, for example, considers only functions. A *function*, mapping a set *X* to a set *Y* permits an element *x* in *X* to be sent to an element *y* in *Y*, or it permits a number of elements, *x1*, *x2*, *x3* in *X* to be sent to a single element *y* in *Y* (Figure 1, left side). The former situation is one-to-one and the latter is many-to-one. Functions may be one-to-one or they may be many-to-one; they may not be one-to-many. They are "single-valued." Graphically, the idea is represented as in Figure 1. When one element of *X* is permitted to map to many elements of *Y*, as in *x* mapping to *y1*, *y2*, *y3* (Figure 1, right half) the associated mathematical transformation is often referred to as a *relation*.

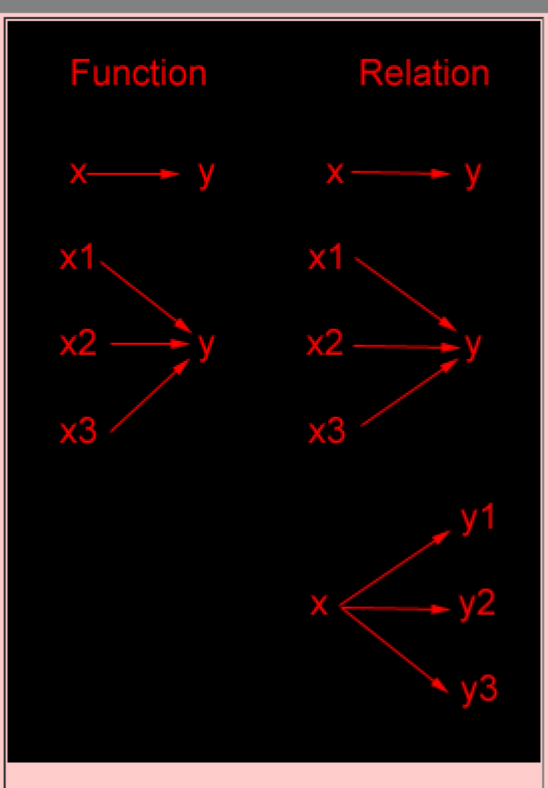


Figure 1. A function requires that each element of *X* be associated with only one element of *Y* (although many different elements of *X* may be associated with the same element of *Y*). A relation removes this restriction, allowing one element of *X* to be associated with many elements of *Y*. Thus, every function is relation, but not every relation is a function.

In the Cartesian coordinate system the same idea may be visualized as in Figure 2. In the case of a function, a vertical line cuts the graph of the function no more than once (Figure 2a shows a one-to-one function and Figure 2b shows a many-to-one function). In a graph that is not a function (not "single-valued"), the vertical line may cut this curve (that is not the graph of a function) in more than one place (Figure 2c shows such a graph).

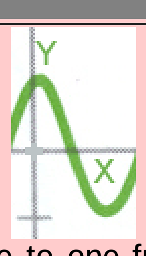


Figure 2a. One-to-one function.

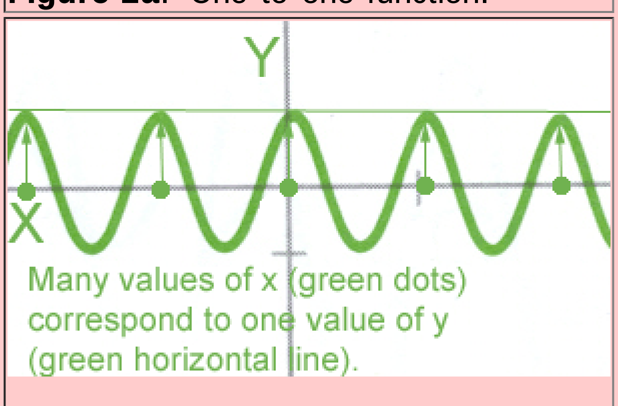


Figure 2b. Many-to-one function. Many x-values (green dots) correspond to one y-value (height of horizontal line).

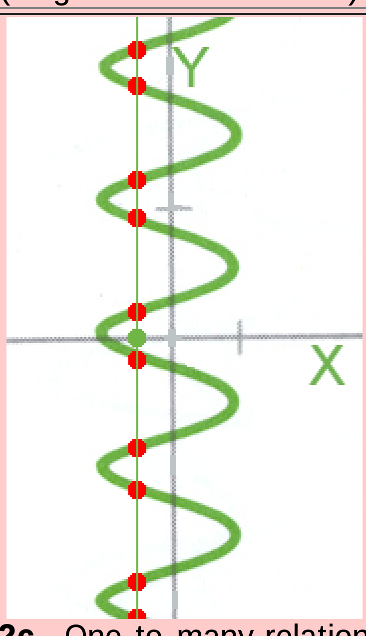


Figure 2c. One-to-many relation. One x-value (green dot) corresponds to many y-values (red dots)

The visual display of the difference between function and relation, the many-to-one and the one-to-many, is clear in the Cartesian coordinate system because the ordering of the function from X to Y is clear in our minds. In a coordinate-free environment, such as the world of the Applet (TM, Sun Microsystems), all that is evident is the structural equivalence of many-to-one and one-to-many transformations (Figure 3). In Figure 3, note the stability of the one-to-one transformation as the graphic moves; the many-to-one and the one-to-many never quite settle down to a totally stable configuration. This lack is a function of pattern involving length of edges joining nodes and dimension of the square universe of discourse in which the Applets (TM Sun Microsystems) live. In the case of Figure 3, it may simply be a function of a particular commensurability pattern of edges and underlying raster; nonetheless, the general consideration as to what sorts of configurations exhibit geometric stability is an important one, particularly as in regard for looking for points of intervention into process (see varroa mite mapplet). K. Sims has noted the importance of such lack of stability in anthropological contexts building on island networks found in Hage and Harary.

Figure 3. Applets (TM, Sun Microsystems) show one-to-one, many-to-one, and one-to-many transformations. Note the structural equivalence between the many-to-one and the one-to-many applets.

The relation is often ignored in mathematical analyses of various sorts. Perhaps that is because the definite nature of single-valued mappings is regarded as important. Is the world, however, single-valued? We consider a few real-world situations in which relations can be observed to be the underlying conceptual force.

Postal Transformation

A simple, convenient example often given to students studying functions for the first time is the following postal example.

Given a set of hard-copy handwritten

letters in envelopes that are to be sent through the conventional U.S. Postal Service network by regular first-class mail.

- My letter can be sent to a single address (one-to-one).
- My set of three different letters can be sent to a single address (many-to-one).
- My one letter cannot go to three different addresses (not one-to-many).

Some might argue that the invention of the printing press permitted one page to go to many. Yet, there is variation from page to page--there are ink splatters, broken type, and so forth.

Still others might assert that photocopying of a page will enable one letter to go many different addresses, as long as the original as distinct from the rest is not included--hence the rise of junk mail. Someone else might argue, however, that any two photocopies differ from each other on account of diminishing the amount of toner available for copies later in the process.

Further, if one considers virtual messages, rather than hard copy messages, then a single e-letter can be sent to a single address (one-to-one), a set of three different e-notes can be sent to a single address (many-to-one), and a single note can go simultaneously to three different addresses (one-to-many). The electronic revolution of our "information age" offers a true postal transformation from the functional to the relational.

Perhaps a common theme in all these refinements of argument will be that to move from one style of mathematical transformation to another in the real-world requires some sort of underlying real-world transformation through invention, revolution, or other remarkable event. Hence, the argument for the printing press, the photocopying machine, and the e-mail/computer all have merit. Indeed, *Solstice,* itself, takes advantage of this one-to-many relational capability!

Home Ownership

As we look around our environment today, of midwestern United States of America, we see a variety of dwelling types and of ownership of them.

- One-to-one ownership: one family owns a single parcel of land, often in a suburban area and elsewhere when land is plentiful and land values are relatively low.
- Many-to-one ownership: many families own a single parcel or building. This style of ownership is often "condominium" or "cooperative" ownership. In the landscape it is evident mostly in more densely populated areas or where land values are relatively high.
- One-to-many ownership: one family owns many residences. This particular situation, not represented as a mathematical function but only as a relation, is perhaps not as common as the two above. Typically, one might expect families with excess wealth to own more than one residence. Our colleague John Nystuen asked where such individuals cast votes. We explore the dynamics of that situation below.

Composition of Transformations

If one were to map the relations listed above for home ownership, a figure similar to Figure 3 would be the result. When voting is added on, the situation becomes more complicated, given that voting is done and counted locally and not nationally.

- In the one-to-one situation, the homeowner registers to vote from his or her single address and there is no difficulty counting the vote.
- In the many-to-one situation, the homeowners register to vote from their single address and there is no difficulty counting the vote. All go to the same polling place to vote.
- In the one-to-many situation, however, a person who owns property in Michigan and in Florida, for example, might attempt to vote in two places even though he/she is only entitled to one vote. Figure 4 shows that when only a single vote is cast, as it should be, the system remains closed, bounded, and manageable (in some sense). When more than one vote is cast, the system may rapidly fall out of order, especially when there are thousands or hundreds of thousands of people who own more than one residence from which they might vote. Some sort of nationalized database on voter registration and residency might make the problem more tractable.

What is important in this case is the composition of mappings: one followed by another. In this case, the two mappings are home ownership followed by voting. When the first is a function, the composition works well in the real-world interpretation. When it is only a relation, there is room for serious manipulation that was not present in the functional characterization. Extra care is appropriate when composing mappings.

Figure 4a. Voter *x* owns three residences, *y1*, *y2*, and y3 and casts the one legal vote, *z*, to which he/she is entitled. Voter *a* owns three residences, *b1*, *b2*, and *b3* and casts one legal vote *c1* (from residence *b1*) and two illegal votes (from residences *b2* and *b3*), *c2*, and *c3*. Note that the legal case is visually manageable in some sense while the illegal case sprawls across the map and is more difficult to track.

Figure 4b. When homeownership and voting become more complicated, the closure and sprawl noted above (in the caption to Figure 4a) become more evident.

Other One-to-Many Situations

- One copy of material may be photocopied according to certain legal constraints; however, when a "single" copy is sold to many, there is likely copyright infringement--one-to-many is once again problematic when the transformations of "single copy" and "selling" are composed.
- In the state of Michigan, the same driver license number can be assigned to two or more individuals. Two individuals with the same month and day of birth, the same first and middle names, the same first letter of last name, and initial parts of the last name the same, have the same Michigan driver license number. For example, James Edward Smithsonian, born July 1, 1900, and James Edward Smithson, born July 1, 1950, would have the same Michigan driver license number.
- Recently a Detroit police officer was discovered to have two different driver licenses under two different names, an impermissible one-to-many relation.
- ArcView GIS v. 3.2 (ESRI) contains a sample script designed specifically to deal with one-to-many situations. Scripts are small add-on programs that address issues not addressed in the main program and that must be separately compiled and run.
- Quadratic Probing is used to resolve collisions, situations where many pieces of data are initially assigned the same data location. Again, this is an undesirable one-to-many situation, as one data location cannot store many pieces of data.
- Marital relationships (men and women):
  - One-to-one: one woman is married to one man (monogamy: customary practice in part of world predominant in mathematical development)
  - Many-to-one: many women are married to one man (polygamy: known, but not customary; some examples exist in European history, in the idea of a harem, and in certain religions).
  - One-to-many: one woman is married to many men.

  Various cultural taboos might lead one to ask what kind of mathematics would have been developed in the 20th century had it been done so predominantly by a society in which fundamental societal relationships are one to many. (One could of course switch the order of men and women in this example.)

The broader societal environment in which mathematics develops may well influence what mathematics gets created. As our human environment changes, what changes do you see that might produce substantial shifts from one transformation to another? Please use the interactive feature of this article.

Share Your Thoughts!

Enter your e-mail address:

☑ Send a copy of this message.

Please enter comments in the text area below. Your constructive ideas will be noted in the next issue of *Solstice*.

Send Message

References

Arlinghaus, Sandra L.; Arlinghaus, William C.; and, Harary, Frank (2001), *Graph Theory and Geography: An Interactive View*. New York: John Wiley and Sons.

Arlinghaus, Sandra L.; Drake, William D.; Nystuen, John D.; Laug, Audra; Oswalt, Kris; Sammataro, Diana (1998), Animaps, *Solstice: An Electronic Journal of Geography and Mathematics*, Volume IX, Number 1. Ann Arbor: Institute of Mathematical Geography.

Gershenson, Daniel E. (1964), *Anaxagoras and the Birth of Scientific Method*. New York: Blaisdell Publishing Company.

Hage, Per and Harary, Frank (1996), *Island Networks: Communication, Kinship, and Classification Structures in Oceania*. Cambridge University Press.

Jeans, James H. (1929), *Eos, or, The Wider Aspects of Cosmogony*. New York: E. P. Dutton and Company.

Kuhn, Thomas S. (1957), *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought*. Cambridge, MA: Harvard University Press.

Kuhn, Thomas S. (1962), *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Quine, Willard Van Orman (1969). *Ontological Relativity, and Other Essays*. New York: Columbia University Press.

Sims, K. The Fiji Islands and the Concept of Spatial Hierarchy, unpublished, 2001.

Maps and Decisions: Allen's Creek Flood Plain, Opportunity or Disaster?

Sandra Lach Arlinghaus

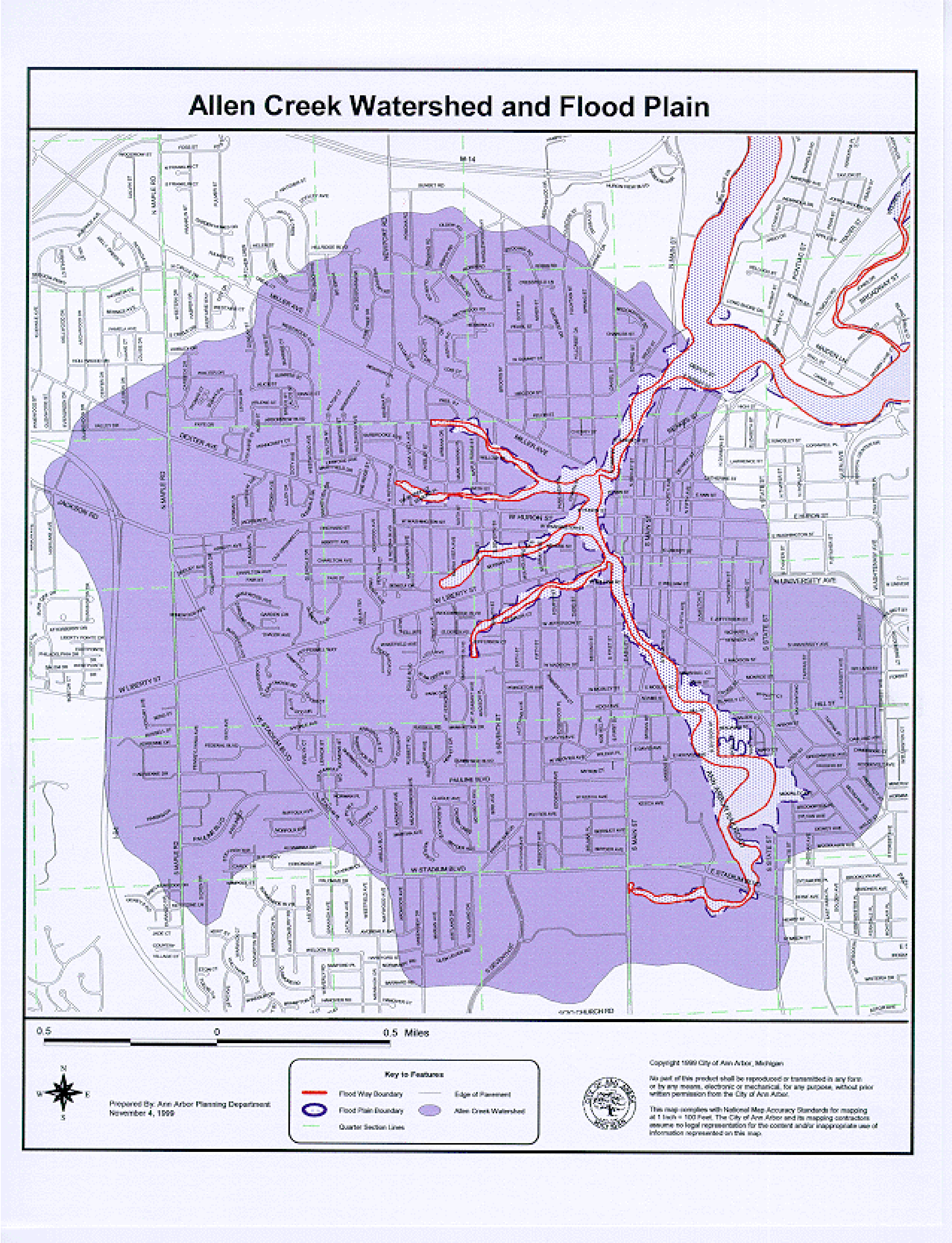
Maps supplied by the City of Ann Arbor (with particular thanks to Merle Johnson, Karen Popek Hart, and Wendy Rampson), as noted (http://www.ci.ann-arbor.mi.us) and by the Southeast Michigan Council on Governments (thanks to Gwo-Wei Torng) (http://www.semcog.org).

- **Link to article.**
- **Link to online map (by author, using ArcView coupled with Image Mapper): eGovernment sample.**
- **Link to maps with aerials, created by the Planning Department, City of Ann Arbor.**
- **Link to related steep slopes Triangulated Irregular Network.**
- **Link to Neighborhood Information System using clickable maps.**

Follow the links to the City of Ann Arbor Planning Department and then to "Public Involvement" and then "Registered Associations" and then "Residential Associations" for example to see contact information displayed using a clickable map. This site, developed in 1998, is an early example of eGovernment.

(Developed on a grant from the City of Ann Arbor to the Planning Department to work in conjunction with the University of Michigan: Wendy Rampson, Rosalyn Scaff, Sandra Arlinghaus, Chandra Hurd).

Map to the right created by the Planning Department of the City of Ann Arbor, November 4, 1999 (Alexis Marcarello).



Maps and Decisions: Allen's Creek Flood Plain, Opportunity or Disaster?

(Please look at the online linked map)

Allen's Creek is a tributary of the Huron River, which bisects Ann Arbor, Michigan, into north and south sides. Allen's creek rises on the south side of Ann Arbor. It flows north to the Huron past residential neighborhoods near the University of Michigan stadium as well as past residences, businesses, and industries in the downtown and nearby west side areas. For much of its length, Allen's Creek is confined in an underground pipe. The sequence of maps shown below, in Figure 1 (left), shows the outline of the creek shed in red (with a stippled red pattern inside the creek shed). The backdrop behind the creek shed shows surface hydrology (shades of blue), parks (green pattern), street pattern, and soil types (shades of earth tones). This sequence is presented, as an animated abstract, to suggest some elements of the complexity of this particular creek shed. A more detailed picture of complexity would need to reflect the degree of accuracy of the maps: flood plain boundaries are plus or minus 40 feet, contours are plus or minus 5 feet, and so forth. The flood plain is the area into which water spills out when the creek rises out of the flood way--the direct channel containing the surging water. The map to the right of the animated map is a static close-up of the same region; it shows the parcel map (Figure 1, right).

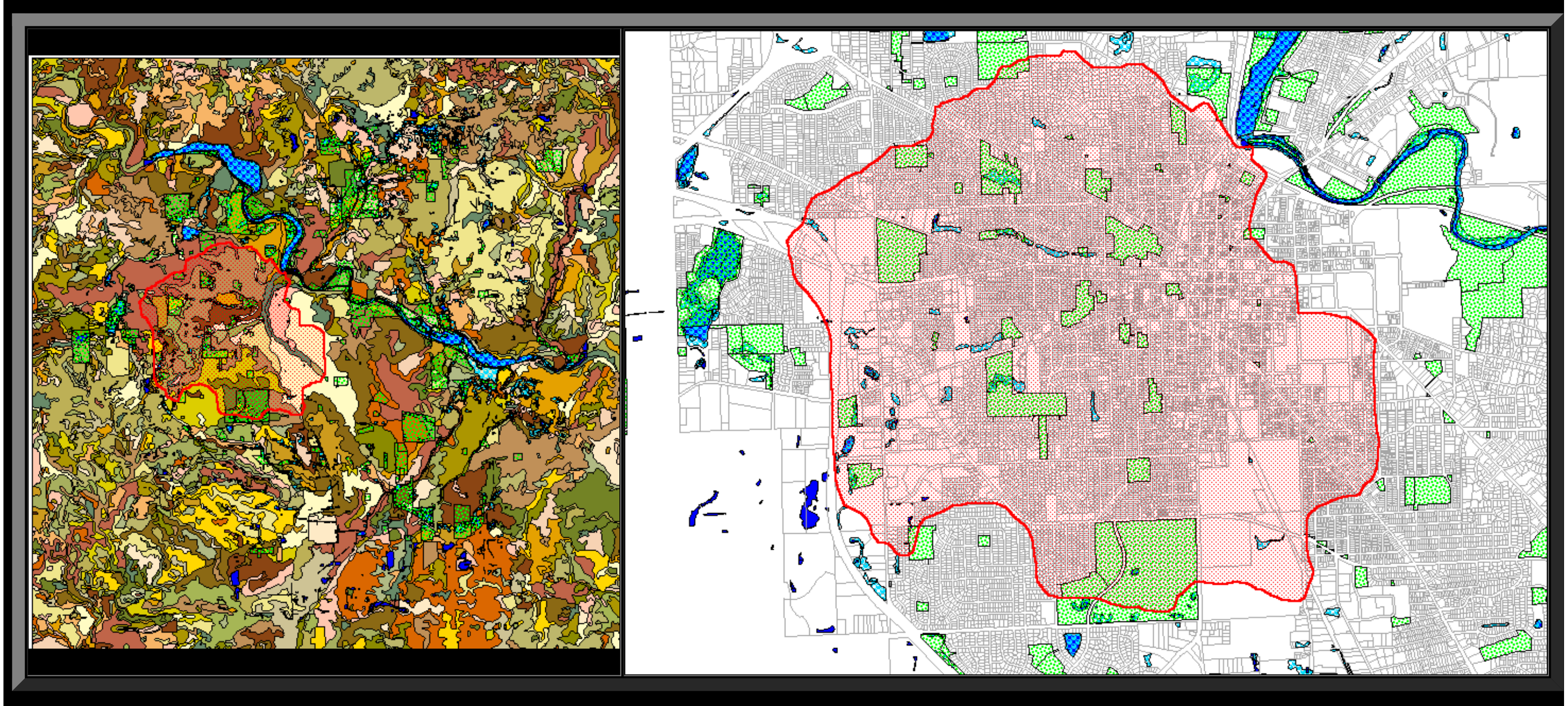


Figure 1. Left: Animated abstract, to illustrate some of the complexity, of the Allen Creek shed showing surface hydrology, parks, streets, and soils. Right: Static close-up of Allen Creek shed, parks, surface hydrology, and City parcels.

The animated abstract and static maps in Figure 1 show only surface hydrology at a gross level; Allen's Creek, itself, is not evident within the water shed. The animated map sequence in Figure 2 shows Allen's Creek, its flood plain, the City parcel map and clipped portions of the parcel map (the theme of shades of yellow is based on parcel size; it could be based on any information for which data was available). Depending on how the clipping is done, various pictures are portrayed. The first clip truncates parcels in the flood plain with the flood plain boundary. Thus, one does not know how much of any particular parcel lies in the flood plain and therefore that view is supplemented with a grayed backdrop of the entire parcel map. More effective, from a standpoint of parcel percentage within the flood plain, is to select all parcels from the parcel map that touch the flood plain boundary. The resulting map is then one that overlaps the flood plain boundary. Yet another parcel map can be created if the creek itself is used, rather than the flood plain, to create such maps. All maps in this sequence have merit; yet which one might a municipality choose to use as a policy statement from which to help in allocation of funds? Each will lead the community in different directions. The different maps shown in Figure 2 select different sets of parcels as "flood plain parcels." Planners of all sorts (professionals and others) should consider this fundamental issue prior to allocating tens of millions of taxpayer dollars for improvements. The maps we draw influence the decisions we make; the decisions we make influence the maps we draw. Maps and decisions, together, influence the conclusions we draw and the policies we make.

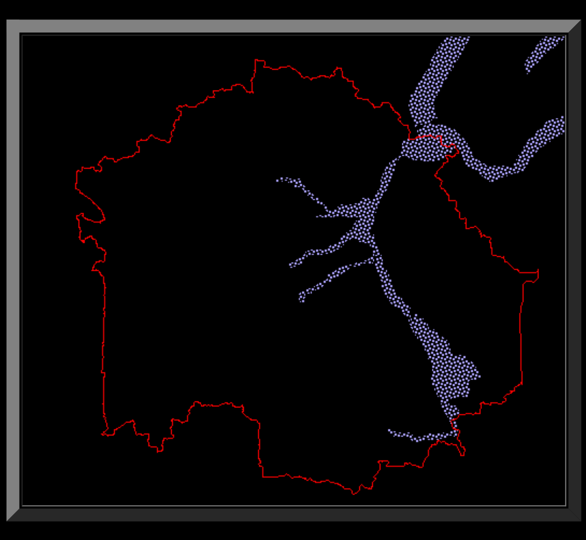


Figure 2. Animated map sequence of different styles of maps that might be made employing Allen Creek, Allen Creek flood plain, and City of Ann Arbor parcels. Which parcel map clipped by hydrology might be viewed as the "official" statement--all have merits and drawbacks and each one selects a set of parcels different from the other.

If one owns the GIS used to make the maps and has access to the base maps, then it is a relatively straightforward matter to create a variety of maps and consider the merits and drawbacks of each. The average taxpayer, however, may not own such software. How, then, might that person, who wishes to participate in a public process, do so? One answer is to distribute the materials using the Internet in such a way that not only can already-prepared maps be distributed, but so, too, can some of the capability of the GIS software be distributed through free software, such as a browser. The linked map shows an Internet map of Allen's Creek and its flood plain. It also shows the City parcel map and street centerlines; the map has some degree of user interaction available. Use the inset map as a context guide; zoom in on the large map; and, use the inset map to navigate around the large map (click on the inset map to do so). Click on the large map to bring up the database that is interactive with the map.

The interactive, online linked map is created using ImageMapper (TM) software applied to maps made in ArcView GIS 3.2 (TM, ESRI) from City of Ann Arbor base maps. The material that is put into the internet map is, of course, the choice of the person who owns the mapping software and the server account on which such maps are distributed. Internet mapping is attractive for a variety of eGovernment possibilities (Randy Deshazo, student College of Architecture and Urban Planning, University of Michigan, first drew my attention to these maps as useful for eGovernment interaction).

Opportunity

As a city, Ann Arbor is reliant on (among other things) taxpayer dollars to keep the City going. The University contributes, of course, to opportunities of various sorts, but as a state university does not contribute directly to the tax base. Thus, the tax base that is drawn upon comes from an unusually small percentage of land within the city: Ann Arbor has high property tax rates in relation to other Michigan cities. Most of the land within the city is already developed. One way to continue to raise funds is to do so through dollars from developers. With sky-rocketing property values, and little available land, developers turn an eye to creative uses of existing land within the city. Some proposals are sensitive to environmental costs; others are less so. Some see Allen's Creek flood plain and flood way as a source of substantial tracts of land that they believe could be successfully developed, sometimes citing arguments that promoting density in the downtown area (where there is substantial existing infrastructure) can reduce sprawl. For them, the flood plain and flood way offer opportunity: their arguments are often couched in terms that suggest opportunity for others as well (sprawl reduction through promoting density, affordable housing, or needed dollars for the city). Peter Allen, local real estate developer and University of Michigan colleague, comments in a note to James Nicita (Allen's Creek Watershed Group and Wayne State University) that we keep in mind the following items:

> "1) An engineering study should include an economic study. The repair and redevelopment of the Allen Creek must look at the options for new construction wherever possible, partly to serve the demand for not only open space but also for office, housing, neighborhood retail, artists, non-profits, etc.
> 2) ...improvements will cost $80 million according to one study. Who will pay for this? Creating a[n]... overlay district to capture the taxes from the new development should be considered.
> 3) Allen Creek goes under several buildings...Daylighting is not an option in places such as this.
> 4) Keep in mind that the city is the biggest landowner in the creekway...."

Ordinances may be revised to allow extra height in exchange for donation of flood plain and flood way segments of existing parcels to parkland: to create continuous build-up of green space for natural hydrological and biological activity. This approach is just one example of a strategy that may have merit. No matter how the issue is argued, however, it is clear that there are substantial economic benefits, to businesses and to the broader community (in terms of wise expenditure of the tax base), to developing and redeveloping parcels of land already in the City. The challenge is to do so in a manner that does not add to the existing environmental burden and to do so in a manner that will help to remedy that burden.

Disaster

On the other side of the issue are environmental arguments. Should one ever build in the flood plain or flood way? These belong to the river and the river will take and use them whenever it needs to do so. To build in them is to offer eventual disaster to residences and businesses located in them. There are already hundreds of structures in the Allen Creek flood plain or flood way (*Ann Arbor Observer*, November, 1999). To build new structures may increase the threat to those already there. Because Allen's Creek is confined within a pipe in the more densely built-up areas of town, there are already reports of spectacular events with manhole covers over Allen's Creek popping like corks during heavy rains (interview of Ethel Potts long-time city resident; also, *Ann Arbor Observer*, November, 1999). The extreme position here might see removal of all structures from the flood plain and flood way parcels, conversion of them into parkland that could serve as a buffer between adjacent non-flood plain properties, and an unearthed ("daylighted") Allen's Creek allowed to follow its natural channel. City of Ann Arbor Planning Director, Karen Popek Hart, notes, however, that "a huge issue...is contamination of soil the pipe lies in--daylighting may not be environmentally 'good' without massive excavation and disposal." If the economic issues dominate, might they tend only to defer the inevitable long-range environmental issues? In the total build-out scenario, after all the flood plains and flood ways are built upon, what next? Redevelopment of parcels offers one promise for continuing funds and if the environmental issues dominate, such sources of funding will be sorely needed.

Conclusion

This local issue points to an obvious need to reconcile economic and environmental needs, not as separate issues but as the complexly intertwined knot of challenges that they are. Viewed more broadly, this local controversy might be seen as a difference in reconciling issues involving long-range and short-range planning. Central to many arguments is a "belief" as to whether the worst case (or even bad case) environmental scenario can occur. This "belief" often rests on maps: what is a flood plain and do the maps represent the situation in a realistic fashion? Some say no: the evidence of experience is what should guide land use. Others say yes: the map is a scientific tool that is applied uniformly across the city and does not play neighborhood favorites (*Ann Arbor Observer*, November, 1999). The heart of the matter is to determine what constitutes a highest and best use of tax payer dollars--one simply cannot know in advance, despite highly persuasive arguments advanced on all sides. Thus, a middle of the road action might arise as the prudent political action--as so often seems to happen in situations involving dilemmas.

Factors that might play into an answer to reconciling the disaster with the opportunity include (but are not limited to):

- Spatial concerns
  - Spatial analysis in assessing risk--use of GIS
  - Map accuracy and creation/updating/enhancement of dynamic maps (GIS) from current data. There may well be gaps, resulting from jurisdictional differences, in existing GIS maps; the flood plain and flood way do not necessarily fall within political boundaries
  - Understanding the evidence of maps. Use of media to educate people that a map is a scientific tool of merit in guiding policy; a map is not merely a pretty picture of a hypothetical forecast.
- Resource concerns
  - Implement a cost-benefit analysis to assess the current fiscal situation: economic and land use issues and costs
    - To the average citizen
    - To affected citizens
    - To affected businesses
    - To the city
    - To the environment
  - Implement a hydrological study to assess the current environmental information: hydrological issues and costs
    - To the average citizen
    - To affected citizens
    - To affected businesses
    - To the city
    - To the environment
- Policy concerns
  - Ordinance review--of city, state, or federal concern?
  - Impact of planning on residents and businesses already there--a property rights/regulatory takings issue (with generic "justice" fundamental).
  - Possible purchase of development rights (interview of Randy Deshazo) or fee simple purchase.
- Educational concerns
  - Getting people to understand the science of the issues.
  - Promoting geographic (and other) literacy. One way might be to use maps with great frequency and to do so in imaginative and interesting ways in a variety of settings.
- Preparing for the future by planning--how to avoid similar, linked situations involving substantial fiscal and environmental cost. One answer could center on master planning by creek shed, rather than by manmade boundaries. Thus, a hypothetical "new" urban area would have, for example, Allen's Master Plan, Mallett's Master Plan, Creek Shed #3 Master Plan, Creek Shed #4 Master Plan, and so forth. While this approach might solve the problem for a brand new hypothetical city, how might a built-up region implement such an approach? A few issues to consider include the policy and other concerns noted above. In addition, one might also consider:

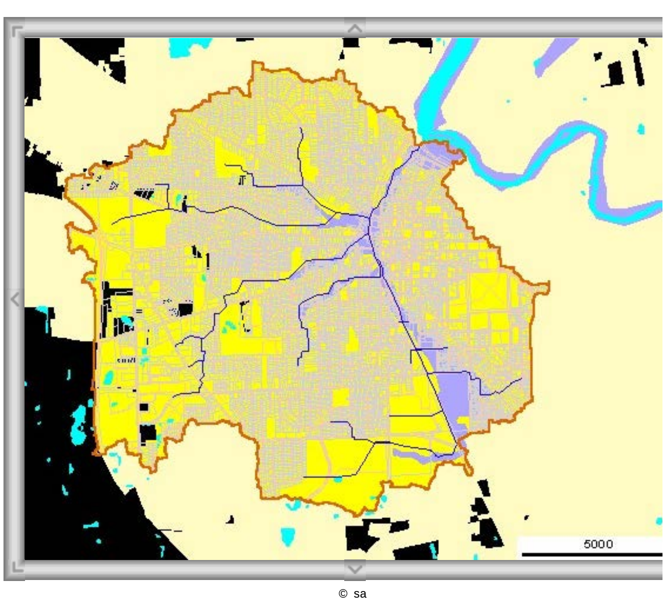
  Annexation issues and regional planning.
    - In 2007, a boundary agreement between the City of Ann Arbor and neighboring Ann Arbor Township permits the city to annex township "islands" contained within the manmade freeway ring outlining Ann Arbor. Some of these parcels lie in flood plains. What sorts of rights should they have?
    - Regional planning offers a powerful tool for addressing matters of broad interest to the larger human community. An eventual challenge with creek sheds as master planning units is to piece together a puzzle of creek sheds across the entire land mass that might serve the world well. How to do so without causing great fear of snatching of territory is a severe difficulty.   City of Ann Arbor Planning Commissioner Donna K. Tope suggests overlay legislation adopted by all jurisdictions in the creek shed as one possible legal tool for implementation of creek shed planning at the local regional level.

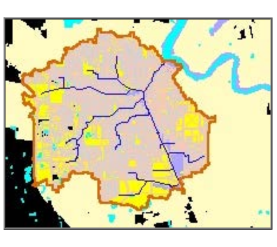
  Increases in impervious surface and related environmental issues such as rate of stream flow, erosion issues, and water quality.
    This linked map (base map courtesy of SEMCOG) shows amount of impervious surface in Washtenaw County, Michigan. The percentages are percentage of impervious surface by Southeast Michigan Council on Governments (SEMCOG) land use parcels.

The wise use of maps (or other models) can lead us to make wise decisions.

Sandra Lach Arlinghaus
The University of Michigan
sarhaus@umich.edu

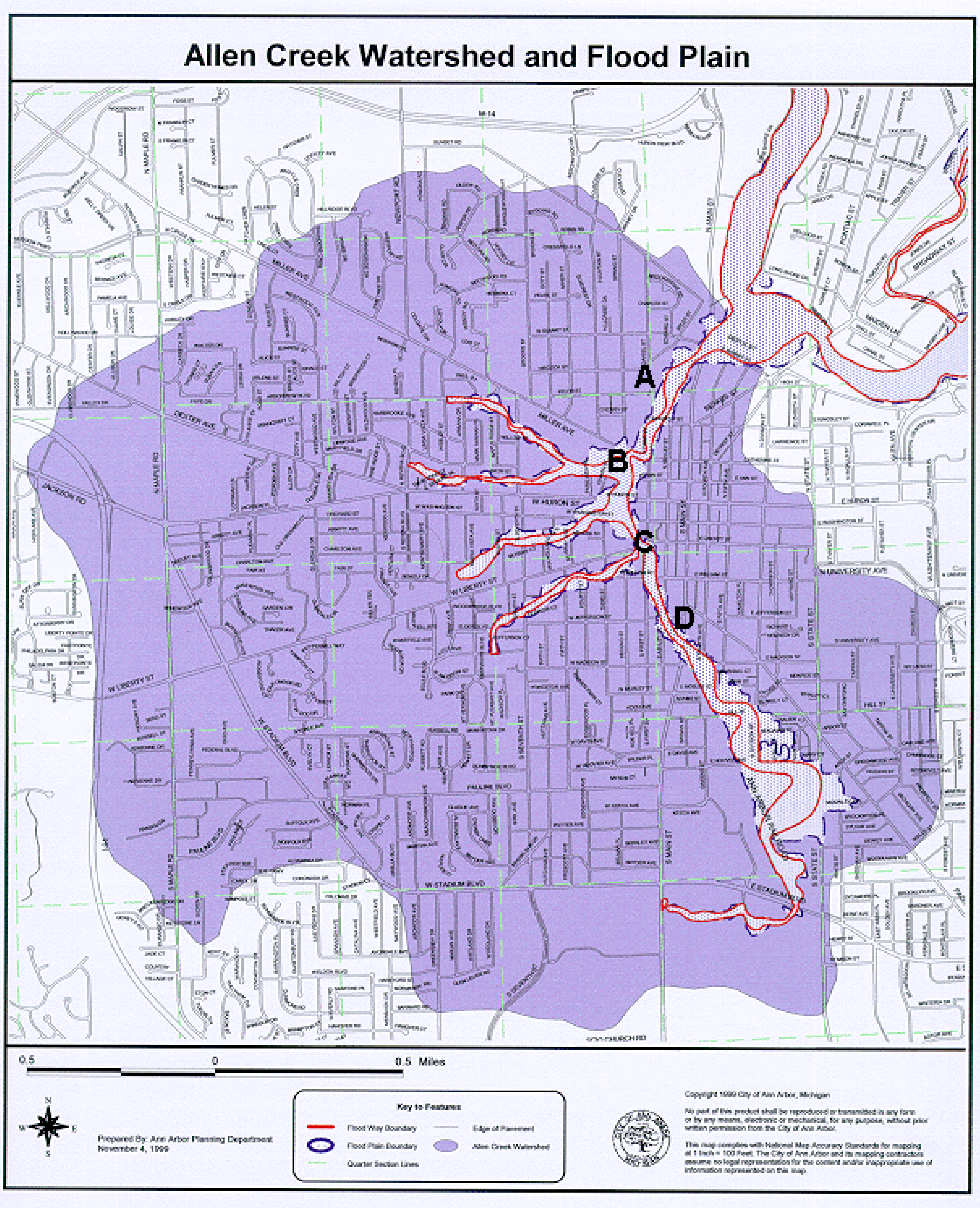
Ann Arbor Parcels in Allen Creek Watershed





Click on the map on the left to receive more information about objects on the map.

On the map below, click on the letters A, B, C, and D to see an attached aerial view of Ann Arbor with the parcel map and Allen Creek Floodway and Floodplain superimposed on each aerial.

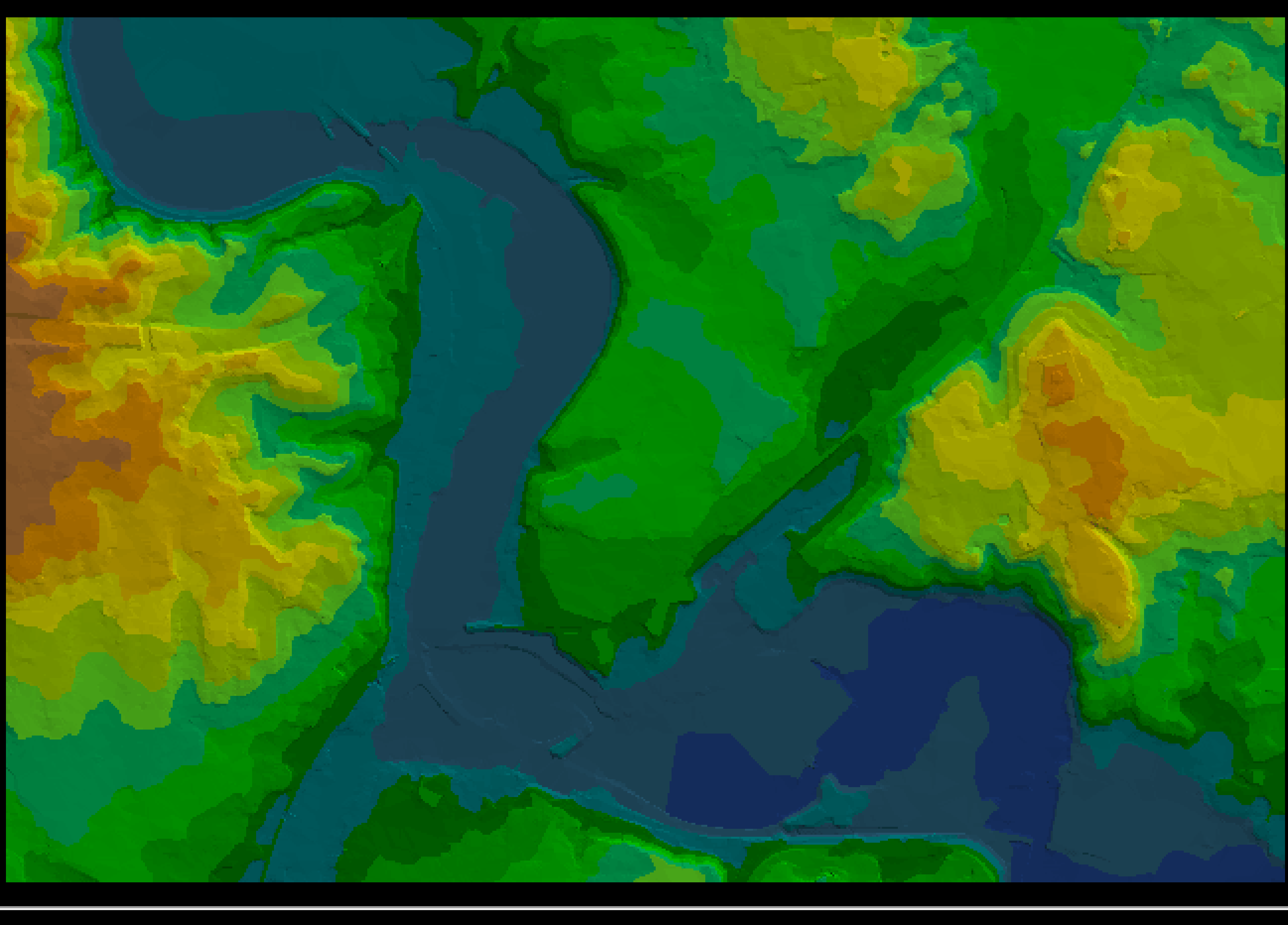


Hard copy of image and GIS work done by the City of Ann Arbor Planning Department (Karen Hart, Wendy Rampson, and Alexis Marcarello).

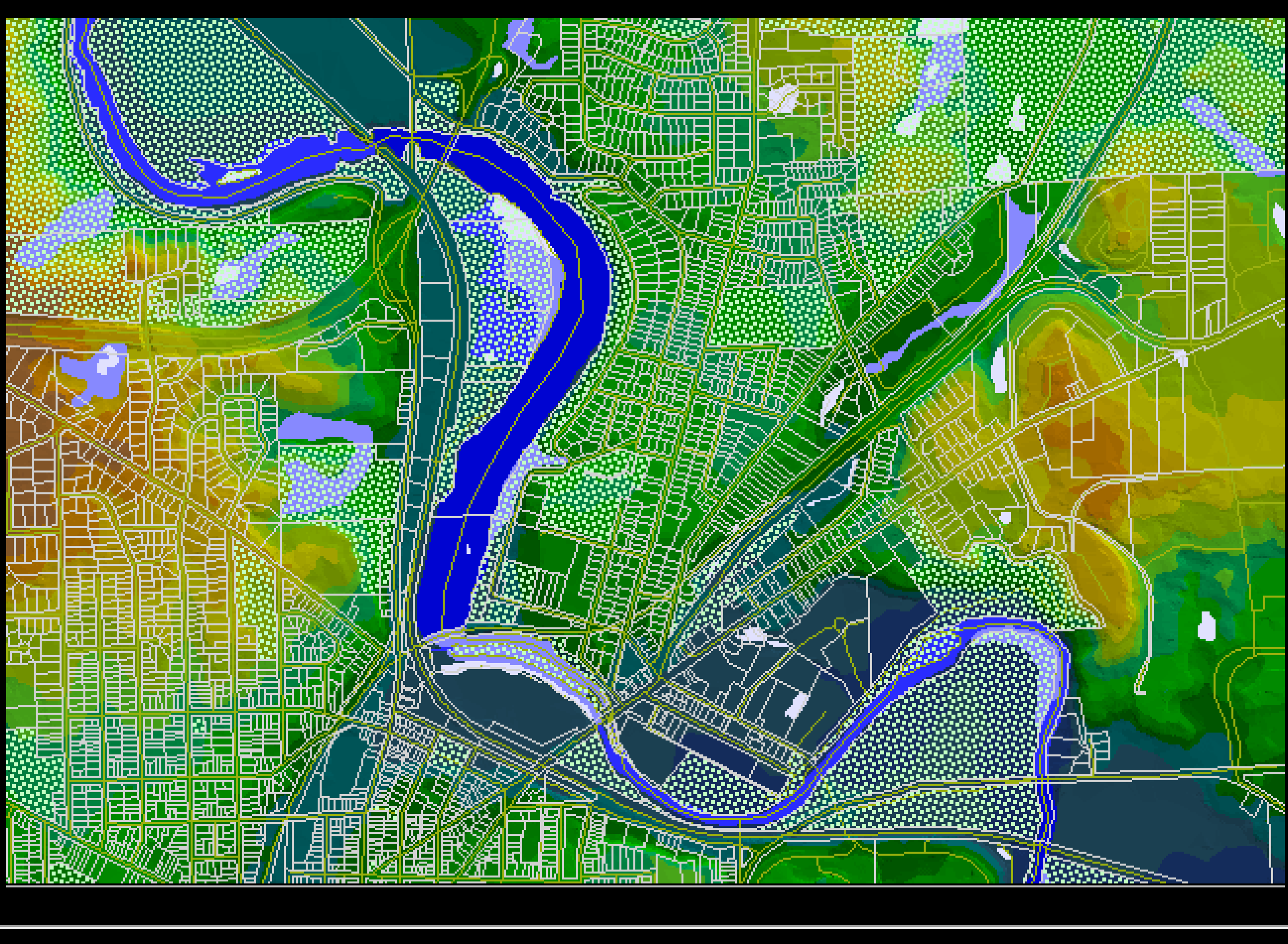
Triangulated Irregular Network
Ann Arbor, Michigan

City of Ann Arbor contour map, with contours at a five foot interval, is used to create a triangulated irregular network in ArcView GIS, 3.2, Spatial Analyst Extension. Steep slopes can be readily visualized and creeks and swales become evident. When this sort of spatial analytic tool is used in conjunction with other existing maps, guidelines for policy of where to develop and not to develop may emerge. Base maps from City of Ann Arbor (thanks to Merle Johnson). Legend is measured in feet above mean sea level. The interval in the legend is five feet. The TIN was calculated from the five foot interval creating 45 separate layers in which to perform calculations. The GIS software, in selecting a default color ramp, did not select 45 colors to show change in grade. It grouped the data into subgroups of 15 to 20 feet by color. Thus, each individual color represents 15 or 20 feet of elevation, ranging from deep blue at 750+ feet to rust color at 975 feet. In particular,

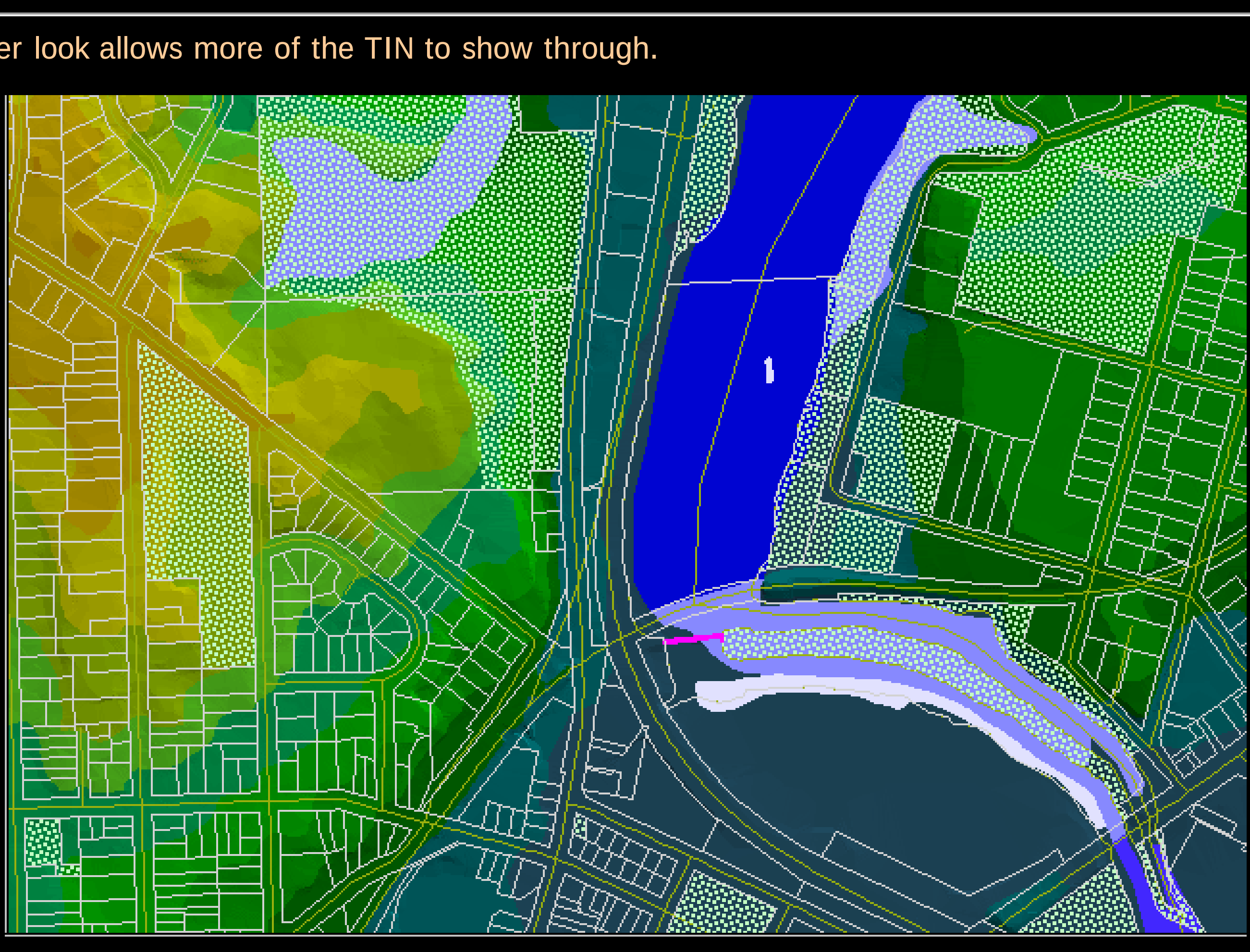
750 to 800 feet: deeper blue to lighter blue, respectively;
800 to 850 feet: deeper green to lighter green, respectively;
850 to 900 feet: blue-green to chartreuse, respectively;
900 to 950 feet: yellow to orange, respectively
over 950 feet, rust.



In the map below, the parcel map is overlain on the TIN as are layers for parks (stippled green), for water (blue), for street centerlines (green lines), and for dams (magenta). Allen Creek enters the river just south of the dam (north is at the top of the map)



A closer look allows more of the TIN to show through.



Book Review of ***Fast Food Nation: The Dark Side of the All-American Meal***
(Eric Schlosser, New York: Houghton Mifflin, 2001.� Available only in hardcover: $25.00)

Kameshwari Pothukuchi, Ph.D.
Wayne State University

If we are what we eat, then we are not well.� Fast food is destroying us: individuals, communities, work and family life, and indeed, our very connections with the world.� This is the alarming yet prodigiously researched message of the best-selling new book by Eric Schlosser, *Fast Food Nation: The Dark Side of the All-American Meal*.

Fast Food is a significant part of contemporary culture and economy: in 1970, Americans spent about $6 billion on fast food; in 2000, more than $110 billion.� Americans drink soda at the annual rate of 56 gallons--or nearly 600 12-ounce cans-- per capita.� McDonald's employs about 1 million people in the US, more than any other organization, public or private.� McDonald's earns the majority of its income not from food sales, but from rental income from its vast property holdings.� The golden arches that signify the firm are arguably the best-recognized symbol across the world, rivaling even the Christian cross.

The book chronicles, with vignettes, statistics, and engaging journalistic prose, the rise of fast food restaurants as they applied industrial practices of mass-production, specialization, and mass-marketing.� To turn kids into faithful, long-term consumers, fast food has forged alliances with toy companies, sports leagues, Hollywood, and our nation's school districts.� Exclusive contracts with chains such as Burger King and Pizza Hut have added to schools' budgets; although as the book documents, the costs of corporate presence in our schools are by no means small.� Fast food's employment of teenagers has accompanied the de-skilling of work, low-wages without benefits, elimination of employee training (even as corporations simultaneously accept hundreds of millions of federal dollars in the name of employee training), union-busting, and the frequent violation of child labor laws.� The book also takes up the industry's little-known practices that keep us hooked: chemicals that are added to flavor the burgers, fries, and milk-shakes, to add to their attractiveness, for example, and the practice of frying potatoes in fat that is 7% soy oil and 93% beef tallow.�

By far the most engaging part of the book deals with the suppliers of fast food�the meatpacking industry--and their social and health impacts. The four largest corporations--ConAgra, IBP, Excel, and National Beef--today slaughter about 84 percent of the nation's cattle, up from only 21 percent in 1970.� The industry has now relocated to anti-union states with cheap labor, such as Iowa, Kansas, Texas, Colorado, and Nebraska; wages in plants here are fifty percent lower than union-worker earnings in the old-style slaughterhouses of Chicago and New York.

The industry, like others, benefited from the Reagan-Bush era of lax anti-trust regulation, weakened federal oversight by OSHA (Occupational Safety and Health Administration), and food safety and environmental inspections.� The book documents many cases of fraud committed by industry leaders in price-fixing, cheating, and under-representing worker injuries and safety violations.� For example, between August 1992 and December 1995, Archer Daniels Midland, "supermarket to the world," conspired with its foreign rivals to over-charge farmers by as much as $180 million.� ConAgra, the third-largest chicken processor was forced to pay $17.2 million in damages when it was found to have deliberately mis-weighed 45,526 truckloads of birds over an 8-year period at a plant in Alabama, systematically cheating thousands of the state's growers.� Corporate officials considering new locations for plants also are not above lying to host communities: in a public forum in July 1988, in Lexington, KY, IBP officials promised worker stability; salaried, not hourly, workers; and smells not unlike "those emanating from your kitchens" (p 166).� As in other communities that are home to meat-packing plants, Lexington residents complain of pervasive odors of burning hair and blood, animal grease, and rotten eggs.

Meat-packing is among the nation's most dangerous jobs.� With line-speeds at 400 cattle per hour--up from 175 cattle/hour in 1980--and as workers wield large knives and cleaners hose water and chlorine heated to 180 degrees F, a third of the meatpacking workforce annually suffers injury that requires medical attention beyond first aid. Many meatpackers admit to using methamphetamine to feel charged and self-confident to confront their gruesome work.� Turnover in processing plants, according to industry reports, is as high as 80%; the author found that during one 18-month period, the Greeley, CO, ConAgra plant hired more than 5,000 different people to fill roughly 900 jobs.� By industry claim, such turnover has little negative effect on productivity and keeps insurance costs low.� Transient labor is easy to control and hard to unionize.� Death rates, however, are high in this work: "[Meat-packing] workers are the ultimate in disposable workers: illegal, illiterate, impoverished, untrained.� The nation's worst job can end in just about the worst way.� Sometimes these workers are literally ground up and reduced to nothing."� In one IBP plant in which two workers died, OSHA imposed a fine on the company of $480 for each worker (p. 178).� Workers face strong pressure not to report injuries; injured workers are often brought back from the hospital to the plant to understate lost work-days; and plants are known to keep two sets of logs--the more optimistic one reported to government health inspectors.

The meat-packing industry, notwithstanding the free-market rhetoric that emanates therefrom, is subsidized by all of us--meat-eaters, vegetarians and environmentalists alike.� In 1987, IBP exacted taxpayer subsidies from the state of Nebraska to the tune of between $13,000 to $23,000 per job.� Despite this, IBP, a company that was launched in 1960 by C J Holman and A D Anderson, with a $300,000 loan from the federal Small Business Administration, moved its headquarters in 1997 to South Dakota, a state without corporate taxes or personal income tax.� Along with other fast food trade groups, it has lobbied to prevent raising the minimum wage, restrict union-activity, and minimize health and safety regulation--all stressed by conservative political agendas especially as epitomized in the 1994 "Contract with America."� Former U.S. Rep. Newt Gingrich (R, Georgia), the Contract's main author, received more money from the restaurant industry than any other congressman; of the top 25 House recipients of restaurant industry funds, only four were Democrats.

The huge feedlots, slaughterhouses and hamburger grinders, and the overall centralization of meat production have provided the means to disperse pathogens that cause severe illnesses more widely than ever before.� E. coli 0157:H7, an especially virulent form of bacteria that now is the leading cause of kidney failure among children in the US, is largely spread through contaminated food.� But it is not the only one.� A USDA (United States Department of Agriculture) study in 1996 found that 7.5 percent of ground beef samples were contaminated with Salmonella, 11.7 percent with Listeria monocytogenes, 30% with Staphylococcus aureus, and 53.3% with Clostridium perfringens.� Furthermore, 78.6 percent of the ground beef samples contained microbes that are spread primarily by fecal material (p 197).� It will surprise many to know that, by law, the USDA cannot demand a recall of contaminated products; it has to rely on the offending company for information on amounts and locations.� Once a company voluntarily decides to pull contaminated meat from the market, it is under no legal obligation to inform the public, even if consumers may continue to be at risk from contaminated products.

Reading this far, the shock of the knowledge that some of the most questionable ground beef in the US is purchased by the USDA for school cafeterias (to go into the free and subsidized meal programs), is probably somewhat tempered.� USDA is required to purchase from the vendor with the lowest price, with no additional safety requirements.� The book reports on plants that supply to the USDA, processing diseased cattle and those dead before arrival to the plant, and mixing rotten meat returned from retail operations.� The meat purchased for schools has standards less stringent than even those imposed by the fast food industry.� Meat exported to the EU is subject to tougher processing standards than for local consumption, thereby requiring slower line-speeds at plants; unsurprisingly, workers appreciate more producing for Europeans than Americans.

In turn, fast food's impacts on the American--and global--landscape and culture have been huge.� For example: restaurant signs became taller and more garish as they competed for the attention of drivers on the emerging highways of the 1950s.� Today, McDonald's uses commercial satellite photography to predict sprawl from outer space so as to be among the first to bid for cheap land along highway exits.� Seven years after it opened its first restaurant in India, McDonald's established a supply network there, teaching Indian farmers to grow iceberg lettuce with seeds specially developed for the nation's climate.� Today, in the US, obesity rates are the highest of any industrialized nation in the world.� Obesity is spreading to China and Japan, countries that have adopted the "Big Mac and large fries" culture.� Germany is home to over 1,000 McDonald's, and is the most profitable overseas market for what has become the biggest restaurant chain in the country.� Across the world, fast food restaurants are targets for anti-globalization and anti-US-imperialism demonstrations.

The book proposes solutions, but without devoting the length to document the ills of the industry.� Free-range, grass-fed cattle production; family restaurants, independent processors, farm-land preservation efforts, and chains with worker-friendly practices ($8/hour wages with health and retirement benefits, sick and vacation leave, etc.) are offered albeit with little conviction as alternatives to the highly concentrated, vertically integrated fast-food industry.� On the policy side, more systemic proposals seek to curb industry malpractice and strengthen consumer, labor, and environmental regulations: ban advertising of foods high in fat and sugar targeted to children; strictly enforce minimum wage, overtime, child-labor and other labor laws; eliminate employee training subsidies to chains that churn workers and maintain low-skilled work; increase safety of school food; integrate food safety responsibility into one federal agency; improve sanitary conditions in the nation's slaughterhouses; improve working conditions in plants; place tougher sanctions on poor industry practices related to worker safety and health; and perhaps equally importantly, view livestock and land as values in their own right, not simply commodities.� These are important proposals; the book falls short of addressing the question of how these are to be implemented. It is, however, no less valuable for such a lack.�

Engaging, with a wealth of detail, and a finely modulated sense of outrage, the book is an important contribution to analyses of the global food system.� It should be useful to students of globalization, corporate control, space and place, culture, urban and rural areas, and sustainable living.� In its documentation of the corrupting nexus of money and power, it is not unlike two other recent books in its genre: *A Question of Intent* by David A Kessler (2001; New York: Public Affairs), an inside look at efforts to uncover Big Tobacco's lies, and *Dispensing with the Truth* by Alicia Mundy (2001; New York: St Martin's Press), which examines the battle over the diet drug Fen-Phen.

Consumers have made the fast food industry what it is today.� This book gives us--as consumers and citizens--some of the tools we need to demand accountability from those in charge of its oversight and, at least partially, to reclaim our food system.

Review of *High Technology and Low-Income Communities: Prospects for the Positive Use of Advanced Information Technology*, edited by Donald A. Sch�n, Bish Sanyal, and William J. Mitchell, MIT Press, 1999.

Richard Wallace
University of Michigan

Does information technology represent a major transformation in human economic interactions or merely the latest step along a gradual continuum?� Will new information technology widen the gap between rich and poor or will it provide low-income communities with the tools to close the gap?� According to the various contributors to *High Technology and Low-Income Communities: Prospects for the Positive Use of Advanced Information Technology*, the answer to both questions is "yes."� In other words, at this time we cannot conclude with much confidence how high technology will affect low-income communities in the long run; we cannot even conclude with certainty that it will have an important effect at all.

Emerging from a colloquium held at MIT in the spring of 1996, this anthology, edited by the late Donald A. Sch�n, to whom the book is dedicated, and his former MIT colleagues Bish Sanyal and William J. Mitchell, brings together the insights of urban planners, social activists, and technological pioneers.� While the first two of these groups are interested primarily in the plight of cities and low-income communities, the latter is interested primarily in the evolution of high technology.� Out of the juxtaposition of these viewpoints arises not a consensus, but both pessimistic and optimistic views on how high technology (used more-or-less synonymously with information technology in the book) is affecting and will affect low-income communities.

For the most part, the most pessimistic views are offered in Part I of the book and authored by leading academics, such as Manuel Castells, Peter Hall, and Leo Marx.� These contributors examine historical, sociological, political, and economic trends to suggest that access to information technology is, and is likely to remain, restricted by class, race, and geography.� Schools in isolated inner-city communities, for example, are less likely to offer high-tech training to their students and their students are less likely to graduate, etc.� With the exception of the chapter by Mitchell, Part I presents largely theoretical arguments that high technology will serve to widen the gaps between rich and poor, creating communities that are as isolated from informational opportunities as inner cities today are often isolated from economic and educational opportunities.

In contrast to the other chapters in Part I, Mitchell�s chapter presents a range of contrasts between physical presence and �telepresence� and generally finds much to recommend the latter.� In so doing, however, he seems to have neglected all the negative possibilities that could arise for low-income communities, such as greater social and geographic isolation, from a telesociety.� For Mitchell, the mere possibility of positive outcomes seems to be good enough; we need not consider the political and economic realities of technological diffusion.� Fortunately, the other authors in Part I are more sensitive to the potential for new technology to differentially benefit those at the top of the socio-economic ladder.

The contributors to Part II of the book are less interested in possibilities and theories and more in documenting the positive use of high technology in low-income communities.� Thus, overall Part II presents a somewhat more optimistic viewpoint, offering concrete examples of how high technology is being used to better life in low-income (and often minority) communities.� In these chapters, we learn about how computers are already being used as tools to improve neighborhoods' access to planning data, empower local communities, and foster improved technological fluency and self-confidence among inner-city youth.� The story in these chapters is not exclusively rosy, however, and within we also hear concerns for technological equality (for example, equal access to the electronic world, especially in the schools, and the technological modernization of the inner city) and how failure to address these concerns will hinder the ability of low-income communities to use high tech to improve their lot.

Absent from Part II, however, and from the book altogether, are empirical comparisons of the use of high technology in low-income and high-income communities.� Without such comparisons, we cannot evaluate whether the positive examples from Part II represent the closing of digital and economic divides or whether they are a few outlying cases preventing even faster growth in the magnitudes of these divides.� Quite possibly, while low-income communities are advancing via high tech as spelled out in Part II, wealthier communities are speeding ahead even faster.

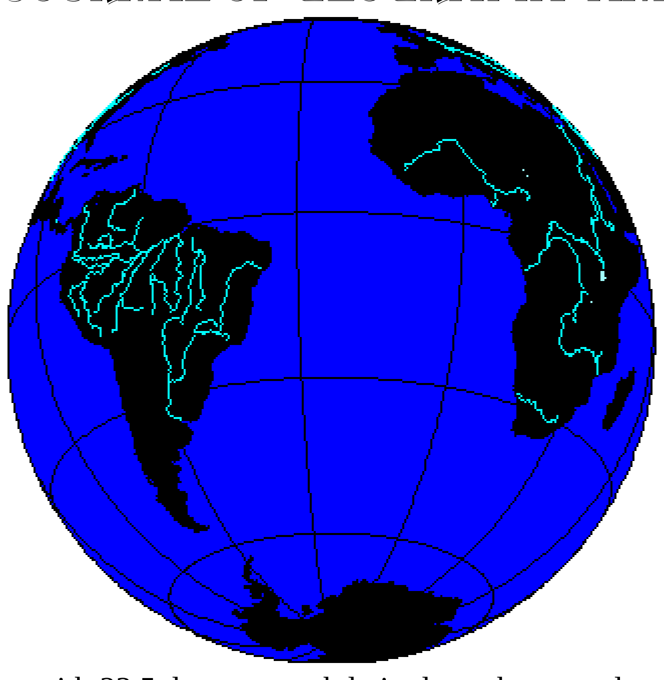
As a result of this important omission, the policy recommendations that emerge in Part III (which consists of a single chapter co-authored by Sanyal and Sch�n) are fairly modest in tone, focusing on equal opportunity in the high-tech realm.� Although the authors do acknowledge that the

> differential capacity to access and manipulate information between upper- and lower-income communities is likely to continue because of the fast pace of technological innovation and the higher-income resident's greater ability to purchase new hardware and software (p. 388),

they do not recommend policies designed to eliminate such mismatched capacities.� Rather, the authors call on government to support minimum data and information needs.� My fear, however, is that such minimums will become increasingly obsolete and inadequate as the well off continually upgrade their technological skills and informational access.� In this scenario, the more pessimistic views expressed in Part I of the book may well prove accurate even if high technology infiltrates and is used in low-income communities.� Much like the supposed equal access to housing, merely regulating equal access to information technology may result in increasingly segregated telecommunities.� My suspicion is, despite the claims of some authors that high technology renders geography less relevant, that the correlations between spatial, economic, and digital segregation will be positive and high.� Little in this volume suggests otherwise.

SOLSTICE:

AN ELECTRONIC JOURNAL OF GEOGRAPHY AND MATHEMATICS



Earth: with 23.5 degrees south latitude as the central parallel.

VOLUME XII
NUMBER 2
DECEMBER, 2001

SOLSTICE: AN ELECTRONIC JOURNAL OF GEOGRAPHY AND MATHEMATICS

http://www.imagenet.org

WINTER, 2001

VOLUME XII, NUMBER 2

ANN ARBOR, MICHIGAN

WebSite: http://www.imagenet.org

Electronic address: sarhaus@umich.edu

MISSION STATEMENT

The purpose of Solstice is to promote interaction between geography and mathematics. Articles in which elements of one discipline are used to shed light on the other are particularly sought. Also welcome are original contributions that are purely geographical or purely mathematical. These may be prefaced (by editor or author) with commentary suggesting directions that might lead toward the desired interactions. Individuals wishing to submit articles or other material should contact an editor, or send e-mail directly to sarhaus@umich.edu.

SOLSTICE ARCHIVES

Back issues of Solstice are available on the WebSite of the Institute of Mathematical Geography, http://www.imagenet.org and at various sites that can be found by searching under "Solstice" on the World Wide Web. Thanks to Bruce Long (Arizona State University, Department of Mathematics) for taking an early initiative in archiving Solstice using GOPHER.

PUBLICATION INFORMATION

The electronic files are issued yearly as copyrighted hardcopy in the Monograph Series of the Institute of Mathematical Geography. This material will appear in a Volume in that series, ISBN to be announced. To order hardcopy, and to obtain current price lists, write to the Editor-in-Chief of Solstice at 1964 Boulder Drive, Ann Arbor, MI 48104, or call 734-975-0246.

Suggested form for citation: cite the hardcopy. To cite the electronic copy, note the exact time of transmission from Ann Arbor, and cite all the transmission matter as facts of publication. Any copy that does not superimpose precisely upon the original as transmitted from Ann Arbor should be presumed to be an altered, bogus copy of Solstice. The oriental rug, with errors, serves as the model for creating this weaving of words and graphics.

Spherical Measures without Spherical Trigonometry

Waldo Tobler
Professor Emeritus, Geography Department
University of California, Santa Barbara, CA 93106-4060
http://www.geog.ucsb.edu/people/faculty_members/tobler_waldo.htm

A common misconception suggests that it is necessary to understand spherical trigonometry in order to calculate properties of a spherical surface. That this is false can be demonstrated by deriving the formula for distance and direction on a sphere without any knowledge of spherical trigonometry. However, some knowledge of the properties of a sphere is required.

Suppose one wants to know the great circle distance between two locations given by their names in latitude and longitude. Call these P_1 (f_1, l_1) and P_2 (f_2, l_2). Using plane trigonometry one can compute the location of these points in a three dimensional rectangular (Euclidean) coordinate system, centered at the origin of the sphere. This yields the locations as vectors in space as V_1 (X_1, Y_1, Z_1) and V_2 (X_2, Y_2, Z_2). The straight line distance between these two points is given by the well known formula: $D_{12} = [(X_1-X_2)^2 + (Y_1-Y_2)^2 + (Z_1-Z_2)^2]^{1/2}$. This is the chord distance between the two points, penetrating the sphere. The chord distance between the two points can be considered to be one side of a triangle, with origin at the center of a circle, whose other two sides have a length equal to the radius of the sphere. Take this radius to be one unit, and call it R. Divide the triangle into two equal parts, by constructing the perpendicular to the chord from the center. Now we know two sides of a right triangle, and the length of the third side (from the center to the chord) can be calculated. From this the angle at the center can be calculated, using any of the trigonometric formulae relating points in a right triangle. Twice this angle is the angle that spans the distance between the two points, that is, it is the angular separation of the points on the sphere.

In more detail, use standard spherical coordinates:
$X_1 = R \cos f_1 \cos l_1$
$Y_1 = R \cos f_1 \sin l_1$
$Z_1 = R \sin f_1$

$X_2 = R \cos f_2 \cos l_2$
$Y_2 = R \cos f_2 \sin l_2$
$Z_2 = R \sin f_2$

The length, L, of the line from the center of the circle to the perpendicular to the chord is, using C as the length of the chord, $L = [R^2 - (C/2)^2]^{1/2}$. Now, from elementary trigonometry, $C/2L = \tan a$, $L/R = \cos a$, $C/2R = \sin a$. Doubling a gives the angle subtended at the center of the circle, and at the center of the sphere. Use the simplest (the third) of these relations to calculate the distance on a sphere.

Example:
Near Santa Barbara, CA: $f_1 = 34°$, $l_1 = -120°$.
Near Zürich, CH: $f_2 = 47.5°$, $l_2 = 8.5°$
$X_1 = R \cos f_1 \cos l_1 = -0.414529$
$Y_1 = R \cos f_1 \sin l_1 = -0.717978$
$Z_1 = R \sin f_1 = 0.559193$

$X_2 = R \cos f_2 \cos l_2 = 0.668169$
$Y_2 = R \cos f_2 \sin l_2 = 0.099859$
$Z_2 = R \sin f_2 = 0.737277$

$C = [(-.414529 - .668169)^2 + (-.717978 - .099859)^2 + (.559193 - .737277)^2]^{1/2} = 1.368491$, $L = 0.729252$ but is not really needed, and continue to use R = 1. Then, from $a = \sin^{-1}(C/2)$, $a = 43.176$ degrees of arc. Twice this value gives 86.35 degrees for the length of the arc on the circle. Now take R= 6378 kilometers to approximate the radius of the sphere. Then the distance between Santa Barbara and Zürich, on the spherical assumption, is $p*a*R/90$ or 9612 km.

No spherical trigonometry has been used. But if one is familiar with vector algebra the result can be obtained more immediately, namely by calculating the angle between the two vectors directly as
$2a = \cos^{-1}(V_1 \cdot V_2 / |V_1||V_2|)$.

For the direction of the second point from the first recall that directions are measured between great circles. In this case we need the direction of the great circle from Santa Barbara to Zürich with respect to the reference direction from North. The plane passing through Santa Barbara, the North Pole, and the origin, cuts the sphere along the North-South great circle and has equation -.717978 X + .414529 Y = 0, from the three-point equation of a plane. The plane spanning the region between Santa Barbara, Zürich, and the origin intersects the sphere along the connecting great circle and has equation -.5851891 X + .6792581 Y + .4383362 Z = 0. The angle between these two planes is 31.9 degrees East of North. (see C. Oakley, 1954, �Analytic Geometry�, Barnes & Noble, pages 179, 185). The area of a polygon on a sphere is equal to $R^2\{p(n-2) + S b_i\}$ where the sum is taken over the n interior angles. Again, no spherical trigonometry has been used.

Solstice: An Electronic Journal of Geography and Mathematics
Volume XII, Number 2
Ann Arbor: Institute of Mathematical Geography

What's At Home? Shelter for the Poor in Low Income Cities

John D. Nystuen
Professor Emeritus, University of Michigan
nystuen@umich.edu

Figure 1. Table of Parameters

Figure 2. People by the Billions

Figure 3. Homeless family in Bombay.

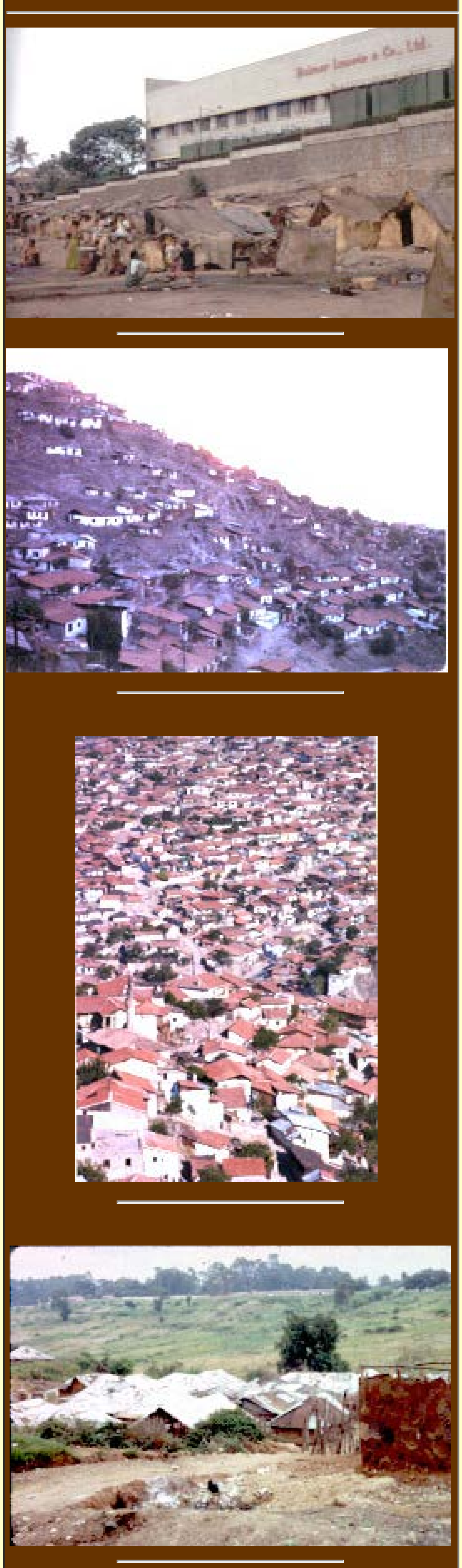


Figure 4. A collage of squatter settlements.

Figure 5. Hong Kong high-rise apartments; 30,000 people live in this complex.

Figure 6. Table of Cities of over Ten Million

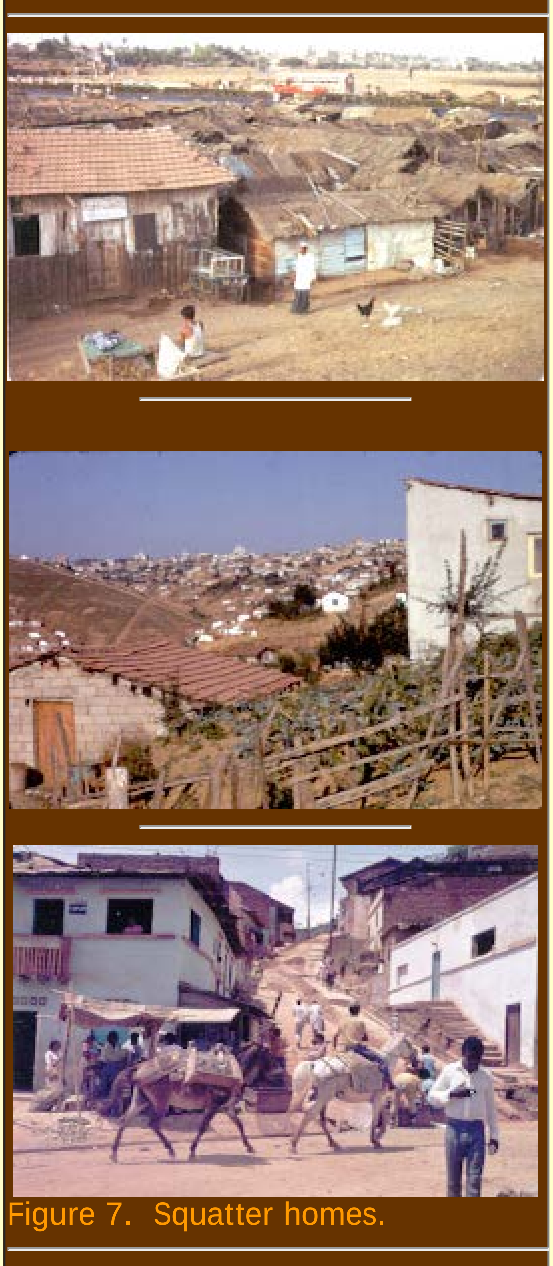


Figure 7. Squatter homes.

Figure 8. What's at Home

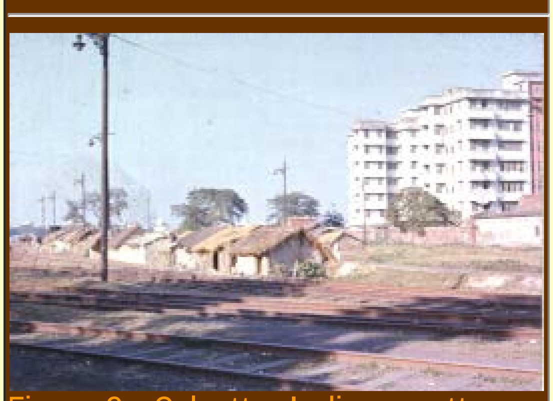


Figure 9. Calcutta, India, squatter settlement along active rail lines: not a good place to raise children.

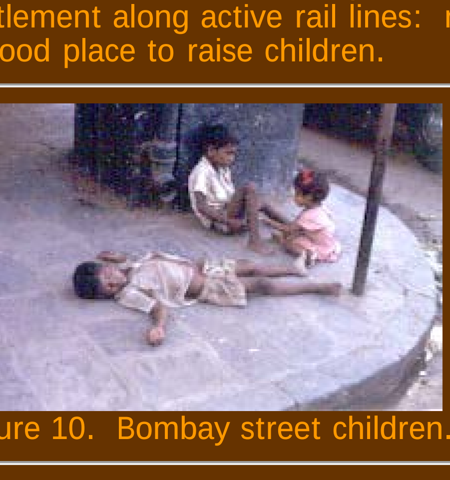


Figure 10. Bombay street children.

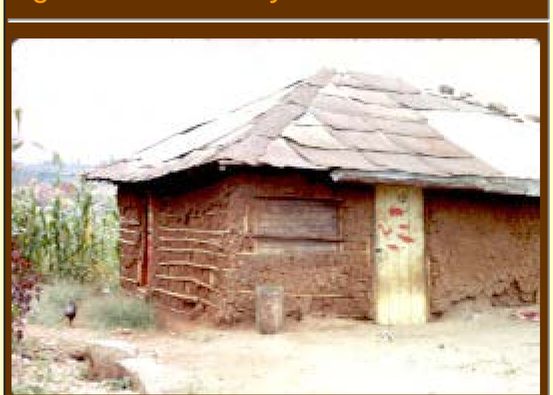


Figure 11. Nairobi, Kenya, Mathes Valley house with lockable door, two windows, and corn crop that must be guarded.

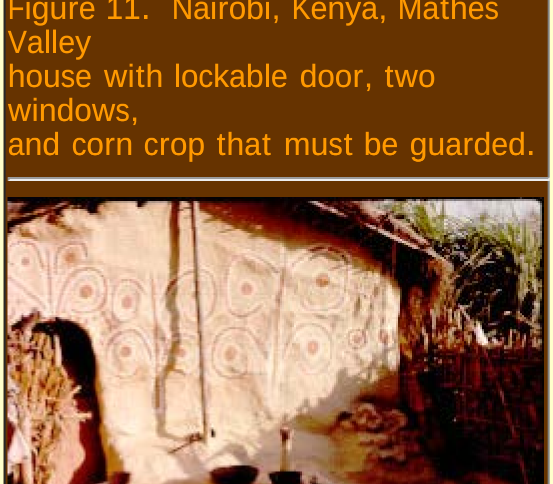


Figure 12. Outdoor kitchen of a home in the Rapki Valley, Nepal

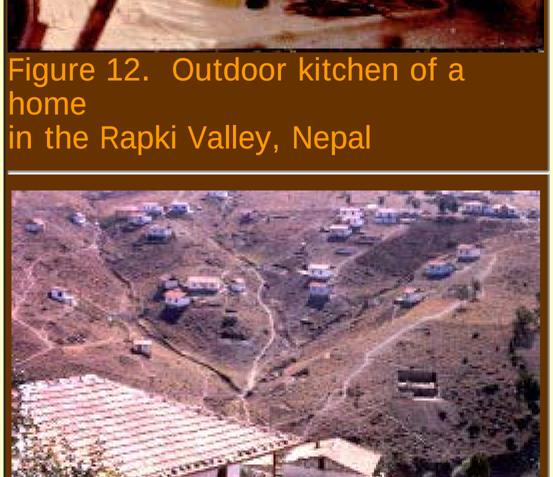
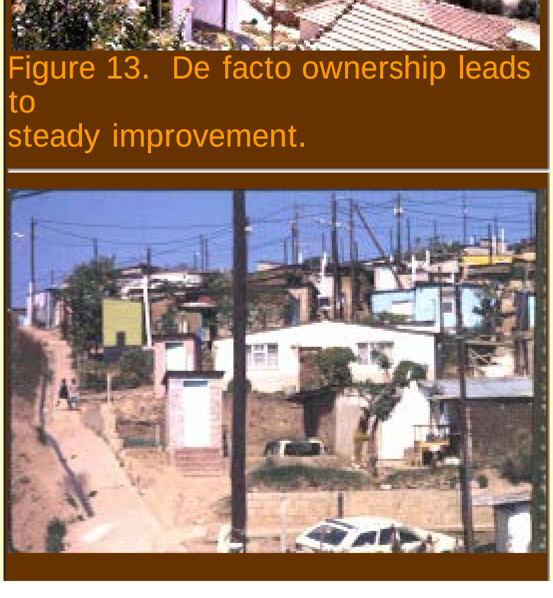


Figure 13. De facto ownership leads to steady improvement.



Finding shelter for the poor in low-income cities is a problem for *now* and for the *future*. The twentieth century saw huge growth in human population. This population is now entering the twenty-first century with enormous and growing needs for sustenance and shelter. Millions of new families are created each year all seeking ways to sustain life, to nurture, and to shelter their children. In the new century, most of the population growth will be in cities. Most of these cities will be poor because their already poor economies simply cannot grow at rates needed to raise the level of living while accommodating their own population growth. In addition these cities receive huge waves of poor, unskilled immigrants who not only are destitute but who are often refugees fleeing oppressive regimes. How do these people live? All these people need shelter. How, in the past seventy years, have four billion more people found shelter? The parameters of this process are migration and growth, poverty, homelessness, and rule of law (Figure 1).

Migration and Growth

In 1930, there were two billion people on earth. It had taken 120 years to grow from one billion. Forty-five years later, in 1975, the population had doubled to four billion people. Twenty-four years later, the population had grown again by two billion people. In the first quarter of the 21st century, another two billion will be added to the total, at least, according to the optimistic forecast by the United Nations, which sees a decline in world population growth but an increasing growth in the urban population. The number of people has increased by the billions (Figure 2).

Poverty

Basic human needs must be met or people die. Food and health are basic. The first need is to be fed. For poor people, most of their income goes toward finding food. Shelter comes next. Those with extremely low incomes are homeless (Figure 3). Generally, opportunities for making a living have been better in urban areas than in rural regions. The consequence has been a vast rural to urban migration. However, city economies are not able to keep pace. Opportunities for making a living are meager. Many people are homeless or live in spontaneous shelters, that is, self-built, squatter settlements or shantytowns squeezed into marginal spaces in and around the city (Figure 4). Such shelters have different names in different places: bustee in India, gegucondu in Turkey, favelas in Brazil. To meet the housing needs in poor cities, appropriate technologies for self-built housing must be utilized. Hong Kong's population grew eight-fold since 1931. Most of this population has been housed in high-rise apartment buildings (Figure 5). Hong Kong is among the wealthy cities of the world and its economy is buoyant. The Hong Kong Housing Authority has provided for seventy percent of the housing demand through a building program financed by loans from the city government. These loans have been or are being paid back on time and with interest. This payback with interest is possible because the occupants, whose incomes have steadily risen, can pay sufficient rent to meet capital and upkeep costs. This process is not an option for cities where the majority of the people live in poverty.

At the turn of the twentieth century, most of the world's poor could not afford to allocate the recommended twenty-five percent or more of their income to pay for shelter. These huge concentrations of poor people are a legacy of the last century. In 1975, five cities had ten million inhabitants or more. Two of these cities, Tokyo and New York were in affluent nations. In the year 2000, nineteen cities had ten million inhabitants or more with four of them in affluent nations (Tokyo, New York, Los Angeles and Osaka). The rest are in low-income nations (Figure 6). By 2015 the estimate is for 23 cities over 10 million. Most of their inhabitants live in self-built housing constructed by people with very low incomes and skills who must rely on building technologies appropriate for those circumstances. Consequently, affordable shelter is frequently inadequate in the extreme. The shelters are likely to provide insecure and inadequate protection against the elements and intrusions. They lack access to urban services, and are likely to occupy land illegally (Figure 7). They are hazardous to life. People constantly strive to improve their housing as a way to improve the quality of their lives.

Homelessness

What is missing when you have no home? Shelter is a complex mix of factors each of which contribute to quality of life (Figure 8). We all seek to create a secure and comfortable home place. In fact, most animals do the same by creating nests or dens in which to raise offspring. To protect children is a specie imperative no less for humans than for animals. Factors that are important for a home place fall into the categories *site* and *situation*, terms that are familiar to geographers. *Site* attributes refer to in-place or inside characteristics such as the design and type of building materials used for buildings, the slope and drainage of the building lot terrain, the temperature range or number of days of sunshine. *Situation* refers to the position of the home place relative to other locations. A home place must have access to community services such as utilities, schools, and generally to connections to the larger society. All these characteristics should be considered when assessing the viability of home places or when planning aid in building human habitats.

Locational (Access) Needs. Three types of outside connections are needed for a home place to function effectively. They are (i) access to physical services, (ii) access to community, and (iii) access to status.

Access to Physical Services A modern American home is serviced by several physical links such as a motorable road, electric power line, and water and sewer lines. There are information links too for mail, newspapers, telephone, and radio/TV. Access to information usually requires a fixed home address and/or fixed receiver equipment, e.g., street address/mailbox, phone jack, or cable TV. Mobile receivers, laptop computers and homepages on the Internet have introduced new spatial dynamics to information exchange by adding a virtual home to the physical home.

Sometimes, depending upon local conditions and availability, services can be provided on-site, such as, well water or a septic tank and drainage field. Such facilities do have neighborhood or locational implications depending upon soil type, aquifer capacity, and nearby housing density. Many of these attributes are absent in the squatter settlements of low-income cities.

Access to Community A home place needs access to social and economic exchange. Principal among these is proximity to work if income is earned outside the home. The home should also be conveniently located relative to other social services, retail stores, government offices, and homes of relatives and friends: in sum, the urban matrix. Schools are important. In Seoul, families move to school districts that have the best schools because students are assigned to school by place of residence. Residential land values in the best districts have soared due to this demand.

In the giant, low-income cities, the people in poverty will crowd into marginal places despite possibly terrible site conditions in order to get access to social and economic opportunities (Figure 9). Low cost, subsidized public transportation is a necessity in large urban areas with a high proportion of the population in poverty. Even modest fares may be a burden to the very poor. They must walk and must therefore crowd housing into places within walking distances of places of opportunity.

Access to Status A permanent home address is often a condition of citizenship. You have to have a permanent address in order to vote. In some places, home ownership is a requirement for voting on property tax proposals. You need to be a resident for your children to attend the public schools or to be eligible for welfare or social services. Children of migrant farm workers in the United States are often denied access to local schools and social services, which only adds to the difficulties in obtaining an education or sustaining health due to their short tenure in any one place.

People of means are inclined to invest far more in their home than is necessary for mere shelter. The home is used for displaying wealth and power to gain or affirm high status in the community. Ostentatious megahouses are characteristic of the nouveau riche in the communities of Silicon Valley and elsewhere across the United States at the end of the last century. The middle class behaves similarly by investing more than is prudent into too large a house and lot. Too much invested in housing leaves assets too concentrated and debt service too high in relation to annual income. The desire to own a large single-family house on a big lot is a major component in urban sprawl.

At the beginning of the last century, Americans believed that a woman's place was in the home. At the end of the century, that attitude had changed with over half the women in the work force outside the home. Still, in many parts of the world, a woman's status is defined by her role in the home. If she is not a family member located in a home place, she is an outcast subject to harassment and danger.

Site Needs. The home place is built or arranged to provide for (i) restoration, (ii) health, and (iii) security. Our home is our castle.

Restoration We have physiological needs that are periodic; foremost among them is the need to sleep. We can sleep anywhere but we find great comfort in returning to our own beds at night (Figure 10). This desire creates the great diurnal movement from homeplace into and back from the urban matrix characteristic of urban life. Other periodic needs are for food and drink. Again, these needs can be met elsewhere but it is efficient and comforting to have a place at home to meet these needs. A place for toiletry and bathing meets a daily need for grooming as we set out for the day. Finally, it is comforting to have a place to relax, to retreat from the alertness necessary in public and/or strange places.

Health The dwelling provides a roof overhead for protection from the elements, rain, snow, cold and heat. It can also be equipped to protect against hazards such as wind, fire, and earthquakes. Keeping the homeplace clean and fresh protects against disease and disease vectors. These elements are deficient to various degrees in squatter settlements. Crowded, unsanitary conditions, flimsy construction, lack of safe water and accumulation of wastes create hazards that threaten the entire urban area with spreading infectious disease or catastrophic fire, wind, or earthquake damage.

Security Strong walls and secure locks can provide for personal safety for one�s self and family. A secure home also affords protection of possessions and wealth (Figure 11). Physical barriers work best when attended to by vigilant concern for who is coming and going. Protection is more readily sustained where private, protected space is buffeted from open public space by semi-public areas. In larger houses, strangers are customarily welcome at the foyer/lobby or in the living room but not the kitchen or bedrooms. In some places, an outside courtyard shared with immediate neighbors can act as a semi-public buffer where strangers are immediately recognized if they enter unannounced (Figure 12).

A sense of security has much deeper roots than mere physical protection. The home place is where your roots are located. It is steeped in memories, memories of childhood, events, commitment, artifacts, landscapes not by sight alone but with memories of smells, sounds, tastes and kinetic senses. People love their homes. When separated in distant places they long for home. They will fight for and die for their home.

The sentiment of home arises from symbolic, shared meaning. Yi-Fu Tuan said that, "A place is a pause in movement�The pause makes it possible for a locality to become a center of felt value" (Tuan, page 138). The repeated returns to pause at home creates its value. Mostly, however, this is a collective achievement. Sharing the place with family and friends is what makes the place a home. The lonely hotel room or the empty house after the children have left and the spouse has died may be a source of bitterness and sorrow rather than joy.

To some the homeplace helps to define an individual's place or the community's place in the cosmos. Divine or supernatural blessings of the home may enhance a sense of security. In Thailand and Indonesia small house temples are placed at the corner of the home lot to invite spirits to protect the inhabitants. Sacred places are usually not in dwelling places but are nearby in the region accessible for periodic visits, if not daily, perhaps annually. Jerusalem is a Holy City; it is sacred for at least three major religions and is, unfortunately, a highly contested place. People will die to maintain control over it.

Rule of Law

An interesting observation is that squatter settlements are more of a problem for democratic regimes where rule of law is respected than they are for totalitarian regimes that rule by terror. The former Soviet Union and its Eastern European satellite states did not have squatter settlement problems because whenever people located housing in places not permitted by the state, the housing was forcibly removed by police or military action. State terror ruled. In contrast, regimes that are more law-abiding do not forcibly move against their citizens unless permitted through court action and approval. Gegucandu means *mushroom house* in Turkish. This refers to the practice of extremely rapid construction of a house, literally overnight like a growing mushroom. The house is illegally built on state owned land and is immediately occupied by a family. Officials can issue a stop order when a house is observed under construction on state land. However, if the house is already occupied, individual rights being observed, it takes a court order to have it removed. Istanbul and Ankara as well as other Turkish cities have thousands of spontaneously built houses on state lands. The courts are so far behind that once occupied, the inhabitants have *de facto* ownership despite having no title to the land (Figure 13). India, the world's largest democracy, also has thousands of squatter settlements that are not arbitrarily removed by state force.

City officials are often at odds with people who construct inexpensive, self-built houses. Squatter settlements are often hazardous. Public safety is always at issue. Settlements may be located on land unsuitable for housing such as in floodways or on very steep slopes: places unworthy for standard housing. Cheap, self-built structures are built without housing codes or subdivision standards. The properties may not be accessible by motor vehicle, which means fire trucks and other emergency vehicles cannot reach residences. They lack public services such as potable water or sewer and waste disposal or treatment. Health

Figure 14. Durban, South Africa, city-installed outdoor privys for sanitation.
Metered electric power supplied direct to houses.

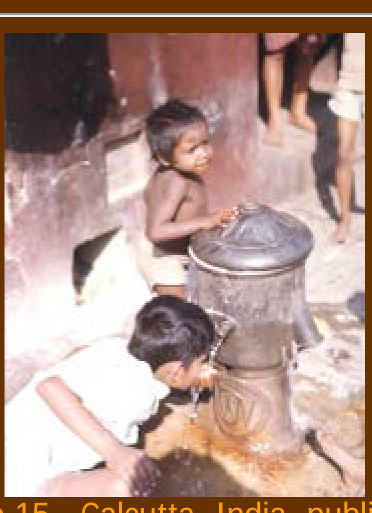


Figure 15. Calcutta, India, public water tap
with continuous flow when water is available.

Figure 16. High occupancy "shotgun house" in low-income neighborhood in the Desire
district of New Orleans, Louisiana, USA.

Figure 17. Ankara, Turkey. Well-cared
for home with fruit trees.

hazards that affect the whole city are the result. City officials are motivated to address such issues because of political pressure from more affluent citizens living in other parts of town (Figure 14). Low-income districts may be overcrowded with too many people per room occupancy. Houses located on property to which there is no title are not eligible for public services. Some of the people living in sub-standard housing may be illegal aliens who shun contact with any officials due to their lack of standing under the law.

Financing improvements in squatter settlements is extremely difficult. The economy of the low-income city is not only weak but the government has difficulty in finding funds to provide necessary public services. Urban public transit needs to be subsidized because the clients are too poor to support the system with fare box payments. If public services cannot be provided directly to private properties, it is difficult to recover costs through service charges. For example, if there is only the capacity to provide widely spaced public potable water stands; charging for the water is not possible. The water is free to all users (Figure 15). When this is the condition, water is usually available for only a short time at each stand, perhaps not even daily. The water is distributed piece-meal district by district to avoid complete loss of pressure in the system. Land taxes are not a major source of income for low-income cities. In New Orleans land tax was assessed by linear front foot; hence, the rise of the long, narrow "shotgun house" (Figure 16). The problem is lack of cadastral surveys assigning property to landowners and lack of spatial information management capacity in assessor's offices.

The public policy approach to these issues shapes the way the urban fabric develops. Millions of people have moved to the large, poor cities of the world and more are coming. The formal economies of these cities cannot cope with the growth. Some accommodation by public officials to the informal economies and to the capacity for self-help exhibited by those with little means is called for. Tapping the energy of poor but able people has been tried through site and service programs in which the city lays out streets and property boundaries and allows the occupants to build their own houses, sometimes with some simple building restrictions such as minimum wall heights. Ownership title is then given to the occupant. When this happens the house and lot are usually continually improved. In time a very suitable home emerges (Figure 17).

References

Yi-Fu Tuan, 1977. Space and Place: The Perspective of Experience Minneapolis: University of Minnesota Press.

United Nations, World Urbanization Prospects: The 1999 Revision, Table 5.
http://www.un.org/esa/population/pubsarchive/urbanization/urbanization.pdf
(downloaded Nov. 1, 2001).

All photos by author.

Solstice: An Electronic Journal of Geography and Mathematics
Volume XII, Number 2
Ann Arbor: Institute of Mathematical Geography.

WORLD URBANIZATION PROSPECTS: THE 1999 REVISION

KEY FINDINGS

World Urbanization Prospects: the 1999 Revision, prepared by the United Nations Population Division, presents estimates and projections of the number of people living in the urban and rural areas of the countries of the world for the period 1950-2030. It also provides estimates and projections for the period 1950-2015 of the population living in urban agglomerations. The *1999 Revision* updates the estimates and projections issued in the *1996 Revision*.

The key findings yielded by the *1999 Revision* are the following:

1. Virtually all the population growth expected during 2000-2030 will be concentrated in the urban areas of the world (figure 1). During that period the urban population is expected to increase by 2 billion persons, the same number that will be added to the whole population of the world. In terms of population size, there are 2.9 billion inhabitants in urban areas today and 4.9 billion are expected in 2030, whereas the world has 6.1 billion inhabitants and is expected to have 8.1 billion by 2030 (table 1).

Figure 1. Annual increments of the world population and of the world urban population, 1950-2030

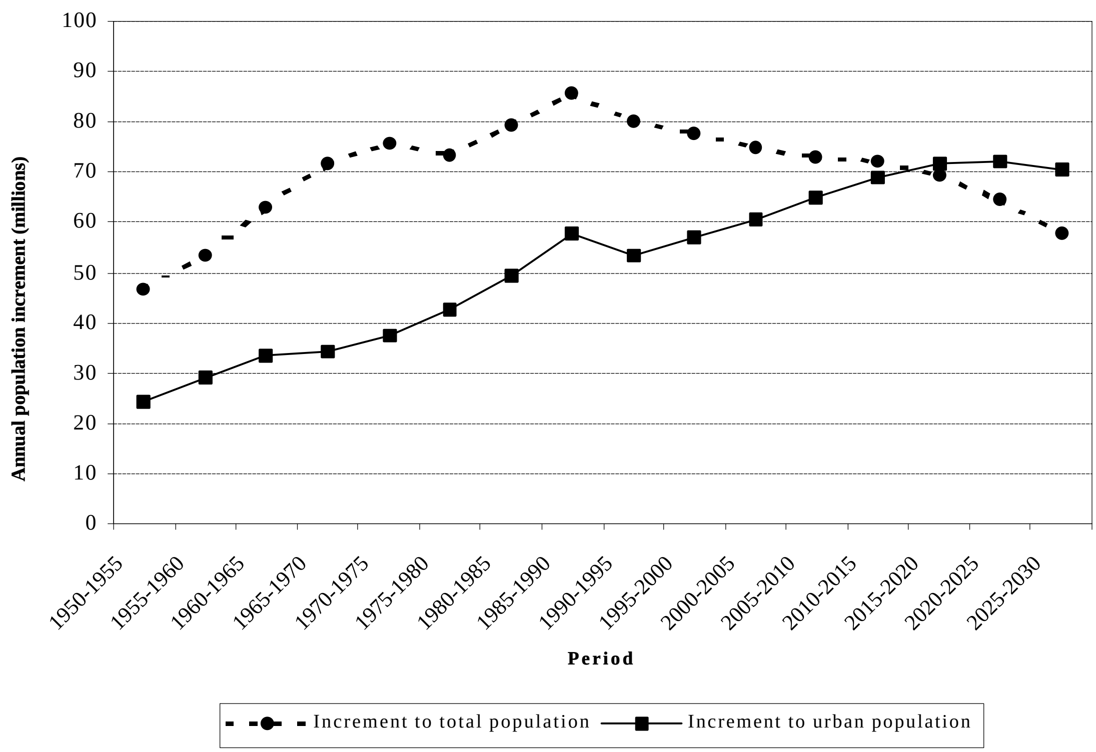


TABLE 1. DISTRIBUTION OF THE WORLD POPULATION BY URBAN OR RURAL PLACE OF RESIDENCE, 1950-2030

	Population (in billions)				*Growth rate (percentage)*		*Doubling time (years)*	
Major area	*1950*	*1975*	*2000*	*2030*	*1950-2000*	*2000-2030*	*1950-2000*	*2000-2030*
				A. Population size and growth				
Total population								
World	2.52	4.07	6.06	8.11	1.75	0.97	40	71
More developed regions	0.81	1.05	1.19	1.21	0.76	0.06	91	1,158
Less developed regions	1.71	3.03	4.87	6.90	2.09	1.16	33	60
Urban population								
World	0.75	1.54	2.85	4.89	2.67	1.80	26	38
More developed regions	0.45	0.73	0.90	1.01	1.41	0.37	49	186
Less developed regions	0.30	0.81	1.94	3.88	3.71	2.31	19	30
Rural population								
World	1.77	2.53	3.21	3.22	1.19	0.01	58	5,313
More developed regions	0.37	0.31	0.28	0.20	-0.50	-1.19	-	-
Less developed regions	1.41	2.22	2.93	3.02	1.47	0.11	47	632
				B. Urban indicators				
	Percentage urban				*Urbanization rate (percentage)*		*Doubling time (years)*	
	1950	*1975*	*2000*	*2030*	*1950-2000*	*2000-2030*	*1950-2000*	*2000-2030*
World	29.7	37.9	47.0	60.3	0.91	0.83	76	83
More developed regions	54.9	70.0	76.0	83.5	0.65	0.31	-	-
Less developed regions	17.8	26.8	39.9	56.2	1.62	1.14	43	61

2. Most of the population increase expected during 2000-2030 will be absorbed by the urban areas of the less developed regions whose population will likely rise from 1.9 billion in 2000 to 3.9 billion in 2030. The urban population of the more developed regions is expected to increase very slowly, passing from 0.9 billion in 2000 to 1 billion in 2030.

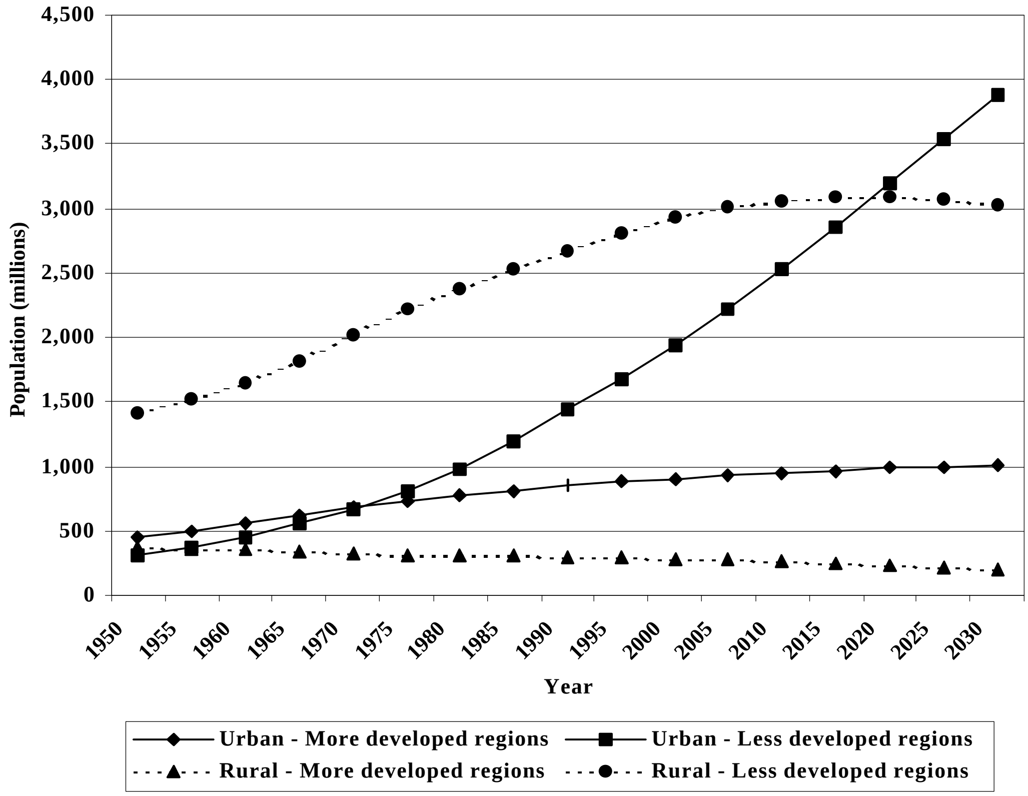
3. During 2000-2030, the world's urban population will grow at an average annual rate of 1.8 per cent, nearly double the rate expected for the total population of the world (1 per cent per year). At that rate of growth, the world's urban population will double in 38 years.

4. Growth will be particularly rapid in the urban areas of less developed regions, averaging 2.3 per cent per year during 2000-2030, consistent with a doubling time of 30 years. In contrast, the rural population of the less developed regions is expected to grow very slowly, at just 0.1 per cent per year during 2000-2030 (table 1).

5. Rural-urban migration and the transformation of rural settlements into cities are important determinants of the high population growth expected in urban areas of the less developed regions over the next thirty years. In combination with the universal reduction of fertility levels that is expected to occur in the future, these changes will lead to the eventual reduction of the rural

population of the less developed regions whose growth rate will first become negative in 2020-2025. That is, as of 2020 the rural population of less developed regions will begin to experience a steady decline similar to that characterizing the rural population of more developed regions since 1950 (figure 2).

Figure 2. Estimated and projected urban and rural population of the more and less developed regions, 1950-2030



6. The rapid increase of the world's urban population coupled with the slowing growth of the rural population has led to a major redistribution of the population. Thus, whereas in 1950, 30 per cent of the world population lived in urban areas, by 2000 the proportion of urban dwellers had risen to 47 per cent and it is expected to reach 60 per cent by 2030. At current rates of change, the number of urban dwellers will equal the number of rural dwellers in the world in 2007.

7. The process of urbanization is already very advanced in the more developed regions, where 76 per cent of the population lives in urban areas. Nevertheless, the concentration of population in cities is expected to continue so that, by 2030, 84 per cent of the inhabitants of more developed countries will be urban dwellers.

8. The level of urbanization is considerably lower in the less developed regions, where just 40 per cent of the population lives today in urban areas. This proportion is expected to rise to 56 per cent by 2030, implying that only by that date will the less developed regions reach a level of urbanization similar to that exhibited by the more developed regions in 1950 (see table 1).

9. There are marked differences in the level and pace of urbanization among the major areas constituting the less developed regions. Latin America and the Caribbean is highly urbanized, with 75 per cent of its population living in cities in 2000. Asia and Africa are considerably less urbanized, with 37 per cent and 38 per cent, respectively, of their populations living in urban areas. Being less urbanized, Africa and Asia are expected to experience rapid rates of urbanization during 2000-2030. Consequently, by 2030, 55 per cent and 53 per cent, respectively, of their inhabitants will live in urban areas. At that time, 83 per cent of the population of Latin America and the Caribbean will be urban (table 2).

TABLE 2. DISTRIBUTION OF THE POPULATION OF MAJOR AREAS BY URBAN OR RURAL PLACE OF RESIDENCE, 1950-2030

Major area	*Population (in millions)*				*Growth rate (percentage)*		*Doubling time (in years)*	
	1950	*1975*	*2000*	*2030*	*1950-2000*	*2000-2030*	*1950-2000*	*2000-2030*
					A. Population size and growth			
Total population								
Northern America	172	243	310	372	1.2	0.6	59	114
Latin America and the Caribbean	167	322	519	726	2.3	1.1	31	62
Europe	547	676	729	691	0.6	-0.2	121	-
Oceania	13	21	30	41	1.8	1.0	39	68
Africa	221	406	784	1,406	2.5	1.9	27	36
Asia	1,402	2,406	3,683	4,877	1.9	0.9	36	74
Urban population								
Northern America	110	180	239	314	1.6	0.9	44	77
Latin America and the Caribbean	69	197	391	604	3.5	1.5	20	48
Europe	287	455	545	571	1.3	0.2	54	450
Oceania	8	15	21	31	2.0	1.2	34	57
Africa	32	102	297	766	4.4	3.2	16	22
Asia	244	594	1,352	2,605	3.4	2.2	20	32
Rural population								
Northern America	62	64	71	58	0.3	-0.6	266	-
Latin America and the Caribbean	98	125	128	122	0.5	-0.2	128	-
Europe	260	221	184	120	-0.7	-1.4	-	-
Oceania	5	6	9	11	1.2	0.5	55	137
Africa	188	304	487	640	1.9	0.9	36	76
Asia	1,158	1,812	2,331	2,272	1.4	-0.1	50	-

B. Urban indicators

	Percentage urban				*Urbanization rate (percentage)*		*Doubling time (in years)*	
	1950	*1975*	*2000*	*2030*	*1950-2000*	*2000-2030*	*1950-2000*	*2000-2030*
Northern America	64	74	77	84	0.4	0.3	-	-
Latin America and the Caribbean	41	61	75	83	1.2	0.3	-	-
Europe	52	67	75	83	0.7	0.3	-	-
Oceania	62	72	70	74	0.3	0.2	-	-
Africa	15	25	38	55	1.9	1.2	37	57
Asia	17	25	37	53	1.5	1.3	46	55

Note: Major areas are ordered according to the percentage urban in 2000.

10. In Europe and Northern America, the percentage of the population living in urban areas is expected to rise from 75 per cent and 77 per cent, respectively, in 2000 to 83 per cent and 84 per cent in 2030. The increase in Oceania is likely to be smaller, from 70 per cent in 2000 to 74 per cent in 2030.

11. Despite their high levels of urbanization, the combined number of urban dwellers in Europe, Northern America, Latin America and the Caribbean (1.2 billion) is not as high as that in Asia (1.4 billion), the least urbanized major area of the world today (table 2). Furthermore, by 2030, Asia and Africa will both have higher numbers of urban dwellers than any other major area of the world.

12. Asia also has and is expected to have the largest rural population of the world during 2000-2030, amounting to 2.3 billion persons today. Africa, with 487 million rural inhabitants in 2000, is expected to see its rural population rise to 640 million by 2030, remaining the second largest during the period. Except for Africa and Oceania, all major areas are expected to experience a reduction of the rural population between 2000 and 2030 (table 2).

13. As a consequence of regional trends, the world rural population will remain nearly stable during 2000-2030, varying between 3.2 billion and 3.3 billion.

14. Although urban areas will encompass an increasing share of the world population, the proportion of people living in very large urban agglomerations is still small. In 2000, 4.3 per cent of the world population lived in cities of 10 million inhabitants or more and by 2015 that proportion will rise to 5.2 per cent. In addition, 2.6 per cent of the world population lives today in cities with populations ranging from 5 to 10 million inhabitants, and the projected figure for 2015 is 3.5 per cent. That is, by 2015, just 8.7 per cent of the world population is expected to live in large urban agglomerations (table 3).

TABLE 3. DISTRIBUTION OF THE WORLD POPULATION AND THAT OF MORE AND LESS DEVELOPED REGIONS BY SIZE OF URBAN SETTLEMENT, 1975, 2000 AND 2015

Major area	*Range of population size*	*Population (millions)*			*Percentage*		
		1975	*2000*	*2015*	*1975*	*2000*	*2015*
World	5 million or more	195	418	623	4.8	6.9	8.7
	1 to 5 million	327	704	1,006	8.0	11.6	14.1
	Less than 1 million	1,022	1,723	2,189	25.1	28.5	30.6
	Rural areas	2,531	3,210	3,337	62.1	53.0	46.6
	Total population	4,075	6,055	7,154	100.0	100.0	100.0
More developed regions	5 million or more	98	112	120	9.3	9.5	9.9
	1 to 5 million	145	219	250	13.9	18.5	20.6
	Less than 1 million	491	571	598	46.8	48.1	49.3
	Rural areas	315	285	246	30.0	24.0	20.3
	Total population	1,048	1,188	1,214	100.0	100.0	100.0
Less developed regions	5 million or more	97	305	503	3.2	6.3	8.5
	1 to 5 million	182	485	756	6.0	10.0	12.7
	Less than 1 million	531	1,152	1,591	17.6	23.7	26.8
	Rural areas	2,217	2,925	3,091	73.2	60.1	52.0
	Total population	3,026	4,867	5,940	100.0	100.0	100.0

15. The proportion of the world population living in small cities is considerably larger, though it is increasing at a slower pace. In 2000, 28.5 per cent of the world population is estimated to live in cities of less than a million inhabitants and by 2015 that proportion will likely rise to 30.6 per cent. Consequently, the trend towards concentration of the population in larger urban settlements has not yet resulted in a marked decline of either the proportion or the number of persons living in small urban settlements.

16. In more developed regions, the concentration of population in small urban settlements is even more marked than at the world level. Thus, in 2000, 48 per cent of the population in developed countries lived in cities of less than one million inhabitants and by 2015 that proportion is expected to rise to 49 per cent. In less developed regions, where most of the population still lives in rural areas, the proportion of people living in small cities is 24 per cent currently and will rise to 27 per cent by 2015 (table 3).

17. In both the more and the less developed regions, the proportion of people living in large urban agglomerations (of 5 million inhabitants or more) is low, amounting to 6.3 per cent in the less developed regions and to 9.5 per cent in the more developed regions today. By 2015, the relative increase in that proportion will be greater for less developed regions, where it will rise to 8.5 per cent, a level closer to the 9.9 per cent that more developed regions will have at that time.

18. Not only do the largest cities account for relatively low proportions of the world population but in addition their share of the annual growth of the urban population is expected to be moderate. During 2000-2015 cities of 5 million inhabitants or more are expected to absorb 21 per cent of the annual increment in the urban population, whereas cities with less than a million inhabitants will absorb 48 per cent (table 4). In both cases, cities in the less developed regions will absorb most of that increase. Thus the large cities of developing countries are projected to account for 20 per cent of the

TABLE 4. DISTRIBUTION OF THE ANNUAL INCREMENT OF THE POPULATION AMONG URBAN SETTLEMENTS OF DIFFERENT POPULATION SIZES, 1975 TO 2015

Major area	*Range of population size*	*Annual population increment (in millions)*		*Percentage of overall urban increment*	
		1975-2000	*2000-2015*	*1975-2000*	*2000-2015*
World	Total population	79.2	73.3	…	…
	Urban population	52.1	64.8	100.0	100.0
	Cities of 10 million or more	7.8	7.5	14.9	11.5
	Cities of 5 to 10 million	1.1	6.2	2.2	9.5
	Cities of 1 to 5 million	15.1	20.1	29.0	31.0
	Cities of less than a 1 million	28.1	31.1	53.9	47.9
More developed regions	Total population	5.6	1.8	…	…
	Urban population	6.8	4.3	13.0	6.7
	Cities of 10 million or more	1.3	0.1	2.4	0.2
	Cities of 5 to 10 million	-0.7	0.4	-1.3	0.6
	Cities of 1 to 5 million	3.0	2.0	5.7	3.1
	Cities of less than a 1 million	3.2	1.8	6.2	2.8
Less developed regions	Total population	73.6	71.5	…	…
	Urban population	45.3	60.5	87.0	93.3
	Cities of 10 million or more	6.5	7.4	12.5	11.4
	Cities of 5 to 10 million	1.8	5.8	3.5	8.9
	Cities of 1 to 5 million	12.1	18.1	23.3	27.9
	Cities of less than a 1 million	24.8	29.2	47.7	45.1

increase in the world's urban population and small cities in those countries will account for 45 per cent of that increase. In fact, the largest shares of the increase in the world urban population will go to cities with less than half a million inhabitants, cities with between 1 and 5 million inhabitants, and cities with more than 10 million inhabitants, in order of importance (table 4), but only in the case of cities with 1 to 5 million inhabitants will that share rise from 1975-2000 to 2000-2015.

19. The increase in the proportion of the population living in large urban agglomerations is mostly the result of a rise in the number of such agglomerations rather than of the rapid growth of the population of most of them. Thus, the number of cities with 5 million inhabitants or more will pass from 41 in 2000 to 59 in 2015. Among those cities, the number of "mega-cities" (those with 10 million inhabitants or more) will increase from 19 in 2000 to 23 in 2015 (table 5). As is well known, most of the large cities are located in developing countries. In 2000, just 10 of the 41 large cities belong to developed countries and only one more, for a total of 11, will be located in developed countries by 2015.

20. Large urban agglomerations do not necessarily experience fast population growth. In fact, some of the fastest growing cities have small populations and, as population size increases, the growth rate of a city's population tends to decline. However, some of today's mega-cities have experienced rather high rates of population growth over the past 25 years. Thus, Dhaka in Bangladesh grew at an average annual rate of 6.9 per cent during 1975-2000 and Lagos, Nigeria, increased at a rate of 5.6 per cent annually over the same period. But they are exceptional cases. Among the 19 mega-cities of today, just 7 grew at rates above 3 per cent per year and 9 experienced moderate or low growth (below 2 per cent per year). In the future, just 4 of today's mega-cities will exhibit growth rates above 3 per cent and 10 will be experiencing very low growth, at below 1 per cent per year (table 6).

21. In terms of population size, Tokyo is the largest urban agglomeration in the world, with 26.4 million residents, and is expected to remain the largest although its population will not grow. It is followed today by Mexico City, Bombay, São Paulo and New York. Of these cities, Bombay is expected to become the second largest mega-city in 2015, followed by Lagos, Dhaka and São Paulo, each of which is expected to have more than 20 million inhabitants by 2015 (table 5).

TABLE 5. POPULATION OF CITIES WITH 10 MILLION INHABITANTS OR MORE, 1950, 1975, 2000 AND 2015
(*in millions*)

	1950			*1975*			*2000*			*2015*	
	City	*Population*		*City*	*Population*		*City*	*Population*		*City*	*Population*
1	New York	12.3	1	Tokyo	19.8	1	Tokyo	26.4	1	Tokyo	26.4
			2	New York	15.9	2	Mexico City	18.1	2	Bombay	26.1
			3	Shanghai	11.4	3	Bombay	18.1	3	Lagos	23.2
			4	Mexico City	11.2	4	São Paulo	17.8	4	Dhaka	21.1
			5	São Paulo	10.0	5	New York	16.6	5	São Paulo	20.4
						6	Lagos	13.4	6	Karachi	19.2
						7	Los Angeles	13.1	7	Mexico City	19.2
						8	Calcutta	12.9	8	New York	17.4
						9	Shanghai	12.9	9	Jakarta	17.3
						10	Buenos Aires	12.6	10	Calcutta	17.3
						11	Dhaka	12.3	11	Delhi	16.8
						12	Karachi	11.8	12	Metro Manila	14.8
						13	Delhi	11.7	13	Shanghai	14.6
						14	Jakarta	11.0	14	Los Angeles	14.1
						15	Osaka	11.0	15	Buenos Aires	14.1
						16	Metro Manila	10.9	16	Cairo	13.8
						17	Beijing	10.8	17	Istanbul	12.5
						18	Rio de Janeiro	10.6	18	Beijing	12.3
						19	Cairo	10.6	19	Rio de Janeiro	11.9
									20	Osaka	11.0
									21	Tianjin	10.7
									22	Hyderabad	10.5
									23	Bangkok	10.1

TABLE 6. POPULATION AND GROWTH RATE OF THE URBAN AGGLOMERATIONS WITH MORE THAN 10 MILLION INHABITANTS, 1975-2015

	Urban agglomeration	*Population (in millions)*				*Growth rate (percentage)*	
		1975	*1999*	*2000*	*2015*	*1975-2000*	*2000-2015*
1	Tokyo	19.8	26.4	26.4	26.4	1.2	0.0
2	Mexico City	11.2	17.9	18.1	19.2	1.9	0.4
3	Bombay	6.9	17.5	18.1	26.1	3.9	2.4
4	São Paulo	10.0	17.5	17.8	20.4	2.3	0.9
5	New York	15.9	16.6	16.6	17.4	0.2	0.3
6	Los Angeles	8.9	13.0	13.1	14.1	1.5	0.5
7	Shanghai	11.4	12.9	12.9	14.6	0.5	0.8
8	Lagos	3.3	12.8	13.4	23.2	5.6	3.7
9	Calcutta	7.9	12.7	12.9	17.3	2.0	1.9
10	Buenos Aires	9.1	12.4	12.6	14.1	1.3	0.7
11	Dhaka	2.2	11.7	12.3	21.1	6.9	3.6
12	Karachi	4.0	11.4	11.8	19.2	4.3	3.2
13	Delhi	4.4	11.3	11.7	16.8	3.9	2.4
14	Osaka	9.8	11.0	11.0	11.0	0.4	0.0
15	Beijing	8.5	10.8	10.8	12.3	0.9	0.9
16	Jakarta	4.8	10.6	11.0	17.3	3.3	3.0
17	Metro Manila	5.0	10.5	10.9	14.8	3.1	2.1
18	Rio de Janeiro	7.9	10.5	10.6	11.9	1.2	0.8
19	Cairo	6.1	10.3	10.6	13.8	2.2	1.7

Figure 3: Share of the average annual increment of the world urban population for more developed and less developed regions by city-size class, 1975-2000 and 2000-2015

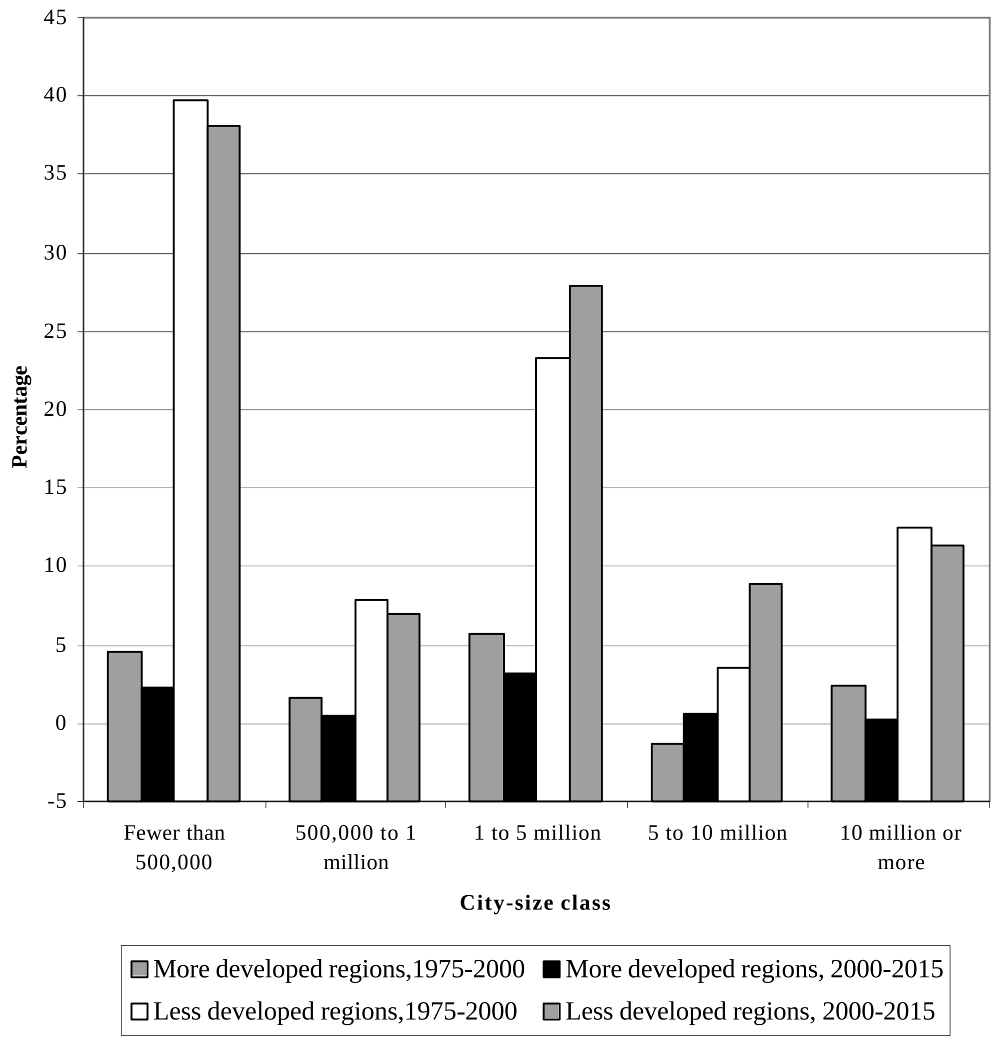


TABLE 7. CLASSIFICATION OF COUNTRIES BY MAJOR AREA AND REGION OF THE WORLD

Africa

Eastern Africa

Burundi
Comoros
Djibouti
Eritrea
Ethiopia
Kenya
Madagascar
Malawi
Mauritius
Mozambique
Réunion
Rwanda
Seychelles
Somalia
Uganda
United Republic of Tanzania
Zambia
Zimbabwe

Middle Africa

Angola
Cameroon
Central African Republic
Chad
Congo
Democratic Republic of the Congo
Equatorial Guinea
Gabon
Sao Tome and Principe

Northern Africa

Algeria
Egypt
Libyan Arab Jamahiriya
Morocco
Sudan
Tunisia
Western Sahara

Southern Africa

Botswana
Lesotho
Namibia
South Africa
Swaziland

Western Africa

Benin
Burkina Faso
Cape Verde
Côte d'Ivoire
Gambia
Ghana
Guinea
Guinea-Bissau
Liberia
Mali
Mauritania
Niger
Nigeria
St. Helena
Senegal
Sierra Leone
Togo

Asia

Eastern Asia

China
China, Hong Kong SAR
Democratic People's Republic of Korea
Japan
Macau
Mongolia
Republic of Korea

South-central Asia

Afghanistan
Bangladesh
Bhutan
India
Iran (Islamic Republic of)
Kazakhstan
Kyrgyzstan
Maldives
Nepal
Pakistan
Sri Lanka
Tajikistan
Turkmenistan
Uzbekistan

South-eastern Asia

Brunei Darussalam
Cambodia
East Timor
Indonesia
Lao People's Democratic Republic
Malaysia
Myanmar
Philippines
Singapore
Thailand
Viet Nam

Western Asia

Armenia
Azerbaijan
Bahrain
Cyprus
Gaza Strip
Georgia
Iraq
Israel
Jordan
Kuwait
Lebanon
Oman
Qatar
Saudi Arabia
Syrian Arab Republic
Turkey
United Arab Emirates
Yemen

TABLE 7 (*continued*)

Europe

Eastern Europe	*Northern Europe*	*Southern Europe*	*Western Europe*
Belarus	Channel Islands	Albania	Austria
Bulgaria	Denmark	Andorra	Belgium
Czech Republic	Estonia	Bosnia and Herzegovina	France
Hungary	Faeroe Islands	Croatia	Gerrmany
Poland	Finland	Gibraltar	Liechtenstein
Republic of Moldova	Iceland	Greece	Luxembourg
Romania	Ireland	Holy See	Monaco
Russian Federation	Isle of Man	Italy	Netherlands
Slovakia	Latvia	Malta	Switzerland
Ukraine	Lithuania	Portugal	
	Norway	San Marino	
	Sweden	Slovenia	
	United Kingdom of Great Britain and Northern Ireland	Spain	
		The former Yugoslav Republic of Macedonia	
		Yugoslavia	

Latin America and the Caribbean

Caribbean	*Central America*	*South America*
Anguilla	Belize	Argentina
Antigua and Barbuda	Costa Rica	Bolivia
Aruba	El Salvador	Brazil
Bahamas	Guatemala	Chile
Barbados	Honduras	Colombia
British Virgin Islands	Mexico	Ecuador
Cayman Islands	Nicaragua	Falkland Islands (Malvinas)
Cuba	Panama	French Guiana
Dominica		Guyana
Dominican Republic		Paraguay
Grenada		Peru
Guadeloupe		Suriname
Haiti		Uruguay
Jamaica		Venezuela
Martinique		
Montserrat		
Netherlands Antilles		
Puerto Rico		
Saint Kitts and Nevis		
Saint Lucia		
Saint Vincent and the Grenadines		
Trinidad and Tobago		
Turks and Caicos Islands		
United States Virgin Islands		

TABLE 7 (*continued*)

Northern America

Bermuda
Canada
Greenland
St. Pierre and Miquelon
United States of America

Oceania

Australia/New Zealand	*Melanesia*	*Micronesia*	*Polynesia*
Australia	Fiji	Guam	American Samoa
New Zealand	New Caledonia	Kiribati	Cook Islands
	Papua New Guinea	Marshall Islands	French Polynesia
	Solomon Islands	Micronesia (Federated States of)	Niue
	Vanuatu	Nauru	Pitcairn
		Northern Mariana Islands	Samoa
		Palau	Tokelau
			Tonga
			Tuvalu
			Wallis and Futuna Islands

TABLE 8. LIST OF LEAST DEVELOPED COUNTRIES

Afghanistan	Guinea	Niger
Angola	Guinea-Bissau	Rwanda
Bangladesh	Haiti	Samoa
Benin	Kiribati	Sao Tome and Principe
Bhutan	Lao People's Democratic Republic	Sierra Leone
Burkina Faso	Lesotho	Solomon Islands
Burundi	Liberia	Somalia
Cambodia	Madagascar	Sudan
Cape Verde	Malawi	Togo
Central African Republic	Maldives	Tuvalu
Chad	Mali	Uganda
Comoros	Mauritania	United Republic of Tanzania
Democratic Republic of the Congo	Mozambique	Vanuatu
Djibouti	Myanmar	Yemen
Equatorial Guinea	Nepal	Zambia
Eritrea		
Ethiopia		
Gambia		

Bisectors, Buffers, and Base Maps

Sandra Lach Arlinghaus
The University of Michigan
http://www-personal.umich.edu/~copyrght
sarhaus@umich.edu

Introduction

In 1911, Thiessen and Alter [21] wrote on the analysis of rainfall using polygons surrounding rain gauges. Given a scatter of rain gauges, represented abstractly as dots, partition the underlying plane into polygons containing the dots in such a way that all points within any given polygon are closer to the rain gauge dot within that polygon than they are to any other gauge-dot. The geometric construction usually associated with performing this partition of the plane into a mutually exclusive, yet exhaustive, set of polygons is performed by joining the gauge-dots with line segments, finding the perpendicular bisectors of those segments, and extracting a set of polygons with sides formed by perpendicular bisectors. It is this latter set of polygons that has come to be referred to as "Thiessen polygons" (and earlier names such as Dirichlet region or Voronoi polygon, see Coxeter [4]). The construction using bisectors is tedious and difficult to execute with precision when performed by hand. Kopec (1963) [11] noted that an equivalent construction results when circles of radius the distance between adjacent points are used. Indeed, that construction is but one case of a general construction of Euclid. Like Kopec, Rhynsburger (1973) [20] also sought easier ways to construct Thiessen polygons: Kopec through knowledgeable use of geometry and Rhynsburger through the development of computer algorithms. The world of the Geographical Information System (GIS) software affords an opportunity to combine both.

Bisectors

A theorem/construction of Euclid shows how to draw a perpendicular bisector separating any pair of distinct points in the Euclidean plane. The animation in Figure 1 illustrates this procedure:

- Given O and O' in the plane.
- Draw a segment joining O and O'
- Construct two circles, one centered on O and the other centered on O', each of radius greater than half the distance between O and O'. The radii are the same.
- Label the intersection points of the circle as A and B. Draw a line through A and B. This line is the perpendicular bisector of |OO'|.

In the final frame of the animation in Figure 1, the highly colorful one, the use of a GIS displays clearly that radius length produces the same position for |AB| independent of choice (greater than 0.5*|OO'|). The last frame was produced in ArcView 3.2 (with Spatial Analyst Extension enabled) using the "calculate distance" feature. It shows the general result, of which Kopec used one element. One need not be limited to choosing the distance between adjacent points--any distance greater than half that distance will produce the same result.

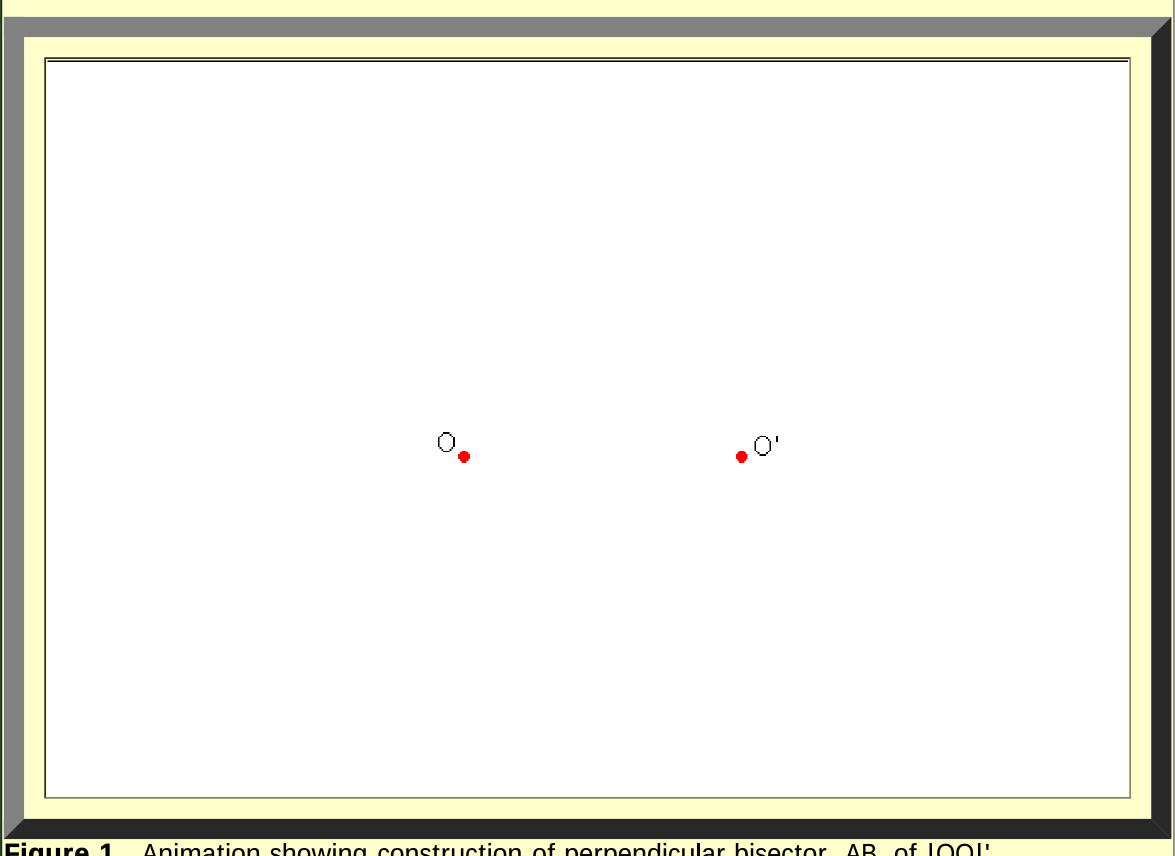


Figure 1. Animation showing construction of perpendicular bisector, AB, of |OO|'.

Buffers

Traditionally one might have used a drawing compass and a straightedge to construct a perpendicular bisector between two points. It is an easy matter to do so, however, using a GIS, as suggested above. If there are more than two points, the matter can become quickly tedious. Again, the GIS offers a quick and accurate way to calculate positions (Figure 2).

- Given a distribution of points in the plane (O and O' are now among this set).
- Create circular buffers around all the points, leaving the entire circle surrounding each point. It has become difficult to visualize the location of the set of perpendicular bisectors that are determined by this circular mass.
- Dissolve arcs within the circular mass. This procedure offers some help in visualizing where bisectors might be, but only a vague picture of bisector position is generated.

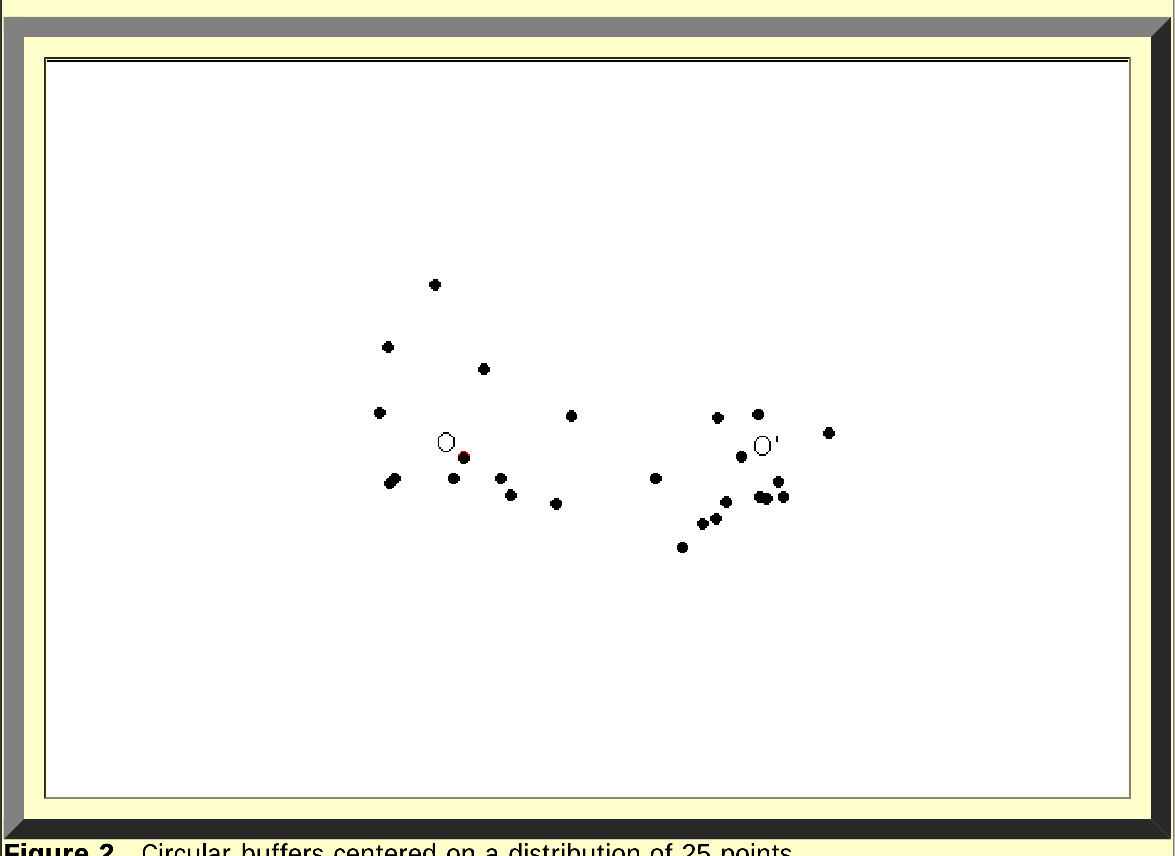


Figure 2. Circular buffers centered on a distribution of 25 points.

To actually position the lines of partition, or Thiessen polygon edges, in the GIS, use the "split polygon" feature available in ArcView or other GIS software, creating a sort of bubble foam (Figure 3 shows one split created in this manner). Numerous websites offer suggestions for use of Thiessen polygons ranging from rainfall regions, to hydrological modelling, to road centerline location (and others) [12, 13, 14].

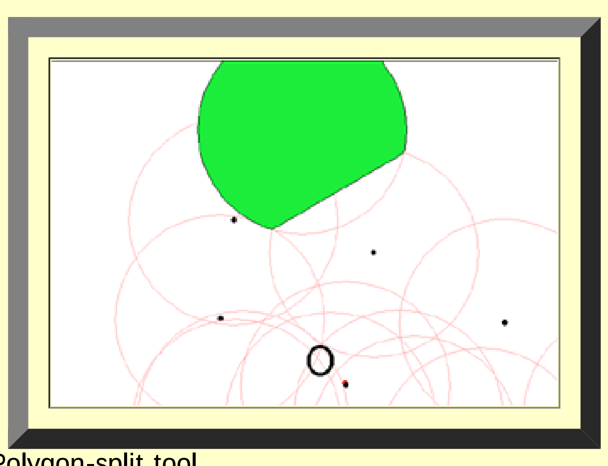


Figure 3. Use of the Polygon-split tool.

One contemporary website demonstrates the mechanics of this sort of approach using one buffer distance [6]. Others employ a variety of software to construct Thiessen polygons [22].

Again, the GIS is helpful: ArcView (Spatial Analyst extension) offers a single tool that quickly calculates Thiessen polygons. Use "Assign Proximity" to create zones around each point. Within each zone, all points are nearer to the distribution point in that zone than they are to any other point in the distribution. In Figure 4, the relationship between perpendicular bisector, buffer (construction of Euclid), proximity zone/Thiessen polygon becomes clear.

- The initial frame shows the result of running the "assign proximity" feature of ArcView 3.2, Spatial Analyst Extension, on the scatter of 25 points. The colorful polygons separate the plane into Thiessen polygons. Within each polygon, all points are closer to the point from the 25 dot scatter that is in that polygon than they are to any other point in the 25 point scatter.
- The second frame superimposes circular buffers; thus, one sees how the Thiessen polygons are a direct consequence of the Theorem/Construction of Euclid.
- The third frame dissolves part of the circular buffer, exposing more clearly the relation between circular buffer and proximity zone as calculated by the computer algorithm in ArcView GIS.

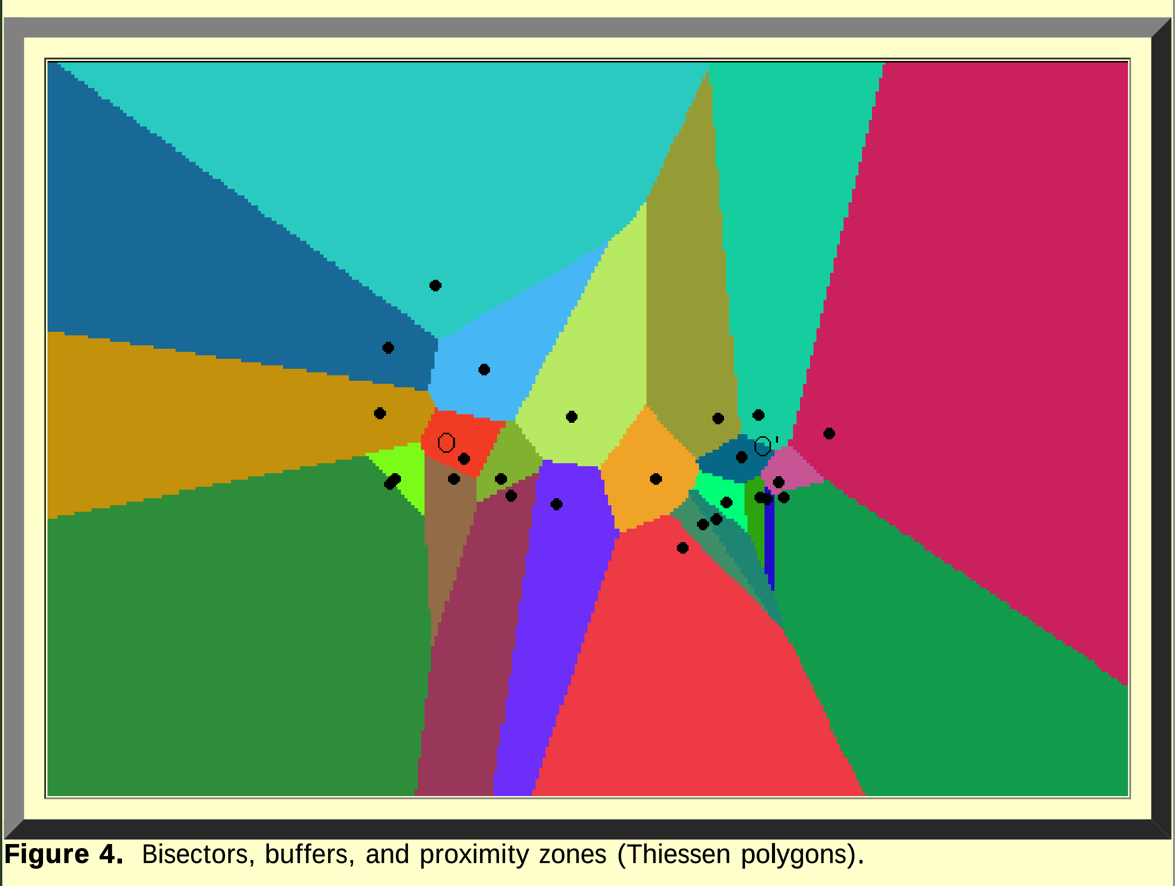


Figure 4. Bisectors, buffers, and proximity zones (Thiessen polygons).

Whether one considers rail networks within sausage-like linear buffers, counts population in buffered bus routes, or selects minority groups from within a circular buffer intersecting census tracts, the buffer has long served, and continues to serve, as a basis for making decisions from maps. Buffers have a rich history in geographical analysis. Mark Jefferson [10, 2] rolled a circle along lines on a map representing railroad tracks to create line-buffers representing proximity to train service and suggested consequent implications for population patterns in various regions of the world. Julian Perkal and John Nystuen saw buffers in parallel with delta-epsilon arguments employed in the calculus to speak of infinitesimal quantities (reprint of Perkal, "An Attempt at Objective Generalization," Michigan Interuniversity Community of Mathematical Geographers, [16, 19]. Jefferson's mapping effort in 1928 was extraordinary; today, buffers of points, lines, or regions are trivial to execute in the environment of Geographic Information Systems software. To paraphrase Faulkner (1949), 'good ideas will not merely endure, they will prevail' [7].

Base Maps

In a recent invited lecture (2001) to The University of Michigan Lecture Series in GIS Education, Arthur Getis noted [15] that he had used circular buffers around point observations and that he used a sequence of nested buffers to successively fill space to eventually include all individuals in the underlying point distribution gathered from field evidence. Thus, viewed abstractly, each set of buffers serves as a base map, with the sequence successively filling more space and including more individual observations in the analysis. A different view might see the Thiessen map as the base map (Figure 5). When it is calculated at the outset, it can serve as a standard against which to test more specialized views at varying buffer radii, on a continuing basis, as the research within buffers evolves. The Thiessen base map serves, therefore, as an "absolute" base map against which to view the "relative" base maps of varying local radii (and other configurations): it is a limit of a sequence of measures based on buffers that increasingly fill more space (but still leave gaps). Getis noted [15] that he and Ord had recently completed an article involving issues of global and local spatial statistical measures [18]. What is suggested here is the appropriate use of a geometric foundation: a use for a Thiessen, space-filling, base against which to test the results of sequences of successive measures in buffers that may not fill the underlying universe of discourse.

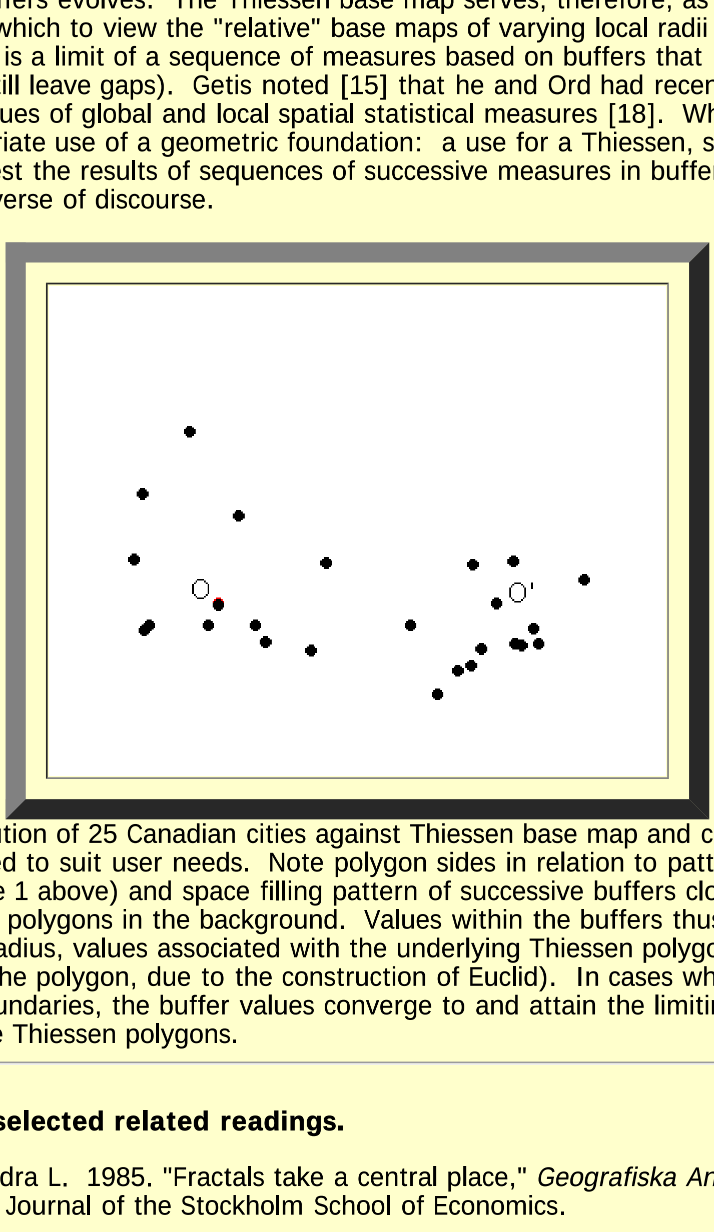


Figure 5. Distribution of 25 Canadian cities against Thiessen base map and circular buffer set. Files may be clipped to suit user needs. Note polygon sides in relation to pattern of intersecting circles (as in Figure 1 above) and space filling pattern of successive buffers closing in on individual Thiessen polygons in the background. Values within the buffers thus approach, with increasing buffer radius, values associated with the underlying Thiessen polygons (as the buffers never fall outside the polygon, due to the construction of Euclid). In cases where clipping matches buffer boundaries, the buffer values converge to and attain the limiting values associated with the Thiessen polygons.

References and selected related readings.

1. Arlinghaus, Sandra L. 1985. "Fractals take a central place," *Geografiska Annaler*, 67B, (1985), pp. 83-88. Journal of the Stockholm School of Economics.

2. Arlinghaus, S., Goodman, F., and Jacobs, D. 1997. Buffers and Duality, *Solstice: An Electronic Journal of Geography and Mathematics*, Institute of Mathematical Geography, Volume VIII, Number 2.

3. Bogue, Donald J. 1950. The structure of the metropolitan community: a study of dominance and subdominance. Ann Arbor, MI.

4. Coxeter, H. S. M. 1961. *Introduction to Geometry*. New York: John Wiley & Sons, pp. 53-54.

5. Dacey, Michael F. 1965. The geometry of central place theory. *Geografiska Annaler*, B, 47, 111-124.

6. Edit Tools 3.1. http://www.ian-ko.com/howto.htm

7. Faulkner, William. 1949. Nobel Prize Acceptance Speech. http://www.nobel.se/literature/laureates/1949/faulkner-acceptance.html

8. Haggett, P.; Cliff, A. D.; and, Frey, A. 1977. *Locational Analysis in Human Geography 2: Locational Methods*. Second Edition. New York: John Wiley & Sons. (Section 13.5).

9. Hargrove, William W., Winterfield, Richard F. and Levine, Daniel A. Dynamic segmentation and Thiessen polygons: a solution to the river mile problem. http://research.esd.ornl.gov/CRERP/DOCS/RIVERMI/P114.HTM

10. Jefferson, Mark. 1928. The Civilizing Rails. *Economic Geography*, 1928, 4, 217-231.

11. Kopec, R. J. 1963. An alternative method for the construction of Thiessen polygons. *Professional Geographer*, 15, (5), 24-26.

12. Ladak, Alnoor and Martinez, Roberto B. Automated Derivation of High Accuracy Road Centrelines Thiessen Polygons Technique. http://www.esri.com/library/userconf/proc96/TO400/PAP370/P370.HTM

13. Murray, Alan and Gottsegen, Jonathan. The Influence of Data Aggregation on the Stability of Location Model Solutions http://www.ncgia.ucsb.edu/~jgotts/murray/murray.html

14. Natural Neighbor Interpolation. http://www.ems-i.com/smshelp/Scatter_Module/Scatter_Scattermenu/Natural_Neighbor.htm

15. Nystuen, J. and Brown, D. 2001. Coordinators, UM GIS Lecture Series. Lecture by Arthur Getis: "Spatial Analytic Approaches to the Study of the Transmission of Disease: Recent Results on Dengue Fever in Iquitos, Peru".

16. Nystuen, J., 1966. "Effects of boundary shape and the concept of local convexity;" Michigan Interuniversity Community of Mathematical Geographers (unpublished). Reprinted, Ann Arbor: Institute of Mathematical Geography.

17. Okabe, A.; Boots, B.; and, Sugihara, K. 1992. *Spatial Tesselations: Concepts and Applications of Voronoi Diagrams*. Wiley Series in Probability and Mathematical Statistics. Chichester: John Wiley & Sons.

18. Ord, J. Keith and Getis, Arthur. 2001. "Testing for Local Spatial Autocorrelation in the Presence of Global Autocorrelation." *Journal of Regional Science*, Vol.. 41, No. 3, pp. 411-432.

19. Perkal, Julian, 1966. "An attempt at objective generalization;" Michigan Interuniversity Community of Mathematical Geographers (unpublished). Reprinted, Ann Arbor: Institute of Mathematical Geography.

20. Rhynsburger, Dirk, 1973. Analytic delineation of Thiessen polygons. *Geographical Analysis*, 5, 133-144.

21. Thiessen, A. H., and Alter, J. C.. 1911. Climatological Data for July, 1911: District No. 10, Great Basin. *Monthly Weather Review*, July:1082-1089.

22. Thiessen Polygons. http://www.geog.ubc.ca/courses/klink/g472/class97/eichel/theis.html

---

Software used

- Adobe, Photoshop, 6.0.
- Environmental Systems Research Institute (ESRI), Redlands, CA.
  - ArcView 3.2
  - ArcView Spatial Analyst Extension
- Gamani, Movie Gear
- Macromedia, DreamWeaver, 3.0
- Netscape Composer