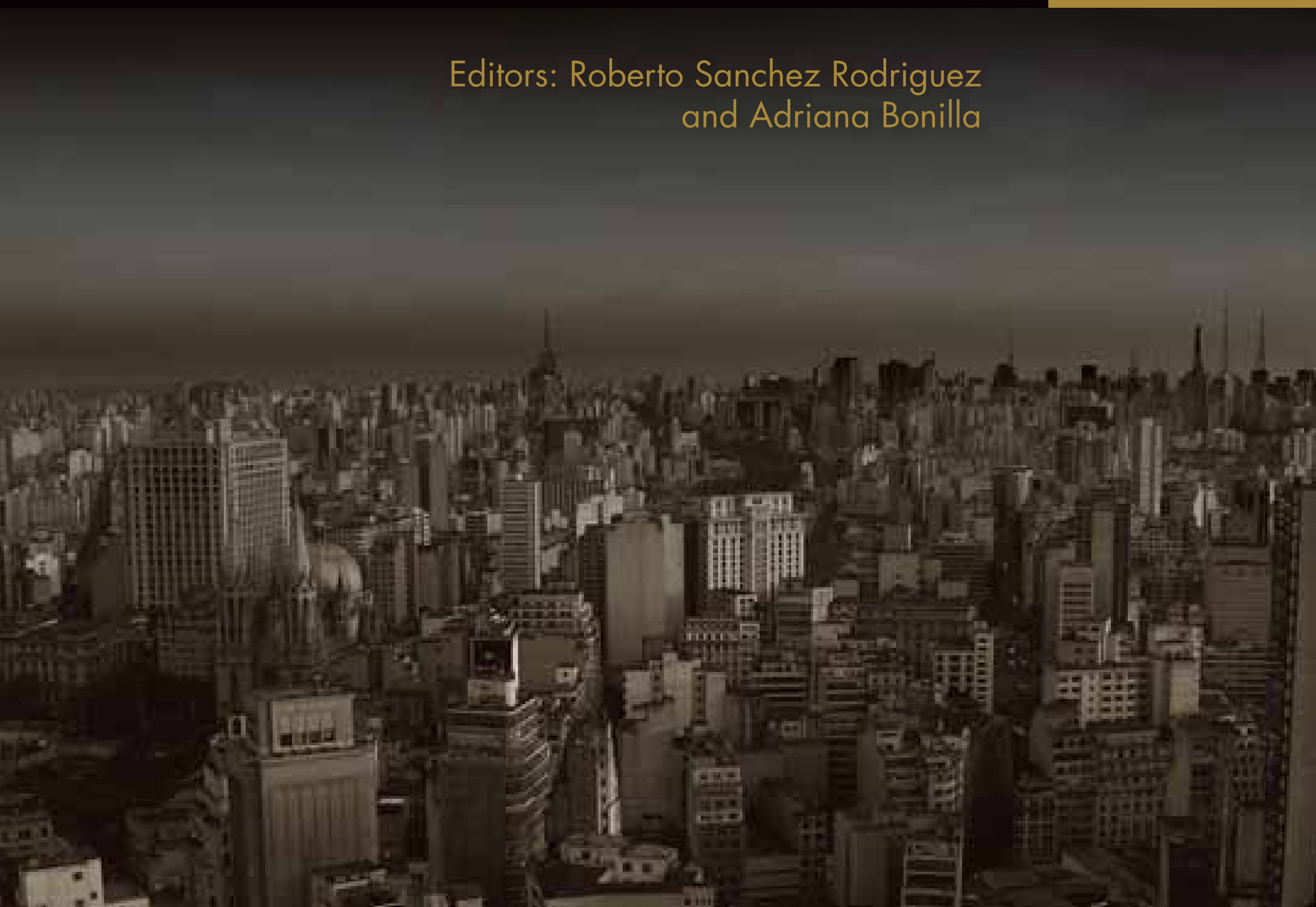
Urbanization, Global Environmental Change, and Sustainable Development in Latin America

Editors: Roberto Sanchez Rodriguez
and Adriana Bonilla



Urbanization,
Global Environmental Change, and
Sustainable Development in Latin America

Urbanization,
Global Environmental Change, and
Sustainable Development in Latin America
IAI, INE, UNEP.
São José dos Campos, Brazil, 2007
204 p.; 19.05 x 26.7 cm.

ISBN 978-85-99875-02-5

1.Urbanization, 2. Global Environmental Change, 3. Sustainable Development, 4. Climate Change, 5. Land Use Change
I. IAI II. INE III. UNEP

Acknowledgments

Publication Coordination
Marcella Ohira
IAI Directorate

Translation
Leticia Sáenz Fernández

Design and Production
Daniel Fachini and Marcus Toledo
Digital Graf Press

Printing
Digital Graf Press

Table of Contents

Preface

Preface

Since 2003 two sub-regions of Latin America, namely Mesoamerica and South America, have been the sub-regions with highest population concentration in urban areas after Australia and New Zealand, Arctic, North America, and Western Europe. Urbanization has become an important of environmental change in many parts of the globe with significant effects on regional development.

Urbanization and increased levels of social activity interact with global-change processes, such as climate and land use change. Understanding these links requires reliable scientific knowledge.

The Inter-American Institute for Global Change Research (IAI) seeks to provide high calibre scientific information that is useful to policy and decision makers and improves their understanding of global environmental change. The IAI's research is a result of the integration of multiple scientific disciplines (natural and social) with the goal of achieving sustainability. Such integration has been built by establishing and developing regional scientific networks of scientists and institutions. IAI's research is beyond the scope of national programs. It has encouraged multinational, inter-hemispheric collaboration at the science-policy interface in the Americas.

The United Nations Environmental Program (UNEP) through its Regional Office for Latin America and the Caribbean (ROLAC) on the other hand promotes use of scientific knowledge generated in the world and especially within the region by partners such as IAI. UNEP believes that improved access to meaningful data and information help increase the capacity of governments and decision-makers in general to use knowledge for decision-making and action planning for sustainable human development.

This book offers insight into our efforts to connect the knowledge on urbanization, global environmental change, and sustainable development in Latin America. By presenting this important publication, we are urging societies and governments to get involved in translating the understanding and knowledge created into decisions and action in order to limit potential negative impacts of urbanization and exploring opportunities for sustainable development.

Holm Tiessen
IAI Director

Ricardo Sánchez
UNEP/ROLAC Director

Foreword

Foreword

This book has its roots in the Training Institute on Urbanization and Global Environmental Change in Latin America, held in Mexico City, Mexico, in October 2004. Organized by the Inter-American Institute for Global Change Research (IAI) and the National Institute of Ecology (INE) of Mexico, the Training Institute addressed theories, models, methods, policy, and local initiatives related to urbanization and global environmental change. While catalyzing interactions among academics, stakeholders, policy makers, and decision makers from Latin America, the workshop explored options for mitigating negative environmental and socioeconomic impacts.

The Training Institute provided a more in-depth understanding of the interactions between global environmental change and urbanization at local, regional, and global scales, allowing participants to develop a comprehensive, integrated perspective of global environmental change and urbanization through multidisciplinary and innovative conceptual and methodological approaches. It emphasized global environmental change both as a driver and an outcome of human (economic, political, cultural, and social) and physical (urban structure, expansion, and land use) processes in urban areas. In this way, urbanization was viewed as both endogenous and exogenous to global environmental change in a tightly coupled system.

In planning the Training Institute, the IAI aimed at developing a cooperative network of professionals in Latin America to exchange data, knowledge, and experience; promote the exchange and training of local professionals; and develop partnerships among governments, industries, and communities, as well as other organizations dealing with the same subject.

Twenty-four people from 13 countries participated in the Institute, and 29 experts from several countries in the region collaborated in the development of the program, sharing their knowledge, experience and research findings.

Articles in this book were written by speakers and participants in the Training Institute, leading experts and professionals working on the theme of urbanization and global change in Latin America. We are most grateful to the authors for their scientific contribution and intellectual input.

This activity was supported by a research grant from the US National Science Foundation (NSF). Additional support has also been provided by INE, IHDP, the United Nations Environmental Programme (UNEP), and by important in-kind contributions from the Mexico-US Foundation for Science (FUMEC) and the Metropolitan Autonomous University (MAU).

The Training Institute and the publication of this book would not have been possible without the commitment and efforts of many individuals and institutions. In particular, we thank Roberto Sanchez Rodriguez (Professor of Environmental Sciences at the University of California, Riverside, and Director of the University of California Institute for Mexico and the United States—UC MEXUS), who provided the intellectual leadership for the Training Institute and who developed and coordinated the program; and Adrián Fernández (President of INE) and Julia Martínez (Coordinator of INE's Program on Global Environmental Change), along with INE staff, for their hard work organizing the workshop in Mexico. Their commitment, dedication, and intellectual input in the months before and after the Training Institute were invaluable.

We also owe special thanks to Ricardo Sánchez (Director of UNEP) and Kakuko Nagatani (Program Officer of the Division of Early Warning and Assessment of UNEP/Regional Office for Latin America and the Caribbean-ROLAC) for their support in co-sponsoring the English edition of this book; Ana Rosa Moreno and Fernanda Guerrero (FUMEC) for administration of the funds; Adriana Bonilla and Maria Marta Laplace for their tireless review of the Spanish version; and Leticia Saenz Fernandez for the translation of the book. Finally, we would like to thank Cláudia Fernandes, Céline Demaret and Dione Nègre (IAI) for their excellent support in the organization and follow-up of this training activity and the resulting publication.

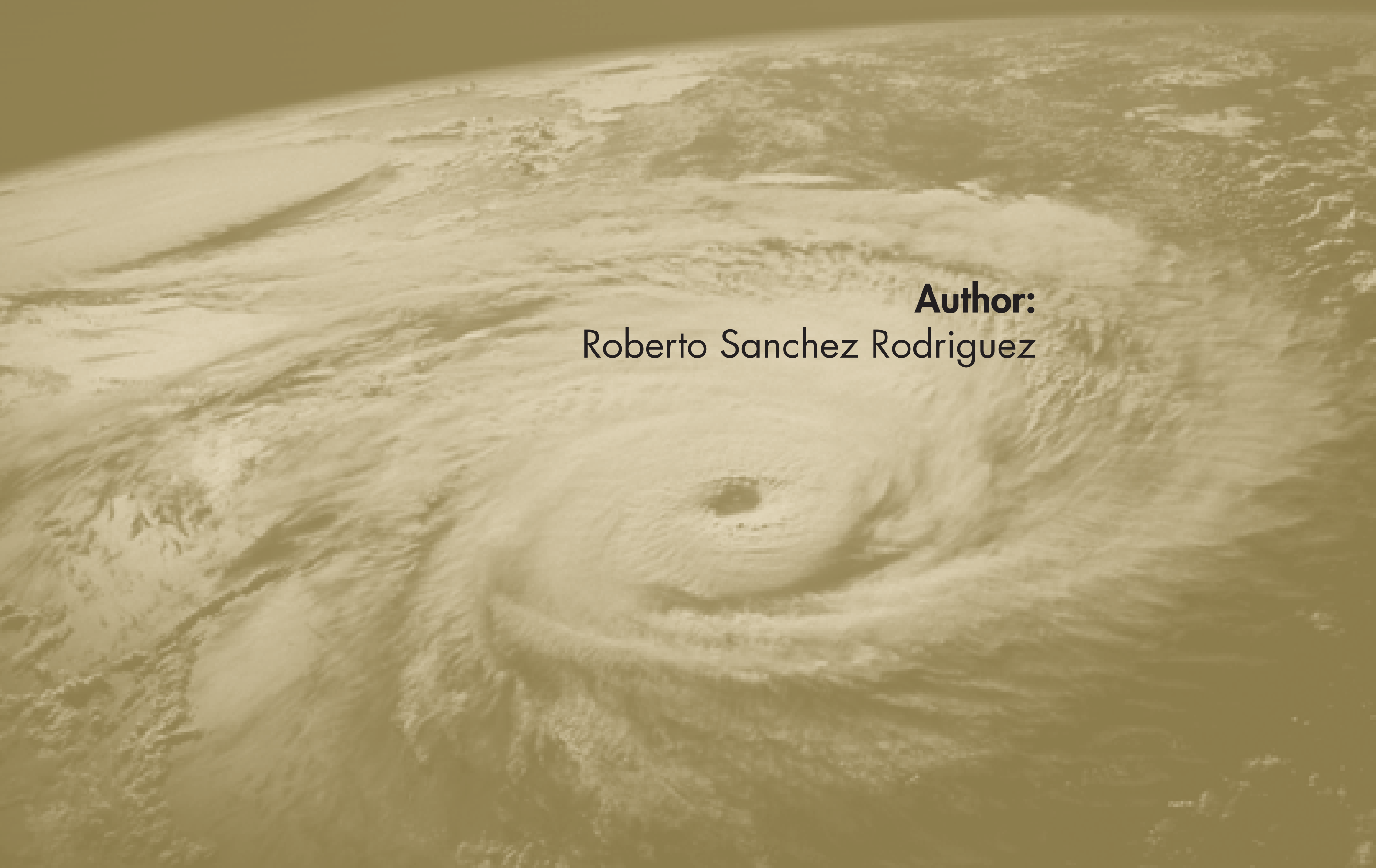
We are excited about the establishment of a network of professionals on urbanization and global change in Latin America as a result of the IAI Training Institute and about the impact of the discussions on the international global-change research community. We hope this initiative will lead to further collaboration and research on urbanization and global change in Latin America. The IAI will continue to encourage work in this direction and will foster collaborative research, science, and the application of information from the scientific community to the policy and decision-making processes.

Marcella Ohira
Training Officer, IAI

Urbanization, Global Environmental Change, and Sustainable Development in Latin America

1

Author:
Roberto Sanchez Rodriguez



An Introduction

The present and future of Latin America is intrinsically associated with the growth of its urban areas. Many of the most significant changes of the so-called globalization take place in urban spaces. One of the clearest indicators is the population. Over half of the total population of the planet, approximately 3.3 billion people, lives in urban areas (United Nations Centre for Human Settlements, UNCHS 2002). The United Nations system has estimated that the urban population of the world will be more than 60% of the total world population by the year 2030. The debate over urban growth is particularly important in Latin America, as it has one of the highest rates of urbanization growth in the world (Cohen 2004). United Nations data (UNCHS 2002) report that the urban population in the region increased from 176.4 million in 1972 to 390.8 million in the year 2000 and is expected to increase to 604 million by 2030. During the same period, the percentage of total population living in urban areas increased from 58.9% to 75.3% and is expected to be 83% of the total population by the year 2030, a proportion similar to that in highly industrialized countries.

Urban areas, in addition, represent a dynamic link between Latin American societies and global, social, economic, political, and environmental processes. They concentrate a very high proportion of the flow of the world's financial capital, most of the manufacturing and production of consumer goods, and the vast majority of trade and services. Many of these economic activities are associated, directly or indirectly, with transnational corporations and international production chains.[1] A clear example of the importance of urban areas in the growth and development of Latin American countries is their significant participation in the generation of the gross domestic product (GDP) of each country. The large cities in Latin America are a clear example of this weight (36% of Brazil's GDP in 1999 was generated in São Paulo and 43% in Lima, Peru).

The importance of urban areas in the economic growth and social well-being of the population lends them a starring role in the discussion of the new development paradigms for the region. Urban sustainability has insistently been suggested at the international and national level as the best approach to guide the present and future growth of urban areas (Drakakis-Smith 1995, Rees and Wackernagel 1996, Satterthwaite 1997, Spangenberg et al. 2002, Myllyla and Kuvaja 2005). The United Nations, the European Union, the World Bank and other international organizations have implemented programs to promote sustainable urban growth. Similar efforts have been adopted by national and local governments in the various regions of the planet, including Latin America. Despite the wide acceptance of sustainable development to guide current and future urban growth, little progress has been made in the transition from regulations to operational approaches that promote the desired balance in urban growth. The discussion over sustainable development in urban areas, in particular in Latin America, has been incomplete and limited to a technical vision of planning and control of some local

[1] The World Bank estimates that over 80% of the future economic growth in poor countries will occur in urban areas (World Bank 2002).

environmental problems. Sustainable development has not been able to transcend rhetoric. On the contrary, the urban areas of Latin America reflect the contradictions and characteristic problems of the societies in the region and are subject to periodic crises. These societies are complex and dynamic, reproducing in their territory the wide range of socio-economic, geo-political interactions and environmental processes at the local, national, regional, and global level. Unemployment and underemployment, environmental degradation, deficiencies in urban services and housing, deterioration of existing infrastructure, problems in guaranteeing access to natural resources vital to urban life (water, power, food, and construction materials), and an alarming expansion of the violence associated with organized crime are but a few of the problems common to the urban areas of Latin America and other poor regions around the world (Moser and McIlwaine 2006). These problems are aggravated by the rapid growth of the population and urban spaces, the unbalances in the urban structure, the accumulated deficit in construction, the expansion and operation of public services, and the economic and financial crises prevalent in the region. The result has been the creation of fragmented urban spaces, of large spatial segregation that increases the social exclusion, a characteristic of the countries in the region (Lopes de Souza 2001, Pirez 2002) and severe environmental problems (Hardoy et al. 1992).

The situation described above illustrates the crises of urban areas in Latin America. Useful contributions to reduce these crises and open opportunities for sustainable development are particularly necessary in two areas. One area is the creation of governance processes that will include the participation of civil society and the private sector in managing the urbanization process (Abbott 1996, Carley and Christie 2001, Pelling 2001). Similar demands have appeared in efforts to update, democratize, and make urban planning efficient (Friedmann 1987, Hull 1998, Radoki 2001, Healey 2002) and in proposals for political decentralization, aimed at transferring the political and administrative power of the federal governments to the local governments (Ribot and Larson 2005). Another area is the need to transcend the limitations of the current approaches that consider urban issues in a fragmented manner, in favor of multidimensional perspectives capable of creating an integrated perspective of the complex and dynamic urban reality (Pelling 2003).

The fragmented vision of the urban issue frequently is the result of simplifying the complex urban reality in order to facilitate the design and implementation of actions aimed at tending to immediate problems (public services, housing, transportation, urban economy, environmental pollution, etc.) and the technical exercise of planning (Harvey 1989, Lefebre 1991, Hull 1998). Unfortunately, this fragmented vision leaves out the wide range of multidimensional interactions (social, economic, political, cultural, physical, environmental, and ecological) of each urban problem. The case of environmental issues in urban areas is particularly relevant in the discussion of sustainable development. The problems of natural resource supply, ecological services, and environmental pollution are considered in isolation from their social, economic, political, and cultural context (Redclift 1994, Bryant and Wilson 1998, Gibbs and Jonas 2000) that enables identification of the range of factors generating those problems and their consequences. This integrated multidimensional vision of the urban issue is fundamental to open opportunities for sustainable development in Latin America.

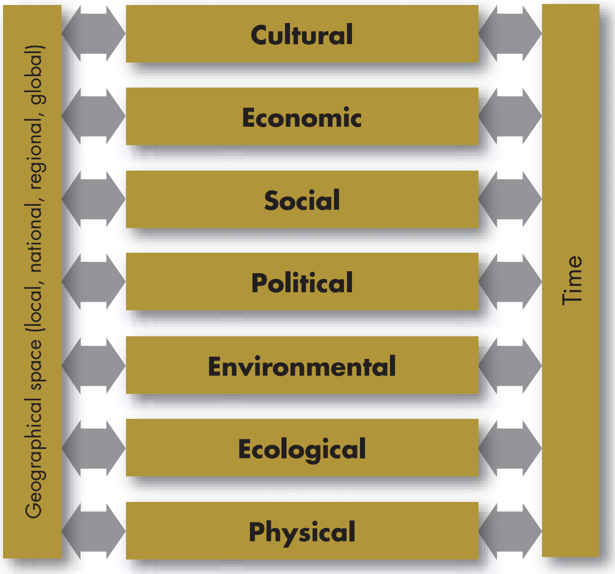
It is worth mentioning that the fragmented vision of urban areas cannot be attributed to lack of knowledge about its different dimensions. Urban studies have a long tradition. Attention to the urban issue in Latin America has had systematic advances since the 1960s. The contributions of the old school of urban studies in Latin America, dating back to the late 1960s, paid particular attention to the social, economic, and political dimension of urban areas in the region (Quijano 1967, Urquidi 1969, Hardoy and Geisse 1972. Later studies contributed to understanding the dramatic transformations of urban areas in the region and their consequences for the economic growth and social well-being of the countries of Latin America (Lomnitz 1972, Boisier 1973, Castells 1974 and 1981, Gilbert 1974, Singer 1975, Segre 1977, Unikel and Necochea 1975, Restrepo 1980, Gilbert and Guggler 1982, Ward 1982, Steinberg 2005). The environmental dimension is introduced into the discussion of the urban issue in a systematic manner in the 1980s and is substantially expanded in the 1990s, based on growing international attention to sustainable development, Agenda 21 of the United Nations, and local, regional, and global problems (Sunkel and Giglio 1980, Leff 1998). Despite the acquired volume of knowledge regarding the various dimensions of urban area growth, little progress was made in the creation of integrated multidimensional perspectives of this growth.

A new series of studies published in recent years helps to understand the benefits of an integrated perspective of urban growth useful to sustainable development. Those studies address important areas such as the role of ecological services for urban life (Hunhammar 1999, Madaleno 2000, Chiesura 2004); urban metabolism documenting the flows of energy and materials in the urban system (Newman 1999, Warren-Rhodes and Koenig 2001); urban ecology (Pickett et al. 1997, Dow 2000, Schrijnen 2000); natural disasters (Federovisk 1990, Blaikie et al. 1994, Hamza and Zetter 1998, Adger 1999, Smyth and Royle 2000); the role of urban culture and its link with the built space (García Canclini 1999); the consequences of urban space—form and function—aggravating violence inside cities (Laws 1994, Moser and McIlwaine 2005); mental health problems (Sturm and Cohen 2004) or the creation of physical obstacles for the physical activity within urban areas that accentuates problems of obesity and its consequences on the health of the population (diabetes, cancer, hypertension, etc.) (Jackson 2003); the impact of the urban form and its economic activities on the creation of microclimates within urban areas (Jáuregui 1971, Jáuregui and Morales 1996, Toyac and Yenigm 1997, Assis and Barros Frota 1999, Jazcilevich et al. 2000); the growing urban and social vulnerability to the negative consequences of natural disasters associated with seasonal and global climate changes (Kirshen and Fennessey 1995, Rosenzweig and Solecki 2001); the creation of corridors and spaces to foster habitats for regional species of flora and fauna (Blair and Launer 1997, Er et al. 2005); strategies to facilitate the integration of marginalized areas with the rest of the urban structure (Benjamin 2004); and the perception of the population regarding environmental problems (Jacobi 1994).

It is interesting to note that, despite the tradition of urban studies and the wide range of existing knowledge about these issues, few efforts have been made to create integrated multidimensional perspectives useful to sustainable development.

Fig. 1. Multidimensional perspectives on urban areas.

Theory and Methods



Understanding the urban crisis in Latin America and proposing actions to reduce it, within the framework of sustainable development, requires a new way of studying urban areas, based on integrated multidimensional schemes. The social, economic, cultural, political, environmental, ecological, and physical dimensions of urban life occur and interact at various geographic scales (local, national, regional, and global) and through time.[2] Figure 1 shows one way to represent that multidimensional perspective and the dynamic interaction between dimensions in time and geographic space. Taking these interactions into consideration contributes to the construction of new theories and methods for the study of urban areas. The multidimensional approach coincides with the efforts to conduct interdisciplinary (Nissani 1997, Schoenberger 2001) and transdisciplinary studies (Giri 2002, Ramadier 2004) on topics related to sustainable development, and it also coincides with the study of the various aspects of global environmental problems. Breaking with the disciplinary culture of excessive specialization in favor of approaches that include interdisciplinary and transdisciplinary thinking is not easy and requires time, but there is growing recognition of the need to complement the disciplinary vision with integrated multidimensional perspectives in the study and management of our daily urban reality.

In this regard, interesting progress has been made in the study of the landscape, as a unit of analysis capable of joining integrated multidimensional perspectives (Fry 2001, Mattews and Selman 2006). These studies are based on the premise that interdisciplinary work is indispensable to understanding the complex relation among ecological, biochemical, and

[2] The geographic scale at the urban level should be considered as the point of liaison between the local and national, as well as regional and global levels. However, the study of urban and environmental aspects requires a finer level of analysis within the city. Jorge Hardoy (1992) states that, in order to understand environmental problems in urban areas, it is necessary to cover a gradient of scales, starting at the household, continuing on to the neighborhood, district or delegation (set of neighborhoods or colonies), and finally ending at the urban level. For example, the problems associated with global biophysical processes (climate variability in the case of floods) have different consequences in different parts of the city. Even within the same neighborhood, some homes may be more vulnerable than others to the negative consequences caused by extreme precipitation and flooding.

social processes in the landscape, including the complex interaction of urban areas with their ecological surroundings. Progress in this area is useful for sustainable development programs.

Another area where interdisciplinary work has been fostered is the study of global changes in the environment (Adger et al. 2005, Lambin 2005). The following are among international scientific studies of the past two decades: the study of a broad range of global biophysical and chemical processes by the International Geosphere-Biosphere Programme (IGBP) (http://www.igbp.kva.se/cgibin/php /frameset.php); the study of the human dimensions of global change by the International Human Dimensions Programme (IHDP) on Global Environmental Change (http://www.ihdp.uni-bonn.de/); the study of biodiversity by the DIVERSITAS International Programme (http://www.diversitas-international.org/); and the study on climate by the World Climate Research Programme (WCRP) (http://www.wmo.ch/web/wcrp/wcrp-home.html).

Despite the important achievements of those programs in their respective areas of study, the research has been carried out with a fragmented disciplinary base. Faced with the need to create integrated perspectives that will contribute to producing better knowledge of the processes of global changes in the environment, the four international programs mentioned above have created an international consortium, Earth System Science Program (ESSP), to implement joint projects (http://www.essp.org/). Four priority issues have been established in this first phase: water, the carbon cycle, human health, and food systems. These projects seek to develop integrated multidimensional approaches based on the contributions made by each international program. It should be noted that the international scientific community has recognized the need to use integrated transdisciplinary approaches in the study of complex realities such as global environmental changes.

Other international scientific programs are also striving to create integrated perspectives of some of these problems. The Intergovernmental Panel on Climate Change (IPCC) is a multigovernmental effort that convenes scientists from very diverse disciplines in a common effort to expand the knowledge about climate change and its possible consequences for mankind (http://www.ipcc.ch/). The Millennium Ecosystem Assessment is an impressive international multidisciplinary effort focusing on creating an updated perspective of the status of ecosystems (www.maweb.org/en/Article.aspx?id=58). At the regional level, it is important to highlight the contributions made by the Inter-American Institute for Global Change Research (IAI) in the study of the biophysical, chemical, and human dimension aspects of global change in the Americas region (www.iai.int). The above-mentioned studies stress the importance of multidimensional work at the local, regional, and global level for sustainable development, although it is important not to lose sight of the fact that these studies should be considered continuous learning processes.

It should be noted that, despite the importance of urban areas to local, regional, and global socio-economic processes and of the enormous significance of those areas as a change factor in regional and global biophysical processes, studies of global environmental changes have paid little attention to the role of urban areas in global-change processes. Among the programs mentioned above, only the IHDP has continuously undertaken some studies and activities regarding this issue. These activities established the basis for the creation of a new international project on the interactions between urbanization processes and global environmental changes in 2005 (http://www.ugec.org). The IHDP and IAI have held international workshops to train young scientists and decision-makers on these topics.

The ESSP carbon cycle project has also started some activities related to the role of urban areas in the carbon cycle at a global level (http://www.gcp-urcm.org/urcm.html). The IPCC has incorporated a section dedicated to human settlements into its reports on the impacts of climate change (IPCC 2001), but the nature of those reports covering a broad range of topics does not allow dealing with urban areas in detail. The same is true of the Millennium Ecosystem Assessment. Other national and international programs focusing on global environmental changes have also paid little attention to urban issues. For example, the United States Environmental Protection Agency developed a program for the creation of national reports (country studies) for the study of climate change in 52 countries in the 1990s (http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublications International.html). The basic methodology of the studies focused on the contributions of the various sectors to climate change and the impact of the latter on those sectors. Urban areas were not included among the sectors in most of the 52 country studies.

Despite the central role of urban areas in socio-economic and geo-political change processes at the local, regional, and global level, as well as in the regional and global biophysical processes, paradoxically little attention has been paid so far at the national, regional, or international level to the complex and dynamic interactions between urban areas and the biophysical and chemical processes of global environmental changes.

This book contributes to increasing the knowledge about these interactions. It was born from the concern of the authors and from the IAI and the United Nations Environment Program—Regional Office for Latin America and the Caribbean—who decided to promote attention to this type of problems in the region. One of the book's objectives is to assist local and national authorities, as well as the broad range of stakeholders participating in the formulation of policies and in the construction of urban spaces, in considering actions and programs that will meet the current needs of cities and, at the same time, enable the reduction of the negative effects of global environmental change. Many of these actions do not imply an additional cost to the programs currently focusing on urban growth. On the contrary, they can contribute to reducing the high cost of the negative impacts of regional and global biophysical processes associated with global environmental change in urban areas in the short and long term.

We are interested in changing the perception that global environmental changes will take place in 25, 50, or 100 years and that, therefore, response can be postponed for the future in order to focus attention on immediate problems. There are two problems with this perception: (1) The local processes influencing regional and local environmental changes are occurring now, and the mitigation and the adaptation necessary to reduce their negative consequences require actions to be implemented in the short term; (2) these mitigation and adaptation actions are directly or indirectly linked to current urban and environmental problems. Investment in the resources necessary to respond to the current problems would yield greater short and long-term benefits if the link between local problems and regional and global processes is taken into consideration.

The book contributes to the discussion of urban sustainability, some environmental and urban aspects related to the biophysical processes of what is known as global environmental change. It is an effort to expand the environmental dimension of urban sustainability beyond the local vision. Many local urban problems, particularly environmental problems, impact and are impacted by the regional and global biophysical processes. These same problems also play an important role in the interactions between urban areas and global environmental changes.

The impacts of these interactions can be classified into two large groups: those originating in the urban areas and having negative effects on the global environment, and those originating from the biophysical and chemical processes associated with global environmental changes having negative impacts on urban areas. Attention to this bidirectional relation has focused on the impacts of urban areas on the global environment (Parikh and Shukla 1995, Smith and Lazo 2001, IPCC 2001), in particular, the effects of greenhouse gas emissions and the so-called heat island effect on global climate change. A series of international, regional, and local initiatives have prioritized the reduction of greenhouse gas emissions in urban areas, in an effort to counteract the rejection and reluctance of some countries to approve the agreements of the United Nations Framework Convention on Climate Change, better known as the Kyoto Protocol. Some of these initiatives are supported by the Global Environment Facility (GEF) of the World Bank and by the International Council for Local Environmental Initiatives (ICLEI)[3] with the support of the World Bank and the United Nations Habitat Program in cities of rich and poor countries.[4]

The impacts of global changes on climate and climate variability in urban areas and their inhabitants have received less attention than the reduction of greenhouse gas emissions in urban areas. One of the most evident negative consequences of the impacts of environmental change is the growing number and magnitude of disasters associated with the climate in urban areas in the last decade. The damage caused by hurricanes and other extreme events related to climate variability in the region has a high, social, economic, and environmental cost for urban areas. The number of natural disasters in recent decades is associated with a series of factors, including a very significant increase in social inequality, unbalances in the growth of urban areas, and severe modifications to the natural landscape (Federovisk 1990, Smith 1992, Cross 2001, Pelling 2003). This set of factors has increased the number of inhabitants vulnerable to being negatively affected by the consequences of natural phenomena

[3] ICLEI mentions 650 municipalities from 30 countries participating in its Communities for Climate Protection campaign (http://www.iclei.org/index.php?id=800. Revised 30 January 2006).

[4] A significant number of cities in the United States have started voluntary greenhouse gas emission reduction programs in response to the US Federal Government's refusal to ratify the Kyoto Protocol that seeks to reduce greenhouse gas emissions at a global level.

associated with climate (hurricanes and tropical storms, droughts, landslides, floods, etc.). A recent United Nations Environment Programme (UNEP) report states that between 1980 and 2000, approximately 75% of the world's population lived in areas affected by some type of natural disaster. In 1999 alone, over 700 large-magnitude natural disasters affected the planet, resulting in over $100 billion in losses. About 90% of the victims of the natural disasters occurring around the world in that year lived in poor countries.

Latin America is one of the regions of the world most susceptible to suffering economic loss and loss of human lives due to natural disasters (Vargas 2002, UNDP 2002). Several of the largest natural disasters associated with climate in recent years have taken place in this region. In 1998, hurricane Mitch left approximately 10,000 people dead in its passage through Honduras, Nicaragua and Guatemala. The floods and landslides of 1999 in Venezuela caused millions of dollars in losses and the death of approximately 30,000 people. The landslides caused by the earthquakes in El Salvador in 2001 killed 1,500 people. The annual floods resulting from tropical storms and hurricanes in several areas of Mexico, Central America, and the Caribbean caused significant material damage and the loss of human lives. The negative consequences of those disasters are particularly evident in urban and peri-urban areas.

However, natural disasters were only part of the negative consequences of climate change and variability in urban areas. There is a broad range of negative consequences to growth and function of economic activities (tourism, trade, services), labor productivity, the social life of the population, the health of inhabitants, and the environment.

Fig. 2. Interactions between urban areas and global environmental change. A conceptual framework.

Figure 2 is a graphic representation of a conceptual approach to the study of the interactions between urban areas and global environmental changes (Sanchez et al. 2005). The approach is based on the recognition of two important premises. The first is that the urban system is the result of alterations to the landscape through social processes expressed in the physical space by the built environment. The impacts of the urban system on the biophysical system or those caused by the biophysical system to the urban space are different, depending on the type of space created (for example, a highly urbanized area as opposed to a marginalized area with incomplete urbanization). It is equally important to understand that the biophysical system, in reality, is the result of the interactions between regional and global biophysical and chemical processes and local, regional, and global socio-economic and political processes. Alterations to the water or carbon cycles, responsible for climate change and other known aspects of global environmental change, are the result of these interactions.

The second premise is the recognition of the bidirectional relation that exists between the urban systems[5] and the biophysical systems. Using light gray short arrows, the diagram shows this bidirectional relation. One side shows the way in which the urban system impacts the biophysical system. Greenhouse gas emissions of urban origin-from transportation, industry, and services- and heat emissions-heat islands-are clearly responsible for this impact. Other responsible factors receiving less attention are the changes in land use and land cover directly or indirectly induced by the urban system, which impact the biophysical system. The demand for construction materials, food, energy, water, and other natural resources cause changes in land use and land cover. For example, the high demand for wood and food in urban areas has caused deforestation with the associated increases in CO_2 gas emissions or alterations in the water cycle of large areas in the case of the demand for water. The short arrow illustrates how the biophysical system impacts the urban area. The natural disasters mentioned above have enormous social, economic and environmental consequences for Latin America.

The diagram presents a second bidirectional flow (dark gray arrows) between the urban system and the biophysical system. This second group of impacts occurs as a consequence of the first. For example, natural disasters, such as floods or droughts, can cause significant migrations to other areas (including urban areas) that result in changes to land use and land cover. These changes, in turn, cause a new series of impacts on the biophysical system. That second group of bidirectional impacts constitutes a new area of study, useful to expand the knowledge about the interactions between urban areas and biophysical processes.

Figure 2 represents a conceptual approach, and therefore makes it possible to consider the contributions presented in this book. It is a collection of the work by a group of Latin American researchers of various disciplines, focused on studying the interactions between global and regional environmental changes and urban areas. These interactions can be grouped into two broad areas: those associated with climate change and variability and those associated with changes in land use and land cover.

[5] Urban system is used here in the sense that the urban area is a complex and dynamic system. That is to say, it is a single urban area. A distinction should be made between this interpretation and the one used in some urban studies that consider an urban system to be a set of several cities.

The chapters of the book cover those two groups: the first three chapters of the book focus on the various aspects of the interactions between climate and urban areas. The next three present case studies of changes to land use and land cover. The last chapter of the book introduces a series of final reflections that may guide future areas of research on the topic and improve the relation between scientific research and the management practices of urban areas in Latin America.

Bárbaro Moya and coauthors discuss the issue of climate variability and urban land use changes in the tourist area of Varadero, Cuba. The chapter features an interesting study of the historic growth of the urban area of Varadero, its physical vulnerability to climate variability and the possible climate change scenarios, and the consequences of increasing sea surface level and extreme climate events. The case of Varadero in Cuba illustrates a broad range of interactions between climate and urban areas, and helps us understand the importance of including actions in urban growth management to reduce their negative consequences. This example also illustrates how the negative consequences of these interactions transcend the local level. In the case of Varadero, one of the main tourist centers in Cuba and an important generator of foreign currency for the country, these damages could have significant consequences for the national economy. The case of Varadero is a useful example for other urban centers in Latin America.

Daniel Comarazamy and coauthors describe what is known as the heat islands generated by urban areas. This is one of the most characteristic phenomena of the interactions between urban areas and climate with greatest implications for the urban areas themselves and their inhabitants, as well as for the regional and global biophysical processes. The work contains an interesting description of this phenomenon based on a case study in San Juan, Puerto Rico. It is worth noting the importance of this topic, which is frequently not taken into consideration when deciding on vegetation and managing urban areas. On the one hand, the structure and extension of the urban area, urban activity (transportation, urban economy, etc.) and its effects on the generation of heat and greenhouse gas emissions are sources of concern, given the high rate of urban growth at the local level and in Latin America. Numerous actions aimed at mitigating greenhouse gas emissions strive to reduce these effects. On the other hand, the way in which urban growth has occurred (form, structure, and activity), without taking into consideration the climate conditions of the area where the human settlement is located, increases the adaptation costs and reduces the options for adapting to the negative effects of climate on the urban center (Evans and de Schiller 1991, Golany 1996). The study of the heat island contributes valid information regarding differences in temperature in the various parts of the city. This information is particularly useful for the identification of areas vulnerable to extreme temperatures and the alternatives to reduce their negative consequences.

Precisely in this regard, the chapter by Fabián Bochaca and Enrique Puliafito offers a complementary study to the discussion of heat islands. The authors present the case of the cool island phenomenon inside the urban area. As they explain, this phenomenon results from variations in temperature and humidity caused by the vegetation (green areas) inside the urban space. Bochaca and Puliafito study the case of Mendoza, Argentina, in detail and calculate the size of the cool island in two of its city parks. The drop in temperature and the increase in humidity at the outskirts of these urban parks extend for a few hundred meters into the city. The temperature and relative air humidity are two important variables in the comfort indices of the population inside the urban space, in particular, in dry tropical areas (Svensson and Eliasson 2002, Wong and Yu 2005). The authors highlight the importance of giving consideration to green areas beyond their function as recreational spaces or their psychological benefits and of incorporating their ecological services. The case study of Mendoza helps to illustrate the importance of considering this knowledge in urban planning and design (Chiesura 2004).

The first three chapters of the book discuss some of the relevant aspects of the interactions between climate and urban areas. It is interesting to note that despite the wealth of studies on urban climate in the various regions of the world (Jazcilevich et al. 2000, Gomez et al. 2001, Baker et al. 2002, Svensson and Eliasson 2002, Ahmed 2003), this knowledge is seldom used in urban planning. This is a particularly relevant aspect in the case of Latin America, given the accelerated rate of urbanization and the scarcity of resources to improve urban functions in the area.

Human beings have always had an intimate relation with climate. The development and collapse of civilizations have a strong link with environmental management and, in particular, with climate management (Manzanilla 1997, Diamond 2005)[6] which, throughout history, has been an important element in the availability of natural resources vital to urban function, the comfort of the population, and in practically all activities of every day urban life. Mankind has undergone several climate adaptation phases, particularly evidenced in the human settlements (housing and urban space). Since the Middle Ages, technological advances have gradually transformed the capacity for adaptation to adverse climate conditions in urban areas. In the last century, changes have been particularly dramatic in the last century, whereby the adoption of mechanical means has facilitated the prioritization of aesthetic aspects over functional aspects in urban design and adaptation to climate. The transformation of cultural patterns influenced by new forms of operation of capitalist consumption societies and the rapid dissemination of that transformation among what has been called the "global society" have left out part of the traditional knowledge on how to adapt to local climate conditions.

[6] There are many interesting publications on the environmental history of mankind. Among the most recent ones is Diamond (2005) on the collapse of civilizations. Other interesting compilations on the issue are available on the Internet (http://www.erica.demon.co.uk/EH/EHsite.html) and (http://www.stanford.edu/group/LAEH/) for the particular case of Latin America.

Urban and housing conditions

Incomplete urbanization in poor countries favors the reproduction of pathogens and vectors

Aggravating factors

- Deficient public services
  - Sewage
  - Drainage
  - Solid waste
  - Drinking water
- Urban growth in hazard prone areas
- Deficiencies in housing

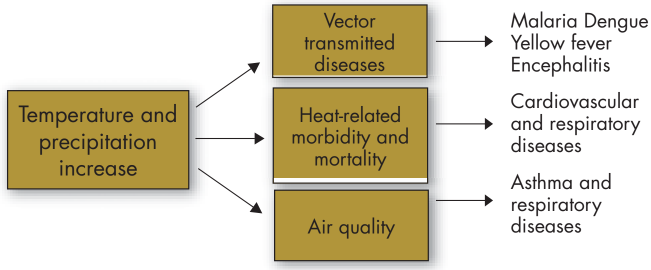


Fig. 3. Temperature and precipitation changes and consequences on health

Source: Adapted from Patz and Balbus 1996

Figure 3 presents an illustration of the wide range of interactions between climate and urban areas, as well as some of the consequences on health resulting from modifications in temperature and precipitation caused by climate change and variability (McMichael 1993, Patz and Balbus 1996, Ziska et al. 2002).

Increases in temperature associated with the heat island in urban areas are aggravated by the heat waves that accompany climate variability, with significant consequences on morbidity and mortality (cardiovascular and respiratory diseases). The heat wave affecting Chicago in 1995 caused 437 deaths (Semenza et al. 1999) and close to 30,000 in Europe in 2003. Higher temperatures can also aggravate existing air-quality problems, increasing the problems of asthma and other respiratory diseases. This is a particularly troubling problem for a significant number of large cities in Latin America that exhibit serious air-quality problems (tropospheric ozone or smog). Increases in temperature are also linked to vector transmitted diseases (dengue, malaria, yellow fever, and encephalitis). Recent studies have documented faster reproduction of the pathogens when temperature increases by two degrees. There are also reports of modifications of the boundaries of the areas affected by these diseases common in tropical zones, as a consequence of climate variability (Epstein 1994, Patz and Balbus 1996).

The health consequences caused by changes in temperature and precipitation mentioned above are aggravated by the deficient conditions of health and housing characteristic of large portions of the urban areas in Latin America. Deficiencies in solid-waste collection, one of the most common and visible problems in Latin American cities, favor the reproduction of pathogens and their transmission vectors. Similar problems are caused by deficiencies in municipal storm drainage or sewage collection systems. Stagnant water resulting from frequent failures in those services (leaks), particularly in marginalized areas with incomplete urbanization or in low-income areas, creates ideal conditions for vector reproduction. Higher temperatures shorten vector reproduction time.

The second part of the book focuses on changes in land use and land coverage.

Erna López and coauthors study urban growth and its consequences at the regional level in the Lake Cuitzeo Basin, Mexico. Based on a reconstruction of the history of land use changes in the Cuitzeo Basin, the second largest lake in Mexico, the work describes the impact of urban growth on the basin. The authors highlight the impact of the city of Morelia (capital of the state of Michoacán) on land use changes in the basin (a 600% growth between 1975 and 2000), the urban and environmental problems that accompany this growth, and their impact on the lake and the basin. The Cuitzeo basin presents a useful case study for a large number of urban areas in Latin America. The large majority of cities in that region have water supply problems, and guaranteeing access to the resource frequently has a significant impact on the bodies of water used as supply sources (surface, such as rivers and lakes, or underground) (Anton 1993). The use of the hydrological basin as a unit of analysis offers the advantage of establishing a regional framework in which to locate the impact of urban growth based on changes to land use and land coverage and available alternatives to establish a better balance between the landscape and the urban areas.

Ricardo Silva Toledo discusses one of the key topics of the urban issue in Latin America: hydrological basin management to guarantee urban-area water supply and the asymmetry of access to the potable water network. Using a case study of the metropolitan region of São Paulo in Brazil, Ricardo Silva studies the integrated management of the Upper Tietê Basin, a densely urbanized area. The work introduces novel management and administration instruments that could be useful for other areas in Latin America. The problem of asymmetry in access to the water infrastructure network is a common, complex metropolitan reality in Latin America, as well as in the rest of the poor countries of the world. The chapter contains a series of reflections relevant to the discussion of the privatization of water resources in Latin America (Trawick 2003). The aspects discussed in this chapter are particularly relevant to the discussion of the impacts of regional and global processes on climate and the social, economic, and environmental consequences over one of the vital resources for human life and urban activities: water.

Cláudia Almeida studies the use of computer models to simulate and forecast urban land-use changes as a useful tool for local urban-growth managers. The models assist decision makers and the wide range of urban stakeholders in visualizing the trends in the physical growth of the city, as well as any conflicts that could arise with the environmental capacity of the area. This tool is also useful to develop scenarios for adaptation to the negative impacts of global environmental changes at the local level: for example, the expansion of the heat island and the possible differences in temperature inside the city, the role of ecological services (green areas, bodies of water, etc.) to mitigate the negative effects of the heat island or to reduce the risk of floods. These are but a few of the benefits of using this tool. After a brief introduction to the urbanization process in Brazil, Almeida uses the city of Bauru in the state of São Paulo, Brazil, as a case study. Bauru experienced an explosive growth of 500% between 1970 and 2000. This growth and the deficiencies in the accompanying urbanization process (problems in covering the demand for infrastructure and urban services, environmental problems, transportation problems, etc.) are similar to those in other cities in Latin America. The chapter shows the successful development of a cellular automata model in the construction of scenarios for the urban growth of Bauru and its use in support of urban planning and urban growth management. At the end of the section, the author stresses the importance of developing and using urban models in a critical way (recognizing their benefits and limitations) as urban-growth decision-making support tools, including their adaptation to the negative effects of global environmental changes.

The last chapter of the book presents a series of final reflections that may guide future areas of research on the topic and improve the relation between scientific research and the management practices of urban areas in Latin America. It emphasizes the importance of making available the existing information on and knowledge of the impacts of regional and global biophysical processes in the urban areas of Latin America to the wide range of stakeholders influencing urban growth. Alternatives are explored to include this information and knowledge into the vast existing international, regional, and national training programs for decision-makers on urban growth and associated environmental problems.

The people responsible for editing this book would like to thank each one of the authors. The variety of case studies presented in the work offers a wealth of knowledge and useful experiences for other urban areas in Latin America. We also thank the IAI and the UNEP—Regional Office for Latin America and the Caribbean—for their interest and support in stressing the importance of studying urban growth and its link to global environmental changes. We are convinced that such contributions are vital to opening opportunities for sustainable development in the region. Finally, we would like to acknowledge the support and patience of Marcella Ohira and Céline Demaret from the IAI, who made editing this book possible, as well as the careful text review by María Marta Laplace (Spanish edition).

References

Abbott, J. 1996. *Sharing the City. Community Participation in Urban Management.* Earthscan Publications Ltd., London, England. 272 pp.

Adger, W. N. 1999. "Social vulnerability to climate change and extremes in coastal Vietnam." *World Development* 27(2):249–269.

Adger, W. N., Brown, K., and Hulme, M. 2005. "Redefining global environmental change." *Global Environmental Change* 15:1–4.

Ahmed, K. S. 2003. "Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments." *Energy and Buildings* 35:103–110.

Anton, D. 1993. *Thirsty Cities. Urban Environments and Water Supply in Latin America.* International Development Research Center, Ottawa, Canada. 180 pp.

Assis, E., and Barros Frota, A. 1999. "Urban bioclimatic design strategies for a tropical city." *Atmospheric Environment* 33:4135–4142.

Baker, L, Brazel, A., Selover, N., Martin, Ch., McIntyre, N., Steiner, F., Nelson, A., and Musacchio, L. 2002. "Urbanization and warming in Phoenix (Arizona, USA): Impacts, feedbacks and mitigation." *Urban Ecosystems* 6:183–203.

Bakker, K. 2003. "Archipelagos and networks: urbanization and water privatization in the South." *The Geographical Journal* 169(4):328–341.

Batterbury, S., and Fernando, J. 2006. "Rescaling governance and the impacts of political and environmental decentralization." *World Development* 34(11):1851–1863.

Benjamin, S. 2004. "Urban land transformations for pro-poor economies." *Geoforum* 35:177–187.

Blaikie, P., Cannon, T., Davis, I., and Wisner, B. 1994. *At Risk. Natural Hazards, Vulnerability, and Disasters.* Routledge, London, England. 277 pp.

Blair, R. and Launer, A. 1997. "Butterfly diversity and human land use: Species assemblages along an urban gradient." *Biological Conservation* 80(1):113–125.

Boisier, S. 1973. "Industrialización, urbanización y polarización." *El Trimestre Económico* XI(1):1–44.

Bolay, J.-C., Pedrazzini, Y., Rabinovich, A., Catenazzi, A., and Garcia Pleyan, C. 2005. "Urban environment, spatial fragmentation and social segregation in Latin America: Where does innovation lie?" *Habitat International* 29:627–645.

Bouland, P., and Hunhammar, S. 1999. "Ecosystem services in urban areas." *Ecological Economics* 29:293–301.

Bryant, R., and Wilson, G. 1998. "Rethinking Environmental Management." *Progress in Human Geography* 22 (3):321–343.

Carley, M., and Christie, I. 2001. *Managing Sustainable Development.* Second edition. Earthscan, London, England. 304 pp.

Castells, M. 1974. *La Cuestión Urbana.* Siglo Veintiuno Editores, Mexico City, Mexico. 544 pp.

Castells, M. 1981. *Capital Multinacional, Estados Nacionales y Comunidades Locales.* Siglo Veintiuno Editores, Mexico City, Mexico. 12 pp.

CEPAL (Comisión Económica para América Latina y el Caribe). 2003. *Manual para la estimación de los efectos socio-economicos y ambientales de los desastres.* CEPAL/ World Bank.

CEPAL-BID (Comisión Económica para América Latina y el Caribe–Banco Iteramericano de Desarrollo). 2000. "Un tema de desarrollo: la reducción de la vulnerabilidad frente a los desastres." *Enfrentando Desastres Naturales, una Cuestion de Desarrollo*—seminar, New Orleans, Lousiana, March 25–26.

Chiesura, A. 2004. "The role of urban parks for the sustainable city." *Landscape and Urban Planning* 68:129–138.

Cohen, B. 2004. "Urban growth in developing countries: A review of current trends and a caution regarding existing forecasts." *World Development* 32(1): 23–51.

Conti, S., Meli, P., Minelli, G., Solimini, R., Toccaceli, V., Vichi, M., Beltrano, C., and Perini, L. 2005. "Epidemiologic study of mortality during the summer 2003 heat wave in Italy." *Environmental Research* 98:390–399.

Cross, J. 2001. "Mega-cities and small towns: different perspectives on hazard vulnerability." *Global Environmental Change Part B: Environmental Hazards* 3(1):63–80.

Diamond, J. 2005. *Collapse: How Societies Choose to Fail or Succeed.* Viking Penguin, New York, NY. 592 pp.

Dow, K. 2000. "Social dimensions of gradients in urban ecosystems." *Urban Ecosystems* 4:255–275.

Drakakis-Smith, D. 1995. "Third World cities: sustainable urban development 1." *Urban Studies* 32(4&5):659–677.

Epstein, P. 1994. "Emerging diseases and ecosystem instability: New threats to public health." *American Journal of Public Health* 85:168–172.

Er, K. B. H., Innes, J. L., Martin, K., and Klinkenburg, B. 2005. "Forest loss with urbanization predicts bird extirpations in Vancouver." *Biological Conservation* 126:410–419.

Evans, J. M., and de Schiller, S. 1991. "Climate and urban planning: The example of the planning code for Vicente Lopez, Buenos Aires." *Energy and Buildings* 15(16):35–41.

Federovisk, S. 1990. "Influencias de la urbanización en un desastre: El caso del área metropolitana de la ciudad de Buenos Aires." *Medio Ambiente y Urbanismo* 8(30):31–49.

Fiszbein, A. 1997. The emergence of local capacity: Lessons from Colombia." *World Development* 25(7):1029–1043.

Friedmann, J. 1987. *Planning in the Public Domain: From Knowledge to Action.* Princeton University Press, Princeton, NJ. 501 pp.

Fry, G. 2001. "Multifunctional landscapes—towards transdisciplinary research." *Landscape and Urban Planning 57*:159–168.

García Canclini, N. 1999. *Imaginarios Urbanos.* 2a Edición. Ediciones Eudeba, Buenos Aires, Argentina. 149 pp.

Gibbs, A., and Jonas, A. 2000. "Governance and Regulation in Local Environmental Policy: The Utility of a Regime Approach." *Geoforum* 31:299–313.

Gilbert, A. 1974. *Latin American Development. A Geographical Perspective.* Penguin Books, London, England. 368 pp.

Gilbert, A., and Guggler, J. 1992. *Cities, Poverty and Development: Urbanization in the Third World.* Oxford University Press, Oxford, England. 352 pp.

Giri, A. 2002. "The calling of a creative transdisciplinarity." *Futures* 34:103–115.

Golany, G. 1996. "Urban design morphology and thermal performance." *Atmospheric Environment* 30(3):455–465.

Gomez, F., Tamarit, N., and Jabaloyes, J. 2001. "Green zones, bioclimatics studies and human comfort in the future development of urban planning." *Landscape and Urban Planning* 55:151–161.

Hamza, M., and Zetter, R. 1998. "Structural adjustment, urban systems and disaster vulnerability in developing countries." *Cities* 15(4):291–299.

Hardoy, J., and Geisse, G. (comp.). 1972. *Políticas de Desarrollo Urbano y Regional en América Latina*. Editorial SIAP, Buenos Aires, Argentina. 374 pp.

Hardoy, J. E., Mitlin, D., and Satterthwaite, D. 1992. *Environmental Problems in Third World Cities*. Earthscan, London, England. 285 pp.

Harvey, D. 1989. *Geografisker Annaler B*. Vol. 71, pp. 3–17. Quoted in Hull (1998).

Healey, P. 2002. "On creating the 'city' as a collective resource." *Urban Studies* 39(10):1777–1792.

Hull, A. 1998. "Spatial Planning. The development plan as a vehicle to unlock development potential." *Cities* 15(5):327–335.

IPPC. 2001. *Climate Change 2001*: *Impacts, Adaptation, and Vulnerability: Summary for Policy Makers and Technical Summary of the Working Group II Report*. IPCC, Geneva, Switzerland. 1005 pp.

Jackson, L. 2003. "The relationship of urban design and human health and condition." *Landscape and Urban Planning* 64(4):191–200.

Jacobi, P. 1994. "Households and environment in the city of São Paulo: problems, perceptions and solutions." *Environment and Urbanization* 6(2):87–110.

Jáuregui, E., and Morales, E. 1996. "Urban effects on convective precipitation in Mexico City." *Atmospheric Environment*. 30(20):3383–3389.

Jazcilevich, A., Fuentes, V., Jáuregui, E., and Luna, E. 2000. "Simulated urban climate response to historical land use modification in the Basin of Mexico." *Climatic Change* 44:515–536.

Kirshen, P., and Fennessey, N. 1995. "Possible climate-change impacts on water supply of metropolitan Boston." *Journal of Water Resources Planning and Management* 121(1):61–70.

Kohl, B. 2002. "Stabilizing neoliberalism in Bolivia: popular participation and privatization." *Political Geography* 21:449–472.

Lambin, E. 2005. "Conditions for sustainability of human–environment systems: information, motivation, and capacity." *Global Environmental Change* 15:177–180.

Laws, G. 1994. "Oppression, knowledge and the built environment." *Political Geography* 13(1):7–32.

Lefebre, H. 1991. *The Production of Space*. Blackwell, Oxford, England. 464 pp.

Leff, E. 1998. *Saber Ambiental: Sustentabilidad, Racionalidad, Complejidad, Poder*. Siglo XXI y PNUMA (Programa de Naciones Unidas para el Medio Ambiente), Mexico City, Mexico. 414 pp.

Lomnitz, L. 1972. *Como Sobreviven los Marginados*. Siglo Veintiuno Editores, Mexico City, Mexico. 232 pp.

Lopes de Souza, M. 2001. "Metropolitan decentralization, socio-political fragmentation and extended suburbanization: Brazilian urbanization in the 1980s and 1990s." *Geoforum* 32:437–447.

Madaleno, I. 2000. "Urban agriculture in Belém, Brazil." *Cities* 17(1):73–77.

Manzanilla, L. 1997. "Early urban societies: challenges and perspectives." In: *Emergence and Change in Early Urban Societies* (L. Manzanilla, Ed.), Springer, New York, NY. 316 pp.

Martinez-Vazquez, J., and McNab, R. 2003. "Fiscal decentralization and economic growth." *World Development* 31(9):1597–1616 .

Mattews, R., and Selman, P. 2006. "Landscape as a focus integrating human and environmental processes." *Journal of Agricultural Economics* 57(2):199–212.

McMichael, A. 1993. *Planetary Overload. Global Environmental Change and Health of the Human Species*. Cambridge University Press, Cambridge, England. 370 pp.

Moser, C. 1998. "The Asset Vulnerability Framework: Reassessing urban poverty reduction strategies." *World Development* 26(1):1–19.

Moser, C., and McIlwaine, C. 2006. "Latin American urban violence as a development concern: Towards a framework for violence reduction." *World Development* 34 (1):89–112.

Myllyla., S. and Kuvaja, K. 2005. "Societal premises for sustainable development in large southern cities." *Global Environmental Change* 15:224–237.

Newman, P. 1999. "Sustainability and cities: Extending the metabolism model." *Landscape and Urban Planning* 44:219–226.

Nissani, M. 1997. "Ten cheers for interdisciplinarity: The case for interdisciplinarity in knowledge and research." *The Social Science Journal* 34(2):201–216.

Parikh, J., and Shukla V. 1995. "Urbanization, energy use and greenhouse effects in economic development." *Global Environmental Change* 5(2):87–103.

Patz, J., and Balbus, J. 1996. "Methods for assessing public health vulnerability to global climate change." *Climate Research* 6:113–125.

Pelling, M. 2001 "Natural disasters?" In: *Social Nature: Theory, Practice, and Development* (Castree, N., and Braun, B., Eds.), Blackwell, Oxford, England. 272 pp.

Pelling, M. 2003. *The Vulnerability of Cities. Natural Disasters and Social Resilience.* Earthscan Publications Ltd., London, England. 212 pp.

Pickett, S., Burch, W., Dalton, S., and Foresman, T. 1997. "A conceptual framework for the study of human ecosystems in urban areas." *Urban Ecosystems* 1:185–199.

Pirez, P. 2002. "Buenos Aires: fragmentation and privatization of the metropolitan city." *Environment and Urbanization* 14(1):145–158.

Quijano, A. 1967. "La urbanización de la sociedad en América Latina." *Revista Mexicana de Sociología* XIX(4):1–35.

Radoki, C. 2001. "Forget planning, put politics first. Priorities for urban management in developing countries." *Journal of American Geographers* 3(3):209–223.

Ramadier, T. 2004. "Transdisciplinarity and its challenges: the case of urban studies." *Futures* 36:423–439.

Redclift, M. 1994. "Development and the environment: managing the contradictions?" In: *Capitalism and Development* (Sklair, L., Ed.). Routledge, London, England. Pp. 123–137.

Rees, W., and Wackernagel, M. 1996. "Urban ecological footprints: why cities cannot be sustainable—and why they are a key to sustainability." *Environmental Impact Assessment Review* 16:223–248.

Restrepo, I. 1980. *Conflictos entre ciudad y campo en América Latina.* Editorial Nueva Imagen, Mexico City, Mexico. 377 pp.

Ribot, J., and Larson, A. 2005. *A Democratic Decentralization through a NaturalResource Lens*. Routledge, New York, NY. 260 pp.

Rosenzweig, C., and Solecki, W. 2001. "Climate change and a global city: Learning from New York." *Environment* 43(3):3–12.

Sanchez, R., Seto, K., Simon, D., Solecki, W., Krass, F., and Laumann, G. 2005. *Urbanization and Global Environmental Change. Science Plan.* International Human Dimensions Program. Bonn, Germany. 60 pp.

Satterthwaite, D. 1997. "Sustainable cities or cities that contribute to sustainable development?" *Urban Studies* 34(10):1667–1997.

Schreider, S., Smith, D., and Jakeman, A. 2000. "Climate change impacts on urban flooding." *Climatic Change 47*:91–115.

Schoenberger, E. 2001. "Interdisciplinarity and social power." *Progress in Human Geography* 25(3):365–382.

Schrijnen, P. 2000. "Infrastructure networks and red-green patterns in city regions." *Landscape and Urban Planning* 48:191–204.

Segre, R. 1977. *Las Unidades Ambientales en América Latina*. Siglo XXI Editores, Mexico City, Mexico. 384 pp.

Semenza, J., McCullough, J., Flanders, W., McGeehin, M., and Lumpkin, J. 1999. "Excess hospital admissions during the July 1995 heat wave in Chicago." *American Journal of Preventive Medicine* 16(4):269–277.

Singer, P. 1975. *Economía Política de la Urbanización*. Siglo XXI Editores, Mexico City, Mexico. 184 pp.

Smith, K. 1992. *Environmental Hazards. Assessing Risk & Reducing Disaster*. Routledge, London, England. 324 pp.

Smith, J., and Lazo, J. 2001. "A summary of climate change impact assessments from the US Country Studies Program." *Climatic Change* 50(1&2):1–29.

Smyth., C., and Royle, S. 2000. "Urban landslide hazards: incidence and causative factors in Niterói, Rio de Janeiro State, Brazil." *Applied Geography* 20:95–117.

Spangenberg, J., Pfahl, S., and Deller, K. 2002. "Towards indicators for institutional sustainability: lessons from an analysis of Agenda 21." *Ecological Indicators* 2(1&2):61–77.

Steinberg, F. 2005. "Strategic urban planning in Latin America: experiences of building and managing the future." *Habitat International* 29(1):69–93.

Sturm, R., and Cohen, D. 2004. "Suburban sprawl and physical and mental health." *Public Health* 118(7):488–496.

Sunkel, O., and Giglio, N. 1980. *Estilos de Desarrollo y Medio Ambiente en América Latina I*. Fondo de Cultura Económica, Mexico City. 663 pp.

Svensson, M., and Eliasson, I. 2002. "Diurnal air temperatures in built-up areas in relation to urban planning." *Landscape and Urban Planning* 61:37–54.

Tayanc, M., Karaca, M., and Yenigun, O. 1997. "Annual and seasonal air temperature trend patterns of climate change and urbanization effects in relation to air pollutants in Turkey." *Journal of Geophysical Research* 102(132): 1909–1919.

Trawick., P. 2003. "Against the privatization of water: An indigenous model for improving existing laws and successfully governing the commons." *World Development* 31(6):977–996.

UNCHS (United Nations Commission on Human Settlements) 2002. *The State of the World Cities Report 2001*. United Nations Publications, New York, NY.

UNDP (United Nations Development Program). 2002. *Climate Risk Management Approach to Disaster Reduction and Adaptation to Climate Change*. Draft summary of the UNDP Expert Group Meeting on Integrating Disaster Reduction with Adaptation to Climate Change, Havana, Cuba, June 19–21.

Unikel, L., and Necochea, V. (Eds.). 1975. *Desarrollo Urbano y Regional en América Latina. Problemas y Políticas.* Fondo de Cultura Económica, Mexico City, Mexico. 732 pp.

Urquidi, V. 1969. "La Ciudad Subdesarrollada." *Demografía y Economía* III(2): 1–19.

Valleron, A., and Boumendil, A. 2004. "Epidemiologie et canicules: analyses de la vague de chaleur 2003 en France." *C.R. Biologies* 327:1125–1141.

Vargas, J. 2002. *Políticas Públicas para la Reducción de la Vulnerabilidad Frente a los Desastres Naturales y Socio-naturales*. Serie Medio Ambiente y Desarrollo, no. 50. División de Medio Ambiente y Asentamientos Humanos, CEPAL, Santiago, Chile.

Ward, P. 1982. *Self-help Housing. A Critique*. Routledge, London, England. 296 pp.

Warren-Rhodes, K., and Koenig, A. 2001. "Escalating trends in the urban metabolism of Hong Kong: 1971–1997." *Ambio* 30(7):429–438.

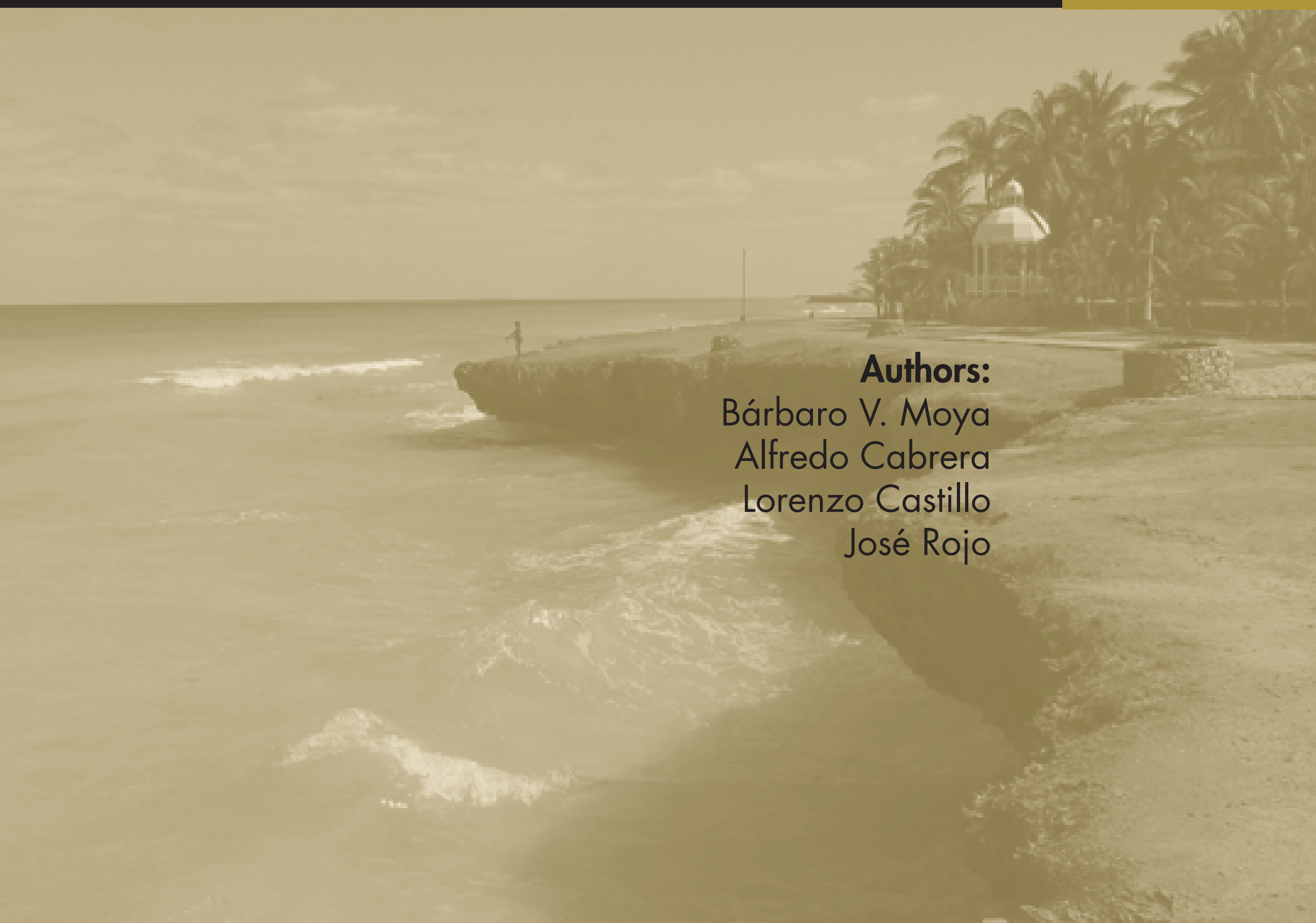
Wong, N., and Yu, C. 2005. "Study of green areas and urban heat island in a tropical city." *Habitat International* 29:547–558.

World Bank. 2002. *World Bank Urban Development* (http://www.worldbank.org/html/fdp/urban/)

Ziska, L., Gebhard, D., Frenz, D., Faulkner, S., Singer, B., and Str, J. 2003. "Cities as harbingers of climate change: Common ragweed, urbanization, and public health." *Journal of Allergy and Clinical Immunology* 111(2):290–295.

Varadero and Global Environmental Change

2



Authors:
Bárbaro V. Moya
Alfredo Cabrera
Lorenzo Castillo
José Rojo

Summary

Varadero is the main beach and sand tourist attraction in Cuba and one of the most appreciated destinations in the Caribbean. It is a resort city developed in the peninsula of Hicacos, province of Matanzas. For decades, this peninsula has been subjected to an intense transformation process expressed in urbanization and tourist exploitation, in addition to the natural vulnerability of the system.

The current situation of global environmental change, conceptualized in this case as climate change and land use variability and change, impacts Varadero negatively.

This study focuses on the physical-geographical and socio-economic characterization, as well as the analysis of the urbanization and tourist exploitation processes in Varadero. The work reviews the historical stages of tourism development and its future perspectives, while considering climate variability and climate scenarios for various periods of time. Different forms of vulnerability, as well as the impacts and effects of environmental global change, are studied, and adaptation measures are recommended under an integral and multidisciplinary adaptation program.

Introduction

Climate change is real and irreversible. The increase of greenhouse gas (GHG) emissions into the atmosphere, derived from industrialized modern lifestyles, has caused a sustained increase in the concentration of these gases and heat retention in the atmosphere which, among other things, is manifested in higher average global temperatures. The decade 1991–2000 witnessed eight of the ten warmest years of the last century, and the period 2001–2005 featured four of the seven hottest years since dependable temperature records have been kept, namely, the late 19th century. This process in known as "global warming."

Climate change occurs in a dynamic world of constant transformation and includes the modification of soil cover and land use, the accelerated growth of urbanization, and increased industrialization and transportation. All these activities are directly or indirectly responsible for an upward trend in GHG emissions, while GHG sinks show a decreasing trend; this increase in GHG concentrations, in turn, has implications for global warming, climate change, society, and the economy.

The models of future scenarios show that some climate changes will occur faster than afforded by the natural variability of the system. Among these changes are higher temperature values; changes in the distribution of precipitation, with areas where the accumulated values of rainfall will increase while others will be reduced; and, in addition, changes in the annual distribution of precipitation, higher sea levels, and more frequent occurrence of extreme weather events.

Natural climate variability and anthropogenic contributions to it and changes in land use and their expression in the environment are all aspects to be considered when discussing environmental global change. Extremely destructive events will have a negative effect on the environment, society, and economy. The negative effect will increase as the climate transformation process becomes more acute. This is a problem of the highest priority and a challenge for the international scientific community, decision makers, and public at large.

The most susceptible regions to the effects of climate change include small island states and coastal areas. Increased sea levels and possible penetration inland, which devastate lives and property, in some cases have become a real threat in the medium term. Added to this scenario, there is the accumulated impact of other probable events, such as floods and storms, as well as droughts and salinization advancing rampantly in many areas of the coast, which, together with the former, reduce the resilience of ecosystems and the capacity to recover from severe impacts.

For Varadero, the establishment of a tourism industry involved actions that make the natural fragility of the system even more acute during the urbanization process. Deforestation of dunes, construction of houses and hotels in inadequate locations, sand extraction, desiccation of mangroves are all examples of this degradation. Increased vulnerability, together with reduced resilience of the environment, aggravates the exposure of people and economic interests to various risks, including the risks posed by future climate change scenarios for this beach.

This framework evidences the need to develop an adaptation strategy that will, first of all, preserve the territory and enable proceeding with the mitigation of impacts and reducing activities that favor global warming. A climate-change adaptation program will result in an adequate tool for managing extreme situations associated with climate behavior and developing an approach with a view to analyzing the vulnerabilities of the territory, climate scenarios, and potential impacts and will constitute an appropriate methodology for an integrated study.

This work aims to present a climate-change adaptation program for Varadero, and its implementation will enable supplementary work on climate variability phenomena. This assumes the application of measures for the future, as well as for extreme weather events and anomalous weather behavior that may occur at any time.

An adaptation program includes a set of evaluations to be used as the basis for taking measures to alleviate negative impacts on the area, and it also includes the physical-geographical and socio-economic characterization of the area. This is supplemented by an analysis of the evolution of urbanization and tourist exploitation, as well as a socio-economic projection for the next years and future land-use changes. Emphasis is placed on the analysis of the evolution process and its future perspectives and their implications for the vulnerability of the land.

The general objective of the work is achieved by outlining a first series of adaptation measures that will allow advising decision makers and the public at large about ways to deal with climate change and environmental global change.

Method

This study seeks to fulfill a series of objectives aimed at the presentation of a diagnosis, the determination and analysis of vulnerabilities and impacts, and the development of adaptation measures. The philosophy of the work is based on a holistic analysis of the components of the environment in question and its relation to adjacent environmental units at different temporal and spatial scales.

The first step is to carry out a physical-geographical characterization of the territory using existing information, our own surveys, and the experiences reflected by studies already done in Varadero. The analysis of the physical-geographical conditions shows how these contribute to the vulnerability of the peninsula to extreme weather events and other climate effects.

The study continues with the socio-economic characterization of Varadero, as well as with the specification of the main economic activities of the territory and future perspectives for development. This part of the study is supplemented by an analysis of the evolution of the urbanization and exploitation process of the area, where the often rigid socially established frontiers between social and natural aspects are made flexible in order to facilitate the integrated analysis of these processes in the anthropogenic-natural environment.

Information regarding future climate scenarios, considering variability and climate change, allows inferring the future situation of this tourist area—with the reservations inherent in any modeling exercise. In order to analyze variability and climate, data from the Varadero weather station (in service for 10 years) were used, as well as the chronology of hurricanes (since 1796), and ENSO event chronology (for more than 100 years). The data series of the Climate Research Unit of the University of East Anglia (CRU, UEA) dating from 1901 was also used, which enabled estimating the behavior of temperatures during some months since the beginning of the last century. This estimation utilizes linear correlation methods and chronological analysis of interrupted series that could be thereby completed. The models of the Intergovernmental Panel on Climate Change (IPCC), IS92a, KYOTOA1, GSA2 were used to generate the scenarios for analyzing future climate changes.

The analysis of social vulnerability to extreme weather events in Varadero, as well as the context and temporal and spatial expressions support the need for an integrated analysis. The review sought expert criteria, as well as information generated from international experiences (applying Delphi), in addition to statistical analysis such as the probabilistic determination of exposure. In addition, calculations were developed on the basis of methodologies for the determination of space lost and chronological statistical analysis, evaluating parameters from the local to the global scale, collected in the Bulto index (Ortiz et al. 1998). This work enabled appreciating the magnitude of the impacts on the space that can be considered to be vulnerable to weather events in Varadero.

Dissemination of results through national events and workshops has been one of the main objectives of this study, in particular given the need to submit and validate the results. High-level specialists discussed the results during these events and workshops. However, the most important activity was the workshop convened by the stakeholders in Varadero, who participated in reviewing the results and developing a plan of action.

Development

General characteristics of the territory

Varadero beach is located at 23 LN and 81 LW, in the Intertropical Zone, very close to the Tropic of Cancer and the Straight of Florida, in the Caribbean Sea. It is on a peninsula approximately 20 km long located on the north coast of the province of Matanzas, the second largest in Cuba, the largest of the Antilles.

Varadero is the most important beach-and-sand tourist attraction in the country. Sun, sand, and beach coexist with urban spaces with a population density of over 500 people per kilometer squared and ever decreasing natural spaces (Figs. 1, 2).

a) b)

Fig. 1.
a) Beach and sand areas.
b) Urban spaces.

Fig. 2. Natural spaces in Varadero. *(Source: Beach Management Office, OMP)*

Physical-Geographical Characteristics

As mentioned before, the area is located in the peninsula of Hicacos, a part of the physical-geographical region of the Heights and Plains of North Havana-Matanzas. It is a sand bar composed of sandstone and calcarenite, as well as fossil dunes. It is 18 km long and between 1 and 2 km wide. It is a low-altitude flat land, about 5 meters above sea level, although some small hills are present. The climate is tropical, with a marked subtropical influence for part of the year, mainly due to its nearness to the subtropical region and the North American subcontinent, where cold fronts originate and modify the weather in the winter season (Alfonso and Florido 1992).

The main features of this landscape include the surface extension of a sand foundation; the distribution of the units in strips parallel to the coast line (Cabrera 1999); the predominance of extremely dry conditions, high salinity, and strong and persistent influence of winds; and little development of edaphic cover. It should also be noted that there is a dominant presence of the flat relief and relief shapes closely associated with land-sea interaction processes. These are young landscapes, developed over late holocenic and pleistocenic plains.

Another general feature of Hicacos landscapes is that surface runoff is almost nonexistent; only weak laminar runoff is seen immediately after rains fall on steep inclines. On the other hand, the sandy conditions of the surface and high permeability due to cracks in underlying or outcropping rocks determine a very high infiltration coefficient. The phreatic level is very close to the surface and exhibits very noticeable synchronic oscillations with daytime tide fluctuations that influence all natural processes. The geo-ecological operation of these landscapes is conditioned by the tropical regime of high temperatures and seasonal rainfall, which, in this case, exhibits relatively low values—less less than 1000 mm per year (Alfonso and Florido 1992).

There is a significant maritime influence in the study area, especially through the thermal effect regulating the creation of a "salinized" environment with strong influence from the wind and the intensification of the physical processes (cumulative and erosive) reflected in the dynamic-functional instability of these geosystems of sandy substrates subjected to intense littoral morphogenesis. These mechanisms, conditioned by the interaction of abiotic components, act as essential factors in the geophysical structure of the study area. Thus, the biotic components are becoming the best indicators of geo-ecological functioning, which can be observed from the weak pedogenic processes, the low net productivity of the coastal xeromorphic thicket and "uveral" strip (sea-grape woodland), as well as from the alteration of the composition and interrelations of the original biocenosis (CESIGMA SA 1998).

All of the above evidences the instability of these landscapes and, therefore, their fragility and susceptibility to impacts from nature and human beings. In addition, given their geographic location, these landscapes are also exposed to severe tropical and subtropical events. Therein lies the natural vulnerability of the system.

Socio-Economic Conditions

One of the most important socio-economic characteristics of the tourist area is that it contains three urban settlements of approximately 22,000 inhabitants. The tourist city—area of interest for this study—has a surface area of 14.4 km^2, of which 58.3% is built, with a population of about 8,000 inhabitants and a density of over 500 hab/km^2. The index of males is 0.989, and the annual growth rate is 1.7. About 56% of the population is between 15 and 49 years old and has a high education level. This significant cultural level resulting from socialized education, the quality of the medical care provided to the population, and the civil defense system offer an advantage to the population in this area in the fight against global environmental change.

There is intense activity in services and small-scale production associated with tourist activities. In fact, the largest employers in the city are in the tourism sector and associated services, areas where the purchasing power of workers is higher than for the rest of the population. On the other hand, in recent years, Varadero has generated 35% of the whole counrry's income received from tourism.

In the last 25 years, the population increased by approximately 1.8 times, a trend that would indicate a future population decrease as a consequence of progressive aging. During the same period, the population between 0 and 14 years has been stable, while the population between 15 and 49 has doubled and the population over 50 has tripled (ONE 1995).

The main oil extraction area of the country is located near Varadero, where over 1.5 million tons of oil and 0.6 million tons of natural gas are extracted annually.

The Urbanization Process in Varadero

The urban history of the peninsula dates from 1492, when a settlement of about 25 indigenous people was exterminated in the colonization process.

But the process of urbanization properly began in 1883, when the town of Varadero (nearly 25 houses) was established in an area located in the southern part, about 3 km from the current Paso Malo canal. At the time, there was no urban infrastructure as such; the houses, grouped but with no clear core, were built of wood boards, guano, and clay roof tiles. Roads were inexistent, and there were only trails leading to the north coast. The population consisted of seasonal dwellers and fishermen (Fig. 4).

Around 1910, the settlement underwent a slight expansion on the eastern section of the peninsula, a trend that continued until the first urban settlements were established on the western part, generally known as the Kawama area. This progressive expansion was maintained and deepened toward the west of the peninsula in the 1990s. Currently, the urbanization process has expanded considerably and covers almost the entire peninsula. There were already glimpses of the historical and natural features of the so-called "Town for the Bathing Season," because of its solitary, wild, and magnificent beach.

The evolution process of urbanization in Varadero can be divided into four main stages (Rojo 1998) (Fig.3):

1. Initial settlement
2. Period 1910–1989 with three subperiods: (1910–1945), (1945–1959), and (1959–1989)
3. Period 1990–1998
4. Period 1998–The Present

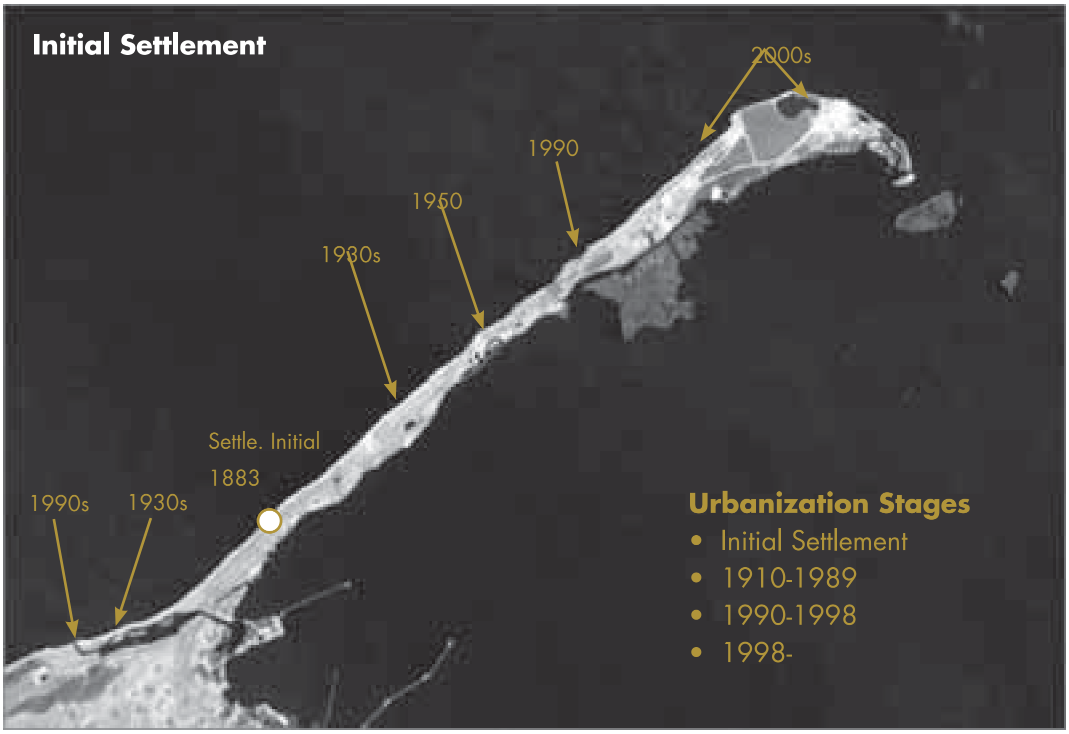


Fig. 4. Recreation of initial settlement. *(Source: Arch. Elena Royo Muñoz, IPF)*

Period 1910-1989

Subperiod 1910-1945

A dirt road was built very close to the beaches of the north, which will later be known as First Street (currently Beach Avenue). Around the time of World War I, the first houses were built on the north coast, and hotels started to appear. Population distribution determined by social status is evident and will continue to be until 1950, represented in the physical-geographical zoning. The northern part of the beach sector was occupied by the mansions of the wealthy class and merchants, the central part was settled by the middle class, and the low-income class (fishermen) occupied the mangrove area to the south.

The architectural style of the era includes wooden structures surrounded by cool porches under wood ceilings covered by clay roof tiles, as well as stone houses (Rojo 1999) (Fig. 5).

In 1926, with the investment of foreign capital, represented by Dupont, land acquired commercial value, and the real estate business was born. This development resulted in the construction of the first aqueduct. There was still no significant city core in the 1930s. Investment mainly targeted guest houses and small hotels scattered in the northern part. Since then, Varadero has expanded in an east-west direction due to its long and narrow shape and the natural limitations of a sand mass to the north and a mangrove area and low coast to the south.

In 1933, the peninsula was hit by the "Hurricane of 33," the most destructive natural phenomenon ever to affect the area, resulting in severe damage from flooding and storm surges in most of the peninsula. Despite this natural disaster, the population was 1,315 people in 1943.

Fig. 5. Typical construction dating from the period 1910–1945

Subperiod 1945-1959

During World War II, a stable lodging capacity was created for occasional dwellers and foreigners. Land exploitation was consolidated with the emergence of the "repartos" (land allocations) to the west and east of the area. The original grid was maintained and expanded, introducing the elements of urbanization management.

Between 1950 and 1958, the government, pressured by transnational tourism corporations seeking the modernization of Varadero, focused on developing the area, which coincided with an avalanche of American loans and investment capital. One result was the opening of the first "Grand Hotel" using American management methods.

Years later, the Paso Malo lagoon on the western tip of the peninsula was transformed into a canal, joining the sea to the north with Cardenas Bay to the south.

The National Planning Board was established in 1955. Together with a group of famous urbanists, it created the Varadero regulation plan. An institution to implement the plan was established in 1957. Varadero has thus become an important tourist attraction center.

On the other hand, the initial city core acquired an engineering layout that provided a level of urbanization to the land. At the entrance to the city, the wooden bridge was substituted by a modern iron and concrete bridge. In new housing structures, wood and stone were replaced by brick or cement blocks and concrete. To the south, construction of a highway took away a portion of the peninsula, encroaching over low-lying and poor natural drainage areas, at a high financial cost.

The activities associated with this impetus of urbanization resulted in wide avenues and buildings, which, although not massive, were large and tall. The core of the city, although small, was well formed and discretely covered the needs of residents and seasonal tourists, supported by its close proximity to the city of Cardenas.

Subperiod 1959-1989

This stage saw the re-emergence of construction activities and the proliferation of apartment buildings. Fishermen huts were replaced by new houses, improving the living conditions of their inhabitants. Sand was dredged from the beach during this period, which seriously affected the natural erosion process, in addition to causing other negative impacts on the coast.

In the 1970s, the population increased to 5,343 people, and area zoning by social status decreased. The central government began the study "Development Scheme for Varadero in 2000" and, at the same time, the five-year plan for the construction of new buildings and housing was approved. This study evaluated the natural potential of Varadero for tourism and contained elements for the location of numerous investments for related activities. It also contributed to the development of the peninsula based on land management criteria and the controlled exploitation of natural resources.

The "Director Plan for the Integral Development of Varadero" (referred to in the rest of this article as the “Director Plan”) was executed, and some houses located over the dunes, which were in poor shape, were demolished. In 1985, hurricane Kate impacted the peninsula, with storm surges, floods, and significant damage, although the consequences were not as serious as in 1933.

Period 1990-1998

This period began with a program for the intense development of Varadero by using Cuban and foreign capital available for investment. Seventeen new hotels were operating by 1995, and the structure of settlements on urbanized islets had been transformed in only 5 years (Fig. 6). The Housing Regulation Law was enacted, and this meant that any new development had to translate into better living conditions for residents as a result of new employment opportunities and the construction of new houses and hotels.

Fig. 6. Urban transformation between 1990 and 1998.

This investment in development was carried out in parallel with improvement of environmental conditions throughout the country through better environmental management. The Beach Management Office was created and assumed a leading role in preserving the beach as the place for tourism development and recreation, the driving force of the urbanization process in the area. This office started and continues to maintain a program aimed at preserving the environment, the land, and the sustainability of the development process in the area. The period witnessed an increase in electricity and water use, associated with more tourism and, in particular, the construction of a golf course. Measures to minimize the impact were taken based on prior investment studies.

During this period, hurricanes Lily and George caused moderate damage.

Toward the end of the period, most of the investment benefiting the beach was undertaken by the Beach Office, with the addition of one million cubic meters of sand, with very favorable results for beach conservation and the rescue of areas lost to erosion processes in recent years.

Period 1998 - The Present

Intense promotion of tourism in the area has continued, resulting in 15,000 rooms visited by over 600,000 foreign tourists each year. Also noticeable has been an increase in the number of national tourists mainly during the summer months.

At the same time, the application of environmental policies continues in response to the improved environmental awareness that has peaked in the previous period. For example, the Beach Management Program applies concepts, principles, and experiences of integrated coastal management and sustainable development. In addition, the program works for the conservation, rescue, and sustainability of the beach. Other examples of more frequent and complete application of the environmental dimension in the area include the creation of an Ecological Reserve in the northern part of the peninsula, an area dedicated to planned and regulated natural tourism. The Center for Environmental Services, the institution responsible for this type of services in the area, is also located there.

Environmental management and control activities in the province have also achieved a superior level of execution, directly reflected in the results of the management and control of the tourist resort. Taking advantage of the potential afforded by the environment has enabled a better level of architectural development (Fig. 7).

Fig. 7. Hotel Meliá Varadero. Its petal shape takes advantage of the various directions of the wind for natural cooling. The central atrium acts as a "chimney" expelling the warm air. The walls around the atrium are covered by hanging vegetation to absorb heat in the evapotranspiration process. Fresh air passes through the doors of the petals, resulting in comfortable temperatures during most of the year. *(Source: CIGET)*

The development achieved by the Director Plan is proof of the close relationship between investment processes and caring for the environment. The application of an integrated analysis and the use of novel techniques and tools guarantee the sustainability of Varadero.

In 2001, hurricane Michelle crossed the province. Winds recorded in Varadero topped 100 km/h. There was damage to buildings and infrastructure, fallen trees, intense beach erosion, deterioration of electric and water services, as well as other minor impacts. The integrated efforts of the weather service, civil defense, government, numerous organizations, and the public at large prevented this hurricane (the strongest in the last 50 years to 2001) from causing even more damage or the loss of human lives.

Currently, more foreign and local tourists are visiting the beach. This increase in tourism has resulted in the overexploitation of some beach sections where, occasionally, the carrying capacity of the ecosystem is exceeded. During these periods, peaks of more than 60,000 tourists have been identified. An additional effect of this large seasonal population is the significant, but not critical, increase in the use of water and electricity.

On the other hand, the technology used for cleaning the beach is not the most appropriate, and it favors wind, water, and laminar erosion, by causing the sand to be less compact and more brittle.

In addition, ENERGAS started operations, a plant that takes the residues from oil extraction processes and converts them into electric energy and raw material for other industrial activities. The energy produced satisfies the demand for electricity of the resort and favors other activities with the supply of natural gas, a less polluting fuel.

Finally, studies of environmental global change in the resort commenced, based on a first approach to climate change in the area and the development of research projects aimed at reducing vulnerabilities and improving adaptation to expected changes.

Perspectives for future development

In the future, Varadero is expected to develop on the basis of the scientific and technical application of sustainability principles.

The new development area is located on the northern-most section of the peninsula, and growth is expected to top 25,000 rooms and one million tourists per year (Cabrera 2000), which would result in a positive impact from increased income for the area and the creation of new jobs. Forecasts call for an increase in constructed surface, which, in turn, will result in loss of green cover. One way to attenuate this outcome is to establish garden areas alternating with new buildings.

Water and electricity use will continue to increase, as well as the amount of waste associated with tourist activities.

Future development of the beach, prioritizing its conservation, is already a reality that will achieve superior execution levels with the inclusion of novel technological concepts and tools of integrated coastal management. Sustainability criteria are well rooted, to the point that one mid-term objective is the promotion of architecture in harmony with the environment.

Future Climate Scenarios

The sufficiently long absence of a series of weather measurements in the study area hinders a local assessment of the effects of global warming, but some manifestations have been observed to show a trend in that direction, and some results at a larger scale, including the island of Cuba, are available. For example, anomalies have been identified in the behavior of some weather variables, mainly temperature and precipitation. Despite the fact that these variables do not represent an integral change in climate conditions, they do reveal a variation in the trend of normal weather behavior (Centelles 1999). In the first case, the values of temperatures in the early morning hours have shown an increase in recent years and a decrease in the daily thermal amplitude.

On the other hand, the multiannual analysis of precipitation shows an increase in accumulated values for the period known as "less rainy," mainly associated with winter in the northern hemisphere, as well as a decrease in accumulated values in the rainy period that coincides with summer in the said hemisphere. Variations to the rainfall regime are associated with an increase in the frequency of occurrence of positive phase ENSO phenomena (El Niño or ENSO). The analysis shows an increase in the occurrence and intensity of drought events.

In summary, a warmer period is observed for the last decade, with an increase in mean temperatures between 0.4°C and 0.6 °C and a decrease in daytime thermal amplitude, as well as an increase in the accumulated values of rainfall in the less rainy period and higher occurrence of droughts.

There is great uncertainty regarding the future evolution of climate in the area. Among others, the following conditions are considered (Moya 2001, 2003)

- Higher temperatures
- Sea level rise
- Higher frequency and intensity of droughts
- Intense precipitation events
- Increased intensity and occurrence of tropical and subtropical storms

The IPCC models are not exempt from these uncertainties (UNFCC 2001, Moya 2002 in IHDW), as they show variations in climate behavior, mainly in temperature, and higher mean sea levels in future years.

Using the models of the First Communication by Cuba to the United Nations Framework Convention on Climate Change (UNFCCC), the simple climate model MAGICC and the scenario generator SCENGEN were applied; scenarios IS92a and KYOTOA1 were obtained for projections of global warming and increased mean sea level for the various climate sensibility options (1.5 °C, 2.5 °C, and 4.5 °C). Part of the results of the model can be seen in the following tables (Tables 1–3), representing the expected values of temperature increases over the year 1990, for 2010, 2030, 2050, 2080, and 2100.

Table 1. Global Warming and Increased Sea Levels for Low, Medium, and High Climate Sensibility, Based on Emission Scenarios IS92a and KYOTOA1 in Selected Years

Emiss. Scen.	Clim. Sens.	Global Warming (°C)				Sea Level Rise (cm)			
		2010	2030	2050	2100	2010	2030	2050	2100
IS92a	Low	0.34	0.63	0.96	1.72	1.68	4.68	8.87	22.79
	Med.	0.47	0.90	1.38	2.52	4.85	12.63	23.30	55.20
	High	0.65	1.25	1.94	3.63	10.17	25.90	44.41	95.93
KYOTOA1	Low	0.32	0.58	0.87	1.53	1.60	4.28	8.01	20.22
	Med.	0.45	0.83	1.25	2.25	4.71	11.91	21.63	50.28
	High	0.61	1.15	1.77	3.26	9.93	24.70	42.2	89.67

Source: First Communication by Cuba to UNFCCC
Emiss. Scen.: Emission Scenario
Clim. Sens.: Climate Sensibility

Other models differ in the magnitude of changes, but they also report variations.

The information resulting from scenarios GSA2 2 is shown in Tables 2 and 3, with expected values for the years 2020 and 2080 in mean temperature (Tt), maximum temperature (Tx), and minimum temperature (Tn), in °C; precipitation, in mm; and solar radiation, in W/M**2. The tables also show the difference (Dif.) with respect to 1990. In the case of precipitation and radiation, the difference is expressed as a percentage with respect to the 1990 value.

Table 2. Climate Scenario for 2020 (according to GSA2)

Months	Tt - °C		Tx - °C		Tn - °C		Precipitation mm.		Radiation W/M**2	
	2020s	Dif.	2020s	Dif.	2020s	Dif.	2020s	Dif.	2020s	Dif.
MAM	25,44	1,27	27,87	1,3	23,25	1,29	2,315	98,9	266,55	99
JJA	27,09	1,42	29,25	1,52	25,35	1,35	3,968	94,6	272,91	102
SON	26,17	1,45	28,42	1,5	24,42	1,37	3,409	101,7	208,52	101
DJF	23,82	1,12	26,15	1,16	21,84	1,11	2,699	101,2	169,9	100
ANN	25,63	1,31	27,92	1,37	23,71	1,28	3,097	98,7	229,47	100

Source: Mean, maximum, and minimum temperature, precipitation, and radiation; taken from IHDW 2002.

MAM = March, April, May
JJA = June, July, August
SON= September, October, November
DJF = December, January, February
ANN = Annual

Table 3. Climate Scenario for 2080.

Month	Tt - °C		Tx - °C		Tn - °C		Precipitation mm.		Radiation W/M**2	
	2080s	Dif	2080s	Dif	2080s	Dif	2080s	Dif.	2080s	Dif.
MAM	32,02	4,54	35,86	4,64	29,03	4,5	3,509	90,7	267,06	102
JJA	30,04	4,34	33,31	4,55	27,74	4,17	4,186	82,1	250,53	104
SON	30,73	4,16	33,9	4,25	28,44	4,15	5,433	100,7	237,77	101
DJF	32,41	4,33	36,08	4,42	29,17	4,51	2,863	102,6	238,16	99
ANN	31,3	4,34	34,79	4,47	28,6	4,34	3,998	93,2	248,38	101

Source: Mean, maximum, and minimum temperature, precipitation, and radiation; taken from IHDW 2002.

MAM = March, April, May
JJA = June, July, August
SON= September, October, November
DJF = December, January, February
ANN = Annual

When considering climate variability and change in Varadero, the multiannual variability of the hurricane season should be taken into consideration, with alternating periods of around 25 years of more or less tropical-storm activity in the area. The most recent of these periods began around 1995, and it is expected to be a cycle of great activity that should last approximately until the year 2022.

Although there is no evidence of the influence of climate change over cyclonic activity in the area, we should consider the impact on the occurrence and intensity of the storms, of an increase in temperatures with additional warming, more availability of heat in Caribbean waters, and this “overheating” would be reflected in two ways: First, the magnitude of this heat in the months of the cyclonic season (higher temperatures in the Caribbean Sea, the Gulf of Mexico and the Straight of Florida) and second, an increase in temperatures during the months outside the cyclonic season. These aspects may, in theory, influence the intensity of tropical storms, as well as the frequency of occurrence, considering even an extension of the season of exposure to tropical cyclones. Therefore, the periods of less activity, during which the impact of one hurricane may occur around every 25 years, could witness more cyclonic events with significant effects. The same would happen in the periods forecasted to experience greater activity. That is to say that, given the increased availability of heat in Caribbean waters, a probable situation in the context of these scenarios, the periods of less cyclonic activity would experience a transition toward moderate activity. But today we cannot speak about climate change in hurricane activity.

Another aspect to be taken into account for future climate scenarios in Varadero relates to the loss of coasts due to a rise in sea level. Since Cuba is a long and narrow island, the winds from the north coast converge with those from the south at a certain point inland. The fact that these are reinforced by the trade winds from the northeast results in this convergence occurring to the south of the center of the province. The availability of heat and water vapor and the convectivity of the area generate clouds that produce thunderstorms and precipitation over the province, which reach Varadero for short periods of time in the afternoon and at night. The loss of significant areas in the Zapata peninsula due to higher sea levels will result in the line of wind convergence shifting to the north, and this shift will have a still unpredictable impact over the area. An increase is forecasted in the exposure of Varadero to convective clouds that will form closer to the Hicacos peninsula. This change could impact the occurrence of thunderstorms, severe local storms, and precipitation in Varadero.

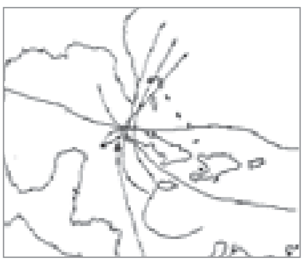
Vulnerabilities

When the physical-geographical and socio-economic aspects are analyzed, including the evolution of the urbanization process, the vulnerability of the peninsula to anthropogenic and natural impacts becomes evident.

The natural vulnerability of the system includes its location and geomorphology very close to the North American continent and the subtropical area, its narrow shape slightly less than 2 km wide at its widest point; its southwest–northeast orientation, as well as the surface amplitude of the sandy foundation, with an edaphic cover that is not well developed; and the prevalence of extreme drought conditions and an unfavorable water balance, with a deficit of over 1,000 mm per year. The relief is flat, low altitude, with young landscapes, exposed to tropical and subtropical storms and a strong and persistent influence of winds.

All of the above shows that these are unstable landscapes and, therefore, very fragile and susceptible to the impacts of nature and man. Therein lies the natural vulnerability of the system (Fig. 8).

a)


b)


c)


Fig. 8. Natural vulnerability of the peninsula.
a) Exposure to subtropical storms, strong winds, and marine and wind erosion. *(Source OMP).*
b) Exposure to tropical storms. *(Source CMP).*
c) Low-altitude landscape above sea level, exposure to sea water penetration and high salinity, drought conditions, and scarce edaphic cover.
(Source: Dr. Paul Geerders)

It is necessary to consider some other aspects as part of urbanization and tourist exploitation, given their effect on land vulnerability. Among the most relevant are the fragmentation of ecosystems since the beginning of the urbanization process, deforestation of dunes as well as mangroves, and elimination of the native vegetation. The establishment of construction over the dune and the introduction, in some cases, of mid-latitude architecture not well adjusted to the tropical conditions that prevail over the peninsula for most of the year aggravate negative impacts to the environment. The continuous extraction of sand led to the disappearance of mangrove areas and the disturbance of the exchange of land-sea flows on the southern coast. Finally, the channeling of the Paso Malo lagoon, which transformed the peninsula into a sort of islet, with consequences on biodiversity and changes in currents, and increased water and electricity use, caused by higher numbers of tourists visiting the area, have also adversely affected the area.

In this context, the high level of stress on the ecosystems from the intense anthropogenization process and the increase in population and economic interests in areas at risk of flooding, increased the fragility, susceptibility, and exposure, with lower resistance and capacity for recovery of the ecosystems of the peninsula (Fig. 9).

a)  b) 

c) 

Fig. 9. Contribution to vulnerability during the urbanization process.
a) Houses imported from high and mid latitudes with high-energy consumption;
b) constructions over the dune; and
c) increases in population and economic interests in flood areas, deforestation, and destruction of dunes.
(Source: OMP)

Other vulnerabilities are associated with climate change and the level of knowledge and information of the population, decision makers, and the scientific community. There is uncertainty regarding what will happen with global warming, what the response of the atmosphere will be, what the impacts of climate change will be, and what effects climate change will have over the environment, society, and the economy. In addition, some unkown aspects of beach dynamics, transportation of sediments, accumulation processes, etc., are pending study and discussion.

Impacts and Effects

Variations in climate behavior involving the natural variability of the system and human contributions will result in a series of impacts and effects on the peninsula. Potential impacts include the following:

- Effects on marine species from warmer waters and changes in coastal ecosystems. Some examples are evident, such as the algae colony in Cárdenas Bay, which has been exposed to high levels of stress, and a decrease in the population has been confirmed, mainly due to pollution in the bay. Warmer waters, together with a decrease in nutrients, will cause an added effect on the stressed community of algae, which may disappear depending on the magnitude of the change. The algae in this colony decisively contributed to the sand formation process on Varadero beach. Upon their disappearance, this process will be altered to an extent that is yet impossible to predict.

- Loss of space from marine invasion. The rise in sea levels will result in invasion of lower areas by the sea (Table 4).

Table 4. Loss of Coastline on Varadero Beaches for 2030 and 2050 (see Table 1 for rise in sea level)

Beaches	Loss of Coastline by 2030 (m)	Loss of Coastline by 2050 (m)
Las Américas	4.59	8.33
Caney	6.09	11.05
Cosmonautas	8.97	16.28

Source: Climate Change in Varadero Research Project. Vulnerability, impacts, and adaptation and First Communication by Cuba to UNFCCC.

- Damage to human settlements from loss of spaces, sea penetration, and flooding. Human settlements in areas of forecasted marine invasion should be relocated.

- Effects on water resources due to overexploitation and the probability of being affected by saline intrusion and greater exposure to the salinization of cultivated soils nearby. The overexploitation to which the current sources of supply are subject, plus the marked water deficit of the area, will favor a lowering of the phreatic mantle. This effect, coupled with the rise in sea level and the location of the coast in a very flat area, increases the possibility of saline intrusion on the sources of fresh water. At the same time, crops planted in low areas located between the coast and the supply source will be further exposed to salinization.

- Loss of tourism potential due to higher temperatures and loss of beach area (receiver/ emitter). An increase in temperatures will affect the thermal cycle of the resort area, which in turn will impact comfort levels, particularly for tourists from high and mid latitudes. Another aspect to be taken into consideration is higher temperatures in the areas where tourists come from—in the case of Varadero, mainly Europeans and Canadians trying to get away from the severe cold of the winter months in the northern hemisphere.

- Increases in the processes associated with beach erosion.

- Increased exposure to storms. Climate variability phenomena, including higher incidence of tropical storms in the Atlantic and the Caribbean, more frequent occurrence of ENSO events with their impact on the area, result in more severe effects for the island of Cuba from tropical cyclones in one case and subtropical storms in the other. Changes in the frequency and intensity of thunderstorms and severe local storms are likely, due to changes in the location of the winds' line of convergence. Loss of spaces on the north and south coasts of the province (very sensitive on the southern coast) due to the rise in sea levels causes a movement in the line of convergence of the winds, which will trigger a variation in climate behavior throughout the province.

- Changes in the environmental conditions for the development of pathogens. Variations in temperature and humidity, as well as transformation of the environment, could favor the appearance of pathogens or increases in the population of transmission vectors, which will be reflected in the incidence of diseases (morbidity). See Fig. 10.

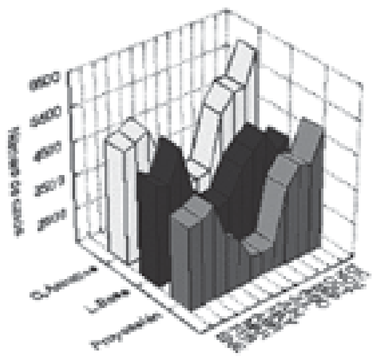


Fig. 10. Behavior of bronchial asthma in Cuba for 2010, as related to the baseline (1961–1990) and the current conditions. *(Courtesy of Dr. Paulo Ortiz Bultó)*

- Increased risk of human and economic losses. The greater probability of extreme weather events, despite the development and effectiveness shown by the civil defense system, represents an additional hazard which, added to the vulnerability, increases the risk of damage and the threat to human lives, the economy, and the environment.

Adaptation

The vulnerability of the area and the irreversibility of climate change and its effects on the environment, as well as the socio-economic and environmental evolution of the resort, and the need to protect human lives above all and then the economic, natural, and social wealth are the elements that justify and urge the development of an adaptation strategy to future scenarios.

The first step includes creating a program that contains adaptation measures and mechanisms for implementation and monitoring of application and results. This program of measures should be developed in an integrated manner and include the criteria of scientists, specialists, and decision makers, as well as physical planning, beach management, tourism, and other economic activities, health, architecture, landscaping, ecology, government, and the population.

The program should provide guidelines for recovery, accomodation, and protection. For recovery, the guidelines should aim at abandoning certain activities and spaces; for adaptation, they should describe measures that would allow for the presence of new scenarios and their impacts; and for protection, they should aim at diminishing vulnerabilities through a stronger defense of the area.

Examples of recovery measures could include

1. Demolition of construction over the dune, respecting the patrimonial value of the settlement and resettlements of the population (it is also a protection measure). This measure avoids the exposure of buildings on the dune to sea penetration and even direct contact with it, when the erosive process has been intense and houses are destroyed by the invasion of the sea, which on the north coast is associated with the arrival of cold fronts from the North American continent. It also protects the dune by diminishing erosion and strengthens beach defense as appropriate.

2. Gradual reduction of population and economic interests in areas susceptible to flooding. This measure reduces exposure of the population to floods and sea penetration in areas of risk.

Accomodation measures could include

1. Diversification of the type of tourism offered. Given the reduction in tourism associated with the beach and the need to maintain the economic income resulting from tourism, other offers, less dependent on the beach, should be made available, including outdoors activities. Among them are the following: cultural, learning, and historical activities, as well as explorations of nature (Fig. 11).

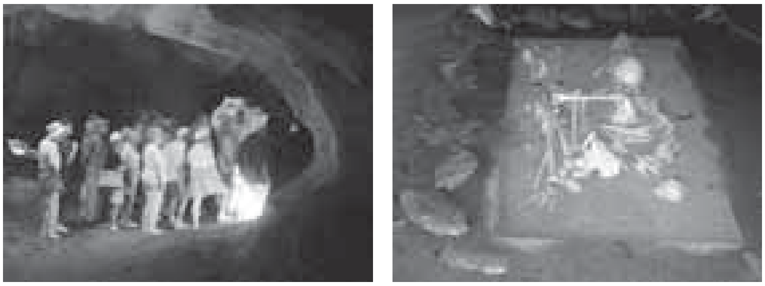


Fig. 11. Example of the potential for archaeological tourism in the area. *(Source: CISAM)*

2. Regulation of water use (protection). The overexploitation of water sources requires preservation of the resources for future scenarios. Therefore, measures to regulate consumption, higher prices, reutilization of irrigation waters, etc., would favor the rational exploitation of water resources.

3. Integrated coastal management. The application of integrated coastal management measures, expressed in beach management, will serve as the framework for application of the adaptation measures that will enable less traumatic adaptation to future scenarios.

4. Development of architecture more in harmony with the environment. Architectural designs in harmony with the environment may allow mitigation of the impacts of change. For example, well ventilated houses would mitigate the effects of higher temperatures; weather-resistant buildings would afford protection against strong storms, floods, and higher temperatures and savings in electricity and water.

5. Maintaining of the civil defense system. Civil defense guarantees care for the population and protection of goods. The system developed in the country has yielded good results by significantly reducing the loss of human lives to weather events and safeguarding property. Continued correct application of this system favors facing environmental changes.

6. Improvement of the meteorological services and early warnings.

Protection measures include

1. Reforestation of dunes. Sowing and reforestation of dunes favor retaining the sand and protecting it from the action of winds and even water, thereby reducing the erosion process.

2. Rescue of native vegetation. Native vegetation has adapted to the particular conditions of dryness, salinity, and edaphic cover and is therefore less vulnerable to the conditions of the land that has achieved an ecological balance with the surrounding area.

3. Rescue of mangroves. Mangroves play an important role in the defense against global environmental change, from acting as habitat for various species to protecting the coast against sea penetration.

4. Replenishing and maintaining of the beach. Affectation of the beach resulting from anthropogenic activities has favored erosion and requires replenishing and maintaining the sand in order to guarantee minimum erosion levels. The application of new beach cleaning mechanisms, using lower impact techniques, will protect the beach against wind and water damage. Together with other beach maintenance and care measures, new beach cleaning mechanisms will improve the defense against rising sea levels and sea penetration and will afford some protection against flooding.

5. Preservation of natural areas under some category of protection. Preserved natural areas under some protection regime will allow a more controlled development of integrated management plans for the conservation of these natural spaces and will favor their protection mechanisms against natural and human impacts.

6. Regulation of the carrying capacity of the beach. Using beach areas over and above their carrying capacity has harmful direct effects on sand compacting and facilitates erosion processes in these areas.

7. A flexible Director Plan that will accept adaptation measures to GCC. The Director Plan, governing over the tourist resort and enriched in recent years with sustainability criteria, should include the adaptation program. This program should be monitored and improved as application results are obtained. This measure will render the Director Plan applicable and functional.

Conclusions

The physical-geographical conditions of the peninsula make it an area vulnerable to global environmental change. The conditions of extreme dryness, high salinity, strong and persistent influence of winds, and scanty development of the edaphic cover; the predominance of a flat relief and its shape closely associated with land-sea interaction processes; and the low altitude above sea level make the area more fragile and susceptible to human and natural impacts. The geographic location of the peninsula also aggravates exposure to severe tropical and subtropical cyclones. Therein lies the natural vulnerability of the system.

The intense anthropogenization process underway in this area since the late 19th century has accentuated the vulnerability of the land. Construction and deforestation of the dunes; construction of the Paso Malo canal, the South Highway, and the golf course; the introduction of architecture imported from other latitudes, the development of urban settlements; and economic interests in areas at risk of floods and sea penetration are some of the causes that help explain the vulnerability of Varadero to weather events.

Slow growth and aging of the population are other important conditions to be taken into consideration, as they increase social vulnerability.

The high cultural level of the population, the quality of medical care available to the population, and the civil defense system, offer an advantage to the population in this area in the fight against climate change.

The climate over the land, according to the models, will have variable scenarios that may include periods with more tropical storm activity in the area.

Varadero faces a series of social, economic, and environmental impacts that represent an unavoidable challenge. This situation requires the development of an adaptation strategy to face future scenarios, as well as current natural and anthropogenic hazards. This adaptation strategy must be integrated and holistic, with an approach to problems that includes solutions and measures to be taken by all decision makers, sectors, stakeholders, and the public at large.

References

Alfonso, A., and Florido, A. 1992. *El Clima de Matanzas*. Editorial Academia, Matanzas, Cuba. 124 pp.

Cabrera, A. 1999. *Los Paisajes Geográficos de la Península de Hicacos: Una Visión Integrada de la Naturaleza y las Geotransformaciones Humanas*. Havana, Cuba.

Cabrera, A. 2000. *Política de Desarrollo de Varadero*. Capítulo Medioambiente. Ministerio de Turismo, Varadero, Cuba.

CESIGMA SA (Oficina de Inversiones Varadero—Varadero Office of Beach Management). 1998. *Diagnóstico de Playa Varadero.* Varadero, Cuba.

Centelles, A. 1999. *Climate Change and Impacts.* National Climatology Conference, Ciego de Ávila, Cuba.

IHDW (International Human Dimensions Workshop). 2002. *Urbanisation and the Transition to Sustainability*. Bonn, Germany. June 2–15, 2002. International Human Dimensions Programme. (Available at: http://www.ihdp.uni-bonn.de/ihdw02/index.htm).

Moya, B. 2001. *Clima y Turismo.* National Climate Center conference. Institute of Meteorology, Havana, Cuba.

Moya, B. 2002. *Climate Change in Varadero, a Prime Tourist Destination of the Caribbean*. Presentation at IHDW 2002, Bonn, Germany.

Moya, B. 2003. *Uso del Recurso Natural Clima para el Manejo Integrado del Turismo en Varadero.* Master's thesis, University of Matanzas, Matanzas, Cuba.

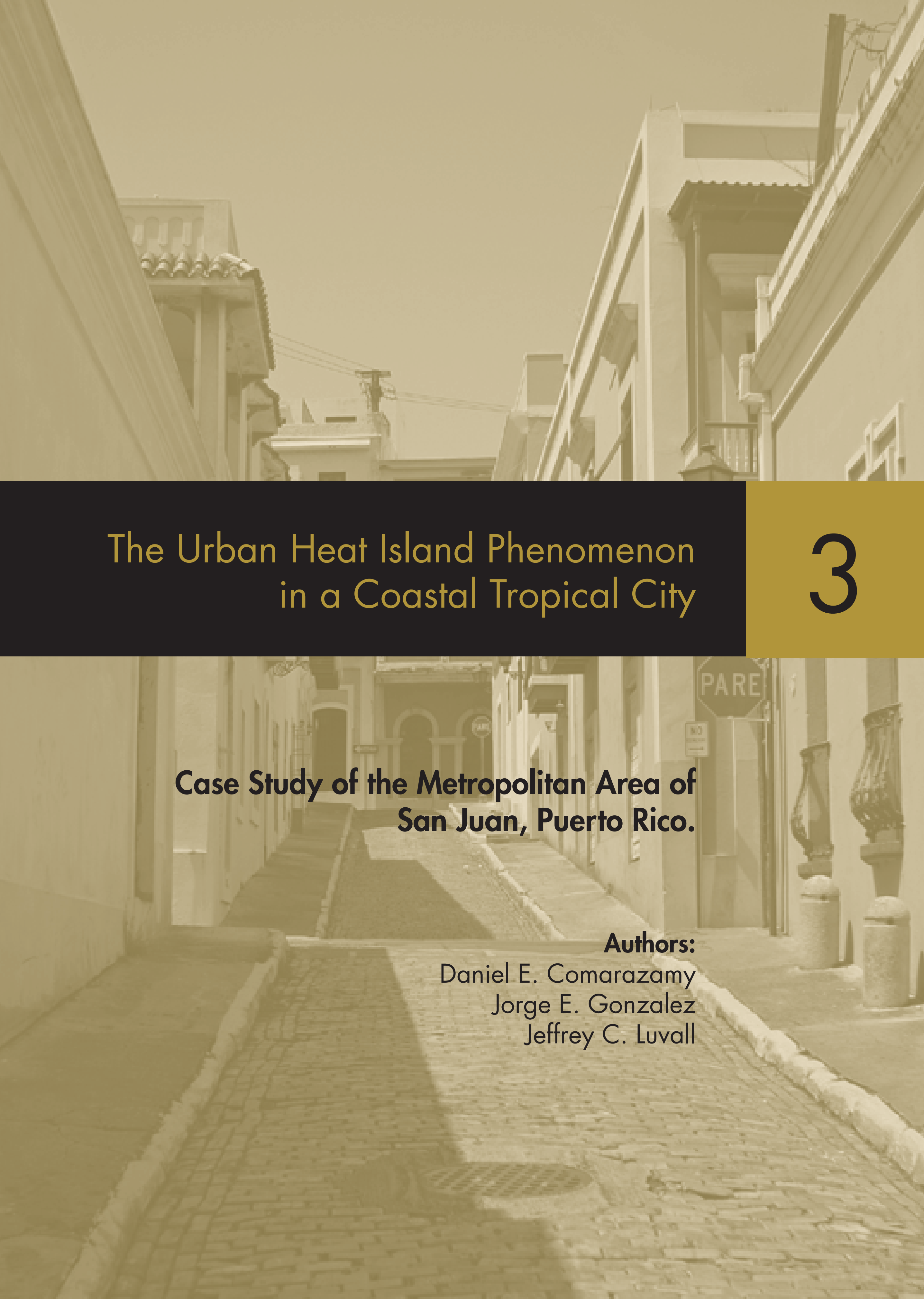
ONE (Oficina Nacional de Estadísticas—National Statistics Office). 1995. *Memorias, Censo de Población y Viviendas de Varadero* (Population Census in Varadero). Provincial Office of Matanzas, Havana, Cuba.

Ortiz, P., Guevara, V., Pérez, A., and Díaz, M. 1998. *A Bioclimatic Index to Evaluate the Impacts of Climate Change on Health*. Research Report. Institute of Meteorology, Havana, Cuba.

Rojo, J. 1998. *El Desarrollo Urbanístico del Antiguo Poblado de Varadero y su Papel como Segundo Polo Turístico en Cuba*. IVth International conference on urbanism, Havana, Cuba.

Rojo, J. 1999. *Reflexiones Acerca de los Códigos Urbano—Arquitectónicos y Ambientales en el Varadero Histórico.* International meeting on territorial planning for tourism. Havana, Cuba.

Government of Cuba 2001. *First National Communication to the United Nations Framework Convention on Climate Change (UNFCCC).* Havana, Cuba.



The Urban Heat Island Phenomenon in a Coastal Tropical City

3

Case Study of the Metropolitan Area of San Juan, Puerto Rico.

Authors:
Daniel E. Comarazamy
Jorge E. Gonzalez
Jeffrey C. Luvall

Ground-based weather stations and temperature sensors were deployed in strategic locations during the Atlas Mission experimental campaign in the San Juan metropolitan area and its surroundings in order to observe climate variations in urban and rural landscapes.

Time series plots of station and sensor data show that heavily urbanized commercial areas (with greater density of concrete and other building materials) have higher air temperatures than urban and suburban residential areas and much higher temperatures than rural areas.

Temperature differences [dT(U – R)] were obtained by subtracting the values of several stations/sensors from a reference urban station, located in the commercial area of San Juan. Time series of dT(U – R) show that the urban heat island (UHI) peaks in the morning, between 10:00 a.m. and noon, to an average difference of 4.5°C between the city and the rural areas. This temporal pattern has not been previously observed in similar studies for continental cities. A high variability between UHI and precipitation patterns has also been observed, even for short events. These results prove that a large land-use density by low buildings features an evident absence of the significant effects of heat storage in urban areas, while highlighting the importance of the surrounding soil and vegetation moisture in controlling the urban tropical climate.

Presented in this article are results of a numerical analysis carried out to quantify the impact of land use and vegetation in cities on various atmospheric variables and to study the reaction of the atmosphere in the presence of an important urban center.

Introduction

It is difficult to conceive that cities in small tropical islands are not exempt from local climate-change events similar to those in large continental cities. Let us imagine, for instance, the tempestuous Honolulu in the Hawaiian Archipelago showing warming tendencies similar to those in Los Angeles or Mexico City.

We have been recently astounded to discover this to be the case of San Juan, Puerto Rico, an affluent tropical coastal city of nearly 2 million people that is growing rapidly and occupying areas that were once rural. Until a few years ago, the forest area close to the metropolitan area of San Juan was recovering from past felling of trees. However, the rapid expansion of the urban area has resulted in the loss of a significant area that had been reforested in recent years. A climatological analysis has revealed that surface temperature has increased over San Juan's surrounding vegetation-covered areas at a rate of 0.06 °C per year for the past 30 years, a trend comparable to other regional climate changes induced by global warming.

These results encouraged the planning and execution of an intense experimental campaign, the Atlas San Juan Mission, in February 2004. The main scientific objective was to research the impact of rapid urbanization over local climate and included remote sensing observations from an airplane, release of weather balloons and data from a weather station, and air temperature sensor network deployed in the urban landscape and its surroundings.

This chapter focuses on the information provided by ground-based sensors during the Atlas San Juan Mission and on the results of simulations conducted with the help of a numerical model of the atmosphere, which show the impact of the San Juan metropolitan area on the different variables of local climate.

Urbanization and UHI

Urbanization is an extreme case of change in land use. Although currently only 1.2% of the Earth's surface is urban, it contains half of its population, with an increasing trend in spatial coverage and density. It is estimated that by 2025, 60% of the world's population will live in cities (UNFP 1999). Human activities in urban environments have local impacts, including changes in the composition of the atmosphere, effects over water cycle components and modifications to ecosystems. Although our understanding of urbanization within the complete Earth-climate system is incomplete, it is important to determine how Earth's atmosphere-ocean-land-biosphere components interact in an interdependent system. The clearest local indicator of climate change resulting from urbanization is the urban/rural convective circulation known as UHI.

UHI is defined as the dome of elevated temperatures observed over urban centers compared with cooler temperatures in rural surroundings (Fig. 1). These contrasts in temperature are larger in clear and calm conditions and tend to disappear in cloudy and windy weather because of thermal and mechanical mixing effects.

Some of the factors fostering the formation of a heat island include the intensive use of various construction materials, mainly concrete and asphalt, although metals and glass also have an effect. These materials have a much higher thermal inertia than natural vegetation-covered surfaces, resulting in large differences in temperature during the first several hours of the night, when all the energy stored during daylight is released into the lower atmosphere over cities.

The balance of energy is significantly affected, as evidenced by the following: a decrease of reflected solar radiation and an increase of emitted infrared energy, decreased flow of latent heat into the atmosphere and increased flow of sensitive heat, increased heat storage in surfaces and obstacles (such as buildings), and anthropogenic heat emissions added to the energy balance equation.

Paved surfaces prevent precipitation from entering the soil and subsoil, and therefore higher amounts of water running along them create a danger of possible flash floods in urban centers. As a result, less moisture is available in green areas for evapotranspiration, a natural phenomenon with a radiative air-cooling effect.

Another not fully understood effect is caused by tall, vertical surfaces and other geometric shapes of the urban landscape that create what is known as the canyon effect. In the spaces between buildings, long-wave radiation emitted by the surface at night is reflected and absorbed by the walls, resulting in trapped energy and higher temperatures. The urban topography also interrupts wind flows and results in decreased heat loss.

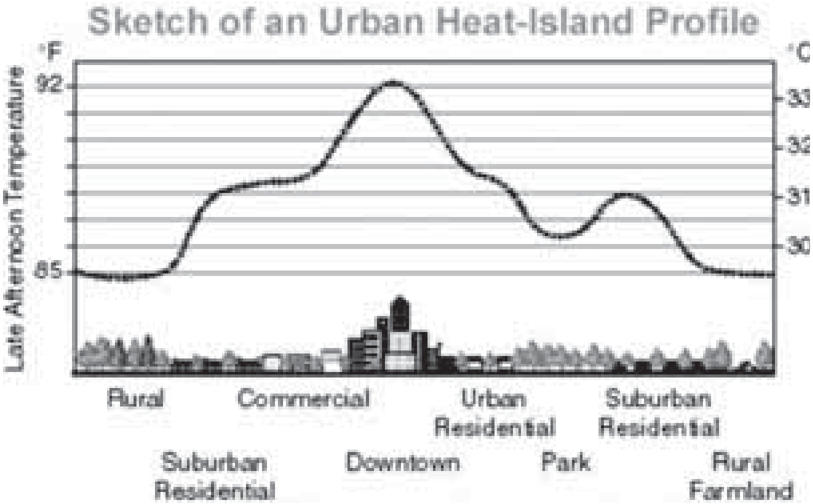


Fig.1. Profile of temperatures typically observed in the large urban centers of the planet. *(Courtesy of Lawrence Berkeley National Laboratory, Berkeley, CA)*

Some of the problems and hazards resulting from a UHI include the following: poor air quality, mainly caused by industry and residual combustion gases; protracted and more-intense heat waves in the cities, hazardous to public health; and high energy use due to increased demand for air conditioning. This high energy use, in turn, contributes to global warming from the power plants that produce it. It is estimated that each kilowatt hour of electricity used can produce up to 1.15 kilograms of carbon dioxide (CO_2), the anthropogenic gas that most significantly contributes to the greenhouse gas effect and global warming (Source: Oak Ridge National Laboratory).

UHI effects of different magnitudes have been reported by several authors for a significant number of cities (Landsberg 1981, Tso 1996, Jáuregui 1997, Gallo et al. 1993, Lo et al. 1997, Bornstein & Lin 2000, Noto 1996, Poreh 1996). Although each city is exposed to different local and synoptic factors that make the study of UHI complex and specific to each site, the general pattern is common to all.

Several experimental and climatological studies have concluded that UHI may have a significant influence on mesoscale circulation and the resulting convection. Heat-island-induced precipitation is an important effect recently being studied for cities around the world.

Past studies have suggested three main factors as possible causes for anomalies in the patterns of precipitation induced by urban centers: mechanical mixing and turbulence as a result of the more rugged surface (z_o) of urban topography; the addition of sensible heat from ascending warm air in the city; and the condensation nuclei of anthropogenic clouds floating in the urban air. It has also been observed that cities, depending on the characteristics of the storms approaching them, tend to split the precipitation systems because of the barrier effect of the buildings. This type of research has been carried out in major cities, including Houston (Shepherd & Burian 2003), Mexico City (Jáuregui & Romales 1996), and Atlanta and New York (Bornstein & Lin 2000).

Research of the impact of changes in soil cover and land use in tropical regions has been limited, and the San Juan field campaign was designed to satisfy the need for this knowledge.

As mentioned previously, the case study of UHI in a coastal tropical city was developed in San Juan, Puerto Rico. The analysis of the characteristics and patterns of UHI consisted of an empirical analysis of the observations and a numerical analysis.

The empirical analysis was based on data obtained over 40 years from existing ground-based weather stations in the San Juan metropolitan area (SJMA) and on data from new weather stations and sensors deployed during the Atlas Mission Campaign. For the numerical analysis, a regional-scale atmospheric model was validated and configured based on the characteristics of the area of interest, and several simulation experiments were designed around the SJMA.

Empirical Analysis

The main objectives of the empirical analysis were to determine the geographic extension of the SJMA and its effect on the environment; to corroborate the existence of a UHI centered over the city of San Juan; and to recognize the typical and determinant features of the UHI in the SJMA.

In order to accomplish the first objective, an aerial photograph of the SJMA taken by the NASA Ames Research Center, California (Fig. 2), in 1993 was used. From this image, the total extension of San Juan was determined to be 310 km^2 for the time the picture was taken, and this information was very useful in designing the numerical simulations to be described below. It is estimated that the area of urban coverage has grown significantly in the last 10 years, and part of the work of the Atlas Mission was to determine its current size.

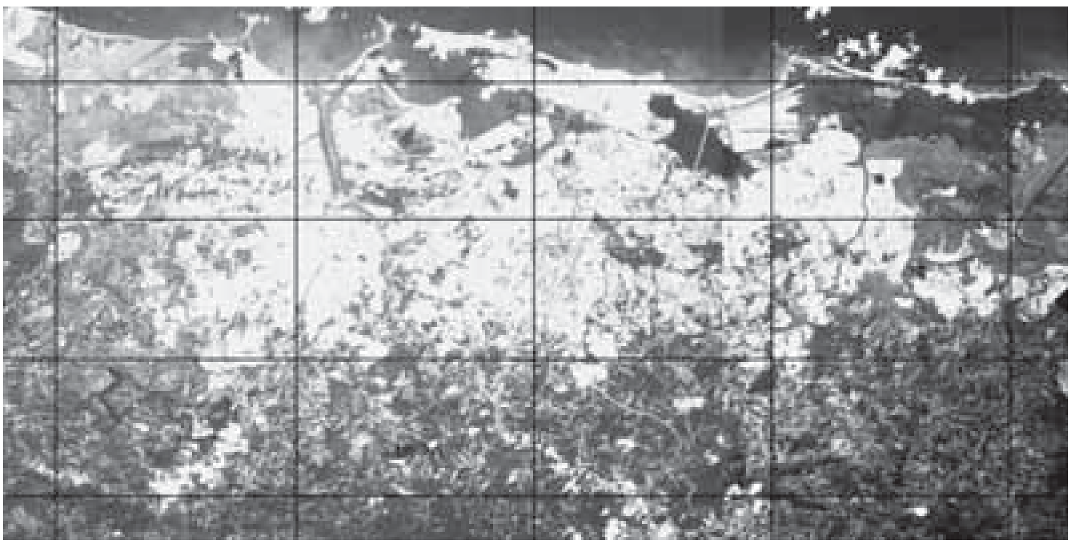


Fig. 2. Aerial photograph of the metropolitan area of San Juan, Puerto Rico, on 11 December 1993.

A climatological analysis of air temperatures at 2 meters above ground level was carried out, based on data from four stations: two were located in the urban area and two in the rural surroundings west of the city. Variations in temperature were analyzed by calculating the differences in daily averages of minimum, maximum, and average values in the urban stations and in the rural stations. Figure 3 shows the results of this exercise, as well as a linear projection into the future, until the middle of this century.

The consistent presence of positive values is a simple and clear indication that temperatures in the city are higher than temperatures in rural areas. The positive curve of the linear regression indicates that this difference could intensify if past and current conditions prevail in the absence of adequate mitigation and urban development policies.

Figure 4 shows the annual pattern of temperature differences calculated in the previous step. It is evident that the largest differences occur during the early months, which are also the driest months, known as the early rainy season in the Caribbean, when convective activity is considerably less than during the late rainy season (Daly et al. 2003, Malmgren & Winter 1999, Taylor et al. 2002). These results agree to those of other studies reporting that UHIs are more intense in stable and calm atmospheric conditions.

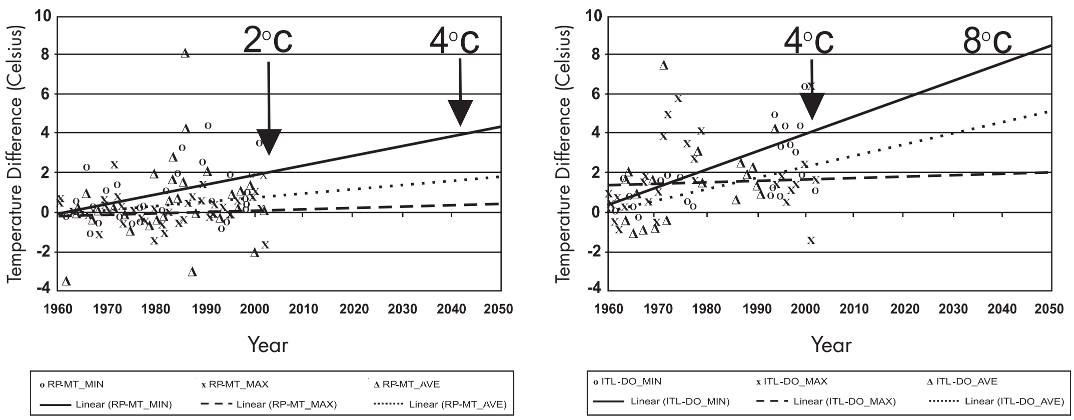


Fig. 3. Daily average by year (for the last 40 years) of minimum, maximum, and average temperature values, in urban and rural locations of the northern coast of the island of Puerto Rico. The solid, broken, and dotted lines represent the projections for minimum, maximum, and average temperatures, respectively.

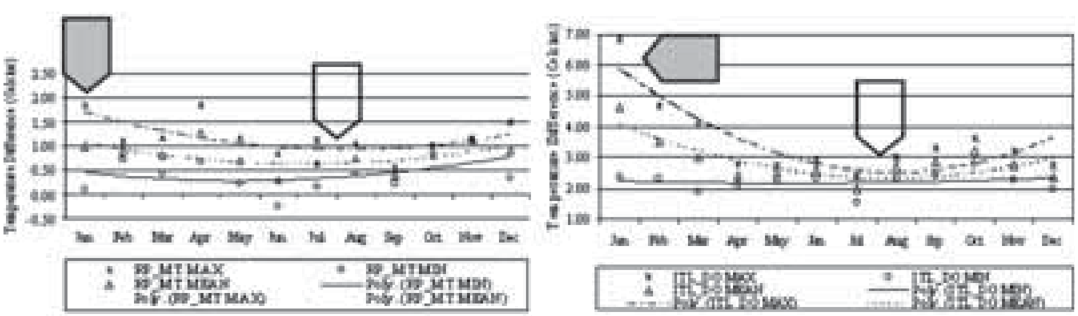


Fig. 4. Annual climatological pattern of temperature differences between urban and rural stations on the northern coast of the island of Puerto Rico.

The results of the climatological analysis verify the existence of a UHI over the SJMA and motivated the development of more-extensive experimental campaigns to determine characteristics and patterns of the UHI that are more specific to San Juan.

Description of the Atlas Mission

The Airborne Thermal and Land Applications Sensor (ATLAS) from NASA/Stennis operates in the visual and infrared (IR) bands. ATLAS is able to sense 15 multispectral radiation channels across the thermal–near IR–visible spectrums. The sensor also incorporates onboard, active calibration sources for all bands. The data must be corrected for atmospheric radiation and must be georectified before analysis. The sensor also operates a 9-inch Zeiss camera for high-resolution photographic work. This ATLAS sensor has been used in other field campaigns to investigate UHI in Atlanta, Salt Lake City, Baton Rouge, and Sacramento, all in the continental United States (Luvall et al. 2005).

The San Juan, Puerto Rico, ATLAS mission was conducted during February 2004 to investigate the impact of the urban landscape and growth on the climate of this tropical city. The flight plan for the mission covered the San Juan metropolitan area, the Yunque National Forest east of San Juan, the city of Mayagüez west of San Juan, and the Arecibo Observatory on the central north coast, for a total of 25 flight lines. The central area of San Juan was covered at 5 m in resolution during day and night flights. The remaining areas were covered at 10 m in resolution. The flights were conducted between February 11 and 16, 2004, in order to analyze the existence of a UHI in San Juan and to support the Atlas sensor data. Several experimental campaigns for data collection were designed and conducted by different teams, in addition to several numerical experiments aimed at a better understanding of the phenomenon and its characteristics.

Weather Station and Surface Sensor Data

The information obtained from balloon sounding launches and the synoptic information provided by the National Centers for Environmental Prediction (NCEP) show that, during the mission, the mid and upper atmosphere in the Caribbean was relatively dry and highly stable (not shown), an ideal condition to study UHIs.

The weather stations and temperature sensors were deployed in strategic places along lines following the climatological pattern of the northeast trade winds in order to analyze possible temperature differences between commercial, residential, and rural areas (Tables 1 and 2). Data from weather stations and temperature sensors show strong indications of a UHI in the SJMA.

Figure 5 shows the interpolated results of surface station average data at noon, recorded at selected locations throughout the SJMA and neighboring rural municipalities. It is clearly seen that the average noon temperatures during the Atlas Mission indicate a pronounced UHI, with the peak of the high temperature dome exactly over the commercial area of the center of San Juan, represented by the stations in the red area. Most of the suburban areas are located to the west of the center of San Juan, shown in green and light yellow. El Yunque tropical forest, east of San Juan, as well as the central mountains south of San Juan, continued to be fairly cool regions. An east-west cross section following the direction of the trade winds indicates the dome of elevated temperatures over the commercial center of San Juan (Fig. 6), exhibiting a profile similar to the definition of the UHI shown in Fig. 1.

Table 1. Ground Stations in the SJMA and Rural Surroundings

Station	Location	Geographical Coordinate		Variables						
		Latitude	Longitude	Temp.	HR	Wind	Precip.	Solar Rad.	Press	Soil Moist
Bayamón Station	Science Park	18º24′41″	66º09′37″	x	x	x	x	x	x	
Polytechnic Station	Hato Rey	18º25′19″	66º03′19″	x	x	x	x	x	x	
Dorado Station UPR Stations	Eco House	18º27′55″	66º19′37″	x	x	x		x		
	Río Piedras 1	18º24′08″	66º03′04″	x			x			x
	Río Piedras 2	18º24′12″	66º02′52″	x			x			x
	Río Piedras 3	18º24′14″	66º02′52″	x			x			x
Río Grande Station	Río Mar Beach Resort	18º22′44″	65º45′22″	x			x			

Table 2. HOBO Sensors		**Latitude**	**Longitude**	**Temp.**
Bayamón Sensor	Science Park – Bayamón Norte	18º24′41″	66º09′37″	x
Cupey Sensor	South Guaynabo	18º21′12″	66º05′13″	x
CUSC Sensor	Santurce – Central SJ	18º26′29″	66º03′31″	x
Guaynabo Sensor	North Guaynabo	18º24′23″	66º06′07″	x
Interamericana Sensor	South Bayamón	18º21′06″	66º11′00″	x
NWS Sensor	North Carolina	18º25′53″	65º59′29″	x
Toa Baja Sensor	Naval Base Sabana Seca	18º27′28″	66º11′47″	x
UPR Bayamón Sensor	East Bayamón	18º22′14″	66º08′36″	x

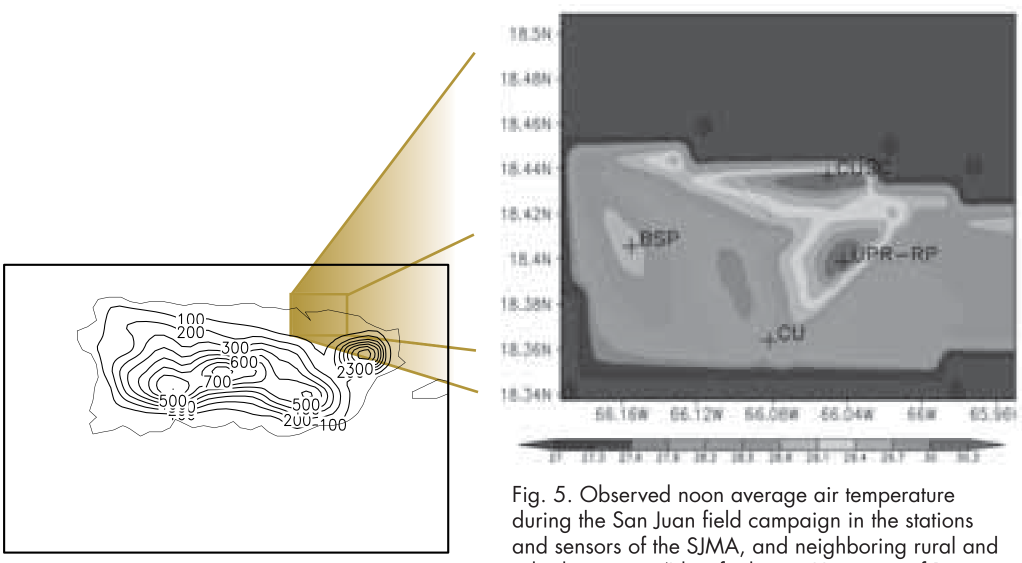


Fig. 5. Observed noon average air temperature during the San Juan field campaign in the stations and sensors of the SJMA, and neighboring rural and suburban areas (Identified sites: University of Puerto Rico—Río Piedras, UPR-RP; Sacred Heart Catholic University, CUSC; Bayamón Science Park, BSP; Cupey, CU). Contours to the left represent elevations.

An analysis of the data gathered shows that peak temperatures occurred in the mid afternoon and ranged from 33°C to 35°C in urban areas and from 26°C to 28°C in suburban and rural areas. Low temperatures consistently reached 20ºC to 22°C in the late evening (around 10:00 p.m. local standard time).

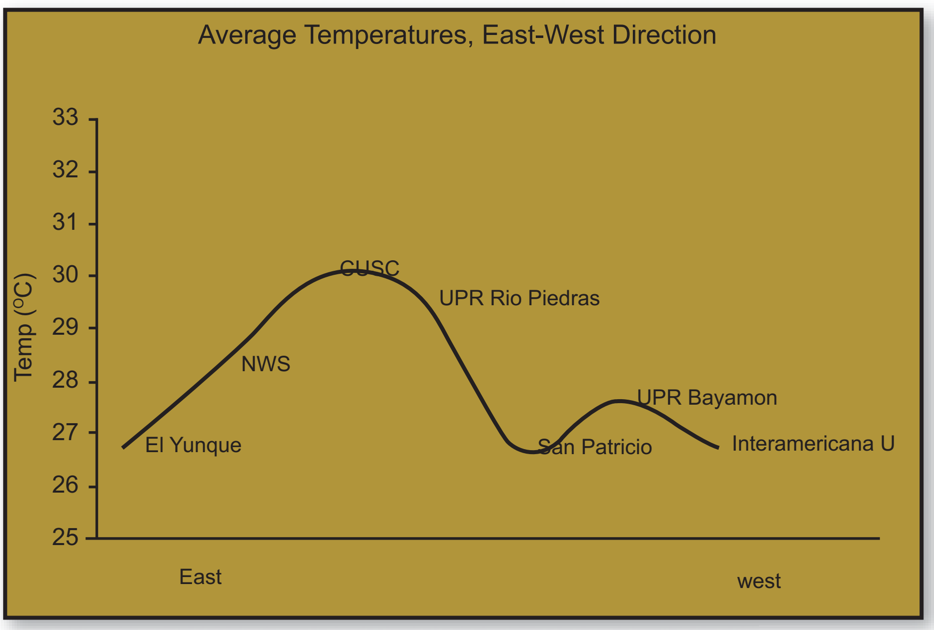


Fig. 6. Cross section of average temperatures during the period 13–16 February 2004 along the east-west gradient line for selected stations and sensors.

Top temperatures in rural areas were substantially lower than those in urban areas in the mid to late morning hours. More specifically, between 9:00 a.m. and noon, average temperature differences were 4.5°C, a temporal pattern not observed in previous UHI studies of large continental cities. It is still not clear why the San Juan UHI peaks in the late morning hours and not in the early evening, a pattern shown in previous UHI experiments conducted in continental cities. It was also observed that there was no appearance of a cool island, a dip of negative temperature difference between urban and rural areas dT(U – R), opposite to the heat island caused by thermal heat storage. These results are summarized in Fig. 7.

The importance of soil moisture content and evapotranspiration in controlling the urban tropical climate, as well as the influence of high concrete density on them, is evidenced by the variability of the UHI pattern with respect to rainfall. Even for relatively small and short precipitation events, on the order of only 8.4 mm recorded during the entire mission by the San Juan National Weather Service station, the temperatures in the commercial core of San Juan and the surrounding residential and rural areas were very similar, showing a low dT(U – R).

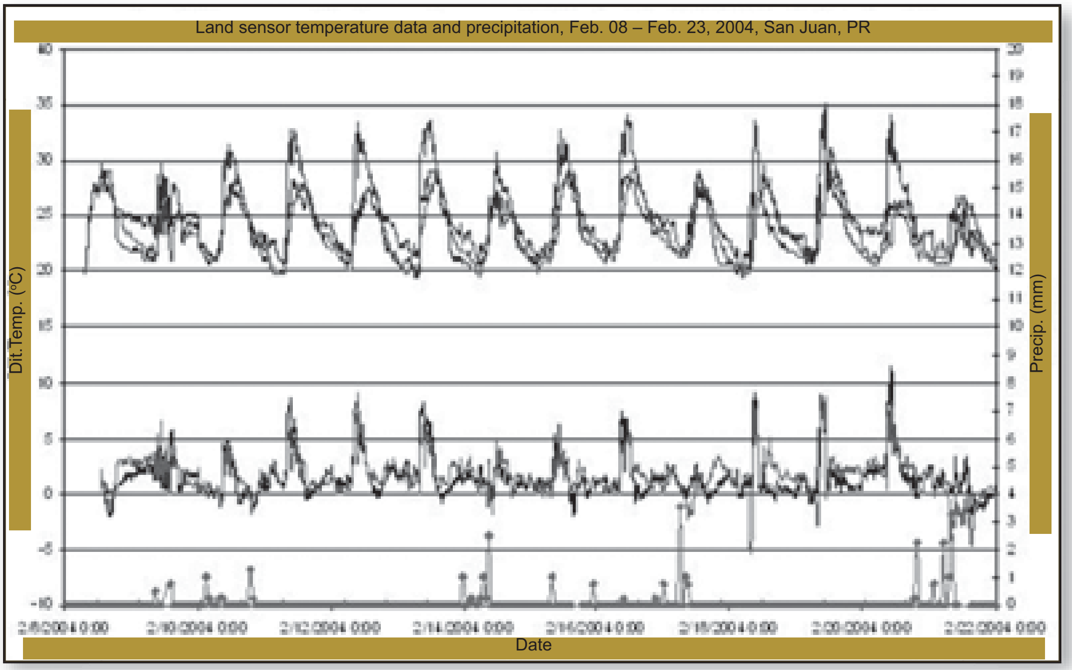


Fig. 7. Time series of observed temperatures (top), temperature differences between the commercial core and rural areas (intermediate), and precipitation in the study area (bottom), for urban (CSCU), suburban (Interamericana) and rural (El Yunque) reference stations.

Numerical Analysis

The main objectives of the numerical analysis were to quantify the impact of land cover and land use (LCLU) in the cities and to study the reaction of the atmosphere in the presence of an important urban center. The regional model used for the study presented in this document is the Regional Atmospheric Modeling System (RAMS), developed by the Colorado State University (Pielke et al. 1992, Cotton et al. 2003).

Model Description and Experiment Design

RAMS is a highly versatile numerical code developed to simulate and forecast meteorological phenomena. The atmospheric model is built around the complete system of nonhydrostatic dynamic equations governing atmospheric dynamics and thermodynamics and the conservation equations for scalar quantities, such as mass and humidity. These equations are complemented by a wide selection of parameters available in the model. The version of RAMS used in the research contains a new module of cloud microphysics described by Saleeby & Cotton (2004), an improvement over the original microphysics package (Meyers et al. 1997, Walko et al. 1995). This new microphysics module includes the activation of cloud condensation nuclei through the use of a Lagrangian plot model that considers the environmental conditions of the cloud for the initial formation of cloud water directly over the aerosol.

The simulations were conducted on three grids, taking advantage of the capacity for communication between the grids of the model. The first grid covers a large part of the Caribbean region with a horizontal resolution of 25 km. The second grid, with hierarchy over grid 1, covers the island of Puerto Rico with a 5-km horizontal resolution. The third grid has hierarchy over grid 2 and is centered on the city of San Juan with a 1-km resolution (Fig. 8). For the vertical coordinate, all grids used the same specification. Spacing of 100 m was used near the surface and stretched in a constant quotient of 1.1 until Z reached 1,000 m. The depth of the model is 22.83 km with 40 vertical layers. Time variable boundary conditions were used. The complexity of the humidity of microphysics was fixed at the highest level. This level incorporates all categories of water in the atmosphere (cloud water, rainwater, pristine ice crystals, snow, aggregates, graupel, and hail) and includes the precipitation process.

Clouds in maritime environments have low concentrations of large drops and a broad spectrum of concentration. All simulations were forced by the same initial and lateral boundary conditions for the period 10–20 February 2004, provided by the NCEP atmospheric fields. The use of this regional atmospheric model has already produced satisfactory results for the Caribbean Basin, simulating the precipitation pattern in the island of Puerto Rico for the months of the early rainy season (Comarazamy 2001).

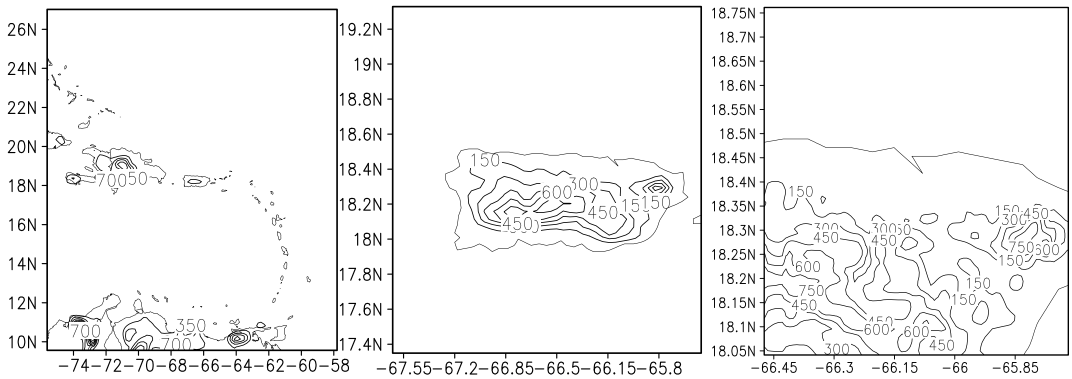


Fig. 8. Representation of the three grids used in the numerical simulations to investigate the impact of urban LCLU on local climate. The topographic contours have 150-m intervals in the three panels.

Three different scenarios were configured to quantify the impact of changes in LCLU in the SJMA through time. First, the standard specification of the surface characteristics used in regional atmospheric models was used. Next, one of the model's routines was modified to represent the extension and urban configuration of San Juan, as observed from the aerial photograph in Fig. 2. The third configuration was designed to represent the possible original vegetation of the area currently occupied by the city, interpolating the surrounding vegetation until the entire area was covered. The runs were called current, urban, and primitive, respectively. The variable modified for these numerical simulations was the so-called vegetation index, defined by the Biosphere-Atmosphere Transfer Scheme (Dickinson et al. 1986). This index includes the physical parameters of albedo, emmissivity, leaf area index, percentage of vegetation, surface rugosity, and root depth. The configuration of the LCLU index used in the three simulations is shown in Fig. 9.

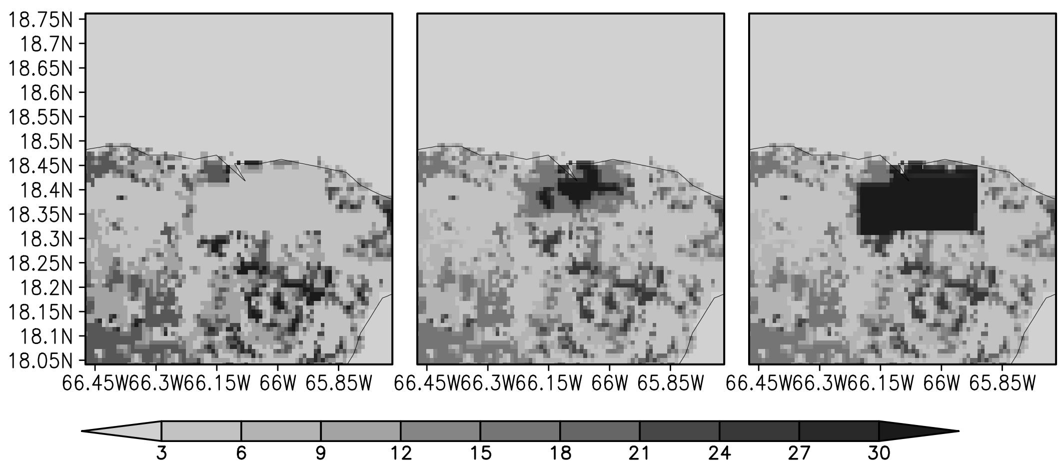


Fig. 9. Specification of the surface characteristics used in the three runs of the atmospheric model, simulating, from left to right, the primitive, current, and urban scenarios.

Air Temperature and Wind Pattern Results

In order to study the impact of urban LCLU on the SJMA, air temperatures at 2 m above ground level, resulting from the three simulated scenarios were analyzed. The analysis consisted of calculating the difference in average values during the warmest period (in this case estimated to be 3 p.m.), according to the following process: urban-primitive, current-primitive, and urban-current. To visualize the effect of the concrete cover of the city of San Juan on the wind pattern, a procedure similar to the daytime sea/land breeze circulation cycle was used.

The results of the analysis of air temperature averages in mid afternoon for the entire simulation period are presented in Fig. 10. According to these results, the atmospheric model predicts that the city of San Juan has an impact on the lower atmosphere of the area it occupies. This impact is reflected in the higher temperatures for the simulations with an urban LCLU specified for the lower boundary. The difference in temperature is more pronounced between the urban and primitive runs, with positive values of up to 2.5°C, especially leeward of the city.

The spatial pattern of temperature differences over the SJMA can be explained by the presence of sustained southwest winds for most of the afternoon (Fig. 11). The three simulations produced the same daytime wind patterns featuring a strong influence of synoptic trade winds from the northeast. However, the difference in warming between the Atlantic Ocean and the northern coast of Puerto Rico induces circulation inland during the day, as can be seen in Fig. 11 and a reversion of the winds toward the ocean at night. Both circulation patterns are oblique, close to 45º, because of synoptic influences.

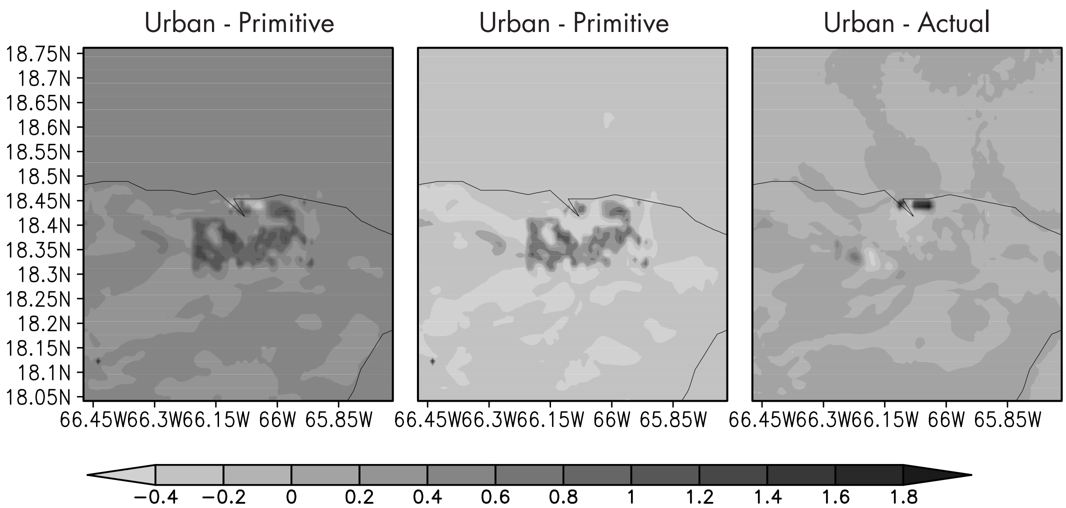


Fig. 10. Spatial distribution of air temperature differences (°C), at 2 m above ground level, for the three scenarios simulated for the analysis. The contour interval is 0.5°C for the first two panels and 0.2°C for the third panel.

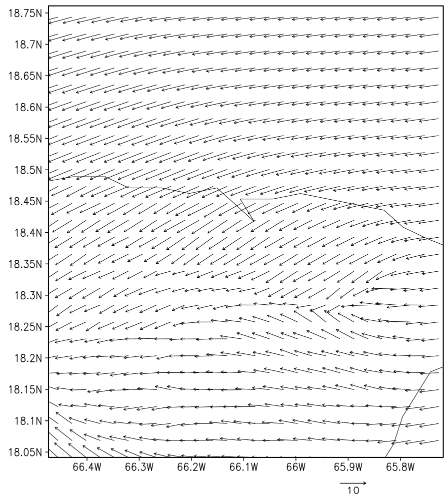


Fig. 11. Average wind field at 3 p.m. local time for the total simulation period of the current run.

The impact of model cells specifying an urban LCLU is also significant. Figure 12 shows that differences in the wind field are found essentially in the area over the city and it also shows the direction of the prevailing winds. A wind acceleration effect on the order of 3 ms^{-1} can be seen, as evidenced by an increase in the magnitude of the vectors represented in the panels showing the urban-primitive and current-primitive differences. This acceleration may be the result of a thermal-mechanical effect caused basically by increased surface rugosity, represented as z_o. The change in z_o to a higher value in the primitive and urban LCLU specifications increases the surface available for heat transfer in the surface-atmosphere interface, while causing a frictional acceleration of the winds approaching at the levels closest to the surface.

It should be noted that in the current and urban simulations, the specification for the city is done with the BATS vegetation index 30 called *urban and built-up,* and is represented by a homogenous concrete slab, affecting the climate variables analyzed from its thermal and mechanical characteristics. When the simulations include the urban topography averaged by cell, the effect could be drastically different. The wind results presented in this document are an indication of how sensitive the vectorial field is to changes in the representation of LCLU in the simulations.

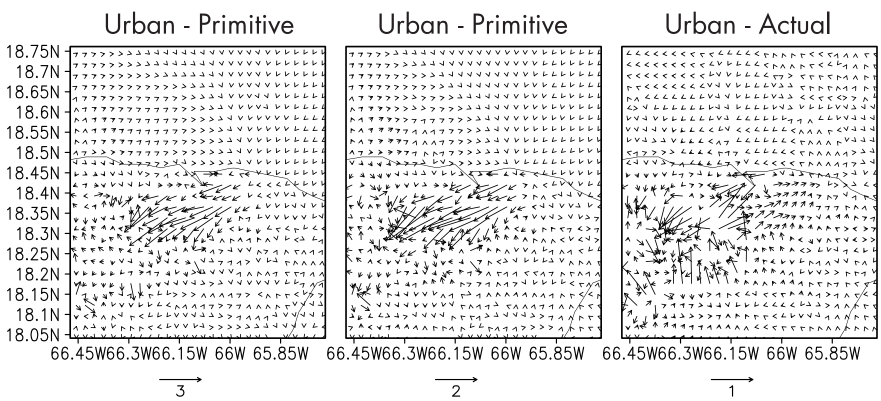


Fig. 12. Average difference in wind field calculated at 3 p.m. for the three simulations.

Summary and Conclusions

Our findings and conclusions are listed below:

- Empirical analysis revealed a real UHI effect over the SJMA, which grows with urban development.

- The UHI over San Juan is more intense during the early rainy season, when atmospheric conditions are more stable than at other times of the year.

- The data of the ground-based stations deployed during the Atlas San Juan Mission experimental campaign revealed hot spots over the commercial areas of the core of the city of San Juan. An east-west cross section of the temperature profile shows a dome of elevated temperature over the center of the SJMA, with consistent UHI values between 5°C and 10°C during the observation period.

- The occurrence of rainfall strongly affects the pattern of the UHI over San Juan, even during weak precipitation events.

- The RAMS atmospheric numerical model was validated to capture the impact of urban LCLU in San Juan on atmospheric variables.

- Analysis of the three simulated scenarios leads to the conclusion that urban LCLU has an impact on the general atmospheric dynamics of the northern coast of the island of Puerto Rico.

- Model results show that the influence exerted by the city of San Juan is to produce higher temperatures in the region where the urban area was represented. This influence was quantified into an increase of between 2.5°C and 3°C in air temperatures and an acceleration of the winds in the area.

- An increase in the urban mass of San Juan causes friction in the synoptic flow, particularly in the areas farther away from the coast.

After investigating the characteristics of the urban environment of the SJMA, we must look for answers to several remaining questions in future research.

Given the presence of UHI in San Juan:

- What is the true effect over the prevailing winds and the impact on sea/land breeze circulation?

- Is there an effect from convective precipitation induced by UHI in San Juan?

- What is the influence on the formation of clouds?
- How does UHI affect the vertical structure of the atmosphere over the city?
- What is the true effect over the water cycle of the area?

Future numerical experiments will be designed to answer these questions and to obtain a more realistic urban representation. These simulations will include a heterogeneous surface with specifications for albedos and emissivities extracted from ATLAS sensor data and urban topography, so important for dynamic terms and heat storage.

Acknowledgments

This effort was partially sponsored by the NASA Experimental Program to Stimulate Competitive Research (EPSCoR) of the University of Puerto Rico–Mayagüez (UPRM) and was carried out at the UPRM; the University of Santa Clara, Santa Clara, CA; and the Global Hydrology and Climate Center, Huntsville, AL (GHCC). The atmospheric simulations were carried out in the High Performance Computer Facilities of the University of Puerto Rico–Río Piedras (UPR). The data from cooperative stations were obtained from the Southeast Regional Weather Center of the United States. Part of the empirical climate analysis was carried out by Alexander Velásquez. Our special thanks go to the following people: Pieter Van Der Meer, Eric W. Harmsen, and Ana J. Picón of UPRM for their collaboration during the Atlas Mission and the analysis of station data; Douglas Rickman of the GHCC for assistance provided during our stay in Huntsville; and to all directly and indirectly involved in the tremendous effort of planning and successfully developing the Atlas Mission experimental campaign in San Juan, Puerto Rico.

References

Bornstein, R., and Lin, Q. 2000. "Urban heat islands and summertime convective thunderstorms in Atlanta: Three case studies." *Atmospheric Environment* 34:507–516.

Comarazamy, D. E. 2001. *Atmospheric Modeling of the Caribbean Region: Precipitation and Wind Analysis in Puerto Rico for April 1998*. Master's Thesis. Department of Mechanical Engineering, University of Puerto Rico—Mayagüez. 95 pp.

Cotton, W. R., Pielke, R. A. Sr., Walko, R. L., Liston, G. E., Tremback, C. J., Jiang, H., McAnelly, R. L., Harrington, J. Y., Nicholls, M. E., Carrio, G. G., and McFadden, J. P. 2003. "RAMS 2001: Current status and future directions." *Meteorology & Atmospheric Physics* 82:5–29.

Daly, C., Helmer, E. H., and Quiñones, M. 2003. "Mapping the climate of Puerto Rico, Vieques and Culebra." *International Journal of Climatology* 23:1359–1381.

Dickinson, R. E., Sellers, A. H., Kennedy, P. J., and Wilson, M. F. 1986. *Biosphere–Atmosphere Transfer Scheme (BATS) for the NCAR Climate Community Model.* Technical Note NCAR/TN-275+STR, National Center for Atmospheric Research, Boulder, CO. 69 pp.

Gallo, K. P., McNab, A. L., Karl, T. R., Brown, J. F., Hood, J. J., and Tarpley, J. D. 1993. "The use of NOAWA AVHRR data for the assessment of the urban heat island effect." *Journal of Applied Meteorology* 32:899–908.

Jáuregui, E. 1997. "Heat island development in Mexico City." *Atmospheric Environment* 31:3821–3831.

Jáuregui, E., and Romales, E. 1996. "Urban effects of convective precipitation in Mexico City." *Atmospheric Environment* 30:3383–3389.

Landsberg, H. E. 1981. *The Urban Climate.* Academic Press. New York, NY. 275 pp.

Lo, C. P., Quattrochi, D. A., and Luvall, J. C. 1997. "Applications of high-resolution thermal infrared remote sensing and GIS to assess the urban heat island effect." *International Journal of Remote Sensing* 18(2):204–287.

Luvall, J. C., Rickman, D., Quattrochi, D., and Estes, M. 2005. *Aircraft-Based Remotely Sensed Albedo and Surface Temperatures for Three US Cities; Color Roofing: Cutting through the Glare*. Roof Consultants Institute Foundation. May 12–13, 2005. Atlanta, GA.

Malmgren, B. A., and Winter, A. 1999. "Climate zonation in Puerto Rico based on principal components analysis and an artificial neural network." *Journal of Climate* 12(4):977–985.

Meyers, M. P., Walko, R. L., Harrington, J. Y., and Cotton, W. R. 1997. "New RAMS cloud microphysics parameterization. Part II: The two-moment scheme." *Atmospheric Research* 45:3–39.

Noto, K. 1996. "Dependence of heat island phenomena on stable stratification and heat quantity in a calm environment." *Atmospheric Environment* 30:475–485.

Pielke, R. A., Cotton, W. R., Walko, R. L., Tremback, C. J., Lyons, W. A., Grasso, L. D., Nicholls, M. E., Moran, M. D., Wesley, D. A., Lee, T. J., and Copeland, J. H. 1992. "A comprehensive meteorological modeling system—RAMS." *Meteorology & Atmospheric Physics* 49:69–91.

Poreh, M. 1996. "Investigation of heat islands using small scale models." *Atmospheric Environment* 30:467–474.

Saleeby, M. S., and Cotton, W. R. 2004. "A large-droplet mode and prognostic number concentration of cloud droplets in the Colorado State University Regional Atmospheric Modeling System (RAMS), Part I: Module descriptions and supercell test simulations." *Journal of Applied Meteorology* 43:182–195.

Shepherd, J. M., and Burian, S. J. 2003. "Detection of urban-induced rainfall anomalies in a major coastal city." *Earth Interactions* 7:1–17.

Taylor, M. A., Enfield, D. B., and Chen, A. A. 2002. "Influence of the tropical Atlantic versus the tropical Pacific on Caribbean rainfall." *Journal of Geophysical Research* 107:10.1–10.14.

Tso, C. P. 1996. "A survey of urban heat island studies in two tropical cities." *Atmospheric Environment* 30:507–519.

UNFP (United Nations Population Fund). 1999. *The State of World Population 1999*. United Nations Publications, New York, NY. In: http://www.unfpa.org/swp/1999/index.htm.

Walko, R. L., Cotton, W. R., Meyers, M. P., and Harrington, J. Y. 1995. "New RAMS cloud microphysics parameterization: Part I: The single-moment scheme.".*Atmospheric Research* 38:29–62.

Dry Island Effect on Intermediate Cities

4

The Case of the City of Mendoza

Authors:
Fabián R. Bochaca
Enrique Puliafito

Summary

Intermediate urban centers featuring the dynamics of constant growth, which results in land use changes, have started to witness the environmental problems commonly affecting the levels of comfort of large city dwellers.

This chapter analyzes the integral behavior of intermediate cities and the dry island effect produced by the impermeabilization of surfaces to the detriment of green areas. The city of Mendoza will be used as the model for this analysis.

In order to understand urban climate behavior in relation to variations in humidity and air temperature, we will focus the study on vegetated areas alternating with impermeabilized surfaces. Doing so requires including the various urban scales at which these spaces combine—from a larger scale to an intermediate scale, and from there to the microscale.

Two types of variables are considered in this analysis: (1) weather variables such as air temperature, relative humidity, wind speed, and direction and temperature of materials; and (2) morphological variables such as percentage of built surfaces, type of materials, and shape and average height of built and green areas.

Empirical verification of how these variations occur in urban centers was carried out by taking several measurements, from dawn until dusk, during the summer, in continuous runs throughout the city of Mendoza.

The study enabled understanding how vegetated areas influence variations in humidity, reflected in changes in the temperature of the urban climate, particularly noticeable in intermediate cities with desert climates, as is the case of the city of Mendoza.

Introduction

Approximately 60% of the urban population lives in intermediate or small cities of less than one million inhabitants, and 30% of the world population lives in cities with desert or semidesert climates (Koerner and Klopatek 2002).

Few studies have analyzed cities of this size, especially any with desert climates. When discussing urbanization processes, in particular the result of these processes, or when referring to the term "city," there is often a tendency to almost exclusively refer to large urban conglomerates. These cities, with a better balanced scale that is more in harmony with the surrounding land, are not subject to environmental problems as acute as noticed in large cities, but are featuring a progressive deterioration in the quality of natural resources (water, air, and soils), shown by development of heat island effects, decrease in environmental humidity, or reduction of green areas and vehicular congestion. All these problems have a tendency to become chronic. Therefore, these areas represent appropriate urban scenarios for intervention in order to avoid repetition at a different scale of the serious climate problems large cities are experiencing in their urbanization process, such as the appearance of dry island or heat island effects.

Urbanization processes associated with changes in land use and reflected in the reduction of green areas and the increase of impermeabilized surfaces have a significant impact on local climate by reducing humidity and increasing average temperatures in the area. Urban growth also results in increased emission of pollutants and greenhouse gases (GHG) with direct effects on air pollution and indirect effects on the mixing layer in cities. These complex processes increase GHG emissions because of additional energy consumption. As a result, reducing green areas in urban centers causes a change in the albedo of the city because of variations in solar radiation absorption by built surfaces, which in turn increase heat storage. At the same time, there is less humidity in the environment.

This local phenomenon also affects the global situation because carbon dioxide (CO_2) emissions impact global climate. As vegetation decreases in urban areas, the balance between respiration and sequestration by photosynthesis is also modified. Furthermore, there are indications that variations in temperature and humidity impact the net flows of CO_2. This process appears to be especially critical in cities with arid or semiarid climates (Koerner and Klopatek 2002).

This is precisely the starting point of our study: the current uncertainties in understanding the behavior of vegetated areas in the city grid and of their effects and adaptation in urban design, as applied to intermediate cities with desert climate.

Vegetation in urban planning

Undeniably, green areas incorporated into the urban layout influence the behavior of climate in a city by causing lower temperatures (Jáuregui 1975). This reduction in temperature is due to two factors: (1) the benefits of shade from urban vegetation which, depending on the morphologic characteristics of the species, foliage density, and orientation, may reduce irradiation on vertical and horizontal surfaces by as much as 80% (Heisler 1986); and (2) the humidity emitted from the vegetation in the physiological processes. These two factors enable the exchange of energy with the environment and influence variations in temperature and humidity. Green areas produce a cooling effect through the exchange of energy between areas adjacent to the limits of the vegetated area and regulate the thermal effect on the environment in two ways: On the one hand, they dissipate energy in the form of latent heat through the elimination of water vapor, generating a cooler and more humid environment than the surrounding area (Barradas et al. 1999); and, on the other, foliage has a reduced energy storage capacity of only 0.008°C s (Nobel 1983), evidenced in lower temperature than that in its surroundings.

An example of a study of green areas analyzing variations in relation to urban surroundings is the case of Chapultepec Park, in Mexico City. The analysis has allowed observing how vegetated areas influence the urban environment (Jáuregui 1991). These large, vegetated areas diminish the heat island effect (Rosenfeld et al. 1995), extending beyond their periphery (Shashua-Bar and Hoffman 2000), increasing their reach according to the influence of morphological factors, such as modifications in the albedo of impermeabilized surfaces, and meteorological factors including wind direction and intensity and relative humidity (Upmanis and Chen 1999).

The dry island effect as change in urban vegetation

The appearance and incorporation of new construction technologies and materials such as concrete and asphalt have favored and accelerated the consolidation of the urban fabric, conceived primarily as an impermeabilized surface.

The increase in impermeabilized surfaces and the decrease in vegetated areas in urban sectors cause fluctuations in the percentages of relative humidity and result in the urban dry island effect, called urban moisture excess at night and urban moisture deficit in the daytime. This phenomenon establishes a direct relation between variations in humidity and increases or reductions in temperatures occurring in rural and urban areas (Charciarek 2001).

The increase in surfaces using materials with a high degree of radiation absorption and low albedo that are exposed to direct sunlight all day, to the detriment of vegetated areas, makes these surfaces very hot, influencing variations in humidity and air temperature both at the microscale adjacent to these spaces (100 to 300 m) as well as in the surrounding area (Rosenfeld et al. 1995). For example, streets and avenues alone cover over 25% of the urban area, without including public space for parking, walkways, or recreational areas

(Shashua-Bar and Hoffman 2003), which reduces the number of areas that can evaporate water vapor into the urban environment.

Asphalt, one of the materials most commonly used in streets, highways, and parking lots in urban areas, is one of the darkest surfaces found in the city; its albedo in a new surface may reach 0.05, which means it absorbs about 95% of the sunlight (Pomerantz et al. 2003).

Green Area Planning in the City of Mendoza

Current green-area planning and design in Latin America, and in particular in the city of Mendoza, Argentina, still include primarily aesthetic criteria that respond only to recreational needs, given the attraction these areas hold as part of the urban landscape, rather than environmental criteria, taking for granted that the mere incorporation of vegetated elements improves the environment. Criteria related to the behavior, function, distribution, and orientation of these green spaces—both isolated vegetated elements and large green areas—are not included.

The urban structure of the city of Mendoza mixes three different types of grids that overlap in the space from the foundation: (1) a water supply network developed by the aboriginal settlers of the area and later adopted by the Spanish colonizers; (2) a grid defined by the characteristic checkboard of functional cities; and (3) another grid arising later because of the interaction of the first two, associated with the appearance in the city of vegetated areas, initially developed inside houses. Both the water supply (acequias) and the vegetation grid were characteristic elements of the city from the beginning and delineated the planning criteria.

In the city of Mendoza, the green-area planning process occurred initially as a way to strengthen the social and political identity of the Mendoza elite, rather than by the adoption of specific environmental criteria.

Later on, the gradual growth of the various vegetated areas and the urban forest allowed seeing the benefits of vegetation beyond its aesthetic appeal. Current use of concrete and asphalt as an active element in the consolidation of the urban grid, has transformed many of the green areas (crop lands, parks, or squares) into impermeabilized surfaces, located both in the peripheral sectors and in the central part of Mendoza.

The use of concepts of urban vegetation developed decades ago makes new planning of these spaces difficult, as required by intermediate cities such as Mendoza, featuring the dynamics of constant growth (Bochaca 2005).

The inadequate use of urban concepts related to parks and green areas is evident in the increase of the dry island effect. Further, this effect is more noticeable and the consequences more intense in intermediate cities with desert climates, as is the case of the city of Mendoza, where humidity is low.

Study Area

Climate in the City of Mendoza

Mendoza is located in the region of Northern Oasis of the Province[1] of Mendoza, at the foot of the Andes Mountain Range, at an approximate altitude of 750 m above sea level (32 53' latitude South, 68 51' longitude West). The city, with a population of approximately 1,100,000 inhabitants, is one of the most important intermediate urban conglomerates of western Argentina.

Its precipitation does not exceed 180 to 220 mm per year, so irrigation of the different green areas is carried out using water from irrigation ditches and canals.

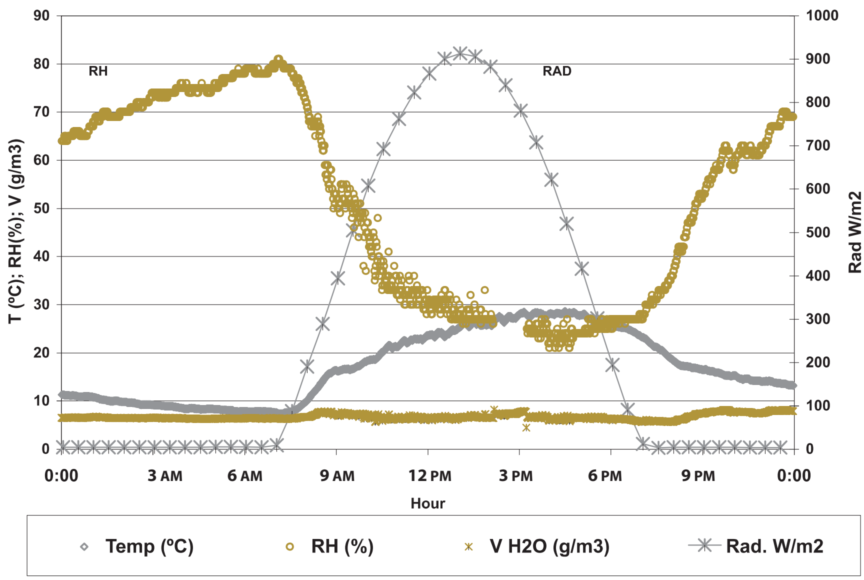


Fig.1. Daily typical variations of water vapor, temperature, humidity and solar radiation.

Figure 1 shows the main characteristics of this region: a high level of dryness, scanty wind intensity, and high "heliofanía" (hours of sunlight). The figure also shows the typical daytime temperature variation (ºC), relative humidity (%), water vapor density (g/m^3), and water vapor, as a function of time of day. It also registers the curve of daytime solar radiation (W/m^2).

[1] The city of Mendoza is a landscape transformed by man, thanks to the use of artificial irrigation, mainly taking advantage of river water to develop crop lands and environmentally inhabitable areas, enabling the creation of urban centers, agricultural, and industrial areas. These oases consist of areas covered by exotic vegetation and are immersed in a natural landscape with desert characteristics. The set of oases from the Mendoza and Tunuyán Rivers, distributed along the margins of these waterways or their canals, comprise the northern oasis of the province, the area where the city of Mendoza is located.

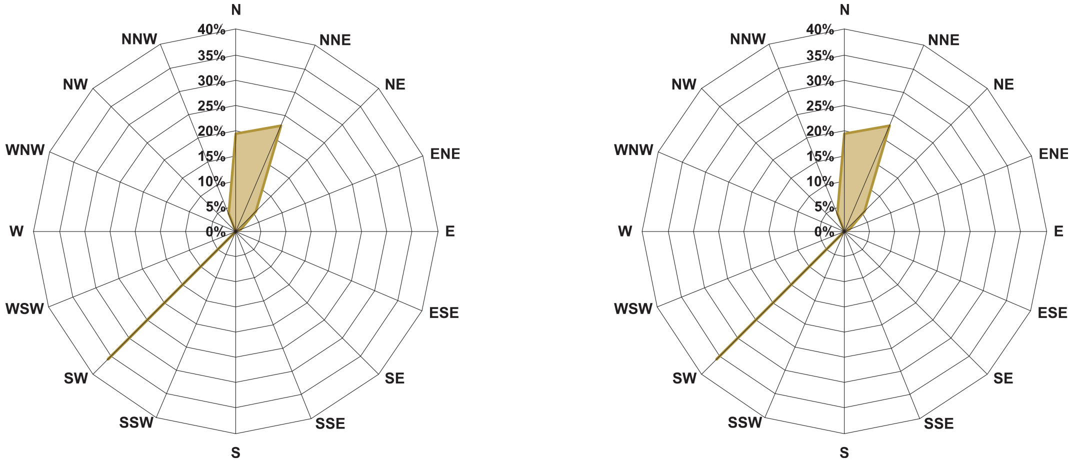


Fig. 2. Daily typical wind frequency (rigth) and wind intensity in meters/second (left).

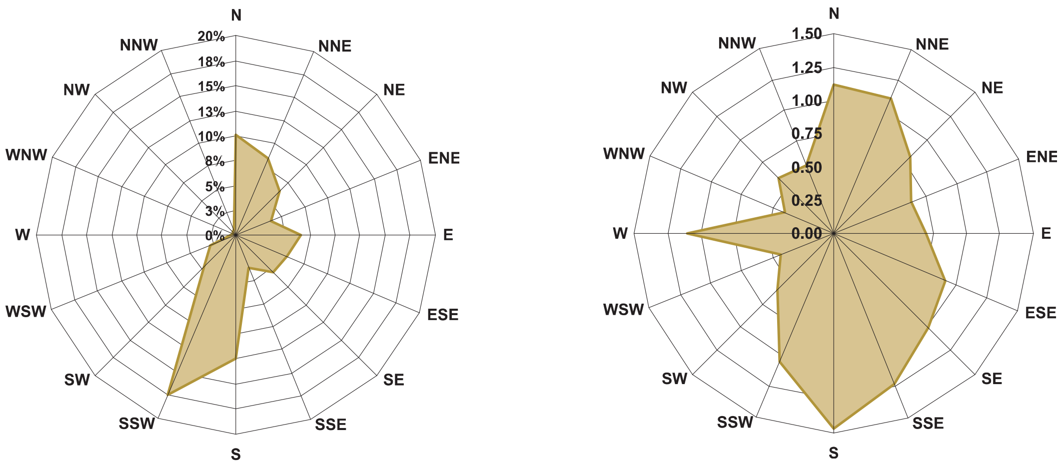


Fig. 3. Annual mean frequency (rigth) and wind intensity in meters/second (left) for 1998.

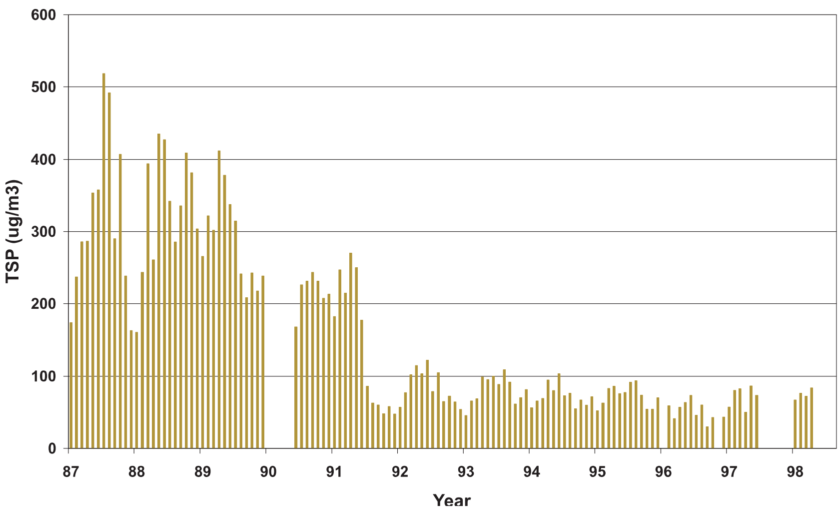


Fig. 4. Monthly measurements of particulate material (μg/m^3) recorded in the center of the city of Mendoza. *(Data from the Direction of Sanitation and Environmental Control, Gov. of Mendoza)*

In general, wind conditions in Mendoza feature a high percentage of calm periods, occasionally interrupted by strong gusts called Vientos Zondas, and there are soft daily cyclical breezes, typical of the valley-mountain area (Figs. 2 and 3).

These characteristics, added to the topography and location in the alluvial valley of the Andes Mountain Range (averaging 5,000 m in height), act as a natural barrier to atmospheric humidity and thus make for a desert, dusty area with a climate that may be hazardous to health and without any chance for air purification (Fig. 4).

The meteorological and orographic conditions of the Great Mendoza, together with various anthropogenic activities, generate a pattern of behavior typical of atmospheric pollution.

The analysis of environmental data in Mendoza enables recognition of some very well defined cycles: The first is a seasonal variation (winter-summer) that establishes an annual pattern featuring high levels of concentration in the atmosphere during the winter months and lower concentrations in the summer months. Figure 4 shows the seasonal variations of daily average values of particles (PST), measured at one of the fixed stations of the Ministry of Environment and Public Works.

Another clearly distinguishable cycle is the typical night-day variation, characterized by valley-mountain type circulation. In the hours after sunset and until dawn, the predominant circulation is from the SSW, while in the daylight hours the circulation is mainly from the NNE (Fig. 2). Given the strong irradiation in Mendoza, there is significant convective circulation in the daytime.

The combination of these effects, added to considerable nighttime cooling and daytime warming of the ground, results in an important daily variation of the mixing altitude and inversion layer. It varies between 50 and 100 m at night to over 1,500 m at noon, depending on the time of the year.

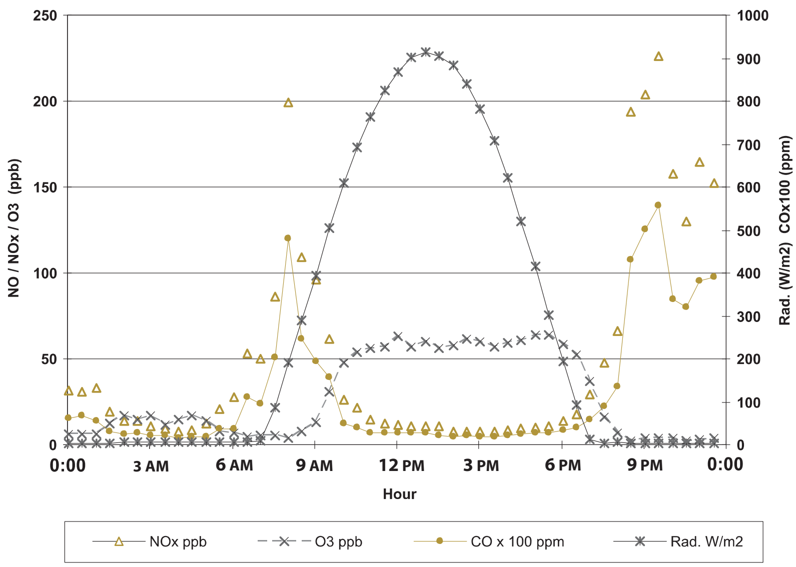


Fig. 5. Typical daytime variation of pollutants. Concentration of carbon monoxide, CO (ppm); nitrous oxides, NO_x (ppb); surface ozone, O_3 (ppb); and solar radiation (W/m^2) as a function of time of day. *(Source: Puliafito et al. 2003)*

Figure 5 shows a typical day through continuous measurements of solar radiation and concentrations of O_3, CO and NO_x (Puliafito et al. 2003). The graph clearly shows the phenomenon described above resulting from human activities, including typical traffic emissions.

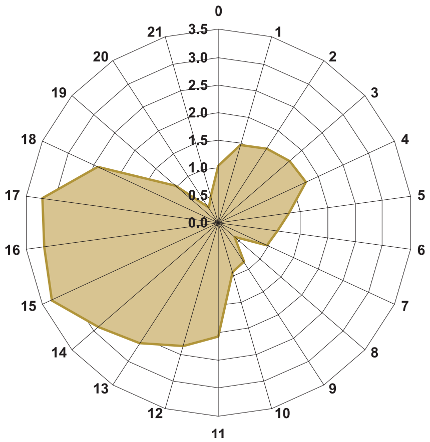
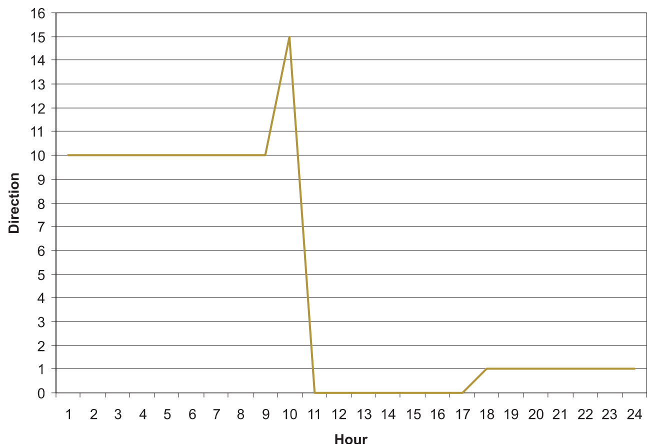


Fig. 6. Typical wind intensity in meter/second (above) and direction (below) as a function of the time of day.



Thus, between 7 and 9 a.m., the peak in the circulation of vehicles at the beginning of daily activities can be seen. At noon, despite the fact that in Mendoza most of the people return home for lunch, this vehicular activity is not as noticeable in the measurements of contaminants, given the more favorable conditions of dispersion by convection. However, between 8 and 9 p.m., when people return home, contaminant measurements are very high due to the reduction of dispersion.

Figure 1 shows variations in temperature, relative humidity, and water vapor as a function of time of day, but solar radiation has been plotted again to show daylight hours. At night, relative humidity is high and decreases as the temperature increases as a result of solar radiation. The higher the temperature, the greater the saturation pressure of water vapor, thereby increasing the capacity of the air to retain water vapor. This results in a decrease in relative humidity, although absolute humidity is more or less constant during the whole day.

Figures 6 complement the meteorological information in Figure 1, showing wind intensity as a function of time of day and direction and frequency and wind direction according to the time of day (Puliafito and Puliafito 2005).

Methodology

The field work examines the microscale of the green areas, together with adjacent areas consisting of impermeabilized surfaces, and analyzes how the distribution of green and impermeabilized areas influences humidity in the sector, as shown by temperature variations from direct measurements and studies of the urban grid of the city of Mendoza.

The design of these public spaces must be understood as elements that enable managing the fabric of the city, regardless of the urban scale, allowing organization of the territory to support different land uses. The incorporation and distribution of vegetated areas in patches within the city grid and its consequences are the main focus of our research. Understanding their behavior when mixed in urban sectors will allow us to interrelate the effects of green areas in regulating urban humidity and temperature.

Field work

The study consisted of taking measurements of humidity, temperature, and wind direction and intensity from dawn until dusk in three continuous runs through the city of Mendoza. The runs began at 5:30 a.m., continued at 2:30 p.m., and ended at 8:00 p.m. Various types of green areas merging with residential sectors were selected as units for the analysis.

The vegetated areas selected are cultivated rural areas, mainly grapevines, residential areas, sectors of the piedmont with xerophytic vegetation, urban parks, and various green spaces inserted in the grid in the form of squares.

The journey of approximately 80 km with an average duration of three hours started from the periphery toward the central area of the city of Mendoza and finished again in the periphery. The work was done during the summer, in January, and the measurements were conducted in 2004 and 2005.

The main focus of this study is to find the causal relations that would show the interaction between the vegetated areas and the different built or impermeabilized surfaces around the green areas and to analyze how these areas influence the variables of humidity and temperature in the city of Mendoza.

Essentially, the measurements respond to a nonexperimental design. The variables analyzed were not intentionally manipulated; that is, we observed behavior in the real environment. The design of the nonexperimental research is transactional or transversal, as we collected the data in the city of Mendoza during a specific period of time, the summer season, during representative summer days with an average temperature of 30°C.

We decided to take measurements in the summer based on two criteria guiding this investigation: first, to observe the variables to be measured at their most extreme, in January, a time of year when solar radiation more directly impacts the surface, particularly horizontal planes, and when the most drastic changes in temperature and humidity occur in the city of Mendoza, especially in urban areas.

Second, we wanted to analyze the process of evapotranspiration of the vegetation in its most active period and to observe the behavior of green areas when mixed with impermeabilized surfaces.

This research adopts a correlation or causal format; that is, we are not interested in the description of isolated variables, but rather in the relations resulting from the different variables measured.

The measuring runs intercept different types of green areas. Depending on their characteristics, they influence the variations in humidity and temperature in the immediately adjacent surroundings. Understanding how these variations originate requires that we study the physiological processes of the vegetation to explain how they affect the urban environment.

Physiology of the Green Areas

Among the physiological processes of the vegetation, we will focus mainly on the process of evapotranspiration, using the bibliography on the topic as a theoretical framework.

Evapotranspiration is a physiological process of plants defined by the capacity of the different species to transpire water vapor through the foliage, adding to the capacity of the soil to evaporate water into the environment (Nobel 1983). Among the main functions, we could mention the following: the processes of photosynthesis, transportation of substances obtained from the metabolism and turgescence of the plant, as the water intervenes in the turgescence of the stomata and on the guardian cells that comprise it. Turgescence determines the aperture and closure of the stomata and therefore the entry or lack of entry of carbon dioxide (CO_2), oxygen (O_2), and mainly, water vapor.

This process is due to the difference in water potential[2] in the interior of the plant (specifically, in the substomatic chamber located in the mesophile) and environmental humidity. The air surrounding the leaf has a lower water potential than the plant as a result of the solar radiation it receives, and the difference between the liquid water inside the plant and the vapor adjacent to the epidermis of the leaf causes an ascending movement of water from the ground up into the atmosphere, that is, from the roots to the leaves. This process not only enables the elimination of water through the stomata, through the pores, in the form of

[2] Water potential is the difference between environmental humidity and the humidity inside a plant.

water vapor, but also allows humidifying the immediate surroundings of the plant with the consequent reduction in the temperature in its border layer.

Evapotranspiration is an inevitable process requiring practically no expenditure of energy from the plant, and the vital functions that determine its growth and development depend on this process.

Evapotranspiration uses only 1% of solar radiation; this is equivalent to a tree evaporating approximately 400 l of water per day consuming about 278 kWh (Pokorn 2001).

The process of elimination of latent heat through evaporation of the land and transpiration of the vegetation cover determines ground temperature being lower or equal to air temperature by comparison with the temperature of surrounding impermeabilized surfaces.

Measurements at Different Urban Scales

The measurements taken in the three runs taken per day through the urban grid of the city of Mendoza are an empirical attempt to understand the behavior of urban green areas regarding variations in humidity and temperature as compared with their surroundings, as described below.

Table 1. Temperature and RH Measurements for the Parks and Urban Center

Measurement	San Martín Park		Urban center		Boundary Urban center		East Lateral Park
	Temp. °C	DT	Temp. °C	DT	Temp. °C	DT	Temp. °C
Dawn	17,2	1,4	18,6	0,5	19,1	1,2	17,9
Midday	30,1	0,8	30,9	1	31,9	0,3	31,6
Dusk	25,4	1,7	27,1	1,1	28,2	0,9	27,3
	RH %	DHR	RH %	DHR	RH %	DHR	RH %
Dawn	67,2	7,7	59,5	0	59,5	5,2	64,7
Midday	31,5	1,8	29,7	1,7	28	0,7	28,7
Dusk	48,5	8,5	40	1,3	38,7	3	41,7

The run begins with measurements taken at 5:30 a.m., a time when solar radiation still has no influence on horizontal surfaces and when it is clearly evident that stored heat (sensible heat) from the previous day has been eliminated from the different surfaces.

The second measurement is taken at 2:30 p.m. This is the time of greatest incidence of solar radiation over horizontal surfaces and the time when the difference in temperature and humidity between vegetated and urban areas is lower since, as mentioned before, there is a variation in the mixing altitude and inversion layer depending on the season and the time of day (Fig. 1 and Table 1). This lower difference in temperature and humidity is also the result of vegetated areas closing their stomata to reduce heat stress while impermeabilized surfaces are still storing heat.

Finally, the third measurement is taken at 8:00 p.m., a time when the sun is no longer out and solar radiation does not have a direct influence. Variations in the humidity and temperature of vegetated and impermeabilized surfaces as a result of stored heat can then clearly be seen.

Variations in humidity and temperature can easily be noticed in vegetated surfaces, as in the case of San Martin Park and in large, impermeabilized areas such as El Plumerillo Airport in the city of Mendoza.
Given the large extension of free surfaces in both sectors and the increase in wind speed, the temperature and humidity in these areas are slightly lower that the values recorded for surfaces closer to the urban sectors, where wind speed is practically nonexistent or approaching 0.2 m/s (Fig.7).

As observed in this figure, differences in humidity and temperature are higher overnight and, in particular, around sunset, when the sun has less influence on horizontal surfaces and, as a result of radiative cooling, temperatures are reduced.

This thermal amplitude is greater in more arid areas because less water vapor is available to act in regulating temperature. In fact, the relative local increase in water vapor in park areas helps regulate thermal variations, thereby achieving lower thermal amplitudes.

These differences in the variables analyzed are more pronounced between approximately 10:00 p.m. and 11:00 p.m.

As we will see below, this behavior is practically the same in the different urban areas where the measurements were taken.

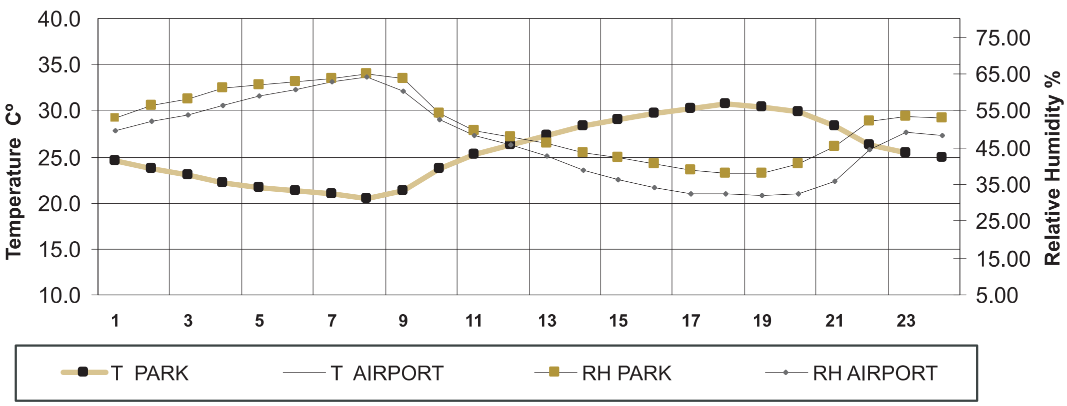


Fig. 7. Temperature difference between the Airport and San Martin Park for January 2004

Run 1 (5:30 a.m.)

The run begins in the peripheral area including 90% vegetated areas, distributed between grapevines, fruit orchards, and gardens in residential areas.

The first measurement taken at 5:30 a.m. indicates a high percentage of relative humidity which, on average, oscillates between 65% and 70%. This variation in humidity would mean an average temperature of 16°C in the predawn hours of a day that will have the following weather characteristics: calm winds (< 0.4 m/s), high number of hours of sunlight (heliofanía), and a temperature of about 30°C ± 2°C near midday. As our trip nears the central area, the increase in impermeabilized surfaces is more noticeable, and there is a 20% decrease in relative humidity and a proportional increase in temperature (5°C), a consequence of the decrease in surfaces with high capacity for evaporation (Fig. 8)

Let's remember that, at this time of the day, the influence of the sunlight is practically none and variations in humidity and temperature are stable. As can be seen in Fig. 8, differences in temperature and humidity are very marked at this time of the day, even without any impact from the sun.

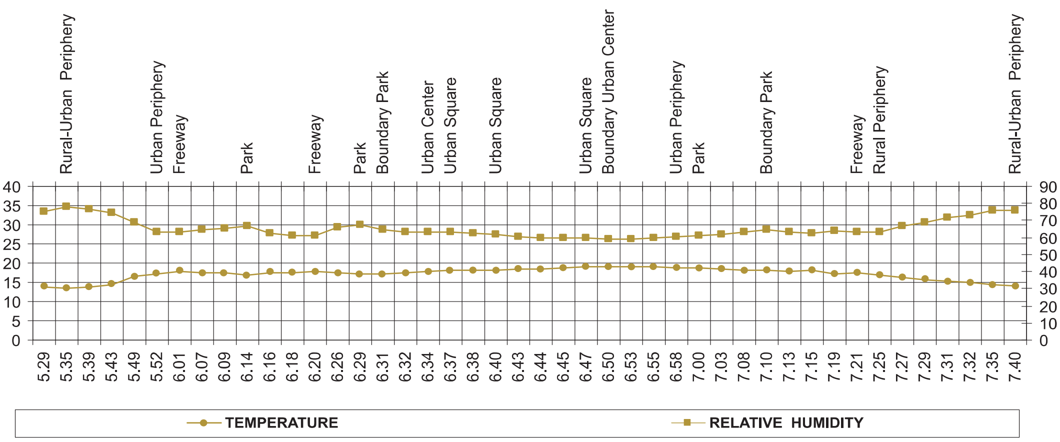


Fig. 8. Temperature and RH measurements during early morning for Run 1.

Run 2 (2:30 p.m.)

Around midday, variations in humidity and temperature between the periphery and the urban nucleus decrease as a consequence of high solar radiation and reduced wind speeds of 0.2 m/s.

This weather condition generates a relative humidity in the periphery that, on average, fluctuates between 32% and 33% and a temperature of 30.7°C. As we near the central area of the city of Mendoza, we observe manifestations of the plains effect as compared with the thermal amplitudes of the periphery, as can be seen in Fig. 9.

Although differences between the center and the periphery exist, these are less than during the early morning hours, with almost parallel HR and T values; humidity is only 9% less and temperature increases proportionally (3ºC) over the temperature of the periphery of the city (Fig.9).

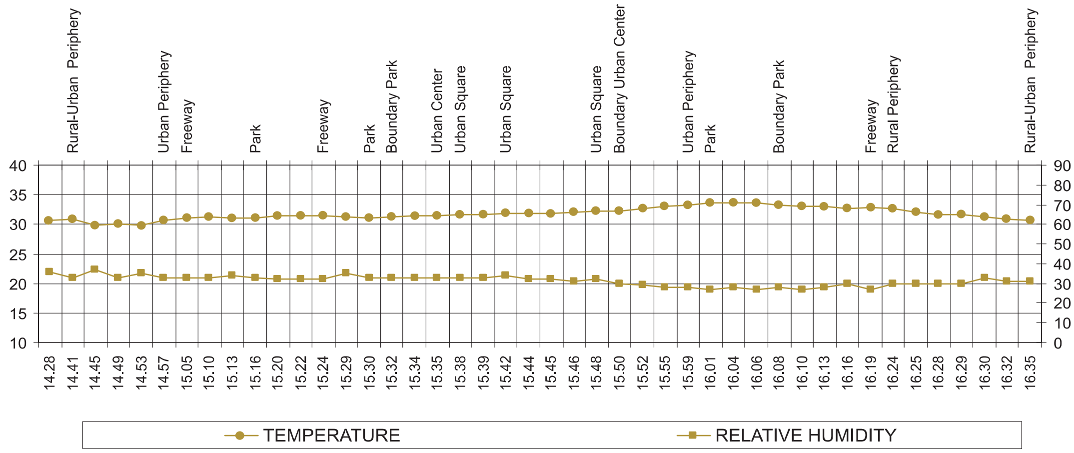


Fig. 9. Temperature and RH measurements in midday for Run 2.

Run 3 (8:00 p.m.)

Near sunset, after 8:00 p.m., when the sun again has no incidence over the various surfaces, we make the last run. This measurement, together with the one taken at sunrise the next day, enables us to observe the heat transfer of the different surfaces and the influence vegetated areas have in increasing humidity and reducing temperatures at the microscale at nighttime.

At the beginning of the measurement, the percentage of humidity is 54% and the average temperature 27ºC. With respect to the central area, there is a difference of 12% in humidity and temperature is 2.10ºC above measurements from the periphery.

These differences are more pronounced at the end of the run, at approximately 11:00 p.m. At this point in the run, humidity commences a rapid ascent starting at 10:00 p.m. and will be practically stable in the early morning hours, 10% to 15% higher than the humidity recorded at the end of the run. It is the same case for temperature that starts to descend until it stabilizes at 9ºC to 10ºC less than the temperature measured at the last point of the trip (Fig. 10).

If we look at the different graphs along the day, we notice a correlation in the variations of humidity and temperature in the areas studied. We can also see that, at the various points of the trip, when crossing a vegetated area larger than 5 ha, there is a variation in the increase of humidity that is directly reflected in a reduction in temperature, evidencing the direct relationship between these variables, mainly in vegetated areas.

A similar effect occurs when we approach sectors near the urban area, with a high percentage of impermeabilized surfaces, where humidity decreases rapidly and favors the appearance of the urban dry island effect. Although the reduction in humidity is primarily due to the daily temperature cycle, a cycle of smaller amplitude can be detected from the variation in the vegetated surfaces. This was verified by the measurements taken in the vegetated and the impermeabilized surface for the same period, which showed differences in humidity and temperature. The reduction of surfaces with evaporation capacity within the urban grid influences the availability of humidity and is translated into water comfort, very important in arid cities such as the one analyzed here.

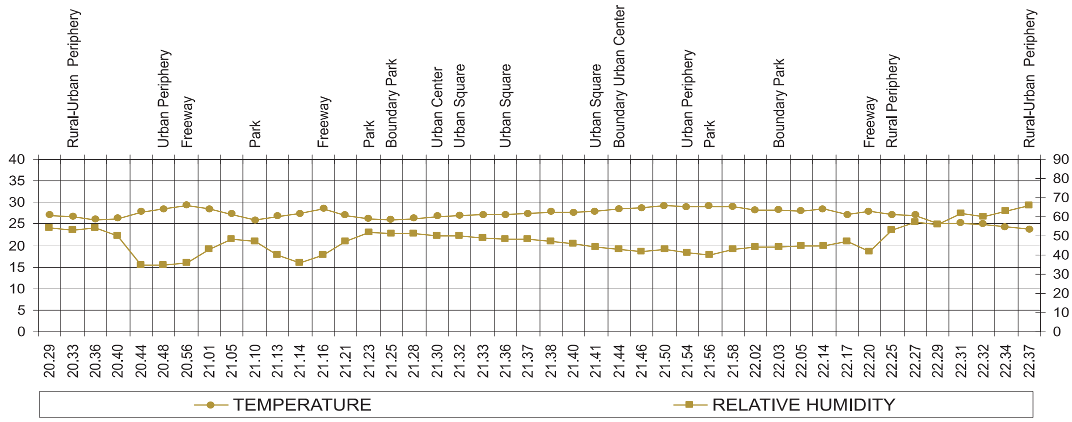


Fig. 10. Temperature and RH measurements at dusk for Run 3.

The Cool Island Effect in San Martín Park

The data collected enables us to observe how, during the day, the variations in humidity are reflected in changes in temperature of different intensities and how this situation is more pronounced when we cross large, vegetated sectors during our trip. This is the case of General San Martín Park, located on the western limit of the city of Mendoza, where its approximately 350 ha produce the effect of a cool island with values similar to those recorded at the periphery in the first few hours of the morning.

Numerous studies have reported similar effects produced by large vegetated areas—for example, Chapultepec Park in Mexico City, which we will use as a theoretical foundation to compare the effect of the cool island produced by a vegetated area (Jáuregui 1975, 1991) with respect to the variables analyzed in San Martín Park.

A comparison of the measurements recorded in both green areas shows variations in temperature with oscillations of 2°C to 3°C with respect to the limits of the park; but the scope and intensity of this effect differ notably in these two vegetated areas, as we will see below.

Chapultepec Park features an influence that extends the cool island effect to a radius of 2 km, practically the width of the park; the measurements taken in San Martín Park show that the influence is not as strong, as the maximum radius of the extension is no more than 300 m, after which there is a slight increase in temperature, proportional to the increase in impermeabilized surfaces.

The cool island effect produced in these large green areas exhibits marked differences in behavior and extension. This phenomenon is due both to geographic factors (sky view factor, height above sea level, and distance form the park border), as well as weather variables (wind, cloud cover, global radiation, air temperature, subsurface temperature, and humidity).

Studies clearly show how wind direction, speed, and intensity increase the advection between the limits of the park and the built areas and also influence the intensity and extension of the cool island effect (Upmanis and Chen 1999).

The configuration of the city, the design of its streets, and its orientation and shape can favor wind speed, which in turn favors or does not favor reduced temperatures. The current consolidation of cities as conglomerates of buildings of different heights breaks the wind flow, dissipating it in different directions and affecting its intensity inside the city (Golany 1996). This effect can be clearly appreciated as we near the city of Mendoza. Although wind intensity is very low, when we enter the urban nucleus of the city, there is a progressive decrease in wind speed and direction, with almost no movement, except for local turbulence as a result of the form and direction in which the vehicles move.

We can thus infer that wind is one of the determining factors in the scope and intensity of the cool island effect produced by a vegetated area. In addition, the energy balance of the vegetation produces the exchange of humidity with the environment.

Regarding the net radiation balance, we have to consider the exchange of energy with the environment, that is, how the heat is conducted from one body to a cooler one. In the case of foliage, leaves possess a temperature that only varies outside the layer of air adjacent to the leaf, and the heat is conducted outside this border layer by fortuitous collision with air molecules. This process is called convection (Nobel 1983).

There are two types of convection: free or forced convection. Our study will focus on forced convection, caused by the wind, which removes the warm air dissipating it outside the border layer of the leaf. This dissipation will be greater as wind velocity increases. However, with a typical wind of 0.2 m/s (0.72 km/h) for Mendoza, forced convection in the vegetation prevails over free or natural convection as a way of dissipating heat.

Heat is conducted outside the layer of air adjacent to the leaf and then removed by forced convection of the surrounding turbulent air, generating a localized effect around the plant. Thus, the cool island effect produced by San Martín Park extends to a radius of less than 300 m, with a wind speed of 0.2 m/s toward the central area, producing the heat transfer by forced convection.

This effect begins to dissipate when crossing a residential sector at an average height of 9 m. Although the area is composed of buildings including a high percentage of vegetated surfaces in the form of private gardens, the incorporation of impermeabilized elements neutralizes the effect of the cool island that the forced convection at 0.2 m/s could generate, progressively exhibiting the dry island effect in the direction of the central nucleus of the city.

Outside the radius of influence within 300 m of the vegetated area, humidity begins to decrease and, gradually, temperature begins to increase toward the urban area approximately 0.20ºC every 300 m, stabilizing in the central area nucleus at 3ºC above the limits of the park.

This phenomenon can be observed near sunset and is more pronounced overnight. Although the cool island effect in San Martín Park has a more limited scope than the one observed for Chapultepec Park, the differences in temperature within the park limits and in the urbanized area coincide (Jáuregui 1975, 1991). See Fig. 12.

It should be noted that outside this radius of influence, between approximately 500 and 700 m, the urban scenario begins to show a higher density of impermeabilized or built surfaces and reduced vegetated surfaces. If we analyze the temperature and humidity graphs, these variations coincide with the point of entry into the urban nucleus, where the difference in humidity in the early morning hours is about 4.5% less and the increase in temperature is 0.7ºC as compared with the park, only 700 m away from the vegetated area, during the period when the sun has no incidence and variations in humidity and temperature have already stabilized.

As we progress inside the urban nucleus, vegetated spaces become scarcer and their size is regulated by the octagonal design of the city of Mendoza, typical of all Spanish colonial cities. These areas are no larger than 1 ha, and there is only one area of approximately 4 ha designed as a central plaza.

Upon analyzing the variations in temperature and humidity in these green areas within the urban fabric of the city of Mendoza, we can observe a decrease in humidity and an increase in temperature.

This increase in temperature is maintained throughout the day, even at night and during the early morning hours, that is, these spaces considered to be green areas within the urban fabric primarily behave as impermeabilized horizontal surfaces.

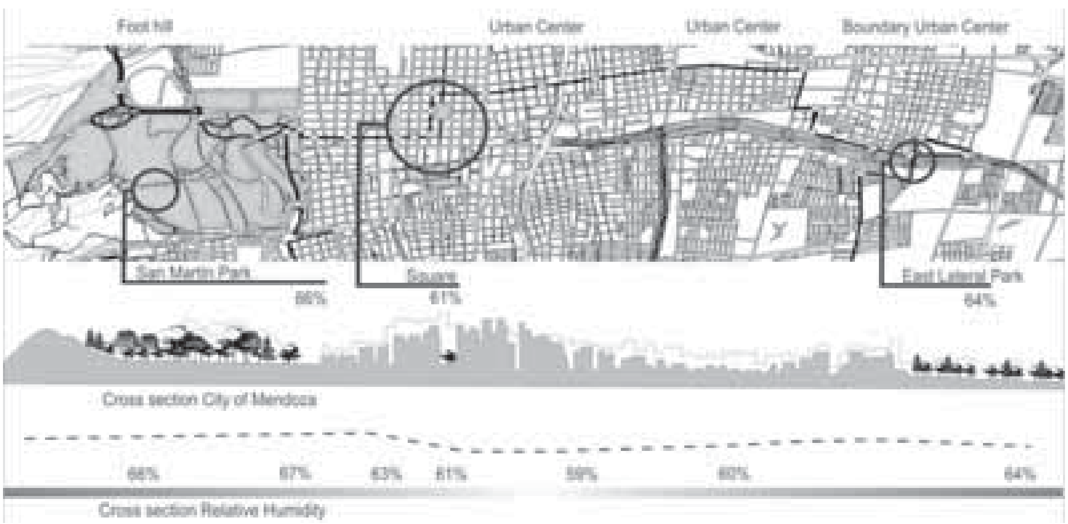


Fig. 11. Variations in HR in the city of Mendoza - East-West urban cross-section.

Although the variations in temperature are very small, about 0.2°C, they provide an indication of how these areas behave in an urban environment. When observing the daily variations in relative humidity in these sectors, we see that they are not consolidated as areas of influence on their immediate surroundings, and they maintain percentages of humidity similar to those of impermeabilized surfaces, oscillating at about 32% ± 2% of relative humidity. Furthermore, when taking specific measurements in the various sectors of these urban squares, we found differences below the relative humidity of the built surroundings, which point to the dry island effect.

We can then infer that the use of highly impermeable materials, such as asphalt in roads or parking lots in urban spaces, should be carefully distributed in order to prevent a decrease in the percentages of humidity that tends to augment the dry island effect and, therefore, negatively influence variations in temperature.

According to the measurements taken in the runs and considering that a normal summer day in the city of Mendoza reaches average temperatures between 30ºC and 32ºC, we noticed that elements such as asphalt record temperatures more than twice as high as ambient temperatures, oscillating at around 61°C ± 2°C. These differences in temperature are more pronounced around midday, while vegetated horizontal elements, irrigated every two days, do not surpass ambient temperature.

These vegetated surfaces have a thermal variation of 15.2°C ± 2°C at 6:00 a.m.; 31.1°C ± 2°C at 3:30 p.m., and 21.1°C ± 2°C at 9:30 p.m. During these same periods, asphalt temperature is always higher than ambient, with measured values of 25.5°C, 58.6°C, and 36.7°C, respectively (Table 2 and Fig. 12).

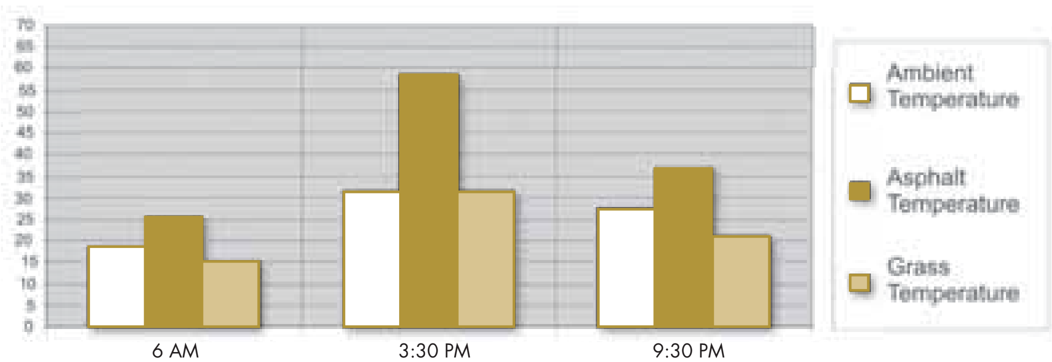


Fig. 12. Difference in temperature between impermeabilized and vegetated areas.

As mentioned above, the behavior of horizontal surfaces impermeabilized with asphalt produces an increase in the surface temperature of the material and the surrounding air, given their high capacity to absorb heat (Kjelgren and Montague 1998). This increase in temperature in the material and surrounding air is clearly observed when considering an avenue adjacent to San Martín Park.

The measurements along this avenue were taken in January 2004 and 2005. During 2004 this avenue expanded to three times its original surface. The layout of this avenue can be considered a large, impermeabilized conic surface consisting of two very different areas: the first is the entry sector, considered representative of any street in the city of Mendoza, 20 m wide. The second area occupies practically 70% of the total area and is 60 m wide.

This avenue was measured in three stages: in the entry sector (20 m wide), in the wider sector, and in an auxiliary circulation road adjacent to the first sector, with spatial characteristics similar to the first tract. The data obtained were to be used as a reference, in order to avoid possible deviations in the measurements.

The measurements taken throughout the day and the comparisons made between the two areas that comprise the avenue described above show a difference in humidity of 2% between both sectors and an increase in temperature of 0.3°C in the wider area. On sunny days with many hours of sunlight, these differences in humidity and temperature occur rapidly, at less than 500 m from the limit of the first tract.

When comparing these data with those from the center of the park, it can be concluded that the impermeabilized surfaces of this avenue have variations of 7% in humidity and 0.5°C in temperature in the morning (5:30 a.m.). At midday (2:30 p.m.), variations are reduced to 3% in humidity and 0.2°C in temperature. At night (8:00 p.m.), the thermal amplitude between both sectors is more noticeable, as the humidity recorded is almost 10% less and the temperature is 2.5°C above the temperature of the center of the park, located 3 km away from the impermeabilized surface.

The Cool Island Effect in the East Lateral Park

Continuing with our run, we enter an urban area close to the central nucleus. This sector has a green area representative of growing urban sectors, defined by residual spaces that the city has left without specific land use, as is the case of the East Lateral Park, located on both sides of one of the main access routes into the city. Conceived as a linear green area approximately 100 m wide and with an average length of 5,800 m, this area is subdivided into ten sectors, each 500 m long. The total area on each side is 20 ha, and the measurements taken represent 50% of the north side of the East Lateral Park.

It is important to note that these are favored residential areas and shopping centers (placed at the periphery of the residential areas) because of ease of access and mobility.[3] From this description, we can see this is a complex scenario in which residential areas coexist with commercial sectors, mixed in with large, impermeabilized horizontal surfaces (parking lots and roads) and vegetated areas, which will be our next analysis scenario.

[3] The term mobility is a concept associated with people or goods; it is used to express facility of movement. On the other hand, accessibility is a concept associated with places or with the possibility of obtaining goods, services, or contacts. Accessibility, therefore, is used either in relation to the cost or difficulty of movement required to satisfy a need, or in relation to the cost or difficulty for supplies or clients to arrive at the place in question.

The East Lateral Park is located in the urbanized area near the central nucleus of the city of Mendoza, in the department of Guaymallén. It extends from the limits of that sector toward the central area. The interior landscaping of this green area does not incorporate walkways or trails of impermeabilized surfaces. Materials such as ground clay tiles, gravel, or brick dust have been used, which allow evaporation from the ground, leading us to believe the interior surface of the park has an evapotranspiration capacity of 100%.

The measurements taken in this space in the three runs through the city provide relevant data regarding the variables of humidity and temperature. The data obtained allow comparisons of the characteristics of the different vegetated areas, and lead to conclusions about the shape and size green areas should have in order to be used as elements of urban design that should optimize the climate characteristics of intermediate cities with desert climates.

The humidity recorded in the East Lateral Park in the early morning hours was 64%, and the temperature was approximately 17°C. At midday, a humidity of 28% was recorded, with temperatures nearing 32°C, and during the night run, a humidity of approximately 42% was recorded, with a temperature of 27°C. The effect of the cool island produced by the Lateral Park extends for no more than 60 m (Table 2).

Table 2. RH and T Difference between the Urban Center and East Lateral Park

Measurements	Urban Center		Difference RT and T		East Lateral Park	
	RH	T	DRH	DT	RH	T
Dawn	59	19	5.75	1.975	64.75	17.025
Midday	29.25	31.375	0.5	0.325	28.75	31.7
Dusk	39	27.675	2.75	0.375	41.75	27.3

Throughout the day, this vegetated area features values approximating the measurements recorded in San Martín Park. As can be seen, there is a small variation most noticeable at midday.

The surroundings of the park consist mainly of asphalted impermeabilized surfaces such as roads, large shopping-mall parking lots, and supermarkets. Over 70% of the residential area is built. This sector also includes higher-density residential areas, for example, buildings over 21 m in height on the south side.

Extension of the Cool Island Effect in Parks of Different Sizes

When comparing the variations between San Martín Park and the East Lateral Park, located on opposite (east-west) extremes of the city of Mendoza, we can see the similarity in the behavior of variations in humidity and temperature throughout the day, but not in the green areas inserted in the urban grid (Fig. 13).

These two areas exhibit marked differences in size but no significant changes in the cool island effect. For example, the East Lateral Park in the northern part of the city has an extension of 10 ha, equivalent to only 3% of the total area of San Martin Park. Despite this difference, there are no significant changes in the cool island effect, as humidity has an average difference of 4% throughout the day, and temperature, a difference of less than 1.5°C with respect to the limits of the park.

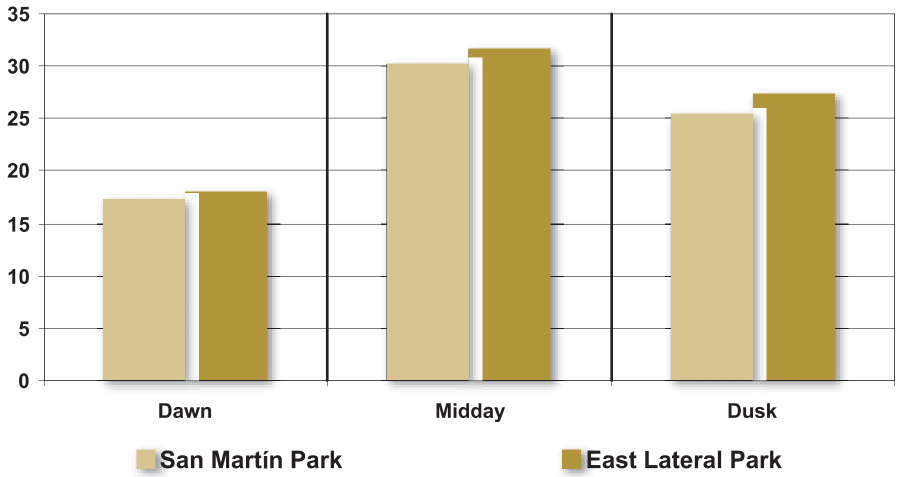


Fig. 13. Variation in temperature (above) and RH (below) between different parks.

Another important aspect to consider is the cool island effect that the vegetated front portion of the park produces over the immediately adjacent urban area. The cool island effect produced by San Martín Park is slightly more pronounced than in the East Lateral Park (Fig. 13).

The San Martín Park has a north-south front of 2 km to the urban area of high building density, with a cool island effect reaching an extension of up to 3 km inside the urban area, while the East Lateral Park has a smaller effect both in intensity and in extension. However, the fronts next to the urban area of the East Lateral Park double those of San Martín Park. Therefore, although the intensity is somewhat lower, the effect over built surfaces along the front is higher.

Discussion

Measurements taken throughout the city of Mendoza allow us to observe the generation and behavior of the dry island effect regarding variations in humidity at the microscale and their influence in reducing temperatures in the surrounding environment. This influence accentuates the importance of vegetated spaces in urban areas to regulate relative humidity and the resulting decrease in the temperature of the surroundings.

Changes in humidity and temperature at the periphery are more noticeable than in the urban nucleus. In the early morning hours, humidity is, on average, 16% above the humidity of the central urban area, and temperature is 5°C below the temperature of the urban area. These differences are especially noticeable in vegetated areas with over 85% of the soil covered with vegetation or with surfaces with high evaporation capacity. Inside the urban nucleus, it is possible to find variations in temperature and humidity near large vegetated areas such as parks, but never over 3°C in temperature and 9% in humidity.

On the other hand, it has been shown that the cool island effect produced by the different vegetated areas extends toward the urban nucleus, from the limit of the parks, with a wind speed of 0.2 m/s. This effect mainly extends as a result of forced convection toward the impermeabilized areas, within a range that varies from under 100 m up to no more than 300 m, depending on the dimension of the vegetated surfaces, as shown below.

The extension of the cool island effect present in these green areas provides some guidelines about the dimensions a park should have in total area and vegetated front in order to be considered an element that would influence a city's environment.

We were able to observe that variations in humidity and temperature inside large vegetated areas (General San Martín Park) are practically constant, but close to the exterior limit, there is a slight decrease in temperature and an increase in relative humidity; that is, the central area of the park exhibits a constant saturation of humidity that regulates temperature.

At the same time, the measurements taken revealed that vegetated areas of about 300 ha in size, with a depth of 2,000 m, achieve an extension of detectable cool island effect of 300 m from the limit of the park toward the urban nucleus; however, their effect can still be perceived softly up to 3 km.

On the other hand, smaller vegetated areas of about 10 ha and 100 m in depth, such as the East Lateral Park, can extend the effect for about 60 m from the limit of the vegetation, a distance more than double its depth.

When comparing the depth of both areas and the extension of the cool island effect, we can see that the East Lateral Park with only 5% of the depth of San Martín Park achieves 20% more of the extension effect than the larger park (Table 3).

The size of the parks in the city of Mendoza exhibit shortcomings as environment-regulating elements. In conclusion, the size and shape of these spaces influence the differences in the variables studied. The size of the vegetated areas triggers variations in humidity and temperature directly related to the extension of the cool island effect, but not to the intensity of the cool island effect, as can be seen in Table 3.

These guidelines allow us to establish some general considerations for designing these areas. From our perspective, the design of parks included in urban environments should take into account, in addition to aesthetic aspects, elements aimed at regulating climate that will further justify their incorporation into the urban grid, in particular for growing cities.

Table 3. RH and T Difference between the Parks

Measurement	San Martín Park		East Lateral Park
Area	350 has.		10,40 has.
	Temp. ºC	DT	Temp. ºC
Dawn	17,2	0,7	17,975
Midday	30,175	1,5	31,675
Dusk	25,475	1,8	27,3
	RH %	HR	RH %
Dawn	67,25	2,5	64,75
Midday	31,5	2,8	28,75
Dusk	48,5	6,8	41,75
Direct influence Cool Island effect	Distance from Park		Distance from Park
	≥ 300 m		≥ 100 m

This aspect of the design of green areas requires thinking about urban planning not as an intervention on the residual spaces the city has no use for, but as an element that promotes order within the fabric of the city, regardless of the scale of the urban project, and that enables organizing the area to support different uses.

The measurements taken allow us to conclude that, when designing green spaces to influence the environment, recreation and relaxation spaces with strong aesthetic values and, therefore, with more impermeabilized surfaces, should be zoned toward the interior of the park. The area meant to influence the climate of the urban environment should be located toward its outer limits, forming a ring next to the urbanized area to maximize the cool island effect.

We observed that the large center of the park many times has no influence over the extension of the cool island effect, but it is an area where the levels of humidity and temperature are more stable. The center of the park is therefore the optimal place to carry out recreational activities.

The zoning responds mainly to two criteria: First, the vegetated areas close to built surfaces produce an exchange of heat that is noticed only in areas with a totally vegetated depth no less than 100 m. After 500 m in depth, this effect is not directly proportional to the depth of the park, but other climatic aspects must be considered.

Second, we should consider that the vegetated front of the park is connected to the urban area which, when designing a park, should received greater consideration than its depth.

As we have been able to observe, the different green areas inserted in the urban grid of the city of Mendoza, with sizes varying between 1 and 4 ha, when containing approximately 60% of impermeabilized surfaces, cannot consolidate the cool island effect, nor are they able to extend this effect to their immediate surroundings, behaving almost like impermeabilized surfaces.

When incorporating urban vegetation, some features such as height, specific bearing, shape, foliage density, and water requirements must be studied and analyzed. Although some of these features are considered in the design of green areas, little thought is given to how they will influence the environment and, even less, to their general and global effects. This lack of concern is the result of thinking of green areas as being regulated mainly by aesthetic criteria, according to which vegetation merely enhances the aesthetic appeal of an urban fixture.

In planning urban green areas, lack of knowledge of area dimensions as a ratio between the percentages of impermeable materials and vegetation to be incorporated, may result in these areas becoming a problem inside the city.

In intermediate cities like Mendoza, where climate is harsh, it is necessary to revise the planning policies pertaining to the design of green areas with a view to rational land and water use.

Mendoza illustrates the importance of climatic conditions in arid areas. In this type of cities, radiation absorbed by horizontal surfaces in the summer months (streets, roofs of buildings, etc.) is high aggravating the impact of high temperatures and low humidity within the urban area. Hence, it is necessary to award attention to the role of parks and other vegetated areas as resources to mitigate the negative impact extreme climatic conditions. Our results highlight the importance of prioritizing the use of vegetated spaces in urban planning.

The dynamics of urban growth, expressed initially as changes in land use, directly disturb the metabolism of anthropogenic and natural ecosystems.

As has been seen, variations in temperature and humidity affect local climate in the city and produce different effects known as urban dry island and urban heat island. This phenomenon not only modifies weather comfort for citizens but also affects global climate because of increased CO_2 flows.

Taking into consideration the variation in thermal and hydric amplitude in arid cities, a significant proportional increase in greenhouse gas emissions is foreseen in order to compensate for the residents' loss in comfort. If we consider the population around the world living in intermediate cities in arid areas, we have to understand the need to deepen the study of the complex urban climate processes in order to mitigate and reduce the effects. The case of Mendoza is a helpful example to other cities in arid areas in Latin America.

Acknowledgments

The authors would especially like to thank Bruno Cavagnaro for his open advice and precise comments; José L. Quero for his support with the measuring equipment; Ana Teresa Gómez, Department Head of the Meteorological Information Center of the National Weather Service, Argentinean Air Force, Air Region Command for the data and information provided; Dr. Ernesto Jáuregui for his comments and the bibliography he so kindly provided; and Dr. Roberto Sanchez Rodriguez for his invaluable support and advice during the preparation of this chapter.

References

Barradas, V. L., Tejeda Martínez, A., and Jáuregui, E. 1999. "Energy balance measurements in a suburban vegetated area in Mexico City." *Atmospheric Environment* 33:4109–4113.

Bellet, C., and Llop, J. M. 2004. "Miradas a otros espacios urbanos: las ciudades intermedias." *Geo Crítica/Scripta Nova* 8(165). Universidad de Barcelona, Spain.

Bochaca, F. R. 2005. "El verde en la estructura urbana de Mendoza." *Arquitectura–Infraestructura* 60:68–71.

Charciarek, T. 2001. *Daily Course of Vapour Pressure and Relative Humidity Differences between Urban and Rural Sites in Lodz*. University of Lodz, Lodz, Poland.

Dimoudi, A., and Nikolopoulou, M. 2003. "Vegetation in the urban environment: microclimatic analysis and benefits." *Energy and Buildings* 35:69–76.

Golany, G. S. 1996. "Urban design morphology and thermal performance." *Atmospheric Environment* 30:45–65.

Heisler, G. M. 1986. "Effects of individual trees on the solar radiation climate of small buildings." *Urban Ecology* 9:337–359.

Jáuregui, E. O. 1975. "Microclima del Bosque de Chapultepec." *Boletin del Instituto de Geografía* 6. Universidad Nacional Autónoma de México, Mexico City, Mexico.

Jáuregui, E. O. 1991. "Influence of a large urban park on temperature and convective precipitation in a tropical city." *Energy and Buildings* 15:457–463.

Kjelgren, R., and Montague, T. 1998. "Urban tree transpiration over turf and asphalt surfaces." *Atmospheric Environment* 32:35–41.

Koerner B., and Klopatek, J. 2002. "Anthropogenic and natural CO_2 emission sources in an arid urban environment." *Environmental Pollution* 116:45–51.

Nobel, P. S. 1983. *Biophysical Plant Physiology and Ecology*. W. H. Freeman and Company, San Francisco, CA. 608 pp.

Pokorn , J. 2001. "Dissipation of solar energy in landscapes controlled by management of water and vegetation." *Renewable Energy* 24:641–645.

Pomerantz, M., Akbari, H., Chang, S.-C., Levinson, R., and Pon, B. 2003. *Examples of Cooler Reflective Streets for Urban Heat-Island Mitigation: Portland Cement Concrete And Chip Seals.* Lawrence Berkeley National Laboratory. Paper LBNL-49283. (http://repositories.cdlib.org/lbnl/LBNL-49283).

Puliafito, E., Guevara, M., and Puliafito, C. 2001. "Modeling air pollution in an industrial area using GIS as an assessment tool." In: *Air Pollution*, vol. 9 of the series *Advances in Air Pollution* (Latini, G., and Brebbia, C., Eds.). Editorial Witt Press, Southampton, England.

Puliafito, E., Guevara, M., and Puliafito, C. 2003. "Characterization of urban air quality using GIS as management system." *Environmental Pollution* 122:105–117.

Puliafito, E., and Puliafito, C. 2005. "Monitoring and modeling air quality in Mendoza, Argentina." In: *Regional and Local Aspects of Air Quality*, vol. 12 of the series *Advances in Air Pollution* (Elson, D., and Longhurst, J., Eds.). Editorial Witt Press, Southampton, England.

Rosenfeld, A. H., Akbari, H., Bretz, S., Fishman, B. L., Kurn, D. M., Sailor, D., and Taha, H. 1995. "Mitigation of urban heat islands: materials, utility programs, updates." *Energy and Buildings* 22:255–265.

Shashua-Bar, L., and Hoffman, M. E. 2000. "Vegetation as a climatic component in the design of an urban street: An empirical model for predicting the cooling effect of urban green areas with trees." *Energy and Buildings* 31:221–235.

Shashua-Bar, L., and Hoffman, M. E. 2003. "Geometry and orientation aspects in passive cooling of canyon streets with trees." *Energy and Buildings* 35:61–68.

Upmanis, H., and Chen, D. 1999. "Influence of geographical factors and meteorological variables on nocturnal urban-park temperature differences—A case study of summer 1995 in Göteborg, Sweden." *Climate Research* 13(2):125–139.

Urban Growth and Its Consequences at the Regional Level in the Lake Cuitzeo Basin, Mexico.

5

Authors:
Erna López
Manuel E. Mendoza
Gerardo Bocco
Alejandra Acosta

In recent years, human activities have been recognized as the strongest force shaping the biosphere and are even more responsible than natural forces for the current changes in the flows and status of the biosphere.

Changes in land cover and land use (LCLU) are the result of the complex interaction between humans and the biophysical environment. These changes affect a broad range of spatial and temporal scales. Understanding them and their social driving forces is vital to understanding, modeling and predicting local, regional, and global changes.

This chapter studies the growth of urban centers (larger than 2,500 people), located within the basin of Lake Cuitzeo, a preservation and study area for several international organizations.

This work is based on the intensive use of aerial photographs taken between 1975 and 2000, as well as geographic information systems (GIS). The study concludes that the population in the basin is mostly urban and tends to concentrate in the 26 urban settlements of the area, mainly the city of Morelia, capital of the State of Michoacán, with an urban footprint that has grown over 600% in recent years.

The main problems faced by the area include lack of planning for the urban growth exhibited by all the cities located in the basin, increased water use by the population and irrigation crops (62%), and lack of waste water treatment plants.

Water entering Lake Cuitzeo consists of residual waters from the city of Morelia and irrigation waters from surrounding crop lands, which has caused uncontrolled expansion of the vegetation around the body of water and the yearly desiccation of part of the lake (second largest in Mexico).

Introduction

Changes in the landscape and ecosystems resulting from human activities are usually so relevant that, even at the global scale, they significantly affect key operational aspects of land systems (Lambin et al. 2001) because they may contribute to local and regional climate change and to global warming (Houghton et al. 1999). In particular, many changes are the primary source of soil degradation (Tolba and El-Kholy 1992). When ecosystem services are altered, their capacity to satisfy even basic human needs starts to be compromised (Vitousek et al. 1997). Each change also partially compromises the vulnerability of places and people to climate and economic and socio-political perturbations (Kasperson et al. 1995).

The factors resulting in changes to LCLU, as well as the consequences of those changes, include several socio-economic and environmental variables. However, the quantitative analysis of the relative importance of these elements to LCLU is not sufficient, as interpretations of how these factors interact to stimulate change vary widely from one region to the next (Skole et al. 1994, Kummer and Turner II 1994). To this effect, the potential impact of LCLU on the physical and social environment has stimulated research of its main causes and effects (Veldkamp and Verburg 2004).

Humans have transformed natural systems since they emerged as the dominant species. There has been a traditional tendency to assume that social and economic progress is invariably associated with increased urbanization and the growing role of cities in the development process (Juppenlatz 1990). The incredible paradox now is that some of the achievements of the scientific and technological progress made for improving living conditions represent a threat to our planet and to the balance of its ecosystems.

According to Grübler (1994), the portion of the planet occupied by human settlements is less than 2%; however, the people living in those settlements require innumerable resources to survive and are mostly responsible for the degradation of forests, crop lands, pastures, and rural areas. The ecological footprint of urban population is critical to assessing changes to the earth's surface.

Currently, one way to spatially define and analyze the growth of human settlements is by using remote sensing (RS) and GIS.

This work analyzes changes in LCLU in the urban settlements of the Cuitzeo Basin between 1975 and 2000.

Study Area

The closed basin of Lake Cuitzeo comprises about 4,000 km^2 and is located in the northern part of the State of Michoacán de Ocampo, between 19 30′ and 20 05′ latitude north and 101 35′ and 101 30′ longitude west. It is part of the physiographic province of the Transversal Volcanic System. The main types of soil in the study area are vertisols, luvisols, and andosols. The basin consists of hills, high slopes, and plains developed over volcanic materials of intermediate to basic composition and lacustrian sediments from the Miocene to the Recent period (Mendoza 2002, Pasquarè et al. 1991).

Lake Cuitzeo has an extension of approximately 300 km^2. This basin is important because the lake is the largest continental wetland in the country, visited by hundreds of migratory birds each year. It is nestled on a high plateau at nearly 2,000 meters above sea level. It is shallow, brackish, and is affected by degradation processes resulting from anthropogenic activities.

Precipitation increases from north to south, while temperature increases from south to north. The spatial distribution of these parameters indicates that the study area is located in a transitional zone, between temperate-dry and temperate-humid climates.

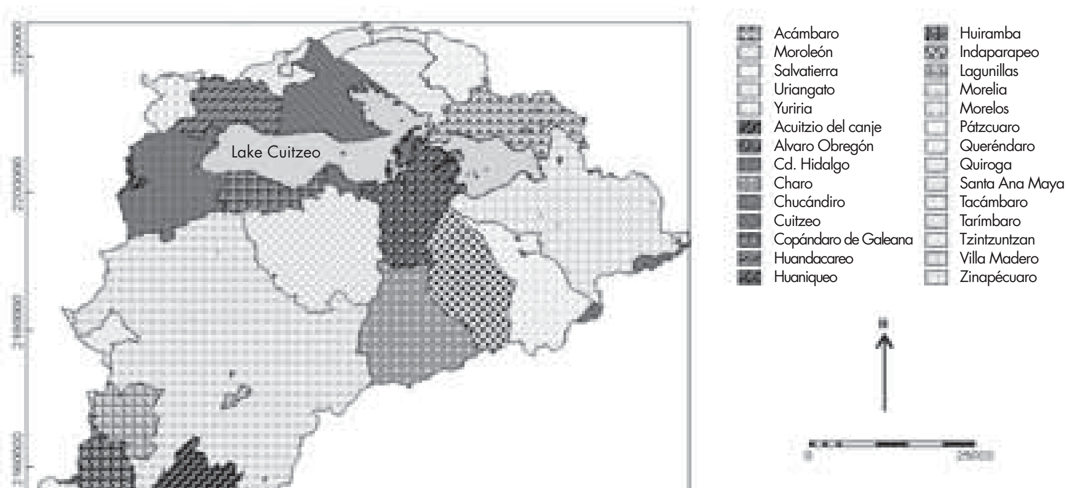


Fig. 1. Map of municipalities located in the Lake Cuitzeo Basin.

Source: Distribution of human settlements in the Lake Cuitzeo Basin.

The basin comprises 28 municipalities (Fig. 1), which were composed of 392 human settlements in 1970, increasing to 687 in 2000 (INEGI 2000) (Fig. 2, Table 1). The population of the basin in 1970 numbered 380,787 inhabitants (16.4% of the state's population), and by 2000 it had grown to 837,773 people (21.6% of the state's population).

The economic activities undertaken in the study area in 1975 were mainly agriculture, grain production in particular, and animal raising (on average, 88% of the economically active population worked on primary activities). By 2000, only 30% of the economically active population remained in the primary sector, and the rest was involved in secondary and tertiary activities (INEGI 1970, 2000).

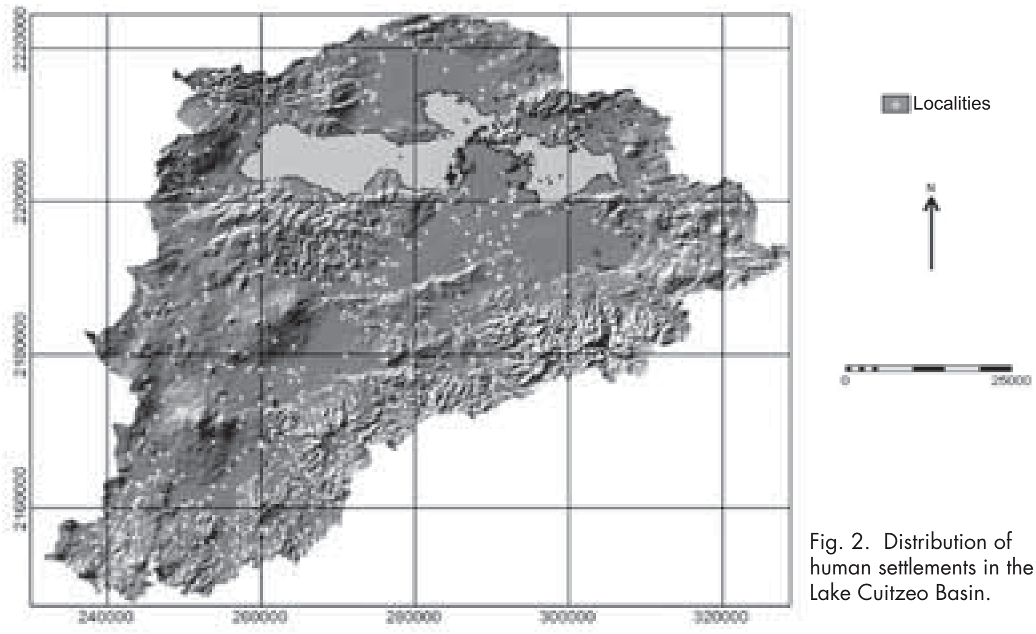


Fig. 2. Distribution of human settlements in the Lake Cuitzeo Basin.

Source: INEGI-CONAPO, localities, conteo 1995
INEGI, Topographics maps, scale 1:50,000

Table 1. Number of Human Settlements by Municipality in the Cuitzeo Basin.

Municipality	Nº. of Rural Settlements		Nº. of Urban Settlements	
	1970	2000	1970	2000
Acámbaro	9	13	1	1
Acuitzio	20	34	1	1
Álvaro Obregón	20	42	1	1
Copándaro	11	14	1	1
Cuitzeo	15	19	1	3
Charo	17	37	1	1
Chucándiro	20	20	0	0
Hidalgo	1	2	0	0
Huandacareo	6	7	1	1
Huaniqueo	0	0	0	0
Huiramba	11	7	0	1
Indaparapeo	15	34	1	2
Lagunillas	8	14	0	0
Madero	0	1	0	0
Morelia	101	216	1	4
Morelos	11	14	0	0
Moroleón	4	5	0	0
Pátzcuaro	3	9	1	1
Queréndaro	14	15	1	1
Quiroga	1	1	0	0
Salvatierra	8	8	0	0
Santa Ana Maya	15	17	1	1
Tacámbaro	0	0	0	0
Tarímbaro	32	61	1	4
Tzintzuntzan	0	0	0	0
Uriangato	7	12	0	0
Yuriria	2	4	0	0
Zinapécuaro	25	47	2	4

Source: *Prepared from INEGI (1970 and 2000)*

Methodology

This work is based on a sequential comparison of black-and-white aerial photographs taken on panchromatic film (Fig. 3). The approximate scale was 1:50,000 for 1975 and 1:37,000 for 2000. The final map scale was 1:50,000. The interpretation of the aerial photographs was carried out using a mirror stereoscope.

The criteria contributed by this analysis enable recognition of the elements to be identified (size, shape, tone, texture, and pattern) according to the LCLU legend generated in this work. The categories for LCLU represent open and semi-open forests, closed forests, shrub lands and pasturelands, plantations, irrigation crops, seasonal crops, human settlements, uncultivated land, bodies of water, and erosion. The accuracy of the interpretation was evaluated using a confusion matrix and, in order to validate the spatial quality of the database, the polygons were verified using the technique described by Bocco and Riemann (1997).

The cartographic material necessary to carry out the research consisted of topographic (1:50,000) and soil charts (1:50,000) from INEGI, as well as the geomorphology by Mendoza et al. (2001). The spatial information was generated and manipulated using the ILWIS program (Integrated Land and Water Information System) versions 1.41 (ILWIS 1990) and 2.23 (ILWIS 1998).

Once the photo-interpretation of LCLU was carried out and validated in the field, this information was digitalized in a vectorial model within the GIS. Next, the digitalized arcs were restituted by automation within the system in order to generate the databases of the land cover maps for the period 1975–2000.

Finally, the spatial superposition of the LCLU databases was carried out in order to identify the most significant changes occurring in the basin for the period under study.

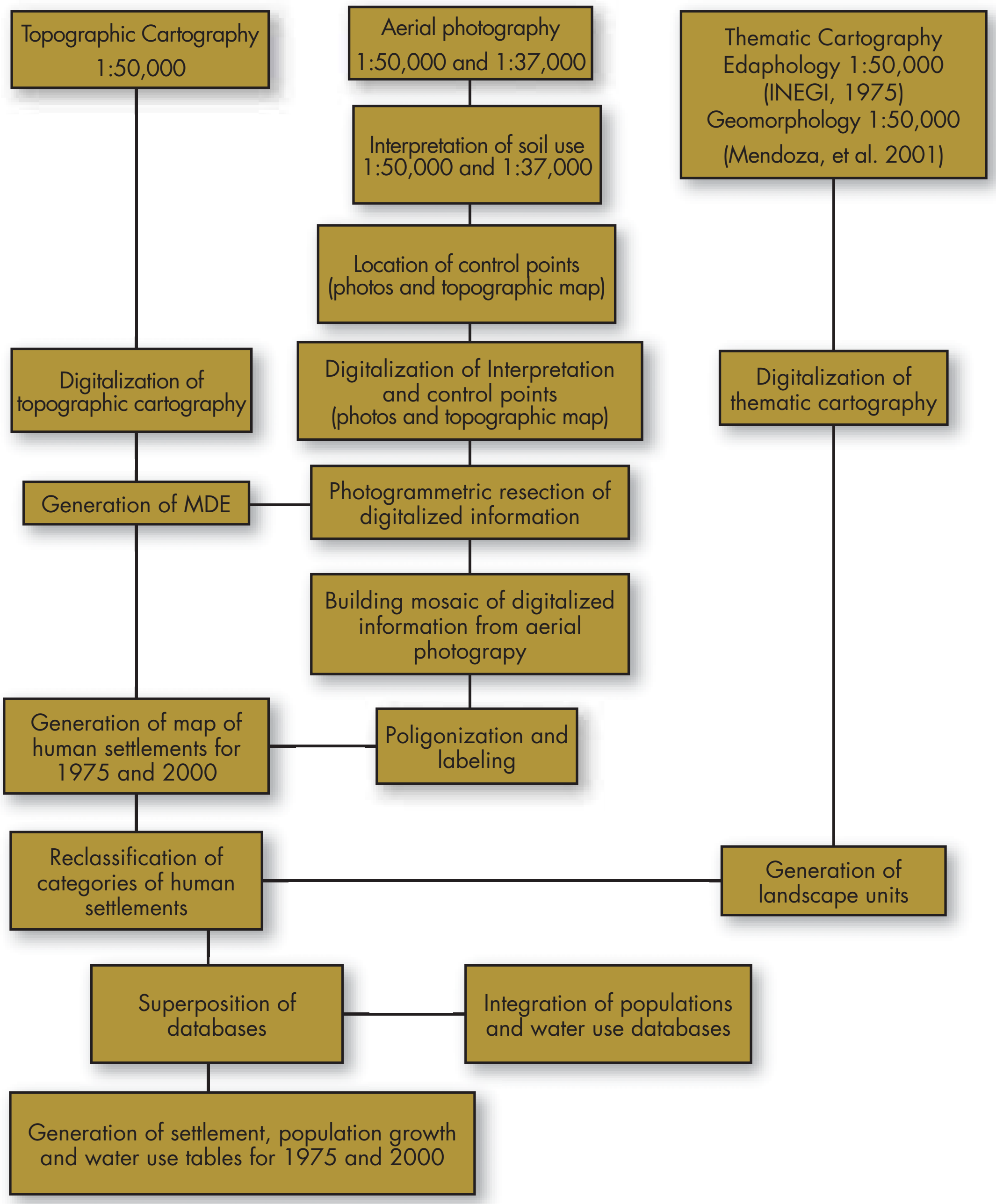


Fig. 3. Diagram of the procedure used in the research.

Results

Database quality

According to the confusion matrix, all categories are above the minimum accuracy value (90%). The accuracy obtained is high because 30% of interpreted polygons were labeled in the field and used as ground truth for photo identification.

The confidence of the geometric correction of the photo interpretation is within the acceptable error for the scale of the work (less than 1 mm on paper—50 m in the field). Regarding the level of confidence of the digital database (Bocco and Riemann 1997), the samplings for the years 1975 and 2000 exhibit confidence levels over 97.

Land cover and land use

Table 2 clearly shows that the predominant types of surface cover in 1975 were, in descending order, seasonal crops, shrub lands, forests, and irrigation crops; for 2000, these were shrub lands, forests, seasonal crops, and irrigation crops. Proportionally, human settlements doubled, indicating a high rate of transformation from other covers to human settlements.

Figures 4 and 5 show the spatial distribution of LCLU for each year. It is clear that temperate forest cover is found on the southern portion of the basin, while shrub lands are present mostly in the central and northern part. The most important human settlement in the basin, the city of Morelia, is located in the central section of the study area.

Table 2. Area and Percentage Occupied by LCLU in the Lake Cuitzeo Basin in 1975 and 2000

Cover Categories	1975		2000	
	Area (ha)	Percentage of Cover (%)	Area (ha)	Percentage of Cover (%)
Forest	67.485	16.9	80.390	20.1
Shrub land	74.475	18.6	94.073	23.5
Postureland	33.743	8.4	27.062	6.8
Seasonal Crops	117.603	29.4	68.344	17.1
Irrigation Crops	56.794	14.2	64.313	16.1
Plantations	897	0.2	3.165	0.8
Aquatic Vegetation	1.999	0.5	5.718	1.4
Lake	37.685	9.4	32.258	8.1
Dam	1.225	0.3	1.638	0.4
Human Settlements	8.115	2.0	23.060	5.8

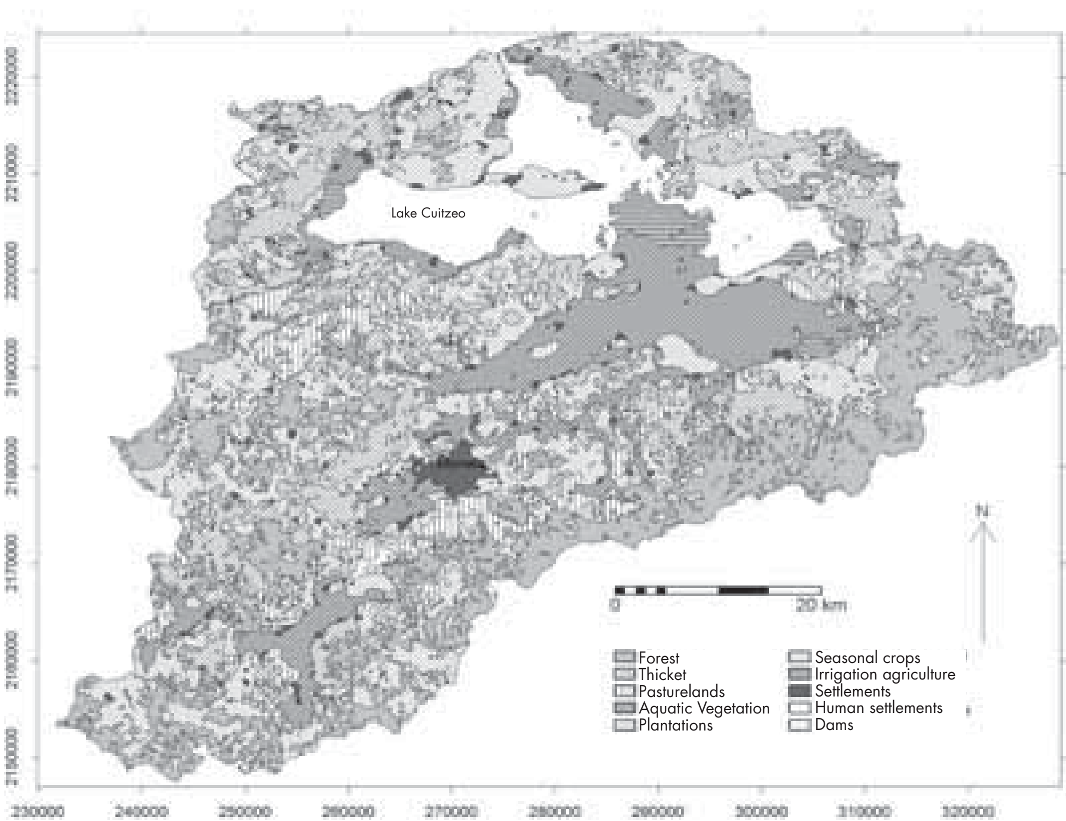


Fig. 4. Spatial distribution of LCLU in the Lake Cuitzeo Basin in 1975.

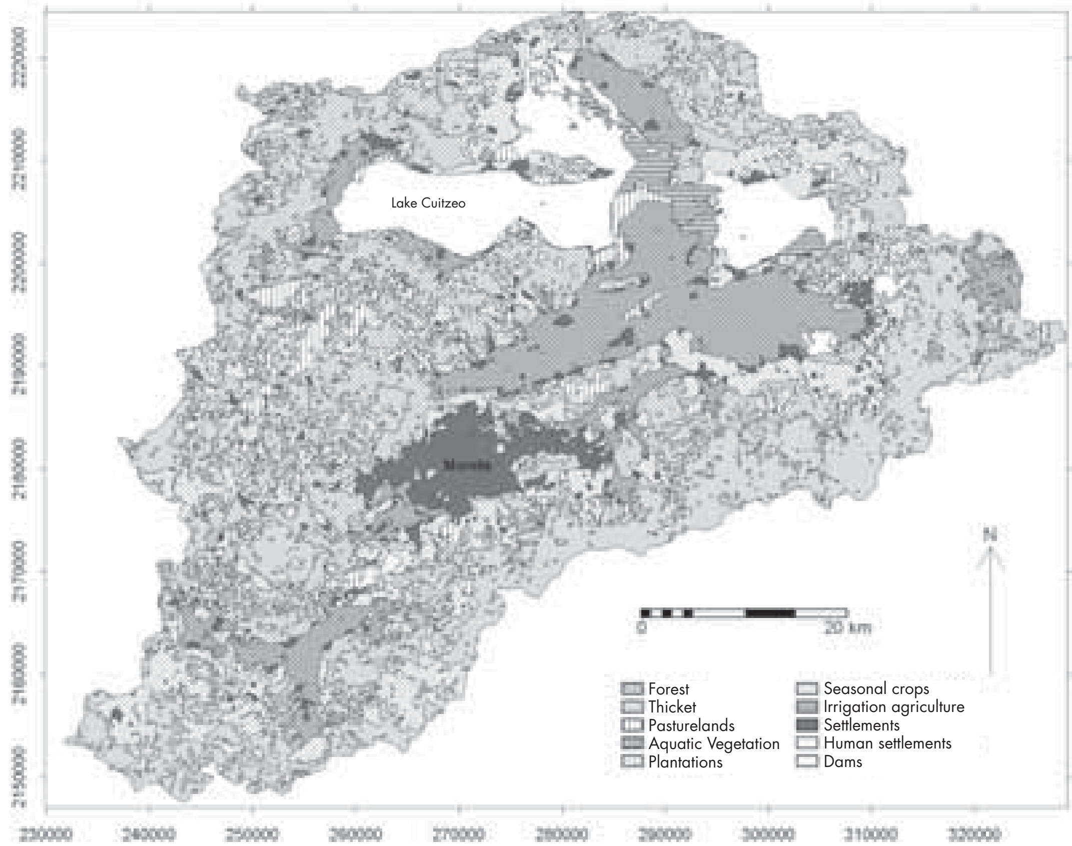


Fig. 5. Spatial distribution of LCLU in the Lake Cuitzeo Basin in 2000.

Analysis of changes in LCLU

The analysis enabled generation of a map of the predominant change processes in the basin (Fig. 6) and calculation of the area affected by these changes (Fig. 7). The processes with the widest distribution are the proliferation of shrub land and the recovery of forests, each accounting for about 10% of the area of the basin. Deforestation (6%) and degradation of forest cover (2%) and urbanization (4%) and reduction of lake cover (1%) are the next processes in relative importance in the basin. These processes can be seen as indicators of the state of the basin.

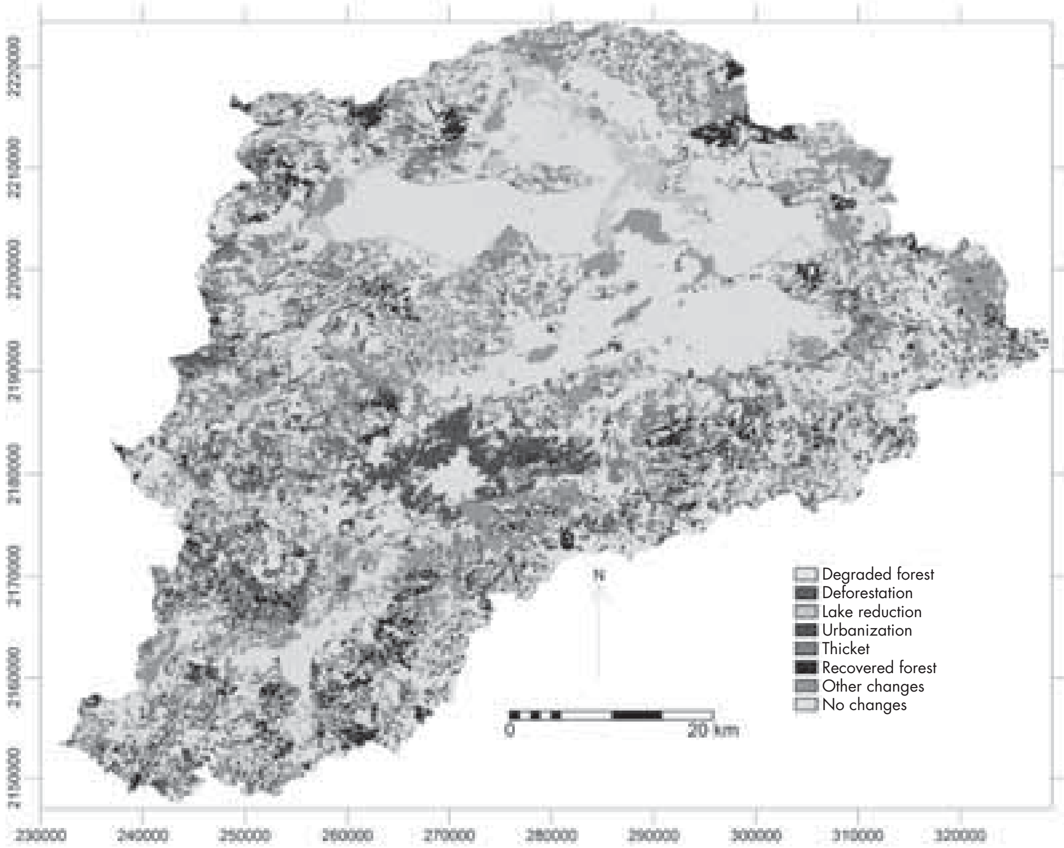


Fig. 6. Map of change processes between 1975 and 2000.

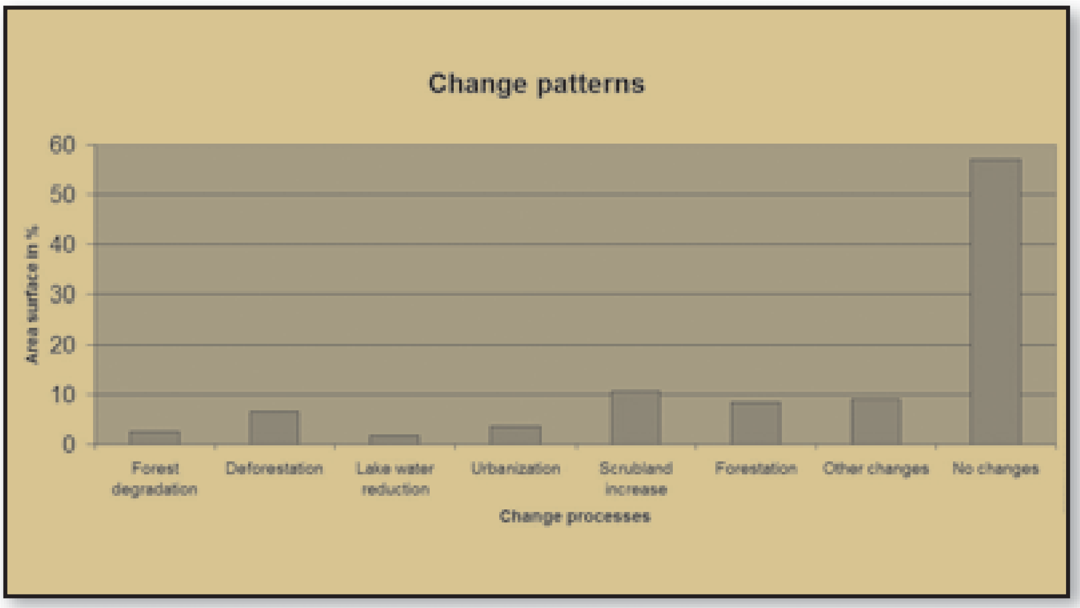


Fig. 7. Surface percentage of main change processes in the Cuitzeo Basin between 1975 and 2000.

Analysis of changes in urban areas

The Cuitzeo Basin comprised 392 human settlements in 1970 and 687 in 2000; in both cases, 4% of the total settlements were urban (Table 3). That is, despite the fact that the total number of settlements (urban and rural) increased by 70% between 1970 and 2000, the percentage of urban settlements was maintained. This work only studied 26 urban settlements, that is, over 2,500 people.

It is important to note that the distribution of human settlements is not totally random. A review of the cover maps (together with the rest of the thematic databases) shows that human settlements are aligned in the east-west and southeast-northeast directions. This alignment is a consequence of the fact that the settlements are located in relatively high and slightly sloped areas; this pattern reflects the need to take advantage of the low and flat lands with better soils for agricultural activities (Morelia-Queréndaro irrigation district) and of settling away from flooding areas. The higher and sloped zones are closely associated with the geological characteristics of the region. In particular, the areas aligned in the above-mentioned directions match active geological faults.

The city of Morelia is an exceptional case within the basin because it is expanding toward steeply inclined areas (active fault escarpments) and flood areas. This expansion pattern is increasing the level of risk and, therefore, the vulnerability of the city's population to natural hazards (Lopez et al 2001).

Table 3. Surface Area of Urban Settlements in 1975 and 2000

Urban Settlements	Area (Ha)	Area (Ha)	Growth 1975-2000	
	1975	2000	Ha	%
Acuitzio del Canje	95	103	8	8
Álvaro Obregón	48	199	151	315
Bocaneo	9	47	38	422
Capula	39	72	33	85
Charo	32	87	55	172
Copándaro de Galeana	47	72	25	53
Cuanajo	47	89	42	89
Cuitzeo del Porvenir	130	209	79	61
Cuto del Porvenir	12	76	64	533
Huandacareo	120	285	165	138
Huiramba	27	52	25	93
Indaparapeo	51	207	156	306
Iramuco	85	139	54	64
Jesús del Monte	10	28	18	180
Mariano E. y San Agustín	91	139	48	53
Morelia	1.830	6.304	4.474	244
Queréndaro	132	215	83	63
San Lucas Pío	6	51	45	750
Santa Ana Maya	75	294	219	292
Tarímbaro	39	316	277	710
Téjaro de los Izquierdo	44	133	89	202
Tenencia Morelos	34	163	129	379
Ucareo	15	37	22	147
Uruétaro	23	54	31	135
Zinapécuaro de Figueroa	97	493	396	408
Total	3.244	10.083	6.839	211

The cities with the greatest relative growth were Bocaneo, Cuto del Porvenir, San Lucas Pío, Tarímbaro, and Zinapécuaro; however, the surface area of 17 of the cities studied increased by over 100% between 1975 and 2000 (Table 3).

These cities are growing because they attract large numbers of people from the rest of the municipality, as well as other parts of the state, and an increase in population results in greater demand for land to build neighborhoods, commercial areas, and schools inside the cities and around their perimeter. The city of Morelia, for example, is the most important city in the area and only represents 66.5% of the total surface of urban growth in the basin (4,474 ha), and houses 79% of the urban population living in the watershed.

The urban population in the basin increased by 215.2% in the period 1970–2000. Table

4 shows the six urban settlements with over 100% growth in population during that study period. Jesús del Monte and Tenencia Morelos witnessed the highest increases in population because of their close proximity to the city of Morelia; Jesús del Monte is currently conurbated with Morelia (Acosta Villegas 2001).

Table 4. Population in the Urban Settlements in the Cuitzeo Basin in 1950, 1960, 1970, 1980, 1995, and 2000

Urban Settlements	Population by Year					
	1950	1960	1970	1980	1995	2000
Acuitzio del Canje	2.965	3.436	3.123	3.059	5.460	5.766
Álvaro Obregón	1.904	2.923	3.592	5.520	7.887	7.911
Bocaneo	1.130	1.457	1.766	1.177	2.307	2.578
Capula	1.961	2.308	2.449	3.355	3.960	4.558
Charo	2.190	2.725	2.541	3.384	4.566	4.568
Copándaro de Galeana	1.448	2.611	3.020	3.223	3.834	3.408
Cuanajo	1.913	1.653	2.958	3.761	4.703	4.978
Cuitzeo del Porvenir	3.493	4.485	4.875	7.036	8.760	8.824
Cuto del Porvenir	1.131	1.544	1.504	1.804	3.256	3.608
Huandacareo	4.121	5.483	5.952	6.723	7.032	6.700
Huiramba	-	1.418	1.588	1.913	2.559	2.630
Indaparapeo	3.059	3.383	3.657	5.795	7.044	6.729
Iramuco	-	-	4.300	5.015	6.368	6.232
Jesús del Monte	510	775	877	803	2.375	2.665
M. Escobedo y Sn. Agustín P.	1.953	2.703	3.548	4.288	5.783	6.238
Morelia	63.245	100.828	161.040	297.544	512.169	549.996
Queréndaro	5.474	5.897	5.810	8.065	8.992	8.544
San Lucas Pío	881	993	979	1.554	2.704	6.835
Santa Ana Maya	3.066	3.784	4.226	5.375	6.371	6.835
Tarímbaro	1.415	1.660	2.654	3.888	5.012	5.006
Téjaro de los Izquierdo	1.530	2.134	2.259	2.404	4.197	4.208
Tenencia Morelos	1.173	1.533	2.184	2.467	10.581	11.379
Ucareo	1.615	1.846	2.208	2.490	2.718	2.580
Uruétaro	945	1.410	1.599	2.011	2.871	2.821
Zinapécuaro de Figueroa	3.095	5.719	7.382	9.481	14.640	14.547
Total population	114.135	169.095	242.655	398.730	652.513	696.243

Prepared from DGE (1950, 1960), INEGI (1970, 1980, 1995, 2000)

One characteristic of the settlements located in the study area is the lack of planning for urban development. The cities located in the basin, especially Morelia, have been undergoing disproportionate growth since 1970, a pattern repeated in large and mid-sized cities of Mexico.

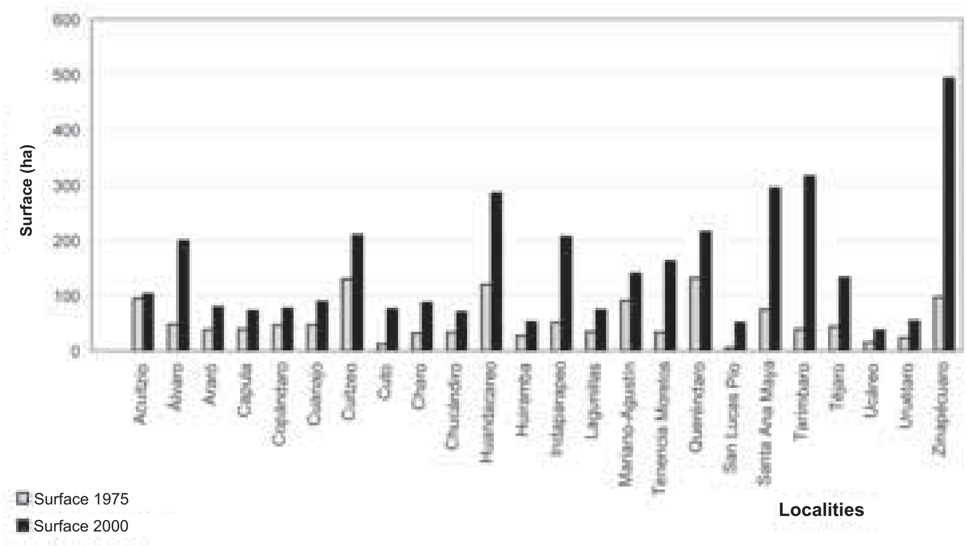


Fig. 8. Surface area of urban settlements in the basin between 1975 and 2000.

* Morelia is not included in the graph because its values are too high by comparison with the other cities.

The types of cover over which urban settlements increased the most were seasonal crops (72%), irrigation crops (42%), and rural settlements (21%) (Table 5). It is important to note that cities are growing on agricultural lands. In addition, as cities grow, they take over other rural settlements around them.

Table 5. Surface Area and Percentage of Cover over which Urban Settlements Increased

Type of Cover	Surface area of Change (ha)	% of Surface Area of Change
Seasonal crops	3389	72
Irrigation crops	1958	42
Rural settlements	987	21
Shrub lands	833	18
Pasturelands	717	15
Forests	81	2
Plantations	58	1
Lake	46	1

The population increase is linked to the volume of water consumed and the volume of wastewater produced in the human settlements. The volume of water consumed by the population in 1970 was 21,490 m^3, increasing in 2000 to 77,800 m^3; that is to say, the amount of water consumed by the urban population increased by 215.5% during the period under study (Table 6).

The area of the research has three wastewater treatment plants, which are insufficient to properly process the water that is released into Lake Cuitzeo. Untreated water is used to irrigate the agricultural fields around the lake.

Table 6. Water Consumption in Urban Settlements in the Cuitzeo Basin

City	Thousands m^3	Thousands m^3	Thousands m^3	Thousands m^3
	1970	1995	2000	2010
Iramuco	0.20	0.30	0.30	0.35
Acuitzio del Canje	0.15	0.26	0.27	0.28
Álvaro Obregón	0.17	0.37	0.38	0.45
Charo	0.12	0.22	0.22	0.24
Chucándiro	0.11	0.10	0.10	0.09
Copándaro	0.14	0.18	0.16	0.20
Cuitzeo del Porvenir	0.23	0.42	0.42	0.48
Mariano Escobedo y Sn. Agustín	0.08	0.14	0.15	0.17
San Agustín del Pulque	0.07	0.14	0.14	0.16
Huandacareo	0.28	0.33	0.32	0.37
Huiramba	0.08	0.12	0.12	0.14
Indaparapeo	0.17	0.33	0.32	0.38
San Lucas Pío	0.05	0.13	0.32	0.26
Lagunillas	0.08	0.11	0.11	0.12
Capula	0.12	0.11	0.22	0.23
Jesús del Monte	0.04	0.19	0.13	0.13
Morelia	17.63	56.08	60.22	70.04
Tenencia Morelos	0.10	0.50	0.54	0.59
Cuanajo	0.14	0.22	0.24	0.27
Queréndaro	0.28	0.43	0.41	0.46
Santa Ana Maya	0.20	0.30	0.32	0.36
Cuto del Porvenir	0.07	0.15	0.17	0.18
Tarímbaro	0.13	0.24	0.24	0.29
Téjaro de los Izquierdo	0.11	0.20	0.20	0.22
Uruétaro	0.08	0.14	0.13	0.16
Araró	0.12	0.09	0.09	0.10
Bocaneo	0.08	0.11	0.12	0.12
Ucareo	0.10	0.13	0.12	0.14
Zinapécuaro de Figueroa	0.35	0.69	0.69	0.82
Total	21.49	62.74	67.16	77.80

The irrigation area near Morelia was 56,794 ha in 1975, an area that increased to 64,313 ha in 2000, a 13% growth (Table 2, Figs. 4 and 5).

According to the National Commission of Water (CNA 2001), in 1975 the water used for irrigation crops reached 190 million cubic meters; in 2000, the volume used for the same activity was 342.8 million cubic meters. Dividing the cultivated area by the volume of water used in the fields showed that in 1975 about 3.750 m^3/ha were used and in 2000 that figure had increased to 5.330 m^3/ha; that is, a larger amount of water per surface area unit was used in 2000 than in 1975.

This information is useful in understanding the current desiccation of Lake Cuitzeo. Originally (before the colonial period), water from the Chico and Grande rivers drained directly into the lake; currently, it is used to satisfy urban, industrial, and agricultural demands for water.

The water now reaching Lake Cuitzeo is scarce and polluted, mainly by organic material from human settlements, fertilizers, and pesticides from irrigated agricultural lands. The lake is currently experiencing a recurring (annual) desiccation process, as it is a shallow system, featuring extreme events about every 10 years (Mendoza et al. 2006).

Conclusions

The use of RS and GIS tools enabled identification of growth in human settlements, agricultural irrigation zones, and the areas over which urban settlements are growing; this work has resulted in a better understanding of the processes occurring in the basin and allowed us to relate those processes to urban-water-consumption levels. The processes identified are similar to those that take place in several large and mid-sized cities in Mexico.

Analysis of the main change processes indicates that deforestation and forest degradation are compensated (in area) by the expansion of shrub land areas and the regeneration of forests. However, the urbanization processes have not been compensated, leading us to infer that the main degradation processes at basin level are associated with the rapid growth of cities and the resulting release of untreated sewage into the Morelia-Queréndaro agricultural irrigation district. Along the route, the sewage waters irrigate agricultural fields and are contaminated by pesticides, herbicides, and fertilizers.

Human settlements in the basin increased by 14,945 ha (almost tripling the area occupied in 1975). During the period covered by our study, water consumption for public use increased by 64% and for irrigation by 45%.

The analysis suggests that the reasons that fostered the original growth of urban development (agricultural soils and water) are currently under strong pressure. The cities are growing over highly productive agricultural lands (vertisols) located in the fluvial-lacustrian plains surrounding the cities, especially Morelia. Increased population implies the use of surface water, greater extraction from aquifers, more waste, and loss and pollution of water.

Acknowledgments

Part of this research was supported by the University of California through the Inter American Institute for Global Change Research, under the project "The Human Dimension of Global Environmental Change in Urban Areas of Latin America. A Network Approach."

The authors acknowledge the support provided by the SIMORELOS Program (CONACyT) under the "Ecological Regionalization, Resource Conservation and Land Use Management in the Lake Cuitzeo Basin" research project, carried out by UNAM-Morelia Campus. Erna López and Manuel E. Mendoza received Ph.D. scholarships from CONACyT and UNAM.

References

Acosta Villegas, A. 2001. *Crecimiento de los Asentamientos Urbanos en la Cuenca del Lago de Cuitzeo y su Consumo de Agua, 1975–2000*. Thesis, B. S. degree in Biology, Facultad de Biología, Universidad Michoacana de San Nicolás de Hidalgo. Ciudad de Morelia, Michoacán. México: 110 pp.

Bocco, G., and Riemann, H. 1997. "Quality Assessment of Polygon Labeling." *Photogrammetric Engineering & Remote Sensing* 63(4):393–395.

CNA (Comisión Nacional del Agua). 2001. *Situación del Subsector Agua Potable, Alcantarillado y Saneamiento.* Comisión Nacional del Agua, Distrito Federal, México. (Available at: http://www.cna.gob.mx/portal/switch.asp?param=4015)

DGE (Dirección General de Estadística). 1950. *VIII Censo Nacional de Población, Michoacán*. Ciudad de México, México. 845 pp.

DGE (Dirección General de Estadística). 1960. *IX Censo Nacional de Población, Michoacán*. Ciudad de México, México. 932 pp.

GRÜBLER, A. 1994. *Technology.* In: *Changes in Land Use and Land Cover: A Global Perspective* (Meyer, W. B., and Turner, B.L. II, Eds.). Univ. of Cambridge Press, Cambridge, England. pp. 287–328.

Houghton, R. A., Hackler, J. L., and Lawrence, K. T. 1999. "The U.S. carbon budget: contribution from land-use change." *Science* 285:574–578.

ILWIS (Integrated Land and Watershed Management Information System). 1990. *User's Manual. International Institute for Aerospace and Earth Science* (ITC), Eschede, The Netherlands. 132 pp.

ILWIS (Integrated Land and Watershed Management Information System). 1998. *User's Manual. International Institute for Aerospace and Earth Science* (ITC), Eschede, The Netherlands. 435 pp.

INEGI (Instituto Nacional de Estadística, Geografía e Informática). 1970. *IX Censo General de Población y Vivienda, México*. Ciudad de México, México. 923 pp.

INEGI (Instituto Nacional de Estadística, Geografía e Informática). 1980. *X Censo General de Población y Vivienda, México*. Ciudad de México, México. 923 pp.

INEGI (Instituto Nacional de Estadística, Geografía e Informática). 1995. *Anuario Estadístico del Estado de Michoacán*. Ciudad de Aguascalientes, México. 382 pp.

INEGI (Instituto Nacional de Estadística, Geografía e Informática). 2000 *XII Censo General de Población y Vivienda, México.* Ciudad de Aguascalientes, México. 987 pp.

Juppenlatz, M. 1990. “The role of urban surveys in Third World development.” *ITC Journal* 4:352–362.

Kasperson, J. X., KASPERSON, R. E., and Turner, B. L. II (Eds.). 1995. *Regions at Risk: Comparisons of Threatened Environments*. United Nations Univ. Press, Tokyo, Japan. 588 pp.

Kummer, D. M., and Turner, B. L. II. 1994. “The human causes of deforestation in Southeast Asia.” *BioScience* 44(5):323–328.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce , J. W., Coomes, O. T., Dirzo, R., Fischer, G., Folke, C., George, P. S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., Skanes, H., Steffen, W., Stone, G. D., Svedin, U., Veldkamp, T. A., Vogel, C., and Xu, J. 2001. “The causes of land-use and land-cover change: moving beyond the myths.” *Global Environmental Change* 11:261–269.

Lopez, E., Bocco, G., Mendonza, M.E., Duhau, E. 2001. “Predicting land-cover and land-use change in the urban fringe. A case in Morelia City, México”. Landscape and Urban Planning 55 (4), 271-285.

Mendoza, M. E. 2002. *Implicaciones del Cambio de Cobertura Vegetal y Uso del Suelo en el Balance Hídrico a Nivel Regional. El Caso de la Cuenca del Lago de Cuitzeo*. Doctoral thesis in Earth Sciences. Universidad Nacional Autónoma de México, Ciudad de México, México. 188 pp.

Mendoza, M. E., López, E., and Bocco, G. 2001. *Regionalización Ecológica, Conservación de Recursos Naturales y Ordenamiento Territorial en la Cuenca del Lago de Cuitzeo, Michoacán*. SIMORELOS-COACyT. Proyecto 983060024. Universidad Nacional Autónoma de México. Morelia, Michoacán, México. 262 pp.

Mendoza, M. E., Bocco, G., Bravo, M., López-Granados, E., and Osterkamp, W. R. 2006. “Predicting water-surface fluctuation of continental lakes: A GIS and RS based approach in Central México.” *Water Resources Management* 20(2):291–311.

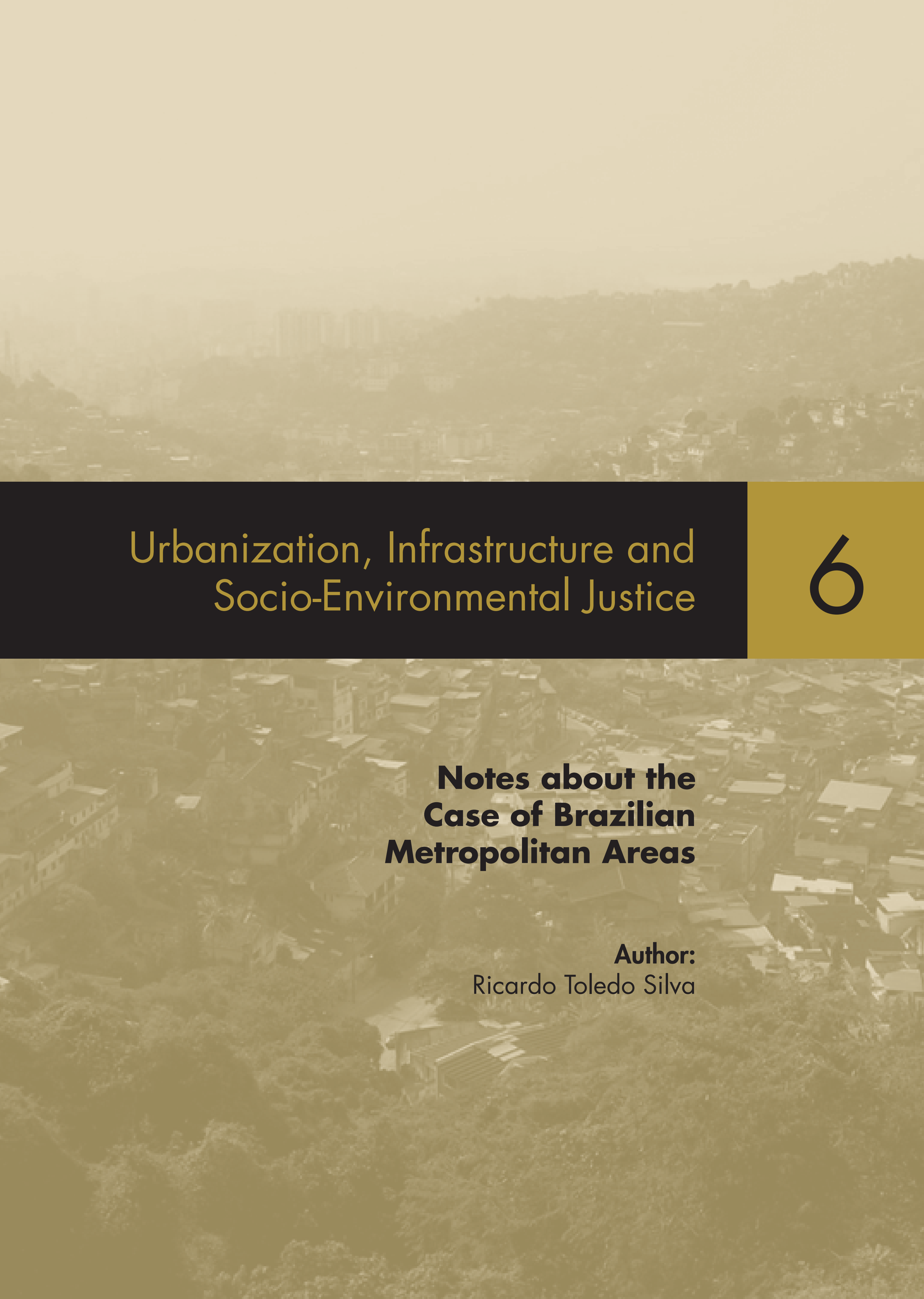
Pasquarè, G., Ferrari, L., Garduño, V. H., Bibaldi, A., and Vezzoli, L. 1991. *Geologic Map of Central Sector of Mexican Volcanic Belt, States of Guanajuato and Michoacán, México.* Map and Chart Series MCH072. Geological Society of America. Boulder, CO.

Skole, D. L., Chomentowski, H., Salas, W. A., and Nobre, A. D. 1994. “Physical and human dimensions of deforestation in Amazonia,” *BioScience* 44(5):314–322.

Tolba, M. K., and El-Kholy, O. A. (Eds.). 1992. *The World Environment 1972–1992: Two Decades of Challenge.* Chapman & Hall, London, England. 884 pp.

Veldkamp, A., and Verburg, P. H. 2004. “Modelling land use change and environmental impact.” *Journal of Environmental Management* 72:1–3.

Vitousek, P. M., Mooney, H. A., Lubchenco, J., and Melillo, J. M. 1997. “Human domination of earth’s ecosystems.” *Science* 277:494–499.



Urbanization, Infrastructure and Socio-Environmental Justice

6

Notes about the Case of Brazilian Metropolitan Areas

Author:
Ricardo Toledo Silva

Summary

This chapter discusses the scarcity of infrastructure and asymmetry of access as structural elements of a complex urban-metropolitan reality requiring planning and management instruments that are flexible enough to find possible solutions but at the same time rigorous in their analysis criteria.

The first part of the chapter analyzes the asymmetries in the supply of network infrastructure and services as an expression of growing social inequality. Paradoxically, asymmetries in access will enable the global offer of services, under a state supply model, to expand on the basis of crossed subsidies generated among the higher income sectors. Given the protection of private supply, a regulatory reform and a fragmentation of the supply are necessary, which drastically diminish the potentially compensatory nature of crossed subsidies. In addition, there are new requirements for a demand to access the services for a more complex social reproduction.

In this situation, the interactions between the different forms of infrastructure and between these and the environment intensify, opening the door to an approach to interactions broader than those in sectors, the origin of crossed subsidies.

The second part discusses the elements of planning and integrated management of densely urbanized basins, on the basis of the experience of applied research groups in the São Paulo University (USP) and Minas Gerais State University (UFMG). This process developed intersectoral integrated management instruments, linking structural and nonstructural measures to satisfy the common objectives of the metropolitan environment. The complexity of the context requires the development of information and decision making support systems focusing on the uniformity of analytical criteria and on the flexibility of the applicable structural and nonstructural measures. The systems point to the complexity of the interactions between the various social and environmental vulnerabilities, which sometimes are aggravated and at other times mutually compensate each other. The integrated management tools described, experimentally developed for Brazilian cities, seem to contain basic elements for managing uncertainties and trade-offs between social and environmental vulnerabilities. Those basic elements can be extrapolated for the broader and more complex context of large urban concentrations simultaneously exposed to the effects of economic globalization and climate change.

Infrastructure, urbanization and social exclusion

This section studies social exclusion represented in the asymmetry of infrastructure supply based on the analysis of privileged-service areas and discusses the strategic option of exclusion as an alternative to enable system expansion which, in general, occurs in the form of crossed subsidies. Through these crossed subsidies, surpluses generated in high-income areas finance the global expansion of the supply. This strategy is supported by the growing need for the geographic integration of networks, as asymmetries in income are manifested in a markedly unbalanced regional complex. Expansion of coverage does not necessarily imply universal access, as the sole presence of the network does not guarantee effective right to use the installed capacities. Upon the collapse of the state supply model, the fragmentation of operational areas for private concessions compromised the model of crossed subsidies. On the other hand, the profile of infrastructure demand is further complicated by the pervasiveness of telework and work conducted at home. If the scenarios of scarcity of natural resources and exclusion of social demand are considered jointly, the outlook of great socio-environmental complexity for which traditional organization forms offer no response becomes even more apparent.

Formation of privileged urban spaces

Access to public infrastructure and network service, in general, constitutes an element of distribution justice. For a long time, urban literature has considered that access to infrastructure was a sort of indirect wage, paid by the society as a whole, under the broad concept of general conditions for labor reproduction. Using essentially different approaches, reference texts for regional and urban research such as Mumford (1961), Castells (1975), and Harvey (1976) agree about recognizing the distribution dimension associated with public service supply.

In his study of the city in history, Mumford (1961) recognizes the dematerialization of a city's relations and institutions, through physical or cultural networks, in its more advanced perspective of progress and modernization. For him, this dematerialization is identified in the concept of network, in the sense of a system accessible from different parts of the territory and with capacities that are distributed in a relatively homogeneous manner. When referring to this ideal network, based on the case of electricity, the core of his argument is that the parts, although relatively independent, could function as a whole, "...compensating for whatever is missing in a particular area" (p. 608). In addition, he recognizes that this identified function of the network goes beyond the technological scope and into the cultural sphere, wherein the deep changes caused later by information technology had been anticipated. Despite this visionary outlook on the structural and democratic nature of networks, Mumford never maintained this would be an inexorable process of social progress associated with the development of cities. He did, however, identify the technological advance of networks with distributive dimensions that point toward the democratization of urban culture.

The more leftist literature on urban research of the 1970s does not deny these dimensions, but it maintains that the structural contradictions of the capitalist economic growth establish strict limits to general access. All analytical studies of public infrastructure in cities juxtapose two functions that must be fulfilled: one in direct support of economic production and another in support of the consumption needs of workers. Through the use of different words in specific studies, this line of urban research is based essentially on the Marxist concept of general conditions for production, separated into the conditions directly pertaining to the accumulation of capital and the conditions necessary for the reproduction of the labor force. Possibly one of the most radical interpretations of this duality of the general conditions for production was formulated by O'Connor (1973). O'Connor proposed that the functions of accumulation and legitimation of the capitalist state are part of the same rationale, and that the largest state investment flows for the benefit of workers occur only to the strict extent of the need for political legitimation. In those terms, the characteristic model is a system in permanent stress, wherein each concession in favor of social reproduction occurs only as the result of a specific political pressure.

The evolution in the supply of public services in the 1980s and following decades, within a scenario that comprises privatization and regulatory reform, seems to support this vision of permanent conflict and specific victories. As much as infrastructure network coverage could expand in cities, the distributive asymmetries seem to have become more rather than less pronounced. It is true that basic access patterns, at the thresholds of physical subsistence, will be generalized and that networks will acquire a scattered presence within the urban footprint. However, these conditions do not lead to universal access, as the number and pattern of the services offered to the different sectors of the demand are ever more asymmetrical. The detection of asymmetries is not a trivial matter and requires information and analysis procedures that go beyond a simple examination of the coverage.

Work on the differences in connectivity and infrastructure capacity in São Paulo metropolitan area (Silva 2000) shows that the complexity of access to services is defined as a function of three basic dimensions: (1) the apparent generalization of coverage, which masks the fundamental differences between the supply patterns of the core capacities; (2) the transformation of the essential demand, which starts to include requirements other than the simple fulfillment of the basic needs for physical reproduction; (3) the ambiguity of potential access rights under the logic of state supply in contrast to the objective access rights under the logic of private supply. These three dimensions would exhibit robust conceptual elements, proved in the later in-depth research on which that article was based.

One of the most provocative methodological procedures related to the detection of distributive differences of the urban footprint has yielded more precise results in the analysis of privileged (or superincluded) spaces, in contrast to exclusion spaces. In theory, differences in access to infrastructure and network services can be detected from the point of view of both the "included" and the "excluded". The results tend to be complementary and to explain each other.

In practice, however, in contexts where exclusion is the norm and inclusion the exception, the analysis of the included portion becomes more precise because the stratification is more detailed. In general, research on urban poverty originating from urban sociology[1] was done directly on the areas considered to be the poorest, in contexts where these were a minority within the urban fabric mainly composed of middle-income districts.

In the case of large urban concentrations in the third world—and Brazilian large cities in particular—poor and excluded areas represent the majority. For this reason, inequality can be more accurately analyzed focusing on the concentration of well-connected areas that do not constitute the majority.

The most analytically robust part—some examples of which will be provided in this chapter—corresponds to the study of the privileged spaces and helps in understanding the financial logic and generation of crossed subsidies intrinsic to the process of expanding infrastructure in Brazilian cities. Long before the alleged fiscal crisis that strangled the state's capacity to invest in infrastructure for social consumption, attempts to generalize supply in Brazil had already given rise to a hybrid financial model, based on the economic self-sufficiency of the services. The apex of this model that originated in the electricity sector since the 1930s is present in the National Basic Sanitation Plan implemented in Brazil since the 1970s.

Responsible for an unprecedented leap in coverage in the country, the model was based on a structure of crossed subsidies, wherein consumers with the largest drains-those with the best supply-subsidized the expansion of the network to the poorer areas. Since it was necessary to use a meaningful scale in absolute number of consumers with greater ability to pay for the services, the aggregation extended beyond the limits of each city to the state level. The logic of territorial integration-and, therefore, of the regional scale of the supply-became the pre-requisite for the viability of expanded coverage based on the payment capacity of the minority.[2]

After the gradual disappearance of the state financing model during the 1980s, the reorganization of the infrastructure started to be defined in a second, more-fragmented model of supply, under which the large complexes of integrated regional supply were unbundled. This is a logical consequence of private financing because, as large supply structures assign part of the billing surpluses of the areas to subsidize areas with deficits, these reduced the net return rates of the set of investments. However, it would be useless to find immediate evidence of a greater concentration of privileged access to services under the protection of the new private supply. The previous model, as has been pointed out repeatedly by numerous analyses of the period, tended to concentrate and exclude, with an unsatisfactory profile of social assistance to the needs of an explosive demand.

[1] Procedures based on the Chicago School models, relying on the stratification of census information for different districts or sectors of the urban fabric.

[2] In the Brazilian studies of the National Basic Sanitation Plan of the 1970s, the territorial integration of that model is commonly attributed to the centralizing nature of the authoritarian regime. In the meantime, the objective analysis of the technical conditions of supply shows that the physical expansion of supply and the magnitude at which it occurred would not have been viable if based on the operations of each municipal system.

The main problem with the contemporary formation of privileged urban spaces, under the neoliberal rule that replaced the state interventionism in existence until the mid 1980s, was the elimination of the regulatory requirements that used to discipline cross subsidization. Even though the previous system was heteronomous and centralized, it channeled subsidized funding flows toward the expansion of the infrastructure, which, in practice, implied some form of distributive justice. The relative stability of the funding scheme based on regulated parafiscal funds more than on tax resources, was guaranteed by the application of return rates lower than market interest. The private supply model established in the early 1990s, without the support of a regulatory reform to substitute the previous social compensation and financial stability mechanisms, shows a clear tendency to a reconcentration of access at the expense of an apparent generalization of the coverage. It is not that the market expanded by social demand is not attractive; on the contrary, the market is very tempting due to its magnitude. But the nearly complete absence of social regulation paradoxically separates this promising market from a large portion of the services, thus reinforcing the reconcentration and the asymmetries of the access. Assessing these asymmetries, given the ambiguity and diversity of their causes, involves methodological procedures far more complex than the basic figures of service coverage, by and large accepted by studies on infrastructure as valid proxies to universal access.

Difference between coverage and access

The expansion of an infrastructure network refers to territorial coverage and the capillarity of each system. Territorial coverage is associated with the presence of arterial distribution structures such as electric power transmission lines, potable water primary networks and trunk sewage collectors. The capillarity is associated with the proportion of individual connections at the final tracts of the network, which express the potential access to the network by houses in the area under study. The larger the percentage of houses connected, the greater the coverage of the area.

This measurement of coverage has long been accepted in urban research as the expression of access and universal service. In fact, in the initial stages of network development, the measurement of coverage gave a fairly accurate idea of effective access by areas of the city. A district that had, for example, 60% of its houses connected to the public water supply network would be clearly less privileged than another with an index of 95% for the same parameter. The differences are evident, since it is physically impossible for the houses in the former district to have better access to potable water than houses in the latter. As systems evolve, however, detecting the differences is not quite so easy.

In a scenario of expanding networks, most urban dwellings will have individual connections, making the coverage standards in the various districts practically homogeneous. But this does not necessarily imply equal access to the distribution capacity of the network. A home connection speaks about a necessary but not sufficient condition of access to the capacities resulting from the system as a whole. Effective access to these potential capacities depends on the balance between production, arterial distribution and capillary distribution capacities in each section of the network. This balance is a rare condition in the large cities of emerging countries, where growth in the demand was very much faster than expansion of the supply.

The analysis of the conditions for accessing the infrastructure in São Paulo metropolitan region (Silva 2000) showed that service to the explosive demand for network services has been largely based on the asymmetrical expansion of the capillary distribution subsystems, without a corresponding expansion in the capacity of centralized production and arterial distribution. This situation leads to an apparent universality of the coverage that masks the distributive unbalances of the system as a whole, as for example, in the case of metropolitan distribution of water in São Paulo up to the late 1990s.[3]

The above-mentioned research about asymmetries between coverage and access (Silva 2000) showed that, already in 1991, the metropolitan coverage of the water supply service was well developed in São Paulo (Fig. 1).

The 2000 census, in general, speaks of a better situation in all areas, but those where coverage is still under 70% are basically composed of the more precarious peripheral districts, indicated in the cartogram for 1991.

Fig. 1. Metropolitan area of São Paulo. Connections to the water supply network as percentage of connected households. 1991. (Silva 2000)

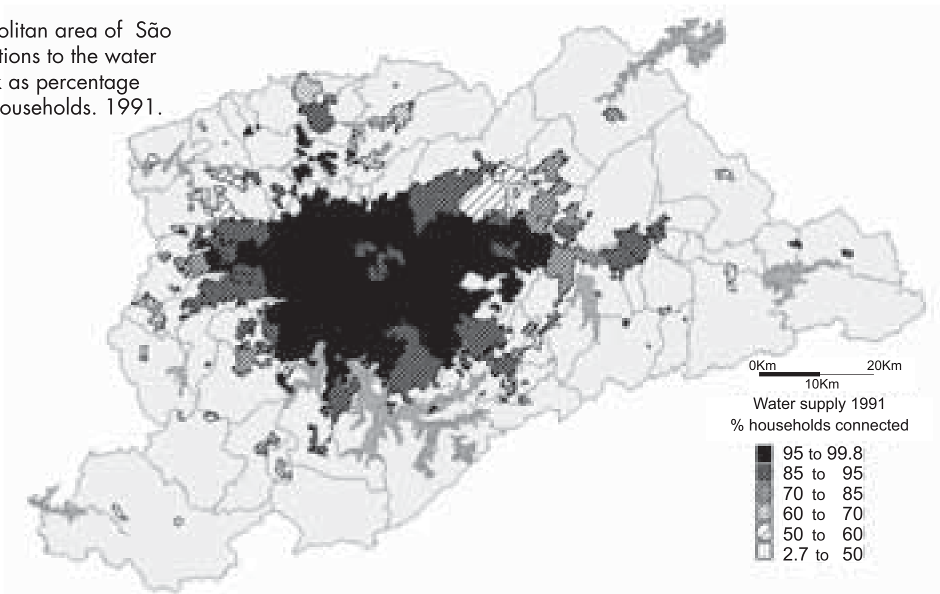


Figure 2 shows the scheme of the metropolitan supply network and the two main productive systems—Cantareira in the north and Guarapiranga in the south—marked with a circle. These two systems produce 33 and 12 m^3/s respectively of a metropolitan total of about

[3] Since the end of the 1990s, the coverage of the public water-supply network in the urban districts of São Paulo metropolitan area is practically universal. According to the 2000 census, only 16 of the 161 metropolitan census districts (including rural districts) featured a coverage equal to or lower than 70%. Of these, 95 of the 96 districts of the municipality of São Paulo (which comprise about 58% of the metropolitan population) had a coverage over 90%, most of them around 98%. Leaving out a probable percentage of temporarily inactive connections and requests for connections, it should be admitted that these higher rates translate into generalized coverage, even in the lower-income districts. Generalized coverage, however, does not guarantee homogeneous access to the service.

59 m^3/s (SABESP 1996 in Silva 2000). Despite the schematic nature of the illustration, it is possible to clearly identify a main supply system that forms an approximate set of concentric rings around the historic center and around a main branch, and that also exhibits some redundancy along the south-southeast vector of the metropolitan area. This redundancy of supply, represented by parallel arterial networks, identifies the areas of the urban tissue served by multiple production systems, as such less vulnerable to intermittent supply. On the other hand, the areas covered by simple derivations, originating in the peripheral nodes of the main systems, would be much more vulnerable to scarcity, as they are univocally linked to a single output or to a secondary production system.

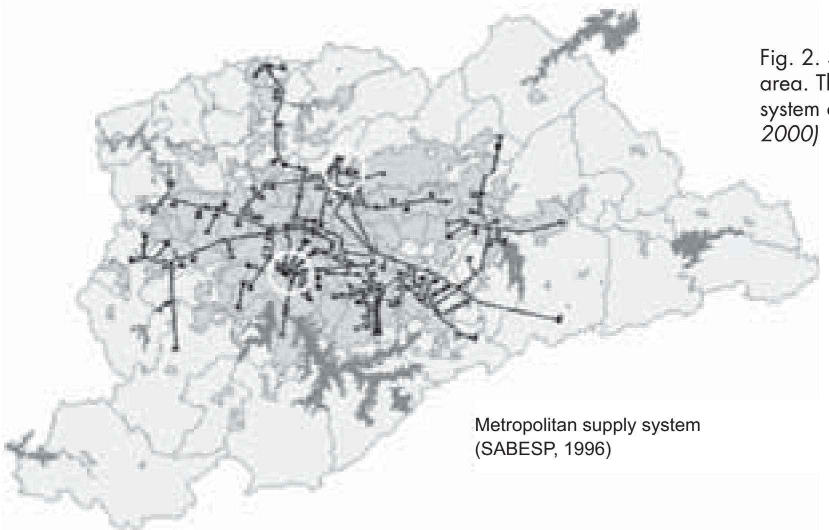
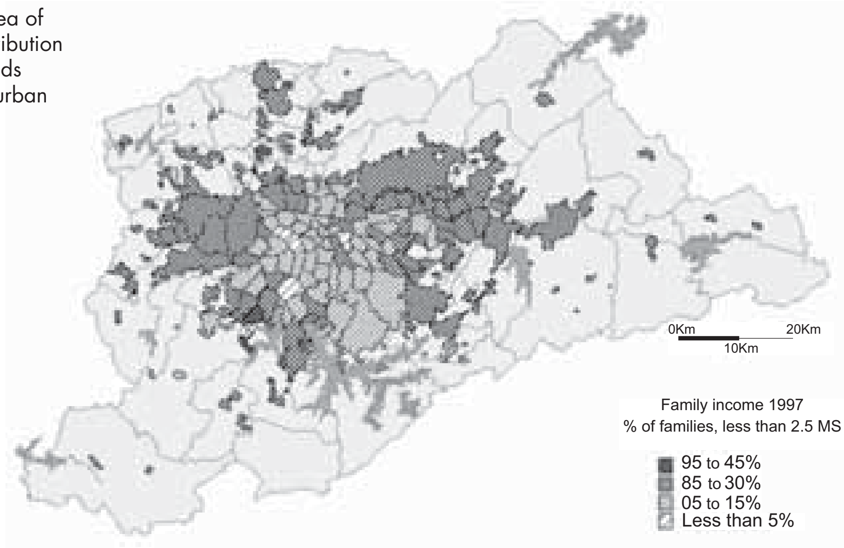


Fig. 2. São Paulo metropolitan area. The metropolitan supply system diagram. *(Source: Silva 2000)*

The operational records of the company responsible for supplying the metropolitan area (SABESP 1996) show that in all areas where the supply system exhibits less redundancy—in all the districts outside the expanded circle of the metropolis—there are records of significant intermittency in the supply. The same holds true for cases in which the coverage was higher. The comparison between the supply system scheme and the water connection coverage map in the metropolitan region (Fig. 1) shows that all the low-coverage peripheral districts are located in the secondary derivation areas of the arterial system. But that relation is not reciprocal: Some of the secondary derivations are located in areas with good coverage as far as the proportion of connected housing units increases, suggesting the possibility of more frequent interruptions to the supply. In fact, the records analyzed in Silva (2000) confirm this hypothesis for the areas subjected to systematic cuts in the supply between 1994 and 1997. The areas with poor coverage at the extreme periphery (less than 70% of the houses are connected) are more subject to seasonal cuts, while the areas relatively well covered located at the periphery to the south, west, and north of the main rings of the supply system suffer from interruptions in the supply throughout the year.

The correspondence between the location of the districts more subject to scarcity and the concentration of urban poverty is visible. Figure 3 shows the larger concentration of low-income houses in the peripheral districts, which in turn are the ones showing the highest rates of demographic growth.

Fig. 3. Metropolitan area of São Paulo. Spatial distribution of low-income households as a percentage of all urban households. 1997. *(Source: Silva 2000)*



The spatial pattern of the concentration of wealth in São Paulo metropolitan area, as in all other Brazilian large cities, occurs around an expanded center, since poverty extends toward the periphery. In the case of São Paulo, this pattern results in significant interference with water reservoirs, which are vulnerable to both point- and nonpoint-source pollution, caused by urban occupation along its margins. The peripheral location of poverty drastically limits the perspective for high middle income and low-density suburban occupation, considered in the past as an alternative for the sustainable use of environmental protection areas.

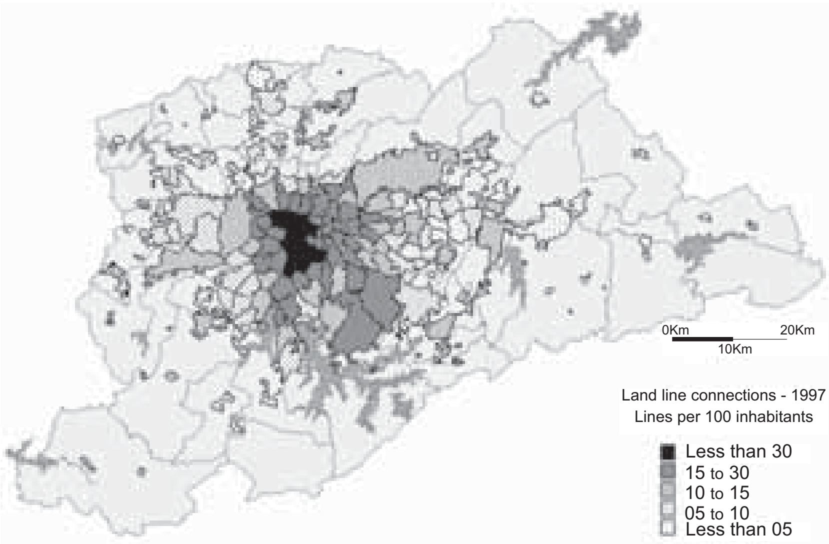
From the analysis of the relation between coverage and access to water supply in the models of the previous example, we can derive an important concept in the interpretation of effective access conditions associated with connectivity. The concept of connectivity involves, according to Dupuy (1987, 1993 in Silva 2000), the simultaneous existence of direct and alternative connections between different points of a network. This condition of redundancy in the connection makes access to the common capacities of each infrastructure system homogeneous and determines universality.

Figure 2 makes it clear that in the expanded metropolitan center, where the sites connected represent the majority in that area, the redundancy of alternative and simultaneous accesses is what guarantees stable service to the demand. If Fig. 3, which defines the spaces of greater and lesser concentration of poor households, is superimposed on the diagram of the arterial network in Fig. 2, there is no doubt about the direct relationship between connectivity and income.

This stratification of connected and unconnected spaces consolidates an urban morphology wherein the privileged spaces continually develop from the center, in flagrant contrast to the urban pattern of large cities in developed capitalist countries. What distinguishes a large emerging city from a large developed city, in terms of the infrastructure, is the territorial coverage of the spaces with alternative and simultaneous access to the installed capacities, which are concentrated in the former and scattered in the latter.

Analyzing now the case of the fixed telephone network, whose metropolitan coverage is much less advanced than the water supply system, it becomes clear that the simple indicator of coverage evidences a strong correlation with the concentration of income. More than the coverage of water supply, the spatial distribution of fixed telephone-line density per 100 inhabitants (Fig. 4) expresses the intense correspondence between capacity/density of network services and the concentration of income.

Fig. 4. São Paulo metropolitan area. Residential telephone connections per 100 inhabitants. 1997. *(Source: Silva 2000)*



The visual correlation is confirmed by the statistical analysis, which shows a significant linear regression coefficient in the reverse relation to the presence of low-income households (Fig. 5).

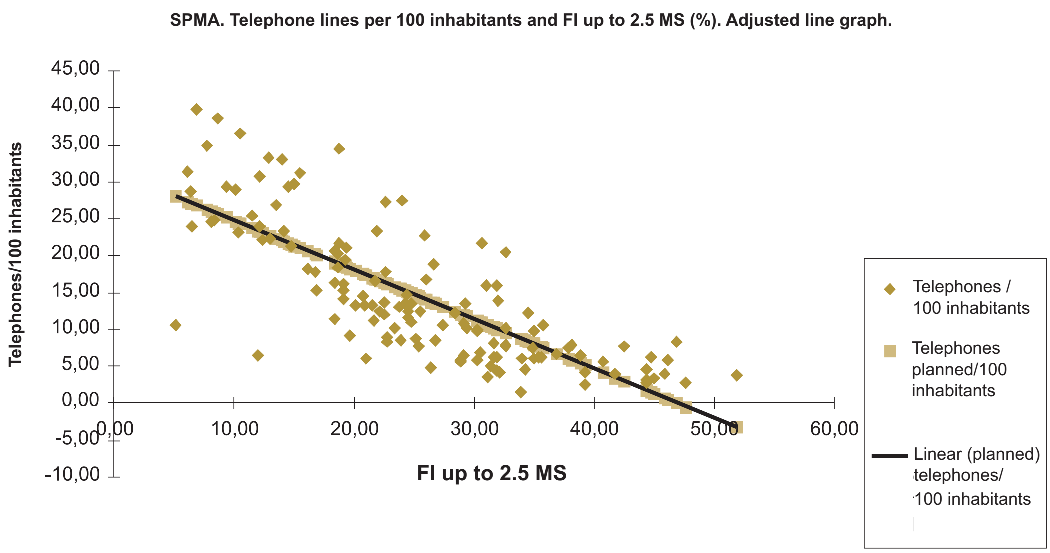


Fig. 5. São Paulo metropolitan area. Regression analysis: Residential telephone connections per 100 inhabitants and percentage of households with income up to 2.5 minimum salaries. 1997. *(Source: Silva 2003)*

The determination coefficient (r^2 adjusted) obtained in the previous correlation was 0.6, which is satisfactory to admit the explanation of the variable "telephone lines per 100 inhabitants" as a function of the concentration of low-income households. However, if instead we look for the reverse correlation with the largest concentrations of low-income households, exhibiting the direct correlation with the concentration of the wealthier households (family income higher than 20 minimum salaries), the determination coefficient is even more significant.

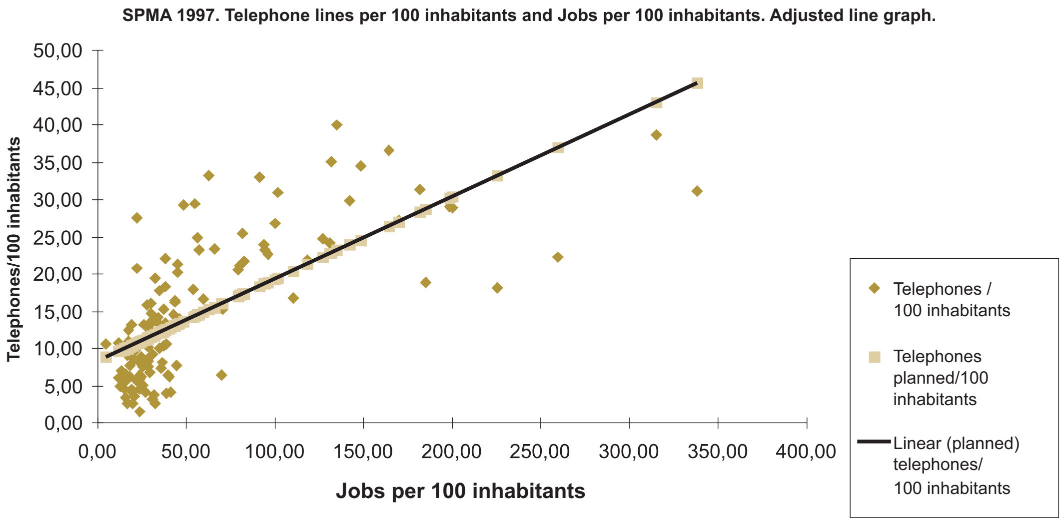


Fig. 6. São Paulo metropolitan area. Regression analysis: Residential telephone connections per 100 inhabitants and percentage of households with income higher than 20 minimum salaries. 1997. *(Source: Silva 2003)*

In this case, the determination coefficient (r^2 adjusted) obtained from the correlation was 0.74, that is, almost 25% more precise than in the previous case, supported on the reverse correlation of low income. Since this is the same data base and the same relation between telephone lines per 100 inhabitants and family income, the comparison between the statistical analysis of Figs. 5 and 6 shows that the study of abundant offer in inclusion spaces can be more expressive about the concentration process than the study about scarcity in exclusion spaces.

Based on this brief analysis of the differences in coverage and effective access to infrastructure in São Paulo, it is possible to make some general observations, which, even if not accepted as premises for other cases of large emerging cities, can at least be introduced as hypotheses to be proved:

a) The asymmetric expansion of capillary distribution networks, in relation to the arterial distribution and central production systems, creates a heterogeneity of access that segregates the poor peripheries although they appear covered by the services.
b) Privileged urban spaces are found within the perimeters of the more homogeneous expansion of the networks in areas adjacent to the center, in contrast to a more scattered process of real estate valuation in the large cities of economically advanced countries.

c) Greater precision is achieved in the study of contrasts and concentration based on the included/wealthier areas, rather than on the direct detection of what is lacking in the excluded/poorer areas.

Conflict due to lack of capacities

In Brazil, the most important urban infrastructure networks privatized to date are electric power and telecommunications. The privatization of water supply and sanitation services has not yet affected large metropolitan concentrations, in their majority serviced by state companies formed under the PLANASA model. These companies, although controlled by the state capital, were regulated as if they were private, which enabled them to obtain loans from the international banking system when the para-statal financial model collapsed, in the late 1980s. The financial scheme implies debt service costs and investment return rates similar to those of private operators, which makes the management logic of state and private lenders very similar.

The studies carried out to date in Brazil on the few cases of private management of water supply and sanitation services have not shown, as a general rule, a practice of abusive rates or a systematic movement to restrict coverage in the poorest areas. On the contrary, the in depth analysis by Vargas (2005) on three services operated under the private concession regime in the states of São Paulo and Rio de Janeiro (including the one in Niterói, in the metropolitan area of Rio) shows that lenders have strived to expand social supply through gains in operational efficiency. However, income from rates has been insufficient to cover, by itself, the social attention goals. In all the cases analyzed, some form of contribution of additional public resources has been negotiated with the regulators.

This movement is no different, in essence, from that observed in the state supply model, when the expansion of social attention benefited in most cases from specific contributions of budget resources or transfer of special credits at subsidized interest rates. There is no record to date of a significant difference in managerial or operational attitude by private lenders in relation to the large state operators regarding the coverage of low-income areas. The greatest difference resides, in our opinion, in the broad planning and regulation strategies, on the sets of services at regional and national scale, which tend to be more fragmented and heterogeneous under the practice of private concessions.

The sectoral strategies of the large state supply systems in force until the mid 1980s included sophisticated formulas for regional compensation and surplus management in order to guarantee continued investment in the expansion of the capacities and coverage of social demand.

The large regional and urban infrastructure institutional systems in Brazil, whether for telecommunications, electricity, environmental sanitation, or urban transportation, were all ruled by institutional financial planning, centralized regulation, and partially decentralized operation. Financial planning was based on the regulation of parafiscal funds and payback instruments and compensation of obligations between the different agents of the system, with a margin for the practice of crossed subsidies and deferral of debts, seeking the least dependence possible from direct fiscal contributions.

This was the formula for the housing and sanitation funding systems under the coordination of Banco Nacional de Habitação–BNH (National Housing Bank), the electric energy system under the coordination of Eletrobrás, the telecommunications system under the coordination of the powerful Telebrás and Embratel, and the urban transportation system under the coordination of Empresa Brasileira de Transporte Urbano–EBTU (Brazilian Urban Transportation Company).

This formula always included a large and powerful parastate entity of national scope with the attributions of financial and operational coordination of the whole; one or more organizations of direct public administration with general regulating attributions; and a system of parastate agent operators, by concession, at the state or regional level. The capillary operation has rarely corresponded to the municipal scale, but rather to states, microregional or metropolitan authorities. That is why the state supply system of the 1950s and later years began to distance itself from the local scale and, as a rule, was considered to be heteronomous and centralizing.

However, the leaps in the expansion of supply were marked in all of them and, as a common feature, were based on formulas to manage scarcity and on crossed subsidies at scales that would allow the generation of surpluses. This model implied a great concentration of power in the central systems of operational coordination and, in fact, they appropriated the competencies of planning and regulation in their sectoral areas. The territoriality of the subsystems was ruled by operational logic, giving rise to clusters that many times were in conflict with the geography of the political and administrative jurisdictions of the territories they comprised. This heteronomous character of the sectoral supply was accentuated by the distortions of the political model imposed by the authoritarian regime in power between 1964 and 1985 in Brazil, which systematically curtailed the autonomy of the states and municipalities.

Despite the distortions and the authoritarian components, the parastate supply developed a logic to manage the scarcity that was able to establish minimum levels of homogeneity of access inside each operational aggregate, despite the brutal inequalities of income that characterize Brazil and the region to this day. In the destination of capacities for economic production and social reproduction, attention to the first never ceased to be the priority, but a series of regulatory and operational artifices allowed the latter to undergo significant expansion. One of them, in all modes of infrastructure with variations in accordance with the specificities of each case, was the "social rate" always associated to minimum levels of remunerated consumption under the marginal cost of provision. In order for this scheme to function, in some part of the supply complex, there always was a demand that paid more than the marginal cost of the service in its own consumption band, which implied working with aggregates of supply and demand that increasingly comprised more territory and restricted the concept of social supply to consumption standards just sufficient to fulfill basic needs. This last dimension was crucial as from a certain aggregated capacity per operational area, the maximum possible had to be designated for uses that would pay the full marginal cost of production and generate surpluses for the expansion of the social supply. To this effect, the existence of privileged demand sectors was always strategically indispensable for the expansion of social supply in the sectoral infrastructure systems in Brazil.

Upon the decline of the state supply model and the adoption of strategies similar to those of competitive goods and services, as a condition for private investment in infrastructure, it was not the individual willingness of each operator that established compensatory access mechanisms in managing the scarcity. Privatization, understood as a broader process that prevails in most infrastructure network modes and services starting in the 1990s, says more about the application of a private logic to the complex of sectoral planning, financing, and regulation, than about the legal identity of the service operators.

As an aggravating circumstance of this decline model, a new profile of consumption needs arises at the level of an emerging social demand, still not studied in depth, but potentially very important. These needs refer to the consumption of public service capacities to generate income at home, not at the factory or the office, since at-home jobs escalate. The research based on a sample of 1041 households in the Municipality of São Paulo, of which 341 were exclusively located in popular neighborhoods and 700 were distributed around the city, showed the significance of at-home work, detected in approximately 15% of the households studied (Silva 2003).

This research shows, among other indicators of the growing use of infrastructure for at-home work, a correlation between residential consumption of electric power and the number of total jobs (Fig. 7), which results in a correlation coefficient (r) of 0.66 and a coefficient (r^2) of 0.44.

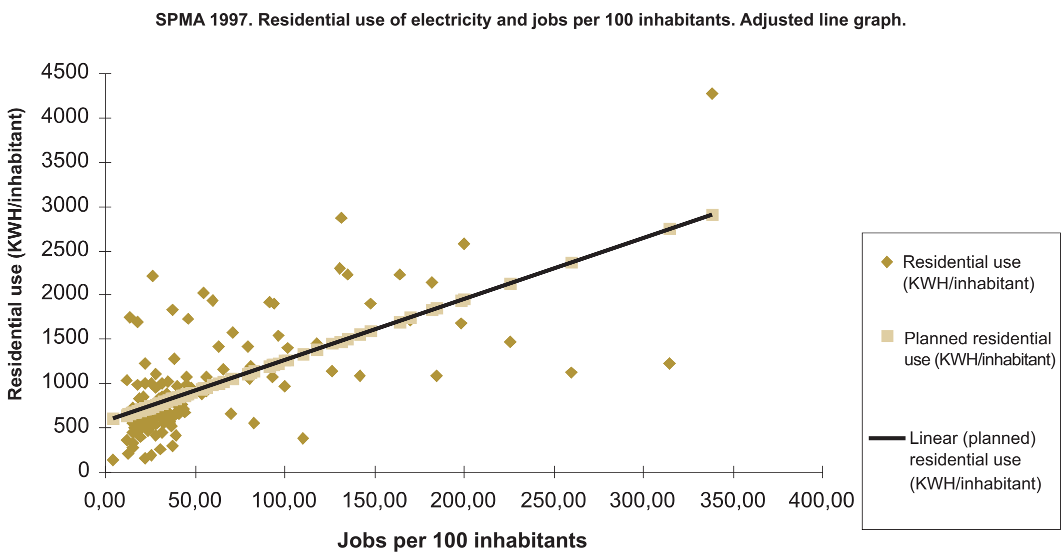


Fig. 7. RMSP (Metropolitan Region of São Paulo). Regression studies. Residential consumption of electric power as a function of the total number of jobs. 1997. (Source: Silva 2003)

It is important to note that the relation between the total number of jobs and residential consumption can include a significant portion of electric power consumption in informal activities, not registered as nonresidential connections. The result is interesting not only because of the correlation coefficient, but also because of how it compares with the correlation coefficient of low family income (concentration of households with family income up to 2.5 minimum salaries), which resulted in a correlation coefficient of 0.48 and a determination of 0.23. Contrary to the case of fixed telephone line coverage, which presents similar correlations for income and employment, in electricity consumption the coefficients are heterogeneous and clearly more expressive in relation to employment. Considering that research on employment refers to total employment, without distinction between assigned portfolio and autonomous or salary worker without an assigned portfolio, that relation is an important indication of the intensive use of public infrastructure and its services by the informal sectors of the economic activity.

Women seem to be mainly working out of their homes: Seamstresses, baby-sitters, manicurists, beauticians, cooks, embroidery and knitting workers, bakers, represent close to 53% of the cases studied. Yet about 20% of at-home work is mostly carried out by men (mechanics, plumbers, electricians, carpenters, informal store/bar owners) and approximately 27% can be carried out by either men or women. This situation is in contrast with the cases described in the reference list, which point to a higher predominance of typically female activities. However, as pointed out in specific research on at-home work in Brazil (Abreu and Sorj 1993, Lavinas et al. 2001) more women still work out of their homes than men. In the future, research should be carried out to compare this condition with the relative increase of homes where females are heads of household, invalidating the complementary character sometimes attributed to female work.

From the answers obtained in the field, it was not possible to assess the specific elasticity in relation to the increasing cost of public services. The later development of the above-mentioned research intends to accomplish this, as the only secondary data available regarding the relative weight of the cost of public services for exercising informal work activities, carried out by PNAD (National Research of Households) in 1997 point to rather significant bands of incidence. Table 1 shows the expense percentages by different groups involved in informal activities in network public services (water, electricity and telephone), based on the processing of the data of research on informal work, according to PNAD 1997, for São Paulo, Rio de Janeiro and Belo Horizonte. There is no information available regarding other years, which makes it impossible to establish a historic series. However, the cut for the base year of 1997 suggests some important relationships of informal activities with infrastructure and network services.

Table 1. Informal Work and Expenditure in Network Public Services as Percentage of Total Expenses for 1997 (Silva 2003)

Activity Groups	SPMA		RIMA		RHMA	
	Percentage over Total	Percentage over Total adjusted*	Percentage over Total	Percentage over Total adjusted*	Percentage over Total	Percentage over Total adjusted*
Total	4,30	7,35	4,88	10,12	3,33	4,83
Mineral extraction and transformation industries	3,83	11,75	5,17	18,38	3,73	5,65
Construction industries	0,28	0,30	2,31	2,70	2,33	2,34
Commerce	2,22	6,08	3,88	12,68	2,29	4,09
Lodging and food services	5,63	13,55	4,85	12,73	3,20	6,21
Transportation services	0,17	0,17	0,01	0,01	0,47	0,47
Repair, personal, residential and entertainment services	8,04	9,93	7,02	8,85	5,27	6,30
Technical and ancillary services	6,85	7,11	9,76	10,52	7,16	8,08
Other services	13,99	13,99	19,90	19,90	37,91	37,91

(Original source: IBGE (1998), Direction of Research, Department of Employment and Performance. PNAD 1997. Comparisons and analysis by the author.)

(*) Adjusted total of the costs relative to raw materials and goods for sale.

The incidence of the cost of network services is significant for most informal activities, with the exception of the transportation services in the three cities and of civil construction in São Paulo. The incidence of the cost of water, electricity and telephone for repair, auxiliary, personal and entertainment services and for technical and ancillary services in general is relative and homogeneously higher in the three cities. The category of "other services" is the one that presents the highest percentile incidences, despite their inhomogeneous behavior in the three cities. In the case of Belo Horizonte, the incidence of the expenditures in water, electricity, and telephone in that category affects a band of approximately 40%.

Faced with this scenario, the strict concept of essential consumption for physical reproduction, which allowed the parastate supply model to reach significant levels of social supply, should be reviewed in depth. Evidently, the minimum needs for physical and sanitation survival that inspired that concept of essential consumption continue to exist and should receive attention. However, the recognition of the greater complexity in social demand is important in order to discard naïve solution attempts, such as the simple re-editing of isolated concession contracts and of social rates for minimum consumption. What occurs today, with the trend toward a greater demand for services to be used in the generation of income by families, is the redefinition of the limits of the capacities for economic production and social reproduction that in the previous supply models were clearly different from one another. The theoretical dichotomy that juxtaposes the supply of infrastructure for production against the supply destined for consumption could possibly continue to be valid. But the tangible limits between these dimensions, in the material and operational planes of the services, certainly appear much more fluid and difficult to identify and, therefore, less susceptible to control by simple compensatory mechanisms in the strict ambit of rate policies.

Perspectives for universal access and the role of regulation

The relationship between infrastructure supply and the creation of privileged spaces in the city is not a new process, but is revived under the protection of the generalized liberalization of the economy and the relaxation of the bureaucratic control instruments. But the inductive power of infrastructure to the creation of new real-estate values is object of controversy in the specialized literature. As stated by Offner (2000), the relation of causality between real estate valuation and infrastructure supply is debatable, since the latter can occur after the former. However, regardless of the order that determines the processes, the concentration of the best supply in high-value areas plays a central role in the definition of unequal access to infrastructure capacities.

In a country like Brazil, which is marked by the concentration of income, it is natural for such unbalances to be aggravated in the context of a deregulated supply, not with regard to the formality of the concession contracts and commercial rights and obligations, but rather in relation to the public nature of the services. And in order to rescue the regulating dimension, it is necessary to consider, together with the sectoral regulation instruments, the multiple institutional systems, which may, as a whole, rescue public control over the services.

The regulation reform of the 1980s in Europe and the United States (Majone 1988) converged in the identification of two spheres other than the sectoral level in the re-regulation process of the public services: (1) the antitrust and (2) the environmental regulation systems.

The relevance of service networks for the economic defense systems (antitrust) is a significantly controversial issue since the origin of the specific regulation agencies and commissions was based on the recognition that these services, as they necessarily constitute monopoly structures, would not be capable of being framed within open market systems.

Although throughout the American and British regulation history of the 20th century prior to the reform of the 1980s there may have been cases of significant antitrust interventions in abusive practices of economic power by public utilities, until then there had been no systematic insertion in the sense of achieving competitiveness in relation with the regulated services as such.

The emblematic British privatization of public services that began in the second half of the 1980s used the technological restructuring of infrastructure networks as an organizational premise for competition. The British neoconservative proposal was based on the assumption that the technological restructuring would imply the transformation of the services into competitive actions, especially due to the unbundling of central production functions and the different levels of service distribution. On the basis of this assumption, sectoral regulation would be significantly reduced and services would acquire relevance—as the competitive activities they would become—for the regulating system of economic activities in general, including that of antitrust. But it turned out that the technological reforms necessary to make the services competitive would require much more time and much more money than forecasted by the proponents of this process (Bishop and Kay 1988). When faced with these limitations, the government decided to privatize entire monopolies with the same technological structure in force under the state supply regime. This disagreement between the theory and the practice of economic liberalization has been repeated in most countries, especially among the poorest, giving rise to the transfer of large networks comprising whole territorial units and all of the vertical spectrum of functions (production, arterial and capillary distribution) based on regulation models in principle focused on competitive technological structures.

To the territorial and functional gigantism of privatized infrastructure complexes, one should add the practice of the combined businesses of large multiscope utilities, with the capacity of dominating, simultaneously, several service networks over the same territorial complex. This type of monopoly not covered within the competency of the sectoral regulator is not typified within the sphere of antitrust, which mainly focus on inhibiting the vertical concentration of specific markets.

From this perspective, the relevance of public services and the particular forms of regulation and control applied to the sphere of urban policy must be highlighted. In fact, there is the possibility of territorial domination over the city and the region by private agents, which is not foreseen among the traditional forms of market domination controlled by economic defense systems. But its effects can be decisive in the creation of privileged areas and in the domination of a production "market" in the city that, more than domination over specific segments of the economy, affects the life of the urban collectivity. The relevance of the infrastructure and the network services to the environmental regulation system can also be defined in these terms, since the majority of these involve interactions and impacts relevant to the natural and built environment.

The interactions occur along the lines of (i) consumption or appropriation of resources such as in the case of hydropower plants, public water supply and natural gas, which compete for the use of surface or underground water and whose prerogative for deciding on priorities rests with the society; (ii) degradation of the physical environment—sewage, solid wastes, emission of pollutant gases, non point-source pollution; and (iii) indirect action over the added severity of natural phenomena that have large environmental impacts and high social costs, such as the increase of flood peaks derived from the construction of waterproof roads and the reduction of soil absorption capacities.

The consumer rights framework has kept an important role in the overall regulation of public services, apart from the sectoral regulation structures. The violations of consumer rights, perpetrated by the Energy Crisis Management Chamber during the 2001 energy crisis in Brazil, made public the central role that the consumer rights system has to fulfill in the institutional complex of public service regulation. Limited by the rigid terms of service licenses and contracts, sectoral regulators are not flexible enough to look after the consumer rights whenever new and unpredictable situations emerge, such as an exceptional shortage of inputs during the 2001 energy crisis.

A systematic regulation structure that would include sectoral, environmental, public defense, consumer rights and urban policy instruments seems the only promising solution for rescuing a sense of public regulation in the institutional complex interacting with the infrastructure and the public services. The institutional structures of metropolitan planning and integrated water-resource management, together with the other suprasectoral regulatory structures, can be effective in regulating the important social, physical-territorial, and environmental dimensions of the infrastructure systems as part of the rules for organization of the commercial services, to which the incipient sectoral regulation systems are predominantly dedicated.

With the institutionalization of the National Water Resource Management System, a new perspective for institutional integration is created for environmental sanitation services as privileged agents of the system in highly urbanized basins. This is the case, for example, of the Alto Tietê Hydrographic Basin, which comprises most of São Paulo metropolitan area territory. The construction of a common plan that would include the services of basic sanitation, urban drainage, and solid waste disposal at the metropolitan scale, has fostered the creation of a common institutional space with the potential to tie in all sectoral actions into common objectives related to the territory. This cannot be understood as a regulatory action in the strict sense, identified as the specific regulation of each one of the services involved, but certainly comprises a complex of institutional relations that determine the regulatory environment for all services involved in that portion of the territory.

Regarding the technological evolution, there are some efforts—still incipient, but not negligible—to create a demand management culture centered on technologies that promote taking better advantage of the available water. Since the programs to control losses in the 1980s, later interrupted for several years at the beginning of the 1990s, concerns have been gradually expressed in Brazil regarding the efficiency of the final use of water for urban supply. Technology and management in that segment are promising, as they have been decidedly supported on a regulation structure in which demand management is the priority. In other segments of water resource management, demand management started to be seen as a priority component of sectoral development, such as in the case of nonstructural measures to control floods.

The intersectoral integration of planning and management instruments, as proposed in the Plan for the Alto Tietê Basin (FUSP 2002), opens the way for a hybrid formula for expansion of the social interest supply that is based both on state investment and the market. Given the manner in which the sectoral components of basin management are integrated, the plan paves the way for the practice of new formulas for crossed subsidies, for an intersectoral coverage, which would expand the perspectives for social supply.

Attention to social demand under the current economic, institutional, and social situation of urban Brazil is three times more complex, as it simultaneously combines the following: (i) the decline of the state supply model; (ii) the lack of definition of a regulatory structure to receive private investment; and (iii) the deep alterations in the profile of the social demand that has its basic needs for reproduction, increasing specific requirements for new forms of at-home work and the generation of income in the urban economy. To these complexities we must add the relation with the environment and the natural processes that increasingly affect life in the cities, involving multiple interactions among the economy, society, urban development, and the environment.

In the theoretical definition of complex systems, the relevance of this set of interactions is clear. Among these interactions, a particular form of aggregated complexity, which can be distinguished from algorithmic and deterministic complexity, has grown in importance (Mason 2001). While algorithmic and deterministic complexities are supported by mathematical equations and some premises about how complex systems work, aggregated complexity strives to understand the holistic nature and the synergy resulting from multiple interactions[4]. The debatable results of most mathematical models applied in urban and sectoral planning help reinforce the relevance of urban-environmental issues within the sphere of aggregated complexity, wherein the effects of multiple interactions differ from the sum of the isolated effects of each process.

Brazilian researchers from São Paulo University (USP) and Minas Gerais State University (UFMG) have been dedicated to the systematic study of the interactions between water resources and urban environment based on aggregated complexity. Given their results, they have proposed highly flexible managerial and operational instruments and intersectoral coverage for the integrated management of densely urbanized basins.

The conceptual structure of those instruments is explained and discussed in the following section, not so much out of a specific interest in the instruments themselves, but rather because of the potential of an inclusive and flexible planning and management process in an ever more-complex urban-environmental reality.

[4] A set of interrelated concepts define a system of aggregated complexity: (i) the relations between entities; (ii) the internal structure and the environment surrounding it; (iii) new lessons and emerging behaviors; and (iv) different means by which systems change and grow (Mason 2001).

Infrastructure, Urban Issue and Environmental Management

This section describes the analysis and proposes new instruments for the integrated management of densely urbanized basins, supported by the studies of the Plan for the Alto Tietê Basin in São Paulo metropolitan area, further expanded for other large Brazilian metropolitan concentrations in general.

Studies focused on specific interactions between the urban issue and environmental degradation. The identity of a social vulnerability does not necessarily coincide with that of an environmental vulnerability, considering the various social segments and spatial units that form the metropolitan complex. The work shows the specificity of the environmental issues in densely populated urban areas, the need to articulate sectoral management with a broader strategic vision, and the role of information as the basic condition for effective social participation.

Specific conflicts in urbanized basins

The technical literature on water resource management considers the following among the basic conflicts in the use of water resources:

- Irrigation
- Hydropower
- Flood control
- Industrial demand
- Urban demand
- Sewage treatment
- Navigation
- Others (recreation, etc.)

These are the classic conflicting uses, present in most Brazilian basins as well. However, we recognize that densely urbanized basins—understood as hydrographic systems whose territory develops predominantly over urbanized areas—do deserve a specific treatment in terms of the particular conflicts to be dealt with.

In the Alto Tietê River Basin Plan, comprehending the hydrologic units that cover the conurbation of the São Paulo metropolitan area, the main specific conflicts involve the following water uses:

a) Urban supply
   1) Residential use
      - essential
      - nonessential
   2) Nonresidential use (common role)

b) Large users (industrial, commercial and large companies in general)

c) Flood control

d) Dilution of pollutants
   1) Point source pollution
   2) Nonpoint-source pollution

The large traditional uses—irrigation and hydropower—also exist in the metropolitan complex of São Paulo and are not negligible. However, their magnitude as compared with typically urban uses, in general, is much less than in rural or mixed basins. The specificity of the conflicts typical of large cities generates priorities for action arranged according to patterns and values different from those applicable in the planning of multiple uses in general. There are less known synergies and intangible values that make the rationale of decisions less clear.

One of the political and cultural values that results from the subjective valuation of water uses is the idea that any kind of residential demand is necessarily essential and, therefore, deserving of subsidies. It is clear that part of this demand, which corresponds to the basic needs of hygiene and health, is in fact essential for the sanitation integrity of all the population. There is no doubt that a level of essential demand fits in this category. There is another category, less known and commented in the previous section of this chapter, which corresponds to a social demand for the basic generation of income and, although it can also be considered essential and deserving of special treatment, it is not of the same nature as the demand for hygiene and health. In addition, there is a part of the aggregated residential consumption that is destined to clearly nonessential uses, such as washing cars, filling swimming pools, and others. In this example, three purposes of supply and demand different from one another are characterized, which at the same time refer to the same physical good, public supply water. The distinction arises at the level of use and the regulation that must be sensitive to these differences.

Trade-offs between environmental and social objectives represent another ambiguity typical of urban uses. One of the most common in urban management defines the relation between low-income occupation and water spring pollution. In the case of São Paulo metropolitan area, the highest rates of demographic growth occur in the periphery, where the main water-supply reserves are located. Since the mid-1970s, metropolitan water resource managers have applied measures to mitigate the impact of this occupation, translated into restrictive criteria and standards for urban land occupation. However, the efficacy of these measures has been systematically compromised by complex urban development processes, pressing to expel the poorer population to the periphery. If a strict cost/benefit analysis rationale were used, limitations to polluting occupation would be fostered by a metropolitan offer of low-income housing matching the marginal cost of the pollution.

These are the characteristics that, in our opinion, justify specific treatment for the management of densely populated basins, different from that applicable to other hydrographic basins in general. In the case of the Plan for the Alto Tietê Basin (FUSP 2002), the complex relations between water quality, availability for urban use and flood control showed that the efficacy of isolated actions in relation with each one of these priorities would be very much limited if no consideration is given to their reciprocal interactions as well as those established between them and the urban occupation process. In the joint treatment of water resource management and the urban development of the metropolis, it was possible to identify forms of socio-environmental vulnerability that could probably be extrapolated for a broader dimension of the relations between the natural and constructed environments, even as it relates to the natural phenomena manifested in unprecedented ways and intensities.

Indicative planning and urban water management

As a comprehensive plan of integrated water management, the Alto Tietê plan has focused on the establishment of strategic measures that could address the combined requirements of urban control from the standpoint of different water uses. In most cases, the application of nonstructural measures of land use control involve compensations that cross the various municipal jurisdictions forming the metropolitan complex. This is the case of restraining urbanization on upper water streams, whose surrounding urban areas are not those suffering the effects of flooding caused by the impermeability they promote. Rather, those suffering the effects of upstream flow/velocity increase are the communities living downstream, which generally belong to another municipality/district different from the one where the preventive measure is applied. There is a geographic and jurisdictional mismatch between the locations where preventive measures should take place and those where only corrective measures could be applied, regardless of the higher economic and social costs of the latter. This is why a comprehensive plan that encompasses a huge complex such as São Paulo must rely on a metropolitan-wide management strategy.

This strategy departs from the concept of integrated management in densely urbanized basins based on four different dimensions of integration/institutional articulation, as follows:

- *Integration between systems or activities directly related to water use:* This concept refers to the basic rationale of integrated water management, with particular emphasis on the main uses at the Alto Tietê Basin, i.e., urban supply, industrial supply, wastewater dilution, flood control, irrigation and hydropower. Small property crops for fresh consumption are particularly important on the East upstream sub-basin, and the plan considers its modernization a strategy to avoid urbanization in that area. The expected increase of water velocity on the upstream segment of the Tietê River, in case of intense urbanization, would seriously aggravate floods in the central area. In terms of hydropower use, the most important interaction is the operational diversion of the main tributary to Tietê, the Pinheiros River. This river has had its flow inverted, so as to fill a huge reservoir at the edge of the Atlantic Plateau, upstreams of a hydropower plant down on the coast, that benefits from a slope of about 800 m. There is a strong use dispute around the main southwest reservoir, Billings, since its full capacity for urban supply would imply either ceasing or dramatically reducing reversion. Still under the concept of direct integration are included the infrastructure and services of solid waste collection and disposal, due to their immediate interference with concentrated and nonpoint water pollution.

- *Territorial and jurisdictional integration with urban planning and management:* This branch of integration includes the municipalities and the whole system of metropolitan planning—still very feeble in São Paulo after the provisions of the 1988 Constitution—aiming at preventive measures regarding urbanization, particularly concentrated pollution loads on surface reservoirs and flood control on upper water streams with possible outcomes on nonpoint pollution. This branch of integration evolved from the former metropolitan protective regulations of 1975, in the sense that it is also centered on the control of urban land use. However, it is worked under an innovative approach, based on objective modeling of correlations, and on an open platform of information, planning and management, aimed at matching water sustainability objectives with local development priorities.

- *Regulatory articulation with infrastructure and public services nondirect users of water resources, but strongly related to land use and potential damages to water sources (for example, housing and urban transport):* The metropolitan systems of urban transport and housing are the main representatives of this third branch of integration, considering the importance of their outcomes to water sustainability. Neither of them is an important water user in itself. But they do condition the metropolitan profile of water demand and sustainability due to their role in structuring the urban/metropolitan territory. In the case of urban transport, the plan strongly recommends development of mass public transport and freezing of the road network—especially on protected areas while simultaneously decompressing areas for alternative settlement of poor peripheral population and avoiding medium/high income developments and standard dense urbanization in the outskirts. For housing strategies, urban upgrading programs in riverside settlements are emphasized, considering the fragility of these settlements to floods and contamination and the extreme operational difficulty of implementing drainage and sewerage interventions in these areas without relevant measures on housing upgrading and internal relocation.

- *Planning and operational articulation with neighbor basins:* The São Paulo metropolitan region is the center of a larger urban territorial complex that encompasses other basins in areas of intense economic activity. Nowaday the São Paulo metropolitan conurbation imports nearly 50% of its water from the northern neighbor basin

Piracicaba, causing a severe water restriction for the urban concentration of Campinas in that area. Because of an incomplete system of sewage treatment and disposal, the metropolis exports wastewater to the hinterland, at the western neighbor basin Sorocaba, and to the coast, through the southeastern slopes. The future absolute expansion of the metropolitan supplies will probably rely on abstraction from the eastern neighbor basin of Paraíba do Sul, in an arrangement envolving the neighbor state of Rio de Janeiro. These cases of interaction make clear why the plan strategy treats the relationship with neighbor basins as a specific component of integration, deserving proper planning and management tools.

The dilemma of planning: enforceable versus incentive-oriented policies

Apart from the very rational recognition of different levels of integration, the plan should also address the articulation of broad water sustainability goals with the municipal priorities in urban and economic development in a politically suitable relationship. As experienced under the metropolitan law of 1975, the formal imposition of state rule is not the best way to deal with normative interactions that necessarily interfere on municipal competencies. The strict enforcement of state regulations is neither politically feasible nor socially fair in a context such as the São Paulo metropolitan region, which includes huge distributive injustices both in regional and socio-economic terms. Besides, it must be kept in mind that a set of predominantly indicative guidelines cannot be enforced as past national policies for electricity, water supply, and others. Based on this understanding, the plan developed a hierarchy of norms and guidelines, aimed at creating real stimuli to metropolitan municipalities with regard to water sustainability targets.

The plan has identified five levels of norms:

- Level 1 - Fully enforceable norms. This level includes all the legal provisions not classified under less stringent levels. It refers particularly to standards directly related to basic requirements on water quality and flood control according to the particular category of the resources involved in the considered area. No negotiation is applicable to this level of norms, which must be fully and unconditionally observed by every agent in the basin area.

- Level 2 - Transitory enforceable provisions. This level refers to transitory general provisions that tend to be overruled by specific norms and codes developed for each specific sub-basin/municipality.

- Level 3 - Norms attached to legal rights of compensation. This level refers to norms that are fully enforceable. As in Level 1, the local level is entitled to a compensation for the restriction on local development. Compliance in this case could be judicially argued by the local jurisdiction should the upper regulatory level fail in its compensatory obligation.

- Level 4 - Norms based on performance. This level refers to norms whose enforcement refers to final results, despite the particular regulatory means applied to achieve these results. This tends to be the case of the local/sub-basin norms of land use, should the correlation models work properly. Once the pollution loads and maximum run-off standards are observed in a given planning area, a wide range of urban standards could be applied, based on internal compensations of loads and flows, combined with different levels of wastewater treatment and nonpoint pollution control (inclusive local detention structures for storm water).

- Level 5 - Encouraged conformity. This level refers to the achievement of desirable but nonenforceable conditions, in line with the objectives of the plan. Once the norms are observed according to the preceding levels, there is still a considerable margin of measures that are desirable in terms of the long-term sustainability of the whole basin. This could be either the case of exceeding the basic performance standards locally fixed or the case of proactive involvement of a given jurisdiction in promoting compliance elsewhere in the basin territory (for example, by receiving and controlling loads originated outside its limits, in support of less capable neighbors). Incentives could be materialized both in terms of financial compensation from the water charges administered by the basin agency and in terms of a higher level of autonomy in self-regulation.

This flexible framework of norms and standards may have a better chance to match water sustainability and local development priorities in a realistic prospect, when compared with the preceding set of metropolitan regulations exclusively based on legal enforcement. However, it relies on a sophisticated management of information bases and decision support models that requires a considerable research effort in order to become applicable in practice.

Converging nonstructural approaches

One of the main features of the Alto Tietê River Basin Plan is the articulation and combination of structural and nonstructural measures conceived in the realm of each water use sector to encourage the maximization of net benefits. On the one hand, the recurrence to existing sectoral trends makes integrated planning and management more applicable since the instruments are in one way or another already known. On the other, it involves difficult articulation between sectors that are not used to cooperate among themselves and need to maximize net benefits in the realm of their own cost and benefit logics. Conceptually, the fields open for a possible convergence of nonstructural measures are the following:

a) *Possible new dimensions of cross subsidization, multisectoral internalization of benefits:* The Brazilian policies on public utility services between the 1960s and the early 1990s were strongly based on cross-subsidization practices to enhance the coverage of low-income users at the expense of the wealthier users. This was generally done by means of increased block rate structures, on the grounds that wealthier users would demand per capita quantities of service systematically larger than poorer users. The assumption has shown generally correct and fair for most infrastructure outputs, including urban water supply. Nevertheless, the absolute economic capacity of integrated sectoral systems, even when organized upon vast territorial jurisdictions—for example, the São Paulo State water supply utility—seems limited in relation to the growing need of low-income demand.

The concept of multisectoral cross-subsidization tends to open new prospects for an integrated expansion of service coverage, since the economy of scale—originally associated to the logic of intrasectoral cross subsidies—would be reinforced by an economy of scope regarding the various water uses on the metropolitan scale. Examples may be limiting pollution loads for the preservation of surface water sources and limiting discharge flows for flood control, both converging to a similar set of nonstructural measures to regulate urban land use, as explained next.

b) *Analogy between target pollution loads for nonpoint pollution control and restrictive discharge flows for flood control:* In the São Paulo metropolitan master plans of water supply and flood control, provisions regarding the control of urbanization are aimed at similar goals in terms of alleviating the relevant structural capacities. From the standpoint of water supply, the limitation of point source pollution in the vicinity of surface reservoirs and their tributaries is aimed at alleviating the costs of water treatment, especially in terms of nutrients' removal. The growing costs of advanced water treatment has justified joint programs with official urban development agencies in order to improve the sanitary conditions of surrounding settlements, up to the extent to which the cost of the upgrading equals the marginal cost of advanced treatment.

   A similar strategy has been adopted in the metropolitan plan of flood control by limiting the upstream flows of urban drainage in order to alleviate midstream and downstream peak flows. Like the target pollution loads for surface reservoirs, the concept of restrictive flows opens a margin for joint programs with urban development agencies—inclusive housing and urban transport—whose cost yardstick is based on the magnitude of the structural expansion needed should the urbanization process follow the present tendency.

   In both cases, the trade-off between the nonstructural joint intervention and the marginal cost of the structural expansion is internally defined in each sector. By applying the principle of multisectoral cross subsidization, we argue that the composed margin for nonstructural intervention—should depollution and flood control logics be combined—would be larger than the sum of the two components sectorally defined. In a prospect of combined strategy, to be held by the Alto Tietê Basin Agency, the benefits of nonpoint source pollution control associated with restrictive discharge flows shall be accounted for the scope of surface water depollution, possibly enhancing the marginal feasibility of integrated intervention.

c) *Pricing the effects of water consuming and polluting and of inducing flood:* Analogies and prospects of coordinated management: The Alto Tietê River Basin Plan has considered user charges applicable not only in terms of water abstraction and pollution, but also for urban developers responsible for decreasing land permeability and increasing urban run-off.

This concept is not yet fully developed in the Alto Tietê Plan but has been part of an important contribution from the State University of Minas Gerais in a further research network, called URBAGUA. In that project, a number of municipalities have been researched and criteria for fixing urban drainage taxation were proposed under the coordination of Prof. Nilo Oliveira Nascimento.

Information bases for a decentralized management

One of the key issues in integrated planning and management is information. The organization of water resources management in Brazil is based on a hierarchy of committees and subcommittees relevant to a hydrographic/territorial hierarchy of basins, sub-basins, and hydrologic units. Nevertheless, the physical configuration of this hierarchy is not strictly or exclusively related to the hydrographic structure. For the sake of a political balance of decisions and responsibilities, it is possible the adhesion of municipalities whose territories are only partially comprised within a given hydrological unit.

A number of different subcommittees and municipalities are included in the same committee, and a number of basin committees can form larger state or national water-resource councils. Therefore, we are talking about planning regulatory and managerial competencies that may be applied to territorial aggregations varying from the more embracing national or regional levels to the capillarity of specific reservoirs and their surroundings. In a system like this, homogeneous criteria for collecting, retrieving, and interpreting information are a crucial precondition for an effective decentralization of planning and management.

In order to facilitate information standardization for integrated management with particular focus on densely urbanized river basins, our research group, under the URBAGUA Network, has developed three software applications to be adopted at the various territorial/jurisdictional levels according to the Brazilian system of water resources management.

a) SAD_URBAGUA:

Connecting expected performance to depollution strategies: This is a decision support tool upgraded from a previous version developed at the Brazilian PROSAB Network, establishing ranges of expected performance of sewage treatment stations according to particular conditions of insertion, loading, and operation. In the present version, the expected performance is linked to a number of physical and environmental variables representative of large urban concentrations, and the results are consistent with the parameters accepted by the main Brazilian program of urban water depollution, PRODES.

According to that program, Brazilian municipalities and state sanitation utilities are entitled to receive federal subsidies for sewage treatment according to the standards of emission monitored in the outlets of their treatment stations. SAD_URBAGUA analyzes the particular conditions of insertion, operation, and loading of different technological alternatives for sewage treatment and correlates the ranges of expected performance with the standards of emission established by PRODES. In this way, the municipalities and other promoting agents may forecast not only the performance and global cost of each technological alternative in its specific conditions, but also the possible amount of federal subsidies eventually accessible.

The application was developed on a worksheet platform, customized for automatic calculation of results according to the inputs. Complex technical information is embedded on the worksheet, but the user has no direct access to it and no possibility of changing the built-in calculation routines. Notwithstanding, the model offers a wide range of choices in combining inputs to allow the simulation of particular scenarios.

<u>Main inputs</u>: Site (topography, permeability, water table level, soil total thickness, impervious soil thickness, rocky masses); available energy sources; available area; budget for investment and operation; population, water consumption (per capita); epidemic diseases risk; affluent load (standard parameters); operational conditions.

<u>Built-in information</u>: Levels of expected performance, according to combined inputs, for about 40 technological alternatives, ranging from very simple primary solutions as septic tanks to composed plants for tertiary treatment.

<u>Access to databases</u>: Restricted.

<u>Outputs</u>: Alternative ranking and scoring of treatment technologies, according to performance, initial cost, operation cost, and others.

b) SIU_URBAGUA:

Relating urban needs and trends to regionally based water management: The System of Urban Information (SIU) organizes the census district data into four groups: (i) demographic tendencies (combining geometric growth rates and densities) to identify expansion and densification trends within the metropolitan space; (ii) socio-economic vulnerability (combining family income, home congestion, and housing precariousness) to identify the urgent social needs; (iii) water and sanitation precariousness (combining individual access to water, sanitation, and solid wastes collection and disposal); and (iv) environmental vulnerability (combining proximity to surface reservoirs, land instability, and flooding occurrences).

Databases on heterogeneous territorial subdivisions—for example, sewerage drainage areas, geo-technological compartments, water supply sectors—were converted to census districts as fundamental deaggregation level. Census districts may be aggregated into sub-basins, basins, municipalities, and various regional bases up to the national level, depending on the scope of the analysis. Although logically organized for the whole spectrum of aggregation, the model has so far been fed only with data of São Paulo metropolitan districts. For broader regional analysis, new inputs should be added to the databases.

To support multipurpose interpretation, variables expressed in different units must be converted to common adimensional indicators. For the sake of expressing positive or negative trends in each of the four main groups of information, principles of fuzzy mathematics have been applied, resulting in a set of composed indicators that express gradients of urban pressure, poverty, sanitary vulnerability and environmental depletion considering socio-economic, technological and environmental data.

The application was developed on a worksheet platform associated with relational databases and geo-referenced information. It has been formatted for centralized databases server, accessible either by intranet or internet.

<u>Main inputs</u>: Selected variables according to the four data groups above, plus selected territorial aggregations and timing.

<u>Built-in information</u>: Databases (as above), calculation routines including fuzzy integral and cartographic bases.

<u>Access to databases</u>: Mediated by the worksheet interfaces.

<u>Outputs</u>: Geo-referenced information, composed adimensional indicators of priorities according to selected variables.

c) SIG_URBAGUA:

Managing multiple sectoral and local projects in a decentralized metropolitan complex: SIG_URBAGUA (meaning "System of Managerial Information") is conceptually the mirror of SIU (urban information, above) in terms of actions and their effectiveness. While the preceding system organizes the information for diagnosis, SIG treats and provides information about the actions interfering with the existing urban-environmental complex.

The territorial, functional and jurisdictional aggregation of data is compatible with the categories defined for diagnosis. Until August 2004, the model has had its main architecture and routines established, but it was very poorly fed with real inputs. Final outputs of this model are aimed at underpinning efficiency and effectiveness assessment of decentralized actions, both for the sake of process evaluation (with possible managerial revision of ongoing procedures) and ex-post evaluation.

Main inputs: Interventions/public works/regulatory initiatives classified functionally according to the affected water uses.

Built-in information: Local and regional priorities according to routine diagnoses defined at SIU_URBAGUA, spatial hierarchy compatible with various levels, and aggregations of diagnoses.

Access to databases: Mediated by the worksheet interfaces; system allows adding information and updating on use.

Outputs: Consolidated reports on actions interfering (positively or negatively) with particular priorities of the considered basin/hydrologic unit, organized by functional, jurisdictional, and timing characteristics.

The prospects of integrated water and urban management in Brazilian metropolitan concentrations

The integration between urban and water resources management is a clear-cut precondition for the effectiveness of most nonstructural measures applied to water planning. Controlling pollution loads or runoff discharges that jeopardize the availability of already scarce resources depends more on decisions and actions taken outside the water institutional system than on actions and decisions that are internally manageable. In the Brazilian water management system, a great deal of importance has been given to the participation of various stakeholders in the decision process. This is why river basin committees are formed by representatives of different levels of government and of the civil society. Participation, however, depends on a reasonable domain of technical data and their connections with policy alternatives.

Poorly informed participation, despite any formal commitments with democratic organization, is fated to fail in matching sectoral and socio-environmental priorities. The subjective language of social participation has no direct connection with the objective decisional logic of infrastructure building and operation. On the one hand, this semantic mismatch may lead vulnerable groups to be swindled by apparently neutral alternatives that actually put their needs in jeopardy. This is the case of low-income peripheral communities supporting policies for increasing absolute water supply capacities when their concrete threshold to access is a problem of distribution and not of overall production. On the other hand, technical information may raise irrational demands and political flags to the status of taken-for-granted social needs. This is the case of political pressures for urgent and costly full recovery of severely polluted water bodies, not immediately usable for supply, while less expensive alternatives for a long-term recovery could be implemented at equal social benefit. In both cases, poorly informed participation misleads decision making about the real needs of the participating groups. This is why in modeling an integrated planning and management strategy for the Alto Tietê System in Metropolitan São Paulo so much importance has been devoted to the urban and managerial information systems, linked to each other as described in the preceding section.

As for the norms and guidelines, the proposed flexibility is aimed at accommodating several conflicting priorities in terms of land use and occupation, considering the reality of a metropolitan complex composed by nearly 40 municipalities, each of them facing specific social and economic demands. This approach, apart from the flexible conception of the normative body, must rely on a metropolitan decisional body that retrieves the extralocal rationale of land use and occupation. This is not a target to be fulfilled in the sole realm of water management, but in a metropolitan system able to look after the public interest of the whole metropolis beyond the sectoral rationale of each infrastructure and service network.

References

Abreu, A. R. A., and Sorj, B. (Eds.). 1993. O Trabalho Invisível: Estudos Sobre Trabalhadores a Domicílio no Brazil. Editora Rio Fundo, Rio de Janeiro, Brazil. 132 pp.

Bishop, M., and Kay, J. 1988. Does Privatization Work? Center for Business Strategy Report series. London Business School, London, England. 93 pp.

Castells, M. 1975. La Question Urbaine. Maspero, París, France. 527 pp.

Dupuy, G. 1987. "Les réseaux techniques. Sont-ils des réseaux territoriaux?" L'Espace Géographique 3:175–84.

Dupuy, G. 1993. "Networks. Research notes in brief." Flux 11:42–47.

FUSP (Fundação de Apoio à Universidade de São Paulo). 2002. Plano da Bacia do Alto Tietê. Relatório Final Versão 2.0. (Available at http://www.comiteat.sp.gov.br.)

Harvey, D. 1976. Social Justice and the City. Edward Arnold, London, England. 336 pp.

Howe, C. W. 1971. Benefit–Cost Analysis for Water Systems Planning. Water Resources Monograph 2. American Geophysical Union, Washington, D. C. 144 pp.

IBGE (Instituto Brasileiro de Geografia e Estatística). 1998. Pesquisa Nacional por Amostra de Domicílios 1997 (National Households Survey 1997). Brasília, Brazil.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2001. Censo Demográfico 2000—Resultados do Universo São Paulo. Brasília, Brazil.

James, L. D., and Lee, R. R. 1971. Economics of Water Resources Planning. McGraw-Hill, New York, NY. 605 pp.

Lavinas, L., Sorj, B, Linhares, L., and Jorge, A. 2001. Home Work in Brazil: New Contractual Arrangements. In: Focus Programme. Seed Working Paper No. 7. International Labour Office, Geneva, Switzerland. 47 pp.

Majone, G. (Ed.). 1988. Deregulation or Re-regulation? Regulatory Reform in Europe and the United States. Pinter Publishers, London, England. 262 pp.

Mason, S. M. 2001. "Simplifying complexity: A review of complexity theory." Geoforum 32:405–414.

Mumford, L. 1961. The City in History. Its Origins, Its Transformations and Its Prospects. Harcourt, New York, NY. 627 pp.

O'Brian, K. L., and Leichenko, R. M. 2000. "Double exposure: assessing the impacts of climate change within the context of economic globalization." Global Environmental Change 10:221–232.

O'Connor, J. 1973. The Fiscal Crisis of the State. St. Martin Press, New York, NY. 296 pp.

Offner, J. M. 2000. "Territorial deregulation: local authorities at risk from technical networks."

International Journal of Urban and Regional Research 24(1):165–182.

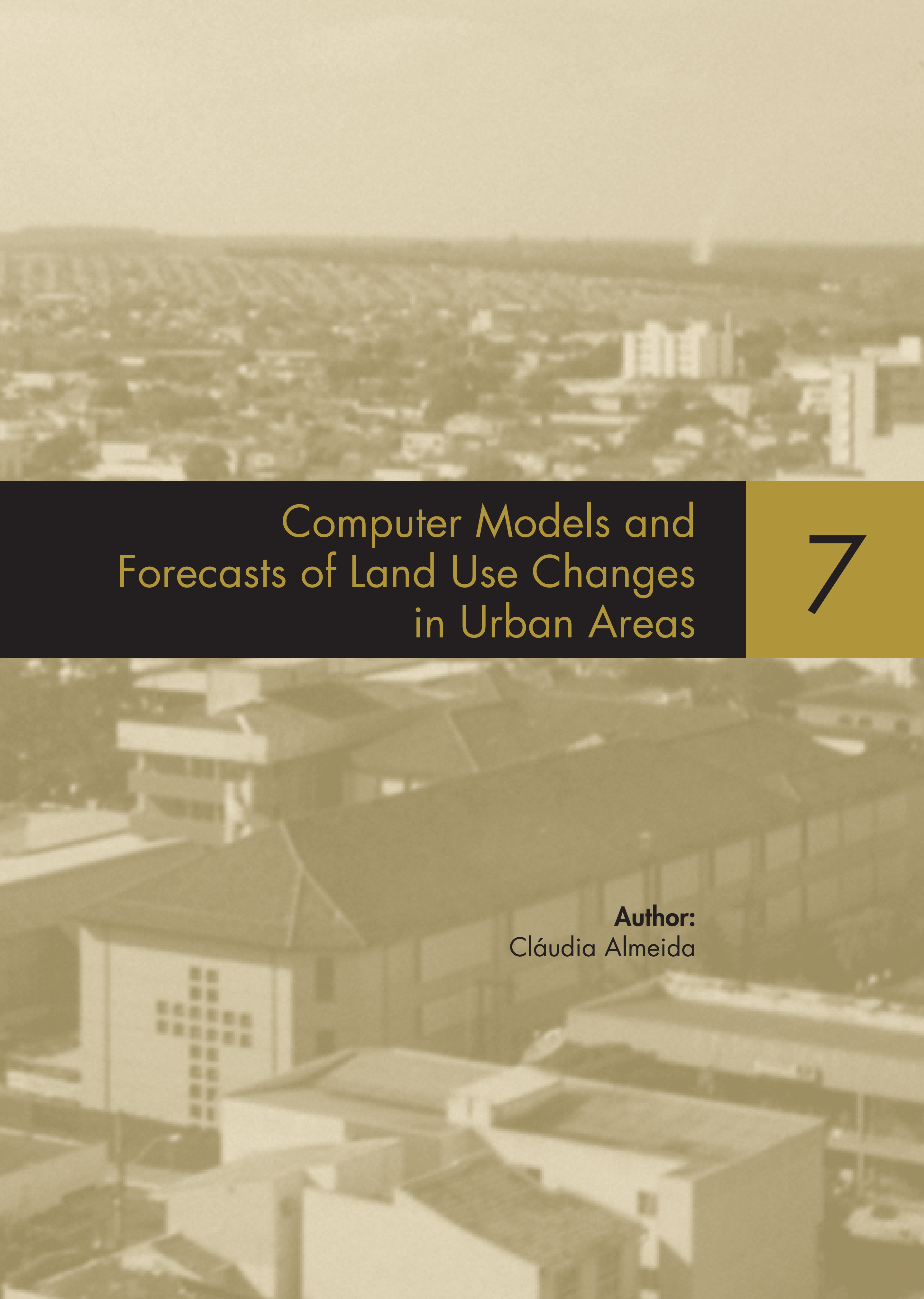
SABESP (Companhia de Saneamento Básico do Estado de São Paulo S/A). 1996. Ecossistema São Paulo. SABESP, São Paulo, Brazil. 48 pp.

Silva, R. T. 2000. "The connectivity of the infrastructure networks and the urban space of São Paulo in the 90s." International Journal of Urban and Regional Research 24(1):139–164.

Silva, R. T. 2003. Acesso a Infra-Estrutura Urbana e Desigualdade Social. Estudo de relações com o trabalho a domicílio. Research report 351683/1996-8. CNPq—Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brasília, Brazil.

SURF (Center for Sustainable Urban and Regional Futures). 2003. Evaluating Urban Futures: Enhancing Quality and Improving Effectiveness. ODPM New Horizons Programme Final Report. Manchester, England. (Available at http://www.communities.gov.uk.)

Vargas, M. C. 2005. O Negócio da Água. Riscos e Oportunidades das Concessões de Saneamento à Iniciativa Privada: Estudos de Caso no Sudeste Brasileiro. Annablume Editora, São Paulo, Brazil. 269 pp.



Computer Models and Forecasts of Land Use Changes in Urban Areas

7

Author:
Cláudia Almeida

Introduction

Urbanization scenario: Brazil in the Latin American and global context

In the last two centuries, but especially in the last two decades, mankind witnessed drastic population changes from rural to urban areas. According to a World Bank report, the percentage of the world population living in urban areas increased from 33.6% in 1960 to 46.6% in 1999, and this figure is expected to reach 75.8% in newly industrialized countries (NICs) and developed nations (Easterly and Sewadeh 2000). Forecasts also indicate that 55% of the world population will be composed of urban dwellers by 2015 (United Nations 1996).

One of the first and most important forces leading these changes in the urban environment of the developed world, since the 19th century and the beginning of the 20th century, was the Industrial Revolution. Increased population, stemming from lower mortality rates and the migration of rural workers to urban centers seriously affected the urban centers of the time. This population increase was aided by the new goods and services made available to urban areas. The new goods and services were supported by better agricultural and industrial productivity, which, in turn, was enabled by rapid technological breakthroughs and the resulting economic development. For example, in England, the population of Manchester increased from 12,000 people in 1760 to over 400,000 in the mid 19th century. London, already a city of one million people at the end of the 18th century, sheltered 2.5 million people by 1851 (Benevolo 1983).

Similar rapid industrialization and growing urbanization processes were experienced by the developing countries of Latin America in the 20th century. Brazil and Argentina entered the industrial production era at a large scale in the 1950s, while countries such as South Korea, Indonesia, and Malaysia underwent the transition from basically rural economies to eminently industrial development in the late 1970s and 1980s.

Between 1950 and 1995, there was a fivefold increase in the urban population of Asia, Africa, Latin America, and the Caribbean: from 346 million to 1.8 billion people. Although Asia and Africa still have more rural than urban inhabitants (Table 1), both feature large contingents of urban dwellers in absolute numbers. United Nations projections sugest urban populations are growing so rapidly that 80% of the world population growth between 1990 and 2010 will occur in urban areas, particularly in Africa, Asia, and Latin America (United Nations 1998).

Two aspects are closely associated with the growth of urban population: an increase in the number of large cities and the historically unprecedented dimension of these large cities.

Table 1. Trends and Projections of Urban Population by Region, 1950–2010

Percentage of Population Living in Urban Areas					
Region	1950	1965	1980	1995	2010*
Africa	14,6	20,7	27,3	34,9	43,6
Asia	17,4	22,4	26,7	34,7	43,6
Latin America and Caribbean	41,4	53,4	64,9	73,4	78,6
Rest of the World	55,3	64,1	70,5	74,2	78,0

* Projections according to a census taken around 1990. The rest of the world includes all countries in Europe, North America, and Oceania. Source: *United Nations 1998, p. 25.*

Only two centuries ago, there were two "mega cities" in the world (1 million people or more)—London and Peking. By 1950, there were 80, and by 1990, there were 293 mega cities. A large (and growing) proportion of these mega cities are in Africa, Asia, and Latin America, and the population of many of these cities grew 10 times between 1950 and 1990 (Hardoy et al. 2001).

In Brazil, for a long time, urban growth and development concentrated in the capital cities of the states along the coast. Some of them began to be recognized as metropolitan areas in the 1970s because of their high demographic density. Given their strategic location and good-quality infrastructure and social services, they were able to ensure strong ties with surrounding regions.

The development strategies adopted by Brazil, as well as by many Latin American countries, were aimed at external markets, with objectives of economic efficiency and increasing competitiveness. The result was the progressive appearance of external economies of aglomeration[1], leading to a highly concentrated spatial development pattern, as mentioned above (Fernandes et al. 1977).

In the meantime, the multicentralized development structure, based on "economies of aglomeration," presented serious limitations. After an initial period of good economic performance, the metropolitan areas started behaving as "diseconomies of aglomeration" because of such problems as higher land prices, the collapse of telecommunications and water supply systems, longer time and higher costs of daily commuting, environmental problems, and an increase in crime.

Policies to overcome these regional unbalances and the adverse effects of spatially

[1] The term "economies of agglomeration" is used in urban economics to describe the benefits that firms obtain when locating near each other. It is related to the idea of economies of scale and network effects, in that the more related firms that are clustered together, the lower the cost of production and the greater the market that the firm can sell into (Wikipedia 2003).

concentrated development were implemented by the Brazilian government since the late 1950s and early 1960s, which resulted in the creation of the Manaus free trade zone (1957); the foundation of the new federal capital, Brasília (1960); the creation of regional development institutions, such as the Oversight Board for the Development of the Northeast (SUDENE, "Superintendência para o Desenvolvimento do Nordeste") in 1959 or the Oversight Board for the Development of the Amazon (SUDAM, "Superintendência para o Desenvolvimento da Amazônia") in 1956; and actions to promote the decentralization of the industrial development in the metropolitan area of São Paulo, among other initiatives.

Among these actions, the Second National Development Plan (II PND), launched in 1974, constituted the most ambitious effort to relocate part of the industries in the metropolitan area of São Paulo to other regions of Brazil. This plan included the creation of industrial development funds and policies to promote exports and agro-industry, as well as to decentralize the production of industrial inputs. Its objectives were partially achieved, as part of the intended effective industrial relocation that occurred in the State of São Paulo. This region offered good infrastructure, rotation crop agriculture, and an unprecedented urban network, consolidated since the expansion of the coffee-growing cycle in the 19th century (Fundação Seade 1992).

Bauru, one of the medium-sized cities in the interior of the State of São Paulo inherited part of the metropolitan industrial development and is the focus of this chapter. The challenge to the study resides in the fact that it witnessed urbanization booms and featured a great diversity of economic specialization in recent decades.

The importance of paying particular attention to the urban areas of the planet and carrying out scientific research on them can be explained by the fact that these areas will not only house most of the world's population, as mentioned above, but also by the fact that they exert control over the global economy in these present times of globalization, managing financial capital flows, natural and manufactured resources, human capital, information, technological and scientific knowledge, and decision-making power. The success or failure of most human enterprises depends on wise and prudent management of their financial and institutional structures, as well as on effective management of the physical infrastructure.

Urbanization and global change: conceptual approaches

The terms "global change" and "global environmental change," as well as "global climate change," have recurrently appeared in the scientific literature of the last decade.

Global change frames the issue in a broad context, in which deep transformation in the production and consumption modes of human society have caused drastic alterations to the earth's biosphere, resulting in a considerable increase of greenhouse gas (GHG) emissions[2], climate alterations, natural resource depletion, and diminished biodiversity, among other

[2] Some of the main greenhouse gases (GHGs) are CO_2 (carbon dioxide), CH_4 (methane), N_20 (nitrous oxide), H_20 (water vapor), SO_2 (sulfur dioxide), NO_X (nitrogen oxides), HC (hydrocarbons), CO (carbon monoxide), and CFC (chlorofluorocarbons).

consequences.

Another concept related to GHG is "radiative forcing," which can be defined as a perturbation of the energy balance in the earth's atmospheric system (W/m^2) which follows a change in the concentration of carbon dioxide (from human actions) or a change in solar radiation (i.e., solar explosions).

Radiative forcing, also called climatic forcing, has a mean annual and global value—positive when it tends to heat the earth's surface and negative when it cools it. The climatic system responds to radiative forcing and tries to reestablish the energy balance. The greenhouse effect can thus be understood as the radiative forcing associated with the increase in the concentration of gases in the atmosphere (Watson et al. 2001).

Within this scenario, the burning of fossil fuels—whether for energy generation, industrial production, or transportation—represents the main source of GHG emissions in developed countries. In developing countries, a considerable part of GHG emissions originate in the burning and felling of forests, a process that releases the carbon contained in the biomass. In the particular case of Brazil, the country with the largest commercial cattle herd in the world, a large percentage of methane emissions is attributed to the digestion activities of these ruminants. And in some Asian countries, irrigated rice agriculture is responsible for most of the methane emissions.

The concept "global change" includes land use and cover change (LUCC) processes. According to Skole and Loveland (1996), these processes "are directly related to many aspects of human health and well-being, including biodiversity, food production, or the outbreak and dissemination of diseases." According to these authors, tropical forest loss, for example, and the associated emission of carbon dioxide and methane gas, as well as alterations in surface run-off and evapotranspiration, lead to modifications in the flow of sensitive and latent heat, in addition to contributing to large-scale loss of species because of forest fragmentation and to increasing the occurrence of infectious tropical diseases in regions disturbed by deforestation.

Together with deforestation, the phenomenon of urbanization itself acquires crucial importance in LUCC processes. The conversion of lands covered by vegetation (natural or secondary), or even occupied by agricultural activities in urban areas, equally contributes to altering the conditions of the local hydrological and climatological regimes. In other words, the removal of plant cover for urban purposes, the occupation of plains, and the rectification of riverbeds lead to greater soil impermeabilization that alters surface water run-off and evaporation rates, impacting the microclimate of cities and progressively reducing the diversity of urban flora and fauna.

According to Pereira Filho (2002), microclimate alterations are perceptible in all large cities, where increased temperature and diminished humidity caused by (1) the absence or scarcity of green areas, (2) the growing impermeabilization of the soil from the use of concrete or asphalt, (3) the increase in construction density hindering adequate ventilation,

(4) the intensification of industrial activities, and (5) the increase of vehicular pollution have resulted in the "heat island" phenomenon (Santamouris 2002). These heat islands not only are uncomfortable, but also are responsible for triggering larger weather phenomena, with associated human and material damages. For example, in the city of São Paulo, southeast Brazil, when the radiation emitted by the soil on hot summer days meets the marine breeze from the South Atlantic, violent storms occur, which frequently cause deaths and floods.

A significant part of the undesirable effects resulting from disorderly or informal urban occupation processes can be prevented / mitigated through planning actions. Maintaining low and flood-prone areas free from human occupation, programming the inclusion of parks and green areas in cities, integrated planning and management of collective transportation systems while maintaining an efficient road network, protecting the urban "ventilation corridors," locating polluting activities in appropriate sites from the environmental standpoint are examples of some possible measures to be adopted by local authorities to enhance the quality of life in cities.

This is the context in which recent geo-information technologies are framed. Computer models designed to simulate and forecast changes in urban land use can provide clues to local managers regarding urban expansion trends, pointing to possible growth vectors with their respective spatial management patterns and prevailing land uses. Based on this information, public authorities can evaluate whether the expansion trends are in accordance with the environmental carrying capacity of the physical site, proposing measures to reorient urban growth. Thus, these computer models are used to prevent urban occupation patterns known to be in conflict with the physical environment.

The next section presents a brief history of these models, while the section after it presents a case study for modelling urban land use dynamics for the city of Bauru, located in the midwestern part of the State of São Paulo, Brazil.

Computer simulation and forecast models of land use changes in urban areas

Theoretical and mathematical models have long been created for urban studies, aiming at clarifying processes of urban and regional change. One of the oldest contributions is Von Thünens' theory of concentric rings, dating back to 1826. According to Von Thünens' rent-locational model, the most intensive use of land will be near the center, and the rent or land values will decrease outwards (Perraton and Baxter 1974).

Other similar approaches in economic theory are the classical triangle of industrial location proposed by Weber in 1909, Christaller's model of central places of 1933, and Lösch's theory of economic regions, developed in 1940 (Merlin 1973, Perraton and Baxter 1974).

Following these simple economic-oriented achievements in urban modeling, a new generation of computerized urban models came into play in the late 1950s and early 1960s (Alonso

1960, Lowry 1964), immediately following the advances in computational facilities at that time and the advent of the Quantitative Revolution.

Important drawbacks of these early models are their oversize, arbitrary and mechanistic structure, and the fact that they could only describe the urban structure at one cross section in time, or at best, compare these static structures incorporating some long-term and often imputed equilibrium (Batty 1976).

In an effort to overcome the shortcomings of the first generation of urban models, new models were created, which attempted to work on a dynamic basis (Crecine 1964, Hill 1965, Paelinck 1970), that is, to present an explicit time dimension, where inputs and outputs vary over time (Wegener et al. 1986). However, these early dynamic models remained fairly nonspatial, especially in the sense that their results could not be spatially visualized. Yet they did incorporate considerable refinements in terms of coping with the complex, and sometimes recursive, spatial interactions among different activities in a city, as well as in terms of adding the (multilevel) time dimension in the quantitative analyses and of employing sophisticated mathematical and theoretical tools—for example, differential equations (Allen et al. 1981).

Generally speaking, the urban models developed from the 1950s until the mid 1980s did not take the spatial dimension into account. When the spatial dimension was considered, the urban space was decoupled into units (usually zones defined according to trip generation, census districts, or other similar criteria), but the output of such models could not be spatially handled. In fact, effective advances in the spatial representation of urban models occurred only by the end of the 1980s, when cellular automata (CA) models started to be largely applied, also impelled by the parallel development in computer graphics and in theoretical branches of complexity, chaos, fractals, and others (Batty et al. 1997).

Stephen Wolfram, one of the most renowned theoreticians on cellular automata defines them as "… mathematical idealizations of physical systems in which space and time are discrete, and physical quantities take on a finite set of discrete values. A cellular automaton consists of a regular uniform lattice (or 'array'), usually infinite in extent, with a discrete variable at each site ('cell'). The variables at each site are updated simultaneously ('synchronously'), based on the values of the variables in their neighborhood at the preceding time step, and according to a definite set of local rules" (Wolfram 1983, p. 603).

CA models have found applications in diverse fields, ranging from statistical and theoretical physics to land use and land cover change, traffic engineering and control, diseases spread, and behavioral biology. The 1990s experienced successive improvements in urban CA models, which started to incorporate environmental, socioeconomic and political dimensions (Phipps and Langlois 1997) and were finally successful in articulating analysis factors of spatial microscale and macroscale (White et al. 1998). Leading theoretical progresses in the broader discipline of artificial intelligence (AI), such as expert systems, artificial neural networks, and evolutionary computation, have been lately included in the scope of CA simulations. As stated in Almeida et al. (2003), methods recently embedded in CA models like those employing contemporary pattern-fitting tools such as neural nets (Wu 1998, Yeh and Li 2001) and evolutionary learning (Papini et al. 1998) are among the most promising for the coming generation of urban CA modeling achievements.

A Case Study: Simulation and Forecasts of Urban Growth and Land Use Change in the City of Bauru, SP, Brazil by Means of CA Model

Study area

Bauru is considered the biggest crossing point among railways, waterways, and highways in Latin America. The city itself was born as a crossing point between railways during the inward advance of the coffee culture in the 19th century. Still today, the city is mainly shaped by the transport system: Its urban framework is organized around four interregional roads and the railway track, which still crosses the city core area.

Bauru is currently regarded as a dynamic regional development pole in the central-west portion of São Paulo State, with an outstanding performance of tertiary activities (commerce and services). In view of its strategic historic development conditions, the city underwent a drastically fast urbanization process. These urbanization booms were followed by speculative processes, leading to the formation of a discontinuous urban fabric, marked by the scattered presence of empty areas, high-rise buildings in the central neighborhoods (Fig. 1), low occupation densities in the outer areas, and the existence of detached, predominantly low-income residential settlements orbiting around the city center.

Fig. 1. Bauru aerial view with high-rise buildings
Source: ITE-FCEB 1998.

Simulation model of urban land use change: 1967-2000

In order to carry out modeling experiments designed to generate forecasts of urban land use change, it is necessary at first to get acquainted with the driving forces or variables governing land use change throughout a sufficiently long time series. These variables concern infrastructural and socio-economic aspects of the city under analysis. In the particular case of this experiment, the simulation time interval ranged from 1967 to 2000, comprising thirty-three years, in which the urban population increased about 500%, rising from 61,592 to 310,442 inhabitants. The acquired knowledge with respect to the variables' role in delineating the spatial patterns of land use change must support the parameterization of the forecast models, which represent the ultimate goal of modeling

Exploratory analysis and variables selection

The exploratory analysis consists of the initial stage of modeling, during which a number of procedures are executed, aiming to evaluate the characteristics of the variables driving land use change. This enables the choice of the minimum and at the same time the best set of variables to explain a certain type of transition (e.g., from nonurban use to residential use). The exploratory analysis and all the remaining stages of the modeling process are accomplished for each consecutive simulation period. In the case of Bauru, these periods were delimited according to the availability of official land-use maps. As these maps were released only in 1967, 1979, 1988, and 2000, the simulation time series contained three periods: 1967–1979, 1979–1988, and 1988–2000.

Initially, the process of variables selection is based on a heuristic procedure, whereby maps of variables are superimposed on the final land-use map in vector format for the considered simulation period (Fig. 2) in such a way as to identify those more meaningful to explaining the different types of land use change.

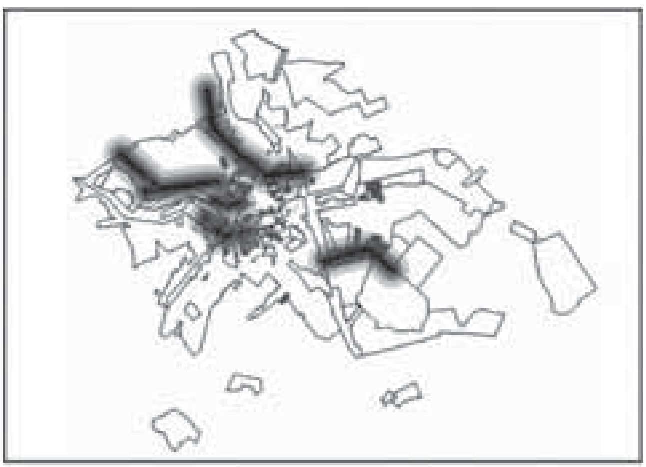


Fig. 2. Illustrative image showing the visual analysis for the identification of variables determining the transition from residential to mixed use in Bauru from 1979 to 1988. The buffers are distances to planned roads; the darker diffused spots are areas of medium-high density; and the darker polygons correspond to social housing.

In order to avoid redundancy in the input data, i.e., select variables with a high degree of spatial dependence or association, the variables underwent pairwise statistical tests, such as the Cramers Index and the Joint Information Uncertainty, with the acceptable threshold set to 0.5 (Bonham-Carter 1994). When this value is surpassed, the variables can be combined into one, or one of the two has to be discarded. Generally, the variable that presents the smallest spatial association with the considered land use transition, i.e., the one which contributes less to explain the transition at issue, is eliminated from the model.

Model parameterization

Models for the simulation of urban land use change are commonly built with empirical methods. In the case study presented here, the "weights of evidence" method has been adopted, which is based on the Bayes theorem of conditional probability. This theorem consists of ratios relating the areas of occurrence of certain variables to the areas where the phenomena under study have taken place (land use transitions). In this way, for each cell of the study area, the probability that a given type of land use change will happen in spite of the previous occurrence of certain variables is

$$P_{x,y}\{R/S_1 \% S_2 \% \ldots S_n\} = \frac{O\{R\} \cdot e^{\sum_{i=1}^{n} W^{+}_{x,y}}}{1 + O\{R\} \cdot e^{\sum_{i=1}^{n} W^{+}_{x,y}}}$$

where $P_{x,y}$ corresponds to the probability of a cell with coordinates $_{x,y}$ to undergo a land use transition R (e.g., from nonurban to residential use); $S_{1\text{-}n}$ refer to the n variables (or evidences) driving land use change; O $\{R\}$ corresponds to the odds of R, which is the ratio of the probability of occurring R $(P\{R\})$ to its complementary probability $(P\{not\ R\})$; and W^{+} represents the positive weight of evidence, which is calculated through the statistical method "weights of evidence" (Bonham-Carter 1994) and indicates the attraction or positive correlation between a certain evidence and a given land-use transition.

Model calibration

Likewise, in the exploratory analysis, heuristic procedures were employed for model adjustment or calibration. Visual comparative analyses were conducted for each type of land use change, considering preliminary simulation results, maps of land use transition and of transition probabilities, as well as the overlay of maps of variables upon the final land-use map in vector format. This comparison is aimed at identifying those variables or evidences which are effectively concurring to distinguish actual transitions from noise in the modeling, and it has been employed for both the variables selection and the definition of the internal parameters of the simulation software DINAMICA.[3]

Simulation and results

Several simulations were carried out by the DINAMICA model, and the best results for each simulation period are presented in Fig. 3. Based upon the carried-out calibration process, it becomes evident that the probability of certain nonurban areas in the city of Bauru to shelter residential settlements largely depends on the previous existence of this type of settlements in their surroundings because this implies the possibility of extending existing nearby infrastructure. It also depends on the greater proximity of these areas to commercial activities clusters and on the available accessibility to such areas.

As to the transition of nonurban areas to industrial use, there are two great driving forces: the nearness of such areas to the previously existent industrial use and the availability of road and railway access. This can be explained by the fact that in the industrial production process, the output of certain industries represents the input of others. In this way, industries tend to cluster around each other, because of the need of optimization of productive processes and input transportation costs. Furthermore, plots in the vicinity of industrial areas are often unsuitable for other uses, which makes them cheaper and, hence, rather advantageous for industrial use.

Regarding the transition of nonurban areas to services use, three major factors are crucial: the proximity of these areas to clusters of commercial activities, their closeness to areas of residential use, and their strategic location in relation to the main urban roads of Bauru. The first factor accounts for the suppliers' market (and in some cases also consumers' market) of services; the second factor represents the consumers' market itself; and the third corresponds to the accessibility for both markets related to the services use.

In turn, the creation of leisure and recreation zones takes place in outer areas with good accessibility, and sometimes along low and flat riverbanks, since these areas are floodable and hence inappropriate for sheltering other urban uses.

And finally, the transition from residential use to mixed use[4] assumes availability of water supplies and the existence of good accessibility conditions. These areas also strive on locating not too far away from the central commercial areas, for they depend on specialized supplies from these areas, yet not too close to them either for reasons of competitiveness.

[3] DINAMICA is a cellular automata model for the simulation of landscape dynamics (land use and land cover change), developed by the Center for Remote Sensing of the Federal University of Minas Gerais (http://www.csr.ufmg.br). The sofware was written in the object-oriented C++ language, and its present version runs on a 32-bit Windows © system (Soares-Filho et al. 2002).
[4] The mixed-use zone basically comprises residential, commercial, and services use. These zones actually play the role of urban subcenters and represent a sort of secondary commercial-center enhancement. At a later stage, they start to attract services and social infrastructure besides commercial activities themselves.

It is worth stating that the natural characteristics of the physical environment have not been considered as impediments to urban land-use change and growth at a more generalized level, since the city site is relatively flat, with mild slopes, and presents no outstanding constraints regarding soil, vegetation, and conservation areas.

Model validation

In order to evaluate the model performance, a method based on multiple resolutions has been employed (Costanza 1989), where the goodness-of-fit between the real and the simulated image is assessed not on a pixel-by-pixel basis but rather by means of sampling windows of different sizes, relaxing thus the rigidity of adjustment between reality and simulations. For the first simulation period (1967–1979), the fit index ranged from 0.941 to 0.944; for the second period (1979–1988), from 0.896 to 0.903; and finally for the third period (1988–2000), from 0.954 to 0.957.

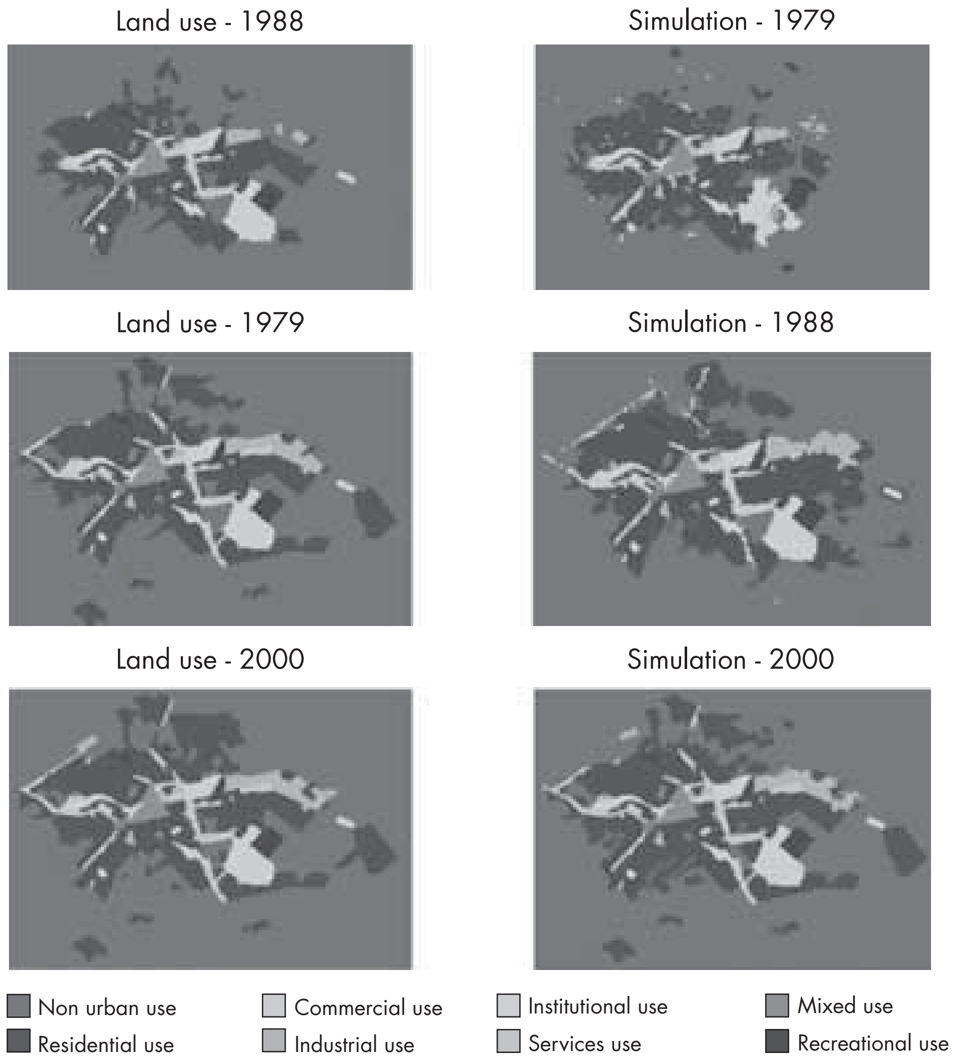


Fig. 3. Real land use and respective simulations for Bauru in the years 1979, 1988, and 2000.

Forecast model of urban land-use change: 2000–2007

Knowing transition trends and patterns from simulation experiments executed over sufficiently long periods enables generating forecast scenarios of urban land-use change. For simplification, this study considers only three types of scenarios: a stationary one, which preserves the transition trends observed in the most recent simulation period; an optimistic one, which slightly overestimates these trends; and a pessimistic scenario, which slightly underestimates such trends.

In models designed to simulate land use change, there are two types of transition probabilities: one global, which estimates the total amount of change for the study area, regardless of the influence imposed by the respective variables; and a local one, calculated for each cell taking into account such variables. In the generation of forecast scenarios, the global probabilities are recalculated, whereas the values of the local transition probabilities remain the same.

In the case of stationary scenarios, the Markov chain is employed to reckon the global transition probabilities, which consists of a mathematical model meant to describe a certain type of process that moves in a sequence of steps and throughout a set of states.

For the nonstationary scenarios, univariate linear regression models were adopted, where the area of a certain type of land use in 2007 (dependent variable) is explained by means of a demographic or economic indicator (independent variable), such as urban population or local industrial gross domestic product (GDP). As previously mentioned, based on slight overestimations and underestimations of these indicators, optimistic and pessimistic global transition probabilities are calculated, respectively. Different results of forecast scenarios for the year 2007 are shown in Fig. 4.

It is worth mentioning that the scenarios point to the maintenance of the ongoing trend of peripheral residential settlements, which underutilize the infrastructure network and hence raise the cost of infrastructure investments in the face of their sprawling pattern (SEPLAN 1997). Another observed tendency indicated by the forecasts is the strengthening of the urban expansion toward the southwest side of the town, exactly where the spring for the city water supply is located. In this way, the current urban policies and initiatives must immediately envisage efficient devices to inhibit such typologies of urban expansion.

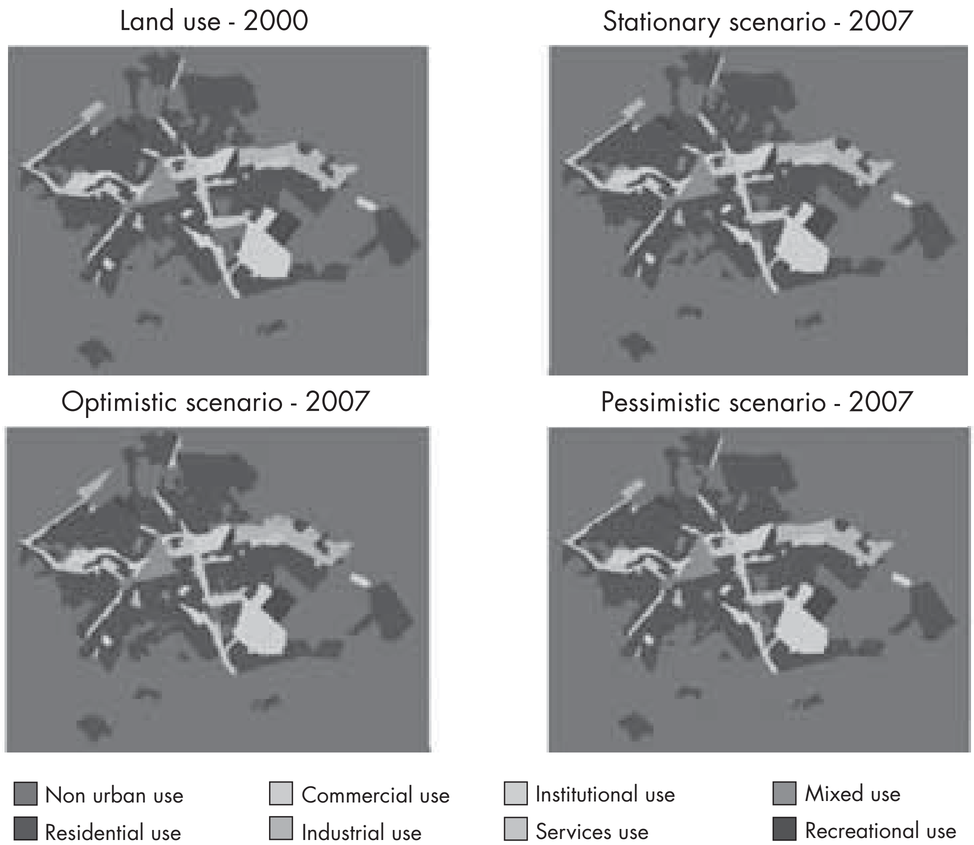


Fig. 4. Stationary, optimistic, and pessimistic scenarios for 2007 and real land use in 2000—Bauru.

Socio-Environmental Dimensions of Urban Growth and Land Use Changes in the Urban Area of Bauru, SP, Brazil

Agents driving urban land-use change: profile and behavior

Changes in the urban scenario are triggered by diverse agents or social actors. Enterpreneurs dedicated to services and commercial activities strive to optimize locational advantages in the urban area of Bauru. They tend to settle close to main roads, not only because of the need for an efficient accessibility to goods and clients, but also because these roads grant visibility to their businesses, attracting potential new clients.

Similarly, industrial plants also struggle for competitive sites, taking into account land price, good accessibility conditions for the supply of raw material and output delivery, as well as the warranty of rationalization in the production process in view of the proximity to other plants interrelated within the same productive chain.

Location choices for leisure and recreation zones, built and managed by local authorities, depend on adequate site amenities, such as landscape assets and good accessibility. Good accessibility is crucial for the survival of such areas.

Peripheral residential areas are meant either for low-income or high-income dwellers. High-income settlements tend to be detached from the main urban agglomeration because they cover large plots with good views, which are usually unavailable within the city. In the specific case of Bauru, there is only one high-income settlement isolated from the main urban agglomeration, located to the east of the town. These settlements usually observe legal environmental restrictions.

Peripheral low-income settlements are usually the result of spontaneous initiatives of poor inhabitants or of informal undertakings carried out by illegal land state enterpreneurs. These settlements are commonly situated away from the main urban agglomeration because land prices are lower. New peripheral settlements tend to be located close to previous ones, because this allows extending existing nearby infrastructure, such as water supply, bus lines, public lighting, electric energy supply, etc. They also tend to be near main access roads to allow dwellers to commute to work and shops located in central areas. Unlike high-income settlements, low-income settlements commonly disregard environmental constraints, and are often found in conservation areas, such as natural parks, forest reserves, or water springs.

It becomes thus evident that the agents of land use change in the city of Bauru observe economic theories of urban growth and change, grounded on the key concept of utility maximization (Papageorgiou and Pines 2001, Zhou and Vertinsky 2001), according to which there is a continuous search for optimal location that would ensure:

- competitive real-estate prices,
- good accessibility conditions,
- rationalization of transportation costs, and
- strategic location relative to suppliers' and consumers' markets.

Impacts of uncontrolled urban growth near water springs on liveability and human health

Informal land occupation in areas of water springs protection not only affects the ecological balance of the natural environment but also damages the quality of life of urban inhabitants who directly depend on such supply sources. The foremost observed effects of informal settlements located around water springs are the following:

- direct discharge of sewage into the water bodies,
- destruction of riparian vegetation,
- silting of water reservoirs,
- floods,
- disturbances in the hydrological balance of the region,

- contamination of water resources, and
- shortages of water supply.

Considering that reliable access to fresh water is a key component of quality of life, it is sensible to state that uncontrolled urban expansion in the proximity of water sources represents a serious threat to liveability and to the health of informal settlement dwellers and city dwellers alike.

The term quality of life is intertwined with the concept of liveability, which can be briefly described as unique combinations of amenity values (open space, urban vegetation, ecological services), historic and cultural heritage, location, and intangibles such as character, landscape and "sense of place" (Bell 2000). "Liveability very much concerns a 'here and now' perspective and basically refers to the things that people see when they walk out the front door. While it is *about* the environment, it is not explicitly *for* the environment" (Brook Lyndhurst Ltd. 2004).

Most of the consequences listed above directly impact liveability—for example, the occurrence of floods, the unpleasant smell which might blow from the reservoirs, the undesirable visual effect of depleted riparian vegetation and contaminated waters, as well as breakages and oscillations in the water supply. The spread of informal urban occupation in the vicinity of water springs and the consequent discharge of waste water directly into them cause a much more serious impact to human health, rendering both the communities living close to the springs (which collect untreated water from such reservoirs) and the inhabitants dependent on this source supply vulnerable to infecto-contagious diseases, such as cholera, hepatitis in its diverse forms, leptospirosis, and schistosomiasis.

Some considerations about the human dimensions of vulnerability to global environmental change

As stated by Hamza and Zetter (1998), "concentration of people and activities on safe sites is not a source of vulnerability. But the unequal distribution of resources, the marginalization of segments of the population and informal activities, and their exclusion from planned and serviced areas is what forces people on unsafe sites; and then vulnerability is a consequence. "This opinion finds support in Watts and Bohles's argument, which considers vulnerability as the "outcome between environmental and socio-economic forces" (Watts and Bohle 1993).

Vulnerability is also defined as "insecurity and sensitivity in the well-being of individuals, households, and communities in the face of a changing environment, and implicit in this their responsiveness and resilience to risks that they face during such negative changes. Environmental changes that threaten welfare can be ecological, economic, social and political, and they can take the form of sudden schocks, long-term trends or seasonal cycles" (Moser 1998).

As exposed by Blaikie and Brookfield (1987) and by Bayliss-Smith (1991), any definition requires the identification of two dimensions of vulnerability: its sensitivity (magnitude of a system's response to an external event) and its resilience (the ease and rapidity of a system's recovery from stress). From the point of view of the human dimensions of vulnerability, sensitivity and resilience are closely interrelated to the economic, social, institutional, educational, and psychological skills of individuals, households, and communities to offer responsiveness and recovery capacity in the face of stress or hardship.

In the particular case of the vulnerability resulting from threats to water resources in Bauru, sensitivity and resilience should be jointly offered by the dwellers and local authorities. As adaptive/mitigation measures to tackle the occurrence of breakages/fluctuations in the water supply and the risk of infecto-contagious diseases, the following are worth mentioning:

- spontaneous or induced relocation of squatters, with public assistance in both cases;
- implementation of sewerage systems in all legalized low-income settlements located in the water spring protection areas;
- creation of a permanent framework for water quality control and emergency management, supported by the local civil defense, envisaging immediate access to alternative supply sources, such as aquifers and water import from neighboring watersheds; and
- launching of environmental awareness campaigns on the importance of water resources conservation in the mass media and in public and private schools.

And preventive public initiatives and actions to refrain the undesired urban sprawl in the vicinity of the water spring would include severe legal restrictions on the approval of new settlements; permanent inspection of spring protection areas; creation of anonymous denouncement channels to alert the public authorities about the eventual mushrooming of new, informal settlement seeds; fiscal and institutional incentives for the implementation of low-income settlements in the eastern and northern sectors of the city, since the spring is located in the southwest side of the town; and finally, the construction of polarizing undertakings in the eastern and northern portions of Bauru—such as malls, business centers, thematic parks—in order to redirect urban expansion toward more environmentally suitable areas.

In fact, forecast models of urban growth and land use change lie in the realm of auxiliary tools to guide and support preventive measures meant to assure safe, comfortable, and environmentally sound conditions to urban life. These models are thus designed to anticipate risks and vulnerability circumstances and, accordingly, to avoid or soften their extent and/or gravity.

Final remarks and directions for future work

According to Almeida et al. (2003), "cellular automata (CA) models have become popular largely because they are tractable, generate a dynamics which can replicate traditional processes of change through diffusion, but contain enough complexity to simulate surprising and novel change as reflected in emergent phenomena. CA models are flexible in that they provide a framework which is not overburdened with theoretical assumptions, and which is applicable to space represented as a raster or grid. These models can thus be directly connected to raster data surfaces used in proprietary geographic information systems."

Although urban dynamic models have been the target of severe criticism, mainly in view of their reductionism and constraints to fully capture the inherent complexity of reality (Briassoulis 2000), it can be argued that they ought to exist, for they offer an incomparable way of abstracting patterns, order, and main trends of real-world dynamics.

Actually, these models should be conceived, handled, applied, and interpreted in a wise and critical form, so that modelers, planners, public and private decision-makers, as well as citizens in general could take the best from what they can offer and sensibly acknowledge their limitations.

Such urban land-use dynamics models demonstrate to be useful for the identification of main urban-growth vectors and their predominant land-use trends, enabling local planning authorities to manage and reorganize (if applicable) city growth according to the environmental carrying capacity of concerned sites and to their present and foreseen infrastructure availability. It is worth strengthening that the modeling forecasts presented in this work focused on water springs, but forecast models of urban growth and land use change can cope with any sort of threat to environmental resources produced by urban expansion processes.

And as final words, Batty concisely exposes the key ideas lying behind the applications and purposes of urban modeling when he says, "… There are many reasons for the development of such models: their role to help scientists to understand urban phenomena through analysis and experiment represents a traditional goal of science, yet urban modeling is equally important in helping planners, politicians and the community to predict, prescribe and invent the urban future" (Batty 1976, p. xx).

References

Almeida, C. M., Batty, M., Monteiro, A. M. V., Câmara, G., Soares-Filho, B. S., Cerqueira, G. C., and Pennachin, C. L. 2003. "Stochastic cellular automata modelling of urban land use dynamics: empirical development and estimation." *Computers, Environment and Urban Systems* 27:481–509.

Allen , P. M., Sanglier, M., and Boon, F. 1981. "Intra-urban evolution—Part II." In: *Models of Urban Settlement and Structure as Dynamic Self-Organizing Systems* (Kahn, D., Ed.). US Department of Transportation, Washington, DC.

Alonso, W. 1960. "A general theory of the urban land market." *Papers and Proceedings of the Regional Science Association* 6:149–158.

Batty, M. 1976. *Urban Modelling: Algorithms, Calibrations, Predictions*. Cambridge University Press, Cambridge, England.

Batty, M., Couclelis, H., and Eichen, M. 1997. "Urban systems as cellular automata." *Environment and Planning B* 24(2):159–164.

Bayliss-Smith, T. 1991. "Food security and agricultural sustainability in the New Guinea Highlands: Vulnerable people, vulnerable places." *Institute of Development Studies Bulletin* 22(3):5–11.

Bell, K. 2000. *Urban Amenity Indicators: The Liveability of Our Urban Environments* (Technical Paper no. 63—Environmental performance indicators: Urban Amenity). Ministry for the Environment, Wellington, New Zealand. (Available at http://www.mfe.govt.nz/publications/ser/tech-report-63-urban-amenity-jun00.pdf.)

Benevolo, L. 1983. *História da Cidade*. Editora Perspectiva, São Paulo, Brazil. 729 pp.

Blaikie, P., and Brookfield, H. C. 1987. *Land Degradation and Society*. Methuen, London and New York. 200 pp.

Bonham-Carter, G. F. 1994. *Geographic Information Systems for Geoscientists: Modelling with GIS*. Pergamon, New York, NY. 414 pp.

Briassoulis, H. 2000. *Analysis of Land Use Change: Theoretical and Modelling Approaches*. Ph.D. Thesis. University of the Aegean, Lesvos, Greece.
(Available at: http://www.rri.wvu.edu/WebBook/Briassoulis/contents.htm.)

Brook Lyndhurst Ltd. 2004. *Liveability and Sustainable Development: Synergies & Conflicts*.

Summary Report for the Office of the Deputy Prime Minister. Brook Lyndhurst Ltd., London, England. 6 pp. (Available at http://www.odpm.gov.uk/stellent/groups/odpm_science/documents/page/odpm_science_031059. pdf)

Costanza, R. 1989. "Model goodness of fit: a multiple resolution procedure." *Ecological Modelling 47*:199–215.

Crecine, J. P. 1964. *TOMN* (Time oriented metropolitan model). CRP Technical Bulletin no. 6. Department of City Planning, Pittsburgh, PA.

Easterly, W., and Sewadeh, M. 2000. *Global Development Network Growth Database*. (Available at http://www.worldbank.org/research/growth/GDNdata.htm.)

Fernandes, C. L. L., Medeiros, C. M., and Mendes, A. G. 1977. "O elemento regional no processo de planejamento do Brasil—Notas preliminares (The Regional Component in the Planning Process of Brazil—Preliminary Notes). In: *Dilemas do Planejamento Urbano e Regional no Brasil* (Cintra, A. O., and Haddad, P. R., Eds.). Zahar Editores, Rio de Janeiro, Brazil. Cap. II, pp. 51–168.

Fundação Seade. 1992. *São Paulo no Limiar do Século XXI* — Cenários da urbanização paulista (São Paulo on the Threshold of the 21st Century—Alternative Urbanization Scenarios), v. 5. Fundação Seade, São Paulo, Brazil. 106 pp.

Hamza, M., and Zetter, R. 1998. "Structural adjustment, urban systems, and disaster vulnerability in developing countries." *Cities* 15(4):291–299.

Hardoy, J. E., Mitlin, D., and Satterthwaite, D. 2001. *Environmental Problems in an Urbanizing World: Finding Solutions for Cities in Africa, Asia and Latin America*. Earthscan Publications Ltd, London, England. 446 pp.

Hill, D. M. 1965. "A growth allocation model for the Boston region." *Journal of the American Institute for Planners* 31:111–120.

Lowry, I. S. 1964. *A Model of Metropolis*. RAND Corporation, Santa Monica, CA (RM-4035-RC).

Merlin, P. 1973. *Méthodes Quantitatives et Espace Urbain*. Mason et Cie Éditeurs, Paris, France. 190 pp.

Moser, C. 1998. "The asset vulnerability framework: Reassessing urban poverty reduction strategies." *World Development*. 26(1):1–19.

Paelinck, J. H. P. 1970. "Dynamic urban growth models." *Papers of the Regional Science Association* 24:25–37.

Papageorgiou, Y. Y., and Pines, D. 2001. "An essay on urban economic theory." *Regional Science and Urban Economics* 31(5):626–630.

Papini, L., Rabino, G. A., Colonna, A., Di Stefano, V., and Lombardo, S. 1998. "Learning cellular automata in a real world: the case study of the Rome metropolitan area." In: *Cellular Automata: Research Towards Industry* (Bandini, S., Serra, R., and Liverani, F. S., Eds.). Proceedings of the Third Conference on Cellular Automata for Research and Industry. Springer-Verlag, London, England. pp. 165–183.

Pereira Filho, A. 2002. "Mudanças climáticas—Aquecimento global já pode ser sentido." *Revista Com Ciência—Revista Eletrônica de Periodismo Científico* no. 34. (Available at http://www.comciencia.br/reportagens/clima/clima06.htm.)

Perraton, J., and Baxter, R. 1974. *Models, Evaluations & Information Systems for Planners*. MTP Construction, Lancaster, England.

Phipps, M., and Langlois, A. 1997. "Spatial dynamics, cellular automata and parallel processing computers." *Environment and Planning B* 24(2):193–204.

Santamouris, M. 2002. "The Athens heat island." *Newsletter of the International Human Dimensions Programme on Global Environmental Change*, no. 3. (Available at http://www.ihdp.uni-bonn.de/html/publications/update/update02 _03/IHDPUpdate02_03_M_Santamouris.html.)

SEPLAN (Secretaria Municipal de Planejamento) de Bauru. 1997. *Plano diretor de Bauru 1996*. Bauru, Brazil. 200 pp.

Skole, D., and Loveland, T. 1996. *Extent and Implications of Land Cover Changes: The View from Space*. USGCRP Seminar. USCCSP & USGCRP, Washington, D.C. (Available at: http://www.usgcrp.gov/usgcrp/seminars/960312SM.html.)

Soares-Filho, B. S., Cerqueira, G. C., and Pennachin, C. L. 2002. "DINAMICA—a stochastic cellular automata model designed to simulate the landscape dynamics in an Amazonian colonization frontier." *Ecological Modelling* 154:217–235.

United Nations. 1996. *World Urbanization Prospects: The 1996 Revision Database*. United Nations Population Division, New York, NY. 839 pp.

United Nations. 1998. *World Urbanization Prospects: The 1998 Revision Database*. United Nations Population Division, New York, NY. 640 pp.

Watson, R. T., and the Core Writing Team (Eds.). 2001. *IPCC Third Assessment Report: Climate Change 2001—Synthesis Report*. IPCC, Geneva, Switzerland. 184 pp.

Watts, M. J., and Bohle, H.-G. 1993. "The space of vulnerability: the causal structure of hunger and famine." *Progress in Human Geography* 17:43–67.

Wegener, M., Gnad, F., and Vannahme, M. 1986. "The time scale of urban change." In: *Advances in Urban Systems Modelling* (Hutchinson, B., and Batty, M., Eds.). Elsevier, Amsterdam, Holland. pp. 175–197.

White, R., Engelen, G., and Uljee, I. 1998. *Vulnerability Assessment of Low-Lying Coastal Areas and Small Islands to Climate Change and Sea Level Rise—Phase 2: Case Study St. Lucia*. United Nations Environment Programme, Caribbean Regional Co-ordinating Unit, Kingston, Jamaica. 90 pp.

WIKIPEDIA – The Free Encyclopedia. 2003. *Economies of AGHGlomeration*. (Available at: http://www.wikipedia.org/wiki/Economies_of_aGHGlomeration.)

Wolfram, S. 1983. "Statistical mechanics of cellular automata." *Review of Modern Physics* 55:601–643.

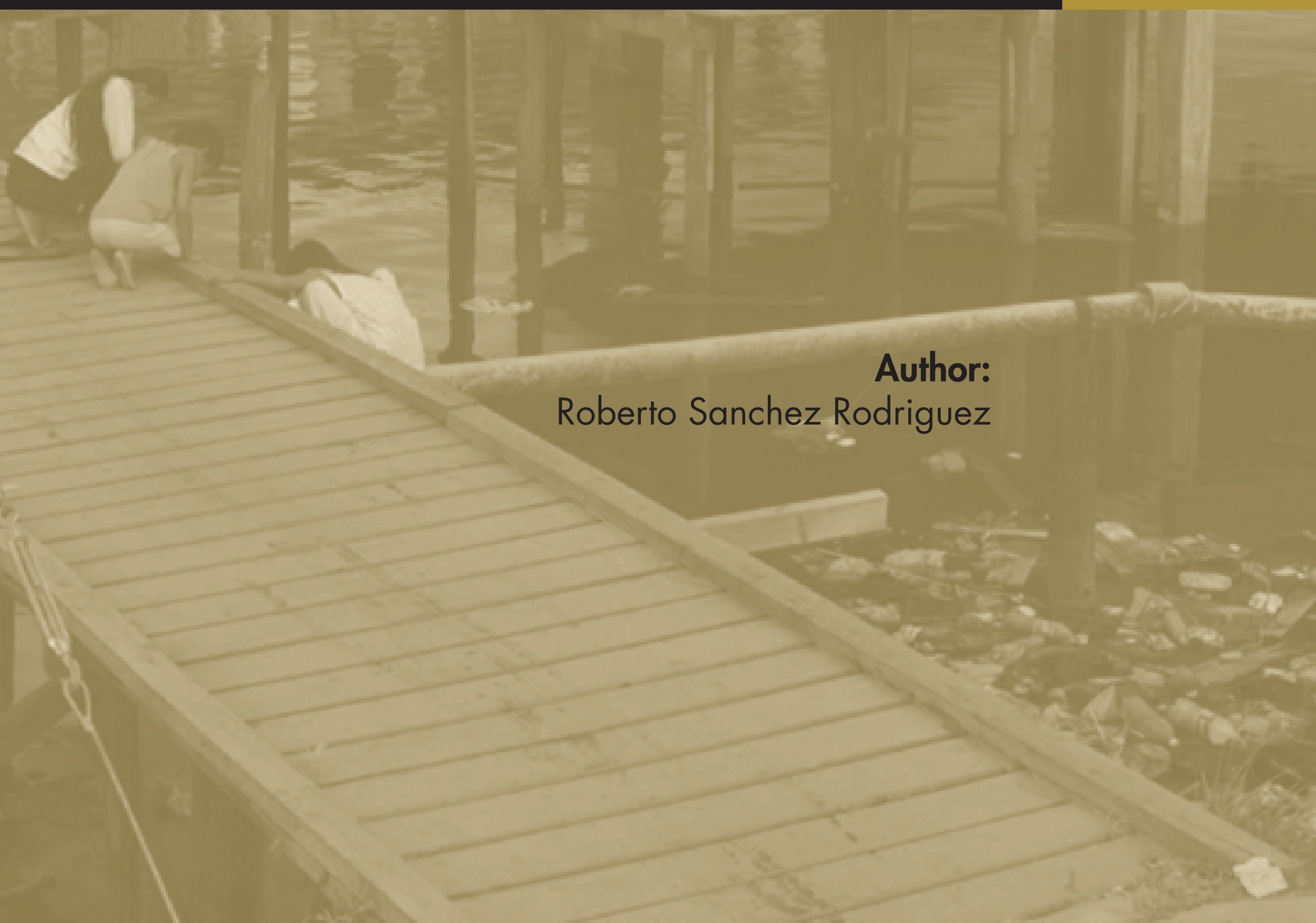
Wu, F. 1998. "Simland: a prototype to simulate land conversion through the integrated GIS and CA with AHP-derived transition rules." *International Journal of Geographical Information Science* 12(1):63–82.

Yeh, A. G., and Li, X. 2001. "Calibration of cellular automata by using neural networks for the simulation of complex urban systems." *Environment and Planning A* 33:1445–1462.

Zhou, D., and Vertinsky, I. 2001. "Strategic location decisions in a growing market." *Regional Science and Urban Economics* 31(5):523–533.

8

Final Considerations



Author:
Roberto Sanchez Rodriguez

The work presented in this book reveals how important it is that the urbanization process in Latin America be directed toward a more balanced growth and better living conditions for millions of urban inhabitants. The book recognizes and analyzes the opportunities afforded by sustainable development during this growth, but stresses the need to base this concept on multidimensional, integrated, and operational perspectives to enable better management of the complex reality of urban systems in Latin America.

Some of the dimensions associated with the interactions between urban areas and the biophysical processes of global environmental changes are incorporated into the discussion on urban growth. That so far scarce attention has been paid to urban growth stresses the need to use new approaches to study, understand, and manage urban areas. It is gratifying to have a rich diversity of accumulated knowledge on urban studies yet surprising that urban reality continues to be considered in disciplinary blocks although it never operates in a fragmented fashion. It is regrettable to see how little effort is invested in taking advantage of this accumulated knowledge in the creation of integrated perspectives for understanding urban growth and opening opportunities for sustainable development. Efforts in this direction should focus on two complementary fields of action: (1) developing new approaches to integrated and multidimensional knowledge on urban areas and (2) reducing the current gap between scientific knowledge and its use by decision makers and other urban stakeholders who influence the urbanization process in Latin America.

Integrated knowledge on urban areas, including regional and global biophysical processes, implies reformulating research questions so that contributions from social and natural sciences are well balanced and 21st century urban realities in Latin America are fully considered. In this regard, recent efforts are striving to build bridges between scientific knowledge and its use by social stakeholders. These efforts recognize the contributions of nonscientific stakeholders (professionals, local decision makers, nongovernmental and community organizations, and other civil society representatives, financial groups, etc.) to the design and development of the scientific research process (Robertson and Hull 2003, Bammer 2005, Naess et al. 2006, Roux et al. 2006, Turnhout et al. 2006). The objective of these efforts is to build a pragmatic and plural body of knowledge, while maintaining its scientific rigorousness. Some authors mention several methods to facilitate joint learning between researchers and other stakeholders on problems and topics of common interest that provide reciprocal benefits (Brown 2003, Bammer 2005). But the search for methods to reconcile differences in disciplinary cultures, interests, and ideologies between academics and other players who define urban growth should be considered an area that requires further exploration.

The search for new approaches to urban growth is very relevant to the urban areas of Latin America. The great social inequality in the region, increased urban poverty, lagging urbanization in most urban centers, and the constant economic and financial crises aggravate the negative consequences of climate change and variability for millions of people. Some authors believe that double exposure to globalization of socio-economic processes and to changes in global biophysical processes (Hamza and Zetter 1998, O'Brien and Leichenko 2000) exacerbates the problems listed above. The recent increase in the number and importance of natural disasters in the region illustrates the consequences of this double exposure.

One obstacle to incorporating the impact of climate variability and change in these new urban growth schemes approaches is the perception that global environmental problems will occur in the distant future and, therefore, that there is no justification to rethink allocation of resources in order to address them. In part, this perception responds to international pressure for prioritizing actions to mitigate global environmental problems over and above the attention to their negative impacts and consequences (Sathaye et al. 1999). These consequences are particularly serious for poor countries, where resources for adaptation are exiguous. Several of the case studies presented in this book illustrate how these impacts aggravate current problems in urbanization processes and the environment. Better dissemination of the link between global environmental problems and local urban-environmental problems will trigger better attention paid to negative impacts and adaptation alternatives in Latin American urban areas.

An example is found in the frequent flooding of a significant number of urban areas in the region (Costa and Albini 1988, Campana and Tucci 2001). Adaptation to the impact of climate variability and change in extreme daily precipitation values may range from simple and low cost, such as considering this impact in storm drainage network planning, to higher-cost multidimensional actions aimed at reducing urban and social vulnerability to floods. For designing storm drainage networks, the carrying capacity of the pipes and drains of the network is calculated to respond to extreme demands based on the rainfall records available for each urban area, plus a safety percentage. However, it does not take into consideration the impact of climate variability or change on extreme daily precipitation values. Because the drainage capacity of the networks is exceeded, floods occur, which endanger the inhabitants of urban areas, disturb urban life, and cause significant economic damage. Incorporating the impact of climate variability and change in the design of these networks would contribute to an efficient operation of the investment made, reducing the risks to the population, urban life, and the cost and damages associated with floods.

It is worth stressing the importance of linking the study of the impacts of climate variability and change to the priorities for urban growth and the opportunities for sustainable development at the local level (Beg et al. 2002). A multidimensional perspective of these impacts is a useful instrument to establish these links. Several authors have expressed concern for climate variability and change aggravating the conditions of inequality within societies and among them (O'Brien and Leichenko 2000, Mirza 2003, O'Brien et al. 2004, Tol et al. 2004, Thomas and Twyman 2005, Paavola and Adger 2006, Reid and Vogel 2006). This concern recognizes that the actions to reduce vulnerability or to open alternatives of adaptation to climate change in a particular social group can aggravate the living conditions of others. Although this is a central aspect of sustainable development, little attention has been paid to it. It is mistakenly assumed that actions benefiting a particular social group will benefit others as well. Negative consequences caused by these externalities could even occur in another geographic area (city, region, or country) and on another temporal scale (Adger et al. 2005). New approaches to the study and management of urban areas should incorporate issues of equity in an integral manner.

Training of stakeholders responsible for guiding urban growth must include these new approaches and their link to global and regional environmental-change processes. The planning of urban land use in response to the demands and needs of urban economy and function would be different if it considered greenhouse gas emissions and the creation of heat islands. On the other hand, this knowledge is equally important to understand the impacts of biophysical processes on urban areas and on the design of adaptation policies and actions. Natural disasters do not trigger only high economic, social, and environmental costs but also negative effects on other aspects of urban life. Incorporating knowledge of these negative effects into the agenda of local decision-makers is an efficient way of contributing to their reduction and at the same time of assisting in the solution of existing urban and environmental problems. This approach would also open opportunities for sustainable development.

The great majority of the current programs for training decision-makers in urban aspects do not take into consideration the interactions with the regional and global environments mentioned above. For example, the United Nations Development Program has training programs in urban management in Latin America. The environmental component of the program is limited to dealing with the problem of solid waste from a traditional perspective. Metropolis, an international association grouping 76 cities, is focused on the solution to problems in large cities. This organization provides training in urban and environmental aspects for local decision-makers and metropolitan government executives in different regions of the world, but its course program makes no mention of the impacts of regional and global biophysical processes, including the impacts of climate variability and change.

The World Bank and Habitat, the United Nations program for urban areas, have a long tradition of urban programs and studies and include a wide range of environmental problems in poor countries. These programs deal partially with some aspects of the interactions between urban areas and global environmental changes, but they do not directly offer specific training on the issue. However, they provide funding to the International Council for Local Environmental Initiatives (ICLEI), whose main mission is to foster Agenda 21 published by the United Nations at the Rio de Janeiro Summit in 1992. Approximately 400 governments from countries around the world are members of the ICLEI. One of the ICLEI programs, which includes training for local governments, is the Communities for Climate Protection Campaign. This is the only program among those offered by international organizations that is directly linked to aspects of global climate change. The program seeks to reduce greenhouse gas emissions in urban areas. Some of the cities affiliated to this program are in Latin America. However, the ICLEI does not offer a training program for the design of adaptation measures to the negative impacts of global environmental changes on urban areas, a priority issue for Latin American countries.

The Latin American Office of the United Nations Environment Program (UNEP) offers support for developing the programs of Agenda 21. Some of these programs consider aspects of global environmental changes, but not in an integral manner. This organization offers training programs for local urban governments jointly with other international organizations, such as the International Union of Local Authorities, Sister Cities programs, and more recently, north-south and south-south cooperation programs between urban areas. All the training programs for local decision-makers mentioned above are a potential resource for local urban-government decision-makers to access the new urban-area management approaches mentioned above.

One of the institutions with which this collaboration could be particularly beneficial is the Inter-American Institute for Global Change Research (IAI). The IAI offers training workshops for academics and decision-makers on issues related to global environmental change. Some of them, related to urban areas, have been carried out in collaboration with UNEP and other international and national organizations, but to date only a small number of decision-makers have had access to that training. Extending the collaboration to other international organizations—such as the World Bank, the Inter-American Development Bank, the United Nations Development Program (UNDP) and Habitat, Metropolis, ICLEI, IHDP, and START—and to other national organizations could significantly increase the coverage of the training workshops and facilitate access for a larger number of professionals and decision makers in the region. This training would guide urban growth according to the realities and needs of Latin American societies in the 21st century.

The case studies in the book agree that the new approaches should consider the accelerated growth of urban areas in the region. A significant percentage of this growth is associated with the increase in poor urban inhabitants. It is estimated that between one-fourth and one-third of urban households in the world live in absolute poverty (UNCHS 2002). This percentage is higher in Latin America given its high urbanization rate and increased poverty and inequity (World Bank 2002). The World Bank (2002) estimates that five out of six new poor in the region lived in urban areas between 1986 and 1998. Many of them live in areas prone to natural disasters under precarious sanitation conditions. The rapid expansion of these areas presents a difficult challenge for the present and future of Latin American cities and is the result of global and regional socio-economic and geopolitical processes operating at various scales, from the global to the local. An important part of this urban growth—up to nearly 50% of the total growth in several cities—takes place outside the formal planning and control schemes. This includes the important role of the real estate market in managing construction of the formal and informal urban space. The difficulty of responding to the demands for land, housing, and urban services of a growing number of inhabitants, as well as of being able to guide urban growth, is a permanent challenge for the authorities of these communities.

It is important to remember the limitations to the capacity or resources of local authorities to solve a significant number of the urban and environmental problems. Frequently, their actions are limited to reducing most important negative consequences. Reducing inequality and social conflicts, violence (in particular as it relates to organized crime), and the social, economic, and political crises characteristic of the region depends on the processes of social change and requires measures beyond those affecting the physical space where those problems exist. Urban growth, vulnerability to the negative impacts of global environmental changes, and, eventually, sustainable development, are processes politically negotiated by a wide range of stakeholders influencing the various dimensions of growth (social, economic, cultural, physical, and environmental). Integrated knowledge of urban growth, including the interactions with global environmental changes, plays a fundamental role in contributing to these negotiations and helping to foresee their negative consequences.

This book seeks to contribute to the construction of this integrated knowledge. In the case of climate, some authors link the knowledge of urban climate with the urban planning process (Scherer et al. 1999, Dessai et al. 2005), although few of them specifically for Latin American cities (Evans and DeSchiller 1991). The chapters by Moya and coauthors, Bochaca and Puliafito, and Comarazamy and coauthors present concrete examples of how this knowledge can guide urban growth. The works by Silva and López and coauthors strengthen the search for interdisciplinary work in the study of urban areas in their regional context, in agreement with recent contributions in favor of interdisciplinary perspectives in the study and planning of landscapes (Linehan and Gross 1998, Fry 2001, Schoenberger 2001) and the management of critical natural resources such as water. Almeida illustrates the benefits and limitations of models useful in the simulation of growth as a particularly helpful tool in developing new methods for fostering scientific research with the participation of a wide range of urban stakeholders.

Finally, it is important to stress that the construction of new approaches to the study of urban areas in Latin America should consider a large gradient of urban centers. Attention tends to be focused on mega cities (over 10 million inhabitants). Their size and rapid growth, until a few years ago, and the fact that many of them are the capital cities of the countries in the region, make them particularly visible and attractive to the communication media and as objects of study. However, the urban problem in Latin America can be found in a gradient of urban areas from small cities to mega cities. Attention to urban problems in the region should provide balanced consideration of small, medium, and large urban centers since they have problems similar to those in mega cities, but they have fewer available resources to tend to their problems.

The introduction to this book began by indicating that the present and future of Latin America is intrinsically linked to the growth of its urban areas. Urban areas are the object of constant controversy. For some, they are a necessary evil in the development of mankind, highlighting all the problems inherent to urban life. For others, they are an indispensable resource for economic growth, social well-being, and for alleviating the pressure on rural areas and natural resources. In the end, urban areas are only the geographical space where the contradictions, the social conflicts and relations, and the conflicts between society and nature are expressed. Their problems are a reflection of the inequity within our societies and among these societies. Proposing alternatives for a better future (sustainable development) implies a process of social change. The authors participating in this publication are interested in contributing to this process, starting with the development of a new understanding of the urbanization process and of ways to respond to the needs of Latin American societies in the 21st century.

References

Adger, N., Brown, K., and Hulme, M. 2005. "Redefining global environmental change." *Global Environmental Change* 15:1–4.

Bammer, G. 2005. "Integration and implementation sciences: Building a new specialization." *Ecology and Society* 10(2):6. (Available at: http://www.ecologyand society.org/vol10/iss2/art6/)

Beg, N., Morlot, C., Davidson, O., Afrane-Okesse, Y., Tyani, L., Denton, F., Sokona, Y., Thomas, J., La Rovere, E., and Parikh, J. 2002. "Linkages between climate change and sustainable development." *Climate Policy* 2:129–144.

Brown, A. L. 2003. "Increasing the utility of urban environmental quality information." *Landscape and Urban Planning* 65:85–93.

Campana, N., and Tucci, C. 2001. "Predicting floods from urban development scenarios: Case study of the Diluvio Basin, Porto Alegre, Brazil." *Urban Water* 3:113–124.

Costa, L., and Albini, D. 1988. "Las inundaciones en el área de Buenos Aires." *Medio Ambiente y Urbanismo* 7:2–19.

Dessai, S., Lu, X., and Risbey, J. 2005. "On the role of climate scenarios for adapting planning." *Global Environmental Change* 15:87–97.

Evans, J. M., and De Schiller, S. 1991. "Climate and urban planning: The example of the planning code for Vicente Lopez, Buenos Aires." *Energy and Buildings* 15(16):35–41.

Friedmann, J. 1987. *Planning in the Public Domain: From Knowledge to Action.* Princeton University Press, Princeton, NJ. 501 pp.

Fry, G. 2001. "Multifunctional landscapes—towards transdisciplinary research." *Landscape and Urban Planning* 57:159–168.

Gornitz, V., Couch, S., and Hartig, E. 2002. "Impacts of sea level rise in the New York City metropolitan area." *Global and Planetary Changes* 32:61–88.

Hamza, M., and Zetter, R. 1998. "Structural adjustment, urban systems and disaster vulnerability in developing countries." *Cities* 15(4):291–299.

Linehan, J., and Gross, M. 1998. "Back to the future, back to basics: The social ecology of landscapes and the future of landscape planning." *Landscape and Urban Planing* 42:207–223.

Mirza, M. 2003. "Climate change and extreme weather events: Can developing countries adapt?" *Climate Policy* 3:233–248.

Moser, C. 1998. "The Asset Vulnerability Framework: Reassessing urban poverty reduction strategies." *World Development* 26(1):1–19.

Naess, L. O., Norland, I. T., Lafferty, W. M., and Aall, C. 2006. "Data and processes linking vulnerability assessment to adaptation decision-making on climate change in Norway." *Global Environmental Change* 16(2):221–233.

O'Brien, K., and Leichenko, R. 2000. "Double exposure: Assessing the impacts of climate change within the context of economic globalization." *Global Environmental Change* 10:221–232.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tomkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., and West, J. 2004. "Mapping vulnerability to multiple stressors: Climate change and globalization in India." *Global Environmental Change* 14:303–313.

Paavola, J., and Adger, N. 2006. "Fair adaptation to climate change." *Ecological Economics* 56:594–609.

Pelling, M. 2003. *The Vulnerability of Cities. Natural Disasters and Social Resilience*. Earthscan, London, England. 212 pp.

Reid, P., and Vogel, C. 2006. "Living and responding to multiple stressors in South Africa—Glimpses from KwaZulu-Natal." *Global Environmental Change* 16:195–206.

Robertson, D., and Hull, B. 2003. "Public ecology: An environmental science and policy for global society." *Environmental Science & Policy* 6:399–410.

Rosenzweig, C., and Solecki, W. 2001. "Climate change and a global city: Learning from New York. *Environment* 43(3):3–12.

Roux, D., Roggers, K., Biggs, H., Ashton, P., and Sergeant, A. 2006. "Bridging the science–management divide: Moving from unidirectional knowledge transfer to knowledge interfacing and sharing." *Ecology and Society* 11(1):4 (Available at: http://www.ecologyandsociety.org/vol11/iss1/art4/)

Sathaye, J., Andrasko, K., Makundi, W., La Rovere, E., Ravindranath, N., Melli, A., Rangachari, A., Imaz, M., Gay, C., Friedmann, R., Goldberg, B., Van Horen, C., Simmonds, G., and Parker, G. 1999. "Concerns about climate change mitigation projects: Summary of findings from case studies in Brazil, India, Mexico, and South Africa." *Environmental Science* *and Policy* 2:187–198.

Schreider, S., Smith, D., and Jakeman, A. 2000. "Climate change impacts on urban flooding." *Climatic Change* 47:91–115.

Scherer, D., Fehrenbach, U., Beha, H., and Parlow, E. 1999. "Improved concepts and methods in analysis and evaluation of the urban climate for optimizing urban planning processes." *Atmospheric Environment* 33:4185–4193.

Schoenberger, E. 2001. "Interdisciplinarity and social power." *Progress in Human Geography* 25(3):365–382.

Thomas, D., and Twyman, C. 2005. "Equity and justice in climate change adaptation amongst natural-resources-dependent societies." *Global Environmental Change* 15:115–124.

Tol, R., Downing, T., Kuik, O., and Smith, J. 2004. "Distribution aspects of climate change impacts." *Global Environmental Change* 14:259–272.

Tompkins, E. and Adger, N. 2005. "Defining response capacity to enhance climate change policy." *Environmental Science & Policy* 8:562–571.

Turnhout, E., Hisschemoeller, M., and Eijsackers, H. 2006. "Ecological indicators: Between the two fires of science and policy." *Ecological Indicators* (in press). (Available at: http://www.sciencedirect.com/science)

UNCHS (United Nations Commission on Human Settlements) 2002. *The State of the World Cities Report 2001.* United Nations Publications, New York, NY. 125 pp.

World Bank. 2002. *World Bank Urban Development* (http://www.worldbank.org/html/fdp/urban/)

9 Contributors' Biographies

All authors

Roberto Sanchez Rodriguez

Completed his BA in architecture at the National Autonomous University of Mexico (UNAM) and his Ph.D. in urban and regional planning at the University of Dortmund, Germany. He is currently a professor in the Department of Environmental Sciences, University of California, Riverside, and director of the University of California Institute for Mexico and the United States (UC MEXUS). His interests are in the inter-linkages among environment and development, urban development, globalization, and global environmental change, and he focuses on the vulnerability of urban areas to climate variability and climate change. Dr. Sanchez Rodriguez was co-chair of the International Scientific Committee of the International Human Dimensions Program of Global Environmental Change (IHDP), and he is currently co-chair of the new IHDP core project on Urbanization and Global Environmental Change.

Daniel E. Comarazamy Figueroa

Graduated from the Technological Institute of Santo Domingo (INTEC) in the Dominican Republic in 1998. He received a Master of Science degree in mechanical engineering from the University of Puerto Rico, Mayagüez (UPRM, 2002), where he worked as specialist researcher in the field of atmospheric modeling and field campaigns. He is currently enrolled in a Ph.D. program in mechanical engineering at the University of Santa Clara, in Santa Clara, California, USA, under the sponsorship of the NASA-EPSCoR program of UPRM. His research topic is the impact of urban development on the local and regional climate of coastal tropical areas.

Jorge E. González

Graduated from the University of Puerto Rico, Mayagüez (1987), where he also received his Master of Science degree in mechanical engineering in 1989. Gonzales received his Ph.D. in mechanical engineering from the Georgia Institute of Technology in the United States in 1994. His academic and research interests include the areas of heat transfer and two-phase flows, environmental application of fluid dynamics and heat transfer, and alternative energy sources, topics he has addressed as professor at UPRM and at the University of Santa Clara, Santa Clara, CA, USA.

Jeffrey C. Luvall

Graduated with a Bachelor's degree in forest ecology from Southern Illinois University, Carbondale, United States in 1974. In 1984 he received a Ph.D. in tropical forest ecology from the University of Georgia in the United States. Since 1985 he has been working as a forest ecologist and micro meteorologist for the NASA Marshall Space Flight Center and the Global Hydrology and Climate Center, both in Huntsville, Alabama, where he uses aerotransported sensors and thermal models to study transfer and transportation between Earth's surface and the atmosphere. Doctor Luvall is an assistant professor in the Department of Atmospheric Sciences at the University of Alabama in Hunstville.

Fabián R. Bochaca

Received his degree in architecture in 1997 and landscape in 2002, both from the University of Mendoza, Argentina. He is currently finishing his Ph.D. in architecture with a scholarship from CONICET (National Council for Scientific and Technological Research). His field of research is the influence of green areas in urban environments on climate. He has participated in research at national and international levels and in numerous urban-park and green-area projects in the city of Mendoza.

Salvador Enrique Puliafito

Received a Bachelor's degree in electronics and electricity (1983) from the University of Mendoza, Argentina, and Ph.D. in engineering (1989) from the University of Braunschweig, Germany, in the area of atmospheric physics. He has participated in research projects on topics related to the determination of stratospheric ozone and tropospheric water vapor at institutes in Germany, Switzerland, and the United States, including four ATLAS missions on board NASA's space shuttle. Dr Puliafito is former director of the Institute for Environmental Studies at the University of Mendoza. He is an independent researcher of CONICET at Universidad Tecnológica Nacional, specializing in environmental issues, in particular in monitoring and modeling of air quality. His current area of work relates to the influence of urbanization processes on global climate change.

Erna López

Graduated from Universidad Nacional Autónoma de Mexico (UNAM) in 1993. She received her Master's degree in Natural Resource Conservation and Management from Universidad Michoacana de San Nicolás de Hidalgo, Michoacan, Mexico in 1998. Her Master's thesis focused on urban growth of a mid-sized city in central Mexico in the period 1960 to 1997. López has a Ph.D. in biology from the Center for Ecosystem Research (UNAM), and her thesis was "Vegetation Cover and Land Use in the Lake Cuitzeo Basin". She currently works on the institutional Macro Project Human Development and Ecosystem Management in Lake Cuitzeo, Michoacán, México, developed by CIECO.

Manuel Mendoza

Graduated with a Bachelor's degree from Universidad Nacional Autónoma de México (1994) and a master's in natural resources from Instituto Tecnológico y de Estudios Superiores de Monterrey (1997). Mendoza received his Ph.D. in earth sciences from UNAM (2002). He did postgraduate studies in the Foreign Academia Unit of the Geography Institute of UNAM, where he currently is lead researcher and professor of the International Master's Program in Integrated Landscape Management (UNAM-ITC Netherlands). His interests include the analysis and management of natural resources using detection techniques including remote sensing and GIS modelling.

Gerardo Bocco

Received his Bachelor's degree in geography from Universidad Nacional Autónoma de México, his Master's in geography from UNAM, his Master's in applied geomorphology from the International Institute for Geo-Information Sciences and Earth Observation, and his Ph.D. in environmental sciences from the University of Amsterdam, ITC, (1990). Bocco is former director general of research in management and conservation at the National Ecology Institute, Semarnat (2001 2005). He is currently lead researcher at the Center for Ecosystem Research, UNAM.

Alejandra Acosta

Received a Ph.D. in biology from Universidad Michoacana de San Nicolás de Hidalgo. Her thesis focused on the growth of urban settlements in the Lake Cuitzeo Basin. She is currently working in the Department of Land Management of the Secretariat for Urbanism and Environment in Michoacán.

Ricardo Toledo Silva

Is an architect and professor at the School of Architecture and Urbanism, University of São Paulo. His research activities focus mainly on urban infrastructure and integrated management. Formerly, he was secretary of urban development (federal government) and senior researcher at the São Paulo State Institute of Technological Research.

Claudia Maria de Almeida

An architect-urbanist, graduated from the University of São Paulo, USP, Brazil (1989). She obtained a Master's degree in infrastructure planning from the University of Stuttgart in Germany (1995). She was assistant professor in the Specialization Course in Environmental Health at the School of Public Health of USP and in Master / Doctorate courses at the School of Architecture and Urbanism at USP. Almeida worked as architect at the Municipal Secretariat of Urbanism in Rio de Janeiro, Brazil. In 2003, she obtained a Ph.D. in remote sensing from the National Institute for Space Research, INPE, Brazil, where she currently conducts research.

Alfredo Cabrera

Received his Licentiate degree in geography from the Enrique José Varona Pedagogical Institute (Instituto Superior Pedagógico Enrique José Varona) in 1979. Cabrera received a Ph.D. in geographic sciences from the University of Havana in 1993. He specializes in the geological aspects of landscapes, protected area and coastal zone management, and environmental and sustainable development theory. He currently directs the Varadero Beach Integrated Management Center. Cabrera is professor for the Environment and Sustainable Development Graduate Program at the University of Girona in Spain and the University of Matanzas in Cuba.

Lorenzo Castillo

Graduated in 1967 with a degree in architecture from the Polytechnic Institute José Antonio Echeverria (Instituto Superior Politécnico José Antonio Echeverria). He has experience in physical planning and land management, in urban and nonurban areas, as well as in bioclimatic architecture and architecture in harmony with the environment. He has worked as project manager and project consultant. Currently Castillo works in the Environment Unit of Matanzas, where he has specialized in best practices for environmental conservation in tourism activities.

José Rojo

Graduated with a degree in architecture from the University of Havana in 1961. He has over 40 years of experience in urbanism and physical planning. Rojo has done work in Bioclimatic Architecture for urbanism purposes. He has worked on the physical planning of the city of Matanzas and other regions of the province. For over 15 years, Rojo directed the Physical Planning Institute in the province of Matanzas. He has also worked as project manager and is currently working on the Director Plan for Varadero.

Bárbaro V. Moya

Received his first degree in engineering in 1993. He has a Master's degree in environmental sciences from the University of Matanzas. Moya was appointed scientific researcher in the Matanzas Provincial Weather Center in 1995, where he had been working since 1981, first as weather observer, later as technician in climatology, and finally as specialist on the topic. He has done field research on weather applications and air quality. In recent years, Moya has been researching the issue of climate change, focusing on adaptation to future scenarios based on vulnerability and impact analysis for various scenarios.

IAI Directorate
c/o INPE Ave. dos Astronautas, 1758
12227-010 São José dos Campos, SP – Brazil
Telephone: (55-12) 3945-6855/56
Fax: (55-12) 3941-4410

IAI Directorate
c/o INPE Ave. dos Astronautas, 1758
12227-010 São José dos Campos, SP – Brazil
Telephone: (55-12) 3945-6855/56
Fax: (55-12) 3941-4410

E-mail: iaibr@dir.iai.int
Website: http://www.iai.int

IHDP

Instituto Nacional de Ecología

UNEP

Casa abierta al tiempo

FUMEC
Fundación México-Estados Unidos para la Ciencia
The United States-Mexico Foundation for Science

ISBN978-85-99875-02-5

9 788599 875025

IAI/ID.37.E/2007