Zonal Organization of Cities and Environment*

A Study of Energy Systems Basis for Urban Society

by

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Ecological Energetic Evolution of Urban Systems: Cross Comparison of Chinese and American Societies#

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Contents

1. Introduction

In our time, cities of the world have become the centers of the intense activity of a technological civilization, with rapid changes in land uses, transportation, population distributions, and quality of life. The results have not always been good, and many cities are in a disastrous state, with bankrupt finances, collapsing utilities, and stressed with social problems. For the older cities of Europe, with buildings of permanent stone construction such as Rome, Italy, all the new development had to be fitted in and around the old structures. For the American cities, where there was a cultural priority on free use of automobiles, great sections were displaced for the super-highways, leaving many areas dysfunctional. In recent decades, Asiatic cities, especially on the rim of the Pacific Ocean, have accelerated growth, and questions were raised as to how these cities would develop, and if the results would be any better than those where the technological revolution was older.

A Taiwan-American Research Project was conducted to compare Chinese and American cities and investigate the basis for the observed trends of development. This report is Part I of the results of the joint project between the Graduate Institute of Urban Planning, National Chung Hsing University, Taipei, Taiwan, and the Center for Environmental Policy, Environmental Engineering Sciences, University of Florida, Gainesville, Florida, sponsored by the Chiang Ching Kuo International Scholar Exchange Foundation, Taipei, Taiwan.

For centuries, human society has been organized around cities as centers of industry, commerce, communication, information, government, and control. In earlier agrarian society, cities were supported by the products of environment converged into the centers, with most people living outside (Figure 1). Then in the last two centuries, using the available energies of fossil fuels, a surge of growth of the human and technological civilization of all over the world was concentrated in huge urban centers with most people living inside (Figure 2). To understand the modern cities, it was clear that we had to learn how the hierarchy of landscapes centered in cities is changed by the huge technology and information and its ultimate basis in resources.

Since the availability of the resource which fueled city change are already beginning to decrease, any understanding of city patterns over time must include projections and planning for a period of descent in concentration toward a more agrarian base once again.

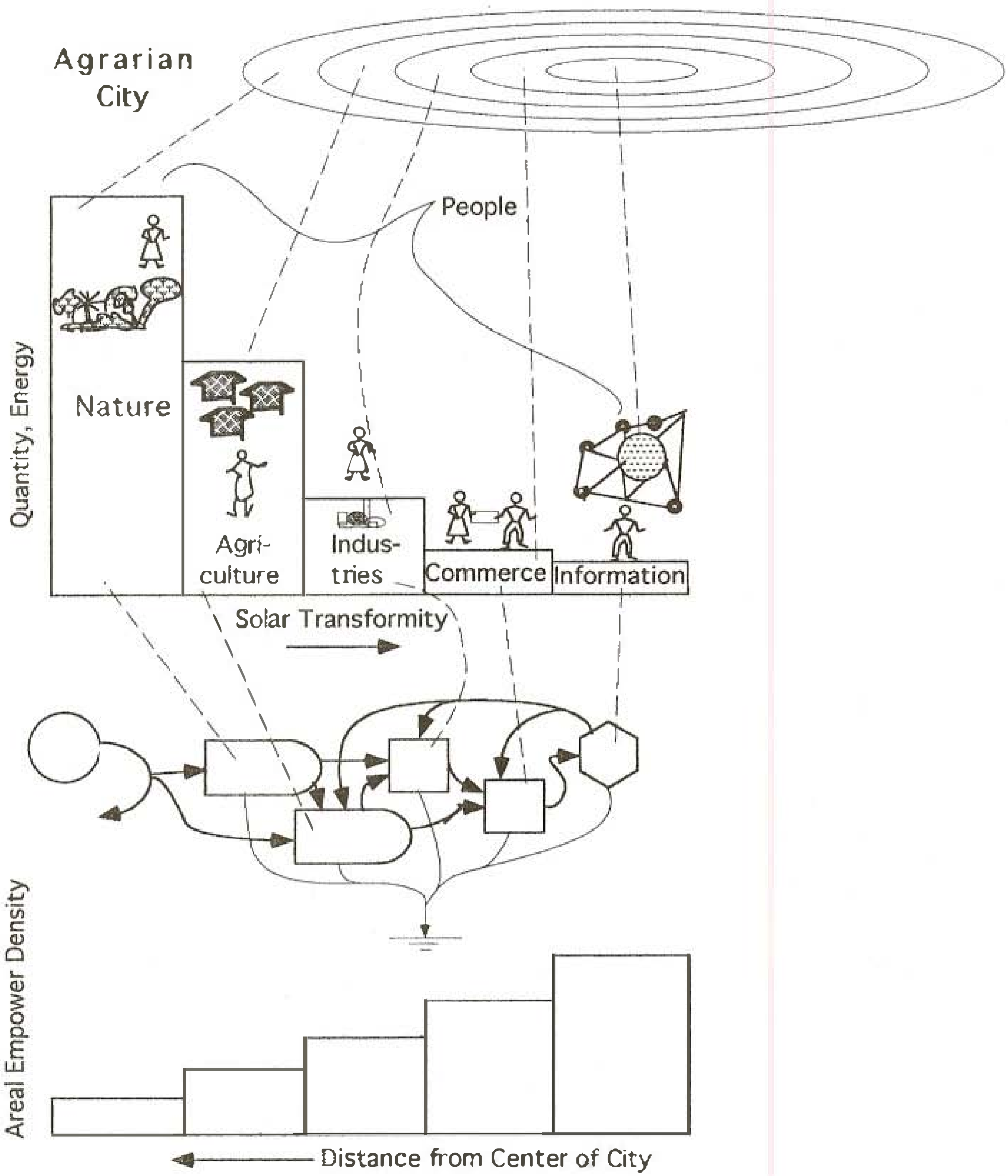

Figure 1. Model for zones of a city in an agrarian landscape, with hypothetical distribution of energy and empower.

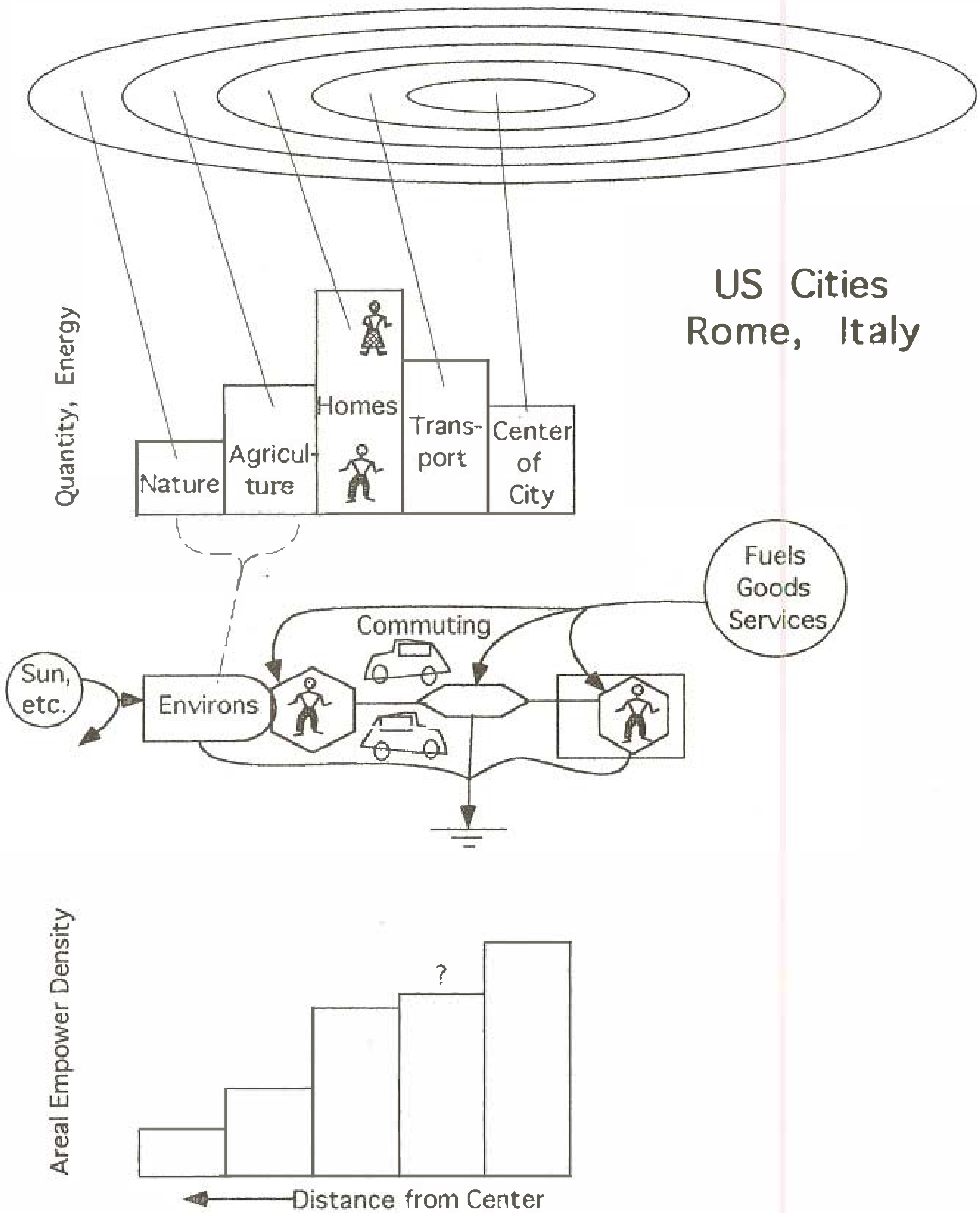

Figure 2. Model for zones of a city in a fuel-based Urban landscape with hypothetical distribution of energy and empower.

Emergy Evaluation. In order to put all resources and human work on a common basis, we have included evaluations of EMERGY, spelled with an "m", a measure of real wealth. Although there is energy in everything including information, we recognize that energies of different kinds are not equal, but can be compared by expressing everything in units of one kind of energy required. In this way, human services are found to require thousands of times more energy of ordinary kinds than do agricultural processes or industrial processes. The EMERGY production and use per unit of time is called Empower. For example, the total EMERGY use per year is the annual empower of a city. Emergy and empower include all inputs, fuels, electricity, environmental, people, etc.

The EMERGY of one kind of energy required to generate a product or service of another kind of energy is the transformity. The more energy transformation steps there are, the higher the transformity. Since everything is related to everything else according to how much was required in the making, transformity measures relative position in a scale of increasing wealth. Since self organizing systems only retain transformations which have an effect commensurate with what into them, transformity measures power to accomplish and control.

EMERGY may be expressed in the dollars of the gross economic product for which that wealth is responsible. Dollars of buying power calculated from EMERGY evaluations are called emdollars. In the Appendix are further definitions and explanations of procedures for calculating Emergy, transformity, empower, and emdollars.

Theory of EMERGY and Landscape Hierarchy. Because ability of energy to do work is used up in any energy transformation, items in the universe can be arranged in a series according to how many transformation steps are used from one item to another. In other words, there is a hierarchy of energy. We believe that this energy hierarchy explains the landscape hierarchy with cities at their center. Chapter 2 on Spatial Organization presents these concepts. These new measures provide ways of representing city functions as derived from converging resources.

In an agrarian landscape, the resources of agriculture and nature are converged to support small cities (Figure 1). Although the total energy flows and land areas may be less in the city, the areal concentration of empower and transformity increases to the center. In the fossil fuel driven landscape, the cities are driven by the use of fuels, minerals, electric power and goods and services generated from these resources. However, these resources only generate their best contribution to wealth when they interact with the environmental resources so as to be mutually amplifying. The city processes reach out to the surrounding zones in their interactions (Figure 2). For example, people with jobs based on industry in the city move out further to live where there is environmental quality, commuting to the city.

The intense use of fuels for excess requirements of individual transportation have distorted American cities, creating a transport-zone that is hardly livable. In Rome, the solution has been to fit more small cars into the spaces available, retaining more of the housing, not displacing people and the buildings of antiquity with highway construction. People going to work appear to spend as much time in transport as they do in American cities, but for shorter distances.

One of the concepts of the energy systems approach to cities is that systems ultimately organize so as to maximize empower production and use. Is the pathology of some American cities, and now appearing in Rome, a result of use of distorted use of fuels by individualistic priorities on cars and freedom of individual transportation, without consideration of what is required for the maximum function of the larger system of all people?

Zonal Concept of this Report. Our energy systems models based on EMERGY hypothesis for the determination of cities and their zones showed promise as being able to generate the patterns of city growth and decline. Hence, the work of this project was concentrated on surveying the zones of cities and then simulating their characteristics for various conditions such as increasing and decreasing availability of fuels, the inflow of information, or immigration. Figures 3 and 4 show hypotheses about city gradients.

Whereas wholly aggregated city models have some utility in dealing with total resource uses, total populations, total trade, etc., the science of urban and regional science has generally directed its efforts toward understanding the landscape structure of the city and its environs. Although there are many spatial models being attempted with Geographic Information Systems, complexity is very high with spatial detail. Perhaps, at this stage of the science, a more attainable, less ambitious objective is to aggregate the city into about 5 units, each representing a concentric zone. In gathering data, transects can be used and averaged. Or lines estimating a concentric zone can be traced, bending the line in an irregular fashion so as to include the items for which the zone is defined. For example, the natural zone (nature zone including wilderness) can include the parks that are on the city periphery, bending the line to include mountains and coastal marshes.

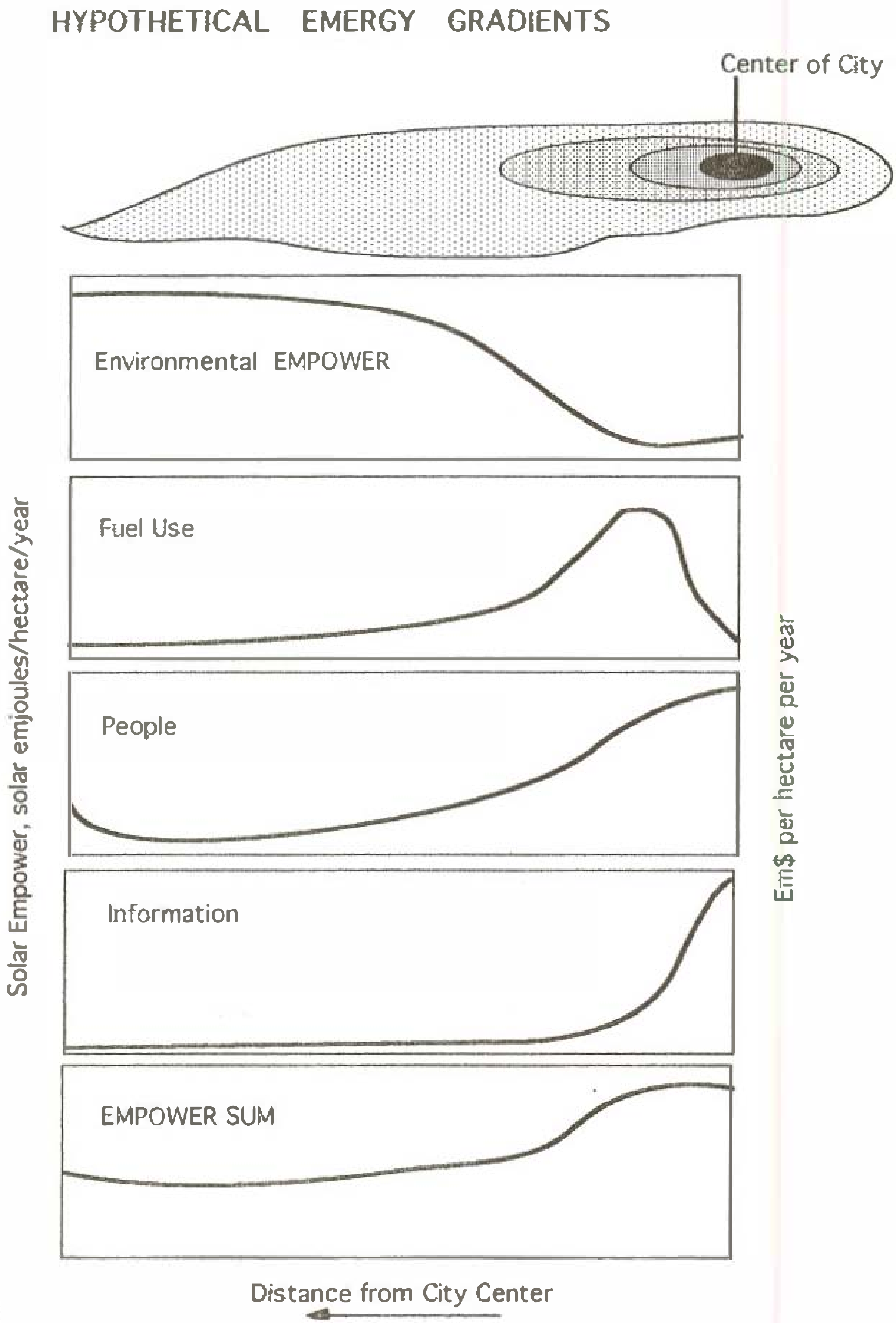

Figure 3. Hypothetical gradients in zonal properties around a city.

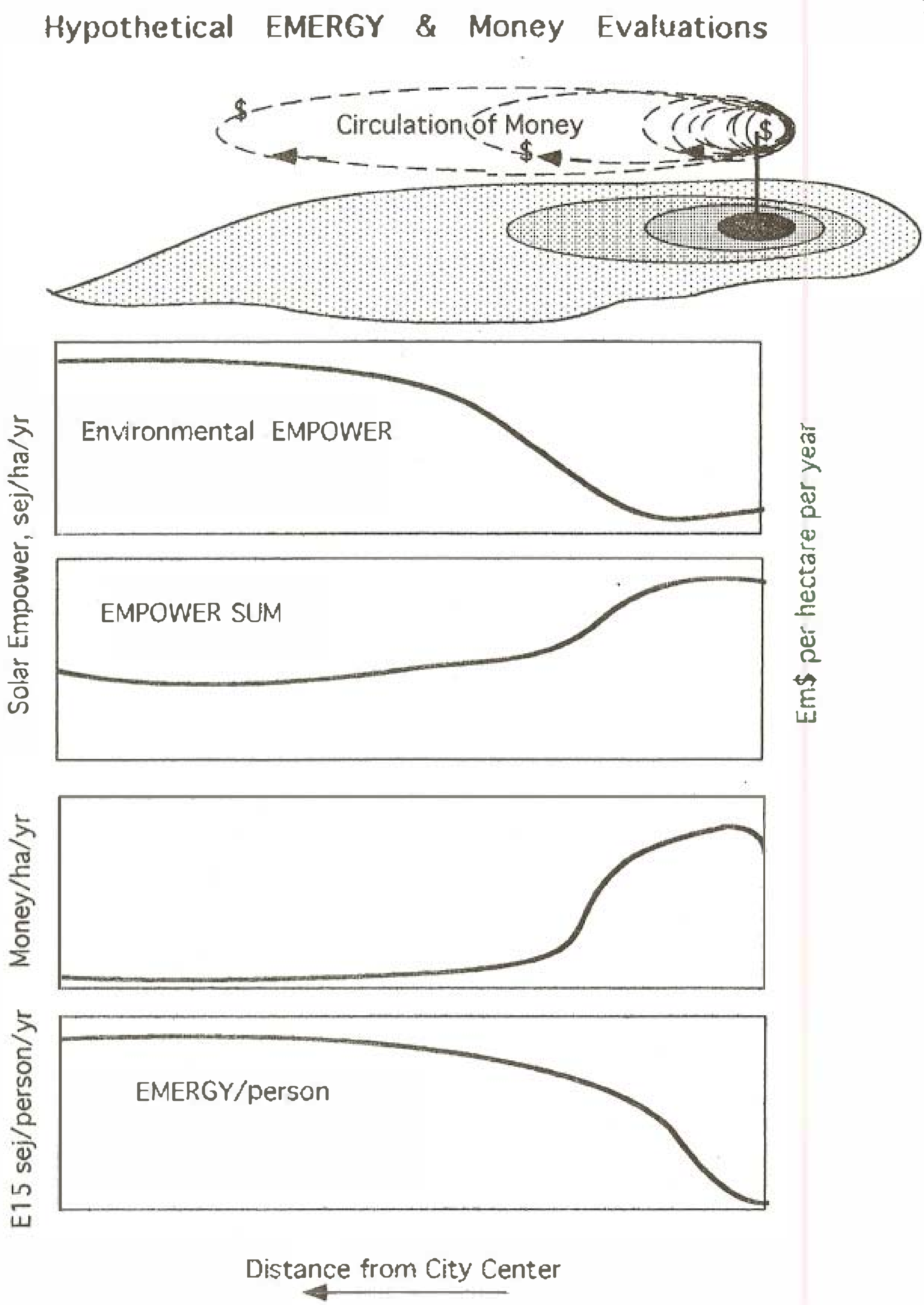

Figure 4. Hypothetical gradients in zones properties around a city.

Chapters 3, 4, and 5 include studies of the transects through Jacksonville and Miami, Florida, and three more northern cities. Transects or literature data were assembled showing changes in population, car use, electric power etc. Then transformity and the concentration of Emergy flows per unit area were evaluated for transects. These were compared with our initial hypotheses (Chapter 2), in which transformity and areal empower density increase towards the center of hierarchy and increase with the total empower inputs to the urban system.

At the same time, study of cities requires that they be compared with the larger state and national systems in which they are a part. Overall EMERGY evaluations were made for Miami, Florida, in Chapter 6 and San Juan, Puerto Rico, in Chapter 7. Both are at one end of an island or peninsula, and in this respect are like our comparison city, Taipei, Taiwan.

City Models. Computer simulation of city models has a long history. Earlier reviews (Mohan, 1979; Batty, 1976) found most models built up from relationships of a few of the parts such as human behavior, employment, population trends, economic data, and land use. Aggregated models of the city as a whole, such as Forrester (1969), without spatial zones, were criticized as leaving out the spatial organization causally dominant.

Transportation is inherently hierarchical, with many small trips toward the center converging successively to larger and larger flows to the center, like a river. Return transportation diverges on these successively branching pathways. The hierarchical correlation of time and space is inherent in many small trips over short time, contributing to fewer longer trips over a longer time. The pattern relating city transportation function to hierarchy was called Ekistics by Doxiadis (1969).

Transportation is one of the main ways energy supports city function. Data on the role of cities in larger landscape were mapped by Batty(1976) by plotting black vectors with width in proportion to transport miles per year, thus showing graphically the inter-zonal flows of EMERGY. The concentration of inter-zonal transport per area was a maximum at an intermediate distance from the center. The excessive use of fuels for transportation changed these middle zones of cities into zones too intensive for optimal living. Any simulation of cities has to include the transport function and its relation to the whole city energetic hierarchy.

A Zonal Simulation Model. In Chapter 8 a city simulation model was made with 5 zonal units, each with production and assets as expected for units hierarchically connected with general systems relationships, as in a food chain (Figure 5). Each zone block draws resources from larger areas in the next zone outward, a feedback from the next zone inward as well as from direct trade input from outside the system. Each zone block can pull land from the zones on either side, depending on the assets in each. The model is spatially hierarchical, since the outer zones have larger areas than the center zones in initial calibration. The simulation showed some features of city growth, such as expansion to incorporate agriculture and natural areas, building an information center. When fossil fuels are added, this process is accelerated. When fuels are made more costly, the landscape returns to a more agrarian zonation.

There are different views on how to use this class of energetics model. The thermodynamic view is that the zones, areas, population, and assets will self organize in the series of autocatalytic models as in the real world, with people changing their culture as needed to fit the models' performance. By this view, the basic pattern and calibrations should not be modified by small scale considerations. The assumption is that the small scale will adapt to the performance of the large scale.

A more humanistic viewpoint modifies the model according to cultural tradition. For example, in the U.S. there is a tendency to put more resources in intra-city transport than is optimum. Do people in Asian cities tend to stay where there are social ties? Special properties can be included by adding special pathways or changing coefficients. Some of the results of model modification are given in Part II (Huang et al., 1995).

Quality of Assets and Catastrophes. One of the differences between cities is the EMERGY that is stored in buildings. Except for the downtown centers, American cities have less permanent housing: more frame houses, brick-front, trailers, and other construction of about 50-100 years turnover time. In other words, the construction, like that of rapidly colonizing ecosystems is a bit weedy, requiring more rapid replacement. Part of this is because the individualistic culture seeks individual, and thus less costly, structure for homes. The old cities of Europe have more of the permanent stone buildings that last centuries, although the insides have to be replaced at 50 year intervals or sooner. The new Asiatic cities may be intermediate, with more EMERGY in housing, although it is shared among more people.

As hurricane Andrew showed in its destruction of Homestead and Florida City (southern Miami, Chapter 6), the flimsy housing of individualistic American housing was mostly destroyed and had to be replaced at great expense. There are two strategies: (1) one to use more energy to resist damage; (2) to put energy into quick reconstruction rather than in resisting catastrophe. Both mechanisms are observed in ecosystems. Transformity may be helpful in classifying structure that is best for one strategy versus the other. More permanent housing shared by more people may be a better solution for winds of a hurricane belt.

References Cited

Batty, M. 1976. Urban Modeling. Cambridge Univ. Press, Cambridge, England.

Doxiadls, C.A. 1968. Man's movement and his city. Science 163:326-332.

Forrester, J.W. 1969. Urban Dynamics. MIT Press, Cambridge, Mass.

Mohan, R. 1979. Urban Economic and Planning Models. Johns Hopkins Univ. Press. 180 pp.

2. Spatial Organization*

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In order to understand how city systems are developing and are expected to change in the future, theoretical concepts about landscapes are set forth in this chapter. Later chapters relate observations and simulation models to these principles and hypotheses.

As part of maximizing system functions, self organization develops geographical patterns. Designs form that process energy and recycle materials between sparse areas and concentrated centers. Landscapes become hierarchical with consumption pulses in the centers. To be successful, human policy and planning of landscapes must follow these geographical principles. By these patterns of organization there is maximizing of empower (rate of EMERGY production and use).

Spatial Pattern for Production, Consumption and Recycle

Wherever we place the window of attention we can find systems of production, consumption, and material recycle (Figure 2). Where the source of energy is entering the system evenly spread out on a broad surface, the production that uses this energy has to be broadly dispersed too. After energy is transformed into more valuable products, these converge spatially to be used by consumers in a center as drawn in Figure 1. For example, in many agrarian landscapes, before the industrial revolution, agriculture around a city supplied food for people and hay for the horses in the center.[1] Although the energy reaching the consumers was much less than the original solar energy, it was higher quality as measured by its higher transformity. The products reaching the city consumers were concentrated as they were converged towards the center.

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*From "The Prosperous Way Down" (Odum and Odum, 1995)

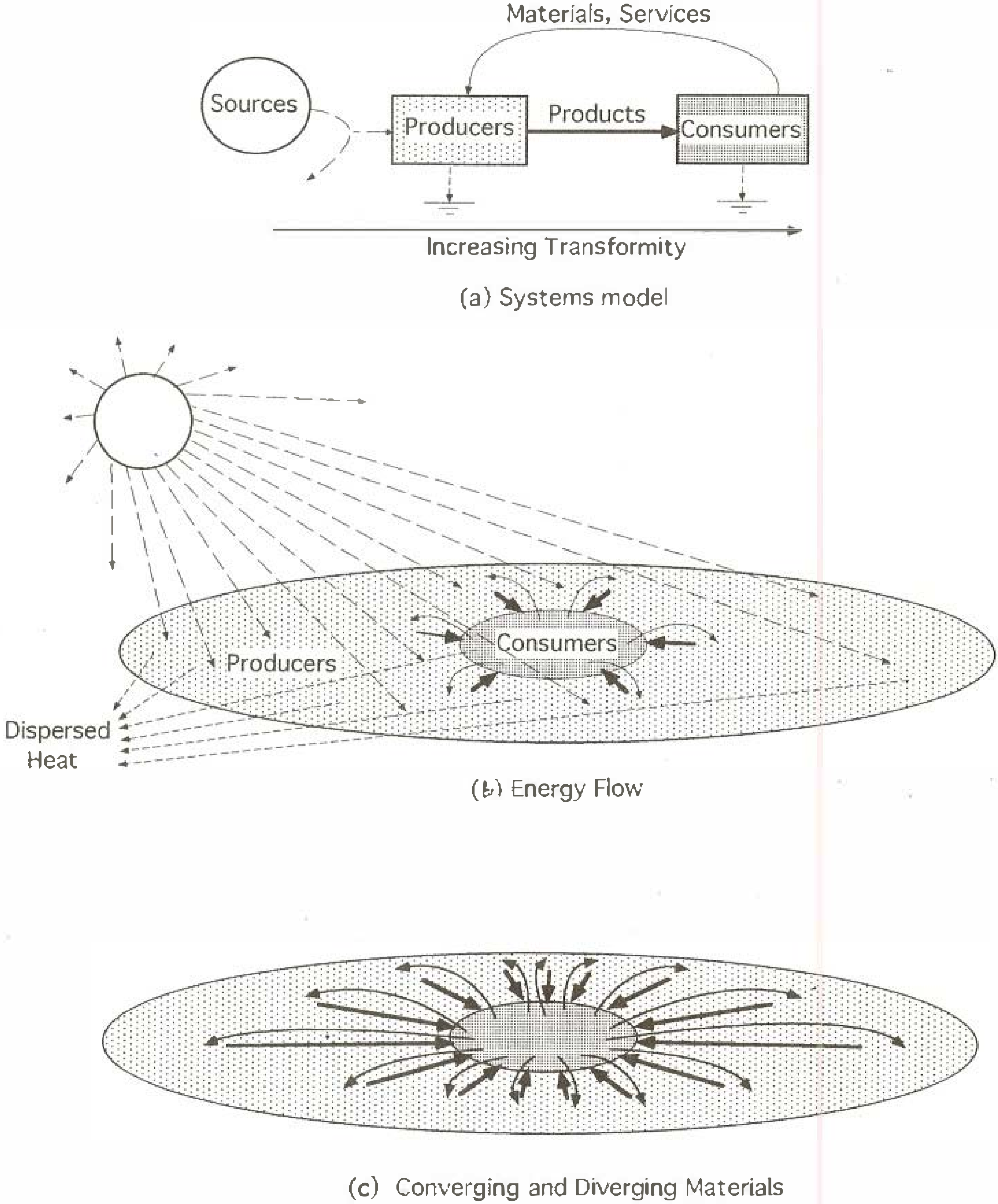


Figure 1. Spatial arrangement of a system of production and consumption. (a) systems model; (b) geographical view of energy flows; (c) geographical view of material cycle.

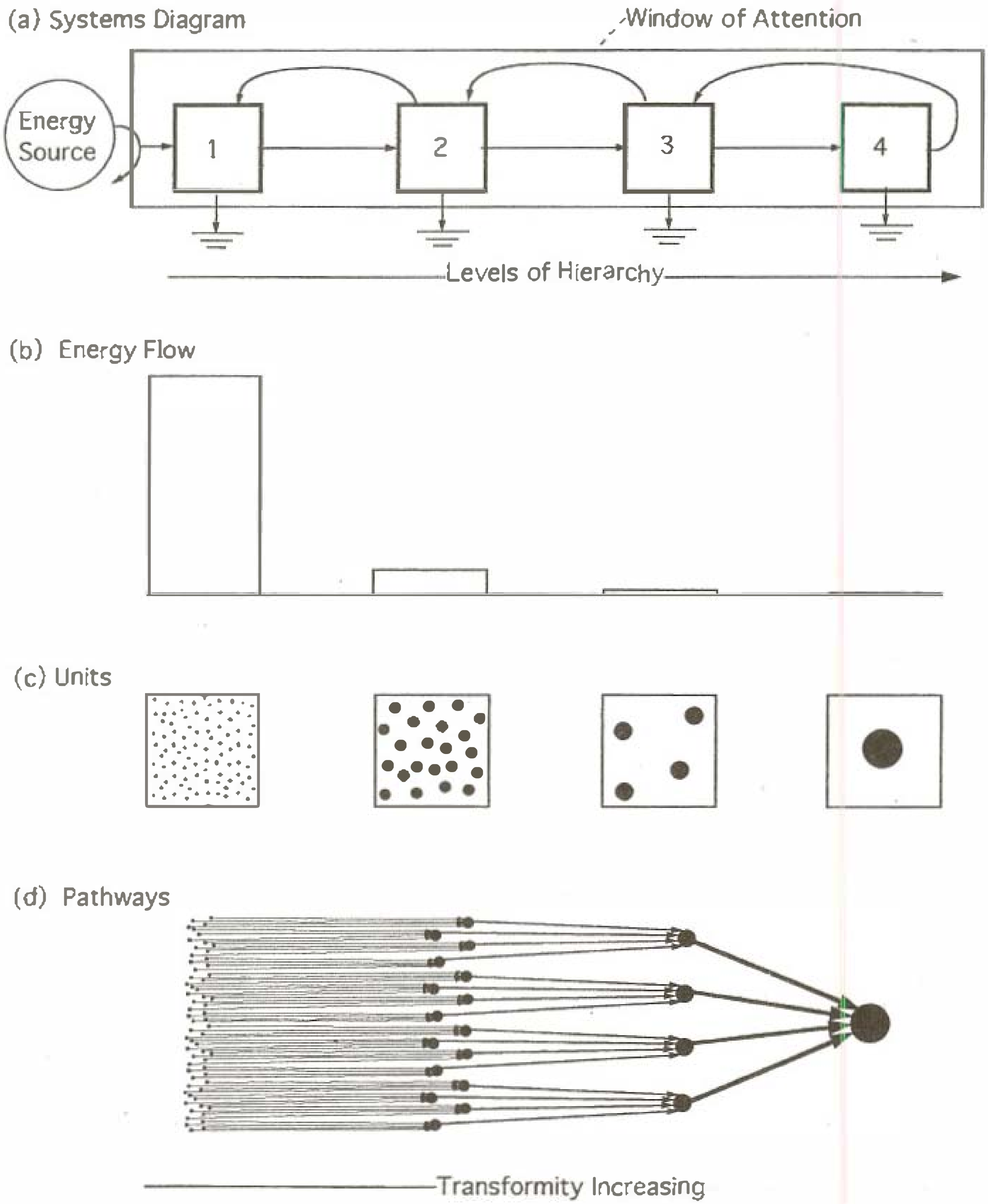


Figure 2. Properties of a system with 4 levels of hierarchy. (a) systems model; (b) energy flow; (c) numbers and sizes of units; (d) energy flows passing up the hierarchy. Not included here feedback flows can be represented similarly but with arrows reversed.

As required for maximum performance, the central consumer part of the system returns services to reinforce the rural system. For example, day laborers and equipment moved from city to the farms. Consumer centers also returned materials released during the consumption process. The agrarian city returned horse manure back to the surrounding farms. Figure1 shows the materials from the center flowing outward to the producers in diverging, dispersing pathways, thus closing the cycle of materials necessary for continued production. Production and consumption are symbiotic; they are cooperatively linked by the products converging to the center and services and by-products diverging back.

This converging and diverging design is observed in many kinds of systems. Cumulus clouds are the centers of converging and diverging airflows. Some reefs of animals are the consumer centers where waters bring products from plants in the surrounding seas, carrying back out the by-products of consumption. Volcanoes are the centers where heat and lavas converge from surrounding areas and are dispersed back outward when there are eruptions.

Good policy for planning a landscape is to arrange to converge and diverge materials in complete cycles. Expenditures on diverging and dispersing wastes back to the rural systems may be as important as those spent to bring products into the centers of an economy. Examples are the recycle of waste waters to forests and transportation arrangements that converge people to the center of cities and recycle them back to their dispersed homes again.

Window of Attention on Multiple Levels of Hierarchy

With a model production-consumption the window of attention is on two levels of hierarchy (Figure 1a). But the real world has many scales of size and time. Each level receives products converging from smaller units spread out over larger areas. Each level in turn produces products for the more concentrated center at the next higher level.

Whether you use the words "Producer" or "Consumer" depends on your window of attention. For example, within an ecological window of interest, fishes are consumers receiving energy from smaller, dispersed producing organisms. The window of attention for a family living off fish sees the fish as the producer and the family as the consumer. On yet a larger scale with a window of attention of economic use, fishermen are the producers and the people in the towns are the consumers. The energy chain in Figure 2 shows the way the energy decreases through successive levels, but the transformities of the products increase. Here sunlight supports phytoplankton, that support zooplankton, that support small fish.

Four levels of energy hierarchy and size are represented in Figure 2 to show the spatial pattern that emerges. From left to right in Figure 2c units get larger and fewer with larger territories of influence, longer turnover times, and higher transformities. Examples are the food chains of aquatic ecosystems, the ecological organization of land ecosystems, and the spatial organization of farms, villages, and cities in an earlier agrarian economy. As with a two level window, the transformity increases with each step from geographically dispersed small units on the left to more centralized units on the right. The total energy flows decline, but the converging pattern brings highly concentrated flows of high EMERGY into the centers. Figure 2d shows the convergence of the pathways passing up the scale of hierarchy. The reinforcing, return feedbacks (shown in Figure 1c and 2a) follow similar patterns except with arrows in reverse direction.

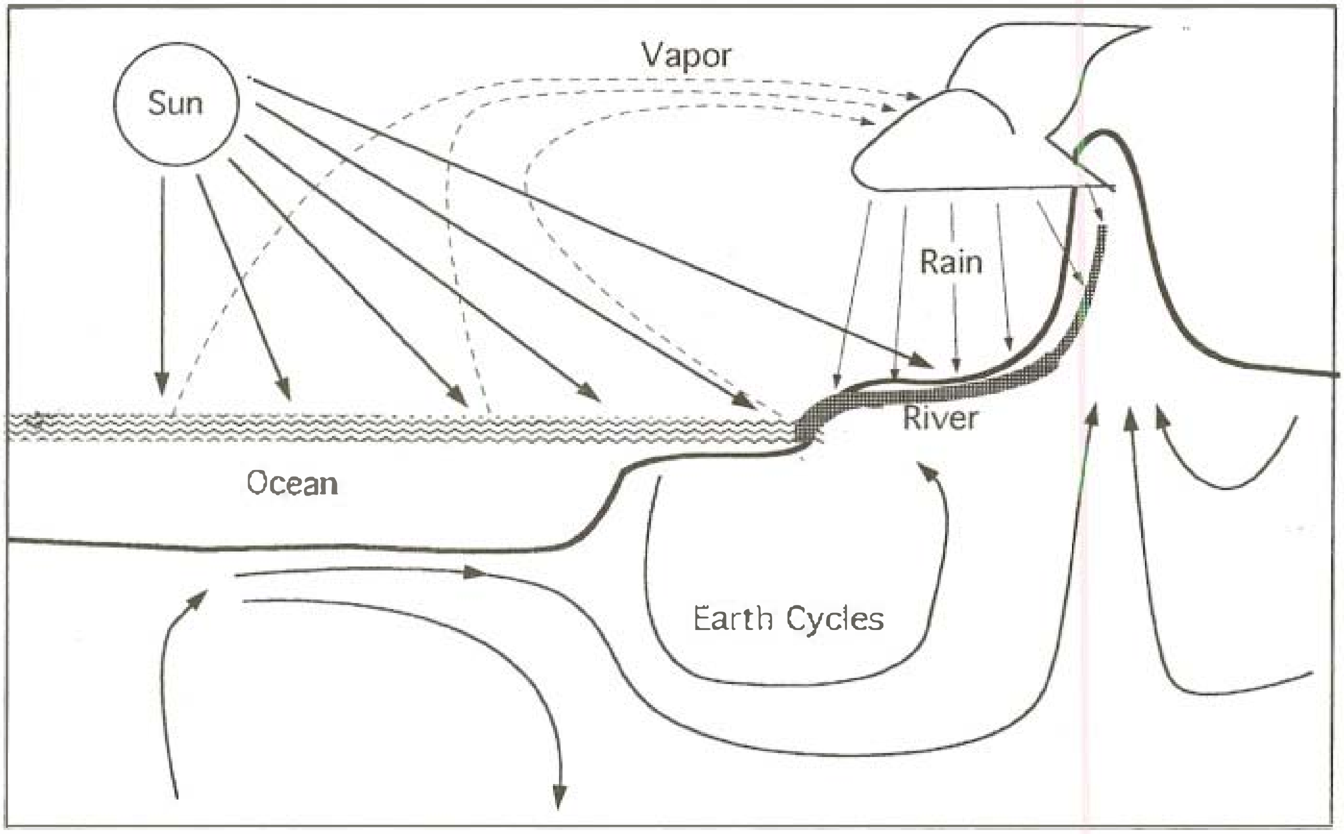
Global Energy Basis

For the planet earth as a whole, there are three main outside sources of energy: the direct sunlight, the tidal energy transferred by means of the pull of gravity of sun and moon with sea, and the intense concentrations of heat deep in the earth from radioactivity and other sources. Since the inflows from these sources are broadly distributed over the earth, the processes of atmosphere, oceans, and geological cycles as they interacted with each other organized a hierarchical spatial pattern that generally fits the basic spatial plan shown in Figure 2; many small units supporting fewer large units.

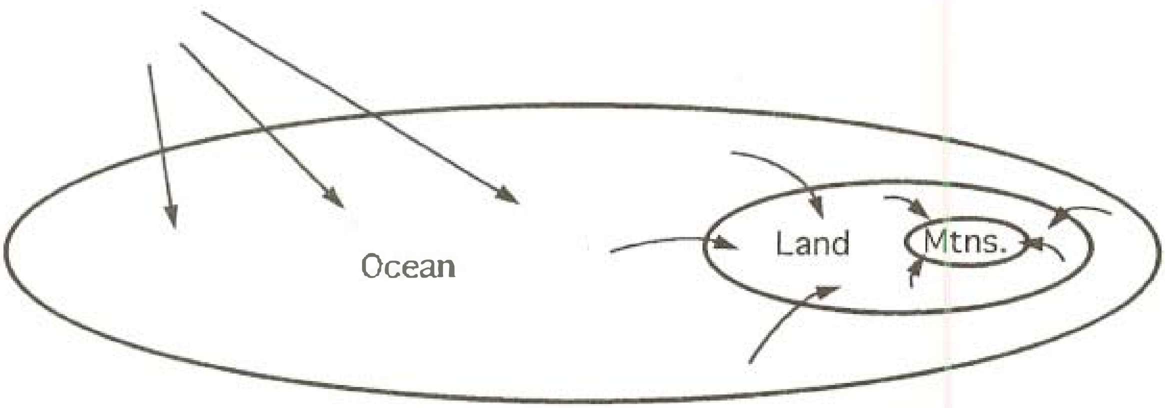
The energy hierarchy of the earth (Figure 3) starts with absorption of sunlight over the globe, especially the seas; its heat transformed into winds, storms, and ocean currents, water vapor converging to land; the falling of freshwater rain and snow over the lands, and the large scale slow cycle of the land driven by the rivers from above and the earth heat from below. The transformities and usefulness of the environmental products to humans tend to increase in the order of this transformation series from left to right.

Geographic Role of Environmental Energy Concentrations

In the places on earth where the natural processes of wind, water, and earth converge, the transformities and concentrations of resources



(a)



(b)

Figure 3. Biogeosphere and its hierarchical organization. : (a) Sketch view in cross section showing circulation of water and earth; (b) areas of the earth showing the hierarchical converging of EMERGY to the mountain centers.

increase. In low energy times of the past, conditions were best for human societies to develop in these places because highest quality resources were located there on which to build a high quality society. Policy for locating developments in the future can be aided by maps of concentration of EMERGY use[2] and transformity so that these beneficial areas can be found.

Rains and snows already have a moderately high transformity when they fall on the land, and they are concentrated (transformed) further as waters run together to form rivers or accumulate as ice flows. Much of the earth surface is organized by the streams and glaciers that sculpture the landscape (Figure 4). In some places the waters converge, as in the example of many tributary streams converging to form the Mississippi River at New Orleans. In other places the waters diverge, as in deltas or waters flowing down and out from conical volcanoes.

In many river systems the upper streams converge. Not only is water flow increased, but valuable substances are joined, especially sediment and organic matter. Transformity is highest at the places where waters and their contents converge most, and here the EMERGY of the whole watershed is available. Here navigation, fisheries, and use of water for urban development is easy. Little wonder that the great cities of the pre-industrial past tended to develop at the end of the hydrologic hierarchy: Cairo and Alexandria on the Nile, Vienna on the Danube, New York on the Hudson, and Shanghai on the Yangtze.

In the lower part of the watershed the physical energy of water running downhill is used to spread water out in flood plains, delta marshes, and agriculture, where it stimulates productivity of the land. An important hypothesis is that geomorphologic self organization of the landscape gets reinforced so that the geopotential of elevated waters can help maximize productive uses of fresh water. Chemical potential energy is the property of fresh water that is used to make plants grow as they transpire the water. Any plans to divert upstream river waters must also evaluate values generated by the lower flood plains and deltas which may be lost. Damming the Nile caused loss of land and estuarine fertility in the delta.

Too often economic development diverts high quality energy without regard for the role these energies have in the landscape as a whole. As a general policy rule:

> Before diverting environmental resources into new economic uses, existing EMERGY contributions of

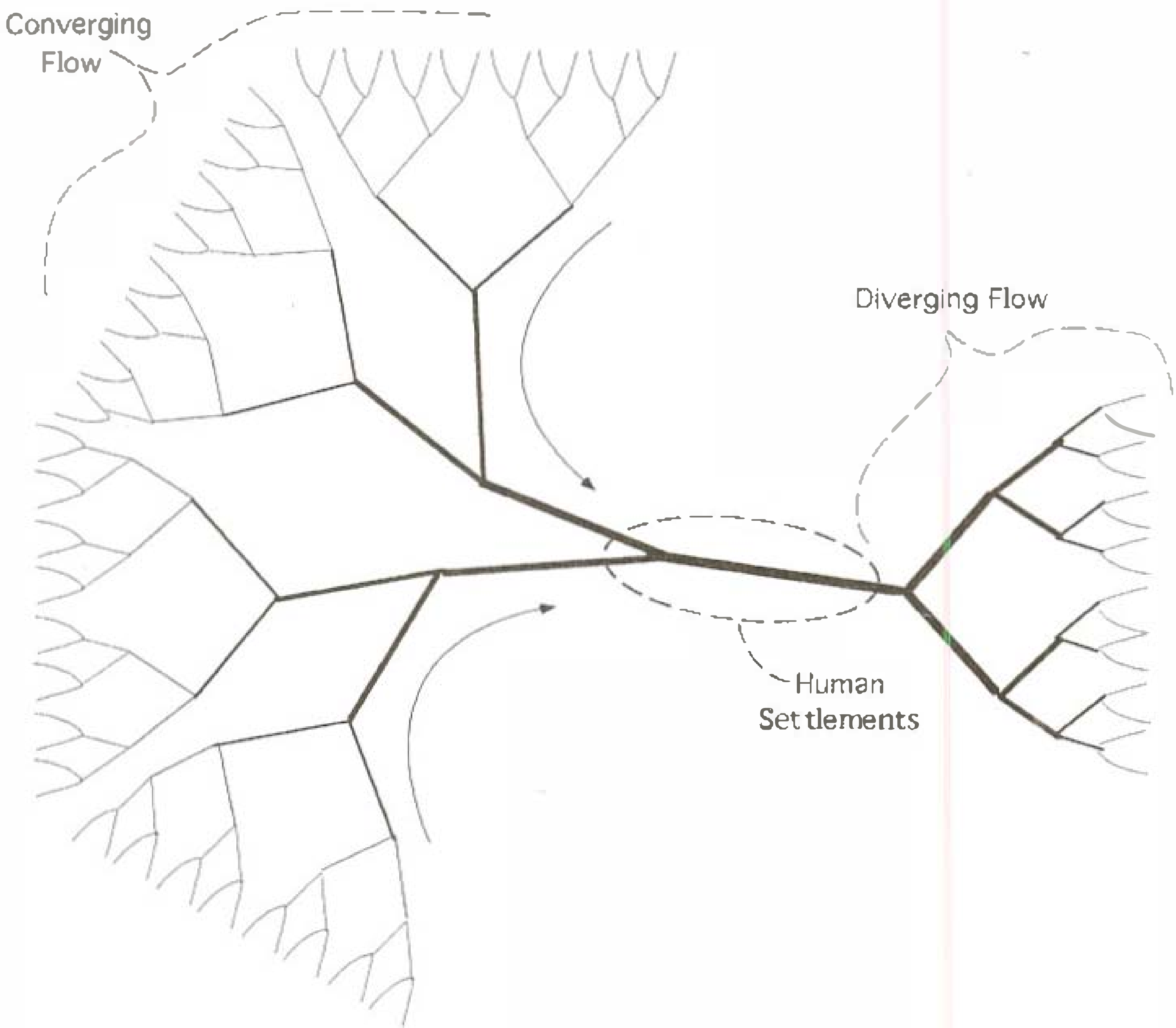


Figure 4. Converging and diverging river network showing historical location of cities in zones of highest transformity and EMERGY availability.

environmental processes should be compared with those to be obtained by development.

Another place were energy flows of the planetary system converge is at the sea coast where the action of water waves and sediments interact to form beaches. Lagoons behind the beach help to convert tidal energy into fisheries. Economic development develops along coastal strips, another example of attraction of high energy areas.

Some energy transformation series are laid out spatially, their hierarchical branching easily recognized like the river system in Figure 4. More often the components of an energy transformation hierarchy are together in the same area, giving a complex view with many small items and large items together. See the landscape sketch in Figure 5. This sketch represents energy hierarchy, since the energy flow through the smaller components is larger than that through the centralized components they support.

Spatial Organization of Human Settlements

The spatial and hierarchical organization of human settlements in agrarian landscapes was recognized early-on[3]. Scattered rural people supported a village and received trade and services back; villages supported towns; towns supported cities. Large, low-transformity energy flows of the rural system were transformed to higher transformity villages whose products were further transformed to higher levels in towns and cities. Transportation and utilities were effective when organized hierarchically, converging toward the centers of higher transformity. People and products were circulated into these centers along converging roads and then returned, diverging again along the same corridors.

The hierarchical distribution of human settlements and the economy on the landscape is summarized with Figure 6. People and information are more concentrated in the centers where transformities are higher. More money circulates in the centers than in the rural areas. The EMERGY/money ratio is highest in the rural areas, where money buys more real wealth, since many environmental resources can be used directly there without use of money. In the city centers, nearly everything for people's needs has to be brought in to be purchased. Money buys less there because a higher proportion of the purchased wealth consists of human services for which payment is required. Knowledge and information is concentrated in centers. Money, materials and information converge as they circulate in and diverge as they circulate out.

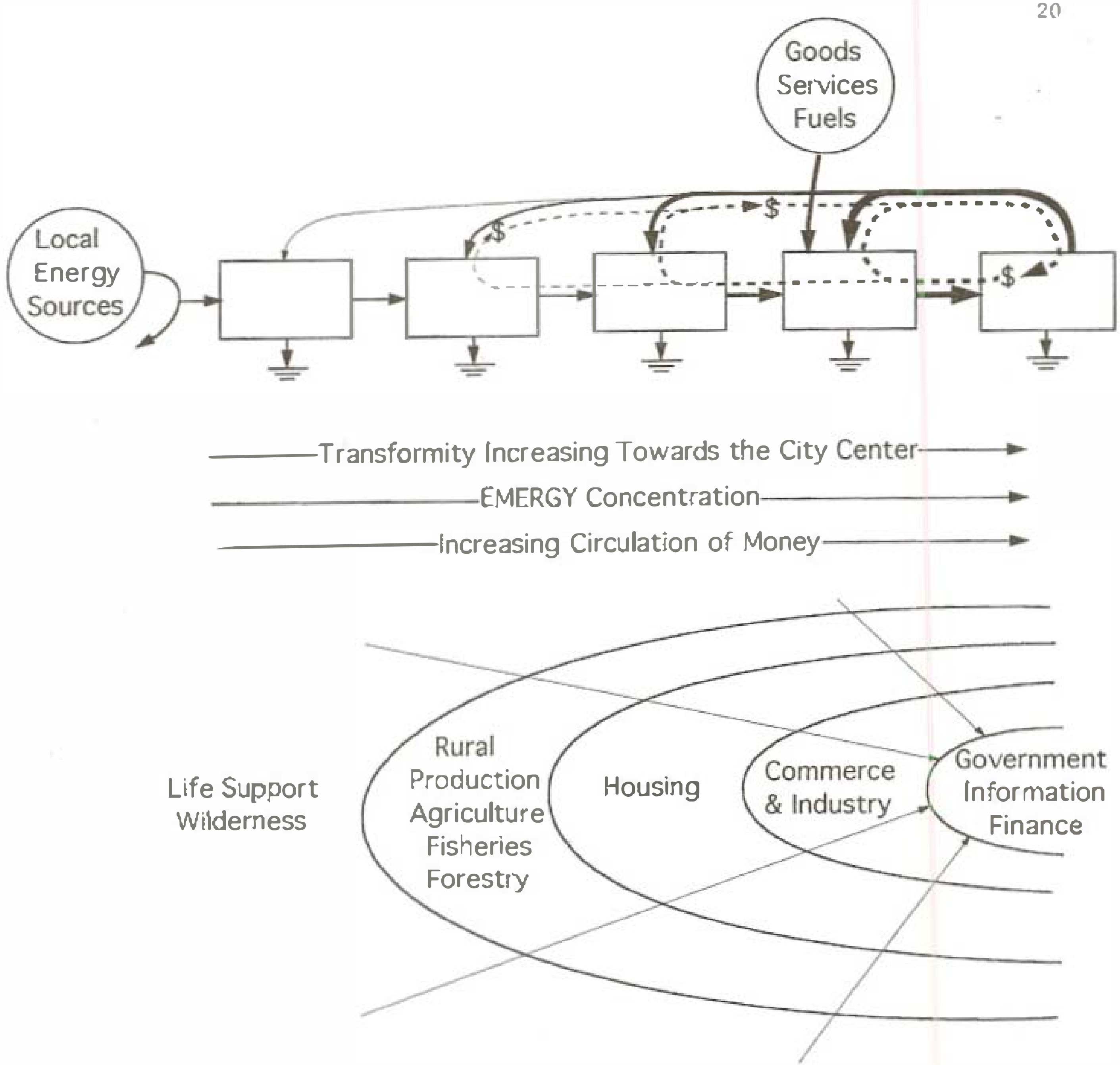


Figure 5. View of the convergence of properties to urban centers showing hierarchical concentration of EMERGY, population, and circulation of money.

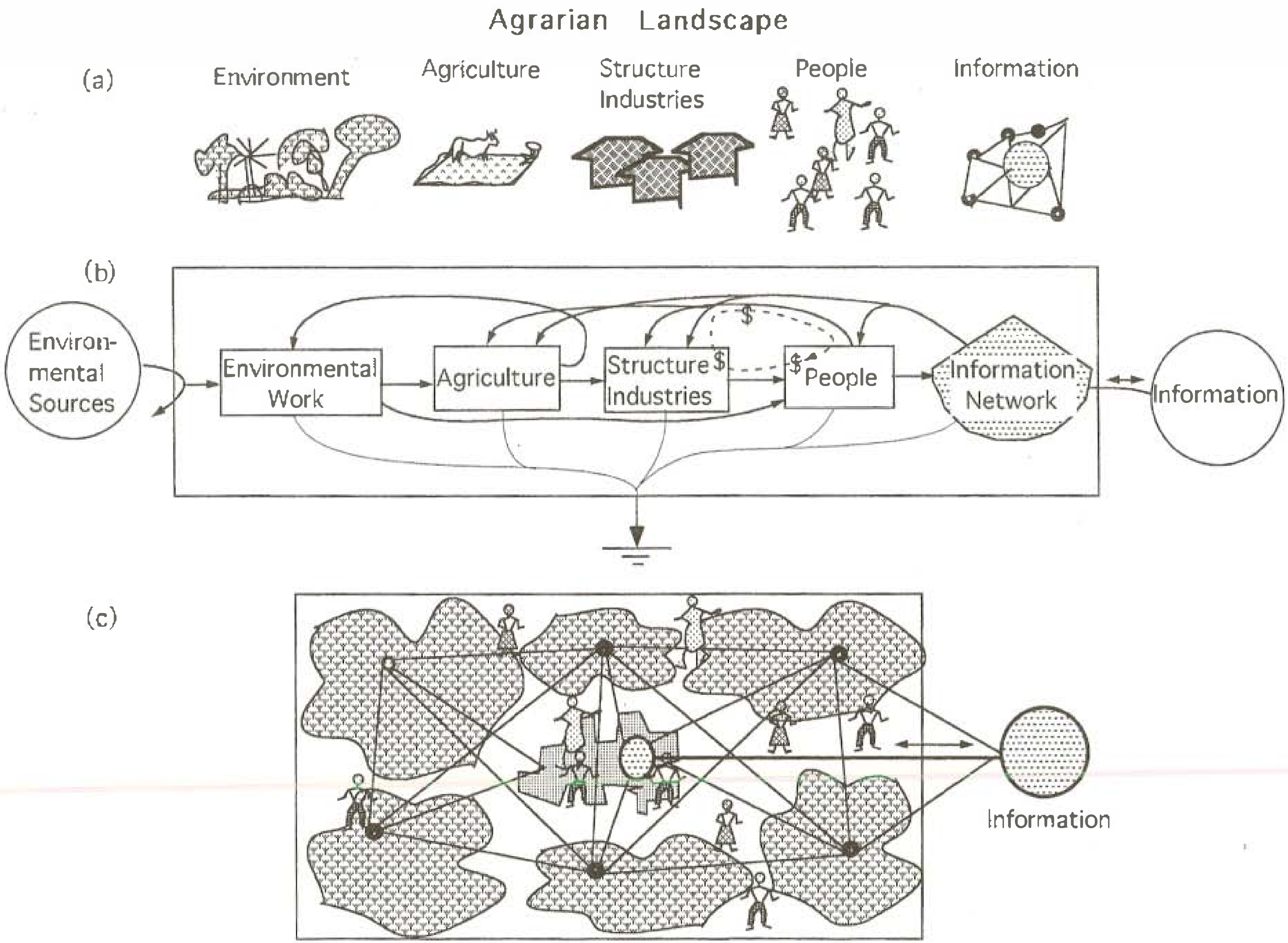


Figure 6. Model of the agrarian landscape of the past mostly running on renewable energies: (a) five zonal areas; (b) energy systems diagram of the zones from rural environment to center; (c) complex view when examined from aerial view.

A Model of Environmental Zones Around Cities

Even in the landscape of the agrarian economy two centuries ago, there were zones of increasing concentration and transformity that a traveler would pass in going from wilderness (where it existed without people) inward to small cities. One way to study complex landscape systems is with detailed maps (geographic information) on a scale that includes environmental systems and the economy.

For simplified policy thinking, the zones can be aggregated into a chain of blocks. For example, Figure 5 has 5 zonal blocks: wilderness, agriculture, town housing, industry-transport, and the center of information and finance (including business, banks, libraries, government). Increasing toward the center are the concentrations of EMERGY use, circulation of money, and transformity. In order to assemble data from a complex real map for the simplified chain model, irregular lines can be drawn on a map to separate activities according to the 5 categories of the aggregated model.

For an agrarian landscape, most of the high concentrations, EMERGY, and transformity originated from the broadly distributed, renewable environmental resources being converged into the city. The sketches in Figure 6 represent the agrarian economy of the past that may come again as part of the long range cycle (Chapter 2). Although information has usually had processing centers, its territory is the whole landscape from which information is drawn and fed back. With larger territory and EMERGY content, the turnover time and time between pulses is longer than the zones further out (at lower level in energy hierarchy). In many agrarian areas, such as Sweden in 1650[4], rural exchange was mostly by barter, whereas sliver coin was used within the cities. Human settlements that self organized over centuries functioned well with natural patterns of energy hierarchy. Good policy in restoring ailing cities may come from re-establishing the spatial hierarchical patterns that maximize empower.

Transformity Matching

As explained in Chapter 1, maximum empower requires a network of reinforcing feedbacks. In other words, each flow must interact in a multiplicative way with another resource of different transformity either an order of magnitude higher or lower. In this way each pathway amplifies or is amplified. Figures 1 and 2 show the way feedback intersections look when diagrammed. Reinforcing interactions link the zones of the city (Figure 5). For example, humans feed back their services to control and facilitate agriculture; information from the city center is fed back from the central city to control and facilitate industry. We suspect that the interaction between levels in the energy hierarchy is most effective with the adjacent level. Information in organizations tends to cascade down one level at a time, and is not so effective in skipping down several orders of magnitude.

Geographic Reorganization with Fossil Fuels

Starting in the 19th Century, the pattern of spatial organization was profoundly changed by the technology and availability of rich fossil fuels and minerals for development. Since these resources form slowly, they were essentially non-renewable for the window of attention of economic development. Accelerated by a competitive race to develop these fuels, the geographic pattern of economic activity was no longer restricted to those areas where the earth energies could converge a series of transformations. Instead of high transformities of human society coming up from the renewable earth energies, development could take place anywhere with access to the fuels and minerals, providing matching interactions could be arranged with lower transformity resources. Figure 7 sketches the patterns of life in the fuel driven hierarchy for comparison with the sketch of the environmental driven agrarian landscape in Figure 6.

With sea transportation and pipelines, fuels were carried directly to develop the cities. Because of the high net EMERGY yields, growth and development was far beyond what was possible from the original regional resources. High levels of people and information developed in the city, putting a strain on the environmental resources of air, land, and water with which fuel use required interactions. Streams of air and water were required for raw materials and waste dispersal. Green spaces were required in matching interaction with human life. Capitalistic investments helped draw in environmental resources in relative short supply. Political power which originally had a rural base was replaced with urban predominance based on the intense fuel and information EMERGY in use there.

Fuels enter the city along with other imported products made abundant because of the availability of cheap fuels (Figure 7). Fuels and derived products then exchange outward for use over the surrounding landscape. A factor in the feasibility and location of development is the necessary matching of the free resources of environment with the

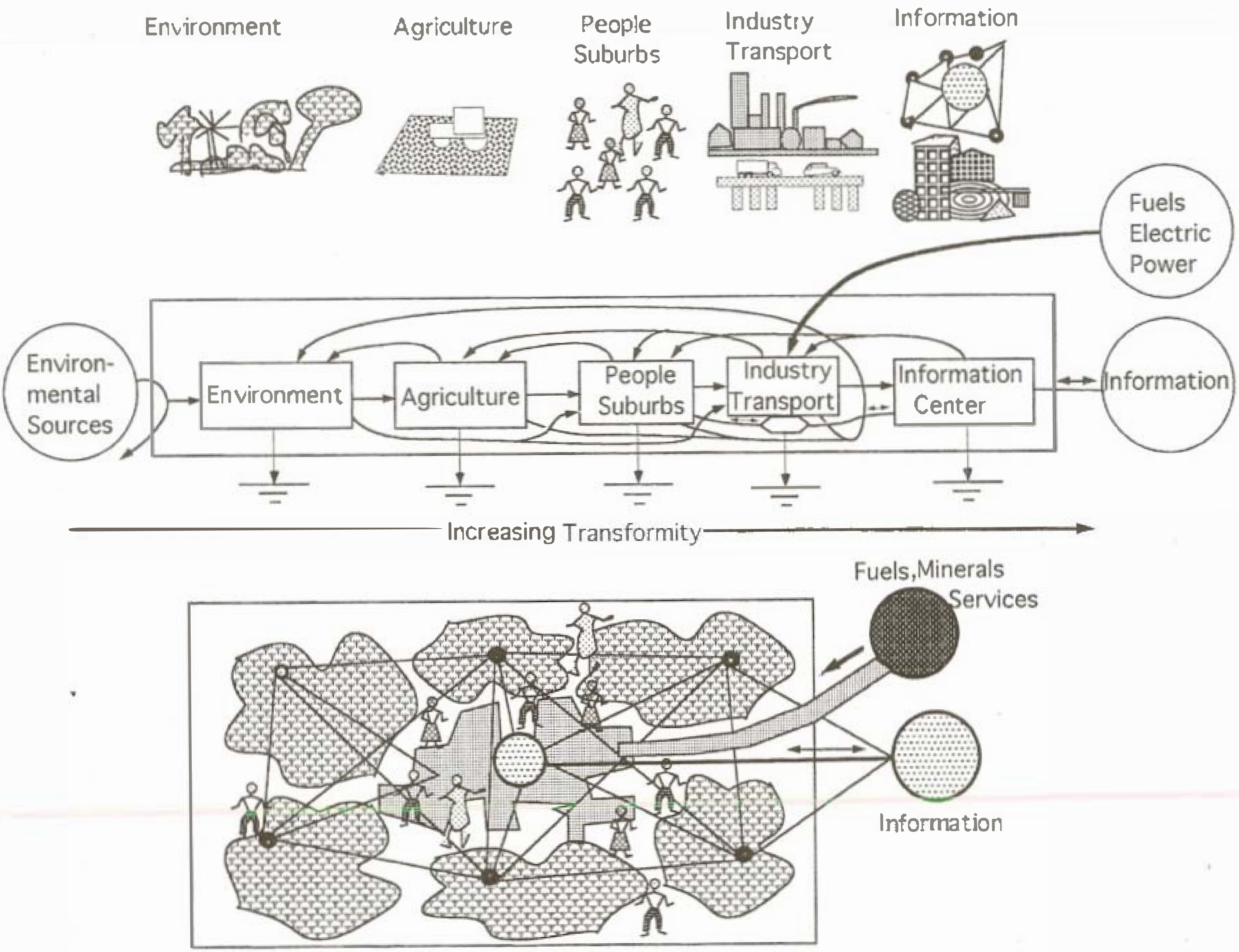


Figure 7. Model of the fuel-based landscape of urban America: (a) five zones with suburban populations outside of the fuel-using transport-industrial areas; (b) energy systems diagram of the zones from rural environment to center; (c) complex view when examined from aerial view

purchased fuels and other resources from outside the local area. The Investment Ratio is useful for evaluating the ratio of these two inputs. If too much has to be purchased compared to what is locally free, then the activity is not economical. An economic activity in an area cannot compete well if its investment ratio is higher than in the surrounding area. The investment ratio is high in the center of cities and low in the rural lower energy areas outside. Maps of investment ratio can be useful to find appropriate areas for economic activities of different intensity. For example, you could expect to make money by putting a copying business with a high investment ratio in the city center but not in a rural area with low ratio.

Electric Power, Information, and Night Lights

Although such books as Toefflers' Third wave dramatize the accelerating global development of information systems (Bucky Fuller's doing more with less through information), there is little mention of its energy basis or of resource limits. Electric power is required to support city people, operate information in computers, educated professionals, business transactors, government leaders, university researchers, medical support, television celebrities, etc.). Electricity has moderately high transformity, intermediate between that of the fossil fuels and the information. It has great flexibility In its uses and has become the main intermediate method of supporting higher levels of human society, especially those concerned with information. With fuels cheap and transportable, electric power plants to support cities and information have been installed everywhere.

All over the earth in the 20th Century, self organization of economic society with available resources has generated a spatial organization of cities running at their center with electric power and information. In Figure 7 note the typical zonation of the energy hierarchy around the modern, high information city. People and information are shown at the top (to the right).

Information that is shared by many people has a large territory and the highest of all transformities on earth. Its means of duplication and processing through the centers of television and computer networks is based on electric power. Spatially, people and the information they process are concentrated in the urban centers. Increasingly, in those countries which are at the hierarchical center of the world system, people and technology are reorganizing around centers of information processing and storage. Part of the learned information of human society is becoming globally shared.

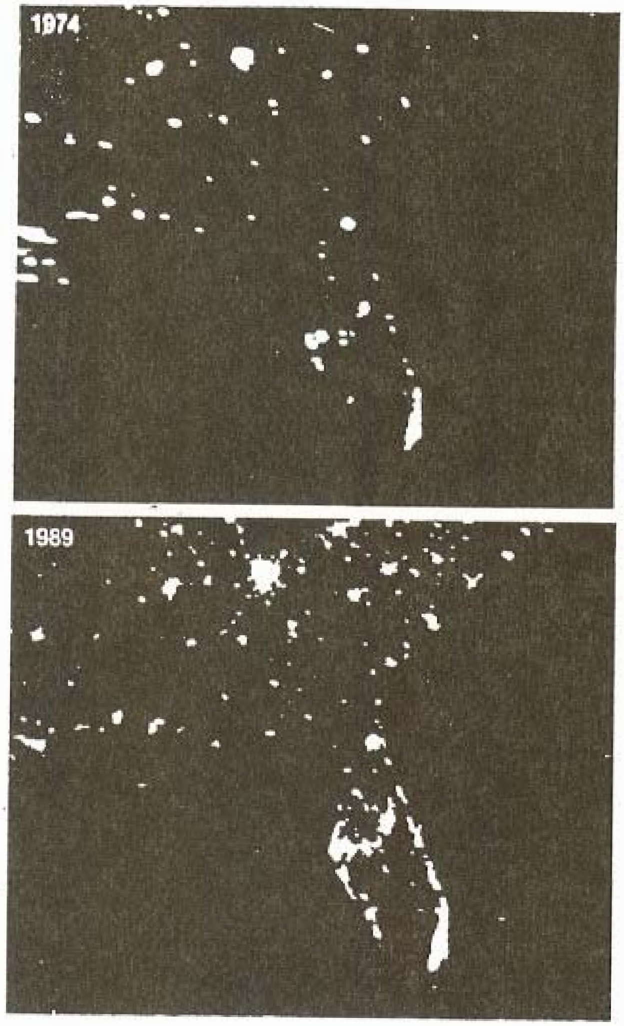
A very dramatic view of the spatial hierarchy of our high energy world systems comes from satellite photos of the earth at night (Figure 8). Each town, city, and metropolitan center is vividly shown by the night lights. The pattern of smaller centers of light of towns around larger areas of large cities shows the spatial patterns of energy hierarchy. Maps of the distribution of population are very similar to the night light photographs. Night lights are one of the ways the urban civilization maximizes its functions by extending the hours when operations can continue. The photograph shows the way the main urban functions of our civilization are derived from electric power.

But electric power, with its transformity about four times that of the fossil fuels, requires huge fuel flows, and diversion of much of the energy of the mountain rivers that used to support other productivity. With less fuels available in the future, availability of electric power may control where the centers of information will continue. In fuel-scarcer times ahead, there may be advantages in locating information centers near hydroelectric power. There may be advantages to those with proximity to mountains with high rain and snowfall.

High EMERGY of Genetic Information

Humanity and the green cover of the earth are also based on the global network of genetic information in the species of plants, animals, and microorganisms. Maintaining biodiversity and global genes has been difficult as the areas are displaced for urban development and the insatiable market demands for environmental products. Opportunity exists to retain the corridors of nature and wildlife by combining them with the corridors of the economic system, such as the riparian borders of waterways, the margins of highways, the lands under power lines, and the other utility strips.

As some of the fuel based information of human society has to be moth-balled, the genetic information diversity in the environment and agriculture neglected in our recent age of growth again becomes more important for maximum empower in the down cycle ahead. For example, agricultural varieties that require less fuels and chemicals will be needed, although they are lower yielding. Conversely, the high yielding agricultural varieties that require high energy inputs need to be kept in



(a)

(b)

Figure 8. Night lights of Florida from U.S. Air Force satellite (Fernald and Purdum, 1992). (a) 1974; (b) 1989.

genetic banks until they are useful, when there are high energy pulses in the future.

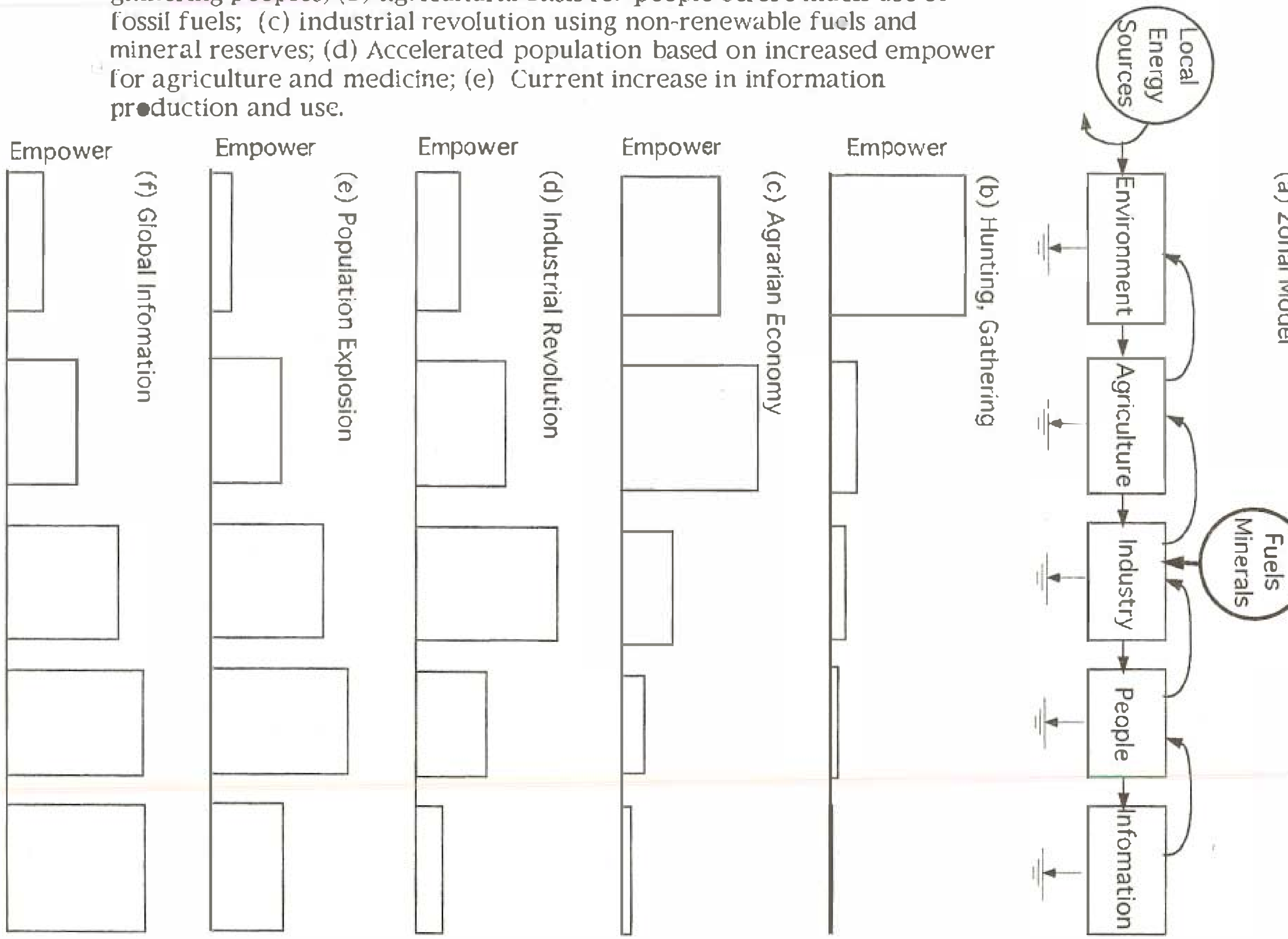
Gaps, Concentrations, and EMERGY Waves

Wherever an area is in a low part of a growth cycle, it appears as a gap in the better developed areas around it. For example, wherever trees are recently down in a forest, there is a gap in the forest cover. Because there are many small, fast growth oscillations and fewer large, slow oscillations, there is a similar distribution in the locations of the gaps. Many studies in geography, landscape ecology, oceanography and other fields have observed the geographical property of many small gaps and few large ones. If one walks along a line passing from gaps to areas in other stages, the ups and downs can be thought of as oscillation over space, the spatial equivalent of pulsing.

The hierarchical centers of consumption in cities have had sharp pulses of growth and decline over history. If a person could have watched from a satellite over centuries, the pulses of light rising and falling, first in one place and then in another, would be like a Christmas tree with flashing lights as civilizations rose and declined. Looking out to space over eons, there are the even longer periods of pulsing of even greater centers of consumption, the stars.

Many urban centers are still growing in their levels of consumption, information, and lights, even though the availability of resources to bring to these centers is already beginning to decrease. The development progression in this century has been an EMERGY wave moving up the energy hierarchy (Figure 9). First was agrarian agriculture, then use of fuels and minerals for the industrial revolution, next a population explosion, concentration of EMERGY in the cities, and finally a world wide sharing of information. Soon the climax recedes, either crashing or descending prosperously, depending on how well we educate the world to share common purpose and information on how to take the staircase down.

Figure 9. Zonal distribution of empower for five stages in the history human development: (a) Environmental systems containing hunting and gathering peoples; (b) agricultural basis for people before much use of fossil fuels; (c) industrial revolution using non-renewable fuels and mineral reserves; (d) Accelerated population based on increased empower for agriculture and medicine; (e) Current increase in information production and use.



Endnotes for Chapter 4, Spatial Organization:

1 Stanhill (1977) quantitatively evaluates the system of highly productive agriculture supporting Paris, France in the last century, with horses, transportation, and recycle of horse manure to the land.

2 The measure of concentration of EMERGY use is "areal empower density", which can be represented in units of solar emjoules per acre per year.

3 Spatial hierarchy was recognized by Christaller (1933) with hexagonal polygons of support and influence around villages and towns in agrarian landscapes of Europe before the industrial revolution. We observed them from an airplane near New Deihl, India in 1970.

4 An EMERGY evaluation was made of the Swedish empire of the 17th Century with its economic and military power based on the EMERGY of its forest and mineral resources (Sundberg et al., 1994).

References Cited

Christaller, W. 1933. Central Places in Southern Germany. 1966 Translation by C.W. Baskin, Prentice-Hall, Englewood Cliffs, N.J.

Fernald, E.A. and E.D. Purdum (eds.). 1992. Atlas of Florida. University Press of Florida.

Odum, H.T. and E.C. Odum. 1995. A Prosperous Way Down. Book Manuscript.

Stanhill, G. 1977. An Urban Agro-ecosystem: the example of 19th century Parks. Agroecosystems 3:269-284.

Sundberg, U., J. Lindegren, H.T. Odum, and S. Doherty. 1994. Forest EMERGY basis for Swedish Power in the 17th Century. Scandinavian Journal of Forest Research, Supplement No. 1, Scandinavian University Press, pp.1-50.

Toeffler, A. and Toeffler. 1995. Creating a New Civilization. Turner Publications, Atlanta, Ga. 108 pp.