community, with reciprocation and small-scale redistribution, during the First Intermediate Two A subphase, and a peasant community, linked by close economic ties to an urban center, in which the relationship was clearly inequitable. The economy of Middle Horizon Teotihuacan was probably a mix of reciprocal, redistributive, and market exchanges comparable to the pattern in contemporary Oaxaca.

The contrast between the two systems is most apparent by a comparison of the two houses of the lineage heads, that for Torremote and that for Maquixco. The data reflect clearly the difference between an official who is essentially a senior kinsmen and a source of redistribution, in the case of the earlier village; and an official who not only does not produce surpluses of technological goods for redistribution to kinsmen, but virtually manufactures no goods at all. His position is more explicitly political.

In summary, for the First Intermediate Phase Two we seem to be dealing with an essentially self-sufficient local community in which ranked individuals functioned to redistribute, over short distances, small quantities of certain finished products. At least some of these materials (e.g., obsidian) were locally unavailable, and some of the finished items were manufactured by a few specialized, or semispecialized, producers who resided within the higher-status households. We feel fairly comfortable in generalizing from the economic pattern we infer for Loma Torremote to the rest of the Basin of Mexico for the First Intermediate Phase Two; that is, all the settlement clusters we have identified as First Intermediate Two polities were probably behaving in much the same manner. At Middle Horizon Maquixco, on the other hand, we have a specialized agricultural community which was totally dependent on a neighboring city for most of its necessities, aside from basic food staples. At Loma Torremote the lineage head was a senior kinsman who functioned as the principal focus of community redistribution, and who underwrote some specialized production. At Maquixco, the lineage head was a much more explicitly political figure who had nothing to do with the production of nonagricultural redistributed goods, and whose principal function was probably to relate the entire local community to a higher organizational level at Teotihuacan.

9

Theoretical Implications of the Basin of Mexico Survey

In Chapter 5 we presented a detailed description of the settlement history of the Basin of Mexico over a period of 3000 years. Although we did occasionally offer explanations for some of the changes we described, our intent was to make that section as descriptive as possible. Here we will explore a number of hypotheses that we believe were responsible for the characteristics of settlement systems during the various phases and for the changes in those systems that occurred during the long period of occupation by sedentary farmers.

From the inception of the project we have emphasized a materialist and ecological approach. More specifically we favored and continue to favor Steward's (1955) culture core paradigm as the most useful theoretical structure; that changes in the exploitative system require changes in social interaction; changes in social interaction produce the need for new organizational rules; and these rules require ideological validation. We have, however, modified this scheme in response to recent developments in culture ecology, particularly in demography, energetics, and quantitative geography. These new developments can easily be adapted to Steward's paradigm, particularly if one shifts from a linear concept of change to a more systemic one, a shift that is becoming increasingly popular among anthropologists.

We enthusiastically endorse this change but have not been impressed with recent attempts to apply it to anthropological problems. The difficulty is that most systemic models that have been proposed do not include in the design any way of assigning different weighting values to the various factors. As Robert Carneiro (1972) has pointed out in a recent seminar, it would be a mistake to assume a democracy of variables. Also needed, to make systemic models useful, are quantitative measures of the individual variables in the particular cases being analyzed, a particularly difficult problem if the system is to include factors such as social and political organization. Our suspicion is that if we do assign quantitative values to the variables, and different weighting values for each factor, that the systemic model will assume a unilineal, or at least a multilineal, character (see Sanders and Webster 1978 for a detailed discussion of this problem).

In summary we feel that a systemic frame of reference has great utility, but would add the warning that useful theory must be simple theory; the fewer the variables and the easier it is to assign quantitative values to them, then the more effective the capacity of the theoretical structure for prediction. An ideal objective would be to isolate four or five variables that explain 80% or more of the variety recorded in the archaeological record. We see no way of accomplishing this task at present, and although our own theoretical structure has some systemic elements to it, in essence, it can be described as a multilineal paradigm. Essentially our procedure is first to suggest several lawlike generalizations that we suspect have considerable validity and explanatory power for the cultural evolution of the Basin of Mexico, then to discuss some of the feedback effects of the social system on the operation of these basic propositions. At our present stage of theory we know of only three lawlike generalizations that govern cultural change: the *law of biotic potential;* the *law of least effort;* and the *law of minimization of risk.*

The law of biotic potential simply states that all species of life have the potential to constantly increase in numbers. This potential is enormous; when sufficient time is allowed (and this involves only hundreds, or at most thousands, of years) even the slowest growing and reproducing animal has the capacity to cover the surface of the earth with its progeny. The law of least effort simply states that when choices between two or more alternate responses to a stress are possible, the choice will be that which produces the greatest gain with the least effort. The law of minimal risk means that when faced by choices the decision will be to adopt that solution which produces the minimal risk.

Virtually all previous evolutionists have explicitly or implicitly utilized the operation of these lawlike generalizations in their theoretical arguments. Carneiro (1970) reviewed the various theories and found that they begin with one of two very different assumptions. One position assumes that the evolution of complex societies, or as it is frequently referred to, the evolution of civilization, is a process of overall progress or improvement of human wellbeing, and the emergence of civilization can therefore be understood as a "volunteeristic" process. Because of the nature of political centralization and economic specialization, both inevitable to the civilizational process, some individuals derive more benefit from the system than others. Since everyone

improves his general well-being, however, even those who occupy the base of the system of social stratification will accept a certain amount of negative reciprocity.

The second position sees the process as both a loss of political autonomy, and an increase in economic cost, to the majority of the population, and the process hence is conceived of as a coercive one; people accept the situation because they have no other choice. There seems to be a general trend toward the latter position in the recent literature and we will generally favor this position. Both positions of course can be adapted to the three basic lawlike generalizations we presented previously.

Carneiro's own theory of the evolution of complex societies assumes that they emerge only through a coercive process. The major stimulus is population growth; in other words, the operation of the law of biotic potential. The process he sees, however, is a direct political one, not necessarily mediated through economic processes, and thus it is not a materialist paradigm. His argument assumes that warfare is universal. In areas of large geographic space (areas he refers to as open environments) and low population density, losers in warfare can escape the penalties of exploitation by fleeing to other areas and hence little political evolution occurs as a consequence of war. In cases where the environment is small (referred to by him as a circumscribed environment), and population density relatively high, then the losers cannot escape the penalty of defeat and must accept an exploitative relationship with the conquerers. Accepting his arguments, the population density of an area need not be unusually high, but the density should be high enough to restrict movement, in the form of out-migration. One factor that would limit migration would be major geographic barriers like high, unproductive mountains, or deserts, or areas of such striking differences from the groups' own habitat that ecological adaptation would be inhibited. Even in such areas where such barriers do not exist, if the area is surrounded by areas of comparable, or at least substantial population buildup, then the group would be socially circumscribed. This means that complex societies could emerge under relatively low conditions of population density. It also means that they should emerge first in smaller, socially or environmentally circumscribed areas, and these areas should show a much faster rate of political evolution than the large ones, providing of course that the small area is sufficiently large to permit a population beyond a few thousand people. This final consideration must be added because there is a very close relationship between complexity of social organization and the size of the society, as Carneiro himself has shown. Apparently the law of least effort operates in terms of social systems as well as economic behavior, that is, people will not organize themselves any more expensively than is necessary. Band societies, for example, tend to have populations maximally in the hundreds, tribal societies maximally in the thousands, and chiefdom societies maximally in the tens of thousands, whereas primitive states have populations in the millions.

Netting (1972) has offered another, essentially nonmaterialist explanation to the evolution of complex society, but again with population growth as the major stimulus. In this case he argues that overt coercion, particularly warfare, is not necessarily the mechanism by which a local group or individuals will surrender their autonomy. His argument is that populations increase at an arithmetical rate, but the frequency of conflicts increases at a geometric rate. Finally a point is reached when it becomes less costly to accept the results of arbitration even if occasionally unfavorable to the litigant, than to continue the feud. Although some of these feuds may be over property, they can be over a great range of situations. The theory is therefore not essentially materialistic since some of these conflicts may not involve property at all. In the African case the individual selected as arbitrator is usually a person who already has a position of prestige in the society, usually a religious leader with very limited economic or political power. Through his role as arbiter, and because he receives gifts from the litigants, he gradually builds up a fund of political and economic power. Much of this power may be transferable to his descendants and ultimately a chiefdom emerges from an essentially egalitarian society.

A more materialist explanation of the evolution of complex society, but still within Carneiro's coercive tradition, is that offered by Esther Boserup (1965). In her book, *The Conditions of Agricultural Growth*, her major objective was to explain variations in agricultural systems. Previous researchers, including anthropologists, have recorded a great variety of agricultural systems in terms of crops, tools, techniques, and, most importantly, degree of intensification of land use. One explanation of these variations was cultural evolution, with the basic assumption that agricultural change was a progressive process starting with simple tools, few techniques, and extensive practices of land use, and ending with more complex tools, elaborate techniques, and intensive patterns of land use. When groups still retained a "primitive" agricultural system it was ascribed to cultural backwardness. These conclusions were particularly held by evolutionists, who started with the assumption that cultural evolution generally was a progressive process and that the changes in agriculture stimulate population growth. Another explanation was environmental, that is, each kind of agriculture was an adaptation, a concession, to variations in soil fertility and was hence in static relationship to the land resource.

Boserup reversed the argument, based on a careful comparison of labor input and crop yield, for the various systems of agriculture. She demonstrated that extensive systems of agriculture have a higher input/output ratio, that is, the farmer gets more calories of crops, in terms of calories of work expended, than from intensive agriculture, and what we call agricultural evolution is a process of gradual decline in per capita income, produced by uncontrolled population growth. Following this argument, when new areas are colonized the extensive agricultural systems will be utilized first; as population increases people will first respond by fissioning into nearby

unsettled areas. Ultimately, as the region is completely colonized and fissioning inhibited, further population growth will require a shortening of the fallow system, and finally the entire area will be occupied by farmers practicing intensive agriculture. Her theory provides us with a more dynamic view of agricultural systems, and variations in degree of intensification at any point in time are due primarily to stages in the colonization process.

In her book, however, she goes beyond explaining agricultural variety. She sees agricultural intensification as causing changes in land tenure from virtually no clearly defined land rights, even on the village level, until ultimately the level of individual holdings is reached. Another effect of the process is increasing economic specialization and social stratification. Social stratification is primarily the product of the land tenure system, and land holding rights become increasingly inequitable as intensification occurs. In her model she assumes population growth as a universal and independent variable. Her theory is essentially in the tradition of cultural materialism, since social, economic, and political changes are mediated through the system of agriculture.

In all three of these arguments there is the suggestion that population growth is an independent variable; that in general, human populations increase, and that population-regulating mechanisms among human beings are generally ineffective. All these assumptions have been questioned, and the whole issue has excited considerable controversy in recent years (see Blanton 1975; Cowgill 1975a; Dumond 1965, 1972; Lee 1972; Logan and Sanders 1976; Rappaport 1971). Briefly, the counter argument is that the very rapid growth that obviously has affected human populations since the Industrial Revolution has misled us into the philosophical assumption that this is the human norm; while in fact, through most of the human history, population growth has been anomalous or at least unusual. Human beings, it is reasoned, like all animal and plant populations, are parts of an ecosystem characterized by a network of homeostatic controls, which regulate population. Factors that regulate population growth include cultural practices as well as natural factors. Taking this position, population growth, particularly rapid rates of growth, are rare phenomena.

One of the arguments against population growth as a causative factor in cultural evolution is the very low rates of growth prior to the Industrial Revolution, a strange argument since cultural evolution has also been an extremely slow process! In fact one can show that although cultural evolution, in an overall sense, has been slow, the rate of growth has been an accelerative one and, as Dumond's (1965) calculations show, population growth has also occurred at an accelerated rate (he calculates a rate of 0.0007–0.0015% per year for the Paleolithic, 0.1% during the period for 8000 B.C.–A.D. 1750, and 0.15–0.40% for the period between A.D. 0–A.D. 1750). Taking the argument one step further it can also be demonstrated that in the case of very small local regions, both population growth and cultural evolution can be enormously accelerated compared to these average rates.

We also question the assumption that nonhuman ecosystems are balanced, static systems. If they were, biological evolution would never have happened. Most researchers, whether anthropologists or biologists, when they study contemporary systems, have been struck by their functional harmony—an observation that leads to the erroneous conclusion that they are static systems. The major problem is our inability to measure small changes that accumulate in systems when our period of observation has such a shallow time depth as a few months, a few years, or at most a generation or two. It is curious that most archaeologists see the cultures they study as dynamic.

We strongly favor the position that population growth is a general phenomenon and that human reproductive behavior generally is unlike that of most other species only in its tendency towards sustained growth. The validity of these positions cannot be argued philosophically, they must be supported by empirical data, and the data are overwhelmingly in favor of population growth as a universal phenomenon. Very simply, if this was not the case we would still be Australopithecines living in South Africa. It is undoubtedly true that the growth rates prior to the Industrial Revolution were much slower (primarily due to a much higher infant mortality), but the fact is that there has been a steady increase in the human populations since Paleolithic times.

The major reasons why human population growth has on the whole been a more sustained, and even accelerative one, when compared to other animal populations, is because of the tremendous significance of learned behavior or culture, which is capable of constant elaboration and development. This means that responses to population pressure are much more apt to trigger responses in the form of changes in the cultural system than population regulation, and these changes either permit larger numbers of people to live in the same area or allow people to expand into new geographic space with strikingly different environmental characteristics.

With respect to smaller geographic areas and relatively short periods of time, the data show much greater variation in the pace of population growth, and these variations require explanation. Our own data from the Basin of Mexico reflect this variability. With very favorable epidemiological, nutritional, and political conditions, pre-industrial farming populations apparently have the capacity to double every 100–200 years, and this has probably been close to the maximum growth rate until the great reduction in infant mortality in the modern era. This rate has been recorded by archaeological studies in a number of areas, and is particularly characteristic of pioneering populations, occupying new environmental regions, where the colonizing population is small and land is in abundance. Apparently, under these conditions, cultural controls are either absent or completely ineffective, and natural checks are of minor significance, so that the maximal growth rate is achieved. Such populations, even on the local level, ultimately tend to level off, whatever the factors are that reduce the growth rate. The reason why

larger geographic regions show slower rates of growth is undoubtedly because the smaller areas within them, which were first colonized, ultimately undergo very reduced growth rates or their populations become completely stabilized. The question is: How does this process of reduction of growth occur and what are the growth-curbing mechanisms?

It is our opinion that the reduction process is a gradual one, that is, if the doubling rate, at the initial phase of colonization, is every 200 or 100 years, it will gradually shift to every 300 or 400 years, and ultimately will reach a point of stability. This process occurs also in many nonhuman ecosystems and has been referred to as environmental resistance. It also is in accordance with our model of how agricultural intensification proceeds. Within a settlement experiencing population growth, the consequent inequities of land distribution will create situations where individual families will be forced to reduce their fertility or increase their mortality, in order to solve their economic problems. The mechanisms by which this is accomplished are undoubtedly numerous and complex. The most effective ways of curbing population growth are infanticide and retarded age of marriage, and both can be considered as economic decisions. Other factors, not directly controlled by economic choice, would be malnutrition and disease, two conditions that are mutually interactive. Within a local region, variations in land pressure from community to community will also produce the same kind of variety in reproductive behavior.

What the data seem to show is that the mechanisms of population control operate so slowly and gradually that frequently the process is not even a conscious one and certainly cannot function to prevent changes in the cultural system. In taking this position then, Boserup's argument, that population growth can be operationally seen as an independent variable, is essentially correct. We have seen virtually no examples in the literature where population growth has been controlled in cases of an agricultural population at a very low percentage of carrying capacity. The most effective means of curbing population growth, and we would argue the only one that can be totally effective over a long period of time, is infanticide, and this seems to be resorted to on a sufficient scale to produce equilibrium of population only very rarely, and under very extreme conditions.

Basically, all of the theories discussed up to this point involve the operation of the noted two laws, the law of biotic potential and the law of least effort. In Carneiro's (1970) discussion of the various theories of the evolution of complex societies he classifies Wittfogel (1957) and his hydraulic civilization theory as a volunteeristic theory. Following Carneiro, it is a theory derived from our third law, the law of minimal risk. We feel that Wittfogel's hydraulic civilization theory in fact is an example of the operation of all three laws. There have been a number of attempts by archaeologists in recent years to apply Wittfogel's ideas to prehistoric evolutionary sequences, generally with negative results. The reasons for this failure we believe stem from (*a*) a basic misunderstanding of the theory, and (*b*) a very naive research design to test it. It is not our intention here to review all of the literature, but a brief summary of the problem is necessary to set the stage for our argument.

What Wittfogel did was to demonstrate a correlation between the large, highly centralized political systems, which he refers to as *oriental despotisms*, with very large scale water management, the latter involving both irrigation and transportation systems. The central features of oriental despotisms are a monopoly of political and economic power by the state, with absolute control over the supporting population, a monopoly that prevents the formation of rival power-controlling institutions. Such states tend to have monarchial institutions, weakly developed mercantile classes, and feudal institutions that are subverted by partible land inheritance. The means by which the state achieves this absolute power is essentially control of water, and the management of this resource requires an elaborate bureaucracy. This type of society he felt was characteristic of Islamic Mesopotamia and China from the Han dynasty to the republic, and was the end product of a long process of internal evolution in those areas; in other words, the development was an example of primary state formation.

A final conclusion of Wittfogel's, and perhaps the one that is most responsible for negative reactions to his theory from some anthropologists, is that other states, evolving in areas of nonhydraulic agriculture, particularly those in which some of the features of the oriental despotism type of state were present, were all cases of secondary state formation; that is, the development occurred under contact or stimulus from pristine or primary states that had evolved in hydraulic regions.

Wholly aside from the validity of this last argument, there has been considerable misunderstanding of Wittfogel's primary argument about state formation and its relationship to hydraulic agriculture, and some of the criticism reflects a curious lack of time perspective on the part of the very anthropologists who are most concerned with testing the theory of cultural evolution—the archaeologists. For example, Adams (1965, 1966) rejects the Wittfogel model as not applicable to third millenium B.C. Sumeria. What is almost incomprehensible in Adams' position is that he rejects both Wittfogel's model of the oriental despotism type of state and large scale hydraulic agriculture as applied to Bronze Age Sumeria. If the sociopolitical system was not yet evolved to the degree that Wittfogel himself would classify it as an oriental despotism, and if the agricultural system was not the large scale centralized irrigation system that Wittfogel is talking about, it is difficult for us to understand what Adams is objecting to. In fact one can interpret the political evolution of Mesopotamia as a gradual process that parallels very closely the evolution of hydraulic agriculture in the same area. Sociopolitically we begin with small early Bronze Age chiefdoms, which evolve into small states during the Late Bronze Age period, and ultimately into large empires, with the institutional characteristics of Wittfogel's oriental despotism, at least by Iron Age times, certainly during Islamic times. This evolution goes hand in hand with a process of gradual artificialization of the natural environment, beginning with a system of agriculture consisting of short feeder canals from the numerous natural tributaries of the region; to small scale, artificial, network canal systems; and finally to a point where the entire river system is canalized. In fact the overall process would seem to justify Wittfogel's argument very strikingly.

The same parallel processes between political evolution and increasing control of irrigation resources can be seen in the culture history of the Peruvian coastal valleys, and yet Andean archaeologists have so far taken issue with Wittfogel's major argument (see Lanning 1967). Sites like Las Haldas, Moche, and Chan Chan are points along a continuum of political evolution of the region, and this evolution goes hand in hand with the development of hydraulic agriculture from small scale floodwater systems, to small scale local canal irrigation, to valley wide systems, and ultimately to transvalley irrigation systems. The difficulty seems to be that most archaeologists visualize hydraulic agriculture as an invention rather than a process. They apparently expect to find a chronological sequence in which large complex canal systems precede archaeological evidence of large complex political systems.

An even more naive treatment of Wittfogel's thesis is represented by ethnographic studies, which propose to test this hypothesis by the use of carefully controlled data from studies of contemporary communities. A classic example of the misuse of Wittfogel is Susan Lees' (1973) study of contemporary irrigation in the Valley of Oaxaca. The Valley of Oaxaca, covering approximately 2500 km^2, is part of a modern republic which covers approximately 2,000,000 km^2, characterized politically by an elaborate bureaucracy including several hierarchical levels and a complex pattern of departmentalization of functions. The political organization at the lowest levels is predetermined by the national constitution and all of these local groups in the State of Oaxaca conform to the organization of the republic generally.

Within the villages, beside the formal political system established by the Federal Government, there are series of other positions of a quasipolitical, primarily religious function, such as the Mayordomias, and very often, special sets of officials who are in charge of water control within the village. Irrigation in the valley is similar to that in the Basin of Mexico, that is, it is used primarily for preplanting to obtain a head start on the rainy season, and rainfall is the primary source of soil moisture. However, because the valley is situated below 2000 m, continuous cropping can occur, and hence irrigation is of particular significance during the dry season. Unlike the Basin of Mexico, however, the systems are very small in size, very frequently restricted in use to single villages, and at most involve only a few villages and a few thousand people.

Apparently, when Lees initiated her project she expected to find an elaborate bureaucracy of water management, and despotic political power within and between communities, according to the classic model of Wittfogel, and she applied this to the tiny irrigation systems and the small scale organization of the area! This initial hypothesis reached a level of absurdity when she attempted to find out whether there were examples of internal despotism within the village and whether one village would despotize over other villages using the same irrigation system. All of this was supposed to happen within the setting of a modern national state! Most of her effort was spent in an analysis of the formal political positions, those established by the Federal Government, and those that were particular, or peculiar, to the community that she studied. What she found was a great variety in arrangements in terms of the distribution of water (*although water was officially managed in every community*) and no evidence of village "despotism." Consequently she rejected Wittfogel's hypothesis.

In our opinion what Lees' study should have done was to focus on the network of informal *patron–client* relationships *within* the village and the relationships of the patron–client system to differential access to irrigated land. If she had done this she would have seen a close relationship between these two variables and would have found informal as well as formal power manipulation within the village. Sokolovsky (1974) was able to do a parallel study of the village of Amanalco in the Texcoco region of the Basin of Mexico which revealed this process in great detail.

Aside from these methodological problems in testing Wittfogel's ideas it would seem logical that hydraulic agriculture is varied enough in its characteristics to require a series of evolutionary models, each dependent on the specific characteristics of the system. Such variables would include the size of the system (particularly whether it is a single community or a multicommunity system), degree to which the population derived nearly all or most of its crops from irrigated land, ratio of water to irrigable land, whether the system occurs in an environment where the risk of unirrigated cropping is high or low, long-term problems such as salinization, and feedback relationships between irrigation and the sociopolitical system.

We also take issue with Carneiro's identification of Wittfogel's theory as a volunteeristic theory. The effects of irrigation on the cultural system are in fact multifaceted and very complex. An important element in the social relations among users of an irrigation system is in fact competition, both intracommunity and intercommunity, as Millon *et al.* (1962) have pointed out in their study of the contemporary Teotihuacan system. To recapitulate, the contemporary Teotihuacan system involves approximately 20,000 people distributed in 15 villages and 6 haciendas. The system has a single source, approximately 80–100 springs concentrated in an area of a few square kilometers. Water is collected from the springs into a single canal, which then splits into two major canals, running down opposite sides of the valley. Much of the agriculture of the valley is not based on the irrigation system, so a substantial population derives its food supply from nonirrigated land, including people within the irrigation villages. The risk of crop failure in unirrigated land is extremely high, so that a major function of the system is to reduce risk. The situation creates patron–client relationships within the village, between people who have access to adequate amounts of irrigated land, and those who do not. Particularly characteristic of the system is intensive competition among the villagers over the use of the water and this competition has at times come close to open warfare. Upstream villages obviously have advantages over the downstream villages in terms of these conflicts, and this is one of the major kinds of confrontation. The intervillage disputes are regulated by a council made up of all the member villages, but even this would not work effectively if it were not for the fact that the Federal Government has established the water regulations and has the power to enforce them when these conflicts become acute. Only because of periodic intervention of the Federal Government has the Teotihuacan system remained relatively stable over the past 30 years.

In the case of the Amanalco system approximately 30 local cooperatives (villages, ranchos, and haciendas) once received regular water allotments from the system. The history of the system over the past 30 years shows a constant process of downstream villagers losing their water rights to the upstream villages, until today, only a fraction of the former irrigation cooperatives have access to the system. This is the product of population growth in the upstream villages, and a shift from subsistence cropping to more intensive garden crops, which require greater amounts of water.

The water regulations of the Amanalco system are also guaranteed by the Federal Government and we are not sure why such regulation has been effective in the Teotihuacan system and has failed in the case of the Amanalco system. We can, however, offer a probable explanation. The Teotihuacan system is twice as large as the Amanalco system in terms of irrigable land and volume of water, and water is distributed to half as many cooperatives. What this means is that the allotment is used by a greater percentage of the population of each village in the system. This probably makes it easier for upstream communities to take advantage of their position in the case of the Amanalco system, since only a small fraction of the villagers in the downstream villages even received water from the system. Those few users probably cannot effectively mobilize the entire community for resistance to abuse by the upstream communities.

POPULATION PRESSURE AND SOCIOPOLITICAL EVOLUTION IN THE BASIN OF MEXICO

In this section we will test the usefulness of the first two lawlike generalizations, the law of biotic potential and the law of least effort, to the problem of cultural evolution of the Basin of Mexico. In a recent paper Logan and Sanders (1976:31–178) designed a population pressure model, based upon Boserup, and applied it to those areas of the Basin that had been surveyed at the time of the writing of the paper. In essence this study is a second attempt to apply the same model but with data from the entire area. The model was originally presented in outline form followed by a detailed discussion. A reproduction of the model follows.

I. Population growth depends on certain favorable combinations of three factors:
   A. Fertility
   B. Mortality
   C. Migration
II. If interaction of factors in I leads to population increase and subsistence stress, the group may respond by:
   A. Physical and social fission
   B. Increase in food production per unit of space by intensifying use of available resources or by exploiting newly incorporated or newly developed resources within the same physical space
III. II-A will be eliminated as a response and II-B will occur if:
   A. Environment is circumscribed and desirable resettlement locales are either occupied or nonexistent
   B. Environmental factors permit II-B
IV. If II-B does occur, this will then stimulate:
   A. Sedentary residence
   B. Differential access to both agricultural and nonagricultural resources, first within settlements and then between settlements
   C. Intrasocietal and intersocietal competition
V. If IV-A, IV-B, and IV-C occur, then the following processes will result:
   A. Occupational specialization in nonagricultural activities
   B. Further intensification of agriculture, including specialization in agriculture in the first stages of the process
   C. Increase in economic exchange networks and the development or elaboration of managerial institutions
   D. Rank differentiation and, ultimately, class stratification
   E. Political linearization, or the emergence of more numerous, increasingly complex political controls
VI. The rate of development of II-B, IV, and V is affected by:
   A. Population size and rate of growth
   B. Size of the circumscribed area
   C. Resource variability within the circumscribed region
   D. Technological base of production and military spheres of culture
   E. Comparable events and processes occurring in nearby geographical areas
VII. The stability of, or decline in, cultural complexity will occur when:
   A. Factors in I result in a stable or diminishing population
   B. II-A is operative
   C. III-B does not permit II-B
   D. Circumscribed areas are excessively small or isolated

In order to test the model a necessary step is the calculation of carrying capacity for the various regions of the Basin in terms of different agricultural systems.

Carrying Capacity

Considerable controversy has developed in recent years over the question of carrying capacity (see Hayden 1975), what it is, how to measure it, and the usefulness of the concept to an understanding of cultural adaption. Much of this controversy has occurred because carrying capacity has been conceived of as a static condition rather than as a dynamic process. The biological definition of carrying capacity as the maximum number of a species of living organisms that an area can sustain, without long-range deleterious effects that reduce the capacity of the area to sustain that same population, is probably of limited utility for cultural ecologists. The problem is that humans, through culture, are able to change their exploitative arrangements drastically as their population increases, and these changes allow for increasingly larger populations to reside in the same area. This is not to say that the process never produces long-range deleterious effects, but in most cases the effects can be arrested by new techniques.

If we accept Boserup's thesis, that the initial colonization of any area by farmers should involve an essentially extensive approach to land use, we can then calculate the carrying capacity of this extensive system. Theoretically a population first fills in an area, to the degree that the carrying capacity of extensive agriculture is approached, and only then should there be a shift to a more intensive agriculture system. Prior to this point, as local populations build up to certain levels, the work cost of agriculture increases, and, in response, physical fissioning occurs. When the fissioning process has resulted in colonization of a defined area, then a shift to a more intensive agricultural system would be the response to further pressure. One could then calculate the carrying capacity of the new system. Successive shifts to increasingly more intensive systems of land use can each be evaluated using the carrying capacity concept, and theoretically we should be able to discern quantitative regularities in the process, that is, changes in settlement, agricultural practices, and techniques should occur at some central value or mode of percentage of carrying capacity.

In the previously cited paper (Logan and Sanders 1976) we estimated that fissioning, during the pioneer stage of colonization, would occur at approximately 20–30% of carrying capacity, and overall changes in the subsistence system should occur, to a degree that is measurable, at 50–80%. The main reason for changes to occur at levels well below carrying capacity relate in part to the feedback effects of the sociopolitical system on the process. Within a community, inequities of land rights may result in some farmers shifting to more intensive patterns of agriculture well before others. Apparently even at relatively low levels of population there is a perception of land as a limited good and the process of competition over this resource results in differential access to it. Between communities the same process of competition may operate to create unsafe zones between politically antagonistic populations, and hence reduce the zone of cultivation artificially. Aside from these feedback effects of social structure on the process, Napoleon Chagnon's studies of the demography of the Yanomamo (Chagnon 1968, 1974) show striking variability in demographic behavior of small groups, much of which is idiosyncratic in nature. This means that some settlements in a given region would be expanding in population at a much faster rate than others, and consequently the process of agricultural intensification would be uneven, even within one of our survey regions.

In a very large area like the Basin of Mexico, where colonization proceeded from a few localities, and where large areas were agriculturally marginal or uncultivable, this process would be expectedly even more uneven, and the initial areas of colonization would experience heavy land pressure while other areas might still be in a stage of pioneer occupation. In part this is because of the essential inefficiency of the fissioning process as a means of population dispersion. As we noted before, the fissioning process involves relatively small-scale, short distance, local movements, rather than large-scale long distance treks. What this means is that even lightly settled frontiers may act as buffers and restrict colonization from well-settled areas, and well-settled areas may act as buffers against population movement from overpopulated regions, precisely what Carneiro describes as social circumscription. The steady increase of population density, and consequent agricultural intensification, in the southern third of the Basin during the First through the Second Intermediate time frame can, in part, be explained by the circumscribing effects of population buildup in the central region.

Our model of the agricultural history of the Basin proposed here is derived essentially from Boserup and assumes a process of increasingly more intensive land use as the population increases. In order to demonstrate this process we need to calculate the carrying capacity of the Basin in terms of different agricultural regimes. This is an exceedingly difficult task and what we have done instead is to establish carrying capacity estimates for a very extensive system of farming and then estimates for a fully intensive agricultural system. These two calculations can then act as control points for estimating the process of intensification. In the previously cited paper by Logan and Sanders (1976) we discussed in detail our methods of calculation. A number of charts from that study have been republished here for reference (see Tables 9.1, 9.4, and 9.5).

Basically our method is a direct application of William Allan's (1965) method of calculating carrying capacity, as presented in his classic study, *The African Husbandman*. He uses three variables, the cultivation factor, the land use factor, and the cultivable land factor. We will begin with the cultivation factor. This refers to the amount of land planted in crops in a particular year, necessary to sustain the average person. In our calculations we have changed the unit of consumption to the extended family (in the mid-sixteenth century averaging seven persons), since the extended family was the production unit (see Table 9.1). Allan's calculation was an empirical one, based on the particular economic system being studied. For example, among relatively

TABLE 9.1
Grain Yields and Cultivation Factors for an Extended Family of Seven[a]

Type of cultivation system	Post-First Intermediate Phase 3: Yield (in kilograms per hectare)	Post-First Intermediate Phase 3: Cultivation factor (in hectares)	First Intermediate Phase 3: Yield (in kilograms per hectare)	First Intermediate Phase 3: Cultivation factor (in hectares)	First Intermediate Phase 1–2: Yield (in kilograms per hectare)	First Intermediate Phase 1–2: Cultivation factor (in hectares)	Early Horizon: Yield (in kilograms per hectare)	Early Horizon: Cultivation factor (in hectares)
Alluvial plain (permanent irrigation)	1400	0.8	1050	0.86	875	1.1	700	1.3
Piedmont (permanent irrigation)	1000	1.1	750	1.2	625	1.5	500	1.8
Alluvial plain (floodwater irrigation)	1000	1.1	750	1.2	625	1.5	500	1.8
Piedmont (floodwater terracing)	800	1.4	600	1.5	500	1.9	400	2.25
Tierra de Humedad	1400	0.8	1050	0.86	875	1.1	700	1.3
Tierra de Humedad (riverine)	1200	0.95	900	1.03	750	1.3	600	1.55
Chinampa	3000	0.37	2250	0.4	1875	0.5	1500	0.6
Pseudo-chinampa	2000	0.55	1500	0.6	1250	0.75	1000	0.9
Alluvial plain (temporal)	1000	1.1	750	1.2	625	1.6	500	1.8
Piedmont (temporal)	400–800	1.4–2.8	300–600	1.5–3.0	250–500	1.9–3.8	200–400	2.5–5.0
Bush fallowing (good land)	1400	0.8	1050	0.86	875	1.1	700	1.3
Bush fallowing (poor land)	800	1.4	600	1.5	500	1.9	400	2.25

[a] From Sanders 1976b.

self-sufficient tribal farmers, where craft specialization and social stratification are weakly developed, the cultivation factor is the amount of land needed to provide food to feed the family. In societies where both social stratification and craft specialization are highly developed, the factor must include additional crop production for marketing and taxation. In this study we are concerned only with the demographic capacity of the agricultural system, not with the redistribution network, so our measure assumes relative self-sufficiency in food production by the family, and is therefore an estimate of the amount of land needed to feed one extended family. Considering the large size of the Basin of Mexico, and the primitiveness of transportation, it is very unlikely that any significant foods were exported from or imported to the area. The only complicating question is whether economic specialization does not produce greater efficiency in terms of agricultural production. We feel that the differences are relatively slight, and hence our methodology is, in fact, a good measure of the demographic capacity of the agricultural system.

In Central Mexico today a variety of agricultural systems are practiced, under a considerable variety of environmental conditions. All these variations affect crop yields, particularly maize, the staple crop. We have abstracted from our studies of contemporary agriculture a set of average productivity figures for the staple crop. These averages include extrapolations for the effects of climatic variables (based on yields over 10-year periods); extrapolations for losses of the harvested crop to other living organisms; and we have selected those values from fields where fertilization regimes are relatively light, in an attempt to approximate pre-Conquest conditions. A major variable, over which we have little control, are changes in the maize plant itself that might have affected its yield. We know, primarily from the Tehuacan project, that maize went through a series of major botanical changes from the inception of domestication from its wild ancestor *teocentli*, to the time of the Conquest.

On the basis of the data on the history of maize in the Basin presented in Chapter 7, yields comparable to modern varieties of maize were possible as early as the First Intermediate Five phase. The remaining problem is to estimate yields for the earlier phases. Kirkby (1973) has made calculations, based on a comparison of ear size, for the less productive, earlier varieties, but we feel that her calculated yields are far too low. Using these calculations she obtains a yield of only 200 kilos per hectare, on lands which today yield 1000, in the Valley of Oaxaca. In the paper by Sanders (1976b) we criticized this figure in terms of the labor cost of cultivation. Even assuming that only two-thirds of the food supply was derived from maize, a family of seven would need to cultivate nearly 5 ha of land a year to feed itself. Based on our field studies of labor input, with wooden or stone tools, this would require an annual labor input, depending on the soil texture, of 375–785 man-days. The return is only 1.5–2.0 kilos of maize for each day of labor, an unacceptable return for a stable agricultural economy. In fact they would have had at least as favorable, and possibly a more favorable, ratio of return by gathering wild plants. For example, for every seven Kalahari bushmen only 520 man days are required for the seven people to feed themselves (Lee 1969). Under these conditions it would be very difficult to explain why a group would become agricultural. Among most contemporary farmers using hand tools (see Sanders 1976b), a yield of 400–500 kilos of grain per hectare is a minimal yield for them to consider it to be worth the effort. With plows, of course, lower yields could be accepted, because the labor input per hectare is less and hence more land could be opened up to cultivation.

Another reason that we doubt Kirkby's conclusion is that the wild ancestor of maize, *teocentli*, yields at least as high as her calculated Early Formative maize, and on some lands, even higher, and almost certainly the process of selection that produced the increased ear size would have at least some effect upon productivity. Kirkby does demonstrate that there is a relationship between ear size and yield per hectare in contemporary fields in Oaxaca, but this is expectable since the same variety of maize is planted on most of these fields and the variation in yield is due to variations in climatological factors which correspondingly affect ear size. It is quite another matter, however, to assume that the primitive varieties of maize were planted using exactly the same regime as those today. If the yield per ear was consistently only one-quarter or one-half as much as it is today, what this undoubtedly means is that the individual plant required lesser amounts of nutritional elements and water for its growth. One would assume therefore that the plants were placed closer together to maximize yields. Another possibility, as suggested by Mangelsdorf (1964), is that the more primitive varieties had greater numbers of ears per plant. If this were the case, then the planting regime might have been comparable to that of more productive varieties, but the total yield per plant somewhat less. With these considerations in mind we will assume an average productivity of Early Horizon maize as approximately one-half the values of modern maize and extrapolate values for the intervening phases.

Finally we need to know the entire range of food resources and their quantitative contribution to the diet in order to make a reasonable estimate of carrying capacity. In some ecosystems a short supply of a relatively minor (in terms of caloric intake) but critical food (particularly proteins) may restrict the carrying capacity to levels considerably below those possible in terms of the main calorie producing foods. The Mesoamerican crop complex includes, however, virtually all of the nutritive elements needed, with an added small ingestion of animal proteins. This means that the productivity of the staple crop can be used as reference data for calculation of carrying capacity. Considering the fact that our maximal figures for the Pre-Late Horizon population are only one-fourth the size of the Late Horizon it would seem probable that the animal and plant protein from the lake and land fauna from uncultivated areas were more than sufficient to meet the major protein requirements. Furthermore, intercropping was a common procedure, so that most of the cultivated plant foods were derived from the same field where the basic caloric staple, maize, was produced. What this means is that data on maize yields can be used to estimate carrying capacity, providing we make a calculation as to the percentage of the diet that was derived from maize products. In poor peasant families today in Mexico this figure may reach as high as 80% of the caloric intake, and we will use this figure for the very dense population of the Late Horizon. For the earlier phases we will assume that only two-thirds of the food intake was derived from maize products, or a grain equivalent like *amaranth*.

The second component in Allan's calculation is the land use factor, that is, the number of units of the size of the cultivation factor needed to support the family or individual indefinitely. The calculation therefore includes the land under cultivation in any one year, plus a number of plots of land of the same size, in the various stages of rest or fallow. A world-wide sample includes examples of a land use factor as high as 20 or 30 (meaning 20 or 30 units are needed for each one in production) down to 1 or even 0.5 in the cases of double cropping regimes. Our specific land use model supposes that the process of intensification is a gradual one. On the basis of Lewis' (1951) studies of swidden or extensive agriculture at Tepoztlan we will use a factor of 5 as representing the system during the early phase of colonization. For fully intensive agriculture, which we postulate, on the basis of abundant data, as present during the Late Horizon, we will use land use factors of 1 or 2. These two calculations will then provide us with points of reference.

The third component is more difficult to evaluate, the cultivable land factor. This is the percentage of the landscape that can be classified as agricultural land. This factor varies according to natural conditions, but also according to the cultural characteristics of the population. Allan's method was first to divide the overall region into a series of major ecological zones. Some entire ecological zones, at least in terms of a given level of technology or crop complex, may, as a whole, be uncultivable (examples in the Basin of Mexico would be the sierra zone and the saline lake zone). These areas would then be subtracted from the total land surface. Even within a zone that was cultivated, however, one never finds 100% cultivability. This is due to topographic, cultural, hydrographic, and climatic variability. In the case of the upper piedmont, for example, much of the region is in the form of very steep hillsides, in some cases without any, or a very thin soil cover; also present are areas of exposed volcanic detritus and deep, wide barrancas.

In Sanders' (1976b) study of carrying capacity, he assumed that, when pre-Late Horizon populations avoided completely entire ecological zones for settlement, even though they were occupied in Late Horizon times, the inhibitory forces to their colonization were sufficient to classify these zones as nonagricultural land. We justify this argument on the basis that not only were the zones avoided for settlement for long periods of time, but they were so even when adjacent zones were obviously experiencing substantial land pressure.

Our settlement surveys indicate that most of the area that was culturally defined as agricultural land during the First Intermediate period was settled by Phase One. In the subsequent First Intermediate Two and Three phases the only significant geographic expansion of population was into the alluvial plain of the lower Teotihuacan Valley. Virtually all of the rest of the population growth involved essentially a filling-in process. This restriction of movement suggests very severe limitations on the ecosystem, on the nature of which we can only offer tentative explanations.

To recapitulate, basically the problem of the prehispanic cultivator was how to adapt a crop that required 6 months to mature to an area where only a minority of the land has a frost–rainfall regime that could insure successful cropping in a majority of the years. The key variables are the fall frosts which, as we noted, begin as early as September but generally occur first during the October months and become extremely severe in November, December, and January. Spring frosts also occur, but these offer relatively minor problems, so minor that villages in the upper piedmont of the Texcoco region today will irrigate their land in February and plant as early as March, in some cases as early as February. Apparently the risk of fall frosts in terms of crop failure is substantially greater than the risk of spring frosts. What is important is that only a small percentage of the Basin includes lands where there is a 6-month period free of frosts in a majority of years, and these lands would be highly favored for settlement, particularly during the early phases of the agricultural adaptation to the area. It should also be reiterated that there is a rainfall gradient from southwest to northeast, and the problem of the frost is further compounded by low average rainfall and great variation in rainfall in some sections. In the south conditions are most favorable, in terms of frost and rainfall, and the cultivable land category during the First Intermediate period includes the alluvial plain as well as the lower and middle piedmont. In the central region the operation of the two environmental parameters of precipitation and frosts would effectively restrict occupation during that period to the lower and middle piedmont, or to a few small areas in the alluvial plain, where natural soil moisture would permit plantings as early as April or May. In the Teotihuacan Valley, primarily the middle piedmont and the upper part of the lower piedmont would fulfill these conditions and, for the far north, only a small area of naturally humid lands on the lakeshore plain would permit successful cropping. Even today, with 4-month varieties of maize, many villages in the northeast plant barley rather than maize, and, in essence, are cash farmers. By the end of the First Intermediate period, with the appearance of a 4-month variety of maize, we have the initiation of a substantial colonization of the alluvial plains in the central regions. The northern portion of the Basin, however, seems to have been virtually unoccupied until the First Intermediate Four phase.

Another deterrent in the expansion of population into certain zones would lie in the feedback relationships between the political system and the exploitative pattern. Even with a 6-month growing season, or with the availability of 4-month maize, large scale drainage and irrigation system projects in the alluvial plain probably could not have been carried out until a point in time when the sociopolitical groupings were sufficiently centralized to mobilize the kind of labor required.

For the Late Horizon, applying our model of intensive agriculture, assuming highly centralized political organization, and varieties of maize adapted to all of the various niches of the Basin, we estimate that 80% of the alluvial plain could have been cultivated, two-thirds of the lands in the lower piedmont, one-half of the lands in the middle piedmont, and approximately one-third of the lands in the upper piedmont. This is an average figure for the Basin. In fact, in some lands within these categories the percentage of cultivable land would be substantially higher or lower. For example, in the upper and middle piedmont of the Xochimilco area only a tiny fraction of the land is cultivable; much of it is volcanic waste land. On the other hand in the upper piedmont of the Texcoco region the cultivable land factor is relatively high.

Population Pressure and Agricultural Intensification

Tables 6.17–6.18 (pages 217–218) and 9.2–9.3 provide the reader with a summary picture of the prehispanic demographic history of the Basin by region—the carrying capacity of the Basin of Mexico, with a land use factor of 5 and with intensive agriculture—and should be referred to for clarification of the discussion to follow. Excluding the Pachuca region, where we lack survey data, the sierra, which was above the zone of agricultural utilization, and the lakes, which were not an agricultural resource until Late Horizon times, the total amount of cultivable land in our surveyed region is 2331 km² or 233,100 ha. Our estimate of the carrying capacity of the same area, plus the chinampa zone in the lakes, with intensive agriculture, is 1,250,000 people. Our various estimates for the population in 1519 are 800,000 (derived primarily from the archaeological data with documentary estimates added in for the large cities like Tenochtitlan, Texcoco, Tlacopan, and others), and 900,000 to 1,100,000 (from documentary sources alone). This means the population had reached from 65–88% of carrying capacity with intensive agriculture.

Considering these raw figures and particularly considering the fact that the pre-Late Horizon population of the Basin never exceeded 250,000, the theory that population pressure produced sociopolitical evolution would seem to be of very doubtful utility. In fact, if we take into consideration all the variables that limited agricultural expansion during the First Intermediate, and apply Boserup's ideas as to how the process of intensification operates, then the model does provide a powerful explanatory framework for at least the early stage of cultural evolution in the Basin. Assuming an extensive system of cultivation, 47,100 ha would be available for annual cropping, in the area of 2331 km². We have included in this calculation the large areas of lower and middle piedmont in the northern third of the Basin

TABLE 9.2
Basin of Mexico: Carrying Capacity, Extensive Agriculture

Categories of land	Basin area (in km²)	Area within survey (in km²)	Cultivable land (in percentages)	Cultivable land (in km²)	Land cropped annually (in km²) (land use factor of 5)
Sierra	1000	200	0	0	0
Pachuca region	1000	0	?	?	?
Area below 2200 m	0	140	80%	112	22
Lake	900	900	0		
Freshwater	160	160	0		
Saline	640	640	0		
Salinized shore	100	100	0		
Deep soil plain	800	800			
Floodplain	200	200	80%	160	32
High water table	200	200	35%[d]	70	14
Well-drained	400	400	80%	320	64
Thin soil plain	400	400	80%	320	64
Upland alluvium	35	35	80%	29	6
Lower piedmont	950	950[a]	65%	617	123
Middle piedmont	1050	950[b]	50%	475	95
Upper piedmont	750	650[c]	35%	228	40
	6000	5125		2331	471

Carrying Capacity

	Basin	Basin and lower middle piedmont	Southern half, lower and middle piedmont	Average cultivation factor
Early Horizon	150,000	70,000	25,000	1.8
First Intermediate 1–2	220,000	100,000	35,000	1.5
First Intermediate 3	250,000	125,000	42,000	1.2
Post-First Intermediate 3	300,000	140,000	45,000	1.1

[a] 670, north half; 280, south half.
[b] 600, north half; 350 south half.
[c] 300, north half; 350, south half.
[d] Without large scale drainage.

which were of doubtful agricultural utility during the early phases of adaptation and the alluvial plain (which was only sparingly used, primarily in the south and west). The total area classified as cultivable lands, assuming that all of these lands were cultivated, would permit a theoretical maximal population of 150,000 people during Early Horizon, 220,000 during the First Intermediate One–Two, and 250,000 in Phase Three. Considering these figures the population of the Basin did not reach carrying capacity in any pre-Middle Horizon phase, even in terms of extensive agriculture.

TABLE 9.3
Basin of Mexico: Carrying Capacity, Maximal Agricultural Intensification

Category of land	Cultivation factor (seven people)	Land use factor	Hectares cultivable land	Land cultivated in 1 year	Carrying capacity
Pachuca region	?	?	?	?	?
Sierra			0		0
Area below 2200 m	1.1–2.2	1–2	11,200	7500	35,000
Lake					
Freshwater	.37	1	10,000	10,000	200,000
Saline lake	.60	1	(Artificially desalinized) 2,500	2,500	30,000
Salinized shore			0		
Deep soil plain					
Floodplain	.95	1	16,000	16,000	120,000
High water table	.80	2	15,000	7,500	65,000
Well-drained—permanent irrigation	.80	1	15,000	15,000	130,000
Well-drained—temporal and flood-water irrigation	1.1	1–2	18,000	12,000	75,000
Thin soil plain					
Floodwater irrigation	1.4	1–2	16,000	12,000	80,000
Temporal	1.4–2.8	2–3	16,000	6,400	20,000
Upper alluvium	1.1	1–2	2,900	2,175	13,800
Lower piedmont					
Permanent irrigation	1.1	1	5,000	5,000	33,000
Floodwater irrigation	1.4	1	20,000	20,000	90,000
Temporal	1.4–2.8	2	36,700	18,500	60,000
Middle piedmont					
Permanent irrigation	1.1	1	5,000	5,000	33,000
Floodwater irrigation	1.4	1	17,500	17,500	85,000
Temporal	1.4–2.8	2	20,000	10,000	35,000
Upper piedmont					
Permanent irrigation	1.1	1	5,000	5,000	33,000
Floodwater irrigation	1.4	2	7,800	4,000	20,000
Temporal	1.4–2.8	3	10,000	3,300	12,000
					1,169,800

If we assume that only the lower and middle piedmont were cultivable lands, and exclude all of the alluvial plains, the carrying capacity drops to 70,000, 100,000 and 125,000. Using these data, by Phase Three the population had exceeded the carrying capacity of swidden agriculture. The carrying capacity of the southern half of the Basin only calculates at 25,000 during the Early Horizon, 35,000 during the First Intermediate One and Two, and 42,000 during the First Intermediate Three. Since virtually all the population of the Basin during the Early Horizon and the First Intermediate One and Two

phases was located in that portion of the Basin, and over half the population was located there during Phase Three, quite obviously the population levels of this portion of the Basin were well above carrying capacity for swidden agriculture by Phase Three times, suggesting the need for some level of agricultural intensification. The process is even more dramatically illustrated in a region by region analysis (see Maps 21, 22, and 23 to illustrate the discussion that follows).

The pattern may be summarized as follows. By First Intermediate One times there was a strip of settlement on the plain and adjacent lower piedmont on the south shore of Lakes Chalco–Xochimilco where the population was very close to carrying capacity with a swidden system. Another continuous strip of comparable land pressure rings the Guadalupe range on the east and south. The balance of the population in the Basin consisted of a series of small population clusters widely spaced over the southern two-thirds of the area.

By the end of the First Intermediate Two phase the entire lower and middle piedmont, with adjacent areas of lakeshore plain, in the Lake Chalco–Xochimilco Basin, had exceeded carrying capacity for a swidden system by a factor of 2 to 3. All of the examples of utilization of the alluvial plain occur at the foot of major zones of piedmont occupation or at the bases of very steeply sloping terrain. In the Texcoco region there was a continuous strip of settlement along the lower and middle piedmont from the Ixtapalapa region to the Patlachique range that had now reached carrying capacity, in terms of swidden agriculture. A comparable zone extended along the east and south sides of the Guadalupe range (including both plain and lower piedmont), and probably along the lower and middle piedmont west of Lake Texcoco. Further to the north were small pockets of population in the Cuautitlan region.

During First Intermediate Three times the processes and patterns we have described reached their maximal expression. The Chalco–Xochimilco lake basin, the Ixtapalapa peninsula, and the Texcoco piedmont–Middle Papalotla river basin all reached a point where the carrying capacity of swidden agriculture was exceeded by a factor of 2–4. The south flank of the Teotihuacan Valley had now reached carrying capacity and a large town emerged at Teotihuacan, based, however, on drainage and permanent irrigation of the alluvial plain. Scattered pockets of population were found on the north flank of the Teotihuacan Valley. In contrast, the Tenayuca region apparently underwent a process of rapid population decline (we say apparently because we surveyed only 30% of the region, due to recent urbanization, and one or two large sites in the unsurveyed area would alter our conclusion) and virtually the entire population of the Cuautitlan region was nucleated at the site of San Jose in the alluvial plain, a striking contrast to previous settlement. With respect to the Tacuba region we have no definite sites and have suggested in our model that perhaps this area was abandoned. In our summary of settlement history we have also suggested that this was a phase of major military confrontation between the various political groupings, particularly between the two large ones at opposite ends of the Basin, Teotihuacan and Cuicuilco, and this region may have been politically unsafe. The northern third of the Basin was still uninhabited.

Our estimates of carrying capacity and of the history of population growth in each of our survey regions, and of the Basin of Mexico as a whole, provide strong support for Boserup's theory. The population levels and the fact that the initial phase of the colonization of the Basin as a whole, and of each of its regions, involved selection of those niches where the risk of crop failure was least, would suggest an extensive approach to cropping. The higher values of our population estimates in those same regions in later times when they exceeded swidden farming would further suggest a process of agriculture intensification. In order to strengthen this latter conclusion, however, we need a variety of data that are independent of our calculations of population, since these are admittedly subject to a relatively wide error, and more importantly, a reliance only on these kinds of data is, in essence, a highly circular argument.

Innovations in the form of a number of specialized tools and techniques of cultivation can be used as indicators of agricultural intensification. As Boserup suggests, long fallow swidden agriculture does not require the labor of turning over the soil; this only becomes necessary with short fallow systems, where competition from grasses and herbaceous plants becomes a serious problem. Soil turning tools would be an indication, therefore, of a process of intensification. In Chapter 7 we summarized the data on tools and techniques for the prehispanic period. Of particular interest was the history of the tool type we described as a hoe. Our admittedly inadequate data do seem to suggest that the hoe appears as a tool in each of the regions when our calculation of population indicated that it had surpassed the levels permitted by extensive cultivation. It appears in the southern Basin as early as First Intermediate Two times but not in the northern regions until the Middle Horizon or later. It should be admitted, however, that no consistent sampling of sites to control more thoroughly the distribution in time and space of this artifact has been undertaken.

Other possible indications of intensification are innovations in techniques such as terracing, permanent irrigation, floodwater irrigation, and drainage systems. Before we summarize the history of these features, it should be pointed out that under some conditions, intensification need not involve these specialized techniques, so that the absence of such techniques does not preclude intensification. Their presence, however, is certain evidence of the intensification process. Contemporary studies of Highland New Guinea agriculture, for example, demonstrate that where land surfaces have only gentle slopes and drainage is good, intensification may involve no new techniques and involves little more than a reduction of fallow (Waddell 1972). In other areas in New Guinea where the potentially productive agricultural land is poorly drained, the intensification process may involve elaborate ditch and ridge systems.

With respect to terracing, to recapitulate, the evidence is incontrovertible for the Late Horizon, when virtually all sloping areas of the Basin were terraced. The association of terraces with sites is made relatively easy by the dispersed nature of the settlement systems. For pre-Aztec times there are a number of periods and phases (Early Horizon, First Intermediate One–Two, First Intermediate Four–Five, Middle Horizon, and Second Intermediate One, Three) when the rural population was nucleated in compact villages or towns and the problem of archaeological association of such sites with nearby areas of prehistoric terracing, from survey data alone, is considerable. We do have evidence of at least residential terracing for sites of the First Intermediate Two and Middle Horizon phases. During the First Intermediate Three and Second Intermediate Two phases rural populations were dispersed and we can, with some confidence, date terracing from those phases. Of course, in a particular area if we have evidence of terracing for two phases of dispersed settlement and the intervening phase of nucleated settlement was of comparable population we can probably safely assume that terracing was present then as well.

The difficulty with all of this pre-Late Horizon data is that the dated terraces are directly associated with residential sites (in fact if they were not we would not be able to demonstrate their contemporaneity), and the areas of terracing that we can actually date are therefore very small. They may be small kitchen gardens associated with houses. This means that it is still possible that most of the agricultural land used by the settlement did not involve terracing as a technique. As we pointed out before, the important data that we need are the amount of land that was actually under terracing, for each of the villages, during each of the time phases, and this is an extremely difficult problem to resolve.

It should be emphasized that our philosophical position with respect to the history of intensification is away from the idea that looks at such techniques as inventions, but rather that intensification is the product of the necessity of increasing labor input, brought about by conditions that require agricultural intensification. In other words, terracing, as we see it, is a process, not an invention. To put it more explicitly, terracing is time consuming and costly, and only resorted to when land availability is reduced to the degree that the fallow cycle must be shortened. As the fallow cycle is shortened, the erosion rate increases, and terracing is adopted to correct the problem. If agricultural land is abundant and erosion rates slow, our argument is that farmers will not invest this heavy labor in terrace maintenance. This means that the appearance of terracing in an area is no indication of its general use in that area, and hence is only a suggestion that some kind of process of agricultural intensification is involved. This warning is directed to ourselves as well as to other archaeologists, and if it seems to our colleagues that we are presenting unnecessary problems in terms of archaeological methods, it is because the process that we are describing is complex and the archaeological methods we use are not always successful in obtaining the data that illustrate the process. What the data on terracing suggest is that as a technique it appears early in our sequence and as a whole its pattern seems to coincide with the phase in a region when population had reached substantial levels. In this sense, the data do justify our argument that the appearance of terracing in the various regions is an indication of population pressure.

With respect to hydraulic agriculture as an indicator of agricultural intensification, the question is more complex. One could argue that its occurrence should occur relatively late in the population history of a region since considerable extra labor input is involved and the law of minimal effort would predict its late appearance. This would be particularly true in an area like the Basin of Mexico, where there are favorable zones of rainfall-based agriculture with reasonably high crop security. On the other hand, in the drier regions of the Basin, risk becomes a major factor and might stimulate its appearance at a very early phase of colonization, as Flannery *et al.* (1967) have argued for the Valley of Oaxaca. Convincing evidence of hydraulic agriculture does seem to appear in the drier regions, however, only when populations reach substantial size, so it seems that the law of least effort does help to explain its appearance. What this means is that the appearance of hydraulic agriculture can be used as a measure of the intensification process. We will return to a discussion of the history of hydraulic agriculture in the Basin since its development also is closely related to the risk factor.

Agricultural Intensification and Sociopolitical Evolution

Our settlement survey, the reconstruction of population levels based on it, and direct evidence of agricultural techniques all strongly support Boserup's assumptions as to the nature of population growth and the impact of such growth on agricultural intensification, and, as such, are an empirical demonstration of the laws of biotic potential and of least effort. Whether the data also support the corollary argument that changes in agricultural systems, and following Netting and Carneiro, the direct effects of population growth, are correlated with changes in social institutions is more difficult to establish from settlement survey data alone, but our data do strongly suggest that the model we presented on page 370 is indeed applicable to the Basin of Mexico in First Intermediate times. The process of physical and social fissioning, as a response to population growth, is dramatically illustrated in each local population and settlement profile, as well as the overall process of settlement of the Basin. The proliferation of hamlets on the frontiers of zones of substantial settlement followed by subsequent shifts in settlement pattern to larger communities in those same frontiers is, in each case, an example of the process.

With respect to political centralization and social stratification, our data from the survey are obviously inadequate but highly suggestive. Fortunately, we do have a substantial body of excavation data that can be combined with the survey to present a reasonably clear picture. Community differentiation between center and outlying settlements seems to correlate very closely with population growth in each of the local regions, beginning as early as the First Intermediate Two phase in the south, appearing as a characteristic pattern in Intermediate Three times in the Texcoco region, and finally appearing contemporary with the rise of Teotihuacan in the northern portions of the Basin. Burial and residential data from a variety of excavated sites—Coapexco, Tlatilco, El Arbolillo, Zacatenco, Ticoman, Loma Torremote, Isla de Terremote, Cuanalan, Chimalhuacan, Venta de Carpio, Tezoyuca, and Tlapacoya—provide interesting data on the process of ranking. What all of these data suggest is that at least some incipient form of ranking began as early as Early Horizon times, and when it appears in a local region it is always in those areas where local populations are substantial and have a tendency to be nucleated at large settlements. These larger settlements, during virtually the entire First Intermediate period, also seem never to have exceeded 2000 or 3000 people, with, of course, the two major exceptions of Cuicuilco and Teotihuacan. This restriction of size probably relates to the limitations of ranking as a mechanism of social integration. The ceremonial construction at these central sites during Phases Two and Three is generally very small and unimposing, again with the exception of the two major centers.

In our opinion all of our data indicate the correlation of a series of processes, population growth, concentration of population in large settlements, intensification of agriculture, and increasing significance of low-level ranking in the sociopolitical system. Most of these political groupings, however, were probably organized along the lines of a simple chiefdom type of organization, with severe limitations in terms of degree of political integration. The restriction of most of the population to zones of relatively low agricultural risk through most of the period also probably retarded the evolution of truly stratified social systems and state formation over most of the Basin of Mexico during this time period.

HYDRAULIC AGRICULTURE AND SOCIOPOLITICAL EVOLUTION IN THE BASIN OF MEXICO

Our present reaction to the data from the Basin of Mexico is that a combination of the laws of biotic potential and the law of minimal effort provide a useful explanation of much of the sociopolitical evolution of the Basin during the First Intermediate One–Three time period. It would be difficult, however, to explain the revolutionary events of the First Intermediate Four phase, subsequent developments during Phase Five and the

Middle Horizon, or the fluctuations in the sociopolitical patterns between the Middle Horizon and the Late Horizon solely on the basis of the operation of these two factors.

The sequences of events that occurred during this long span of time, from the beginning of the First Intermediate Four phase until the Late Horizon, we feel, primarily reflect the operation of the third ecological law, the law of minimal risk, and the effects of the feedback processes of the sociopolitical system itself upon the ecosystem. The major reason why the third law assumes greater significance during this time is because this is the first time in which there was a substantial occupation of the drier regions of the Basin. Boserup's theoretical paradigm was designed primarily on the basis of the data from humid regions and is most useful under the conditions where the risk factor is minimal. In the case of the arid regions the factor of risk probably is more significant than the operation of the law of least effort.

There are two major problems in testing Wittfogel's (1957) theoretical paradigm with the Basin of Mexico data that are very different in nature. The first problem is the evolutionary significance of the various hydraulic agricultural systems. Were they large and economically significant enough to have major effects on the sociopolitical evolution of the area? The second question concerns the archaeological evidence for the history of such techniques. Recently there have been a number of criticisms of the value of Wittfogel's (1957) theoretical concepts as applied to irrigation in the Basin of Mexico. Basically, the criticism is that the irrigation systems were too small and able to supply only a fraction of the food supply; thus, they neither required complex bureaucratic management nor stimulated conflict and competition. In this section we will offer a counterargument to these criticisms.

With respect to permanent spring-based irrigation, we have detailed data on two of the systems—on the San Juan Teotihuacan system and the Texcoco Piedmont (Amanalco) system. The San Juan springs system is apparently dying, according to evidence which shows that the output of water has steadily declined over the past 50 years. To recapitulate, in the 1920s Gamio *et al.* (1922) estimated the flow of water at the springs to be 1000 liters per second. In 1956 Sanders found the springs to have a flow of 580 liters (according to the federal water regulations); at the time the springs regulated 3652 ha of land. In the early 1960s, Millon *et al.* (1962) estimated the flow of water at only 540 liters. Finally, a recent publication shows the output since then has dropped to below 400 liters per second (Comisión Hidrológica de la Cuenca del Valle de México 1968). (Current data also show greater month-to-month variability than previously.)

The major cause of the declining output of the San Juan springs in the twentieth century has been the perforation of artesian wells, both within the Valley of Teotihuacan and in the bed of Lake Texcoco. Between 1519 and 1920, enormous amounts of land eroded in the Valley as a result of population decline from disease, the abandonment of agricultural lands on the piedmont, and their conversion to grazing lands. What effect this erosion has

had is unknown, but there may have been even more water in the system in 1519 than in 1920. Also, the long period of occupation from the First Intermediate Phase One to the Late Horizon witnessed a continuous process of deforestation, which certainly must have affected the drainage in the area to a great degree. (See Figure 7.8, page 257, showing the twentieth-century irrigation system in the Teotihuacan Valley.) Other permanent water resources on a smaller scale were probably available in First Intermediate times; some may still have been functioning as late as the apogee of Teotihuacan. Mooser, in fact, has postulated the existence of a series of springs within the archaeological zone in Middle Horizon times that provided an additional flow of 100 to 200 liters per second (Lorenzo 1968). What this means is that the Late Horizon irrigation system could have been at least 1.7 times larger than the recent system, and the Middle Horizon system approximately twice as large and capable of serving a total of 7200 ha of land. In the Texcoco piedmont 31 springs were still functioning in the 1920s (see Table 9.4). In Table 9.4 we have grouped the springs, not in terms of the present routing of the canal system, but in terms of the natural drainage of the area before canalization. (See Figure 7.13, page 274, which shows the spring locations and the structure of the twentieth-century irrigation system in the Texcoco area.)

What is the agricultural significance of the two systems? On the basis of our studies of the contemporary system, an average yield of 1400 kilos of maize, with minimal or no use of animal fertilizer, is a reasonable calculation. If we assume somewhat lower productivity, because less well-developed varieties of maize may have been used in the Middle Horizon

TABLE 9.4
Texcoco Springs of the 1920s[a]

Irrigation system		Water flow (in liters per second)	Irrigable area (in hectares)
Rio Papalotla			
Cluster 1 (springs 1–6)		280	—
Cluster 2 (springs 10–13)		23	—
	Total	303	1818
Rio Jalapango			
Cluster 1 (springs 7–9)		30	—
Cluster 2 (springs 32–34)		38–48	—
	Total	68–78	408–462
Rio Coxacuaco			
Cluster 1 (springs 14–24)		35	—
Cluster 2 (springs 25–27)		8	—
Cluster 3 (spring 28)		4	—
Cluster 4		5	—
	Total	52	300
	Grand Total	423–433	2526–2580

[a] From Sanders 1976b.

period, this figure might be lowered to 1050 kilos. Another variable to be considered is the percentage of irrigated land that would be devoted to maize production as opposed to other crops. On the basis of patterns of land use in the Teotihuacan Valley today (where land is devoted either to maize or to a humidity-demanding commercial crop like alfalfa), one could argue for 100% maize utilization. However, we have prepared two models, one calculated at 100% and the other at a 65% cultivation in maize.

Finally, to calculate the carrying capacity for the two systems we offer two alternate subsistence models, one based on a 80% caloric intake derived from maize, the other 65%, with the assumption that the former is generally applicable to Late Horizon subsistence, the latter to all of the pre-Late Horizon phases. Assuming an average per capita daily need for a total population, all ages and both sexes, of the size and weight of the prehispanic Mesoamerican, of 2000 kcal, carrying capacity estimates for the Teotihuacan and Amanalco irrigation systems are as given in Table 9.5.

Citing a sixteenth-century source, Palerm (1961b) reports that the Coyoacan system served the needs of 23,000 *vasallos*. It is not clear what the term *vasallos* refers to, but it obviously was a major system, at least comparable to the Texcoco piedmont complex. Although we lack detailed quantitative

TABLE 9.5
Carrying Capacity of Permanent Irrigation, Texcoco and Teotihuacan Regions[a]

		65% Dependence on Maize			
		100% Planted in maize		65% Planted in maize	
System	Land area (in hectares)	1400 kg per hectare	1050 kg per hectare	1400 kg per hectare	1050 kg per hectare
Contemporary Teotihuacan system	3,600	39,600	28,800	25,740	18,720
Middle Horizon, Teotihuacan system	7,200	79,200	57,600	49,480	37,440
Middle Horizon, both systems	9,700	116,700	77,600	69,355	50,440

		80% Dependence on Maize			
		100% Planted in maize		65% Planted in maize	
System	Land area (in hectares)	1400 kg per hectare	1000 kg per hectare	1400 kg per hectare	1000 kg per hectare
Contemporary Teotihuacan system	3,600	32,400	21,600	21,060	14,040
Middle Horizon, Teotihuacan system	7,200	64,800	43,200	42,120	28,080
Middle Horizon, both systems	9,700	87,300	60,200	56,745	39,130

[a] From Sanders 1976b.

data on the Cuautitlan system, in terms of the sixteenth-century population of the area and distribution of canals on colonial maps and recent aerial photos, it must have been minimally comparable to the Texcoco or Coyoacan complex. Spring flow, according to Recursos Hidraulicos (Memoria de la Obra . . . 1975), exceeds that from the San Juan springs.

Taking the average yields from permanently irrigated land for the Late Horizon (1400 kilos for the alluvial plain and 1000 kilos for the piedmont areas), assuming the permanent water resources were maximized, that all the land was planted in basic grains, and that the population derived 80% of their calories from the grain products, then the permanently irrigated land (20,000 ha) would have sustained a maximum population of 120,000 people.

With respect to floodwater irrigation it is difficult to assess the maximal capacity of this resource. In a recent publication by the Instituto Mexicano de Recursos Naturales Renovables (Mesas Redondas Sobre Problemas del Valle de Mexico, Mexico 1963) the total average annual precipitation for the Basin of Mexico is calculated at 6,717,000,000 m^3. Of this, 4,704,000,000 m^3 filtrates into the soil (of which 133,000,000 m^3 flows to the surface in the form of springs) and 343,000,000 m^3 flows through the barranca–river systems. These figures, however, refer to the present day drainage basin, a combination of artificial and natural drainage systems, that drains an area of 9600 km^2. We have roughly calculated the surface drainage of our smaller region at 70% of these figures, or 240,100,000 m^3. In fact it would be a little higher since those areas that the study includes, which are excluded in our studies, such as the Apan Basin, have an average annual precipitation that is comparable to the drier regions of the Basin. Since irrigation water is used for very different purposes, dependent on the season, we must break this total figure down by seasons. The ratio of rainfall in the Basin of Mexico from winter through the fall is approximately 1:4:10:5. This means that approximately 12,000,000 m^3 flows during the winter, 48,000,000 m^3 during the spring, 120,000,000 m^3 during the summer, and 60,000,000 m^3 during the fall.

The winter flow would have little use for agriculture. The spring flow could theoretically be used for the same purpose as the permanent irrigation, that is, preplanting (with the difference that the local variability year to year would be very high). Taking the average measure of 1200 m^3 per irrigation, theoretically, the spring flow in the Basin could be used to irrigate 40,000 ha of land. Summer irrigation is primarily used as a supplement, and the flow for this function could be used to provide water for 100,000 ha. During the fall, contemporary farmers use floodwater, not so much for the standing crop, but as a technique of water storage for the spring planting. We estimate that 50,000 ha of land could theoretically be irrigated for this purpose. What the data suggest is that 40,000 ha of land could be provided with water for preplanting irrigation, and that the same land could be given two–three irrigations during the growing season, to supplement the rains, and an additional irrigation in the fall for water storage in the subsoil for the following year. In actual fact the figures for preplanting irrigation would be considerably lower than this since some of the rainfall during the spring season would fall at widely spaced intervals and in such small amounts that there would not be enough buildup of water behind dams to allow simple gravity irrigation. Furthermore, much of the rain falls in areas where irrigation is either unnecessary or topographic situations make it unfeasible with prehispanic technology.

Finally, also falling under the rubric of hydraulic agriculture is what we have referred to as drainage agriculture, including the chinampas of the lake system—the most productive kind of agriculture in the Basin. Considerable areas along the lakeshore were probably characterized by swampy conditions, the water table lying within a few meters of the surface. As a result of increased cultivation, erosion, and development of irrigation–drainage ditch networks, this zone undoubtedly went through a process of gradual lowering of the water table between Early and Late Horizon times. Much of the immediate lakeshore plain was probably still characterized by a relatively high water table at the time of the Spanish Conquest and hence was characterized by high yields and crop security. The extent of this zone is not known. In the case of the chinampas, however, on the basis of Armillas' survey of the southern lakes and Palerm's analysis of the dike system in Lake Texcoco, we estimate that there were approximately 12,000 ha of chinampas in 1519.

On the basis of Sanders' study of productivity, the 12,000 ha of chinampas could have sustained at least 228,000 people. This means a total population of 348,000 or at least one-third of the population of the Basin of Mexico in 1519 could have been supported from either chinampas or permanent irrigation agriculture. When one adds to these figures the area of unknown size of drainage agriculture along the lakeshore and the use of floodwater irrigation, then the economic significance of hydraulic agriculture in terms of the Late Horizon population can hardly be overemphasized, and was undoubtedly critical.

Aside from the matter of demographic capacity and crop security, hydraulic agriculture has another equally important economic effect—productivity—as measured by the input–output ratio. In our discussion of Boserup's model of agricultural dynamics we noted that the intensification process commonly leads to a gradual decline in input–output ratios, or per capita income, as an economist would put it. This decline can be measured energetically, in terms of kilocalories, of work expended to produce kilocalories of food, or in a less precise measurement, of work hours or days in proportion to yield. In all cases Boserup cites, intensification results in an increase in work input per unit of land cultivated. In some cases this is accompanied by a decrease in yield, the product of losses in soil fertility. Even in cases when special practices may stabilize or even increase yield however, she argues that the increases do not entirely compensate for increased work input, and the result is still a decline in ratio.

The input–output ratio has obvious significance in terms of the capacity of households to produce surpluses to sustain non-food-producing elements in the population. We suggest that in humid environments, where soil fertility is a general problem, the process of intensification may result in a decline of income to the degree that the capacity of the system to support non-food producers, and hence complex social systems, is seriously impaired. In semiarid and arid environments, where soil fertility is a less serious problem, the same difficulty may arise because of the insecurity of cropping with extensive practices. Hydraulic agriculture has such a striking effect on productivity in semiarid and arid regions (because of the added nutrients brought in with the water) that the increased yield and regularization of such yields may in fact compensate for the increased labor input.

The problem of providing sufficient surpluses for market exchange and taxation is exacerbated with a Neolithic technology. Our experimental studies with Neolithic tools, intensive use of the land, but no irrigation, show a work input that varies from 70–150 man days per hectare, dependent on soil texture. Dry farming yields vary from 400 to 800 kilos per hectare, with contemporary races of maize, and with adjustments for crop losses during bad years. An extended family of seven would require approximately 1120 kilos of grain for its basic needs during the Late Horizon. This means that approximately 200 man days of input into agricultural work would be necessary to provide the caloric minima. In terms of the demands of other kinds of work, and the limitation of work input imposed by this climatic regime, it is doubtful that this work input could be increased by more than 50%. By adding irrigation, the increase in yields almost doubles, with only a slight increase in labor input. Chinampa agriculture would result in a yield of four times the maximal yield of dry farming, with little extra labor input, thus enhancing enormously the capacity of the food producer to support a non-food producing population. What our data suggest is that when agriculture did expand into the higher risk areas of the Basin of Mexico, particularly when the process was accompanied by increasing social stratification, then the stimulus to develop technology to increase and regularize yields would have been considerable.

With respect to the evidence for the history of hydraulic agriculture, the data in Chapter 7 may be summarized as follows. During the Late Horizon, on the basis of ethnohistoric and archaeological sources, all hydraulic resources, floodwaters and permanent water resources, and virtually all naturally humid lands were fully utilized throughout the Basin. Floodwater and permanent irrigation appear as early as the First Intermediate period in the southwestern and west central portions of the Basin, at times when population densities reached relatively high levels. Small-scale drainage agriculture along the southern lake shores may also have begun that early. In the central portions of the Basin, drainage agriculture, on a fairly substantial scale around the San Juan springs, dates from the First Intermediate Three phase, and permanent canal irrigation on a large scale was probably present during the First Intermediate Four–Five, Middle Horizon time period. Floodwater irrigation was also apparently widely distributed in the central portions of the Basin as well. Although drainage agriculture probably began early, and was of considerable significance during the early phases of the growth of Teotihuacan, the major expansion of this system of farming was during the fifteenth century, with the large-scale conquest of the southern lakes.

In summary, the economic significance of hydraulic agriculture would seem to be considerable. As we have argued previously the indirect effects of the various hydraulic systems on social stratification could have been revolutionary. Whether the irrigation systems were large enough to have required, in Wittfogel's terms, an elaborate managerial bureauocracy is perhaps debatable. The settlement system during the period of the emergence and growth of Teotihuacan in the Teotihuacan Valley–Texcoco regions very clearly suggests the presence of centralized control, but this control, we believe, would not have necessitated a separate managerial administrative set. We rather suggest the presence of a single power-holding institution—what the Hunts (1976) have referred to as role embeddedness. This is not to deny that almost certain presence of lower level officials who functioned to distribute water and organize labor for maintenance.

The organization of the drainage of the lakes and their subsequent conversion and use as cultivated land during the sixteenth century was clearly a state organized and administered project, as were the subsequent public works involved in the protection of the system—the network of dikes (a system minimally 80 km in length) to regulate the flow of water (Palerm 1973). These projects were of a scale, and the skill needed to maintain them of such a nature, that it is likely that there was a professional class of administrators to safeguard the system. Bearing in mind the limitations of our data and the character of irrigation in the Basin of Mexico we present the following tentative model for the functional relationship between the development of hydraulic agriculture and the state in Central Mexico.

HYDRAULIC AGRICULTURE AND STATE FORMATION IN THE BASIN OF MEXICO

The emergence of Teotihuacan in First Intermediate Three times as a large town, its explosive growth in Phase Four, and its ultimate climax during the Middle Horizon reveals a process of state formation and urbanism unparalleled in prehispanic Mesoamerica until the rise of Tenochtitlan and the Mexica state in the fifteenth century. Although one can trace many aspects of the Teotihuacan culture back through the various phases of the First Intermediate period in the Basin of Mexico, its emergence represents a revolutionary break with the past, and a complete redesign of the ecosystem of the Basin. This redesign involves major changes in population distribution, settlement types, and environmental exploitation.

In Chapter 5 we presented an analysis of the Teotihuacan ecosystem in terms of basic zones of resource utilization. Zone 1 was the city and its immediate agricultural resource, basically the middle and lower alluvial plain of the Teotihuacan Valley and the middle and lower Papalotla plain. In this area there were virtually no rural settlements, and we argued, on this basis, that a substantial percentage of the population of the city were farmers. In the cited paper by Sanders *et al.* (1976) we presented an agricultural model for this nuclear zone. We assumed full use of hydraulic resources (the two major spring sources at San Juan and Amanalco) and calculated the total potential of permanently irrigated land in Middle Horizon times at 9700 ha. Physically the two irrigated regions were separated by the Patlachique range through most of their extension, but merged at the lakeshore, to form one continuous zone. Assuming 100% cropping of grain on such lands, 65% per capita caloric intake from grains, and a yield of 1400 kilos per hectare, the irrigated land could have supported 116,700 people. Even if we assume a lower yield, to the First Intermediate Three level of 1050 kilos, then it still would have the capacity to support a population of 79,200 people. In either case much of the support of the city, with respect to staple crops, could have come from this zone of intensive cultivation, which lay within a radius of 15 km of the city. Differential access to the land and control of the water could have been a major factor in the patterning of the Teotihuacan class structure and political organization.

This pattern of land use is clearly an inconvenient one from a purely agricultural point of view, but we must remember that Teotihuacan was also a major craft and mercantile center. In the model of Teotihuacan economy, Sanders, Parsons and Logan suggested a parallel to the contemporary Yoruba of Nigeria, who also live in large nucleated settlements, and where the household has a multifaceted economy, involving agriculture, craft, and mercantile activities. Under these conditions the household is faced with the options of what kind of settlement arrangement is most convenient. Among the Yoruba it is apparently more convenient to reside in the nucleated community and travel out to the outlying fields, and this is the model we are suggesting for Teotihuacan. The remainder of the agricultural food supply for the city could have been provided from the surplus production of the numerous settlements in Zone 2, particularly if those populations were using the irrigation resources of that region. We noted in our previous discussion that virtually all of the population in this area is distributed in close relationship to hydraulic resources.

We admit that this model goes far beyond the data, but the various data that we have described previously at least suggest it as a very strong hypothesis, and it would be very difficult to design an alternative one to explain the population distribution and settlement types for the period in question. The events prior to and after the establishment of the First Intermediate Five–Middle Horizon ecosystem also offer strong support for the model's validity. For example, the large First Intermediate Three population in the Papalotla basin vanishes during Phase Five and the region continues to be unoccupied during Phase Five and the Middle Horizon. A reasonable explanation of this settlement change is that the First Intermediate Three population moved to Teotihuacan, but continued to cultivate land in this area. As soon as Teotihuacan lost its extraordinary preeminence as a major political and commercial center, the Second Intermediate Phase One population immediately reoccupied the same zone. Presumably the colonists were the same people who formerly lived at Teotihuacan and cultivated these lands.

In the case of the Teotihuacan Valley the process is similar, but also different in some respects. During First Intermediate Three times a large town emerged at the head of the irrigation system and its growth is directly related to the initiation of canal irrigation and drainage agriculture in the vicinity of the springs. After Teotihuacan declined as a major center, the population of the city dropped back down to the First Intermediate Three level and the balance of the population, the farming class of the city, was distributed along the edge of and within the irrigated plain, precisely the contemporary settlement system.

Basically our evolutionary and historical model of the impact of canal irrigation on the institutions of the Basin of Mexico involves the following stages.

(1) During the First Intermediate period a number of local groups began to experiment with hydraulic agriculture. Many of these experiments involved small-scale drainage and permanent canal irrigation. Most of the cases occur in the drier central portion of the Basin. The immediate effect of this shift was to cause a change from a ranked to a stratified social system. At Teotihuacan, the zone of highest agricultural risk, the process was faster than elsewhere and was large in scale. The result was the emergence of a town of approximately 40,000 people by the end of the phase. As we have noted previously, this was also a phase of intensive conflict among the various political groupings.

(2) Teotihuacan, with its advantage of size, and location near the largest permanent irrigation system in the Basin, emerged as the major power. As a result of the conflicts that emerged during Phase Three, the population of the Basin of Mexico was substantially reduced during Phase Four. For reasons as yet unclear, the remnants were not only ruled by Teotihuacan, but nucleated at the city itself. This would, if our model is correct, be the phase of maximum expansion of the irrigation resources of the core area.

(3) During the successive First Intermediate Five and Middle Horizon phases Teotihuacan became a Mesoamerican as well as a local Basin of Mexico political and economic power. The city now had a secure agricultural base, conveniently located in terms of distance and ease of control, had developed a major extraregional commercial trade network, and had completely redesigned the ecosystem of the Basin.

The subsequent history of the Basin of Mexico involved a number of phases of political decentralization (Second Intermediate Phases One–Three) and centralization (Second Intermediate Two and the Late Horizon). In the case of the two phases of political centralization, the relationships between the center, its sustaining area, and hydraulic resources are a virtual reproduction of the Teotihuacan pattern (see Figure 9.1).

FEEDBACK MECHANISMS AND PROCESSES

Up until this point we have focused heavily on the operation of the three basic laws of cultural evolution as prime movers, primarily in terms of their economic and ultimately political effects. However, as these laws operate to stimulate the emergence of new sociopolitical institutions, the institutions themselves become part of the cause and effect system, and may act in a systemic way as motivators of change.

This point was heavily stressed by Flannery (1972) in his paper, "Cultural Evolution of Civilizations." As social stratification becomes more intense, along with other kinds of intrasocietal differentiation, more elaborate and complex political controls and organization are necessary. Ultimately a professional managerial class emerges, with little direct relationship, and often only a very general knowledge, of the means of production at the base of the system. Decisions as to how the environment is to be used are increasingly made by people who are not directly exploiting it. Decisions are often made for self-serving reasons, in terms of their own needs rather than in terms of the functioning of the total system. Sometimes the process even creates ecological disasters, as in the case of salinization in lower Mesopotamia, and possibly soil erosion in the Classic Maya Lowlands. We would argue, however, that the decisions made by the ruling class are based upon our three basic laws—but in terms of their own subsystem—not the system as a whole. It is for this reason, we believe, that many anthropologists often see decision-making in complex societies as nonecological.

We have previously discussed the effect of stratification on carrying capacity in terms of the process of competition, both internal and external, to the societal system. In Oscar Lewis' (1951) study of contemporary Tepoztlan, for example, he asserts that the village is land deficient. In fact, if one were to take the agricultural resource of this community and divide it up equally among the various families, there would be no land shortage. The system of stratification, in which a substantial percentage of the land holdings are private, produces inequities in land distribution, so that, with respect to the bulk of the population, there is in fact land shortage. What we are assuming is that a process comparable to this operated in prehispanic times to create inequities of land availability to lineages or to villages.

Another kind of feedback effect relates to the character and nature of capital works in agriculture such as canal and dam construction. In our previous discussion of hydraulic agriculture, we suggested that the retardation of colonization of alluvial plain in several of our regions may have

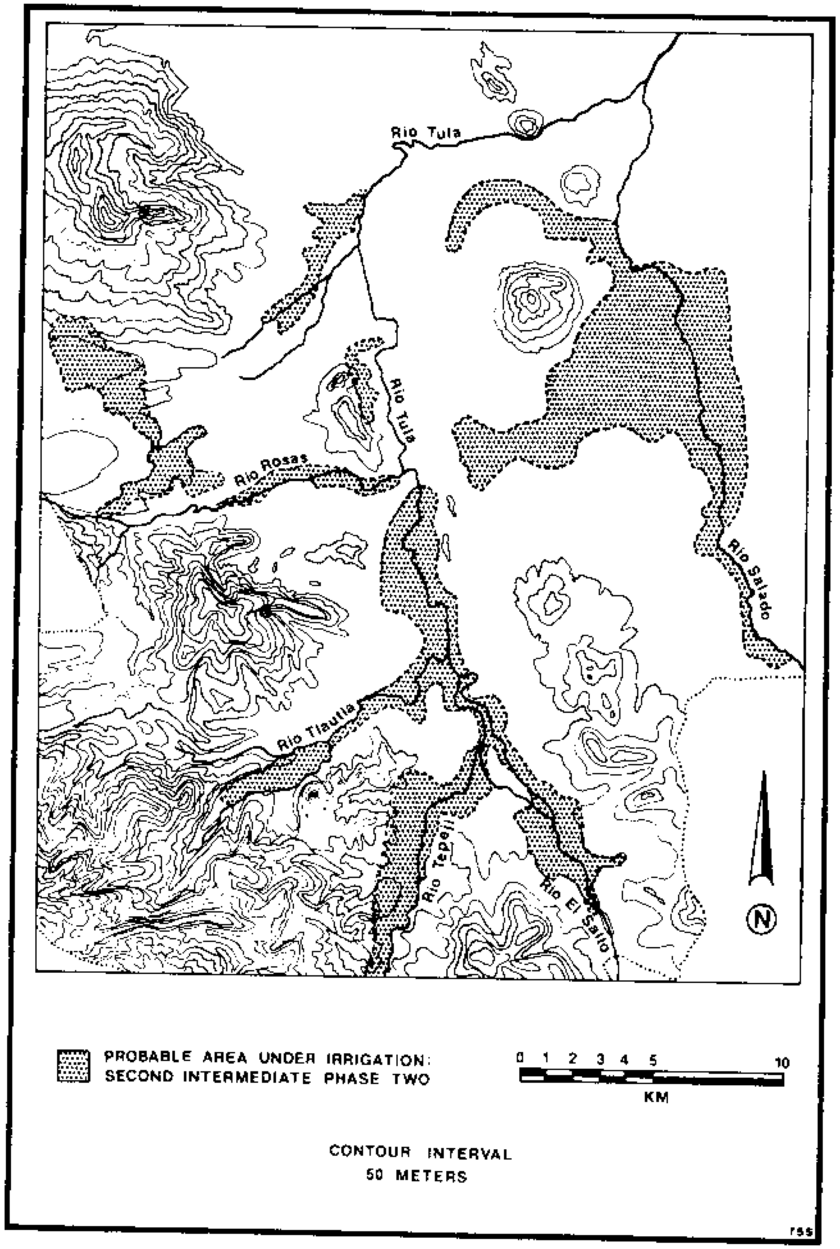

Figure 9.1. Probable area under irrigation in the Tula region during the Second Intermediate Phase Two. (After Mastache 1976.)

occurred because the level of sociopolitical organization that would be needed to construct and to maintain such systems had not yet evolved. More specifically, our reference was to the emergence of large-scale drainage works in the alluvial plain of the Texcoco region, which may have been delayed until a level of sociopolitical organization emerged that was capable of mobilizing the labor for such a project. This is obviously a complex process since the organization was available by the First Intermediate Four phase, yet it still was not undertaken. This, however, can be ascribed to the major reshuffling of population during that phase and use of the labor elsewhere (i.e., the Teotihuacan Valley). It is no accident that the first large-scale application of a system of drainage agriculture was carried out in the Teotihuacan Valley, where both the population and political organization were available to carry it off successfully.

It may seem to the reader that we are reversing our arguments since previously we have argued that the emergence of the state at Teotihuacan was a product of hydraulic agriculture. In fact, we are doing precisely that, since the relationships really are systemic in nature and it would be very difficult to sort out the direction of cause and effect. This is particularly true of archaeological case examples, but we have strong doubts that this can be done even with ethnographic data. Our argument is that if such systems are constructed by the political leaders, then the control of the water distribution is very apt to be a politically centralized one. Even in the cases of gradual accretion of such systems some kind of political solution is needed to resolve disputes and to maintain the system. As the system grows in size and includes greater numbers of separate physical and social communities, the potential for conflict will increase proportionately, and customary law ultimately will need to include some kind of more forceful sanctions in order for the system to function.

A more dramatic example of a feedback process of this type is the effect of large demographic and political centers on their sustaining area. As a generalization we would argue that the larger a political center becomes, the greater its effect on the overall system, and this is dramatically illustrated by the effects of Teotihuacan, Tula, and Tenochtitlan on the ecosystem of the Basin of Mexico. In the case of Teotihuacan, what is involved is a complete restructuring of the ecosystem, accompanied by revolutionary changes in settlement pattern and population distribution. Major patterns that took 1500 years to evolve were suddenly and dramatically reversed or altered. This begins with the massive relocation of at least 80% of the population of the Basin at the city during Phase Four and ends with the reestablishment of a new settlement system in the countryside during Phase Five and the Middle Horizon. While it can be argued that a variety of ecological processes stimulated and made possible these changes—that is, the rapid evolution of hydraulic agriculture and consequent colonization of the alluvial plains, and the appearance of new varieties of maize—it would be difficult to argue simple linear causation here. The location of the city and its early growth are clearly related to a set of ecological factors and processes as we have described, but our argument is that the presence of the city in First Intermediate Three times produced its own dynamic of change. Millon (1976) has made a similar argument, influenced by points made by Jane Jacobs (1969) in her book *The Economy of Cities*, in which she discusses the dynamic effects of the city on the countryside.

In this book Jacobs' major thesis is that the growth of the city causes intensification of agriculture in its immediate area. She takes the argument one step further and insists that agriculture itself was created by a people living in nucleated settlements (therefore classified by her as urban settlements), whose economy was based on hunting and gathering of unusually rich local resources. Obviously, this is simply a restatement of some of Binford's (1968) early arguments about the origin of agriculture but with the concept of nucleation of population added to his model. The thesis is not supported by recent data on the history of agriculture in Mesoamerica, where agriculture was clearly developed by populations not living in large nucleated settlements. This is not, however, to deny Jacobs' basic argument that cities have an enormous effect upon rural settlement and the way in which land is used in their vicinity. Her theoretical argument is of course strongly supported by our model of Teotihuacan economy, with the various zones of exploitation, and the role of these zones in the city's economy. The Middle Horizon land use and settlement system in the Cuautitlan, Temascalapa, and Zumpango regions, and the northern flank of the Teotihuacan Valley, can hardly be explained in terms of our population growth, population pressure, or our hydraulic models. In all of these areas there were very small pre-First Intermediate Five populations, and this condition was followed by explosive growth over a very short period of time. This growth also involved planned settlements and major use of the hydraulic resources of the area, in the form of floodwater and permanent irrigation. Outside of Zones 1 and 2, the balance of the population distribution and nature of settlement makes little sense except in terms of the needs of the city.

The effects of Teotihuacan on the rural areas, however, go even further afield than the Basin of Mexico, and if our model is correct we should have included a larger region for our analysis. To explain further, we noted, in Chapter 2, that the Proyecto Aleman included a large-scale settlement survey of the Tlaxcala–Puebla region, under the direction of Angel Garcia Cook. At the Paris meetings of the International Congress of Americanists we presented a comparative study of the settlement history of the Basin of Mexico with this region. The Tlaxcala–Puebla region appears to be more precocious in its evolution during the Early Horizon and First Intermediate periods as compared to the Basin of Mexico. This is indicated by differences in population size, size of major sites, evidence of site stratification, and intensification of agriculture. In general, the evolution of the Puebla–Tlaxcala region is approximately 300 years ahead of the developments in the Basin of Mexico. For example, the levels that were reached in the Late Early Horizon phase in the former region were hardly achieved in the Basin of Mexico until the First Intermediate One phase; developments characteristic of the First Intermediate One phase were not achieved in the Basin of Mexico until Phase Two, etc. While the explanation for this variation is undoubtedly complex, we believe that it does relate primarily to environmental differences between the two regions. All of central Tlaxcala, along with a large section of west Puebla, even in areas above 2240 m, has a shorter frost season, and this favorable situation is combined with approximately 25% more rainfall than the Basin of Mexico (see Figure 4.1, page 83). This means that the Puebla–Tlaxcala region was much more favorable in terms of early agriculture than the Basin. During the long First Intermediate period, and considering limiting factors previously described, this region had a much higher percentage of cultivable land, and hence could support substantially larger populations. By First Intermediate Three and Four times this advantage is gone and the Basin reaches the same level as the Tlaxcala–Puebla region and ultimately surpasses it.

Interestingly, the drier, cooler, northern area around Calpulalpan and Apizaco had virtually no population during the First Intermediate period, yet this area was densely settled during the First Intermediate Five–Middle Horizon. Of even greater interest is the fact that the architectural and ceramic styles of sites in this colonized region are identical to those at Teotihuacan, whereas the old First Intermediate population in the south still retains independence in ceramic styles. It seems difficult to escape the conclusion that this northern zone was colonized directly by Teotihuacan. The distance from Teotihuacan is comparable to that of the Cuautitlan region and should be included as part of our Zone 2. One purpose of this colonization was probably to provide further agricultural support for the city, but a more important function was probably to secure trade routes to the Gulf Coast (see Map 20).

Another example of Teotihuacan colonization is the Tula region. This region also had a very small pre-First Intermediate population, and yet by the First Intermediate Five and Middle Horizon times, there was a very substantial population in the area, living in large nucleated settlements, some of which were larger than any towns in the Basin of Mexico (excluding, of course, Teotihuacan itself, and probably Azcapotzalco). When all of the population of the Basin of Mexico and the surrounding regions is plotted on a map, Teotihuacan assumes a central position in terms of its distribution, rather than a peripheral one.

This pattern of rural–urban relationships and the processes involved are virtually duplicated in the case of Tula. The northern third of the Basin (including the Zumpango, Cuautitlan, Teotihuacan, and Temascalapa regions) are comparable in terms of settlement densities and sizes of settlements to our Zone 2 during the Teotihuacan phase period, and the Texcoco, Tenayuca, Tacuba, and Xochimilco regions are comparable to Zone 3 during Middle Horizon times. Presumably, settlement surveys north, east, and west of the Tula region will show a substantial concentration of population thinning out toward the peripheries. This model would agree very closely with ethnohistoric statements about the domain of Tula, in which a large region north and west of the city was considered part of its political domain. To what degree the presence of Tula changed the agricultural economy of the immediate region is not clear, but recent studies by Mastache (1976) and Crespo (1976) reveal that a substantial percentage of the Tula region can be permanently irrigated. Our estimate from their maps is that approximately 10,000 ha of land are capable of irrigation from several independent, permanent, water resources (see Figure 9.1). Their studies also show a striking correlation of the Middle Horizon and Second Intermediate Two settlement with the distribution of irrigated land. Our calculation is that at least half the population of the Tula region could have been supported, during the maximum prosperity of the city, by the production from these irrigated lands.

Tenochtitlan illustrates similarities and differences in the rural–urban relationships when compared to Teotihuacan and Tula. A major distinction is the fact that the intensification process had been completed over the entire Basin of Mexico. Nevertheless the growth of the city is closely and clearly related to the expansion of drainage agriculture on the lakeshore, and most particularly, to the colonization of the lakes themselves. Much of this colonization was organized by the state, which, throughout the Late Horizon, was a major entrepreneur of irrigation works. As Calnek (1972) has pointed out, based on his analysis of documentary sources, and the indirect evidence from Armillas' (1971) surveys of the chinampas, the expansion of chinampa agriculture was essentially a fifteenth-century phenomenon and was a planned colonization. Calnek's major point is that existing state organizations were the entrepreneurs that created the chinampa area as an agricultural resource, and the evolution of chinampa agriculture did not produce the Late Horizon states. Once created, however, it is equally clear that the use of these lands enormously modified the Aztec political system, its economic institutions, and the stratification of Aztec society, a classic example of our suggested feedback process. Furthermore, although intensive agriculture was practiced all over the Basin of Mexico in 1519, approximately 40% of the population was concentrated in an area of 600 km² around the city, thus reproducing the pattern of population imbalances we described for the earlier cities. This was made possible by the evolution of drainage agriculture, and it must have been a powerful factor in promoting stability to the political system.

In recent years there has been an increasing focus on foreign trade as a mechanism in state formation. We do not see this as a productive line of research, at least for prehispanic Mesoamerica, for a variety of reasons. In a book by Howard Odum (1971) a very important theoretical point is made about human energy systems. Virtually the entire continuum of societies studied by anthropologists, from bands to preindustrial states, can be

classified into one type of energetic system, one in which the great majority of the energy produced is consumed within the local community, and conversely most of the energy consumed is produced within that community. Even within communities a substantial percentage of energy utilized and consumed is within the family. Energy flow between families, and particularly between physical communities, therefore, has a relatively low value. The actual range is probably from 5% to 30%. To the cultural evolutionist, of course, this is a significant variation, and is thus the focus of this analysis. The range, however, does seem insignificant when one compares it to modern industrial societies where energy flow from and to communities probably everywhere exceeds 95%. The larger the geographic region the greater the contrast between industrial and nonindustrial societies. The limiting factor in nonindustrial societies clearly relates to the *human* energetic costs of production and distribution.

The meaning of these points to studies of the ecosystem of ancient states and their centers seems obvious. First, the major determinants of social stratification must be sought in terms of differential control or access to basic resources within a relatively short radius of those centers. Even in societies where animal power is utilized, the major source of power is still human energy; hence the *control of agricultural land* is the most significant single factor affecting stratification. Second, the life support radius for central places, whether urban or nonurban, must be a relatively short one for those goods that are both bulky and consumed at a rapid rate. Lightweight goods, with low consumption rates and limited use, can of course be brought from considerably greater distances, but these goods have only a marginal effect on the functioning of the ecosystem.

Obviously, following this model, the significance of long-distance trade, in an energetic sense, will be proportional to the efficiency of the transportation and production systems. The case of Mesoamerica involves primitive transportation, in most cases the human back, and equally primitive production systems. To take the specific case of Middle Horizon Teotihuacan, accepting Spence's estimate of the number of people at Teotihuacan who produced obsidian for the long-distance market, assuming that a comparable ratio of local to foreign producers was characteristic of the other crafts, then maximally 20,000 people should be involved in foreign trade, or less than 10% of the population of the Basin of Mexico. In fact this number was undoubtedly much less since we know that many of the major crafts, such as ceramics and ground stone, were nearly entirely for local consumption. It is doubtful that more than 10,000 people actually derived a substantial percentage of their incomes from the long-distance trade, at the peak of Teotihuacan's history.

With respect to local or internal trade, on the other hand, the movement of goods from household to household was undoubtedly considerable, and, in Odum's terms, the transfer of energy was close to the maximal of the range for preindustrial societies. In a previous section we have described the Aztec redistribution system in which a substantial percentage of the goods used by the average household was obtained through the market system, or through the tax redistribution network.

In two papers Sanders (195›, 1968) has argued that the great microgeographic complexity of Mesoamerica both permitted (in the sense of the short distance to zones of differential production) and stimulated (in the tendency of localization of resources) an intensive pattern of economic symbiosis, particularly in highland regions. Following this theoretical argument, out of the need to safeguard these exchange networks, political centralization developed. Beside the need to safeguard the system, its control, like hydraulic agriculture, altered the political positions themselves that were designed to regulate them, and provided added opportunities for status occupants to expand this political power. An additional aspect of the theoretical argument is that the great frequency and regularity of market encounters would reduce the parochiality of local group feeling and act to validate the large political system. The model was designed on the basis of contemporary and Late Horizon patterns of the settlement, population, and resource utilization, where all environmental zones were inhabited, and one would expect very clearly defined territorial rights over such resources by the local community.

The model is probably very useful in explaining the degree of integration achieved by local and supralocal states during the Late Horizon. In Sanders' original formulation, however, the purpose was to explain how centralized political systems emerged in earlier times. It was seen as a mechanical process brought about by the need for exchange. The very divergent settlement system from earlier times, particularly during the First Intermediate period, when the first stages of political centralization were achieved, weakens considerably the explanatory value of this model. For example, not only was virtually all of the First Intermediate population distributed in a narrow band along the lower–middle piedmont, but much of it was in a dozen or so communities. Each of these central communities presumably had control of a territory that extended upslope and downslope from the zone of cultivation, in many cases from the sierra to the lakeshore. The location of settlements is such that nearly all resources are readily accessible. If economic specialization and symbiosis were important it would be among segments of the same physical community. Local specialization therefore would not seem to be a variable that stimulated the evolution of simple chiefdoms or small states during this period. The growth of large central communities, however, would act as a stimulus toward internal specialization, particularly as the overall population in the agricultural strip approached carrying capacity.

The localized distribution of resources with respect to the Basin as a whole, however, could have been a factor in the evolution of the larger centers and states during the First Intermediate Three–Four–Five, Middle Horizon, Second Intermediate Two, and Late Horizon phases and periods, since a number of key resource have very limited distribution in the Basin, and would not be locally accessible to small states. Among these would be

obsidian, lime, basalt, chert, fresh water reeds, protein foods, salt, and fine quality ceramic clays.

SPATIAL ANALYSIS AND CULTURAL EVOLUTION IN THE BASIN OF MEXICO

Recently a number of archaeologists have attempted to apply spatial models, derived from quantitative geography, to prehistoric situations. The major effort has been the application of central place theory to prehistoric societies that show clear evidence of social stratification and economic specialization. To do this they have borrowed models directly from the geographers and have applied them with very unconvincing results. We suggest that these efforts will continue to meet with marginal success until they return to the huge ethnographic literature to generate their own spatial models. The basic theory behind such models in geography is undoubtedly sound and to a great extent derives from maximization and minimization principles in economics. The point is that the geographers' models are all drawn from much more complexly organized socioeconomic systems than the prehistoric societies that we have tried to apply them to. Most particularly they derived from marketing economies and the distribution of central place relates very closely to the market principle of competition and profit.

Our best documented data derive from the Late Horizon, and this was also the phase of greatest institutional complexity in terms of the prehispanic time range. At the time of the Conquest one could define three definite levels of community stratification. The first level included the great conurbation of Tlatelolco–Tenochtitlan and its constellation of lakeshore towns. Including only those communities that were probably more urban than rural in their lifestyle (Azcapotzalco, Tlacopan, Coyoacan, Huitzilopochco, Mexicaltzingo, and Ixtapalapa), the total population of this cluster was between 200,000–300,000 people, about 20% of the population of the Basin.

The next level includes all of the dependent centers that had resident *tlatoanis*. If one counts separate physical communities this would involve approximately 40 settlements. Counting the multiple *tlatoani* communities as separate communities would raise the number to 60. These centers had populations of 2000–20,000 people and were relatively evenly distributed throughout the Basin, but with a strong tendency toward a lakeshore and alluvial plain orientation. Below this level were the thousands of rural settlements, varying in populations from a few score to a thousand or two. We would estimate that perhaps 20–30% of the population lived in the second-level communities, and the balance, 40–60%, in the rural settlements. This distribution is a reasonable one in terms of principles of social stratification, particularly if one assumes, as the data suggest, that a substantial percentage of the population of the second-order communities were farmers. Texcoco's position, in terms of the pattern, was peculiar in that it formally ranked with

Tenochtitlan politically, and exercised suzerainty, even up to the time of the Conquest, over a substantial number of communities in the Teotihuacan–Texcoco regions. Its political power, however, had suffered a serious decline after the death of Nezahualcoyotl, and Tenochtitlan was rapidly emerging as the only first-order center by 1519.

Although we have described the system as though it were a neat political hierarchy with discrete administrative domains, in fact the social system of the Basin was exceedingly complex and highly fluid. At the upper end were a number of royal families with access to the surplus labor of the balance of the population. The domains that served these families varied considerably in size, and the dependent populations of individual *tlatoanis* were in many cases physically interdigited. The relationship between the noble class and the commoners was essentially an exploitative one, although the rulers did provide economic and political services.

Much has been made of the state organized redistributive economy in the recent literature, and certainly there was a redistributive aspect to the political system of the Basin of Mexico. The degree to which taxes of agricultural surpluses were redistributed during the years of poor agricultural harvest is not clear, but considering the energetic limitations of Aztec agriculture, we doubt that the tax in agricultural produce was sufficiently large to sustain the entire population of one of the local states through an entire harvest year. In the case of the larger political systems, of course, this process could work more effectively, since small quantities of surpluses from large areas could then be diverted to small, crisis areas that were suffering from agricultural deficiencies. The highly localized nature of rainfall in the Basin would make it very likely that small areas would suffer crop crises, but unlikely that a very large area would undergo this stress. One could therefore argue that the larger political groupings did have some redistributive functions, and that this would be a major stimulus toward centralized political organization.

Another economic function of the *tlatoani* was to organize and safeguard the marketplace. What is not clear from the documentary sources, however, is whether all of the *tlatoani* centers had marketplaces. All cases of marketplaces that are known seem to have occurred at political centers, so there was a coincidence in these two functions in terms of central place. What little data we have seem to indicate that the entire range of crafts was not found in each of the market centers and that there was considerable local specialization of markets. For example, Ecatepec was a center of salt manufacture, and Acolman had a major dog market; most of the ceramics seemed to have been produced at Cuautitlan and Texcoco. Tenochtitlan–Tlatelolco had the largest market, the only one that served the entire Basin of Mexico and included the entire range of products.

Another characteristic of the market system is that most transactions really were not profit oriented, and so in this sense it was not a market economy. Recent studies of contemporary markets in Oaxaca show that most exchanges, even though they are mediated by money, are not profit oriented (Cook and Diskin 1976). The object is for people from one village who do not have ready access to a particular resource or product of that resource necessary for the maintenance of their lifestyle to obtain products from a village which is located in a favorable situation. Basically, therefore, it is a system by which a population residing in a region of great environmental diversity can obtain all of the raw materials or finished products that are necessary for its needs. As such the only marketplace that could concentrate all the necessary resources was in a major political center. Analyzing the system from an economic point of view, the prehispanic market was a special type of redistributive system.

Considering the character of the natural environment, the distribution of raw materials, the character of the market, and of the political institution, it seems obvious that the central place models produced by geographers are of only marginal value, even when applied to the Late Horizon settlement system. What we need are spatial models that derive from contemporary socioeconomic systems that are comparable to the Aztec one. When we move to the pre-Late Horizon periods the applicability of known spatial models is considerably less. What spatial model, for example, is useful for the Middle Horizon situation in the Basin of Mexico, in which over one-half of the population resides in a single central place, and the rest of the population is very unevenly distributed in the surrounding area? One could argue, as we did previously, that the significant regional unit for the understanding of the Middle Horizon settlement system should be expanded to include some areas outside of the Basin of Mexico; but, of course, as one moves further from the central city, transportation costs rise to a point where these areas can no longer be considered an important part of the immediate sustaining area of the center. Even including these areas, we do not obtain a consistent hierarchical ordering of communities. The major reason why the Late Horizon settlement system approximates most closely the known central place models is precisely because of the considerably denser population and the location of the central city at a very convenient spot in terms of transportation, particularly involving the use of the lake system. What this does is to increase the efficiency of transportation considerably beyond that of the Middle Horizon, and to provide a better geographic setting for the operation of central place principles.

Moving to the First Intermediate One period when the Basin was politically fragmented, but where we do have evidence of site hierarchy, one of the curious characteristics of the settlement system is that each of the small polities (for example, in First Intermediate Two–Three, and Second Intermediate One and Three times) reproduces the Middle Horizon pattern on a smaller scale. By this we mean that over half, in some cases nearly all of the population, is concentrated in the central community and the satellite settlements included only a small percentage of the total population. As in the case of small Aztec centers, the small First Intermediate centers were essentially large agricultural settlements. They were larger than the dependent rural settlements most probably because they were located closer to more productive agricultural land. What all of this points out is the essentially agrarian character of early states, and hence central place models will have to be adapted to this very different context.

ENVIRONMENTAL CHANGE AND CULTURAL EVOLUTION IN THE BASIN OF MEXICO

A major question that obviously would have a significant effect on the process of prehispanic adaptation to the Basin of Mexico is the possibility of significant changes in the environment, either natural or man made. Unfortunately, most of the studies that have been addressed to this question have focused on the macrochanges that occurred during the final stages of the Pleistocene. What is needed is information on relatively minor cycling in rainfall and temperature over the past 3000 years. From our previous discussion it is clear that over much of the Basin even minor variations would have striking effects on crop productivity and security.

In his 1970 report Sanders summarized the current opinion as to the possibility of minor fluctuations in rainfall. This summary was based on pollen cores described by Sears (1952) and Kovar (1970), and changes in lake levels described by Lorenzo (1956). The following sequence of events was postulated.

1. During the Early Horizon and First Intermediate One phase lake and rainfall levels were high, and environmental conditions were quite favorable for extensive agriculture.
2. During the First Intermediate Two phase the decline in *Quercus* pollen and the lowering of the lake level indicate that conditions were becoming progressively more arid.
3. During the First Intermediate Three–Four phase oak pollen and the lake level had reached a nadir, suggesting a corresponding decrease in precipitation.
4. An upswing to more favorable conditions occurred by the First Intermediate Five phase.
5. Rainfall and lake levels then dropped during Middle Horizon and Toltec times, but rose again to the First Intermediate One level during the Late Horizon.

It should be mentioned that this reconstruction of climatological events has not met with universal acceptance. For example, Kovar (1970:24) notes that the rate of evaporation of the lakes was greater than the annual contribution of precipitation. Thus, over time one would expect the lake level to decrease. Counteracting this process, as population densities increased throughout the Basin, the stripping of the original forest canopy exacerbated

the rate of soil erosion, and the net result might have been a later rise in lake levels. Unfortunately, these considerations do not explain why the lake level dropped during the Second Intermediate period.

More importantly, the reconstruction is contradicted by recent studies of the climatological history of the Puebla–Tlaxcala area, a region adjacent to the Basin of Mexico, and situated at the same elevation. One would expect close correspondences between the two areas and yet the sequence is almost reversed. Conditions are described as warmer and drier than today during the Early Horizon, gradually become colder and wetter during the First Intermediate, reaching a peak about the time of Christ, become increasingly drier and warmer to about A.D. 900, when the trend is reversed, to achieve another maximum of rainfall and minimum of temperature by A.D. 1519 (Heine 1973). Although the Valley of Oaxaca is considerably lower in elevation, (1500–1600 m), and much further from the Basin of Mexico, a recent study of climatic conditions during the Early Horizon–First Intermediate shows a close parallel to the Puebla–Tlaxcala profile (Flannery and Schoenwetter 1970). Data from the Tehuacan Valley, at the same elevation as the Valley of Oaxaca, in contrast, suggest that the present day climatic regime has been fairly constant since about 7000 B.C. (Smith 1967:249), but we wonder whether minor pulsations of a few hundred years or less would have had much of an effect on faunal–floral species composition and distribution.

It should be emphasized in all of this discussion that the changes involved are relatively minor ones, 20–30% increases or decreases in rainfall, and variations in average annual temperature of a degree or two. Such variation would not alter the basic problem of adaptation in the Basin of Mexico, but they would have significant effects on crop productivity and security. By way of evaluation, we would raise a question as to Heine's assumption that the post-Pleistocene climatic cycling necessarily involves a combination of colder temperature with wetter conditions and drier conditions with warmer temperature. This is undoubtedly the case for the major Pleistocene fluctuations, but there is a strong suggestion, from meteorological data gathered at the Tacuba station in the Basin of Mexico, that over the past 100 years there has been a correlation of low average annual temperature with dry years. A combination of this nature would of course put even more severe stresses on agricultural utilization of the Basin.

A very close correspondence between minor climatic cycling and settlement history for the Basin of Mexico should exhibit the following pattern (see Figure 9.2 for a graphic presentation of the following correlation).

1. An Early Horizon environment both cooler and drier than present; this would limit agricultural population to a very restricted area and explain the initially slow rate of population growth.
2. A succeeding period of increasing rainfall and increase of mean annual temperature through the First Intermediate One–Three period. This is a period of rapid population growth and spatial expansion.

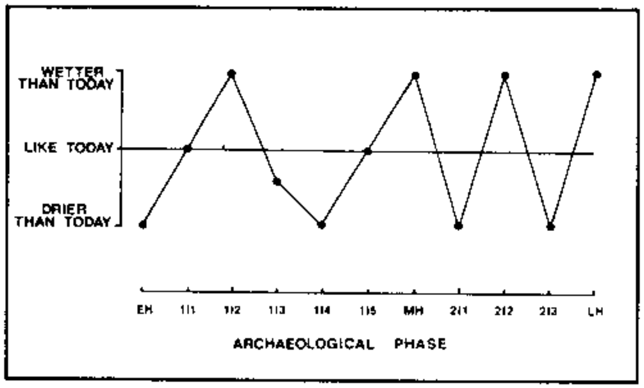

Figure 9.2. Graph showing perfect correlation between population history and climatic change in the Basin of Mexico.

3. A brief phase of cooler, drier conditions during the First Intermediate Four phase. This is a phase of rapid evolution of irrigation agriculture, relocation, and contraction of population.
4. A phase of increasingly wetter and warmer climate, coincident with population expansion into the drier portions of the Basin—the First Intermediate Five and Middle Horizon.
5. A cool, dry phase coincident with the Second Intermediate One phase, a phase of population reduction and contraction to the more favorable portions of the Basin.
6. A warm, wet phase coincident with the explosive growth of Tula, large population concentration in the drier portions of the Basin, and general expansion of the Mesoamerican frontier northward—the Second Intermediate Two phase.
7. A drier, colder phase, which coincides with the Second Intermediate Three phase, a phase of population reduction and retraction southwest to the more favorable portions of the Basin.
8. A warmer, wet phase corresponding to the Late Horizon, a phase of maximum population growth.

Unfortunately, the postulated climatic cycling does not correspond closely with this profile, but again it should be emphasized that very few excavations have been conducted to specifically define minor climatic phasing in the Central Plateau.

Another major question is that of possible environmental changes produced by the human utilization of the landscape. The most significant variables that might have feedback effects on human adaptation would be changes in soils and the water table. If swidden agriculture was widespread during the earlier phases of colonization, one would expect some erosion,

both gully and sheet, to result, particularly in the drier portions of the area, since rainfall tends to be more torrential in character, and weed and crop growth is less exuberant in such areas. It is possible that many of the deep barrancas in the area were formed as the product of this early removal of protective vegetation

Along with intensification of cropping regimes the emergence of terracing would decelerate this process considerably, perhaps even stabilize it. The most massive sheet erosion clearly occurred during the Early Colonial period, when a combination of population decline and introduction of grazing animals led to abandonment of many hillside lands from cultivation, and their conversion to pasture.

During the early phase of colonization when forests, fields, and secondary bush covered the area, many streams may well have had shallow beds and, if not permanent flows, at least periods of steady, prolonged runoff, in contrast to the present day pattern, where even the runoff from heavy rains flows only a few hours through the barranca system. The removal, first of vegetation, ultimately of some of the soil cover, would probably also affect the water table in such a way as to lower it in the adjacent plains and reduce the flow of water in the springs. In all probability there were numerous springs that no longer function. Mooser has suggested that there were springs within the limits of the Middle Horizon city that provided a flow of 100–200 liters per second. Recent measurements of the water flow for the Amanalco and San Juan springs show a steady decline since 1920, in this case brought about primarily by the perforation of deep wells.

Armillas in his study of the chinampas of Lake Chalco–Xochimilco (1971), has suggested that the sudden and explosive growth of chinampas in the lakes during Late Horizon times may have been made possible by a change in the hydrographic conditions; namely, a process of sedimentation that reduced a body of open water to a swamp. Conceivably this sedimentation could have been produced by the three major cycles of swidden agriculture: during the Early Horizon–First Intermediate One phase; during the First Intermediate Four–Five, Middle Horizon; and finally, during the Second Intermediate Two phase, when the southern Basin had a very small population.