TOPICAL REVIEW

PREHISPANIC IRRIGATION AGRICULTURE IN NUCLEAR AMERICA

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I. INTRODUCTION*

AMONG ARCHAEOLOGISTS CONCERNED WITH THE STUDY OF CULTURAL REGULARITIES in the evolution of the early civilizations, few general hypotheses have stirred such controversy as that which postulates a causal link between the phenomenon of irrigation agriculture and the origins of the state. Adumbrated initially by Karl Wittfogel in the 1920s and stated by him most completely in *Oriental Despotism* (1957), the hydraulic theory has been subject to much discussion and to varying fates in recent literature and research history. Although Wittfogel's original formulation was based chiefly on Old World data, the theory has had major impact on research and interpretation in the New. The first large-scale use of the approach in American archaeology followed World War II, when the Institute of Andean Research sponsored the Viru Valley Project in North Coastal Peru (Bennett, 1948; Willey, 1953). In recent years American archaeology has become concerned with questions of process beyond the limits of simple historical reconstruction (Binford and Binford, 1968). Concepts

* Given the recency of much of the field work cited in this paper, many substantive data remain unpublished. I wish to express my thanks to those who have graciously permitted me to quote often preliminary results of their recent work and recent thinking sent to me as personal communications. Thus, many investigators have contributed significantly to the preparation of this paper, although they are in no way responsible for its conclusions, with which many of them would probably more or less disagree. Special thanks go to Pedro Armillas for showing me selected areas of his chinampa survey in the southern Valley of Mexico; to Kent V. Flannery for taking me to Hierve el Agua, Oaxaca; to M. Edward Moseley, Carol J. Mackey, and Kent C. Day for my extremely productive stay with the Harvard Chanchan Project, Trujillo, Peru; to Richard S. MacNeish and Gary Vescelius for an instructive visit to Ayacucho; and to Thomas C. Patterson for reporting data from his recent research on the Central Coast of Peru and for copies of several unpublished manuscripts. This paper has benefited further from comments and suggestions from Edward Calnek, Marvin Harris, Jeremy A. Sabloff, and William T. Sanders.

derived from systems theory (Flannery, 1968a; Hole and Heizer, 1969) are increasingly invoked to explain the cause-and-effect feedback mechanisms involved in the evolution of culture. Concomitantly, a virtual explosion of data has occurred concerning the chronology, size, and sociological and demographic matrix of New World irrigation systems. Thus, both investigative techniques and theoretical frameworks have undergone considerable recent modification and the body of relevant data is large and growing. While some might consider the hydraulic agriculture hypothesis a dead issue, such is not the case. Changes in the total conceptual context of any theory, and new evidence both pro and con, necessitate reevaluation of the theory.

Such a reevaluation is the aim of this paper. We will not attempt an exhaustive view of all the literature on irrigation systems, but will instead deal selectively with certain problems that have constituted foci of contemporary debate. The overall perspective of this study will be ecological and evolutionary, dealing with the changing relationships through time of populations to their physical and social environments. We view irrigation as merely one aspect of a total adaptive system, with its causal nexus and its effects varying with the nature of the environment, the size and structure of the population it serves, and the overall agricultural technology. An irrigation system is seen, therefore, not as a unique entity which wherever and whenever it occurs must have everywhere the same implications, but instead as the tangible outcome of the intersection of a number of cultural processes which operate in specifiable ways under specified conditions. Since considerations of agricultural productivity in general are thus of major importance, we cannot simply dichotomize irrigated vs. nonirrigated cultivation. Irrigation is, after all, far from the only technological means used to augment agricultural production; thus its resemblances and differences vis-à-vis other such methods are necessary considerations for its study. Given a population of cultivators, their problems will vary from one environment to another. Each environment will impose different kinds of limiting factors on population growth, factors which may differ in the degree of their severity from one case to another. Thus, the adaptive responses manifested by these populations may also differ: an adaptive response in one area may not occur in another. Single-factor explanations of cultural evolution are, accordingly, necessarily limited and simplistic. In our concern with evolutionary regularities, we will treat the interaction of various processes that may in typology seem different, yet act in specifiable ways to produce similar results.

Of what Fried (1960, 1967) has termed the pristine states—civilizations whose growth was essentially autochthonous—two are located in the New World, in Mesoamerica and the Central Andes. These constitute the principal nuclear areas of the pre-Columbian Western Hemisphere, areas within which culture-historical processes had wide and significant extra-local repercussions. At the time of the conquest these regions supported unusually large populations of high density, populations characterized by the possession of social systems generally conforming to the criteria of civilization set forth by Childe (1950). The sequence of cultural development in these areas thus constitutes evidence essential to the investigation of the causal dynamics involved in the evolution of this type of society. The observation of the fundamental similarities of all these early civilizations, in both the Old World and the New, is not recent (Steward, 1949). Attaching a classificatory label such as "early civilizations" or "pristine states" is not an end in itself, but is merely a recognition of their non-uniqueness. Mesopotamia, Egypt, China, the Indus Valley, Mesoamerica, and the Central Andes share certain basic common characteristics: all are societies of large size, based on social stratification, economic diversity and specialization, and institutionalized use and control of internal and external force. Their economic bases were also remarkably similar: all the early civilizations were founded on the intensive cultivation of a cereal staple and, specifically, on irrigation cultivation. Empirical observation suggests in turn that we are dealing with a lawful, regular process of cause and effect. If these multiple instances indicate that this kind of society constitutes what Steward (1955a) calls a cross-cultural type, it remains to ask why. The observed forms are considered the results of certain regular, non-idiosyncratic factors in stipulated interrelation with each other. Thus, the forms observed are capable of explanation. It is to these problems that this paper will be addressed.

Major emphasis in American archaeological literature on the role of irrigation in the development of complex societies is notable by 1949, with the publication of Armillas' "Notas sobre los sistemas de cultivo en Mesoamerica," and Steward's "Cultural Causality and Law." A symposium at the 1953 meetings of the American Anthropological Association was published in 1955 under Steward's editorship, as *Irrigation Civilizations: A Comparative Study.* The implications of the hypothesis for research strategy had been instrumental in determining the course of the Viru Valley Project, and this influence continued into the 1960s. Both the Teotihuacan and the Tehuacan Valley Projects were in part modeled after the Viru work, and were concerned with the total relationships of populations to environments and with the history of land use. One of the principal aims of the Teotihuacan Valley Project was, indeed, the testing of the irrigation hypothesis in a critical area where data on the antiquity of hydraulic cultivation had been lacking—quite uncomfortably so—at the time of the Irrigation Civilizations symposium..

By the middle 1960s, however, a good deal of controversy attended the theory. Adams (1966) questions its utility in explaining either the Mesopotamian or the Mesoamerican sequences, while Lanning (1967) explicitly rejects the postulated causal relations between irrigation and state formation in Peru. The association of large-scale irrigation and of large-scale complex polities is not the point at issue. But a correlation is not, speaking analytically, necessarily a cause. To define a cause, both clear establishment of chronological precedence and stipulation of the mechanisms by which that cause operates must be considered. For the present, it is observed merely that after an initial impact of substantial scope on the research direction and theoretical emphasis of American archaeology, the theory is coming increasingly under fire. It has certainly been misunderstood and consequently misapplied, and there seem indeed to be a number of phenomena it explains only with difficulty, if at all. One of the purposes of this paper might be stated as that of clarification of the circumstances in which the theory has explanatory power (and why), and those in which it does not.

In neither of the New World civilizations have we any written records except for the very latest periods of their growth. We are therefore left with only archaeological evidence in answer to any questions we ask concerning their development. Much of the evidence is fragmentary and its potential significance not readily apparent. Although considerations of agricultural productivity, for example, involve material traits, the processes themselves are no longer directly observable. We will thus employ contemporary evidence in conjunction with archaeological data in an attempt to reconstruct and interpret the productive systems of the past. This in turn creates methodological problems of operationalization, and of assessment of the reliability of inference. Still further problems are raised in that much of sociopolitical organization is nonmaterial and must be reconstructed from the material remains these organizations have left behind them. Speaking more generally, we are reconstructing causes no longer directly observable from the nature and magnitude of their effects; the development of a methodology for this sort of inference is just beginning in American archaeology.

II. THE COMPARATIVE STUDY OF AGRICULTURAL SYSTEMS IN NUCLEAR AMERICA

Irrigation systems, small or large, ancient or modern, wherever they occur, generally comprise an aspect of what Steward (1955a) calls the culture core—i.e., features empirically determined to be closely connected to the subsistence base of the society or, more generally, to be intimately related to the adaptation of a population to its environment (Sanders and Price, 1968). The importance of irrigation may thus vary from one ecosystem to another. In an arid or semi-arid region, control of the supply and distribution of water may be essential to the survival of an agricultural population; in more naturally humid areas, artificial water control would be responsible for proportionately less of the total subsistence base. The drier environment can, of course, be exploited by some means other than agriculture; if so, the attendant demographic and sociological consequences will be radically different, and beyond the scope of the present discussion. No geographic area has a fixed carrying capacity; carrying capacity is instead a variable, dependent on geographic factors in interaction with the technology of the population. At least certain critical subzones of the areas in which all the early civilizations developed qualify as arid or semi-arid. It remains to investigate whether irrigation would have been either necessary or sufficient for substantial and dependable agricultural production in some of these subzones, and what other alternatives may have existed. Since the data on productivity to be presented below are modern, there may be some question concerning the reliability of projecting them into the past. The relevant methodological problems will be treated as they arise; under specified conditions it is regarded as fully legitimate and necessary to proceed in this fashion.

Irrigated and nonirrigated agriculture: productivity differentials

We cite data on production from selected areas in the contemporary Valley of Teotihuacan. The four communities compared (Sanders, 1957) differ primarily in their access to water; there are no marked differences in soil types within the valley except that differences in soil depth affect its capacity for long-term moisture retention. Sanders (1965:23) notes that the average annual precipitation in Teotihuacan Valley is 547.54 mm., occurring primarily from late May to early September, and with high probability of up to 50 per cent variation in any given year above or below this mean annual figure. While Sears (1951) postulated that the Classic period—the apogee of Teotihuacan civilization centered in this valley—was even drier than today, the evidence of the Teotihuacan Valley Project, based on diachronic analysis of lake levels and pollen cores, suggests instead the absence of any major climatic shifts from Pleistocene times to the present. Essential similarity of climate is thus one reason supporting the cautious use of contemporary production to shed light on a past ecosystem. Another such reason is that in spite of sharp differences in distribution and composition of the population, its overall size during the Classic was approximately that of the present (Sanders, 1965: Fig. 14). A point to which we shall subsequently return is that since there would seem to be at least approximate correlation between population size and agricultural intensiveness (Boserup, 1965; Sanders and Price, 1968), it is probable that the Classic productive system overall was at least as intensive as that noted at present, for at least some areas. One drawback to using contemporary production figures from this area as a reflection of the past is that the system of crop rotation practiced today—an important part of the total technology of agricculture—involves post-conquest staple crops of European introduction, especially wheat and barley. Barley in particular is a favored dry-season crop in the area because of its tolerance of both cold and drought. Another problem is that the degree to which the contemporary varieties of maize represent improvements over those planted in Classic times is unknown. However, contemporary data can suggest quite clearly the extent and significance of local variation in the productivity of the land, and the degree to which the land is modifiable with different kinds of technology.

An example of one of the poorer agricultural situations in the Valley of Teotihuacan is the community of San Francisco Mazapan, located in the middle valley above the permanent springs at San Juan, which provide water for the canal irrigation system of the lower valley. Rainfall agriculture at San Francisco (Sanders, 1957:330) will produce yields of .5 ton of maize per hectare in the first year, .5 ton of barley in the second; in 24 years a hectare of land will yield 6 tons each of maize and barley, since the land is not rested except between harvests. A more improved situation is found in the middle valley community of San Pablo Ixquitlan, where a combination of deep planting to take advantage of conserved soil moisture and floodwater irrigation techniques are used. A hectare of land in San Pablo will produce 1.2 tons of maize in one annual crop and, in 24 years of cultivation, 28.8 tons.

Permanent canal irrigation is practiced today in the lower valley, below the springs at San Juan. The most advantageous situation is that of Santiago Atlatongo, the only community with rights to unlimited access to water (Sanders, 1957, 1965; Millon *et al.*, 1962). A hectare of perennially irrigated land will produce in its first year 2 tons of maize and 2 of wheat, normally with at least one and usually two irrigations per crop. In its second year, the yield is 1.4 ton of barley; over 24 years the total production will be 24 tons each of maize and wheat, and 16.8 tons of barley (Sanders, 1957:330). A more representative situation is found at Calvario Acolman, where water is rationed and farmers are restricted in the number of irrigations they can give per crop. This fact is reflected in the lower yields per hectare in this situation of "medio riego:" 1.35 tons of maize and 1.1 tons of wheat in the first year, .9 tons barley in the second. In 24 years of continuous production a hectare will yield 16.2 tons of maize, 13.2 tons of wheat, and 10.8 of barley.

Several observations may be made on the basis of the preceding data. There is an obvious difference in the productive regimes of the middle and lower valleys, in that only in the lower valley is a dry-season crop possible. Within the middle valley, rainfall agriculture alone produces the lowest yields. Production is improved over 100 per cent with the use of more intensive methods—deep planting and floodwater irrigation. Floodwater irrigation, unlike the canal system, is, however, restricted to the rainy season. In that the rain will occur earlier on the hill slopes and generally be more abundant there than on the valley floor (Sanders, 1965:24), this permits a farmer to plant earlier, and his crop to receive more water, than would be the case with exclusive dependence on rainfall. Since the growing season for maize is limited by fall frosts from October to March (the area lies entirely above 2,000 meters altitude), the earlier planting possible with floodwater irrigation provides an insurance against crop destruction by frost. But since no floodwater occurs during the dry season, only one crop a year is possible.

For the lower valley, permanent springs provide irrigation water for double-cropping. Availability of water rather than of land today limits the expansion of the agricultural system (Millon, 1954; Sanders, 1957, 1965): there is more potentially irrigable land than there is water supply. Thus, the enormous productive differential between rainfall and irrigation farming is best shown in the yields of Santiago Atlatongo, where farmers often provide two irrigations each to the maize and wheat crops, or four per year. This is not possible in other lower valley communities, where water restrictions make three irrigations per year a maximal figure, and yields are correspondingly lower. The canal irrigation offers all the advantage of the floodwater system—permitting sowing prior to the onset of the rains, making available additional water during growth (often critical in the frequent years of below-average rainfall). In addition, the permanence of the water source permits a winter crop as well, particularly of a frost-resistant cultigen such as wheat. The use of artificial water sources increases yields substantially, and minimizes risk of crop loss in a bad year.

The question of the necessity of irrigation for the production of maize in Teotihuacan Valley is an old one. Gamio (1922) concludes that it is necessary, while Armillas (1948) suggests that it is not. Millon (1954) supports Gamio, particularly in view of the suggestion that the Classic period may have been significantly drier than the present. The question thus asked, however, is simplistic in ecological terms. Clearly irrigation is not "necessary" to produce a crop, in that an agricultural population inhabited the Teotihuacan Valley prior to the development of techniques of artificial water control; some farmers even today produce a maize crop through exclusive dependence on rainfall. Evaluating the efficiency of an agricultural system depends not only upon strictly climatic considerations, however, but also upon the size of the population involved. Every techno-environmental system everywhere has within it varying factors which act to limit population growth. Such factors, empirically, will not be everywhere the same ones. As a population possessing any exploitative technology approaches the carrying capacity of its environment under that regime, there will be population pressure which, over time, will act to stabilize further growth. Emigration, famine, malnutrition and disease, competition and conflict are all natural means of inhibiting growth and permitting a population to be contained at the level permitted by its food supply, whether this food is naturally occurring or artificially produced.

Technological changes are considered adaptive when they result in a *substantial increase in the numbers and densities of human beings, or in he markedly increased efficiency of the individual human producer* (Sanders and Price, 1968:9; italics theirs). In an environment such as Teotihuacan Valley, irrigation would clearly represent one such adaptive change. We will discuss the question of the chronology of irrigation in a later section of this paper. For the moment, we consider the demographic situation of a population that has reached a ceiling to be of fundamental importance in technological change. If the origins of innovation are regarded as essentially random, the survival of innovation is non-random. A population at or near its limit will be most likely to adopt any technique that will increase productivity, even where such a technique involves greater labor input. As Boserup states (1965:117):

> As long as the population of a given area is very sparse, food can be produced with little input of labour per unit of output and with virtually no capital investment, since a very long fallow period helps to preserve soil fertility. As the density of population in the area increases, the fertility of the soil can no longer be preserved by means of long fallow and it becomes necessary to introduce other systems. . . .

The overall history of both Teotihuacan Valley and the Valley of Oaxaca in Mesoamerica, and of the Viru Valley in Peru tends to substantiate this relationship.

Under these circumstances, what irrigation does is to remove one of the major environmental limitations on demographic growth or, rather, to raise its ceiling significantly and permit the stabilization of population at a higher level. Phrased another way, it raises the total carrying capacity of the land. The question for Teotihuacan Valley is not one of the necessity of irrigation for the production of the staple crop, maize, in this environment. Instead, it concerns the extent to which the presence of irrigation raises, and its absence lowers, the demographic limit for a population dependent on the cultivation of this staple.

Teotihuacan Valley is actually not an extreme example for the question of the necessity of irrigation—in most years sufficient rain falls to produce at least some maize. It is not an either-or, but a more-than-vs.-less-than situation. The Nile Valley or the Mesopotamian Plain, with little or no precipitation, would be entirely dependent on artificial control of exotic water if an agricultural population is to live there at all. For Mesopotamia, Braidwood and Howe (1962:140) postulate that the occcupation of the riverine plain by cultivators did not occur until Halafian times; Adams (1960:25) suggests that until then the population of the alluvial plain consisted primarily of riverine food-collectors, with the cultivators living elsewhere. We suggest that the effective agricultural utilization of this area, under natural conditions either swamp or desert, would not have been possible without the use of artificial water control. This is a kind of necessity that is lacking in Teotihuacan Valley, but would for the most part obtain for most of coastal Peru.

The foregoing considerations are clearly recognized too by Wittfogel in his concept of hydraulic density. Hydraulic density is highest in those situations where all water is exotic, where cultivation depends entirely upon the artificial creation of oases, where the difference in agricultural productivity between nonirrigated and irrigated land is the difference between zero production and any production, and where a population is thus entirely dependent on irrigated land for its subsistence. Hydraulic density lowers in proportion to the increased relative productivity of nonirrigated land, whether through the cultivation of alternative drought-resistant crops or through nonagricultural exploitation of alternative resource bases. The concept merely describes the degree of dependence of producers upon an irrigation system and, thus, the impact of such a system on a total economy. Hydraulic density would today be clearly higher for the inhabitants of coastal Peru than for the inhabitants of Teotihuacan Valley. In turn, it would be higher for Teotihuacan Valley than for the Valley of Guatemala, where rainfall agriculture is not only possible but is indeed the only system generally practiced, and where there is no lack of rainfall.

In the agricultural regime briefly summarized for Teotihuacan Valley, two principal techniques of raising the demographic ceiling imposed by low rainfall—canal irrigation and floodwater irrigation—were discussed. One major reason for the frequent misinterpretation of the hydraulic theory is that, in our view, canal irrigation is often considered as a unique entity. We prefer at this time to stress instead its functional similarity to other technological means of solving the problems of a growing population of cultivators in an arid to semi-arid environment. If, as the Teotihuacan data cited thus far suggest, the major effect of artificial water control is to increase production, then there are seen to be a number of other ways to accomplish this end. Irrigation, in sum, must be viewed in context—as part of the more general question of agricultural intensification.

Types of agricultural system

The classification of agricultural systems along a continuum of relative intensiveness involves the manipulation of two major parameters, land area and labor input, in relation to each other. More extensive systems involve comparatively larger areas, combined with comparatively little labor to produce a crop; more intensive systems compensate with greater labor input for a lesser quantity of total land exploited per cultivator. This continuum has been divided in somewhat different ways by Wolf (1966:20–21), who considers hydraulic agriculture a subtype, and by Boserup (1965:15–16), who regards it as one possible variant of intensive agriculture. For both, the relative length of the fallow portion of the cycle is an important diagnostic of labor input per unit of land; in general, the shorter the fallow, the more intensive the system. The differences between Wolf's long-term, sectorial, and short-term fallowing systems represent points along the continuum; similarly does Boserup's distinction between forest-fallow and bush-fallow. The distinction of subtypes may vary, depending in part upon environmental variables; all very broadly constitute variants of what is essentially slash-and-burn, swidden, or shifting cultivation. In contemporary Mesoamerica a highland variant of comparatively long duration, called *tlacolol* by Lewis (1951), may be distinguished from the classical tropical lowland forest swidden systems. The major differences are environmentally conditioned; if lowland soils are more subject to loss of productivity through leaching and through weed competition than are highland ones, then lowland fields must also be fallowed more frequently. In comparing the extensive systems of the lowlands and highlands of Mesoamerica, the minimal fallow period possible with maintenance of productivity depends on the time minimally necessary for the growth of more easily cleared woody plants to the point where these are dominant over herbaceous plants. In the highlands, control of competing vegetation is generally easier, and the soils are less subject to fertility loss through leaching; the major problem in many parts of the highlands is rather erosion on slopes, unless technology—and thus labor—is expended to control this factor. Typical of nearly all relatively extensive systems is that productivity is dependent primarily upon the characteristics of the natural environment itself, far less upon human modification of these characteristics.

Productivity of land per hectare under extensive cultivation is thus extremely variable. Furthermore, most total habitats contain within them niches of greater or lesser productivity, given equivalent labor input. The differential utilization of such natural differences may be the first small, almost accidental step toward overall maximization of what a region as a whole will produce. In general, the first cultivators in a region will tend to select those lands which are most productive; as an area fills up, there will be competition for these lands, and only when they are all occupied will people tend to exploit other niches. In extensive cultivation, factors such as soil type and quantity of precipitation affect crop yields directly, and also indirectly as well: these would be major determinants of the speed of regeneration of natural vegetation, thus affecting the frequency of planting of any given plot and thus its productiviy though time.

Extensive cultivation in some environmental settings can be enormously productive. At El Puente, Tabasco, in the Grijalva flood plain (Sanders, 1957:312), land is planted two years in succession for a total of three crops, two summer and one winter. The first crop yields some 2,500 kg. of maize, followed by a winter crop of 1,500 and a second summer crop of 1,500 kg. per hectare. The land is then rested for six years, for a 1:3 cycle, unusually short for swidden agriculture. The total yield per planting cycle per hectare is thus some 5,500 kilos of maize, and over a 24 year period to allow for fallow, some 18 tons of maize. Yields reduce somewhat per planting if a 1:2 cycling is used instead of the 1:3.

Yields per planting are thus better than yields from floodwater-irrigated lands in Teotihuacan Valley, and with considerably less labor input; they nearly approach the yields possible only with permanent irrigation. But the differences between these systems show in the need for the larger landholding required by the Tabascan farmer to accommodate the fact that a sizable percentage of his land will be in fallow in any given year. As Sanders points out, moreover, the Grijalva floodplain is probably the best land in the area, in terms of both its productivity per planting and in the frequency with which it may be cultivated. Steggerda (1941), working in northern Yucatan, a subhumid area with extremely thin soil, is dealing with far less than an optimal situation. A first-year milpa will produce 1,500 kg. of maize per hectare, but this yield drops to 600 in the second year, with no dry season crop; a field is cultivated two years and then rested 8–12, for a 1:4–1:6 cycle. Over 24 years a hectare will produce only 3.2 tons of maize. In parts of the Yucatan peninsula where population is extremely small, such as Quintana Roo, even the length of the optimum or that of the minimum permissible fallow cycle is unknown (Sanders, 1957:231). There is plenty of land, few people, and it is easier and more productive to cultivate new land each year.

Variations of slash-and-burn agriculture have been discussed at such length in a paper ostensibly devoted to a discussion of the development of irrigation, for several reasons. It may be well to summarize them at this point. First, whatever else irrigation may or may not explain, it is a system of agriculture which, where used, increases productivity per hectare over the yields possible without its use. It is thus advisable to examine irrigation systems within this more general context; it is only one of a number of alternative means of increasing productivity. The variations observed in contemporary nonirrigated cultivation can provide a baseline, and can delineate the range of productivity of extensive systems in a variety of environmental settings. This is essential for comparative purposes. Even within extensive systems, certain types of intensification are possible and, under some circumstances, practiced. We have observed that differential land utilization within a habitat which, while requiring perhaps little additional labor input, nonetheless acts to maximize production, can, like many labor-intensive situations, generate competitive pressures with a growing population.

As the following section of this paper will elaborate more fully, extensive cultivation is not only logically and typologically simpler and less expensive in terms of capital and labor requirements, but it has chronological priority as well. Extensive cultivation, of one type or another, in some areas, at some points in time, is succeeded by more intensive cultivation, which may also assume several forms. In other areas, extensive cultivation persists into the present. The result of any intensive form of production is the maximization of yield per unit of land even where this is accompanied by a decrease in yield per unit of labor invested. We are thus dealing with the general question of changes in human behavior through time. It is simplistic to assign any unique explanatory priority in cultural evolution to the development of irrigation alone—or to any single system of production—without careful comparative analysis of its function within the ecosystem as a whole.

III. THE INTENSIFICATION OF PRODUCTION: VARIATION AND CHRONOLOGY

Typologically and chronologically, extensive systems of production are simpler and in general earlier than intensive ones. This is not to imply that everywhere intensive cultivation has replaced extensive. Extensive systems similarly vary among themselves in the amount of labor involved, in their productivity, and in the extent to which additional labor input can significantly raise production. A combination of environmental and demographic factors is regarded as the most powerful determinant of the form of any productive system. Similar parameters must be invoked to explain why particular means of intensifying production were adopted in some areas at particular points in their development. The ultimate effects of technological change cannot be analyzed without reference to the antecedents of such change. While a change from a longer to a shorter fallow cycle is per se a technological intensification of production, the changes to be considered in this section will differ in that they involve human modification of the environmental parameters themselves through technological means. In this respect they differ in principle from other observed changes in land use patterns. The systems to be described below are various; canal irrigation in some ways resembles, in other ways differs from, other members of the class of types of intensive agriculture.

Thus far, the chronology of intensive agriculture in the New World is unclear. Current trends, the result of recent research, have been to consider such phenomena considerably earlier, in both absolute and relative terms, in comparison to the estimates of only ten years ago. The origins of domestication in some areas now go back to approximately 6,000 BC for some cultigens. Palerm (1955) could cite no specific archaeological evidence for irrigation in Central Mexico prior to the Postclassic. On the basis of sound reasoning and indirect evidence, Armillas (1951) believed that intensive systems of production in Central Mexico were at least Classic in date, associated with the florescence of Teotihuacan. Steward (1955b) concurred with Armillas that what seemed in every typological respect to constitute an Irrigation Civilization, but which yet evidently lacked irrigation agriculture, was anomalous. To Armillas, the contrasts of size and scale, and of those material remains that indicate the characteristics of sociopolitical organization—contrasts between Teotihuacan and its antecedents—indicated a fundamental economic change. Additional evidence adduced by Palerm for probable antiquity included the almost pan-Central Mexican distribution of irrigation at the time of the conquest, and the great degree of dependence of these populations on this mode of production at that period. These are still valid arguments. Furthermore, the use of certain kinds of indirect archaeological evidence must be considered legitimate, justifiable, and necessary. In a sense, the very lack of substantive data on a topic regarded as of fundamental explanatory significance in the 1950s was itself a major determinant of research strategies in Mesoamerica to the present time. The result is that at this writing, concrete data exist to demonstrate the existence of irrigation in parts of Mesoamerica well into the Formative period. It is interesting, though hardly surprising, that these data derive from the central highland area, where irrigation techniques were of known importance in the Postclassic. For Mesoamerican agriculture it is in these areas, not the lowlands or the coast, where aridity is likely to be the principal limiting factor in productivity or expansion.

By the middle 1950s, however, the antiquity of irrigation in coastal (particularly north coastal) Peru was well documented. Collier (1955) affirms an economy based on canal irrigation by his Late Formative and infers the beginnings of this pattern in the Early Formative (Early Intermediate Period and Early Horizon, respectively). The Viru Valley Project had both direct evidence in the form of datable ancient canal systems, and indirect evidence based on the number, size, and location of settlements. By some inexplicable paradox in the research history of the past two decades, the balance of data between Mesoamerica and the Central Andes has more than been redressed. If the model for this kind of investigation was developed initially in Peru, the impression at this writing is that after the pioneering work of the Viru Valley Project, Andeanists turned most of their attention to other problems. It was left to researchers in other areas, largely in Mesoamerica, to refine the original models and explore their implications. Since the current revival of interest in processes and patterns of land-use systems in the Andes is extremely recent, and little data from this renewal of research effort have yet been published, the present discussion necessarily compares relatively recent Mesoamerican data with relatively familiar Peruvian evidence. Much of the former will thus be considerably fuller, reflecting greater sophistication in data collection and interpretation.

This is unfortunate, for the overall similarities in cultural development between these two regions are striking, so much so that the lack of comparably detailed data for critical and presumably comparable stages in each is frustrating. In parts of both these highly complex and internally diverse environments aridity is a fundamental challenge to cultivators. It is interesting that in Mesoamerica lack of water is a problem primarily in the highlands, while in Peru it is the Pacific coast that is nearly desert. Thus, in Mesoamerica the heartland of the origins of domestic maize became in later times the area of greatest antiquity and greatest diversity of techniques of agricultural intensification involving water control. In Peru, on the other hand, the area in which cultivation was most probably developed—the highlands—is almost unknown in terms of its history of land use; the antiquity of irrigation in the Andean highlands is as problematical now as it was in 1955. Finally, the relationship between irrigated and nonirrigated areas in Mesoamerica has been sufficiently clarified at present to permit some statement of cultural dynamics, while no such interpretative possibilities exist for Peru, where we cannot be certain that an unirrigated area is so merely as an artifact of research or its lack.

Irrigation is merely one episode in the overall evolution of agricultural systems. For Mesoamerica, two areas, the Valley of Oaxaca and Tehuacan Valley, have yielded virtually entire local sequences, from the apparent initial experimentation with domesticated foods into the beginnings of the application of labor-intensive techniques of food production, and well into the historic high civilizations. Preclassic irrigation is known from the site of Amalucan, Puebla. The Teotihuacan Valley provides somewhat later information than Oaxaca and Tehuacan, probably as the function of a somewhat different demographic history. If the succeeding discussion should seem sketchy, this fact reflects the incompleteness to date of publications of work that is still in progress.

Mesoamerica

Flannery *et al.*, (1967) and MacNeish (pers. comm.) have suggested that some form of water control is probable as early as the development of agriculture. At the very least, an agriculturally based population will tend to utilize differentially the various sectors of its environment. This differential land use is the basis of what Wolf (1966) calls an infield-outfield system, and is theoretically possible whatever the components of that system in terms of labor; irrigation, for example, is not necessary. If any type of niche within a habitat is naturally more productive, and is thereby cultivated more actively than other, less productive niches, then an infield-outfield system is present. Coe (1968) has suggested this as the economic basis of the site of San Lorenzo as early as the San Lorenzo phase (1200–900 BC). The favored zone, potentially capable of supporting a virtually permanent agriculture, is the natural levee area of the Río Chiquito; its fertility would be annually renewed by flooding. The outfield sector of the economy would be slash-and-burn cultivation (length of fallow cycle unknown) in the less desirable non-riverine areas. Neither infield nor outfield component was ever irrigated; the annual flooding of the river levees was important to agriculture not in that it provided water, but preeminently in that it provided fresh soil. Southern Veracruz is not overall a notably arid zone.

In the Valley of Oaxaca, by the Middle Formative, more advanced techniques of agricultural intensification are clearly documented for the San José (1200–900 BC) and Guadalupe (900–600 BC) phases. For the San José phase (Flannery *et al.*, 1967; Flannery, 1968b.), most settlement is concentrated in an alluvial area with a water table 3 meters or less from the surface; little habitation is found in areas of lower water table, suggesting differential environmental utilization. A system Flannery calls pot-irrigation is still practiced in this sector of the Valley of Oaxaca, where a series of wells tap the high water table:

> An acre of land may have ten of these small wells, which are filled in during the plowing season and then reopened when water is needed. Water is drawn up from each well in a 3-gallon pot and poured gently around the individual corn plants. By means of this system, farmers within the 3-meter water-table zone often achieve three harvests a year. At any time of the year, dry season or wet, this belt of pot-irrigated allu-

https://doi.org/10.1017/S0023879100041054 Published online by Cambridge University Press

vium resembles a huge patchwork of small but highly productive gardens. *Riego a brazo* requires no large labor force or centralized control; it is carried out on an individual-household basis. However, the zone where this technique can be used constitutes a very small percentage of the valley-floor area in Oaxaca . . . it cannot be used at all in low-water table areas like the Valley of Tehuacan (Flannery *et al.*, 1967: 450).

This technique is associated with other labor-intensive techniques for increasing yields, such as seedbedding and transplanting; thus land need not be rested at all, even between harvests.

Orlandini (1967) reports the excavation near Mitla of such a well, associated with artifacts of the Guadalupe phase. While there is no indication that the technique was exploited as intensively as observed at present, there is conversely no indication that it could not have been. Population was not small—the San José phase at San José Mogote occupied an area of some 20 hectares, and clearly non-agricultural specialists on at least a part-time basis constituted part of the population. Population growth continued into the Guadalupe phase. Even in Middle Formative times the Valley of Oaxaca shows a level of agricultural and sociological development well removed from earliest beginnings. While apparently not so large or so politically complex a society as Olmec, the Valley of Oaxaca engaged in regular trade relationships with the Gulf Coast. Once a technique such as pot-irrigation was developed, its geographical expansion into all those limited areas suitable for its use would probably have been rapid; the evidence for this conclusion is in the increasing numbers and sizes of village sites through the period.

Early in the Late Formative (Monte Alban I) Flannery notes the expansion of settlement into other environmental niches, outside the zone of high water table—additional evidence of the rapidity with which the latter zone had filled in demographically:

Most sites outside the high alluvium at this period are on perennial streams, and, like the present villages of the piedmont zone, they are located not downstream, at the point where most water is available, but upstream, where the water can be most effectively diverted for irrigation (Flannery *et al.*, 1967: 453).

The site of Hierve el Agua (Neely, 1967) dates from this Late Formative Monte Alban I phase. It covers a square kilometer of hillside below a series of springs rich in travertine which have, in the course of time, effectively fossilized the entire system. This complex involves dry-stone terracing of the slope, a series of catchment basins, and main and subsidiary canals feeding the terraces, all completely traceable. The number of similar sites is unknown, but it is highly unlikely that in any respect other than its spectacular preservation Hierve el Agua is unique.

Any type of differential land use would, with growing population, tend to stimulate competition and demographic pressure. Some lands, naturally more productive, would tend to fill up first, and only later would people begin to occupy less favorable zones, less productive and requiring greater labor. The result of this process of demographic expansion may in time lead to diversification of production within the region as a whole—differential crop repertoires in different niches, for example, or different technology applied to agricultural production in these varied niches. Canal irrigation in the slopes adjacent to the Valley of Oaxaca was important in that it opened up a new sector for agricultural utilization:

In Oaxaca, canal irrigation of the Hierve el Agua type is applicable to a very tiny portion of the valley, and it is no more productive (in terms of labor input relative to crop yield) than pot-irrigation. Moreover, many canal-irrigating villages are so high in the piedmont that only summer crops can be grown. What canal irrigation *did* do was to open up an additional niche within the valley which had not previously been agriculturally productive (Flannery *et al.*, 1967: 453).

This we interpret as at once a result and a cause of population pressure. Demographic expansion in the zone initially favored for cultivation entirely filled that niche with the existing technology. Two probable responses occurred: 1) population was forced into less productive zones and 2) in the favorable zone itself there was a probable intensification of technology to the limit of the regime. Process 2) would have begun to occur as well among the inhabitants of the marginal or fringe zones. That the empirical results—in the high-water-table zone the production of three harvests per year, in the piedmonts canal irrigation of probably a single crop—were different reflects the difference in environmental setting. Techniques applicable to one setting did not work in the other.

It is unfortunate that another early site of irrigation is thus far published in only sketchy preliminary form (MacNeish, 1964). The dates are again Middle to Late Formative, and the type of system seems quite different from the type noted for Hierve el Agua. On the basis of personal communications from NacNeish and from Woodbury, and on the basis of the geomorphological report of Brunet (1967), it seems that impounding of water by damming a *barranca* was involved. The full reports are as yet unpublished. MacNeish (1964) estimates a population of between 1,800–3,600 people for Tehuacan Valley during the relevant Ajalpan and Santa María phases; some 60 sites are known for these periods. Chronologically there seems to be on the basis of published data, a correspondence with at least the later phases of the San José-Guadalupe-Monte Alban I sequence of the Valley of Oaxaca.

In spite of the considerable environmental differences between the Tehuacan Valley and the Valley of Oaxaca, these two areas share certain basic similarities. Both lie predominantly in the *tierra templada* altitude zone (1,000–2.000 meters elevation) and both are semiarid. Sanders and Price (1968) have suggested this environmental setting as a natural habitat of wild maize. In the tierra templada, frost hazard is lacking; Flannery *et al.* (1967: 449) observe that the Nal-Tel and Chapalote varieties of maize are not well adapted to the *tierra fría* zone above 2,000 meters. Thus, both the Tehuacan Valley and the Valley of Oaxaca show long local sequences from Archaic food-collectors through incipient to progressively more intensive agriculture. More detailed comparisons will be possible, however, only when both the Oaxaca and the Tehuacan Projects are fully published.

The sequence in Teotihuacan Valley is sharply different, in that the earliest components are lacking. Indeed, if the suggestion of Tolstoy and Paradis (1970) is adopted, it may be that the entire Basin of Mexico was only sparsely populated until rather late in the Middle Formative. The evidence of Teotihuacan Valley suggests that its heavy agricultural occupation does not begin until early in the Late Formative, with some late Middle Formative traces. Since the entire Valley of Teotihuacan lies in the tierra fría, it would have constituted a relatively marginal agricultural setting, given its combination of aridity and frost. With reference to the Basin of Mexico itself, it is marginal, just as the Basin would have been marginal to areas such as Oaxaca, parts of Puebla, and probably Morelos, given an essentially extensive productive system.

It is primarily the evidence from diachronic settlement patterns that demonstrates the shift from extensive (tlacolol) to intensive (irrigation) cultivation in Teotihuacan Valley (Sanders 1965). Following the suggestion of Armillas (1951) we regard this shift in productive techniques as basic to the emergence of Teotihuacan civilization. If evidence from Oaxaca and from Tehuacan is important because of the local continuity of incipient to intensive agricultural practices, it is overwhelmingly in Teotihuacan Valley that we have our best linkage to date between intensive agricultural practices, productivity, demographic growth, and the emergence of a sociopolitical organization of a particular type. That irrigation is later in absolute time in Teotihuacan Valley than in Oaxaca is a function of the differential demographic history, largely a product of the fact that Teotihuacan Valley would have been marginal for cultivators of the early varieties of maize, and would have been avoided for settlement where more favorable areas (such as the southern part of the Basin of Mexico) still were available for occupation.

The chronological phasing in Teotihuacan Valley includes a sequence from Altica (similar to and perhaps slightly earlier than Vaillant's El Arbolillo materials), Chiconautla, Cuanalan (generally resembling Late Ticoman), Patlachique-Tezoyuca, and Tzacualli (Teotihuacan I). Altica, the earliest agricultural occupation, is scanty, but the sizes and numbers of Formative sites taken together suggest a steady population growth in the valley through the period. Prior to the Cuanalan phase, the bulk of settlement occurs in the higher, steeper slopes of the Patlachique Range (Sanders, 1965), with little occupation in or adjacent to the alluvial valley floor. These hilly areas are today badly eroded, cut by barrancas and with frequent exposure of bare *tepetate*—a pattern probably postdating the concentration of settlement here (Sanders, 1965: 154). Sanders feels that the Formative population prior to Tzacualli was small, probably not more than 10,000, and that the sites were for the most part small shifting hamlets:

> Fifty-nine percent of all pre-Tzacualli sites were located on the elevated southern flank of the Valley and 81 percent in terrain located above the major Classic and post-Classic settlement. This predilection for hilly or elevated terrain obviously reflects a strikingly different pattern of land use than in later times (Sanders, 1965: 154).

The implication of the settlement pattern evidence is that the valley bottom was used only sporadically, if at all, for agriculture. With so small a population, there would have been comparatively little need to conserve land by concentrating residences away from farmland, and the settlement in the hills suggests that these slopes were at the time the most favorable areas. This, plus the fact of settlement instability, suggests a tlacolol type of productive system. Under such a regime the alluvial valley floor is actually a poor niche; rainfall is earlier in onset and is more abundant in the hills, and it is the lower-lying areas that are more subject to frost (Sanders, 1965:155). By Cuanalan times, the type site is a comparatively large nucleated village at the edge of the alluvial plain, and by Tezoyuca times, there is a large settlement at the archaeological zone of Teotihuacan (Sanders, pers. comm.). This implies the beginnings of the downward shift of population as, presumably, the demographic pressure in the hills built up and the erosion problems concomitantly became more acute.

Thus a new zone necessarily came under cultivation. Given the tremendous population growth accompanying this shift, it is extremely probable that something other than rainfall agriculture was used. That the new zone became significantly more productive than the old, and the formerly favored area became demographically marginal, indicates that major technological change was involved. Sanders (1965:151) cites the botanical evidence from pollen cores analyzed by Anton Kovar; cores taken from the springs at El Tular near Atlatongo show a sudden drop in the percentage of sedges from 30–37 per cent to 2–10 per cent of the samples. Since there is no other evidence, from pollens or lake levels, of any valley-wide climatic changes or general dessication, the implication is that the water from the springs was artificially taken elsewhere, thereby drying up the swampy area at the margins of the springs themselves.

In the hill slopes of Cerro Gordo an anomalous pattern of drainage observed today is postulated to be the result of former human activity in the area. These changes would be difficult if not impossible to date, even more so than actual canals, which can be dated only by demonstrated association with settlements. Thus the features to be discussed below are of unknown age:

> Several cases of small barrancas whose topographical relationships were divergent from the natural hydraulic pattern were noted in this area. . . . Several cases were noted of structures that appeared like small barrancas, but in which the flow was inverted; that is, a barranca would feed off a large barranca at its source and diverge from the path of the main barranca as it ran downslope. In several cases the small barranca would run from one large barranca to another, a pattern that never occurs in natural drainage, but which is typical of floodwater canals today. . . . We feel certain that they are not natural features and the probability that they are ancient canals is very high. They have no functional relationship to modern floodwater irrigation and terrace systems in the Cerro Gordo area. . . . (Sanders, 1965: 148–149).

Thus, in Teotihuacan Valley we have no direct evidence of Classic irrigation, of either floodwater or permanent type. No canals were located in datable contexts or in direct association with settlements. Our inference that Classic Teotihuacan was irrigation-based relies on indirect evidence of several kinds—botanical data suggesting the drying out of the immediate margins of springs, and aberrant drainage patterns on hill slopes that might represent abandoned canals eroded into barrancas. Probably our most conclusive evidence for a major shift in land use, however, is based on exactly the reasoning that led Palerm, Armillas, and Millon to call Classic Teotihuacan an Irrigation Civilization in the 1950s—the evidence of demography and settlement pattern. Beginning as early as Cuanalan times, there is a progressive downslope movement of population concentration. At first tentative, it is well established by the Classic, when most of the population of the valley actually lived at the city itself. The shift in settlement location is correlated with an increase of population to some 135,000, with some 85–100,000 actually living in the city (Millon, 1967). Lower Teotihuacan Valley—when irrigated, the prize agricultural land today—shows very few settlements contemporary with the zenith of the city, and those rural villages which existed seem to have specialized in maguey cultivation in the upper piedmonts (Sanders, 1966).

The location and form of the city further suggest an irrigation base. While the geomorphological history of this valley is thus far only incompletely known, it is possible (Mooser, 1968) that the location of the springs now at San Juan may have been closer in the past to the Classic city, and that springs now dry formerly existed at the base of Cerro Gordo at the city's northern edge. Teotihuacan's location is strategic with reference to a permanent water supply for the lower valley. The city, moreover, crosses the Río de San Juan, which is canalized where it traverses the settlement in order to make it conform to the grid of streets (Millon, 1967). An elaborate drainage system carried rainfall from individual patios of apartment houses, into gridded alleys, ultimately to the drains of the main street (Miccaotli) and into the river. The existence of a system of drains by no means constitutes a "hydraulic society," in Wittfogel's or any other terms. It cannot do so, primarily because the crucial factor—augmenting productivity and thus the size and total energy content of the society—is lacking. It does, however, indicate that a complex technology of water control existed, a technology which could also have been available for application to agriculture. Indeed, for a city the size of Teotihuacan to have been supported at all, it must have been so applied.

Direct evidence of canal irrigation during the Formative is, however, present at the site of Amalucan, in addition to the Oaxacan and Tehuacan evidence previously cited. Located from suspiciously regular lines of unknown function on aerial photographs, (Fowler, 1966, 1969), the canals, when trenched, are seen to be deliberately excavated into a clayey subsoil and show a complex stratigraphy of silting and cleaning (Fowler, 1969). Concerning its source: ". . . the main line connects with an irregular line wich seems to be the scar of an old barranca or stream bed which is not man-made" (Fowler, 1969:213). The entire Amalucan site is of Formative date. Fowler cites radiocarbon dates from a similar site at Totimehuacan, not far away, as 500–200 BC, for materials similar to those of the large mound 1 at Amalucan.

This provides a tentative latest date, for

> . . . the line indicating the canal on the aerial photograph runs directly into the side of the main pyramid, mound 1. Some of the aerial photographs studied show that the line continues on the other side of the pyramid. This *suggests* that the canal system may have been in existence before mound 1 was constructed. . . . This land, in other words, may have been reclaimed from its use as a water-distribution system to one where the main ceremonial and political precinct of the town was built (1969: 215).

It is in the Classic, however, that we have our first evidence of what might in demographic terms be called a large-scale hydraulic system—large-scale in terms of the total population dependent on it. We shall later return to the problem of relative scale, in the next section of this paper. At this point, we merely observe that such a system, even if inferred on the basis of largely indirect evidence, has ample precedent from the area broadly termed highland Central Mexico. Artificial water control exists, if on an expectably smaller scale, from the Middle and certainly into the Late Formative. Thus, the Classic system would have a long period of technological experimentation behind it; this seems, in our view, to add weight to the probabilities for the interpretation of the Classic. The irrigation system of Classic period Teotihuacan Valley was probably very similar to hydraulic systems known from much of the Basin of Mexico in the Postclassic.

When the Classic is compared to the Postclassic, however, the differences in distribution become apparent. These in turn correlate with demographic differences for the Basin of Mexico as a whole. If, however, the change between Formative and Classic is viewed as a change in principle—a quantitative change of such an order as to be considered a qualitative change—that between Classic and Postclassic is by comparison merely quantitative. The Postclassic can be pictured as a period of demographic filling in, of population maximum, and of concomitant spread of the economic and productive patterns of the Classic to larger areas. If Teotihuacan Valley during the Classic was densely populated and intensively cultivated, the adjacent Texcoco Plain was not. J. L. Parsons' (n.d.) survey indicates a scanty Classic population, concentrated in the piedmonts, with little evidence of any but sporadic agricultural use of the alluvial plain. Sanders (pers. comm.) has suggested that this area in Classic times constituted an agricultural hinterland, worked with extensive methods, for the population concentration at Teotihuacan. The model here (Sanders and Price, 1968:150) is of a magnified infield-outfield system. The tendency from Classic times to the conquest was one of the expansion of infield (intensive) techniques at the expense of outfield (extensive) ones—a replacement that occurred as part of a cause and effect feedback system intimately related to population growth.

Thus in Late Postclassic times, much of the irrigable land in the Basin of Mexico was actually irrigated. The Texcoco Plain and Texcotzingo systems (Palerm, 1955; Wolf and Palerm, 1955) are Late Postclassic in date. Other major systems existed in Cholula, the Izucar Valley, and Cempoala in Veracruz (Palerm, 1955:36), all associated with dense population concentrations and a fully developed urbanism. In the southern part of the Basin of Mexico, there is clear evidence of the existence of techniques of intensive agriculture in addition to canal irrigation: extensive terrace systems on hill slopes and *chinampa* agriculture in the shallow fresh-water lakes.

Armillas and Sanders (pers. comm.) have reported an abundance of Aztec pottery on the terraces of the southern Valley of Mexico. Teotihuacan Valley supported terracing, probably combined with floodwater irrigation, certainly in Aztec times and perhaps in Teotihuacan times as well (Sanders, 1965). In the southern Basin of Mexico, terraces are still used and are still highly productive (Sanders, 1957). Probably one of the most spectacular ecosystems in Mesoamerica, however, is the chinampa system, of which only a few remnants still survive the large-scale colonial drainage of the lakes and the massive siphoning off of fresh water for industrial Mexico City. Chinampas and terraces are responses far more to lack of land than to lack of water: both are reclamation techniques—terraces of course obviously so—artificial techniques of extending a cultivable zone.

Chinampas are artificial islands built up from the floor of Lakes Chalco and Xochimilco by alternating layers of mud with layers of aquatic vegetation. They may have been begun initially by trenching to drain swamps on the margins of the lake. The banks of chinampas are tree-lined to consolidate the edges; since the chinampas stand in water they are perpetually irrigated. The long, narrow, rectangular shape and the porosity of the soil facilitate percolation of water; additional water may be supplied as necessary by the cultivator from his boat with a long-handled scoop. Chinampa soil is rich in organic matter; the application of green fertilizer to these fields serves the double purpose of maintaining fertility and keeping the canals free of vegetation that would otherwise hamper navigation. West and Armillas (1950) have described the system in more detail than is possible here. Sanders (1957:331) estimates that a hectare of chinampa land planted annually in maize will yield 4 tons a year, and over 24 years, 96 tons. He also observes (1957:83–85) that maize is today an uneconomic use of this land, that an enormous diversity of truck crops and flowers, both aboriginal and European, bring in higher cash returns than maize on the Mexico City market. Seedbedding and transplanting are used to keep chinampas in continuous production, and 2–4 harvests a year, depending on the crop rotation practiced, are possible. Labor investment is huge, and this area today shows an enormous diversity of agricultural techniques based on fine differentiation of land types.

There are few published data on the antiquity of chinampa cultivation. Coe (1964) believes that the system is of Classic origin, on the basis of the discovery of Teotihuacan II figurines; he postulates the development of chinampas as the economic base of the expansion of the Classic city. This seems to us to be too early, on several grounds. First, if chinampa agriculture did constitute the economic base of Teotihuacan, the location of the city becomes inexplicable. One would expect the major city to be located far nearer its food source: Tenochtitlan certainly was. One would also expect to find a large, dense, Classic population in the southern part of the Basin of Mexico—and evidence of such a concentration does not exist. Second, surface survey of a zone of well-preserved fossil chinampas by Pedro Armillas and the author demonstrated vast quantities of Aztec pottery, a few Toltec sherds, and no Classic. Such results would seem to indicate that the bulk of the chinampas are probably Aztec in date, with possible inception of the system in the Early Postclassic. Today the chinampa area is the densest rural settlement area of the Basin of Mexico, or anywhere else in the Mexican highlands. Purely agricultural villages may reach 5,000–6,000 people and are tightly nucleated; towns are much larger (Sanders: 1956, 1957). In the Late Postclassic a string of cities and towns occupied the lakeshore plain from Tenochtitlan in an arc through Xochimilco and Chalco to Texcoco. Chinampas were integral parts of the city of Tenochtitlan itself. Although the maximum extent of this type of cultivation is unknown, it probably completely filled the fresh-water lakes of Chalco and Xochimilco, and may have been found in areas of normally salty Lakes Texcoco and Zumpango, where salinity could be artificially controlled (cf. Sanders and Price, 1968: Fig. 10).

There is, however, one possibility of chinampas or a chinampa-like system of cultivation associated with the growth of Teotihuacan, located not in the southern Valley of Mexico but in Teotihuacan Valley itself. This type of agriculture, still practiced in a limited area near the springs at San Juan, involves not the construction of artificial islands but rather the ditching down to ground water around long narrow fields kept today in continuous production. The process combines swamp drainage with the exploitation of a naturally high water table. Sanders postulates that by the end of the Patlachique phase, the upper hill slopes of Teotihuacan Valley were deforested and badly eroded. Such deforestation would in turn tend to lower the water table in the valley floor to the point where this type of system would have been practicable in terms of labor investment, although the water table was still considerably higher than its level in most of this area today. Mooser (1968) suggests an extensive series of springs at the base of the loma extending between Cerro Gordo and Cerro Malinalco—in other words, immediately below the Patlachique and Tzacualli phase towns at Teotihuacan. The presently isolated small spring of El Tular near Atlatongo in the lower valley would have comprised a part of this formerly more extensive system. Sanders (pers. comm.) estimates an area of some 1,000 hectares of land with high water table in Terminal Formative, Protoclassic, and Classic times that could have been cultivated using a system similar to that observed in contemporary San Juan. He suggests that this area could have fed the Patlachique and Tzacualli phase settlements, and comprised an important part of the sustaining area of the Classic city. The contemporary San Juan system, if this is considered in fact a variant of chinampa cultivation, thus represents a remnant. In addition, the greater amount of total water available from springs for canal irrigation indicates that the potentially irrigable area of the lower valley would have been significantly larger than is the case today.

Associated with chinampa agriculture in Aztec times was a state-initiated system of dikes and causeways for flood control. Flooding is the principal hazard in this type of agriculture, for two major reasons. First, an unusually heavy rainy season can flood growing crops and wash away sizable chunks of chinampa land itself. Second, with flooding very often comes salinity. The Lake Texcoco system in pre-conquest times was an internal drainage, lacking a natural outlet. Lakes Chalco and Xochimilco are shallower and spring-fed, and are thus fresh water. Texcoco, the deepest of the series of lakes, was largely salty. The flood control program, sponsored by Tenochtitlan and Texcoco, involved careful manipulation of relative lake levels, to keep the chinampas from drowning, and more particularly to prevent overflow of Lake Texcoco into Lakes Chalco and Xochimilco.

We have thus far traced the history of the increasing intensiveness of Mesoamerican agriculture from Early Formative times to the Late Postclassic and the Spanish conquest, with attention to methodological and interpretative problems and to underlying causal dynamics. The tendencies have been the correlation of population growth and concentration with intensification of the methods of primary production. Under population pressure, yield per unit of land area is maximized at the expense of yield per unit of labor input, to the point that labor is used, not only to compensate for lack of land, but actually to create additional land. Concomitantly (Flannery *et al.*, 1967), the result is the increased diversity of agricultural methods used within a region or subregion, each finely adapted to a finely differentiated niche, and all jointly acting to increase production in the area as a whole. Such specialization, which has both technological and sociological aspects, will be considered in a later section of this paper.

Our model is one of initial widespread use of extensive agricultural techniques throughout Mesoamerica, with considerable local variation as a function of geographic variation. In some areas, as population grew, various types of intensive methods were developed as adaptations to the expansion of cultivation into zones not previously utilized, and as means of increasing yields on lands already cultivated. These technological innovations occurred, furthermore, at different times in different places, depending chiefly upon local demographic processes. Generally, the smaller the population in comparison to the total area of cultivable land, the more likely that extensive techniques will be used first: this is a frontier situation. The best lands, productive with the least amount of labor, will be selected first; only later, as the area fills in, will less productive lands be occupied. The intensification of production is thus a response to demographic pressure, and acts in turn as a stimulus to further and continued population growth. When the limits of any technological regime are reached, population can either stabilize at that level or, under some circumstances, develop or adopt technological changes that permit greater numbers and densities to occupy the area.

The Central Andes

As previously noted in this paper, the Peruvian data are, by contrast with the Mesoamerican, grossly incomplete where paradoxically they seemed so abundant ten years ago. The major problem is the lack of information concerning highland agricultural development, particularly for the early periods of incipient cultivation and

https://doi.org/10.1017/S0023879100041054 Published online by Cambridge University Press

the emergence of agriculturally based communities comparable to the Purron of Tehuacan Valley. Recent work by MacNeish (pers. comm.) near Ayacucho has suggested the strong probability of an early focus of independent New World domestication of maize in the Peruvian highlands. Next to nothing is known of the antiquity or processes in the domestication of other Andean cultigens—potato, sweet potato, quinoa and the other chenopodia, to mention the basic staples. This is a critical problem in the study of South American agriculture; most of our Andean data come from studies on the coast, where in all probability cultivation was introduced from the highlands. Few if any members of the Andean repertoire of domestic food plants appear to be natives of the coast or to have wild ancestors or relatives there: it is impossible for a population to obtain control of a species that does not exist in its environment. Like the agriculturists of the Mesopotamian Plain cited above, the first cultivators on the coast of Peru must have brought it with them.

For coastal Peru, there is a long history of preagricultural occupation and a complex series of cultures. Economically the people were all food-collectors, exploiting a number of natural ecological niches of the coastal habitat. Fog-vegetation lomas provided one such niche for winter-season occupation (Lanning, 1967), but the most productive subzone of this habitat was the coast itself, with its access to unusually rich fishing grounds. These permitted the growth of large and sedentary populations which "harvested" seafood like a cultivated crop. Lanning (1967:59) describes the typical Preceramic VI period site (2500–1800 BC) as containing:

> . . . large quantities of mussels, clams, and other shellfish; bones of fish, sharks, rays, sea lions, cormorants, gulls, pelicans, and other shore birds; and remains of tunicates and seaweed. The relative abundance of one or another of these foodstuffs varies greatly from site to site and from level to level within a single site, but, taken together, they are almost always far more abundant than plant remains.

Agriculture thus provided only a small supplement to the diet. The agricultural system would thus have been only a minor determinant of the settlement pattern. We note the analogy with the La Victoria site on the Pacific Coast of Guatemala (Coe and Flannery: 1964, 1967). During the Ocos-Cuadros-Jocotal and Conchas I and II phases, populations tended to increase but to concentrate in the coastal-riverine sector of their habitat. In the Crucero phase (300 BC-BC/AD) the heavy occupation shifted from this formerly favored area to the agriculturally more productive piedmont sector, also the locus of Classic and Postclassic settlement. Again, as we have noted for the Valley of Oaxaca and for Teotihuacan Valley, the concentration of the bulk of settlement is a sound basis for the inference of subsistence patterns. At La Victoria, as agriculture gradually became dominant over coastal gathering, the most productive part of the environment changed, as reflected in the location of settlements.

Much the same process is evident in coastal Peru. Sites of Preceramic VI and of the Initial Period (1800–900 BC) (Lanning, 1967: Maps 3 and 4) are overwhelmingly concentrated on the coast itself, at or near the mouths of rivers, although Patterson (n.d.) traces the beginning of the demographic shift upvalley on the central coast to this period. It is not until the Early Horizon (900–200 BC) (Map 5) that large numbers of substantial sites begin to be located upriver from the coast. If agriculture is an incidental supplement to a diet based on a seafood staple—and the settlement pattern suggests this—we would not expect intensive techniques of production. For the Preceramic VI, Lanning states:

> Farmlands probably took the form of narrow strips along the sides of the rivers and around springs and freshets. Flood farming has been postulated for some of the coastal valleys, but even this technique would have been limited to rather narrow strips along the river banks, because it is difficult to envisage a post-Pleistocene flow sufficient to flood the whole of any of the coastal valleys. Riverside lands could be counted on to give only a summer crop, but lands in the vicinity of one of the rare springs formerly found on the coast might have yielded a winter crop as well (1967: 61).

The technique involved is thus an environmentally-conditioned variant of swidden. Annual cropping would be possible, as at San Lorenzo, because of annual renewal of fertility through silting of the river's immediate floodplains. A difference between the Peruvian situation and that at San Lorenzo is, of course, that the flooding on the Peruvian Coast was the only source of water for agriculture, and, in comparison to San Lorenzo, the marginal lands in these coastal valleys—those removed from the riverine strip—would have been completely unproductive. For Peruvian flood farming, the areas at the mouths of the rivers would be most favorable in that here there would be in most valleys somewhat larger tracts usable in this fashion. Furthermore, these areas have the additional advantage of proximity to the marine resources that still constituted the bulk of the diet. Settlements such as Las Haldas had estimated populations of 500–1,000, and possibly much larger (Lanning, 1967: 63–64). Lanning estimates the total coastal population as between 50–100,000 by 2000 BC. Cultivated maize is pan-Peruvian by the Initial Period; the question is one of its relative importance in terms of particular local ecosystems.

Lanning links the development of an efficient and productive agriculture to the spread of the Chavin cult in the Early Horizon, a period marked by an increased reliance on this subsistence base all over coastal Peru. The evidence again lies in the shift in settlement patterns; Collier (1955) and Kidder *et al.* (1963) regard the upriver, inland movement of occupation as indicative of this process. That there was probably an ecological-demographic forcing situation determining this shift is suggested:

> Coastal settlements multiplied until every good fishing station was occupied by a village, and only then, when the possibilities of the littoral harvesting pattern had reached their limits, did people begin to move into the valleys in large numbers and to take up the life of full-time farmers (Lanning, 1967: 106).

Once this process gained momentum, the productive potential of the river floodplain cultivation system would be rapidly exhausted. If farming is to be anything but ancillary to the total diet, the amount of immediately riverine land per valley would be inadequate for the support of a population of any size. Pressure would rather quickly force the exploitation of other ecological niches. Much the same process occurred, as has been noted, as population growth began to exceed the capacity of the 3-meter water-table zone in the Valley of Oaxaca, or of the upper slopes of the Patlachique Range in Teotihuacan Valley. In coastal Peru the forcing situation would probably have been more acute than in either Mesoamerican example: there is seldom any rain in these valleys. Except for the river levees themselves, irrigation is essential to produce a crop. Thus, the expansion of irrigation agriculture on at least a small, local scale is inferred from the expansion of permanent settlement inland from the immediate coasts. Kidder (1964:458) believes that the large size of some of the inland coastal sites of this period would require irrigation for their support, even where direct evidence of canal systems has been obliterated by later occupations. Patterson (n.d.) suggests that local irrigation systems were functioning in upvalley central coast settlements as early as the preceramic Gaviota phase (1900–1750 BC), accompanied by a demographic shift inland. Patterson and Lanning observe the relationship of settlement pattern to both irrigation and conflict in the Chillon Valley (1964: 115):

> Toward the middle of the Early Horizon, we have, for the first time, a significant number of habitation sites in the valley. These sites are found on hilltops, at least one of which is fortified. Their appearance at this time is likely to be connected with increased military activity, since they are easily-defended positions, and may be associated with the construction of a small-scale irrigation system.

The subsequent history of irrigation in coastal Peru involves the gradual geographic and demographic expansion of what began as essentially local systems, first into valley-wide and ultimately into transvalley networks linking several rivers and several population units. These processes occur most spectacularly during the Early Intermediate through Late Intermediate periods. The Lumbra Quebrada system in the Chancay Valley (Patterson, pers. comm.) dates from Early Intermediate Periods 2–3 (25–175 AD); in the Chillon and Rimac Valleys of the central coast, irrigation is established by Early Intermediate Period 7 (400–475 AD). A village of Early Intermediate Period 7 date in the Lurin Valley is laid out along both sides of a canal, providing excellent chronological and functional associations (Patterson, pers. comm.).

It is from the north coast that our best evidence comes, particularly from the small Viru Valley (Willey, 1953). Today some 7,000 hectares are under irrigation, with Holmberg suggesting a variation between wet and dry years of 2,000 hectares (Willey, 1953:20). Evidence from settlement pattern surveys suggests a prehistoric cultivated area some 40 per cent greater, or up to 9,800 hectares (Willey, 1953: 394, and Fig. 4). The maximal extent of the Viru system was reached in Late Gallinazo times, with an estimated population of 25,000, which thereafter remained stable for a time and subsequently declined (1953:394–395). That the extent of irrigation was greater for prehistoric times than for the present applies to the north coast generally, beyond the confines of Viru; Kosok (1965) suggests this also for the Moche and Chicama Valleys.

https://doi.org/10.1017/S0023879100041054 Published online by Cambridge University Press

From Early to Late Puerto Moorin times in Viru, there is a marked shift in the settlement pattern. Early settlement is found in the upper reaches of the valley, where steeper gradients facilitated tapping the stream and diverting water into canals. We have a parallel here with the early piedmont settlement in the Valley of Oaxaca, cited previously (Flannery, *et al.*, 1967). However, for Viru, a glance at the map of this approximately wedge-shaped valley will indicate the limited quantity of arable land in this subzone. Late Puerto Moorin, and Early and Middle Gallinazo settlement are found in the lower valley flats, where silting and subsequent occupation may have obscured many sites (Willey, 1953:391). Willey suggests a change in agricultural technology to have been a factor responsible for this shift of settlement, with its attendant alterations of the relationships of population to land. As in our previous discussion of Mesoamerica, changes in a productive regime may open up new zones to cultivation and alter the relative productivity of one such zone in comparison to another:

> Successful farming in the Huacapongo, based on irrigation, would have drawn settlers into this region. Subsequently, as experience in irrigation techniques developed, a more complex canal and distributary system would have come into being with the result that the basin of the Lower Valley would have been opened to irrigation farming. The much greater amount of suitable land in this part of the Valley would have, thus, attracted villagers in the ensuing Late Puerto Moorin and Early Gallinazo interval. Although there is no indisputable evidence that canal irrigation began as early as the Puerto Moorin Period, the probabilities are that it did (Willey, 1953: 392).

On the basis of the large number of sites and their increased size, Willey considers Late Gallinazo to represent the population peak of the Viru Valley, a peak of some 25,000, maintained into the subsequent Huancaco and Tomaval phases and declining thereafter. Habitation sites are found in all parts of the valley, a suggestion of the intensiveness of exploitation. Willey considers irrigation to have embraced a single valley-wide system, and that it was probably accompanied by valley-wide political integration. The large population centers, along with the quantity and monumentality of public architecture—exceeding any earlier constructions—suggests a local state which, in the Huancaco phase, was conquered from the Moche Valley. This conquest would be the culmination of a postulated period of intervalley competition and conflict begun in Gallinazo times; clearly, processes parallel to those of Viru were going on in the adjacent Moche Valley as well. The conflict and increased militarism seem, again, based on demographic pressure:

> . . . after Late Gallinazo there was little room for the expansion of irrigation and cultivation. In effect, a ceiling had been set by a maximum combination of the amount and availability of water and the amount and topography of the land. This ceiling on arable land was also a ceiling on population expansion without new food types or food transportation from outside the Valley (Willey, 1953: 393–394).

It could be hypothesized that the expansion of Moche into a multi-valley state by military conquest could have been the result of the pressures induced by the demographic ceiling. One way in which a state can obtain new resources is by conquering an adjacent area and siphoning off its surplus. A similar process may also explain the constant warfare that obtained between the Sumerian city-states (Adams, 1966).

In both the Sumerian and coastal Peruvian examples, such warfare appears to precede the expansion of the irrigation systems themselves. As a solution to the problem of population pressure, it is a limited one in that it is necessarily temporary (Sanders and Price, 1968). Within at most a generation or two, the initial problem again reemerges. If such temporary advantage accrues to the stronger combatant at the expense of the weaker, and even where sufficient numbers on one or both sides are eliminated to reduce the pressure, the total carrying capacity of the region as a whole is not increased by competition of this kind. Any gains are thus short-term, regardless of whether the societies involved perceive them as such. The advantage of warfare at this stage of the demographic cycle lies primarily in the fact that it requires less input of labor and of capital than does the expansion of the technology. In turn, the presence of this type of chronic warfare itself alters the selective pressures upon both the technology and its attendant sociopolitical organization. Intensification of the techno-economic base, and any innovation fostering this, would under such circumstances be more likely to be adopted by the societies involved, in spite of the greater energy-input requirements.

Although Collier (1955:21) implies that transvalley irrigation may have begun as early as the Early Intermediate Period and may thus have constituted the technological underpinning of the multivalley Moche state, recent work in the Moche Valley (Moseley, pers. comm.) indicates this date as too early, on the basis of evidence to be considered below. It is thus more advisable to regard the Moche state—which incorporated the Chicama, Moche, Viru, Santa and Nepeña Valleys—as based on a different type of dynamic, suggested in the preceding paragraph. Since Viru was in Moche and post-Moche times a politically marginal area—probably because of its small size and limited demographic potential—it is somewhat unfortunate that the data that at this writing are most fully published derive from Viru. Work in progress in the heartland of the Moche and later Chimu states—i.e., in the Moche and Chicama Valleys—will provide a fuller picture of these extremely complex developments, against which the tentative model above can be tested.

Kosok (1965:88; cf. also map p. 86) notes that the contemporary Moche Valley has some 25,000 acres under cultivation; he estimates that the ancient cultivated area was twice that, and that the cultivated area of the Chicama Valley may have been as much as triple that of Moche. We have previously observed the difficulties inherent in the direct dating of irrigation features, which are best dated on the basis of their association with settlements that are themselves directly datable. The location of the two major sites of the Moche Valley—Moche of the Early Intermediate and Chanchan of the Late Intermediate—provides the initial evidence against a possible Early Intermediate Period dating of transvalley irrigation on the north coast. Moche is located south of the Moche River, suggesting that the water for the immediate sustaining area of the settlement derived entirely from that river. Chanchan, on the other hand, is situated well to the north of the Moche River, at the north side of the valley, and thus effectively between the Moche and Chicama Rivers. The change in the location of the largest sites of their respective periods in the Moche Valley may be taken as indicative of changes in the technology of hydraulic management, changes involving a shift from single-valley to multivalley canal systems.

The work of the Harvard Chanchan Project (Moseley, pers. comm.) is providing more concrete associational evidence that the transvalley canal system linking Moche and Chicama coincides chronologically with the height of Chanchan as the capital of the Late Intermediate Chimu Empire. Mapping of the system, with associated agricultural fields, is still under way. Chanchan, however, is linked to the junction point of the "Grand Canal" system by clearly traceable roads. Chimu roads, where they cross parts of the canal system, do so in at least one observed instance over stone bridges: the canal thus flows underneath, in a culvert beneath the roadway, indicating that both features were in use at the same time. The mapping work done to date provides evidence of an extremely complex system, involving a number of alternative possible strategies for water distribution in an area that today is largely extreme desert. The larger canals are stone-lined, and at least one of them observed by this writer has stepped or terraced inner walls.

Settlement pattern data highlight the nodal position of Chanchan in the operation of this system. Its strategic location and its linkages by road to the critical points of the system permit the canals to be dated by association with the city and with each other. The question of the date of inception is still open, but it seems clear that the maximal development of techniques of water control in this area coincides with the maximal development of Chanchan. Kosok (1965) estimates the population of the city as 50,000 at its Late Intermediate Period height, as the capital of the Chimu Empire; West (1970) raises this figure to a minimal estimate of 68,000 and perhaps as high as 100,000. The degree of dependence of the city upon the Moche-Chicama canal system is shown in the success of the tactics employed in the Inca conquest of Chanchan (Day, 1970): cutting off the irrigation system at the point where the rivers were joined.

Besides the function of this canal system in providing water to permit the agricultural exploitation of the Moche Valley, thus providing the major part of the subsistence base of the immediate sustaining area of the city, it may have had more subtle indirect effects upon the total ecosystem. According to Day (1970) the water supply of the city derived largely from wells dug down to tap ground water. These today are dry. Day postulates that runoff, drainage, and seepage from a thoroughly irrigated Moche Valley may well have raised the water table in the lower reaches of the valley significantly above the level presently observed, thus helping to assure the urban water supply. As will be discussed below, this elevation of the water table would also have affected the practice and distribution of a specialized type of sunken-field cultivation in the lower reaches of the Moche Valley, an agricultural technique probably also contemporary with the apogee of Chanchan.

In contrast to our knowledge of these developments on the coast, little is known of the history of highland agriculture. Nonetheless, Lanning (1967:149–150) suggests that the elaborate terrace systems of the highlands were probably begun during the Late Intermediate Period; in many of the highland basins in the Andes agricultural and demographic expansion were probably more inhibited by the amount of land available than by the amount of water. As is the case with the terracing of the southern part of the Basin of Mexico, terracing is an effective solution to the problem of a shortage of arable land. When the demographic situation had reached this level of pressure in the Peruvian highlands is unknown.

The significance of terrace systems in the heartland of the Inca Empire, however, is incontrovertible. A large percentage of the natural landforms of the Cuzco Basin have been completely obscured by such remodeling, probably to the point of obscuring also most of the evidence of the earlier demographic history of the region. Observation of surface features apparent today indicates the association of terraces with water sources, either permanent (spring-fed) or seasonal, at elevations above the terraces. In some of these instances, what were at the time of observation (the dry season) dry barrancas, may represent either former springs now dry, or simply rainy-season runoff. Permanent springs, such as those of Tambomachay, for example, would permit year-round cropping. Tapping a barranca with seasonal flow would have more limited effects on agricultural productivity, similar to those noted for Mesoamerican floodwater irrigation, chiefly in increasing both the security and the yield of the single annual crop. Along the Urubamba Valley from Cuzco to Machu Picchu this same association between hilltop water source, hillside terrace system, and larger or smaller Inca site is notable. Ollantaytambo and Machu Picchu are perhaps the largest and most spectacular examples. At Machu Picchu, some direct association of stone water channels with parts of the terrace system is still preserved, along with cisterns and catchment basins. The springs here are permanent (although their flow diminishes somewhat in the dry season), and their location above the settlement adds to the defensibility of the site.

Other intensive cultivation techniques in addition to canal irrigation (relatively early on the coast; of unknown age in the highlands) and terracing (probably of relatively late date in the highlands on any large scale; date of small-scale local inception unknown), are noted to date from various time periods in the central Andes. They will be considered briefly at this point. We will discuss first a technique which, like canal irrigation, is an adaptation to the natural aridity of the coast: what Willey (1953) calls *pukio* and what Parsons (1968) calls *mahamae* cultivation.

The pukio technique functionally resembles several of the deep-planting techniques known from Mesoamerica, but differs from these in form. Pukios are sunken fields comprising areas of from several hundred to several thousand square meters in area (Moseley, 1969:485). They are constructed by excavating the entire surface to soil layers adjacent to ground water; thus the most economic location for them, in terms of labor input, is the coast, adjacent to the sea. Here the combination of the downward slope of the land surface and the more elevated water table makes the excavation of such fields more practical. Parsons (1968:85) claims that this type of agriculture may have been associated with the early stages of cultivation on the coast, but this (Moseley, 1969) seems unlikely. They are not closely associated with preceramic or early ceramic sites; in many such sites access to marine resources rather than to arable land was the major determinant of location. Indeed, it seems that pukio cultivation would constitute an unnecessarily laborious productive technique where cultivated plants comprised only a minor supplement to the diet. Sunken gardens, instead, are associated with sites of the Middle Horizon or later. In Viru, they would thus be associated with a population maximum, used together with a valley-wide system of canal irrigation. Parsons (1968) cites the presence of pukios also at Chan Chan, suggesting that their use may reflect difficulties in management of the canal system. This was, however, a period of maximal development and sophistication of hydraulic management at the transvalley level; Moseley (1969) believes rather that sunken fields are a supplement to an irrigation system that had already reached the limits of its expansion. Particularly in years of reduced flow, the downstream areas would be those most subject to water shortages; it is there, too, that pukio cultivation offers a reliable and economic alternate means to secure sufficient water to produce a harvest. We have earlier cited Day's (1970) evidence of the functional interrelation of the irrigation system, operating at maximal capacity, and the maximal efficiency of sunken-field cultivation, based on the effect of an irrigated upper valley upon the elevation of the water table in the lower. Given a higher water table in the Late Intermediate Period, less labor would be required to construct such fields. Additionally, those fields closest to the shore would be less likely to be affected by brackish water, as many such fields are when in use today.

What is in a sense a near opposite of the sunken gardens is the ridged field system. Discovered only comparatively recently in various parts of South America (Parsons and Denevan, 1967), their functions were probably various and their chronology, aside from the fact that they are pre-Columbian, thus far a matter of speculation. Parsons and Denevan note ridged field patterns in several areas of lowland South America—near Guayaquil, Ecuador; the Llano de Mojos in northeast Bolivia; the coast of Surinam; the Mompos Depression of Colombia. Their function appears to have been primarily to provide drainage; all these areas are marshy or subject to seasonal flooding. Ridged fields, however, are located also on both the Peruvian and Bolivian shores of Lake Titicaca:

> . . . ridged field patterns are to be found only on level terrain which was marshy or subject to occasional inundation. It is also evident that most of them are to be found within a short distance from the lake at a relatively low altitude. Over 92 per cent of the fields are within 30 kilometers of the lake, and although the lake itself has a mean level of 3803 m, 98 per cent of the fields are below 3850 m and the highest fields are at 3890 m above sea-level, to the northeast of Ayaviri on the flanks of L. Orurillo (Smith, Denevan, and Hamilton, 1968: 355).

The total areas estimated for the Titicaca ridged fields are, in Peru 78,104 hectares, including a single large block of 56,533 hectares between Juliaca and Paucarcolla; in Bolivia, 3,952 hectares. While above the altitude range of maize, the area will produce potatoes, oca, olluco, and the chenopodia. Various patterns of ridges are notable, but the functional or chronological significance of this variation is unknown. One function, as in the lowland South American examples, seems to have been as an adaptation to marshy ground; Coe (1964) has postulated this as an origin of the chinampas of the Valley of Mexico, which the Lake Titicaca ridged fields somewhat resemble. The Titicaca examples, however, show no evidence of actual construction of artificial islands. Some of the ridge patterns may also have acted to conserve and distribute water (Smith *et al.*, 1968:361); both drought and frost are major agricultural hazards in this area. Mean annual precipitation ranges from 623 mm. at Puno to 828 mm. at Capachicha, and is concentrated from October to March, with frequent months of under-average rainfall during this rainy season. Conserved water could provide the reserve needed for dependability of harvest in years of lowered or irregular rainfall, and the presence of standing water would also act to mitigate frost damage.

Today largely uncultivated due to salinity and to local emphasis on herding rather than agriculture, the Titicaca ridged fields were cultivated in Inca times, but their antiquity is unknown (Smith *et al.*, 1968:363–366). Given their proximity to Tiahuanaco, it is tempting to speculate that they were in use by the Middle Horizon. Smith *et al.* suggest the possibility of their inception during the Early Horizon, in that a small collection of Chiripa sherds was taken nearby; but their association with the ridged fields does not seem to be direct. An Early Horizon date seems too early, in many of the same ways that a Classic date for the Mexican chinampas seems too early. The bulk of the surface collection from the Titicaca ridged fields is Inca, but they have never been excavated, and settlement survey work in the area is at best scanty.

IV. IRRIGATION: SOCIOPOLITICAL DYNAMICS AND THE GROWTH OF CIVILIZATION

Having previously treated first the relationship of irrigation to other types of agricultural techniques, and second, the relative chronology of various types of intensive agriculture in selected areas of Nuclear America, we may now consider the nature of the relationship between irrigation and sociopolitical structure. It is here that controversy in contemporary anthropology is most acute. One of the reasons for this fact is the general failure to take into account the parameters previously discussed, notably the interrelated factors of agricultural productivity in general, and population growth. Only in this fashion can the impact of irrigation be evaluated: if irrigation is postulated to have certain effects, then what other techniques or processes might have similar kinds of impact on local ecosystems? We shall in turn relate these considerations to general problems of the interpretation of the evolution of social organization.

Childe (1950) states several characteristics of civilization as a culture type, among them large size, social stratification into distinct classes, and economic specialization. Writers on social organization from Durkheim (1933) to Fried (1967) have used the distinguishing criterion of institutionalized force to define the state: the state exists when some body in the overall structure arrogates to itself all legitimate use of internal and external force. Put another way, the state is founded on relationships of differential power. This returns us immediately to the criterion of social stratification, defined by Fried (1960) as differential access to strategic resources. Economic power is ultimately political power as well; the two are inextricably interwoven. Some resource bases, among them hydroagriculture, are inherently more controllable in this fashion than are others. The relation between what archaeologists term "civilization" and what in political terms is called the state may be debated by some. However, for the present discussion the two terms may be considered equivalent, and will be used interchangeably (Sanders and Price, 1968). In the case of the New World pristine states which developed in Mesoamerica and the Central Andes, or analyses of social and political structure are necessarily based on the material remains these societies have left in the sequence of their development. It is a methodological requisite that we establish a degree of equivalence between archaeological remains and the kind of society that produced them. This will be the operational basis of our inferences concerning the evolution of culture (Sanders and Price, 1968: Ch. 2).

A basic archaeological criterion of civilization is that of architectural monumentality (Childe, 1950). The existence of large-scale public works of any kind tells us something about the society that built them: they are the material expression of a kind of social organization. White (1949, 1959) maintains that cultural evolution is based on the increase of the total energy content of the society. Monumental architecture is, in a real sense, the frozen, permanent indication of the amount of energy harnessed; it is thus possible to compare societies on this quantitative basis. It is further possible to consider social organization of any kind as a sort of flow diagram of the utilization of energy captured and consumed by a population. Monumental architecture, because the capital and labor (energy) investment in its construction is high, is thus a legitimate and justifiable indication, not only of total energy capacity, but of the fact that this energy was used in a particular way. It is an aspect of technology that has very clear sociological requisites and implications.

Large-scale irrigation systems, if they are functionally similar to various other kinds of agricultural methods in their effects on productivity (see preceding pages), are functionally similar in other respects to any other kind of architectural monumentality. They share with pyramids, temples, fortification walls, palaces, and burial mounds the need for large quantities of systematically amassed materiel; a large, organized and directed labor force; and a diversity of labor force, from unskilled hewers of wood and drawers of water, to professional specialists in engineering, architecture, planning, and administration. Thus, on the level of process, the existence of large-scale hydraulic works of the kind described by Wittfogel (1957) can be analyzed as resembling any monumental civic construction, in that similar kinds and organization of resources and manpower are requisite for them all. Where hydraulic works differ from these other examples is precisely where they resemble chinampas, terraces, pukios, etc. They represent energy inputs that result in augumented productivity: they are capital investments in a way that temples, palaces, and fortifications are not. Irrigation systems require investment of energy to produce more energy, where monumental pyramids and massive walls can be viewed as taking energy out of circulation. The latter category of monumentality is thus more properly considered an effect or product of a certain kind of society whose techno-environmental causal bases lie elsewhere (Sanders and Price, 1968:9). The question is the extent to which canal irrigation can be regarded as a major component of these techno-environmental causal bases, and can thus be seen as a determinant of institutional structure.

Irrigation agriculture is not, as the previous two sections of this paper demonstrate, a unitary phenomenon of unique characteristics. Irrigation in general shares many of the causes and effects common to other systems of intensive agriculture. Further, not all systems of canal irrigation are themselves strictly alike. Many of the characteristics in which irrigation systems differ among themselves are those which determine the actual or potential scale or degree of monumentality of the system. Many of these determinants are basically environmental. The conditions of construction and use of an artificially controlled water source and its impact on the size and institutions of a population are not everywhere the same.

Most obviously, environments vary in the degree to which control of water supply is necessary to the successful exploitation of the habitat by cultivators; environmental challenges largely govern the direction and degree of success of cultural responses. In some environments such as coastal Peru or parts of the American southwest the total productivity of the region is sharply and dramatically increased with irrigation; without it, very little land will produce a reliable harvest. In the Teotihuacan Valley, the difference, while highly significant, is less drastic than the situation on the Peruvian coast. Even on the Peruvian coast, however, carrying capacity does not reduce to zero without irrigation: cultivation is not the only means of possible or observed subsistence, and a sizable population can be maintained by marine food collecting. But if population is to expand beyond the limitations imposed by this mode of life, a shift in technology and economy to agriculture is necessary to open up additional niches of the habitat to occupation. And if such a shift is to provide more than merely an occasional supplement to the diet—that is, for its expansion of the demographic ceiling of the valley to be significant—in coastal Peru that shift must include the technology of water control, since there is no rainfall. A similar analysis is possible for the shift in the Mesopotamian Plain whereby cultivators assumed dominance over riverine collectors—not so much by replacing them, since the contemporary Marsh Arabs continue to practice a similar way of life, but by substantially outnumbering them. Such a change indicates a shift in the subzone of the region which is most favorable to occupation by man: more people can live by cultivation in the plain than by collecting wild foods from the river. For them to have done so would involve water control since, like the Peruvian coast, the most striking orographic characteristic of this environment is its near-total lack of precipitation.

What is, or is not, a limiting factor to demographic expansion will vary from one environment to another, depending upon physical geography and also upon the size and technological repertoire of the population. To continue our consideration of environmental parameters, the quantity, nature, and degree of permanence of the water source will induce differences among and between various empirical instances of irrigation cultivators. For cultivators, normally either land or water limitations will be the most critical inhibitor of expansion. Any population, human or animal, can expand only to the extent permitted by that resource basic to its way of life that is in the shortest supply. In the Teotihuacan Valley, there is more land irrigable with existing technology than there is available water. Thus the irrigation system observed today is at its limit and cannot in practical terms be further expanded (Millon, 1954; Millon *et al.*, 1962; Sanders, 1965). By Middle Horizon times in north coastal Peru (Willey, 1953; Moseley, 1969), the expansion of the river-fed canal systems was already supporting as many people as it could. All available water was in use; where there was no water, the rest of the presumably otherwise cultivable valleys remained desert, lacking any demographic potential. The result was a relative isolation of the valleys from each other, in a fashion parallel to the situation obtaining in the American southwest, though on a larger scale.

In the southwest, the Pueblo Sphere of Kroeber (1939:136) includes a total area estimated at 44,600 square kilometers, and a total population of 33,800, for an overall density of 1.3 per square kilometer. The southwestern population is distributed in a number of small clusters, some internally quite dense, but each separated from the others by considerable stretches of uninhabited desert. Each of these nucleated settlements has fewer than 5,000 and most under 3,000 inhabitants; densities of individual groups cited by Kroeber range from .21 to 2.71 per square kilometer. The subsistence base of many of these pueblos is irrigation agriculture, particularly floodwater and seasonal-spring irrigation. Each is surrounded by unused land for which no water is available. In some instances, however, it may be land rather than water that is the critical resource in the shortest supply. In the southern part of the Basin of Mexico, for example, the lakeshore plain is narrow, and the response to this restriction under increasing population pressure has been the terracing of the adjacent hill slopes and the creation of chinampas as artificial islands in the lakes. While the chinampas are also permanently irrigated by virtue of their location, most of the terraces observed today are dry (Sanders, 1957). The spectacular terracing of the Cuzco Basin seems to represent a similar solution to a similar problem.

The nature of the water source, particularly its seasonality or permanence, as well as its quantity, will affect the technology and sociology of its exploitation. In the Teotihuacan Valley, there is a marked difference between the floodwater canals of the middle valley and the spring-fed perennial flow into the lower valley canals. Only rainy-season agriculture is possible with a floodwater system. If the yields and the security are increased over the levels possible with rainfall alone, the total harvest per

https://doi.org/10.1017/S0023879100041054 Published online by Cambridge University Press

year cannot be expanded through double-cropping. Thus, the carrying capacity of lower valley land is much higher than that of the middle valley. Conversely, the absence of an appropriate permanent water source in the middle valley limits the use of any perennial irrigation there. The valleys of the south coast of Peru were similarly limited in their demographic growth; they are drier than the north coast valleys, and many of their rivers are either seasonal or are dry before they reach the Pacific.

The carrying capacity of an environment cannot therefore be assumed as given, or evaluated without reference to the total technology of the population. This is the basic methodological error in the discussion by Meggers (1954) of environmental potential; she compares environments and their relative productivity on the basis of a 1950 technology as a baseline. However, the productivity of environments in comparison with each other has notably shifted through time, as the preceding pages have indicated. Many of these shifts, inferred on the basis of settlement distribution, are directly attributed to changes in technology which modify those factors of an environment affecting production and carrying capacity. For some environments, modifiability is a function of investment of labor; success in this case is a function of the extent to which the output of the land is increased by the additional labor input. In other words, it may be uneconomic to invest labor if the return on the labor is less than the input required. For other environments, the technology for "reclamation" may simply not exist.

The technology exists today, for example (as it did not in pre-Columbian times), to pump water from the Columbia River drainage in Oregon and Washington to the Napa Valley of California. It is expensive to utilize this technology, and yet economic to do so because other soil and climate factors make it possible for this region to then produce an immense variety of truck garden crops of high market value, often either out of season or uncultivable elsewhere in the country. Concomitantly, an efficient transportation system exists to get this produce quickly to areas in which maximum demand exists. If the Napa Valley, however, used this complex and expensive irrigation technology to produce wheat or cotton, which can be grown as well and more cheaply elsewhere, the cost of irrigation would be too high, and the profiits too small. Similarly, if there were no means to deliver the produce to its market, or if there were no demand, again there would be no economic basis for the heavy investment in irrigation.

For still other environments no technology yet exists that is capable of intensifying methods of agricultural production. Lowland tropical forest regions in general constitute such an example. The only way to produce maize in, say, southern Veracruz or Tabasco, is by swidden cultivation. Fallow cycles may be longer or shorter depending on population. Where land is plentiful and people few, there may be no effective cycling at all until all virgin territory has been occupied and used. But there are natural, effectively environmental, limitations (empirically variable) on how short the fallow period can be. In some of the best lands in Tabasco a 1:3 cycle is used, and yields fall off if this is reduced to 1:2. The amount of land to which so short a fallow cycle is applicable is, moreover, limited. In parts of Yucatán the cycle may range from

1:6 to 1:10 or longer. Increased weed competition and thus greater labor required, in combination with yields declining from loss of fertility through leaching, make cultivation for longer than two successive years uneconomic. Along river levees of the Gulf Coast, nearly permanent cultivation may be possible (Coe, 1968), where annual inundation and silting renew fertility; but the total quantity of such land is limited. Intensification of agricultural production by technology in practicable terms in the lowland tropics generally takes the form of production based on tree crops which do not deplete the soil to the extent of annual cultivation of cereals. Given such a specialization, in turn, the region involved necessarily depends upon importation of staples from elsewhere, and upon access to markets for its own produce.

Thus, in only a few settings will irrigation be the key to demographic expansion. Its functions in raising carrying capacity may vary. It may increase productivity in a zone already cultivated by more extensive techniques by increasing yield, security of harvest, or by permitting multi-cropping, the production of new crops, or more productive varieties of existing crops. It may open additional areas for agriculture, areas that prior to irrigation were unused or only marginally productive. In the course of the development of the early New World civilizations, hydraulic systems in parts of these nuclear areas could be expanded until at their maxima they were the economic bases of the large, complex societies discovered by the Spaniards. While many other societies were and are known to practice irrigation agriculture, these for various reasons never attained the scale or degree of complexity of the high civilizations.

Irrigation alone, therefore, is incapable of fully explaining the growth of civilizations. Irrigation cultivation, while freeing a population from some of the limitations on its growth, may itself be subject to limitations—both environmental and technological—in its expansion. We must look to some of the parameters discussed above, and to their functional implications, for an explanation of why some irrigated systems grow large, to include increasingly larger numbers of people and extents of territory, while others remain small, simple, and local.

Not all irrigation constitutes hydraulic agriculture of the kind described by Wittfogel. And if Wittfogel (1957) does include a discussion of the American southwest, he strays from his central point and to that extent dilutes his own argument. No one can consider a southwestern pueblo to be anything but an essentially egalitarian tribal group, however dependent on irrigation it may be for subsistence, however high its hydraulic density. Groups of this size and degree of complexity are clearly competent to manage this level of technology without the kinds of sociopolitical institutions described for the Irrigation Civilizations. Their reliance on irrigation has not per se transformed them into Irrigation Civilizations.

Wittfogel's Oriental Society is characterized by a centralized and highly despotic bureaucracy as the locus of power and entrepreneurship in the society, often incorporating both ecclesiastical and secular arms (understandably, since both church and state are institutions of social control). The bureaucracy is the group of full-time specialists, maintained from the surplus of the primary producers; economic, political, and military power are concentrated in the hands of these specialists. Wittfogel maintains (1955, 1957) that the power of this group derives in turn from the requisites of hydraulic agriculture and the need for centralized direction and control of the hydraulic works in order to keep them functioning efficiently. The capital and labor needs for construction and maintenance of large-scale irrigation systems are such that, first, only the central bureaucracy could undertake these projects successfully: no other segment of the society could afford them. Second, the competitive situation, within the society and between societies, is greatly exacerbated when the basic means of production are artificial; some central authority is thus necessary to control the use of force and to adjudicate disputes which could potentially disrupt the entire system. Third, the cooperative nature of the labor requisites, on a large scale, suggest the advantages of centralized control in the massing of manpower when and where needed. Fourth, the hydraulic management needs per se give to a group in control extremely effective sanctions and thus enormous power to back up its demands. As Childe (1946:90) observes, "Rain falleth upon the just and the unjust alike, but irrigating waters reach the fields by channels the community has constructed. And what society has provided, society can also withdraw from the unjust and confine to the just alone." The government, in other words, need not even call out the army to enforce its decisions: all it has to do is turn off the water.

If it is agreed that Wittfogel's hypothesis of the causal linkage between a particular kind of economy and a given form of government is applicable only to large-scale systems, two basic questions may then be asked. First, how large is large enough? Second, does hydroagriculture "cause" the state, or does a strong central government then "cause" hydroagriculture? We consider these two interrelated questions below.

How large is large enough?

We have alluded to the question of relative scale and expandability of irrigation systems above, in order to point out the techno-environmental parameters that may act to impede or to permit growth. The size of the system is in turn a major determinant of the labor and management needs involved. Since this, in Wittfogel's developmental scheme, is the underlying dynamic on which the argument linking production to political structure rests, it merits more detailed examination. Our best evidence is obtained through the use of the comparative method. Both ethnographic and archaeological data are relevant to what is essentially a problem of defining the situation in which a qualitative change is likely to result from the operation of essentially quantitative processes.

Millon (1962) has questioned the Wittfogel hypothesis of the relationship between centralized authority and irrigation agriculture. He has observed quite correctly that the dynamics of water management are, on the basis of comparative ethnography, far more variable that Wittfogel's theory would indicate. His example of the Sonjo (Gray, 1963) and the case of Pul Eliya (Leach, 1961) are small, single-community systems. They thus resemble both the contemporary southwest and the inferred situation for a system such as Hierve el Agua. Comparatively small population groups are involved in all these cases—in the case of Pul Eliya, only 146 people, irrigating a total of 135 acres. Under such circumstances, in spite of the reliance upon artificial water control, kinship and sodality ties are sufficient to integrate the society, and to control both water supply and distribution and the labor requisie for maintenance of the system. Where the source of water is both local and limited in quantity, the questtion of disputes between different communities competing for its control is less likely to arise. And where quantity limits expansion, kinship and other essentially egalitarian ties are sufficient to control intra-community competition and conflict. Millon cites a Balinese example in which parts of several settlements are involved in irrigation cooperatives, but the numbers include only 5500–7500 people each—again, evidently below the level at which centralization of authority becomes an effective solution to the problems of management and control.

Irrigation systems in general do have requisites different from most other types of agriculture in that, no matter how small their scale, cooperative rather than individual effort is generally necessary to use and maintain them effectively: the productive unit is therefore larger than the single household. Such cooperation of course need not be amicable; indeed it is fraught with conflict. However, the need for cooperative labor means, in effect, that the amount of total output of the system per unit of labor expended will be greater if a number of workers pool their efforts than it would be if the same number of workers each operated independently, each expending the same amount of effort. Expansion of the system will be efficient and economic only when additional labor investment will add more than the value of its own input to the total output of energy, by bringing more land under cultivation or by adding to the yields from land in production. When putting additional labor into the land does not result in this kind of increased output, the agricultural situation, no matter what its technology, may, following Geertz (1963) be referred to as "involuted."

If cooperative enterprise is a virtual necessity for irrigated land at even the single-community level, this is not necessarily the case for other kinds of productive systems. In the several varieties of swidden, while farmers may cooperate in one or several of the necessary operations, the labor is essentially individual. Three farmers clearing three fields together involves the same input-output ratio as each of three farmers separately clearing each of three fields; it is merely additive rather than multiplicative. Pot-irrigation, while an intensive technique in that it maximizes production per hectare by means of labor investment (Flannery *et al.*, 1967) is similarly an individual-household enterprise; cooperation of larger groups does not result in increased output. Both the enormous yields and the enormous labor inputs of contemporary chinampa agriculture in the southern Valley of Mexico similarly involve an essentially individual rather than cooperative patterning. Terracing is, in a sense, an intermediate case. The labor investment to produce a crop in terraced agriculture not simultaneously involving floodwater or permanent irrigation is again basically individual. But terraces usually occur in groups rather larger than the isolated holding of an individual family. Terraces, like irrigation canals, require continuous upkeep to maintain them in good repair. While chinampas also require such attention, a single farmer's eroded chinampa menaces the security of no one but himself. A single disintegrating terrace, however, can threaten the productivity of all the holdings located below it. Thus, like small irrigation systems operating at the single community level, community-level cooperation is generally advantageous in terrace cultivation.

When either geographical or technological factors, or the combination of both, inhibit the expansion of an irrigation system and its demographic ceiling, the system will stabilize at that level. While the economic advantages of cooperative labor in its management will still obtain, the total labor force will remain sufficiently small so that centralized institutions of control will not be necessary. Nor could they be supported: there would not be enough work for such specialists to do to justify their upkeep. Size and elaborateness of any institution of social control will depend directly on the size of the society; the number of chiefs, so to speak, depends on the number of Indians.

It is difficult and perhaps ultimately somewhat arbitrary to attempt precise definition of the point along the continuum where quantitative changes may be analyzed as qualitative ones. We may observe that a kind of variable, critical-mass phenomenon is evidently involved, in which the absolute size and density of population must be viewed not by itself but in relationship to parameters such as the degree of environmental circumscription (Carneiro, 1961), the degree of environmental diversity, the overall technological level of the population and thus the extent to which differential utilization of different sectors of the habitat may be both possible and economically efficient. Specialization and symbiosis (Sanders, 1956) may thus themselves be viewed as adaptive developments, techno-economic and sociopolitical means of raising the demographic ceiling of a total region and thereby responding to conditions of population pressure (Sanders, 1968). However, if, as we have done, we stress the applicability of Wittfogel's hypothesis only to large-scale hydraulic and social systems, at least an attempt must be made, despite these cautions, to define the range within which a "small" system becomes for the purposes of analysis a "large" one.

Again we turn to the comparative method for assistance. There is clearly a difference of degree that operates as a difference in kind if we compare, say, Hierve el Agua with the Chicama-Moche transvalley system. All change proceeds quantitatively just as all process is incremental; the poles of the continuum are clear, but the intermediate ground far less so. Comparative data, both ethnographic and archaeological, may perhaps help to clarify and order this middle range. If we are to speak of "large" systems, such analysis will be critical. Armillas (1948), for example, considers the hydraulic systems of Late Postclassic Central Mexico to have been essentially "cantonal." The multiplicity of individually limited water sources, and their localized distribution, effectively barred the development of a unified and centralized basin-wide single system. Limitations of geography thus restricted the size and distribution both of population dependent on a single system, and the possibility of merging several smaller systems into a single larger and more highly centralized one. Adams

(1966) similarly notes the late inception of a pan-Mesopotamian single, huge irrigation network—in the Iron Age. It is our view that such super-systems are far larger than either necessary or sufficient for explanation of the sociological concomitants and consequents of large-scale irrigation. Clearly, techno-environmental parameters limit the possibility or probability of this degree of expansion; in Mesoamerica it was not feasible, while in Mesopotamia this did ultimately occur, but as the end product of long, individual sequences of localized growth. While Wittfogel's formulations are clearly applicable to such super-systems, these dynamics can be regarded as operative at levels well below this point.

The contemporary Teotihuacan system, "small" in Millon's sense (1962), serves all or parts of 16 villages. Overall, the contemporary, Aztec, and Classic populations were similar in size (Sanders, 1965) though varying in composition and distribution. The settlement pattern of the Classic, described in a previous section of this paper, implies that some 85–100,000 people at least—the population of the city of Teotihuacan itself—were ultimately wholly or partly dependent on the productivity of this system. Furthermore, this same evidence of settlement patterns strongly implies the conclusion that the regulation of the system involved a high degree of centralized control. First, Teotihuacan is the largest single settlement in the entire Basin of Mexico, and very probably in all of Mesoamerica at the time; its pan-Mesoamerican repercussions were immense and far-reaching in nearly all aspects of culture (Sanders and Price, 1968; L. A. Parsons, 1969: Ch. 5; Parsons and Price, 1970). Second, Teotihuacan, while not the only Classic period settlement in Teotihuacan Valley, does seem to have virtually depopulated the lower valley—the permanently irrigated sector of its immediate sustaining area; its presence evidently inhibited significant population expansion in the Texcoco Plain area as well, though this zone, as previously indicated, more probably constituted a part of the outfield aspect of the economy of Classic primary production.

Sanders and Price have suggested (1968:195–196) a parallel with the post-conquest Spanish policy of *congregación*, or enforced nucleation of population. As in the post-Hispanic instance, imposition of a settlement policy and its enforcement involves the wielding of considerable power. The Classic period lower valley settlement pattern seems largely uneconomic and anti-ecological. It is generally more efficient for farmers to live on or near their holdings, and particularly so when they have no access to any mode of transport more efficient than feet. Yet, as we have described, the few rural villages in the lower Valley of Teotihuacan contemporary with the height of the city seem to have exploited the upper piedmont in which they are located, and to have had no access at all to the irrigated valley floor. The explanation may lie in the inferred imposition of a congregación, which would in turn imply strong central authority. The settlement pattern looks as though access to the prized lower valley lands may have actually been contingent on city residence, where the central authority could exert considerable socioeconomic control over the population, and could in short have behaved very much like an Oriental Despotism. The sanctions involved would have been extremely potent and not difficult to apply. The overall degree of local centralization, on the basis of the settlement pattern, thus seems strikingly higher than that observed at present in Teotihuacan Valley.

For the Viru Valley, we have previously cited Willey's estimate (1953) that a population maximum of 25,000 was reached by Late Gallinazo times, and the suggestion of Moseley (1969) that the irrigation system had also reached it maximal capacity then. It is also in Late Gallinazo times that truly monumental architecture appears in Viru, particularly so at the largest site of the period. On this evidence, Willey postulates the existence of a local state based on control of a unified, valley-wide irrigation system. In the Moche Valley, the Huaca del Sol and Huaca de la Luna date from approximately this period or somewhat later, at the peak of Moche military and political expansion. That expansion, however, indicates that a parallel process to that of local state formation in Viru was probably contemporary with or somewhat earlier than the Viru developments. We shall return subsequently to the questions of militarism and conquest states, in a different but related context.

As additional comparative material in this question of scale, we cite the evidence on size of system from Mesopotamia. Braidwood and Reed (1957) estimate an average population of some 17,000 for each of the Sumerian city-states by approximately 3000 BC. Associated with each such unit is considerable monumental civic architecture, thriving long-distance commerce, and social stratification, which are among Childe's previously mentioned criteria for the archaeological recognition of civilization. Parallel to the evidence of militarism in north coastal Peru in Moche and immediately pre-Moche times (Willey, 1953; Lanning, 1967), and in Central Mexico in Teotihuacan times (Sanders and Price, 1968), the Sumerian city-states were in a constant state of warfare with each other (Adams, 1966). That the local irrigation systems of Sumer only much later coalesced into the unified pan-Mesopotamian system is for the present irrelevant. It does, however, appear to be the case that each individual local city-state system was large enough to produce the effects observed, just as with the individual Viru, Moche, or Teotihuacan systems.

Irrigation: cause and effect

The question of whether irrigation causes the state is of course far too simplistic, and in that form cannot be answered. As indicated in the preceding pages, the answers lie in a consideration of the dynamics of a large number of processes and their interrelationships in time and space. Every observed period of each empirical example represents merely one possible way in which these parameters may intersect and crystallize. To put the case so is by no means to deny that regularities exist; it says only that such regularities are those of process and are thus extremely complex, so much so that neither a dogmatically unilineal approach, nor any explanation based on the operation of any single factor taken in isolation will be adequate to deal with them.

In general, for any factor to be regarded as the cause of any given effect, that factor must precede the observed effect in time. Any analysis of causality is therefore necessarily diachronic. A second requisite for the attribution of causality, broadly

https://doi.org/10.1017/S0023879100041054 Published online by Cambridge University Press

stated, is that the process by which the presumed cause produced the presumed effect must be stated. Analysis must therefore be functional as well. Third, the concept of causality is itself a probabilistic one, rather than a model of inevitable push-pull. What "inevitably" really means, then, is the statement of a relatively high degree of probability: that "it must follow as the night the day" is a prediction (or retrodiction) of the likelihood of occurrence of the event or pattern in question (Harris, 1968).

Both synchronic and diachronic evidence strongly suggest that the use of canal irrigation precedes the state. On synchronic grounds we can observe today a large number of relatively small and typologically simple societies which practice irrigation agriculture. Although typological simplicity need not logically or necessarily imply chronological priority, worldwide archaeological evidence is conclusive that in the evolution of world culture, such societies are indeed found to antedate the later emergence, in some areas, of progressively larger and more complex polities. Archaeological evidence further suggests that the emergence of such large and complex polities is, in the instance of the pristine states, associated with an economic base of large-scale irrigation agriculture. As the larger societies developed from smaller ones, so too are the roots of large-scale hydroagriculture found in small-scale, local intensifications of the productive system. Neither arises full-blown. An association, a correlation, is, however, not a cause. This consideration underlies the immediately preceding treatment of the problem of scale.

The hypothesis that large-scale hydraulic agriculture is the cause of certain kinds of state organization is, if strictly construed, open to question as stated. At least as early as 1955, when Wolf and Palerm investigated the Acolhua irrigation system, they raised the point (1955:274) that, "If our dating of the Texcocan system is correct, we must recognize that we are dealing with a case in which the state did not grow out of irrigation, but preceded it." And they state (p. 275) that, "Once established, of course, irrigation probably operated in turn to centralize and intensify political controls." Their doubts, with the perspective of hind sight, seem to be based on lacunae in the data then available. The recent evidence of the relationship of hydraulic agriculture to the growth of Teotihuacan, evidence that was lacking in 1955, would have been more to their original point. The Acolhua state was, in Fried's terms, a secondary state, formed in response to pressures emanating from preexisting states and, indeed, a historical descendant of a good thousand years of state organization existing in its immediate vicinity. No one, furthermore, to our knowledge, has ever doubted the capacity of states once formed to undertake such projects, and thus this point is not, for us, an issue. It does, however, underlie several more recent criticisms of the hydraulic theory, of which two will be discussed in more detail below.

Adams (1966) has argued that the state precedes the development of large-scale irrigation in Mesopotamia. His argument rests on the fundamental misconception that "large-scale" necessarily implies pan-Mesopotamian; we have previously treated this question. The level of inclusiveness of only the single city-state system appears to have been ample to demonstrate the association of large-scale irrigation agriculture and this level of political organization. That the Mesopotamian states of the Iron Age were, not unexpectedly, themselves much larger than the Sumerian city states would tend to strengthen rather than vitiate the connection we propose. If Braidwood and Howe's suggestion (1962) is adopted, to the effect that significant agricultural occupation of the Mesopotamian Plain began during the Halaf phase, such occupation vindicates the assumption of the chronological priority of irrigation-based cultivation over the state in this region. Such occupation would necessarily have involved the basic techniques of irrigation and drainage in order for the area to have supported cultivators at all. Halafian culture almost certainly did not involve states; a more reasonable chronology for the emergence of the state in Mesopotamia would postulate a Late Predynastic, certainly Early Dynastic, date.

Another recent proponent of the state-precedes-irrigation hypothesis is Lanning, who asserts (1967:94) that small states existed on the Peruvian Coast by 1800 BC (the Initial Period). It is his interpretation of his evidence—the sites of La Florida and Las Haldas—that we consider highly dubious. He considers that the La Florida pyramid and the Las Haldas temple were of necessity constructed as intercommunity enterprises, and his own population estimates (1967:63–64) can in fact be invoked in support of that suggestion. A site with a population of 500–1,000—or even twice or three times that number—is, however, not construed by the present writer as the capital of a state. In actuality it far more closely resembles a village. The ceremonial functions of the structures in question are fully accepted, as is the hypothesis that they were built by and served a population from several different settlements in their respective areas. What is very strongly doubted is that intercommunity cooperation at so feeble a demographic level would either require or imply state institutions. Such an assumption is not substantiated archaeologically or ethnographically, and particularly not when the sites involved are so very small. A more reasonable dating of the emergence of the state on the Andean coast would involve an Early Intermediate Period placement.

The debate concerning the which-came-first question is, in our view, sterile when asked in so simplistic a way, in obvious expectation of a yes-or-no answer that is equally simplistic. In other words, we regard this as a pseudo-problem. It is our contention that the expansion of a productive system based on hydraulic agriculture and the attendant social complexity are related in a positive feedback system of cause and effect that is essentially self-reinforcing and self-intensifying. The rapidity of this process will be variable, depending upon a number of ecological and evolutionary parameters previously cited. Growth of productive base and of sociopolitical structures are aspects of the same adaptive and ecosystemic processes. The ultimate cause of both is population pressure, which determines the natural selective forces that govern the the survival, adoption, and spread of any innovations that act to raise the demographic ceiling. Expansion so caused in turn sets off further expansion in both productive base and sociopolitical complexity. This entire cycle acts to strengthen the power of the developing or developed state institutions. Not all irrigated productive systems, moreover, will develop in the fashion summarized below. As we have suggested, growth may be aborted and stabilization occur at much lower levels.

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We envision the causal complex as one involving demography, production, and social organization in the broadest sense. These parameters are all interrelated, suggesting that changes anywhere in the system including them all will bring about compensatory changes elsewhere in that system. As we have stated previously, these processes of change tend, under some circumstances, to intensify and reinforce each other. First, as the energy content of the system as a whole increases, there will be more and larger problems in coordination and administration; kinship and sodality organization and, increasingly, even simple ranked structures will, as overall size increases, become increasingly inadequate as sole means of control and direction. Second, as there is more work for an emerging bureaucracy to do, the greater is the likelihood that it will be composed of full-time professional specialists, supported from the surplus production of others. Third, as the system grows, this group will acquire increased power within the society. Growth means increasing numbers of people dependent on the expanding hydraulic agriculture and thus subject to the sanctions imposed by the group in control. The latter thereby grows more powerful and more able to exact the surpluses in both labor and kind from the rest of the society. Fourth, the services performed by this group not only enrich its members but provide some benefit for everyone in the society, although some sectors of society will profit more than others. Taxation, tribute, corvee labor, sharecrop arrangements, etc., are simply particular examples of what Wolf (1966) more generally terms a fund of rent. Last, if the processes of growth are to continue, this additionally strengthens the power of the controlling group, which has unimpeded access to the largest share of the capital and labor requisite for further expansion. It would thus have no serious potential competitor in exploiting new sources of wealth (these may be expanded hydraulic works, large-scale commerce or manufacturing, or any other potentially profitable enterprise).

Social stratification, competition, and militarism

The preceding two paragraphs have followed Wittfogel's own discussion quite closely, even where the terminology used is in some respects different. They have provided a brief summary of a series of interrelated processes which underlie and generate social stratification, the differential access to strategic resources. For a fundamentally agrarian population, those resources are land and water. In the case of the emerging state described above, virtually the entire population of primary producers have only restricted access to the means of production, contingent on their payment of some form of rent or taxes. If an agricultural population lives in an environment where the major problem in the productive cycle is shortage of water (not all agricultural populations) and where the solution to that problem has been canal irrigation (not all arid-land cultivators) and where the principal challenge to expansion of such a productive system has been labor or technological input (not all irrigation cultivators), we can trace a distinctive cause-and-effect system in which social stratification is inherent. The reasons are primarily economic: a nonegalitarian social organization is required to keep the productive system going at full capacity, to compel the cleaning and repair of canals, and to allocate the water which is available only through human agency. That these structural arrangements are adaptive is seen in the observation that the societies which have them are larger in size and in energy content than those which lack them. This is in evolutionary terms the indication of an adaptive trait, defined as one which tends to increase the number of its carriers.

Other inequalities too are inherent in hydraulic agriculture as its scale increases. Some of these are, of course, paralleled in other agricultural systems as well, and are viewed therefore as merely intensified in a hydraulic regime. We have previously noted that very few habitats are so uniform that they do not contain within them some sectors that are more productive than others, given the same amount of energy input. In the first stages of agricultural occupation of an area, these lands will be occupied first; only when they have been filled to capacity will people be effectively forced into other zones in the environment. As the area fills demographically, a resource formerly abundant relative to the group dependent on it becomes a resource in comparatively short supply. There will thus be competition, within a society or between societies, for access to that resource. This process of competition (Sanders and Price, 1968), far from unique to irrigation cultivators, is probably best considered a human universal. As the society or societies in question grow larger, the scale of the competition—both internal and external—escalates correspondingly. Probably the competitive situation on the Peruvian Coast developed quite rapidly, as cultivators began to exploit the narrow strip of annually flooded lands along the margins of the rivers. Such a limited area would fill up quite rapidly; the ultimate solution to the problem—the development of artificial irrigation on an initially small and progressively expanded scale—was undoubtedly preceded by considerable conflict. Patterson (pers. comm.) notes the presence of fortified sites and the practice of taking trophy heads on the central coast by the late Early Horizon. Similarly, at San Lorenzo there would have been a significant difference in productivity between the river-levee lands and areas removed from the immediate floodplain. This would have been less striking than the Peruvian coast situation, but nonetheless present. Coe (1968) postulates an effectively infield-outfield agriculture as the economic base of San Lorenzo, but there would probably have been a certain amount of competition over the choice lands. Initially in Teotihuacan Valley, choice lands were the upper hill slopes; the settlement pattern in Late Formative-Protoclassic times suggests competition, presumably over land, in this area (Sanders, 1965). Ethnographic examples of this sort of competitive pressure are numerous in various parts of the world. Competition is not unique to emerging or developed states, and competitive situations may occur both within and between societies.

The powerful exacerbation of these general competitive conditions by the introduction of irrigation into a local ecosystem is due in large measure to the controllable nature of this vital resource—the water supply. The dependence of the population on an artificial, technologically created resource—especially in environments like the Peruvian coast which are sharply circumscribed by aridity—makes that population unusually vulnerable. Relationships of true political and economic power are impossible among hunters and gatherers: these are small societies, integrated by kinship, where population growth is reflected in fissioning of bands and consequent growth of numbers of bands. The strategic resource is wild food, and people cannot "control" game, or the production of wild plants. Among shifting cultivators, and particularly those in open environments the productive resource, land, can be differentially controlled. But the need to do so comes only when the environment is completely filled in to its limits, or nearly so. With non-permanent cultivation, the impetus for control of land is rather weaker than is the case with permanent fields. There is, however, a marked difference in the possible degree of social control, and thus of internal competition, where the productive potential of the land depends wholly or in large part upon an artificial resource; it will be greatest particularly where the contrast in productivity between irrigated and nonirrigated land is sharpest (Aschmann, 1962).

Other bases of conflict are present in societies dependent on irrigation agriculture (Millon *et al.*, 1962), particularly so where these irrigation systems serve a number of separate communities economically linked through common dependence on a single resource base. What one swidden farmer does, affects his neighbors or the residents of the next village only minimally if at all. This is not true in irrigated systems where, if farmers upstream use too much water, there may be none at all available for downstream users. Riparian controversies between upstream and downstream users of the modern Teotihuacan Valley system are rife, often to the point of exploding into armed conflict between villages. Their common dependence on this resource base has acted to favor political integration on a regional level, but this need not imply that it is at all pacific. Sanders and Price (1968) have suggested that centralized control is an adaptive solution to the problems posed by this kind of conflict.

At a higher level of development, examples are numerous of the conflicts arising between entire polities that have reached a ceiling of expansion. Among the archaeologically known Irrigation Civilizations, this process seems to have been basically similar in Mesopotamia (Adams, 1966) and in coastal Peru durng the Early Intermediate (Willey, 1953; Patterson and Lanning, 1964; Kosok, 1965). The relationship between intersocietal warfare or militarism and agricultural production has been alluded to above; the formation of the multi-valley Moche conquest state is particularly interesting. If, like Viru, the Moche Valley ecosystem had reached its maximal expansion, the only remaining economical way of procuring additional needed resources would be by the external conquest and expropriation of those resources from someone else. The Moche conquests may, as Collier (1955) implies, have involved the initial inception of transvalley irrigation between Moche and Chicama; the Mesopotamian evidence suggests, however, that this would not have been necessary. Often, external conquest, for instance the Mesopotamian case, is more economic and involves less labor, than further intensification of the local productive base; in the case of Moche, such intensification may not have been possible. Sanders and Price

(1968) suggest that the control of internal force within polities of this type effectively pre-adapts them for external expansion as well.

Competition, cooperation, and expansion are basic ecological processes applicable to the analysis of first the internal dynamics of individual societies, and second to the kinds of relations obtaining between and among the societies of a region (Sanders and Price, 1968). Questions such as those involving the nature of militaristic expansion of civilizations cannot be satisfactorily or intelligibly explained apart from this more inclusive context. The pre-adaptation of state institutions for such expansion is characteristic of societies at this level of development. But this too must be regarded as one special class or case of a more general consideration: what determines which areas are nuclear and which marginal? More colloquially, what are the determinants of the balance of power, and how do these determinants change through time?

All ecological processes are diachronic. Thus, each phase must be viewed in terms of what precedes and follows it: we are dealing not merely with a sequence of forms but with the explanation of processes of change. Palerm and Wolf (1957:9) consider a nuclear area as one of "massed power in both economic and demographic terms;" Sanders and Price define it (1968:51) as a particularly vigorous focus of culture change where "such change had strong extra-local repercussions." In general, an ecological explanation of the processes of cultural development must take into account not only particular local adaptive problems and their solutions, but also the ways in which adjacent local developments of this sort impinge on each other. The total environment of any human population necessarily includes the factor of other human populations as well. Since the adaptive processes involved are diachronic, the balance may shift through time—an area may be nuclear (an innovating center) in one period, and marginal (a receiver of influences) in another.

Mesoamerican prehistory offers an instructive illustration of the processes involved. At a time when the subsistence base involved exclusive dependence on wild foods, the demographic potential of sectors of this complex environment varied considerably with the range and quantity of naturally occurring food resources. The nuclear area in the origins of maize agriculture—an intensification of environmental productivity—was a zone that included a number of tierra templada, highland, semi-arid, mountain basins. At this time other regions, such as the Pacific Coast of Guatemala, continued to support a sedentary population of littoral and marine gatherers (Coe and Flannery, 1964, 1967). As the essentially extensive techniques of the developing agriculture became more widespread in Mesoamerica, the possession of this technology altered the carrying capacity of each area in which it was applied, and in this fashion altered the former relationship of areas to each other. The best zone for hunting and gathering in the La Victoria vicinity, for example, became almost depopulated with a change to an agricultural subsistence base.

By the Middle Formative the Gulf Coast Plain of Mexico had very clearly become nuclear with respect to Mesoamerica as a whole. For an overall population having access to basically extensive techniques of agricultural production, this is the area in which yields so obtained are highest. The highland zones that are the apparent hearth of agricultural origins will produce similarly high yields per hectare only with a labor input considerably greater than that necessary for production on the Gulf Coast. Tracts of arable land cultivable with available technology were also more limited in the highlands, while the Gulf Coast is a comparatively more open environment. Thus, differential agricultural potential can be seen as the major factor underlying the Middle Formative florescence of Olmec culture. Compared to other regions, this area of southern Veracruz-Tabasco was precocious and very definitely nuclear. From this zone the first of the Mesoamerican horizon styles spread into areas from the Valley of Mexico to Chalchuapa in El Salvador. The cultural preeminence of this Olmec area is evident in a comparison of the contemporary sites at San Lorenzo in Veracruz and San Jose Mogote in Oaxaca. San Lorenzo is clearly a larger and more internally differentiated society, as judged by both the quantity and complexity of building activity, which we are using as an indicator of the total energy content of the society. Olmec, similarly, was a nonegalitarian society not dependent on hydraulic institutions, Coe (1968) to the contrary. Flannery (1968b) and Parsons and Price (1970) have developed a nonhydraulic model based on trade that is capable of generating nonegalitarian society at this demographic level, which is considerably smaller than that of the Classic civilizations.

Olmec was surpassed as a locus of demographic and economic influence only as the highland areas not only initiated but expanded the capacity of labor-intensive means of production. As we have observed, these highland areas turned out, in the long run, to be more improvable by technological means than the lowlands. Some technological experimentation of this sort seems contemporary with the apogee of Olmec, but its initial impact on total productivity was necessarily small. The eclipse of Olmec did not occur until the Late Formative, when the nuclear area shifted to and thereafter remained in the highlands. It seems that in this particular empirical instance, the productivity based on increased reliance on an efficient irrigation agriculture in the highlands was largely responsible for the shift: an area that supports a larger and denser population will have an advantage over other competing areas, whatever the time period, whatever the specific characteristics of the economic base involved.

In Mesoamerica, given the specific characteristics of those environmental factors that affect agriculture and thus demographic potential, it was irrigation which largely determined the competitive balance among societies. That claim, however, hardly shows reliance on our part upon a single-factor explanation. There were differentials of similar sorts in the Middle Formative, based on the interrelation of completely different kinds of productive parameters; there were no hydraulic societies in Mesoamerica at that time period. The implication that irrigation was responsible for the balance of power in Classic and Postclassic Mesoamerica is based essentially on its impact on the productivity of different ecological niches relative to each other. We use these points as part of a statement of functional relationships rather than as reliance on a monistic panacea.

By the early sixteenth century the Basin of Mexico supported a number of highly differentiated ecological niches, including a great diversity of agricultural techniques, specialized crops adapted to various sectors, and both full- and part-time specialists in the production of an enormouus repertoire of nonagricultural goods and services, these last supported ultimately from surpluses produced by cultivators and obtained from them by regular market exchange, taxation, and tribute. Between the Classic and the conquest the agricultural history appears to have comprised largely a process of filling in, of expanding intensive techniques to the virtual maximum permitted by the limitations of geography. In addition, a number of additional labor-intensive methods of production, notably chinampas, were added to the total agricultural technology. The Teotihuacan, Toltec, and Aztec expansions involved the formation of conquest-based supra-local and supra-regional states, with the archaeological spread of horizon styles that blanketed local traditions on a virtually pan-Mesoamerican basis. We turn now to an examination of the role played by hydraulic agriculture in these developments.

Clearly not all of the Basin of Mexico was, or could ever be, irrigated. During those phases in the overall sequence when the entire area was more or less unified politically, and certainly during the maxima of empire, such unity was based on something other than the single integrated hydraulic system which never existed. Sanders and Price (1968:186–187) explain the complex dynamics as follows:

> If one considers, however, the interplay of the two processes of competition and cooperation within the geographical setting of Central Mexico, the role of hydraulic agriculture seems clear. The complex interdigiting of hydraulic and nonhydraulic zones with their consequent variations in population density, the short distances between hydraulic zones, and the dramatic contrast in productivity between hydraulic and nonhydraulic agriculture in a sharply circumscribed environment would provide an extremely competitive social environment. The combination of a system of agriculture that requires cooperation, the consequent uneven distribution of population, and a competitive social environment would all act to stimulate the development of highly organized, centralized political systems. Once the communities of a hydraulic zone were organized in this fashion the resultant state would enjoy an obvious competitive advantage over neighboring nonhydraulic zones and more distant hydraulic zones of smaller size or less efficient organization.

Therefore, even the "cantonal" nature of the individual systems could have been effective in the direction of the political development of the region as a whole. No such region was isolated, and events within these regions had considerable impact in the areas adjacent to them. These zones, if individually quite small, yet functioned as nodes in processes affecting areas at greater or lesser remove from them. Even by the sixteenth century, any single system integrated from 10,000 to a maximum of only 100,000 people. While Wittfogel—although pointing out the powerful expansive capacities of irrigation states—tends to stress the internal political dynamics of their organization, Sanders and Price emphasize instead the effects of the existence of such units in the context of larger symbiotic units, internally diverse and mutually interdependent. These "external" effects are an essential component of the processes of the formation of empire. Indeed, "internal" factors cannot be considered apart from "external" ones, since there is a feedback linkage between the two.

Yet the internal dynamics of the individual hydraulic clusters themselves are thrown into sharpest relief particularly during the periods of interregnum, when the level of sociocultural integration in Mesoamerica reverted to the smaller scale of the city state. These are exceptionally stable units which periodically are incorporated into large territorial empires; the latter, however, are less stable through time. This may well be a function of the cantonal nature of the productive system. At the city-state level there is a high degree of coincidence between the productive and the political systems. Concerning the Texcoco system, Wolf and Palerm (1955:276) state:

> The irrigation cluster discussed here lent a cohesion to the Old Acolhua domain which it might not have acquired otherwise. It is important to note that the limits of the domain coincided closely with the limits of irrigation in the area. Huexotla, marginal to the system of water distribution, was also marginal politically. The domain retained its unity even when the political structure of Texcoco reached out to include a wider area and a larger and more diverse population. Certainly, once the state expanded, the very marginal location of the domain in the narrow corridor leading from north to south along the eastern shore of the lake would have tended to reduce the area to secondary importance, had irrigation not provided a permanent backbone of political cohesion.

We have previously discussed the competitive relation of irrigated and non-irrigated zones to each other in Central Mexico. The "permanent backbone of political cohesion" of the Texcocan state described by Wolf and Palerm represents one example, a special instance of what Sanders (1968:103) refers to as "niche dominance." The locus of political power in a region—within a state, as here, or between entire polities—will be situated in that ecological niche which is superior to adjacent ones in productivity and demographic potential. This zone will constitute a nuclear area. The niche dominance effect should be enhanced as the total population of the region as a whole increases and, more significantly, as the productive differential between the component niches is increased. The concept (Wittfogel's hydraulic density is another special case) is thus a general statement of competitive relations, and summarizes the processes by which even a cantonal hydroagriculture can lead to political centralization in an area. In a sense, any agriculturally "infield" area could produce these effects to some extent as it interacts with the "outfield" area and its population; our postulated dominance of riverine over inland niches for the Gulf Coast Olmec can be explained in this fashion. Sanders considers chinampa cultivation in sixteenth century Xochimilco to have exerted a niche dominance effect comparable to that of the Texcocan irrigation system, producing an approximately similar political and demographic centralization. He contrasts the more decentralized and perhaps inherently less stable situation of sixteenth century Chalco, which lacked both hydraulic agriculture and a single consistently dominant niche.

Extant data from Peru highlight a number of interesting similarities and differences when compared to the Mesoamerican sequence. The two areas in general exhibit remarkably parallel large-scale resemblances of development, resemblances that have long been observed. Both areas constitute what Bennett (1948) and Armillas (1948) term co-traditions: alternating phases of local cultural development periodically crosscut by horizon styles temporarily unifying entire diverse regions into virtually a single cultural province, though not always, apparently, on the basis of military conquest. The earliest of the major horizons in each region—Olmec in Mesoamerica, Chavin in the Central Andes—seem unaccompanied by any process recognizable as empire formation. The later instances—Teotihuacan, Toltec, Aztec in Mesoamerica; Tiahuanaco-Huari and Inca in the Central Andes—do seem to involve militarism, conquest, and some degree of incorporation of conquered populations into a single political system. In parts of both Mesoamerica and the Central Andes hydraulic agriculture, well prior to the conquest, constituted the principal subsistence base for large, dense, economically specialized populations.

It is these overall similarities that make one major difference that much more puzzling and paradoxical. In Mesoamerica, the development of hydraulic agriculture gave to those areas possessing it a consistent competitive advantage. Where the spread of a horizon style did involve conquest and empire formation—the Classic and Postclassic—the nuclear area for these events was the irrigation-based Meseta Central. The reasons for this phenomenon have been discussed above. The wave of conquest spread out of the irrigated highlands into the nonirrigated lowlands to the south. In Peru, current knowledge points to the coast, particularly the north and north-central coasts, as the heartland of the early development and maximal expansion of hydraulic agriculure. All the pan-Peruvian horizon styles, however, are of highland origin, and all the Central Andean empires have a highland core. It was always the highlands that conquered and incorporated the irrigated coast.

We have previously noted the near absence of data concerning the evolution of highland agricultural systems. This dearth of information makes the fact that this area was consistently the seat of empire virtually impossible to explain. The repeated conquests of the coast from the highlands presupposes a demographic advantage in the highlands—otherwise they could not have succeeded in gaining this kind of systematic access to the resources of the coast (probably the principal motivation for the cycles of conquest). But the nature of the subsistence base that evidently supported this presumed demographic superiority is totally unknown. The principal problem in most highland areas is more likely to be a shortage of arable land than a scarcity of water; this too, presumably, would vary from one basin to another. The apparent productive precocity of the coast, detailed earlier in this paper, may be merely an artifact of inadequate comparative research and thus a function of lack of data. At present, the phenomenon that the irrigated areas of Mesoamerica were nuclear, and those of Peru apparently marginal, cannot be satisfactorily explained, but only noted as one of a number of outstanding problems in the interpretation of the development of pre-Columbian civilization in the New World.

V. CONCLUSIONS

The aims of this paper have been largely explanatory. We have attempted to provide a conceptual framework for clarifying the interrelationships of agricultural productivity, demography, the internal dynamics of certain kinds of society, and the relationships between societies. Cultural evolution is seen ultimately as the result of a series of ecological processes operating in time, to intensify or to neutralize each other. No single practice or trait can be assigned as a priori causal preeminence; but some kinds of causal parameters will be more powerful determinants of development than will others. The most important characteristic of the ecological method lies in its broadly interactive approach, which includes consideration of certain kinds of sociopolitical factors as part of the total ecosystem of a people. Thus. it is not the existence of irrigation agriculture as an entity to which causation can be uncritically attributed that concerns us. We ask instead what its reprecussions are throughout the ecosystem in particular cases and, thus, by relying on process and function rather than on form, we may examine other cultural phenomena which may, under specified circumstances, produce similar effects.

Irrigation, for cultivators in arid lands, has its initial impact on the productive cycle itself. So too may other technological practices. Conversely, an artifact or structure may represent some cultural means of water control but lack impact on the productive potential of the environment. Coe's (1968:64) stone drain at San Lorenzo is such an example; so is the system of drains observed at Teotihuacan. These represent energy utilization by a population in exactly the way a colossal stone head or a pyramid does: the materials used must be collected, and energy is expended to give these raw materials their final form. While there are practical advantages to removing the rainwater from one's patio, these do not increase the total energy content of the society. Thus, not all observed technology of water control can be analyzed in the same manner. Processes and functional implications as well as form must be considered; not all water control necessarily represents investment of energy that produces more energy.

Besides their impact on productivity in many instances of their occurrence, artificial water works are significant because they represent not only a critical resource on which a greater or lesser percentage of the population depends, but also a critical resource which is controllable with great ease. Irrigation is not unique in this respect. Any factor on which a population is dependent may at some level of demographic growth impose a ceiling on further expansion, but some kinds of resources are more subject to technological and sociological controls than are others. Particularly in some phases of demographic expansion, access to trade routes may function as an equally, or nearly equally, vital resource. Where populations have grown to the point where egalitarian direction of trade relations is no longer sufficient to secure regular and consistent access to goods needed but not locally produced, access to trade institutions may stimulate both a nonegalitarian social structure and some degree of economic centralization. This seems to have been the case in Middle Formative Mesoamerica, as we have previously observed. A similar interpretation is the basis of Steward's (1955b) treatment of a Teotihuacan for which, at the time, no substantive evidence existed to support its status as an Irrigation Civilization.

https://doi.org/10.1017/S0023879100041054 Published online by Cambridge University Press

The basis of political power may lie in the controllability of the "lifeline" of the population in the ecosystem in question, whatever that lifeline may be. The impact of irrigation in this respect is extremely powerful, but under certain conditions other parameters may operate, to a greater or lesser extent, to produce similar effects.

The relationship between irrigation and centralization is therefore not considered unique. Both centralization of authority and internal social differentiation may be responses to a number of different empirical factors. While irrigation agriculture is inefficient without cooperative effort, such cooperation may be stimulated, again in certain stated demographic and geographic contexts, by other factors. Access to markets, as cited, may be such a factor, especially in areas of close microgeographic zoning where intense specialization has been a response to population growth and a solution to the problem of maximizing overall production. The economy of each component of such a symbiotic region (Sanders, 1956) depends on regular access to the produce of all other components. Although swidden agriculture, as another example, is usually regarded as strongly centrifugal, the approach of the demographic ceiling may be accompanied by centralized control of the agricultural cycle and the allocation of farmland. There is some indication that this or a related process may have been operative in Late Classic Maya society. The point is that environmental circumscription which deters expansion may be sociological as well as strictly geographical. Under such conditions, the land itself becomes controllable, far more so than is usually characteristic of swidden systems. In circumstances where increasing numbers depend on a resource available in limited supply, that resource becomes more controllable sociologically than it would otherwise be; sanctions may be applied easily and made to stick.

The sociocultural effects of irrigation are, as we have noted, very powerful in all these respects. They will be especially powerful where the combination of geography and productive technology permit, in time, the expansion of small local systems—and small local populations—into large supralocal ones. But irrigation is not unique in this respect. The approach we advocate is an essentially multilinear one: it cannot be assumed that "the same" trait formally defined will always behave functionally in the same way in all ecosystems. "The same" trait may be a response to different challenges in different contexts. Similarly, traits that are formally quite different may, depending upon total context, produce quite similar kinds of effects. These are necessarily matters for empirical determination.

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