# An Analysis of Ancient Egyptian Settlement Patterns Using Location-Allocation Covering Models

Richard L. Church* and Thomas L. Bell**

*Department of Geography, University of California, Santa Barbara, CA 93106
**Department of Geography, University of Tennessee, Knoxville, TN 37996

**Abstract.** Location-allocation models may be used to focus upon a multiplicity of factors potentially underlying settlement pattern development. We describe several such maximal covering models and their applicability in understanding the degree of political centralization in the Nile Valley during the Ramessid period (ca. 1317–1070 B.C.). The results of the covering models support the contention that the main objective of the Ramessid bureaucracy in choosing sites for administrative centers was to maximize control of the Nile Valley population and the agricultural labor power they provided, to supply much needed land rent-taxes to the royal coffers. Even when a premium is placed upon centrality (i.e., spatial coverage) at the expense of maximizing the population which could be served from a set of administrative centers, capitals of eight political subdivisions (nomes) appear consistently in the solution sets. Factors not accounted for in the covering model, such as trade routes and selected resource deposits, may account for the close spacing of three nome capitals. In general, the results of the covering models tend to minimize the administrative/economic role of several east-bank towns towards the middle of the study region and those near the Faiyum Depression. Covering models demonstrate that three other nome capitals which were of minor consequence during the Ramesside were also inefficiently located. Two non-capital sites appeared consistently in the optimal sets of administrative centers. Both had a mayor in residence, supporting Butzer's contention that mayors may have been more important to the functional viability of administrative centers during the Ramessid period of the New Kingdom than the traditional nome structure, which had been in place from Old Kingdom times onward. The location-allocation modeling results reinforce many of the contentions of field archaeologists about the nature of Egyptian society.

**Key Words.** Egypt, New Kingdom, location-allocation modeling, maximal covering location problem, Ramessid pharaohs, Nile River.

FOR several years there has been welcome and synergistic interchange between geographers and archaeologists interested in unraveling the mysteries of settlement systems of ancient societies (see, for example, the work of Johnson 1972, 1977; Marcus 1973; Hodder and Orton 1976; Clarke 1977; Crumley 1979). While cooperation between cultural geographers and cultural anthropologists is a long-lived and venerated tradition in both fields, the geographers from whom archaeologists have recently sought advice and counsel are theoretically-oriented economic geographers rather than more traditional cultural geographers. Gamble (1987) asserts that archaeologists' interests in a more systematic locational analysis of archaeological settlement systems, than had previously been the case, were first piqued by Haggett's (1966) *Locational Analysis in Human Geography* as referenced in Clarke (1968). Several archaeologists found merit in using the insights derived from location theory, especially central place theory and rank size regularities, in their own work. Gamble, an archaeologist who has chronicled this cooperative interface period, suggests that after a brief flirtation with geographical location models, archaeologists became disenchanted with the one-way nature of the relationship and have waned in their ardor for the promise once held by geographic location theory (Gamble 1987). As recounted by Gamble, many archaeologists felt that geographers were condescending, continually denigrating the scanty nature of archaeological settlement data and the lack of firm temporal content on the artifactual evidence. Gamble feels the reaction of most geographers is ironic in light of the heavily derivative nature of geographic location theory. Why is it acceptable for geographers to borrow heavily from economics but to feel reticent to share geography's cumulated knowledge with another discipline seeking guidance on locational issues?

Gamble's view of the recent period of the geography-archaeology interface seems jaundiced to us. Many mistakes were undoubtedly made by the application of inappropriately specified models, but surely more insight was gained than harm inflicted to either discipline. The probable reason for archaeology's current disenchantment with theoretical economic geography is, in our opinion, that many archaeologists and geographers have not progressed beyond the classic statements of location theory. Unrealistic assumptions about the environment (e.g., isotropic surfaces), movement and consumer behavior (e.g., distance minimization) have led to an impasse on new breakthroughs. Only when the shackles and strictures of the classic theories give way to the flexibility of location-allocation models can real progress in innovative application be achieved. This paper continues to expand the interface between archaeology and geography by illustrating the utility of location-allocation modeling for analyzing archaeological settlement systems. We believe that continued cooperation between archaeology and geography is both feasible and desirable.

## Statement of Problem

We present a test of the ability of a location-allocation covering model to simulate the spatial pattern of the top levels of a settlement hierarchy within a politically complex society in which there is evidence of bureaucratic centralization of authority. That society is pharaonic Egypt during the administration of the powerful Ramessid pharaohs (Kauffman 1981; Bell and Church 1987). The Ramessid period of dynastic Egypt during the New Kingdom (ca. 1317–1070 B.C.) offers an adequate database with which to test the ability of location-allocation covering models to simulate settlement-siting criteria. Most of the major settlements had been in place from Old Kingdom times onwards, but the settlement system had been disorganized and poorly administered until the rise of these powerful pharaohs.

The region used is the immediate Nile floodplain from the first cataract near Aswan to just south of Cairo excluding the Faiyum Depression and the Nile delta. A total of 128 major settlements are included in the data set which contains 23 distinct administrative units called nomes (Fig. 1).

Written records from the Ramessid period on papyri point to dramatic functional differentiation among settlements along economic, religious, and administrative lines. Butzer's list of New Kingdom settlements in an "attribute roster" of functional importance comprises the most thorough site inventory to date (Butzer 1976, 61–70). In addition to the status of the settlement as a nome capital, the "attribute roster" records the "presence of elite or royal cemeteries, of a mayor, of one or more temples, of attached villas or suburbs, and of a fortress or quarry." (Butzer 1984, 928). This settlement inventory includes the relative importance of sites as religious, economic, and administrative centers and forms the database for the model of settlement administration developed here. These settlement data have been updated to take into account the information on Egyptian towns appearing in the *Lexikon der Agyptologie* since 1976 (Helck and Otto 1972–), as well as data by Kemp (1977).

Even this settlement inventory remains incomplete on at least two accounts. In general, small villages would have had none of the administrative or religious functions necessary to merit mention in the average papyrus text, and their archaeological remains are rarely evident. The Wilbour Papyrus is the only source to list sites of all sizes and functional status, but covers only a small portion of the valley near the Faiyum Depression (Gardiner 1948). A second problem with the textual evidence on papyri is that it is almost exclusively comprised of New Kingdom records from Weset (also called Thebes or Luxor, which is settlement 29 in Fig. 1). Therefore, coverage of the region imme-

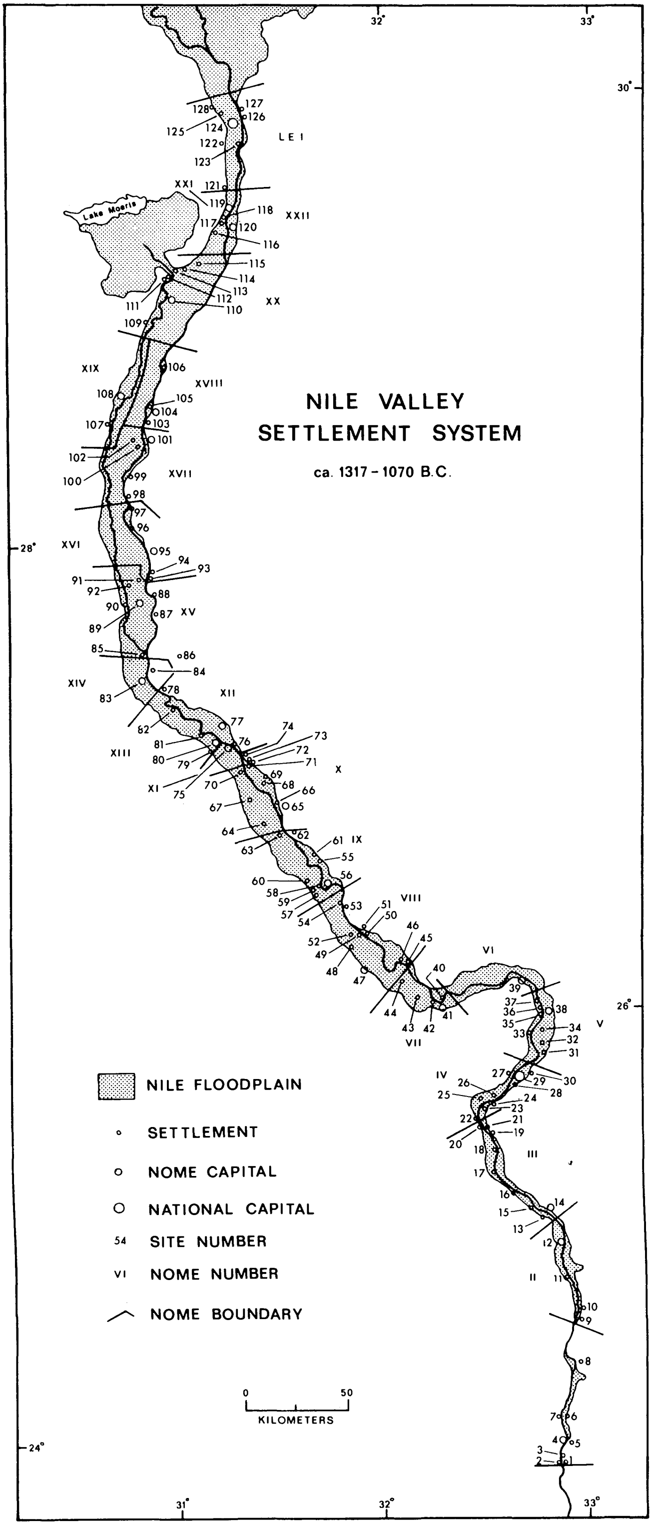


**Figure 1.** The Nile Valley settlement system in Upper Egypt during the period of the Ramessid pharaohs (New Kingdom, ca. 1317–1070 B.C.). Source: Bell and Church 1987, 80.

diately surrounding Weset is fairly complete, but is more fragmentary in most of the administrative units (nomes) north of Dandara (also called Inu, which is settlement 39 in Fig. 1) (O'Connor 1972).

The textual sources reveal the hierarchy of major administrative centers operative in Ramessid Egypt. The most important towns in the system were the national capitals, Menfe (also called Memphis, which is settlement 124 in Fig. 1) and Weset (29), dominating respectively the northern and southern parts of Egypt. These cities alternated in primacy based on the regional affiliation of the pharaoh in power, and, as a result of dominant national security concerns. Menfe (124) initially was the primary seat of government during the Ramessid period, but by the mid-13th century B.C., the functional capital shifted to Pi-Ramasse (also called Tell Dabba, not shown on Fig. 1) in the eastern Delta and later to Tanis in the Delta (not shown on Fig. 1), although by the mid-12th century B.C. pharaonic power was seemingly split between Weset (29) in the southern part of Upper Egypt and Menfe (124) to the north (Kemp 1972).

Next in hierarchical importance were the capitals of the nomes or provinces, into which Egypt was divided from the Old Kingdom onwards. There are twenty-four nomes present in the section of the Nile Valley of interest here (23 in Upper Egypt and the southernmost nome of Lower Egypt). Nome capitals may have been dominant in the administrative, economic, and religious activities of the nomes. Many had held that status for hundreds of years since the Old Kingdom. In the New Kingdom era immediately preceding the Ramesside, all of the nome capitals included in the incomplete Rekhmire list were identified as centers for the collection of annual taxes on cereals, animals, and other products (Helck 1974). Most of the known mayors, a key figure in provincial administration, were also associated with nome capitals. Other towns were known to have had mayors and to have collected taxes, but it may be inferred from the Wilbour Papyrus that the capitals were more important than other towns in the nomes because they controlled more land. The Wilbour Papyrus also suggests that administrative changes could affect the status of a nome capital. The capitals of H-Nesu (104), Spermeru (108), and Shena Khen (119) were relatively unimportant by the time of the New Kingdom. O'Connor concluded from his analysis of New Kingdom papyri that the settlement pattern of Upper Egypt was:

> "dominated by a network of major towns, the functions of which were to exploit the agricultural and human resources of the country, and to control its chief means of communication, the Nile, in the interests of a highly centralized government" (O'Connor 1972, 688).

## The Maximal Covering Location Problem

The objective of maximizing the control of a population by a central authority through a set of regional administrative centers is analogous to the underlying premise of the maximal covering location problem (MCLP) (Toregas and ReVelle 1972; Church and ReVelle 1974, 1976).

Scott has noted that the economic systems which are most appropriately analyzed by location-allocation models:

> "correspond on the one hand to a system of complete centralization of decision-making, and on the other, to complete decentralization of decision-making (where perfect competition exists).... It is in the nature of such systems to seek out cost-minimizing solutions" (Scott 1971, 1).

The former condition is suggested to have been operative in Ramessid Egypt. The degree of political centralization as measured by the degree to which population and, therefore, agricultural land could be efficiently administered from a set of administrative centers might be assessed using such a covering model.

The focus of the maximal covering location problem is on the supplier of services (e.g., the central decision-maker). In Ramessid Egypt, the main objective of settlement location is hypothesized to have been the maximization of administrative control (i.e., coverage) of the populace by the pharaoh and his agents in order to maximize the collection of rent-taxes. The maximal covering model can thus be used to indicate the extent to which this hypothesis is valid.

It is not always possible to achieve total population coverage with a given number of facilities and a particular maximum covering distance. The next best thing would be to cover as much of the population as possible within a specified distance. That is, the problem would be to maximize the number of people controlled (i.e., "covered") within a defined maximum service distance by locating a fixed number of administrative centers (e.g., one administrative center for each of the 23 nomes of upper Egypt). The MCLP can be used to analyze the efficiency of the configuration of Ramesside administrative centers in terms of their maximization of political/economic control.

The mathematical formulation of the model utilized is as follows:

$$\text{Minimize: } Z = \left[W_1\left(\sum_i A_i\bar{Y}_i\right) - W_2\left(\sum_j B_jX_j\right)\right]$$

$$\text{Subject to: } \sum X_j + \bar{Y}_i > 1 \text{ for all } i \in I$$

$$\sum X_j = p$$

$$X_j = 0, 1 \text{ for all } j \in J$$

$$\bar{Y}_i = 0, 1 \text{ for all } i \in I$$

where:

$I$ = the set of demand nodes (sites to be "covered")
$J$ = the set of administrative centers
$S$ = the distance beyond which a demand node is considered "uncovered"
$D_{ij}$ = the shortest distance from node i to node j
$X_j = \begin{cases} 1 \text{ if an administrative center is allocated to } j; \\ 0 \text{ if otherwise} \end{cases}$
$\bar{Y}_j = \begin{cases} 1 \text{ if the node is not covered;} \\ 0 \text{ if otherwise} \end{cases}$
$A_i$ = the population to be "covered" at a demand node i
$B_j$ = preference valuation (e.g., rank, score)
$N_i$ = $j \in J \mid D_{ij} \leq S$
$p$ = the number of administrative centers to be located
$W_1$ = objective function weight for coverage (non-negative)
$W_2$ = objective function weight for preference (non-negative)

$N_i$ is the set of administrative center sites eligible to "cover" demand point i. A demand node is "covered" when the closest administrative center to that demand point is at a distance less than or equal to S. A demand node is "uncovered" when the closest administrative center to that point is at a distance greater than S. The objective is to find the minimum number of people left "uncovered" if p facilities are located (Church and ReVelle 1974).

The above formulation has been used in determining the bureaucratic efficiency of Nile River administrative centers. A linear programming formulation of the model specified above was used to arrive at a set of optimal solutions. Two sets of weights were used as surrogates of importance ("population") for each Nile Valley site. The first measure was a composite score based on the value of socioeconomic attributes selected from Butzer's (1976) roster. Not surprisingly, the highest individual site scores were Menfe (124) and Weset (29), each with a score of 14. The sum of all scores for the 128 settlements was 509. The second measure was an ordinal scale of relative site importance ranging in value from 1 to 4 based on the interval scores (Table 1). The sum of the ordinal rank scores was 213 for the 128 settlements. In the absence of better data, these interval and ordinal weights were used as both an approximate measure of site population and as an evaluative measure of the importance of the site within the major settlement system hierarchy.

The MCLP was solved within a multi-objective trade-off framework in which two decision-making criteria were assumed. First, the importance of the settlements selected as administrative centers as measured by either the interval score based on the socioeconomic attributes of the sites or the ordinal rank of the sites was maximized. This criterion is referred to as "preference." Secondly, the number of sites left "uncovered" within a specific covering radius S is minimized. This criterion is referred to as "covering." The weights assigned to either of these two criteria was allowed to vary between 0.0 (i.e., of no importance and, therefore, computationally identical to a single objective problem) and 1.0 (i.e., of total importance and, again, a single objective problem). Weighted values that are greater than 0.0 but less than 1.0 mean that *both* proposed criteria (preference and covering) enter into the siting evaluation process.

Sites with higher scores and ranks are chosen as administrative centers if a high weight (approaching 1.0) is assigned to preference ($W_2$), whereas a weight of $W_2 = 0$ will discount any input from the score and/or rank data. In such a situation, all sites which might serve as administrative centers would be weighted equally

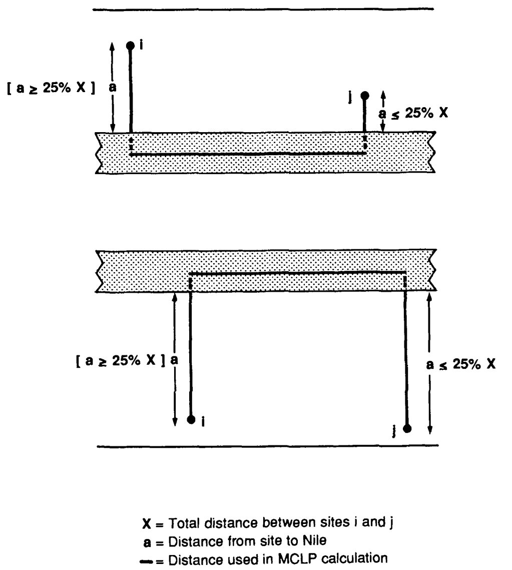


**Figure 2.** An illustration of inter-site distance calculation.

and the choice of an administrative center would be based solely on locational accessibility of the administrative center relative to surrounding settlement sites. By varying the objective function weights for $W_1$ (covering) and $W_2$ (preference), points are generated on a trade-off curve. Each point represents an optimal solution for a different combination of weights for coverage and preference given a specified covering distance.

## Choosing an Appropriate Covering Distance

The choice of the appropriate covering distance is an important one, for which there are no firm archaeological precedents. The first approximation of a maximal covering distance used for the Nile Valley settlement data was 19 km. This figure was based on a calculation of the average linear spacing of 23 principal sites over the length of the region of interest from the first cataract at Philae to the northern boundary of Lower Egyptian Nome 1, just south of present-day Cairo, approximately 873 km in length. It is reasonable to assume that an administrator might travel such a distance in the course of his duties. Likewise, a peasant attending a religious or state ceremony in the capital might travel at least this far. These would not constitute frequent journeys, nor would they usually be entirely on foot. Most travel of government personnel, as well as movement of grain and exotic goods, was by boat on the Nile. Most nome capitals, at the time of the Ramessid pharaohs, were located either directly on the river or linked to it by canal or major tributaries such as the Bahr Jussuf (Butzer 1976). Even the poorest peasants made use of local ferry services to travel from bank point to bank point. References to these ferry services are common in textual sources and depicted in temple and tomb paintings and reliefs (Kees 1961, 9).

The second estimate of appropriate covering distance was 22 km which was half of the mean river distance between nome capitals (44 km).

## Calculation of Site Location

The location of each site in the settlement system was calculated as a function of three variables: (a) distance from site to the Nile, (b) river mileage from the First Cataract, and (c) bank side. All measurements were taken from either the Defense Mapping Agency 1:100,000 topographic maps of the Nile Valley area (Defense Mapping Agency 1960) or corresponding Survey of Egypt 1:100,000 map sheets (Survey of Egypt 1940). Settlement locational placement was based on either the known and documented location of the archaeological site or the modern settlement noted as being in the general location of the site (Gardiner 1947; Butzer 1960; O'Connor 1972). The site-to-Nile distance was measured as the shortest straight-line distance between the site and the present-day bank of the Nile River. These data may not be a precise reflection of the actual intersite distances during the Ramesside as the course of the Nile has shifted considerably eastward since then. Butzer (1984, 929) notes that most major Ramessid sites were located on high banks "allowing for longer term shifts in river axis and meander geometry." The eastward shift of the Nile may have destroyed archaeologically valuable sites on the East bank but the method employed to measure site-to-Nile distance should result in a relatively stable, albeit not exact, set of inter-site distances.

River mileage was calculated as the distance from the island of Senmet (Bigga) at the First

**Table 1.** Summary Table of Data Displayed Graphically in Figure 3

| Solution sets | Sum of coverage values | Sum of preference value for admin. ctrs. | No. of nome capitals in solution | % Pop. covered by solution | % Nome capitals in solution |
|---|---|---|---|---|---|
| 19 km: Coverage (nodes)[a] Preference (ranks)[b] | | | | | |
| *p*1 | 123 | 38 | 03 | 96.1 | 13.0 |
| *p*2 | 123 | 49 | 08 | 96.1 | 34.8 |
| *p*3 | 119 | 60 | 12 | 93.0 | 52.2 |
| *p*4 | 111 | 68 | 16 | 86.7 | 69.6 |
| *p*5 | 90 | 74 | 20 | 70.3 | 87.0 |
| 19 km: Coverage (scores)[c] Preference (scores) | | | | | |
| *p*1 | 495 | 126 | 07 | 97.2 | 30.4 |
| *p*2 | 492 | 155 | 10 | 96.7 | 43.5 |
| *p*3 | 471 | 196 | 15 | 92.5 | 65.2 |
| *p*4 | 465 | 202 | 16 | 91.4 | 69.6 |
| *p*4a | 402 | 221 | 20 | 79.0 | 82.6 |
| *p*5 | 436 | 219 | 19 | 85.7 | 87.0 |
| 22 km: Coverage (nodes) Preference (ranks) | | | | | |
| *p*1 | 124 | 46 | 06 | 96.9 | 26.1 |
| *p*3 | 122 | 70 | 15 | 95.3 | 65.2 |
| *p*5 | 100 | 74 | 19 | 78.1 | 82.6 |
| 22 km: Coverage (nodes) Preference (scores) | | | | | |
| *p*1 | 124 | 126 | 07 | 96.9 | 30.4 |
| *p*2 | 124 | 163 | 11 | 96.9 | 47.8 |
| *p*3 | 119 | 199 | 16 | 93.0 | 69.6 |
| *p*4 | 115 | 210 | 18 | 89.8 | 78.3 |
| *p*5 | 100 | 221 | 20 | 78.1 | 87.0 |
| 22 km: Coverage (scores) Preference (scores) | | | | | |
| *p*1 | 505 | 109 | 06 | 99.2 | 26.1 |
| *p*2 | 505 | 161 | 11 | 99.2 | 47.8 |
| *p*3 | 499 | 180 | 13 | 93.0 | 56.5 |
| *p*4 | 485 | 213 | 16 | 89.8 | 69.6 |
| *p*5 | 432 | 221 | 20 | 78.1 | 87.0 |

[a] Total sum of nodes = 128 (i.e., the 128 settlements are treated as having equal weight).
[b] Total sum of rank = 213.
[c] Total sum of scores = 509.
Source: Bell and Church 1987, 85.

Cataract, along the main river channel as depicted on the 1:100,000 scale maps, to the point in the center of the present-day main channel which is an extension of the site-to-Nile measurement line. The model was constructed so that intersite distance calculations are dependent on both bank side and the site-to-Nile distance. If the site chosen as an administrative center location ($X_j$) and the node to be covered ($Y_i$) are on the opposite bank sides, then site-to-Nile distance is added to river mileage in the calculation. If, on the other hand, both sites are on the same side of the river and the distance from site-to-Nile is less than or equal to 25 percent of the entire trip length between sites, then both site-to-Nile and river mileage are used. If, however, the site-to-Nile distance is greater than 25 percent of the entire trip length, then only river mileage is used as an approximation of overland foot travel distance (Fig. 2). A matrix of inter-site distances was formulated in this manner in an attempt to account for local traffic between neighboring settlements where use of the river as a transportation route might have been illogical or less efficient than foot traffic.

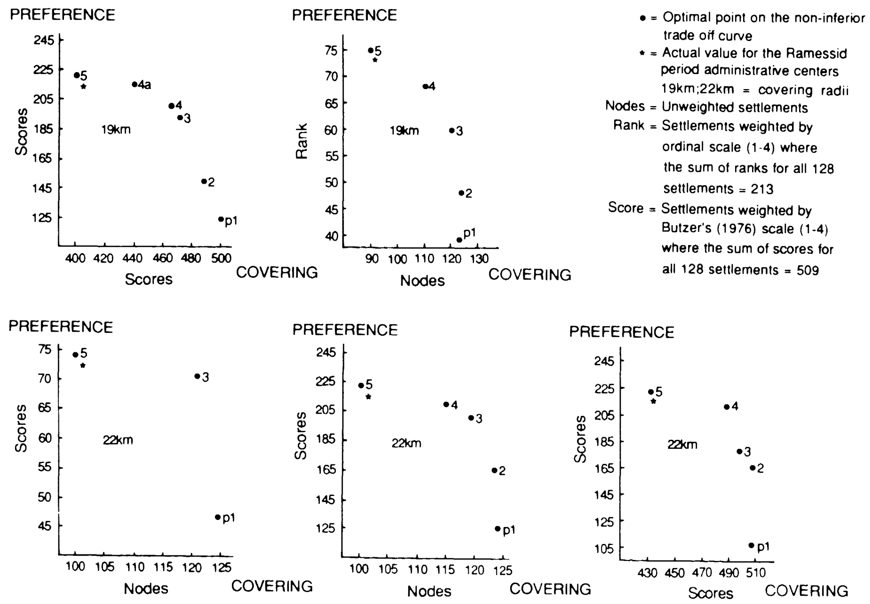


**Figure 3.** Trade-off curves illustrating solutions to the maximal covering location problem (MCLP) when 23 administrative centers are chosen from among 128 Upper Egypt settlements extant during the Ramessid Period. Source: Bell and Church 1987, 84, used by permission, Van Nostrand Reinhold.

## Implications of the Covering Results for the Ramissid Settlement System

The first set of objective function weights for each pairing of coverage and preference variables was always 1.0 for coverage and 0.0 for preference. This pairing is designated the p1 solution set in Figure 3 and can be interpreted as the maximization of coverage of demand points at the expense of any importance placed on the functional value of the sites chosen as administrative centers.

The second set of objective function weights calculated were diametrically opposed to the first, with coverage given a weight of 0.0 and preference a weight of 1.0. In these solutions, designated by the p5 points in Figure 3, 23 administrative centers with the highest functional score or rank are chosen from the set of sites first, in an attempt to optimize the functional (or "population") value of these centers.

Coverage and preference values for the p1 and p5 solution sets are plotted on a graph, with coverage values on the X axis and preference on the Y axis. The slope of the line formed by connecting these two points is calculated and is utilized to determine the set of objective function weights for preference and coverage in the next (p3) run (Cohon et al. 1979). The p2 objective function weights are, likewise, determined by the slope of the line connecting points p1 and p3, while the p4 objective function weights are calculated from the slope of the line connecting points p2 and p5 (Table 1). Five points were usually sufficient to define the general shape of the non-inferior trade-off curve.

The application of the MCLP to the Nile Valley data shows a high degree of compatibility between the objectives of coverage and preference (Table 1). The interested reader is referred to Kauffman (1981, Table 3, 73–75) for a complete listing of the set of 23 administrative centers selected by the location-allocation model to optimize the varying objective function weights and covering radii.

The percentage of "population" covered by the solutions ranges from a low of 70.3 percent to a high of 99.2 percent. Although the p1/p2 solution sets generally do not include a high percentage of nome capitals, the sites chosen as administrative centers (i.e., facility locations) are, in most cases, those whose scores are within the range of nome capital scores or which are close nome capital neighbors. Eight capitals are, however, present in all but one of the p1/p2 solution sets: (4) Yebu, (12) Edjbo, (14) Nekhab, (29) Weset, (56) Khant Min, (75) Shashotep, (83) Kos, and (124) Menfe. When p3 solution sets are taken into account, four more nome capitals are regularly included: (38) Gebtyu, (39) Inu, (41) He Sekhem, and (65) Djuka. These solution sets were generated with relatively little weight placed on the preference objective. Such a result suggests that the hypothesis of maximization of control over the Nile Valley population by the designation of spatially efficient nome capital locations is a plausible interpretation of Ramessid administrative goals.

Eleven capitals were present in 70 percent or more of all the solution sets. All except (39) Inu and (110) Ninsu were present in the p1 through p3 solutions. One non-capital site, (8) Enboyet, was also present 83 percent of the time. This site has a rather high score value for a non-capital. It is located almost equidistant from (4) Yebu and (12) Edjbo, the nearest nome capitals. Textual sources suggest Enboyet had a mayor, a high administrative figure most often associated with nome capitals (Gardiner 1947). The results of the location-allocation covering procedure suggest that mayors may have been key administrative agents of the pharaoh in certain regions of the Valley. This is especially true for the small but densely settled population of the extreme southern portion of upper Egypt. Here, the distance between capitals is two to three times that of the rest of the Valley. Another area where mayors may have played an important administrative role is in the densely settled and populous northern part of the Valley. Here, they may have constituted significant supplementary figures to nome capital personnel. In this northern region, (52) Tjeni and (116) Mertum both have mayors and are present in approximately 40–50 percent of the solution sets.

The presence or absence of certain nome capitals and other centers with a mayor in the MCLP solutions varies somewhat as a function of the coverage distance radius utilized as well as the objective function weights. Sensitivity of the modeled results to these parameters indicates the importance of further archaeological research on the issue of the extent of territorial hegemony of administrative centers.

Two nome capitals, (77) Pi Nemty and (95) Hebnu, are rarely included in any solution. Their continued status as capitals, despite their spatial inefficiency, must be explained by cultural, economic, or physical variables exogenous to the covering model. Pi Nemty (77) is located close to two other capitals, (75) Shashotep and (80) Siyawti. It is possible that Pi Nemty's survival as a capital was a function of the high density of settlement in the area during Ramessid times. An alternative explanation for the viability of these three closely-spaced capital sites is their link with important trade routes. Pi Nemty (77) controlled access to a major alabaster and gold trade route across the Eastern Desert. Siyawti (80), on the opposite bank of the Nile, was a primary port for the trade goods moving between the Kharga Oasis in the Western Desert and the Nile Valley (Kees 1961, 97).

Hebnu (95), although not a port of entry for caravan routes through the desert, nonetheless owed its continued prominence to its earlier role as the southern terminus of the defenses of the northeastern frontier against Asia during the time of the Middle Kingdom. While its role as a defense command post was considerably lessened throughout the New Kingdom, the inertia which it had built up as a center of population and political prominence was sufficient to carry it through later periods marked by heightened national security and prosperity (O'Connor 1972). In general, the Middle Kingdom was a period of new settlement creation whereas the New Kingdom period, including the Ramesside, was a time of settlement consolidation and renewal of existing sites. Favoritism bestowed by a grateful pharaoh for past accomplishments may certainly have played a role during this settlement consolidation phase.

Three designated nome capitals, (104) H Nesu, (108) Spermeru, and (119) Shena Khen, were relatively unimportant as administrative centers during the Ramessid period (O'Connor 1972). None of these sites is present in more than 40 percent of the solutions. Such a result is to be expected if their inefficient location was a prime factor in their decline from prominence. The political importance of Spermeru (110) and H Nesu (108) may have been overshadowed at the time by that of Hardai (101) which had become an important Ramessid administrative and economic center (O'Connor 1972).

In a number of instances, close neighboring sites to known capitals were designated as more appropriate administrative center locations by the covering model. The two non-capital neighboring sites with the highest rates of inclusion (Nekhen [13]—11 times and Sako [102]—14 times) are among those which Butzer specifies as being alternate capitals (Butzer 1976). That all these non-capitals had mayors in residence underlines their importance as administrative liaisons to the pharaoh outside of, or in addition to, the formal nome capital network. This result also lends support to the hypothesis that the spatial arrangement of mayors may have been functionally more important during the Ramessid era than that of the traditional nome structure.

## How Efficient Was the Ramessid Administrative System?

If the Ramessid pharaohs administered Upper Egypt during the New Kingdom as a highly centralized bureaucracy, as implied by the textual evidence interpreted by archaeologists, then one would expect the actual pattern of administrative nome capitals to be fairly efficiently located in order to best control the population. The degree to which the 23 nome capitals serve (i.e., "cover") their own populations as well as the remaining 105 settlements is shown in Figure 3. The concern may be simply to determine spatial coverage of settlements treated as unweighted points by these nome capitals. Such a concern would be important to the pharaohs who wished to maximize revenue/tribute from the areally extensive agricultural pursuits.

Alternatively, the purpose may be to determine the extent to which the set of nome capitals "cover" the population in Upper Egypt where population is estimated from the surrogate score and rank measures of settlement importance (Butzer 1960). Local populations were presumably located so that they could be organized to work the land conveniently. In either case, the system developed under the Ramessid pharaohs was very effective indeed. Whether the administrative covering radius is 19 or 22 kilometers, the values of coverage of the system of nome capitals come close to the optimal non-inferior trade-off curve (Fig. 3).

It is unclear whether the combinatorics of selecting so many administrative capitals (23) to serve such a limited number of major settlements (128) might cause high values of administrative coverage to be achieved irrespective of the sites chosen as nome capitals. Put another way, might it be possible to simply choose 23 sites at random to serve (i.e., "cover") the 128 settlements in a highly efficient manner? In this covering problem almost one in five of the total sites is entered into the covering solution.

The degree to which the Ramessid configuration is significantly better than that obtained by random selection was the specific focus of a second location-allocation modeling effort. A program was written which, using a random number generator, was capable of testing thousands of configurations of 23 sites randomly chosen to serve the entire settlement system. For each of these randomly generated configurations, the degree to which the 23 selected administrative centers "covered" the other settlements (measured both in their unweighted and weighted forms) was recorded.

In every test performed, the null hypothesis of no difference could be rejected at the .001 level of significance confirming that the efficiency of the Ramessid pattern was highly unlikely to have occurred by chance. One such test for an administrative covering radius of 19 kilometers is shown in Figure 4. The X-axis is calibrated to show the number of settlements covered (treated as unweighted points) and the Y-axis shows the frequency of times a particular coverage value was obtained when the model was programmed to generate 5000 solutions at random (Fig. 4). The average random solution could only cover 82 settlements whereas the system administered by the Ramessid pharaohs covered 91. The best random solution covered 105 settlements. Only 274 random solutions (5.5 percent of the total) covered more effectively than did the Ramessid pattern of administrative centers.

The results obtained when the settlements were weighted was even more striking. When settlement magnitude is measured by hierarchical rank, the actual Ramessid pattern of nome capitals produces a coverage value of 164 (of a possible 213) when the coverage radius is 19 kilometers. Of 5000 randomly generated solutions, only 13 (.2 percent) had a higher coverage value. Also when settlement "population" is measured by Butzer's attribute roster scoring method, the Ramessid pattern of nome capitals produces a coverage value of 410 (of a

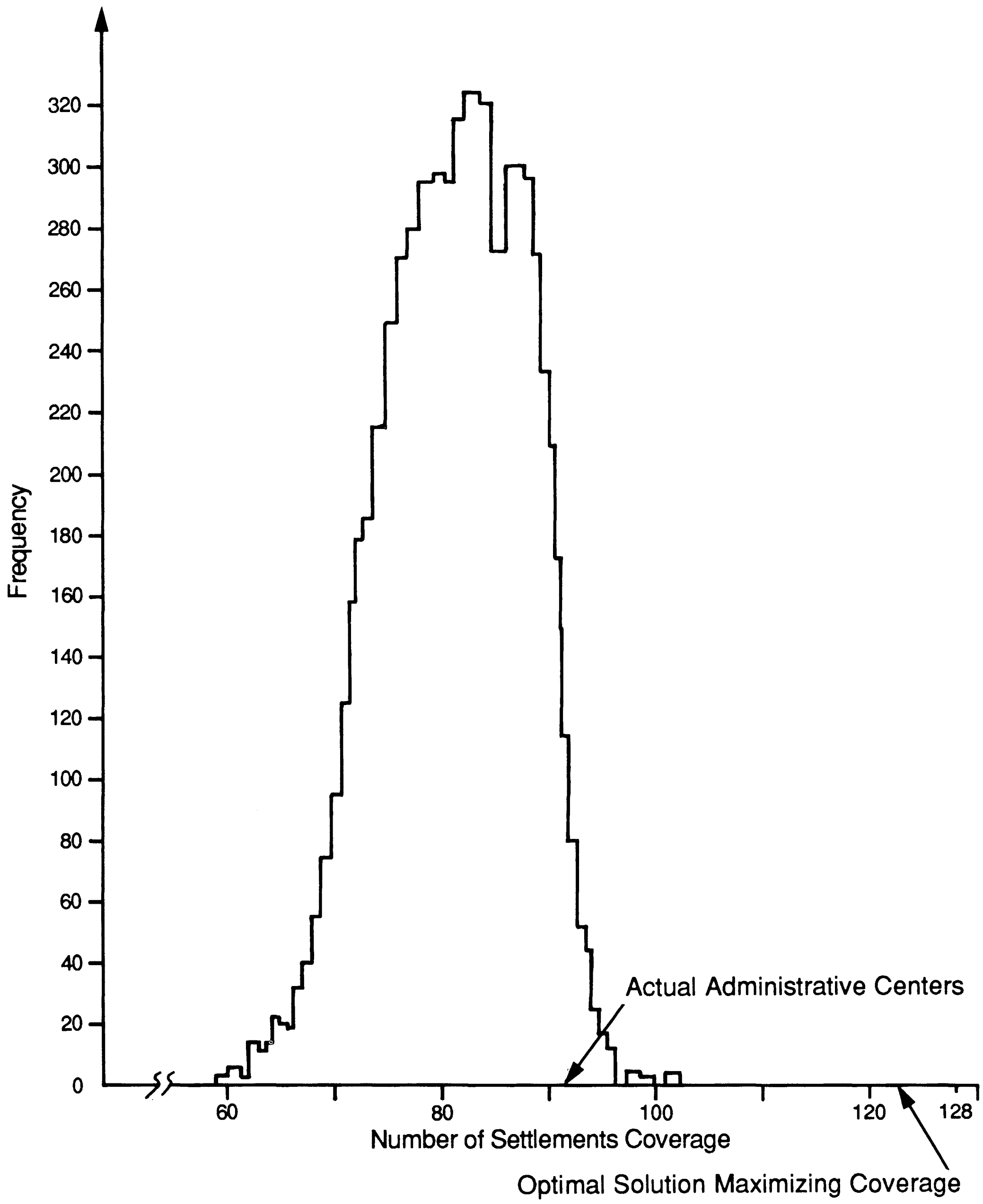


**Figure 4.** Frequency distribution of the degree of coverage of 128 unweighted Upper Egypt settlements generated by 5000 randomly chosen sets of 23 administrative centers.

possible 509) with a coverage radius of 19 kilometers. Only four (.08 percent) of the randomly generated solutions produced a higher value.

The same results hold when the coverage radius is increased to 22 kilometers. The application of the location-allocation program which generates random configurations compared to both the optimal solution and to the configuration of nome capitals actually used

**Table 2.** Comparison of Optimal, Actual and 5000 Randomly Generated Configurations of 23 Sites Used to Cover 128 Nile Valley Settlements

| | Covering radius | | | |
|---|---|---|---|---|
| | 19 km | | 22 km | |
| Unweighted (maximum value = 128) | optimal | 123 | optimal | 124 |
| | actual | 91 | actual | 102 |
| | random ($\bar{x}$) | 82 | random ($\bar{x}$) | 87 |
| Rank of settlements (ordinal—maximum value = 213) | optimal[a] | N.A. | optimal[a] | N.A. |
| | actual | 164 | actual | 177 |
| | random ($\bar{x}$) | 139 | random ($\bar{x}$) | 146 |
| Score of Settlements (interval—maximum value = 509) | optimal | 495 | optimal | 505 |
| | actual | 410 | actual | 435 |
| | random ($\bar{x}$) | 318 | random ($\bar{x}$) | 333 |

[a] Optimization problem (LP) not run with settlements measured by rank. Optimization runs are, however, available when the objective is defined as maximizing the rank of the 23 administrative sites entered into the solution.

during the Ramessid period is summarized in Table 2. Such results clearly indicate the efficiency of the Ramessid administration and independently confirm the conclusions of archaeologists working from textual evidence and field excavations. This is not to say that the Ramessid pharaohs chose administrative centers. Nome capitals had been in place for a considerable length of time. The relative fortunes of these capitals waxed or waned in a gradual population adjustment process throughout the New Kingdom period. By the time of the Ramesside, the relationship between the set of major settlements and agricultural lands that could be effectively cultivated was extremely close.

## Conclusions

The working hypothesis, that the main objective of the set of Ramessid regional administrative centers (i.e., nome capitals and/or mayors) was to maximize control (measured in terms of coverage) of the Nile Valley population, is supported by the results of the maximal covering location problem (MCLP). There is a close correspondence between the objectives of coverage (i.e., spatial efficiency) and preference (i.e., choosing important settlements as nome capitals) for all points on the trade-off curve. The trade-off curve represents a full range of weighting combinations for the two objectives. The amount of population covered by a solution is never less than 70 percent and ranges to almost 100 percent. Stated more simply, the New Kingdom Ramessid administrators, building on the experience of their predecessors, seem to have followed a plan of administrative center location which closely fits the objectives and constraints of the proposed model of maximal covering. This result holds true whether all sites are weighted equally or when site population is estimated as a functional weighting of attributes. Since these administrative centers (nome capitals) were present long before the Ramesside, one must conclude that they were a necessary but not sufficient condition for effective local administration.

The robust nature of model solutions given the disparate weights assigned to the objectives and the two different covering radii employed in the tests suggests that the archaeologically surveyed sites are a fairly good representation of the main administrative centers extant during the Ramessid period. The model results may be used to substantiate O'Connor's suggestion that the Ramessid pharaohs engaged in a conscious policy of forced settlement around administrative centers, with outlying land used mainly for the pasturage of animals (O'Connor 1972). By the time of the Ramesside, the relationship between population distribution and the areal extent of lands which could be effectively cultivated was quite strong, whether conscripted into a courvee labor force as O'Connor suggests or employed in a more conventional manner.

The goodness-of-fit of the simulation results with the known archaeological system suggests that in spite of the very important physical changes in the area, such as the reduction of the Nile's sinuosity and its eastward channel shift, the basic pattern of inter-site relationships has remained much the same. The Ramessid pharaohs appear to have administered Upper Egypt as a highly efficient settlement system.

This study emphasizes the vital link between geography and archaeology and serves as an antidote to those such as Gamble (1987) who have a pessimistic outlook on such interdisciplinary interaction. In this particular case, the results of the location-allocation covering models support most of the hypotheses put forward by field Egyptologists.

In other societal contexts, such geographic models have called into question the speculative hypotheses of archaeologists about the nature of spatial organization (see, for example Bell and Church [1985] for a reinterpretation of Smith's [1979] speculation on the nature of Aztec political structure). Whether such geographic model applications confirm or deny the inquiry of archaeologists, the point is this: There is much to be gained by the symbiotic interaction among geographic and archaeological researchers at the interface of these two intriguing disciplines.

## Acknowledgments

We wish to acknowledge the financial support of the Human Geography and Regional Science and Anthropology branches of the National Science Foundation under grant NSF SES 79-23686. The techniques of analysis used in this research were developed as part of the grant. We also wish to thank Barbara Kauffman for sharing the data upon which the models discussed in this paper are based. Her insights were invaluable for the present research as were those of several anonymous reviewers. Any errors in the interpretation of the modeled results remain those of the authors.

## References

**Bell, Thomas L., and Church, Richard L.** 1985. Location-allocation modeling in archaeological settlement pattern research: Some preliminary applications. *World Archaeology* 16(3):353–70.

———**, and** ———. 1987. Location-allocation modeling in archaeology. In *Spatial analysis and location-allocation models,* ed. A. Ghosh and G. Rushton, pp. 76–100. New York: Van Nostrand and Reinhold Co.

**Butzer, Karl W.** 1960. Archaeology and geology in ancient Egypt. *Science* 132:1617–24.

———. 1976. *Early hydraulic civilization in Egypt.* Chicago: University of Chicago Press.

———. 1984. Siedlungsgeographie. In *Lexikon der Aegyptologie,* ed. W. Helck and E. Otto, vol. 38, pp. 924–33. Wiesbaden: Otto Harresowitz.

**Church, Richard L., and Revelle, Charles.** 1974. The maximal covering location problem. *Papers of the Regional Science Association* 32:101–18.

———**, and** ———. 1976. Theoretical and computational links between the p-median, location set-covering and the maximal covering location problem. *Geographical Analysis* 8:406–15.

**Clarke, David L.** 1968. *Analytical archaeology.* London: Methuen.

———**, ed.** 1977. *Spatial archaeology.* London: Academic Press.

**Cohon, J., et al.** 1979. Generating multiobjective trade-offs: An algorithm for bicriterion problems. *Water Resources Research* 15:1001–10.

**Crumley, Carole L.** 1979. Three locational models: An epistemological assessment for anthropology. In *Advances in archaeological method and theory,* ed. M. Schiffer, vol. 2, pp. 141–73. New York: Academic Press.

**Defense Mapping Agency.** 1960. *Egypt 1:100,000 Series P677, Editorial.* Washington: Defense Mapping Agency.

**Gamble, Clive.** 1987. Archaeology, geography and time. *Progress in Human Geography* 11(2):227–46.

**Gardiner, A. H.** 1947. *Ancient Egyptian Onomastica, 2 Volumes.* Oxford: Oxford University Press.

———. 1948. *The Wilbour Papyrus,* vol. 2, Commentary. Oxford: Oxford University Press.

**Haggett, Peter.** 1966. *Locational analysis in human geography.* New York: St. Martins Press.

**Helck, W.** 1974. *Die Altagyptischen Gaue.* Wiesbaden: Reichert Verlag.

———**, and Otto, Ed., eds.** 1972–. *Lexikon der Agyptologie.* Wiesbaden: Otto Harrassowitz.

**Hodder, Ian R., and Orton, C. R.** 1976. *Spatial analysis in archaeology.* Cambridge: Cambridge University Press.

**Johnson, Gregory.** 1972. A test of the utility of central place theory in archaeology. In *Man, settlement and urbanism,* ed. P.J. Ucko et al., pp. 769–85. Cambridge, MA: Schenkman.

———. 1977. Aspects of regional analysis in archaeology. *Annual Review of Anthropology* 6:479–508.

**Kauffman, Barbara.** 1981. The maximal covering location problem as a simulation of decision making in Ramessid Egypt. Master's thesis, Department of Anthropology, University of Chicago.

**Kees, H.** 1961. *Ancient Egypt: A cultural topography.* Chicago: University of Chicago Press.

**Kemp, B. J.** 1972. Temple and town in ancient Egypt. In *Man, settlement and urbanism,* ed. P. Ucko et al., pp. 657–80. London: Duckworth.

———. 1977. The City of el-Amarna as a source for the study of urban society in ancient Egypt. *World Archaeology* 9(2):123–39.

**Marcus, Joyce.** 1973. Territorial organization of the lowland classic Maya. *Science* 180:911–16.

**O'Connor, D.** 1972. The geography of settlement in ancient Egypt. In *Man, settlement and urbanism,* ed. P. Ucko et al., pp. 681–98. London: Duckworth.

**Scott, A. J.** 1971. *An introduction to spatial allocation analysis.* Resource Paper No. 9. Washington: Commission on College Geography, Association of American Geographers.

**Smith, Michael E.** 1979. The Aztec marketing system and settlement patterns in the Valley of Mexico: A central place analysis. *American Antiquity* 44:110–25.

**Survey of Egypt.** 1940. *Grundkarte: Agyptan 1:100,000.* Cairo: Survey of Egypt.

**Toregas, C., and ReVelle, C.** 1972. Optimal location under time or distance constraints. *Papers and Proceedings of the Regional Science Association* 28:133–43.