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War, Peace, and the Computer: Simulation of Disordering and Ordering Energies in South Vietnam

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Ecosystem Modeling in Theory and Practice:
An Introduction with Case Histories

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Preface. This work was undertaken and finished during the height of military conflict in South Vietnam, before withdrawal of U.S. military personnel. The consequences of the United States intervention and subsequent withdrawal are now quite apparent and agree in general with our computer projections. Our original contract did not include provisions for a change in government.

The ending of the "Vietnam War" marked the beginning of the end for "democracy" in South Vietnam. For as the simulation results in this investigation show, the 6-year war from 1965 to 1970 left the country of South Vietnam with little infrastructure to continue prolonged conflict with their neighbors to the north. Without massive aid programs of both military and civilian aid (to increase the internal productivity of the country) there was little doubt that the country would fall. Of course, the external subsidy to the "winning" side, not simulated here, was a very important factor in the ultimate disposition of the war.

The simulation results indicated that even with a twofold increase in aid over those amounts in 1971, it would require as long as 10 years for South Vietnam to recover to the levels of productivity experienced before the "6-year war." As a result the country was particularly vulnerable to continued conflict. With these things in mind it was of little surprise that the government of South Vietnam surrendered to that of North Vietnam on May 7 of this year. Perhaps this simulation will be of some use to the new political structure responsible for the welfare of the people of South Vietnam.

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Any system that maintains continuous life must develop a balance between ordering and disordering processes. For example, ecosystems are dependent upon photosynthesis to build structure and to provide a base for the food chain. But ecosystems also require the catabolic processes of death and bacterial decay to make room for new organisms and to release nutrients needed for new plant growth from dead organisms. If one or the other of these two processes were to dominate for a long period of time, the system eventually would no longer be able to function properly. An important component of this anabolic-catabolic relationship is the ability of a system to rebuild structure after some disruption. For example, when a large tree topples in a forest because of a windstorm the successional communities are able to use the nutrients from the decomposition of that and other trees. New biotic

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structures soon fill the clearing aided by the increased sunlight energy that reaches the forest floor and eventually produce another large tree to replace the one that toppled.

Social systems also are dependent upon both the proper balance between constructive and destructive forces, and the ability to repair damaged structure. The crowded, complex systems of today's civilization continuously require large flows of energy from industrial and biotic sources to repair and replace structures damaged by entropic degradation. If these ordering processes are disrupted by war or other large disorders, the physical structure of society will suffer. On the other hand, if ordering energies are available to rebuild social structure, as was the case with the Marshall plan following World War II, the social effects of war may be mitigated to some extent.

This chapter investigates with the aid of an analog computer the country of South Vietnam, during the period 1960 through 1970, from the point of view of the ordering energies of biotic and industrial processes and the disordering energies of war. It includes calculations of the disordering effects of the extensive United States' bombing, herbicide spraying, and Rome plowing on ecosystems and cities. Quantitative calculations are made on the changes in land quality following these disruptions and the ways in which these changes effect the economy and population distribution patterns of the people of South Vietnam. Finally, we investigate what some of the ramifications of different levels of U.S. foreign aid, and hence new ordering energies, might mean to the reconstruction of Vietnam.

A MODEL OF VIETNAM

Figure 1 is a diagram of some major energy processes of the country of South Vietnam at war. It shows the major compartments and flows of energy and materials throughout the country. The circles to the left represent forcing functions, in this case the *ordering energies* available to South Vietnam. These are the materials and energies that are used in the normal processes of the country for construction and maintenance of structure (e.g., biomass, buildings, agricultural systems, etc.). S_1 is all incoming goods, both United States' material aid and imported goods from the World Market. S_7 is all money sent to South Vietnam in the form of aid, and S_6 is all the natural energies (sun, tides, wind, rain, etc.) that help maintain the natural structure of the country. The circles to the right represent the *disordering energies* that are forcing functions for the country at war, that is, the materials and energies that are used for war and thus increase the processes of disruption and entropy. S_2 is all the energies available to the Viet Cong and North Vietnamese military structure to make war. S_3, S_4, and S_5 are the three major disordering energies of the U.S. and South Vietnam military structure.

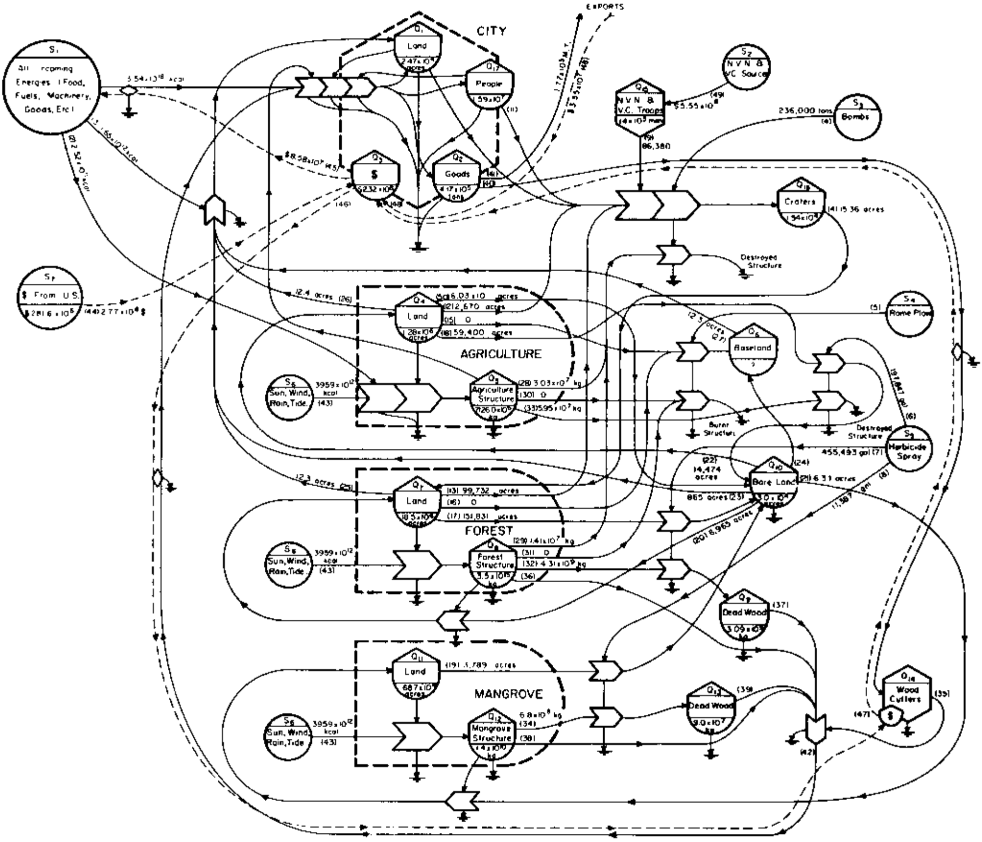


Figure 1 Major energy processes of South Vietnam while at war. Numbers in parentheses (30) indicate reference to a calculation of a rate constant explained in the Appendix. Subscripted letters (Q_4, S_2) indicate reference to calculation of storages and sources in Appendix. Dashed lines (----) are flows of money. Solid lines (——) indicate flows of materials and energies. Details are available from author, or see "The effects of herbicides in South Vietnam," Part B: working papers.

The land categories (city, agriculture, forest, and mangrove) each are separated into their respective components (or storages). The city system has within it land, people, goods, and a storage of money. The natural systems have two components each: land area and biotic structure (i.e., standing crop of biotic structure). The land storage and the forcing functions interact to produce social structure.

The components to the right of the natural systems, those of craters, base land, bare land, and dead wood, are components that are considered storages of disordered land and structure as it is transferred from one land use category to another by the impact of the disordering energies of war.

In Figure 1 the rates of material and energy flows, and the quantities stored in each of the components of the country have been calculated for the year 1965, the beginning of the escalation of the United States involvement in the Indochina War. (Calculations and sources for the calculations are summarized in Appendix I, and detailed calculations may be obtained from the author; see also "The Effects of Herbicides in South Vietnam," Part B: working papers, National Academy of Sciences, February 1974.) Evaluation of the flows of the different disordering energies gives perspective to their effects on the many processes of the country; in all cases herbicides account for the greatest disruption.

Another way to understand the effects that the disordering energies have had on the processes of the country is to calculate the percentage of the ordering energy budget of South Vietnam disrupted by these war activities. Column 1 in Table 1 shows the cumulative energy budget (i.e., the ordering energies) for the 6-year period, 1965 to 1970. Columns four, five, and six show our estimates of the total amounts of disordered energy introduced to the country by each of the disordering operations of bombing, herbicides, and Rome plowing. Column seven shows the percentage of the total ordering energy budget that was disrupted for each of the various subsystems of the country.

During the 6-year period of major United States' involvement in the Indochina War (1965 to 1970), 10.7% of the total natural and man-derived energy budget of South Vietnam was disrupted directly by war. This represents a relatively small fraction of the country's man-derived and natural energy budget, although it does not account for secondary interactions, feedback operations, and time delays that may cause further disruption of normal processes and may increase the overall effects of the war.

ORDER AND DISORDER IN VIETNAM

It is well known that many ecological systems are stress adapted and to a certain extent even depend upon some form of stress to accelerate regenerative processes and recycle nutrients. Just as fire-climax forests and prairies are stress adapted and depend on pulses of fire to recycle nutrients (Chapter 23), the country of South Vietnam possibly could be considered a stress-adapted system. Conflict and large-scale warfare has been the rule rather than the exception since the Geneva Agreements of 1954 and even before with a long and bitter conflict between the Communist-led Vietminh and the French armed forces. In some systems frequent chronic stress, such as grazing in grasslands, results in greater overall production by reducing diversity and releasing disordered materials for reconstruction and repair. Could the same apply to a chronic 30-year war and the country of South Vietnam? Or is the

Table 1 Comparison of Disordered Energy.

	Cumulative Energy Budget 1965–1970[g]	Fossil Fuel Equivalent[h]	Fossil Fuel Work Equivalent	Disordered Energy in F.F.W.E. Bombs[i]	Disordered Energy in F.F.W.E. Herbicides[j]	Disordered Energy in F.F.W.E. Rome Plow[j]	% of Energy Budget in F.F.W.E. Disordered
Human settlements[a]	116.4	1	116.4	9.10[k]	4.9[k]	–	12.1%
Agriculture systems[b]	672.0	0.005	3.4	0.12	0.04	0.01	5.0%
Forest systems[c]	6660.0	0.005	33.3	1.52	0.89	0.20	7.8%
Mangrove systems[d]	366.0	0.005	1.8	0.06	0.68	–	40.4%
Estuarine systems[e]	174.0	0.005	0.9	–	0.05	–	5.7%
Other natural[f] energies (wind, tide, thermal gradient)	15882.0	0.0005	7.9	?	?	–	?
Total	23870.4		163.7	10.80	6.56	0.21	10.7%

[a] The sum of purchased foods, foreign aid, and fuel. Purchased goods and foreign aid not including fuel were \$2.6 $\times$ 10^8 and \$5.1 $\times$ 10^8, respectively, multiplied by 1.4 $\times$ 10^4 kcal/dollar to convert to equivalent fossil fuel energies required to generate the same work (10.7 $\times$ 10^{12} kcal). Add to this, fuel (8.66 $\times$ 10^5 metric tons)(10^6 g ton^{-1})(10 kcal g^{-1}) = 8.66 $\times$ 10^{12}. 10.7 $\times$ 10^{12} + 8.66 $\times$ 10^{12} = 19.4 $\times$ 10^{12} kcal.

[b] The chemical potential energy entering the system as agriculture production was estimated by multiplying the land area in agriculture (7.31 $\times$ 10^6 acres) by the estimated gross photosynthesis (1.6 $\times$ 10^5 kcal $acre^{-1}$ day^{-1}) and then by 100 days. (Estimated time crops are in leaf each year, assumed two growing seasons of 50 days each because of monsoon climate.) (1 acre = 0.405 ha.)

[c] The gross photosynthesis of inland forests was estimated by multiplying the land area in forests (1.9 $\times$ 10^7 acres) by the estimated gross photosynthesis (1.6 $\times$ 10^5 kcal $acre^{-1}$ day^{-1}) (Rodin, 1967) and then by 365 days.

[d] The gross photosynthesis of mangrove systems was estimated by multiplying the area (0.69 $\times$ 10^6 acres) by the estimated gross photosynthesis (2.4 $\times$ 10^5 kcal $acre^{-1}$ day^{-1}) (Golley, 1962) and then by 365 days.

[e] The gross photosynthesis of estuarine systems was estimated by multiplying the area (1.0×10^6 acres) by the estimated gross photosynthesis (8.0×10^4 kcal $acre^{-1}$ day^{-1}) (Odum, 1973) and then by 365 days.

[f] The sum of the natural potential energies: (rivers (644×10^{12} kcal/yr), tides (152×10^{12} kcal/yr), and rain as runoff (119×10^{12} kcal/yr) (Odum, 1973). See Chapter 21.

[g] A cumulative energy budget was calculated as prewar values before disordering energies were introduced. It was calculated by multiplying the annual energy budget of each subsystem times the time span (6 years).

[h] See Chapter 7 for a consideration of energy-quality factors used here. F.F.W.E. here = F.F.E. in Chapter 7.

[i] Natural and man-derived energies disordered by bombs was calculated by multiplying the land area disordered each year from 1965 to 1970 by the estimated gross production and then by the number of years remaining in the 6-year period. Based on statements by Ewel (1970) it was assumed that recovery of tropical forest systems in 6 years was negligible. Gross production lost was then converted to fossil-fuel equivalents as in Chapter 7.

[j] Natural energies disordered by herbicides was calculated by multiplying the land area disordered each year from 1965 to 1970 by the estimated gross production and then by the number of years remaining in the 6-year period.* For agriculture sprayed, I assumed only a 1-year loss. I assumed no recovery of forest systems, based on statements by Tschirley (1969), and, again based on statements by Tschirley (1969), no recovery of mangroves. Estuarine system disruption was estimated as that part of the estuary within herbicided area (33%). Gross production lost was then converted to Fossil Fuel Equivalents as in Chapter 7. The Rome plowing operation started in 1968. It involved five companies of 30 Catapillar D-8 bulldozers, each fitted with a special $2\frac{1}{2}$ ton blade made in Rome, Georgia (thus the name). Its function was to scrape clean areas of known or suspected enemy activity by felling and piling all trees and undergrowth.

[k] City land area disordered by bombs and herbicides was 8.7 and 4.2%, respectively. It was assumed that an equal percentage of the total energy budget was disrupted.

* This area was measured on official Department of Defense herbicide spray-run maps, scale of 1:1,000,000; year by year totals for Mangrove land sprayed are as follows: 1965, 4700 acres; 1966, 96,330 acres; 1967, 197,600 acres; 1968, 68,666 acres; 1969, 90,155 acres; 1970, 11,609 acres.

effect of chronic disordering a seriously degraded economic and cultural system?

The 6-year involvement of the United States in the Indochina War resulted in an escalation of disordering energies that could be represented by an additional stress pulse of 10.7% over and above the disordering resulting from previous military engagements. Far more important than the magnitude of this overall stress are the percentages of the energy budgets that were disrupted from each of the subsystems of South Vietnam. Column 7 in Table 1 lists the percentages of each subsystem disordered. A comparison of these indicates that while the country had a 6-year stress pulse of 10.7%, individual stresses account for major local effects, and interactions of these components may magnify the overall stress.

For example, the mangrove systems were stressed nearly 41% (i.e., productivity was reduced by 41%): a stress that appears to have reduced the ability of the system to recover in a short period of time. Data gathered by NAS personnel while surveying ecological effects of herbicides in Vietnam indicate a lack of recovery, possibly due to loss of seed source. It has been suggested recently that mangrove systems are an important part of the food chain in estuarine systems. A stress of this magnitude could have severe effects on estuarine systems that, in turn, will affect the human settlements by a loss of food source. This may be particularly important since fish (which are in large part dependent upon mangrove-based food chains) are an important protein source in this protein-deficient land, where animal protein makes only 4 to 5% of the per capita calorie intake (Fuller, 1963).

The productivity of the forest systems of the country were reduced nearly 8%; a stress that probably will have little effect on the individual system, but if such factors as quantity of wood destroyed and regeneration time are taken into account, the human settlements depending on the forest systems as an auxiliary energy source may feel the stress far more than the forest itself. It has been estimated by Westing (1972) that 6.2 billion board feet of marketable lumber was destroyed by aerial bombardment and herbicide application from 1965 to 1970 in South Vietnam.

The human settlements of South Vietnam had 13% of their land area and an equal percentage of their fossil fuel-derived energy budget disordered during the 6-year period (1965 to 1970). These effects are increased by normal population growth, an increased movement to urban regions due to relocation of refugees, reduced agriculture production (5.2%), reduced estuarine production (9%), and reduced forest production (8%). Again the direct stress is magnified and will require many years to recover.

The systems diagram is another way of showing these same effects. Figure 2 is a diagram of the gross energy budget for the country of South Vietnam showing all the main energy flows, constructive and destructive, including those of nature and man-derived energies of the cities. Energy of low quality,

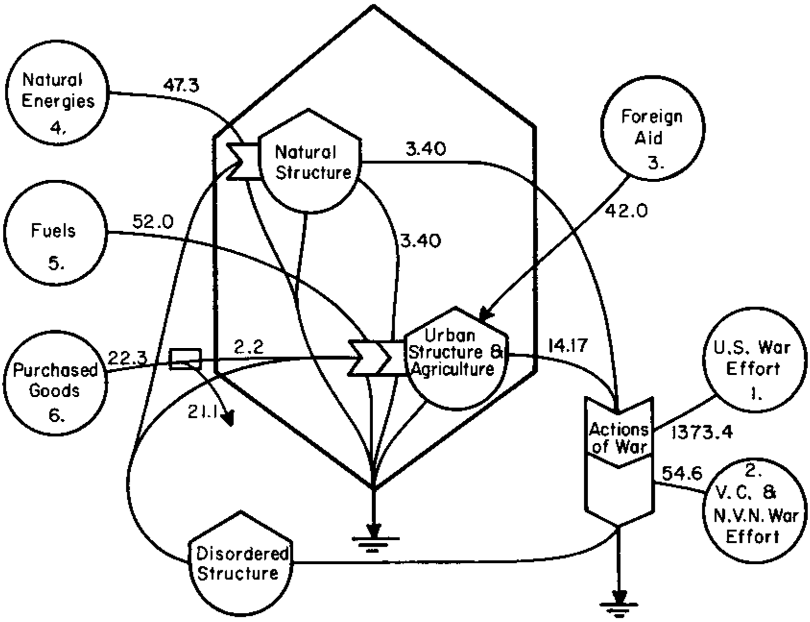


Figure 2 Simplified energy budget of South Vietnam, 1965 to 1970. Numbered footnotes given below:

* 1 U.S. war effort was calculated by adding the incremental costs of the war in Vietnam for the years 1965 to 1970. The incremental costs are the costs that represent the "net difference between wartime and peacetime needs" of the U.S. Military (U.S. Congress. House Committee on Appropriations, Dept. of Defense Appropriations for 1970, pt. VII. Hearings, Washington, U.S. Government Printing Office, 1970. p. 395). The total war effort (981×10^8 dollars) was then multiplied by 1.4×10^4 kcal dollar^{-1} (the mean industrial energy use per dollar spent for the United States) to obtain the energy expenditure. This figure includes the U.S. industrial energy used to manufacture as well as ship war materials to South Vietnam.

2 Viet Cong and North Vietnamese war effort was estimated by assuming steady increase from $555 million (Thayer, 1969) to $765 million in 1970 (A. P., Gainesville Sun, Gainesville, Florida. April 2, 1972). The total war effort (3.9×10^9 dollars) was then multiplied by 1.4×10^4 kcal dollar^{-1} to obtain the energy expenditure.

3 U.S. Aid was calculated by adding the official aid for the years 1965 to 1970. (Annual Statistical Bulletin, No. 14.) The official aid (3.03×10^9 dollars) then was multiplied by 1.4×10^4 kcal dollar^{-1} to convert to potential energy entering the system.

4 Natural energies are all those energies entering the country from the chemical potential energies of gross photosynthesis of ecosystems and the chemical potential energies of rivers, tides, thermal heating, winds, and rains as runoff.

5 Fuel inputs are from "Vietnam Statistical Yearbook." For the 6-year period (5.2×10^6 metric tons), this was multiplied by 10^6 g metric ton and by 10 kcal g^{-1} to convert to calories of work.

6 Purchased goods were calculated by adding the import arrivals from Annual Statistical Bulletin No. 14 for the years 1965 to 1970. The import arrivals (1.59×10^9 U.S. dollars) were then multiplied by 1.4×10^4 kcal dollar^{-1} to convert dollars to the potential energy equivalent.

such as sunlight, is calculated as the chemical potential energy after transformation by photosynthesis and expressed in equivalent fossil-fuel work potential. High-quality energies such as urban technological materials and machines are expressed in equivalent fossil-fuel energy required to generate work necessary for their production (Chapter 7).

When many of the details of small component flows of energy through the country such as in Figure 1 are eliminated by a larger-scale view, certain patterns and some consequences of the war become more obvious. The magnitudes of ordering and disordering energies, the difference in the levels of the U.S. war effort and the Viet Cong/North Vietnam war effort, and the differences in aid as compared to imported energies begin to show the magnitude of the disordering effect of war on both the biotic and economic structures of South Vietnam.

During the 6-year period from 1965 to 1970 the ratio of destructive energies of war to the constructive energies of nature and the city was approximately 1:10. The impact of a pulse disorder-to-order ratio of 10% will release materials and increase repair mechanisms required for rejuvenation, which in the short run may increase productivity. However, a disordering pulse that alters the landscape by removing 4,722,800 acres from productive lands and reduces productivities in an additional 5,600,000 acres of lands had reduced drastically the stability of the landscape (Appendix I). Increased gross production in both the natural and urban systems may not produce a stronger or more stable system, but on the contrary the result could be a highly variable, subsidized economy with decreased stability. Certainly, the decreases in rural hamlet and village populations as the inhabitants left the war zones for the urban areas, the decreases in industrial and agricultural production, and increases in imports of consumer goods would reflect an economy having less occupational and industrial diversity—an economy that is highly unstable because of its need for increased flows of high-quality fossil fuels in a world of decreasing availability of these fuels.

While the total disordering energies were significant in themselves, it is interesting to note the differences in magnitude of the United States' war effort compared to the Viet Cong and North Vietnamese. The United States, fighting a war on unfamiliar terrain and using very sophisticated mechanisms, spent 25 times the energy in its war effort as the Viet Cong/North Vietnamese. The Viet Cong and North Vietnamese using the techniques of jungle warfare kept concentrations of troops and supplies at a minimum, thus making it nearly impossible for the concentrated war effort of the U.S. to overpower it. The end result was more a disordering of the natural environment than troops, with less damage to the Viet Cong and North Vietnamese war effort than some people expected.

But more important, the diagram shows where the most stress was inflicted by the actions of war. For example, the natural system, while having a large absolute loss in comparison to the urban systems, was stressed 7.2%. The urban system (i.e., the manbuilt-technological economy) had 12.2% of its energy budget disrupted. Other consequences of the war (secondary interactions) such as the shift in population from rural areas to the urban centers, the loss of population as casualties of war, and shifts in land use have magnified this stress.

SIMULATION MODEL OF VIETNAM

The war obviously has caused many human casualties and disrupted cities and valuable ecosystems. But the disordering of lands and the accompanying transfer from one land use category to another might or might not be a "bad consequence" of the war in the long run, depending on future aid patterns and one's personal point of view. For example, those who advocate increased agricultural production for the country view the change from forest to bare land as accomplishing the first step in the process of bringing more land into agricultural production. This seems to be the case as long as there are the necessary energies (such as U.S. Aid) available that can be added to the country's own reserves to complete this transfer.

The actions of war have disordering energies on not only the physical, natural, and man-made systems, but on the social and economic systems as well. As a consequence of the war there has been a massive switch from a rural to an urban population. This shift in population has caused the expansion of the urban centers and at the same time a decrease in the nation's industrial and especially agricultural productivity. This in turn has caused increased dependence on U.S. aid and purchased imports.

The effects that disordering energies have had on the country of South Vietnam can be assessed completely only through time. One aid toward this assessment is the use of the systems diagram translated into the language of the analog computer which can make projections into the future. Such a simulation can give new insight into the cumulative effects of all disordering energies. Figure 3 is a simplified version (for the purposes of simulation) of the changing land use model in Figure 1. This diagram shows the action of war accelerating the recycling of minerals and the potential reuse of disordered lands and materials. These are all components that, when fed back with an accompanying energy input, are available for and stimulate reconstruction. Evaluation of the rates gives a perspective of those changes that are important, and computer simulations show the cumulative effects on South Vietnam's energy budget as well as the costs of reordering.

Calculations and sources of information for the Rates of Flows and the Storages in Figure 3 are summarized in Appendix I. War Effort (W) and United States Aid (A) are forcing functions generated to depict the escalation,

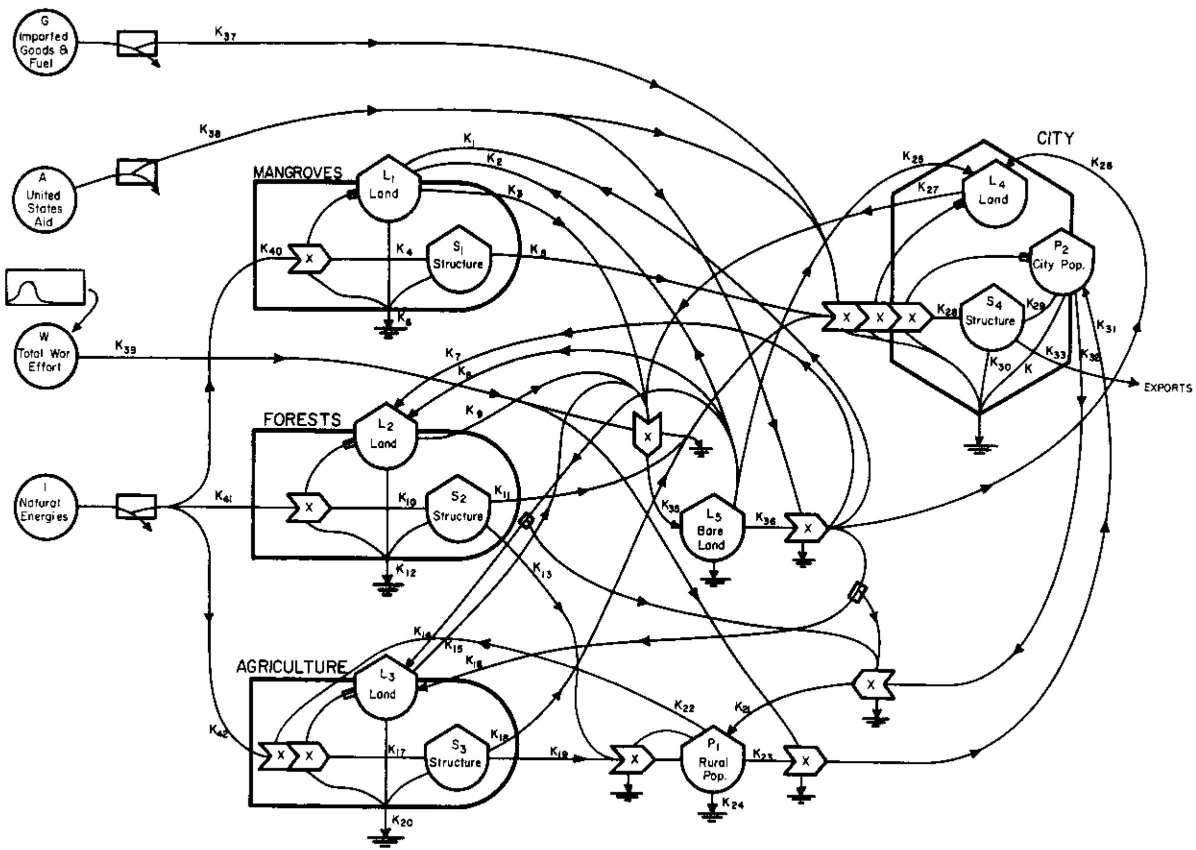


Figure 3 War-stress model, country of South Vietnam. See legend for Figure 1. Calculations are found in Appendix I

and later deescalation of U.S. involvement in Indochina. The initial conditions of the War Effort (W) were set at the conditions of 1950, the approximate level of conflict prior to U.S. involvement. In 1965 the level increases reaching a maximum in 1967, then decreases to an estimated level of conflict equal to that prior to 1965. The equations used in the model are given in Appendix C.

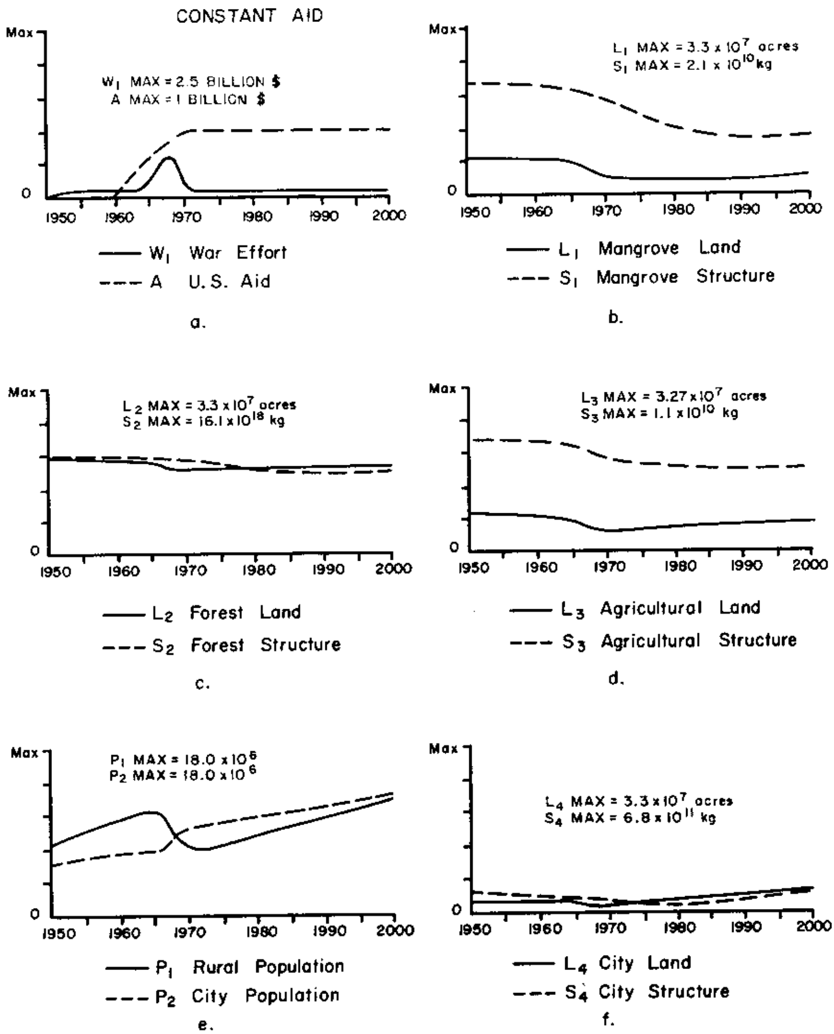


Figure 4 Graphs showing results of simulation with constant aid.

United States aid (A) is set at zero until 1960, then increases at a rate consistent with reported U.S. Aid. In the first simulation (Figure 4*a* to *f*) aid was held constant after 1970 at the reported level of aid in 1970. In the second simulation (Figure 5*a* to *f*) aid was increased after 1970 at the same rate to a maximum in 1985, then terminated. And in the third simulation (Figure 6*a* to *f*) aid was decreased steadily after 1970 terminating in 1980.

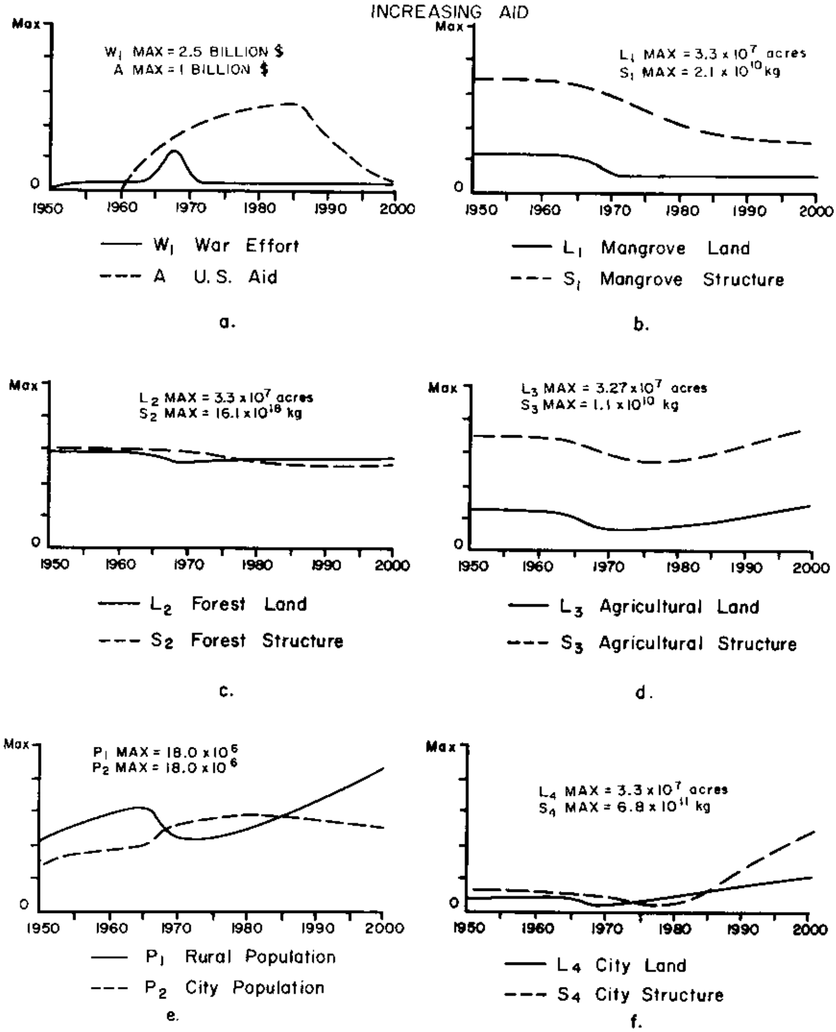


Figure 5 Graph showing results of simulation with aid increased.

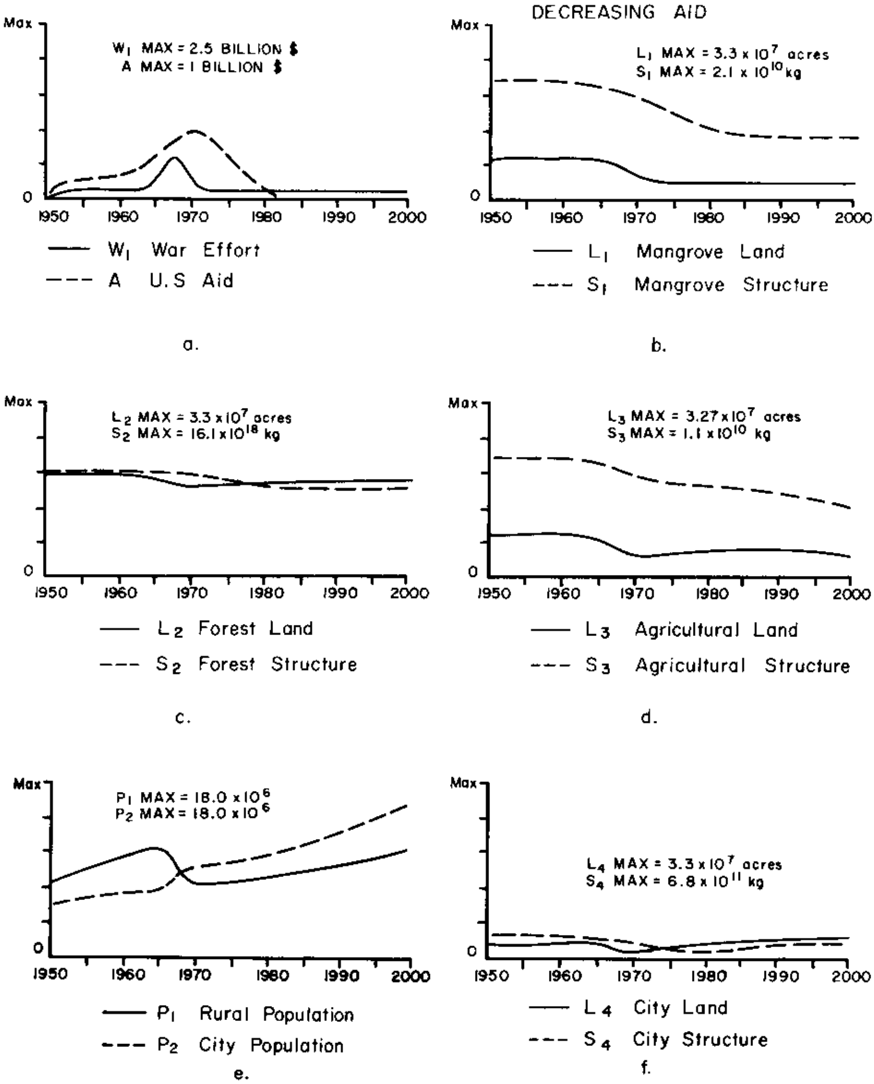


Figure 6 Graphs showing results of simulation with aid decreased.

Figures 4, 5, and 6 are computer-generated graphs from the first, second, and third simulations of the model. The graphs indicate a steady-state system from 1950 to 1965 (with slight decreases in certain storages, L_2, S_2, L_3, S_3) until escalation of the war in 1965, causing decreases in all compartments of the system except the human settlements.

The mangrove systems (Figure 4*b*) show the expected disruption anticipated by the calculations in Table 1. However, the structure component (S_1) continues to decrease after the pulse disordering of war, due to increased demand for wood as charcoal. There is no recovery in the simulation in agreement with the report of NAS site visit personnel that recovery of deforested mangrove systems exhibited little regrowth due to the loss of seed source. Provisions for an artificial seeding program are not included in this model. In the second simulation the mangrove structure decreases due to increased demands of the human settlements. In the third there is little change as foreign aid supplies much of the nation's fuel requirements.

The forest systems (Figure 4*c*) of the country exhibit a slight decrease in biomass in the first simulation due in part to the increased demands of the growing populations in the human settlements. Recovery, as expected, does occur, but the system does not reach the level of productivity exhibited at the beginning of the simulation run. In the model the transfer coefficient for the flow returning to forest land from bare land as a result of U.S. aid is extremely small, since there are no active reforestation programs underway in Vietnam to date. Normal recovery by succession is a long process with bare areas invaded first by grasses and bamboo, retarding the overall recovery to initial levels of productivity.

The agricultural systems (Figure 4*d*) show the greatest change due to the disruption by war, the decreases in the rural population, and the increased urban demand. In the first simulation, the structure or biomass does not recover to the initial level after disruption. Increased aid in the second simulation (Figure 5*d*) provides the industrial energy and other resources necessary to increase agricultural production to a level slightly higher than the initial, by transferring more land back into production, increasing the movement of refugees back to the rural areas, and by increasing fossil-fuel subsidy to crops (i.e., fuel-intensive fertilizers, irrigation, pesticides, tractors, etc.). In the third simulation (Figure 6*d*), by cutting off aid production remains lower than the level obtained in simulation 1, as might be expected; since land transfers are decreased, the rural populations remain in the cities and increased agriculture production is difficult because of a lack of farmers and a sufficient fuel subsidy.

Consequences of the population shifts (Figure 4*e*) are felt throughout the system and are very important in the overall economic well-being of the country. In the first simulation the movement of the rural population to the cities puts additional burdens on the entire system because of a decreased "producer" population and an increased "consumer" population. Manipulation of this flow during sensitivity analysis caused extreme changes in most compartments. If the rate of movement to the urban areas was decreased all components exhibited faster recovery rates, and the loss of agricultural production was not as great. If the rate of movement was increased the opposite occurred. This "system sensitivity" to the movement of the populations begins to indicate the extent to which the country's economic stability is aggravated by the secondary effects of the refugee problem. In the second simulation (Figure 5*e*) movement back to the rural areas is facilitated by an increased flow of agricultural land back into production. In the third simulation (Figure 6*e*) diminishing aid retards the return of the rural population, although both components increase due to normal population growth.

The human settlements (Figure 4*f*) show smaller visible changes, but are interesting in view of the time delay involved in the buildup of city structure (S_4) following the increased urban expansion (L_4). By the year 1970, an increase in city land area is apparent. However, due to shortages of materials, energy, and industrial capacity, and pressure from an increased population, a time lag of 10 years is required before the materials and energies are available for growth of city structure. Recovery to the initial levels of urban structure does occur by the year 2000, but this does not meet the demands of the larger population. Increasing aid in the second simulation (Figure 5*f*) meets these demands easily. The increase in city structure in this case begins to show a runaway growth, possibly an undesirable consequence. In the third simulation (Figure 6*f*) decreased aid prolongs the time delay and reduces the final structure value.

OVERALL PERSPECTIVE

Consequences of the war in Vietnam were difficult to evaluate directly. The immediate effects of the disordering energies have caused an 11% disruption of the 6-year cumulative natural and industrial energy budget (1965 to 1970) of the country. The herbicide program accounted for nearly half this disruption: an interesting consequence, indicating the high-amplifier disordering value of the relatively low energy cost herbicides. Delays in ending the present level of conflict may cause delays and reductions in the recovery rate of order in the country. As long as needed materials and energies are diverted from the job of reconstruction to that of fighting brush wars with the Viet Cong and North Vietnamese, reordering of the country may be delayed. Economic stability in many systems is related to the diversity of normal occupations and components; and as suggested earlier, continued conflict may result in maintaining a low diversity and a potentially unstable economical position. The economy of South Vietnam has been seriously distorted by the burden of military spending, inflation, physical destruction, and population dislocation.

These conditions also have distorted South Vietnam's import/export balance. In order to curb the magnitude of runaway inflation caused by both the increased purchasing power of a population that is money subsidized and a shortage of available goods, the Saigon government has encouraged vast increases in imports, particularly consumer goods (Table 2).

Table 2 Balance of Trade[a] (in Millions of U.S. Dollars).

	1965	1967	1968	1969	1970
Exports (based on customs data)	25	16	12	12	12
Imports (based on licensing data)	660.4	581.5	628.8	740.1	641.0

[a] "Impact of the Vietnam War." 1971.

The economy can be brought back into balance with production more nearly equaling consumption only if energies are diverted from war and used as a stimulator (or pump) on reconstruction and reordering. These energies combined with energies and materials released by disordering could stimulate recovery of the disrupted zones of the overall system. As recovery takes place structure is built to obtain and use additional energies, and a diversity of structural components is integrated to more effectively "trap" and utilize (or maximize) these new energies.

On the other hand, with continued conflict the system may be developing special adaptations to war-stress energies so that they are not so destructive to the overall processes. Consider, for example, increases in black-market activities, prostitution, and the abandonment of the village hamlet in favor of individual families scattered throughout the countryside, supporting themselves by subsistence farming. The former two examples are activities that maximize the use of new energies as a result of the war (war-time goods and G.I. dollars); the latter is an adaptation for survival, that is, concentrated villages, when bombed or burned tend to lose more structure per unit of disordering energy than a dispersed population of individual houses scattered throughout a countryside.

In the first sections of this paper it was shown that the war resulted in a measurable disordering of structure and processes by 11% over the 6-year period of U.S. escalation of war activities; and that disordering energies amounted to approximately ten times the ordering natural- and fossil-fuel based energies. To the intuitive mind, figures of this magnitude should have little effect on the overall processes of the country over long time periods.

However, when the war stress model was simulated, additional stresses and sensitivities (loss of food and material sources, and radical changes from producing to consuming populations as a result of population dislocation) were revealed that give new insight into the magnitude of disordering and expected recovery time.

Other models simulated for the country of South Vietnam but not reported here suggest that if aid is provided there will be a regrowth and in some instances increased productivity in a relatively short period of time. This parallels the case of Germany and Japan after the second World War. However, the reordering and recovery of Germany and Japan under the Marshall Plan were accomplished with a great expenditure of outside "ordering energy" during a time of increasing fossil fuel availability and utilization. In addition, Germany and Japan had extensive industrial-based economies with a wide diversity of components and occupations and had fought internally subsidized wars that provided the base for new postwar industrialization. South Vietnam, to the contrary, had little industrialization and was fighting an "externally subsidized" war. It did not reap the benefits of war energies adding new industrial structure.

The war-stress-model simulation indicates that the same rapid reordering experienced by Germany and Japan may be unrealistic in Vietnam; that repair and reconstruction to levels of order equal to those before 1965 can be accomplished only with increasing aid.

U.S. economic assistance to South Vietnam amounted to nearly $3 billion as of 1970 at a level of approximately $400 million per year. The model indicates that the overall system of the country has been distorted to such a degree that reordering aid must increase for the next 15 years to a level of approximately $500 million or a total of nearly $8 billion if the country is to recover rapidly. With constant aid at 1970 levels it will take nearly 30 years to achieve levels of production and structure equal to those of 1970, but even then they will not meet the demands of a growing population. If aid decreases (the most likely circumstance in light of increased demand for and expense of fossil-fuel energies and the surrender of South Vietnam), recovery and reordering within the next 30 years is most unlikely.

The model presented here is a preliminary attempt to simulate a very complex problem. Results of its simulation give insight to overall sensitivities not apparent otherwise, as well as the role of U.S. aid as the stimulator for regrowth. While the model is dependent on data and relationships that are not known with precision, general trends can be drawn that indicate the length of disruption to South Vietnam's economic system under different aid conditions. With more complete data and a greater understanding of the war process and its relationship to order and disorder, this model could be updated and run again.

One basic assumption in our model was that future patterns of, for example, distribution of aid between urban and rural areas, would be similar to existing patterns. This, of course, might change dramatically with changes in the political structure of South Vietnam. While our model was not specifically designed to look at such political parameters they could be included in other runs.

Wars have long been a characteristic of human society and may increase as competition for increasingly limited resources grows stronger. By attempting to understand wars within a broader, more objective context, by studying their long-term effects, and by understanding their relationship to available energies, it might be possible to avoid wars that may be especially counter-productive to various national interests during periods of decreasing energies. In past times of abundant energy supplies war was often a stimulator of domestic economy. However, foreign wars, in particular, require the diversion of large quantities of energy to be successful. Might it not be wise in the future to give any projected war a dry run on the computer? Would this have saved us the agony of the unpopular war in Vietnam with its accompanied destruction of natural and agricultural systems and untold human misery? Could such a model have told us in 1965 that if we were to help the South Vietnamese people we would need to supply extensive ordering energies of aid for many years as well as the disordering energies of military aid? Or, carried to the extreme, might this concept evolve, like the armies of old who chose their Davids and Goliaths to save the slaughter of thousands, into a future state where the wars are fought only on computers? To the simulation victors go the digital spoils!

LITERATURE CITED

Annual Statistical Bulletins, Office of Joint Economic Affairs, U.S. AID, Vietnam. Vols. 11, 12, 13, 14.

A. P. Wire Service. *Gainesville Sun*. Gainesville, Florida. April 2, 1972.

Background Material Relevant to Presentations at the 1970 Annual Meeting of the AAAS, Herbicide Assessment Commission of the American Association for the Advancement of Science. Meselson, Westing, Constable, Revised. 1/4/71.

Congressional Record. Senate. January 28, 1972.

Ewel, J. J. 1970. Experiments in arresting succession with cutting and herbicides in five tropical environments. Ph.D. dissertation. University of North Carolina, Chapel Hill. Unpublished.

Fuller, R. B. 1963. *Inventory of World Resources, Human Trends and Needs*. Phase 1, Document 1 of World Resources Inventory. Southern Illinois University, Carbondale.

Golley, F., Odum, H. T., and R. Wilson. 1962. "The Structure and Metabolism of a Puerto Rican Red Mangrove Forest in May." *Ecology*, **43**: 9–19.

Haitung, M. and G. H. Raets. 1968. Capacidad fisicu y rendiminiento de obreros foretales en diferentes condiciomed climatics del tropico. *Instituto forestal latono America De Incestigacion y Capacitacion. Boletin* No. **26:** 3–31.

Impact of the Vietnam War. 1971. Committee print by Foreign Affairs Division, Congressional Research Service, Library of Congress, U.S. Government Printing Office, Washington.

Kellman, M. C. 1970. *Secondary plant succession in tropical montane Mundanao*. Australia National University, Canberra. 174 p.

Odum, E. P. 1963. *Ecology*. Holt, Rinehart and Winston, New York.

Odum, H. T. 1971. *Environment Power and Society*. Wiley, New York.

Odum, H. T. 1974. *The effects of herbicides in South Vietnam*, Part B: Working Papers. "Models of Herbicide, Mangroves and War in Vietnam." National Academy of Sciences, National Research Council, Washington D.C.

Orians, G. H., and E. W. Pfeiffer. 1970. Ecological effects of the war in Vietnam. *Science*, **168**(8931): 544–554.

Pfeiffer, E. W., and A. Westing. 1971. Land war. Three reports. *Environment*, **13**(9): 2–15.

Report on the War in Vietnam, Commander in Chief Pacific (as of 30 June, 1968). Superintendent of Documents, U.S. Government Printing Office, Wash., D.C.

Richey, J. E. 1970. The role of disordering energy in microcosms. Master of science thesis. University of North Carolina, Chapel Hill. Unpublished.

Rodin, L. E. and N. I. Bazilevic. 1967. *Production and Mineral Cycling in Terrestrial Vegetation*. Oliver and Boyd, Edinburg. 288 pp.

Tschirley, F. H. 1969. Defoliation in Vietnam. *Science* **21**: 779–786.

Snedaker, S. C. 1970. Ecological studies on tropical moist forest succession in eastern lowland Guatemala. Ph.D. thesis, University of Florida. 131 pp.

Tergas, L. E. 1965. Correlation of nutrient availability in soil and uptake by native vegetation in humid tropics. M.S. thesis, University of Florida. 64 pp.

Thayer, G. 1969. *The War Business*. Simon and Schuster, New York.

U.S. Congress. House. Committee on Appropriations. Dept. of Defense Appropriations for 1970 pt. VII. Hearings, Washington, D.C. U.S. Government Printing Office. 1970.

Vietnam subject index maps. 1970. Research files of the Engineer Agency for Resources, Inventories, and Vietnam Research and Evaluation Information Center, Bureau for Vietnam.

Vietnam Statistical Yearbook. 1970. National Institute of Statistics, Republic of Vietnam, Presidency of the Republic, Directorate General of Planning.

Westing, A. H., and E. W. Pfeiffer. 1972. The cratering of Indochina. *Sci. Amer.* **226**(5): 21.

APPENDIX I CALCULATION OF DISORDERED LANDS BY YEAR

Statistics were not available on the categories and extent of land disordered. In the absence of pertinent data the following assumptions were necessary.

1. *Bombing*. In the 6 years from 1965 to 1970, 5,556,100 tons of air munitions and 128,500 tons of sea munitions were expended (Impact of the Vietnam War, 1971). For the purposes of the model and lack of sufficient data it was assumed that 75% of the air munitions alone were capable of producing

craters equivalent to that of a 500-lb bomb (30 ft in diameter) with a blow down (cleared area) of 100 ft in diameter (Pfeiffer, 1971). This is probably an overestimate of the number of 500-lb bombs dropped. However, when compared with all crater-producing munitions, the calculated cratered area is conservative at best. From these calculations, 16,668,000 five-hundred-pound bombs were dropped on South Vietnam in 6 years. This compares to 21 million estimated by Westing and Pfeiffer (1972).

It was assumed that the bombing was spread evenly throughout the country, since the principal bombing method used was "carpet bombing." From the relative amount of the total area of the country in each of the four major land use categories (city land, 0.06; agricultural land, 17.2%; forest land, 58.8%; mangrove land, 1.6%), the percentages of bombs dropped in each of these was calculated. The number of crater-producing bombs dropped in each land use category was then multiplied by the cleared area produced by one bomb (0.18 acres).

Year	Total Bombs	City Land (cleared acres) $\times 10^2$	Agriculture Land (cleared acres) $\times 10^4$	Forest Land (cleared acres) $\times 10^4$	Mangrove Land (acres) $\times 10^4$
1965	0.96×10^6	1.2	2.9	10.0	0.28
1966	1.5×10^6	2.4	4.8	16.5	0.45
1967	2.8×10^6	3.2	8.8	30.0	0.83
1968	4.3×10^6	4.7	13.4	46.0	1.26
1969	4.2×10^6	4.5	13.0	44.0	1.22
1970	2.9×10^6	3.3	9.1	31.0	0.86

2. *Herbicides.* In the 6 years from 1965 through 1970 a total of 5,092,228 acres of forest and 1,035,882 acres of cropland have been sprayed. Of the 5.1 million acres of forest sprayed 486,140 acres were mangroves.* The acres of defoliated land for each land use category were calculated in the following manner:

First, agriculture land sprayed was assumed to be 90% defoliated for that year (assuming that some land might be replanted in that year) and the following year the land was replanted. Thus only one year's yield is lost. Second, forest land area sprayed was assumed to be 20% defoliated based on statements from Meselson et al. (1970) that "some estimates indicate that one out of every eight or ten trees is killed by a single spraying and that 50 to

* This area was measured on official Department of Defense herbicide spray-run maps, scale of 1 : 1,000,000; year by year totals for mangrove land sprayed are as follows: 1965, 4700 acres; 1966, 96,330 acres; 1967, 197,600 acres; 1968, 68,666 acres; 1969, 90,155 acres; 1970, 11,609 acres.

80 percent are killed in areas where more than one spraying has occurred." Therefore, a conservative estimate of 20% killed was assumed. Third, 90% of mangrove land sprayed was defoliated based on statements by Tschurley (1969) that mangroves are particularly susceptible to defoliants and that one application at the normal rate employed in Vietnam is sufficient to kill most of the trees, and possibly because of loss of seed source there has been little or no reestablishment of the forest. The following table shows the year-by-year total land sprayed with herbicides and consequently removed from production from each of the land-use categories.

Year	Total Area Herbicided (10^4 acres)	City Land Affected (10^2 acres)	Agricultural Land Out of Production (10^4 acres)	Forest Land Out of Production (10^4 acres)	Mangrove Land Out of Production (10^4 acres)
1965	22.2	0.4	6.5	3.0	0.42
1966	84.3	1.5	10.2	13.0	9.6
1967	170.8	2.8	22.1	26.0	19.8
1968	133.1	2.6	6.4	24.0	6.9
1969	128.7	2.4	6.6	22.6	9.0
1970	25.3	0.6	3.3	4.2	1.2

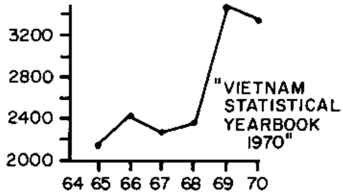
3. *Rome plowing operation.* According to available information, 350,000 acres of forest land were estimated as being cleared from 1968 to 1970 by the Rome Plow Operation. Westing and Pfeiffer (1971 and 1972) have calculated the area of plowed land at approximately 750,000 acres. They further estimate that of this "126,000 acres (were) of prime timberlands accessible to lumber operations, and 2,500 acres of producing rubber trees." These figures do not include prime timberland that is not accessible to lumber mills but contributes to the total energy budget of South Vietnam. It was assumed that 350,000 acres of forests and 90,000 acres of agricultural land were cleared by the Rome Plow Operation. The land areas cleared each year were assumed to be equal, because it was assumed the operation proceeded at a constant annual rate.

Year	Agriculture Land (10^4 acres)	Forest Land (10^4 acres)
1968	3.00	11.66
1969	3.00	11.66
1970	3.00	11.66

Appendix B

Imports (thousands of metric tons)

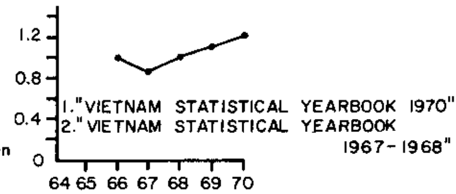
1965	2,159
1966	2,423
1967	2,269
1968	2,387
1969	3,469
1970	3,358 *



Fuel to South Vietnam (thous. metric tons) (partial data)

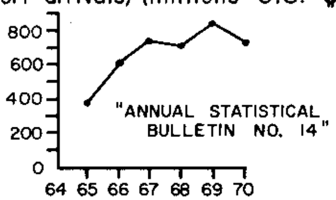
1966	1.005[2.]
1967	0.862[2.]
1968	1.062[1.]
1969	1.128[1.]
1970	1.210[1.] *

* Only six month figures were given for these years, so figure was doubled for year total.



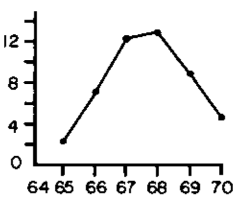
Money Spent for Goods & Fuel by Vietnam (inport arrivals) (millions U.S. $)

1965	387.7
1966	607.2
1967	744.0
1968	707.5
1969	837.7
1970	715.1



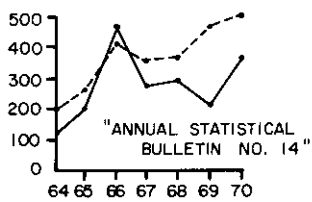
Structure Destroyed by War (thousands of acres)

1965	2.12
1966	7.34
1967	12.12
1968	12.87
1969	8.89
1970	4.54



U.S. Aid (US $ millions)

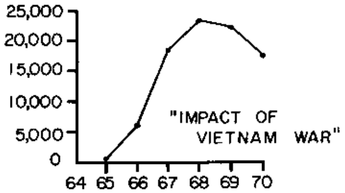
	(solid line)	Official Aid (dashed line)
1965	202.3	265
1966	478.9	406
1967	271.6	356
1968	295.5	370
1969	206.7	477
1970	369.4	504



Appendix B cont'd.

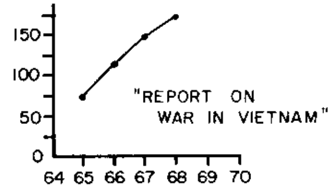
U.S. War Appropriations (US $ millions)

1965	100
1966	6,000
1967	18,000
1968	23,000
1969	22,000
1970	17,000



Fuel to War Effort (millions of barrels) (partial figures)

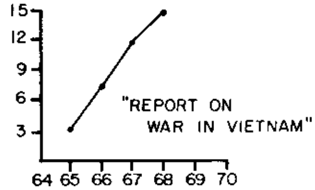
1965	73,881
1966	112,995
1967	146,697
1968	173,766*



Military Goods (thousands of tons) (partial figures)

1965	3,300*
1966	7,280
1967	11,800*
1968	14,840

* Only six month figures were given for these years, so figure was doubled for year total.



Appendix C

MANGROVE: $\dot{L}_1 = +K_1 L_5 A + K_2 L_5 - K_3 [L_1 + L_2 + L_3 + L_4] W$

$$\dot{S}_1 = +K_4 L_1 I - K_5[(s_1+s_2+s_3)(G+A)(L_4)(P_2)] - K_6 S_1$$

FORESTS: $\dot{L}_2 = +K_7 L_5 A + K_8 L_5 - K_9[(L_1+L_2+L_3+L_4) W]$

$$\dot{S}_2 = K_{10} L_2 I - K_{11}[(s_1+s_2+s_3)(G+A)(L_4)(P_2)] - K_{12} S_2 - K_{13}[(s_2+s_3)(P_1)]$$

FARMS: $\dot{L}_3 = +K_{14} L_5 + K_{16} L_5 A - K_{15}[(L_1+L_2+L_3+L_4) W]$

$$\dot{S}_3 = K_{17} L_3 I - K_{18}[(s_1+s_2+s_3)(G+A)(L_4)(P_2)] - K_{19}[(s_2+s_3)(P_1)]$$

$$\dot{P}_1 = K_{21}[(K_{14} L_5 + K_{16} L_5 A) K_{32} P_2] - K_{23} P_1 W - K_{24} P_1$$

CITIES: $\dot{L}_4 = +K_{25} L_5 + K_{26} L_5 A - K_{27}[(L_1+L_2+L_3) W]$

$$\dot{S}_4 = K_{28}[(s_1+s_2+s_3)(G+A)(L_4)(P_2)] - K_{29} S_4 - K_{30} S_4 - K_{33} S_4$$

$$\dot{P}_2 = +K_{31} P_1 W + K_{29} S_4 - K_{32} P_2 [K_{14} L_5 + K_{16} L_5 A]$$

$$\dot{L}_5 = K_{35} - L_1 - L_2 - L_3 - L_4$$