In World3 when the development cost per hectare DCPH increases (as potentially arable land PAL gets scarce), the marginal productivity of land development MPLD decreases relative to the marginal productivity of agricultural inputs MPAI. This leads to a smaller fraction of agricultural investment allocated to land development FIALD—in other words, a greater emphasis on intensifying the cultivation of existing land. This sequence of events has already taken place in Asia, leading the President's Science Advisory Committee to state:

> We have carefully considered the basic question of whether the developing world can continue to attempt to meet food needs largely through extension of traditional agriculture and increasing imports or whether it will be necessary to shift to the far more difficult method of increasing production by intensifying agriculture and improving yields. Our analysis indicates that future food needs cannot be provided by imports, either concessional or commercial and at least in Asia, not by cultivation of new lands. They must, of necessity, be provided by increased yields in the developing countries. [PSAC 1967, vol. 1, p. 40]

Loop 3: Land Erosion and Urban-Industrial Use

Erosion is the process of detachment and transportation of earth materials (rock, soil) by geologic agents (water, wind, gravity). A distinction is often made between geologic (natural) and accelerated (man-induced) erosion and between water and wind erosion.

Water erosion is a very common geologic process. It is caused by such factors as the amount and seasonal distribution of rainfall, the general topography of the land, the type of vegetation, and the nature of soils and subsoils (Buckman and Brady 1960). Water erosion is responsible for many significant changes in the earth's surface over long periods of time. Water has leveled mountains and has created deserts as well as fertile valleys and deltas. This erosion process generally occurs over millions of years, however, and the land-destructive forces are in general balance with geologic land-creating occurrences. The intervention of man has often disturbed this equilibrium by affecting the determinants of erosion (type of vegetation, condition of soil, shape of surface). The process of cultivation removes natural ground cover and replaces it by soil-exposing crops, a process that has tended to enhance the washing away of soil.

Whereas water erosion is a problem in areas with high rainfall, wind erosion is more common in arid and semiarid regions. Wind erosion is closely related to the moisture content of the soil, wind velocity, soil surface conditions, and soil characteristics. Again, cultivation has often aggravated the destructive forces of nature; mismanagement of plowed lands, as well as overgrazing, has encouraged wind erosion.

From a short time perspective, erosion may not appear to be an important determinant of global food production. Over a two-hundred-year period, however, the loss of arable land through erosion could become a significant dynamic force. Evidence of erosion from mankind's past activities covers large areas of land from the American great plains to the once-forested coast of the Mediterranean. Many of

	1882 (billion hectares)	Percent	1952 (billion hectares)	Percent	Change 1882–1952 (billion hectares)	Percent
Forest	5.2	45.4	3.3	29.6	−1.9	− 36.8
Desert and wasteland	1.1	9.4	2.6	23.3	+1.5	+140.6
Built-on land	0.87	7.7	1.6	14.6	+0.73	+ 85.8
Pastures	1.5	13.4	2.2	19.5	+0.7	+ 41.9
Tilled land	0.86	7.6	1.1	9.2	+0.24	+ 24.5
	9.53	83.5	10.8	96.2	+1.27	+ 12.9
Area not especially utilized	1.81	16.5	0.27	3.8	−1.54	− 79.9
Total	11.34	100	11.07	100	−0.27	− 2.4

Figure 4-55 Changes in land utilization, 1882–1952
Source: Abridged and adapted from "Changes in the World's Land-Use Balance Sheet, 1882–1952" in *World Balance Sheet* by Robert R. Doane (Harper & Row, 1957), p. 24.

the world's large deserts—the Kalahari and the Sahara, for example—are currently expanding into surrounding areas at rates of several miles per year. Between 1882 and 1952, world deserts grew by an average of 25 million hectares per year (Doane 1957)—though not only at the expense of arable land. By cutting down forests and exhausting land by too intensive use, man has actually wasted almost as much land as he has developed. In fact, one estimate is that the net addition of arable land between 1882 and 1952 was only 240 million hectares, or one-fifth of the total arable land in 1952 (Figure 4-55). Another estimate puts the present global erosion loss at perhaps 10 million hectares per year (Borgstrom 1970*b*). All such estimates are uncertain, since virtually no studies of erosion on a global scale have been conducted.

Average Life of Land ALL To calculate the erosion rate of arable land AL in World3 we began by determining the average time constant of erosion under traditional agricultural practices. We call this time constant the average life of land normal ALLN.

In its natural state the surface of the earth is being eroded at a rate of 1 centimeter every 80 to 200 years (Bear 1965). Using an estimated average global topsoil depth of 40 centimeters (the depth of soil can vary from a few centimeters to 30 meters or more), we assumed that under natural ground cover the global soil stock would erode significantly over a period of roughly 10,000 years. Under traditional agriculture, which usually involves minor disruption of the natural ground cover, we assumed that erosion proceeds somewhat faster. We therefore chose the average life of land normal ALLN (the time constant for the exponential decay of arable land under traditional agriculture) as 6,000 years.