cally be obtained from arable land without the use of modern agricultural inputs. The grazing land yield is only about 2 percent of the present world average cultivated land yield of around 2,000 vegetable-equivalent kilograms per hectare-year (section 4.5). Full utilization of all grazing land would result in a mere 140 billion ($35 \times 4 \times 10^9$) vegetable-equivalent kilograms per year, or less than 10 percent of the current world grain production of 1,815 billion vegetable-equivalent kilograms per year (Figure 4-8). Finally, the potential global meat output from grazing land—20 billion kilograms of meat per year—is only about one-fourth of the present global meat production of 78 billion kilograms per year (U.N. 1970*a*, p. xxxi). Most livestock is being raised today on grain cultivated on arable land rather than on grasses from grazing land. In summary, the food output from grazing land is relatively unimportant.

On the basis of estimates of the rate at which plankton fix carbon in the ocean, that is, the rate at which biomass is created at the lowest level in the marine food chain, it is usually accepted that there is a maximum possible sustainable catch of fish from the ocean. Measured in kilocalories, the potential fish output from the ocean amounts to about 100×10^{12} kilocalories per year (CRAM 1969, p. 107). Since we assumed 3,500 kilocalories per kilogram of crops (see Figure 4-20), the maximum world fish catch is equivalent to roughly 30 billion vegetable-equivalent kilograms per year. This upper limit is even smaller than the potential food production from grazing land. In the late 1960s the total catch was around 60×10^{12} kilocalories of fish per year, or about 60 percent of the maximum catch (Ryther 1969). Although fish are an important source of protein, the caloric output from the oceans is relatively unimportant.

Yields from both ocean and grazing land might conceivably be increased by improved technologies. However, for these new technologies to have a significant impact, yields of both oceans and grazing land would have to be increased by several hundred percent. We have assumed that such developments are unlikely to occur over the next few decades (see CRAM 1969, chaps. 4, 5), although they were included as test policies in the model runs. Figure 4-8 summarizes the preceding discussion.

	Arable Land	Oceans	Grazing Land
Current output (billion vegetable-equivalent kilograms per year)	1,815	18	< 140
Potential output (billion vegetable-equivalent kilograms per year)	20,000[a]	300[b]	1,400[b]

[a]Estimate assuming all potentially arable land (3.2 billion hectares) is cultivated at 10 times the traditional land yield, that is, at 6,000 vegetable-equivalent kilograms per hectare-year. It is not certain that food output of this size can be sustained for long periods of time. See later discussion of the numerical values chosen.

[b]Estimate assuming all oceans and grazing land could produce 10 times their currently estimated maximum yields, that is, respectively, 1,000 trillion kilocalories of fish per year and 50 kilograms of meat per hectare-year. Even using this unwarranted assumption, potential food from oceans and grazing land is only of the order of magnitude of the current output from arable land.

Figure 4-8 Current and potential food output from the world's arable land, oceans, and grazing land

Thus for the purposes of World3 the current and potential food output from the oceans and the world's grazing lands is insignificant compared with the output from agricultural land. We therefore chose to neglect these two sources of food in the world model. Hence "food" in World3 is defined as the total production of the world's arable land, measured in vegetable-equivalent kilograms.

Throughout this report the terms "arable land" and "harvested area" are used according to the strict FAO definitions:

> The expressions "arable land" and "harvested land" are used as follows: (a) arable land includes all areas which are used from time to time or full-time to grow crops and includes area under annual crops, area under permanent crops (tree crops, bananas, sugar cane), area under temporary grass and fodder crops, and fallow; (b) harvested area includes the harvested area of annual crops, and permanent crops. [FAO 1970*a*, p. 42]

Note that "arable land" includes fallow land as well as land actually cultivated in any given year.

The Fundamental Postulate of the Agriculture Sector

The world model is based on the fundamental assumption that there is an upper limit to the total amount of food that can be produced annually by the world's agricultural system. In more detail, it is assumed that there is some upper bound on the amount of land that can be brought under cultivation and that the land yield—the annual output from each hectare—is also bounded. Thus the equations of the agriculture sector reflect upper bounds on both arable land and land yield. The parameters of the postulate, namely, the exact values we chose to put on the two upper bounds, are specified in section 4.5.

The implication of the basic assumption is that investments in raising arable land area and annual output per hectare must exhibit decreasing marginal returns, until at some point additional investments yield no return. This assumption of decreasing marginal returns is consistent with real-world trends, although there is probably no current real-world example of zero marginal returns to agricultural investment.

Two Concepts of Land Wastage

In World3 we assumed that capital investments in agriculture can increase total food output in two ways: by increasing the stock of arable land through land development, and by increasing land yield through the application of modern agricultural inputs. The agriculture sector also distinguishes between two phenomena that can reduce overall food production. We defined "land erosion" as an irreversible process, taking place over centuries, that physically removes land from production. In other words, land erosion reduces the amount of arable land by physically eliminating the land (usually into freshwater systems and ultimately the ocean). The rate at which land erodes can be large or small, depending on the human action taken to