control the erosion rate, but we assumed that the direction of land movement cannot be changed. The erosion rate can become zero, but it will never become negative.

In World3 we also assumed that the total food output can be reduced through a reduction in land yield caused by lower land fertility—a reduction in the humus and nutrient content of the soil. Such degradation of the land's fertility occurs only when insufficient resources are allocated to the enhancement of the natural soil regeneration mechanisms; thus the regeneration forces do not manage to keep up with the continually occurring degradation forces. The decay of land fertility is assumed to be reversible, so that higher current investments in land maintenance will restore the soil and undo damage resulting from earlier negligence. The reversible process of land fertility degradation and regeneration occurs within decades and is thus much faster than the irreversible erosion process.

The distinction between a long-term, irreversible process and a short-term, reversible process is made clear in Held and Clawson's classification of the three influences man can have on soil: "The numerous effects which modern man exerts upon soil may be divided into three general categories: (1) permanent impairment, (2) temporary damage, and (3) improved productivity" (Held and Clawson 1965, p. 23). Category (1) is represented in the model by land erosion, (2) by land fertility degradation, and (3) by raising the land yield through agricultural inputs. Because of the dynamic differences among these categories, such as differing time lags and economic determinants, each of the three categories was modeled as a distinct element in the agriculture sector.

The Aggregation of the Sector

We chose to include all arable land in a single level, so the model reflects in a single quantity the aggregate of all different cultivable lands with their varying characteristics. This aggregation of land would not be permissible if the model were to be applied to designing detailed land development plans. However, the purpose of the agriculture sector in World3 was to represent the aggregated dynamic response of total food output to the influence of aggregated agricultural investment, persistent pollution, and population pressures. We were primarily interested in the characteristics of food production that are common to all types of land, and a high level of aggregation is all that is needed, given the purpose of this particular model. Because of the wide variance in real-world agricultural parameters, conclusions drawn from this sector should not automatically be considered valid in a practical, specific situation unless the conclusion is robust with respect to major parameter changes. The structure of the model is generally applicable to agricultural subsystems, but for each specific application, parameter values characteristic of each subsystem must be substituted for the general global averages used here.

Technology in the Agriculture Sector

Technological change affects relationships in the agriculture sector in a variety of ways. Some of the effects of advances in technological capability are included endogenously in the sector. For instance, we assumed that the allocation of more

investment to increasing land yield will have roughly the same success in the total global agricultural system as in the localized areas where these investment-intensive methods were developed. Such an assumption implies that the obstacles posed by different soils, climates, and traditional cultivation procedures will be overcome by technological advance. In the same manner we assumed that the allocation of investment to land maintenance—that is, to regenerate land fertility—will always succeed as well on a global scale as in localized regions. Again, this implies that technological advances will be able to combat fertility degradation problems regardless of where they occur and regardless of the size of the inflicted area.

The agriculture sector also includes several fixed relationships that could be changed in the real world through technological advances if the decision should be made to develop the needed technology. Examples of such relations are:

1. The increase in the costs of developing new land as the land area not yet cultivated diminishes. The cost could be reduced through developing cheaper forest removing equipment, improved water transportation schemes, and population relocation plans.
2. The reduction in land yield caused by a higher level of air pollution in the ambient air. The drop in yields could be reduced by developing pollution-resistant strains or by directly controlling air pollution.
3. The marginal improvement in global land yield caused by a certain increase in investment in modern agricultural inputs per hectare. The possible gains in yield might be increased over those observed in localized regions by unprecedented, regionally specialized innovations in, for example, grain and fertilizer types.
4. The amount of regeneration of land fertility resulting from higher investment in land maintenance. The effectiveness of maintenance might be increased through better soil conservation programs.
5. The increase in irreversible soil erosion caused by pursuing a higher land yield. This relation falls into a somewhat special category because the rate of erosion accompanying a specific land yield depends not only on technological capability but also on the farmers' decision to employ a cultivation procedure that minimizes erosion. In many cases, the available erosion-reducing procedures are not used, simply because erosion is such a slow process that the farmer can rarely observe the erosion damage caused by his cultivation methods. Thus the relation between yield and erosion can change in the real world through both educational and technological innovation.

None of the technologies that affect these relations were included endogenously in World3. We assumed throughout the model that new technological advances that are not a part of current trends do not occur automatically but, rather, as the result of man's deliberate action to ameliorate a problem. We chose to simulate decisions to act and the ensuing technological breakthrough by exogenous changes in the appropriate model relationships. These changes can be made at any time in the computer run when the modeler speculates that a technological breakthrough might occur. Examples are shown in the simulation runs in section 4.6.