The adjustment of urban-industrial land UIL to the current need UILR defines the rate of land removal for urban industrial use LRUI, which is the number of hectares removed from the stock of arable land for urban-industrial purposes every year:

```
LRUI.KL=MAX(0,(UILR.K-UIL.K)/UILDT)                    119, R
UILDT=10                                               119.1, C
    LRUI   - LAND REMOVAL FOR URBAN-INDUSTRIAL USE
                (HECTARES/YEAR)
    UILR   - URBAN-INDUSTRIAL LAND REQUIRED (HECTARES)
    UIL    - URBAN-INDUSTRIAL LAND (HECTARES)
    UILDT  - URBAN-INDUSTRIAL LAND DEVELOPMENT TIME
                (YEARS)
```

Urban-Industrial Land UIL Finally, the total urban-industrial land UIL level is arrived at by accumulating the land removal for urban-industrial use LRUI over time:

```
UIL.K=UIL.J+(DT)(LRUI.JK)                              120, L
UIL=UILI                                               120.1, N
UILI=8.2E6                                             120.2, C
    UIL    - URBAN-INDUSTRIAL LAND (HECTARES)
    DT     - TIME INTERVAL BETWEEN CONSECUTIVE
                CALCULATIONS (YEARS)
    LRUI   - LAND REMOVAL FOR URBAN-INDUSTRIAL USE
                (HECTARES/YEAR)
    UILI   - URBAN-INDUSTRIAL LAND INITIAL (HECTARES)
```

To arrive at an estimate of the global urban-industrial land area UIL in the year 1900, we made the assumption that UIL in 1900 was growing at the same rate as the steadily increasing urban-industrial land required UILR. In other words, we chose the 1900 level of UIL so that the rate of land removal for urban-industrial land LRUI in 1900 exactly matched the annual increase in urban-industrial land required UILR at that time. In World3 we assumed the global average industrial output per capita IOPC to be 40 dollars per person-year in 1900 (see Chapter 3), indicating UILR of 9.3 million hectares (from Figure 4-60) for the 1.65 billion people living at that time. Using the average global population growth rate of 1.2 percent per year between 1900 and 1970 as an approximation to the growth rate of urban land required, the equation for LRUI requires that the 1900 level of UIL be 8.2 million hectares.

Loop 4: Land Fertility Degradation

It is well known that yields from arable land can be greatly increased by the use of modern agricultural inputs, as represented in loop 2 of the agriculture sector. It is not known whether modern inputs are free from undesirable side effects when they are used intensively over long periods of time—they have not yet been used intensively for long periods. The long-term viability of the very intensive use of modern agricultural inputs is being questioned, however (see Borgstrom 1970*a* and *b*; Brown 1970*b*, p. 170). It is argued that the same inputs that increase yield in the short run may, in the long run, depress the intrinsic ability of the soil to support vegetation. The mechanisms by which this may happen include salinization of the soil by irrigation, the destruction of nitrogen-fixing bacteria by fertilizers, the evolution of pesticide-resistant insects, the compaction of the soil by heavy machinery, and the poisoning of soil microorganisms by persistent pollutants. On the other hand, proponents of modern agricultural inputs argue that no such damage will occur if the inputs are used in the proper manner—that is, in accordance with present knowledge about soils and their cultivation.

Unfortunately, present land yield data cannot be used to resolve this argument unambiguously, for land yields represent a composite index of the processes of short-term artificial enrichment and possible long-term reduction of soil fertility. As pointed out earlier, in our terminology the land yield LY is equal to the land fertility LFERT multiplied by the land yield multiplier from capital LYMC, which is assumed to increase when more agricultural inputs are employed per hectare. Neglecting for a moment the yield-depressing effect from air pollution:

$$\mathrm{LY} = \mathrm{LFERT} \times \mathrm{LYMC}$$

Thus it is possible that land *yields* may increase while land *fertility* decreases; LYMC may go up faster than LFERT goes down. Some writers believe that is what has actually happened in the world during this century:

> The fact that crop yields are rising does not necessarily mean that the basic capacity of soils to produce also is going up or even is unimpaired. There is some evidence that the inherent productiveness of many field soils has been on the down grade. [Buckmann and Brady 1960, p. 541]

Since the existing information is not sufficient to resolve this dispute, and since it is very unlikely that either of the extreme views is the correct one, we chose to include in World3 a representation of a weak fertility-reducing effect of long-term, intensive use of agricultural inputs. If the effect is included in the model structure, it becomes very simple to test the implications of the more extreme points of view —very strong fertility-reducing side effects or no side effects at all—through the variation of a single set of model parameters.

Land Fertility LFERT The land fertility LFERT is defined as the average ability of one hectare of arable land AL to produce crops without the use of any modern agricultural inputs. Hence LFERT is the output a traditional farmer would obtain from the land using only traditional seed, natural compost or manure, hand or animal labor, and natural water supply. The land fertility LFERT is measured in vegetable-equivalent kilograms per hectare-year. We assumed that the average value of LFERT for virgin land, that is, the inherent land fertility ILF, is equal to 600 vegetable-equivalent kilograms per hectare-year. (See the discussion of land yield LY under loop 2.)

The fertility of any land area is a complex function of the organic and inorganic content of the soil, the climate, and the incident solar radiation, the last two of which we assume to be invariant. Apart from the macronutrients of carbon, hydrogen, and oxygen that can be obtained from air and water, plants also depend on a large number of other nutrients—phosphorus, potassium, calcium, iron, and perhaps some other elements that have not yet been identified by plant physiologists. Most of these nutrients are made available to plants by the natural weathering of rocks and especially by the microorganisms in the soil that break down insoluble organic matter and release acids that can dissolve mineral nutrients from rock particles. Essential ni-