decline in food production must be a result of a decline in either of these two variables. In the standard run, both arable land and land yields eventually decline.

Run 4-2A shows yield LY peaking around the year 2040. Its decline is due to falling land fertility LFERT and increasing air pollution (not plotted here). Run 4-2D demonstrates the mechanisms that cause the decline in land fertility LFERT. As in the historical run, (Figure 4-69) land fertility regeneration LFR lags slightly behind land fertility degradation LFD between 1900 and 2000. From 2000 to 2050 the land fertility regeneration time LFRT is reduced to its minimum value of two years by the growing fraction of agricultural inputs allocated to land maintenance FALM. Despite the success of land maintenance efforts in speeding up the land regenerative mechanisms, land fertility continues to fall because of the degrading effects of the continually increasing persistent pollution index PPOLX.

After the year 2050 the decline in land fertility LFERT is greatly exacerbated by the decline in the food ratio FR. When food per capita drops very low, the urgent short-term need for more food causes a smaller fraction of agricultural inputs to be allocated to land maintenance. As land maintenance is abandoned, the regenerative mechanisms slow down (LFRT increases toward 20 years), and land fertility LFERT falls sharply.

The decrease in LFERT, coupled with a falling land yield multiplier from air pollution LYMAP, causes land yield LY to fall after the year 2045 despite the sharp rise in agricultural inputs per hectare AIPH (Run 4-2A). As AIPH exceeds 1,000 dollars per hectare-year, the land yield multiplier from capital LYMC becomes saturated at its highest value—ten times the value possible without agricultural inputs.

Run 4-2B shows the mechanisms that lead to a decline in arable land AL. The growth in the land development rate LDR must eventually cease as potentially arable land PAL approaches zero and development costs per hectare DCPH become very high. Around the year 2020 almost all potentially arable land PAL is developed, and the marginal return to developing further land becomes so low that investment is diverted to agricultural inputs. As the fraction of investment allocated to land development FIALD decreases, (Run 4-2C) the rate of land development LDR drops sharply (institutional delays not represented in this simple model would make the investment transition less abrupt).

Meanwhile, land erosion LER and land removal for urban-industrial use LRUI continue to grow because of the exponential rise in population and industrial output, which causes arable land AL to decline. During the interval from 2050 to 2070, the annual amount of land removed for urban and industrial use LRUI decreases slightly, and then continues to increase after 2070. This behavior is caused by the first-order delay in the hypothesized relationship between the amount of land required for urban and industrial use per capita UILPC and the industrial output per capita IOPC. As IOPC grows, the required amount of UILPC eventually reaches a constant upper limit. From this point on, further growth in the *total* amount of urban industrial land required UILR is due only to the growth in population POP; therefore, its exponential growth rate is slower than it was before 2050. The rate of land removal for urban-industrial use LRUI responds to this changing rate of increase only after a first-order delay, with a delay time UILRDT of 10 years. The slight overshoot, decline, and then continued increase in the land removal rate LRUI illustrate its delayed adjustment to a slower rise in the demand for urban-industrial land.

The growth in land erosion LER is caused by the rise in land yield LY. As LY declines, LER also declines. One might expect erosion to continue to grow even after land yield LY declines, since one would expect overintensive cropping practices to continue in the face of rising food shortages (this undesirable side effect of the land erosion–land yield formulation is discussed in section 4.5).

Sensitivity Runs—Limits to Food Production

The upper limit to the production of food in World3 is determined by two constraints: the maximum amount of potentially arable land available (PALT) and the maximum yield obtainable from that land once it is developed (the maximum value of the land yield multiplier from capital LYMC). The sensitivity of the agriculture sector to possible errors in the estimates of these two constraints will be investigated here.

In section 4.5 we hypothesized a relationship between agricultural inputs per hectare AIPH and land yield LY. It was assumed in the standard run that increased inputs can increase yield by a maximum factor of 10 above the inherent land fertility. Figure 4-71 shows two other possible estimates of the land yield multiplier from

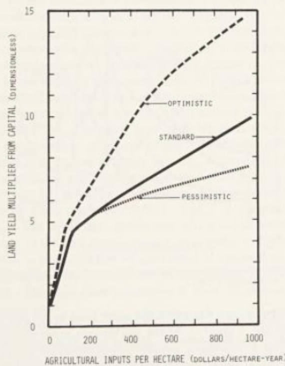

Figure 4-71 Standard, pessimistic, and optimistic estimates of the land yield multiplier from capital table