FINAL EXAM SOLUTIONS

1. As part of the Kyoto Protocol, the United States agreed to reduce its emissions of greenhouse gases to 7 percent below the 1990 level by 2008 to 2012. U.S. emissions have increased steadily since 1990, however; in fact, emissions of carbon dioxide rose from 1340 million metric tons of carbon (MtC) in 1990 to 1480 MtC in 1997.

   A. If U.S. carbon-dioxide emissions continue to rise at the 1990–97 rate, what would be the annual rate of emission in 2010? (5 points)

   $$\left(\frac{1480}{1340}\right)^{\frac{1}{7}} - 1 = 0.0143\ /\ \text{yr} = 1.43\%\ /\ \text{yr}$$

   $$1480(1.0143)^{13} = 1780\ \text{MtC / yr}$$

   B. What percentage reduction below the "business-as-usual" case (part A) would be necessary to achieve the Kyoto target? (5 points)

   $$\text{Kyoto target} = (0.93)(1340) = 1246\ \text{MtC / yr}$$

   $$\text{Required reduction} = 1 - \frac{1246}{1780} = 0.30 = 30\%$$

2. It is estimated that planting a million trees in Los Angeles would reduce summer temperatures by 4 °F, saving $175 million per year in cooling costs.

   A. If each tree costs $300 to plant and $75 per year to maintain, is this a cost-effective way to reduce electricity consumption? (5 points)

   Annual savings per tree = $175 – $75 = $100/yr

   Initial investment = $300

   $$\text{Payback period} = \frac{\$300}{\$100\ /\ \text{yr}} = 3\ \text{yr}$$ **This is very cost-effective.**

   B. Trees reduce carbon emissions by reducing electricity consumption. If a kilowatt-hour of LA electricity costs $0.1 and results in the release of 100 grams of carbon, estimate the reduction in emissions. (5 points)

   $$\left(\frac{\$175}{\text{tree}\cdot\text{yr}}\right)\left(\frac{\text{kWh}}{\$0.10}\right)\left(\frac{0.1\ \text{kgC}}{\text{kWh}}\right) = 175\frac{\text{kgC}}{\text{tree}\cdot\text{yr}}$$

C. Trees also sequester carbon. Which has a greater effect on emissions: sequestration or reduced electricity consumption? Assume the trees mature in 50 years, at which time they contain 5 tons of carbon. (5 pts)

$$\left(\frac{5000\,\frac{\text{kgC}}{\text{tree}}}{50\,\text{yr}}\right) = 100\,\frac{\text{kgC}}{\text{tree}\cdot\text{yr}}$$ **Elec savings more important than sequestration.**

3. You have received a large grant to evaluate the effects of acid deposition in Japan over the next fifty years. Divide the assignment into several major components and outline the tasks that would have to be performed under each. (15 points)

1. Sources of acid precursors in East Asia (SO_2 and NO_x)
   A. Electricity production/consumption scenarios
   fraction from coal burning; sulfur content of coal; emission controls
   B. Transportation scenarios
   vehicle-miles of cars, trucks; emission controls
   C. Mining/smelting scenarios
   D. Other releases
2. Atmospheric transport and deposition
   Conversion of SO_2, NO_x into acids, fraction deposited dry, in rain, and in snow in Japan (make use of models already developed)
3. Soil chemistry
   Measure buffering capacity of soils in Japan
   Estimate depletion of carbonates, leaching of nutrients, toxic metals into waterways
4. Aquatic chemistry
   Estimate pH of lakes in various watersheds
5. Ecosystem effects
   Estimate effects of forests, lakes, agriculture
6. Human effects
   Estimate effects on buildings and monuments, of metals in water supply.
7. Estimate costs associated with (5) and (6)

4. It is estimated that there are 10 million species on Earth, of which 70 percent are found only in tropical forests. Between 1960 and 1990, the area covered by tropical forests declined from 2.20 to 1.76 billion ha.

A. Estimate the total loss of species during this time period. Assume that $S \approx S_0(A/A_0)^{0.25}$, where S is the number of species and A is the area of the forest. (5 points)

$$\textbf{Species loss = 7 million – (7 million)}\left(\frac{1.76}{2.20}\right)^{0.25} = 380{,}000 \cong 400{,}000$$

loss rate = 13,000 ≅ 10,000/yr

B. How does this compare to the natural rate of extinction? (2 points)

The natural rate of extinction is probably about a few per year, so the rate calculated above is 1,000 to 10,000 times the natural rate.

C. What are the uncertainties in the above analysis? (3 points)

First, we don't how a good definition for "species." Second, we don't know how many species exist—there could be more than 100 million. Third, the SAR relationship is based on natural phenonmena that have developed over millions of years. We don't know how extinction depends on forest loss, or the pattern of forest loss. Fourth, this doesn't include extinctions from other causes, such as habitat pollution or degredation, hunting, introduction of non-native species, climate change, etc.

5. The 1990 amendments to the Clean Air Act reduced U.S. sulfur dioxide emissions from 20 to 10 Mt. In addition, it reduced NO_x emissions from automobiles from 1.0 to 0.4 grams per mile. Which provision will have the greatest effect on acid deposition? Assume that NO_x is mostly NO_2, and that equal fractions of SO_2 and NO_2 are converted to H_2SO_4 and HNO_3, respectively. What important consideration does this simple calculation ignore? (10 points)

   Assume that all the NO_2 and all the SO_2 are converted to HNO_3 and H_2SO_4. In that case, the reductions in SO_2 and NO_2 are equal to the following reductions in H^+:

$$\left(\frac{10\cdot 10^6\ \text{t}(SO_2)}{\text{yr}}\right)\left(\frac{10^6\ \text{g}}{\text{t}}\right)\left(\frac{\text{mole}(SO_2)}{64\,\text{g}(SO_2)}\right)\left(\frac{2\ \text{mole}(H^+)}{\text{mole}(SO_2)}\right) = 3\cdot 10^{11}\,\text{mole}(H^+)$$

$$\left(\frac{0.6\ \text{g}(NO_2)}{\text{mi}}\right)\left(\frac{\text{mole}(NO_2)}{46\,\text{g}(NO_2)}\right)\left(\frac{\text{mole}(H^+)}{\text{mole}(NO_2)}\right)\left(\frac{15{,}000\ \text{mi}}{\text{car}\cdot\text{yr}}\right)\left(200\cdot 10^6\ \text{cars}\right) = 4\cdot 10^{10}\,\text{mole}(H^+)$$

   In other words, the reduction in SO_2 is roughly 8 times as important in terms of reducing the concentration of H+ in rainfall. In pH units, this is a difference of roughly one unit.

   The most glaring shortcoming of this approach is that it ignores regional patterns of emission and deposition. The avoided emissions and depositions of SO_2 are concentrated in the northeast, while the avoided emissions of NO_2 are spread much more uniformly around the country.

6. In 1985, 300,000 metric tons of $CFCl_3$ (CFC-11) were produced. The residence time of CFC-11 in the atmosphere is estimated at 60 years.

   A. If production remained constant, estimate the steady-state concentration of CFC-11 in the atmosphere, in ppbv (5 points).

$$S = F\tau = \left(\frac{300{,}000\,t(CFCl_3)}{yr}\right)\left(\frac{10^6\,g}{t}\right)\left(\frac{mole(CFCl_3)}{137.5\,g(CFCl_3)}\right)(60\,yr) = 1.3\cdot 10^{11}\,\frac{mole(CFCl_3)}{yr}$$

$$C = \frac{S}{V} = \frac{1.31\cdot 10^{11}\,mole(CFCl_3)}{1.78\cdot 10^{20}\,mole(atm)} = 7.4\cdot 10^{-10} = 0.7\,ppbv$$

B. CFC-11 is destroyed in the stratosphere, not the troposphere. What is the steady-state concentration in the stratosphere? Assume that 90 percent of the atmosphere is in the troposphere and 10 percent is in the stratosphere, and that CFC-11 has a residence time of about 10 years in the troposphere. (5 points)

$$S_t = F_t\tau_t = \left(2.2\cdot 10^9\,\frac{mole}{yr}\right)(10\ yr) = 2.2\cdot 10^{10}\,mole(CFCl_3)$$

$$S_s = S - S_t = 1.3\cdot 10^{11} - 2.2\cdot 10^{10} = 1.1\cdot 10^{11}\,mole$$

$$C_s = \frac{S_s}{V_s} = \frac{1.1\cdot 10^{11}\,mole}{0.1(1.78\cdot 10^{20})} = 6.1\,ppbv$$

7. What do we mean by the term “biodiversity”? What are the main threats to biodiversity? Why is it important to preserve biodiversity? (15 points)

There is no precise definition of the term “biodiversity.” It is most often taken to mean number of species, but it can also mean diversity of habitat or ecosystem, or genetic diversity.

Regardless of how the term is defined, the main theats to biodiversity are (1) the conversion, destruction, degradation, or pollution of natural habitat, (2) introduction of non-native species, (3) hunting or harvesting, (4) fire or fire suppression.

Many reasons are given for wanting to preserve biodiversity. These most often relate to the potential economic value of biodiversity to humanity: a source of crop strains and drugs or opportunities for recreation. Nonmarket values to humans include pest and waste control and aesthetic, scientific, or religious value. Biodiversity may also have intrinsic value. In other words, a species may have value—a “right to exist”—apart from humanity.

8. You read an editorial stating that there has been no observed increase in ultraviolet radiation or skin cancer in the United States, contrary to the dire predictions of environmentalists; concern over ozone depletion is greatly exaggerated, and the ban on CFCs is unnecessary. Write a short response. (15 points)

No, we haven’t seen increases in UV or skin cancer, but no one predicted that we would see such increases—yet. Small changes in UV are very hard to

measure, and increases due to the loss of stratospheric ozone may be offset by increases in ground-level ozone (which is toxic to humans). Small changes in the incidence of skin cancer would also be difficult to detect, and will occur many years after exposure.

The link between CFC emissions, ozone depletion, increased UV, and skin cancer is undisputed by the scientific community. The evidence is especially persuasive in the Antarctic, where unusual atmospheric conditions have combined with chlorine from CFCs to lower ozone levels by as much as 65 percent, increasing UV by as much as 150 percent. Increases in skin cancer have already been detected in Australia.

The Montreal Protocol and its amendments were enacted to halt the destruction of ozone before it reached dangerous levels in more populated areas such as the U.S. Baring unexpected events such as a major volcanic explosion, scientists expect ozone levels to reach a minimum around the turn of the century. But because of the long lifetimes of CFCs in the atmosphere, the ozone layer won't recover fully until the middle of the next century.

Although the worst may be averted, even the small decreases in ozone that have been observed over the U.S. will have serious consequences. A 2 percent decrease in ozone will cause result in 15,000 additional cases of cancer and 800 additional deaths per year, in the U.S. alone. Worldwide, these numbers would be about five times greater.

Delaying compliance with the Protocol and its amendments until we see signs of dramatic increases in UV or skin cancer would be foolish, since such damage would take decades to reverse, during which time we would condemn hundreds of thousands of people to premature death. Nor has industry requested a delay in compliance. Affordable substitutes are on the market right now that can perform the same functions as CFCs without threatening the ozone layer.

The Montreal Protocol and its amendments represent a landmark achievement in the efforts of the world community to deal with global environmental problems before they becomes a catastrophe. Don't steal defeat from the jaws of victory.