DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
UNIVERSITY OF CALIFORNIA, BERKELEY
E11 ENGINEERED SYSTEMS AND SUSTAINABILITY, FALL 2006

MIDTERM EXAM SOLUTIONS (TOTAL: 100 POINTS)

Name: ______________________________

Student ID: __________________________

Instructions: Answer the questions that follow directly on these pages in the spaces provided. Use the back of the page if you need more room for your answer. If you believe there is insufficient information provided to answer a question completely, state reasonable additional assumptions *clearly* and proceed from there.

This exam is closed-book/closed-notes.
No calculator is needed.

Time: 50 minutes.

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Question	Points	Grade
1a	6	
1b	6	
1c	3	
2a	9	
2b(i)	4	
2b(ii)	10	
3a	10	
3b	6	
3c	6	
4a	4	
4b	4	
4c	3	
4d	6	
5a	3	
5b	4	
5c	8	
5d	8	
Total	*100*	
Bonus a	6	
Bonus b	4	
Exam Total		

QUESTION 1: SUSTAINABILITY (15 POINTS)

a) Define (in 1-3 sentences) the term "sustainable development." (6 points)

Answer: Either of the two definitions below, which were discussed in class, is acceptable. Also acceptable are reasonable variants of the two definitions below, which capture the general idea of meeting society's development needs in a way that preserves the long-term integrity of ecological systems.

1) "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

2) "Improving the quality of life while living within the carrying capacity of ecosystems. This manner of living uses no more resources than can be naturally replenished."

Grading: 6 points for either of the answers above or a reasonable variant; 4-5 points for providing an answer that didn't fully capture the general idea of sustainable development; 0 points for no answer or no reasonable effort.

Feedback: No major problems. Note that it is important to address improving the quality of life while preserving ecosystem integrity and not to ignore temporal (i.e., time) considerations (i.e., that the manner of development must preserve ecosystem integrity both now and in the future). Also, development must not compromise the ability of future generations to meet their needs ("not compromising the needs of future generations," which means something entirely different, was a common mistake).

b) Explain briefly why the consumption of a resource that can be considered renewable (for example, wood or fishes) can in fact be non-sustainable. (6 points)

Answer: There are several acceptable answers for this question. Examples of how the consumption of a renewable resource can be non-sustainable include: consuming the resource faster than it can be replenished, harvesting the resource in manner that damages other vital parts of the ecosystem (e.g., clear cutting of forests or bottom trawling for fishes), and when potentially non-sustainable resource inputs (e.g., fertilizers, diesel fuel) are required in the life cycle of the renewable resource.

Grading: 6 points for an answer that addresses at least one non-sustainable aspect associated with the consumption of a non-renewable resource (such as the examples above); 4-5 points for providing an answer that isn't fully realistic; 0 points for no answer or no reasonable effort.

Feedback: No major problems. Note that when describing the depletion/extinction of a renewable resource, the critical point is that the rate of resource consumption exceeds the rate of resource replenishment.

c) Using the renewable resource wood as an example, list three strategies for making the consumption of wood-based products (e.g., furniture, paper, lumber) more sustainable. (3 points)

Answer: Any answer that describes a realistic solution (at any life-cycle stage) that can be expected to make the consumption of wood products more sustainable is acceptable. Examples include: harvesting the wood at a rate that permits natural replenishment, increased recycling of wood waste to reduce dependence on virgin resources and/or to reduce stress on landfills, harvesting wood in a manner that doesn't damage other vital parts of the ecosystem (e.g., no clear cutting), use of renewable energy for harvesting wood, processing into final products, and transporting throughout the supply chain, making vital habitats for critical species (e.g., old growth forests) off limits to harvesting, and designing wood products to last longer to reduce the dependence on virgin resources.

Grading: 1 point for each reasonable strategy; 0 points for no answer or no reasonable effort.

Feedback: No major problems. Note that recycling, reusing, and reducing consumption of a wood-based product essentially accomplish the same thing (namely, they can reduce the rate at which we harvest virgin wood resources). However, since these are indeed 3 different strategies, full credit was given for each answer. Also, increasing the energy efficiency of harvesting can help make wood consumption more sustainable, but increasing the efficiency of harvesting might not help (if the efficiency gain means we simply remove more wood in less time).

QUESTION 2: POPULATION GROWTH (23 POINTS)

a) List three major methods for projecting population growth and list one advantage and one disadvantage associated with each method. Please use the column format provided below. (9 points)

Answer: For each method discussed in class, any of the below (or reasonable variants) are acceptable answers. Three methods must be named and one advantage and one disadvantage must be listed for each method.

Population Growth Modeling Method	**Advantage(s)**	**Disadvantage(s)**
Annual growth	*Easy to use, based on readily available annual population data; good for short term forecasting; good for small growth rates*	*Assumes growth occurs in discrete steps when growth is actually continuous; assumes growth continues unabated forever*
Exponential growth	*Offers a continuous model of growth that is more realistic than discrete annual growth; easy to use; good for short term forecasting; good for small growth rates; models reasonably well the growth in human population over the last 5,000 years*	*Assumes growth continues unabated forever*
Logistic growth	*Acknowledges that growth cannot continue unabated forever and must reach some maximum carrying capacity; best model for long-term population growth patterns*	*Difficult to estimate carrying capacity; carrying capacity can change over time (due to such factors as technological progress, behavior changes, or environmental improvements)*
Demographic	*Permits very detailed modeling of populations based on key demographic data such as age, income, and fertility rates; method is based on actual data that are representative of specific populations; commonly used by demographers so is a proven method*	*Very data intensive; models can be complex and thus not easy to use or interpret*

Grading: 1 point for each correct method, advantage, and disadvantage listed; 0 points for no answer or no reasonable effort.

Feedback: No major problems.

b) The general equation for the logistic growth curve can be represented by:

$$P(t) = \frac{K}{1 + e^{-r(t-t_m)}} \qquad \textit{where} \quad r = \frac{r_o}{1 - \frac{P_o}{K}}$$

i) Name and define the key logistic growth modeling variable that is represented by K in the above equations. (4 points)

Answer: There are two parts that must be answered correctly to get full credit. First, name the variable (P_{max}) that is represented by K. Second, define the variable: (1) P_{max} is the carrying capacity, which is the equilibrium condition in which the total demands of the population for food, water, waste disposal, and natural resources are in balance with the capability of the environment to supply those needs. Or, (2) P_{max} is the maximum population that can be sustained and defines a stable level with no further growth.

Grading: 2 points for naming the variable (either P_{max} or carrying capacity is acceptable) and 2 points for defining the variable. If the definition isn't a reasonable variant of the two examples offered above, only 1 point is given for defining the variable; 0 points for no answer or no reasonable effort.

Feedback: Points were taken off mostly for not naming AND defining the variable as instructed.

ii) Consider a population of wolves that was introduced into a wildlife refuge in the year 2000. Wildlife biologists expect that the growth of the wolf population will follow a logistic growth pattern over time and predict that the wolf population will reach one-half of the refuge carrying capacity in the year 2050. They further predict that the annual growth rate (r_o) of the wolf population in the year 2050 will be 5%. Based on these predictions, calculate the year in which the wolf population can be expected to reach 1/1.37 (i.e., 73%) of the refuge carrying capacity. (To solve this problem, consider that $e^{-1} = 0.37$ and assume that the initial wolf population in 2000 is very small compared to the refuge carrying capacity.) (10 points)

Answer: First, it is necessary to calculate the initial exponential growth rate (r), recognizing that at the midpoint time (t_m) = 2050, the annual growth rate (r_o) = 0.05 and the ratio P_o/P_{max} = 0.5 (these three values are given in the problem statement).

$r = r_o/(1 - P_o/P_{max}) = 0.05/(1-0.5) = 0.05/0.5 = 0.1$

Then, it is necessary to solve for t when $P(t)/P_{max} = 1/1.37$. Recognizing that $e^{-1} = 0.37$:

$P(t)/P_{max} = 1/(1 + e^{-r(t-tm)}) = 1/(1 + e^{-1})$ *and thus* $e^{-1} = e^{-r(t-tm)}$ *so it follows that*

$-1 = -r(t-t_m) \rightarrow t = 1/r + t_m$

Since $r = 0.1$ *and* $t_m = 2050$, $t = 1/(0.1) + 2050 = 10 + 2050 =$ ***2060***

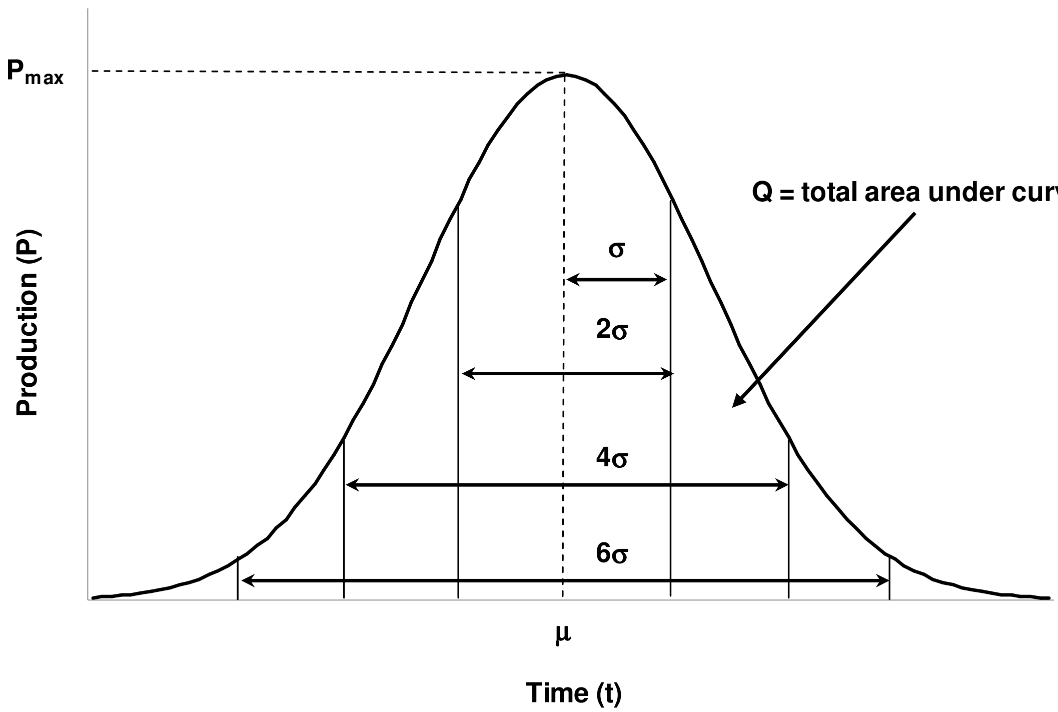
Grading: 5 points for correctly solving for r = 0.1 and 5 points for solving correctly for the year 2060; as discussed in class, if it was assumed that P_o/P_{max} = 0 and calculated that r = 0.05 leading to the year 2070, only 1 point was docked (since r_o was given for 2050, not for 2000); for answers not conforming to the aforementioned conditions, 6-8 points were given if a reasonable level of effort was displayed but incorrect answers; 0 points for no answer or no reasonable effort.

Feedback: There were a lot of incorrect answers and calculation strategies for this problem. Please be sure to check the solution and work the problem again if you got it wrong to ensure that you understand the solution and proper use of the given equations.

QUESTION 3: RESOURCES (22 POINTS)

a) Draw the Gaussian/Hubbert's curve, label the axes, and label and define the four main parameters. (10 points)

Answer: An acceptable drawing includes both axes labeled properly and the explicit labeling of each of the four main curve parameters: (1) peak or maximum production P_{max}*, (2) standard deviation* σ*, (3) mean or year of peak production* μ*, and (4) total resource production* Q*. In addition to the drawing, it was required to define each of these four main parameters.*



Grading: 4 points for drawing the correct graph shape, 2 points for labeling the axes, 0.5 points for each parameter that is labeled properly, 0.5 points for each parameter that is defined properly (at minimum, the full name of each parameter is required). 0 points awarded for no answer or no reasonable effort.

Feedback: No major problems. Note that Hubbert's curve models the production of a resource, not the growth of a population!

b) Assume that the production of oil from the Drillville, TX oil field can be modeled using the Gaussian/Hubbert's curve. The total reserves contained in Drillville's oil field have been estimated at 10 billion barrels. Assume a standard deviation of 20 years, and recall that in the Gaussian/Hubbert's curve, 2σ = 68.3%, 4σ = 95.4% and 6σ = 99.7% of the area

under the curve centered about the mean. If in 2006, Drillville has already extracted 9.77 billion barrels from its oil field, in what year did the Drillville oil field reach peak production? (6 points)

Answer: First, recognize that the total amount of oil reserves (Q) is equal to 10 million barrels and that 9.77 billion barrels is 97.7% of Q. Next, recognize that at the mean or peak production year μ*, 50% of Q has been extracted. Then, recognize that one-half of the area under the curve within* 4σ *(centered about the mean) is 95.4%/2 = 47.7% of Q. Thus, 97.7% of the oil reserves has been extracted when* $t = \mu + 2\sigma$*. Finally, solve for* $\mu = t - 2\sigma = 2006 - 2*20 =$ ***1966****.*

Grading: 6 points for correct answer (1966); 4-5 points for reasonable effort but incorrect answer (however, only 2 points were given if the answer was that the peak year occurred later than 2006, which is impossible since 97.7% of resources had already been extracted by 2006!); 0 points for no answer or no reasonable effort.

Feedback: There is no need to know the Hubbert's curve equation to solve this problem.

c) In the Drillville oil field example in part (b), how many barrels of oil can Drillville expect to produce from its oil field over the next 20 years (i.e., between now and 2026)? (6 points)

Answer: In 2026, $t = \mu + 3\sigma$ *(i.e., 1966 + 3*20). Recognize that one-half of the area under the curve within* 6σ *(centered about the mean) = 99.7%/2 = 49.85% of Q. Thus in 2026, 99.85% of Q has been extracted, which is 9.985 billion barrels. The amount of oil that can be extracted between 2006 and 2026 is therefore 9.985 – 9.77 =* ***0.215 billion barrels.***

Grading: 6 points for correct answer (0.215 billion barrels); 4-5 points for reasonable effort but incorrect answer (however, only 2 points were given if the answer was that the extraction between 2006 and 2026 would be greater than 2.3 billion barrels, which is impossible since only 2.3 billion barrels were left in the total oil reserves in 2006!); 0 points for no answer or no reasonable effort.

Feedback: There is no need to know the Hubbert's curve equation to solve this problem.

QUESTION 4: LIFE-CYCLE ASSESSMENT (17 POINTS)

a) What are the major life-cycle stages that one must consider when performing a complete LCA of a car? (4 points)

Answer: i) Goal and Scope definition; Inventory analysis; Impact assessment; Interpretation/Improvement Analysis; ii) Raw materials extraction; Manufacturing; Use; Disposal

Grading: Both types of answers were ok. 1 point per main stage. (-0.5 pts if goal and scope definition is put as a last step of a LCA)

Feedback: "Goal and Scope definition" is the first step of a LCA.

b) Define (in 2-4 sentences) what a functional unit is. (4 points)

Answer: A functional unit is a common unit measuring the service provided by different alternatives. This unit allows a fair comparison between different alternatives.

Grading: if correct definition but wrong example (e.g. kgCO2), 1 point off.

Feedback: The functional unit is NOT the same as a reference unit (e.g. a reference substance measuring the impact on a midpoint category).

c) What might be an appropriate functional unit for comparing the life-cycle environmental impacts of an oil-based paint to a water-based paint? (3 points)

Answer: FU = m^2-yr; FU = certain area protected during a certain time.

Grading: if answer is "amount of paint" = -2 pts; if only time = 1 pts; if only surface mentioned = 2 pts; if area/times = -0.5 pts; if something else than "area x time" is mentioned = only 2 pts.

Feedback: Most of the person forgot either to mention the time or the area. The functional unit is NOT the "amount of paint per area and time": the functional unit is ONLY the "area x time".

d) List six major environmental impact categories (i.e., midpoints). (6 points)

Answer: Example of midpoint impact categories Carcinogens effect; Non-carcinogens effect; Respiratory effects caused by inorganics; Ozone layer depletion; Radiation; Respiratory effects caused by organics; Aquatic ecotoxicity; Terrestrial ecotoxicity, Terrestrial acidification & nitrification; Land occupation; Global Warming; Mineral extraction; Non-renewable energy extraction; Water consumption; Noise; etc.

Grading: 1 point per category considered acceptable.

Feedback: Categories like "Air emissions" or "Water emissions" are now recognized as not being a relevant form to express midpoint categories, but were considered acceptable since several outdated studies use these categories (by simply summing the air emissions). The emission of a specific substance (e.g. CO2, NOx, etc.) is NOT an impact category.

QUESTION 5: ELECTRICITY GENERATION AND EMISSIONS (23 POINTS)

a) In class, we learned that the most common method of generating electricity is to drive an electromechanical generator using a turbine that is rotated by a working fluid. The most widely-used working fluid is high-pressure steam. List three other working fluids that are also commonly used to rotate a turbine. (3 points)

Answer: water; air (wind); hot exhaust (or combusted) gas

Grading: 1 point per acceptable answer.

Feedback: The air IS a FLUID. The wind is not a fluid, but an atmospheric phenomenon. However, the word "wind" was considered acceptable.

b) Explain (in 1-3 sentences) the difference between primary energy and final energy. (4 points)

Answer: The primary energy is the energy that is put as input in the power plant. It is the energy contained in the fuel before it is burned (or in the water for hydroelectric dam). The final energy is the energy that one gets at the power outlet (in the house for example). The final energy is always lower than the primary energy because of the losses throughout the system (power plant + transmission).

Grading: 2 points for a correct answer for primary energy; 2 points for a correct answer for final energy;

Feedback: losses in the transmission systems have to be taken into account in the difference between primary and final energy.

c) Assume that for coal burned in U.S. power plants, the average ash content is 10% by weight and that 10% of the ash is converted to bottom ash. If U.S. power plants burn 1 billion metric tons of coal each year, how many metric tons of flyash would U.S. power plants emit to the air each year if no end-of-pipe pollution controls were employed? (8 points)

Answer: 10% of the ash is converted to bottom ash, thus 90% of the ash will leave as fly ash!

*Amount of fly ash = 1 billion tons of coal * 0.1 ton of ash/ton of coal * 0.9 ton of fly ash/ton of ash = 1E+9 * 0.1 * 0.9 = 1E+9 * 0.09 = 0.09 billion tons of fly ash = 90 millions tons of fly ash.*

Grading: 2/6 if wrong approach; 4/8 if something forgot; 6/8 if not read correctly; 7/8 if calculation mistake; 6/8 if billion interpreted as 1E+6 instead of 1E+9.

d) Assuming that the coal burned in U.S. power plants each year from part (c) contains 1.5% sulfur by weight, how many metric tons of SO_2 would U.S. power plants emit to the air each year if no end-of-pipe pollution controls were employed? (Some useful molecular weights: S = 32, O=16.) (8 points)

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*Answer: 1.5% = 0.015, thus there is 0.015 ton of S/ton of coal. Thus there is 1 billion tons of coal * 0.015 ton of S/ton of coal = 15 millions tons of S emitted.*
*Since 1 mol of S creates 1 mol of SO2, one has 32 g (i.e. 1 mole of S) of S creating 64 g of SO2 (i.e. 1 mole of S (=32) + 2 moles of O (=2*16)). Thus one has 64/32 = 2 tons of SO2 per ton of S.*
*Thus 15 millions tons of S emitted represents 15 millions tons of S emitted * 2 tons of SO2/ton of S = 30 millions tons of SO2 emitted.*

*Grading: 2/6 if wrong approach; 4/8 if something forgot; 4/8 if "/2" instead of "*2"; 4/8 if MW (SO_2) $\neq$ 64 g/mol; 6/8 if not read correctly; 7/8 if calculation mistake.*

Feedback: The molecular weight of O is 16. Thus the molecular weight of O_2 is 32!

BONUS QUESTIONS (10 POINTS)

a) If you want to determine which mode of transportation is least polluting for transporting lumber from Seattle to Los Angeles, which alternatives for transportation mode would you consider in your analysis and what would be your functional unit? (6 points)

Answer: The mode of transportation studied would be "truck", "train", and "boat". The functional unit would be "one ton of wood for 1 mile (or for 1 km, or from Seattle to Los Angeles).

Grading: 3pts for the functional unit; 3pts for the modes of transportation. One needs to have at least the "boat", "train" and "truck" to get the 3 pts. Other weird transportation modes accepted, but no credit accorded.

Feedback: Please read the question carefully. Several students answered like if we asked for passenger transportation!

b) In the typical steam cycle for electricity generation, name the four major sources of energy loss occurring between the input of fuels into the power plant and the use of electricity by customers. (4 points)

Answer: 1) Conversion of fuel to steam in boiler, 2) Conversion of steam to electricity, 3) Electricity use for auxiliary processes, 4) Transmission and distribution to customer.

Grading: 1 point per "acceptable" answer.

Feedback: Sources of loss occurring before the input of fuels into the power plant were considered no valid.

THE END