Free-Response Section

Scoring Guidelines

Question 1: Design an Investigation — 10 points

Learning Objectives: ERT-1.D STB-3.G STB-4.H

General Scoring Note:
When scoring questions with multiple correct answers, only score the first response given.

(A) The diagram below shows the cycling of carbon.

(i) **Identify** a process shown in the diagram that removes carbon from the atmosphere. — **1 point** 2.A ERT-1.D

Accept one of the following:

- The Photosynthesis
- Absorption of CO_2 into ocean

(ii) **Identify** a process shown in the diagram that sequesters carbon from the atmosphere for a geological period of time. — **1 point** 2.B ERT-1.D

Accept one of the following:

- Formation of fossil fuels (coal, oil, and gas)
- Formation of limestone from sediments in the ocean

(iii) Based on the diagram, **explain** how the combustion of fossil fuels has led to an imbalance in the carbon cycle. — **1 point** 2.C ERT-1.D

Accept one of the following:

- Carbon that was sequestered in coal, oil, or natural gas is combusted and increases the amount of carbon dioxide in the atmosphere.
- Excess carbon is released into the atmosphere from anthropogenic sources, not natural sources, leading to carbon dioxide concentrations that increase faster than can be removed through photosynthesis/absorption into the ocean.

(iv) **Explain** the role of decomposition in the carbon cycle. — **1 point** 1.A ERT-1.D

Accept one of the following:

- Decomposers cycle carbon from tissue/biomass of dead or decaying organisms into the atmosphere or water as released CO_2 from aerobic decomposition. (Anaerobic decomposition releases CH_4 into the atmosphere).
- Decomposers convert organic material ($C_6H_{12}O_6$) into CO_2 during aerobic respiration.
- Decomposers convert organic material ($C_6H_{12}O_6$) into CH_4 during anaerobic respiration.

Total for part (A) — **4 points**

(B) Scientists are interested in researching how carbon dioxide in the oceans affects their pH. They design a laboratory experiment in which they inject different concentrations of carbon dioxide into saltwater tanks containing calcium carbonate shells. The tanks are kept at the same, constant temperature. After several days, the scientists measure the pH of the saltwater tanks and observe its effects on the calcium carbonate shells.

(i) **Identify** the independent variable in this experiment. **1 point**

4.B

STB-4.H

Accept one of the following:

- Concentration of CO_2
- Amount of CO_2 injected into the saltwater tanks

(ii) **Describe** a control group that could be used in this experiment. **1 point**

4.C

STB-4.H

Accept one of the following:

- The pH of the tanks before different concentrations of carbon dioxide were injected (the baseline pH)
- A tank kept at the same, constant temperature with no carbon dioxide injected

(iii) **Explain** the effect of carbon dioxide on the pH of the oceans. **1 point**

1.C

STB-4.H

Accept one of the following:

- Increased CO_2 dissolves in oceans, leading to formation of carbonic acid, decreasing the pH of the water/increasing acidification.
- Additional CO_2 in the ocean disrupts the carbonate buffering system and the ocean becomes more acidic/the pH of the ocean decreases.

(iv) **Describe** the effect of water temperature on the amount of dissolved gases in water. **1 point**

1.B

STB-3.G

Accept one of the following:

- As water temperature increases, the amount of dissolved oxygen (DO) decreases.
- As water temperature decreases, the amount of dissolved oxygen (DO) increases.
- Gases become less soluble in water as the temperature of the liquid decreases.

(v) **Describe** how the results of the experiment would change if the temperature of the tanks was decreased. **1 point**

4.E

STB-3.G

STB-4.H

- More CO_2 would have dissolved in tanks, which would increase acidification/ decrease in pH/cause a larger observed pH change.

(vi)	**Describe** how a decrease in ocean pH can affect marine organisms. **Accept one of the following:** • A decrease in pH can cause the calcium carbonate shells of marine organisms to become weak or thin and break easily. • A decrease in pH will make it harder for mollusks to form their shells. • A decrease in pH will make it harder for corals to form their exoskeletons. • An increase in acidity/decrease in pH may be outside the range of ecological tolerance for many species and could cause a population decline. • A decrease in pH can negatively affect the ability of marine organism to maintain homeostasis.	**1 point** 7.A STB-4.H
	Total for part (B)	**6 points**
	Total for question 1	**10 points**

Question 2: Analyze an Environmental Problem and Propose a Solution — 10 points

Learning Objectives: STB-3.N STB-3.F EIN-3.D STB-3.K STB-3.M ENG-3.E

General Scoring Note:
When scoring questions with multiple correct answers, only score the first response given.

The waste generated by humans is both an environmental and human health concern.

(A) Many countries now use centralized sewage treatment plants to treat the wastewater from houses and businesses.

(i) **Describe** a main goal of primary treatment in a modern sewage treatment plant. — **1 point** 1.A STB-3.N

Accept one of the following:

- Large debris/solid waste is physically separated from wastewater using screens/grates/other means.
- Sludge/solid waste settles out in tanks.

(ii) **Describe** a main goal of secondary treatment in a modern sewage treatment plant. — **1 point** 1.A STB-3.N

Accept one of the following:

- Microbes (bacteria, fungi, viruses, etc.) are used to break down organic matter.
- Aeration in the sludge tank aids microbes in the breakdown of organic matter.

(iii) Many sewage treatment plants use tertiary treatment as the final step in wastewater treatment. **Describe** one advantage of this process. — **1 point** 7.C STB-3.N

Accept one of the following:

- Kills most microbes, including pathogens, decreasing the spread of disease in humans
- Removes nutrients like phosphorus and nitrogen, decreasing the amount of nutrients in surface waters/reducing the potential for algal blooms

(iv) If a sewage treatment plant malfunctions or if low-income areas lack sanitary waste disposal, raw sewage can be introduced into surface waterways. **Describe** one potential environmental problem or one potential human health problem that can result from the presence of raw sewage in surface waters. — **1 point** 7.A STB-3.F EIN-3.D

Accept one of the following:

- Environmental problem: Eutrophication from excess nutrients in water with sewage overflow, decreases dissolved oxygen levels in water as decomposers respire while breaking down waste (which stresses or kills aquatic organisms, such as fish)
- Human health problem: Disease-causing organisms/pathogens introduced to surface water could be consumed in drinking water and spread infectious disease (such as cholera, hepatitis A, gastroenteritis, giardia)

(v)	**Identify** one water parameter that could be measured to determine whether raw sewage is present in surface waterways. **Accept one of the following:** • Fecal coliform test • A test for density of fecal coliform bacteria which, while generally harmless, live in human intestines and indicate potential for disease-causing organisms. • A test for disease-causing organisms, such as bacteria or viruses, in water • Dissolved oxygen (DO) test • Biological oxygen demand (BOD) test • Turbidity • Conductivity • Total suspended solids (TSS) • A test that measures the amount of oxygen a quantity of water uses over a period of time at a specific temperature	**1 point** 7.B STB-3.F EIN-3.D
	Total for part (A)	**5 points**

(B)	The United States Environmental Protection Agency (EPA) refers to the trash or garbage that can be placed in landfills (landfilled) as municipal solid waste (MSW). MSW can include such items as bottles, cardboard boxes, food, grass clippings, furniture, tires, computers, and appliances. The total MSW generated and the total MSW landfilled from 1960 to 2015 in the United States are shown in the graph below.	
(i)	**Describe** the trend in total MSW generated from 1960 to 2015. **Accept one of the following:** • The total MSW generated increased. • The total MSW generated increased, with a brief leveling off between about 2005 and 2010.	**1 point** 5.A STB-3.K
(ii)	**Compare** the trends in the total MSW generated and the total MSW landfilled between 1990 and 2000. **Accept one of the following:** • The total MSW generated increased between 1990 and 2000, but the total MSW sent to landfills decreased slightly during that same period. • The total MSW generated increased between 1990 and 2000, but the total MSW sent to landfills remained nearly the same during that period.	**1 point** 5.B STB-3.K
(iii)	Explain a probable reason for the trend in the total MSW landfilled described in (b)(ii). **Accept one of the following:** • Increased programs to increase the tonnage of MSW recycled, reused, or reduced through conservation measures were instituted after 1990. • Programs to increase the tonnage of MSW composted increased after 1990. • Programs to increase the tonnage of MSW burned to produce electricity increased after 1990.	**1 point** 5.E STB-3.M
	Total for part (B)	**3 points**

(C) One environmental problem in landfills is that organic materials such as food scraps and yard waste can decompose and produce methane over time. Methane is flammable and can be very dangerous in large concentrations.

(i) **Propose** a solution to reduce the risk of flammable methane from concentrating in landfills.

1 point

7.E

ENG-3.E

STB-3.M

Accept one of the following:

- Flare/burn the methane from venting and release by products into the air
- Collect the methane (to use as fuel) and burn it to power turbines for electricity generation.
- Incinerate all organic material instead of sending it to a landfill.
- Compost all organic material instead of sending it to a landfill.

(ii) **Justify** your solution proposed in (c)(i) by explaining an additional benefit to the solution besides reducing the amount of flammable methane concentrating in the landfill.

1 point

7.F

ENG-3.E

STB-3.M

Accept one of the following justifications.

Solution proposed in (c)i.	**Justification of Solution with an Additional Benefit**
Flare/burn the methane from venting and release by products into the air	• Can reduce the release of methane (a potent greenhouse gas) into the atmosphere
Collect the methane (to use as fuel) and burn it to power turbines for electricity generation.	• Produce energy/generate electricity for personal or consumer use (economic benefit) • Capture methane to reduce the release of methane (a potent greenhouse gas) into the atmosphere • Decrease reliance on coal and other fossil fuels that must be extracted for electricity generation
Incinerate all organic material instead of sending it to a landfill.	• Produce energy/generate electricity for personal or consumer use (economic benefit)
Compost all organic material instead of sending it to a landfill.	• Use of compost for organic fertilizer for personal or consumer use (ecological or economic benefit) • Reduce need for synthetic fertilizers in farming by using compost

Total for part (C) 2 points

Total for question 2 10 points

Question 3: Analyze an Environmental Problem and Propose a Solution (doing calculations) — 10 points

Learning Objectives: STB-1.E EIN-1.C STB-1.A

(A) Preserving high-quality agricultural land is important so that countries can grow enough food to feed their populations.

(i) **Describe** one agricultural practice that can lead to the degradation of agricultural land. — **1 point** 7.A STB-1.E

Accept one of the following:

- Plowing/tilling the soil increases soil erosion (by breaking up the soil structure) and reduces fertility
- Using monocultures/growing only one crop over and over will deplete the soil of nutrients
- Clearing a field to plant crops can lead to soil desiccation
- Overgrazing by livestock leads to a loss of soil cover and increases soil erosion
- Concentrated animal feedlots (CAFOs) can lead to compaction of soil from animals on grasslands
- Leaving a field fallow, without a cover crop, can lead to desiccation.

(ii) **Describe** a potential solution or technique that can prevent or reduce degradation of agricultural land. — **1 point** 7.B STB-1.E

Accept one of the following:

- Contour plowing uses the contours of the land to minimize soil erosion.
- Terracing, growing crops on the side of hills or mountains in a number of flat areas like a series of steps, reduces soil erosion.
- Windbreaks use one or more rows of trees/shrubs to protect an area from wind, which reduces soil erosion.
- Perennial crops remain in the soil year-round/can survive several years, which reduces the need for replanting and improves structure of the soil/ reduces erosion
- Cover crops/green manures are grown to protect and enrich the soil/improve soil properties and prevent erosion
- No-till agriculture/zero till agriculture does not disturb the soil increasing the retention of organic matter/decreases soil erosion/helps retain water in soil
- Strip cropping uses different crops in alternate strips to prevent soil erosion
- Crop rotation uses a series of different types of crops in the same area over seasons to prevent a loss of soil nutrients/to increase soil fertility and decrease erosion
- Polycultures uses a series of different types of crops grown at the same time to increase diversity using less land and decreasing wastes
- Addition of green manure, compost, limestone, and /or sulfur helps to retain soil moisture and increase organic material in soil

- Rotational grazing involves moving animals through a series of pastures, which benefits the grasses in the pastures/decreases soil compaction/ increases soil fertility
- Free-range livestock operations often use diverse grasses to feed animals, which improve soil quality. If animals are moved from area to area, they can fertilizer the area with manure.
- Agroforestry incorporates the cultivation of trees with agriculture that improves soil quality and decreases erosion

Total for part (A) **2 points**

(B) A less developed country with a rapidly expanding urban population is concerned that its growing urban population will eventually expand to a level where there would not be enough land to grow the food it needs to support its population.

(i) Excluding importing food, **propose** a solution to address the concerns of reduced land on which to grow food. **1 point** 7.E EIN-1.C

Accept one of the following:

- Improve yields per hectare through use of genetically modified (GM) crops/ high-yield crops/technology, etc.
- Plant rooftop gardens in urban areas.
- Use vertical farming techniques
- Grow only crops for food, since plants produce more kilocalories per hectare than livestock.
- Build up, not out, in urban areas/require high density buildings in urban areas.
- Reduce population growth by family planning, etc.

(ii) For your solution in (b)(i), **explain** an additional potential advantage of the solution. **1 point** 7.F STB-1.A

Accept any of the following additional advantages:

Solution proposed in (b)i.	**Additional Potential Advantage of Solution**
Improve yields per hectare through use of genetically modified (GM) crops/ high-yield crops/technology, etc.	• Can preserve remaining habitat for biodiversity • Reduced use of pesticides/ herbicides • Reduced water requirements

Plant rooftop gardens in urban areas.	• Can preserve remaining habitat for biodiversity • Can insulate buildings • Can reduce stormwater runoff • Can offset heat island effect • Provides green space for urban dwellers • Can grow crops on existing buildings so no additional land is required • Can produce food for human consumption/Can sell crops for profit	
Use vertical farming techniques	• Can allow for similar crop yield in a smaller footprint	
Grow only crops for food, since plants produce more kilocalories per hectare than livestock.	• Can preserve remaining habitat for biodiversity • Reduced pollution of waterways with livestock waste because of elimination/reduction of livestock • Reduced methane emissions because of elimination/reduction of livestock	
Build up, not out, in urban areas/require high density buildings in urban areas.	• Can preserve remaining habitat for biodiversity • Can lower ecological footprint of individuals because of reduced transportation, etc.	
Reduce population growth by family planning, etc.	• Can preserve remaining habitat for biodiversity • Reduced greenhouse gas emission, reduced resource extraction, etc. because of reduced population growth	
	Total for part (B)	**2 points**

(C) A table for the population size in the country is shown below.

(i) Based on the table, **calculate** the percent change of the population size in this country between 2009 and 2017. **Show** your work. **2 points** 6.B 6.C EIN-1.C

1 point for correct setup to calculate the percent change of the population size

$$\frac{(4.6 - 2.7)}{2.7} \times 100$$

1 point for the correct calculation of the percent change of the population size

$$\begin{aligned} &= 70.37\% \\ \text{percent change} &= 70.4\% \\ &= 70\% \end{aligned}$$

Total for part (C) **2 points**

(D) An average person in the country needs 2,450 kilocalories (kcal)/day of food to meet their full nutritional needs. The average number of kcal per hectare (ha) produced from available food in the country is 15,737,000 kcal/ha.

(i) **Calculate** the amount of land that would be needed to produce enough kilocalories to feed a person for one year in this developing country. **Show** your work. **2 points** 6.B 6.C EIN-1.C

1 point for the correct setup to calculate the amount of land

$$\frac{2.45 \times 10^3 \text{ kcal/person}}{\text{day}} \times \frac{3.65 \times 10^2 \text{ days}}{1 \text{ year}} \times \frac{1 \text{ ha}}{1.5737 \times 10^7 \text{ kcal}}$$

1 point for the correct calculation of the amount of land

$$\begin{aligned} \text{amount of land} &= \frac{0.0568 \text{ ha/person}}{\text{year}} \\ &= \frac{5.68 \times 10^{-2} \text{ ha/person}}{\text{year}} \end{aligned}$$

(ii) **Calculate** how much land would have been needed to feed the population of this country in 2017. **Show** your work. **2 points** 6.B 6.C EIN-1.C

1 point for the correct setup to calculate the amount of land needed in 2017

$$4.6 \times 10^6 \text{ people} \times \frac{5.68 \times 10^{-2} \text{ ha/person}}{\text{year}}$$

1 point for the correct calculation of the amount of land needed in 2017

$$\begin{aligned} \text{amount of land} &= 2.614 \times 10^5 \text{ ha} \\ &= 261{,}400 \text{ ha} \end{aligned}$$

NOTE: If the student did not correctly calculate part (d)(i), the response for part (d)(ii) can earn points if the incorrect values were used correctly in the equations in part (d)(ii).

Total for part (D) **4 points**

Total for question 3 **10 points**