# HS-ESS3-1

Students who demonstrate understanding can:

**HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.** [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

## Science and Engineering Practices

**Constructing Explanations and Designing Solutions**

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

## Disciplinary Core Ideas

**ESS3.A: Natural Resources**

- Resource availability has guided the development of human society.

**ESS3.B: Natural Hazards**

- Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations.

## Crosscutting Concepts

**Cause and Effect**

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

- - - - - - - - - - - - - - - - - - - - - - - -

***Connections to Engineering, Technology, and Applications of Science***

**Influence of Science, Engineering, and Technology on Society and the Natural World**

- Modern civilization depends on major technological systems.

## Observable features of the student performance by the end of the course:

| | | | |
|---|---|---|---|
| 1 | Articulating the explanation of phenomena | | |
| | a | Students construct an explanation that includes: | |
| | | i. | Specific cause and effect relationships between environmental factors (natural hazards, changes in climate, and the availability of natural resources) and features of human societies including population size and migration patterns; and |
| | | ii. | That technology in modern civilization has mitigated some of the effects of natural hazards, climate, and the availability of natural resources on human activity. |
| 2 | Evidence | | |
| | a | Students identify and describe* the evidence to construct their explanation, including: | |
| | | i. | Natural hazard occurrences that can affect human activity and have significantly altered the sizes and distributions of human populations in particular regions; |
| | | ii. | Changes in climate that affect human activity (e.g., agriculture) and human populations, and that can drive mass migrations; |
| | | iii. | Features of human societies that have been affected by the availability of natural resources; and |
| | | iv. | Evidence of the dependence of human populations on technological systems to acquire natural resources and to modify physical settings. |

| | | |
|---|---|---|
| | b | Students use a variety of valid and reliable sources for the evidence, potentially including theories, simulations, peer review, or students' own investigations. |
| 3 | Reasoning | |
| | a | Students use reasoning that connects the evidence, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to describe*: |
| | | i. The effect of natural hazards, changes in climate, and the availability of natural resources on features of human societies, including population size and migration patterns; and |
| | | ii. How technology has changed the cause and effect relationship between the development of human society and natural hazards, climate, and natural resources. |
| | b | Students describe* reasoning for how the evidence allows for the distinction between causal and correlational relationships between environmental factors and human activity. |

## HS-ESS3-2

Students who demonstrate understanding can:

**HS-ESS3-2.** **Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*** [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

### Science and Engineering Practices

**Engaging in Argument from Evidence**
Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).

### Disciplinary Core Ideas

**ESS3.A: Natural Resources**

- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

**ETS1.B: Developing Possible Solutions**

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary)*

### Crosscutting Concepts

- - - - - - - - - - - - - - - - - - - - - - -

***Connections to Engineering, Technology, and Applications of Science***

**Influence of Science, Engineering, and Technology on Society and the Natural World**

- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.
- Analysis of costs and benefits is a critical aspect of decisions about technology.

- - - - - - - - - - - - - - - - - - - - - - -

***Connections to Nature of Science***

**Science Addresses Questions About the Natural and Material World**

- Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Science knowledge indicates what can happen in natural systems — not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

| Observable features of the student performance by the end of the course: | | |
|---|---|---|
| 1 | Supported claims | |
| | a | Students describe* the nature of the problem each design solution addresses. |
| | b | Students identify the solution that has the most preferred cost-benefit ratios. |
| 2 | Identifying scientific evidence | |
| | a | Students identify evidence for the design solutions, including: |
| | | i. Societal needs for that energy or mineral resource; |
| | | ii. The cost of extracting or developing the energy reserve or mineral resource; |
| | | iii. The costs and benefits of the given design solutions; and |
| | | iv. The feasibility, costs, and benefits of recycling or reusing the mineral resource, if applicable. |
| 3 | Evaluation and critique | |
| | a | Students evaluate the given design solutions, including: |
| | | i. The relative strengths of the given design solutions, based on associated economic, environmental, and geopolitical costs, risks, and benefits; |
| | | ii. The reliability and validity of the evidence used to evaluate the design solutions; and |
| | | iii. Constraints, including cost, safety, reliability, aesthetics, cultural effects environmental effects. |
| 4 | Reasoning/synthesis | |
| | a | Students use logical arguments based on their evaluation of the design solutions, costs and benefits, empirical evidence, and scientific ideas to support one design over the other(s) in their evaluation. |
| | b | Students describe* that a decision on the “best” solution may change over time as engineers and scientists work to increase the benefits of design solutions while decreasing costs and risks. |

## HS-ESS3-3

Students who demonstrate understanding can:

**HS-ESS3-3.** **Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.** [Clarification Statement: Examples of factors that affect the management of natural resources include costs of resource extraction and waste management, per-capita consumption, and the development of new technologies. Examples of factors that affect human sustainability include agricultural efficiency, levels of conservation, and urban planning.] [*Assessment Boundary: Assessment for computational simulations is limited to using provided multi-parameter programs or constructing simplified spreadsheet calculations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

### Science and Engineering Practices

**Using Mathematics and Computational Thinking**
Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system.

### Disciplinary Core Ideas

**ESS3.C: Human Impacts on Earth Systems**

- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.

### Crosscutting Concepts

**Stability and Change**

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

- - - - - - - - - - - - - - - - - - - - - - -

***Connections to Engineering, Technology, and Applications of Science***

**Influence of Science, Engineering, and Technology on Society and the Natural World**

- Modern civilization depends on major technological systems.
- New technologies can have deep impacts on society and the environment, including some that were not anticipated.

- - - - - - - - - - - - - - - - - - - - - - -

***Connections to Nature of Science***

**Science is a Human Endeavor**

- Science is a result of human endeavors, imagination, and creativity.

| Observable features of the student performance by the end of the course: | | | |
|---|---|---|---|
| 1 | Representation | | |
| | a | Students create a computational simulation (using a spreadsheet or a provided multi-parameter program) that contains representations of the relevant components, including: | |
| | | i. | A natural resource in a given ecosystem; |
| | | ii. | The sustainability of human populations in a given ecosystem; |
| | | iii. | Biodiversity in a given ecosystem; and |

| | | |
|---|---|---|
| | | iv. The effect of a technology on a given ecosystem. |
| 2 | Computational modeling | |
| | a | Students describe* simplified realistic (corresponding to real-world data) relationships between simulation variables to indicate an understanding of the factors (e.g., costs, availability of technologies) that affect the management of natural resources, human sustainability, and biodiversity. *(For example, a relationship could be described that the amount of a natural resource does not affect the sustainability of human populations in a given ecosystem without appropriate technology that makes use of the resource; or a relationship could be described that if a given ecosystem is not able to sustain biodiversity, its ability to sustain a human population is also small.)* |
| | b | Students create a simulation using a spreadsheet or provided multi-parameter program that models each component and its simplified mathematical relationship to other components. Examples could include: |
| | | i. S=C*B*R*T, where S is sustainability of human populations, C is a constant, B is biodiversity, R is the natural resource, and T is a technology used to extract the resource so that if there is zero natural resource, zero technology to extract the resource, or zero biodiversity, the sustainability of human populations is also zero; and |
| | | ii. B=B1+C*T, where B is biodiversity, B1 is a constant baseline biodiversity, C is a constant that expresses the effect of technology, and T is a given technology, so that a given technology could either increase or decrease biodiversity depending on the value chosen for C. |
| | c | The simulation contains user-controlled variables that can illustrate relationships among the components (e.g., technology having either a positive or negative effect on biodiversity). |
| 3 | Analysis | |
| | a | Students use the results of the simulation to: |
| | | i. Illustrate the effect on one component by altering other components in the system or the relationships between components; |
| | | ii. Identify the effects of technology on the interactions between human populations, natural resources, and biodiversity; and |
| | | iii. Identify feedbacks between the components and whether or not the feedback stabilizes or destabilizes the system. |
| | b | Students compare the simulation results to a real world example(s) and determine if the simulation can be viewed as realistic. |
| | c | Students identify the simulation's limitations relative to the phenomenon at hand. |

## HS-ESS3-4

Students who demonstrate understanding can:

**HS-ESS3-4.** **Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*** [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

### Science and Engineering Practices

**Constructing Explanations and Designing Solutions**

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles and theories.

- Design or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

### Disciplinary Core Ideas

**ESS3.C: Human Impacts on Earth Systems**

- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

**ETS1.B: Developing Possible Solutions**

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary)*

### Crosscutting Concepts

**Stability and Change**

- Feedback (negative or positive) can stabilize or destabilize a system.

- - - - - - - - - - - - - - - - - - - - - - - -

***Connections to Engineering, Technology, and Applications of Science***

**Influence of Science, Engineering, and Technology on Society and the Natural World**

- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

| **Observable features of the student performance by the end of the course:** | | | |
|---|---|---|---|
| 1 | Using scientific knowledge to generate the design solution | | |
| | a | Students use scientific information to generate a number of possible refinements to a given technological solution. Students: | |
| | | i. | Describe* the system being impacted and how the human activity is affecting that system; |
| | | ii. | Identify the scientific knowledge and reasoning on which the solution is based; |
| | | iii. | Describe* how the technological solution functions and may be stabilizing or destabilizing the natural system; |
| | | iv. | Refine a given technological solution that reduces human impacts on natural systems; and |
| | | v. | Describe* that the solution being refined comes from scientists and engineers in the real world who develop technologies to solve problems of environmental degradation. |
| 2 | Describing criteria and constraints, including quantification when appropriate | | |
| | a | Students describe* and quantify (when appropriate): | |
| | | i. | Criteria and constraints for the solution to the problem; and |
| | | ii. | The tradeoffs in the solution, considering priorities and other kinds of research-driven tradeoffs in explaining why this particular solution is or is not needed. |
| 3 | Evaluating potential refinements | | |

| | | |
|---|---|---|
| | a | In their evaluation, students describe* how the refinement will improve the solution to increase benefits and/or decrease costs or risks to people and the environment. |
| | b | Students evaluate the proposed refinements for: |
| | | i. Their effects on the overall stability of and changes in natural systems; and |
| | | ii. Cost, safety, aesthetics, and reliability, as well as cultural and environmental impacts. |

## HS-ESS3-5

Students who demonstrate understanding can:

**HS-ESS3-5.** **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.** [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [*Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

### Science and Engineering Practices

**Analyzing and Interpreting Data**
Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using computational models in order to make valid and reliable scientific claims.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

***Connections to Nature of Science***

**Scientific Investigations Use a Variety of Methods**

- Science investigations use diverse methods and do not always use the same set of procedures to obtain data.
- New technologies advance scientific knowledge.

**Scientific Knowledge is Based on Empirical Evidence**

- Science knowledge is based on empirical evidence.
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

### Disciplinary Core Ideas

**ESS3.D: Global Climate Change**

- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.

### Crosscutting Concepts

**Stability and Change**

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

| Observable features of the student performance by the end of the course: | | | |
|---|---|---|---|
| 1 | Organizing data | | |
| | a | Students organize data (e.g., with graphs) from global climate models (e.g., computational simulations) and climate observations over time that relate to the effect of climate change on the physical parameters or chemical composition of the atmosphere, geosphere, hydrosphere, or cryosphere. | |
| | b | Students describe* what each data set represents. | |
| 2 | Identifying relationships | | |
| | a | Students analyze the data and identify and describe* relationships within the datasets, including: | |
| | | i. | Changes over time on multiple scales; and |
| | | ii. | Relationships between quantities in the given data. |
| 3 | Interpreting data | | |

| | | |
|---|---|---|
| | a | Students use their analysis of the data to describe* a selected aspect of present or past climate and the associated physical parameters (e.g., temperature, precipitation, sea level) or chemical composition (e.g., ocean pH) of the atmosphere, geosphere, hydrosphere or cryosphere. |
| | b | Students use their analysis of the data to predict the future effect of a selected aspect of climate change on the physical parameters (e.g., temperature, precipitation, sea level) or chemical composition (e.g., ocean pH) of the atmosphere, geosphere, hydrosphere or cryosphere. |
| | c | Students describe* whether the predicted effect on the system is reversible or irreversible. |
| | d | Students identify one source of uncertainty in the prediction of the effect in the future of a selected aspect of climate change. |
| | e | In their interpretation of the data, students: |
| | | i. Make a statement regarding how variation or uncertainty in the data (e.g., limitations, accuracy, any bias in the data resulting from choice of sample, scale, instrumentation, etc.) may affect the interpretation of the data; and |
| | | ii. Identify the limitations of the models that provided the simulation data and ranges for their predictions. |

## HS-ESS3-6

Students who demonstrate understanding can:

**HS-ESS3-6.** **Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.** [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [*Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

### Science and Engineering Practices

**Using Mathematics and Computational Thinking**
Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations.

### Disciplinary Core Ideas

**ESS2.D: Weather and Climate**

- Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. *(secondary)*

**ESS3.D: Global Climate Change**

- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

### Crosscutting Concepts

**Systems and System Models**

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

| Observable features of the student performance by the end of the course: | | |
|---|---|---|
| 1 | Representation | |
| | a | Students identify and describe* the relevant components of each of the Earth systems modeled in the given computational representation, including system boundaries, initial conditions, inputs and outputs, and relationships that determine the interaction (e.g., the relationship between atmospheric $CO_2$ and production of photosynthetic biomass and ocean acidification). |
| 2 | Computational modeling | |
| | a | Students use the given computational representation of Earth systems to illustrate and describe* relationships among at least two of Earth's systems, including how the relevant components in each individual Earth system can drive changes in another, interacting Earth system. |
| 3 | Analysis | |
| | b | Students use evidence from the computational representation to describe* how human activity could affect the relationships between the Earth's systems under consideration. |