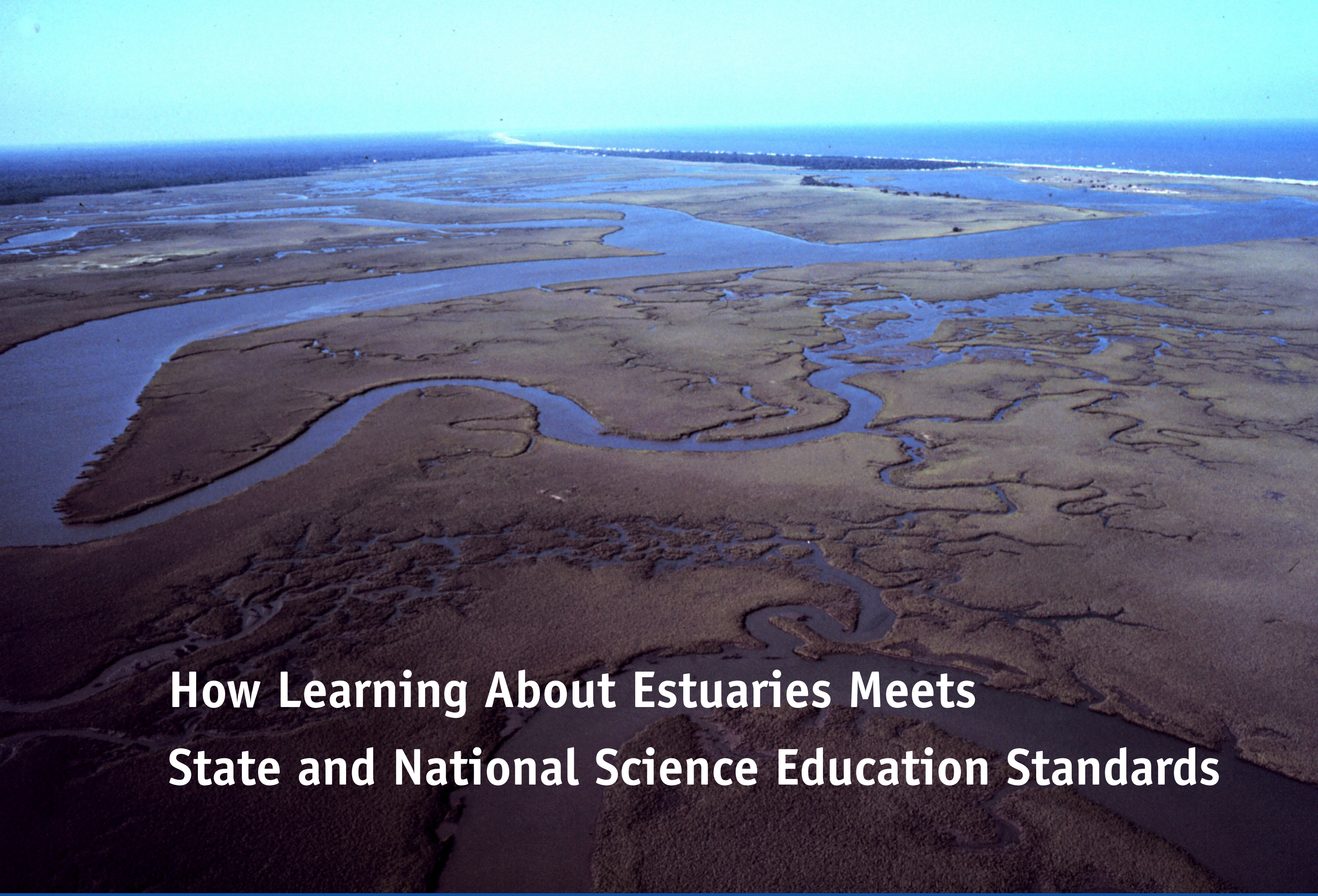

How Learning About Estuaries Meets State and National Science Education Standards

TERC Center for Earth and Space Science Education

NOAA National Estuarine Research Reserve System

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Daniel Barstow
TERC

James K. L. Hammerman
TERC

Atziri Ibañez
NOAA National Estuarine
Research Reserve System

Center for Earth and Space Science Education
TERC, Inc.
2067 Massachusetts Ave.
Cambridge, MA 02140

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Executive Summary

When NOAA's National Estuarine Research Reserve System (NERRS) launched the *K-12 Estuarine Education Program* (KEEP), a major educational outreach program relating to the science of estuaries, it also decided to conduct a national study to see how education about estuaries can address state and national standards. TERC, an educational non-profit, was contracted to conduct this study, the results of which are published here. This study examines broadly the concepts and skills that can be embedded in estuaries learning activities, and specifically *Estuaries 101*, NOAA's newly released high school curriculum materials. This study and the curriculum were developed in collaboration with NERRS.

Estuaries offer a wonderfully rich context for science education. Estuaries are dynamic environments with a daily flux of water and a remarkably diverse range of life and ecosystems. As a result, they offer learners a convergence of such fields as Earth systems science, biology, chemistry, geography, geology, and marine science. Students can explore estuaries through field trips, web-based "virtual tours," physical models, and classroom experiments. They can develop skills of inquiry, collect and analyze data, observe scientists in the field, exploore complex issues, and conceive of creative solutions to real-world problems. With a wealth of archived and real-time data from *in situ* sensors, students have access to the same data used by scientists, helping them understand the tidal, diurnal, and seasonal dynamics of these marvelous ecosystems.

For this study, we compared the learning goals for *Estuaries 101* with the *National Science Education Standards* (NRC, 1996) as a common framework. Because individual states define and vet their own standards based on this framework, we also examined a sample of state standards to illustrate the diversity among states. In some cases, differences among states reflect issues of local relevance (e.g. coastal states might have a greater emphasis on oceans and coastal processes), or policy priorities (e.g. the balance between content and process standards). Throughout this study, we looked at high school level standards. While *KEEP* ultimately will become a full K-12 program, the first released *Estuaries 101* modules are for high school. They are designed as supplemental modules, for inclusion in Earth science, biology and physical science courses, although they may also be used by other educators.

This study focused on four levels of concepts and skills:

1. **estuaries** – We began with a narrow focus, searching for the term "estuaries" and directly related terms in national and state standards. This is often the first level that people consider when deciding to use curriculum materials—if their state standards include "estuaries" per se.
2. **big ideas in science** – We next broadened the scope, to explore how activities about estuaries could support the learning goals of the three major subject domains of the modules—Earth science, biology and physical science—looking especially at the "big ideas" in each field.
3. **developing science thinking skills** – Next we focused on how estuaries modules could meet standards for science thinking skills, such as inquiry, experimental design, and data analysis. These fundamental skills permeate science, and are well supported by *Estuaries 101* activities.
4. **ocean and climate essential principles** – In an effort to create a common framework for ocean and climate literacy, NOAA and other agencies have developed a set of essential principles for each of these fields. We cross-referenced the *Estuaries 101* modules with these important documents.

We found that many concepts and skills related to learning about estuaries are part of the national and state science standards. Although "estuaries" per se only appears prominently in a few state standards, the underlying science concepts embodied in estuaries have broad connections throughout the standards. For example, most state science education standards refer to understanding "Earth as a system," with interwoven cycles and processes relating to land, air, and water. Estuaries provide engaging and accessible examples of these processes at work. Estuaries also integrate key concepts in biology (e.g. habitat adaptations), chemistry (e.g. salinity analysis), and physics (e.g. wave motions). Furthermore, most state standards call for inquiry-

based learning through hands-on experiments, direct observations and active use of data—all of which occur as students explore estuaries.

Conclusion #1:

The specific word "estuaries" does not have a prominent role in most state standards, but terms related to estuaries do. Related concepts, such as "tidal environments" and "fresh and saltwater habitats" are included in the standards of nearly a quarter of the states. Hence, we can increase the relevance of *Estuaries 101* by pointing to such terms in describing the learning goals and activities.

Conclusion #2:

Most of the topics in the *Estuaries 101* modules align well with the big ideas in life, physical and Earth science, as well as the over-arching "unifying concepts and processes". This is true at both the national level and in the individual state standards and can serve as a compelling argument for teachers to use the *Estuaries 101* activities.

Conclusion #3:

The *Estuaries 101* modules align well with standards for science process and thinking skills. This is true in the national standards, and in the several state standards that we surveyed. Estuaries are an especially good domain for developing and applying these skills; a point which we can emphasize in establishing the value of the estuaries modules.

Conclusion #4:

The *Estuaries 101* modules strongly support ocean and climate literacy. The appeal and value of the estuaries modules to help students learn about and apply these principles will increase as the *Ocean Literacy* and *Climate Literacy* documents become more visible and increase their influence on state and national standards.

Introduction

We live in an educational environment dominated by standards and high stakes testing. Driven especially by the mandates of the No Child Left Behind Act, states have defined education standards in science (and other domains), with explicit learning goals for elementary, middle and high school students. Most states have also developed tests that students must pass at selected grade levels and, in some states, to graduate from high school. While experts differ on the merits and problems associated with this heavy emphasis on standards-based education, it is the dominant reality in which educational innovations must operate.

Hence, when NOAA's National Estuarine Research Reserve System (NERRS) launched the *K-12 Estuarine Education Program* (KEEP), a major educational outreach program relating to the science of estuaries, it also decided to conduct a national study to see how learning about estuaries can meet state and national standards. TERC, an educational non-profit, was contracted to conduct this study, the results of which are published here. This study examines broadly the concepts and skills that can be embedded in estuaries learning activities, and specifically *Estuaries 101*, NOAA's newly released high school curriculum materials. This study and the curriculum were developed in collaboration with NERRS.

Estuaries offer a wonderfully rich context for science education. Estuaries are dynamic environments with a daily flux of water and a remarkably diverse range of life and ecosystems. As a result, they offer learners a convergence of such fields as Earth systems science, biology, chemistry, geography, geology, and marine science. Students can explore estuaries through field trips, web-based "virtual tours," physical models, and classroom experiments. They can develop skills of inquiry, collect and analyze data, observe scientists in the field, exploore complex issues, and conceive of creative solutions to real-world problems. With a wealth of archived and real-time data from *in situ* sensors, students have access to the same data used by scientists, helping them understand the tidal, diurnal, and seasonal dynamics of these marvelous ecosystems.

While curriculum materials about estuaries have inherent value, in this educational climate we also need to understand how the curriculum addresses state and national science education standards. While *Estuaries 101* addresses topics in math, technology and the social sciences, we focus here on its primary domain of science. In this analysis, we start with a narrow view focusing on estuaries-specific standards, then expand to a broader view, illustrating how estuaries activities can help students learn some of the "big ideas" in science and develop essential science research and thinking skills.

Standards differ considerably from state to state. While the *National Science Education Standards* (NRC, 1996) provide a common framework, each state defines and vets its own standards. In some cases, differences among states reflect issues of local relevance (e.g. coastal states might have a greater emphasis on oceans and coastal processes), or policy priorities (e.g. the balance between content and process standards). Some differences simply reflect the natural differences among people on the Standard-setting committees of each state. Regardless of the cause of these differences, the task of aligning the estuaries-related learning goals with the Standards of all fifty states and Puerto Rico is daunting, and attempts to do so often lead more to massive multi-column checklists than useful insights.

Hence, we use the *National Science Education Standards* as a common framework, and sample from state standards to illustrate the diversity among states. For our sample states, we selected California, Illinois, Massachusetts, Virginia and Washington, as relatively populous representatives of the nation. They include western and eastern coastal states, and an inland state. They cover a range of sizes, have diverse student populations, and all have reasonably well-defined science standards. While not a statistical sample, this represents some of our nation's diversity.

We conducted our analysis at four levels of concepts and skills:

1. **estuaries** – We began with a narrow focus, searching for the term "estuaries" and directly

related terms in these standards. This is often the first level that people consider when deciding to use curriculum materials—if their state standards include "estuaries" per se.

2. **big ideas in science** – We next broadened the scope, to explore how activities about estuaries could support the learning goals of the three major subject domains of the modules—Earth science, biology and physical science—looking especially at the "big ideas" in each field.

3. **developing science thinking skills** – Next we focused on how estuaries modules could meet standards for science thinking skills, such as inquiry, experimental design, and data analysis. These fundamental skills permeate science, and are well supported by *Estuaries 101* activities.

4. **ocean and climate essential principles** – In an effort to create a common framework for ocean and climate literacy, NOAA and other agencies have developed a set of essential principles for each of these fields. We cross-referenced the *Estuaries 101* modules with these important documents.

Throughout, we looked at high school level standards. While *KEEP* will ultimately become a full K-12 program, the first released *Estuaries 101* modules are for high school. They are designed as supplemental modules, for inclusion in Earth science, biology and physical science courses, although they may also be used by other educators.

1. Estuaries Per Se and Related Terms

1a. Estuaries per se

If you ask someone from a state department of education, school district or a teacher about including a module on estuaries in their high school science curriculum, they will likely first check to see if the term "estuaries" appears in their state standards. Hence, we searched for the specific topic of "estuaries" in National and state standards.

Remarkably, the word "estuary" does not appear at all in the *National Science Education Standards* (NRC, 1996). As detailed below, other related concepts do, but not the word "estuary."

For the state-by-state analysis, we used a comprehensive database of Earth and environmental science education standards recently completed by TERC as part of a NOAA-funded study of ocean and atmosphere concepts in science education standards (Hoffman, 2007).

Only four state standards (Alabama, Mississippi, Virginia & West Virginia) specifically cite "estuaries" at the high school level, most typically in Earth science and biology. For example:

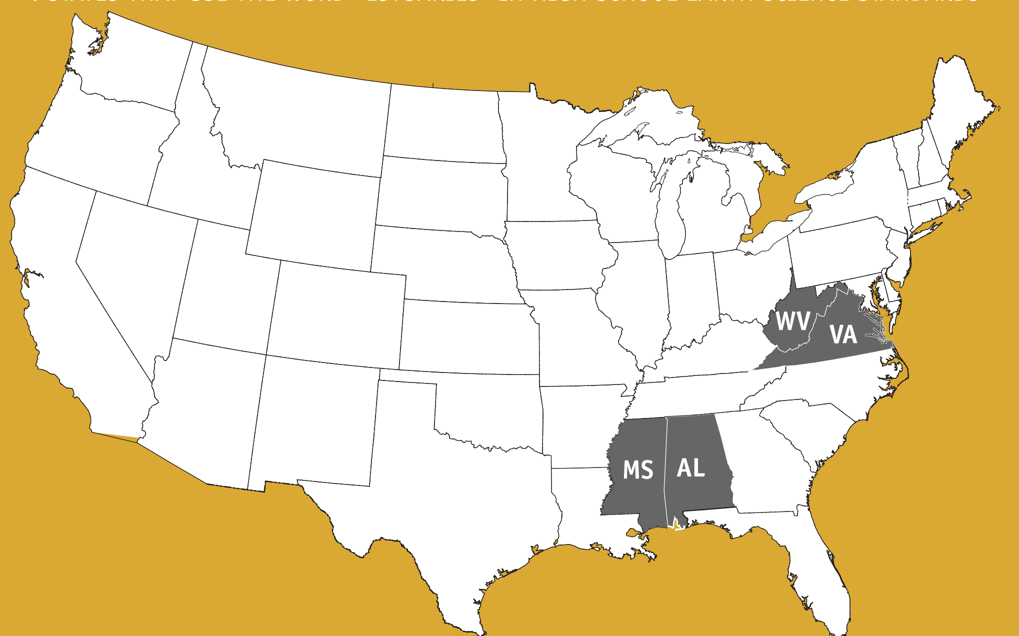
- Describe components of major marine ecosystems, including estuaries, coral reefs, benthic communities, and open-ocean communities. *(Alabama)*
- Describe the abiotic and biotic characteristics of a bay, sound, estuary, and marsh. *(Mississippi)*
- Estuaries, like the Chesapeake Bay, are areas where fresh and salt water mix, producing variations in salinity and high biological activity. *(Virginia)*
- Investigate and discuss the impact that humans may have on the quality of the biosphere such as depletion of the rainforest, pollution of estuaries, strip mining, depletion of fossil fuels and deterioration of ozone layer. *(West Virginia)*

1b. Estuary-Related Terms

We next broadened our search to include estuary-related terms, such as marine and salt water environments, freshwater habitats, tidal environments, wetlands, brackish, bay, salt marsh, coastal swamp.

In the *National Science Education Standards*, we still find little reference to these terms. We find statements about oceans, land, life and their interactions, but these are described in broad general-

4 STATES THAT USE THE WORD "ESTUARIES" IN HIGH SCHOOL EARTH SCIENCE STANDARDS



izations (e.g. *Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the Earth system*), rather than specific details related to estuaries. This reflects the philosophical approach taken by the developers of the National standards, who focus on big ideas, expecting states, districts and teachers to embody these in specific topics.

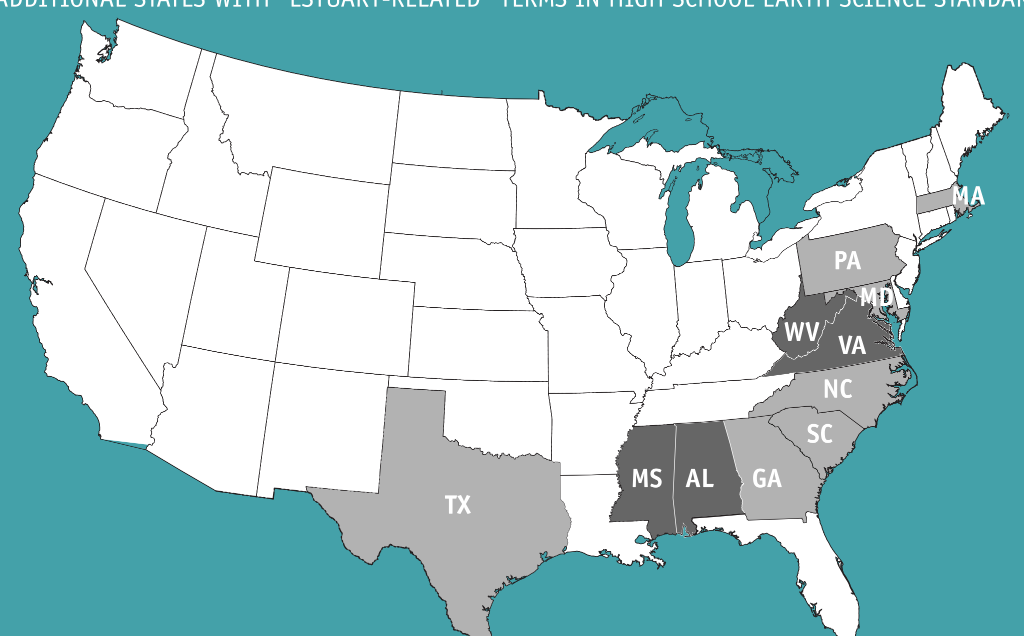
In a detailed review of the Earth science standards for all fifty states, we found seven states (Georgia, Massachusetts, Maryland, North Carolina, Pennsylvania, South Carolina & Texas) that include estuary-related terms in their high school Earth and space science standards in addition to the four cited above that include estuaries per se. For example:

- Investigate and analyze environmental issues and solutions for North Carolina's river basins, wetlands, and tidal environments, including water quality, shoreline changes and habitat preservation. *(North Carolina)*
- Explain the behavior and impact of the earth's water systems, including distinguishing salt from fresh water and the life contained in them. Identify ocean and shoreline features, such as bays, inlets, spits, tidal marshes. *(Pennsylvania)*
- Demonstrate an understanding of Earth's freshwater and ocean systems. *(South Carolina)*
- Examine the dependence of organisms on one another and their environments, including Earth's major terrestrial biomes and aquatic communities. *(Georgia)*
- Identify and compare the physical properties of fresh water and salt water. *(Maryland)*
- Explain what causes tides and describe how they affect the coastal environment. *(Massachusetts)*
- Differentiate among freshwater, brackish, and saltwater ecosystems. *(Texas)*

Conclusion #1:

The specific word "estuaries" does not have a prominent role in most state standards, but terms related to estuaries do. Related concepts, such as "tidal environments" and "fresh and saltwater habitats" are included in the standards of nearly a quarter of the states. Hence, we can increase the relevance of *Estuaries 101* by pointing to such terms in describing the learning goals and activities.

7 ADDITIONAL STATES WITH "ESTUARY-RELATED" TERMS IN HIGH SCHOOL EARTH SCIENCE STANDARDS



2. Estuaries as a Vehicle for Studying Big Ideas in Earth, Life and Physical Science

Looking more broadly, estuaries-related education can help students understand and apply "big ideas" in science. For example, students learn about diverse habitats and how life adapts to them, daily and annual cycles of change, the physical properties of water, and so on. Estuaries can provide a powerful context for learning these big ideas. While estuaries are hardly the only context for learning such big ideas, they are a rich and fertile one, supporting a study of many key ideas in Earth, life and physical science. Here we find strong connections between the *Estuaries 101* curriculum and the National and state standards.

2a National Standards for "Big Ideas"

Earth Science

The Earth science module of *Estuaries 101* focuses on the physical forms and features of estuaries; estuaries as transition zones; salinity; water circulation; tides; watersheds; and the effects of weather and seasonal changes on estuaries. All of these concepts relate to big ideas in the Earth science section of the *National Science Education Standards*. Most notably:

Energy in the Earth System

- The sun is the major external source of energy.
- Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents.
- Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans.

Geochemical Cycles

- Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.
- Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter.

Origin and evolution of the Earth System

- Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the earth system.

While this report focuses on high school standards, the middle school section of the *National Standards* include other key ideas related to estuaries, such as:

- A variety of cycles connect and continually circulate energy and material through the components of the Earth system.
- Water circulates through the crust, oceans and atmosphere.
- Gravitational interaction of the sun, moon and Earth explains tides.
- Water is a solvent. As it passes through the water cycle, it dissolves minerals and gases and carries them to the ocean.

Biology

The biology module of *Estuaries 101* focuses on estuaries as diverse habitats for life, with marine, freshwater and terrestrial environments in close proximity; life cycles; food webs; effects of the tidal dynamics on life; restoring estuarine communities; and nutrients in the estuary. These relate well to the life science section of the *National Science Education Standards*. For example:

Cell

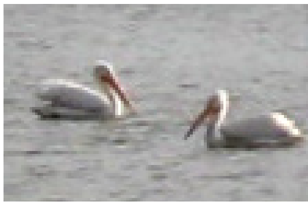
- Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules.
- The process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.

Biological Evolution

- Organisms are classified into a hierarchy of groups and subgroups based on similarities which reflect their evolutionary relationships. Species is the most fundamental unit of classification.

Interdependence of Organisms

- Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers.



- Organisms both cooperate and compete in ecosystems. The interrelationships and interdependencies of these organisms generate ecosystems.
- Human beings live within the world's ecosystems. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption.

Matter, Energy and Organization in Living Systems

- Living systems require a continuous input of energy to maintain their chemical and physical organizations.
- The distribution and abundance of organisms and populations in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials.

Behavior of Organisms

- Organisms have behavioral responses to internal changes and to external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes.

Physical Science

The physical science module of *Estuaries 101* deals mostly with estuarine chemistry and physics, especially through water quality profiles; patterns of mixing salinity, temperature and density; dissolved oxygen and life; and the effects of a chemical spill such as phosphate. These relate to several physical science concepts in the *National Science Education Standards*:

Structure and Properties of Matter

- The physical properties of compounds reflect the nature of the interactions among its molecules.

Chemical Reactions

- Chemical reactions occur all around us. Complex chemical reactions involving carbon-based molecules take place constantly in every cell.
- Chemical reactions may release or consume energy.

Motions and Forces

- Gravitation is a universal force that each mass exerts on any other mass.

Conservation of Energy

- All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.

Interactions of Energy and Matter

- Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.

Unifying Concepts and Processes

The *National Science Education Standards* also describe some of the big ideas in science that underlie and transcend the specific subject domains. These "unifying concepts and processes" are fundamental ideas in science. The *Estuaries 101* curriculum provides powerful cases that illustrate several of these concepts. For example:

Systems, order and organization

- A system is an organized group of related groups or objects that form a whole.
- Systems have boundaries, components, resources, flow and feedback.

Evidence, models and explanation

- Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.
- Models are tentative schemes or structures that correspond to real objects, events or classes of events, and that have explanatory power.

Change, constancy and measurement

- Evidence for interactions and subsequent change and the formulation of scientific explanations are often clarified through measurement and quantitative distinctions.

Evolution and equilibrium

- Evolution is a series of changes, some gradual and some sporadic, that accounts for the present form and function of objects.

Form and function

- Form and function are complementary aspects of objects, organisms and systems in the natural and designed world.

2b. Sample State Standards for "Big Ideas"

We reviewed standards from five sample states (California, Illinois, Massachusetts, Virginia and Washington) to see how they represent the big ideas in life, physical and Earth science at the high school level, and how well these big ideas align with the *Estuaries 101* modules. As these examples show, the *Estuaries 101* modules provide powerful and compelling contexts for students to learn these big ideas.

California

A close look at just one example illustrates how well the *Estuaries 101* modules support and align with big ideas in science. The high school biology standards for California include the core concept of ecosystems:

- Stability in an ecosystem is a balance between competing effects. *(Biology)*

  The California standards then elaborate on the concepts embedded in this big idea:

  1. Students know that biodiversity is the sum total of different kinds of organisms and is affected by alterations of habitats.

  2. Students know how to analyze changes in an ecosystem resulting from changes in climate, human activity, introduction of nonnative species, or changes in population size.

  3. Students know how fluctuations in population size in an ecosystem are determined by the relative rates of birth, immigration, emigration, and death.

  4. Students know how water, carbon, and nitrogen cycle between abiotic resources and organic matter in the ecosystem and how oxygen cycles through photosynthesis and respiration.

  5. Students know a vital part of an ecosystem is the stability of its producers and decomposers.

  6. Students know at each link in a food web some energy is stored in newly made structures but much energy is dissipated into the environment as heat. This dissipation may be represented in an energy pyramid.

7. Students know how to distinguish between the accommodation of an individual organism to its environment and the gradual adaptation of a lineage of organisms through genetic change.

The *Estuaries 101* modules include virtually all of these concepts. In other words, the modules serve as a vehicle for students to learn and apply these big ideas in a real world context.

Other examples from California of big ideas covered in the *Estuaries 101* modules include:

- Variation within a species increases the likelihood that at least some members of a species will survive under changed environmental conditions. *(Biology)*
- Solutions are homogeneous mixtures of two or more substances. *(Chemistry)*
- Temperature, pressure, and surface area affect the dissolving process. *(Chemistry)*
- Acids, bases, and salts are three classes of compounds that form ions in water solutions. *(Chemistry)*
- Heating of Earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents. *(Earth Science)*
- Each element on Earth moves among reservoirs, which exist in the solid earth, in oceans, in the atmosphere, and within and among organisms as part of biogeochemical cycles. *(Earth Science)*
- Students know properties of ocean water, such as temperature and salinity, can be used to explain the layered structure of the oceans, the generation of horizontal and vertical ocean currents, and the geographic distribution of marine organisms. *(Earth Science)*

We can find such big ideas in all state science standards. Here we present some illustrative examples from the other states in our sample study:

Illinois

- Living things interact with each other and with their environment. *(Biology)*
- Physical, ecological and behavioral factors that influence interactions and interdependence of organisms. *(Biology)*

- Analyze the processes involved in naturally occurring short-term and long-term Earth events (e.g., floods, ice ages, temperature, sea-level fluctuations). *(Earth Science)*
- Analyze factors that influence the relative motion of an object (e.g., friction, wind shear, cross currents, potential differences). *(Physics)*

Massachusetts

- Earth is a dynamic interconnected system. *(Earth Science)*
- Chemical elements form organic molecules that interact to perform the basic functions of life. *(Chemistry)*
- Ecology is the interaction among organisms and between organisms and their environment. *(Biology)*

Virginia

- Investigate and understand the chemical and biochemical principles essential for life, including water chemistry and its impact on life processes. *(Biology)*
- Pressure, temperature, and volume changes can cause a change in physical state. *(Chemistry)*
- Investigate and understand how to read and interpret maps, globes, models, charts, and imagery, including bathymetric charts, topographic maps, weather maps, aerial photography and satellite images. *(Earth Science)*

Washington

- An organism's ability to survive is influenced by the organism's behavior and the ecosystem in which it lives. *(Biology)*
- Describe the role of an organism in a food chain of an ecosystem (i.e., predator, prey, consumer, producer, decomposer, scavenger). *(Biology)*
- Describe the path of substances (i.e., air, water, mineral nutrients) through a food chain. *(Biology)*
- Analyze sound waves, water waves, and light waves using wave properties, including frequency and energy. *(Physics)*
- Weathering and erosion change the surface of the Earth. *(Earth Science)*

Conclusion #2

Most of the topics in the *Estuaries 101* modules align well with the big ideas in life, physical and Earth science, as well as the over-arching "unifying concepts and processes". This is true at both the National level and in the individual state standards and can serve as a compelling argument for teachers to use the *Estuaries 101* activities.

3. Estuaries as a Context to Develop Scientific Thinking Skills

The *Estuaries 101* modules help students develop science thinking skills, in addition to content knowledge. Students learn to design and conduct experiments, conduct field observations, analyze data, use spreadsheets, visualizations and other technological tools, work effectively in teams, prepare research reports, and communicate findings to others. These skills are an essential element of effective science education, and well represented in the *Estuaries 101* modules.

For example, in the *Estuaries 101* physical science module, students select a reserve, study its physical characteristics, and then create water quality profiles using archived and real-time data from buoys and other sensors. They examine salinity, pH, dissolved oxygen and nutrients, compare the values on graphs, and look for correlations among the data. They develop explanations based on their understanding of the reserve and the underlying chemistry. All of these activities involve scientific thinking skills.

3a. National Standards for Scientific Thinking

The *National Science Education Standards* describe these skills under the rubric of "science as inquiry." The standards present a spiraling development of inquiry skills, with increasing levels of depth and sophistication as students progress from elementary to middle to high school. At the high school level, students should actively design, conduct and draw conclusions from scientific investigations, and these investigations should derive from questions and issues that have meaning for students.

The *Estuaries 101* curriculum provides an engaging and meaningful context for students to develop and apply skills of "science as inquiry," such as the following from the high school inquiry standards:

Identify questions and concepts that guide scientific investigations

- Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment.

Design and conduct scientific investigations

- Designing and conducting a scientific investigation requires students to clarify the question, method, controls, and variables; organize and display data; revise methods and explanations; and publicly present the results.
- Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations.

Use technology and mathematics to improve investigations and communications

- A variety of technologies, such as hand tools, measuring instruments, computers, and calculators, should be an integral component of scientific investigations.
- Students should use measurements for posing questions, formulas for developing explanations, and charts and graphs for communicating results.

Formulate and revise scientific explanations and models using logic and evidence

- Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical.
- Students should engage in discussions and arguments that result in the revision of their explanations, based on scientific knowledge, the use of logic, and evidence from their investigation.

Recognize and analyze alternative explanations and models

- Students analyze an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best.

Communicate and defend a scientific argument

- Students develop abilities associated with accurate and effective communication, including writing and following procedures, expressing concepts, reviewing information, summarizing data, developing diagrams and charts, constructing a reasoned argument, and responding appropriately to critical comments.

3b. Sample State Standards for Scientific Thinking

Most states mirror the National standards, with a strong emphasis on scientific thinking. Most detail these process skills in a special section of their standards, and advocate that students develop and apply these skills while learning content knowledge, interweaving these components through labs, fieldwork, and classroom experiences. For high school, these skills are often delineated as part of the requirements for lab science courses.

We reviewed the five sample states to see how well the *Estuaries 101* modules align with each state's standards for scientific thinking skills. This process involved understanding how each state structured and presented its standards for science process and thinking skills, and then finding examples that match the skills listed above. We found a remarkably strong correlation with all five states.

California

The *Science Content Standards for California Public Schools* includes a section on the nature of "Investigation and Experimentation." In two-pages of detailed descriptions, this section of the California science standards for high school defines the skills students should develop through lab science experiences. Correlating well with the *Estuaries 101* modules, students should use skills such as:

- Ask meaningful questions and conduct careful investigations.
- Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.
- Recognize the usefulness and limitations of models and theories as scientific representations of reality.
- Read and interpret topographic and geologic maps.
- Analyze the locations, sequences, or time intervals that are characteristic of natural phenomena.

Illinois

The *Illinois Learning Standards* emphasize problem solving, communication, and the use of technology as major components of scientific inquiry. At the high school level Illinois students are expected to

have the skills and knowledge to independently design and conduct investigations and to objectively review and report findings of their investigations. Relevant standards include:

- Design a scientific issue investigation which addresses a proposed hypothesis(es), proposing applicable survey instruments, or selecting associated research, analysis, and communication components.
- Conduct an inquiry investigation, using technologies for observing and measuring directly, indirectly, or remotely, completing multiple, statistically-valid trials, or accurately and precisely recording all data.
- Design an issue investigation, proposing applicable survey and interview instruments and methodologies, selecting appropriate simulations, or projecting possible viewpoints, variables, applicable data sets and formats for consideration.
- Report, display and defend the process and findings of an issue investigation, critiquing findings by self and peer review, generating further questions or issues for consideration, evaluating comparable issue resolutions or responses for action, or generalizing public opinion responses.

Massachusetts

In the *Science, Technology and Engineering Standards for High School*, Massachusetts begins with an overarching structure for inquiry-based learning and science process skills, in four broad categories:

- Make observations, raise questions, and formulate hypotheses.
- Design and conduct scientific investigations.
- Analyze and interpret results of scientific investigations.
- Communicate and apply the results of scientific investigations.

The document then makes the point that "scientific skills should be taught and assessed through examples drawn from the Earth and Space Science, Biology, Chemistry, and Introductory Physics standards so students understand that what is known in science does not stand separate from how it is known." Hence, it presents specific skills within the standards for each subject domain. Examples relevant to the *Estuaries 101* modules include:

- Read, interpret, and analyze ground-based observations, satellite data, and computer models to demonstrate Earth systems and their interconnections.
- Properly use instruments, equipment, and materials (such as scales, probeware, meter sticks, microscopes, computers, etc.) including set-up, calibration (if required), technique, maintenance, and storage.
- Use and refine scientific models that simulate physical processes or phenomena.
- Use mathematical operations to analyze and interpret data results.
- State questions raised by an experiment that may require further investigation.

Virginia

Scientific investigative and thinking skills are the foundation principles for each grade level or course in *Virginia's Science Standards of Learning Curriculum Framework*. Inquiry standards for the high school Earth Science course emphasize investigation of Earth as a system through the use of modern technologies. Standards relevant to the *Estuaries 101* modules include:

- Analyze how science explains and predicts the interactions and dynamics of complex Earth systems.
- Compare different scientific explanations for a set of observations about the Earth.
- The student will plan and conduct investigations in which technologies, including computers, probeware, and global positioning systems (GPS), are used to collect, analyze, and report data, and to demonstrate concepts and simulate experimental conditions.
- The student will investigate and understand how to read and interpret maps, globes, models, charts, and imagery (e.g., aerial photography and satellite images).

Washington

One of the three overarching components of Washington's *Science K-12 Grade Level Expectations* focuses on students' knowing and applying the skills, processes, and nature of scientific inquiry. Washington's inquiry standards are particularly applicable to estuaries as they focus on the processes of investigating systems. This systems-based approach to scientific inquiry is exemplified by the following standards:

- Analyze how physical, conceptual, and mathematical models represent and are used to investigate objects, events, systems, and processes.
- Understand how to plan and conduct systematic and complex scientific investigations.
- Generate a logical plan for a simple field investigation with the following attributes:
  - Identify multiple variables
  - Select observable or measurable variables related to the investigative question.
- Explain how to improve the validity of an investigation (e.g., control more variables, better measuring techniques, increase sample size, control for sample bias, include experimental control condition when appropriate, include a placebo group when appropriate).

Conclusion #3:

The *Estuaries 101* modules align well with standards for science process and thinking skills. This is true in the National standards, and in the five state standards that we surveyed. Estuaries are an especially good domain for developing and applying these skills; a point which we can emphasize in establishing the value of the *Estuaries 101* modules.

4. Essential Principles of Ocean and Climate Literacy

Literacy in the essential principles of ocean and climate science are crucially important. Two recent documents, *Ocean Literacy Essential Principles,* and *Climate Literacy Essential Principles*, developed by NOAA, other federal agencies and science and education organizations, provide a common framework of nationally approved, scientifically accurate, and pedagogically appropriate core principles in each of these two fields.

However, National and state standards do not adequately deal with these concepts. A NOAA-funded study of Earth science standards in all fifty states (Hoffman & Barstow, 2007) found a need to strengthen ocean literacy in these standards. Several states are already revising their standards to improve their treatment of ocean concepts. An informal review of climate literacy in state standards shows a similar challenge, and encouraging signs that 15 of the states are already planning on enhancing the role of climate in their standards.

Estuaries can provide a powerful vehicle for presenting some of these essential principles. We provide here examples from the *Estuaries 101* modules that support some of these essential principles.

Essential Principles of Ocean Literacy

1. **The Earth has one big ocean with many features** – Estuaries lie at the interface between land and the ocean. By exploring estuaries, students learn about the ocean as well as about estuaries and related coastal features.

2. **The ocean and life in the ocean shape the features of the Earth** – The dynamic interactions of river flows, ocean currents, tides and waves are constantly changing the land and the life that lives in estuaries.

3. **The ocean is a major influence on weather and climate** – Students explore the effects of weather on estuaries, and learn about the effects of the ocean in moderating temperatures, feeding energy into storm systems, and establishing the region's climate.

4. **The ocean makes Earth habitable** – Students investigate how ocean currents provide an influx of nutrients and support a food chain that reaches throughout the estuary and beyond.

5. **The ocean supports a great diversity of life and ecosystems** – Estuaries are among the most biologically diverse areas in the world, with different

species thriving in ecosystem niches throughout each estuary, with an even greater diversity across a range of estuaries.

6. **The ocean and humans are inextricably interconnected** – Students explore how the human presence affects the estuarine environment and vice versa. They also engage in stewardship activities to help ameliorate human effects on estuaries.

7. **The ocean is largely unexplored** – Like the ocean and its depths, we have much to learn about the dynamics of estuaries, as students learn by asking questions about estuaries, using observational data to pursue answers and realizing how much more lies ahead for further exploration.

Essential Principles of Climate Literacy

1. **Life on Earth has been shaped by, depends on, and affects climate** – Estuaries are exquisitely sensitive to the climate. Students see this by comparing estuaries across different climatic environments.

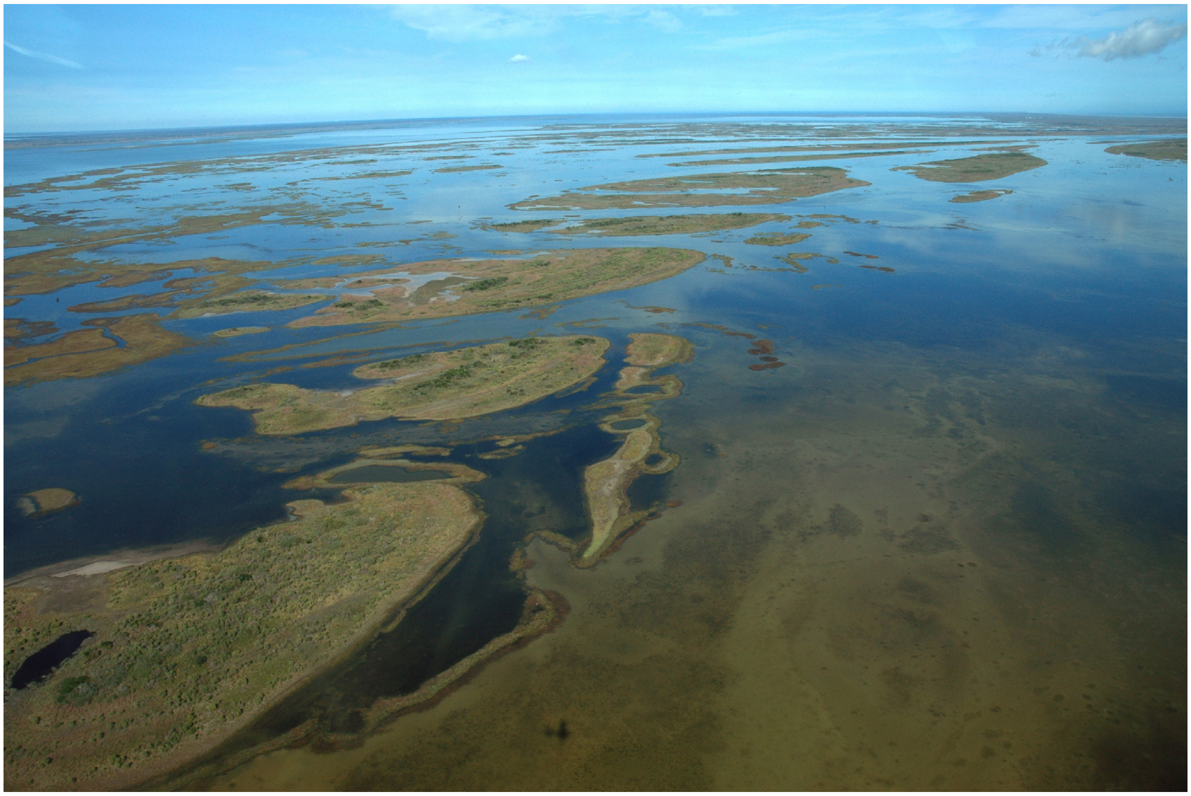
2. **We increase our understanding of the climate system through observation and modeling** – Observation and modeling lie at the heart of the inquiry-based approach used in the *Estuaries 101* modules. Students use data and models to explore featured estuaries, including their climatic conditions.

3. **The sun is the primary source of energy for the climate system** – Students learn about insolation and the central role of the sun in estuarine systems. They track solar energy as it warms the water on daily and annual cycles, and as it is converted to food by algae and other aquatic plants and on through the food chain.

4. **Earth's weather and climate systems are the result of complex interactions** – Students see the complexity in the rich diversity of habitats and life throughout individual estuaries and across a range of estuaries.

5. **Earth's weather and climate vary over time and space** – By comparing estuaries, students learn about the tremendous variety of weather and climate conditions, and how they vary from one location to another and across seasonal cycles.

6. **Evidence indicates human activities are impacting the climate system** – Estuaries are essential harbingers of climatic change. Students learn about experiments scientists are now conducting in estuaries to monitor climatic change, including changes in seasonal variation, possible global warming, and sea level rise.



7. **Earth's climate system is influenced by complex human decisions involving economic costs and social values** – Students learn how their own behavior is part of a larger picture—that it impacts not only nearby estuaries, but also the larger climatic system of which we are all a part. They also learn about the social and economic factors that affect our ability to work constructively to reduce the scope and impact of climate change.

Conclusion #4

The *Estuaries 101* modules strongly support ocean and climate literacy. The appeal and value of the estuaries modules to help students learn about and apply these principles will increase as the *Ocean Literacy* and *Climate Literacy* documents become more visible and increase their influence on state and N ational standards.

General Recommendations

Having completed this study, we wanted to add some more general recommendations regarding standards and *Estuaries 101*.

1. Disseminate information about estuaries and standards to teachers, administrators and others who will decide whether or not to use *Estuaries 101*.

People will most likely make their initial judgment about *Estuaries 101* focusing on whether "estuaries" per se are part of their curriculum. As detailed in this report, the value of *Estuaries 101* goes well beyond estuaries, helping students understand and apply big ideas of science in this rich context, develop scientific thinking and problem solving skills, and integrate biology, chemistry, physics and Earth science. Hence, NOAA should provide supportive information (such as this report, or more usefully a simple summary of its key points) to teachers, administrators and others to help them make decisions with a deeper understanding of the educational values of *Estuaries 101*.

2. Promote *Estuaries 101* as an answer to the curriculum needs identified by the *Ocean* and *Climate Literacy Frameworks*.

The *Ocean* and *Climate Literacy Frameworks* are getting increased attention in science education. Several states are reviewing their standards to strengthen inclusion of key ideas from these frameworks. This is especially true for climate, with its high visibility and sense of transcendent importance and urgency. By presenting *Estuaries 101* as a vehicle to help convey some of these core concepts and ideas, NOAA can expand its base of interested teachers.

3. Correlate *Estuaries 101* with geography, math and technology standards.

Estuaries 101 addresses other learning goals beyond science. We recommend that NOAA also cross-reference *Estuaries 101* with geography, math and technology standards. For example, *Estuaries 101* is exceptionally strong in data analysis, with rich data sets, graphs, spatial analysis, correlation among a range of measurements and use of computers to support this analysis. In geography, *Estuaries 101* helps students understand a wide range of physical environments and the connections between physical and human geography. A more detailed analysis will present a compelling case for *Estuaries 101* supporting learning in diverse subject domains.

4. Conduct research and evaluation on *Estuaries 101*.

Correlation with standards is one thing, demonstrating success is another. We recommend that NOAA fund research and evaluation studies to document the benefits (and challenges) of *Estuaries 101* for meeting standards. This should include use of sample state assessment items, as well as custom-built assessments that directly measure the articulated goals of *Estuaries 101*. Such studies should also look at the context of implementation, assessing for example, the need for teacher professional development and other supports that help assure success in student learning. This research might also include a national study to determine current levels of student (and teacher) understanding of key concepts and skills relating to estuaries, to get baseline information.

5. Correlate with key state standards.

In this document we focused on five illustrative states (California, Illinois, Massachusetts, Virginia, and West Virginia). We recommend that NOAA correlate *Estuaries 101* learning goals with all fifty states' science education standards. This will help educators and decision-makers see the explicit benefits of *Estuaries 101* for meeting state standards. This analysis should go beyond estuaries per se, to also include the big ideas and broader concepts in life, Earth and physical science, as well as scientific thinking, problem solving, data analysis and other skills, as detailed in this report.

6. Keep a rich vision in mind.

It is tempting to reduce a standards analysis to a simple checklist of standards and topics. While such a checklist has some value, it also has a danger of trivializing the power of *Estuaries 101*. The curriculum doesn't gain its power from marching through topics. Rather it provides a rich and challenging set of investigations into the real world of science. It pushes students to think deeply about these wonderful environments, develop and apply big ideas in science, integrate data and field observations, and creatively solve problems to understand and sustain our natural environment. Hence, NOAA should keep this rich vision in mind, as it promotes use of these educational materials.

Appendix

Sample Earth Science Standards Related to *Estuaries 101* Principles and Concepts

Principle 1:

Estuaries are interconnected with the world ocean and with major systems and cycles on Earth.

- The learner will build an understanding of the hydrosphere and its interactions and influences on the lithosphere, the atmosphere, and environmental quality. NC, 9-12
- The student will describe natural forces and apply them to the study of Earth/Space Science. MD, 9-12
- Describe a system, specifying its boundaries and subsystems, its relation to other systems, its input and output and feedback. ME, 9-12
- Earth is a dynamic system, and all atmospheric, geological, and oceanographic processes interrelate and influence one another. VA, 9-12
- Explain how the oceans affect other processes on Earth. MS, 9-12
- Many of the phenomena that we observe on Earth involve interactions among components of air, water, and land. NY, 9-12

CONCEPT: Estuaries are part of important biological, chemical and physical cycles such as food webs, nutrient cycles, and hydrologic cycles. For example, estuarine salt marshes can sequester carbon and filter out toxic substances or nutrients from groundwater.

- Water is continually being recycled by the hydrologic cycle through the watersheds, oceans, and the atmosphere by processes such as evaporation, condensation, precipitation, runoff, and infiltration. MA, 9-10
- Know that Earth's system contains a fixed amount of natural resources that cycle among land, water, the atmosphere, and living things (e.g., carbon and nitrogen cycles, rock cycle, water cycle, ground water, aquifers). NM, 9-12
- Water is continually being recycled by the hydrologic cycle through the watersheds, oceans, and the atmosphere by processes such as evaporation, condensation, precipitation runoff, and infiltration. DC, 9-12
- Evaluate the role of living organisms within the Earth system cycles. TN, 9-12
- Explain the importance of biogeochemical cycles in an aquatic environment. AL, 9-12
- Explain how water flows into and through a watershed. Explain the role of aquifers, wells, porosity, permeability, water table, capillary water, and runoff. MA, 9-12
- Demonstrate how dynamic processes such as weathering, erosion, sedimentation, metamorphism, and orogenesis relate to redistribution of materials within the Earth system. AZ, 9-12
- Students know the global carbon cycle: the different physical and chemical forms of carbon in the atmosphere, oceans, biomass, fossil fuels, and the movement of carbon among these reservoirs. CA, 9-12
- Students know the relative residence times and flow characteristics of carbon in and out of its different reservoirs. CA, 9-12
- Know that Earth's system contains a fixed amount of natural resources that cycle among land, water, the atmosphere, and living things (e.g., carbon and nitrogen cycles, rock cycle, water cycle, ground water, aquifers). NM, 9-12
- Explain how plate tectonics influence the geochemical cycles and the formation of the Earth's surface. ME, 9-12
- Rocks, water, carbon dioxide, oxygen, carbon and other nutrients cycle through different forms as a result of cycle biological and geologic processes. KS, 9-12
- Summarize the location, movement, and energy transfers involved in the movement of water on Earth's surface (including lakes, surface-water drainage basins [watersheds], freshwater wetlands, and groundwater zones). SC, 9-12

CONCEPT: Estuarine ecosystems are affected by changes in global systems and cycles such as climate and weather cycles. For example, sea level rise can inundate salt marshes, reducing the habitat available for resident species and eliminating the flood protection important to upland areas.

- Identifying the impact of periodic weather phenomena on coastal regions. AL, 9-12
- Analyzing and comparing models of cyclic change as used within and among scientific disciplines (for example, water cycle, circular motion, sound waves, weather cycles). CO, 9-12
- Identifying and describing the dynamics of natural systems (for example, weather systems, ecological systems, body systems, systems at dynamic equilibrium). CO, 9-12
- Students will apply an understanding of constancy and change to explain physical and biological systems. ME, 9-12
- Explain how a system at equilibrium is affected by change. NE, 9-12
- Through systems thinking, people can recognize the commonalities that exist among all systems and how parts of a system interrelate and combine to perform specific functions. NY, 9-12

CONCEPT: Estuaries form an interface linking watersheds and oceans, and receive groundwater and surface water from their entire watersheds. Estuaries are affected by air quality and precipitation from far beyond watershed boundaries.

- Oceans redistribute matter and energy around the earth, through surface and deepwater currents, tides, waves, and interaction with other earth spheres. MA, 9-10
- Explain how water flows into and through a watershed, e.g., aquifers, wells, porosity, permeability, water table, capillary water, runoff. MA, 9-10
- Describe factors that impact current and future water quantity and quality including surface, ground, and local water issues. AZ, 9-12
- Identify water quantity and quality in a local watershed. TX, 10-12
- The student knows the interactions that occur in a watershed. TX, 11-12
- Identify the characteristics of a local watershed such as average annual rainfall, run-off patterns, aquifers, locations of river basins, and surface water reservoirs. TX, 11-12
- Analyze the impact of floods, droughts, irrigation, and industrialization on a watershed. TX, 11-12
- Differentiate among freshwater, brackish water, and saltwater ecosystems. AL, 9-12
- Comparing components of marine water to components of inland bodies of water. AL, 9-12
- Explain how water flows into and through a watershed. Explain the role of aquifers, wells, porosity, permeability, water table, and runoff. MA, 9-12
- Explain how water flows into and through a watershed (e.g. properly use terms precipitation, aquifers, wells, porosity, permeability, water table, capillary water, and run off). DC, 9-12

Principle 2:

Estuaries are dynamic ecosystems with tremendous variability within and between them in physical, chemical, and biological components.

- Explain the interaction of the continuous processes of waves, tides, and winds with the coastal environment. AL, 9-12
- Discuss physical and chemical properties of saltwater. AL, 9-12
- Describe components of major marine ecosystems, including estuaries, coral reefs, benthiccommunities, and open-ocean communities. AL, 9-12
- Identify and compare the physical properties of fresh water and salt water. MD, 8
- Describe the abiotic and biotic characteristics of a bay, sound, estuary, and marsh. MS, 9-12
- Describe the composition, circulation, and distribution of the world's oceans, estuaries, and marine environments. NJ, 5-6
- Determine how physical properties of oceans affect organisms (e.g., salinity, depth, tides, temperature). UT, 7-12
- Describe the physical dynamics of the oceans (e.g., wave action, ocean currents, El Nino, tides). UT, 9-12
- Earth-moon interactions (relationship between lunar phase and tide, tidal bulge and rate of lunar revolution, tides and Earth-moon distance, sidereal and synodic lunar months). MD, 9-12
- Analyze the physical and biological dynamics of the oceans. UT, 9-12

CONCEPT: Estuaries have various geologic origins and morphology.

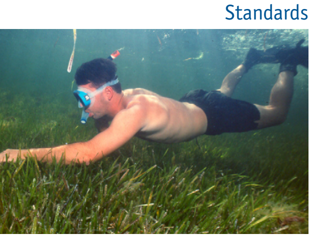
- Analyze the mechanisms that produce the various types of shorelines and their resultant landforms: - Nature of underlying geology. - Long and short

term sea-level history. - Formation and breaking of waves on adjacent topography. - Human impact. NC, 9-12

- Explain how physical and chemical weathering leads to erosion and the formation of soils and sediments, and creates the various types of landscapes. Give examples that show the effects of physical and chemical weathering on the environment. Use satellite images to illustrate the effects of these processes. MA, 9-12
- Explain how physical and chemical weathering leads to erosion and the formation of soils and sediments, and creates the various types of landscapes. Give examples that show the effects of physical and chemical weathering on the environment. MA, 9-12
- Identification of the major watershed systems in Virginia including the Chesapeake Bay and its tributaries. VA, 7-12
- Explain how waves, currents, tides, and storms affect the geologic features of the ocean shore zone (including beaches, barrier islands, estuaries, and inlets). SC, 5
- Earth is a dynamic interconnected system. The evolution of Earth has been driven by interactions between the lithosphere, hydrosphere, atmosphere, and biosphere. Over geologic time the internal motions of Earth have continuously altered the topography and geography of the continents and ocean basins by both constructive and destructive processes. MA, 9-12
- Plate tectonics operating over geologic time has changed the patterns of land, sea, and mountains on Earth's surface. AZ, 9-12
- Students will explore the actions of water, wind, and gravity that create landforms and systems of landforms (landscapes). GA, 9-12
- Relate the past and present actions of ice, wind, and water to the types and distributions of erosional and depositional features in landscapes. GA, 9-12
- Plate tectonics operating over geologic time has changed the patterns of land, sea and mountains on Earth's surface. CT, 9-12
- How geologic processes are evidenced in the physiographic provinces of Virginia including the Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau. VA, 9-12
- Landforms are the result of the interaction of tectonic forces and the processes of weathering, erosion, and deposition. NY, 9-12
- Explain the results of the interaction of the shore with waves and currents. SC, 9-12

CONCEPT: Estuaries can change slowly over hundreds to thousands of years. For example, they are transformed by changes in sea level, precipitation and vegetation patterns within their watershed, and sediment movement.

- Observe and explain how rivers and streams are dynamic systems that erode and transport sediment, change their course, and flood their banks in natural and recurring patterns. DE, 9-12
- Interactions among the solid Earth, hydrosphere, and atmosphere have resulted in ongoing evolution of the earth system over geologic time. DC, 9-12
- Relate the distribution of biomes (terrestrial, freshwater, and marine) to climate regions through time. GA, 9-12
- Identify and describe how natural processes, such as natural disasters, cyclic climate change, flooding, volcanic eruptions, drought, soil erosion, sedimentation in watersheds, natural selection, population cycles, extinction, forest fires, and deforestation change the environment. MD, 8
- Sea level, glaciers and sea ice, biome location and distribution, emergent and submergent coastlines. MD, 9-12
- Landform change (surface & groundwater, coasts, glacial processes, desert processes). MD, 9-12
- Compare the formation of dunes, reefs, barrier/volcanic islands, and coastal/flood plains. MS, 9-12
- Physical and chemical changes (tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations). VA, 7-12
- The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. VA, 9-12
- Research and report on changing ocean levels over geologic time, and relate changes in ocean level to changes in the water cycle.



CONCEPT: Estuaries can also change quickly, within hours or days. They are constantly shaped by water flowing from uplands as well as tidal cycles moving and mixing of fresh and salt water within the estuary. They can be dramatically changed by single, severe events such as a hurricane or the building of a levee.

- Explain what causes tides and describe how they affect the coastal environment. MA, 9-12
- Explain what causes the tides and describe how they affect the coastal environment. MA, 9-10
- Evaluate the effects of tides, tidal bores, and tsunamis. TX, 11-12
- Describe the effects of natural phenomena such as hurricanes, floods, or drought on aquatic habitats. MS, 9-12
- Investigate the impact of catastrophic events such as forest fires, floods, and hurricanes on the environment of New Jersey. NJ, 7-8
- Identify and explain the mechanisms that cause and modify the production of tides, such as the gravitational attraction of the moon, the sun, and coastal topography. DC, 9-12

CONCEPT: The dynamic nature of estuarine processes presents a challenge to the organisms living there. Organisms that reside in estuaries are adapted to the rhythm of change. For example, tides can change local sea level by several feet each day, leaving sessile organisms alternately inundated with water or exposed to air.

Principle 3:

Estuaries support an abundance of life, and a diversity of habitat types.

- Identify reasons coastal waters serve as an important resource. AL, 9-12
- Classifying biota of estuaries, marshes, tidal pools, wetlands, beaches, and inlets. AL, 9-12
- Arrange various forms of marine life from most simple to most complex. AL, 9-12
- The location and structure of Virginia's regional watershed systems. VA, 6
- Estuaries, like the Chesapeake Bay, are areas where fresh and salt water mix, producing variations in salinity and high biological activity. VA, 7-12
- Compare the marine life and type of water found in the intertidal, neritic and bathyal zones. PA, 12
- Identify ocean and shoreline features, (e.g., bays, inlets, spit, tidal marshes). PA, 7
- Compare the effect of water type (e.g., polluted, fresh, salt water) and the life contained in them. PA, 7

CONCEPT: Estuaries provide vital nursery and spawning grounds for numerous fish and invertebrates, including a significant proportion of commercially harvested species.

CONCEPT: Estuaries incorporate diverse habitat types. Oyster reefs, salt marshes, mangroves, mud flats, and freshwater tidal marshes can be found in estuaries.

- Differentiate among freshwater, brackish, and saltwater ecosystems. TX, 10-12
- Evaluate evidence that Earth's oceans are a reservoir of nutrients, minerals, dissolved gases, and life forms: - Estuaries. - Marine ecosystems. - Upwelling. - Behavior of gases in the marine environment. - Value and sustainability of marine resources. - Deep ocean technology and understandings gained. NC, 8
- Differentiate among freshwater, brackish water, and saltwater. AL, 9-12
- Describing adaptations in the marine environment. AL, 9-12

CONCEPT: Estuarine plant and animal species have specialized physical, biological, and behavioral adaptations which allow them to survive in the ever-changing estuarine environment. For example, some plants that grow in salt marshes can excrete excess salt through their leaves.

- Students know properties of ocean water, such as temperature and salinity, can be used to explain the layered structure of the oceans, the generation of horizontal and vertical ocean currents, and the geographic distribution of marine organisms. CA, 9-12
- Students will explain how life on Earth responds to and shapes Earth systems. GA, 9-12

CONCEPT: Estuaries provide a rich food source for a wide variety of organisms.

Principle 4:

Ongoing research and monitoring is needed to increase our understanding of estuaries and to improve our ability to protect and sustain them.

- Identifying and testing a model to analyze systems involving change and constancy (for example, a mathematical expression for gas behavior; constructing a closed ecosystem such as an aquarium). CO, 9-12
- Analyze systems to explain phenomena and design solutions to problems. ME, 9-12
- Analyzing how science explains and predicts the interactions and dynamics of complex Earth systems. VA, 9-12
- All students will analyze the interaction of human activities with the hydrosphere:, MI, 9-12
- Analyze interactions within an ecosystem (e.g., water temperature and fish species, weathering and water pH). UT, 9-12
- Compare the results of predictions on the same phenomena from multiple models to determine the strengths and weaknesses of each model. ME, 9-12
- Students will use models to explain phenomena and test ideas. ME, 9-12
- Use mathematical and graphic models to design, or learn about objects and processes. ME, 9-12
- Use graphs and equations to identify and analyze patterns of change in systems that have counterbalances and those that don't. ME, 9-12
- Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design. NY, 9-12
- Identifying patterns of change is necessary for making predictions about future behavior and conditions. NY, 9-12
- The student will demonstrate that data analysis is a vital aspect of the process of scientific inquiry and communication. MD, 9-12
- Make objective observations and perform error analysis on collected data. AR, 9-12
- Review information, explain statistical analysis, and summarize data collected and analyzed from an investigation. MA, 9-12
- Students will analyze the biological, physical and human interactions that shape and alter earth's systems. ME, 9-12

CONCEPT: Through research and monitoring in the National Estuarine Research Reserve System and elsewhere, humans gather scientific data in estuaries that allows us to better understand estuarine processes and to track changes in estuaries. For example, the System Wide Monitoring Program allows scientists to track short-term variability and long-term change.

- Investigate and analyze environmental issues and solutions for North Carolina's river basins, wetlands, and tidal environments: - Water quality. - Shoreline changes. - Habitat preservation. NC, 9-12
- The student will investigate and understand the natural processes and human interactions that affect watershed systems. VA, 6
- Compare and contrast present-day maps, land images, and aerial photographs of Delaware to those of the past. Identify changes that have occurred in the topography of Delaware, and investigate reasons for the changes using a variety of resources (e.g., historical records, local experts, library documents). DE, 9-12
- Predict and evaluate how change within a system affects that system. NE, 9-12
- Students investigate, through laboratory and fieldwork, the universe, Earth, and the processes that shape Earth. They understand that Earth operates as a collection of interconnected systems that may be changing or may be in equilibrium. Students connect the concepts of energy, matter, conservation, and gravitation to Earth, the solar system, and the universe. Students utilize knowledge of the materials and processes of Earth, planets, and stars in the context of the scales of time and size. IN, 9-12

CONCEPT: Technology plays an important role in how estuarine data is collected, analyzed, and interpreted. Technological innovations have led to increased understanding of estuaries. Technology such as dataloggers, sampling equipment, and remote sensing can provide data which can help people identify the cause of degraded water quality and verify the recovery of a restored system.

- Select appropriate equipment for scientific field investigations in marine environments. AL, 9-12
- Read, interpret, and analyze a combination of ground-based observations, satellite data, and computer models to demonstrate Earth systems and their interconnections. MA, 9-12

- The understanding of global and local changes that result from the interactions of ocean systems has increased substantially as a result of continuous advances in science and technology. DE, 9-12
- Use data from a variety of sources (e.g., NOAA, NASA, EPA, U of DE, USGS, AGU) to correlate significant changes in local and global weather (global warming, El Niño) to interactions of ocean systems. DE, 9-12
- Select and use appropriate technologies (e.g., computers, calculators, CBL's) to enhance the precision and accuracy of data collection, analysis, and display. SC, 9-12
- Explain how physical and chemical weathering leads to erosion and the formation of soils and sediments, and creates the various types of landscapes. Give examples that show the effects of physical and chemical weathering on the environment. Use satellite images to illustrate the effects of these processes. MA, 9-12
- Use a combination of ground-based observations, satellite data, and computer models to demonstrate Earth systems and their interconnections. Explain why it is necessary to use all of these tools together. MA, 9-12
- Use various types of technology, like manually operated and electronic devices, for measurement and calculation as a vital component of scientific investigations. b. Use common mathematical functions (linear, exponential, etc.) to analyze and describe data. c. Use statistical and graphing data analysis techniques. d. Recognize that the accuracy and precision of the data, and therefore the quality of the investigation, depends on the instruments used. e. Use equipment properly and safely. KS, 9-12

CONCEPT: Estuarine research is interdisciplinary. The expertise of many different specialists (e.g., meteorologists, sociologists, geologists, biologists, chemists, economists, computer scientists, engineers, and community planners) is required to study and to understand estuaries.

- Describe how science and technology could be used to solve all or part of a human problem and vice versa (e.g., understanding erosion can be used to solve some flooding problems). WA, 6-8
- Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning. NY, 9-12

CONCEPT: Since estuaries incorporate many interacting factors and conditions, research investigations must be carefully designed and results must be considered in context.

Principle 5:

Humans, even those living far from the coast, rely on goods and services estuaries provide.

CONCEPT: Estuaries provide social services and cultural value to humans. For example, millions of people use estuaries for recreational activities such as fishing, bird watching, and boating.

- Economic and public policy issues concerning the oceans and the coastal zone including the Chesapeake Bay. VA, 7-12
- Relate the nature and distribution of life on Earth, including humans, to the chemistry and availability of water. GA, 9-12

CONCEPT: Estuaries provide flood protection to human communities. Coastal wetlands absorb and slowly release water from storms, mitigating storm surge and preventing floods.

- Evaluate the effectiveness of human interventions designed to reduce the effects of rising sea level and waves on coastal erosion. SC, 9-12

CONCEPT: Estuaries provide significant economic value to humans. For example, many species of fish, crabs, and shellfish which live in estuaries for part or all of their lives provide essential food for humans.

- Describing commercial, economical, and medicinal values of marine plants and algae. AL, 9-12
- Identify economic resources found in marine areas. PA, 10

Principle 6:

Human activities can impact estuaries by degrading water quality or altering habitats; therefore, we are responsible for making decisions to protect and maintain the health of estuaries.

- These processes of ecosystems include maintenance of the atmosphere, generation of soils, control of the hydrologic cycle, and recycling of nutrients. Humans are altering many of these processes, and the changes may be detrimental, beneficial, or both to ecosystem function. KS, 9-12

CONCEPT: Human activities within an estuary system, its watershed, and in distant areas impact the biological, chemical, and physical components of estuaries. For example, land use changes within an estuary's watershed can change erosion and subsequent sedimentation rates within the estuary, affecting water clarity or bottom substrate.

- Identifying the positive and negative impact of humans on coastal regions. AL, 9-12
- Describe positive and negative effects of human influence on marine environments. AL, 9-12
- Human activities-agriculture, fishing, manufacturing, energy production. Quantity of water-rate of use, urbanization. Oceans-oil spills, garbage, global warming, marine life. Fresh water pollution-industrial waste disposal, agricultural runoff, herbicides, pesticides, sewage, acid rain, nutrient levels. Ground water-landfills, leaching, disposal of toxic wastes. Purification technology- filtering, chlorination. Limits to natural resources. MI, 9-12
- Summarize the advantages and disadvantages of devices used to control and prevent coastal erosion and flooding. SC, 9-12
- Evaluate the effectiveness of human interventions designed to reduce the effects of rising sea level and waves on coastal erosion. SC, 9-12
- Identify Investigate how human activity has changed the land, ocean, and atmosphere of Earth. (example: forest cover, chemical usage). SD, 9-12
- Describe factors that impact current and future water quantity and quality including surface, ground, and local water issues. AZ, 9-12
- Assess the impact of human activities on the cycling of matter and the flow of energy through ecosystems. NJ, 9-12
- Describe how human activities affect the quality of water in the hydrosphere. MI, 9-12
- The student will investigate and understand how freshwater resources are influenced by geological processes and the activities of humans. VA, 9-12
- Demonstrate the possible effects of atmospheric changes brought on by things such as acid rain, smoke, volcanic dust, greenhouse gases, and ozone depletion. IN, 9-12
- Describe how natural ecosystems provide processes that affect humans, how humans are changing some of these processes, and the possible impacts on humans. ME, 9-12
- Evaluate erosion and depositional processes: - Formation of stream channels with respect to the work being done by the stream (i.e. down-cutting, lateral erosion, and transportation). - Nature and characteristics of sediments. - Effects on water quality. - Effect of human choices on the rate of erosion. NC, 9-12
- Explain how geological and ecological processes interact through time to cycle matter and energy, and how human activity alters the rates of these processes (e.g., fossil fuel formation and combustion). GA, 9-12

CONCEPT: The quantity and quality of goods and services provided by estuaries to humans is dependent on the good health of estuarine ecosystems. For example, real estate values can decline in areas near overenriched or eutrophic estuaries.

- Making informed judgments related to resource use and its effects on Earth systems. VA, 9-12
- Evaluate water resources: - Storage and movement of groundwater. - Ecological services provided by the ocean - Environmental impacts of a growing human population. - Causes of natural and man-made contamination. NC, 9-12

CONCEPT: Humans can use their understanding of estuaries to make decisions on how to best protect and manage estuaries, while still allowing for the enjoyment of estuaries. For example, when a city on an estuary improves its wastewater treatment, eliminating sewage outfalls, the water quality in the estuary improves.

- Identify and evaluate the drawbacks (e.g., design constraints, unintended consequences, risks) and benefits of technological solutions to a given problem (e.g., damming a river for flood control, using pesticides to eliminate mosquitoes, genetic engineering of cells, use of satellite communications to gather information).
- Design solutions to problems identified within a system. NE, 9-12
- Natural systems can reuse waste, but this capacity is limited. Recycling and environmentally sound decisions improve the quality of human life. KS, 9-12

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For a downloadable database and annotated PDFs of the standards used in this study, visit the web sites www.terc.edu or www.oesd.noaa.gov and find the report titled: *Revolutionizing Earth System Science Education for the 21st Century*.