# *Earth System Science* (ESS) Analysis and Model

**Target Grade Level**
Earth Science (8th Grade)

**Duration**
5-7 class periods

## Michigan Content Expectations

- **E2.1 Earth Systems Overview**
  The Earth is a system consisting of four major interacting components: geosphere (crust, mantle, and core), atmosphere (air), hydrosphere (water), and biosphere (the living part of Earth). Physical, chemical, and biological processes act within and among the four components on a wide range of time scales to continuously change Earth's crust, oceans, atmosphere, and living organisms. Earth elements move within and between the lithosphere, atmosphere, hydrosphere, and biosphere as part of geochemical cycles.
- **E2.1B** Analyze the interactions between the major systems (geosphere, atmosphere, hydrosphere, biosphere) that make up the Earth.
- **E2.1C** Explain, using specific examples, how a change in one system affects other Earth systems.
- **E2.4B** Explain how the impact of human activities on the environment can be understood through the analysis of interactions between the four Earth systems.

## Learning Objectives

Students will be able to:

1) Identify the study of Earth Science as the study of four Earth systems.
2) Identify each Earth system and their primary characteristic: hydrosphere- liquid Earth; atmosphere- gaseous Earth; lithosphere- solid Earth; and biosphere- living Earth.
3) Create a cyclical concept map that identifies each of the four Earth systems and their primary characteristic. Each Earth system will be labeled with the system name, their primary characteristic, and an example of an Earth feature and process within that system.
4) Name and label 2 interactions between 2 of the four Earth Systems on the concept map.
5) Define and explain an Earth Science 'event' in terms of their origin, cause, and the type of changes that occur (as a natural or human-caused change, subtle or sudden, short- or long-term, and positive or negative).
6) Identify at least 3 examples of an Earth Science 'event' and explain their origin, cause, and type of changes that occur.
7) Name, label, and describe interactions between an 'event' and 2 of the four Earth Systems on a concept map.
8) Use the complete ESS model by identifying 10 interactions together, between an 'event' & the four Earth Systems and the 6 connections between the four Earth Systems.
9) Identify interactions as cause-and-effect connections by using the guiding questions and keywords to generate detailed and thorough descriptions.
10) Create a cyclical concept map that identifies 5 interactions with cause-and-effect connection descriptions.
11) Illustrate their cause-and-effect connection understandings through 2 image drawings. Label each image as natural or human-caused, subtle or sudden, short- or long-term, and positive or negative.
12) Define 'human impacts' as interactions with, connections to, and changes on Earth systems.
13) Identify 'human impacts' as among all Earth systems and identify specific 'human impacts' among all Earth systems.

14) Create an ESS concept map that analyzes one 'human impact' as an 'event'.
15) Identify and label all 10 interactions as cause-and-effect connections by using the *guiding questions* and *keywords* to generate detailed and thorough descriptions (from Lesson 3) using complete sentences on the concept map.
16) Distinguish and label 'cause' and 'effect' on specific interactions on the concept map.
17) Illustrate their human impacts as cause-and-effect connection understandings through 2 image drawings and label each as natural or human-caused, subtle or sudden, short- or long-term, and positive or negative.
18) Identify origins of *Earth System Science* (ESS) analysis (who, what, when, where, and why).
19) Name Earth Systems, features, and interactions from NASA photography.
20) Navigate *Earth System Science Pathfinder* to investigate a NASA presently operating research mission.
21) Illustrate their understanding of a NASA research mission by creating an ESS model of their investigation.
22) Explain the value of the ESS model in NASA research questions and missions.

## Unit Summary

*Unit comments*

This Unit is designed to be used in a few of different ways. In whole or in parts, all of these ways enhance and utilize holistic understanding of Earth System Science.

1. It can be implemented in succession, Lessons 1 to 5.
2. It can be implemented from Lessons 1 to 4 to provide solid ESS knowledge, understanding, and use, reserving Lesson 5 for later use.
3. Or Lesson 4, Human Impacts, can be implemented *first* with a few revisions, reserving the succession of Lessons 1 to 5 at a later time. If this implementation is chosen, Lesson 4 is conducted as a quick review while choosing the 'Test Evaluation' for Lesson 4 evaluation.

*Purpose of teaching and learning Earth System Science*

Earth has accumulated a laundry list of environmental issues: expanding droughts and wildfires; escalating numbers and strength of tornadoes and hurricanes; spreading invasive species; increasing endangered species, and millions of dollars toward restoration and protection. These unprecedented concerns make headlines everyday all over the world. Helping students make sense of contemporary events as they relate to Earth science can be a challenge for any teacher. Earth science concepts are no longer compartmentalized because Earth as it exists is always changing and interconnected. This Unit introduces a teaching method and model that will support students in demonstrating holistic Earth science understanding throughout the year: *Earth System Science* (ESS) analysis and model (Figure 1).

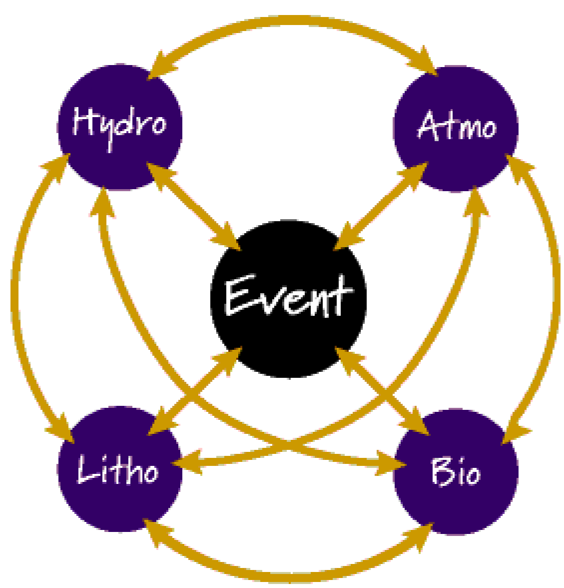


**Figure 1. Earth System Science (ESS) model developed by NASA and used as tool with Earth science secondary students. Illustration used with permission of *Exploring the Environment*® ([www.cotf.edu/ete](www.cotf.edu/ete)).**

Using the ESS model will enhance and reinforce the following ideas in the Earth Science curriculum:

- Earth is comprised of four systems: hydrosphere- liquid Earth; atmosphere- gaseous Earth; lithosphere- solid Earth; and biosphere- living Earth

- Earth's four systems are always connected to each other
- Earth's systems are impacted by and interact with both naturally-occurring and human-caused events

ESS models benefit both the student and the teacher. As thousands of scientists and policymakers can attest to worldwide, the model enhances holistic understandings of Earth and its processes. ESS ensures the transformation of static concepts to dynamic interactions. It is equally valuable for science as it is for pedagogy. ESS models continually build on prior student knowledge, student expectations are scaffolded, and numerous 'correct' answers build students' learning confidence. ESS provides a visual way to make connections between complex ideas in Earth science with writing as a tool to solidify understanding.

Developing holistic Earth system science understandings through ESS can easily be adapted for use throughout the year in Earth science curriculum. Further, it enhances the goals of the next generation of science standards by using Earth systems as a framework; focusing on cause-and-effect relationships between systems; and by recognizing and analyzing human impacts throughout the process. This is all accomplished in a way that is easily demonstrated by middle-school students as well as their teachers. From incremental Earth changes to cataclysmic Earth events, the model traces cause-and-effects, supporting students in holistic understandings of Earth system connections. The ESS model is a solid and fluid structure, an organized and creative framework. It connects students and teachers to real-world issues, science, and the existence of Earth as a series of interacting systems.

*Earth System Science and Graduate research*

For each and every environmental issue, there is a slew of complex *scientific objective* explanations PLUS a slew of complex *human subjective* explanations. Understanding Earth Science requires an understanding of humans; Earth System Science puts the human back in Science. As an environmental anthropologist (the study of the relationship between nature and humans), my graduate research program is called *Environmental and Energy Policy*, in the Social Sciences department, and it requires knowledge and understanding of both the natural and social sciences—it is holistic. I have applied this holistic perspective to the work I am most passionate about: global, invisible, chemical contamination; public health protection; environmental justice; and public environmental outreach. Global policy intended to 'regulate' harmful toxic substances focuses on three primary regimes: direct restrictions and limitations of chemical production and use; toxicological safety standards; and public risk communication. Each of these policy regimes is currently undergoing scientific paradigm shifts in knowledge of natural and social systems. The previously disconnected and compartmentalized (frog's eye view) is slowly being replaced for the interconnected and multidisciplinary (bird's eye view). Further, the value of seeing frogs and birds as part of the same story is also being acknowledged and implemented across the sciences. But even more interesting, and relevant, is that humans survived and thrived on Earth using holistic knowledge and understanding millions of years before (Western) 'science'.

Earth System Science and my graduate research have overlapping themes and objectives: holistic scientific understanding, real world environmental issues, and the significance of the *human*. The following is a brief summary of research work:

> Since the early 1970s in the U.S., policy regulating the harmful effects of toxic chemicals has relied heavily on prescriptive fish consumption advisories (FCAs). The policy's intent is to protect the public's risk exposure by advising limiting or eliminating fish consumption. These advisories have been criticized for multiple shortcomings, primarily because they lead to disparate risk exposure among target groups, concentrating risk onto multiple sensitive populations. An ethnographic study of one Ojibwa nation in the Upper Peninsula of Michigan, the Keweenaw Bay Indian Community (KBIC), reveals the

incompatibility of the FCA framework within their tribal harvesting as well as conflicting ideologies of 'fish' and risk. As a sovereign nation with a continued, substantial reliance on fishing, homogenized FCAs expose environmental and treaty-right injustices posed by federally-mandated, state-implemented FCAs and the multiple contaminants they intend to 'regulate'. My research explores the larger story of Ojibwa harvesting continuity, its cultural meanings, and an array of harvesting confrontations, both political and personal, within the FCA context. Because limiting or eliminating fish consumption is viewed as a risk to Ojibwa culture, sustaining tribal fish harvesting increases Ojibwa health risk exposure. Policies designed to minimize contaminant risk exposure must be re-evaluated and re-formulated to protect human health beyond the general public, focusing on sensitive populations with different perspectives of risk.

For students, *and* the general public, to understand my research—chemical characteristics and their global travels and accumulations—a holistic, interconnected Earth understanding is a must. Further, for students, *and* the general public, to understand Ojibwa peoples' Earth perspective—a holistic, interconnected Earth with humans as a part—Earth System Science is a must. The Ojibwa people are not the only community that retains a holistic understanding; these communities exist across the globe. Their voices can be better heard, understood, and applied when more people know and understand interconnected Earth systems. Sensitive populations are not the only communities that are at risk in present day. Environmental issues are priority concerns for the global public as they affect our choices, values, and beliefs about environment, government, economics, education, religion, the food we eat; human rights, freedom, and justice, and finally, if not especially, the health of our children and families.

Today's secondary students inherit the consequences of the past. But they also inherit the benefits of present day learning. Earth System Science, and the support offered in national education standards, is a giant leap toward creating a generation of scientists, policy-makers, and a general public knowledgeable of holistic understandings.

*Expected Prior Student Knowledge*
**E2.1A** Explain why the Earth is essentially a closed system in terms of matter.

## Lessons Table

| Title and Description | Learning Objectives | Content Expectations |
|---|---|---|
| <u>Lesson 1</u>: ***Earth System Science* (ESS) Analysis: An Introduction and Model**<br><br>"What is the *Earth System Science* (ESS) analysis model?"<br><br>This is the introductory lesson of a five part unit in *Earth System Science* (ESS) analysis using the ESS model. It is designed and intended to be used early on in the curriculum year. This lesson will introduce the study of Earth Science as *Earth System Science* (ESS) in the following three ways: 1) by identifying the study of Earth Science as the study of four Earth systems; 2) by recognizing and distinguishing between the primary characteristics of the four systems; and 3) by illustrating the four systems as always interacting and connected to each other. They will then complete an ESS concept map that will illustrate their accomplishment of the Learning Objectives. | 1, 2, 3, & 4 | **E2.1** |

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|---|---|---|
| <u>Lesson 2</u>: ***Earth System Science* (ESS) Analysis: Introducing the 'Event' and More Connections**<br><br>"What's an *Earth System Science* (ESS) 'Event'?"<br><br>This lesson is the second stage in learning ESS analysis and using the model. The focus is on tying in an 'event', either of natural or human origin, to the Earth systems and identifying additional connections. Using the structure of the ESS model, this lesson will introduce an event to ESS analysis in the following three ways: 1) by describing an event as when 'something happens or changes' on Earth, as subtle or sudden, short- or long-term, or positive or negative; 2) by identifying and explaining examples of events; and 3) by illustrating 2 specific events and the interactions between the events and the four Earth systems. The 2 event examples are the introduction and impact of Nutria in the North American Coastline ecosystem and the construction plans of the Belo Monte Dam in Brazil. They will then complete an ESS 'Event' concept map that will illustrate their accomplishment of the Learning Objectives. | 5, 6, & 7 | **E2.1** |
| <u>Lesson 3</u>: ***Earth System Science* (ESS) Analysis: The Complete Model as CAUSE-and-EFFECT Connections**<br><br>"How many *Earth System Science* (ESS) connections are there?!"<br><br>This lesson uses the complete ESS model (lesson 1 + 2) by focusing on the interaction descriptions as cause-and-effect connections. Students will learn to employ *the guiding questions* and *keywords* that bring out detailed and thorough descriptions for all 10 of the connections: the 4 connections between the 'event' & the four Earth Systems and the 6 connections between the four Earth Systems. This lesson will use the complete ESS model as cause-and-effect connections in the following three ways: 1) by bringing all 10 interactions together in the ESS model; 2) by using the guiding questions and keywords to generate cause-and-effect descriptions; and 3) by distinguishing cause-and-effect connections as natural or human-caused, subtle or sudden, short- or long-term, and positive or negative. They will then complete an ESS 'cause-and-effect' concept map that will illustrate their accomplishment of the Learning Objectives. | 8, 9, 10, & 11 | **E2.1B**<br>**E2.1C** |
| <u>Lesson 4</u>: ***Earth System Science* (ESS) Analysis: Investigating Events as 'Human Impacts'**<br><br>"Where are humans in *Earth System Science* (ESS)?"<br><br>In this lesson, students will explore where humans fit into Earth systems and where humans are in *Earth System Science* (ESS) analysis. Students will explore 'human impacts' as 'events' and 'human impacts' as interactions with, connections to, and changes to Earth systems. Using their prior knowledge of 'human impacts' and ESS analysis, students will engage in an activity that identifies multiple 'human impacts', Earth system features, and the consequences of and solutions to human impacts. This lesson will use the complete ESS model investigating events as 'Human Impacts' in the following three ways: 1) by focusing on 'human impacts' as changes to Earth systems; 2) by using the *guiding questions* and *keywords* to generate 10 cause-and-effect descriptions; and 3) by distinguishing between 'cause' or 'effect' connections and identifying them as natural or human-caused, subtle or sudden, short- or long-term, and positive or negative. They will then complete an ESS 'human impacts' concept map that will illustrate their accomplishment of the Learning Objectives. | 12, 13, 14, 15, 16, & 17 | **E2.1B**<br>**E2.1C**<br>**E2.4B** |

| Lesson 5: ***Earth System Science*** **(ESS) Analysis: History and Present**<br><br>"Who uses *Earth System Science* (ESS)?"<br><br>This is the final lesson in the five part unit in *Earth System Science* (ESS) analysis. This lesson will look at the history of ESS and its present use. Developed by the NASA Advisory Council's *Earth System Sciences Committee* in 1983, the Committee published for the first time how Earth systems interact in a 1988 report. The model is currently used by multiple organizations from the United Nations Environment Programme (UNEP) to the Intergovernmental Panel on Climate Change (IPCC). Today, tens of thousands of scientists contribute to Earth system science globally using the model, and ESS is used at major Universities across the globe. Students will need computer access for the duration of this lesson. Students will learn the origins of *Earth System Science* (ESS) analysis and who uses the model in the present day in the following three ways: 1) by viewing NASA photography and identifying Earth systems, features, and interactions in the photos; 2) by exploring actual NASA presently operating research missions; and 3) by illustrating their understanding of actual NASA research missions using the ESS model and explaining the value of NASA (or other) research questions and missions through writing. Their completion of an ESS model and writing will illustrate their accomplishment of the Learning Objectives. | 18, 19, 20, 21, & 22 | **E2.1B**<br>**E2.1C**<br>**E2.4B** |
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## Materials and Equipment

- Computer and LCD projector, speakers
- Multi-colored chalk/dry erase markers
- Multi-colored pencils and/or markers
- Lessons 1-5 handouts; provide a printed copy for each student
- Computer access for students

## Evaluation Plan

Students will be evaluated throughout the Unit on their understanding of Earth Science systems, features, and interactions by their creation of concept maps and writing using the Earth System Science (ESS) analysis and model. Every lesson incorporates informal evaluations, no 'points' are gained; and every lesson incorporates a formal evaluation, assignments for 'points'. All evaluations are intended to draw on a variety of students' skills, allowing students to be evaluated on what they know using their skill strengths, and allowing students to strengthen other skills that may be weaker. And finally, evaluations are intended to elicit a diverse set of 'correct' answers: no two students will create exactly the same model, maps, descriptions, or writings. ESS holistic learning and thinking requires diverse contributions. (Scientific holistic learning and thinking requires diverse contributions in the real world.)

*Informal evaluations*

A primary goal of this Unit is to implement all five lessons by keeping this mind: student-teacher implementation will be 50-50. During each lesson, students will participate through note taking, partner work, and completing parts up on the board for their fellow students. They will contribute to teaching their classmates and be evaluated on their understanding by explaining each of their contributions. Further, students will evaluate their fellow classmates work by editing, revising, and/or confirming all board contributions and participation. Some of the best teaching and learning will come from students adding to each other's work, and confirming each other's work. Also during the lesson, the teacher will implement specific check points outlined in each lesson.

*Formal evaluations*

Following each lesson, students will be evaluated on incorporating each of the lessons' learning objectives into their model and writing. Teaching the ESS model is scaffolded with each lesson with the new objectives highlighted in specific ways; each evaluation focuses higher point values on the new objectives. The repetition of drawing the model, connecting Earth systems, and describing interactions is intended to solidify holistic scientific thinking through doing and seeing.

*Evaluation through writing*
In each evaluation, the importance of *writing* cannot be stressed enough; students will be expected to describe and discuss ESS understanding and significance through writing. Each evaluation scaffolds writing expectations. Clear and holistic writing ensures that students have gained clear and holistic thinking. (This insight was gained through hindsight and each lesson was revised to reflect a greater importance of writing in each lessons' evaluation.) The two primary goals of each writing activity draws attention to explanation and *reflection*: Explain what you know *and* the importance of knowing. Students must describe the importance of knowing Earth System Science in their own lives, to real world problems, and to think about future solutions. Writing allowed students to reflect on the sheer complexity of Earth Science issues, social institutions, and human beliefs and values.

## Resources


1. Earth System Science (ESS) for teachers' background knowledge: http://www.qem.org/NASA-NSFConfPresentations/%20Thurs%20130/ruzek22feb07reva.ppt.pdf
2. Earth System Science (ESS) Analysis and Model: http://www.cotf.edu/ete/ESS/ESSmain.html
3. Nutria Information Document (attached to Lesson 2)
4. Video link (5:51): Reel Earth: Nutria-licious http://www.youtube.com/watch?v=QxdWZXyXEMY
5. Video link (3:35): Nutria Hunted to Save Wetlands http://www.youtube.com/watch?v=exf4PcMMk1g&feature=related
6. Video link (10:40): Defending the Rivers of the Amazon, with Sigourney Weaver http://www.internationalrivers.org/resources/sigourney-weaver-narrates-google-earth-tour-of-belo-monte-dam-3444
7. *The Scientific and Historical Foundations of Earth System Science*, Dr. Robert W. Corell: http://eospso.gsfc.nasa.gov/ess20/docs/corell_abstract.pdf
8. ARES: Earth Expedition and Beyond: http://ares.jsc.nasa.gov/ares/eeab/
9. The Gateway to Astronaut Photography: http://eol.jsc.nasa.gov/
10. Earth System Science Pathfinder: http://science.nasa.gov/about-us/smd-programs/earth-system-science-pathfinder/