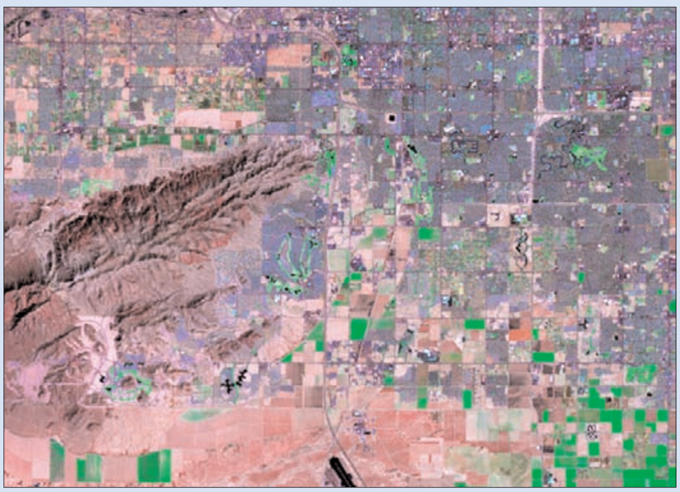
National Aeronautics and Space Administration

# Quantifying Changes in the Land Over Time

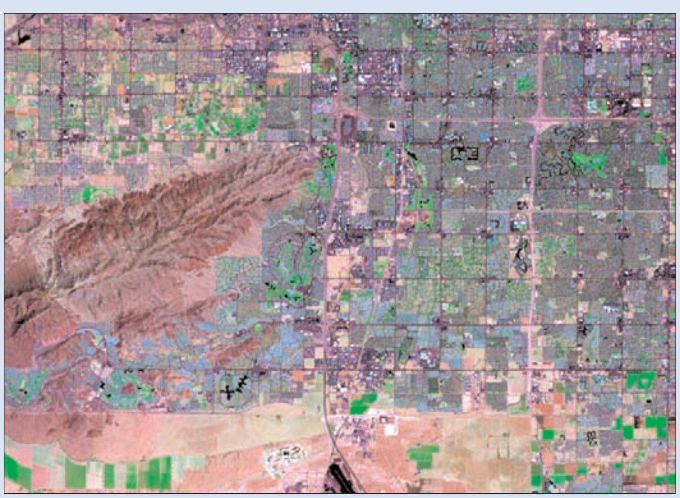
## A Landsat Classroom Activity



1991

Southeast Phoenix, Arizona, USA

2000



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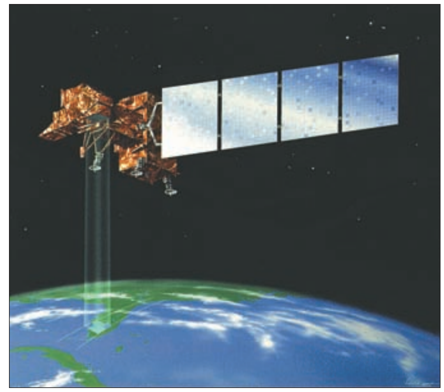
## Guide for Teachers

Landsat satellites have been observing Earth since 1972. The duration and consistency of Landsat observations enables student investigations of regional and global changes in the land and their communities over time.

# Purpose

To enable students to analyze land cover change; to help them grasp the extent, significance, and consequences of land cover change; and to introduce them to the perspective of space-based observations

### Why study land cover change?

Our land is changing. Land covered by forest is changing to farmland, land covered by farmland is changing to suburbs; cities are growing.  Shorelines are shifting; glaciers are melting; and ecosystem boundaries are moving. As human population numbers have been rising, natural resource consumption has been increasing both in our country and elsewhere. We are altering the surface of the Earth on a grand scale.  Nobel Prize recipient Paul J. Crutzen has said, “Humans have become a geologic agent comparable to erosion and [volcanic] eruptions…”

Land cover change has effects and consequences at all geographic scales:  local, regional, and global.  These changes have enabled the human population to grow, but they also affect the capacity of the land to produce food, maintain fresh water and forests, regulate climate and air quality, and provide other essential “services.”  (See Foley, et. al, in Appendix 5.)  It is critical for us to understand the changes we are bringing about to Earth’s systems, and to understand the effects and consequences of those changes for life on our planet.  Landsat satellites enable studies of change at the regional or landscape scale.

The first step in understanding change is monitoring, and the second step is analysis.  Doing this activity will enable your students to take these steps at an introductory level.

# Overview

Students learn to identify kinds of land cover (such as roads, fields, urban areas, and lakes) in Landsat satellite images. They decide which land cover types allow the passage of water into the soil (are pervious) and which types do not allow it (are impervious). They consider some effects of increasing impervious surface area on ecosystem health.

Students then make land cover maps using two Landsat satellite images taken about a decade apart. They quantify the change of land cover from pervious to impervious surface during that time period. They make predictive maps of what they think the nature and extent of land cover change in the area will be in the year 2025, and speculate about the consequences for the availability of water for people and ecosystems. Students justify their predictive maps and their thoughts about the consequences of change in writing.

This activity uses Landsat images of Phoenix, Arizona, USA. Teachers who wish to conduct the activity using Landsat images of their students' own communities can do so. See, "Find and Download Your Own Free Landsat Data," below.

**Grade Level:** Gr. 7-10

**Time Required:** Two 45-minute class periods

## Goals for Student Learning

### Students will:

- Experience the practical value of remote sensing at an introductory level
- Learn to interpret, assess, and predict changes in the nature and spatial extent of land use at the landscape (regional) scale, using land remote sensing images
- Begin to appreciate the extent of urban development and the impacts on natural resources as land cover changes
- Perceive a regional (landscape scale) context for local change
- Develop skills of visual analysis of remote sensing images

## Objectives

### As a result of going through this activity, students will:

- Be able to identify some major land cover types in a land remote sensing image
- Make maps of land cover at a regional (landscape) scale
- Quantify land cover change over time
- Predict ways and directions that an urban area might grow
- Realize that land cover / land use in our country is changing in significant ways, and that this has implications for management of the natural resources we depend on
- Begin to appreciate the value of planning in urban growth to protect natural resources

# National Standards – SCIENCE

## National Science Education Standards

**Grades 5-8**

**Understandings about science and technology (8EST2.3)**

Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size and speed. Technology also provides tools for investigations, inquiry, and analysis.

**Grades 9-12**

**Science in Personal and Social Perspectives (12FSPSP) Environmental Quality (12FSPSP4.3)**

Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, over-consumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth.

**Science as Inquiry (12ASI) Abilities necessary to do scientific inquiry (12ASI1.3)**

Use technology and mathematics to improve investigations and communications. A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results.

**(12ASI2.4)** Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.

## Benchmarks for Science Literacy

(By the American Association for the Advancement of Science, Project 2061)

**Grades 6-8**

**3A. The Nature of Technology. Technology and Science.**

Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

**4C. Processes that Shape the Earth**

Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the earth’s land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms.

# National Standards - GEOGRAPHY

## National Geography Education Standards

### The World in Spatial Terms

Standard 1: How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information.
Standard 3: How to analyze the spatial organization of people, places, and environments on Earth's surface.

# Activity Steps at a Glance

(To review the activity in detail, please see the Guide for Students.)

## Engage.

**Step 1.** Review movies about the roles of satellites in our lives and about the growth of an urban area, Phoenix, AZ (5 min.)

**Step 2.** For homework, read the one-page section of this activity, "Background on Land Cover Change." and the article, "Looking for Lawns."

## Explore.

**Step 3.** Do the GLOBE Program activity, Getting to Know Your Satellite Imagery, attached at the end of the Guide for Students. (20 min.)

**Step 4.** Visually explore and become familiar with the 1990 Landsat image, list any identifiable features and land cover types. (10 min.)

**Step 5.** Identify types of land cover in the 1990 image, and decide which are pervious/impervious to water. (10 min.)

## Explain.

**Step 6.** Visually compare the 1990 and 2000 Landsat images and write about differences (change over time). (10 min.)

**Step 7.** Make a map of land cover types in 1990 using transparency with grid. (10 min.)

## Elaborate.

**Step 8.** Comparing the 1990 land cover map to the 2000 Landsat satellite image, count and record the numbers of grid squares representing land cover that have changed from pervious to impervious surfaces, or from impervious to pervious surfaces. (15 min.)

**Step 9.** Calculate the percent change from pervious to impervious surface area. (5 min.)

### Evaluate:

**Step 10.** Optional. If two or more student teams analyze change in the same geographic area, compare teams' results and comment on any differences. (15 min.)

**Step 11.** Respond to guiding questions provided. (15 min. in class or homework)

**Step 12.** Optional. Assuming the same rate and nature of change, make a predictive map of land cover in 2025. Describe and explain the 2025 map and any ecological consequences that might be expected from the change. (15 min. in class or homework)

## Student Prerequisites

### Students must:

- have a basic level of ability to understand and interpret visual representations of Earth's surface from above, such as maps and aerial photographs;
- understand the meaning of wavelengths of light;
- be able to define "electromagnetic spectrum," at an introductory level.

## Materials and Tools

A checklist of all materials and tools is provided in Appendix 1.

- Movie about Satellites
- Movie of Phoenix, AZ
- Classroom activity, Getting to Know Your Satellite Imagery
- Color prints of Landsat satellite images of Phoenix, AZ (one set of images per two students – as students will work in pairs). The data will be refered to as the 1990 and 2000 images throughout this activity. The exact aquisition dates for the Phoenix images are March 18, 1991 and April 19, 2000.

**Alternate Option 1:** Instead of using the satellite images of Phoenix, AZ, you may use pairs of images from one of the three sources listed below.

**Sources of Existing Change Pairs**

USGS Landsat Image Gallery (Go to, "Change Over Time.")

Monitoring Land Use Change with Landsat, (Go to, "Featured Data.")
Featured sites: Atlanta, GA; Bahrain; Baltimore, MD; Derby, VT; Kansas City, MO; Lake Meade, NV; Las Vegas, NV; New Haven, CT; New Orleans, LA; New York, NY; Philadelphia, PA; Philadelphia, PA and points west; Providence, RI and points east; Schenectady, NY; Washington DC and Northern Virginia; Washington DC and points northwest.

Earthshots: Satellite Images of Environmental Change

**Alternate Option 2:** You can find and download Landsat images of your students' own communities for use in this activity. See, "Find and Download Your Own Free Landsat Data," below.

About image dates: The dates of the satellite images to be used for this activity will vary depending on the teacher's chosen geographic location of interest. The objective for student learning is to use satellite observations far enough apart in time that students will be able to see significant changes in the land over time. The Global Land Cover Facility at the University of Maryland provides two free global sets of Landsat data from approximately 1990 and approximately 2000.

Throughout this activity, the dates 1991 and 2000 will be used. Teachers using images other than those of Phoenix, AZ provided with this activity will need to let their students know the dates of the particular images selected for this class.

- Pens suitable for writing on transparencies
- transparencies printed with grid (one per student)
- Grid on white paper (one grid per pair of students)
- Any available maps, aerial photographs, or other representations of the area of interest, both historical and current, as well as literature about how the land has changed.

Sources of such resources include local government agencies and libraries; surveying organizations; mapping agencies; local or regional government planning agencies; university departments of geography, remote sensing, natural resources and geosciences; highway and transportation departments; architectural firms; police and emergency services; utility agencies such as those for electricity, water and telephone; forestry planning and management agencies; and farmers and farm organizations.

Teachers may wish to have students find this information as a research project.

## Teacher Preparation

1. Review the whole activity, including the background material provided. You may also wish to read some of the publications listed in Appendix 5, References for Students and Teachers. (Those publications may be assigned for high school student reading.)

2. Students will be making a map of land cover types (five or six), using a transparency with a grid on it. Teachers can either identify the four or five land cover types to be used by students, or they can have students themselves decide what land cover types they want to use. The exercise of having students decide their own land cover types can (a) provoke valuable thinking and (b) help students to learn that their decisions are shaped by the questions they will ask of the Landsat images of change. Middle school students will need more guidance with this task than high school students will need.

If you wish to identify the land cover types for your students before the activity, make that list for them. Each land cover type needs to be represented on the map by a letter or symbol, such as:

| | |
|---|---|
| S | Suburban |
| U | Urban |
| H | Highways and Roads |
| F | Forest |
| G | Grassland |
| W | Water |

3. Download, print, and make student copies of:
   Landsat satellite images — one set of 1990 and 2000 images per student in both the "7,4,2" color combination and the "3,2,1" color combination. If color printing costs are a limiting factor, print just the "7,4,2" color combination. Images: 1991/3,2,1; 1991/7,4,2; 2000/3,2,1; 2000/7,4,2 (~3 Mb/ea.)

   Transparencies with grids (one per student, with a few extra in case of student mistakes)
   Student Guide (below) and GLOBE activity, Getting to Know Your Satellite Imagery, including worksheets.

4. Make sure the pens your students will use for the land cover maps on transparencies will work well for outlining areas of land cover. The pens should have fine tips. Try one of your "candidate" pens on a spare transparency.

## Classroom Management

In **Step 4** students familiarize themselves with the 1990 Landsat image and identify whatever features and land cover types that might be recognizable to them. Students may need some guidance, so encourage them to recall what they learned from the GLOBE activity in Step 3. Be sure they read and understand "About the Colors of Landsat Images," provided in the Guide for Students, Step 4. Point out that features with straight lines, rectangles, and perfect circles are usually made by people.

In **Step 5** students determine five or six specific land cover types to be seen in the satellite image, and they make a class list. Students in Grades 9-10 may be more adept at this task than students in earlier grades. So at this point you may wish to hold a guided class discussion about how to study the image and what the land cover types might be. Use the land cover key provided in Appendix 3 if needed.

**Step 5** also entails students deciding whether or not the land cover types of interest are pervious or impervious to water. You may wish to have a guided discussion with your students on what that means. For short background reading on the question, please go to Appendix 4.

In **Step 8** students count all the grid squares representing different land cover types in a satellite image. This can be a very time consuming task, depending on the size of the area under investigation. So for this project, teachers may wish either to have the whole class deal with just a fraction of the satellite image, or to assign different student groups to examine different portions of the total image. Dividing the image into quadrants is a useful approach. After student groups have recorded data about their assigned quadrants of the image, the class can compile data from all student groups. Compiled student data can also be used by individual students to complete the final calculations and analysis for the activity.

**Step 10** is optional, written for classes in which more than one group quantifies land cover change in the same geographic area of the satellite image.

## Find and Download Your Own Free Landsat Data
### — for almost any land surface on Earth.

This activity will become most meaningful for students when they can study changes in landscapes that are familiar to them. Landsat data of any area from about 1990 and about 2000 (give or take two or three years) can be acquired at no charge through the University of Maryland Global Land Cover Facility.

Please note the files from GLCF are data, not images. Special software is needed to make use of them. The software, MultiSpec©, is free. Find it and an excellent tutorial at:
MultiSpec© (download)
http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/

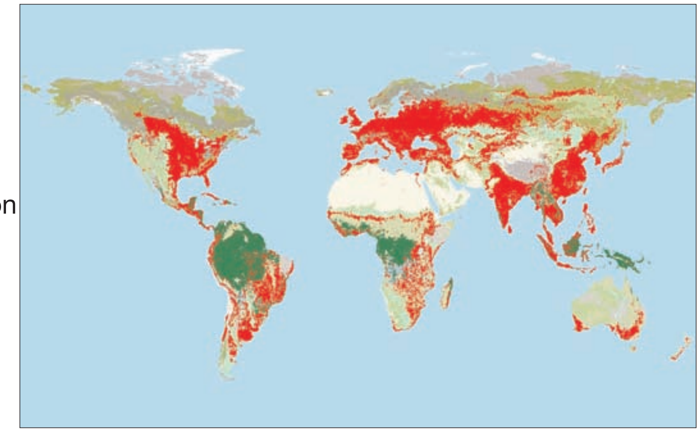
MultiSpec™ Tutorial
http://www.dhba.com/globe/globe.html
(Scroll down, a little more than halfway down the page.)

Before seeking to download data for classroom use, visit the Landsat Education tutorials page, and work with the tutorial, "Finding, Importing, and Making Subsets of Free Landsat Data," at this URL:
http://change.gsfc.nasa.gov/create.html

## Student Learning Assessment

Appendix 2 provides a chart for teachers to record student levels of achievement on each of the products students create during this activity. The chart lists each student product and associated indicators of achievement. A five-point scale is used. The appendix also provides guidelines on how teachers can calculate the total student grade for the activity, based on the five-point scale.

## Background on Land Cover Change

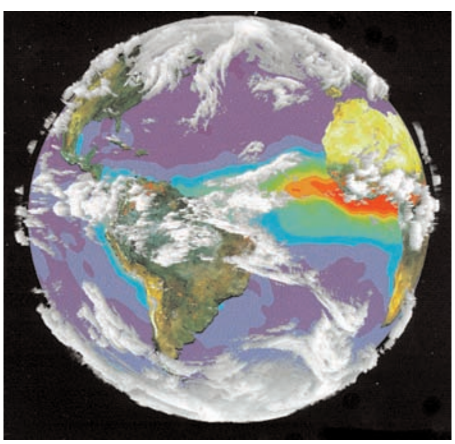


In approximately 10,000 BCE, the world population was 6-10 million, and the percent of land cover in agriculture was negligible. In the map at right, red indicates areas of the world currently dominated by agriculture. The world population is now about 6.5 billion, and agriculture covers 43 percent of the land area (Marc Imhoff, 2005).

Our land is changing. Forest is changing to farmland, farmland is changing to suburbs; cities are growing. Shorelines are shifting; glaciers are melting; and ecosystem boundaries are moving, As human population numbers have been rising, natural resource consumption has been increasing both in our country and elsewhere. We are altering the surface of the Earth on a grand scale. Nobel Prize recipient Paul J. Crutzen has said, “Humans have become a geologic agent comparable to erosion and [volcanic] eruptions…”

Land cover change has effects and consequences at all geographic scales: local, regional, and global. Human changes to the land are enabling our own populations to grow, but they also are affecting the capacity of ecosystems to produce food, maintain fresh water and forests, regulate climate and air quality, and provide other essential functions necessary for life. It is critical for us to understand the changes we are bringing about to the Earth system, and to understand the effects and consequences of those changes for life on our planet.

The first step in understanding change is monitoring, and the second step is analysis. Doing this activity will equip you to do those two steps at an introductory level.



Composite image of NASA global visualizations from several satellites. NASA’s Earth observing satellites enable us to monitor and explore our planet at the global scale.

Change in land use and land cover can be detected at the local, regional (landscape), continental, and global scales by sensors on Earth-orbiting satellites. Satellite technology enables us to accurately quantify change at the global scale for the first time in human history. Satellites such as Landsat bring us the big picture. And with observations of Earth from space, we can most easily grasp how events in one place are affected by or affect life in other places. For example, we can observe air pollution traveling from one continent to another.

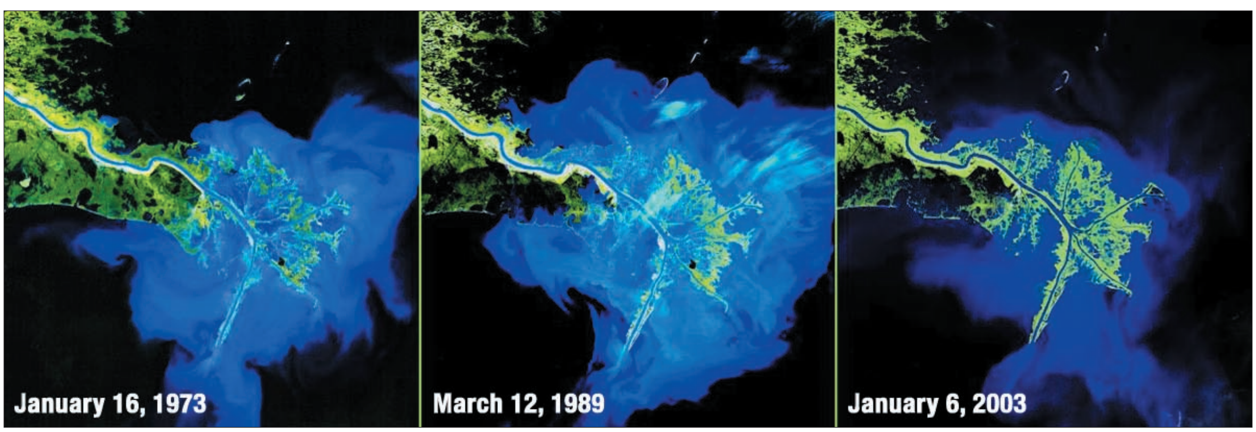
Landsat satellites have been observing the Earth’s land surface since 1972, providing us with an invaluable record of landscape scale change. For more background about NASA’s Earth observing satellite program, visit these Web sites:
NASA Earth Science
Landsat at NASA
Landsat at USGS

## Guide for Students

**Earth-orbiting satellites are causing a revolution** in the ways people find out about the health of our planet and how they solve many practical problems. Working with satellite data involves a great deal of challenge, mystery, risk, and fun, and it is above all creative. **The job market is growing** for people who can integrate data from remote sensing, geographic information systems, sensor networks, and other geospatial technologies, and the market is expected to continue to grow over the next decades. For more about such "geospatial" jobs, go to: http://www.asprs.org/career.

Sensors on satellites give us the regional and global perspectives for where we live and the issues we face, such as the sources of pollution in the air we breathe, how cities are growing, or how coastlines are changing in response to hurricanes and sea level rise. Sensors on NASA satellites collect data about the atmosphere, oceans, ice, biosphere, and land used to make daily global maps of our changing planet. The Landsat series of satellites enables us to see change in the land surface over time.

Information from Earth-orbiting satellites must be checked against observations people make on the ground, in order to be sure we are interpreting the satellite data correctly. Such field campaigns are a critical aspect of NASA research. (Photograph courtesy of Don Deering)




The Landsat series of satellites enables us to see change in the land surface over time. The Mississippi River deposits sediments from the central United States into the Gulf of Mexico and thereby builds the Mississippi Birdfoot Delta in Louisiana. Upon reaching the Gulf, the river's velocity slows, reducing the river's capacity to carry suspended mud and sand. This sediment is deposited in a fan pattern. Clearly, significant change has occurred in just three decades. Compare a specific part of one image to the same part of an image from a later year to discover some details of this remarkable sequence.

## What You Need to Know about Landsat Satellites for This Activity

When NASA's astronauts began traveling to the moon for the Apollo missions, they took photographs of our planet and sent them back to Earth. People began to think about what we could learn from this new vantage point of space if we used other kinds of instruments (sensors). The first Landsat satellite with a special sensor was launched in 1972.

As this classroom activity is being finalized, Landsat 5 and 7 are both orbiting the Earth at an altitude of about 705 kilometers (438 miles), and sending data to Earth for us to use. You can find out exactly when they will be over any given location by visiting the NASA Satellite Overpass Predictor Web site.

A new Landsat-type satellite called the Landsat Data Continuity Mission (LDCM) is planned and will be launched sometime after 2010. More information about LDCM is available on the NASA LDCM and USGS LDCM Web sites.

Landsat 5 and 7 orbit the Earth from pole to pole as the Earth turns under them. This means that each satellite revisits the same geographic area on Earth every 16 days. Sensors on board the Landsat satellites detect light reflected from the Earth's surface. (They do not use lasers or radar.) They detect both visible light and infrared light.

Each Landsat scene covers an area 185 km by 172 km (115 miles by 107 miles). A grid system of "paths" and "rows" is used to provide a reference number for each scene.

The spatial resolution of Landsat data is 30 meters (98.5 feet). This means each pixel in a Landsat image represents an area on Earth's surface that is 30m X 30m. ("Pixel" is short for picture element. A pixel is a single point in a graphic image. Computer monitors display pictures by dividing the display screen into thousands (or millions) of pixels, arranged in rows and columns. The pixels are so close together that they appear connected—the same is true of a satellite image. If you look at a computer monitor with a magnifying lens, you can see the individual pixels. If you zoom in close enough on a satellite image you can also see the pixels. **Counting the number of pixels of one color or another is one way to quantify land cover change using a satellite image.**

What we've learned with Landsat is helping us to explore other planets in the solar system as well as our own. If you find yourself enjoying using your "spatial" skills to do the land cover change analysis in this activity, you may consider a career in geospatial technology.

## About Color in Landsat Images

The sensors on Landsat 5 and 7 make observations in both visible and infrared (invisible) wavelengths of the electromagnetic spectrum. We cannot see infrared wavelengths of light without special technology that converts it to wavelengths we can see.

When measurements of infrared light are converted to visible images, we must assign colors to the data in order to see it. Therefore some Landsat images show false color. You will learn more about color in Landsat images in Step 4, below. For more information about Landsat visit http://landsat.gsfc.nasa.gov and http://landsat.usgs.gov/.

**Step 1. Review these movies (provided):**
"Satellites" – about the role of Earth observing satellites in helping to monitor changes on our planet
"Phoenix" – about the growth of this city in Arizona

**Step 2. For homework,** read the one-page section of this activity, "Background on Land Cover Change" and the article, "Looking for Lawns."

**Step 3. Guided by your teacher in the classroom, do the GLOBE Program activity,** Getting to Know Your Satellite Imagery.

Before starting the activity, discuss as a class: What experiences, if any, have you had of changes in the landscapes where you live? For example, has there been any major construction, such as new housing developments, shopping malls, highways, or bridges? Or, in contrast, are any large areas being allowed to revert to natural land cover?

**Step 4. Visually explore and familiarize yourself with a 1990 Landsat image (**provided by your teacher).

Your teacher will give you two Landsat satellite images from around 1990 and 2000 (give or take two or three years). The images will have different colors: one will be "true color" and one will be "false color." (See, "About the Colors of Landsat Images," below.) Your task for this step is to look over the false color image and identify all the land cover types you can. (The true color image may help you to feel comfortable with the image.) You may work with classmates to do this.

Participate in a class discussion about land cover types in this image guided by your teacher, then identify as many of them (roads, agricultural fields, urban or suburban areas, etc.) as you can.

### Read this first:

## About the Colors of Landsat Images

**True color** images show how the land would look if you were observing it from space with your own eyes.

But our eyes don't tell us everything there is to know. Sensors such as the one on Landsat give us extra insight into nature. The sensor on the Landsat satellite makes observations of light reflected from the Earth in both visible and **infrared** (invisible) wavelengths of the electromagnetic spectrum. So with Landsat, we can see more about nature than we can when we use our eyes alone.

The **false color** Landsat image your teacher will give you shows information in some infrared wavelengths of light. Normally infrared wavelengths are invisible to us. In order for you to be able to detect it, information about these infrared wavelengths have been colored in a special way in this "false color" pair.

Compare the true color and false color images. Do the true color images show you the most about difference in land cover, or do the false color images show you the most? Which would you choose to detect land cover change over time, true color or false color?

**We'd like to suggest you use the false color images for this activity!**

**Now you know that Landsat images are not photographs.** They contain more information than photographs do. In fact, the Landsat 5 and 7 sensors observe seven distinct wavelength ranges of the electromagnetic spectrum. Those seven "bands" of data are powerful tools for studying the land and what's on it.

**Here are some details about the false color images provided for this activity:**
The pair of false color images provided for this activity show mid-infrared, near infrared, and visible green wavelengths, or Bands 7, 4, and 2 in Landsat lingo.

Tones of red or pink in the 7, 4, 2 images represent the reflection of **mid-infrared** wavelengths from the Earth's surface. They comprise Band 7, which measures wavelengths of 2.08 to 2.35 micrometers (µm). (A micrometer is one millionth of a meter.) Mid-infrared wavelengths are useful for distinguishing between kinds of minerals and rocks, and for observing the moisture content of vegetation.

Tones of green in the 7, 4, 2 images represent **near infrared** wavelengths reflected from the Earth's surface. They comprise Band 4, which measures wavelengths of 0.76 to 0.9 µm. Near-infrared wavelengths are useful for observing soil moisture, distinguishing between kinds of vegetation, and seeing the boundaries of bodies of water.

Tones of blue in the 7, 4, 2 images represent **visible green** wavelengths reflected from the Earth's surface. They comprise Band 2, which measures wavelengths of 0.52 to 0.6 µm. Visible green wavelengths are useful for observing different kinds vegetation and for monitoring vegetation health, as well as for identifying human-made features such as roads, buildings, and parking lots.

**One more note:** You may not be able to identify every kind of land cover in these images. **You are not alone.** Scientists don't make positive identifications using just the satellite images/data. They must always check what they think they find in satellite images against what they find to be true from observations on the ground. (This process of checking their data with observations on the ground is termed "ground truthing.") Working with geographic areas already familiar to you makes the identification/checking process easier.

**Work with a partner during Steps 5 through 9 of this activity.**

### Step 5. Identify types of land cover in the 1990 image.

A. With your partner, identify the types of land cover you find in the 1990 satellite image. Identify five or six types. Some examples of land cover types are urban, suburban, water (lake, river, or ocean), forest, grassland, wetland, shoreline, or anything you see covering significant amounts of the land surface. Be prepared to share your list with the class.

B. Now make a class list of the land cover types in the satellite images.

C. Still working as a class, decide which of your land cover types allow water to penetrate the surface (are pervious), and which types do not (are impervious). Keep both a class record and your own individual record of this list of land cover types that are impervious vs. pervious. You will need it later in the activity.

**Step 6. Visually compare the 1990 and 2000 Landsat images.**

Spend some time examining the two images. **Familiarize yourself with the similarities and differences** in these images that are about a decade apart. Get a general sense of how much the land cover has changed over that time: where, how, and by how much. Focus on one part of the geographic area at a time to identify specific areas of change.

Use the Student Worksheet for Step 6 to write about what you observe and think as you visually assess the changes from 1990 to 2000. Include any questions or concerns you have, or anything you find confusing.

Each student should complete a worksheet for this step.

**Something you need to be aware of** is that the 1990 image and the 2000 image show different seasons of the year. The 1990 Phoenix image shows the land cover on March 18, 1991, and the 2000 Phoenix image shows the land cover on April 19, 2000. (We would have provided images of the same seasons for this activity if it had been possible, but it was not possible.) As you compare the two images of land cover, keep the difference in seasons in mind.

**Pointers about the Desert Ecosystem**
Remember that the natural ecosystem of Phoenix is desert. Areas that show visible bright green have likely received water recently.

**Step 7. Make a map of land cover types in 1990 using a transparency with grid** (provided by your teacher).

You did a visual, **qualitative** assessment of about a decade of land cover change in Step 6; now you will begin a **quantitative** assessment of the change.

Place your transparency with grid over the 1990 satellite image. Mark the corners of the image on the transparency so that if you move the transparency off the satellite image you can put it back again exactly where it was.

Using the classification scheme for land cover types that your class decided upon in Step 5, make a map of land cover change by **tracing carefully around each land cover type with a colored marker.** Remember, you decided as a class which kinds of land cover were pervious to water and which kinds were impervious. **Label each area** with your symbol for its land cover type and also with your symbol for either pervious or impervious (probably P or I).
**Make a legend** for your transparency grid, which is now becoming a map. Be sure to label this map

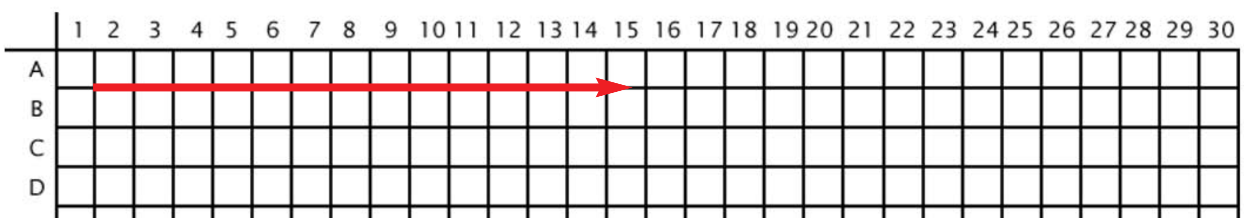
with the year the satellite image was made, and with your name, your partner's name (if you're working with a partner), and today's date.

**Step 8. Comparing your 1990 land cover map to 2000 Landsat satellite image, count and record the numbers of grid squares representing land cover that have changed from pervious to impervious, or from impervious to pervious.**

Place the transparent 1990 land cover map over the 2000 Landsat image, and identify the dominant land cover – pervious or impervious — for **each grid square** on the map.

There are two roles in this step. One student partner compares the 1990 map to the 2000 satellite image and identifies the grid squares that have changed — from pervious to impervious land cover or from impervious to pervious land cover. The other partner marks the equivalent changed squares in the grid provided on Student Worksheet for Step 8.

Systematically study each square on your grid map to determine whether or not there has been change so that you include each grid square. One way to do that is to work from upper left to right across each row, one row at a time.




Use the row letters (A, B, C…) and column numbers (1, 2, 3…) to keep careful track of the specific grid squares as you communicate with your partner.

**You may notice** that some grid squares contain more than one land cover type. The most dominant land cover type in that grid square dictates which land cover type to assign to that square. For example if a square is 75 percent Vegetation and 25 percent Water, use the code for Vegetation. Some students may disagree about which type is dominant. Professional land cover analysts occasionally disagree too.

**Step 9. Calculate the percent change from pervious to impervious surface area**, using the Student Worksheet provided.

**Step 10. If another team of students in your class analyzed land cover change in the same geographic area you did, compare the results of their work on Step 9 to your team's work on that step.**

Did your team identify the same kinds of land cover changes as the other team did?

If your team did identify the same kinds of land cover as another team, did the two teams arrive at the same percent change from pervious to impervious surface area (or from impervious to pervious surface area)? If not, discuss between teams how your perceptions and/or methods of calculating change may have been different. Provide notes about this discussion on the Student Worksheet for Step 10.

**Step 11. Respond to questions on the Student Worksheet for this step.**

**Step 12. Assuming the same general rate and nature of change, make a predictive map of land cover in 2025 for the same geographic area. Describe and explain the 2025 map and any ecological consequences that might be expected from the change.**

Describe the map and any changes you project from pervious to impervious surface or from impervious to pervious surface. (Remember to take the effects of major transportation arteries and geologic features such as mountains and rivers into account.) Explain why you have predicted this kind and amount of change.

## Student Worksheet for Step 6:
## Visually Comparing 1990 and 2000 Landsat Images

Name: Date:

**Use this worksheet to record notes about your visual comparison of the 1990 and 2000 Landsat images.**

Here's a tip: Don't try to study all of the two images at one time. Choose one small geographic area to look at, and compare it with that same area in the 2000 image. Then choose another.

What changes in land cover from 1990 to 2000 do you see? What land cover types seem to have decreased in extent? What types seem to have increased? Identify specific areas of change and which quadrant of the image they're in: northeast, northwest, southeast, or southwest.

Make note of any questions or concerns you have, or anything you find confusing.

## Student Worksheet for Step 8: Recording Land Cover Changes

Date:

Names:

**Use this worksheet to indicate grid squares representing land cover types that have changed from 1990 to 2000. Use one symbol to represent change from pervious to impervious surface, and another symbol to represent change from impervious to pervious surface. If no change has occurred, leave blank.** *(One worksheet will serve two students for this step.)*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| B | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| F | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| I | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| K | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| L | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| N | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| O | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| P | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Q | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| U | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Y | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Z | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| AA | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| BB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CC | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DD | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Student Worksheet for Step 9:
## Calculating Percent of Land Cover Type Changes

Name: Date:

**Use this worksheet to calculate the percent change from pervious to impervious surface area.**

Referring to your records from Step 8, note the following numbers:

(a) Total number of squares on the transparency grid (a)

(b) Number of grid squares that changed from pervious to impervious land cover types between 1990 and 2000 (b)

(c) Number of grid squares that changed from impervious to pervious land cover types between 1990 and 2000 (c)

Which number is larger, (b) pervious to impervious, or (c) impervious to pervious?

In most geographic areas where land cover types are changing, (b) will be larger than (c).
If (c) is larger than (b), your geographic area is not experiencing urban growth.

To determine the percent of land cover changed from pervious to impervious, calculate the following:

$$\frac{\text{(value for b) X (100)}}{\text{value for a}}$$

To determine the percent of land cover changed from impervious to pervious, calculate the following:

$$\frac{\text{(value for c) X (100)}}{\text{value for a}}$$

## Student Worksheet for Step 10:
## Comparing Different Teams' Results for the Same Areas of Change

Name: Date:

**Complete this worksheet if another team of students in your class analyzed land cover change in the same geographic area your team did.**

1. Compare your two teams' completed Student Worksheets for Step 8, "Recording Land Cover Changes." How do the teams' worksheets differ, if at all? Describe differences in the space provided below. Please be as specific as you can.

2. Compare your completed Student Worksheets for Step 9. How do your two teams' worksheets differ, if at all? Please be as specific as you can.

3. What, if anything, do the difference between teams' results tell you about science as a human activity?

4. If you have any other comments about the differences between your team's results and the other team's results, please write them here:

## Student Worksheet for Step 11

Name: Date:

**Write your responses to the questions below in the space provided.**

1. (A) How comfortable are you with the accuracy of your data and the conclusions you drew from this information? Why?

   (B) How might you improve the accuracy of your map and your calculations, if at all?

2. Which land cover type changed the most, and which land cover type changed the least? Why do you think this is the case?

3. Researchers indicate that if ten percent of the land cover in a given watershed changes, the water cycling through that watershed changes in significant ways. Water quality is affected, and run-off increases.

   (a) How concerned should people be about the cycling of water in the area you have studied with Landsat?

   (b) What specific ecological effects of land cover change should be looked into for the geographic area you studied? (Consider air, water, soil, and living things.)

   (c) What data would we need to investigate some of those ecological effects?

# Appendix 1

## Checklist of Materials and Tools

- ☐ Movie about Satellites
- ☐ Movie of Phoenix, AZ
- ☐ Classroom activity, Getting to Know Your Satellite Imagery
- ☐ Color prints of Landsat satellite images of Phoenix, AZ (one set of images per two students)
- ☐ Transparencies printed with grid (one per student)
- ☐ Pens suitable for writing on transparencies
- ☐ Grid on white paper (one grid per pair of students)
- ☐ Any available maps, aerial photographs, or other representations of the area of interest, both historical and current, as well as literature about how the land has changed

# Appendix 2

## Learning Assessment Record Chart for Teachers

Use this chart to record student levels of achievement for each of the student products you assign. The chart uses a scale of 5-1. Your check in the 5 column represents the highest level of achievement, and your check in the 1 column represents the lowest level.

| Student Product | Indicator of Achievement | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|
| 1. Map of land cover from the GLOBE activity, "Getting to Know Your Satellite Imagery" | IA. The map is complete. It shows all four layers of geographic information: water bodies, transportation features, buildings and developed areas, and vegetated areas. | | | | | |
| | 1B. The map is clearly drawn and labeled. It is easy to understand and interpret. | | | | | |
| II. Class decisions about land cover types (Step 5) | IIA. Student participates in brainstorming discussions. | | | | | |
| | IIB. Student shows curiosity and asks questions. | | | | | |
| | IIC. Student indicates openness to new ideas. | | | | | |
| | IID. Student reaches conclusions only when all available facts are in hand. | | | | | |
| | IIE. Student uses logical arguments. | | | | | |
| III. Visual comparison of 1990 and 2000 Landsat images (Step 6) | IIIA. Student response uses complete sentences. | | | | | |
| | IIIB. Student response describes specific changes in land cover for specific geographic locations identified by grid square letter and number. | | | | | |
| IV. Land cover change map (1990-2000) (Step 8) | IVA. The map is complete. | | | | | |
| | IVB. The map is clearly drawn and labeled. It is easy to understand and interpret. | | | | | |
| | VC. The map features the same land cover types as established by the class. | | | | | |
| V. Calculating Percent, Land Cover Changes (Step 9) | VA. All calculations have been done. | | | | | |
| | VB. Calculations are free of errors. | | | | | |
| VI. Comparing Different Teams Results for the Same Areas of Change (Step 10) | VIA. Differences in the two (or more) teams' results are described specifically. | | | | | |
| | VIB. Possible reasons for differences are thoughtfully addressed. | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | VIC. (Extra credit) Student response refers to the requirement of science methodology that most work must be done multiple times in a reproducible manner with the same results, in order to be acceptable for publication. | | | | | |
| VII. Student responses to guiding questions (Step 11) | VIIA. Student uses complete sentences. | | | | | |
| | VIIB. Student provides specific and detailed explanations. | | | | | |
| | VIIC. The response to Question 3 requires knowledge of ecology, which is not taught through this activity. However the student should demonstrate at least some level of thoughtful speculation about the consequences of land cover change. | | | | | |
| VIII. Predictive land cover map for 2025 and description of map (Step 12) | VIIIA. The map is complete. It shows all land cover types used by the class for this activity. | | | | | |
| | VIIIB. The map is clearly drawn and labeled. It is easy to understand and interpret. | | | | | |
| | VIIIC. The student explanations of land cover changes depicted on the map take into account any geographic or political features that might not be suitable for the land cover changes indicated, such as rivers, rocky areas, mountainsides, or political boundaries. | | | | | |
| | **Student total scores for each column** | | | | | |

**To calculate a student's grade on this activity:**
Total the number of checks in each of the five columns, then multiply the number of checks in each column times the achievement level it represents.

*Example: If student X scored —*
4 in the Level 5 column
9 in the Level 4 column
8 in the Level 3 column
2 in the Level 2 column
0 in the Level 1 column —

*Then —*
4 x Level 5 = 20 points
9 x Level 4 = 36 points
8 x Level 3 = 24 points
2 x Level 2 = 4 points
Total Score = 84 points

Use this approach only if student work on all products should be equally weighted.

## Appendix 3

# Phoenix Land Cover Key

**To teachers and students:** It will be tempting to use this land cover key without making your own class key. Avoid the temptation if time allows, because you'll learn more by creating your own key.

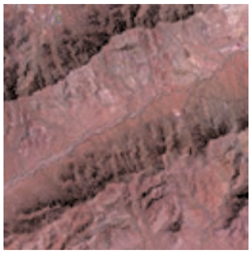
Here's a reminder about what the colors mean in the false color images provided for this activity (which are known as 7, 4, 2 images in Landsat terminology): These images show mid-infrared, near infrared, and visible green wavelengths.

Tones of red or pink in the 7, 4, 2 images represent the reflection of **mid-infrared** wavelengths from the Earth's surface. They comprise Band 7, which measures wavelengths of 2.08 to 2.35 micrometers (μm). (A micrometer is one millionth of a meter.) Mid-infrared wavelengths are useful for distinguishing between kinds of minerals and rocks, and for observing the moisture content of vegetation.

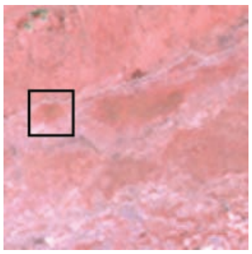
Tones of green in the 7, 4, 2 images represent **near infrared** wavelengths reflected from the Earth's surface. They comprise Band 4, which measures wavelengths of 0.76 to 0.9 μm. Near-infrared wavelengths are useful for observing soil moisture, distinguishing between kinds of vegetation, and seeing the boundaries of bodies of water.

Tones of blue in the 7, 4, 2 images represent **visible green** wavelengths reflected from the Earth's surface. They comprise Band 2, which measures wavelengths of 0.52 to 0.6 μm. Visible green wavelengths are useful for observing different kinds vegetation and for monitoring vegetation health, as well as for identifying human-made features such as roads, buildings, and parking lots.

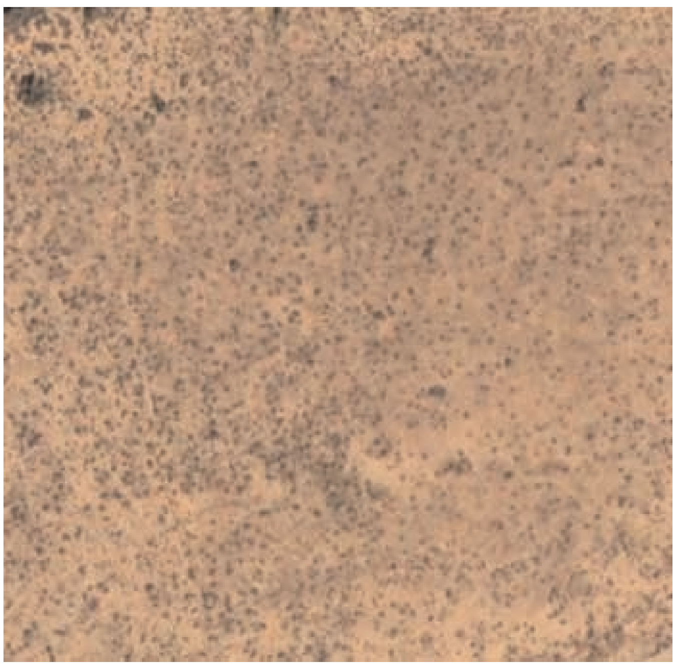
Visual examples of Landsat imagery can be found on the next few pages.



Mountains. This is part of Phoenix South Mountain Park. The shadows cast by mountains can often help you to visually identify mountain features in Landsat images.



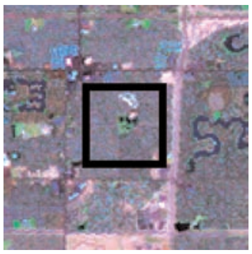
Non-vegetated or lightly vegetated terrain



Up close, the area in the black square above looks like the this.

This is some sort of shrub/brush (perhaps mesquite) with lots of bare ground between plants. This image is from Digital Globe's QuickBird satellite.

Agricultural Fields. The bright green areas are vegetated fields and the pink areas are unplanted fields. In Landsat images, agricultural fields can often be recognized by their rectilinear appearance.



Urban, densely developed terrain.

Up close, the area in the black square looks like the image below:

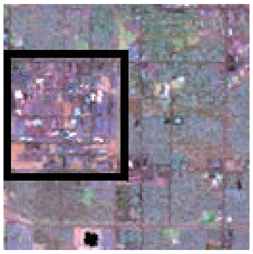
This image is from Digital Globe's QuickBird satellite. It shows a densely built neighborhood with a park at its center.

Densely populated residential urban area with three golf courses. Phoenix is known for its many golf courses. The bright green of the fairways, teeing grounds, and putting greens help you identify golf courses on Landsat images. Can you find other golf courses in the large Phoenix images? Are there new golf courses on the 2000 image?

This is an example of a golf course under development.

Today up close, the golf course looks like this:

This image is from Digital Globe's QuickBird satellite.



Mixed use urban area, densely situated buildings.

Up close, the area in the black square looks like an area of large buildings, most likely these are warehouses.

Image above is from Digital Globe's QuickBird satellite.

# Appendix 4

## About Pervious and Impervious Surfaces
### (Land Cover Types)

When rain falls or the snow melts on pervious surfaces such as grassland or fields, that water percolates through the ground, reaching and replenishing our ground-water supply. But when rain or snow falls on surfaces such as pavement and sidewalks, it can't get through. Those surfaces are **impervious** to water. The water glides along the pavement and picks up contaminates along the way such as oil, gas, fertilizers, sediment and even bacteria. When the water does finally reach a **pervious** surface, or a water body, it can be full of all these pollutants. That can introduce a huge surge of contamination into our water supply. On the other hand, when precipitation falls on pervious surfaces, it gradually penetrates the ground, and many contaminants are naturally filtered out before they reach the ground-water supply.

"There is a link between impervious surfaces within a watershed and the water quality within the watershed. In general, once 10-15 percent of an area is covered by impervious surfaces, increased sediments and chemical pollutants in runoff have a measurable effect on water quality. When 15-25 percent of a watershed is paved or impervious to drainage, increased runoff leads to reduced oxygen levels and impaired stream life. When more then 25 percent of surfaces are paved, many types of stream life die from the concentrated runoff and sediments." (NASA Goddard Space Flight Center News Release, "New Satellite Maps Provide Planners Improved Urban Sprawl Insight." http://www.gsfc.nasa.gov/gsfc/earth/landsat/sprawl.htm )

## Appendix 5

# References For Students and Teachers

## About Land Cover Change

**Land Cover Classification**
http://earthobservatory.nasa.gov/Library/LandCover/

**Changing Global Land Surface**
http://earthobservatory.nasa.gov/Library/LandSurface/

**Analyzing Land Use Change in Urban Environments**
http://landcover.usgs.gov/urban/info/factsht.pdf

**A Guide to Land-Use and Land-Cover Change (LU/LCC)**
(Includes LU/LCC and the Hydrological Cycle, LU/LCC and Climate Change; and LU/LCC and Urbanization)
http://sedac.ciesin.columbia.edu/tg/guide_frame.jsp?rd=LU&ds=1

Foley, et al., 2005. "Global Consequences of Land Use." Science Vol. 309, 22 July 2005, pp. 570-574 (www.sciencemag.org)

**Urban Heat Island: Atlanta, Georgia**
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17489

**Deep Freeze and Sea Breeze: Land Cover Mapping in Florida**
http://earthobservatory.nasa.gov/Study/DeepFreeze/deep_freeze.html

## Images of Land Cover Change

**Landsat Change Over Time** (Nov 2004)
http://change.gsfc.nasa.gov

**Landsat Change Over Time Gallery**
http://landsat.usgs.gov/gallery/change/

## About Landsat

**NASA's Landsat Web Site**
http://landsat.gsfc.nasa.gov/

**USGS Landsat Web Site**
http://landsat.usgs.gov/

## Landsat Education

**NASA's Landsat Education Web site**
http://landsat.gsfc.nasa.gov/education/

## About Free Software to Analyze Landsat Data

**MultiSpec Software download**
http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/

**MultiSpec Tutorial**
http://www.dhba.com/globe/globe.html
(Scroll down, a little more than halfway down the page.)

## About Free Landsat Data

**Landsat 7 Data Downloads for Use with MultiSpec Software**
http://l7downloads.gsfc.nasa.gov/downloadP.html

**University of Maryland, Global Land Cover Facility (GLCF)**
http://glcf.umiacs.umd.edu/index.shtml

**Get Your Own Landsat Data Set - Tutorial**
http://change.gsfc.nasa.gov/create.html

## More About Where to Get Landsat Data

**Seamless Data Distribution System (SDDS)**
http://seamless.usgs.gov
Enables a user to view and download many geospatial data layers, such as National Elevation Dataset, National Land Cover Dataset, High Resolution Orthoimagery, and many more.

**Landsat Orthoimagery Mosaic**
http://seamless.usgs.gov/website/seamless/products/landsatortho.asp
Description
Orthoimagery combines the image characteristics of a photograph with the geometric qualities of a map. The Landsat Mosaic orthoimagery database contains Landsat Thematic Mapper imagery for the conterminous United States. The more than 700 Landsat scenes have been resampled to a 1-arc-second (approximately 30-meter) sample interval in a geographic coordinate system using the North American Horizontal Datum of 1983. Three bands have been selected from the seven spectral bands available for each frame. These are bands 4 (near-infrared), 3 (red), and 2 (green), typically displayed as red, green, and blue, respectively. The image is a full-resolution (spectral and spatial), 24-bit color-infrared composite that simulates color infrared film as a "false color composite".
These data have been created as a result of the need for having geospatial data immediately avail-

able and easily accessible in order to provide geographic reference for Federal, State, and local emergency responders, as well as for homeland security efforts. Orthoimages also serve a variety of purposes, from interim maps to field references for earth science investigations and analysis. The digital orthoimage is useful as a layer of a geographic information system. This data can be used to provide reference information for Web browsers and for map applications at a scale of 1:100,000 or smaller. Larger scale orthoimagery such as digital orthophoto quadrangles will be more accurate, but often at the expense of timely updates.

## About Geospatial Careers

American Society for Photogrammetry and Remote Sensing career brochure
http://www.asprs.org/career/

### Professional Geospatial Associations

American Congress on Surveying and Mapping (ACSM)
American Society of Photogrammetry and Remote Sensing (ASPRS)
Association of American Geographers (AAG)
Geospatial Information and Technology Association (GITA)
Urban and Regional Information Systems Association (URISA)
GIS Certification Institute (GISCI)
Management Association for Private Photogrammetric Surveyors (MAPPS)
National States Geographic Information Council (NSGIC)
University Consortium for Geographic Information Science (UCGIS)