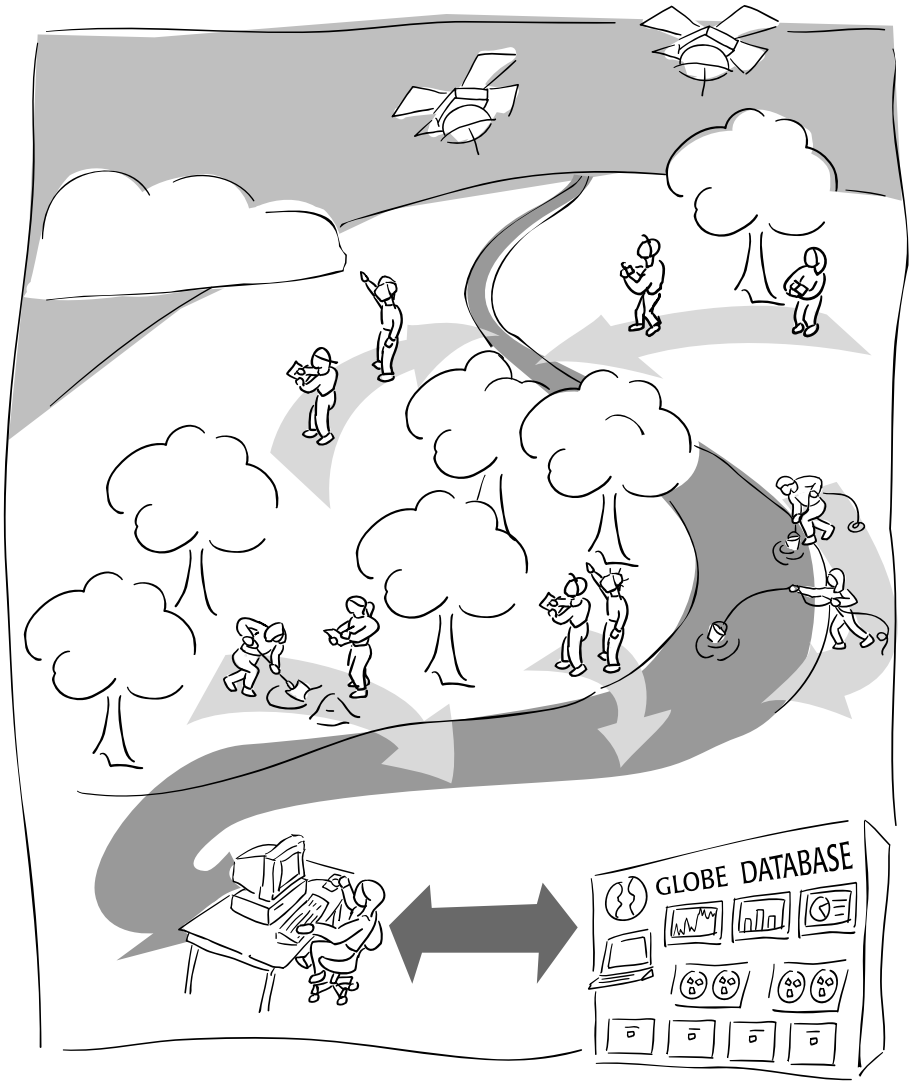
Toolkit



for the GLOBE® Teachers' Guide

Table of Contents

GLOBE Measurements and Their Instruments

GLOBE environmental measurements are in five study areas: Atmosphere/Climate, Hydrology, Land Cover/Biology, Soils, and Phenology. The following pages summarize the current specifications for the instruments. The GLOBE measurements and instruments are differentiated by skill level.

Measurement	Instrument	Skill Level
Atmosphere/Climate		
Cloud Cover/Type	Cloud chart	All
Aerosols	Sun photometer, digital voltmeter	Middle, Secondary
Barometric Pressure	Aneroid barometer or altimeter	All
Relative Humidity	Digital Hygrometer, Thermometer (calibration or Maximum/minimum)	All
	Sling Psychrometer, Instrument shelter, Calibration thermometer	All
Precipitation, Liquid	Rain gauge	All
Precipitation, Solid	Snowboard, Rain gauge, Snow depth pole	All
Precipitation pH	pH indicator paper	Primary
	pH pen, two pH buffers (7 and 4 or 10)	Middle
	pH meter, three pH buffers (7, 4, and 10)	Secondary
Air Temperature: Maximum, Minimum, and Current	Maximum/Minimum thermometer, Calibration thermometer, Instrument shelter	All
Surface Ozone	Ozone test strip scanner, ozone chemical test strips, ozone measurement station, sealable bags, wind direction device	All

Measurement	Instrument	Skill Level
Hydrology		
Transparency — Deep Water Sites Only	Secchi Disk, 5 m rope	All
Transparency — Surface Water	Turbidity tube	All
Water Temperature	Organic liquid-filled thermometer	All
Dissolved Oxygen	Dissolved oxygen kit	Middle, Secondary
Water pH	pH indicator paper	Primary
	pH pen, two pH buffers (7 and 4 or 10)	Middle
	pH meter, three pH buffers (7,4, and 10)	Secondary
Electrical Conductivity – Fresh Water Sites Only	Total dissolved solids (conductivity) tester, calibration solution	All
Salinity – Brackish and Salt Water Sites	Hydrometer, 500 mL clear plastic graduated cylinder, organic liquid-filled thermometer	All
Salinity Titration Method– Brackish and Salt Water Sites	Salinity kit	Optional Middle, Secondary
Alkalinity	Water alkalinity kit	Middle, Secondary
Nitrate	Water Nitrate kit	Middle, Secondary
Soil		
Soil Characterization – Field Slope, Horizon Depth, Structure, Color, Consistence, Texture, Carbonates	Clinometer, Camera, Meter stick, Color chart, Sample cans, Other containers, Shovel or Auger	All
Soil Characterization – Lab Bulk Density, Particle Size, Particle Density, Soil pH, Fertility	Drying oven, 100 mL Graduated cylinder, 500 mL clear plastic graduated cylinder, Hydrometer, Thermometer, Dispersing solution, 100 mL Erlenmeyer flask, heat source, pH paper, pen or meter and pH buffers, Soil NPK kit	All
Soil Moisture	Balance, Meter stick, Drying oven (soils), Sample Cans, Other soil containers, Auger (depth sampling), 50 m tape measure (transect)	All

Measurement	Instrument	Skill Level
Soil		
Gypsum Block Soil Moisture	Soil moisture meter, Gypsum blocks, PVC piping	Optional, Secondary
Infiltration	Dual ring infiltrometer	Optional, All
Soil Temperature	Soil thermometer	All
Automated Soil and Air Monitoring Protocol	4-Channel data logger and software, 1 Air temperature sensor, 3 Soil temperature sensors, Data logger-to-computer interface cable, Watertight box, Desiccant, Instrument shelter	Optional Middle, Secondary
Phenology		
Green-Up	Dichotomous keys, Compass, Camera	All
Green-Down	Dichotomous keys, Compass, Camera, GLOBE Plant Color Guide	All
Land Cover/Biology		
Land Cover Mapping	Remote sensing image, MultiSpec software	All
Species Identification	Dichotomous keys	All
Biometry Tree Circumference Tree Height Canopy Cover Ground Cover	Clinometer and densiometer (both may be student-made), 50 m tape measure	All
Biometry Grass Biomass	drying oven (plants)	All
GPS		
Latitude and Longitude of study sites	Global Positioning System receiver	All

Scientific Instruments for GLOBE Measurements

A number of instruments, supplies, and pieces of equipment are needed to conduct the GLOBE measurements properly. Many of these can be purchased from suppliers while some can be made by students or individuals in the school community. The GLOBE measurement protocols are broken into three types, depending on the degree of commitment to their support and expectations as to their training and implementation by GLOBE schools. These types are Basic, Advanced, and Optional. The following tables list the instruments needed for each type of measurement. GLOBE measurements are also differentiated by skill level. In the KIT Column of the following tables, P, M, and S indicate that an instrument is included in a primary (P), middle (M), or secondary (S) level kit. Each such kit includes the minimum set of instruments which most schools will need to purchase in order to do the **Basic** GLOBE protocols appropriate for their educational level. A indicates that the instrument is included in a kit for all advanced protocols. E indicates that purchase of this instrument is extra and that it is not included in a kit either because most schools should already have access to one, because schools in an area can reasonably share one instrument, or because the instrument is needed only if certain options within the GLOBE protocols are chosen. C indicates that the instrument can be constructed at the school or with local assistance.

Basic Measurements

Instrument	KIT(P,M,S,E,A,M)	Measurement	Skill Level
Cloud chart	E[1]	Cloud Cover/Type	All
Digital Hygrometer	P,M,S[2]	Relative Humidity	All
Sling Psychrometer	P,M,S[2]	Relative Humidity	All
Maximum/Minimum Thermometer	P,M,S	Air Temperature - Max/Min.and Current Temperature	All
Calibration thermometer (Organic liquid-filled thermometer)	P,M,S	Air Temperature, Relative Humidity, Water Temperature, Salinity, Soil Particle Size	All
Instrument Shelter	P,M,S,C	Air Temperature, Relative Humidity, Automated Soil and Air Temperature	All
Rain gauge	P,M,S	Precipitation, Liquid, Solid	All
Snowboard	M	Precipitation, Solid	All
Snow depth pole	E, C	Precipitation, Solid	All
pH indicator paper	P	Precip. pH, Water pH, Soil pH	Primary

[1] One copy provided to each GLOBE teacher at training.

[2] Only one of these instruments should be included in any one GLOBE kit.

Basic Measurements (continued)

Instrument	KIT(P,M,S,E,A,M)	Measurement	Skill Level
pH pen	M	Precip. pH, Water pH, Soil pH	Middle
pH 7 buffer	M,S,C	Precip. pH, Water pH, Soil pH	Middle, Secondary
pH meter	S	Precip. pH, Water pH, Soil pH	Secondary
pH 4 and pH 10 buffers	M,S,C	Precip. pH, Water pH, Soil pH	Middle Secondary
Total dissolved solids (conductivity) tester	P,M,S[3]	Electrical Conductivity - Fresh water sites only	All
Calibration solution	P,M,S,C[3]	Electrical Conductivity - Fresh water sites only	All
Hydrometer	P,M,S[4]	Salinity — Brackish/salt water sites only	All
500 mL clear plastic graduated cylinder	P,M,S[4]	Salinity — Brackish/salt water sites only	All
Secchi Disk, Rope	E,C	Transparency — Deep water site only	All
Turbidity tube	C	Transparency — Shallow water site	All
Remote sensing image data	See footnote[5]	Land Cover Mapping	All
Dichotomous keys	E[6]	Species Identification, Green-Up, Green-Down	All
50 m tape measure	P,M,S	Site Layout, Tree Circumference, Tree Height	All
Compass	E	Land: Qualitative and Quantitative study layout, Biometry study layout, Green-Up, Green-Down	All
Clinometer	E,C	Tree Height, Slope	All
Densiometer	C	Canopy Cover	All
Plant clippings drying oven	E	Grass Biomass	All

[3] Include in kit only for freshwater sites.

[4] Include in kit for brackish/salt water sites only.

[5] Remote sensing image data provided by GLOBE.

[6] Choose a dichotomous key appropriate to local vegetation; a generally applicable dichotomous key will be provided to each teacher at training.

Instrument	KIT(P,M,S,E,A,M)	Measurement	Skill Level
Dutch auger[7]	E	Soil: Profile, Bulk Density, Soil Moisture	All
Sand auger[7]	E	Soil: Profile, Bulk Density, Soil Moisture	All
Peat auger[7]	E	Soil: Profile, Bulk Density, Soil Moisture	All
Bucket auger[7]	E	Soil: Profile, Bulk Density, Soil Moisture	All
Shovel	E	Soil: Profile, Bulk Density, Soil Moisture	All
Camera	E	Soil Profile, Land: Site Layout, Green-Up, Green-Down	All
Meter stick	E	Soil: Depth, Soil Moisture	All
Color chart	P,M,S	Soil Color	All
Distilled white vinegar	E	Soil: Free Carbonates	All
Acid squirt bottle	P,M,S	Soil: Free Carbonates	All
#10 sieve (2 mm mesh)	P,M,S	Soil: Bulk Density	All
Soil drying oven	E	Soil: Moisture, Bulk Density	All
Balance	E	Gravimetric Soil Moisture, Soil Bulk Density	All
Soil cans – 15	E,C	Gravimetric Soil Moisture Soil Bulk Density — Pit or surface method	All
Other soil containers	E	Gravimetric Soil Moisture, Bulk Density	All
100 mL graduated cylinder	P,M,S	Soil pH, Bulk Density	All
Garden trowel	E	Gravimetric Soil Moisture	All
Dual Ring Infiltrometer	E,C	Soil: Infiltration	All
Soil Thermometer	P,M,S	Soil: Temperature	All
Plant Color Guide	P,M,S	Green-Down	All
Global Positioning System receiver	E[8]	Latitude, longitude and elevation	All

[7] Select auger appropriate for local soil type.

[8] If you do not have access to a GPS receiver please contact your GLOBE Country Coordinator or, in the United States, the GLOBE Help Desk.

Advanced Measurements

Instrument	KIT(P,M,S,E,A,C)	Measurement	Skill Level
Sun photometer	E	Aerosols	Middle, Secondary
Digital Voltmeter	E	Aerosols	Middle, Secondary
Aneroid Barometer	A	Barometric Pressure	All
Altimeter	A	Barometric Pressure	All
Ozone test strip scanner	A	Surface Ozone	All
Ozone chemical test strips	A	Surface Ozone	All
Ozone Measurement Station	C	Surface Ozone	All
Sealable bags	E	Surface Ozone	All
Wind direction device	E, C	Surface Ozone	All
Dissolved oxygen kit	A	Dissolved Oxygen	Middle, Secondary
Water alkalinity kit	A	Alkalinity	Middle, Secondary
Water Nitrate kit	A	Hydrology: Nitrate	Middle, Secondary
Hydrometer	A[9]	Soil: Particle Size	All
500 mL clear plastic graduated cylinder	A[9]	Soil: Particle Size	All
Dispersing solution	A	Soil: Particle Size	All
100 mL Erlenmeyer flask	A	Soil: Particle Density	All
Heat source	A	Soil: Particle Density	All
Soil NPK kit	A	Soil Fertility	Middle, Secondary
Safety Equipment — Plastic gloves and goggles	A	Hydrology: Dissolved Oxygen, Alkalinity, Salinity Titration, Nitrate	Middle, Secondary
MultiSpec software	See footnote[10]	Unsupervised Clustering	Middle, Secondary

[9] Needed only if such equipment have not been purchased for salinity measurement (Basic Measurement - brackish/salt water sites only).

[10] Downloadable from Purdue University http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/Index.html

Optional Measurements

Instrument	KIT(P,M,S,E,C)	Measurement	Skill Level
Salinity kit		Salinity — Titration Method	Optional, Middle, Secondary
Soil moisture sensors (4 required)		Soil Moisture Sensor	Optional, Secondary
Soil Moisture Meter		Soil Moisture Sensor	Optional, Secondary
PVC Pipe		Soil Moisture Sensor	Optional, Secondary
4-Channel data logger		Automated Soil and Air Temperature	Optional, Middle, Secondary
One air temperature sensor and three soil temperature sensors		Automated Soil and Air Temperature	Optional, Middle, Secondary
Water tight box		Automated Soil and Air Temperature	Optional, Middle, Secondary
Desiccant		Automated Soil and Air Temperature	Optional, Middle, Secondary

GLOBE Instrument Specifications

All GLOBE instrument specifications described below represent the minimum specifications necessary to collect scientifically valid data. GLOBE schools may use instruments that meet or exceed these specifications. For example, the GLOBE specifications for pH paper call for a range of 2 to 9 pH units. A pH paper with a range of 1 to 14 exceeds specifications and may be used by GLOBE schools.

Atmosphere/Climate

Cloud Cover/Type - All Skill Levels

Instrument Specifications: Cloud Chart

The GLOBE cloud chart shall display at least one visual example of each of the 10 basic cloud types - cirrus, cirrostratus, cirrocumulus, altostratus, altocumulus, cumulus, nimbostratus, stratus, cumulonimbus, stratocumulus. Sky cover will be visually estimated. The GLOBE Program will provide a cloud chart to each trained U.S. teacher and to each GLOBE Program Country Coordinator.

Aerosols – Middle, Secondary

Instrument Specifications: Sun Photometer

The GLOBE sun photometer has two optical/electronic channels, one with an effective aerosol optical thickness wavelength of 505 nm and the other with an effective AOT wavelength of 625 nm, where "effective aerosol optical thickness wavelength" is defined in Brooks, David R., and Forrest M. Mims III: Development of an inexpensive handheld LED-based Sun photometer for the GLOBE program. *J. Geophys. Res.* **106**(D5), 4733-4740, 2001. (That is, the algorithms presented in this paper are an integral part of the instrument specification.) The LED detectors for each channel must be obtained directly from the GLOBE Aerosols Science Team.

The detectors and their associated battery-powered electronics are housed in an enclosed plastic or metal box approximately 15 cm long by 5 cm high by 8 cm wide. The detectors must be mounted in a plane such that the LED chips themselves (embedded in a standard T-1-3/4 epoxy housing) are 12.5 cm from one end of the case and that end must contain a 5.5 mm (7/32") diameter sun aperture hole. The round end of the LED housing, which acts as a lens in usual LED applications, must be flattened and polished. There must be a clear line of site from this aperture hole to each detector. No internal light baffling is required.

Sunlight is aligned on the detectors through the use of two alignment brackets mounted on the outside of the case. Sunlight passes through a round hole in the front bracket and then shines upon two alignment marks on the rear bracket (one for each channel). When the sunlight spot is centered over an alignment mark, it should also be centered over the LED for the corresponding channel. (Alternate means of aligning the sun on the detectors are acceptable.)

The electronics consist of two low-power op-amp-based transimpedance amplifiers (or their functional equivalents) to convert the LED current to a voltage on the order of 1-2V in full sunlight. Noise, gain, temperature drift, and other op amp performance characteristics should be similar to that of Linear Technology LTC1050 or LTC1051 op amps. (Generic 741-type op amps or their dual equivalents are not suitable for this instrument.) Bypass capacitors should be included in the resistive feedback loops to prevent self-oscillation.

The sun photometer's output should be monitored either by attaching an external digital voltmeter to pin jacks mounted on the case, or through a built-in digital meter. A built-in meter should display at least three digits to the right of the decimal point for output in the 1-2V range.

Instrument Specifications: Digital Voltmeter

A digital voltmeter (or multimeter) with a DC volts setting that is either: (i) auto-ranging within the range 0-20VDC or (ii) manually selectable for range settings of 0-2VDC and 0-20VDC. For inputs of less than 10VDC (that is, up to 9.999V), the meter must display three digits to the right of the decimal point.

Barometric Pressure – All Skill Levels

Instrument Specifications: Aneroid Barometer

The aneroid barometer must have a clear scale with a pressure range between 940 and 1060 millibars. The scale should be readable to the nearest whole millibar and have an accuracy of 3.5 millibars over its entire range. A set needle should be on the face of the barometer. This barometer will be most useful for stations whose elevation is less than 500 meters above sea level. Schools at higher elevations will need to use an altimeter.

Instrument Specifications: Altimeter

An altimeter is a special type of aneroid barometer designed to provide heights (using standard temperature and pressure values), as well as true atmospheric pressure readings. The scale must be given in millibars and extend from 650 millibars to 1050 millibars. Accuracy must be 3.5 millibars over the range of the instrument. This instrument is for the measurement of atmospheric pressure at elevations over 500 m.

Relative Humidity – All Skill Levels

Instrument Specifications: Digital Hygrometer

The digital hygrometer must provide a digital readout of relative humidity to the nearest 1%. Over a range of 20-95%, accuracy must be at least 5%. The digital hygrometer should include a stand to allow the unit to be placed upright on the floor of the instrument shelter, while measurements are being taken. Calibration is done by the manufacturer and should be warranted for at least two years, with subsequent recalibration available. Batteries should be included. The unit should not be left outside on a daily basis.

Instrument Specifications: Sling Psychrometer

The wet bulb and dry bulb temperatures shall be measured with a sling psychrometer, which consists of two spirit-filled thermometers. The thermometers shall be readable only in degrees Celsius, with scales marked in increments of 1.0° C, and the scales must be capable of supporting temperature estimations to the nearest 0.5° C over a range of –1° C to 35° C. The psychrometer must be in a sturdy protective case or have spirit bulbs mounted on a rigid plate, and be provided with handle necessary for whirling or slinging. Thermometers must be factory calibrated to an accuracy of +1.0° C, which will provide relative humidity accuracy of 5%. Both scales should be adjustable for calibration, or the spirit bulbs replaceable. Each scale must be clearly marked to indicate Celsius. Siting and installation instructions are provided in the *Atmosphere Chapter*.

Instrument Specifications: Calibration Thermometer

The Calibration Thermometer described in Air Temperature may be used for this measurement.

Instrument Specifications: Maximum/Minimum Thermometer

The Maximum/Minimum Thermometer described in Air Temperature may be for this measurement.

Instrument Specifications: Instrument Shelter

The Instrument Shelter described in Air Temperature will be used for this measurement.

Surface Ozone – All Skill Levels

Instrument Specifications: Ozone Chemical Strips

The ozone chemical strips contain a solution of tin(II) chloride dihydrate and 1,5-diphenylcarbazide dissolved in reagent-grade acetone. When exposed to air, ozone reacts with the mixture and triggers a colorimetric reaction resulting in the formation of a pink color. Ground level ozone concentrations can be measured by quantifying the color change on an exposed chemical strip using an ozone optical reader.

Instrument Specifications: Ozone Test Strip Scanner

The ozone test strip optical reader operates as a simple spectrophotometer consisting of a light emitting diode (LED) emitting light near 540nm, and a photo diode that captures the reflected light off the exposed chemical test strip and converts it into an electrical voltage. The reader must be calibrated so that the voltage measured can be displayed as an ozone concentration in parts ozone per billion parts of air (ppb). Zero ozone level must be set by inserting an unexposed ozone test strip into the reader and storing the voltage produced. Any absorption at 540 nm above this value will be measured as a specific ozone concentration.

Instrument Specifications: Ozone Measuring Station

Directions for constructing an ozone measuring station are provided in the *Instrument Construction, Site Selection, and Set-Up* section of the *Atmosphere Chapter.*

Instrument Specifications: Wind Direction Instrument

Any device capable of displaying wind direction, such as weathervane. Directions for constructing a wind direction instrument are provided in the *Instrument Construction, Site Selection, and Set-Up* section of the *Atmosphere Chapter.*

Precipitation, Liquid - All Skill Levels

Instrument Specifications: Rain Gauge

Precipitation will be measured with a clear view plastic rain gauge with a collector that is at least 102 mm in diameter. The rain gauge must be at least 280 mm in height with a scale indicating rain collected of 0.2 mm or less on an inner clear cylinder. It must have the capacity to measure rainfall of 280 mm without overflowing. The shape of the outer part must also be cylindrical, and overflow from the inner cylinder shall be directed to the outer part of the rain gauge. The outer cylinder must be capable of being used in the inverted position to gather a snow sample for measurement of the water content of snow. The rain gauge must be provided with the necessary hardware for installation on a pole. Instructions for siting are provided in the GLOBE Program Teacher's Guide.

Precipitation, Solid - All Skill Levels

Instrument Specifications: Snowboard

The depth of daily snowfall will be measured with a plywood board which is approximately 40 cm X 40 cm x at least 1 cm thick.

Instrument Specifications: Rain Gauge

The rain gauge described in Precipitation, Liquid will be used for this measurement.

Instrument Specifications: Snow Depth Pole

For snow depths less than 1 meter, a meter stick is recommended. When the snow is deeper than one meter, a snow depth pole is used. This can be made from a 2 meter pole by placing two meter sticks end to end on this pole.

Precipitation pH - All Skill Levels

The same instruments described in Hydrology: Water pH will be used for this measurement.

Air Temperature - All Skill Levels

Instrument Specifications: Maximum/Minimum Thermometer

Air temperature shall be measured with a maximum/minimum thermometer. The maximum/minimum thermometer shall be readable only in degrees Celsius, with maximum and minimum scales marked in increments of 1.0° C, and the scales must be capable of supporting temperature estimations to the nearest 0.5° C. The thermometer must be in a sturdy protective case, and be provided with the necessary hardware for installation. It must be factory calibrated to an accuracy of +1.0° C. Both scales must be adjustable for calibration. Each scale must be clearly marked to indicate Celsius, and have indicators such as "+" and "-" on each scale to indicate direction of increasing and decreasing temperature. In addition, each scale must be clearly marked to identify which scale is maximum and which is minimum. Siting and installation instructions are provided in the GLOBE Program *Teacher's Guide*.

Instrument Specifications: Calibration Thermometer

The maximum/minimum thermometer will be calibrated with a second thermometer which is an organic liquid-filled thermometer with a temperature range of -5° C to 50° C. The thermometer must be factory calibrated and tested with standards traceable to N.I.S.T (The National Institute of Standards and Technology - United States) to an accuracy of +0.5° C, with 0.5° C scale divisions. It must be supplied with a metal jacket with holes at the bulb end to allow for circulation and a hole at the top by which to hang the thermometer in the instrument shelter for calibration of the maximum/minimum thermometer.

Instrument Specifications: Instrument Shelter

An instrument shelter is required to house the maximum/minimum thermometer and the calibration thermometer to assure scientifically usable air temperature measurements. The instrument shelter must be constructed of a material with a thermal insulation value which equals or exceeds that of seasoned white pine wood (approximately 2.0 cm thick). It must be painted white with exterior grade paint. The shelter must be vented, and be large enough to allow air circulation around the thermometer. The inside dimensions must be at least 45 cm high, 24.0 cm wide, and 12.0 cm deep. The shelter must have a hinged door on the front, be louvered on the front and sides, and have holes in the bottom and holes at the uppermost part of the sides to increase ventilation if the louvers do not extend to the top of the sides. The door must contain a lock. The instrument shelter must be mountable onto a wall or post. The top of the shelter must slope downward toward the front. The parts of the shelter must be securely fastened to each other, either using screws or with nails and glue. Joints must be sealed with weather resistant caulking compound. Detailed instructions on constructing an instrument shelter are provided in the *Instrument Construction, Site Selection, and Set-Up* section of the *Atmosphere Chapter.*

Hydrology

Water Temperature: - All Skill Levels

Instrument Specifications: Organic Liquid-filled Thermometer

The calibration thermometer described in Air Temperature will be used for this measurement.

Transparency - All Skill Levels

Instrument Specifications: Secchi Disk Apparatus (for deep water sites only)

5 m length of rope and a disk with a diameter of 20 cm. The disk shall be colored with paint or other

appropriate means such that alternate quadrants of each side are black and white. The disk must be made so that it will not be disfigured or damaged by repeated immersion in water, including sea water. It must be weighted such that it remains horizontal while it is lowered by the rope in the water.

Instrument Specifications: Turbidity Tube (for surface water)

Clear plastic tube, approximately 1.2 m long and 4.5 cm diameter with a white cap that fits securely on the end of the tube. The end cap must display a pattern consisting of alternating black and white quadrants on the side that is viewed by looking down the tube.

Water pH - All Skill Levels

Note: The instrument requirements for this measurement vary according to skill level. Please select the appropriate instrument for your students.

Skill Level - Primary

Instrument Specifications: pH Paper

The pH of standing water at this skill level will be measured with pH paper which can be purchased in strips or rolls. The pH paper must have ± 1.0 pH unit accuracy, with a range of 2 to 9 pH units. For water samples with low conductivity the pH paper must be accurate in low conductivity levels.

Skill Level - Middle

Instrument Specifications: pH Pen

The pH of standing water at this skill level will be measured with a pH pen. The GLOBE instrument must have an accuracy of 0.2 pH units with a range of pH 1 to pH 14. The operating temperature range must be 0 C to 50 C. The pH pen must be capable of being calibrated using two known pH buffer solutions: a pH 7 buffer and either a pH 4 or 10 buffer.

Skill Level - Secondary

Instrument Specifications: pH Meter

The pH of standing water at this skill level will be measured with a pH meter. The pH meter must have an accuracy of 0.1 pH unit, and a range of pH 1 to pH 14, at temperatures from 0 C to 50 C. The device shall automatically compensate the reading when it is placed in solutions of differing temperature. The pH meter must be capable of being calibrated automatically using three known pH buffer solutions: pH 4, 7, and 10.

Skill Level - Middle, Secondary

Instrument Specifications: Buffers

pH buffer solutions are required to calibrate the pH pen and meter. The buffer solutions should have a value of pH 4.0, pH 7.0 and pH 10.0.

Dissolved Oxygen - Middle, Secondary Skill Levels

Instrument Specifications: Dissolved Oxygen Kit

A dissolved oxygen test kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Enables measurement of dissolved oxygen with an accuracy of at least +/- 1 mg/L
- Contains all the chemicals and special containers to perform this measurement based on the Winkler titration method. This method is described in *Standard Methods for the Examination of*

Water and Wastewater, 19th edition, 1995, a publication of the American Public Health Association, Washington, DC.

- Contains clear instructions for using the kit to make this measurement using a procedure based on the Winkler titration method.

Alkalinity - Middle, Secondary Skill Levels

Instrument Specifications: Water Alkalinity Kit

A water alkalinity kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Enables measurement of total alkalinity with an accuracy of at least 6.8 mg/L as $CaCO_3$ (low range, under 136 mg/L), and 17 mg/L as $CaCO_3$ (high range, above 136 mg/L).
- Contains all chemicals and containers needed to perform the alkalinity titration, including: 1) Bromocresol green-methyl red indicator and scoop for adding the required amount to the sample, 2) sulfuric acid for titration, and method of delivering acid to sample to achieve the required accuracy, 3) measuring containers and bottles for titration. This method is described in 19th edition, 1995, a publication of the American Public Health Association, Washington, D.C.
- Contains clear instructions for using the kit to make this measurement, based on acid titration to a Bromocresol green-methyl red end point.
- Plastic gloves and safety goggles

Instrument Specifications: Safety Equipment

Plastic gloves and safety goggles must be used in making this measurement.

Electrical Conductivity (for fresh water sites) - All Skill Levels

Instrument Specifications: Electrode-type Total Dissolved Solids Tester (Conductivity Meter)

This device shall measure electrical conductivity of liquid solutions using two metal electrodes separated by a fixed distance. The device shall be designed to be hand-held, and battery powered, with no electrical power cord attached. The device shall employ a method to automatically compensate the indicated conductivity value relative to changes in the temperature of the solution. The measurement range shall be at least from 0-1990 microSiemens/cm, with a resolution of 10 microSiemens/cm, an accuracy of +/- 2% full scale, and an operating temperature of 0-50 C. The device shall be capable of calibration using a standard solution.

Instrument Specifications: Calibration Standard

A solution of KCl and water or NaCl and water that has a conductivity of about 450 microSiemens (225.6 mg/L KCl or 215.5 mg/L NaCl).

Salinity (for brackish and salt water sites) -All Skill Levels

Instrument Specifications: Hydrometer Method

The same instrument described in Soil Particle Size will be used for this measurement.

A 500 mL clear plastic cylinder and an organic liquid-filled thermometer for use with the hydrometer are required. The 500 mL cylinder for Soil Particle Size may be used. The calibration thermometer for Air Temperature may be used.

Instrument Specifications: Salinity Titration Method - Optional, Middle, Secondary Skill Levels

A salinity kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Range: 0 - 20 parts per thousand (ppt)*
- Smallest increment: 0.4 ppt
- Method/chemistry: chloride titration
- Approximate number of tests: 50
- Contains clear instructions for using this kit to make this measurement, based on the chloride titration method.

*Titrator must be refillable for use in higher salinity waters.

Nitrate - Middle, Secondary Skill Levels

Instrument Specifications: Water Nitrate Kit

A nitrate kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Range: 0 - 10 ppm NO_3-N
- Smallest increment: 0.05 ppm NO_3-N for the range 0 -1 ppm NO_3-N; 0.5 ppm NO_3-N for the range 1 - 10 ppm NO_3-N
- Method/chemistry: cadmium reduction
- Approximate number of tests: 50
- Contains clear instructions for using this kit to make this measurement, based on the cadmium reduction method.

Soil Characterization

Soil Slope - All Skill Levels

Instrument Specifications: Clinometer

The clinometer described in Land Cover: Tree Height will be used for this measurement.

Soil Profile - All Skill Levels

Instrument Specifications: Camera

It is assumed that a camera with color film is available locally.

Instrument Specifications: Meter Stick

A durable ruler with gradations every cm and mm.

Soil Structure - All Skill Levels

Instrument Specifications: None

Color - All Skill Levels

Instrument Specifications: Color Chart

A soil color chart designed especially for the GLOBE Program can be purchased. It contains at least 200 colors and uses the Munsell System of Color Notation. This flip chart is weather-resistant and has large color chips which are edge-mounted for ease of reading. The color range includes all hues found in the full set of International soil colors, yet provides a selected set of values and chroma to aid color identification for students. Manufacturers who wish to prepare another version should contact the GLOBE Program for the complete list of colors.

Soil Consistence - All Skill Levels

Instrument Specifications: None

Soil Texture- All Skill Levels

Instrument Specifications: None

Free Carbonates - All Skill Levels

Instrument Specifications: Vinegar

Distilled white vinegar. Household vinegar may be used.

Instrument Specifications: Acid Squirt Bottle

A bottle capable of safely holding at least 200 mL of acid is required.

Sample Preparation for Bulk Density, Particle Size, Soil pH, and Fertility Protocols - All Skill Levels

Instrument Specifications: Sieve

Number 10 sieve with 2 mm mesh attached to a frame.

Soil Bulk Density - All Skill Levels

Instrument Specifications: Graduated Cylinder -100 mL

Glass graduated cylinder with a capacity of 100 mL marked in 1 mL or smaller divisions, with graduations covering at least the range from 10 mL to 100 mL.

Instrument Specifications: Balance and Augers

The same balance and auger used for Gravimetric Soil Moisture will be used for Bulk Density.

Instrument Specifications: Soil Sample Cans and Other Soil Containers

Cans and containers should meet the same specifications as given for these items for Gravimetric Soil Moisture

Soil Particle Size - All Skill Levels

Instrument Specifications: Hydrometer

The hydrometer used should meet the following requirements:

- Calibrated to specific temperature for water and sample (e.g. 15.6 C / 15.6 C
- Range (specific gravity / no units): 1.0000 - 1.0700
- Smallest increment (no units): 0.0005

Instrument Specifications: Thermometer

The Calibration Thermometer described in Air Temperature will be used for this measurement.

Instrument Specifications: 500 mL Clear Plastic Graduated Cylinder

One 500 mL capacity plastic graduated cylinder, marked at least at the 500 mL level. Cylinder must be clear plastic, not frosted plastic and not glass.

Instrument Specifications: Dispersing Solution

Sodiumhexametaphosphate powder or a 10% solution of either sodiumhexametaphosphate or a detergent that does not produce suds.

Soil Particle Density – All Skill Levels

Instrument Specifications: 100 mL Erlenmeyer flask

A heat-resistant Erlenmeyer flask with a cap, capable of holding 100 mL of solution.

Instrument Specifications: Heat source

A heat source capable of bringing 100 mL of a water and soil solution to a gentle boil and maintaining this boil for at least 10 minutes.

Soil pH - All Skill Levels

Instrument Specifications: pH measurement devices

The same instruments described in Hydrology: Water pH will be used for this measurement.

Instrument Specifications: Graduated Cylinder -100 mL

The same instrument as described in Bulk Density will be used for this measurement.

Soil Fertility - Middle, Secondary Skill Levels

Instrument Specifications: Soil NPK (Macronutrients) Kit

The test kit must:

- Contain unit-dose reagents and containers needed to extract soil nutrients from 50 samples and to perform 50 tests of each: soil nitrogen; soil phosphorus; and soil potassium.
- Employ methods based on the Spurway extraction method, the zinc reduction/chromotropic acid method for nitrogen, the ascorbic acid reduction method for phosphorus, and the sodium tetraphenylboron (turbidimetric) method for potassium.
- Contain clear instructions, including diagrams, for using the kit.
- Contain a water resistant color chart for interpreting the results of colorimetric tests and a turbidity chart for the turbidimetric test.

Soil Moisture and Temperature

Gravimetric Soil Moisture - All Skill Levels

Instrument Specifications: Balance

This balance must have the capacity to weigh 300 grams with an accuracy of +/- 0.1 gram. It can be either mechanical or electronic. It is assumed that a balance is available locally, for example in a high school science laboratory.

Instrument Specifications: Drying Oven (soils)

Drying oven capable of holding a temperature of 95 C - 105 C for at least 10 hours or a temperature of 75 C - 95 C for 24 hours. The oven must be ventilated, and have interior dimension of at least 25 cm x 30 cm x 25 cm. It is assumed that an oven is available locally, for example in a high school science laboratory.

Instrument Specifications: Microwave Drying Oven

Any microwave oven compatible with school use.

Instrument Specifications: Soil Sample Cans

15 round sample tins. A metal container with a diameter 7 cm, and height 5 cm, with a removable cover is appropriate as are small round, cleaned food cans. Cans must be capable of having a small hole punched in their bottoms.

Instrument Specifications: Other Soil Containers

15 containers large enough to have soil samples transferred into them directly from an auger without loss of sample. Glass jars, plastic food containers with lids, or other containers that can be covered and that can hold the soil samples while they are dried in the drying oven selected.

Instrument Specifications: Dutch Auger For Combination Soils

Dutch (or Edelman) auger for combination soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Dutch Auger For Sandy Soils

Auger designed for sandy soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Bucket Auger

Bucket (or Riverside) auger designed for hard and brittle soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Peat Auger

Auger designed for peat soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Block Soil Moisture - Optional, Secondary Skill Level

Instrument Specifications: Soil Moisture Sensors

Electrical resistance-type sensors; approximate dimensions: 70 mm high x 20 mm diameter; concentric electrodes (stainless steel) with a gypsum core to moderate salinity effects; embedded in a resistant granular matrix; surrounded by a synthetic membrane and a stainless steel jacket; sensors must be field worthy for more than two years; insulated lead wires (~1.5m) must be soldered to electrodes.

Instrument Specifications: Soil Moisture Meter

Hand-held AC conductivity meter for use with granular matrix sensors (described above); push button calibration/compensation and push button digital reading. Conductivity may be normalized/scaled but any conversion to other units must be documented by a robust calibration curve and conditions affecting this conversion. The unit must have two terminals which enable attachment and removal of electrical conductor wires on a daily basis. The unit must be battery powered and rugged for use in remote locations.

Instrument Specifications: PVC Piping

The PVC pipe assists in placing the soil moisture sensors in the ground. It should be 90 cm in length and approximately 2 cm in diameter. Additional PVC piping is required to mark the location of the sensors. These should be 23 cm long with a diameter of approximately 5 cm. Four pieces of this material are required.

Infiltration — Optional, All Skill Levels

Instrument Specifications: Dual Ring Infiltrometer

Two concentric metal cylinders. The inner one must have a diameter of 10 cm to 25 cm. The outer one must have a diameter at least 10 cm larger than the inner cylinder. Both cylinders should be 10 to 15 cm high and open at both ends. Steel cans may be found which will work for this apparatus.

Soil Temperature- All Skill Levels

Instrument Specifications: Soil Thermometer

A 11 cm to 20 cm stainless steel probe, heavy-duty construction dial or digital thermometer with a range of at least -10 to 50 degrees C (Celsius scale required) and an accuracy of 1% full scale (over a range of no more than 200 degrees C) or better is required. The sensor should be in the bottom third of the probe. The sensor should give stable readings after less than 60 seconds in an isothermal bath. Batteries, if required, should be included. The sensor should be adjustable with the calibration procedure and achievable accuracy clearly stated. Dial thermometers must be sealed against fogging and be covered with shatterproof glass or plastic. Scale graduations of 1.0 degrees C and 0.1 degrees C are preferred for dial and digital thermometers, respectively. Glass stem thermometers are NOT acceptable.

Automated Soil and Air Monitoring – Optional, Middle, Secondary

Instrument Specifications: 4-Channel Data Logger

A self contained, programmable data logger capable of collecting and storing data from four temperature sensors (one air, possibly internal, and three soil - external channels). Data logger must be capable of collecting data at 15 and 60 minute intervals (sampling frequency) and storing at least 3750 measurements (time/date stamped) per channel (8kb capability is preferred) in nonvolatile memory. The time accuracy must be ±1 minute per week. The temperature must be recorded with at least 7 bits of resolution. The logger must be powered by a user-replaceable lithium-grade battery, with a continuous use lifetime of one year. It must have operational ranges of -20 to +70 degrees Celsius in a 0 - 95% relative humidity, non-condensing environment.

Instrument Specifications: Data Logger Computer Interface and Software

Computer interface cables and appropriate software for launching the logger and retrieving the data must be available. The computer interface must be MS WINDOWS compatible. MAC compatibility is desired but not essential. The software must allow the data to be exported as an ASCII text file and should provide some basic graphical display of the data.

Instrument Specifications: Air and Soil Temperature Sensors

Air temperature can be sensed internally if the response time is less than 15 minutes, otherwise, a short (0.3 meter) cable (and 4th external channel) must be available. The soil temperature sensors must be designed to work for years buried up to 1 meter deep in unsaturated soils. Their cables must be between 3 and 6 meters in length. All sensors and cables must be weather and sun-resistant since they will be deployed outside on a continuous basis. All sensors should have an accuracy of ± 0.5 degrees Celsius (at 20 degrees Celsius) and a range of -30 to +100 degrees Celsius.

Instrument Specifications: Watertight Box

Instructions for constructing a watertight box are provided in the *Automated Soil and Air Temperature monitoring Protocol.*

Instrument Specifications: Desiccant

100 mL of $CaSO_4$ or other dehydrating agent.

Instrument Specifications: Instrument Shelter

The Instrument Shelter described in Air Temperature will be used for this measurement.

Land Cover/Biology

Land Cover - All Skill Levels

Instrument Specifications: Landsat Thematic Mapper (TM) Image, MultiSpec software.

The GLOBE Program will provide a TM image to all US schools. MultiSpec software is available for downloading from the Internet.

Species Identification - All Skill Levels

Instrument Specifications: Dichotomous Keys

Dichotomous keys for tree identification are not available from a central supplier; they need to be acquired locally.

Biometry

Layout of the Biology Site - All Skill Levels

Instrument Specifications: Tape Measure

50 m tape, graduated one side, marked in 2 mm or smaller units.

Tree Circumference - All Skill Levels

Instrument Specifications: Tape Measure

The tape measure described in Layout of the Biology Site will be used for this measurement.

Tree Height - All Skill Levels

Instrument Specifications: Tape Measure

The tape measure described in Layout of the Biology Site will be used for this measurement.

Instrument Specifications: Clinometer

The clinometer may be made by students from plans in the GLOBE Teacher's Guide, or may consist of a moveable dial within a metal case and lens viewer. For the moveable dial version, the scale must be graduated from 0-90° in 1° units.

Canopy Cover - All Skill Levels

Instrument Specifications: Densiometer

The densiometer may be made by students according to instructions in the GLOBE Teacher's Guide.

Ground Cover - All Skill Levels

Instrument Specifications: None

Grass Biomass - All Skill Levels

Instrument Specifications: Balance

This balance must have the capacity to weigh 300 grams with an accuracy of +/- 0.1 gram. It can be either mechanical or electronic. It is assumed that a balance is available locally, for example in a high school science laboratory.

Instrument Specifications: Drying Oven (plants)

This oven must be capable of holding samples at 50-70 C for up to two days and must be ventilated

to allow moisture to escape. The interior dimensions of the oven must be at least 25 cm x 30 cm x 25 cm. It is assumed that an oven is available locally, for example in a high school science laboratory. The oven should be designed for drying biological samples or food and should not be a conventional cooking oven, which could present a fire hazard in this application.

Phenology

Green-Up – All Skill Levels

Instrument Specifications: Dichotomous Keys

Dichotomous keys for tree identification are not available from a central supplier; they need to be acquired locally.

Instrument Specifications: Camera

It is assumed that a camera with color film is available locally.

Green-Down – All Skill Levels

Instrument Specifications: Plant Color Guide

A guide made of weather-resistant paper that contains reference color chips based on the Munsell System of Color Notation. The following colors should be displayed: 5G 8/4, 5G 7/4, 5G 6/2, 5G 4/2, 5GY 3/2, 5GY 4/8, 2.5Y 8/6, 2.5Y 8/12, 5YR 7/12, 5GY 7/12, 5GY 6/10, 5GY 5/10, 2.5Y 6/6, 5Y 8/4, 7.5YR 8/4, 7.5YR 6/4, 7.5YR 5/4, 7.5YR 3/4, 5R 3/4, 2.5R 4/2, 2.5R 4/4, 2.5R 4/6, 2.5R 4/8, 2.5R 4/12. Each color chip must be positioned near a cutout that allows color comparison between plant leaves and the reference chips.

Instrument Specifications: Dichotomous Keys

Dichotomous keys for tree identification are not available from a central supplier; they need to be acquired locally.

Instrument Specifications: Camera

It is assumed that a camera with color film is available locally.

GPS

Latitude, Longitude and Elevation of GLOBE Study Sites - All Skill Levels

Instrument Specifications: Global Positioning System (GPS) Receiver

The instrument must be capable of:

- Expressing latitude and longitude in whole degrees, minutes and decimal minutes to the nearest 0.01 minutes and
- Displaying time on screen in units of UT hours, minutes, and seconds,
- Using the WGS-84 map datum, and
- Displaying elevation in meters.

Manual Classification

A Tutorial for the Beverly, MA , Image

The following tutorial is provided as an example of how a manual interpretation land cover map is made for the Beverly, MA, TM image. See Figure TK-1. After completing this tutorial as a training exercise, each step presented should also be done by your students, but using the TM image of your own area (both the original 512 X 512 pixel TM image, and color enlargements made by the teacher and distributed to groups of students). Figure TK-1 shows a false-color infrared image of a 101 by 101 pixel (3 km x 3 km) enlargement of the Beverly, MA image. The enlarged area is Manchester-by-the-Sea, MA, and will be used to illustrate the process of performing a "manual" land cover classification. Note that water and vegetation types are much more readily distinguished if the false color IR image is used to make the land cover map.

The following steps are used in the manual interpretation method:

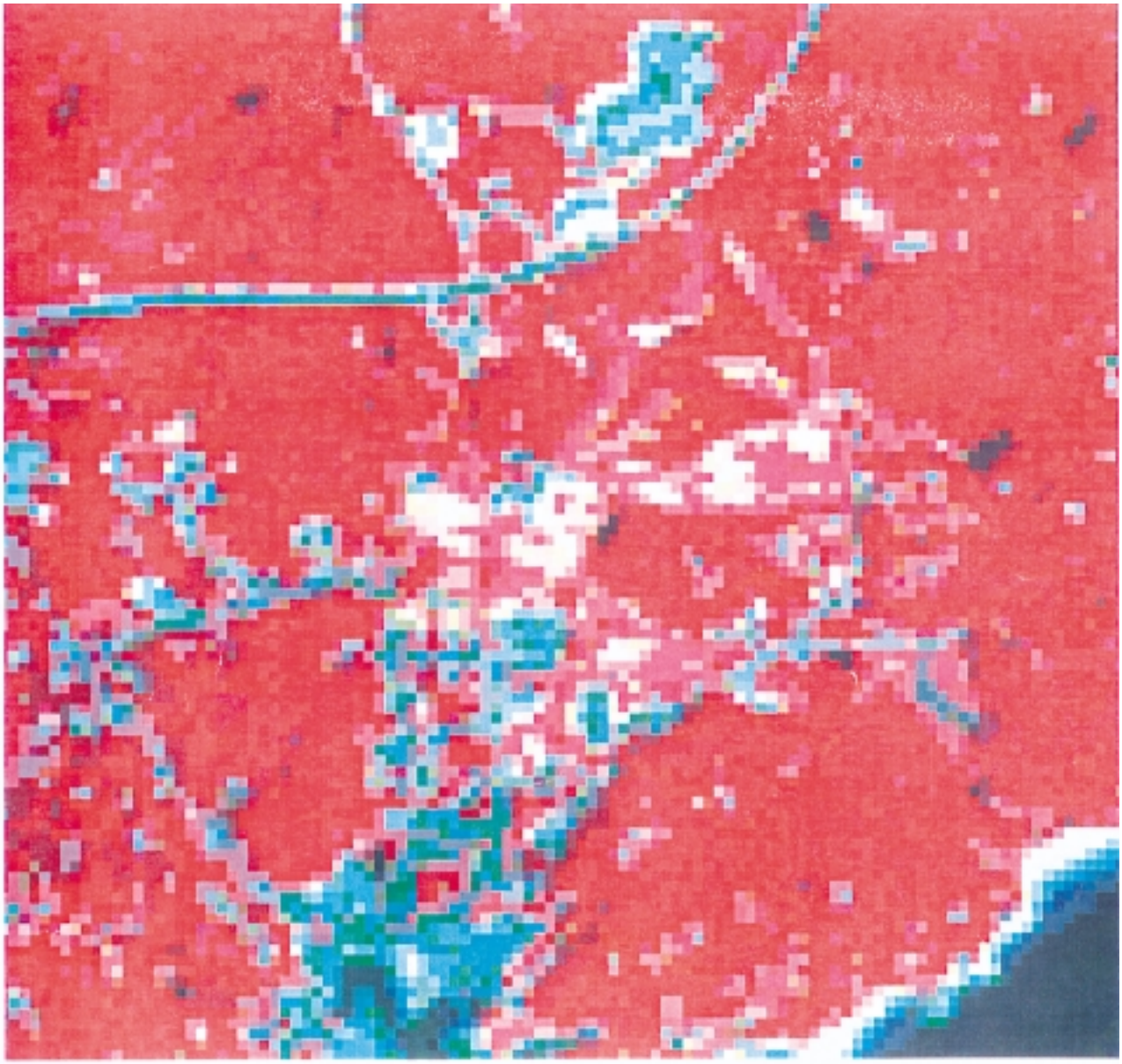
1. Select the Landsat TM image to be mapped (the 3 km X 3 km Manchester-By-The-Sea false color IR print provided as Figure TK-1.) In the false color IR image, actively growing green vegetation will appear red (hardwoods and fields are bright red, evergreens are dark red to black), water is black, while urban areas and bare soils are blue. This image has been enlarged from the original 512 X 512 pixel (15 km X15 km) image of Beverly, MA, to produce Figure TK-1. You may choose to do this using an enlarging color xerox, or you may need to arrange to print copies from your Landsat file, using MultiSpec. You may have four or more small groups of students working on different enlarged portions of the original 512 X 512 pixel image of your area.
2. Overlay an 8.5 X 11 inch sheet of clear plastic on top of the colored print of the image, using tape to hold it firmly in place. Once the overlay is in place, mark the location of the image edges on the overlay so that it can be placed in exactly the same position if it is removed. This will also allow you to place the overlay on either the true color image or the false color IR image in order to take advantage of the discrimination capabilities of each type of image.
3. The classification process involves carefully outlining the different land cover types seen on the image, using either colored crayons or felt-tip marking pens. Use different colors to represent each different land cover class, and assign to each the appropriate number for its specific MUC Level 4 land cover classification (MUC is the Modified UNESCO Classification system. It can be found in the *Land Cover/Biology Investigation*.)

- Outline the water bodies as shown in Step 1 using the MUC Level 2 class 72 for Marine, 63 for tidal river, and 64 for a lake (note that in some cases, no Level 3 or Level 4 categories have been developed for the MUC system).
- Outline the urban/transportation features next, and shown in Step 2. The MUC category 93 (transportation) is assigned in this case.
- Outline urban features next, as shown in Step 3. These features include commercial and industrial (#92); residential (#91); and a golf course, labeled "other" (#94).
- Finally, outline the various forest vegetation types, such as 0192 to indicate evergreen forests typical of eastern Massachusetts, 0222 for mixed hardwoods and softwoods, and 0231, for mainly hardwoods (deciduous), as shown in Step 4.

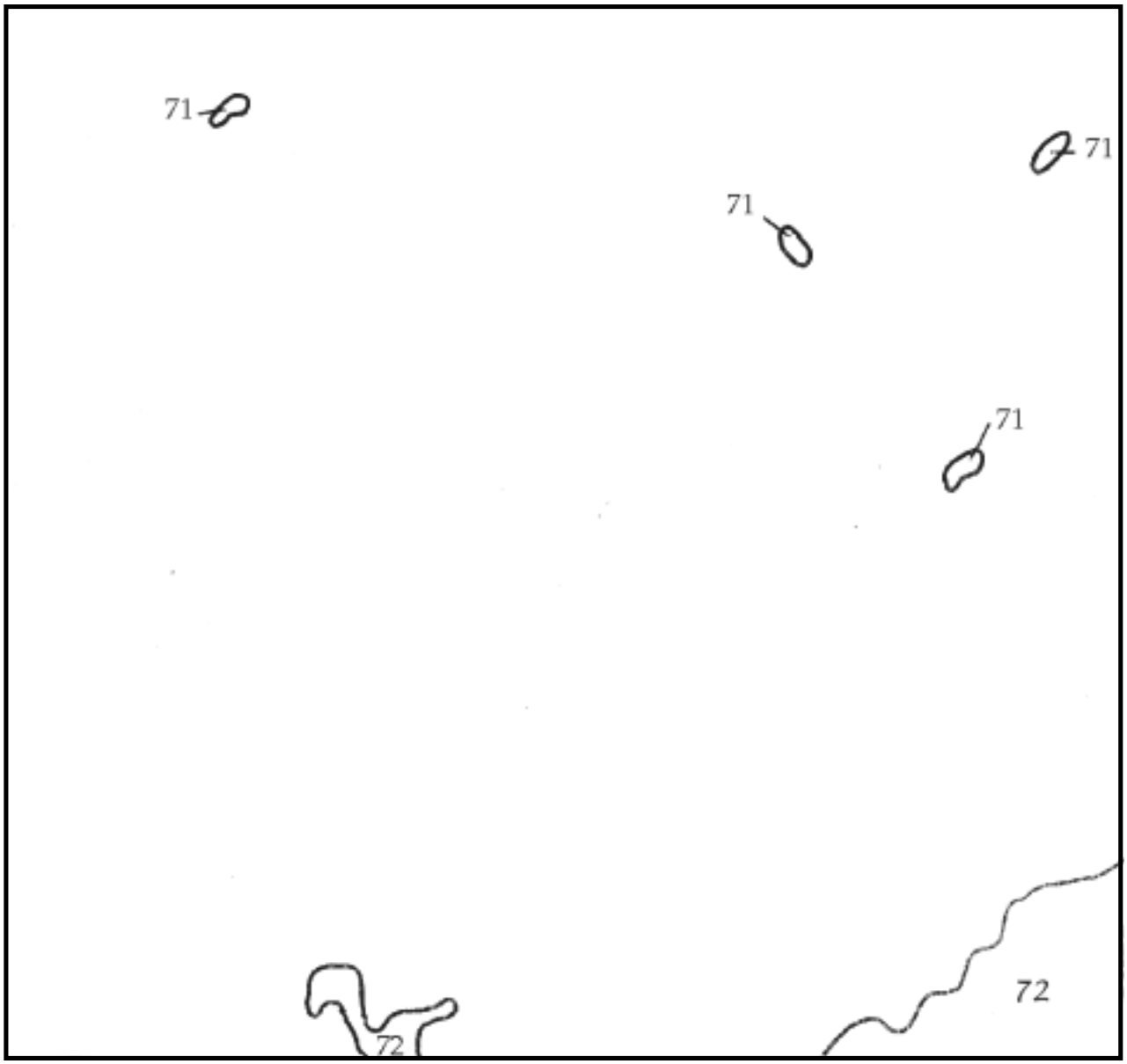
The final product (Step 4) represents a land cover map for the Manchester-By-The-Sea, MA, area. In this example, it will not be possible for you and your students to field

check any of the questionable cover types (ie, the gravel pit marked with a question mark (?) in Step 3). If your students are not sure of a specific area or class for your own images, have a discussion as to what the class might be and ask a student living near the area to provide a ground assessment on the way to or from school. This activity is likely to take several class periods to complete. Ask your students to be as careful and specific as possible in outlining and assigning classes to the various patterns seen on their images. Good Luck!!!

Figure TK-1: Beverly Landsat Scene



Step 1

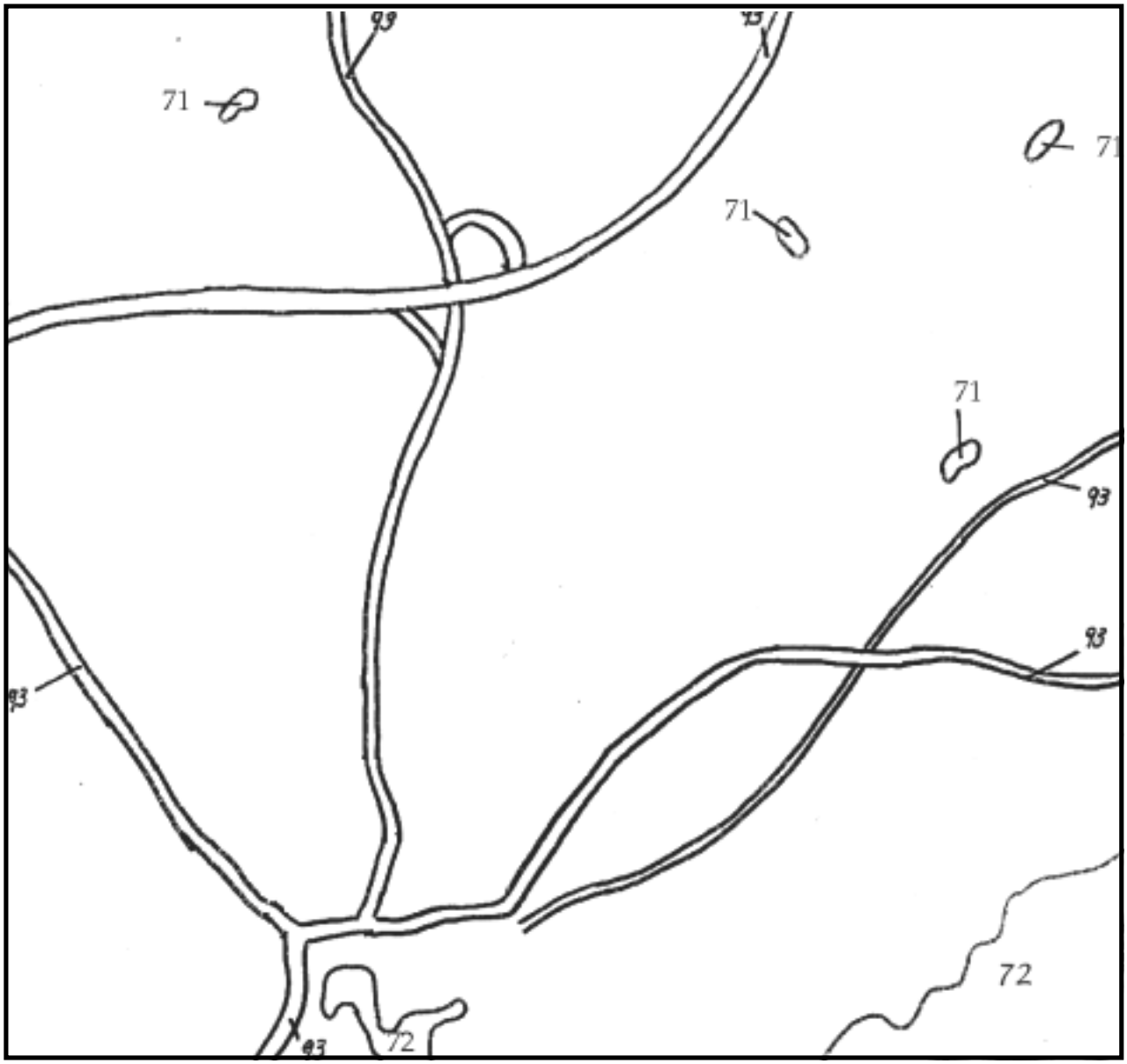


Step 1: Areas of water are outlined

72=marine

71=freshwater

Step 2

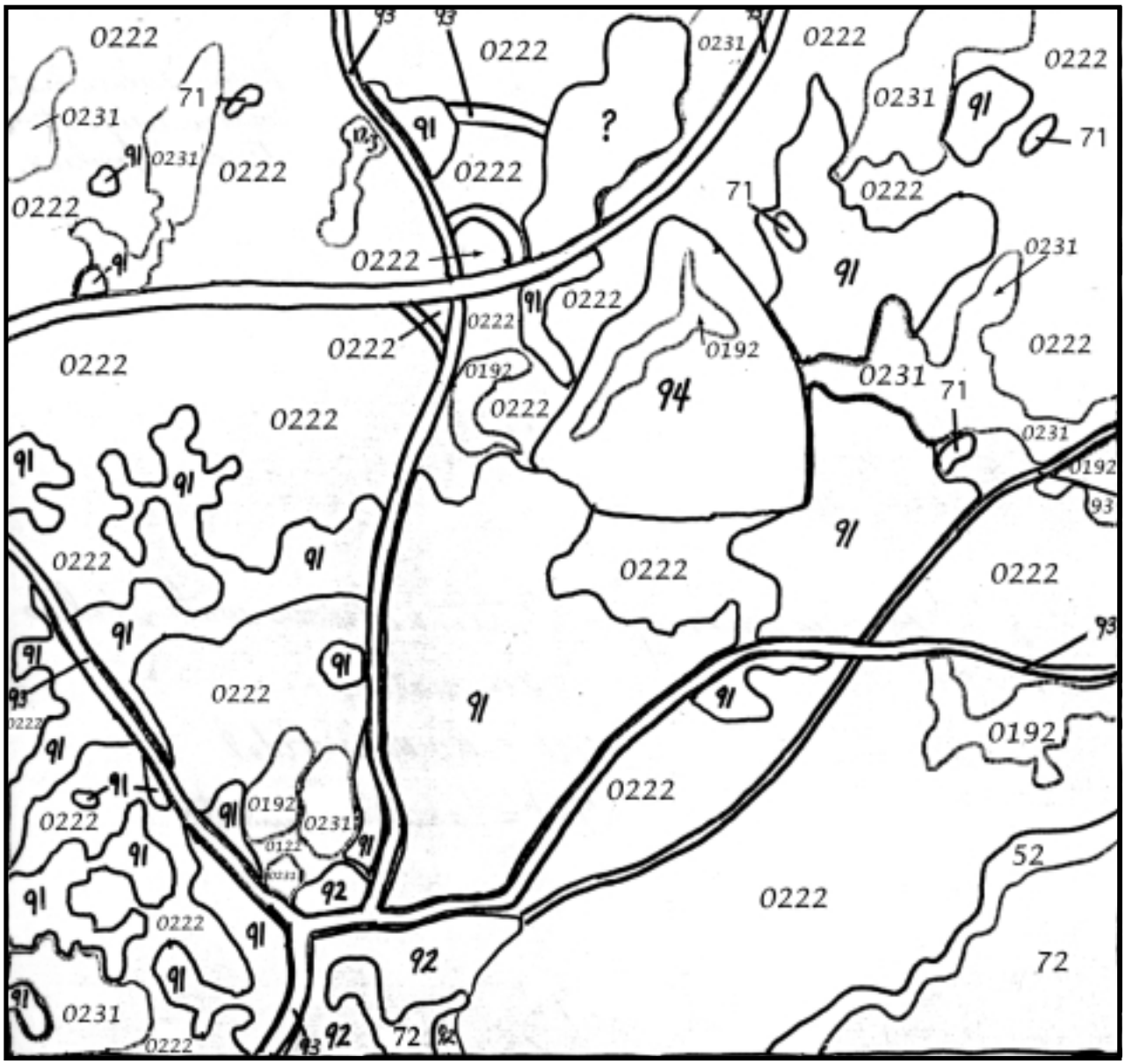


Step 2: Transportation features are outlined (roads, railways, etc)

Step 3

Step 3: Outline Urban Features (residential areas, commercial and industrial areas, etc.) Note that the gravel pit (? area) looks like commercial but needs to be ground checked.

Step 4



Step 4: Vegetated areas are outlined for the final step.

0192=Evergreens

0222=Mixed hardwood/softwood-mainly deciduous forest with some evergreens

0231=Hardwood(deciduous)-mainly deciduous forest without evergreens