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Development of a Water Education Module for Middle School Students under the Guidance of the Chihuahuan Desert Nature Park and based on EPSCoR funded Research on Evapotranspiration along the Middle Rio Grande

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**Development of a Water Education Module for Middle School Students under the
Guidance of the Chihuahuan Desert Nature Park and based on EPSCoR funded
Research on Evapotranspiration along the Middle Rio Grande**

By

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Committee

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A Professional Project Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Water Resources
Water Resources Program
The University of New Mexico
Albuquerque, New Mexico

April 28, 2008

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COMMITTEE APPROVAL

The Master of Water Resources Professional Project Proposal of **Alicia Paz-Solís** entitled **Development of a Water Education Module for Middle School Students under the Guidance of the Chihuahuan Desert Nature Park in Las Cruces, New Mexico and Based on EPSCoR funded Research on Evapotranspiration along the Middle Rio Grande** is approved by the committee:

Chair

Date

Abstract

In 2004, a study by S.S. Papadopoulos determined that riparian evapotranspiration (ET) along the Middle Rio Grande (MRG) accounts for 37% of the total water budget in this stretch of the river. Transferring important findings such as this to middle school age students presents both a challenge and an opportunity to provide authentic research based information to tomorrow's water managers and inspire their curiosity regarding water issues in New Mexico. This Professional Project presents two activities that incorporate selected aspects of the ET research funded by New Mexico's Experimental Program to Stimulate Competitive Research (EPSCoR) along the Middle Rio Grande. The first activity is entitled *Plant Transpiration* and the second one is *Remote Sensing*.

The two activities were developed as part of the Water Module of the Chihuahuan Desert Nature Park in Las Cruces, New Mexico and have been aligned to meet New Mexico Science Content Standards for 5th through 8th grade. Currently, the activities were tested in Albuquerque classrooms, and will soon be presented in a teacher workshop in Las Cruces. The Plant Transpiration activity transfers the core question of the current ET research of whether non-native plants lose more water due to ET processes than native plants. The Remote Sensing activity presents Landsat 7 images as a valuable tool for studying the environment from a new perspective. A number of researchers and educators from across New Mexico provided valuable input in developing the two activities.

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Thank you to Dr. Kristin Vanderbilt in the Biology Department at the University of New Mexico for being so incredibly patient and spending many hours going over my ideas with me.

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Their vision drove this project.

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The Water Resources Program at the University of New Mexico for their support of multi-disciplinary work.

I would like to express my deepest gratitude to my parents Miguel A. Paz Cuentas and Alicia S. de Paz for their unwavering love and support throughout my entire education and years of life. Their immense value of education makes this project very meaningful to me. I hope to have in some way contributed to the education of children on such vital research. Thank you to my sisters Mariceli Paz Solis and Evelyn Paz Solis for their unconditional love and support. This Professional Project would not have been possible without my family's support. They are the greatest source of strength and inspiration in my life... ¡GRACIAS FAMILIA!

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1. Introduction and Background

Areas of dry climate like New Mexico face limited water supplies. Almost 40% of the Middle Rio Grande (MRG) water budget depletions are due to evapotranspiration (ET) processes (S.S. Papadopoulos, 2004). For this reason, research that accurately quantifies ET is paramount. Sound research allows water managers to make well informed decisions regarding the eradication of invasive species like salt cedar. Transferring ET research concepts and technology to middle school students will bring real life research into their classroom. Thus, awakening their interest in water related research in New Mexico, and potentially influencing the way in which they will manage the state's most precious resource.

The goal of this Professional Project is to build a bridge between hydrological research and middle school education. Specifically, ET research funded by the New Mexico Experimental Program to Stimulate Competitive Research (NM EPSCoR) and middle school education imparted by the Chihuahuan Desert Nature Park in Las Cruces, New Mexico. NM EPSCoR assists the National Science Foundation (NSF) by strengthening research and education in science and engineering. Through funding from the NSF, NM EPSCoR gathers the expertise of scientists from different universities across New Mexico. The University of New Mexico, New Mexico Tech and New Mexico State University are part of this collaborative effort. Educational efforts by EPSCoR intend to provide a link between NM EPSCoR's joint research and K-16 education (NM EPSCoR, 2006).

As EPSCoR's Education Partner, the Chihuahuan Desert Nature Park provided a space for this Project to be developed. The Park is a non-profit organization that imparts science education to K-12 students and to adults. The director Dr. Stephanie Bestelmeyer expressed an interest in developing activities as part of their Water Module that would incorporate aspects of the EPSCoR research. Educational material that is derived from actual research is highly valued in school settings. Evidence of this is found in Science Education literature which states that very little work has been done in translating

research findings to science education. Transferring science into education can offer more authenticity and inclusiveness in a classroom. In recent years educators have suggested that science education curricula could be enhanced by drawing inspiration from the studies of scientists (Bowen, 2007). The material developed for the Water Module of the Park answers the need for instructional material that directly reflects the current ET research.

ET studies along the MRG are done through the use of state of the art instrumentation and by using tools like remote sensing by Landsat 7 satellite images. ET research rests on findings such as the S.S. Papadopoulos study. It is also supported by annual estimates of the extent of riparian zone ET along the Middle Rio Grande corridor that range from $150 \times 10^6 \text{ m}^3$ to $375 \times 10^6 \text{ m}^3$ (Coonrod and McDonnell, 2001). The research constitutes an ongoing process that continuously provides valuable insights, and finds new inspiration and technological tools. This Project presents the development of two activities that reflect the importance of ET investigation and technology along the Middle Rio Grande. The first activity relates to understanding and quantifying *Plant Transpiration*. The second activity has to do with studying the environment from a new perspective and calculating ET through *Remote Sensing* (See Appendix B for activities).

The activities incorporate important aspects of the ET research and intend to make classroom instruction more authentic and inspiring. Both activities have been aligned to meet New Mexico Science Content Standards for grades 5th - 8th and follow the format established by the Chihuahuan Desert Nature Park. The activities developed in this Project present science to middle school students as a method for addressing important questions that directly influence water management in the state. It is unique instructional material based on first-hand knowledge of the research and a personal commitment to education and outreach. The Constructivist Learning Model was taken into account while developing this material (See Figure 1). In essence, the activities reveal an alternative to building a bridge between research and education outreach. It is not the only way to accomplish this goal. Science is dynamic and so is science education, constantly incorporating new ideas, practices and procedures that take place in different contexts (Wheeler, 2000).

Researchers and educators at the University of New Mexico, New Mexico State University, the Chihuahuan Desert Nature Park, and the New Mexico Museum of Natural History provided valuable input in developing the two activities. Pilot testing for both activities was done in La Mesa neighborhood, and in Governor Bent Elementary school in Albuquerque. The activities will also be presented this year in a teacher workshop in Las Cruces. Additional pilot testing will provide insight which will enrich the material, and allow for further development.

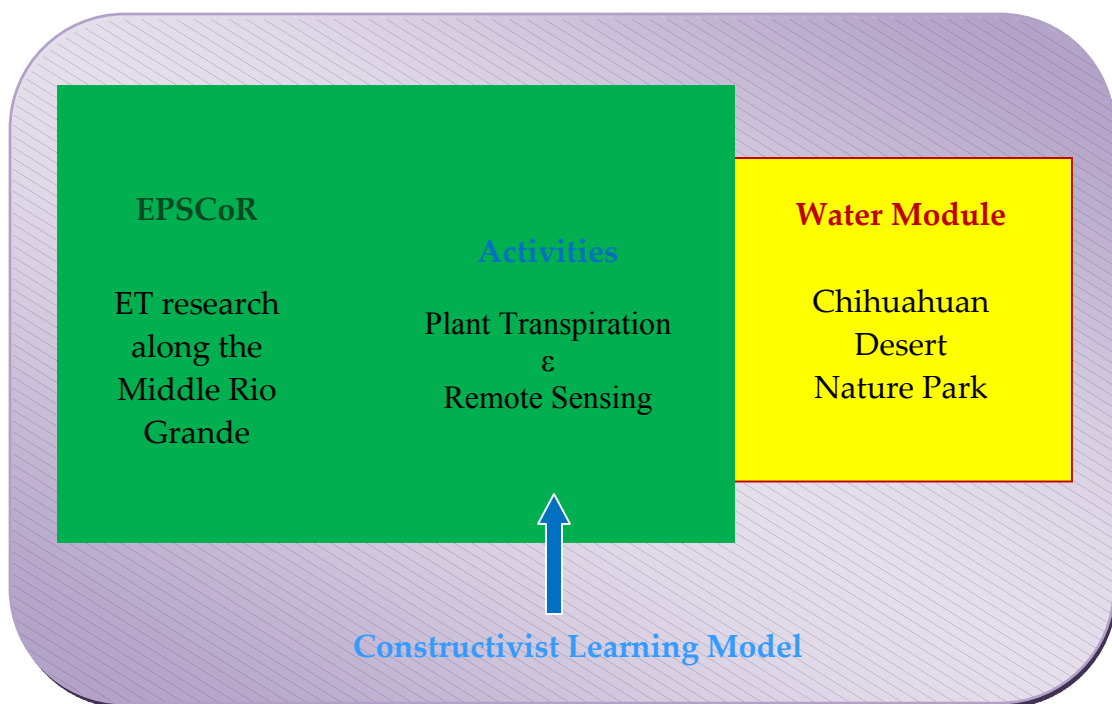


Figure 1. Development of activities for Water Module

2. Plant Transpiration Activity

The Plant Transpiration Activity emphasizes ET concepts, and the importance of quantifying plant transpiration losses in the water budget along the Middle Rio Grande. It makes use of visual aids, a hands-on plant transpiration experiment with data sheets, and an interactive scale model. Alignment with the New Mexico Science Content Standards can be found in Section 2.4 of this report. Development of this material relies on the student's prior knowledge of the Water Cycle as outlined in the Standards. Figure 2 shows a diagram of this activity.

2.1. Description

Visual aids for this activity describe basic ET research concepts and technology. The goal of the visuals is to illustrate what ET is, and how it related to the Water Cycle. It also presents research parameters such as cottonwood and salt cedar tree species. A plant transpiration experiment and data sheets were developed for students to investigate whether or not native plants are better at conserving water than non-native plants. Thus, bringing the research question into the classroom, and placing students at the center of the investigative process. A 1/32" scale model of a typical ET study site was developed to bring the study site to the students by creating a memorable depiction.

Plant Transpiration Activity Diagram

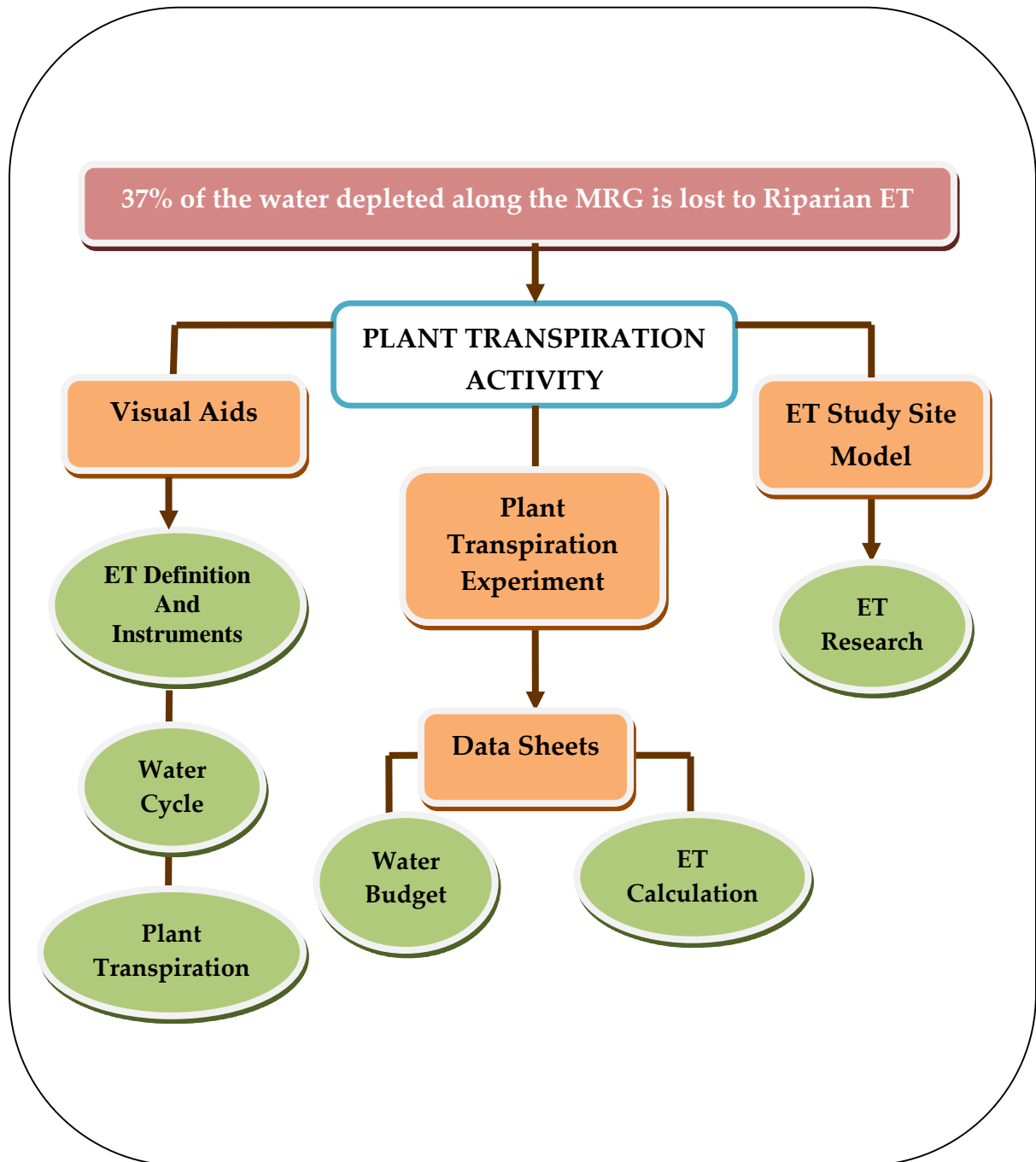


Figure 2. Plant Transpiration Activity diagram

Visual Aids

There are seven visual aids labeled PT-1 to PT-7 in the Teacher's Guide of the Plant Transpiration Activity (Appendix B). The first visual PT-1 (See Figure 3) encourages students to search their own background and experience for any knowledge they might have regarding ET. The visual implies one right answer, and in the process of looking for one image students will be exposed to at least four important aspects that relate to the research. PT-2 (See Figure 4) shows the leaves of a native cottonwood tree and a non-native salt cedar tree. The idea is to introduce students to two of the main tree species that the ET research has focused on, and to discover what they already know about the two trees. PT-3 (See Figure 5) is of the Water Cycle from a tree's perspective. ET is shown as moisture lost to the atmosphere by evaporation from the soil and water, and plant transpiration. PT-4 (See Figure 6) shows Plant Transpiration by using the image of a Mountain Mahogany which is a desert native plant. PT-3 and PT-4 connect the ET research in the Bosque with the Plant Transpiration Activity in the classroom.



Figure 3. Visual aid PT-1

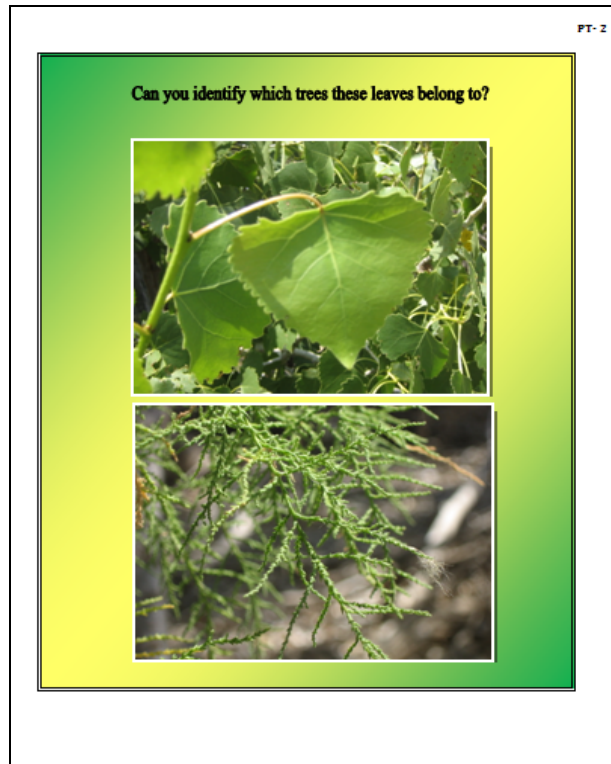


Figure 4. Visual aid PT-2

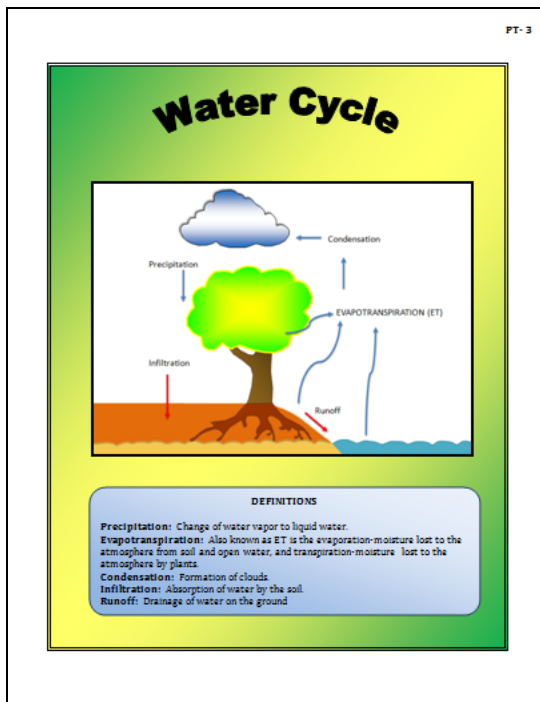


Figure 5. Visual aid PT-3

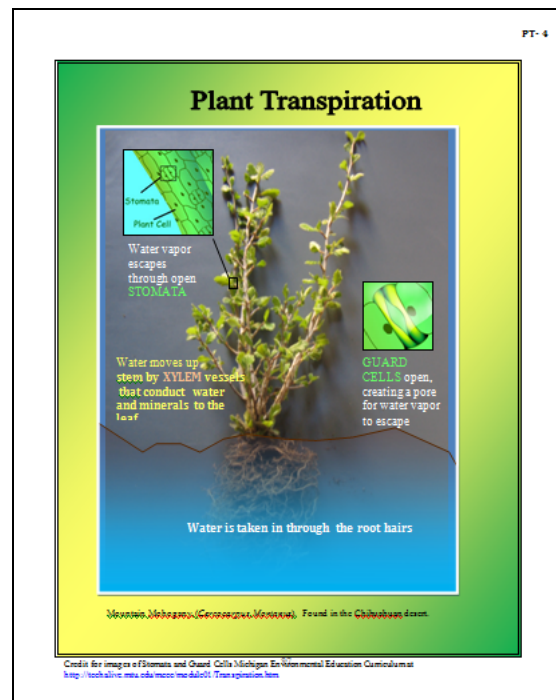


Figure 6. Visual aid PT-4

PT-5 (See Figure 7) shows the environmental factors affecting ET. Factors affecting plant transpiration are light, temperature, relative humidity, and wind (Yip, 2003). These are presented in a cartoon that places emphasis on wind and humidity as they are considered to be the two most important factors in the research. PT-6 (See Figure 8) shows an ET tower with affixed Anemometer. The latter can be explained to students as the “claw-like” device used to measure (vertical) wind speed. New Mexico EPSCoR Tower network was established along the Middle Rio Grande with funding from the National Science Foundation’s EPSCoR to improve state research infrastructure. The four most characteristic sites are Shirk, Belen, Sevilleta and Bosque del Apache. The northern sites, Shirk (Albuquerque) and Belen, have three-dimensional 25-m tall eddy covariance ET towers and are cottonwood dominated. The southern sites, Sevilleta and Bosque del Apache (south of Socorro), are mainly salt cedar stands with 15-m tall ET towers (EPSCoR Fluxnet, 2006).

PT-7 (See Figure 9) shows the Plant Canopy Analyzer. This instrument records indirect optical field measurements of Leaf Area Index (LAI). LAI measures density of vegetation. The LAI measurements shown are average quantities obtained at the Shirk (cottonwood) and Bosque del Apache (salt cedar) sites during the summer of 2006. The LAI for salt cedar was measured to be twice as high as that of cottonwood.

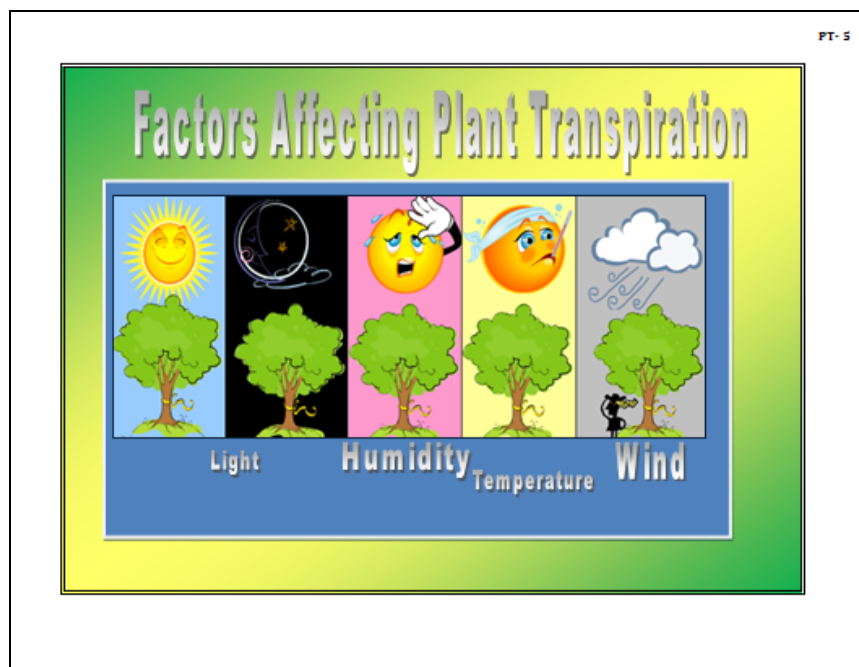


Figure 7. Visual aid PT-5



Figure 8. Visual aid PT-6

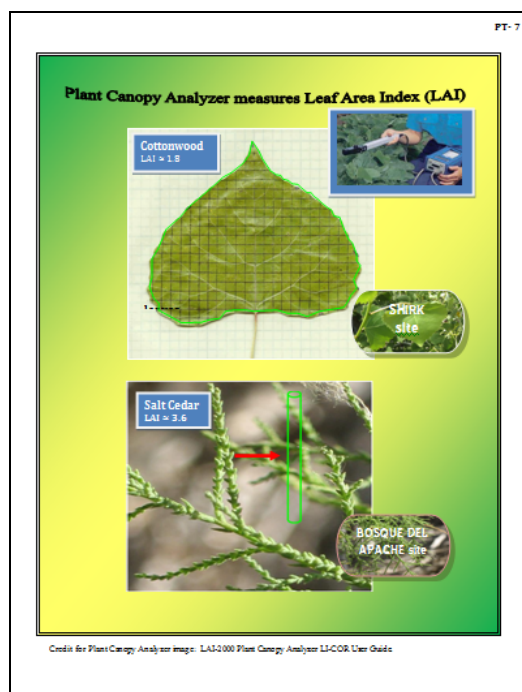


Figure 9. Visual aid PT-7

Plant Transpiration Experiment

This part of the Plant Transpiration activity gives students the opportunity to test the hypothesis of whether or not native desert plants are better at conserving water than non-native plants. The background for this experiment is set by data sheet #1, Water Depletions for the Middle Rio Grande (See Figure 10). It presents a pie diagram of the top five water losses in the Middle Rio Grande after the 2004, S.S. Papadopoulos study. The number one loss is due to riparian ET, followed by agriculture, reservoir evaporation, open water, and urban use. Students have to infer what those losses are by studying the pictures in each piece of the pie. This exercise illustrates that the largest percentage of water lost in the MRG is due to evapotranspiration in the riparian forest. Water scarcity and high ET losses give vital importance to the ET research in this region.

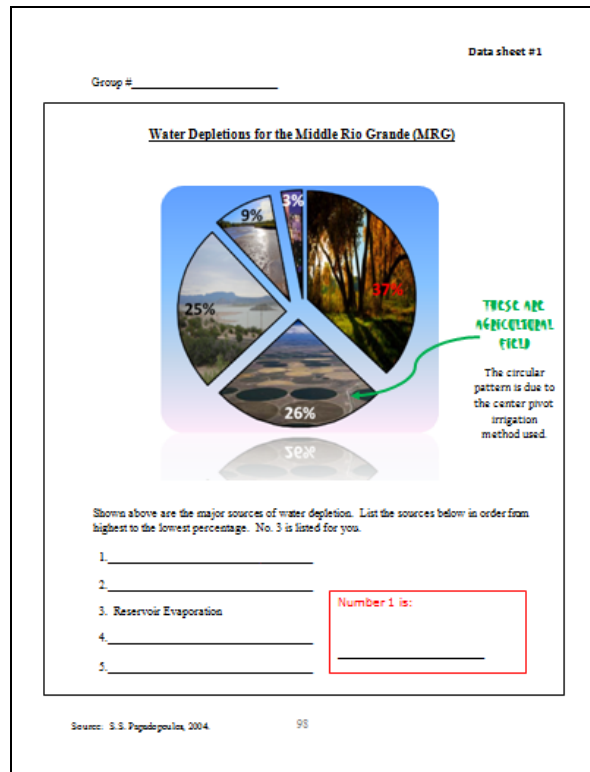


Figure 10. Water depletion for the MRG data sheet

In order to reinforce that ET is a high loss, an additional data sheet is provided with data for precipitation, evapotranspiration, infiltration and run off for a semi-arid basin. In data sheet # 6 (See Figure 11) students are asked to add each of these quantities for a 24-hour period, and see how the average ET value compares to the other three quantities.

Data sheet #6

Water Budget for a Semi-arid Basin

Which is higher? Runoff or Evapotranspiration?

1) Add up the columns and calculate the total precipitation, runoff, evapotranspiration, and infiltration for one day (24 hours).

Hour	Precipitation (inches)	Runoff (inches)	Evapotranspiration (inches)	Infiltration (inches)
1	0.00075	0.00004	0.00191	0.00000
2	0.00141	0.00007	0.00153	0.00000
3	0.00027	0.00001	0.00107	0.00000
4	0.00001	0.00000	0.00088	0.00000
5	0.00000	0.00000	0.00037	0.00000
6	0.00000	0.00000	0.00019	0.00000
7	0.00000	0.00000	0.00013	0.00000
8	0.00000	0.00000	0.00011	0.00000
9	0.00000	0.00000	0.00010	0.00002
10	0.00000	0.00000	0.00010	0.00001
11	0.00000	0.00000	0.00008	0.00000
12	0.00000	0.00000	0.00007	0.00000
13	0.00000	0.00000	0.00007	0.00000
14	0.00000	0.00000	0.00007	0.00000
15	0.00000	0.00000	0.00011	0.00000
16	0.00000	0.00000	0.00038	0.00000
17	0.00011	0.00000	0.00101	0.00000
18	0.00043	0.00001	0.00153	0.00000
19	0.00037	0.00001	0.00199	0.00000
20	0.00030	0.00001	0.00227	0.00000
21	0.00417	0.00023	0.00265	0.00000
22	0.00685	0.00040	0.00260	0.00000
23	0.00508	0.00037	0.00258	0.00003
24	0.00556	0.00088	0.00169	0.00000
Total				

2) Based on your total number, which of this water budget's losses is higher: Runoff or Evapotranspiration?

Adapted from: A catchment water budget for a semi-arid basin, Galvin, J., 2006, 276-278 Physical Hydrology, Earth and Planetary Science, University of New Mexico, Fall 2007.

Figure 11. Water budget data sheet

The plant transpiration experiment consists of a *potted plant weighing method* (See Figure 12) and a *plant transpiration observation* component (See Figure 13). The potted plant weighing method is a simple weighing technique with controlled variables. The data obtained will be used to calculate two different quantities. The *percentage of weight (water)* lost by the plant, and a *rate of plant transpiration* in units of grams per centimeter squared of leaf area. The area for the second calculation is obtained from a simple *leaf area estimation* method. The plant observation involves placing the plants under a large plastic container with lid once for a few hours during the experiment. The set up for this experiment and the process followed to calculate both of these values is explained in detail in the Methods section of this report.

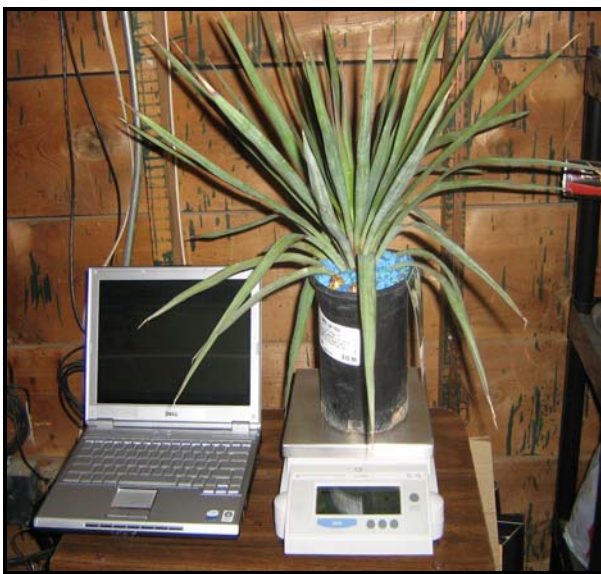


Figure 12. *Potted plant weighing method*



Figure 13. *Plant transpiration observation set up*

Scaled Model for a Typical ET Study Site

A Kit for building an ET Study Site (See Figure 14) was developed to capture the students' interest and introduce them to aspects of the ET research. Directions on how to build the Site are provided in the Student's Guide. This part of the activity will provide the opportunity to visualize the physical setting of the ET Towers and groundwater wells in the Bosque. Students will learn research related concepts as they are building the Site. The pins at the end of each tree can be thought of as the "roots" of the phreatophytes (cottonwood and salt cedar). Phreatophytes obtain water from a permanent ground supply, or from the water table. Deep rooted phreatophytes are considered some of the greatest consumers of water along rivers in the southwest (Robinson, 1958). The pins go into the "soil" similarly to the roots of trees. The "groundwater wells" will go into the "soil" to measure groundwater levels. In an actual ET site, there is a center well, and four wells located 40 m from it in every cardinal direction. The ET tower is located near the center well. It is from this location that the Tower records micrometeorological data. The scaled model of the ET Study Site accurately illustrates the setting of a typical ET study site at a scale of $1/32'' = 1' - 0''$ (See Figure 15). It can be also be utilized to explain research findings on how salt cedar trees can make denser stands and transpire more than

cottonwoods; or that taller cottonwoods can shade shorter trees which can lower transpiration rates (McDonnell, 2006).



Figure 14. Kit for building an ET Study Site



Rio
Grand
e

Figure 15. ET study site model at 1/32" scale

2.2. EPSCoR Research

ET is defined as combined evaporation-moisture lost to the atmosphere from soil and open water, and transpiration-moisture lost to the atmosphere by plants.

Evapotranspiration measures the total moisture lost to the atmosphere from the land surface (Campbell, 2007). The research is based on the necessity to accurately quantify ET depletions due to riparian vegetation along the Middle Rio Grande. The Middle Rio Grande is defined as the Rio Grande corridor contained between Otowi gage in the north and Elephant Butte Reservoir gage in the south (Dahm, et.al, 2002). Water management decisions in this reach need to be made regarding the eradication of invasive species, such as salt cedar. Research has determined that salt cedar is a drought tolerant tree species that consumes vast amounts of water and is able to grow dense stands (Cleverly, 1997).

The southwestern United States is a region that faces water scarcity. Riparian zone evapotranspiration losses along the Middle Rio Grande (MRG) are estimated to account for up to 37% of the total water budget, followed by agriculture at 26%. Next are reservoir evaporation at 25%, open water evaporation at 9%, and urban depletion at 3% (S.S. Papadopoulos, 2004). This study constitutes one of the most recent and accurate estimates of ET depletions in this reach of the river. In addition, studies by the New Mexico Interstate Stream Commission (NMISC, 2003) estimate that water use by riparian vegetation constitutes 30 to 40 percent of the total water consumption for the basin. Concerns over the increase in water consumption of non-native species like salt cedar have led to a debate over the importance of eradication of these species to maintain riparian health. Salt cedar is a salt tolerant shrub that displays dense growth (Robinson, 1965).

The research has focused on native and non-native tree species as a basis for deciding where the most water saving can be allocated. ET measurements involve the use of ET towers that measure micrometeorological variables on a continuous basis. ET estimations along the MRG suggest that for salt cedar to consume more water it would

need to form denser stands than the native counterpart (Cleverly et. al, 1997). Some additional factors affecting transpiration rates that need to be accounted for are the size and distribution of stomata (Monteith, 1965).

Both the native cottonwood and the invasive salt cedar are phreatophytes. A phreatophyte is a deep-rooted plant that obtains water from a permanent ground supply or from the water table. The term comes from the Greek word *phreat* which means well (Campbell, 1964). Salt cedar is a facultative phreatophyte, meaning that it is able to survive under conditions where it doesn't have access to ground water. Cottonwood, on the other hand, is an obligate phreatophyte that requires permanent groundwater. The high evapotranspiration rates of salt cedar can lower the water table competing with the cottonwood for survival. In addition, salt cedar can tolerate different stress conditions including heat, cold, drought, flooding, and high salinity (Di Tomaso, 1998). Salt cedar evapotranspiration varies with weather factors along with stand density and water availability (Davenport, 1982). Salt cedar is thought to assume a more dominant role because it has superior drought tolerance and the ability to make high density stands and high leaf area (Cleverly, 1997).

A recent publication on plant water use by native versus invasive plants in the Middle Rio Grande stated that based on data gathered and analyzed to date, the present strategy of salt cedar eradication and replacement with native cottonwood and willow does not seem to increase water savings in areas of shallow ground water (Cleverly, et. al, 2007). Presently, research continues to focus on understanding the effects of the eradication of invasive tree species mainly salt cedar in this area.

Dr. Dianne McDonnell has studied the difference of ET rates amongst native and non-native species along the Middle Rio Grande reach. McDonnell's research findings outlined that canopy structure has an effect on transpiration rates. Salt cedar transpires at higher rates for the same leaf area because it has more open canopy. The canopy of cottonwood trees are more tree-like and tend to shade the lower canopy causing lower transpiration rates (McDonnell, 2007). McDonnell's dissertation states that although there is a good reason to believe in the removal of salt cedar, density of vegetation of any tree species has a large influence on how high or how low the transpiration rates are.

Furthermore, climate conditions have a large impact on plant transpiration. Research that determines the transpiration rates in the riparian MRG corridor continue to present new findings. A recent concern has to do with the risk faced by riparian ecosystems due to global climate changes. Raising temperatures affect ET rates, cloud characteristics, soil moisture, snowfall and snowmelt patterns. Climate change constitutes an emerging source of uncertainty for water resources managers (Mc Donnell, 2007).

EPSCoR Research Incorporated into Plant Transpiration Activity

EPSCoR research on ET answers the need for accurately quantifying water losses by natives and non-native tree species along the Middle Rio Grande. The most important native species are the cottonwood (*Populus deltoides*), and the sandbar willow (*Salix exigua*). The main non-native species are the Russian olive (*Elaeagnus angustifolia*) and the salt cedar (*Tamarix chinensis*). The activity focuses on two of the better known tree species, cottonwood and salt cedar. The technology for measuring ET along the Middle Rio Grande stretch involves 3D Eddy Covariance Towers, and instrumentation that records micrometeorological data on a continuous basis. Basic ET concepts and instruments like ET Tower, Anemometer, and Plant Canopy Analyzer are illustrated in the activity through visual representations.

Plants lose large amounts of water through the process of evapotranspiration. In order to reinforce this concept an additional research finding will be presented. Annual estimates of the extent of riparian zone ET along the Middle Rio Grande corridor range from $150 \times 10^6 \text{ m}^3$ to $375 \times 10^6 \text{ m}^3$ (Coonrod and McDonnell, 2001). In order to get a visual idea of the higher figure, students will be asked to try and imagine *375 football fields filled with water to a depth of 100 m (approximately a 50 story building)*. This is the approximate amount of water lost to ET processes along the Middle Rio Grande during one single year.

The aspect of the research that is incorporated into the Plant Transpiration Experiment is the quest for discovering whether native tree species or non-native tree

species lose more water due to transpiration, native and non-native plants will be used instead of trees. Since Leaf Area Index is a very significant factor in measuring ET, the plant experiment incorporates plant *leaf area estimation*. The experiment has been designed to show that desert plants are in fact better at conserving water than plants from environments with high precipitation by transpiring at lower rates. It will also offer students a concrete visualization of the plant transpiration process. The method used for the plant experiment is explained in the Methods section of this report.

Finally, a 1/32" scale model was developed to illustrate what a typical ET research study site looks like. A scaled ET Tower and Anemometer are also depicted in the model. This instructional tool provides an opportunity to provide definitions for phreatophyte and ground water wells. It can also be used to depict ET research findings.

2.3. Research Transfer Methods

The conceptual framework for the *Plant Experiment* is to the credit of the Chihuahuan Desert Nature Park. The concept for the transpiration experiment was developed by Stephanie Bestelmeyer and her staff at the Park. This includes consulting with Dr. Zohrab Samani of New Mexico State University, Department of Civil and Geological Engineering. These activities were also developed under the guidance of Dr. Julie Coonrod from the Civil Engineering Department and Dr. Kristin Vanderbilt from the Biology Department. They contributed with the expertise, and evaluated both activities for accuracy of data and visual representation. Valuable insight was gained from Dr. James Cleverly also from the Department of Biology. Dr. Linda Schaffer from the Education Department provided guidance on educational methods. Selena Connealy, Chief of Education at the New Mexico Museum of Natural History, reviewed the activities and provided insight as well.

The Constructivist Learning Model (Yager, 1991) is often used for science teaching in classrooms. This model places the student at the center of the learning process

influencing the learning process all along. Student Based Learning does not only depend on what the teacher presents, instead it is the interactive result of what information is encountered and how the student processes it based on perceived notion and existing personal knowledge (Yager, 1991). This concept was taken into account when developing the activities presented here. The Constructivist model promotes group learning, where two or three students discuss approaches to a given problem (Yager, 1991). The visual aids developed for these activities are meant to encourage students to speculate and bring their own experiences into the classroom. Instructional material has been developed to build on their previous knowledge, clarify misconceptions, and develop new understanding of plant transpiration and ET research. The worksheets and data sheets are designed to be completed in groups, allowing students to exchange information and benefit from one another's experiences.

The technique of visual representation was used to construct key concepts in the minds of the students. Research on middle education instruction supports the use of illustrative images to communicate abstract concepts (Barton, 2008). Furthermore, research on formal operation asserts that middle school students cannot learn ideas they cannot witness, and need representative platforms and ways to convey the immaterial (Barton, 2008). Visual aids for the activities were created to build a bridge between the abstract and the concrete, and to make the ET research immediate and real to students.

The visual aids are educational tools created specifically for the Plant Transpiration Activity. Images of stomata and guard cells were taken from a power point presentation used by Dr. Cliff Dahm from the Biology Department at the University of New Mexico (BIOL 514, Ecosystem Studies, Fall 2006). The water budget for a Semi-arid Basin data sheet was obtained from Dr. Joe Galewsky from Earth and Planetary Science at the University of New Mexico (EPS 576, Physical Hydrology, Fall 2007). Images used have been adapted from the internet and from personal photographs. Every image that was acquired online or from a textbook has been credited. Microsoft word and Paint were used for editing and "drawing" some of the images.

Plant Transpiration Experiment

Cost of materials: The materials include the native plants which cost around ten dollars each, and non-natives ranging from twelve to twenty dollars each. The plastic container with lid costs around nine dollars.

The Plant Transpiration Experiment is meant to illustrate the process of plant transpiration while presenting two ways of quantifying it. This experiment was done with fourteen different plants. The results of which did not show that native plants were better at conserving water. The experiment was conducted until a plant which was native to a desert climate, the Curved Leaf Yucca, proved to be more efficient than other plants in its water use. Based on the educated opinion that a plant of the desert should indeed be better at conserving water, this result is the most logical. The results of the “successful” experiment are presented here. In the event that different plants than the ones suggested here are used, the experiment would be just as valuable. The scientific process is not about right or wrong answers, but about exploration.

The Plant Transpiration experiment connects the research to education by way of science inquiry. The hypothesis is whether or not native desert plants are better at conserving water than their non-native counterparts. The *potted plant weighting method* presented here works well when the Yucca is used as the native plant to be compared to a water loving plant like the Helleborus or the Blue Lilly Turf. A box plot statistical analysis was done to determine whether there was enough variance between the Yucca and the rest of the plants. The results of the plant experiment presented here are statistically significant at a 5% significance level (See Appendix A).

A procedure which was considered for this experiment was to gather cottonwood and salt cedar branches place them in water and cover their leaves with plastic in order to measure transpiration by collecting the water that would appear in the bag. The problem with this approach is that the branches dried up very quickly; placing them in water containers does not ensure their survival (See Figure 16).



Figure 16. Salt cedar and cottonwood branches.

This technique for the transpiration experiment was suggested by Dr. Zohrab Samani in Department of Civil and Geological Engineering at New Mexico State University. Samani's idea was developed into the *potted plant weighing* method (See Figure 12). It involves covering the soil with about 2 inches of Epoxy covered aquarium gravel, and assuming that the losses due to soil evaporation are negligible. The plant is set under normal climatic condition, and its weight is recorded on a daily basis. This is a straight forward technique, and it should be easily implemented in the classroom

The Plant Experiment presents two possibilities of measuring plant transpiration. The first is through calculations of relative *percentage of water lost* by the plant. The second calculation is a *transpiration rate* measured in grams per centimeter squared. The last calculation requires an estimation of leaf area for each plant. This is easily done by using engineering paper, tracing the outline of a unit leaf of the plant, and multiplying it by the total number of leaves (See Figure 17).

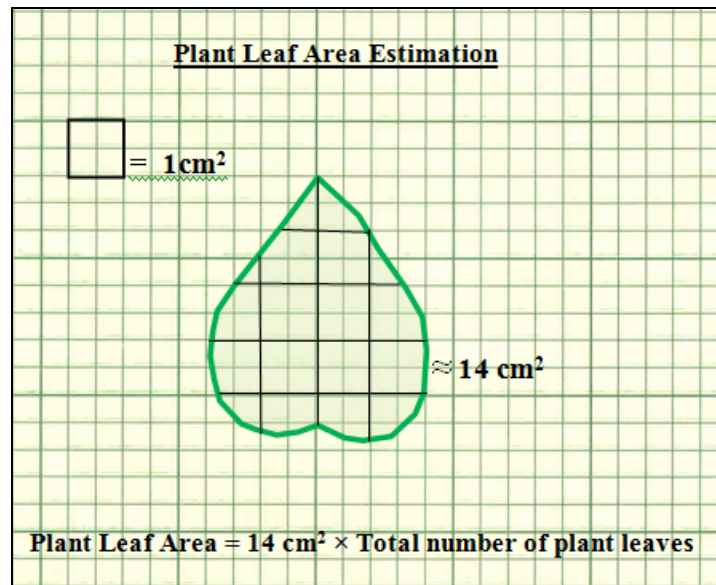


Figure 17. Leaf area estimation

Perhaps the most challenging aspect of developing this experiment was selecting suitable plants. The final recommendations are presented at the end of this section. For non-native plants, it is not recommended to use a Jade for instance because it is a succulent plant that does not exhibit many stomata. Although commonly thought to be a native plant, The Penstemon (*Penstemon cardinalis*) is not a recommended choice as this particular variation thrives in wet environments, and does not exhibit the water saving adaptation of desert plants.

Figure 18 shows the required materials for the plant transpiration experiment, and examples of native and non-native plants. Clockwise from the top: Metric scale, Ivory Prince (*Helleborus*), Curved Leaf Yucca (*Yucca recurvifolia*), Apache Plume (*Fallugia paradoxa*), Mountain Mahogany (*Cercocarpus montanus*), and *Liriope muscari* (Blue Lily Turf), potting soil, and Epoxy coated aquarium gravel. Native plants are the Curved Leaf Yucca, Apache Plume, and Mountain Mahogany.



Figure 18. Materials for Plant Transpiration Experiment.

Calculations of relative *percentage of weight (water) lost*, and *transpiration rate* in grams per centimeter squared of leaf area are presented in Table 1, 2, 3 and 4. Figure 19 and 20 show bar diagrams of the results.

Plant Transpiration Experiment										
Percentage of Weight (Water) Lost (Day 1 - Day 3)										
	Start	Day 1	Weight Loss (grams)	Percentage Lost	Day 2	Weight Loss (grams)	Percentage Lost	Day 3	Weight Loss (grams)	Percentage Lost
NATIVES										
Apache Plume	2371.7	2221	150.7	6.35%	2102.9	118.1	5.32%	2090	12.9	0.61%
Mountain Mahogany	2184.1	2103.2	80.9	3.70%	2032.1	71.1	3.38%	2024.4	7.7	0.38%
Yucca	1839.3	1790.6	48.7	2.65%	1722.3	68.3	3.81%	1707.6	14.7	0.85%
NON-NATIVES										
Blue Lily Turf	1984.8	1873.1	111.7	5.63%	1715.20	157.9	8.43%	1634.9	80.3	4.68%
Helleborus	1564.4	1390	174.4	11.15%	1240.5	149.5	10.76%	1226.2	14.3	1.15%

Table 1. Percentage of weight (water) lost (Day 1 – Day 3)

Plant Transpiration Experiment Percentage of Weight (Water) Lost (Day 4 - Day 6)							
	Day 4	Weight Loss (grams)	Percentage Lost	Day 5	Weight Loss (grams)	Percentage Lost	Day 6
NATIVES							
Apache Plume	2053.5	36.5	1.75%	2042.5	11	0.54%	2008.2
Mountain Mahogany	1998.2	26.2	1.29%	1989.3	8.9	0.45%	1964.9
Yucca	1700.7	6.9	0.40%	1695.2	5.5	0.32%	1620.6
NON-NATIVES							
Blue Lily Turf	1572.4	62.5	3.82%	1551.1	21.3	1.35%	1493.7
Helleborus	1131.4	94.8	7.73%	1105.7	25.7	2.27%	1048.4

Table 2. Percentage of weight (water) lost (Day 1 – Day 6)

Plant Transpiration Experiment Summary of Weight Percentages Lost						
	Day 1	Day 2	Day 3	Day 4	Day 5	Averages
NATIVES						
Apache Plume	6.35%	5.32%	0.61%	1.75%	0.54%	2.91%
Mountain Mahogany	3.70%	3.38%	0.38%	1.29%	0.45%	1.84%
Yucca	2.65%	3.81%	0.85%	0.40%	0.32%	1.61%
NON-NATIVES						
Blue Lily Turf	5.63%	8.43%	4.68%	3.82%	1.35%	4.78%
Helleborus	11.15%	10.76%	1.15%	7.73%	2.27%	6.61%

Table 3. Summary of Percentage of weight (water) lost.

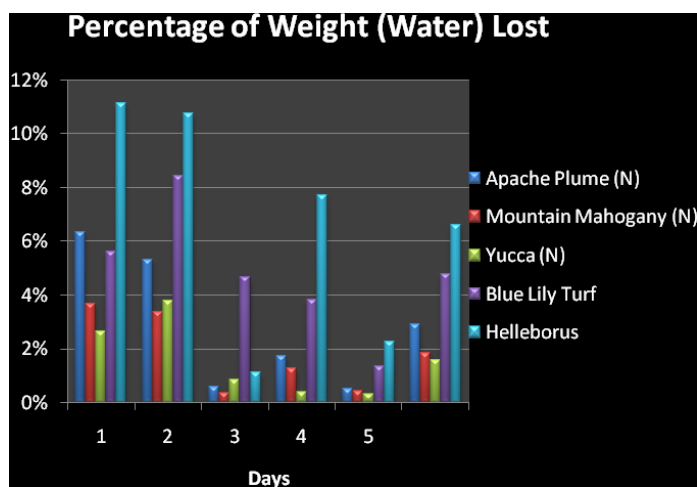


Figure 19. Percentage of weight (water) lost

Plant Transpiration Experiment Transpiration Rate (grams/cm ²)							
	Plant Leaf Area (cm ²)	Day 1	Day 2	Day 3	Day 4	Day 5	Average Rate (grams/cm ²)
NATIVES							
Apache Plume	200	0.7535	0.5905	0.0061	0.1825	0.0550	0.3175
Mountain Mahogany	164	0.4933	0.4335	0.0038	0.1598	0.0543	0.2289
Yucca	1517	0.0321	0.0450	0.0085	0.0045	0.0036	0.0188
NON-NATIVES							
Blue Lily Turf	770	0.1451	0.2051	0.0468	0.0812	0.0277	0.1012
Helleborus	702	0.2484	0.2130	0.0115	0.1350	0.0366	0.1289

Table 4. Plant Transpiration rates

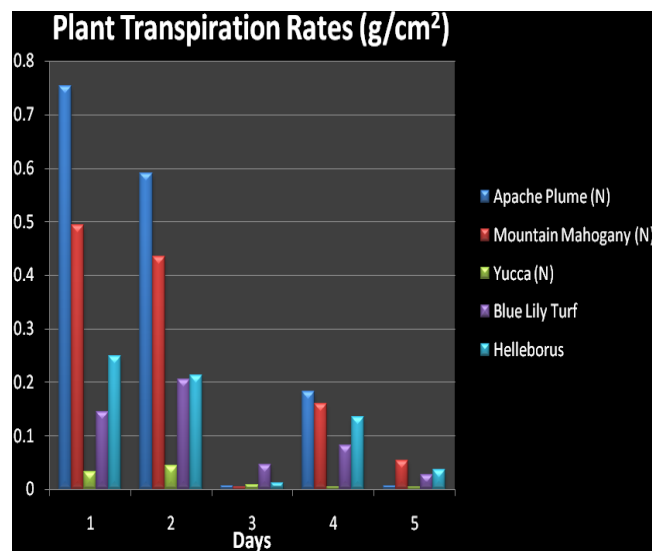


Figure 20. Plant Transpiration rates

Plant Transpiration Experiment Summary of Results			
	Area (cm ²)	Percentage of Weight (Water) Lost	Transpiration Rate (grams/cm ²)
NATIVES			
Apache Plume (N)	200	2.91%	0.3175
Mountain Mahogany (N)	164	1.84%	0.2289
Yucca (N)	1517	1.61%	0.0188
AVERAGE		2.12%	0.1884
NON-NATIVES			
Blue Lily Turf	770	4.78%	0.1012
Helleborus	702	6.61%	0.1289
AVERAGE		5.70%	0.1151

Table 5. Summary of results

Results of Plant Transpiration Experiment

Table 5 shows that the average values for the *percentage of water lost* are lower for the natives (2.12%) than for the non-native plants (5.7%). These results favor the hypothesis that native plants transpire less, and are therefore better at conserving water. The calculation for *rate of transpiration* is slightly greater for the natives (0.19 g/cm^2) than the non-natives (0.12 g/cm^2). The Curved Leaf Yucca has the lowest individual values of 1.61% for water weight lost to transpiration, and 0.0188 g/cm^2 for transpiration rate. From these results alone, it could be said that the Yucca is that best out of the five plants in conserving water.

Since the goal of this experiment is to demonstrate that native plants transpire less than non-native plants, the results of the experiment with three native and two non-native plants were analyzed with a box plot statistical analysis technique. The statistical procedure is a general linear model ANOVA (ANalysis Of VAriance) procedure for a completely randomized block design. The results were found to be statistically significant at a 5% significance level. Thus, there is enough variation in comparing the Curved Leaf Yucca to the native and non-native plants (See Appendix A for box plot analysis calculations).

The *percentage of water lost* calculation provides clear results for analyzing the plant's weight lost in relation to its initial weight. This experiment illustrates that it is possible to quantify plant transpiration. It does not however, take into account stomata distribution in the plant's leaves and it assumes that all the weight (water) being lost by the plant is a result of the transpiration process. The experiment was conducted under normal climatic conditions. The plant transpiration observation requires that the plants only need to be inside the container once for about four hours during the experiment (See Figure 13). This last set up constitutes an excellent way for students to “see” the plant transpiration process as water begins to form inside the container's walls. A control was set up to determine that the “water” formed inside the container is due to plant transpiration only. The container set as a control remained dry after being exposed to the same climatic conditions and for the same amount of time as the plants (See Figure 21).



Figure 21. Setting a control

Recommendation for Plant Selection

It is recommended in the Teacher's Guide that the Curved Leaf Yucca (*Yucca recurvifolia*) be used as the native plant for the plant experiment. The Yucca, presents a compelling example of water conservation by a plant native to arid climates. Although, it has the highest *plant leaf area*, it still transpired less than the other four plants. To ensure successful results a curved leaf Yucca could be compared to a non-native water loving plant, such as the Ivory Prince (Helleborus). The result of the comparison is in Figure 22.

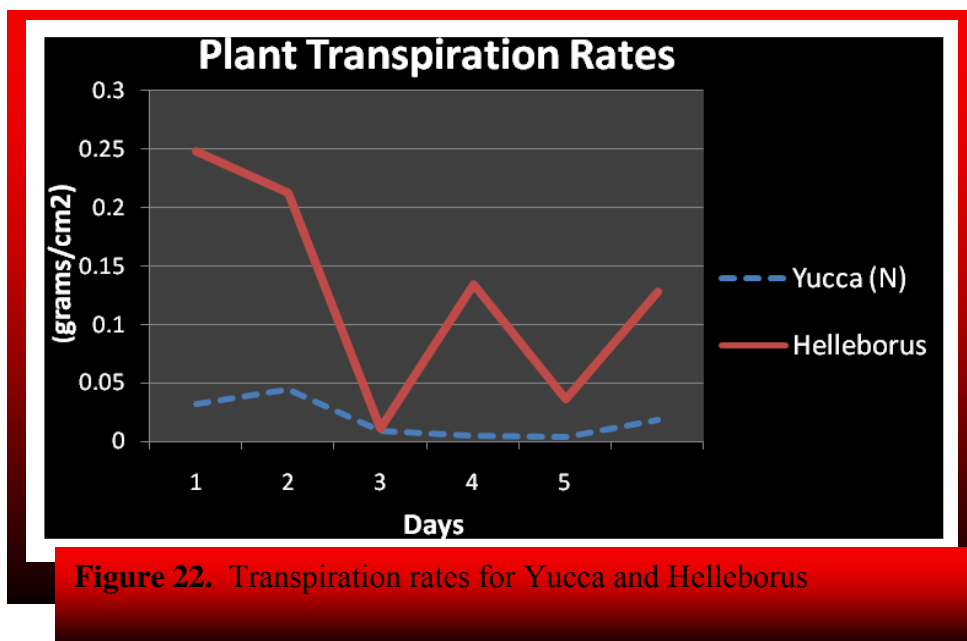


Figure 22. Transpiration rates for Yucca and Helleborus

Depending on how many groups of students there are in each class, any number of pairs (one native and one non-native of) plants can be used. In a class of thirty students, use six pairs of natives and non-natives plants in groups of five students each. This way there will be replication in the analysis and an assessment of variability among plants. It is recommended that each group of students use a non-native water loving plant, and compare it to different native Yucca varieties. This experiment was done with fourteen different native and non-native plants, and the Curved Leaf Yucca (*Yucca recurvifolia*) was by far the best at conserving water. The strong public desire for water conservation practices in this part of the country makes using a plant that is adapted to the desert climate, and conserves water accordingly a powerful analogy as to what nature can teach us when it comes to efficiency and sustainability. A native plant “knows” that in areas of dry climate it is not possible to use large amounts of water. Also known to human beings this concept is translated to water conservation methods such as Xeriscaping, water reuse, and well informed water management practices in general.

Nurseries in Las Cruces that carry different varieties of one gallon size Yucca plants are Enchanted Gardens and Guzman’s Garden Center. Enchanted Gardens has the Soaptree Yucca (*Yucca elata*) and the Banana Yucca (*Yucca baccata*), Guzman’s Garden Center carries the Red Tip Yucca (*Hesperaloe parvifolia*) and the Spanish Dagger Yucca (*Yucca gloriosa*). Guzman’s Gander suggested that the state flower, the New Mexico Yucca (*Yucca glauca*) could be found along trails in Las Cruces. This plant could potential be repotted and used for the study.

Recommended non-natives are the Ivory Prince (*Helleborus*), Blue Lily Turf (*Liriope muscari*), Blue Muffin (*Viburnum dentatum*), and Gold Maiden (*Euonymus japonicus*). In case that the different Yucca varieties will not used, recommended native plants are the Apache Plume (*Fallugia paradoxa*) and the Mountain Mohogany (*Cercocarpus montanus*).

Scaled Model for a Typical ET Study Site

The scaled model of an ET Study site was inspired by Dianne McDonnells' cartoon illustration found in her 2006 PhD defense entitled "Scaling Riparian Evapotranspiration to Canopies along the Middle Rio Grande Corridor in Central New Mexico" (See Figure 23).

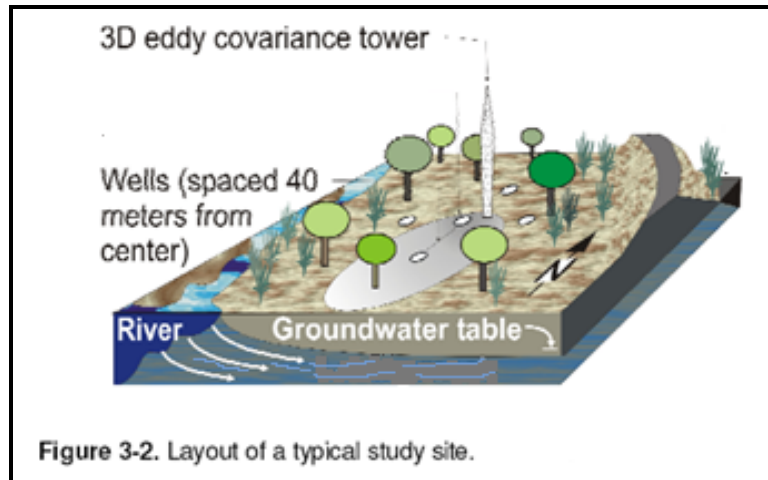


Figure 23. Cartoon of the layout of a typical study site (McDonnell, 2007)

The Student Guide contains "instructions" on how to build the Site. Dr. James Cleverly tested the Kit and Site for accuracy of representation (See Figure 24). This included the "ET Tower" and "Anemometer" needing to be above the canopy to take measurements. Additionally, it was agreed that the model could be used to describe the concept of "phreatophyte." The "trees" have pins (roots) at the ends that have to be "buried" into the soil. It can be explained to students that a phreatophyte is a deep rooted plant that obtains its water from a permanent ground water supply or from the water table. Cottonwood and salt cedar are both phreatophytes. Salt cedar, however is able to survive under conditions where groundwater is inaccessible (DiTomaso, 1998). Research concepts that can be illustrated through this instructional tool are explained in Section 2.1 of this report.



Figure 24. James Cleverly tests the ET Study Site.model.

Cost of materials: The materials for building this model can be found at art supplies stores, bookstores, and craft stores. For a 1/32" scale model, the plot area is made of a 32" by 40" tan color foam (makes four "Sites"). This can be substituted with corrugated cardboard of the same size at a cost of four dollars. The ET Tower is made out of one-ply museum board, as well as the Kit, the scale human figure, and the "river." This board can be replaced with a white coated chip board for four dollars. The "cottonwood trees" are made with 1/8" diameter Bass wood sticks, and with 7/8" diameter Styrofoam spheres painted with green acrylics, the "trunks" are painted brown. The Bass wood costs around thirty-four cents a stick (two sticks were used), and the fifteen spheres used cost of two dollars. The least expensive acrylic paints cost around two dollars each tube. The salt cedar trees are made with Bass wood and painted with acrylics.

The "Ground water wells" are 3/8" long and 1/16" in diameter silver color tube shaped beads used for making jewelry. The "roots" of the trees are Thumbtacks. The "drill" is a T-pin. The wells, roots and drill cost about two dollars. The materials were cut to size with a number 11 X-Acto knife and straight edge, both cost six dollars. The parts were glued with Elmer's glue, and a hot glue gun at a cost of five dollars.

The total cost for making one site model is approximately seven dollars. This amount takes into account that the glue, pins, beads, acrylic paints and boards will be used to make four models. The X-Acto knife and the straight edge are a onetime expense of seven dollars. The knife and straight edge are used to cut the “Site” and “trees” to the desired sizes. The only part of the Kit that needs to be replaced is the “Site” as it gets holes when students plant the “trees” in the “soil.” If the Kit will not be used simultaneously by forty different groups of students, it is not necessary to have an ET Study Site Kit for each of the Science Investigation Kits of the Park.

2.4. New Mexico Science Content Standards

The Plant Transpiration activity aligns with a number of standards for 5th through 8th grade. In broad terms it relates to Scientific Thinking and Practice, Physical Science standards that have to do with changes in phases (evaporation, condensation). Also Life Science and Earth Science standards as they relate to the Water Cycle. It also meets Science and Society standards of watershed community decisions regarding water use. Listed below are the specific standards met.

5th Grade

- 1-1-1-1 Plan and conduct investigations, including formulating testable questions, making systematic observations, developing logical conclusions, and communicating findings.*
- 1-1-1-2 Use appropriate technologies (e.g., calculators, computers, balances) to perform scientific tests and to collect and display data.*
- 1-1-1-3 Use graphic representations (e.g., graphs, tables, labeled diagrams) to present data and produce explanations for investigations.*
- 1-1-1-4 Describe how credible scientific investigations use reproducible elements including single variables, controls, and appropriate sample sizes to produce valid scientific results.*
- 1-1-1-5 Communicate the steps and results of a scientific investigation.*
- 1-1-2-1 Understand that different kinds of investigations are used to answer different kinds of questions (e.g., observations, data collection, controlled experiments).*
- 1-1-2-2 Understand that scientific conclusions are subject to peer and public review.*
- 1-1-3-1 Use appropriate units to make precise and varied measurements.*
- 1-1-3-2 Use mathematical skills to analyze data.*

- 1-1-3-3 Make predictions based on analyses of data, observations, and explanations.*
- 2-1-1-2 Describe how matter changes from one phase to another (e.g., condensation, evaporation).*
- 2-2-1-4 Describe how human activity impacts the environment.*
- 3-1-1-1 Describe the contributions of science to understanding local or current issues (watershed and community decisions regarding water use).*

6th Grade

- 1-1-1-1 Construct appropriate graphs from data and develop qualitative and quantitative statements about the relationships between variables being investigated.*
- 1-1-1-2 Examine the reasonableness of data supporting a proposed scientific explanation.*
- 1-1-1-3 Justify predictions and conclusions based on data.*
- 1-1-2-1 Understand that scientific knowledge is continually reviewed, critiqued, and revised as new data become available.*
- 1-1-2-2 Understand that scientific investigations use common processes that include the collection of relevant data and observations, accurate measurements, the identification and control of variables, and logical reasoning to formulate hypotheses and explanations.*
- 1-1-2-3 Understand that not all investigations result in defensible scientific explanations.*
- 1-1-3-1 Evaluate the usefulness and relevance of data to an investigation.*
- 2-2-1-1 Understand how the water cycle is essential to most living systems.*

7th Grade

- 1-1-2-3 Analyze and evaluate scientific explanations.*
- 1-1-3-2 Use mathematical expressions to represent data and observations collected in scientific investigations.*
- 1-1-3-3 Select and use an appropriate model to examine a phenomenon.*
- 2-3-2-3 Know that changes to ecosystems sometimes decrease the capacity of the environment to support some life forms and are difficult and/or costly to remediate.*

8th Grade

- 1-1-1-2 Use a variety of technologies to gather, analyze and interpret scientific data.*
- 1-1-2-1 Examine alternative explanations for observations.*
- 1-1-2-3 Know that scientific knowledge is built on questions posed as testable Hypotheses, which are tested until the results are accepted by peers.*
- 1-1-3-1 Use mathematical expressions and techniques to explain data and observations and to communicate findings (e.g., formulas and equations, estimation, mean).*
- 2-1-1-7 Know that phase changes are physical changes that can be reversed (e.g., Evaporation, condensation).*

- 2-1-1-8 *Describe various familiar physical and chemical changes that occur naturally (e.g., photosynthesis).*
- 2-2-1-1 *Describe how matter moves through ecosystems (e.g., water cycle).*
- 2-3-2-2 *Understand the unique role water plays on Earth, including:
properties of water related to processes in the water cycle: evaporation,
condensation, precipitation, surface runoff, percolation.*

3. Remote Sensing Activity

The region where evapotranspiration research takes place is the Middle Rio Grande (MRG). The MRG extends 320 kilometers between the Otowi Bridge and Elephant Butte stream gages. Remote sensing provides researchers a perspective of the MRG that would not be possible otherwise. The Remote Sensing Activity presents remote sensing by Landsat 7 satellite as a tool for investigating the environment. The instructional material developed includes visual aids and worksheets that illustrate the use of Landsat 7 technology. Alignment of this activity with the New Mexico Science Content Standards can be found in Section 3.4 of this report. Figure 25 shows a diagram of this activity.

3.1. Description

This activity presents basic concepts and applications of remote sensing and provides visual aids describing Landsat 7 technology, and applied ET research. Students will be asked to identify features in New Mexico by analyzing “false-color” images. Additionally, they will perform ET calculations by combining information from the images, and James Cleverly’s RIO ET-DATA web site, and think of their results in terms of annual estimates of the riparian zone ET for the MRG corridor of $150 \times 10^6 \text{ m}^3$ to $375 \times 10^6 \text{ m}^3$ (Coonrod and McDonnell, 2001).

Lastly, they will complete a digital art exercise. The idea behind this exercise is for students to gather information about the environment through “remote sensing” on a “pixel by pixel” scale. A pixel is defined as “a two dimensional picture element that is the smallest non divisible element of a digital image.” Each pixel in the image has a value (Jensen, 2005). For Landsat, the pixel size is 30 m by 30 m. Digital remote sensor data are usually stored as matrix of numbers. Each digital value is located at a specific row and column. The digital art is analogous to the remote sensor matrix of numbers.

Remote Sensing Activity Diagram

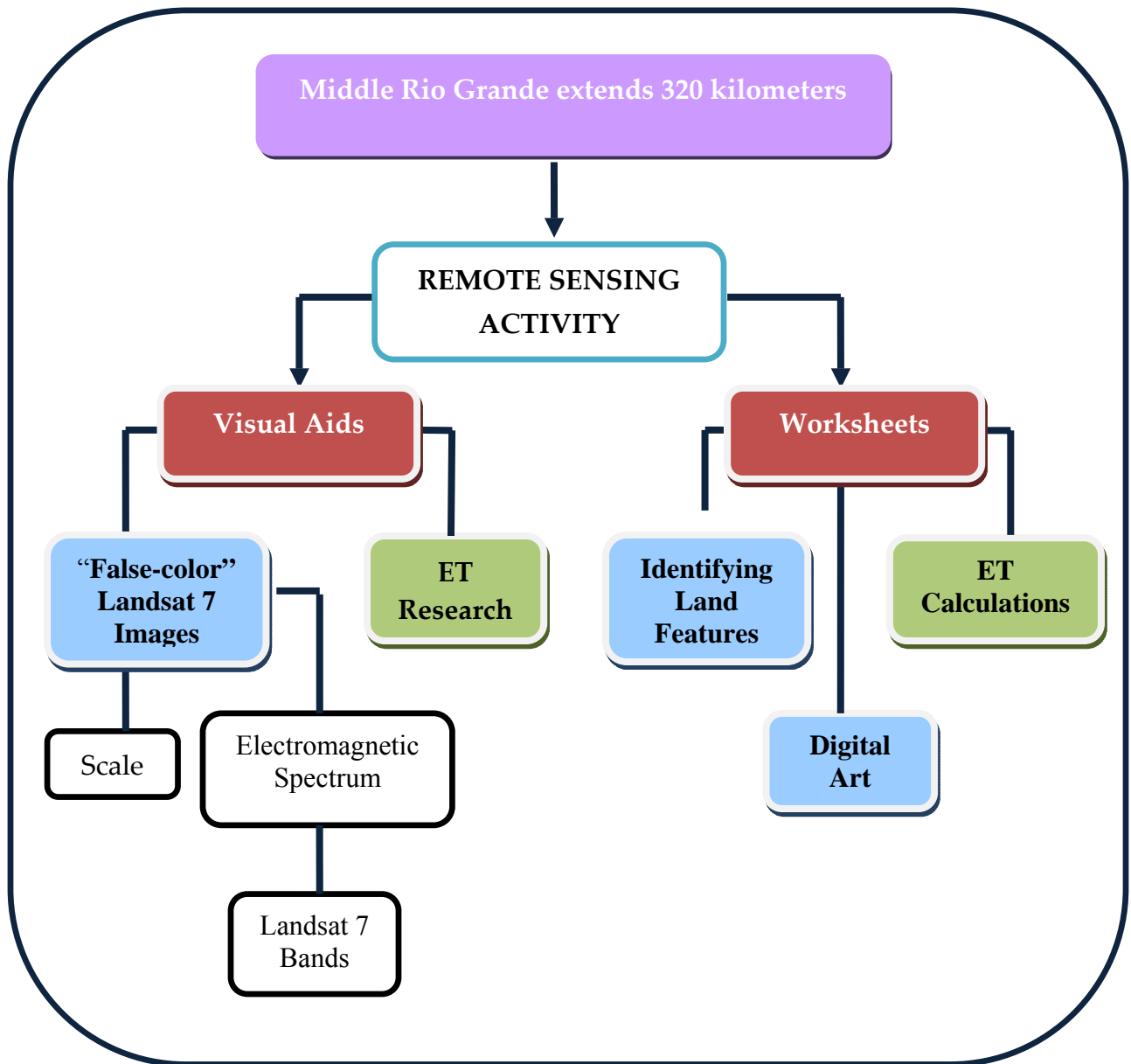


Figure 25. Remote Sensing Activity Diagram

Visual Aids

There are six visual aids labeled RS-1 to RS-6 in the Teacher's Guide of the Remote Sensing Activity (Appendix B). RS-1 (See Figure 26) shows aerial perspective, the image zooms into a cactus and water; and then zooms out revealing more information about the site. This visual provides the opportunity to ask students to imagine if they could fly over the Bosque and the Rio Grande; would the environment look very different than if they were standing near a cottonwood tree?

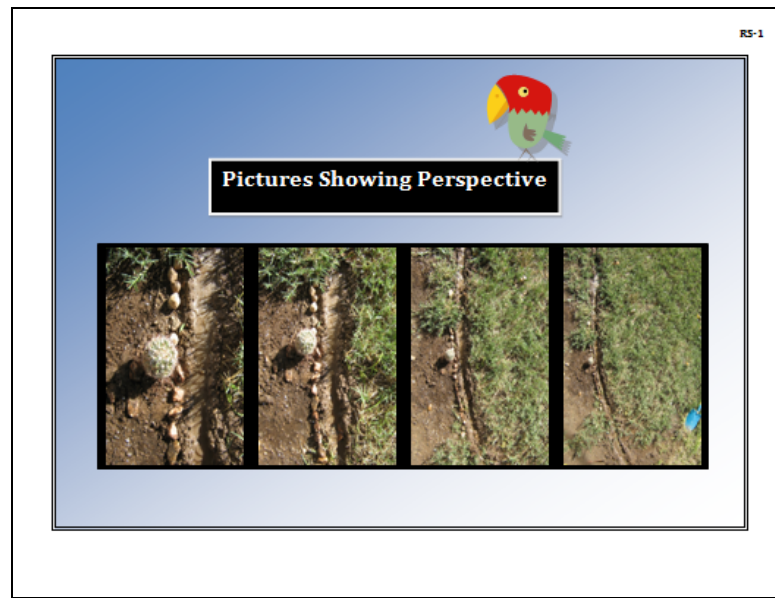


Figure 26. Visual aid showing perspective

The next three visuals provide background information of “false-color” Landsat 7 images. RS-2 shows the Electromagnetic Spectrum and RS-3 (See Figure 27) shows the seven bands of Landsat 7. Both images were adapted from NASA’s Landsat 7 Compositor. RS-4 has strategically selected images showing examples of “false-color” images (See Figure 28).

RS-3

Landsat 7 Enhanced Thematic Mapper (ETM) Bands		
Spectral sensitivity of Landsat 7 Bands		
Band Number	Wavelength Interval	Spectral Response
1	0.45-0.52 μm	Blue-Green
2	0.52-0.60 μm	Green
3	0.63-0.69 μm	Red
4	0.76-0.90 μm	Near IR
5	1.55-1.75 μm	Mid-IR
6	10.40-12.50 μm	Thermal IR
7	2.08-2.35 μm	Mid-IR

Adapted from NASA website: <http://landsat.gsfc.nasa.gov/education/education.html>. Accessed 01/2008

Figure 27. The 7 Bands of Landsat 7

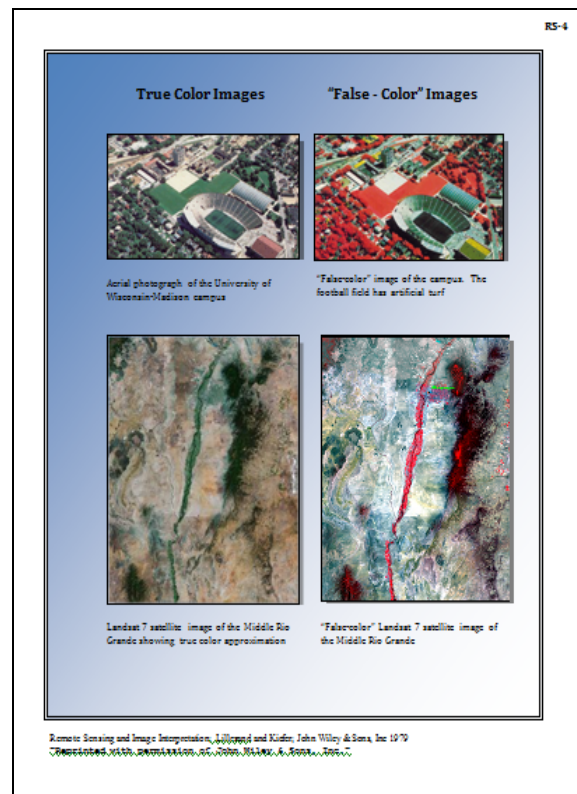


Figure 28. Landsat 7 "false-color" images

The next two images incorporate features of the ET research. RS-5 is a map of four Landsat 7 scenes for the state of New Mexico (See Figure 29). RS-6 shows a map outlining the Middle Rio Grande and "ET Towers" located at four of the main study sites of Shirk and Belen (cottonwood) and Sevilleta and Bosque del Apache (salt cedar). The towers have been placed in close approximation to their real location in the riparian forest of the Rio Grande (See Figure 30). The information in visual RS-5 and RS-6 are needed to complete some of the worksheets

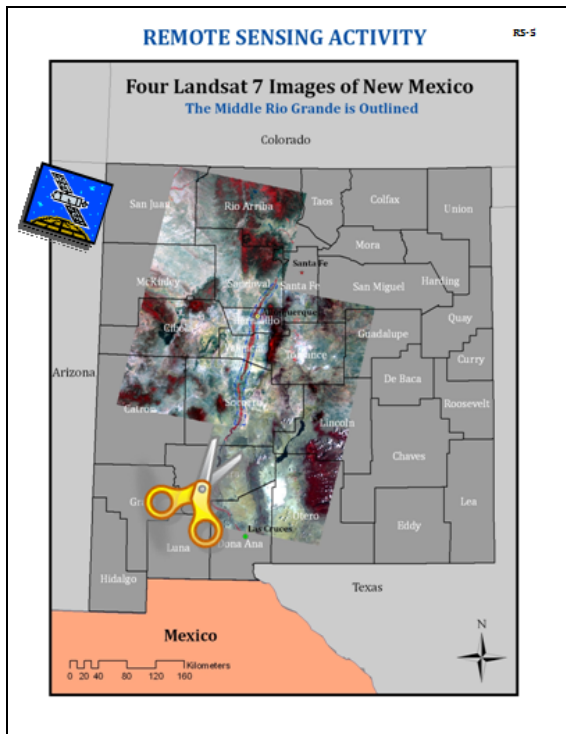


Figure 29. Landsat 7 Images for New Mexico

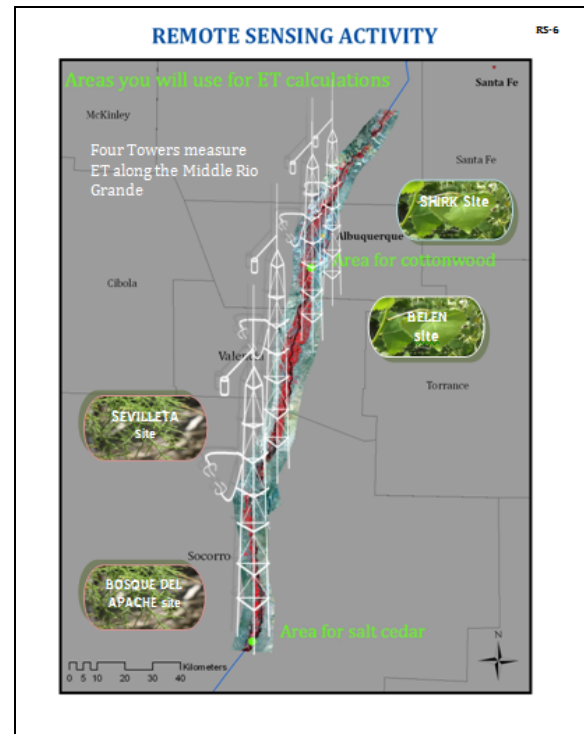


Figure 30. The MRG and ET Towers

Worksheets

This activity contains ten worksheets which have been divided into four different tasks. First task is *Identifying Features in New Mexico* by analyzing “false-color” Landsat 7 images. The second task is recognizing *World Agriculture Pattern*. The third task involves *ET Calculations* combining Landsat 7 images with real ET data. The fourth task is a *Digital Art* exercise that illustrates the concepts of satellite images matrix format for data collection, pixel size, and image processing by way of color assignation. Answers to worksheet #1, #2, #7, #9 and #10 are provided as part of the Procedure section in the Teacher’s Guide for the Remote Sensing Activity. The answers to worksheet #3, #4, #5, #6 and #8 can be found immediately after the visual aids (See Appendix B).

Identifying Features in New Mexico

Worksheet #1 (See Figure 31) asks students to provide their own ideas as to what the image represents. It is a “false-color” image showing agricultural fields in Torrance County, New Mexico. Center pivot irrigation is common in the United States, and the reason for the circular shaped fields. Prior to completing this first worksheet, students will not have knowledge of “false-color” images. This will be explained when they are given the right answer and by the visual aids. Students have described the images as being abstract art, red blood cells, or a gym with red bouncy balls. They are encouraged to use their imagination for the activity, but they will be led towards “false-color” Landsat 7 images.

Visual RS-5 (See Figure 29) is used with worksheets #3 and #4. These are “false-color” images that will be used for identifying feature in New Mexico. Worksheet #3 (See Figure 32) includes important water bodies in Rio Arriba County, New Mexico. Heron Lake is a reservoir in Rio Arriba County, in northern New Mexico. The lake is part of the San Juan-Chama Diversion Project, which transfers water from the San Juan River into the Rio Grande. The other bodies of water are El Vado Lake, and Abiquiu Lake, water of the Rio Chama is impounded by the Abiquiu Dam. Worksheet #4 will reinforce interpretation of “false-color” Landsat 7 images by asking students to identify features that look different from each other in the image. This includes water, volcanic areas, sodium chloride, and gypsum material. These are found in Elephant Butte Reservoir, El Mal Pais National Monument, Laguna del Perro (salt dry lake bed) and White Sands National Monument.

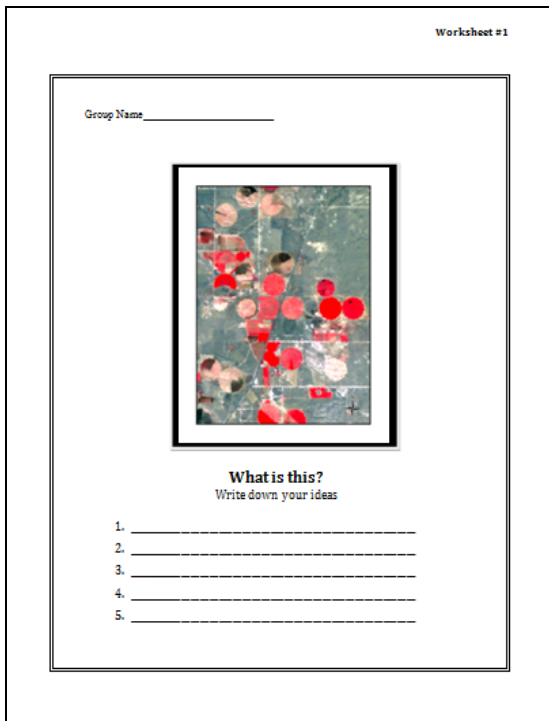


Figure 31. Remote Sensing Activity

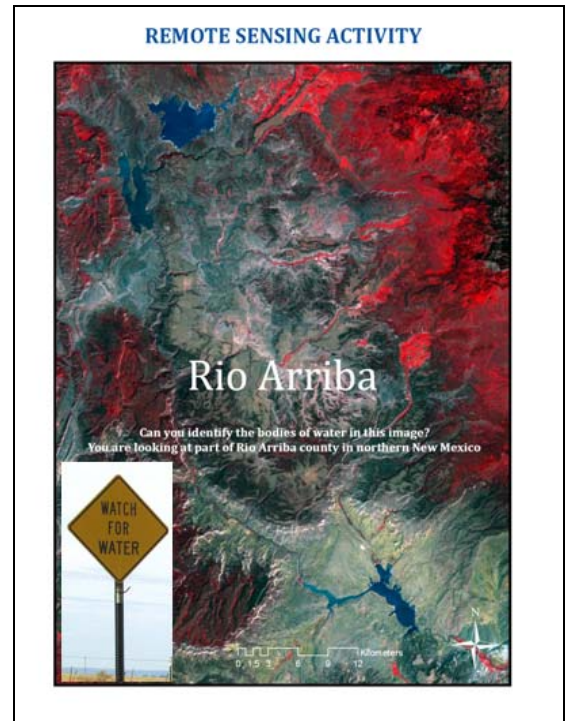


Figure 32. Remote Sensing Activity

World Agriculture Pattern

Worksheet #2 (See Page 119 in Appendix B) reinforces the concept of irrigation pattern, and it broadens the experience by showing students patterns from across the world. Thus, they will learn that there exists agricultural irrigation patterns other than circular, and also it will give them exposure to another application for satellite images. In fact, Landsat was predetermined by the need to monitor agricultural vegetation on a world scale (Drury, 1998). Since agriculture represents the next significant loss in the Water Depletions for the Middle Rio Grande after riparian ET (See Figure 10), investigating other agricultural irrigation practices has educational relevance.

ET Calculations

Visual RS-6 (See Figure 30) is used with worksheets #5 and #6. Worksheet #5 (See Figure 33) has Landsat 7 images for a given salt cedar and cottonwood area along the Middle Rio Grande, and worksheet #6 is the data table for ET calculations. Students will go to James Cleverly's RIO ET- DATA web site <http://bosque.unm.edu/cleverly/bosque/data.html> to obtain data and perform straight forward ET calculations which they will report in units of volume. The areas used for this calculation are obtained by visually estimating it using the scale bar in the map. After students have made their predictions, they will be shown a close up image of the sites showing the 30 m by 30 m Landsat 7 pixel size resolution, and they will be able to "count" the squares to get exact area measurements (See Figure 34). The areas used are located in the Shirk (north) cottonwood site and the Bosque del Apache (south) salt cedar site.

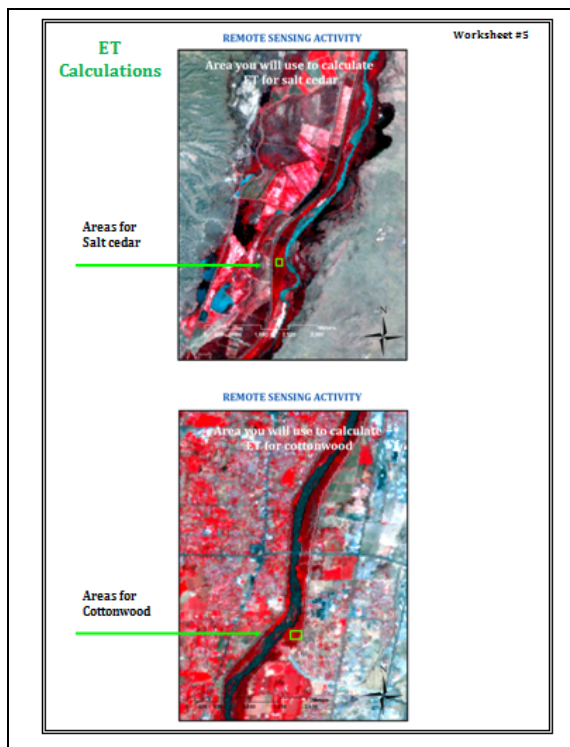


Figure 33. ET Calculation

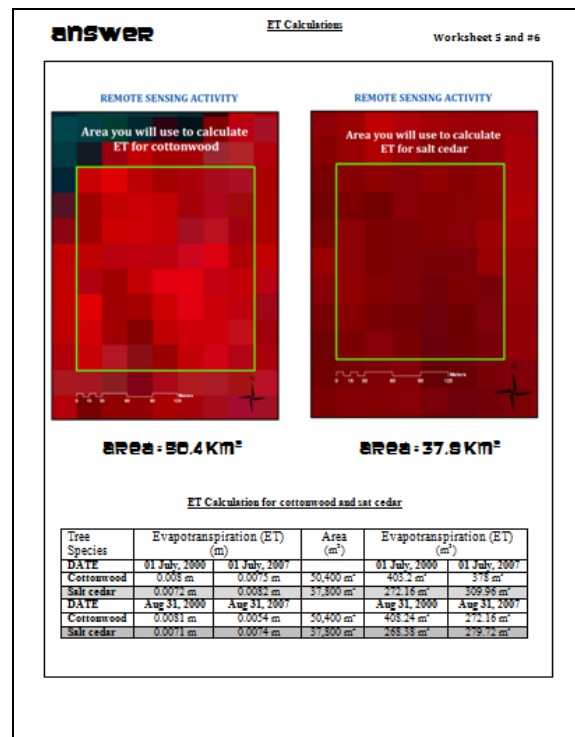


Figure 34. Et Calculation answers

Digital Art

The final task is to complete a Digital Art exercise, the first part is creating a Satellite image “false-color” composition in worksheet #7 (See Figure 35). This task allows for a rapid assessment of “false-color” image understanding and reinforces concepts of band assignation of Landsat 7 by computer software. Worksheet #9 and #10 are matrices containing three types of (number and color) coded vegetation which will be used to complete the blank map in worksheet #8 (See Figure 36).

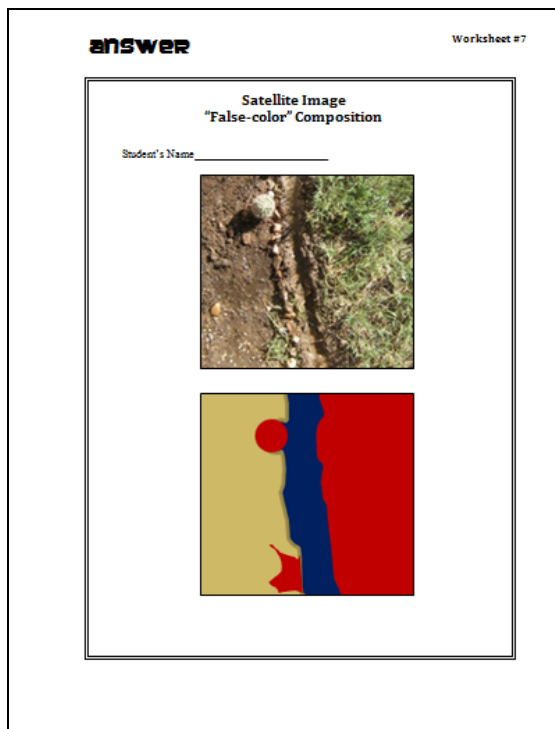


Figure 35. Answer for worksheet #7

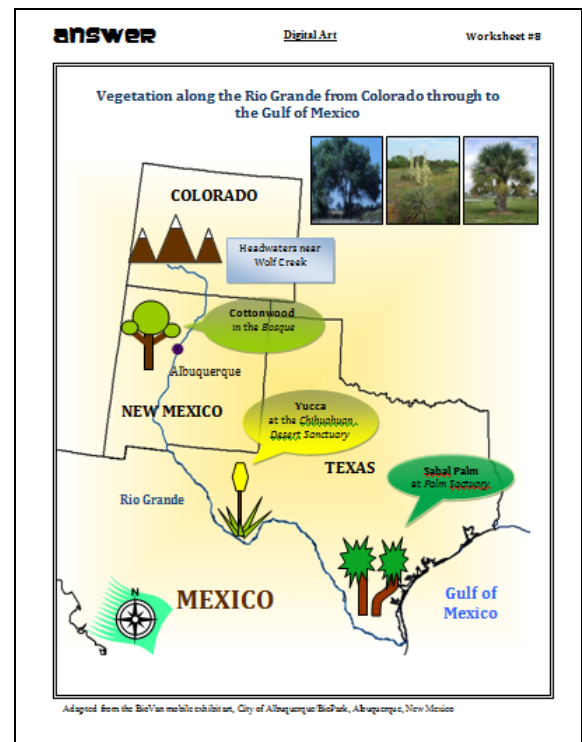


Figure 36. Answers for worksheet #8

3.2. EPSCoR Research

Investigating ET depletion requires that scientists understand the complexity and function of non-uniform landscapes. Remote Sensing by satellite offers researchers a valuable tool for studying the Middle Rio Grande from a new perspective.

As with aerial photography, satellites capture information about the environment at a scale that would not be possible otherwise. Every object emits radiation but in different amounts and wavelengths. The different wavelengths and frequencies make up the electromagnetic spectrum. The human eye is sensitive only to some of these wavelengths (colors of the rainbow) (NASA, 2005). Other parts of the spectrum such as near-infrared wavelengths are not visible to the human eye and are not perceived as light. Although humans are not able to see past the visible spectrum, satellites can “see” past the color red, into the infrared, and past the color violet and into the ultraviolet (NASA, 2005). Satellite images are valuable tools for studying vegetation as plants and trees reflect near infrared light.

From high above the earth, the Landsat 7 satellite uses an instrument that collects seven images at once. Each image shows a specific section of the electromagnetic spectrum, called a band. Landsat 7 has seven different bands. The bands measured by Landsat make it possible to distinguish water, vegetation, and dry non-green areas. Red, near infrared (NIR), and mid-infrared (MIR) bands are useful in detecting chlorophyll, vegetation, soil moisture, water and leaf structures. These bands are considered the most suitable for differentiating vegetation types (McDonnell, 2006).

Vegetation is the part of the natural world most easily analyzed using remote sensing. Most images comprise reflectance data in the very-near infrared, red and green, expressed as red, green, and blue in a color image. This part of the spectrum is where chlorophyll has its maximum absorption and plant cells reflect most radiant energy. The low reflectance of plants in red and their very high infrared response causes vegetation to be rendered in various shades of red in false-color composites while other surfaces appear in grays, blues, yellows, and browns (Drury, 1998).

Features along the landscape absorb, reflect, or scatter light in different ways. As a result every feature has a unique spectral signature. Using Landsat 7 spectral bands it is possible to differentiate wet areas, green canopies, green grasses, and non-vegetated or non-green areas. Moreover, the way vegetation reflects energy depends on the size of the plant cells and the thickness of the cell walls, so that the reflected radiation provides a “signature” for the type of vegetation present (Smithsonian, 2000). It is this aspect of Landsat 7 images that makes it possible for researchers to classify vegetation along the Middle Rio Grande and then determine the ET rates for each vegetation type. The towers only measure ET at the plot scale. Dianne McDonnell developed a method for taking ET data and Landsat 7 images to expand ET estimation from the tower sites to the regional scale. Since the goal of the research is to understand different transpiration rates of native and non-native plants a parameter called the Leaf Area Index (LAI) is used. LAI measures density of vegetation and it accounts for distribution of stomata in plant leaves. McDonnell’s model is based on LAI, vegetation classification, climate, and landscape topography.

EPSCoR Research Incorporated into Remote Sensing Activity

Remote sensing is used in the research as a valuable tool for extracting information from the environment without coming in direct contact with the object being studied (Jensen 2005). The activity incorporates this important idea by inspiring exploration of areas around New Mexico, and by discovering vegetation in Colorado and Texas. The activity takes the students to South America, Asia, and Europe to explore agricultural patterns in remote locations. Research uses ET Towers measurements and relates them to information extracted from satellite images. For this purpose, students will visit James Cleverly’s website RIO ET-DATA. Students will use current ET in combination with Landsat 7 satellite images.

The concept guiding this activity is tied to the importance of remote sensing as a tool for studying the environment from a unique perspective. The target area of the ET research is the Middle Rio Grande (MRG). The Middle Rio Grande is defined as the Rio

Grande corridor contained between Otowi gage in the north and Elephant Butte Reservoir gage in the south (Dahm, et.al, 2002). Visuals have been developed to present students with the area being studied including four of the most important ET Study Sites. The concept of scale is also presented by using pictures that show perspective.

ET depletion investigations require that scientists understand the complexity and function of non-uniform landscapes. Landsat 7 images are used to study evapotranspiration along the Middle Rio Grande. This activity offers a background on Landsat 7 satellite images. The Electromagnetic Spectrum and the properties of light are explained in the Teacher's Guide. False-color images are presented and explained at great length. The worksheets are self-explanatory and incorporate the research aspect of deriving meaningful information from the environment by way of remote sensing. This activity connects to the research by way of discovery and development of techniques to extract specific information from satellite images.

3.3. Research Transfer Methods

ET research employs remote sensing by Landsat 7 satellite to study the stretch of the Middle Rio Grande. The activity presents background information on the technology behind Landsat 7. Four Landsat 7 images were used to create the visual aids and worksheets for the activity. They are for the month of June of 2000, 2001, and 2002 (See Figures 37 and 38). Landsat 7 images are designated by path and row numbers. The following are path and row numbers for the images used.

p33r37_06102000, path 33, row 37 (June 10, 2000)

p34r35_06042001, path 34, row 35 (June 04, 2001)

p34r36_06042001, path 34, row 36 (June 04, 2001)

p33r36_06162002, path 33, row 36 (June 16, 2002)

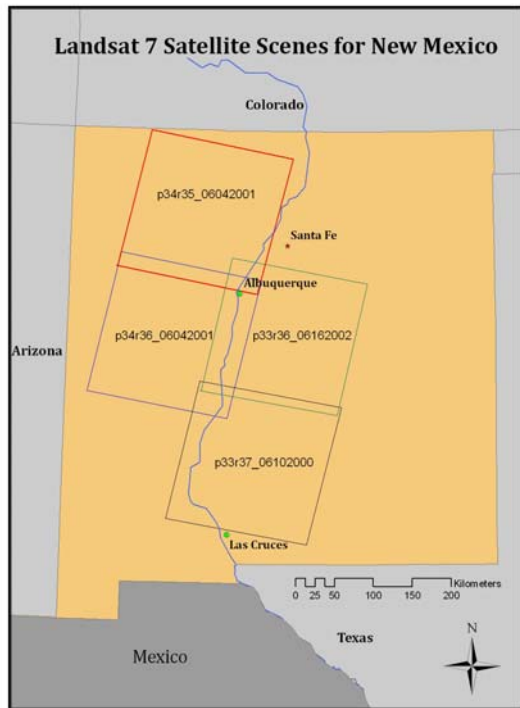


Figure 37. Landsat 7 Scenes paths and rows

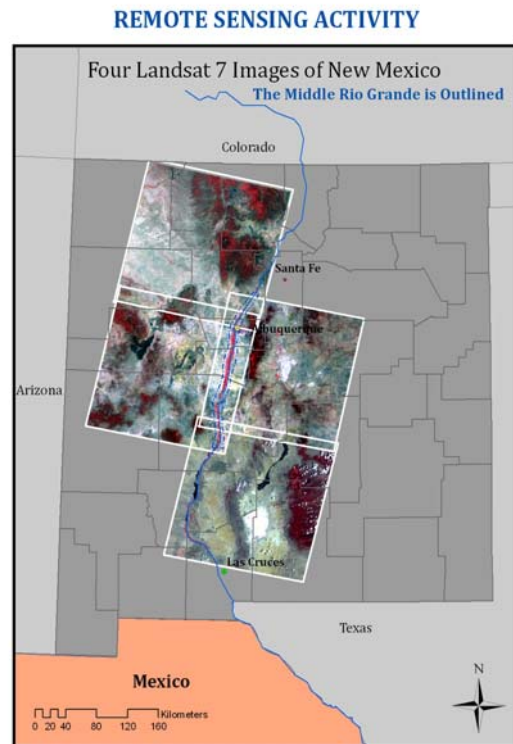


Figure 38. Landsat 7 Scenes for New Mexico

ArcGIS version 9.2 was used to process the images. The visual aids were created based on existing information by NASA's Landsat 7 Compositor (Electromagnetic Spectrum and Landsat 7 bands) at <http://landsat.gsfc.nasa.gov/education/compositor/>. RS-4 is a very effective visual to illustrate "false-color" images. The aerial photograph of the University of Wisconsin-Madison campus was reprinted with permission from John Wiley & Sons, Inc. This images shows that artificial turf does not look red in the false-color image. The worksheet containing world agricultural pattern, was develop with information obtained from NASA's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on the Terra satellite at <http://asterweb.jpl.nasa.gov/gallery-detail.asp?name=agmontage>.

The worksheets contain close up images of Landsat areas, and incorporate the ET research aspect that deals with studying an area remotely. Remote sensing is a tool based

on scientific principles. It is also an art as interpretation of the data greatly depends on the knowledge and life experience of the person analyzing the data (Jensen, 2005).

A box of colored pencils is listed as required material for this activity. Students will “create” their own false-color image. Satellite images use a matrix format for recording information pixel by pixel. Each pixel of the matrix has a column and row cell address. They will use color pencils to capture numerical data in a matrix of rows and columns. Following this process they will discover three plant species in New Mexico, Texas and Colorado. Part of the value of this component of the activity is that it presents remote sensing without the use of software. This can be very helpful for settings where access to GIS software is limited. The inspiration for this came from hand drawn map found on the side of the City of Albuquerque Bio Van.

3.4. New Mexico Science Content Standards

The Remote Sensing activity aligns with standards for 5th through 8th grade. In broad terms it relates to Scientific Thinking and Practice, Physical Science standards that have to do with energy travel as waves and light emission and scattering. It also meets Science and Society standards of watershed community decisions regarding water use. Listed below are the specific standards met.

5th Grade

- 1-1-1-1 Plan and conduct investigations, including formulating testable questions, making systematic observations, developing logical conclusions, and communicating findings.*
- 1-1-1-3 Use graphic representations (e.g., graphs, tables, labeled diagrams) to present data and produce explanations for investigations.*
- 1-1-2-1 Understand that different kinds of investigations are used to answer different kinds of questions (e.g., observations, data collection, controlled experiments).*
- 1-1-3-1 Use appropriate units to make precise and varied measurements.*
- 1-1-3-2 Use mathematical skills to analyze data.*
- 1-1-3-3 Make predictions based on analyses of data, observations, and explanations.*
- 2-2-1-4 Describe how human activity impacts the environment.*
- 3-1-1-1 Describe the contributions of science to understanding local or current issues (watershed and community decisions regarding water use).*

7th Grade

- 1-1-1-1 Use a variety of print and web resources to collect information, inform investigations, and answer a scientific questions or hypothesis.*
- 1-1-3-2 Use mathematical expressions to represent data and observations collected in scientific investigations.*

6th Grade

- 1-1-1-2 Examine the reasonableness of data supporting a proposed scientific explanation.*
- 1-1-1-3 Justify predictions and conclusions based on data.*
- 1-1-2-1 Understand that scientific knowledge is continually reviewed, critiqued, and revised as new data become available.*
- 1-1-3-1 Evaluate the usefulness and relevance of data to an investigation.*
- 2-1-2-4 Understand that some energy travels as waves (e.g., light), including: different wavelengths of sunlight (e.g., visible, ultraviolet, infrared).*

8th Grade

- 1-1-1-2 Use a variety of technologies to gather, analyze and interpret scientific data.*
- 1-1-2-1 Examine alternative explanations for observations.*
- 1-1-3-1 Use mathematical expressions and techniques to explain data and observations and to communicate findings (e.g., formulas and equations, estimation, mean). Understand how light and radio waves carry energy through vacuum or matter by: separation of white light into different wavelengths by prisms and visibility of objects due to light emission or scattering.*

4. Conclusions

4.1. Pilot Testing of Activities

Changes as a result of pilot testing are reflected in the activities in Appendix B, the modifications made are described in this section.

Pilot Test #1

The first pilot testing of the activities took place on March 24th with a group of four 5th grade students of La Mesa neighborhood in Albuquerque. It was done over a period of approximately two hours. This neighborhood is mainly comprised of Mexican immigrants, and in many cases the children are just starting to learn English. For this particular situation, the pilot testing the activity was translated to Spanish. The cottonwood was “el Alamo” and the salt cedar “el Cedro Salado.” Students seemed very engaged and said that they enjoyed the activity.

Pilot Test #2

The second pilot testing of both activities was done on April 22nd at Governor Bent Elementary School. Ms. Sheila Hofstedt, per request of Dr. Julie Coonrod, was kind enough to allow an hour visit to her 5th grade classroom of five students. The students in her class are part of the gifted program and Ms. Hofstedt explained that they are at the intellectual level of 7th graders. The activities were modified to fit the time allotted by the teacher which was about an hour. Students were very thankful and said that they had enjoyed learning new things.

Plant Transpiration Activity

Pilot Test #1

All of the visual aids (PT-1 to PT-7) were used to explain concepts of the ET research to La Mesa students. As part of the Plant Transpiration Experiment students calculated the area of a cottonwood leaf using engineering paper (See Figure 39) which is part of the Plant Transpiration Experiment. They also completed data sheet #1: Water Depletion for the MRG (See Figure 40). Finally the *Kit for building ET Study Site* was assembled (See Figure 41). Students were given a brief explanation as to why studying ET depletions is important. Data sheet #1 helps demonstrate that ET is the highest water depletion (37%) in the MRG stretch. They responded well to the use of images in the pie chart and were able to describe what each one represented. The only image they were not familiar with was of the agricultural fields, they did not have the word ‘agricultura’ in their vocabulary. The process of building the ET Study Site involved students collaborating as a group. This activity engaged every student, and they enjoyed thinking of themselves in the middle of a real ET study site.



Figure 39. La Mesa neighborhood student completes Leaf Area estimation



Figure 40. La Mesa neighborhood student works on data sheet #1



Figure 41. La Mesa neighborhood Students use Kit to build ET Study Site

Pilot Test #2

All of the visual aids (PT-1 to PT-7) were used with students at Governor Bent School. PT-1 was used to introduce ET to the students. They were familiar with the Water Cycle, PT-3 was used as a review of what they already knew and plant transpiration was emphasized with PT-4. Since they knew the concepts of evaporation and transpiration, they were encouraged to think of what ET could be based on those two familiar processes. They came up with different answers, but did not have the word ‘evapotranspiration’ in their vocabularies. Ms. Hofstedt suggested giving them the answer after a few attempts. It is a good idea to start with PT-1 because it awakened the students’ curiosity, and they were interested to look at every image. The sequence for presenting the visual aids does not have to be the one given here. The visuals can be used in the order that they are needed. Some students were able to recognize the cottonwood in visual PT-2, but none of them recognized the salt cedar and said it was a Pine tree. This was taken as an opportunity to explain to them some research findings on the presence of salt cedar in the MRG.

PT-5 was used to show the factors affecting plant transpiration. Students responded well to this visual, and they noticed that emphasis was placed on Wind and Humidity. PT-6 and PT-7 were also interesting to students. They were fascinated by the image of the ET Tower and Anemometer. Overall, students responded well to the visual aids. They wanted to look at them and participate by answering questions. Perhaps one of the best received visuals was PT-5 for Factors Affecting Plant Transpiration. The acceptance of this particular visual may have to do with the fact that it has more of the humor of a children’s cartoon than the other visuals.

Based on the Plant Experiment of the activity, students completed data sheet #1- Water Depletions for the Middle Rio Grande. The most challenging image for students to interpret was the pivot irrigated agricultural fields as many students have never been on an airplane. An explanation of this image was included in data sheet #1 as a result. Ms. Hofstedt contributed with the wording of the questions which was changed accordingly.

The *Kit for building ET Study Site* was assembled (See Figure 42). Students were very interested and wanted to take part in building the Site. Since this is a very straight forward exercise, a conversion factor from inches to meters was added. The Site has grid squares of 30m by 30m which makes it very easy to place the groundwater wells in the right position. As a result of this pilot, it was decided that students will have to figure out the value of each grid square on their own.

The ET Study Site provided the opportunity to discuss aspects of the research. Such as Anemometer location above the canopy to obtain measurements, the concept of phreatophytes was also illustrated. Students were very interested to find out that the Plant Canopy Analyzer is used by climbing on the tower and taking measurements from the top. Their teacher emphasized how amazing it must be to have a view of the Bosque del Apache at 25 meters high. This last observation provided a nice introduction to the Remote Sensing activity.



Figure 42. Governor Bent Elementary School Students use Kit to build ET Study Site

It is expected that the background information provided in the visual aids, the data sheets and the plant transpiration experiment will be very effective in translating the target concepts that have been outlined throughout this Project.

Remote Sensing Activity

Pilot Test #1

Visual aids RS-1, RS-5 and RS-6 were used to explain concepts of the research to La Mesa students. Students were presented with the material on a laptop computer screen. This works, but it is not as effective as having hard copies. RS-6, Middle Rio Grande and Towers, was effective in making a connection between the ET Towers and use of Landsat 7 images. Students recognized the Towers in the visual and made the connection. Students completed worksheet #1: What is this? which is a “false-color” image of center pivot irrigated fields in New Mexico. They were very curious to find out what the image represented.

The part of the activity which was tested in its entirety was the *Digital Art* exercise. Worksheet #7: Satellite Image “False-Color” Composition was straight forward and proved to be a rapid assessment of students’ understanding of Landsat 7 “false-color” images (See Figure 43). Worksheet #8: (Blank map) was completed with the information from the matrices found in worksheets #9 and #10 (See Figures 44 and 45). As a result of this pilot, the instructions for this activity were clarified and revised. This part of the activity should be included because it appeals to students, and they feel that they are a part of the learning process.



Figure 43. La Mesa neighborhood student completes worksheet #7



Figure 44. La Mesa neighborhood student completes worksheet #10



Figure 45. La Mesa neighborhood student completing worksheet #8

Pilot Test #2

All of the visual aids (RS-1 to RS-6) were used with students of Governor Bent School. The Remote Sensing activity requires a considerable amount of background information before the students feel comfortable with the technology. RS-1 captured the students' interest and they wanted to find out how the pictures had been taken. Their questions provided an opportunity to explain that remote sensing by satellite provides a different perspective in which to study the environment. RS-4 was effective in illustrating "false-color" images. It allows for self-guided exploration and students enjoy figuring out that vegetation looks red, unless it is artificial turf. In RS-6, students made the connection between the ET Tower in the model, and the ET Towers that appear along the Middle Rio Grande. This was a successful representation as they made the connection between data gathering by ET Towers and Landsat 7 satellite images. It was explained to them that the data from the Towers can be combined with the information from the images and ET can then be calculated.

Worksheet #1: What is this? (See Figure 46) generated different responses from this group of students. The most common one was that it looked like modern art, or abstract art. They also said ‘red blood cells’ and ‘a gym with red bouncy balls.’ Having already completed data sheet #1 in the Plant Transpiration activity, some students remembered that center pivot irrigation created circular field patterns. In light of this and in the event that both activities were done together, it will be more effective to show worksheet #1 (Remote Sensing Activity) before data sheet #1 (Plant Transpiration Activity). Thus, students will see the Landsat 7 false color image for the very first time, and might feel more comfortable speculating what the image represents.



Figure 46. Student on far right works on worksheet #1

Worksheets #3 and #4 were presented, but there was not enough time for students to look for the features in New Mexico. It might be safe to say that these worksheets along with worksheet #2 would have been engaging and instructional.

Worksheet #7: Satellite Image “False-Color” Composition was also completed by this group of students. They enjoyed this activity, and displayed a similar feeling of ownership of their work that La Mesa students had previously demonstrated (See Figure 47).



Figure 47. Students work on worksheet #7

Pilot testing at Governor Bent Elementary was completed by the students in two groups of two and three students each. Group work for the two activities was effective. Groups of four might be ideal so that every student has the opportunity to clearly see the visuals and worksheets. Another hour would have allowed for completion of the activity. The ET calculations and the remaining digital art would have been interesting and instructional to the students.

It is expected that the background information provided in the visual aids and the worksheets for the Remote Sensing Activity will be very effective in translating the target concepts that have been outlined throughout this Project. Further pilot testing of both activities will be conducted by the Chihuahuan Desert Nature Park in Las Cruces, New

Mexico. The Park has established programs to test activities in groups of middle school students.

Final Reflections

The pilot testing of these activities, and the defense of this project brought to light important questions such as ways of assessing the students' understanding of these valuable concepts. The effectiveness of these activities is reason for further study. Education is in many ways an experimental and experiential process. Insight on ways to enrich and enhance these activities is gained every time they are presented and/or implemented.

The scope of this Professional Project encompasses transferring the research and technology into educational activities for middle school students. There are questions that will originate in a classroom which at this point are unforeseeable. One such question has to do with students' possible misinterpretation of the ET studies. In other words, if plants use up as much water as the research suggests, why not clear the Bosque completely and conserve all that water? There are of course ecological and environmental reason as to why this would not be the right course of action. This explanation might satisfy the average student, but another student might challenge it. Education is a long process, it does not happen overnight. The diversity of each student's background and prior knowledge adds to the complexity of the instructional process. Since science guides this research and accurate quantification of water depletions is the focus, the answers offered to students must reflect this as well. Language provides some insight on the connectedness of the Bosque and the Rio Grande. Bosque means forest in Spanish but to New Mexicans it means *Riparian Forest*. Riparian is an area that is adjacent to the river. It is in the Spanish names of the riparian forest and the river that a strong connection exists.

4.2. Research and Education Integration

Recent literature in science education says that little work had been done in translating findings from science studies to science education (Bowen, 2007). Similarly, an important part of EPSCoR's mission has to do with the need for building a link between their hydrological and education components. This need is based on sound documentation stating the Math and Science Crisis facing the nation (EPSCoR, 2006).

This professional project attempts to create a platform for educational outreach directed towards middle school students. Introducing students to current real-life questions that researchers embark upon can provide inspiration and bring a new component that could enrich their regular classroom activities. There is in today's science classrooms a lot of pressure due to standardized based testing. The New York Times informed on December of 2005 that a report by the Thomas B. Fordham Institute brought forth concerns regarding the focus on reading and math as subjects required for testing under the federal law of No Child Left Behind. This law has turned attention away from science. Outreach efforts in science could fill gaps that have been created by pressure on teachers and students to focus their efforts into math and reading and not on science. Science is dynamic, and is constantly incorporating new ideas, practices, and procedures with fast changing technologies. All of this valuable information must be transfers to the community through education and outreach efforts.

Students are an important target audience to engage in the ongoing scientific dialogue as they are open to new ideas, and have an inquisitive nature about their environment. According to a recent national poll of students ranging from ages eleven to eighteen, by a Washington-based polling firm, Peter D. Hart Research Associates, it is children, not parents, who worry more about the declining environment and who also do more about it (Roberts, 1998). This professional project proposes outreach to expand middle school students' interest in water issues affecting the region, and to have them ask questions that echo those being asked by scientist, *do native desert plants lose more water than their non-native counterparts*. This is the driving question of the EPSCoR research, and it can also be the driving question for a middle school plant transpiration experiment.

The United Nations Conference on Environmental and Development or “Earth Summit” in Rio de Janeiro in June 1992 had words of wisdom regarding education and the environment.

“Education is critical for promoting sustainable development and improving the capacity of the people to address environments and development issues...It is critical for achieving environmental and ethical awareness, values and attitudes, skills and behavior consistent with sustainable developments, and for effective public participation in decision-making.” (UNCED 1993, Chapter 36, p.2).

Appendix A

Box Plot Analysis

1) Hypotheses of Interest No 1

Null hypothesis: There is no difference among the three groups of plants (group 1 is Apache and Mountain, group 2 is Blue Lily Turf and Helleborus, and group 3 is Yucca).

Alternative hypothesis: There is at least one difference among the three groups of plants.

BLOCK: There are five blocks. Each block consists of 5 random measures of plant transpiration.

FACTOR: This factor has three levels, level 1 is the combination of two native plants, Apache and Mountain), level 2 is the combination of two non-native plants, Blue Lily Turf and Helleborus, and level 3 is one plant Yucca alone.

RESPONSE 1: The response variable is the measure of plant transpiration rate in grams/centimeter squared (grams/cm²).

The **p-value** obtained for the FACTOR was **0.004**, therefore, there is enough evidence to conclude that "There is at least one difference among the three groups of plants." This result is statistically significant. The side-by-side box plot shows that the Curved Leaf Yucca is more efficient than the other four plants in terms of transpiration rate. The Yucca displays the lowest mean transpiration rate with respect to the other two groups.

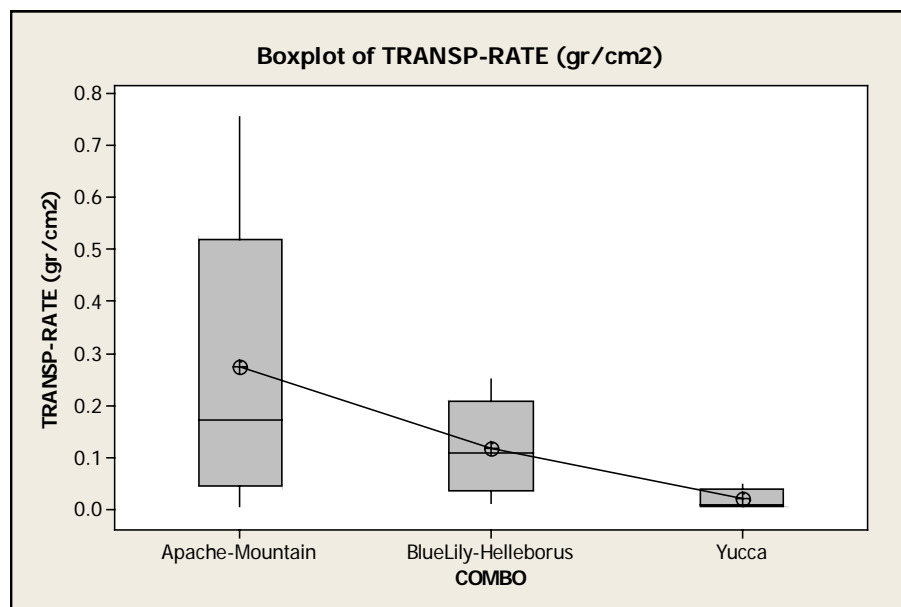


Figure 1. Box plot (Transpiration Rate in grams/cm²) of native plants, non-native plants and Yucca.

RESPONSE 2: The response variable is the measure of percentage of water lost. The **p-value** obtained was **0.001** and the result was also statistically significant.

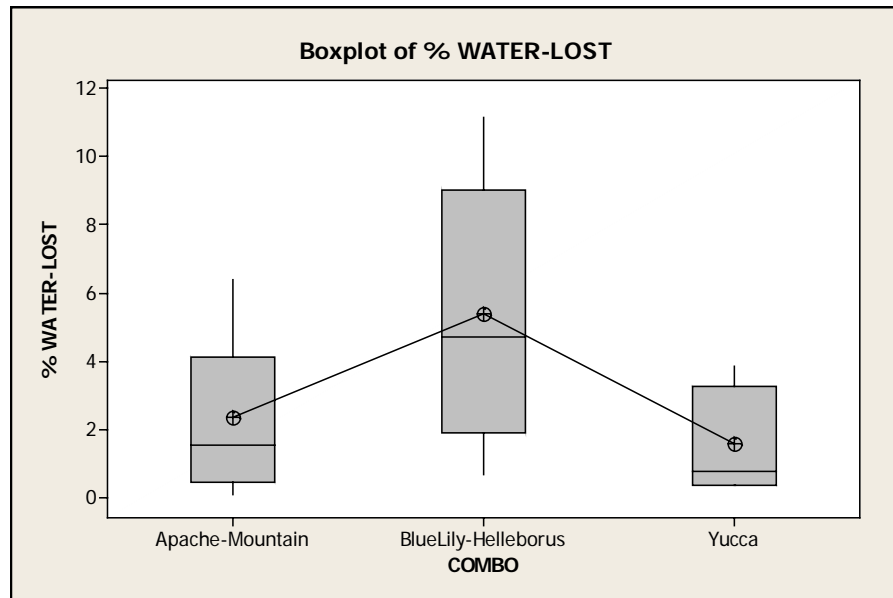


Figure 2. Box Plot (Percentage Water Lost) native plants, non-native plants and Yucca.

2) Hypotheses of Interest No 2

Null hypothesis: There is no difference among the three plants, Blue Lily Turf, Helleborus, Yucca.

Alternative hypothesis: There is at least one difference among the three plants.

BLOCK: There are five blocks. Each block consists of 5 random measures of plant transpiration.

FACTOR: This factor has three levels, level 1 is the plant Blue Lily Turf, level 2 is Helleborus, and level 3 is Yucca.

RESPONSE 1: The response variable is the measure of plant transpiration rate in g/cm². The **p-value** obtained for the FACTOR was **0.017**, therefore, there is enough evidence to conclude that "There is at least one difference among the three plants". This result is statistically significant. The Previous graph shows the efficiency of the Yucca plant in terms of the transpiration rate. The Yucca shows the lowest mean transpiration rate with respect to the other two plants.

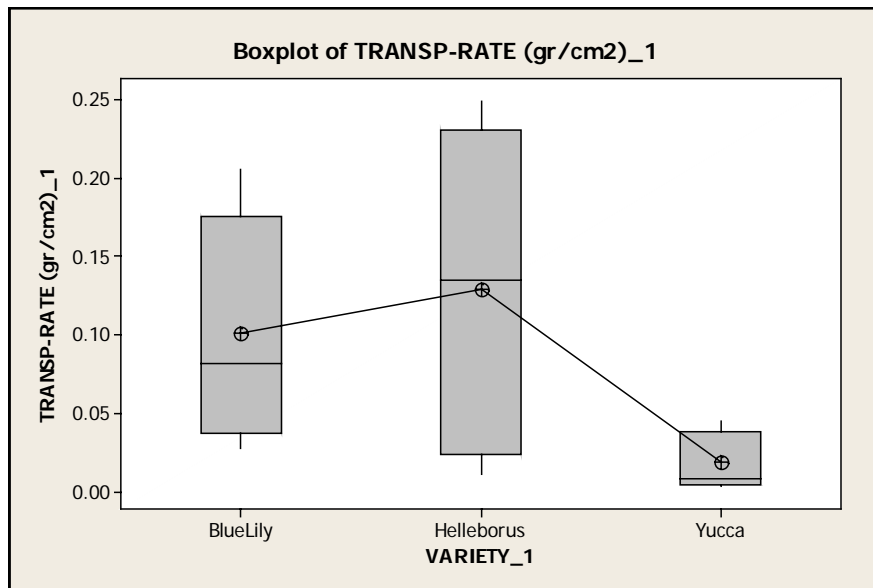


Figure 3. Box Plot Blue Lily Turf, Helleborus, and Yucca (Transpiration rate in grams/cm²)

RESPONSE 2: Percentage of water lost, the p-value obtained was 0.014 and the result was also statistically significant.

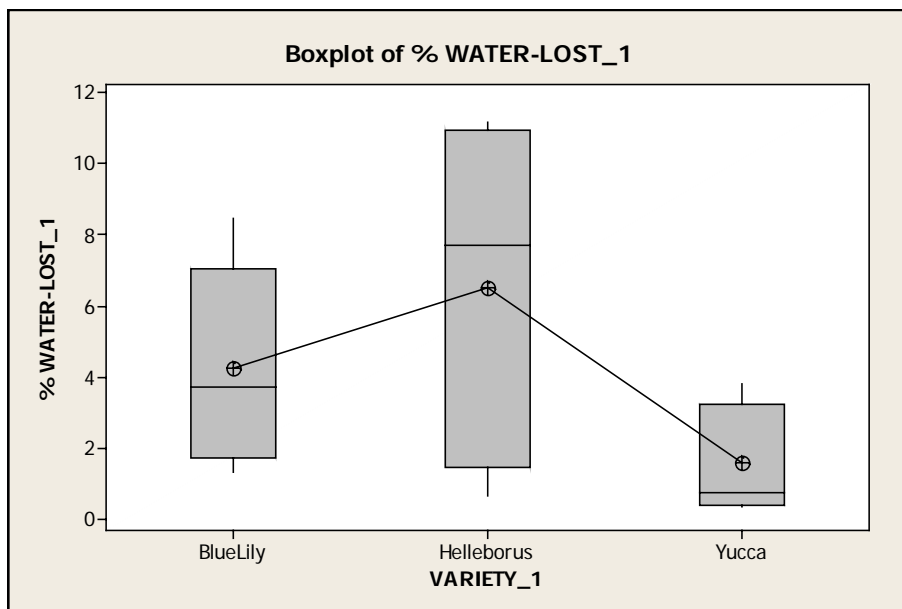


Figure 4. Plot Box Blue Lily Turf, Helleborus, and Yucca (Percentage water lost)

3) Hypotheses of Interest No 3

Null hypothesis: There is no difference between two groups of plants, group 1 is Blue Lily Turf and Helleborus, and group two is Yucca alone.

Alternative hypothesis: There is a difference between the two groups of plants.

BLOCK: There are five blocks. Each block consists of 5 random measures of plant transpiration.

FACTOR: This factor has two levels, level 1 are the plants Blue Lily Turf and Helleborus, and level 2 is Yucca alone.

RESPONSE 1: The response variable is the measure of plant transpiration rate in g/cm². The **p-value** obtained for the FACTOR was **0.005**; therefore, there is enough evidence to conclude that "There is a difference between the two groups of plants". This result is statistically significant. The above graph shows how efficient the Yucca plant in terms of the transpiration rate. The Yucca plant shows the lowest mean transpiration rate with respect to the other group.

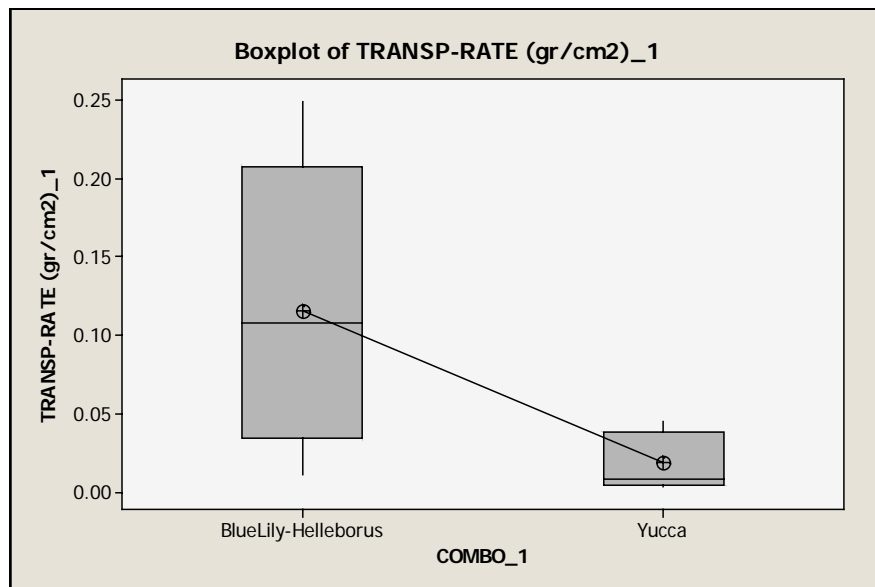


Figure 5. Box Plot Blue Lily Turf and Helleborus together and Yucca (Transpiration rate in grams/cm²)

RESPONSE 2: I conducted a similar analysis for the RESPONSE percentage of water lost, the **p-value** obtained was **0.012** and the result was also statistically significant.

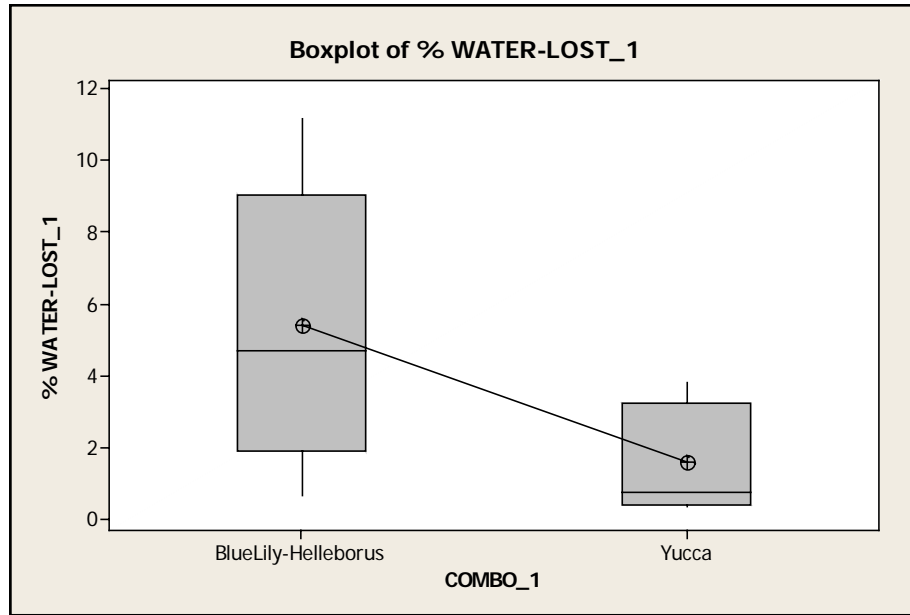


Figure 6. Box Plot Blue Lily Turf and Helleborus together and Yucca (Percentage Water Lost).

Appendix B

Plant Transpiration Activity

Includes:

- 1) Teacher's Guide
- 2) Sample Data Sheets
- 3) Student's Guide
- 4) Blank Data Sheets

PLANT TRANSPIRATION - Teacher's Guide

ABSTRACT: The southwest of the United States is a region that faces water scarcity. Riparian zone evapotranspiration (ET) losses along the Middle Rio Grande (MRG) are estimated to account for up to 37% of the total water budget (S.S. Papadopoulos, 2004). Annual estimates of the riparian zone ET for the MRG corridor range from $150 \times 10^6 \text{ m}^3$ to $375 \times 10^6 \text{ m}^3$ (Coonrod and McDonnell, 2001).

Research funded by New Mexico Experimental Program to Stimulate Competitive Research (NM EPSCoR), focuses on investigating whether native or non-native tree species lose more water through ET processes in the MRG. Through visual aids, a plant transpiration experiment, and a scale ET Study Site model, this activity will illustrate the importance of accounting for plant transpiration losses in the water budget as it relates to native and non-native plants.

GRADE LEVEL(S): 5th – 8th

OBJECTIVES:

- Students will be able to describe ET research conducted along the MRG.
- Students will be able to observe that native and non-native plant species transpire at different rates.

NEW MEXICO SCIENCE CONTENT STANDARDS

5th Grade

- 1-1-1-6 Plan and conduct investigations, including formulating testable questions, making systematic observations, developing logical conclusions, and communicating findings.*
- 1-1-1-7 Use appropriate technologies (e.g., calculators, computers, balances) to perform scientific tests and to collect and display data.*
- 1-1-1-8 Use graphic representations (e.g., graphs, tables, labeled diagrams) to present data and produce explanations for investigations.*
- 1-1-1-9 Describe how credible scientific investigations use reproducible elements including single variables, controls, and appropriate sample sizes to produce valid scientific results.*
- 1-1-1-10 Communicate the steps and results of a scientific investigation.*
- 1-1-2-1 understand that different kinds of investigations are used to answer different kinds of questions (e.g., observations, data collection, controlled experiments).*
- 1-1-2-2 Understand that scientific conclusions are subject to peer and public review.*
- 1-1-3-1 Use appropriate units to make precise and varied measurements.*
- 1-1-3-2 Use mathematical skills to analyze data.*
- 1-1-3-3 Make predictions based on analyses of data, observations, and explanations.*
- 2-1-1-2 Describe how matter changes from one phase to another (e.g., condensation, evaporation).*
- 2-2-1-4 Describe how human activity impacts the environment.*
- 3-1-1-1 Describe the contributions of science to understanding local or current issues (watershed and community decisions regarding water use).*

6th Grade

- 1-1-1-4 Construct appropriate graphs from data and develop qualitative and quantitative statements about the relationships between variables being investigated.*
- 1-1-1-5 Examine the reasonableness of data supporting a proposed scientific explanation.*

- 1-1-1-6 *Justify predictions and conclusions based on data.*
- 1-1-2-1 *Understand that scientific knowledge is continually reviewed, critiqued, and revised as new data become available.*
- 1-1-2-2 *Understand that scientific investigations use common processes that include the collection of relevant data and observations, accurate measurements, the identification and control of variables, and logical reasoning to formulate hypotheses and explanations.*
- 1-1-2-3 *Understand that not all investigations result in defensible scientific explanations.*
- 1-1-3-1 *Evaluate the usefulness and relevance of data to an investigation.*
- 2-2-1-1 *Understand how the water cycle is essential to most living systems.*

7th Grade

- 1-1-2-3 *Analyze and evaluate scientific explanations.*
- 1-1-3-2 *Use mathematical expressions to represent data and observations collected in scientific investigations.*
- 1-1-3-3 *Select and use an appropriate model to examine a phenomenon.*
- 2-3-2-3 *Know that changes to ecosystems sometimes decrease the capacity of the environment to support some life forms and are difficult and/or costly to remediate.*

8th Grade

- 1-1-1-2 *Use a variety of technologies to gather, analyze and interpret scientific data.*
- 1-1-2-1 *Examine alternative explanations for observations.*
- 1-1-2-3 *Know that scientific knowledge is built on questions posed as testable Hypotheses, which are tested until the results are accepted by peers.*
- 1-1-3-1 *Use mathematical expressions and techniques to explain data and observations and to communicate findings (e.g., formulas and equations, estimation, mean).*
- 2-1-1-7 *Know that phase changes are physical changes that can be reversed (e.g., Evaporation, condensation).*
- 2-1-1-8 *Describe various familiar physical and chemical changes that occur naturally (e.g., photosynthesis).*
- 2-2-1-1 *Describe how matter moves through ecosystems (e.g., water cycle).*
- 2-3-2-2 *Understand the unique role water plays on Earth, including: properties of water related to processes in the water cycle: evaporation, condensation, precipitation, surface runoff, percolation.*

MATERIALS:

Plant Transpiration Experiment:

- *A native plant and non-native plant in a one gallon size container each.
- Metric scale.
- Potting soil
- Epoxy coated aquarium gravel.
- Scaled engineering paper.
- Large (approx. 73Qt) plastic container with lid.
- A 12 inch/30 cm ruler.

***IMPORTANT:** Depending on how many groups of students there are in each class, any number of pairs (one native and one non-native of) plants can be used. In a class of thirty students, use six pairs of natives and non-natives plants. This way there will be

replication in the analysis and an assessment of variability among plants. It is recommended that each group of students use a non-native water loving plant, and compare it to different native Yucca varieties. This experiment was done with fourteen different plants, and the Curved Leaf Yucca (*Yucca recurvifolia*) was by far the best at conserving water).

Nurseries in Las Cruces that carry different varieties of one gallon size Yucca plants are Enchanted Gardens has Soaptree Yucca (*Yucca elata*), Banana Yucca (*Yucca baccata*), Guzman's Garden Center has the Red Tip Yucca (*Hesperaloe parvifolia*), Spanish Dagger Yucca (*Yucca gloriosa*). It was also suggested that the state flower, the New Mexico Yucca (*Yucca glauca*) could be found along trails in Las Cruces. This plant could potential be repotted and used for the study.

Recommended non-natives are the Ivory Prince (*Helleborus*), Blue Lily Turf (*Liriope muscari*), Blue Muffin (*Viburnum dentatum*), Gold Maiden (*Euonymus japonicus*). Avoid non-native succulents like the Jade. Recommended native plants are the Apache Plume (*Fallugia paradoxa*) and the Mountain Mohogany (*Cercocarpus montanus*).

1) Visual aids: Seven visual aids are provided: Which image represents ET?, Can you identify which trees these leaves belong to?, Water Cycle, Plant Transpiration, Factors affecting plant transpiration, ET Towers and Anemometer, Plant Canopy Analyzer measures Leaf Area Index (LAI).

2) Plant Transpiration Experiment/Data sheets: Water depletions for the Middle Rio Grande, Plant Transpiration Rates, Graph and analysis of results, Percentages of Water Lost, Averages of plant transpiration experiment, Water Budget for a Semi-arid Basin.

3) ET Study Site: Directions are provided for students to build a scaled model of ET site.

BACKGROUND: Riparian zone ET losses along the Middle Rio Grande are estimated to account for up to 37% of the total water budget (S.S. Papadopoulos, 2004). Through the natural process of transpiration tree communities found along the river, account for the highest water loss in the Middle Rio Grande stretch. This activity will present evidence to illustrate this concept. The plant transpiration experiment is meant to illustrate the natural process of plant transpiration through stomata. This process is affected by factors such as humidity, wind and leaf structure. EPSCoR funded research asks whether cottonwood (native) or salt cedar (non-native) transpire more water. If salt cedar is removed to restore the original Bosque vegetation, will this reduce ET?

1) Definitions:

Basin: The entire geographical area drained by a river and its tributaries.

Evapotranspiration: Also known as ET is defined as combined evaporation- moisture lost to the atmosphere from soil and open water, and transpiration-moisture lost to the atmosphere by plants. Evapotranspiration measures the total moisture lost to the atmosphere from the land surface, and as such it forms an important variable in understanding the local operation of the hydrologic cycle (Campbell, 2007). ET is usually measured in millimeters per day (mm/day) or inches per hour (in/hr). It can also be reported in units of volume.

Leaf Area Index: Also known as LAI, this is an important parameter in ET calculations as it relates to the distribution of stomata within a canopy (McDonnell, 2007). LAI refers

to the total “one-sided” area of photosynthetic tissue per unit area of ground. LAI values for the Bosque near Albuquerque are about 3, and evergreen forest would have LAI values as high as 12.

Phreatophyte: A deep-rooted plant that obtains water from a permanent ground supply or from the water table. Both cottonwood and salt cedar are phreatophytes.

Riparian: Refers to the area that is adjacent to the river.

The Middle Rio Grande (MRG): Defined as the reach between the Otowi Bridge and Elephant Butte stream gages. This portion of the Rio Grande is about 320 kilometers or approximately 200 miles.

Stoma (singular = stomata): Comes from the Greek word for “mouth.” Microscopic pores or “stomata” through which plants are able to transport water upward through their tissues, to later put it back into the atmosphere as water vapor.

Water Budget: Mass balance of water gains and losses. A water budget should 'account' for all water. The hydrologic cycle defines a true water budget. The Papadopoulos study is accounting for depletions and saying that 37% of water depletions are attributed to ET.

Concepts:

Plant Transpiration: Plants transpire vast quantities of water. Only one percent of all water a plant absorbs is used in photosynthesis, while the rest is lost through transpiration. Transpiration, along with evaporation of moisture on land, provides almost two-thirds of the atmospheric moisture that falls as precipitation on land surface. The remaining one-third comes from the evaporation of the vast oceans (National Center for Atmospheric Research, <http://www.ucar.edu/learn/index.htm>)

In this activity plant transpiration is measured in two ways, by percentage of weight (water) lost and by grams (weight loss) per centimeters squared (leaf area). As with human perspiration, plants tend to transpire more with increased temperature, sunlight intensity, water supply, and size. When it gets too hot, though, transpiration will shut down. Transpiration occurs as the Sun warms the water inside the leaf causing some of the water to change its state to water vapor, which escapes through the stomata. As molecules of water vapor at the top of the leaf in the plant are lost to transpiration, the entire column of water is pulled upwards. Some important transpiration functions include:

- Cooling the inside of the leaf because the escaping water vapor contains heat.
- Keeping water flowing up from the roots, through the stem, to the leaves.
- Ensuring a steady supply of dissolved minerals from the soil.

Other factors influencing transpiration rate include leaf shape and size, pores (stomata) distribution, and leaf surfaces. Where a particular plant grows often depends upon how it has adapted its transpiration rate to a particular climate. Environmental factors affecting plant transpiration are light, humidity, temperature and wind.

Leaf Area Index: Leaf Area Index, also known as LAI is used in the research to calculate density of vegetation. In the field it is measured with an indirect optical device known as the Plant Canopy Analyzer. LAI is an important parameter in ET calculations as it relates to the distribution of stomata within a canopy (McDonnell, 2007). LAI as well as leaf structure are very important factors in quantifying plant transpiration processes. Research findings assert that salt cedar transpiration varies with weather

factors, stand density and water availability (Davenport, et al., 1982). In addition, salt cedar is thought to have superior drought tolerance compared to native species and the ability to produce high density stands and high leaf area (Cleverly, et al., 1997).

TIPS FOR ENTIRE CLASS PARTICIPATION: Visuals ***PT-1*** and ***PT-2*** are intended to be assess any prior knowledge students may have of ET and cottonwood and salt cedar. The answer to ***PT-1*** is that EVERY image represents ET. ***PT-2*** asks students to tell everything they know about the two tree species. The following questions may also be used to focus students on the plant transpiration activity:

Plants lose a lot of water through the process of evapotranspiration. Can you guess how much is lost in the Bosque along the Middle Rio Grande in one year?

You could fill 375 football fields with water to a depth of 100 m (approximately a 50 story building) with all the water that is lost to ET processes along the Middle Rio Grande during one year.

Think of a cactus, and compare it to a regular house plant. Which do you think will use more water?

Cacti use a specialized mode of photosynthesis that enables them to conserve water and manufacture sugars at the same time, unlike most plants, which must lose water whenever they make sugars (Bowers, 1986).

PROCEDURES: The visual aids created for this activity are meant to “tell a story” about the ET research along the Middle Rio Grande. They are meant to be seen in color to be most effective. This may involve the use of a screen projector, or laminated copies to be shared in groups where the image is displayed to the entire class.

1) Visual Aids: The visual aids will provide the students with an opportunity to construct their knowledge on the concepts and will prepare them for the activity itself. ***PT-2*** introduces two of the main “characters” in the research; the native cottonwood and the invasive salt cedar. Salt cedar has the ability to concentrate salt in its leaves. As the leaf litter gathers under the tree, this increases the salinity of the soil (Coonrod and McDonnell, 2001). Salt cedar can consume large amounts of water, and constitutes a hot topic of debate in the water resources management community. Mainly, the question is whether eradicating salt cedar will in fact reduce ET in the stretch of the MRG riparian corridor.

PT-3 is a representation of the Water Cycle highlighting evapotranspiration. The compound word for evaporation and transpiration, often referred to as ET is elusive and foreign to many adults, let alone children. Separating the word into evaporation and transpiration helps students to make the connection with ET. ***PT-4*** shows a *Cercocarpus Montanus* (Mountain Mohogany) to illustrate the plant transpiration. Placing emphasis on “stomata” and the role that this microscopic pores have in the process through which plants lose water to the atmosphere in the form of water vapor. ***PT-5*** shows factors affecting plant transpiration. Researchers have remarked that wind and humidity are considered to be the two most important factors, and should be emphasized. ***PT-6*** and ***PT-7*** shows photographs of the ET Towers and the Plant Canopy Analyzer. The Towers play a crucial role in the research. The towers and instruments constitute state of the art

technology for measuring ET on a regular basis. The “claw like” instrument is called an Anemometer. It measures vertical wind speed, and it is situated above the canopy. Students will “see” what a research site looks like, and the positioning of the ET tower, and groundwater wells on the site when they build the ET Site Study model ($1/32'' = 1\text{ft}$)

2) Plant Transpiration Experiment/Data Sheets: It is important to make a distinction between evapotranspiration measurements in the Bosque and the measurement of plant transpiration for this activity. ET in the Bosque is measured by three-dimensional eddy covariance instruments that are attached to towers. The towers are located at strategic points along the Middle Rio Grande. For the individual potted plants used for this activity, a simple *Potted Plant Weighing method* will be used. As part of this calculation a *Leaf Area Estimation* will also be conducted. In addition, a *Plant Transpiration Observation* will be carried out through the use of a sealed plastic container.

Important assumptions:

- Plant weight loss is all due to transpired water.
- Epoxy gravel coating will prevent evaporation from the soil.

Potted plant weighing method: Plants will be left indoors for the duration of the experiment.

- 1) Each group will have a one gallon native and one non-native plant.
- 2) Water each plant 250 mL prior to starting the experiment.
- 3) Make sure all plants have the same amount of soil. This will eliminate error in sample variability.
- 4) Make sure to leave enough space for 2 inches of gravel to cover soil.
- 5) Carefully cover soil with 2 inches of Epoxy gravel to avoid loss of water through soil evaporation.
- 6) Record the weight of plants after adding the gravel.
- 7) Weigh plants daily at the same time and record weight.
- 8) Perform calculations outlined in data sheets.
- 9) Continue process for 5 to 7 consecutive days.

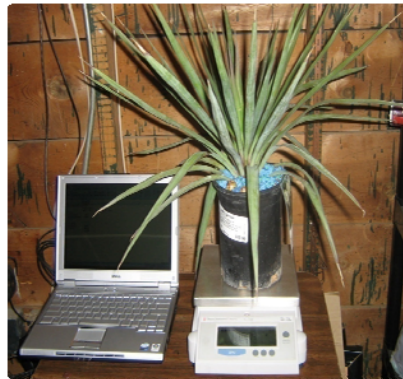


Figure 1. *Potted plant weighing method*

Leaf Area Estimation: In order to get a rate for plant transpiration of grams per centimeter squared (g/cm^2). The weight loss of each plant (grams) will then be divided by the leaf area of the plant (cm^2). By doing this, transpiration will be distributed according to each plant's leaf area. The leaf area for each plant will have to be estimated (See Student Guide for sample).

Plant Transpiration Observation: The plants will be under the sealed plastic container once for a period of 4 hours. This is important because it makes the transpiration process visible to the students. The plants will transpire and there will be water droplets inside the wall of the container.



Figure 2. Plant transpiration observation

Setting a Control: It is also important to verify that these droplets are caused by plant transpiration. This is an excellent way for students to verify that the plant does indeed lose water during the transpiration process.



Figure 3. Control

Data sheet #1 illustrates the Papadopoulos study of 2004. It shows percentages and images. Students write down water depletions for the MRG from the highest to the lowest. **Data sheet #2** is for Plant transpiration rates (grams/centimeters²). Plant leaf area will be calculated using engineering paper. **Data sheet #3** asks students to do a graph and answer a few questions accordingly. **Data sheet #4** is for Percentages of weight (water) lost. This calculation determines what percentage of the original weight (water) was lost by the plants. **Data sheet #5** is for class averages. **Data sheet #6** has a catchment water budget for a semi-arid basin. It is meant to illustrate that ET is a significant value.

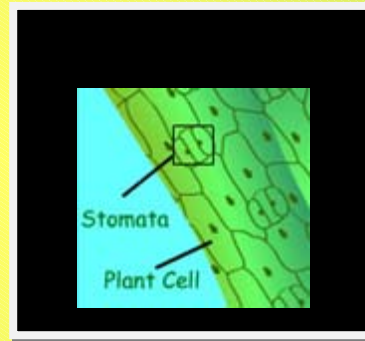
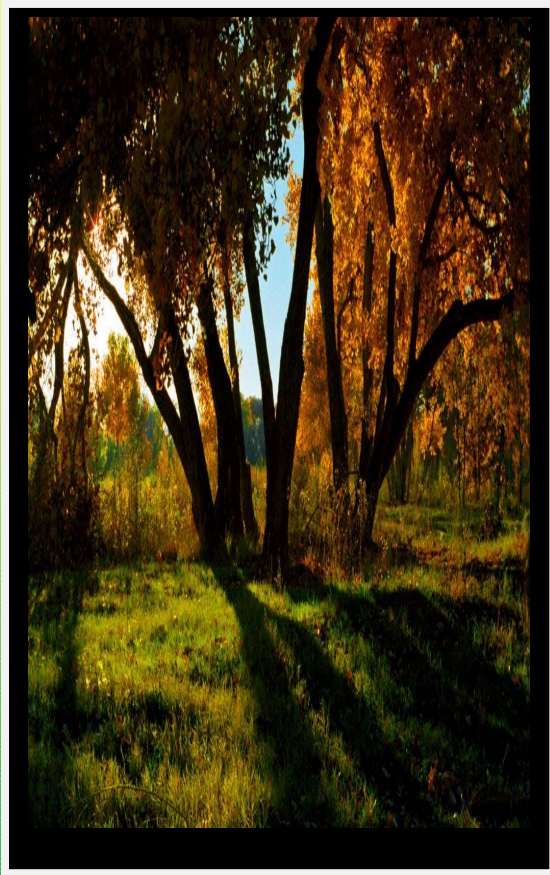
3) ET Study Site model: This model will allow students to see in 1/32" scale what an ET study site looks like. Additional concepts that can be illustrated with the model are:

- The pins at the end of each tree can be thought of as "roots." Phreatophytes obtain water from the ground water table. The pins go in the "soil" similarly to the roots of the cottonwood and salt cedar.
- The ground water wells will also be "buried" in the soil. The concept of the wells measuring ground water levels may also be explained.
- Emphasize that the ET Tower (and Anemometer) must be on top of the canopy in order to take measurements.
- Explain that salt cedars can make dense stands and transpire more than cottonwoods. Also, illustrate that cottonwood can "shade" each other and transpire less. Use 10 "salt cedar" and 5 "cottonwoods" and ask which will transpire more. The answer would be the salt cedars as they are denser.

CONCLUSIONS: Upon completion of this activity, students should be able to recognize that evapotranspiration constitutes a tremendous water loss, and how that loss is measured. They will be able to "see" the transpiration process of plants, and compare the rates of native versus native plants regarding water loss through transpiration. These are some follow up questions:

- Why are researchers concerned about losses through evapotranspiration?
- How is evapotranspiration measured?
- How would you calculate the leaf area of a salt cedar shrub like leaf?.
- Would cutting down all the trees in the Bosque fix the problem of ET losses?

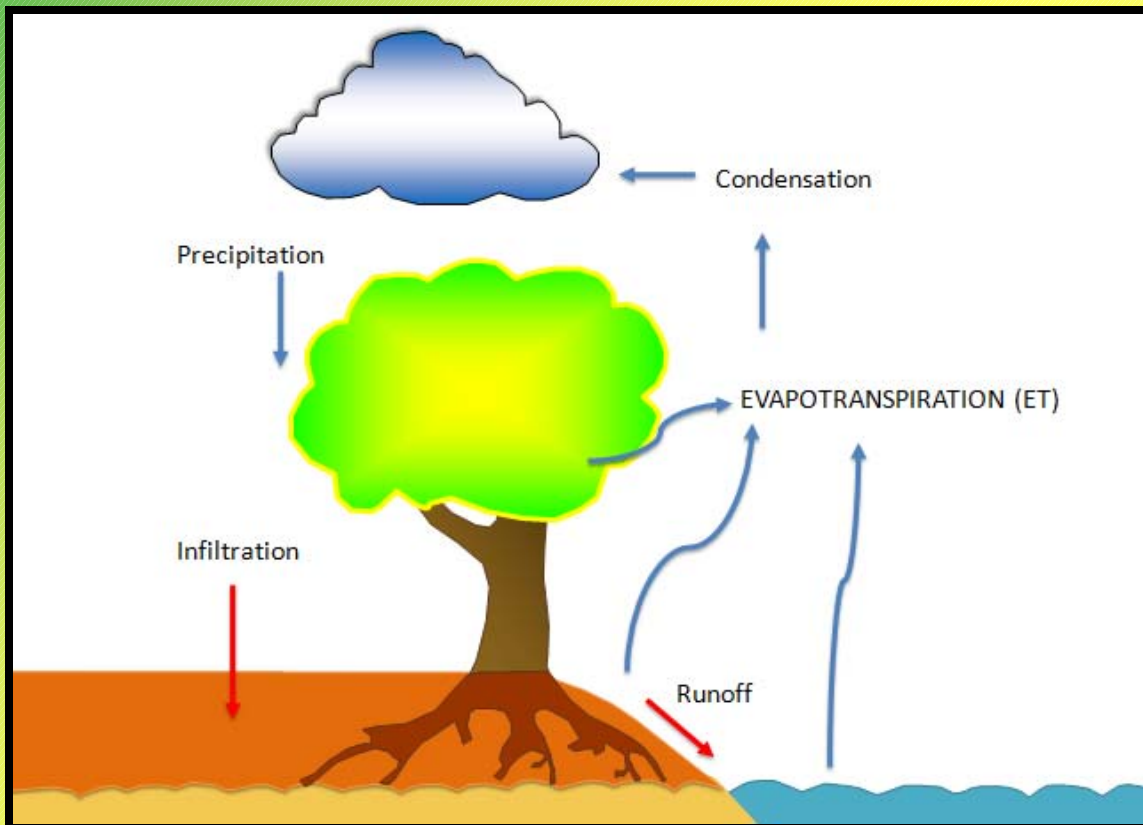
Which image relates to ET?



Can you identify which trees these leaves belong to?



Water Cycle



DEFINITIONS

Precipitation: Change of water vapor to liquid water.

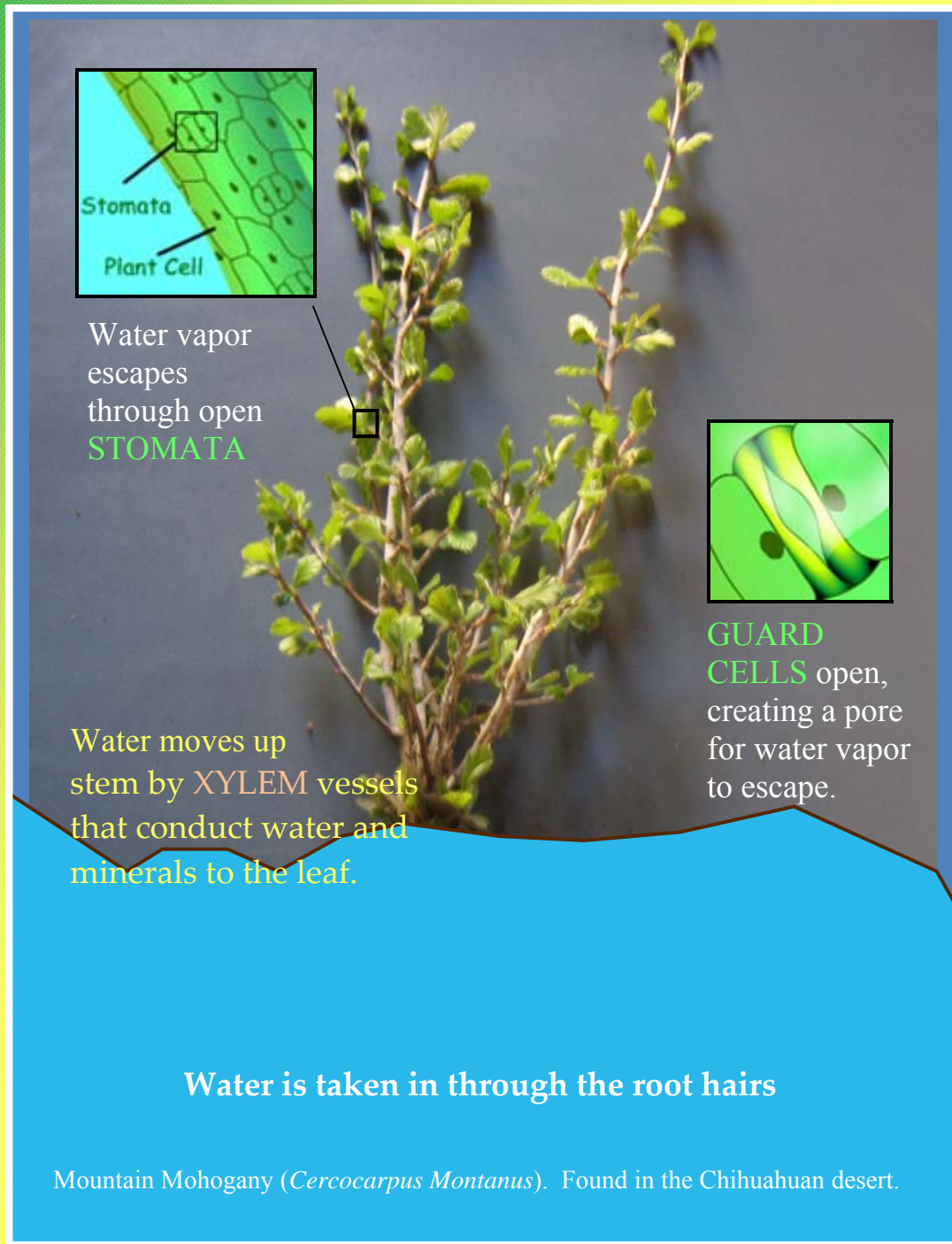
Evapotranspiration: Also known as ET is the evaporation-moisture lost to the atmosphere from soil and open water, and transpiration-moisture lost to the atmosphere by plants.

Condensation: Formation of clouds.

Infiltration: Absorption of water by the soil.

Runoff: Drainage of water on the ground

Plant Transpiration



Credit for images of Stomata and Guard Cells Michigan Environmental Education Curriculum at <http://techalive.mtu.edu/meec/module01/Transpiration.htm>

Factors Affecting Plant Transpiration



Light

Humidity

Temperature

Wind

ET Tower

(Right)

ET is computed along the Middle Rio Grande from the towers every 30 minutes. The instruments on the towers measure temperature, humidity and radiation changes.



Anemometer

(Left)

Measures wind velocity.

Credit: Cliff Dahm, Department of Biology at the University of New Mexico.

Plant Canopy Analyzer measures Leaf Area Index (LAI)

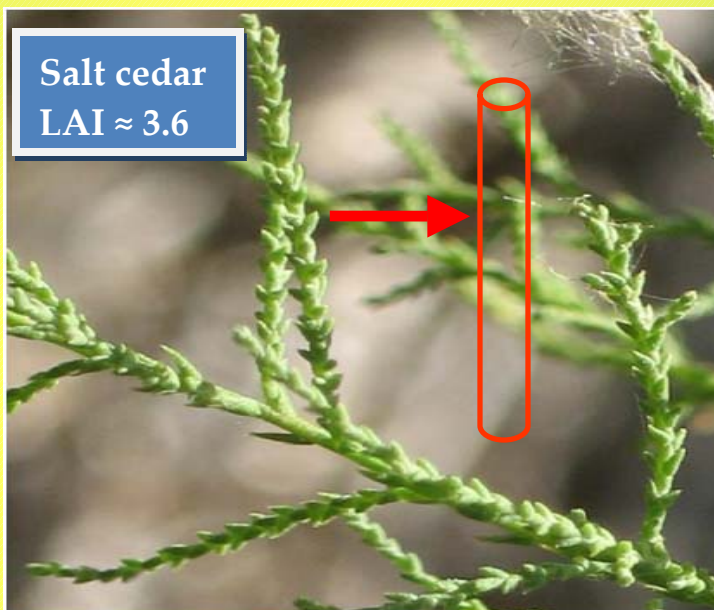
Cottonwood
LAI ≈ 1.8



SHIRK
site



Salt cedar
LAI ≈ 3.6



BOSQUE DEL
APACHE site



Credit for Plant Canopy Analyzer image: LAI-2000 Plant Canopy Analyzer LI-COR User Guide.

PLANT TRANSPIRATION - Samples

My observations of Plant Transpiration Experiment Data Sheet

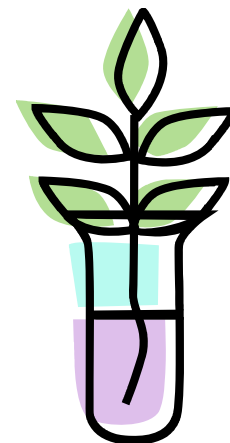
Date experiment started: April 6, 2008
ongoing

Date experiment ended:

Location of the experiment: A residence in Albuquerque

Time: Collected data every morning

My group number: _____



Answers

Data sheet #1: Water Depletions for the Middle Rio Grande (MRG)

1. Riparian
2. Agriculture
3. Reservoir Evaporation
4. Open Water
5. Urban

Number 1 is: **RIPARIAN!**

Plant Transpiration Rates

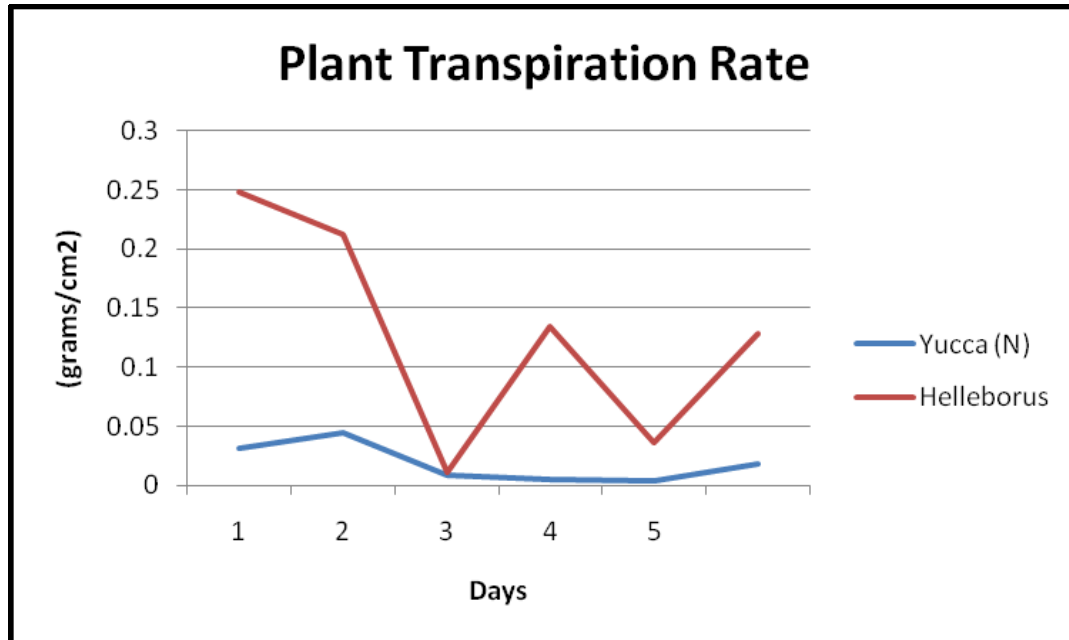
Record data and calculations of your Plant Transpiration experiment in the following table

Group # _____

Day	Native plant Yucca				Non-native plant Helleborus			
	Weight (g)	Weight loss (g)	*Leaf area (cm ²)	Transpiration rate (g/cm ²)	Weight (g)	Weight loss (g)	*Leaf area (cm ²)	Transpiration rate (g/cm ²)
Initial	1839.3	0	1517	0	1564.4	0	702	0
1	1790.6	48.7	1517	0.0321	1390	174.4	702	0.2484
2	1722.3	68.3	1517	0.0450	1240.5	149.5	702	0.2130
3	1707.6	14.7	1517	0.0085	1226.2	14.3	702	0.0115
4	1700.7	6.9	1517	0.0045	1131.4	94.8	702	0.1350
5	1695.2	5.5	1517	0.0036	1105.7	25.7	702	0.0366
Average				0.0188				0.1289

*Use engineering paper for this estimation

Graph of Plant Transpiration Rates



- 1) According to your results, which plants were better at conserving water, the natives or the non-natives?**

This particular experiment used a Yucca (native plant) and a Helleborus Ivory Prince (non-native). The results in the form of a rate (g/cm²) clearly showed that the Yucca, native to the hot and dry parts of North America, transpired less, and is therefore better at conserving water. The Helleborus is an exotic water loving plant originating in Europe. This may have to do with why it lost more during transpiration than the Yucca.

- 2) Were your results what you were expecting? If they were not, can you think of reason why?**

It is expected that the native Yucca would lose less water through transpiration. It is better at conserving water because it has adapted to the hot and dry desert environment.

- 3) Do you see “high” or “low” in the graph, what do you think they represent?**

In this experiment, the lowest numbers for transpiration rate occurred when the plants were brought indoors

Percentages of Water Lost

Use the data from the Plant Transpiration Rates table to calculate the percentage of water loss for each plant. Record the data in the following table.

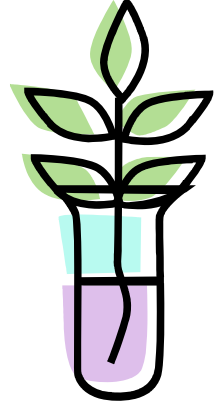
Day	Native plant Yucca			Non-native plant Helleborus		
	Weight (g)	Weight loss (g)	Percentage	Weight (g)	Weight loss (g)	Percentage
1	1839.3	48.7	2.6%	1564.4	174.4	11.2%
2	1790.6	68.3	4%	1390	149.5	10.8 %
3	1722.3	14.7	0.9%	1240.5	14.3	1.2%
4	1707.6	6.9	0.4%	1226.2	94.8	7.7%
5	1700.7	5.5	0.3%	1131.4	25.7	2.3%
			1.6%			6.6%

Answers

Data Sheet #5: Water Budget for a Semi-arid Basin

Answers: Precipitation = 0.02511 inches, Runoff = 0.00203 inches, ET = 0.02168 inches, Infiltration = 0.00006 inches. ET is the highest with 0.02168 inches per day (in/day).

Plant Transpiration Activity



My Hypothesis:

Native plants are better at conserving water than non-native plants.

MATERIALS:

Plant Transpiration Experiment: You will be assigned to a group to do this experiment.

- A native plant and non-native plant in a one gallon size container each.
- Metric scale.
- Potting soil
- Epoxy coated aquarium gravel.
- Scaled engineering paper
- Large (approx. 73Qt) plastic container with lid.
- Pen or pencil for recording data.
- A 12 inch/30 cm ruler

Visual aids: Your teacher will show you images that will help you to understand ET research concepts.

Data sheets: You will learn about ET concepts and will use to record data from your Plant Transpiration experiment.

ET Study Site scale model: This activity is very straightforward and fun. The directions on how to build an ET Study Site are given at the very end. You will need a 12 inch/30 cm ruler in order to calculate distances.

Procedure for Plant Transpiration Experiment:

Important assumptions:

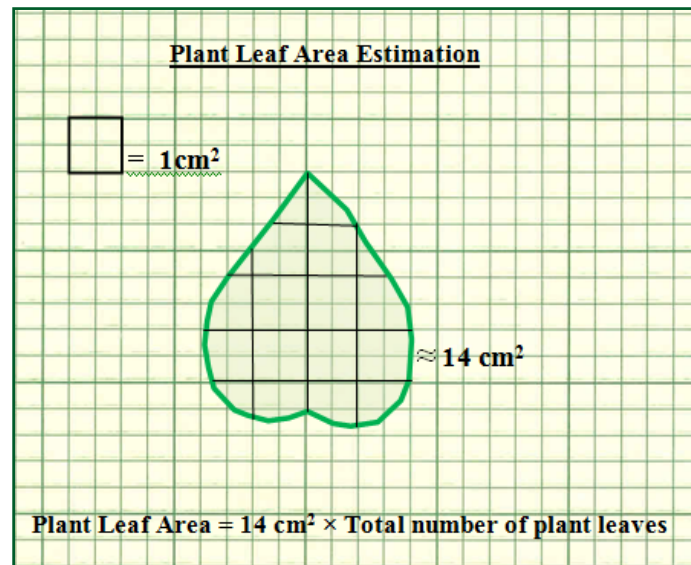
- Plant weight loss is all due to transpired water.
- Epoxy gravel coating will prevent evaporation from the soil.

Potted Plant Weighing Method

- 1) Plants will be left indoors for the duration of the experiment.
- 2) Water each plant 250 mL prior to starting the experiment.
- 3) Make sure all plants have the same amount of soil and that you leave enough space for 2 inches of gravel to cover the soil.
- 4) Carefully cover soil with 2 inches of Epoxy gravel to avoid loss of water through soil evaporation.
- 5) You will use a *Potted plant weighing method* to measure how much water plants lose to transpiration.
- 6) Use the metric scale to record the weight of the plants after adding the gravel.
- 7) Record the information in your data sheet.
- 8) Leave the two plants indoors for one day.
- 9) Weigh plants again the next day and record the information in your data sheet. The plants will weigh less every day.
- 10) Continue this process for six days and record the data.

Leaf Area Estimation

In order to get a rate for plant transpiration of grams per centime squared (g/cm^2). The weight loss of each plant (grams) will then be divided by the leaf area of the plant (cm^2). The leaf area for each plant will have to be estimated. The diagram below describes an easy way for you to do this.



Plant Transpiration Observation

- 1) You will do this **once** during the experiment.
- 2) Find a place near a window where there is some sunshine.
- 3) Place the lid of the plastic container upside down on a flat surface.
- 4) Set the plants on top.
- 5) Carefully place the lid of the plastic container over the plants, and make sure it snaps close.
- 6) Leave the plants inside for 4 hours.
- 7) Check on the plants and describe what you see.

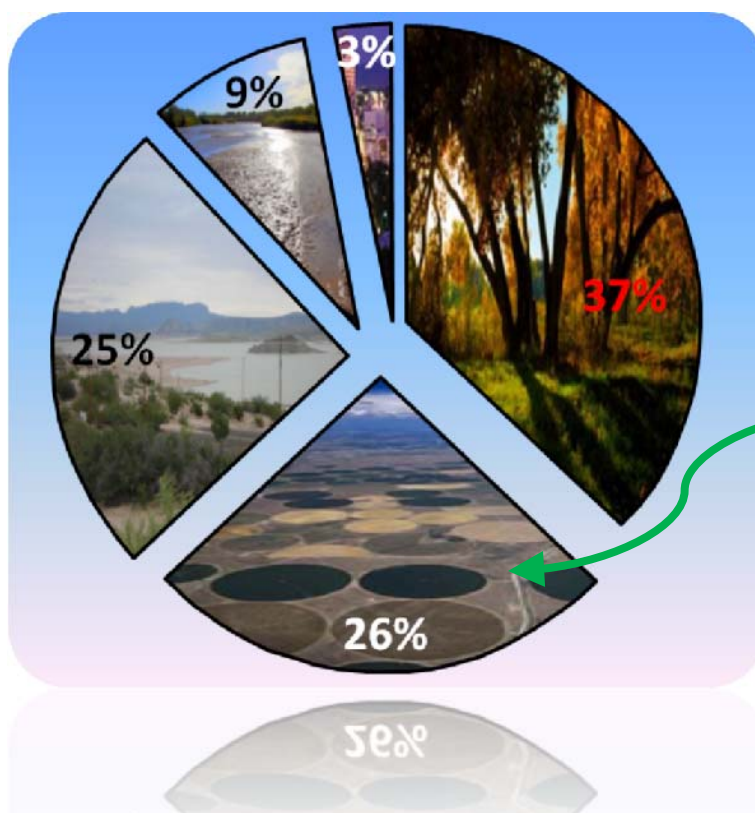
Setting a Control

You will set a control to verify that the water droplets that you see in the container are caused by plant transpiration. This can easily be done by placing the same container in the same spot, but empty this time. Did anything happen?

CONCLUSIONS: Talk about your experiences after completing the Plant Transpiration Activity. Do you have any questions, concerns or ideas that you would like to share. Try to think about the following questions:

- Why do you think researchers concerned about losses through evapotranspiration?
- How is evapotranspiration measured?
- How would you calculate the leaf area of a salt cedar's shrub like leaf?
- Would cutting down all the trees in the Bosque fix the problem of ET losses?

Group # _____

Water Depletions for the Middle Rio Grande (MRG)

These
are
agricult
ural
fields

The circular
pattern is due

Shown above are the major sources of water depletion. List the sources below in order from highest to the lowest percentage. No. 3 is listed for you.

1. _____
2. _____
3. Reservoir Evaporation
4. _____
5. _____

Number 1 is:

Source: S.S. Papadopoulos, 2004.

Plant Transpiration Rates

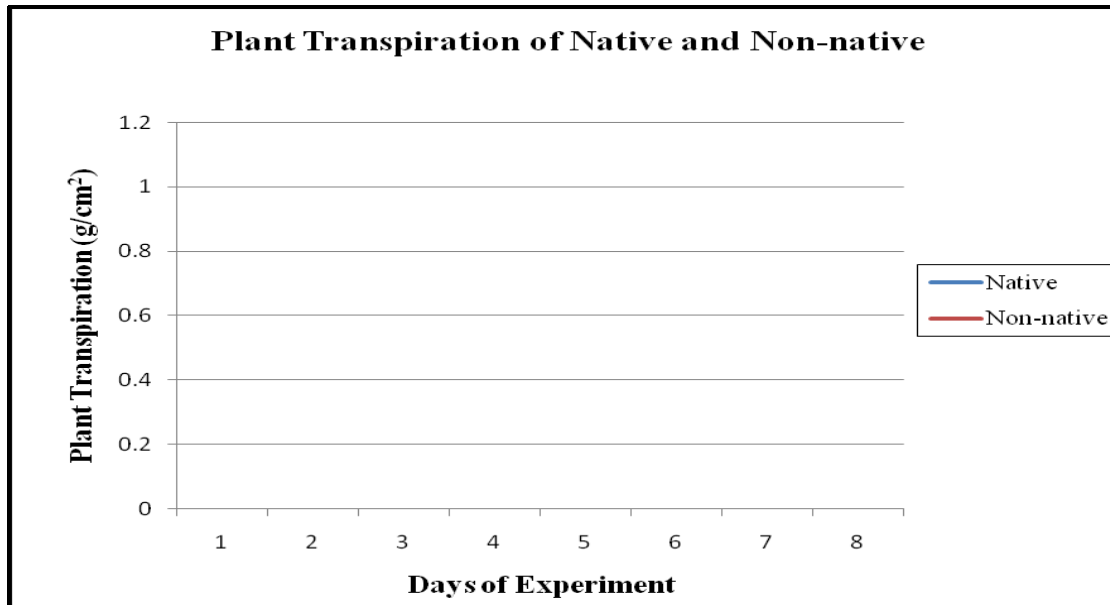
Record data and calculations of your Plant Transpiration experiment in the following table

Group # _____

Day	Native plant				Non-native plant			
	Weight (g)	Weight loss (g)	*Leaf area (cm ²)	Transpiration rate (g/cm ²)	Weight (g)	Weight loss (g)	*Leaf area (cm ²)	Transpiration rate (g/cm ²)
1								
2								
3								
4								
5								
Average								

*Use engineering paper for this estimation

Graph of Plant Transpiration Rates



- 1) According to your results, which plants were better at conserving water, the native or the non-native?

- 2) Were your results what you were expecting? If they were not, can you think of reason why?

- 3) Do you see “highs” or “lows” in the graph, what do you think they represent?

Percentages of Water Lost

Use the data from the Plant Transpiration rate table to calculate the percentage of water loss for each plant. Record your results in the following table.

Day	Native plant			Non-native plant		
	Weight (g)	Weight loss (g)	Percentage	Weight (g)	Weight loss (g)	Percentage

Averages for Plant Transpiration Experiment

Record the results obtained by each group and compute the average values.

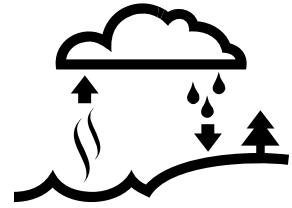
Group #	Native plants		Non-native plants	
	Transpiration rate (g/cm ²)	Percentage of Water Lost	Transpiration rate (g/cm ²)	Percentage of Water Lost
1				
2				
3				
4				
5				
6				
Average				

What conclusions can you derive from the average results of this experiment?

Water Budget for a Semi-arid Basin

Which is higher? Runoff or Evapotranspiration?

- 1) Add up the columns and calculate the total precipitation, runoff, evapotranspiration and infiltration for one day (24 hours).



Hour	Precipitation (inches)	Runoff (inches)	Evapotranspiration (inches)	Infiltration (inches)
1	0.00075	0.00004	0.00191	0.00000
2	0.00141	0.00007	0.00153	0.00000
3	0.00027	0.00001	0.00107	0.00000
4	0.00001	0.00000	0.00068	0.00000
5	0.00000	0.00000	0.00037	0.00000
6	0.00000	0.00000	0.00019	0.00000
7	0.00000	0.00000	0.00015	0.00000
8	0.00000	0.00000	0.00011	0.00000
9	0.00000	0.00000	0.00010	0.00002
10	0.00000	0.00000	0.00010	0.00001
11	0.00000	0.00000	0.00008	0.00000
12	0.00000	0.00000	0.00007	0.00000
13	0.00000	0.00000	0.00007	0.00000
14	0.00000	0.00000	0.00007	0.00000
15	0.00000	0.00000	0.00012	0.00000
16	0.00000	0.00000	0.00056	0.00000
17	0.00011	0.00000	0.00101	0.00000
18	0.00043	0.00001	0.00153	0.00000
19	0.00037	0.00001	0.00199	0.00000
20	0.00030	0.00001	0.00227	0.00000
21	0.00417	0.00023	0.00265	0.00000
22	0.00665	0.00040	0.00260	0.00000
23	0.00508	0.00037	0.00236	0.00003
24	0.00556	0.00088	0.02169	0.00000
Total				

Based on your total number, which of this water budget's losses is higher: Runoff or Evapotranspiration?

Adapted from: *A catchment water budget for a semi-arid basin*, Galewsky, J., EPS 576-Physical Hydrology, Earth and Planetary Science, University of New Mexico, Fall 2007.

ET Study Site Model

Kit for building Site:

- 1) Plot area
- 2) River
- 3) 15 cottonwood tree species
- 4) 15 salt cedar tree species
- 5) Ground water wells
- 6) Human scale figure
- 7) ET Tower

Scale: $1/32'' = 1 \text{ ft} = 98.4 \text{ ft}$

Directions to building your ET Study Site

- ✓ There are native (cottonwood) and non-native (salt cedar) tree species on the site.
- ✓ The sites are oriented around a series of groundwater wells. There are 5 wells at each site with one well located at the center.
- ✓ The other 4 wells are located 40 meters in each cardinal direction from the center well.
- ✓ There is an ET tower near the center well.
- ✓ The “hook-like” instrument is called an anemometer. It measures vertical wind speed.

Remote Sensing Activity

Includes:

- 1) Teacher's Guide
- 2) Sample Data Sheets
- 3) Student's Guide
- 4) Blank Data Sheets

REMOTE SENSING – Teacher’s Guide

ABSTRACT: The region where evapotranspiration research takes place is the Middle Rio Grande (MRG). The MRG extends 320 kilometers between the Otowi Bridge and Elephant Butte stream gages. Remote sensing provides researchers a perspective of the MRG that would not be possible otherwise.

This activity presents basic concepts and applications of remote sensing and provides visual aids describing the ET research using remote sensing by Landsat 7 satellite. Students will be presented with four Landsat 7 “false-color” scenes for New Mexico. They will be asked to identify features, and perform ET calculations by combining information from the images, and James Cleverly’s RIO ET DATA web site. They will compare their results to about annual estimates of the riparian zone ET for the MRG corridor range from $150 \times 10^6 \text{ m}^3$ to $375 \times 10^6 \text{ m}^3$ (Coonrod and McDonnell, 2001). Lastly, students will complete a digital art exercise.

GRADE LEVEL(S): 5th – 8th

OBJECTIVES:

- Students will be able to recognize that remote sensing by Landsat 7 is a valuable tool for extracting information about the environment.
- Students will be able to explain how to do calculations using Landsat 7 images.
- Students will recognize the matrix and pixel size format of Landsat 7 images.

NEW MEXICO SCIENCE CONTENT STANDARDS

5th Grade

- 1-1-1-3 *Plan and conduct investigations, including formulating testable questions, making systematic observations, developing logical conclusions, and communicating findings.*
- 1-1-1-3 *Use graphic representations (e.g., graphs, tables, labeled diagrams) to present data and produce explanations for investigations.*
- 1-1-2-1 *Understand that different kinds of investigations are used to answer different kinds of questions (e.g., observations, data collection, controlled experiments).*
- 1-1-3-1 *Use appropriate units to make precise and varied measurements.*
- 1-1-3-2 *Use mathematical skills to analyze data.*
- 1-1-3-3 *Make predictions based on analyses of data, observations, and explanations.*
- 2-2-1-4 *Describe how human activity impacts the environment.*
- 3-1-1-1 *Describe the contributions of science to understanding local or current issues (watershed and community decisions regarding water use).*

7th Grade

- 1-1-1-2 *Use a variety of print and web resources to collect information, inform investigations, and answer a scientific questions or hypothesis.*
- 1-1-3-2 *Use mathematical expressions to represent data and observations collected in Scientific investigations.*

6th Grad

- 1-1-1-4 *Examine the reasonableness of data supporting a proposed scientific explanation.*

- 1-1-1-3 *Justify predictions and conclusions based on data.*
- 1-1-2-1 *Understand that scientific knowledge is continually reviewed, critiqued, and revised as new data become available.*
- 1-1-3-1 *Evaluate the usefulness and relevance of data to an investigation.*
- 2-1-2-4 *Understand that some energy travels as waves (e.g., light), including: different wavelengths of sunlight (e.g., visible, ultraviolet, infrared).*

8th Grade

- 1-1-1-2 *Use a variety of technologies to gather, analyze and interpret scientific data.*
- 1-1-2-1 *Examine alternative explanations for observations.*
- 1-1-3-1 *Use mathematical expressions and techniques to explain data and observations and to communicate findings (e.g., formulas and equations, estimation, mean). Understand how light and radio waves carry energy through vacuum or matter by: separation of white light into different wavelengths by prisms and visibility of objects due to light emission or scattering.*

MATERIALS: Visual aids and Worksheets provided.

- 1) Maps of New Mexico showing geographical features
- 2) Internet access
- 3) Colored pencils
- 1) **Visual aids:** Photographs illustrating scale, The Electromagnetic spectrum, The 7 bands of Landsat 7, Examples of “false-color” images, Landsat 7 images of ET research along the Middle Rio Grande.
- 2) **Worksheets:**
 - a) **Identifying Features in New Mexico: “False-color” Landsat 7 Images:** *What is this?* Rio Arriba County Lakes, National monuments, Elephant Butte Reservoir, Laguna del Perro. **NEED MAPS OF NEW MEXICO.**
 - b) **World Agriculture Patterns** by Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on the Terra satellite.
 - c) **ET Calculations:** Areas for cottonwood and salt cedar, ET calculations using real ET data for the Middle Rio Grande.
 - d) **Digital Art:** This part of the activity requires the use of colored pencils. Includes: Satellite image “False-color” composition, Blank map, Digital Art for Information Sender, Digital Art for Information Receiver, Color Coding for Information Processor.

BACKGROUND: Remote sensing is the science and art of obtaining information about an object, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. Measuring evapotranspiration (ET) on site represents a great challenge. Remote sensing provides an alternative for scientists and engineers to scale ET. Estimates based on meteorological measurements from the ET Towers are combined with Landsat 7 images to estimate ET along the Middle Rio Grande.

Concepts:

The Electromagnetic Spectrum: (See RS-2). Every object emits radiation in different amounts and wavelengths (radiation travels in a wave-like manner and the distance between peaks is known as the wavelength). The different wavelengths and frequencies make up the Electromagnetic Spectrum. The human eye is sensitive only to some of these wavelengths (the colors of the rainbow). Other parts of the spectrum such as near-

infrared wavelengths are not visible to the human eye and are not perceived as light. Satellites can “see” past the color red, into the infrared, and past the color violet and into the ultraviolet.

The Primary Colors of Light: The primary colors of light are red, green and blue, not to be confused with the primary colors of pigment (red, yellow and blue). No object has light of its own. What we see as color is caused by light hitting an object, which is either reflected or absorbed. All the colors that exist in the world are made up of a combination (in different amounts) of these three colors (See <http://www.oms.edu/visit/tech/colormix.cfm>). This is important because GIS software assigns red, green and blue to Landsat 7 bands 4, 3, and 2. This combination makes “false-color” images.

Landsat 7 Satellite Images: From high above the earth, the Landsat 7 satellite uses an instrument that collects seven images at once. Each image shows a specific section of the electromagnetic spectrum, called a band. Landsat 7 has seven different bands (See RS-3). The bands measured by Landsat make it possible to distinguish water, vegetation, and dry non-green areas. Red, near infrared (NIR), and mid-infrared (MIR) bands are useful in detecting chlorophyll, vegetation, soil moisture, water and leaf structures. These bands are considered the most suitable for differentiating vegetation types. The Landsat 7 images used in this activity were obtained during the month of June for 2000, 2001, and 2002.

p33r37_06102000, path 33, row 37

p34r35_06042001, path 34, row 35

p34r36_06042001, path 34, row 36

P33r36_06162002, path 33, row 36

“False-color” Images: (See RS-4). Geographic Information Systems software is employed in producing a common band combination of band 4 (near-infrared), band 3 (red), and band 2 (green), which makes vegetation appear as shades of red because vegetation reflects a lot of near infrared light. The brighter the red, the healthier the vegetation will be. Soils with little or no vegetation range from white to greens and browns. Water will range from blue to black. Clear, deep water is dark, and sediment laden or shallow water appears lighter. Clouds and snow are both white.

Spectral Signatures: Features along the landscape absorb, reflect, or scatter light in different ways. As a result every feature has a unique spectral signature. Using Landsat 7 spectral bands it is possible to differentiate wet areas, green canopies, green grasses, and non-vegetated or non-green areas. The way vegetation reflects energy depends on the size of the plant cells and the thickness of the cell walls, so that the reflected radiation provides a “signature” for the type of vegetation present (Smithsonian,

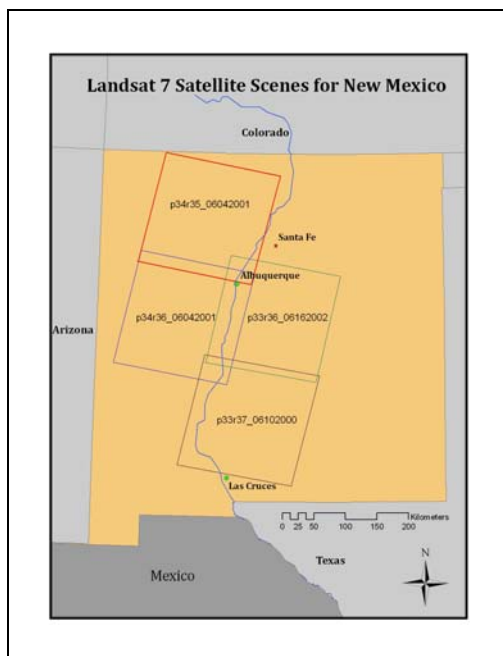


Figure 1. Landsat 7 scenes used for activity

2000). It is this aspect of Landsat 7 images that makes it possible for researchers to classify vegetation along the Middle Rio Grande and then determine the ET rates for each vegetation types.

TIPS FOR ENTIRE CLASS PARTICIPATION: The following questions may also be used to focus students on the remote sensing activity.

- Have they heard of remote sensing?
- Have they been on top of a very tall building looking down? What is that like?
- How can researchers look at the Middle Rio Grande 200 miles stretch?
- What are the primary colors of light?
- Bring an apple to class and ask the question: Why does an apple appear red? *-An apple appears red because it absorbs blue and green light and reflects red light.*

Worksheet #1 is intended to be used for class participation and assessment of prior knowledge. Students may get into small groups, and decide what they think the image represents. **ANSWER: This is a Landsat 7 image of central pivot irrigation field patterns, located in Torrance County, New Mexico.**

PROCEDURES: Visual aids provided for this activity have to be seen in color to be effective. This may involve the use of a screen projector, where the image is displayed to the entire class. Alternatively, a number of copies could be laminated and shared in groups. Students will complete the worksheets in groups of four or five.

Visual Aids: **RS-1:** Ask students to imagine if they could fly over the Bosque and The Rio Grande. What would they see? **RS-2:** Human vision covers only a very small part of the electromagnetic spectrum. Satellites are able to “see” the invisible. **RS-3:** Vegetation has high reflectance in the near infrared part of the have to “look for” a dry salt bed lake. Ask them to speculate what color this feature might look like in a “false-color” image. *It looks white because it reflects all the visible colors of the spectrum.* **RS-4:** Notice that artificial turf does not look red in the “false-color” image. Visuals **RS-5** through **RS-8** show “false-color” images for New Mexico and the Middle Rio Grande.

1) Worksheets: Use visuals **RS-5**, and **RS-6** along with worksheets.

- **#1 Identifying features in New Mexico:** **Answer** is in **Tips for Entire Class Participation** Section.

- **#2 World Agriculture Patterns:** **ANSWERS:** **1-b), 2-c), 3-d), 4-f), 5-e), 6-a)**
- **#3 and #4:** **Answers** are given at the end of visual aids.
- **#5 and #6 ET Calculations:** **Answers** are given at the end of visual aids.

Students will calculate ET in units of volume. They will use real data from James Cleverly’s RIO ET DATA website. <http://bosque.unm.edu/~cleverly/bosque/data.html>. They will estimate areas for cottonwood (50.4 km²) and salt cedar (37.8 km²). This area will be multiplied by the ET data. Students will be asked to think of their answer in terms of annual estimates of the riparian zone ET for the MRG corridor ranging from **150 × 10⁶ m³ to 375 × 10⁶ m³** (Coonrod and McDonnell, 2001). The last figure is equivalent to *375 football fields, filled with water to a depth of 100 m (approximately a 50 story building).*

- **Digital Art:** For **Answer** to **#7** see Fig. 2 below. Students will create a “False-color” Satellite image Composition. **Answer** to **#8** is given at the end of visual aids. For **Answers** to **#9** and **#10** see Fig. 3 below. Students will be in groups of three and they

will have collaborative roles. First, they will label the three states shown. The information needed to “fill out” the map is in the results of the digital art exercise. The point of this exercise is for students to gather information about the environment through “remote sensing” on a “pixel by pixel” scale. A pixel is defined as “a two dimensional picture element that is the smallest non divisible element of a digital image.” Each pixel in the image has a value (Jensen, 2005). Digital remote sensor data are usually stored as matrix of numbers. Each digital value is located at a specific row and column. It is important that you tell students that satellites store information as a matrix made up of pixels. These digital art samples are meant to be analogous to the remote sensor matrix of numbers.

The **“information sender”** will have the original matrices with the numbers assigned to each “pixel.” Using row numbers, and column letters, he/she will read the numbers in each “pixel” to the **“information receiver.”** Shortcuts can be taken, as it is not necessary to read the digital information “pixel” by “pixel.” For instance, they can say: “Row number 1 has all zeros, except for columns e, f, g, h, and i.”

The **“information processor”** will be given the following code:

For INFORMATION PROCESSOR

0 = White, 1 =Yellow, 4 = Light Green, 5 = Dark Green, 9= Brown

Satellite images provide the necessary information to classify vegetation in the environment. Classifying vegetation is possible through the use of Landsat 7 images and computer software. This process is called digital image processing. It is not a simple process however, as it requires knowledge of biology and the ability to conjure up algorithms to relate parameters to one another and produce meaningful results.

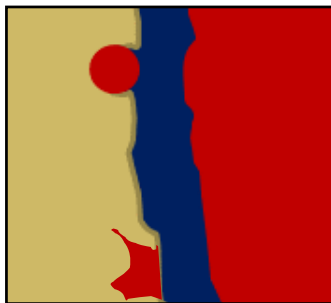


Figure 2. Answer for Worksheets #7.

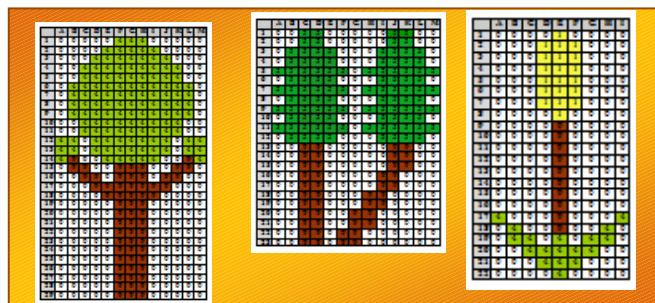
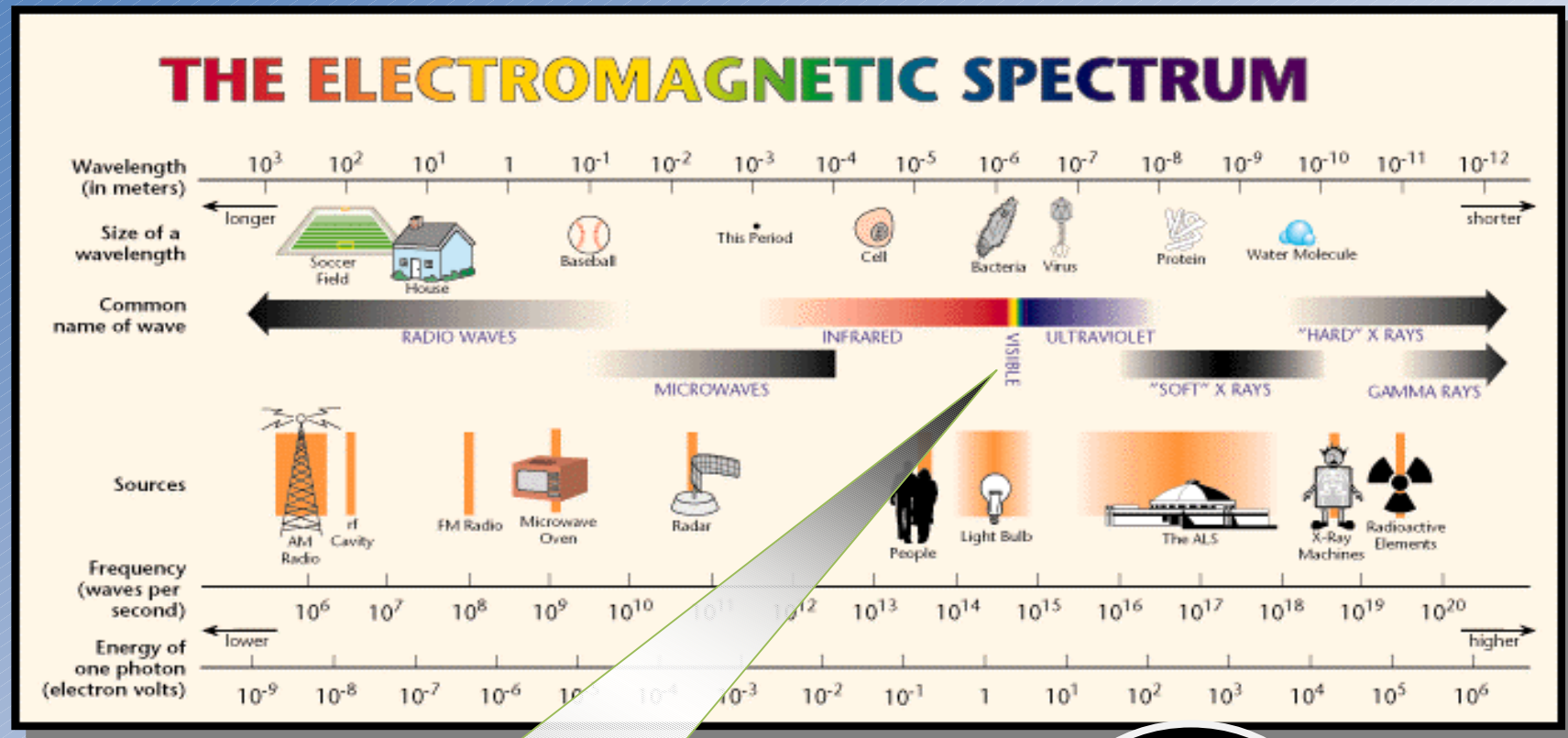


Figure 3. Answers for Worksheets #9 and #10

CONCLUSIONS: Upon completing the Remote Sensing activity, students should have an understanding of the remote sensing process by satellite, and “false-color” images. Ask them follow up questions, like why do they think satellite images are valuable and useful to researchers, what is a “false-color” image?



The Electromagnetic Spectrum



The Visible Spectrum



Adapted from NASA. On line at <http://landsat.gsfc.nasa.gov/education/compositor/> Accessed 01/2008

Landsat 7 Enhanced Thematic Mapper (ETM) Bands

Spectral sensitivity of Landsat 7 Bands		
Band Number	Wavelength Interval	Spectral Response
1	0.45-0.52 μm	Blue-Green
2	0.52-0.60 μm	Green
3	0.63-0.69 μm	Red
4	0.76-0.90 μm	Near IR
5	1.55-1.75 μm	Mid-IR
6	10.40-12.50 μm	Thermal IR
7	2.08-2.35 μm	Mid-IR

Adapted from NASA online <http://landsat.gsfc.nasa.gov/education/compositor>. Accessed 01/2008

"False-color" Images

True Color Images



Landsat 7 satellite image of the Middle Rio Grande showing true color

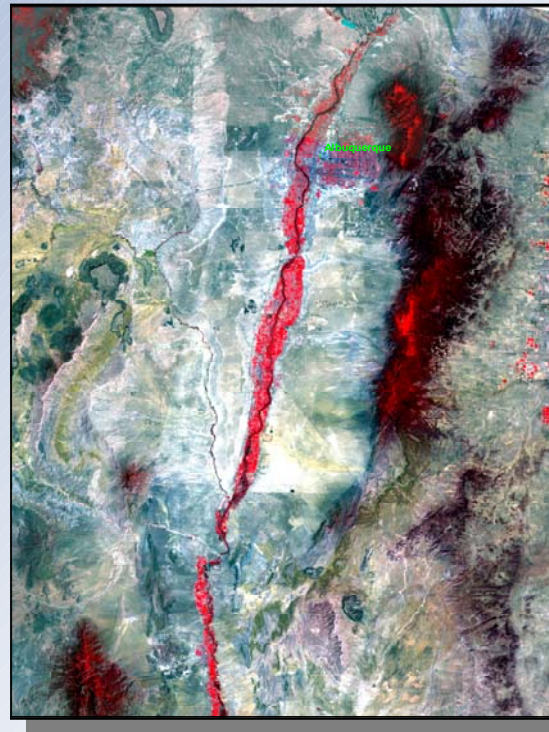
"False - Color" Images



"False-color" Landsat 7 satellite image of the Middle Rio Grande



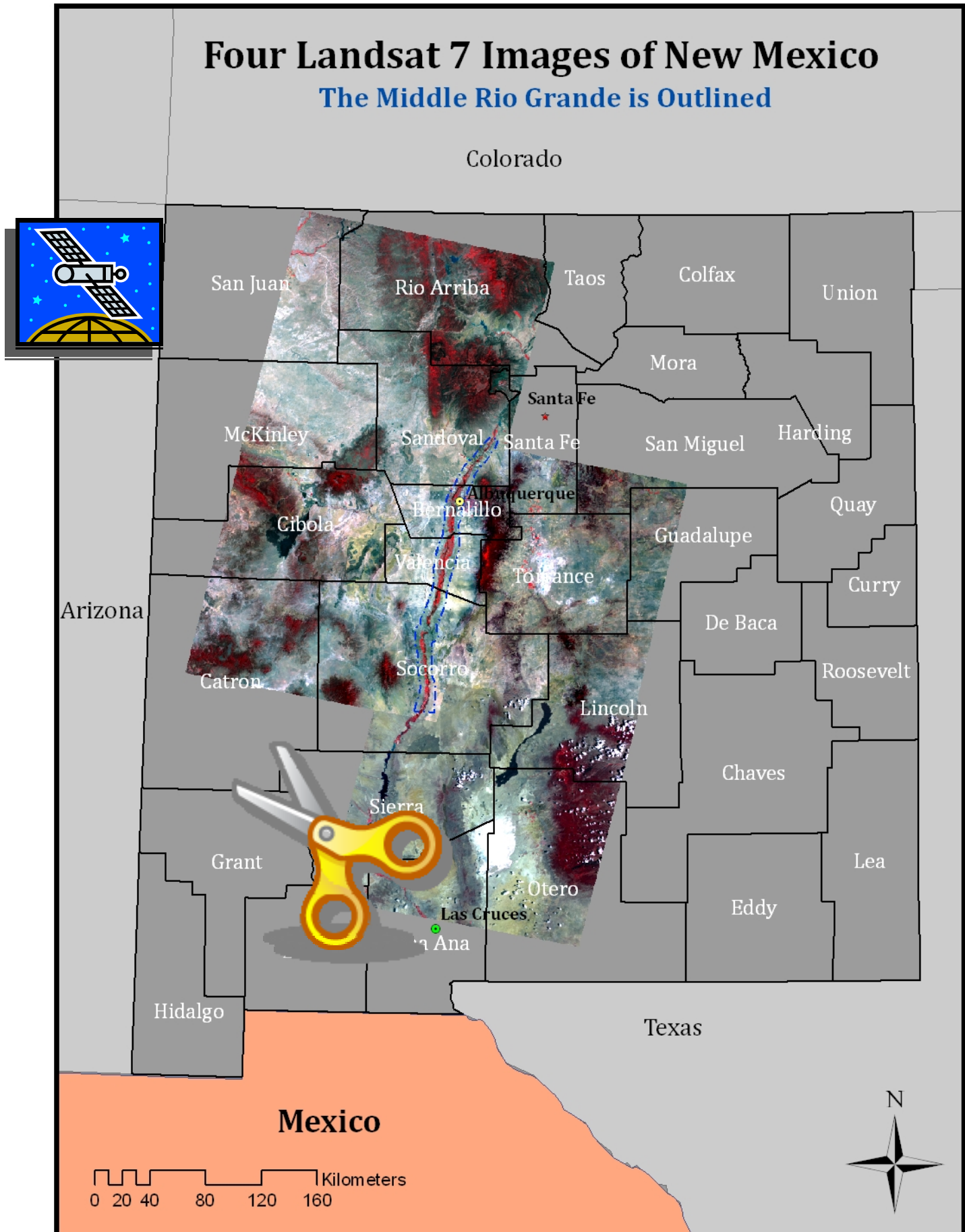
Aerial photograph of the University of Wisconsin-Madison campus



"False-color" image of the campus. The football field has artificial turf

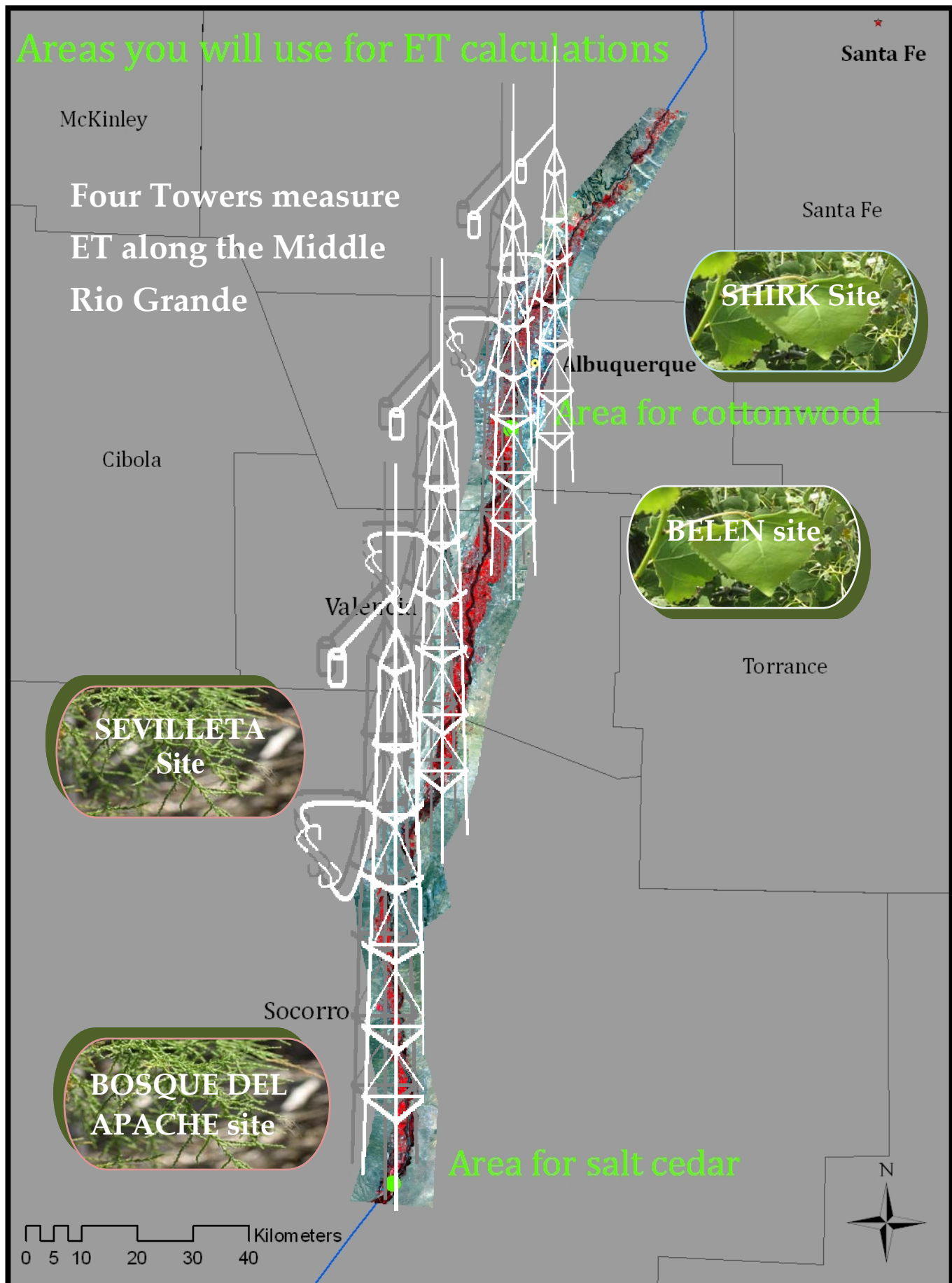
Remote Sensing and Image Interpretation; Lillesand and Kiefer; John Wiley & Sons, Inc 1979
 "Reprinted with permission of John Wiley & Sons, Inc."

Four Landsat 7 Images of New Mexico The Middle Rio Grande is Outlined



REMOTE SENSING ACTIVITY

RS-6

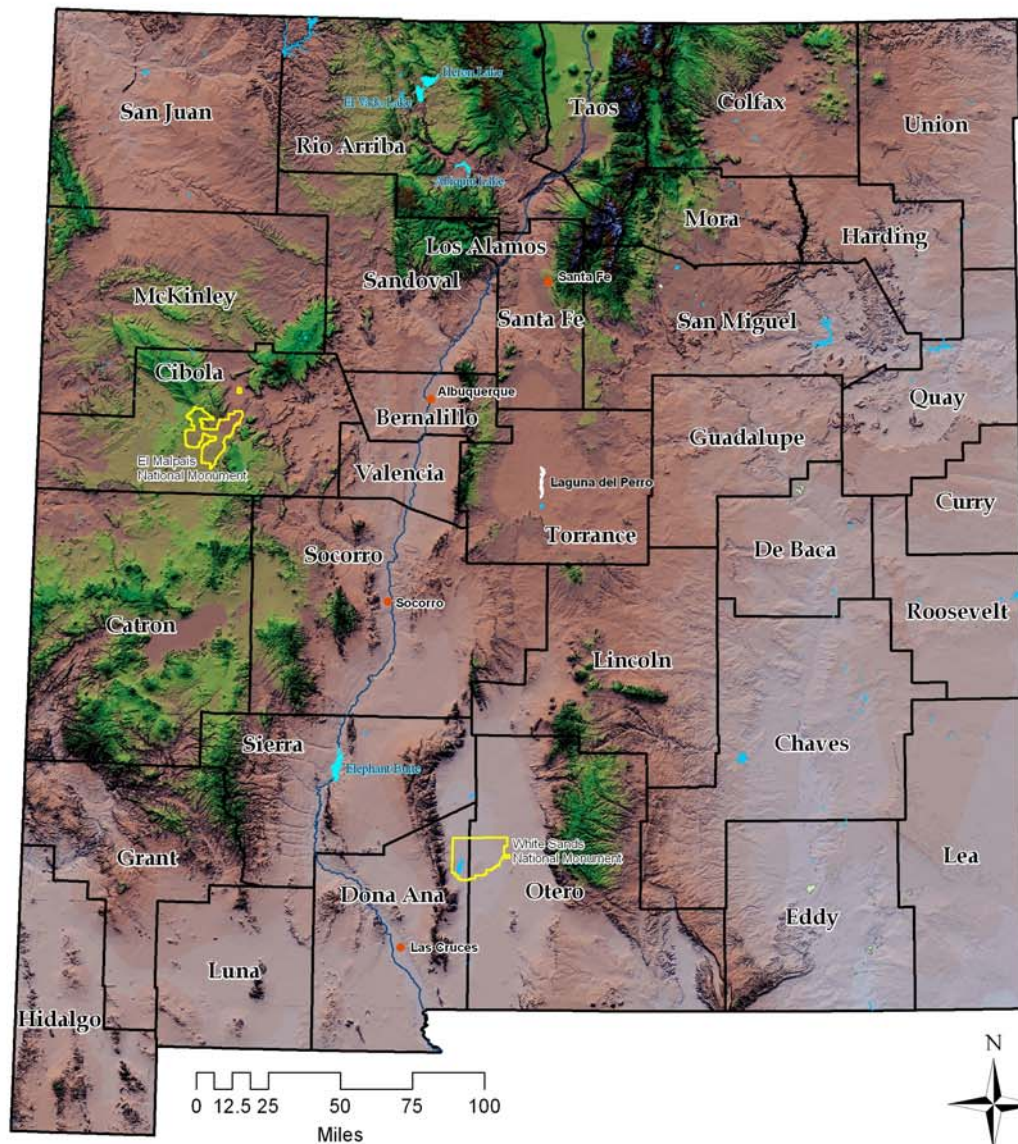


Identifying Features in New Mexico

Answers

Worksheet #3 and #4

Relief Map of New Mexico



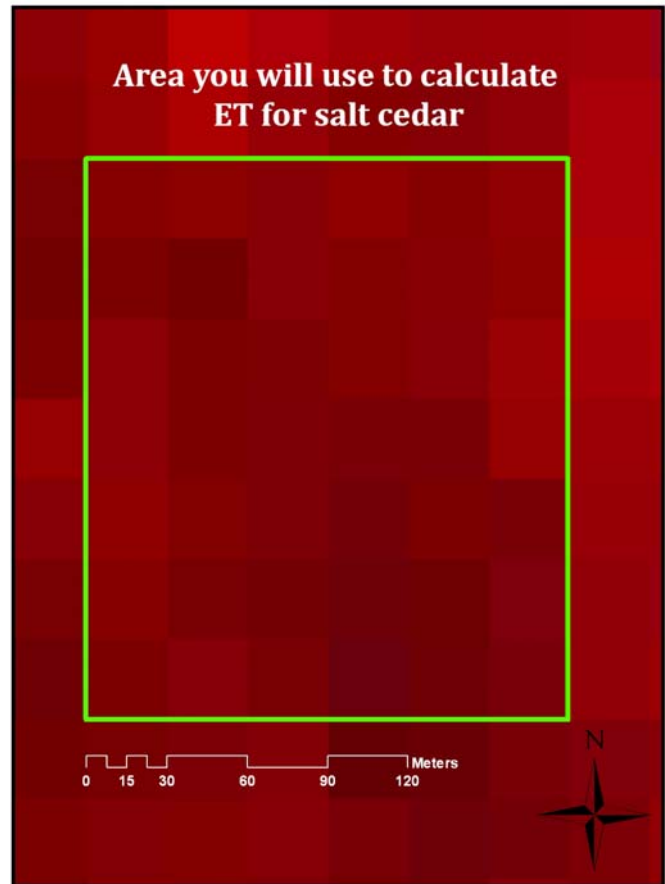
ANSWERS: 1-Heron Lake, 2-El Vado Lake, 3-Abiquiu Lake, 4-El Mal Pais National Monument, 5-Laguna del Perro (dry salt lake bed), 6-Elephant Butte Reservoir, 7-White Sands National Monument.

REMOTE SENSING ACTIVITY



Area = 50.4 Km²

REMOTE SENSING ACTIVITY



Area = 37.8 Km²

ET Calculation for cottonwood and sat cedar

Tree Species	Evapotranspiration (ET) (m)		Area (m ²)	Evapotranspiration (ET) (m ³)	
DATE	01 July, 2000	01 July, 2007		01 July, 2000	01 July, 2007
Cottonwood	0.008 m	0.0075 m	50,400 m ²	403.2 m ³	378 m ³
Salt cedar	0.0072 m	0.0082 m	37,800 m ²	272.16 m ³	309.96 m ³
DATE	Aug 31, 2000	Aug 31, 2007		Aug 31, 2000	Aug 31, 2007
Cottonwood	0.0081 m	0.0054 m	50,400 m ²	408.24 m ³	272.16 m ³
Salt cedar	0.0071 m	0.0074 m	37,800 m ²	268.38 m ³	279.72 m ³

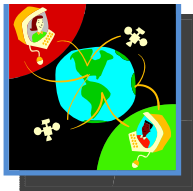
Answers

Vegetation along the Rio Grande from Colorado to the Gulf of Mexico



Adapted from the BioVan mobile exhibit art, City of Albuquerque/BioPark, Albuquerque, New Mexico

Remote Sensing



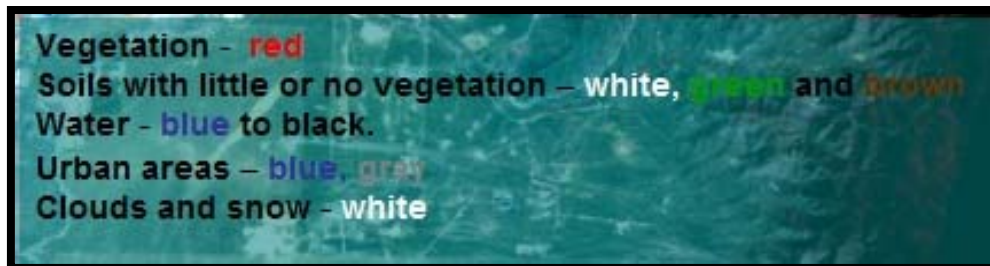
Questions:

- What types of information can we gather from remote sensing by Landsat 7 satellite?
- What are some of the advantages it provides?

Procedure: Your teacher will explain remote sensing by Landsat 7 concepts. Complete the following worksheets.

Worksheets:

Use this code to complete worksheet



NOTE: Features that look white in a satellite images reflects all the colors of light. Remember this when looking for the dry salt lake bed, and White Sands National Monument.

- Identifying Features in New Mexico:** You will look at “false-color” Landsat 7 images of New Mexico. These worksheets are self-explanatory. You are a voyager discovering new features in the landscape. You will do this by using maps of New Mexico provided by your teacher.
- World Agricultural Patterns:** You also explore what agriculture patterns are like in different continents around the world! When you have exhausted your resources, you will be given a relief map of New Mexico that reveals each mystery feature.
- ET Calculations:** This is an ET Calculation for cottonwood and salt cedar along the Middle Rio Grande. You will calculate ET for the specified dates. From a satellite image you will “guess estimate” what the area is for cottonwood and for salt cedar. Your teacher will tell the actual areas for each tree species. This data will be used to

calculate and report ET as a volume (m^3). You will visit James Cleverly's RIO ET DATA website at <http://bosque.unm.edu/~cleverly/bosque/data.html> and pick any dates for when you would like to know ET values. This date could be random, or maybe even your birthday.

d) **Digital Art:**

Satellite Image “False-color” Composition: You will create a “false-color” satellite image using color pencils and knowledge of how vegetation, water, and soil appear on this type of image. There are no exact answers, but if you follow the color assignment you will come get a very close approximation.

Blank Map

- 1) Label the states shown in the map
- 2) The information needed to “fill out” the map of New Mexico, Colorado and Texas will come from the matrices you completed in the Digital Art exercise.

There are three parts to completing this worksheet. Get into groups of three each. One of you will be the “information sender,” the second will act as the “information receiver,” and the third one will be an “information processor.” Satellites collect images in a matrix made up of pixels. Each pixel has a cell address. None of you will know what the images represent until the very end of the activity

- As the “**information sender**” you will have the original tables with the numbers assigned to each “pixel.” Using row numbers, and column letters you will read the number in the “pixel” out loud to the “information receiver.” Shortcuts can be taken, as it is not necessary to read the digital information “pixel” by “pixel.” For instance, you can say: “*Row number 1 has all zeros, except for columns e, f, g, h, and i.*”
- As the “**information receiver**” will hear the digital information for each pixel and write them down in the column letter and row number that the “information sender” dictates to him/her.
- As the “**information processor**” will follow a chart with color designation for each digit (number) on each pixel. You will follow that code that your teacher will give you to color each pixel and uncover the information sent and received.

Conclusions: Talk about your experiences after completing the Remote Sensing Activity. Do you have any questions, concerns or ideas that you would like to share.

Group Name _____



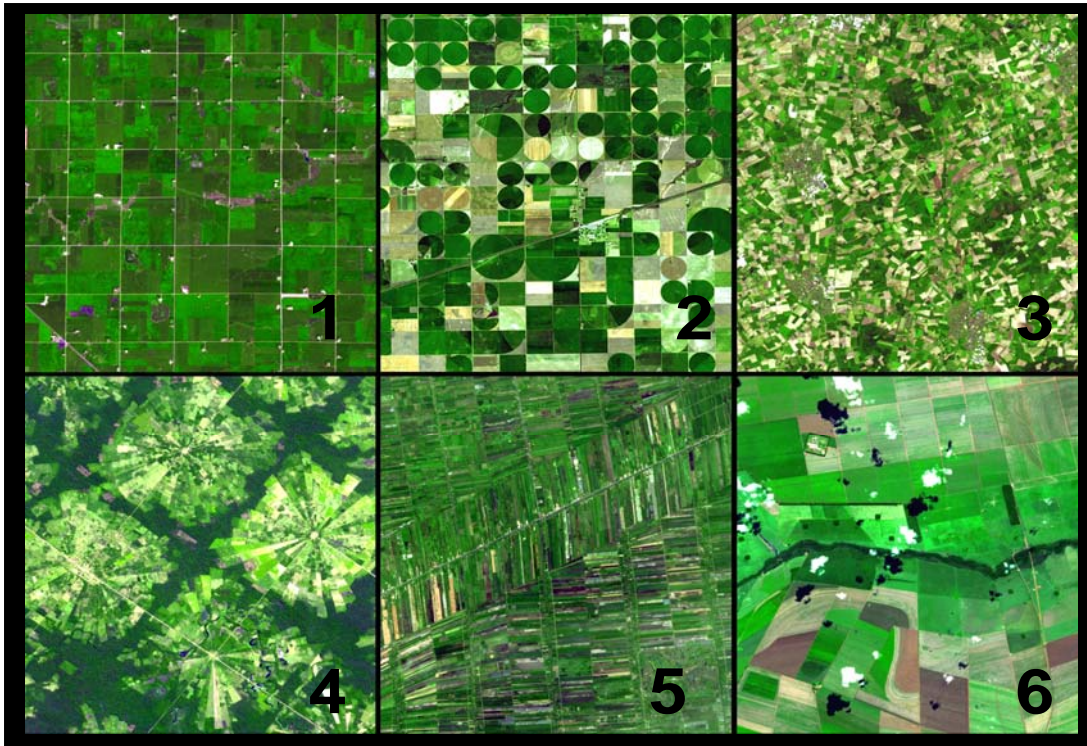
What is this?

Write down your ideas

1. _____
2. _____
3. _____
4. _____

Group Name _____

World Agriculture Patterns



Match the image with the country it belongs to (The US appears twice).

- Cerrado in southern Brazil has **huge farms** and **large field sizes** due to cheap cost of land and the flatness of the terrain.
- Minnesota looks like a very **regular grid pattern** reflecting early 19th century surveying. The size of the fields is a function of mechanization and efficiency.
- Kansas uses center pivot irrigation which gives the agricultural fields a **circular shape**.
- Northwest Germany has **small size and random pattern** of fields left over from the Middle Ages!
- Outside of Bangkok, Thailand rice paddies are fed by an extensive network of canals that is hundreds of years old, they appear as **small skinny rectangular** fields.
- Near Santa Cruz, Bolivia there are **pie or radial shaped** fields that are part of a settlement scheme; at the center of each unit is a small community.

ANSWERS: 1. _____ 2. _____ 3. _____ 4. _____ 5. _____

Adapted from NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team

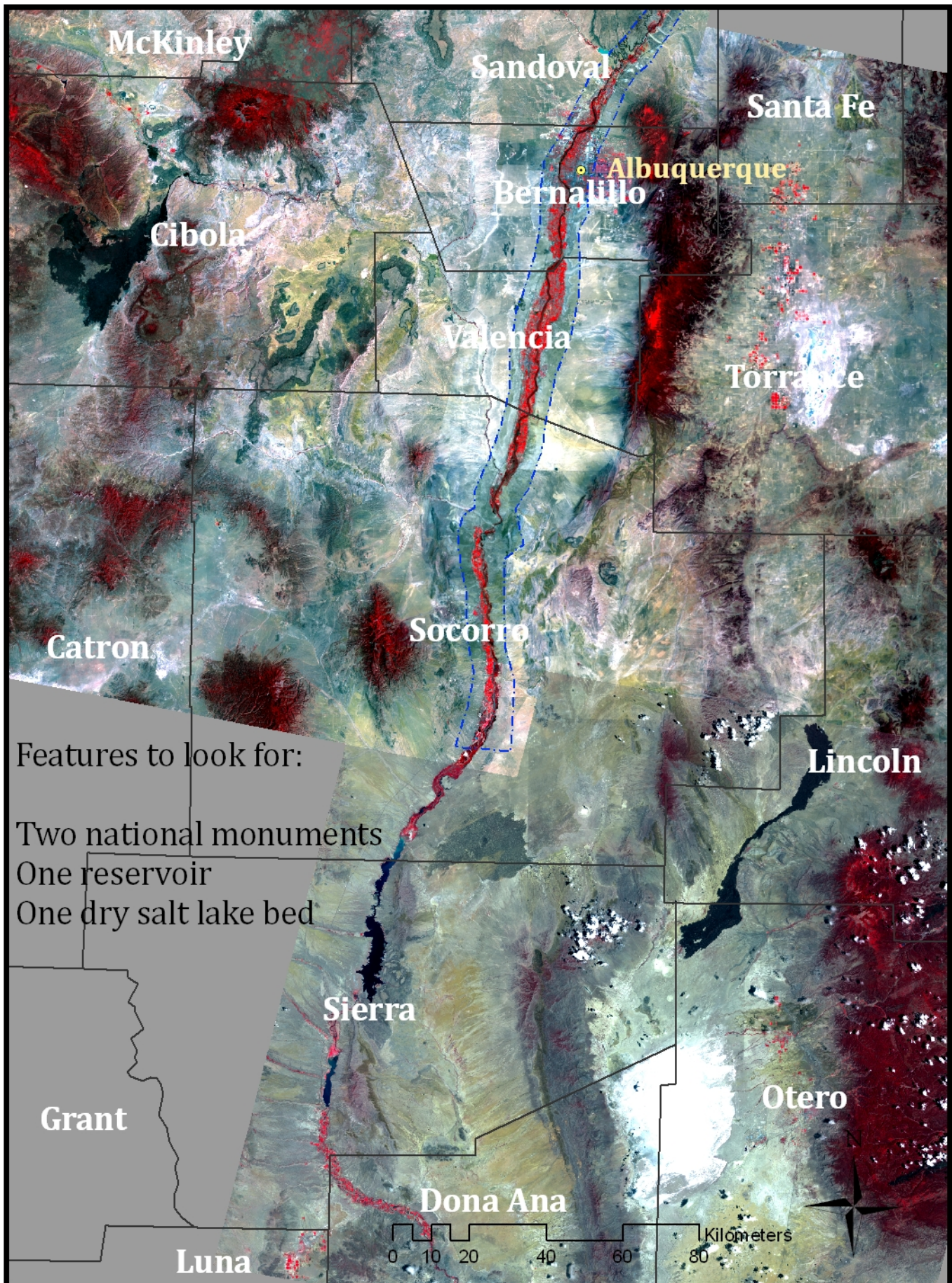
Rio Arriba

Can you identify the bodies of water in this image?
You are looking at part of Rio Arriba county in northern New Mexico



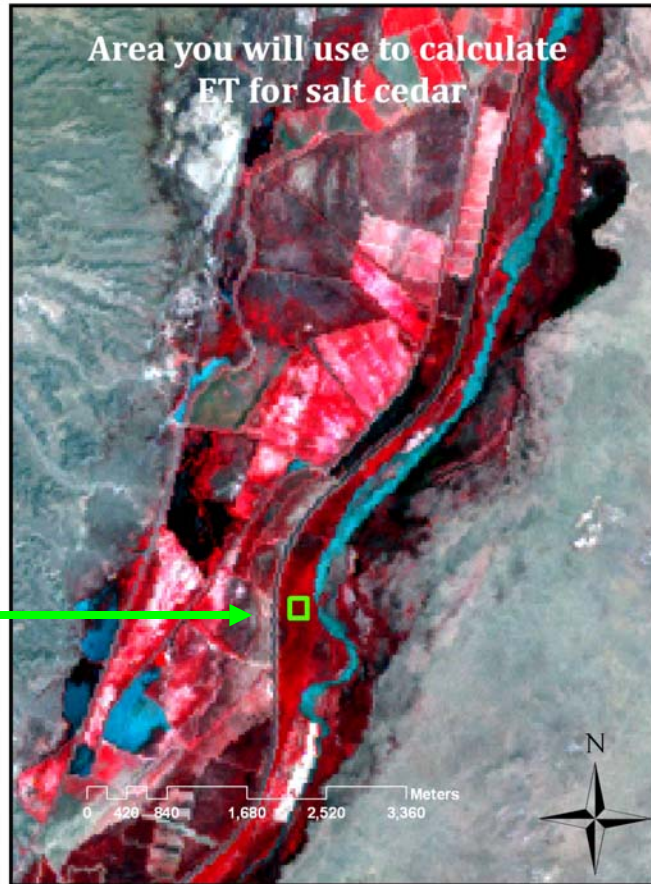
REMOTE SENSING ACTIVITY

Worksheet #4

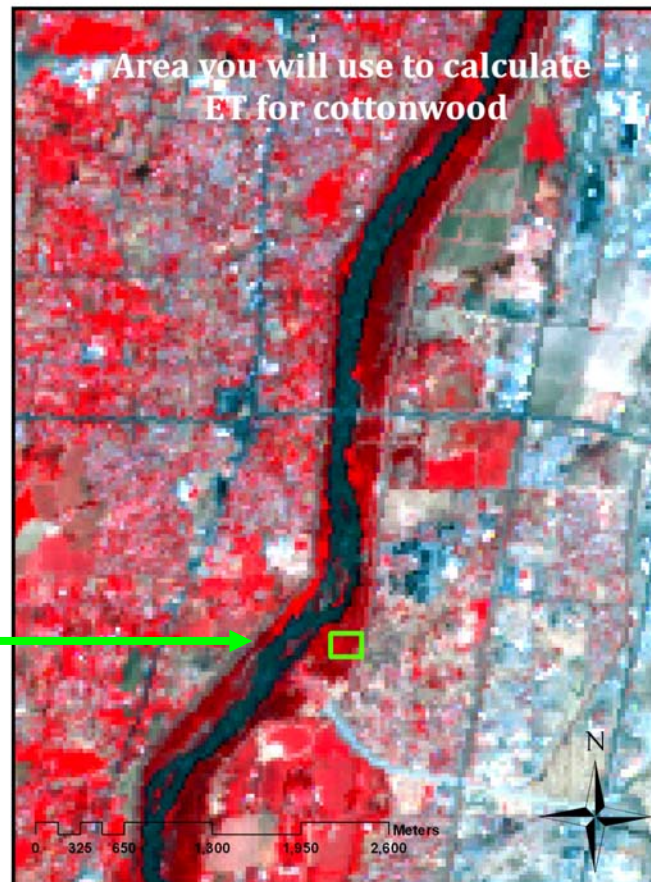


ET Calculations

Area for
Salt cedar



Areas for
Cottonwood



ET Calculation for cottonwood and salt cedar

- 1) The Monsoon is the time when it rains the most in New Mexico. These values are from the beginning and the end of the Monsoon season. Approximate the area from given map. Then you will check with your teacher to see how close you got!

Tree Species	Evapotranspiration (m)		*Area (m ²)	Evapotranspiration (m ³)	
DATE	01 July, 2000	01 July, 2007		01 July, 2000	01 July, 2007
Cottonwood	0.008 m	0.0075 m			
Salt cedar	0.0072 m	0.0082 m			
DATE	Aug 31, 2000	Aug 31, 2007		Aug 31, 2000	Aug 31, 2007
Cottonwood	0.0081 m	0.0054 m			
Salt cedar	0.0071 m	0.0074 m			

*Estimate the area by looking at the scale bar on the map.

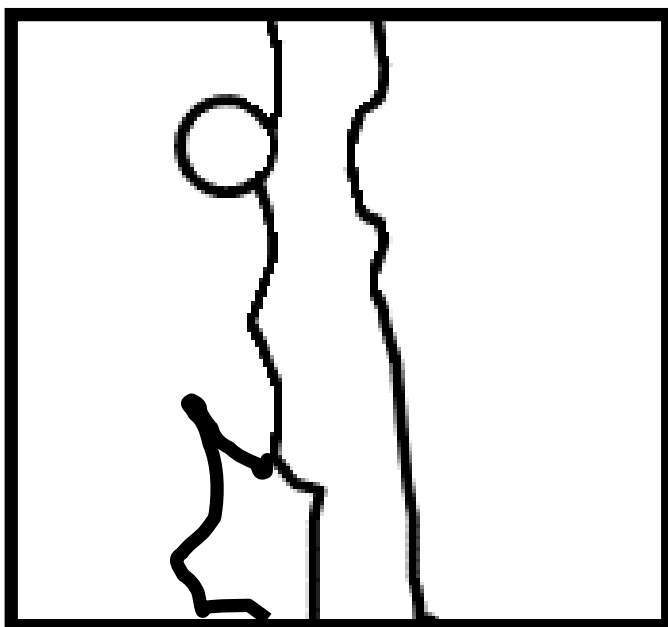
- 2) Visit the RIO ET DATA website <http://bosque.unm.edu/~cleverly/bosque/data.html> and fill in the table with values of your choice (your birthday for example).

Tree Species	Evapotranspiration (m)		*Area (m ²)	Evapotranspiration (m ³)	
DATE					
Cottonwood					
Salt cedar					
DATE					
Cottonwood					
Salt cedar					

*Estimate the area by looking at the scale bar on the map.

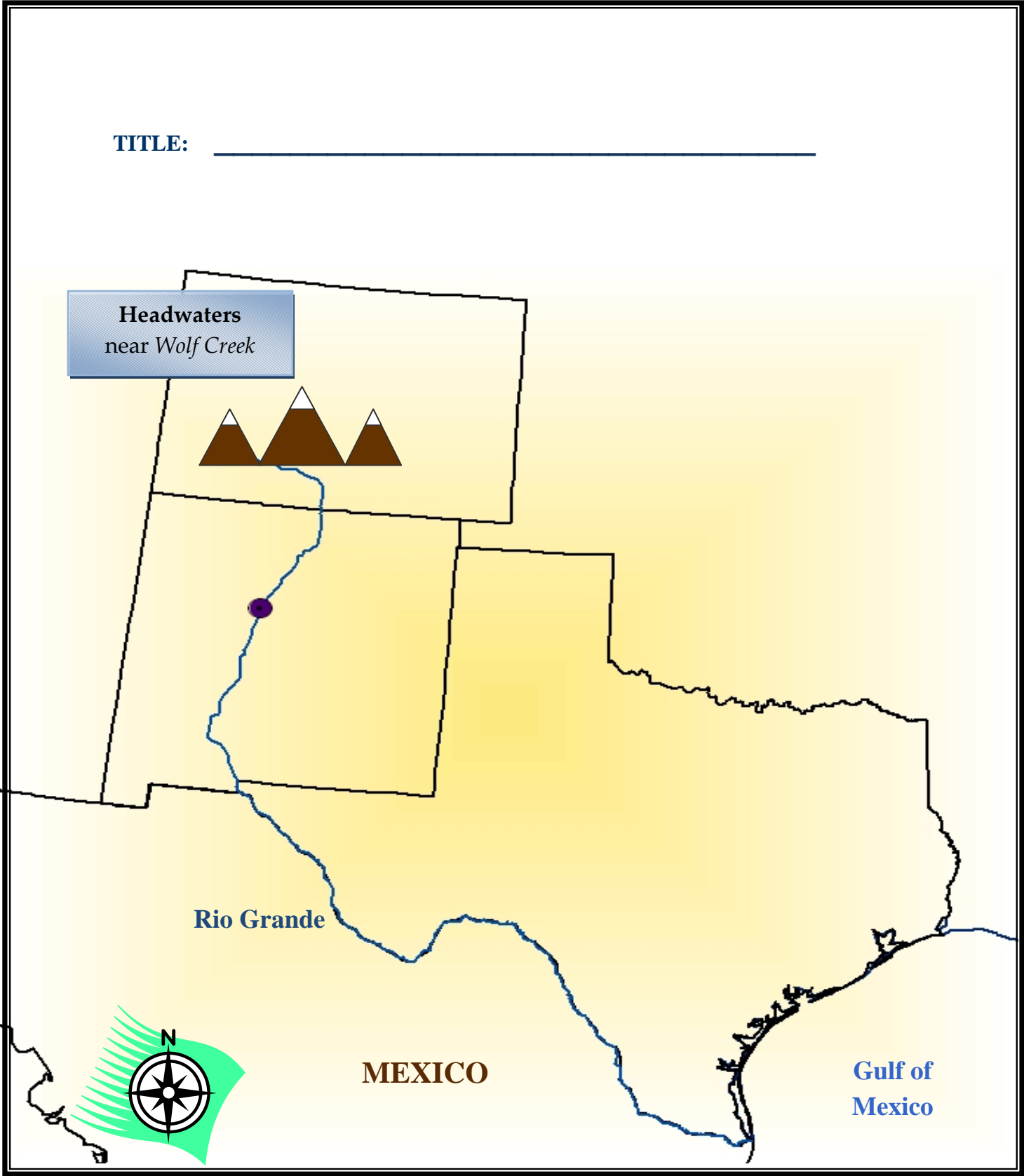
Satellite Image
“False-color” Composition

Student's Name _____



Student's Name _____

TITLE: _____



Group Name _____

For INFORMATION SENDER

Matrix 1

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	0	0	5	5	0	0	0	0	0	5	5	0	0
2	0	0	5	5	0	0	0	0	0	5	5	0	0
3	0	5	5	5	5	0	0	0	5	5	5	5	0
4	0	5	5	5	5	0	0	0	5	5	5	5	0
5	5	5	5	5	5	5	0	5	5	5	5	5	5
6	0	5	5	5	5	0	0	0	5	5	5	5	0
7	5	5	5	5	5	5	0	5	5	5	5	5	5
8	0	5	5	5	5	0	0	0	5	5	5	5	0
9	5	5	5	5	5	5	0	5	5	5	5	5	5
10	0	5	5	5	5	0	0	0	5	5	5	5	0
11	5	5	5	5	5	5	0	5	5	5	5	5	5
12	0	5	5	5	5	0	0	0	5	5	5	5	0
13	0	0	9	9	0	0	0	0	0	9	9	0	0
14	0	0	9	9	0	0	0	0	0	9	9	0	0
15	0	0	9	9	0	0	0	0	0	9	9	0	0
16	0	0	9	9	0	0	0	0	0	9	9	0	0
17	0	0	9	9	0	0	0	0	0	9	9	0	0
18	0	0	9	9	0	0	0	0	0	9	9	0	0
19	0	0	9	9	0	0	0	0	0	9	9	0	0
20	0	0	9	9	0	0	0	0	0	9	9	0	0
21	0	0	9	9	0	0	0	0	0	9	9	0	0
22	0	0	9	9	0	0	0	0	0	9	9	0	0
23	0	0	9	9	0	0	0	0	0	9	9	0	0

Matrix 2

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	0	0	0	0	0	4	4	4	0	0	0	0	0
2	0	0	0	0	4	4	4	4	4	0	0	0	0
3	0	0	0	4	4	4	4	4	4	4	0	0	0
4	0	0	4	4	4	4	4	4	4	4	4	0	0
5	0	0	4	4	4	4	4	4	4	4	4	0	0
6	0	4	4	4	4	4	4	4	4	4	4	4	0
7	0	4	4	4	4	4	4	4	4	4	4	4	0
8	0	4	4	4	4	4	4	4	4	4	4	4	0
9	0	4	4	4	4	4	4	4	4	4	4	4	0
10	0	0	4	4	4	4	4	4	4	4	4	0	0
11	0	0	4	4	4	4	4	4	4	4	4	0	0
12	4	4	0	4	4	4	4	4	4	4	0	4	4
13	4	4	0	4	4	4	4	4	4	4	0	4	4
14	4	9	0	0	4	4	4	4	4	0	0	9	4
15	0	9	9	0	0	9	9	9	0	0	9	9	0
16	0	0	9	9	0	9	9	9	0	9	9	0	0
17	0	0	0	9	9	9	9	9	9	9	0	0	0
18	0	0	0	0	9	9	9	9	9	0	0	0	0
19	0	0	0	0	0	9	9	9	0	0	0	0	0
20	0	0	0	0	0	9	9	9	0	0	0	0	0
21	0	0	0	0	0	9	9	9	0	0	0	0	0
22	0	0	0	0	0	9	9	9	0	0	0	0	0
23	0	0	0	0	0	9	9	9	0	0	0	0	0
24	0	0	0	0	0	9	9	9	0	0	0	0	0
25	0	0	0	0	0	9	9	9	0	0	0	0	0
26	0	0	0	0	0	9	9	9	0	0	0	0	0
27	0	0	0	0	0	9	9	9	0	0	0	0	0
28	0	0	0	0	0	9	9	9	0	0	0	0	0
29	0	0	0	0	0	9	9	9	0	0	0	0	0

Matrix 3

	A	B	C	D	E	F	G	H	I
1	0	0	0	0	1	0	0	0	0
2	0	0	0	1	1	1	0	0	0
3	0	0	0	1	1	1	0	0	0
4	0	0	0	1	1	1	0	0	0
5	0	0	0	1	1	1	0	0	0
6	0	0	0	1	1	1	0	0	0
7	0	0	0	1	1	1	0	0	0
8	0	0	0	0	1	0	0	0	0
9	0	0	0	0	9	0	0	0	0
10	0	0	0	0	9	0	0	0	0
11	0	0	0	0	9	0	0	0	0
12	0	0	0	0	9	0	0	0	0
13	0	0	0	0	9	0	0	0	0
14	0	0	0	0	9	0	0	0	0
15	0	0	0	0	9	0	0	0	0
16	0	0	0	0	9	0	0	0	0
17	4	0	0	0	9	0	0	0	4
18	0	4	0	0	9	0	0	4	0
19	0	4	4	0	4	0	4	4	0
20	0	0	4	4	4	4	4	0	0
21	0	0	0	4	4	4	0	0	0
22	0	0	0	0	4	0	0	0	0

Group Name_____

For INFORMATION RECEIVER

Matrix 1

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2													
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23													

Matrix 2

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
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7													
8													
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29													

Matrix 3

	A	B	C	D	E	F	G	H	I
1									
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20									
21									
22									

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