Transactions of the Missouri Academy of Science

Volume 43 (2009)

About the Academy

Scientists of the State of Missouri organized in 1934 to form the Missouri Academy of Science. By April 6, 1934, a Constitution and By-Laws were prepared. On August 14, 1934, the organization was incorporated.

The purpose of this Academy was presented in the fourth article of agreement as follows:

This non-profit corporation is organized for the purposes of promoting the scientific spirit, and of promoting cooperation between the scientific interests of Missouri. It proposes to accomplish these purposes:

a. By holding meetings for the presentation of scientific papers embodying the results of original research, teaching experience, or other information of scientific interest.
b. By fostering public interest in scientific matters, through open meetings, press release and in other such ways as seem feasible.
c. By encouraging local scientific organizations in every possible way.
d. By promoting acquaintance in harmonious relationships between scientists in Missouri and among all who are interested in science.
e. By supplying, so far as finances permit, a medium for the publication of results of original work, particularly those of special interest in the state.
f. By concerning itself with legislation on scientific matters, and providing opportunity for discussion of such legislation.
g. By working in any and all other ways which may prove feasible for the advancement of science in Missouri.

The academy held its first organizational meeting on April 13-14, 1934 with 250 people attending. At the December 1934 meeting, more than 400 people registered. By May 1935, there were more than 750 members of the Academy. Statewide interest at a high level continued until activities made necessary by World War II caused disruption of Academy affairs except for some activity in the College Section.

Post-war revival of Academy activities started at an April 20, 1963 meeting at Drury College. From the group of twelve persons who initiated the reactivation of the academy in 1963, the membership has grown steadily to more than 800 members. Activities of the Academy have expanded to include the awarding of modest grants for projects proposed by high school and college students, and to sponsor the establishment of a Junior Academy of Science. Since its reactivation in 1963, the Missouri Academy of Science has regularly held annual meetings at sixteen different sites around the state.

Presently, 36 colleges and universities around the State of Missouri hold an Institutional Membership status. Membership into the Academy is a year-round opportunity. Benefits include four *Bulletins*, one annual *Transactions*, and annual meeting lower pre-registration fees.

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A Selective Survey of Microbial Flora in the Water of Seven Missouri Caves

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Abstract: *A variety of microbiological techniques are being used to isolate and identify microbial species from water samples collected in caves, including Missouri caves. In this study, water was collected from seven caves located in five different counties distributed across the Missouri Ozarks with a goal of species identification and viable library development. Forty individual species of microbes were identified from these cave waters, many found in multiple locations, identified by pure culture technique and biochemical characterization. Most are ubiquitous species, such as Escherichia coli or various Bacillus species, typically represented in enteric or soil samples while others are unique like Aeromonas veronii, a leech symbiont. A frozen archive of all identified species was created for possible future studies. This project represents the first microbial biodiversity listing for these seven Missouri caves.*

Key words: *Missouri, microorganisms, karst, cave*

Introduction

Caves are a unique and important component of the Missouri karst landscape (Elliott and Ashley, 2005). The ability to protect and conserve karst resources such as caves and springs is dependent upon the ability to develop a knowledge base concerning these resources. This karst knowledge base should include information about geological formations, cave maps, dye tracing studies, speleothem distribution, biodiversity studies, etc. The more complete our knowledge base is, the more substantiated are efforts to protect the resource. Understanding the impact of a contaminant spill in karst areas is incomplete if there is no understanding of the biota present before the spill. Ameliorating the impact of urban development on karstland is greatly supported by studies that have previously documented subterranean life in the area. Detecting and addressing cave vandalism is more successful if inventories of speleothems and graffiti have been conducted prior to the vandalism.

The Missouri Cave Life Database (CLD) was initiated in 1998 (Elliott and Ireland, 2002) to document the biodiversity of caves in the state. Analysis of data from the CLD has provided a better understanding of zoogeography of cave life and allowed the ranking of Missouri caves on the basis of overall distribution and abundance of cave biota and the presence of cave species of conservation concern (Elliott, 2007). Most entries in the CLD contain information about cave animals (invertebrates and vertebrates). This study is set to provide additional information relevant to an understanding of microbial communities in Missouri caves.

Recent studies on cave bacteria often involve coliform counts in reference to groundwater pollution (Lerch et al., 2001). Taylor and colleagues (2000) inventoried the bacterial fauna of select Ozark caves which were within the range of an endangered amphipod species. Pasquarell, et al. (1995) investigated the impact of surface agriculture on karst groundwater quality. Barton (2006) reported on the use of molecular probes to characterize the microbial community involved with cave and speleothem formation. Much interest has developed regarding caves as habitats where microbial extremophiles are found (Boston et al., 2001). Drenovsky et al. (2008) have emphasized the need to include information on microbial communities in studies evaluating general ecological processes in diverse microhabitats. This study presents findings concerning a survey for chemoheterotrophic, mesophilic microbes isolated and identified from water sources in seven Missouri caves.

Materials and Methods

Caves included in the study

Bear Cave, Crawford County, MO. Bear Cave is located within the Huzzah Conservation Area (managed by the Missouri Department of Conservation) at the base of a bluff approximately 100 meters from the Courtois Creek. Bear Cave formed in the Cambrian, Eminence, geological formation. The cave is approximately 200 meters in length with a small intermittent stream flowing through much of the accessible passageway. Surface cover above the cave is typical Ozark deciduous forest. No private homes or service buildings are located above the cave. The cave is open-access and receives moderate visitation by cavers.

Great Spirit Cave, Pulaski County, MO. Great Spirit Cave is located within the Great Spirit Cave Conservation Area (managed by the Missouri Department of Conservation). Great Spirit Cave formed in the Ordovician, Gasconade, geological formation. The cave is approximately 3400 m in length with isolated drip pools throughout the cave. Land cover above the cave is typical Ozark deciduous forest. No private homes or service buildings are above the cave. The cave is gated to protect bat populations and receives minimal visitation by cavers. Historically, the cave was a tour cave.

Woody Cave, Christian County, MO. Woody Cave is located on private property with adjacent homes within 100 meters of the entrance. Woody Cave formed in the Mississippian, Burlington, geological formation. The cave includes a pool within the twilight zone and a small stream that meanders through much of the cave passageway. Land cover above the cave includes some forested patches and areas planted in grass.

Hercules Lookout Cave, Taney County, MO. Lookout Cave is located within the Hercules Glade Wilderness Area of the Mark Twain National Forest (managed by the U.S. Forest Service). Hercules Lookout Cave formed in the Ordovician, Jefferson City, geological formation. The cave is approximately 80 meters in length and contains a stream throughout much of its passageway. Land cover above the cave is typical Ozark deciduous forest. The cave is open-access but probably receives minimal visitation by cavers. An earlier homestead in the area included a spring-house fed by water delivered by a pipe from the cave. The spring-house is still present although in great disrepair.

Lone Hill Onyx Cave, Franklin County, MO. Lone Hill Onyx is located within the Meramec State Forest (managed by the Missouri Department of Conservation). Lone Hill Onyx Cave formed in the Cambrian, Eminence, geological formation. The cave is approximately 1200 meters in length and contains a gravel stream bed throughout much of its passageway. It also contains isolated pools fed by dripwater. Land cover above the cave is typical Ozark deciduous forest. No private homes or service buildings are above the cave.

Mushroom Cave, Franklin County, MO. Mushroom Cave is located within Meramec State Park (managed by the Missouri Department of Natural Resources). Mushroom Cave formed in the Cambrian, Eminence, geological formation. This cave is approximately 1000 meters in length with a stream bed (substrate alternating between gravel and silt) along the major passageway. Land cover above the cave is typical Ozark deciduous forest. No private homes or service buildings are above the cave.

Tumbling Creek Cave, Taney County, MO. Tumbling Creek Cave is located on the property of the Ozark Underground Laboratory (OUL) and contains approximately 3000 meters of mapped passageway. Tumbling Creek Cave formed in the Ordovician, Jefferson City, geological formation. It has the highest biodiversity of any cave west of the Mississippi River (Elliott et al., 2005). Dripstone pools are common throughout the cave. Tumbling Creek winds through the main cave passage and exits the natural entrance during high water flow. Water also sinks to a lower level and exits the cave through subterranean flow to appear again at several springs in the area. A karst window has been excavated to allow access to the subterranean stream approximately 200 meters downstream of the natural entrance. Land cover above the cave is diverse including pastureland, typical Ozark deciduous forest, and restored glade and savannah habitats. Private homes and service buildings are located above the cave.

Procedures For Sample Collection and Processing

Microbial sample collection — Using sterile 125 ml Nalgene bottles, three replicate samples were taken from water sources of interest within the seven caves. Where depth would allow, bottles were gently submerged in streams or pools without agitation of the sediment. In very shallow locations, sterile 50 ml pipettes were used to obtain water samples. All samples were stored on ice or in the refrigerator until analyzed.

Microbial plating and isolation — 0.5 ml water samples of undiluted, 10^{-1}, and 10^{-2} diluted samples in 0.85% saline were individually applied to plates of Tryptic Soy Agar (TSA), Plate Count Agar (PCA), m-Fecal Coliform Agar (mFC), Sabouraud Dextrose Agar (SAB-DEX), and Columbia Blood Agar with 5% sheep blood (CBA) in duplicate (Becton Dickinson). In the case of CBA, twice as many plates were prepared so samples could be incubated both aerobically and anaerobically at 37°C. TSA and PCA plates were incubated at 30–35°C, mFC at 45°C, and SAB-DEX at 25°C. All plates were incubated for 7 days, counted for colony numbers, visualized for colony distinctiveness, and isolated colonies of interest were propagated in pure culture and frozen at -70°C for long-term storage.

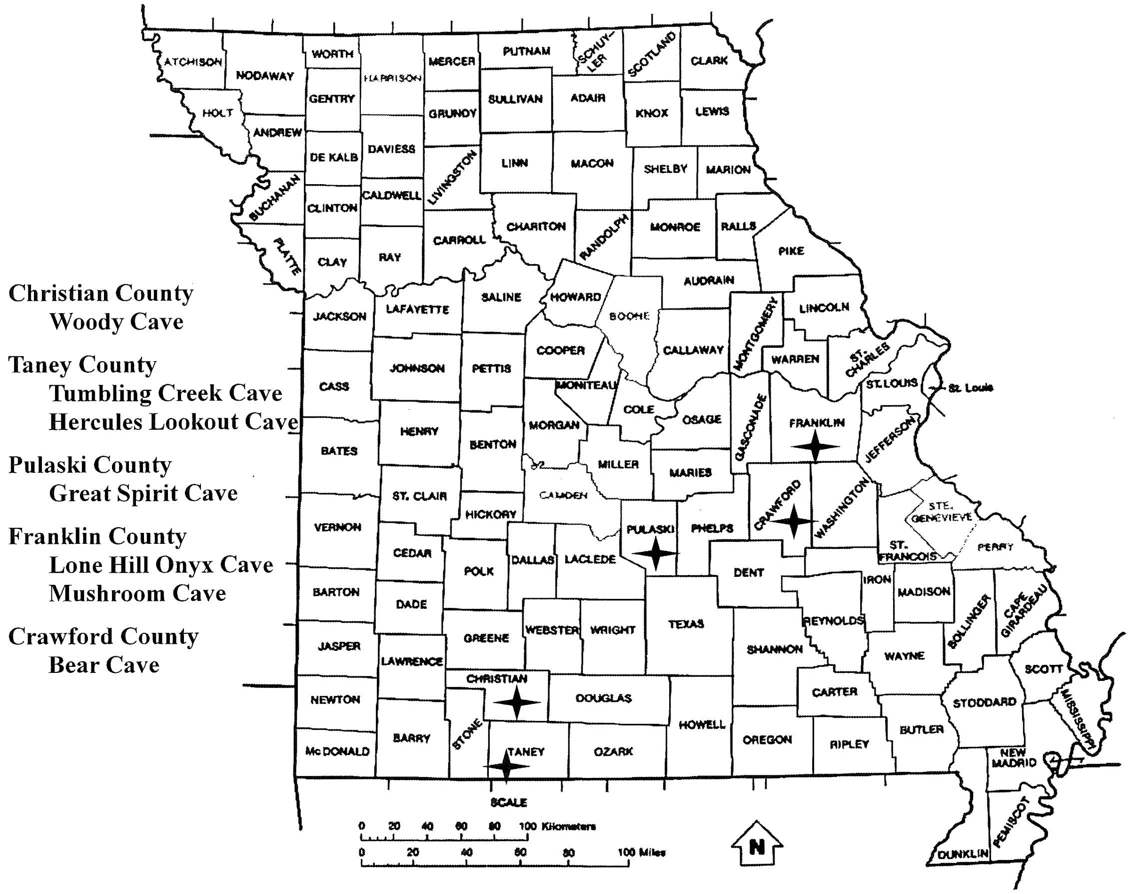
Pure culture preparation and storage — Isolated colonies of interest were picked and grown for 24 hrs in 5 ml nutrient broth. A 0.5 ml aliquot of this suspension was added, along with sterile glass beads to distribute the cells and 2–3 ml sterile 0.1% peptone solution, to the surface of a 75 mm tissue culture flask containing 50 ml of the same media on which the species was isolated. After 24–48 hrs of growth, 7–8 ml sterile 10% dextrose solution was used to wash the flask surface and recover the cells. Cell suspensions were pipetted until smooth and distributed in 1 ml aliquots for freezing and storage at –70°C.

Microbial identification — Pure culture samples were grown on appropriate agar plate media for 20–24 hours and then suspended in sterile saline to a concentration equivalent to the appropriate McFarland standard (McFarland 0.5 for G+ and *Bacillus*, 1.0 for G-, 2.0 for yeast, 3.0 for anaerobes) as described for the Vitek system. Identification was performed by automated biochemical testing on a Vitek model 32 instrument with software version 10.01 as per standard instrument protocol (bioMerieux, Inc., Durham, NC).

Results and Discussion

Water samples were taken from forty-four locations associated with seven Missouri caves from five counties: Bear Cave (Crawford Co.), Great Spirit Cave (Pulaski Co.), Woody Cave (Christian Co.), Hercules Lookout Cave (Taney Co.) , Lone Hill

Figure 1. Missouri county distribution of seven cave locations sampled for aquatic microbes during this study.



Onyx Cave and Mushroom Cave (Franklin Co.), and Tumbling Creek Cave (Taney Co.) (see Fig. 1). The caves from which water was sampled were chosen out of convenience and at times when laboratory access and resources for conducting the study were available. Water samples were collected between 2003 and 2005 when caves were accessible. Study caves included caves that ranged in size from almost 100 meters to 3000 meters in length. Caves were chosen that were isolated from heavy human development and surface construction.

Each sample was plated on each of five different microbial media as described. Tryptic Soy Agar and Plate Count Agar are both useful in the general cultivation of many heterotrophic microorganisms, varying only slightly in protein source, with the latter as a standard for bacterial quantification of contaminated water and milk. m-Fecal Coliform Agar is selective for fecal coliform microbes based on lactose fermentation and Sabouraud Dextrose Agar is a slightly acidic medium for the cultivation of yeast and filamentous fungi. Columbia Blood Agar is an enriched medium for cultivating fastidious microbes. Together, these media allowed the best opportunity to culture the greatest variety of chemoheterotrophic microbes possible from the cave water samples. In addition, Columbia Blood Agar is commonly used in anaerobic incubation and mimics the anaerobic conditions found in many stagnant waters. Even with the diversity of microbial media utilized, many microbe species in the samples cannot be cultured in the laboratory. In fact, less than one percent of organisms present in natural habitats can be cultured (Staley, 2006). Likewise, the use of the Vitek system limits the identifiable species to only those found in its software database, based upon biochemical characteristics.

Table 1 lists the species isolated and identified in each Missouri cave in this study. Forty individual species have been identified. Many species were identified in all or a variety of the caves such as *Escherichia coli*, *Serratia marcescens*, *Citrobacter* species, and various *Bacillus* species due to their ubiquitous nature, found in mammal feces or in soil. Other species were only identified once such as *Rahnella aquatilis*, a rarely found intestinal bacterium, *Pantoea agglomerans*, a Gram-negative bacterial plant pathogen, or *Aeromonas veronii*, a leech symbiont and potential opportunistic human pathogen. *Salmonella* species, though specifically identified in only one cave during this study, are a common reptile and amphibian microbiota and would be expected to be present. The number of different species identified from each cave is not indicative of the absolute microbial biodiversity within the waters of that cave but rather a function of the quantity of samplings in that cave location, the ability to cultivate the species present, and the quality of colony isolation. Twenty-seven individual species

Table 1. Identified microbes from the seven surveyed Missouri caves

Species	Location within cave	Isolation media	Species identity % confidence
Bear Cave (Huzzah)			
Citrobacter freundii complex	flowing stream	mFC	99
Cryptococcus luteolus	flowing stream	SAB-DEX	85
Hafnia alvei	drip pool	SAB-DEX	99
Saccharomyces cerevisiae	flowing stream	PCA	99
Salmonella species	drip pool	SAB-DEX	91
Serratia liquefaciens	flowing stream	SAB-DEX	99
Serratia marcescens	flowing stream	SAB-DEX	99
Great Spirit Cave			
Aeromonas caviae	drip pool	PCA	97
Aeromonas veronii biovar *sobria*	drip pool	CBA anaerobic	86
Alcaligenes xylosoxidans ssp. xylosoxidans	drip pool	TSA	96
Bacillus sphaericus	drip pool	PCA	95
Brevundimonas vesicularis	drip pool	TSA	98
Citrobacter braakii	drip pool	mFC	99
Citrobacter freundii complex	drip pool	mFC	99
Escherichia coli	drip pool	mFC	99
Klebsiella pneumoniae	drip pool	SAB-DEX	91
Pseudomonas aeruginosa	drip pool	mFC	99
Serratia liquefaciens	drip pool	SAB-DEX	99
Sphingomonas paucimobilis	drip pool	PCA	96
Woody Cave			
Acinetobacter junii	flowing stream	SAB-DEX	99
Hercules Lookout Cave			
Citrobacter braakii	flowing stream and pipe flowing from cave to springhouse	mFC	99
Enterobacter amnigenus biogroup 2	flowing stream	mFC	92
Escherichia coli	flowing stream and pipe flowing from cave to springhouse	mFC	99
Lone Hill Onyx Cave			
Bacillus sphaericus	flowing stream	PCA	99
Citrobacter amalonaticus	flowing stream	mFC	90
Citrobacter braakii	flowing stream	mFC	99
Citrobacter farmeri	flowing stream	mFC	98
Escherichia coli	flowing stream and drip pool	mFC	99
Pantoea agglomerans	drip pool	SAB-DEX	99
Pseudomonas putida	flowing stream and drip pool	SAB-DEX	94
Serratia plymuthica	flowing stream	mFC	97
Staphylococcus capitis	drip pool	SAB-DEX	84
Yersinia federiksenii	drip pool	SAB-DEX	85

Table 1. *Continued*

Species	Location within cave	Isolation media	Species identity % confidence
Mushroom Cave			
Citrobacter braakii	flowing stream and dripping from borehole in ceiling	mFC	99
Citrobacter freundii complex	flowing stream and dripping from borehole in ceiling	mFC	99
Escherichia coli	flowing stream	mFC	99
Klebsiella pneumoniae	flowing stream	mFC	99
Tumbling Creek Cave			
Acinetobacter calcoacaticus-baumannii	flowing stream and artificial isolated pool	CBA aerobic	99
Acinetobacter junii	flowing stream	PCA	99
Bacillus cereus	artificial isolated pool	CBA anaerobic	98
Bacillus megaterium	flowing stream	SAB-DEX	99
Bacillus sphaericus	flowing stream	PCA	99
Chromobacterium violaceum	flowing stream	CBA aerobic	99
Citrobacter braakii	flowing streams, isolated pools, natural entrance, and karst window	mFC	99
Citrobacter farmeri	karst window	mFC	99
Citrobacter freundii complex	Springhouse spring, isolated pool, flowing stream, natural entrance, and karst window	mFC	99
Citrobacter youngae	karst window	mFC	99
Cryptococcus luteolus	flowing stream	SAB-DEX	94
Enterobacter aerogenes	flowing stream	mFC	98
Enterobacter cancerogenus	flowing stream	mFC	99
Enterobacter cloacae	flowing stream	mFC	99
Escherichia coli	flowing stream, isolated pools, natural entrance, and karst window	mFC	99
Hafnia alvei	flowing stream and isolated pool	mFC	99
Klebsiella pneumoniae	flowing streams and isolated pools	mFC	99
Pseudomonas putida	flowing stream and isolated pool	PCA	99
Rahnella aquatilis	flowing stream	SAB-DEX	99
Rhodotorula glutinis	isolated pools	SAB-DEX	92
Serratia fonticola	flowing stream	SAB-DEX	99
Serratia marcescens	flowing stream	mFC	99
Sphingomonas paucimobilis	flowing stream	PCA	88
Staphylococcus sciuri	flowing stream	PCA	99
Stenotrophomonas maltophilia	flowing stream	SAB-DEX	99
Vibrio parahaemolyticus	flowing stream	PCA	99
Yersinia frederiksenii	isolated pools	CBA anaerobic	85

Note: identified species are a selective survey of the microbial flora in these cave waters and are not intended to represent the entire microbial biodiversity of any location.

were identified in Tumbling Creek Cave, more than twice as many as any other cave, likely due to the higher frequency of visits made to this cave collecting more water samples than any other cave.

It is important to note that this study was designed to be a selective survey and inventory, not a comprehensive or quantitative analysis of all cellular microorganisms found in each of the sampled waters of each of these seven Missouri caves. No effort was made to control for cave or watershed variables (ie. surface land use, land cover, stream flow rates, extent of recharge zone, etc.) that are known to affect microbe presence. It is not proposed that the species identified constitute the microbial make-up of any of these cave waters. Rather, this study begins the identification and cataloging of microbes in order to further the biodiversity understanding of each cave.

Water samples, even after 100-fold dilution, often generated plates with over 100 microbial colonies. This created a glut of colonies to isolate and investigate. Time and resources naturally limited identification of every isolated colony. Of the microbes which grew and formed colonies visual distinctiveness was used to selectively perform automated biochemical species identification by the Vitek system. As an example, if all isolated colonies on a plate showed the same colonial morphology, color, and relative size then only one colony was selected. In converse, if a plate contained several distinct colonies based on color, colonial morphology, elevation, texture, or size then multiple unique colonies were subcultured, identified, and frozen for future study. The selective nature of the sampling protocol does not allow quantitative comparisons among the sampled caves or cave microhabitats.

Several microbial methods can be used to provide information about the role of microorganisms in their habitats (Drenovsky et al., 2008). These methods are important in studies examining structure (i.e.biodiversity) and function (i.e. nutrient cycling) of ecosystems and the study of ecosystem structure and function begins by identifying species present. The molecular approach of identifying microbes through sequencing ribosomal RNA genes is a common modern approach and efficiently provides a wealth of information (Barton and Jurado, 2007) but relies on accuracy in the molecular databases. It also indicates the species was once present but may not currently be alive and contributing to the ecosystem. The culture methods used here to identify microbial species by biochemical testing are time and resource consuming but provide live specimens. An estimated 180 laboratory hours were needed to culture and identify the bacterial species discovered in these cave water samples. Pure cultures are required to conduct the automated biochemical testing using the Vitek model 32 instrument. The Vitek system compares the biochemical features of the unknown sample with the biochemical features in a dictionary of more than 550 known bacterial and fungal species. The Vitek procedure also provides a probability statement regarding the confidence of species identification (see Table 1). It is possible that these pure cultures contain species which are actually new to science or unknown in the Vitek database but exhibit the same metabolic properties of known species in the Vitek dictionary. Therefore, archived frozen samples of all identified species have been created. In fact, more individual colonies have been frozen than could be identified and a viable library of both identified and unidentified microbes from these Missouri caves now exists.

Summary

Forty species of microbes have been identified from seven caves from five Missouri counties. The species identified mainly represent common soil or enteric bacteria, though some rare species were also found. These identifications contribute to the understanding of cave biodiversity within the state. A major contribution of this study has been the development of a library of viably frozen microbes from Missouri caves which are now available for further analysis and laboratory testing.

Acknowledgments

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CoCoRaHs in Missouri: Four Years Later, the Importance of Observations

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Abstract: *On 1 March 2006, Missouri became the 11th state to join the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS). CoCoRaHS is a national volunteer network of individuals who have agreed to measure and report precipitation observations daily. This program was established in 1998 by the Colorado State Climate Office. On 12 March, 2006 CoCoRaHs quickly demonstrated its usefulness during the severe weather events of that day when there were several reports of large hail. Since then, Missouri CoCoRaHS network receives about 250 reports per day. This data can be used to study severe weather events such as the passage of Tropical Depression Gustav and Tropical Storm Ike through Missouri over a 10 day period bookended by 4 and 14 September 2008. Here we will compare the CoCoRaHS volunteer rainfall totals to RADAR derived estimates taken from the National Weather Service (NWS) as well as the Cooperative Site measurements. CoCoRaHS data was even incorporated by the local NWS to summarize these events. CoCoRaHS data is currently used by all six NWS offices and the four River Forecast Centers that serve the state of Missouri as well as by other state and federal agencies and several television stations. The data have been used to dispatch flash flood information to the NWS and to make flood and drought assessments for the Missouri departments of Agriculture and Natural Resources. Public works departments, insurance companies, contractors and farmers have also used the data for documentation and management decisions. The Missouri CoCoRaHS network has proven to be a very valuable tool for precipitation measurement, and here we demonstrate this by comparing the CoCoRaHS data to different types of precipitation graphics provided by the NWS.*

1. *Introduction*

Most people are familiar with the sound of rain, but to a certain group of people this is the sound of opportunity to help scientists embark on the study of precipitation and its distribution within weather events (e.g., Market and Cissell, 2002). These studies can help scientists gain an understanding of the dynamic mechanisms leading to the formation, maintenance, and decay of these events. The volunteer observers who help scientists, hydrologists, meteorologists, climatologists and other personnel through precipitation reports, observations, and analysis are the members of the Community Collaborative Rain, Hail and Snow (CoCoRaHS) Network.

CoCoRaHS is a unique, diverse and non-profit organization comprised of mostly amateur volunteers who measure precipitation once-per-day nationwide. The coordinators of the organization begin with those on the national level, and then down to the state and regional levels. The most important attribute of CoCoRaHS however, is the vast network of its volunteers. Volunteers in the organization are meteorological professionals at universities, the NWS, television stations, and the general public, and these are comprised of people from different ethnic backgrounds. Volunteer weather observation has a long history in the United States, especially within programs under the direction of the NWS. Examples are the National Oceanic and Atmospheric Administration (NOAA) Cooperative Observers program (COOP — COOP, 2009) established in 1890, or SKYWARN which was established about 35 years ago (SKYWARN, 2009).

Members of CoCoRaHS, although diverse in many ways, all have one thing in common: they all love the weather. Weather is a fascinating subject that directly impacts how we live, when and where to conduct outside activities, and the kind of products we buy each day. One mission of the meteorological community is the observation, reports and analysis of precipitation. Thus, the purpose of CoCoRaHS is the observation, report, and analysis of precipitation in order to provide scientists with the highest quality data for educational purposes and research applications.

Why is the CoCoRaHS organization so focused on the precipitation characteristic of weather? Precipitation is a vital and essential part of our lives. Precipitation affects all of us in a variety of ways, falls in many forms and varies greatly in amount and intensity throughout the world. There are many factors to look at when analyzing precipitation: precipitation amounts are affected greatly by topography, strength of a storm system, amount of moisture in each system, and season, among others.

The creation of the CoCoRaHS network was a direct result of a devastating localized flash flooding event that occurred on 28 July, 1997 over Fort Collins, CO (CoCoRaHS, 1998). A series of thunderstorms produced over a foot of rain in several hours in certain parts of the city; other parts of the same city only got moderate rainfall. Event rainfall totals from 28–29 July, 1997 ranged from 14.5 inches over Western parts of Fort Collins (in the Foothills), while Eastern sections of the city (in the plains) reported less than two inches. For a period of 90 minutes, extreme downpours totaled more than five inches during the worst part of the event.

The devastating flash flood killed five people and produced over $200 million dollars in damage. One year later, a group organized under Dr. Nolan Doesken of the Colorado Climate Center at Colorado State University created a network to observe precipitation, rainfall rates, and other attributes for localized events. The network for precipitation reports, observations and analysis has now expanded into a national organization in all 50 United States.

In this paper, an overview of CoCoRaHS in Missouri will be provided in section two. In section three, a comparison of the CoCoRaHS observations to radar derived estimates of precipitation will be compared for two remnant hurricanes which crossed Missouri in 2008. Finally, a summary of this work will be given, and the conclusions will be reviewed.

2. *COCORAHS in Missouri begins March 2006*

CoCoRaHS has been a national organization since 1998, but Missouri's affiliation began officially on 1 March 2006. Missouri was the 11th state to join the network. The usefulness of CoCoRaHS observations in Missouri were demonstrated on 12 March 2006 when a severe weather outbreak impacted a large part of the midwest. (see Fig. 1). Several individuals forwarded their reports during the severe weather, thus CoCoRaHS in Missouri was born. Note that on that day there were three reports of two-inch hail stones, including a report of three-inch hail stones near Columbia, MO. CoCoRaHS hail reports, as well as intense rainfall reports, are forwarded to their respective NWS Office.

There are currently 877 CoCoRaHS observers listed in the Missouri data-base, and of these, 372 have reported within the last month. Missourians routinely submit about 250 reports daily. During the month of June, 2009, for example, submissions ranged from a low of 247 (22 June 2009) to a high of 317 (3 June 2009) reports on any given day. The average daily state reporting total was 282. The number of observations is larger following days when rainfall occurs statewide. There were also 19 hail reports during June, 2009, but no more than four on any particular day. During the cold season, snowfall reports have been useful in identifying locally heavy snowfall snow accumulations, especially away from urban centers. It is difficult to assess the demographics of age since few participants added this voluntary information upon signup. There were volunteers of all age groups found in Missouri. Professional meteorologists (academic, government, and private sector) accounted for only 14 of the total observers.

CoCoRaHS now has observers in 113 of the 114 counties in Missouri. The spatial distribution across the state shows that the number of observers is strongly weighted toward the southwest part of Missouri which includes much of the KY- 3 TV (Springfield, MO NBC affiliate) viewing area, and the county warning area of the Springfield National Weather Service (SGF). KY – 3 TV has been very active in recruiting CoCoRaHS observers and using this data. Eight of the ten counties with the most observers were in southwest Missouri. The number of observers is also strongly correlated to urban areas and/or university centers. Table 1 shows the number of observers in the four largest urban centers and the surrounding counties. Table 2 shows the top ten counties by number of observers.

CoCoRaHS observers are asked to submit their rain gauge readings online at http://www.cocorahs.org each morning for the 24-hr period ending at 7 a.m. local time. Each observer is asked to purchase, or is given, a standard four-inch diameter, raised-edge rain gauge. These gauges are made of heavy duty plastic and are recommended by the national CoCoRaHS coordinators. The data produced by the network is used in a variety of ways and applications. The data are currently used by all six National Weather Service Forecast Offices (NWSFO) and four River Forecast Centers serving Missouri. There are also other state and federal agencies that incorporate the CoCoRaHS reports, observations and data into their services. The data have been especially helpful with dispatching flash flood information to the NWS. The Missouri Departments of Agriculture and

Figure 1. The CoCoRaHS map of Missouri for 12 March 2006 showing hail size.

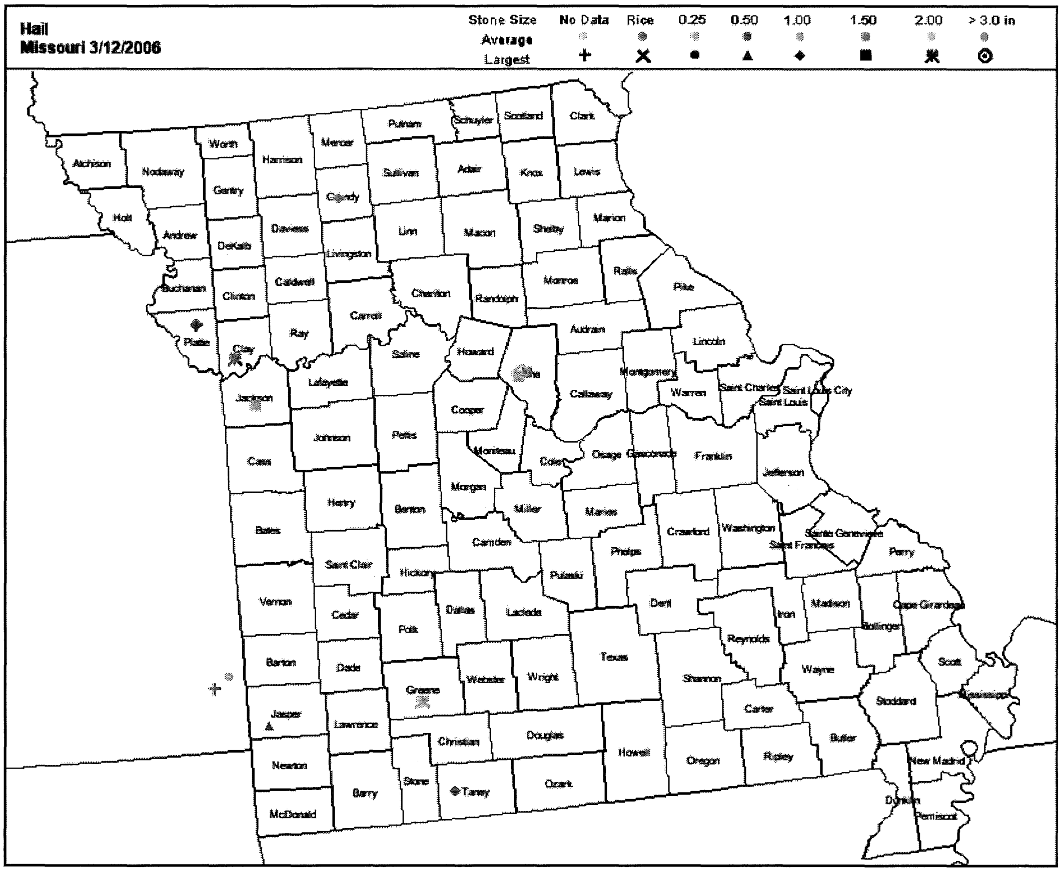


Table 1. The number of observers in the counties surrounding the four largest urban areas in Missouri.

Urban Areas	Observer Numbers
Springfield	183
Columbia	81
Saint Louis	67
Kansas City	66

Table 2. The top eleven number of observers in Missouri counties.

County	Observer Numbers
Greene	71
Boone	42
Christian	42
Texas	30
Stone	25
Taney	23
Lawrence	21
Barry	20
Howell	20
St. Louis	20
Webster	20

Natural Resources use this information for flood and drought assessments. CoCoRaHS data has even been used for documentation and management decisions for different work departments, insurance companies, contractors, farmers and agricultural interest occupations, and even in a court of law.

3. *Two case studies*

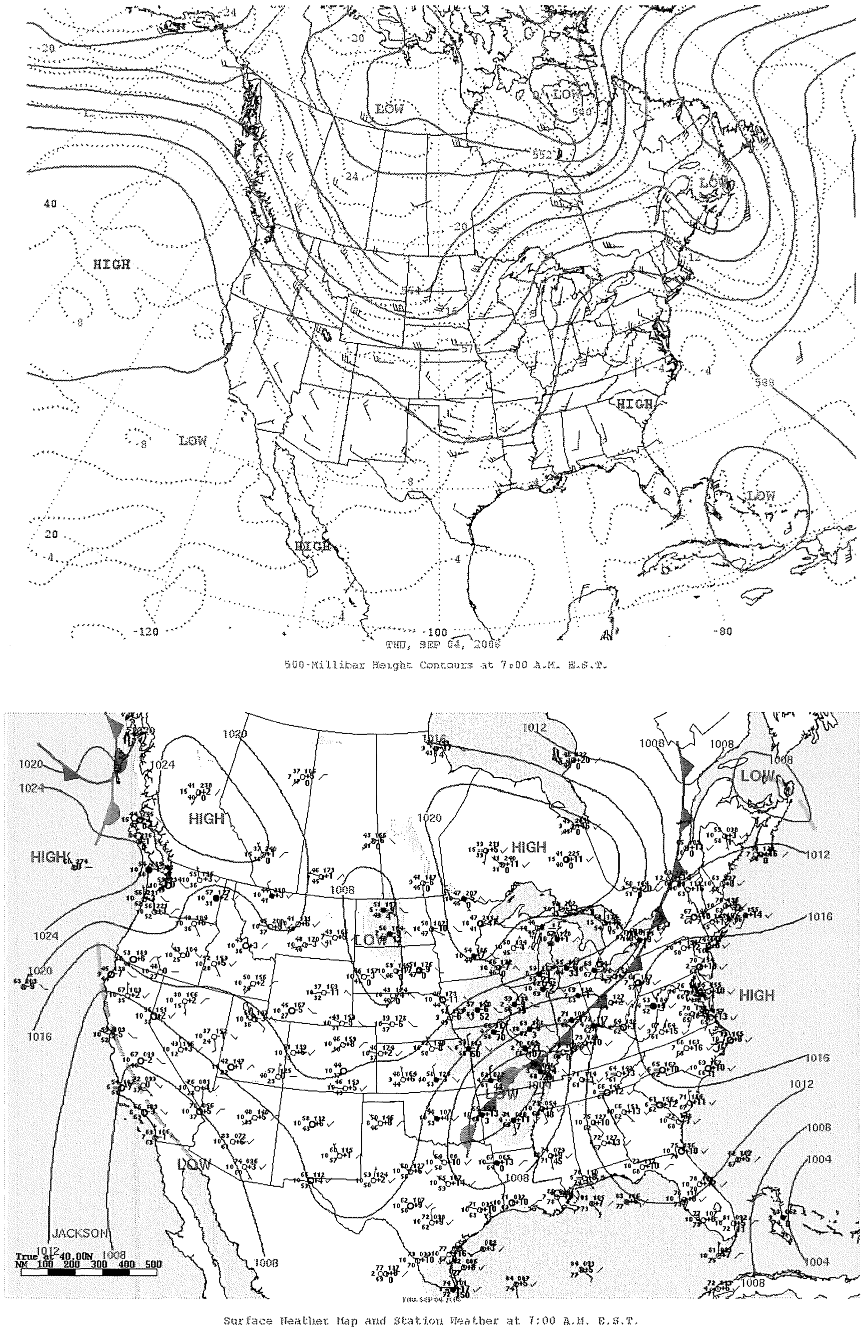
A particular set of events showed the importance of data in the network, the remnants of Hurricane Gustav and Hurricane Ike. There were many reports provided from the CoCoRaHS network of volunteer observers for each case. We will look at and compare data from the CoCoRaHS observers and the data from the National Weather Service Offices that were particularly affected by these disturbances.

a. Hurricane Gustav

The remnants of hurricane Gustav moved through the state during 3–4 September 2008. Rainfall amounts varied greatly in parts of the state, and the Midwest as Gustav became an extratropical system.

The remnants of Gustav interacted with a 500 hPa trough and a slow-moving cold front that merged with the remnant

Figure 2. The 500 hPa (top) and surface map (bottom) for 1200 UTC 4 September 2008.

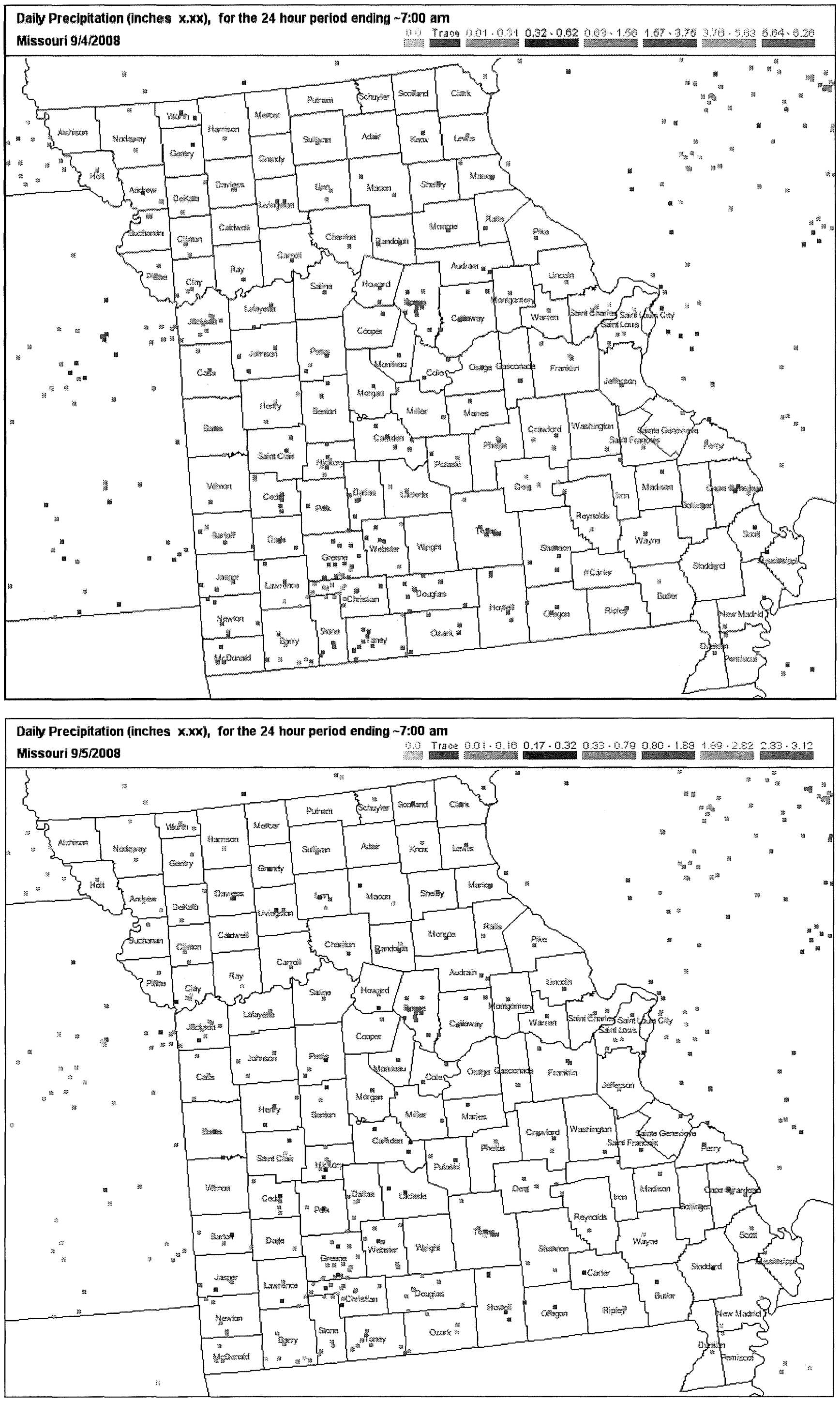


tropical depression (Fig. 2). The cold front aided in transitioning the tropical storm to an extratropical system (NWS EAX, 2008a). The remnants of Gustav induced a wave of low pressure on the frontal boundary (MRCC, 2008a). Additional evidence that the remnants of Hurricane Gustav were transitioning from a tropical storm to an extratropical system is shown in Fig. 3. Heavy precipitation is noted across both Missouri and Arkansas where Gustav merged with the cold front.

The heaviest period of precipitation occurred between 1900 LDT 3 September and 0700 LDT (1200 UTC) 4 September (NWS SGF, 2008a). Rain continued though 1200 UTC on 4 September 2008, thus, we can compare rainfall amounts for the 24-h period following 1200 UTC as well.

Figure 3 shows the observed values of rainfall from CoCoRaHS precipitation reports plotted on a county map of Missouri for the mornings of 4 and 5 September 2008. Note that the heaviest values on 4 September 2008 were found in the southwest part of the state and were on the order of three to six inches. The next morning, two to four inch rainfall amounts were found in the Saint Louis area. This can be compared to graphical data

Figure 3. The daily CoCoRaHs maps for 1200 UTC 4 September, 2008 (top) and 1200 UTC 5 September, 2008 (bottom).



showing amount of precipitation received across Missouri including the NWS storm radar estimates (Fig. 4) and Midwestern Regional Climate Center graphical data which used CoCoRaHS reports to compile the precipitation map (Fig. 5). Note that the total composite in Fig. 5 agrees well with the amounts shown on the two separate CoCoRaHS maps shown in Fig 3.

The data that were compiled from the NWS and the Midwestern Regional Climate Center all incorporated CoCoRaHS observation data. The use of CoCoRaHS reports and

Figure 4. The radar estimated one day precipitation (in) accumulations for approximately 1500 UTC 3 September to 1500 UTC 4 September, 2008.

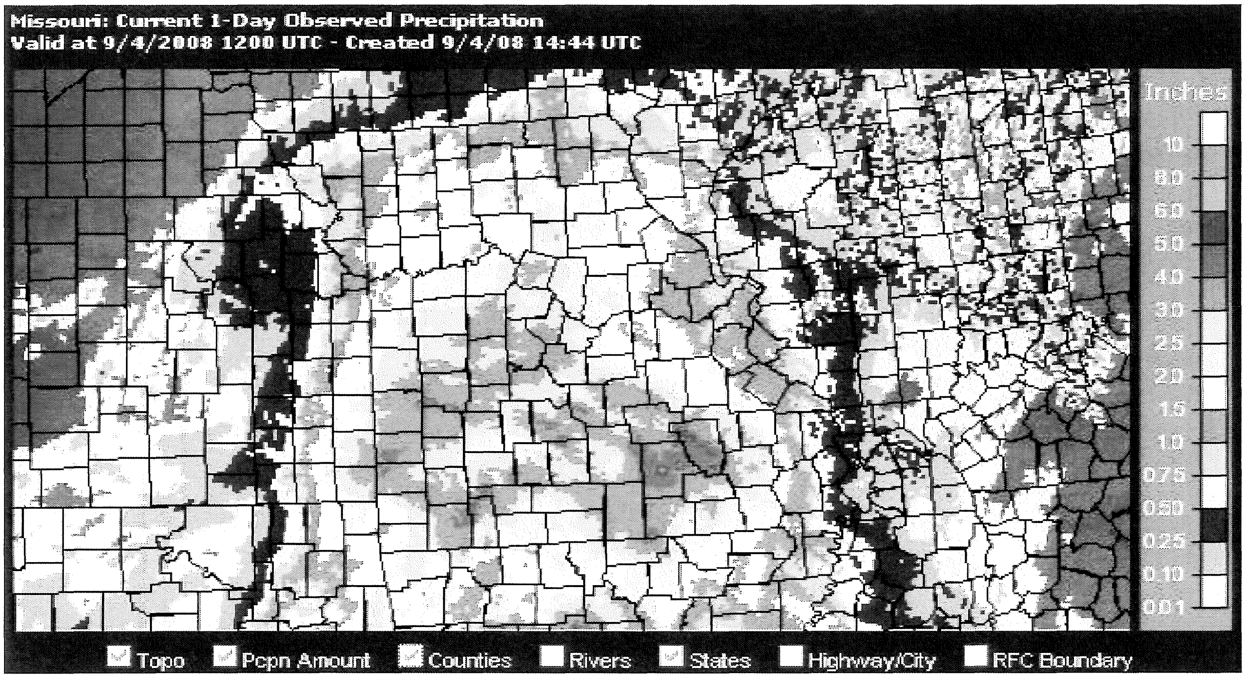
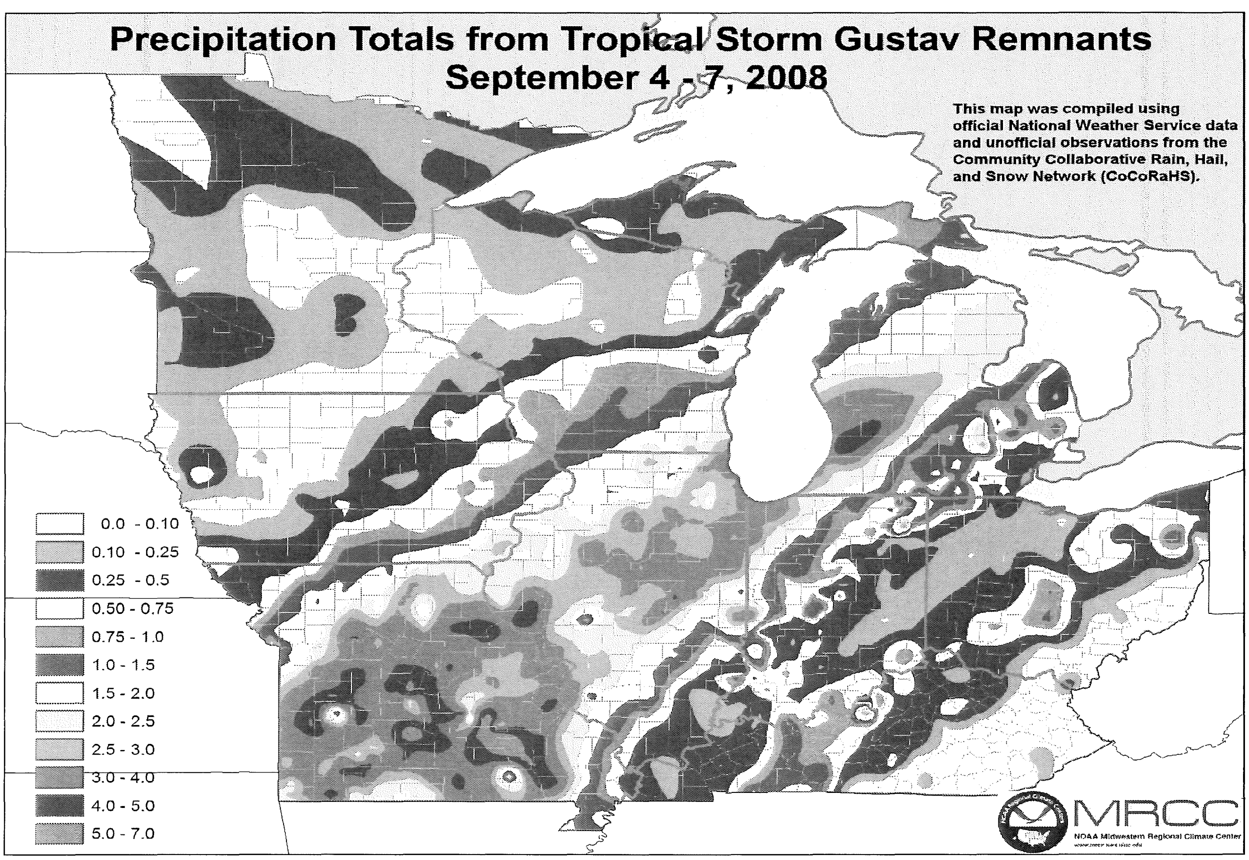


Figure 5. The composite total precipitation for the midwest for Gustav (taken from the Midwest Regional Climate Center — http:// mrcc.isws.illinois.edu).

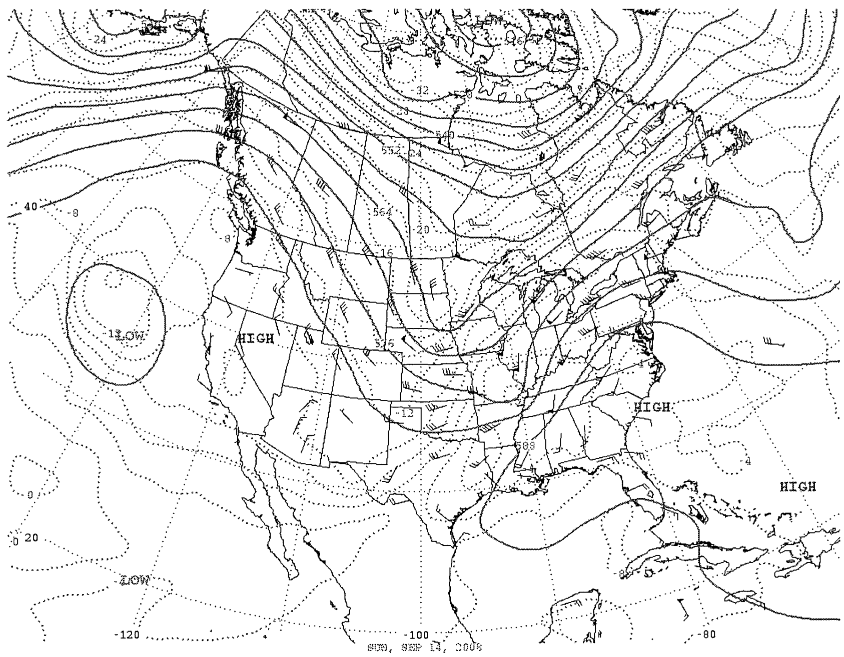


observations in this particular event is a strong indication that the data provided were indeed valuable and reliable.

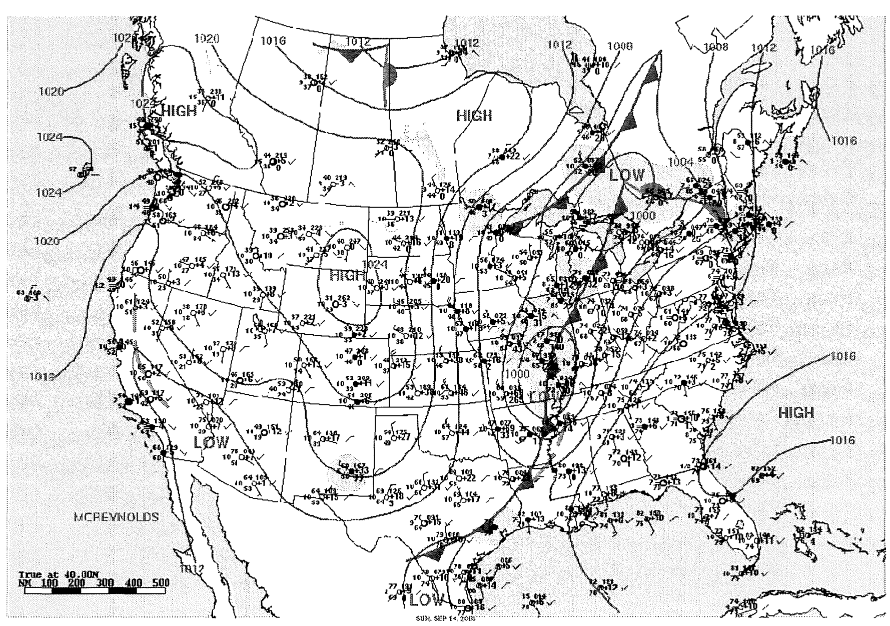
b. Hurricane Ike

The second significant event to affect the Midwest during September 2008 was the remnants of Hurricane Ike. Hurricane Ike came ashore in Texas about 300 miles west of where Gustav did, but on 13 September, 2008. The storm moved through Missouri on 14 September, 2008 (Fig. 6). An examination of the 500 hPa and surface maps suggests the synoptic situation was very similar, including the presence of an upper air trough and a slow moving cold front approaching from the west. The remnants of Hurricane Ike had more moisture available to work with than the remnants of Gustav, as temperatures and dew points were 5–9° F (2.5–5° C) warmer across the state (Fig. 2

Figure 6. As in Fig. 2, except for 1200 UTC 14 September, 2008.

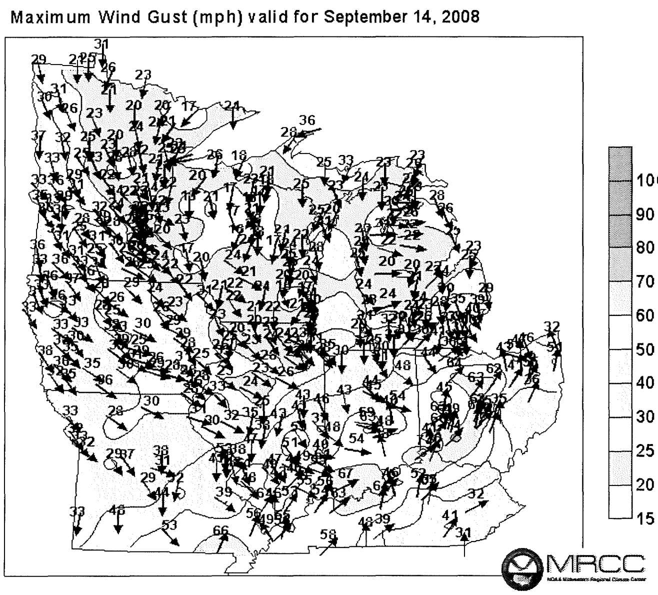


500-Millibar Height Contours at 7:00 A.M. E.S.T.



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

Figure 7. The maximum wind gusts across the upper midwest during 14 September 2009, and associated with the remnants of Ike (taken from the Midwest Regional Climate Center — http://mrcc.isws.illinois.edu).



and 6). There were some factors, however, with this disturbance that made Ike a more significant event than the remnants of hurricane Gustav. The remnants of Hurricane Ike were still classified as a tropical storm throughout Southwest Missouri to very near the city of St. Louis (Fig. 7 and http://www.nhc.noaa.gov/tracks/2008atl.jpg). The system would interact with an upper air vorticity maximum later (not shown), which would re-invigorate the storm as a strong extra-tropical cyclone with winds up to 80 mph in Ohio.

The observers from CoCoRaHS were ready to help especially since the remnants of Hurricane Gustav occurred just 9 days earlier. As describe above, one of the major factors in the excessive rainfall produced by the remnants of Hurricane Ike was a cold frontal boundary draped across the Missouri region (NWS EAX, 2008b). The cold front acted as a lifting mechanism for the likely enhancement of thunderstorm development during 13 September, 2008 (Fig. 8), and the rainfall was greater with this front that the one associated with Gustav. The abundance of moisture produced by the remnants of Hurricane Ike combined with the frontal boundary. This added to the unusually high amounts of rainfall. (Figs. 9, 10)

The stronger remnants of Hurricane Ike were clearly visible on RADAR with an eye-like feature noted in the image of 0600 UTC 14 September, 2008 (Fig. 11). The strength of the disturbance was great enough to produce several EF-0 tornados in eastern Kansas and west central Missouri (NWS SGF, 2008b, MRCC, 2008b). Strong wind gusts caused power outages around St. Louis County (NWS LSX, 2008). The storm also produced copious amounts of rain and caused wide-spread flash flooding and river flooding events (NWS LSX, 2008). The storm claimed three lives in Missouri. Damaging winds were reported as far north as upstate New York.

Before the arrival of the remnants of Hurricane Ike the atmosphere indicated precipitable water values as high as 2.20 inches. Climatologically, the water content of the atmosphere was greater than two standard deviations above normal for July (NWS EAX, 2008b). There were also many locations from southeastern Kansas to central Michigan that received upwards of 7 inches of rain (Fig. 10).

Figure 8. As in Fig. 4, except for 1200 UTC 12 September to 1200 UTC 13 September, 2008.

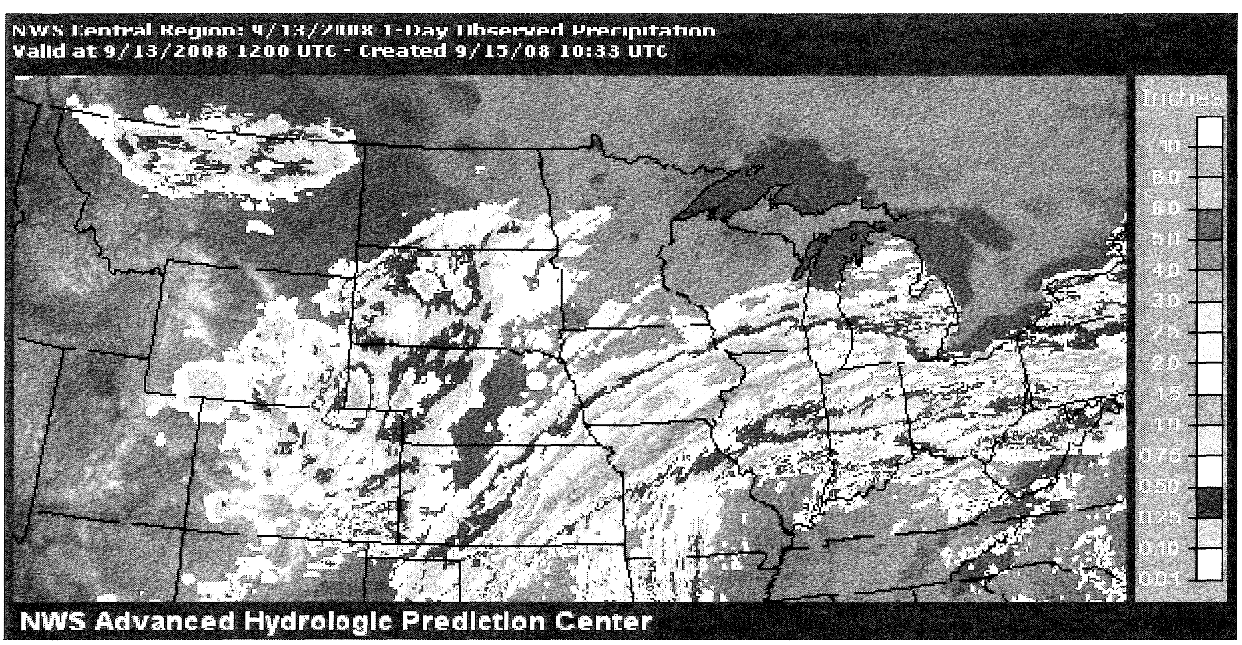


Figure 9. As in Fig. 4, except for 1200 UTC 13 September to 1200 UTC 14 September, 2008.

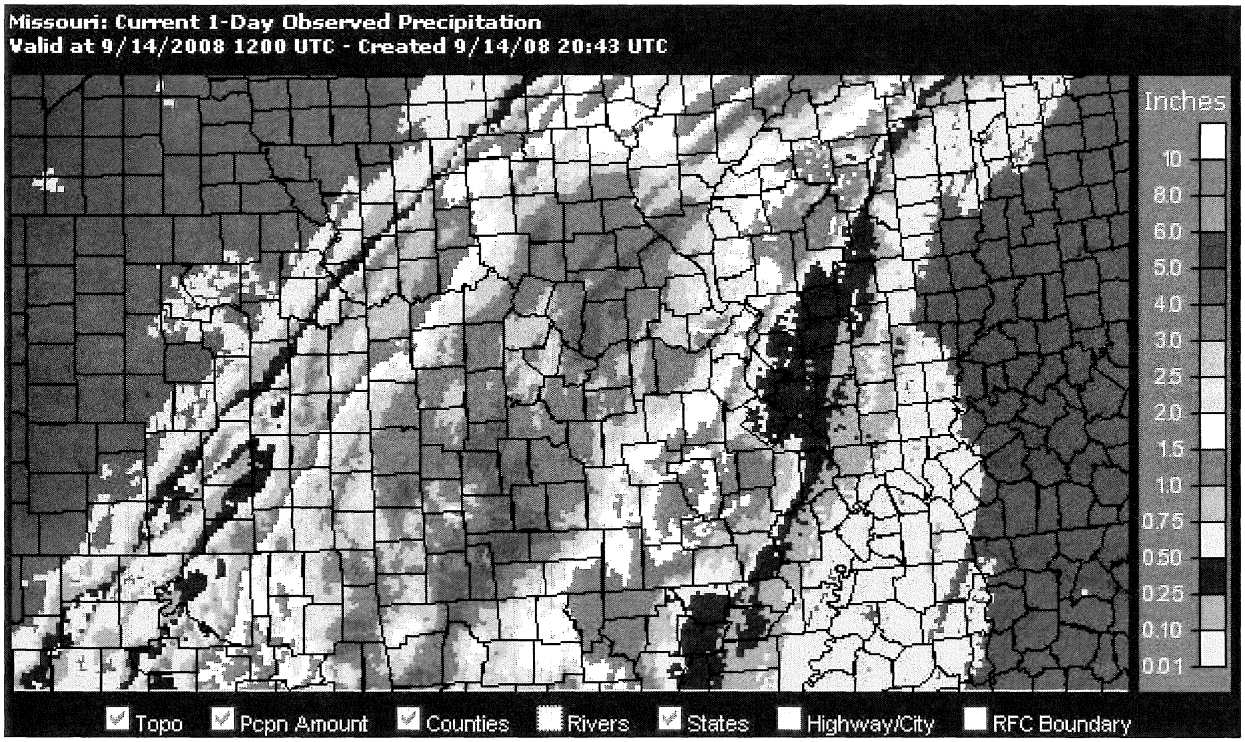


Figure 10. As in Fig. 5, except for 12–15 September 2008.

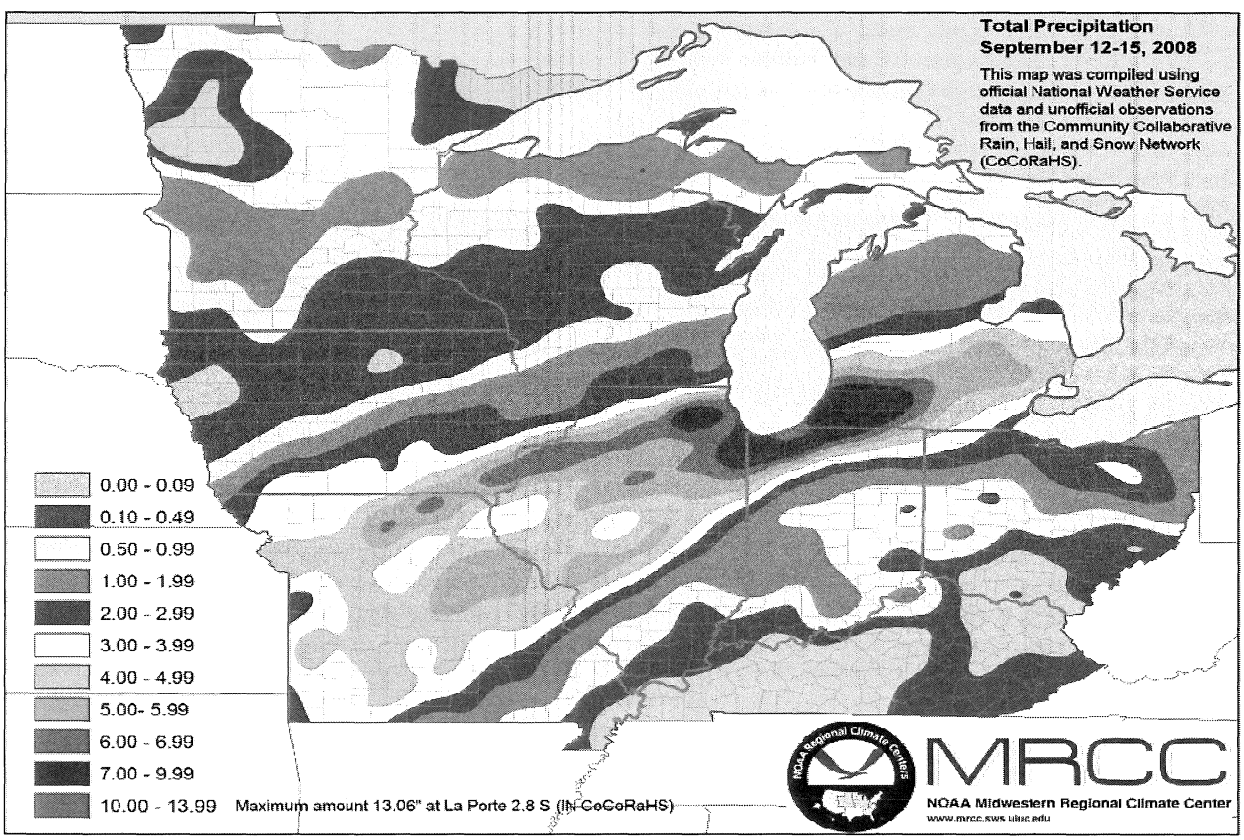
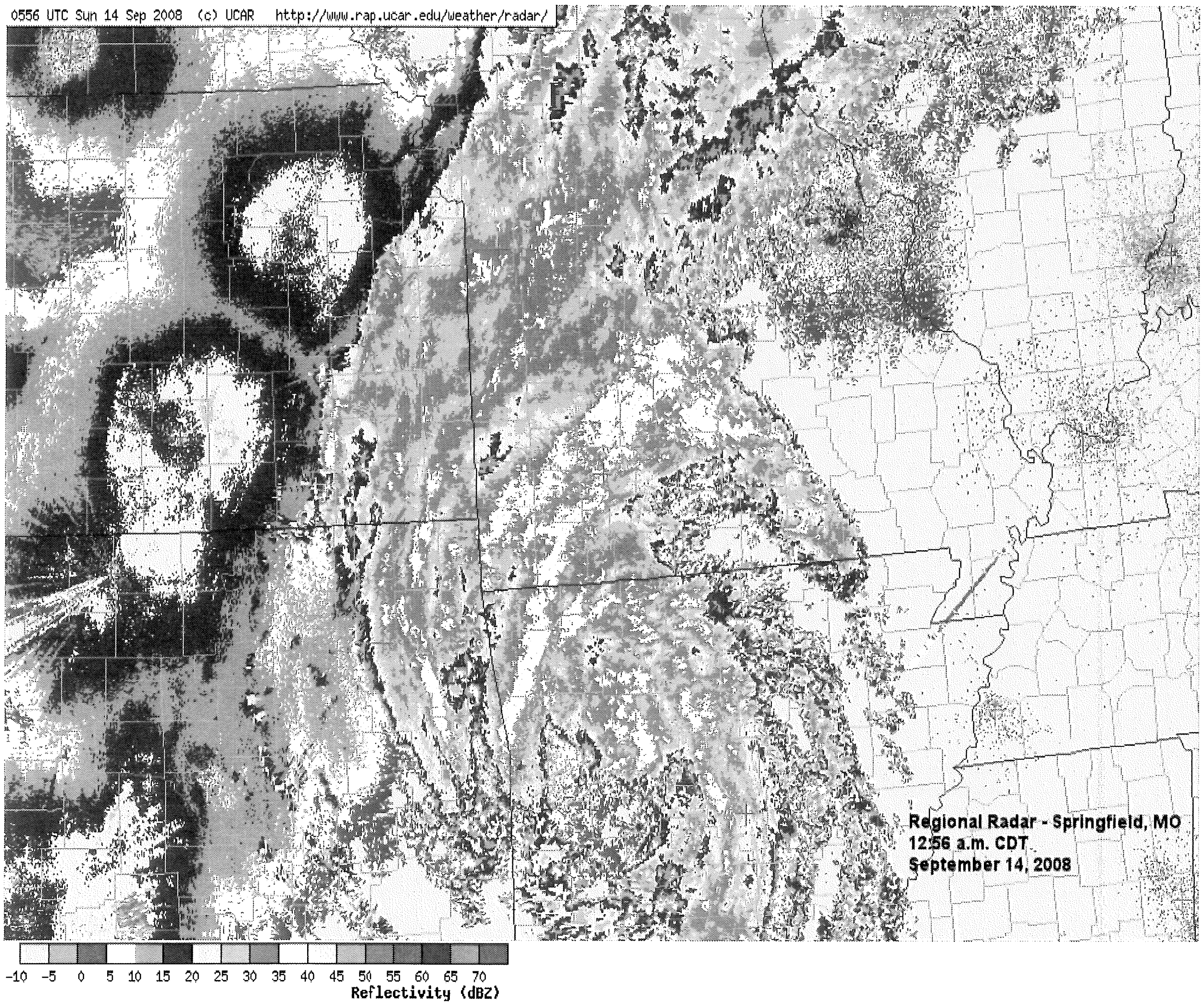


Figure 11. The radar image from the Springfield, National Weather Service Office from 0600 UTC 14 September, 2008.



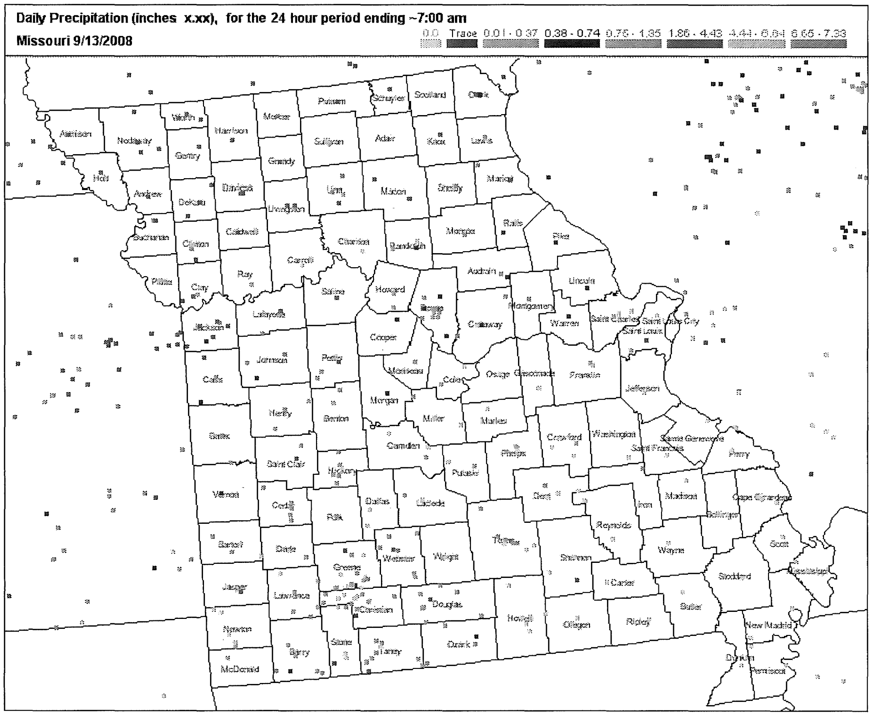
The Missouri CoCoRaHS network was a valuable tool in assessing rainfall reports throughout the state of Missouri for this particular event. The CoCoRaHS data were incorporated in the storm reports for NWSFOs with County Warning Areas in Missouri. The data from radar rainfall estimates and reports from coop observers, automated systems produced a great amount of information for the significant weather event. It is noted here that all of this information is collated into the graphical products produced by the NWS. The CoCoRaHS reports (Fig. 12), are congruent with the values shown in these products (Fig. 9). It should also be noted that inadequate RADAR coverage in places such as northeast Missouri may yield poorer estimates and can be augmented by the other types of data discussed above and CoCoRaHs data.

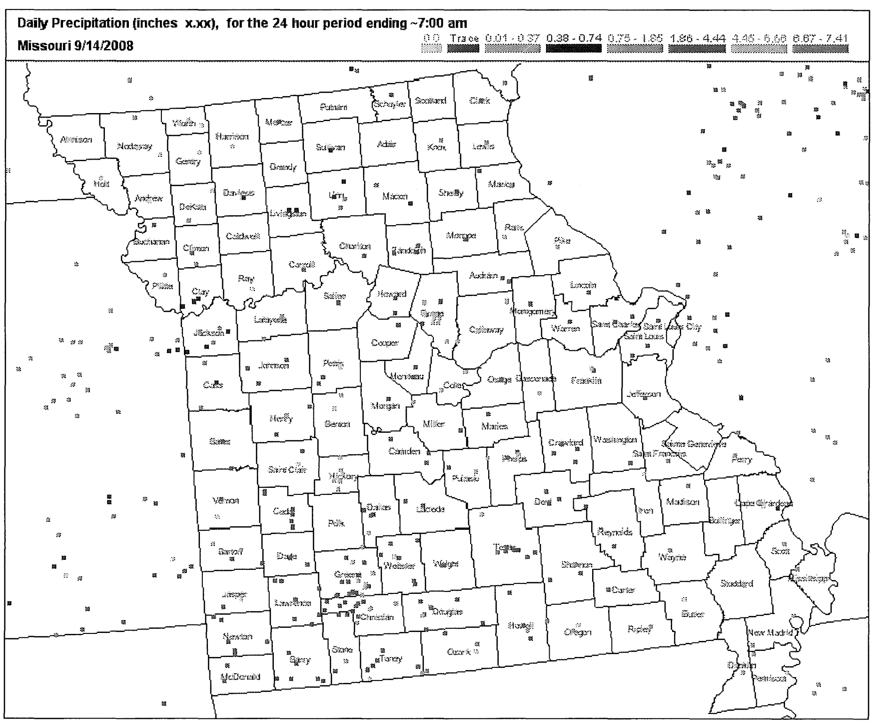
4. *Summary and Conclusions*

The CoCoRaHS network reports all forms and types of precipitation, rates of precipitation, and special occurrences happening at time of observation and can be reported. The CoCoRaHS data and reports show the general areas of precipitation amounts, but may also focus on individual county or metropolitan rainfall amounts. This kind of finer detail can be used in more detailed studies than those performed here, as information such as this is imperative to understanding and analyzing these complex weather phenomena occurrences from a mesocale view all the way down to a microscale view. This is where CoCoRaHs data has the most potential for use.

A cursory synoptic examination of the remnants of hurricane Gustav and Ike demonstrated that volunteer precipitation measurements are as consistent and accurate as those measured from professional observers, automated rain gauges and even higher order technology such as radar derived precipitation estimates. NWS (personal communication) personnel have noted some errors in CoCoRaHs data. However, some offices are able to quality control the data, and the state coordinators also perform quality control. Thus, CoCoRaHS information demonstrated reliability as a method for providing ground truth for future improvements of radar techniques.

Figure 12. As in Fig. 3, except for 1200 UTC 13 September (top), and 1200 UTC 14 September 2008 (bottom).





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A Brief Look at Petroglyphs and Pictographs: Rock Art of the United States and Beyond

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What are petroglyphs and pictographs? Petroglyphs are designs pecked, chipped, carved, or abraded into rock surfaces, such as cliff faces, or large boulders (2). With petroglyphs the outer patina (3) that might be covering the rock, is removed to expose the lighter colored stone beneath. Pictographs are designs painted on rock surfaces. Both are often classified as Rock Art. Petroglyphs come in two forms. The first can be either chipped or pecked into the rock (figure 1) and is composed as a series of tiny dots. The second form, is ground into the rock (figure 2), leaving deep smooth grooves and gives a much more three dimensional appearance.

The deeply etched type of petroglyphs are very common in the Pacific Northwest, west of the Cascade range. The etched designs in the Coastal area tend to represent mythical animals or stylized faces (Figures 3 and 4).

Pictographs (Figure 5), designs painted on the rock surface, are less common than pictographs. A third, even less common type of rock art is a combination of petroglyph and pictograph. The design is first carved into rock, then paint is applied to accent the carving and highlight the design (Figure 6). Of the three types of Rock Art, petroglyphs are by far the most numerous today. One major reason for this is that rain and weathering tend to destroy painted designs and as a result pictographs today are normally found only in dry, arid regions of the West and the Southwest of the United States and in Eastern British Columbia and Alberta, Canada , while petroglyphs are found in nearly every state and province of the United States and Canada (5).

The most common color found in pictographs is red (figure 3) and comes from iron (III) oxide. Other colors include white (calcium carbonate), black (charcoal), yellow (another form of iron oxide) and green (copper ore). The last two are by far the most common.

The pigment was made by grinding it with a binder, such as animal fat, water, or even saliva, into a paste which was applied to the rock surface with a "brush" or the fingers. In both the United States and Canada there are rare instances of the paste being sprayed, probably by spitting, over the hand to give a negative image of the hand (7). Examples of this technique can be seen in only five counties of the Big Bend Region of Texas and only occasionally in the rest of the U.S. and Canada (8).

The designs represented in Rock Art are of various types but have been categorized into 5 major classes (9): a) rectilinear (series or groups of straight or intersecting lines, Figure 7), b) circulinear (curved lines, sunbursts Figure 8), c) anthromorphic (human likenesses, Figure 1 and 9), d) zoomorphic (animals: either real such as sheep, goats, snake, *etc.* or mythical (Figure 1 and 10), and e) phylomorphic (representation of plants and flowers). A sixth category could be added which includes man-made items such as rifles (figure 5). It was not considered in the original classification, and that is of man-made items such as the rifles (Figure 5).

The first recorded petroglyph site in the U.S. and Canada was Dighton Rock which was on the banks of the Taunton River in Massachusetts. The rockwas first described by Cotton Mather in 1690 and since its discovery numerous explanations have been given for the meaning of the designs. In 1781 the Frenchman Antoine Court de Gebelin claimed the rock commemorated a visit to North America by seamen from ancient Carthage. In 1807 Samuel Harris saw in the designs words in Phoenician. Others have interpreted the designs to be passages from the Bible, writing of Vikings, or a treaty between a Portugese sailor and the local Indians (11). A much better and more realistic interpretation of the designs is that they are of Indian origin and their meaning known only to the maker and possibly members of his clan (12) (see below).

Elements of the design can in some cases give an idea as to its age. For example, the rifle designs (Figure 5), cannot be older than the early to mid-1800's, since rifles were not in that region before that time. Designs of horses in Rock Art can be dated to after the 1700's in the plains area because horses were not in the region before that time. In Figure 1, the mountain sheep at the left of the figure has an atlatl in its back. The atlatl was a weapon used before the introduction of the bow and suggests the age of this petroglyph to be prior to this particular time frame.

Some designs have raised many questions about dating of Rock Art. One of the most controversial is the Mastodon petroglyph found outside of Moab, Utah (Figure 12). The age of this design has been suggested to be several thousands of years old, dating back to the time when Mastodons were still in the

Figure 1. Moab, Utah.

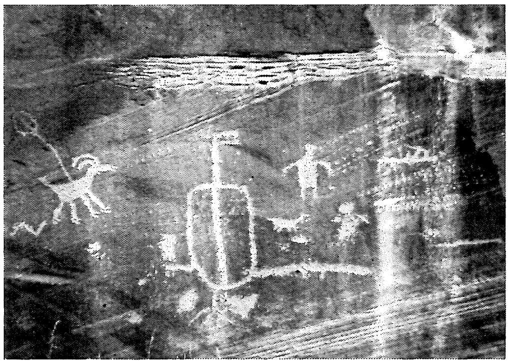


Figure 2. Viking Ribstone, Viking, Alberta, Canada.

Southwest. Another widely held explanation for the design is that it is a "recent" petroglyph of "mythological origin." Another explanation that has been suggested is that the design was executed after someone had seen an elephant. The Mastodon petroglyph was first reported in the early 1880's. Even in the arid southwest which aids in preserving petroglyphs, it is unlikely that the carver would ever have seen such an animal in the time frame that this petroglyph was made (13).

Other means have been used to estimate the relative age of designs. One is the comparison of designs with those found on pottery or on baskets that have been found in archaeological material. Relative dating can also be done by superimposition of one design upon another. The lower design is then assumed to be of an older age than the top one.

Petroglyph designs in general are hard to date (14), but most are not thought to be much older than a thousand years. Pictographs are younger and probably date to the early 1800's. In 1884, James Teit (15) in 1884 came to the Canadian Okanagan region and became a good friend and champion of the tribes of the Okanagan and wrote that most of the pictographs he saw, based upon talking to natives of the area, were between 60 and 100 years old.

According to Teit, petroglyphs and pictographs are not graffiti, nor doodles nor a form of "writing" (14, 15). They were made for a number of reasons and appear to be in large part based upon the culture that made the designs. There are several explanations for the designs. The first was to record history, travel, or migration of a clan. These events are sometimes depicted by a spiral. Some petroglyphs appear to show trails. The second was to commemorate the history of the clan, such as a memorable hunt. The third was used to mark hunting sites. In California large petroglyph sites in the Coso Range depict mountain sheep. These sites were on the annual migration route of the animals (4). the area surrounding the designs has been thought to be hunting blinds. The designs are thought to be used to encourage the fertility of the animal, to lure the animals to the hunting blinds or to pay respect for the animal's sacrifice (4). The fourth explanation may be that of a spiritual nature.

In many cultures, young boys and girls were sent out at the time of puberty to find a "Guardian Spirit," a supernatural power that would protect and give special powers to the youth. For a boy, the power might be to become a hunter, fisherman, warrior, *etc.*, or for a girl the special skills might be to become a gifted weaver or potter. The youth, to acknowledge receiving a Guardian Spirit, would go to a special place, as dictated by the

Figure 3. Petroglyph of mythical animals found at Sproat Lake Provincial Park on Vancouver Island, British Columbia, Canada.

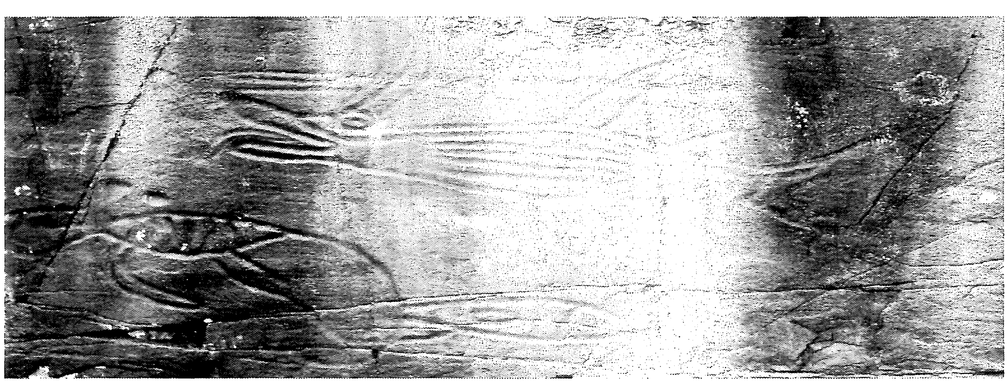


Figure 4. This petroglyph boulder was originally on Harstine Island, but moved to Tumwater, Washington. Note the 6 inch ruler in the picture to gain some idea of the size of the design.

Figure 5. Pictograph of rifles from Milk River Provincial Park, near Lethbridge, Alberta, Canada.

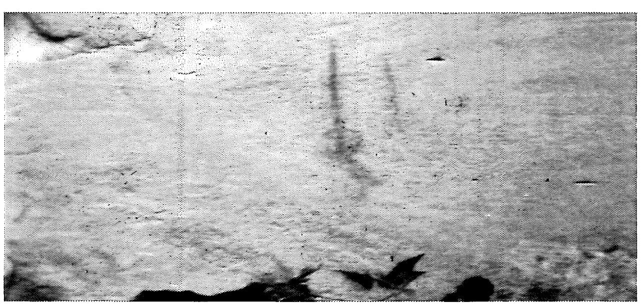
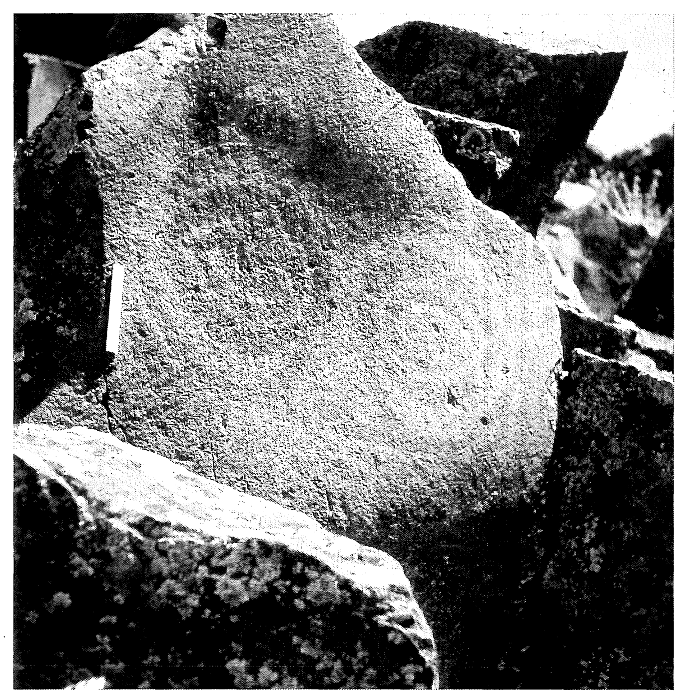


Figure 6. Tsagaglalal (She Who Watches Over") at Horsethief Lake State Park, Washington. The combined pictograph/ petroglyph is on a bluff overlooking the Columbia near The Dalles, Oregon. Note the 6 inch ruler on the left side of the design.



Guardian Spirit and prepare a glyph before returning to the village. The Cabinet Rapid site on the west bank Columbia River in Washington has been attributed to designs of weaving (16) which were pecked (Figure 13) into the rock by girls retuning from spirit quests.

James Teit had personal knowledge, from several tribes in the Canadian Okanagan, of the obligation of a youth to find a Guardian Spirit (15). The practice of finding a Guardian Spirit however was not limited to the Okanagan but was reported to be wide spread throughout the Pacific Northwest. Although the practice has not been as extensively documented in regions other than the Pacific Northwest, there are some reports from

Figure 7. Rectilinear design from Buffalo Eddy, Idaho. The designs are on a series of basalt boulders and shelves leading down to the Eddy but facing away from the Snake River.

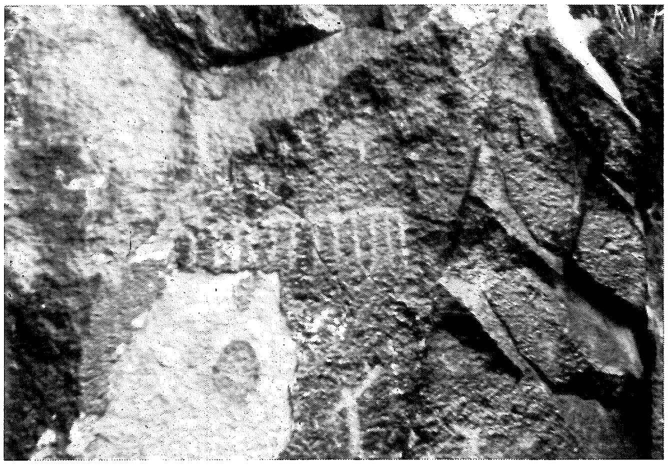


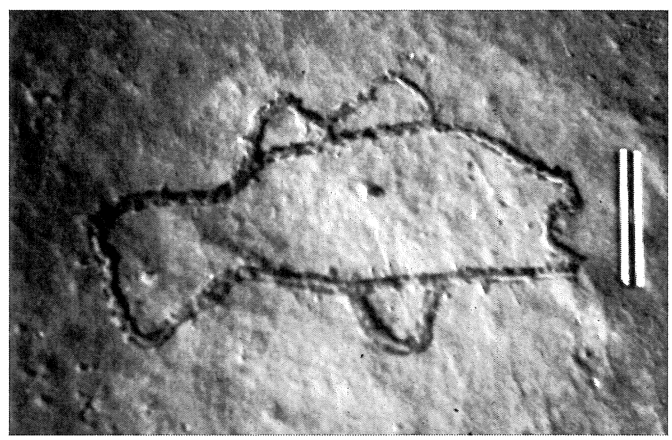
Figure 8. Circulinear pictographs designs on an isolated boulder about 10 miles north of Horsethief Lake State Park. Note the size of the designs based upon the 6 inch ruler on the far right bottom of the boulder.

the Plains and the Canadian Shield areas that youths from there were sent out on Spirit Quests.

Rock Art sites appear to have held special meaning. It is very rare to find an isolated design. Usually, where there is one petroglyph or pictograph there are others in the immediate area. Some of the sites are relatively small consisting of less that a dozen designs, while other sites are very extensive, for example, Dighton Rock (Figure 11) has several dozen designs. Pictograph Point at Mesa Verde, Colorado, is a petroglyph panel containing up to 100 designs, some overlapping others. Sand Island outside Blanding, Utah, has designs along the cliff face that cover over a quarter of a mile.

Figure 9. Anthromorphic designs of humans at Gingko State Park, Washington. These designs were originally on the cliffs overlooking the Columbia at Beverly, Washington, but were moved to the park with the building of Wanapum Dam.

Figure 10. Zoomorphic design from Leo State Park in Southeastern Ohio.



For some of us, seeing Rock Art is thrilling. After you see the first site you will become addicted to seeing and finding more as many of us have!

Acknowledgments

This paper could not have been written nor could the pictures of the petroglyphs and pictographs have been collected without the help of especially my wife, Donna, and my three sons, Michael, Craig and Thomas. Together we have climbed the rocky slopes, walked for miles along overgrown trails sometimes to find the site and other times unable to find the site.

Figure 11. Copy of Mallery's (8) reproduction of a drawing prepared for the Rhode Island historical society around 1830. This is one of 10 drawings of the rock that were prepared by various people from 1680 to 1830, and the one that has become the standard for the designs on the rock.

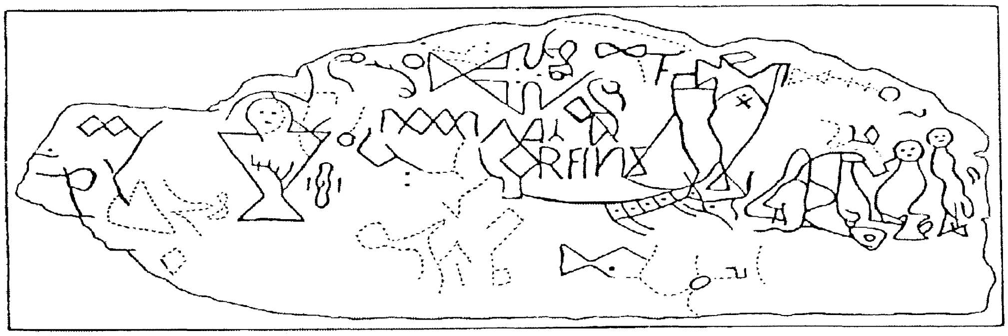
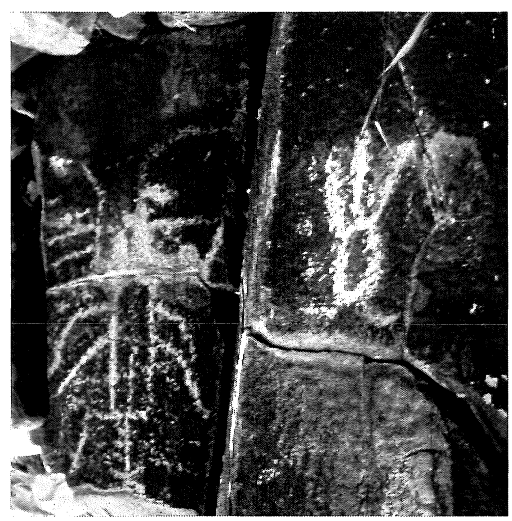


Figure 12. Mastodon petroglyph found on the cliffs above the San Jaun River outside Moab, Utah.

Figure 13. Petroglyph site on the west bank of the Columbia at Cabinette Rapids. This site like a large number of other petroglyph and pictograph sites along the Columbia River has been destroyed behind dams.



SELECTED BOOKS ON THE PETROGLYPHS AND PICTOGRAPHS

Barnes, F.A.; "Canyon Country Prehistoric Rock Art," Wasatch Publishers, Inc., Salt Lake City, UT, 1982 (covers the petroglyphs and pictographs of the Great Basin area of Arizona, Colorado, New Mexico, and Utah)

Diaz-Grandos, C.; and Duncan, J.R.; "The Petroglyphs and Pictographs of Missouri," The University of Alabama Press, Tuscaloosa, AL, 2000. (covers the rock art of Missouri only)

Grant, C.; " Rock Art of the American Indians," Thomas Y. Crowell Company, New York, 1967. (general overview of Rock Art in the United States and Canada).

Grant, C.; "Canyon de Chelly: Its People and Rock Art," The University of Arizona Press, Tucson 1978 (deals specifically with the Rock Art of Canyon de Chelly)

Hill, B and R. Hill; "Indian Petroglyphs of the Pacific Northwest." University of Washington Press, Seatle, 1974, (general view of the Rock Art of the Pacific Northwest west of the Cascade Mountains with locations of the sites.)

Muench,D; "Images in Stone" Brown Trout Publishers, Inc. San Francisco, CA, 1995 (photos of mainly sites West of the Rockies and some from Baja California).

SELECTED EASY TO REACH PETROGLYPH AND PICTOGRAPH SITES

Minnesota:

1. Jeffers Petroglyphs, located off US 71 about 20 miles north of Windom in SW Minnesota
2. Pipestone National Monument off US 75 near the town of Pipestone in SW Minnesota

Missouri:

1. Thousand Hills State Park, outside of Kirksville
2. Washington State Park, Southeast of St. Louis

New Mexico:

Petroglyph National Monument, on the west side of Albuquerque

Oklahoma:

Heavener Runestone State Park at Heavener, South of Poteau (these carvings have been attributed to Norse explorers)

Texas:

Hueco Tanks State Park, about 12 miles east of El Paso on Highway US62

NOTES AND REFERENCES

1. THIS PAPER IS A SUMMARY OF THE PRESENTATION AT THE Annual Meeting of the Missouri Academy of Science Awards Banquet, April 18, 2008 which looked at a number of Rock Art sites across the United States and Canada.
2. Designs on portable rocks are not normally considered petroglyphs or pictographs.
3. Patina, also called "Desert Varnish" occurs when the medium gray color of the rock has been oxidized to a shiney dark brown or black (4).
4. Grant, C.: W. J. Baird and J. K. Pringle. "Rock Art of the Coos Range." Maturango Museum, China Lake, California. 1968.
5. A study of the petroglyphs and pictographs United States in 1940 (4) found only 7 states where Rock Art was not reported. Since this report, Rock Art sites (mainly petroglyph sites) have been found In 5 of these states. A similar situation is found for Canada with Rock Art in every Providence.
6. Tatum, R.M., "Distribution and Bibliography of the Petroglyphs of the United States," *American Antiquity*. **12**, 122–5 (1946).
7. This technique is quite common with the pictographs of Australia.
8. Jackson, A.T., "Picture Writing of Texas Indians," The University of Texas Press, Austin, 1938.
9. For one of the earliest classifications of Rock Art into design categories and subcategories, that is still recognized as one of the most useful see: D. Nordquist, "An Approach to the Stylistic Analysis of Petroglyphs," *Washington Archaeologist*, **6**(#5,6, and 8) 1962.
10. Mallory, G., "Picture-Writing of the American Indians," reprinted from 10th Annual Report of the Bureau of Ethnology, Government Printing Office, Washington, D.C. 1893. Reprinted by Dover Publications, Inc., New York, 1972.
11. Willoughby, C., "Antiquities of the New England Indians," The Peabody Museum of American Archaelogy and Ethnology, Cambridge, Mass, 1935.
12. Brecher, R. and E. Brecher, "The Enigma of Dighton Rock," American Heritage, 9, 62–64 (June, 1958).
13. While it was been doubted that the design dates from the time that mastodons were still in the Southwest, a whelk shell pendant has been excavated from the Holly Oak Site in Delaware site that also depicts a mastodon or elephant. Kraft, J.C.; and R.A. Thomas, "Early Man at Holly Oak, Delaware," *Science*, **192** 756–61 (1972).
14. Several explanations have been given for why the designs were executed. See for example: Heizer, R. F.: and M. R. Baumhoff. "Prehistoric Rock Art of Nevada and Eastern California," University of California Press, Los Angeles, 1962, and Grinnell, G. B.: "Blackfoot Lodge Tales," University of Nebraska Press, Lincoln, 1962.
15. One of the most accurate accounts of why the designs were made comes from Teit. Teit, J "Notes on Rock Painting in General Spencer Bridge," Curator MS, Division of Anthropology, Provincial Museum, Victoria, British Columbia, Canada, as cited in Conner, J. "Pictographs: Indian Rock Painting in the Interior of British Columbia," Wayside Press, Ltd., Vernon, B.C. Canada, 1968.
16. Mosher, K.H., and M.W. Mosher "The Cabinet Rapid Petroglyph Site," *The Minden* , **5**. 7–9 (December, 1985).

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A Global Sand Budget— A Discussion of Sand Generation, Use and Destruction. Are We Running Out of Sand?

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Abstract: *Recent articles on soil erosion sound the alarm regarding the large amount soil that is being lost due to modern agricultural practices, and there is a general concern that we may be destroying our sand and soil resources at rates that greatly exceed generation and preservation rates. There is also a general concern in the sand and aggregate industry as to whether sand is a renewable natural resource. The paper is unique and important to soil science as well as geology because it pulls together data from diverse sources in an attempt to summarize global rates of sand and soil generation from parent material, rates of sand consumption by humans, and rates of sand loss to humans through erosion and transportation to the oceans.*

While there is considerable literature on rates of soil erosion, there is remarkably little literature on rates of sand or soil generation from parent materials. Where rate numbers were found they were commonly local, and not global. They were commonly highly variable, and many conversions were required to put them in common, global units. Through a number of assumptions and calculations, the following conclusions have been made for global sand rates.

(1) Sand is being generated from primordial granites at rates estimated at 1.6 billion tons/year. (2) Sand is being generated from soils at rates that range between 0.06 and 450 billion tons/year globally with an average of the most reasonable sources at 5.0 billion tons/year. (3) Sand today, through erosion and natural causes, is lost to the oceans at rates estimated at 4.8 billion tons/year. (4) Modern erosion rates are considered to be an order of magnitude greater than pre-human erosion rates, or about 0.5 billion tons/year. (5) Construction grade sand is currently mined at approximately 4.5 billion tons/year and industrial grade sand is consumed at about 0.2 billion tons/year for a total human usage estimated at 4.7 billion tons/year.

Thus, total sand consumption by humans is slightly less than global generation rates, and an argument can be made that sand is a renewable natural resource. However, if modern rates of erosion and loss to the oceans are considered, then we are losing considerable ground with regard to total sand and soil availability.

Key Words: *Sand, Rates, Generation, Consumption, Destructionen*

Introduction

Are we running out of sand? Is there enough sand? Is sand a renewable natural resource? These are questions that have been posed to and by geologists for many years, but have recently come to the forefront. The August, 2008 cover of *GSA Today* (newsmagazine of the Geological Society of America) poses the question "Is there enough sand?" The cover of the issue is backed by a picture of the Grand Canyon where there has been a raging debate over how to maintain sand bars in the Canyon. There is also an interest in industry as to whether sand and aggregate can be considered to be renewable natural resources. This paper attempts to address the global sand budget including rates of sand formation from parent rocks, rates of sand formation from soil, rates of sand destruction by natural causes, rates of sand used by humans, and rates of sand being lost to oceans through erosion and runoff as presented in the literature.

Definition of "Sand"

Geologists, soil scientists and engineers all agree that sand is a grain size term, yet surprisingly, all three groups define its boundaries slightly differently and even within these groups, there are variations. For a full discussion on the definition of sand, see Barnhart (1962) or Folk (1980). For purposes of this paper, the geologist's definition will be used where the upper grain size boundary is 2 mm and the lower is 1/16 mm (0.0625 mm) as defined by Folk (1980). It is significant to note that sand is a grain size term and has nothing to do with mineralogy. The black sands of Hawaii are composed of basalt fragments and dark colored minerals. The lime sands of the Bahamas are composed primarily of the remains of organisms which are composed of calcite or aragonite. The White Sands of New Mexico are composed of gypsum. Sand can be composed of anything. Most sand, however, is composed primarily of the mineral quartz (SiO_2) and is referred to as silica sand. This article will focus on silica sand.

Origin of Silica Sand

The ultimate origin of virtually all quartz sand is the break down and weathering of granite or granite-like rocks, such as gneiss or diorite. The typical granite is composed of 30% quartz, 30% orthoclase (potassium feldspar), 30% plagioclase (sodium-calcium feldspar) and 10% other minerals such as micas or hornblende (Blatt, 1996).

Geologists consider the earth to be about 4.6 billion years old (Dott and Batten, 1988, Levin, 1978, Stanley, 1999). The following two paragraphs are paraphrased from these same references which are well established textbooks on Historical Geology. The primordial crust was composed of magmas and rocks of basaltic composition, similar to oceanic crust of today, and contained no granite and no quartz. Slowly, through magmatic differentiation, granitic crust formed. The oldest continental crusts are dated at about 3.8 billion years. Continental crust is less dense than oceanic crust, and continental crust floats on oceanic crust. Eventually the continental crust appeared above sea level and weathering and decomposition of granites began. The original atmosphere was almost certainly quite different than that of today, containing greater amounts of different acids including sulfuric acid, hydrochloric acid with little or no oxygen. The break down rate (weathering) of granite is primarily a function of feldspar breakdown. As weathering occurs, the granitic material decomposes. On decomposition, the feldspars and other minerals, which have a strong cleavage, undergo hydrolysis (see next section) and are converted to clay minerals. But, quartz which is chemically very stable and has no cleavage takes longer to decompose. On weathering, some silica dissolves, and during transportation by water and wind, grains become more rounded. But overall, the composite quartz grains remain quartz grains, but get smaller and more rounded.

Through transportation by wind and water, the quartz grains become segregated from clay particles and eventually become deposited in any of a number of different environments. Typical environments for sand deposition are in dunes, as sand bars in rivers, as delta front sands in deltas, as beach sands in barrier islands or as turbidite sands in submarine fans. Through diagenesis (the process whereby sediment is changed to sedimentary rock) the sands become compacted and cemented to form sandstones (sedimentary rocks). These rocks can then be recycled through weathering, decomposition, transportation and re-deposition. Through silica overgrowths on originally rounded quartz grains, it can be demonstrated that many quartz grains have undergone several generations of deposition, diagenesis, weathering transportation and re-deposition.

Through geologic time enormous volumes of quartz have thus become concentrated in sands, such as in the Sahara desert, and in sandstones, as in the Navajo Sandstone of Arizona, Utah and Wyoming. The Navajo Sandstone is the cliff-forming quartz sandstone in Zion Canyon National Park where it is over 1800 feet thick. Although the ultimate source of sand is granite, recycled sand comes from many subsequent sources including sandstones, soils, loess and many other rock types.

Rates of Sand Generation

Variables: Before discussing grossly generalized rates of global sand generation, it is important to recognize that there are a huge numbers of variables involved in making such estimates. These variables include (1) composition of the source rock or soil, (2) climate, especially humid versus arid types, (3) exposure to ground water, and (4) composition of the atmosphere.

Source rock composition: Obviously the composition of the source rock or soil can be very important. If sand is derived from a poorly consolidated sandstone such as the Navajo Sandstone of Utah or the St. Peter Sandstone of Missouri, sand generation will be very rapid. The St. Peter Sandstone near Pacific, Missouri is mined with a fire hose and a front-end loader. Sand and soils derived from loess, wind blown glacial sediments can form very rapidly. Conversely, in the Pacific Northwest of the U.S. or Hawaii where there is very little granite or pre-existing quartz, silica sand generation will be very slow or almost non-existent.

Exposure to water: Hydrolysis is the most important processes whereby granite and feldspars are decomposed to form clays with the liberation of free quartz. An example for hydrolysis of orthoclase (potassium feldspar –30% of a granite) is given by Blatt *et. al.* (1980, p. 259) as:

$$3\ KAlSi_3O_8 + 12\ H_20 + 2\ H^+ \rightarrow KAl_3Si_3O_{10}(OH)_2 + 6\ H_4SiO_4 + 2K^+$$

(Orthoclase) (Illite — clay mineral)

Further weathering of illite under the right conditions creates kaolinite and ultimately other clay minerals.

Hydrolysis of feldspars occurs very rapidly in humid climates or upon exposure to ground water. Thus, in tropical locations, granite and feldspars decompose rapidly. In arid climates, granites and feldspars decompose very slowly. In humid climates where freeze-thaw cycles are common, water penetrates along the cleavage planes of feldspars causing both hydrolysis of the feldspar as well as fracturing. Decomposition can occur very rapidly under such circumstances. In arid climates, feldspars and granite break down slowly.

Rates of sand creation: There is a considerable literature on the rates of soil erosion and sediment being removed from the continents by rivers and deltas (Troeh *et.al.*, 1999, Montgomery, 2007 Wilkinson & McElroy, 2007). Much of this literature is aimed at sounding the alarm at how fast our soils are being removed by humans and by modern agricultural practices. But, there is very little literature on the rates at which either soil or sand are being formed. The only estimate of the rate of sand creation is that of Kuenen (1959, p. 23) in which he states that "Several years ago, in a study on the total amount of sediment in the earth's crust, I concluded (Kuenen, 1945) that the yearly production of quartz sand must be on the order of 0.05 km^3." Unfortunately, in looking at Kuenen's (1945) article referenced in his 1959 paper, there is no reference to any rates of sand accumulation. Neither article discusses the procedure that he used to make these calculations. Kuenen's (1959) data is shown in Table 1 and appears to be based primarily on deep sea sedimentation rates. The approximate area of the land surface of the earth is 150×10^6 km^2. By dividing Keunen's annual volume of 0.05 km^3 by this area, one can calculate that the average global rate of quartz sand formation is 0.000333 mm/year. Or, the reciprocal indicates that it takes 3,000 years to form one vertical mm of sand globally. Deep sea sedimentation rates are not considered here to be representative of where most sand or sediment is deposited. The largest quantities of sediment are deposited near the shoreline in close proximity to major delta systems, not in the deep ocean basins. Although Kuenen's (1959) numbers may be appropriate for deep ocean basins, they are not representative of global sedimentation rates.

Rates of soil formation and sand creation from soil: Although there is very little in the literature on the rates of sand formation, another approach to estimating rates of sand formation would be to search the literature for rates of soil formation and assume that sand constitutes some percentage of that soil. Remarkably, a search of the literature reveals very little on the rates of soil formation or the global percentage of sand in soil. Buol *et. al.* (1973), gives data from ten different authors on the rates of soil formation. Close inspection of this data reveals that the rates are primarily of topsoil formation, not soil from parent igneous rocks. These rates vary enormously—from 0.78 to 450 billion tons of sand/year (Table 1) and are primarily a function of the parent material. Seven of

Table 1. Rates of Sand and Soil Formation Estimates.

Reference	Sand or Soil	Global Estimate or Source Rock Type	Data as originally given	Global Rate of Sand/Soil Formation (mm/Year)	Global Rate of Sand Formation*** (mm/Year)	Global Sand Formation Rate (Giga tons/year)
Kuenen (1959)	**Sand**	Global Estimate	0.05 cubic km/yr	0.00033	0.00033	0.06
Owens & Watson (1979)	Soil-Min	Rhodesian Granite	**4.1mm/1000 yrs**	0.00410	0.00123	0.24
Owens & Watson (1979)	Soil-Max	Rhodesian Granite	11 mm/1000 yrs	0.01100	0.00330	0.64
White et. al. (2001)	Soil-Min	Feldspar Decay Rate	4 mm/million yrs	0.00400	0.00120	0.23
White et. al. (2001)	Soil-Max	Georgia Granite	7 mm/million yrs	0.00700	0.00210	0.41
Buol et. al. (1973)	Soil-Min	Tropical Soil	750 yrs/cm	0.01333	0.00400	0.78
Buol et. al. (1973)	Soil-Max	Volcanic Ash	1.3 yrs/cm	7.69231	2.30769	450.00
Wakatsuki et. al. (1992)	Soil-Min	Global Estimate	370 kg/ha/yr	0.02960	0.00888	1.73
Wakatsuki et. al. (1992)	Soil-Max	Global Estimate	1290 kg/ha/yr	0.10320	0.03096	6.04
Anthoni (2000)	Soil-Min	Global Estimate	1mm/400 yrs	0.00250	0.00075	0.15
Anthoni (2000)	Soil-Max	Global Estimate	1mm/200 yrs	0.00500	0.00150	0.29

*** Assumes sand comprises 30% of soils globally.
Conversion Factors: Surface area of the earth = 150,000,000 square km.
One cubic kilometer converts to .00666 mm globally
One kg/hectare/year converts to .00008 mm/year globally at 1.3 gm/cc.
1 mm = 13 metric tons/hectare, 1 square km = 100 hectares
1 mm/year = 195 billion tons/year globally
1 Gton = 1 Gigaton = 1 Billion tons = 1×10^9 tons
Note: The author recognizes that rules of significant digits are ignored in this table. They are ignored in order to keep the decimal points lined up—which serves to illustrates the large variation of the different estimates.

the ten soils are derived from loess, which is wind-blown sand and silt derived from glacial material.

Owens and Watson (1979) in a study of Rhodesian granites using solubilities concluded that soil was formed from these granites at rates ranging between 0.0041mm/year to .011mm/year.

Anthoni (2000) indicates that soil forms globally at rates between 2000 and 4000 years per centimeter (Table 1). If it is assumed that the average is 3000 years per centimeter and that 30% percent of all soils are sand, then it can be calculated that quartz accumulates at a rate of 1,000 years per mm, or at a rate of about three times that of Kuenen's original estimate. Anthoni's information is from the internet. Although information from the internet is not peer reviewed and may not be reliable, Anthoni's (2000) article is included here because it is the only reference found giving soil formation rates directly from parent rocks on a global basis.

Because quartz sand is mostly derived from granite, another approach to determining rates of sand creation is to determine the rates of breakdown of feldspars and granites. White *et. al.* (2001), in studying the rates of breakdown of the Panola and Davis Run regoliths of the Piedmont Province of the southeastern United States concluded that plagioclase decomposed at rates ranging from 0.004 mm/year to 0.007 mm/year. They also concluded that plagioclase breaks down at approximately four times the rate of potassium feldspar and that the rates were highly dependent on the hydraulic conductivity of the rock.

Wakatsuki *et. al.* (1992), using geochemical mass balance relationships, estimated the rates of soil formation on a global scale between 370 and 1290 kilograms per hectare per year with an average rate of 700 kg/ha/yr. Converting Wakatsuki *et.al.* (1992), Owens & Watson (1979) and White *et al.* (2001) numbers to billions of tons/year, and averaging, it is estimated that sand is being generated from primordeal rocks at rates of 1.6 billion tons/year.

Percentage of sand in soil: This author found no references whatever on a global estimate of sand in soil in the literature. Instinctively, this author would have guessed about 30% based on the percent of quartz found in granite, the ultimate source rock for sand. Another approach is to assume that the amount of sand in sedimentary rocks might reasonably approximate the percentage of sand in soil. Blatt (1982) and Blatt and Tracy (1996) indicate that sedimentary rocks are composed of mud rocks (65%), sandstone (20–25%), carbonates (10–15%) and others at 1%. They indicate that the mud rocks are composed of 35% sand, 60% clay and 5% other material. Sandstones are composed of 75–80% sand sized material (includes quartz and feldspars), 5% clay and 15% other. And at least some sand is found in the "other" sedimentary rock types. A weighted average of these indicates that sedimentary rocks are composed of 39–40% sand. Thus several lines of evidence suggest that a conservative estimate for sand in soil is 30%, and 30% is the estimate that will be used here.

Destruction and Removal of Sand by Natural Processes

In estimating a global sand budget, it must also be recognized that sand can be destroyed by natural processes. Sand sized quartz is destroyed by three main processes. The first is simple abrasion in a stream, on a beach, in a wind blown environment or by a glacier. Simple collision of grains as they move through such media knocks extending corners off of the grains causing them to be more highly rounded. The corners that get knocked off are very fine and are a significant source of silt sized quartz.

The second process involves recrystallization of quartz on deep burial and/or shearing along fault planes. As sedimentary rocks are buried deeper and deeper in the earth, they become exposed to greater and greater temperatures and pressures. As the minerals are exposed to greater pressure and temperature, they recrystallize. Recrystallization is a natural part of metamorphism. Clay minerals can recrystallize and can even form feldspars, and quartz commonly recrystallizes or partially recrystallizes to much finer grained polycrystalline quartz.

The third process is melting in the deep interior of the earth. On very deep burial (on the order of 20,000 meters +/- depending on thermal gradients), minerals, including quartz, melt. The average clastic sedimentary rock (shales and sandstones) derived from weathering of granite can melt to form an igneous melt of granitic composition. Sand sized quartz is destroyed by melting, but will commonly reappear in the next mountain building process as the granitic melt cools down to form granite.

Rates of sand destruction and removal: Although there are simply no good estimates of the rates of sand destruction in the interior of the earth through melting, there are a number of different estimates of sand and soil lost to humans through erosion or sediment discharge through rivers. Shaffer (2006) summarized sediment discharge from rivers to the oceans from the major continents of the world. Table 2 summarizes the end members of this data at 18.3 billion tons/year (Holeman, 1968) and 13.5 billion tons/year (Milliman and Meade, 1983). Using an average of the two (and again assuming that 30% of that sediment load is sand) it is calculated that about 4.8 billion tons of sand are lost to the oceans each year.

Sand is lost through processes other than erosion by water. Physical abrasion, chemical solution and wind erosion are other means of removing sand. Kuenen (1959), Pettijohn *et. al.* (1972) and others agree that these rates are very difficult to quantify and are almost impossible to measure. In addition, these processes may be offset by storage effects in that at least some modern sediment is trapped in lakes created by humans.. Thus, river discharge to the ocean is only one way to estimate the amount of sand and soil lost to humans.

Erosion rates from soil estimates: Several authors have estimated sediment loss due to erosion in basins or by chemical mass balance estimates (Table 2). Montgomery (2007)

Table 2. Rates of Sand and Soil lost to Humans through River Discharge and Soil Mass Balance Estimates.

Source	Means of Estimation	Data as originally given	Soil Lost Globally (G tons/yr)	Sand Lost* Globally (G tons/yrs)
Holeman (1968)	River Sediment Discharge	18,300 million tons/year	18.3	5.5
Milliman & Meade (1983)	River Sediment Discharge	13,505 million tons/year	13.5	4.1
Troeh et. al. (1999)	Soil loss rates	1 metric ton/hectare/year	15.0	4.5
Wakatsuki et. al. (1992)	Geochemical balance	906 kg/hectare/year	13.6	4.1
Wilkinson & McElroy (2007)	Phanerozoic soil loss	16 meters/million years	3.1	0.9
Wilkinson & McElroy (2007)	Neogene soil loss	62 meters/million years	12.1	3.6
Wilkinson & McElroy (2007)	Modern soil loss	600 meters/million years	117.0	35.1
Montgomery (2007)	Soil loss rates	4 orders of magnitude variation	Variable	Variable

* Assumes sand comprises 30% of soils.
Note: 1 G ton = 1 Gigaton = 1 Billion tons = 1 X 10 ^ 9 tons

indicates that soil losses due to erosion vary by four orders of magnitude depending on the soil type, climate conditions and geographic terrain. Typical rates are from .01 mm/year to over 10 mm/year with erosion from plowed fields being on the order of 1 mm/year. Troeh *et al.* (1999, p. 66) indicate that “A rate of 0.5 ton/ac (1 mt/ha) per year is considered typical for geologic erosion from gently sloping soils.” Wakatsuki *et. al.* (1992) through geochemical mass balance equations estimate losses of 906 kg/hectare/year or 13.6 billion tons of soil per year. These rates are all fairly consistent (Table 2) ranging from 13.5 to 18.3 billion tons of soil/year or 4.1 to 5.5 billion tons of sand/year using a 30% sand/soil ratio. An average of these is 4.8 billion tons of sand/year and is considered to be a reasonable estimate of current losses through erosion.

Wilkinson and McElroy (2007) estimate that Phanerozoic erosion rates are on the order of 16 meters per million years (.016 mm/year), Neogene erosion rates are on the order of 62 meters per million years (.062 mm/year), and modern rates are on the order of 600 meters/ million years (0.6 mm/year). These data indicates that modern agricultural and industrial practices are causing modern erosion rates that are at least an order of magnitude greater than past, pre-human, geologic processes.

Extraction of sand by humans: Silica sand extracted by humans has been classified into two categories, industrial sand and construction grade sand. Construction grade sand is sand that is mined as aggregate. Industrial sand is sand that is mined for specific industrial use, such as in the glass and ceramics industries or as propant material for fracturing in the petroleum industry. Dolley (2002) estimates that quartz sand extracted by humans for industrial use is 100 to 300 million tons/year. Wellmer and Becker-Platten (2002) estimate that global industrial sand and gravel usage in 1988 was roughly 15 billion tons. Assuming that sand represents 30% of this, sand usage is on the order of 4.5 billion tons/year and total sand consumption is 4.6 to 4.8 billion tons/year which will be averaged here to 4.7 billion tons/year.

Summary of global rates of sand formation, destruction, extracted and loss: (1) Sand is being generated from primordial granites at rates that range from 0.23 to 6.0 billion tons/year, with an average of reasonable estimates at 1.6 billion tons/year. (2) Sand is being generated from soils and other rock types, including recycling of previously existing sand, at rates that range between 0.06 and 450 billion tons/year with a best estimate at 5 billion tons/year. (3) Sand is conservatively estimated to be discharged to the oceans through rivers and deltas at a rate of 4.8 billion tons/year. (4) Industrial sand is mined at a rate estimated at 100 to 300 million (not billion) tons/year. (5) Construction grade sand is mined at a rate estimated at 4.5 billion tons/year, and total sand extraction is estimated at 4.7 billion tons/ year.

How much sand is present in the world and how long will it last?

Pettijohn *et. al.* (1972, p. 5) cites eight authors who have estimated the total volume of sediment on earth. These estimates range between 3.0×10^8 and 13.0×10^8 cubic kilometers and average 6.8×10^8 cubic kilometers. Assuming that 30% of this is sand and that the average porosity of sand on earth is 26%, the total volume of sand on earth is roughly 1.5×10^8 cubic km. Assuming that quartz has a density of 2.65 gm/cc, this converts to approximately 4000 billion tons of total sand on earth. If silica sand is being generated at a rate of 5 billion tons/ year, being consumed at 4.7 billion tons/year, and being lost to the oceans at 4.8 billion tons/year, this total sand supply will last for over 850 years. Assuming pre-human erosion rates of 0.5 billion tons/year, this sand supply will last 20,000 years.

Is sand a renewable natural resource?

Although under possible revision, the Environmental Protection Agency {Guiding Principles 4, 1995) has used the following definition: Renewable: Renews itself in decades, but not exceeding ten decades. The language of proposed Guiding Principle 4 was ultimately finalized in 1999. The final guidance simply defines any resource that can be renewed within 200 years as "renewable" {See 64 Fed Reg. 45810 at 45843 (Aug 20, 1999)}.

Whether sand is a renewable natural resource is debatable. On the one hand, because sand is being generated at rates that exceed consumption by humans (5.0 compared to 4.7 billion tons/year), it can be argued that sand is a renewable natural resource. However, if sand lost to the oceans is taken into consideration (4.8 billion tons/year), then sand is clearly not a renewable natural resource. If pre-human rates of erosion and loss to the oceans are considered (0.5 billion tons/year) instead of modern day rates, then sand available for consumption (5.0 minus 0.5 = 4.5 billion tons/year) compared to modern usage rates (4.7 billion tons/year) are close to being in balance, though a net loss is favored slightly. Because of the high degree of variability and uncertainty in all numbers presented here, it is really not clear whether sand can be considered a renewable natural resource.

Conclusions

Total quantities of quartz sand and sandstone in the world are enormous. At the best estimates of present rates of consumption there is enough sand in the world to last for over 850 years. A review of the literature plus calculations concludes that globally: (1) Sand is estimated to be generated from soils and parent material at approximately five billion tons/year. (2) Sand today, through erosion and natural causes, is lost to the oceans at a rate estimated at 4.8 billion tons/ year. (3) Pre-human erosion rates are estimated to be an order of magnitude less than those of today, or about 0.5 billion tons/year. (4) Construction grade sand is mined at approximately 4.5 billion tons/year (5) Industrial grade sand is consumed by humans at approximately 0.1 to 0.3 billion tons/ year. (6) Thus, total sand consumption by humans is estimated at approximately 4.6 to 4.8 billion tons/ year, which is averaged to 4.7 billion tons/year. (7) If sand generation rates (5 billion tons/year) are compared against consumption rates by humans (4.7 billion tons/year), an argument can be made that sand is a renewable natural resource. (8) However, if a total sand budget is considered, including modern erosion rates and loss to the oceans, sand cannot be considered a renewable natural resource.

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A Possible Heat Island Effect from a Small Rural Community

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Abstract: *The purpose of this paper is to understand whether or not heat that is radiated from the business district of a very small community impacts the local temperature field in the outer and inner portions of the community as a function of one or more variables (wind speed, wind direction, and degree of cloud cover). Previous studies of larger communities in the region showed that wind speed, direction, or cloud cover could lead to differences in the strength of the heat island effect even for a community of about 20,000 to 25,000 residents. Here we study the impact of a community which has fewer than 10,000 residents, and demonstrate that there was circumstantial evidence for a heat island effect.*

Keywords: *Heat island effect, climatology, microclimate, urban influences*

1. *Introduction*

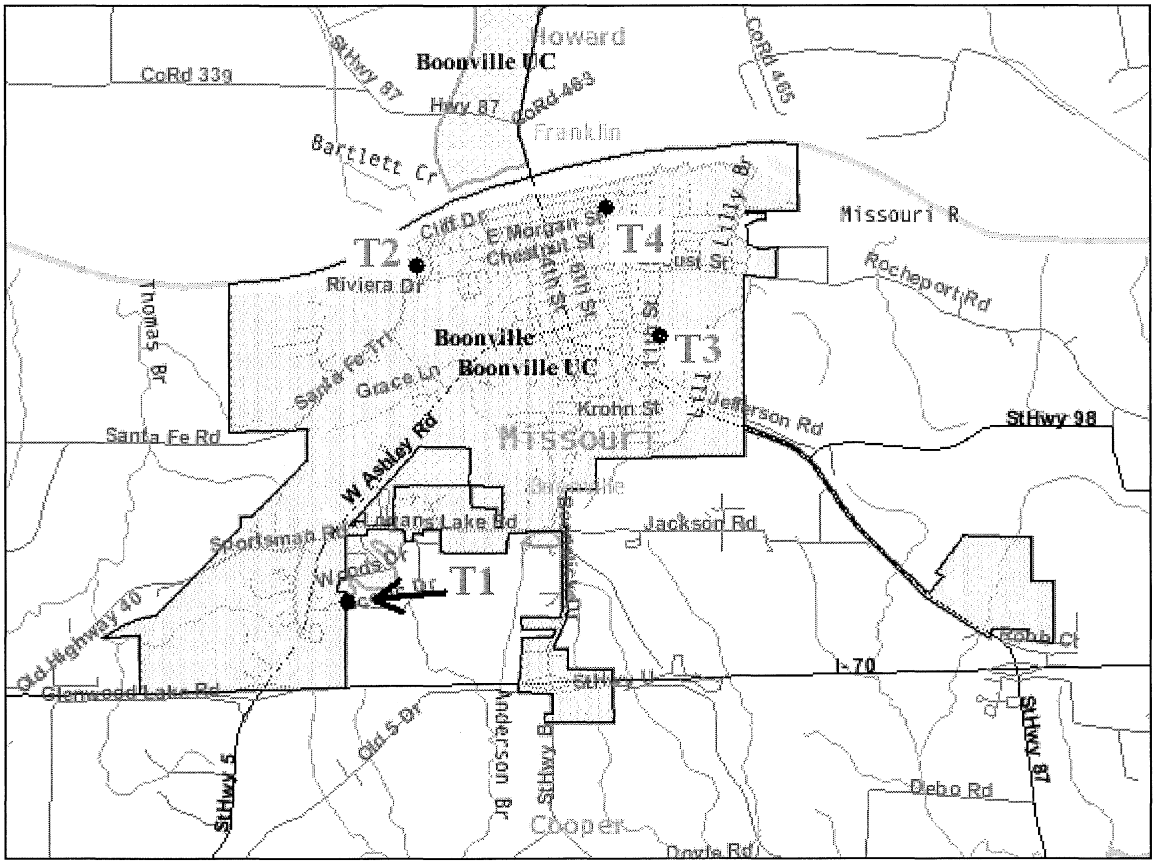
Previous studies of the heat island effect have shown that cities in Missouri smaller than St. Louis or Kansas City can have a significant impact on the surrounding environment (e.g., Akyuz et al., 2004; Grathwohl et al. 2006; Buckley et al. 2008). Akyuz et al. (2004) demonstrated that the city of Columbia, MO was on average 0.6°–1.8° C (1°–3° F) warmer than its surroundings, and could be as much as 10° F warmer, and Buckley et al. (2008) found a similar impact. Neither study found a large impact on local precipitation distributions. Additionally, other studies such as Ackerman (1985), Melhuish and Pedder (1998), and Pinho and Manso-Orgaz (2000) find a significant heat island effect for Chicago, Reading, UK, and a city in Portugal somewhat smaller than Columbia, MO, respectively. Here we define the heat island effect as the difference between the mean surface temperature for a thermometer placed in an urbanized area and a properly sited instrument in a rural location (e.g., Changnon, 1981). Then Grathwohl et al. (2006) found that Sedalia, MO impacted the temperature fields nearly as much as Columbia, MO during the spring season of 2005. Their study also showed that variables such as wind speed and cloud cover impacted the intensity of the heat island effect. They showed that sunny, less windy days display a larger heat island effect.

In this study, which follows Akyuz et al. (2004) and Grathwohl et al. (2006), we will examine the possibility of the heat island effect occurring as due to a rural community of around 8,000 residents. The test site is Boonville, MO, which is located on the southern banks of the Missouri River and is about 32 km (20 mi) west of Columbia, along Interstate 70 (which runs along the southern side of town). Boonville is situated on the bluffs overlooking the river and has an approximate elevation of 180–245 m (approximately 600–800 ft) above sea level. The dimensions of Boonville are about 13 km (8 mi) east-to-west and about 10 km (6 mi) north-to-south, including the town and residential areas.

2. *Data Analysis and Methods*

Collection of the temperature data took place from 1 September through 30 November 2006 (91 days). This covered the fall season and is longer than the six week period used by Grathwohl et al. (2006), but shorter than the year period studied by Akyuz et al. (2004) or Buckley et al. (2008). Each day, the 24-h maximum (91) and minimum temperatures (91) were observed at each station and were collected at approximately 5:00 pm CDT/CST (2200/2100 UTC). Once these data were collected, the thermometers were reset for the following day. There were four thermometers situated at one of four corners of the town area primarily in the residential areas (Fig. 1). The second thermometer (T2) and fourth thermometer (T4) instruments were located closest to the town center, while the first thermometer (T1) was located in a more "rural" locale. The third thermometer (T3) was located in a less urbanized area. As in the Columbia, MO study, we could not place a thermometer in the center of the business district where the impact should be strongest. We could not guarantee the integrity of the instrument and proper siting at the same time. T1 was positioned near the southwest corner of town. T2 was positioned near the

Figure 1. A map of Boonville, MO and the surrounding regions. The location of each thermometer is marked with a gray "Tx", where x is the instrument number referred to in our study.



northwest corner, T3 was positioned near the southeast corner, and T4 was positioned near the northeast side of town. The instruments at stations T1, T2, and T4 used digital Sper-Scientific thermometers. Station T3 used a Fisher Scientific maximum / minimum mercury thermometer. Based on the calibration of the thermometers in a controlled temperature room of 21.6° C (71.0° F), each thermometer was within the margin of error for the control room temperature (Table 1). This calibration was performed once and at this one temperature. There was a slightly larger difference between T1 and T3. The digital thermometers are accurate to within (+/– 1° C) or [+/– 1.8° F] as stated in the literature which accompanied the instruments. Additionally, as proposed by Akyuz et al. (2004) and references there-in, any measureable heat island effect should be larger than the thermometer error to be significant. Finally, the discussion will use English units rather than metric since in the United States English units are still the standard for surface temperature observations, and the exact units are not germane to the findings.

Table 1. The temperature recorded on each thermometer at calibration time.

Instrument	Reading	Difference from the Control
Grathwohl (T1)	22.4° C / 72.4°F	0.8° C / 1.4° F
Neckermann (T2)	22.4° C / 72.4°F	0.8° C / 1.4° F
Bradshaw (T3)	21.2° C / 70.1°F	–0.4° C / –0.9° F
Moore (T4)	21.9° C / 71.5°F	0.3° C / 0.5° F

3. *Results*

3.1 Average temperatures

Once all of the data had been collected, analysis began by first taking the averages of the maximum and minimum temperatures and the overall means (Table 2 and 3). Upon analyzing the averages of the raw data, the overall mean temperatures within the Boonville area were different by 3.7° F with the greatest mean temperature being found for a site closer to the town center (T2) and the lowest temperature found in a less built-up area (T3) (Table 2). An examination of these numbers

Table 2. The monthly and seasonal mean temperatures (°F) for the Boonville stations.

	T1 mean (°F)	T2 mean (°F)	T3 mean (°F)	T4 mean (°F)	Max Diff (°F)
September	67.6	68.9	65.4	68.2	3.5
October	56.5	57.4	53.6	56.4	3.8
November	51.9	49.8	45.5	49.4	6.4
avg daily	58.8	58.9	55.1	58.0	3.7

Table 3. The monthly and seasonal mean maximum and minimum temperatures (°F) for the Boonville stations.

	T1 max (°F)	T1 min (°F)	T2 max (°F)	T2 min (°F)	T3 max (°F)	T3 min (°F)	T4 max (°F)	T4 min (°F)
September	77.3	57.8	80.5	57.3	77.3	53.5	80.1	56.2
October	66.4	46.6	68.5	46.3	64.6	42.6	68.4	44.3
November	63.4	40.4	60.1	39.5	55.0	36.0	62.4	36.4
avg daily	69.1	48.4	69.9	47.8	66.0	44.2	70.4	45.5
Std. Dev	11.5	11.1	13.0	11.1	13.7	11.3	11.9	11.6

demonstrates that this difference is larger than both instrumental differences found during the calibration and the instrumental error. While this is a fairly small sample (but larger than the number of instruments used by Grathwohl et al. (2006) and Buckley et al. (2008)), the heat island effect for the town of Boonville is likely real and consistent with values predicted in Aguado and Burt (2001) for a town of this size. The month-by-month results were similar to that of the overall result, with T2 consistently being the largest or second largest value, and T3 recordings the smallest values.

A breakdown of the results using the maximum and minimum temperatures demonstrated that the maximum temperatures were larger most of the time for both T2 and T4, which were closer to the town center. This result is consistent with that of Grathwohl et al. (2006). For the minimum temperatures, T3 and T4 were consistently smaller while T1 was larger than the others. This may be due to elevation differences, as T1 is farthest from the river valley. Cooler temperatures at lower elevations are most noticeable during the morning hours when the atmosphere is least turbulent. This cooling may be overwhelming any heat-island effect for this early time of day.

Additionally, an examination of the daily values of the heat island effect found that the largest daily values in the dataset were on the order of 10–15° F. This was observed on 9 individual days. The largest daily value (15° F, 19 Nov) is consistent with those found in other studies and were as large as those for daily heat island values observed in big cities.

3.2 Average temperatures in relation to wind speed

One problem with completing this study for a town like Boonville is that there is no official weather station to record variables such as temperature, precipitation, or average wind speed. Akyuz et al. (2004) found that the heat island effect in Columbia, MO was stronger under light wind conditions, which is consistent with the findings of Oke (1982). In order to assign a wind speed and direction for Boonville, it was useful to find an average by utilizing observations at official weather stations in close proximity (less than 50 miles) to Boonville, such as Columbia and Sedalia. This provides a general idea of the larger-scale wind conditions likely to be occurring at Boonville. During the three-month study, the greatest daily average wind speed was about 14 mph, while the lowest was about 4 mph. This made it practical to divide the data into three categories: Category 1 (0–5 mph), Category 2 (6–10 mph), and Category 3 (10 mph and greater). Days were classified into each category as long as the average wind speed was in that category and the majority of the hours during the day fell into that bin (similar to Akyuz et al., 2004). Using this scheme for wind speeds, six days fell into Category 1, 34 fell into Category 2, 30 fell into category 3, and 21 days were unclassified. By choosing not to classify days that had wind speeds that fell into more than one category, it allowed for better dependability in the results (Table 4).

Akyuz et al. (2004) and Grathwohl et al. (2006) showed that less windy days resulted in larger differences among their urban and rural stations. The results here demonstrate that there is only a 0.6° F reduction in the heat island effect as wind speed increases. While this may be a real effect, we feel this is too small a value to state with any confidence that wind speeds were influential since the spread between the calibrated instruments was larger than this value. Two points of interest to note in these results are: a) for the lightest wind speeds the T1 maxima are closer to the T3 values than to the T2 or T4 values, and b) the temperatures were lower as the wind speeds became higher. This second result could be explained by the fact that September values primarily made up the lighter wind categories, while

Table 4. Average Temperatures (°F) for the Boonville based on wind speed.

	(T1 max °F)	(T1 min °F)	(T2 max °F)	(T2 min °F)	(T3 max °F)	(T3 min °F)	(T4 max °F)	(T4 min °F)
Cat 1	71.8	54.0	76.3	53.2	71.5	50.8	74.5	53.3
Cat 2	69.3	48.7	70.0	47.9	66.3	44.2	70.7	46.0
Cat 3	68.8	47.8	69.4	47.5	65.7	43.7	69.7	43.3
Unclass.	64.4	45.8	64.3	44.8	60.5	41.5	65.8	43.8

stronger winds were found in November. This is likely due a difference between the synoptic character of the prevailing winds during the warm weather regime (lighter and southerly) and cold weather regimes (stronger and northwesterly) that prevail in this part of the United States.

3.3 Average temperatures in relation to wind direction

Calculating the average wind direction for Boonville was done the same way as it was for wind speed. By taking a common and average mean wind direction for each day, it made it simple to divide the days into four categories for wind direction. This study did account for days when the wind direction crossed between northwest and northeast (we did not take an arithmetic average during these days). These days were separated by category, and the number of days observed for each category are shown in Table 5.

Table 5. Categories for wind directions.

Category	Degrees	Days
Category 1	0–90	9
Category 2	91–180	36
Category 3	181–270	17
Category 4	271–359	29

In this section, the data in Table 6 is displayed by using the relative rank of each instrument for the maxima and minima along with the largest differences found among the temperature data. Interestingly, T3 was consistently the coolest temperatures measured by an instrument, except when the winds were coming from the southwest. There is a large shopping center and parking area to the southwest of T3.

With a northeast wind, it was hypothesized that T1 might be warmer due to this same shopping center. However, in contrast with T3, the impact of the shopping center was not as pronounced with the maximum temperatures. The minimum temperatures did become warmest at T1 under the northeast wind. It was also surprising that T2 maintained a high ranking since to the north and west there is the Missouri River and nothing but trees and farms in those directions. However, warmth from Boonville could be influential under the northeast wind scenario. These results show a possible displacement of the heat island effect which is consistent with the observations of Akyuz et al. (2004).

3.4 Average temperature in relation to cloud cover

The only station in close proximity to Boonville that records cloud cover was the Columbia weather station. With the understanding that the cloud cover over Columbia should be

Table 6. Rank of each instrument based on wind direction (1=warmest 4=coolest), along with the largest temperature differences (°F) between each.

	T1		T2		T3		T4	
0–90	Max	Min	Max	Min	Max	Min	Max	Min
	3	1	1	1	4	4	2	2
Largest temperature difference=				Max: 4.6° F			Min: 4.0° F	
91–180	Max	Min	Max	Min	Max	Min	Max	Min
	1	1	1	2	4	4	1	3
Largest temperature difference=				Max: 5.6° F			Min: 6.1° F	
181–270	Max	Min	Max	Min	Max	Min	Max	Min
	3	1	1	2	3	3	2	3
Largest temperature difference=				Max: 5.1° F			Min: 6.0° F	
271–359	Max	Min	Max	Min	Max	Min	Max	Min
	2	1	1	2	4	4	1	2
Largest temperature difference=				Max: 7.3° F			Min: 4.6° F	

reasonably close to what Boonville would typically observe for an entire day under the same synoptic regime, we used these observations in order to correlate temperatures to cloud cover.

The cloud cover observations are recorded by the National Weather Service using the following descriptions for cloud cover; Fair, Sunny, Clear, Partly Cloudy, Mostly Sunny, Mostly Cloudy, Partly Sunny, Cloudy. The type of precipitation that was falling at the particular hour is also recorded but not used here. Splitting these descriptions into two categories made it easier to see how cloud cover might play a role in influencing temperature variance. Category 1 consisted from fair to mostly sunny (less than 50% cloud cover), while Category 2 consisted of mostly cloudy and overcast (greater than 50% coverage). The observations at Columbia were augmented by visual observations from the authors.

Finally, a breakdown of these temperatures for cloudy (more than 50% sky cover) versus less-cloudy days (less than 50% sky cover) (not shown) would reveal similar results to those in Tables 2 and 3, with the exception that the diurnal cycle is clearly larger (higher maxima and lower minima) for the less cloudy days. The relative differences among the warmest and coolest stations were 0.6° F larger for the less-cloudy days. Thus, it is difficult to determine if cloud cover was a factor in a manner similar to Akyuz et al. (2004) and Grathwohl et al. (2006). Roughly 50% for the days (42) were clear, while the remainder (49) were considered cloudy.

4. *Summary, discussion and conclusions*

An examination of a possible heat island effect for the small town of Boonville, MO was performed following Grathwohl et al. (2006). The data were collected at four sites in and near Boonville over the fall months (September, October, and November) in 2006. Three instruments were digital (T1,T2, T4) and one was a mercury thermometer (T3). These were calibrated in a room in order to determine the spread of the instruments. Instrument T3 was approximately 2.3° F cooler than the other instruments.

In spite of this, T3 was on average 3.7° F cooler than the rest of the instruments indicating a possible heat-island effect on the order of 1.5° F for Boonville, MO. While this does not prove that Boonville does impact the local temperature field, there is strong evidence that the heat island effect suspected here is real. These points should be considered as strong circumstantial evidence;

a) this mean value (1.5° F) is consistent with some of the observations found by Akyuz et al. (2004) for the larger community of Columbia, MO,
b) the value is consistent with that predicted for a small community shown in Aguado and Burt (2001),
c) instruments T2 and T4 were located close to the downtown and consistently warmer than T1 and T3. T3 and T1 were located near less urbanized areas. An instrument was not placed in the heart of Boonville due to logistical issues (see Akyuz et al., 2004).
d) instrument T3 was no longer the absolute coolest instrument, in spite of the calibration under a southwest wind (shopping center located to the southwest).

However, it is cautioned that there are points which provide evidence against stating with certainty that there is a heat island effect for Boonville and these are the;

a) lack of a dense instrument network,
b) small sample size, and
c) lack of statistical significance for these results.

In our experiment, it was difficult to determine whether or not there was a significant impact due to cloud conditions and wind speed as in Akyuz et al. (2004) and Grathwohl et al. (2006). The difference between instruments T2 and T4 versus T3 was 0.6° F greater for sunnier days and calmer days than for cloudier and windier days. While this result is physically consistent with what would be expected, the small value and the small sample size preclude making a definitive statement about the impact of a small community like Boonville on the environment. Additionally, the elevation differences across Boonville make identification of the heat island effect difficult for such a small town. In closing, future studies are needed in other Missouri communities of this size in order to substantiate the idea of the heat island effect for a small rural community.

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Decomposition Rate and Community Structure of Leaf-packs in an Urban and Rural Stream in Southwestern Missouri

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Abstract: *Previous studies demonstrated significantly lower diversity and density of aquatic invertebrates in a southwestern Missouri urban stream, Turkey Creek, below a large mall in comparison to above mall sites and a rural stream, Jones Creek. Such invertebrate declines might affect leaf decomposition rates in these streams. We estimated decomposition rate and macro-invertebrate community structure using experimental leaf-packs composed of freshly dried red elm leaves. Thirty-six leaf-packs housed in polyester mesh (2 by 4 mm) bags were anchored in riffles at the three sites. Bags were recovered after 15 and 36 days, invertebrates were removed and identified, and leaf residue air dried. Decay rates as fraction lost/day after 15 days were 4.20%/day Turkey Creek above mall, 4.43%/day Turkey Creek below mall, and 4.45%/day at Jones Creek. After 36 days decay rates were 2.14%/day Turkey Creek above mall, 2.15% Turkey Creek below mall, and 2.36%/day Jones Creek. Rates were not significantly different between sites (ANOVA, $P = 0.55$ at 15 days and $P = 0.23$ at 36 days). Decay constants calculated by regressing % dry mass remaining and days in stream were −0.040/day for both Turkey Creek above and below mall and −0.056/day for Jones Creek. Shredders were primarily represented by the cranefly larvae Tipula abdominalis in both TC sites and by T. abdominalis and the isopod Lirceus hoppinae in JC. Collector-gatherers, primarily net-spinning caddisflies Cheumatopsyche, Ceratopsyche, and Chimarra, as well as the dipteran family Chironomidae, numerically dominated leaf-packs. Leaf decomposition may be more related other factors, physical fragmentation, microbial processes, and seasonal differences in leaf abundance, than shredding in these streams. Dominance of collector-gatherers appears to indicate leaf-packs serve primarily as habitat and not a direct energy source for many stream macroinvertebrates.*

Key Words: *leaf decomposition, urban stream, macroinvertebrate*

Introduction

Seven southwestern Missouri streams in Jasper, Newton, and McDonald Counties are on the state 2008 303(d) list as impaired, including Turkey Creek on the Missouri Southern State University (MSSU) campus (Missouri Department of Natural Resources, 2009). These impairments are related to land use issues including agriculture (nutrients, coliforms), past mining (zinc), and private and commercial land development (sediment). Although measures such as macroinvertebrate density and taxonomic richness are useful in evaluating stream integrity, rate measures such as nutrient uptake, production, and detritus processing may provide greater insight into stream integrity and function because such rates are dependent on multiple stream variables (Benke, 1984; Young et al., 2008).

The rate of detritus processing is thought to be a useful indicator in stream integrity (Young, et al., 2008). Leaf decomposition rate has been used to evaluate the effects of agriculture and urbanization (Paul et al., 2006), acid drainage from coal mining (Barnden and Harding, 2005), and toxic materials such as zinc (Niyogi et al., 2001; Carlisle and Clements, 2005) and arsenic (Chaffin et al., 2005) on watersheds. In shaded headwater streams, leaf fall provides the primary energy base for the stream community. Autumnal leaf abscission adds a major pulse of organic carbon to the stream that is processed by bacteria, fungi, and macroinvertebrates. The process of leaf decomposition (reviews by Hynes, 1975; Webster and Benfield, 1986; Cummins et al., 1989; Webster et al., 1999) begins with an initial rapid leaching of labile compounds, followed by colonization by bacteria and fungi (Carter and Suberkropp, 2004). Macroinvertebrate shredders feed on the bacteria and fungi enriched leaves, converting the larger particles to fine matter that in turn are processed by filtering collectors (Webster and Benfield, 1986). Shredding macroinvertebrates play a significant role in processing leaves, especially in low order streams. Removal of shredders by insecticide application reduced leaf decay 50–74% as well as significantly reduced production of fine particulate organic matter in a headwater Appalachian stream (Cuffney et al., 1990). The rate at which shredding invertebrates process leaves depends not only on leaf type, but also temperature, nutrient availability, and the potential macroinvertebrate community (Anderson and Sedell, 1979;

Cummins et al., 1989). Parallel to these biological processes is the physical fragmentation due to stream discharge patterns (Ferreira et al., 2006; Paul et al., 2006).

Humans alter these processes, especially in urban settings (Paul and Meyer, 2001; Meyer et al., 2005). Such changes include a more rapid discharge from an increase in impervious surfaces (roads, parking lots) and increased sedimentation (bank collapse, construction, and illegal in-stream vehicle traffic). Urban watersheds also contribute toxic run off, including hydrocarbons, metal ions, and pesticides. Turkey Creek in this study also suffers from the residual effects of past lead and zinc mining (Harrell et al., 2007).

Previous unpublished studies in these streams indicate higher species richness in the upper reaches of Turkey Creek and Jones Creek in comparison to Turkey Creek below the mall. In studies over the past six years 108 taxa have been documented at the Jones Creek site, 110 in three sites in Turkey Creek above mall, and 89 taxa in three sites below mall in Turkey Creek. Taxa losses below mall are primarily among the Plecoptera and Ephemeroptera. Riffle benthos densities were significantly lower in below mall sites in a fall 2007 study ($93/ft^2$) in comparison to Turkey Creek above mall ($215/ft^2$) and Jones Creek ($586/ft^2$) (ANOVA, $n = 15$, □ = 0.05, $P = 0.002$). A preliminary leaf-pack study in 2007 indicated rapid shredding of dried red elm leaves after four weeks at all sites. Leaf packs contained high densities of filtering caddisflies and blackflies and the shredding cranefly *Tipula abdominalis*. The shredding isopod, *Lirceus hoppinae*, was only common in Jones Creek (Heth, unpublished data).

The objectives of this study were to compare decomposition rates of red elm leaf-packs and associated macroinvertebrate assemblages at three sites. Two sites were within an urban stream above and below a major shopping mall, and the third was within a nearby rural stream. We tested the null hypothesis that decay rates were similar all three sites. We suspected, however, because of urban and mining influences, that decay rates would be lower in the urban sites, especially the site below the mall, in comparison to the rural stream.

Study Sites

Turkey Creek, located in Jasper County of southwestern Missouri, becomes a permanent stream at the town of Duenweg and flows westward through Joplin (city population 49,000, metropolitan area 173,000) to its confluence with the Spring River in Kansas. At Missouri Southern State University (94.28°W, 37.05°N), Turkey Creek is a second order shaded Ozark stream. At the west edge of campus is the major shopping mall for the region, Northpark Mall. Above mall sites are located upstream from the mall in an area surrounded by the college and suburban housing. Below mall sites are downstream from the mall to a major roadway. Major disturbances at the below mall sites include an abandoned lead and zinc mine near north edge of the mall and four parking lot storm-water outlets. Jones Creek, also second order, is located (94.16°W, 37.04°N) on a cattle ranch 18 km east of MSSU just upstream from Interstate 44. Both Turkey Creek and Jones Creek are groundwater driven streams with similar geology and discharge (Table 1). Both have relatively intact riparian zones composed primarily of red elm (*Ulmus rubra*) and American sycamore (*Planatus occidentalis*). Substrate in both streams is primarily a cobble-pebble mix of chert and limestone.

Table 1. Physical characteristics of Turkey Creek, above and below mall (TCAM, TCBM) and Jones Creek (JC) fall 2008.

	TCAM	TCBM	JC*
T, °C	22.4	22.7	16.0*
pH	7.6	7.5	7.9
conductivity, $\mu S/cm$	329	348	293
DO, mgO_2/L	7.1	7.1	8.0
discharge, m^3/sec	0.72	0.79	0.88
nitrate, mg NO_3^{-1}/L	12.4	4.4	8.8
phosphate, mg PO_4^{-3}/L	0.4	0.1	0.7

*Turkey Creek readings 1–3 pm Sept. 17–19, cooler temperatures reflect JC 8 am Sept. 20 reading.

Methods

Methods followed suggestions in Webster and Benfield (1986), Benfield (2006), and Young et al. (2008). Beginning September, 2008, 12 replicate experimental leaf-packs were randomly placed in riffles in each of three sites, above and below mall in Turkey Creek (TCAM, TCBM) as well as in riffles upstream of Interstate 44 in rural Jones Creek (JC). Leaf-packs were composed of 50 fresh red elm leaves air dried for one week and housed in polyester bags of 2 by 4 mm mesh (small laundry bags). Bags and dry leaves were weighed to nearest 0.01 mg. Bags were secured to the streambed with rebar and backed with small boulders to simulate natural conditions. Four bags at each site were removed at 15 days and the remainder at 36 days. Retrieved bags were placed in separate plastic bags, refrigerated, and processed within two days.

Leaf-packs were rinsed over 0.15 mm mesh sieves to remove fine sediments. All leaf material greater than 4 mm remaining within the bags was retained and air dried for one week before weighing. Material remaining on sieves was preserved in 80% ethanol and stained with rose bengal. All macroinvertebrates visible under 10X magnification were removed and later identified to nearest practical taxon, usually genus for crustaceans and insects. Decomposition rates were calculated as fraction of weight lost (weight lost/initial weight) divided by days in stream. Assuming exponential decay, the decay constant, $-k$ ($W_t = W_o e^{-kt}$) (Petersen and Cummins, 1974) was calculated by regressing days in stream with percentage of leaf mass remaining.

The macroinvertebrate community was summarized as total macroinvertebrates per bag, total number of Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies) (EPT), and total numbers of larger shredders (primarily the cranefly *Tipula abdominalis* and the isopod *Lirceus hoppinae*). Taxonomic richness was summarized as the number of taxa identified within each of these orders per bag.

Five of the 36 bags were lost to tampering in the field. One-way ANOVA (Data Analysis, Microsoft Excel) was used to detect significant differences in both the 15 and the 36 day decomposition rates. Macroinvertebrates per leaf pack are presented as means along with 95% confidence intervals. Statistical significance was accepted at $P < 0.05$.

Results

Over the course of this study, leaf-packs lost an average 77.0% dry mass in TCAM, 77.5% in TCBM, and 87.0% in JC. Decomposition rates (Figure 1), calculated as fraction lost per day, were not significantly different across sites (ANOVA, $P = 0.55$ at 15 days and $P = 0.23$ at 36 days). Rates for 15 days and 36 days at TCAM were 4.20%/day and 2.14%/day, 4.43%/day and 2.15%/day at TCBM, and 4.45%/day and 2.36%/day at JC. Assuming exponential decay, decomposition rates estimated by regressing days in stream with % remaining mass were $-k = 0.04$ for both sites in Turkey Creek and $-k = 0.06$ for JC. Using only beginning and ending percentages as an alternative procedure (also in Petersen and Cummins, 1974) values for $-k$ were 0.042 for TCAM and TCBM and 0.064 for JC. Although not quantified, red elm leaves in this study appeared to be primarily fragmented, not skeletonized.

Because we expected a relationship between macroinvertebrate densities in leaf-packs and decomposition rate, we regressed numbers of macroinvertebrates/leaf-pack against

Figure 1. Decomposition rates of red elm leaf-packs as (fraction loss of dry mass)/day from above and below mall at Turkey Creek and from Jones Creek from 0–15 and 0–36 days, ± 95% CI.

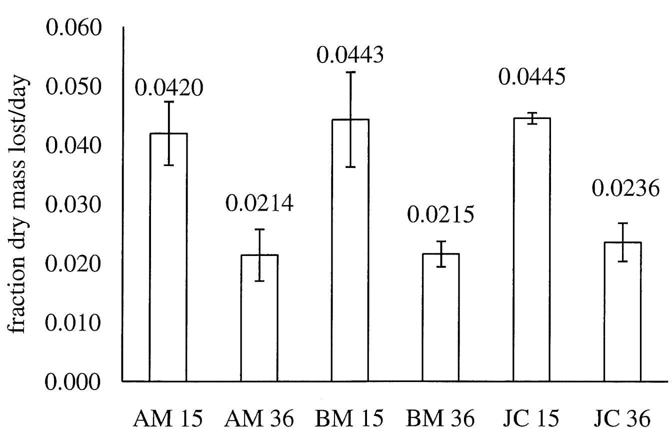
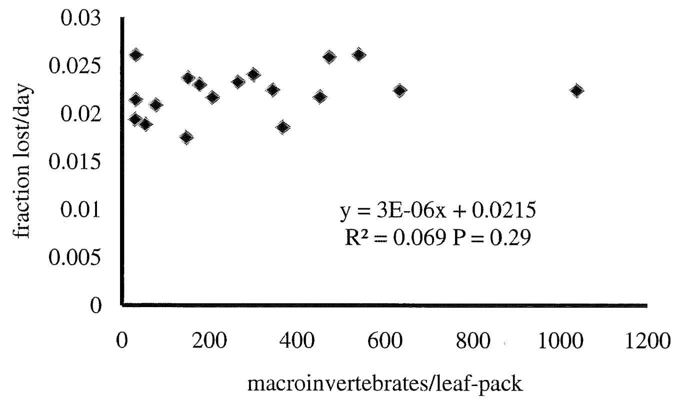


Figure 2. Effect of number of macroinvertebrates in leaf-packs on fraction lost/day at 36 days.



fraction lost/day for all samples combined (Figure 2). The relationship was both a poor fit ($R^2 = 0.069$) and non-significant ($P = 0.29$). Regressing separately each of the time periods and each site did not improve fit (data not shown). We expected colonization to increase the density of macroinvertebrates in the leaf-packs over time, but we were concerned the number of macroinvertebrates might decline as the amount of leaf habitat was reduced, and so we also regressed remaining leaf mass against numbers of macroinvertebrates in the leaf packs (Figure 3). Again, the relationship was a poor fit ($R^2 = 0.067$) and non-significant ($P = 0.16$).

Macroinvertebrate numbers and taxa richness were somewhat reduced in Turkey Creek leaf-packs in comparison to Jones Creek, but variability was high (Table 2, Figure 4). Densities were higher at 36 days in TCAM and JC but were lower in TCBM. Seventy-eight taxa were indentified from the 11644 macroinvertebrates collected, 75 in JC, 34 in TCAM, and 38 in TCBM (Table 2). EPT taxa richness was highest in JC leaf-packs with means of 8.0 at 15 days and 7.3 at 36 days (Figure 4). EPT richness declined from the first to the second

Figure 3. Relationship between number of macroinvertebrates per leaf-pack and remaining dry mass (g), all bags 15 and 36 days.

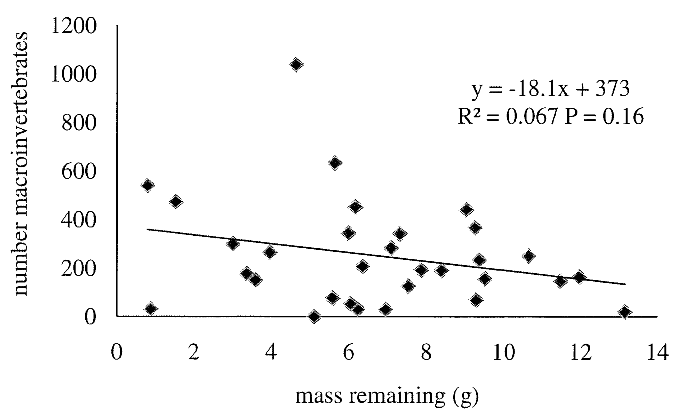
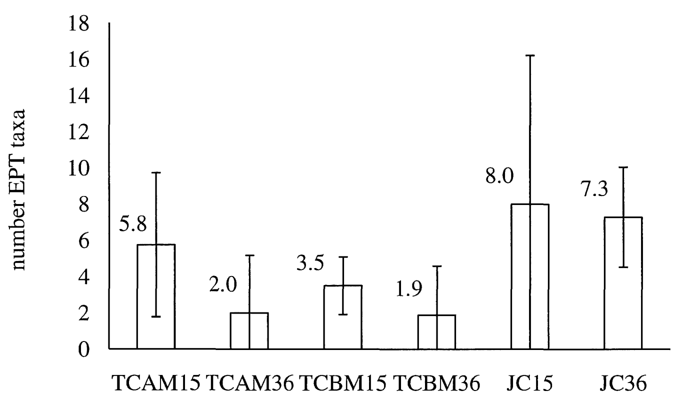


Table 2. Number of macroinvertebrates collected in leaf-packs (n = bags recovered), and taxa richness at each site at 15 and 36 days, Turkey Creek above and below mall, Jones Creek, fall 2008.

	TCAM	TCBM	JC	total
total numbers	1156 (n = 8)	2667 (n = 12)	7821 (n = 11)	11644
mean 15 days + 95% CI	133 ± 170	228 ± 160	255 ± 203	
mean 36 days + 95% CI	206 ± 289	116 ± 167	421 ± 336	
shredders				
mean 15 days + 95% CI	5.25 ± 16.7	0.25 ± 0.80	16 ± 27.3	
mean 36 days + 95% CI	27.3 ± 59.6	0.88 ± 3.23	59.6 ± 80.2	
taxa present				
15 days (mean)	16 (9.8)	21 (10)	26 (14)	38
36 days (mean)	16 (7.7)	20 (9.8)	36 (15.4)	46
total 15 and 36 days	23	28	57	58
Chironomidae genera	11	10	18	20
total taxa + Chironomidae	34	38	75	78

Figure 4. Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness in red elm leaf-packs at three sites, TCAM, TCBM, and JC at 15 and 36 days, ± 95% CI.



sampling date (Table 2, Figure 4), but overall richness remained unchanged (Table 2). Four Ephemeroptera species were collected in TCAM and three in TCBM but only the collector, *Baetis flavistriga*, was common. Sixteen species of Ephemeroptera were found in JC. Plecoptera diversity and numbers were low at all sites, low numbers of *Allocapnia* in TCAM and TCBM and *Allocapnia* and *Agnetina* in JC. For Trichoptera, the collector-filtering *Chimarra* and *Cheumatopsyche* were common at all three sites. High numbers of other collectors, primarily Chironomidae (non-biting midges) and Oligochaeta, were found at all sites. Within the numerically dominant Chironomidae, 18 genera were identified in JC, 11 in TCAM, and 10 in TCBM. Of the most common organisms collected in these leaf-packs (Table 3) only two are classified as shredders, the isopod *Lirceus hoppinae* and the large cranefly larvae, *Tipula abdominalis*. No isopods were found in TCAM or

Table 3. Most common macroinvertebrates, average numbers per leaf-pack, Turkey Creek above mall and below mall, and Jones Creek, 15 and 36 days, fall 2008.

	TCAM15	TCAM36	TCBM15	TCBM36	JC15	JC36
Dugesia dorotocephalia	2.5	14.7	3.0	0.6	1.3	13.3
Oligochaeta	1.8	14.3	19.0	10.3	3.8	33.3
Lirceus hoppinae	0.0	0.0	0.0	0.0	15.8	33.0
Copepoda	0.5	0.3	3.5	1.1	1.8	1.1
*Baetidae spp.	2.5	0.0	9.5	1.1	16.5	9.4
Chimarra	37.0	26.7	23.0	11.9	22.3	44.3
Cheumatopsyche	33.8	58.7	10.3	10.1	22.0	23.0
Simulium	3.5	0.3	0.8	3.8	4.0	0.0
Tipula abdominalis	5.3	27.3	0.3	0.8	0.0	23.3
Chironomidae	39.8	61.3	154.0	72.8	157.0	223.0

* primarily *Baetis flavistriga* TCAM and TCBM

TCBM, while *Lirceus hoppinae* was abundant in JC (Table 2). *Tipula abdominalis*, found at all sites, was reduced in the TCBM leaf-packs. Collector-gatherers and filterers numerically dominated the macroinvertebrate assemblages in leaf-packs at all sites.

Discussion

Decomposition rates in this study, as either fraction lost/day or as an exponential decay constant –k, fall within the range of moderately fast (–k = 0.005 – 0.10/day) decomposing leaves (Petersen and Cummins, 1974; Webster and Benfield, 1986; Allan, 1995). Decay rates were similar to –k = 0.04/day reported for agricultural and urban streams (Paul et al., 2006) but less than the very rapid rates, –k = 0.137/day, reported for green dried alder and maple leaves in Michigan streams (Maloney and Lamberti, 1995). Rapid decomposition is expected for dried green red elm leaves, with their rough surfaces conducive for colonization, as well as for green leaves that retain labile sugars and amino acids. *Ulmus* species in Italian and American streams decomposed rapidly with –k values ranging from 0.013 to 0.036 (Gazzera et al., 1993).

Decay rates did not agree with our initial assumptions. As expected, mass loss was rapid in the initial 15 day period (0.042–0.046/day). Decomposition over the 36 day interval was almost half as rapid (0.022–0.024/day. Leaves are assumed to lose mass quickly due to rapid leaching of soluble materials (Hynes, 1975). We initially hypothesized decay rates would be greatest in rural JC with its past history of higher taxa richness and higher densities, especially its high densities of the shredder *Lirceus hoppinae* than the two sites in Turkey Creek. We expected urban influences in both TCAM, and especially TCBM, with the presence of the mall and adjacent abandoned zinc mine, to have a measureable effect on decomposition rates. Although rates, either as fraction lost/day or decay constant –k, were slightly greater in JC than in TCAM and TCBM, differences were not significant. Decay rates were almost identical for TCAM and TCBM.

Taxonomic declines in TCAM and TCBM in comparison to JC, including the loss of the crustacean shredder *Lirceus hoppinae*, may be the result of urban and mining influences on those sites. Low macroinvertebrate taxa richness and density have long been noted in urban streams (Paul and Meyer, 2001; Meyer et al., 2005). The elevated zinc concentrations in Turkey Creek waters have been implicated in high crustacean mortality of the cladoceran *Ceriodaphnia* (Harrell et al., 2007) and the amphipod *Hyallela azteca* (Ankley et al., 1996). High zinc concentrations have also been associated with depressed shredder densities and low leaf decomposition rates (Carlisle and Clements, 2005).

However, this study suggests macroinvertebrate densities, even high densities of shredders *Lirceus hoppinae* and *Tipula abdominalis*, are not primarily responsible for the rate of leaf decomposition in the three sites of our study. Higher shredder densities in JC did not significantly raise decomposition rates in that stream in comparison to TCAM and TCBM. Macroinvertebrate densities did not correlate well with either decomposition rates or with the amount of mass remaining in leaf-packs. Those observations, coupled with the fragmented rather than shredded appearance of leaves in our experimental leaf-packs, suggest other factors besides macroinvertebrate shredding are more important in leaf breakdown in these streams at this season. Several alternative mechanisms may influence breakdown rates at our sites. First, microbial action, the weakening of leaf-tissue by fungi and bacteria, and physical abrasion, especially during spates, may be more important than shredding macroinvertebates in degrading leaves. Australian studies suggested microbial action may be more important than even physical abrasion and shredding in urban streams (Imberger et al., 2008). No major spates occurred during the time of our study. Second, mechanisms controlling leaf decomposition may differ in urban and rural streams. In a study of Maine streams that differed in catchment land use, the degree of leaf tissue softening (microbial action) was greater in urban than in agricultural streams, but overall decomposition rates (a combination of multiple factors) were greater in agricultural streams (Huryn et al., 2002). Differences, however, were not significant. In streams of the Atlanta area, decomposition of chalk maple leaves (–k = 0.0465/day) in urban streams was similar to decomposition in agricultural streams (–k = 0.0474/day) (Paul et al., 2006). The authors suggested physical processes due to storm-water runoff were the major contributor to leaf decomposition in urban streams while biological processes, primarily microbial, fungal, and macroinvertebrate shredding, dominated in nutrient enriched agricultural streams. And third, seasonal differences may obscure the effect of shredding macroinvertebrates on leaf decomposition. Leaf-packs, an abundant food resource in fall, may become limiting for shredding macroinvertebrates in later seasons as leaves degrade and spates transport leaves out of the streambed (Graca et al., 2001). In late winter and spring, shredding macroinvertebrates could be expected to exert stronger influences on a more limited resource.

At all sites the macroinvertebrate assemblages were dominated by collector-gatherers and filterers, especially the net-spinning caddisflies and the Chironomidae. This suggests leaf-packs may play a significant role in stream ecosystems apart from a direct energy source (Robinson et al., 1998). Collector-gatherers and perhaps even many shredders are dependent on leaf-packs as sediment traps, feeding on fine particulate organic materials generated both within and without leaf-packs. Trapped particulate matter was positively correlated to macroinvertebrate density in leaf-packs composed of both real and plastic leaves (Dangles et al., 2001). In a similar study, the shredding amphipod *Gammarus pulex,* although reduced in numbers in comparison to real leaf-packs, was still common on plastic leaf-packs (Hoffman, 2005). The common shredder, *Lirceus hoppinae*, may prove to be as much dependent on fine particulate matter trapped in leaf-packs as on the leaf material itself.

Although leaf-pack decomposition rates did not discriminate among these three sites, further studies might be expanded into the winter season when leaf material is more limiting. Such studies might also include the use of plastic leaves to distinguish macroinvertebrates that utilize leaf-packs as habitat and a source of fine particulate matter from those that utilize leaves as a direct energy source.

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Paraboreochlus (Diptera: Chironomidae): A New Midge Record for Missouri

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Abstract: *We report first record on occurrence of the midge genus* Paraboreochlus *in Missouri based upon aquatic macroinvertebrate community samples collected during September 2002 from a reach of Caney Fork Creek in the Ozark Highlands in Cape Girardeau County. Select water quality characteristics from the reach are also presented.*

Key Words: *Missouri, wadeable streams, Chironomidae,* Paraboreochlus

The chironomid subfamily Podonominae is represented by five genera — *Boreochlus*, *Lasiodiamesa*, *Paraboreochlus*, *Trichotanypus*, and *Parochlus* in North America (Coffman and Ferrington 1996). The genus *Paraboreochlus* has a Holarctic distribution (Hayford 2009) and is represented worldwide by three recognized species — *P. minutissimus* in Europe (Lindegaard 1995) and east to north-central Mongolia (Hayford 2009), *P. okinawanus* in Japan (Kobayashi and Kuranishi 1999), and *P. stahli* in the Nearctic Region (Coffman et al. 1988). *Paraboreochlus stahli* has been reported from northwestern Pennsylvania and southeastern Kansas (Coffman et al. 1988), New York and North Carolina (Donley et al. 1999), and Maine (Epler 2001). We identified a larval specimen of *Paraboreochlus* from a macroinvertebrate community sample collected 26 September 2002 from a reach of Caney Fork Creek, a spring-fed, 2nd order, wadeable stream in Cape Girardeau County in the Ozark Highlands Ecological Section of Missouri (Cleland et al. 1997, Nigh and Schroeder 2002) (Fig. 1). Watershed area of the reach we sampled at Caney Fork Creek is 17.2 km^2, mean wetted-width of the reach was 8.0 m, and mean depth was 29.7 cm. Substrates were primarily large with 75.2% of particles larger than 64 mm.

We collected macroinvertebrate community samples from Caney Fork Creek with 500 µm mesh aquatic kick nets in riffles, pools, and submerged rootmat habitats according to methods outlined by Sarver et al. (2002). The *Paraboreochlus* specimen we collected from Caney Fork Creek was found in a riffle habitat sample. Podonominae larvae are known to inhabit rheobiontic and hyporheic cold-stenothermal habitat associated with mosses in springs, seeps, and small streams (Donley et al. 1999, Epler 2001). Because little information is available on water quality characteristics associated with *Paraboreochlus*, select water quality characteristics from the reach of Caney Fork Creek where the specimen was collected are presented in Table 1. The reach where we collected *Paraboreochlus* had a higher, more basic, pH and greater calcium concentration than has been associated with *P. stahli* by Donley et al. (1999). Donley et al. (1999) reported larvae of *P. stahli* (n = 164) were collected in southeastern New York from the lateral hyporheic zone of softwater streams with pH 4 to 6 and Ca^{+2} of 0.02 to 0.2 meq/L.

We mounted midge larvae and pupae collected from Caney Fork Creek on glass-slides and examined the specimens using a compound light microscope. Taxonomic keys and descriptive information provided in Wiederholm (1983, 1986), Coffman and Ferrington (1996), and Epler (2001) were used to identify specimens. Larvae of the Podonominae are identified by structure of the labrum, absence of premandibles, structure of the antennae, degree of development of the prementum and ventromental plates, and the long procerci (Brundin 1983). Some morphological characteristics distinguishing *Paraboreochlus* larvae from those of other Podonominae are a short, annulate 3rd antennal segment slightly shorter than the 2nd antennal segment, a mentum with one protruding median tooth and 6–8 lateral teeth, two long, dark supraanal setae, and long, slender procerci that are lighter anteriorly and darker posteriorly with each procercus bearing 7–8 dark setae — one of which is longer than the procercus (Brundin 1983, Epler 2001). Coffman et al. (1988) used material collected from Pennsylvania in the description of *P. stahli* and indicated pupae from southeastern Kansas assigned to *P. stahli* differed in minor details from those collected in Pennsylvania. Although the larval specimen of *Paraboreochlus* we collected from Caney Fork Creek was not identified beyond genus, it is probably *P. stahli*. The specimen is retained in a reference collection at the Missouri Department of Conservation, Resource Science Center, Columbia, Missouri.

Figure 1. Map of states with reported records for *Paraboreochlus stahli* and location of the reach of Caney Fork Creek where *Paraboreochlus* was collected in Missouri 26 September 2002.

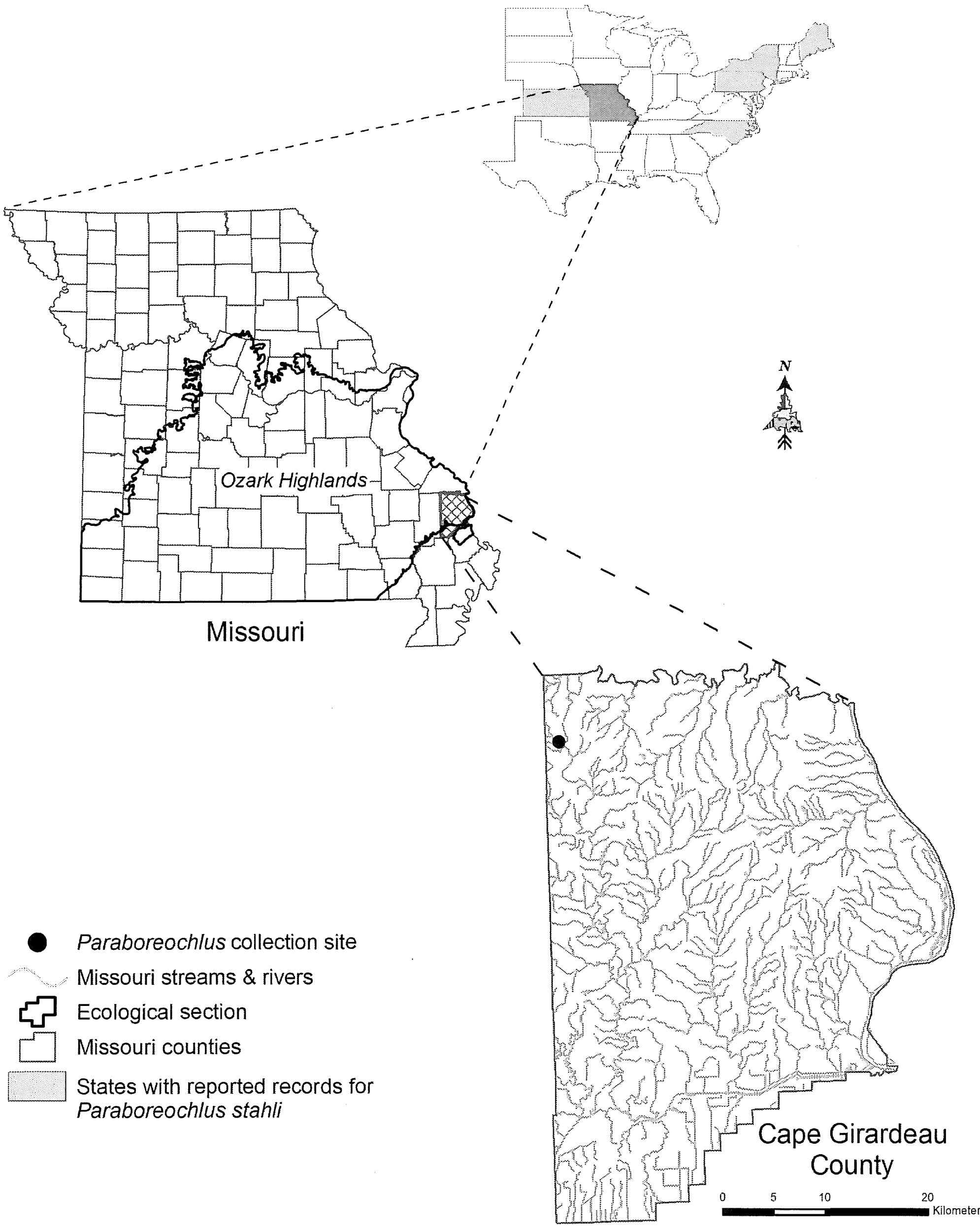

Table 1. Select water quality characteristics from the reach of Caney Fork Creek where *Paraboreochlus* was collected in Missouri 26 September 2002. Temp = water temperature (°C), Cond = conductivity (µmhos/cm), WH = water hardness (mg/L $CaCO_3$), Turb = turbidity (NTU), DO = dissolved oxygen (ppm), TP = total phosphorus (mg/L), TN = total nitrogen (mg/L), NH = ammonia (mg/L), Ca = calcium (mg/L), Mg = magnesium (mg/L), Cl = chloride (mg/L).

Temp	Cond	pH	WH	Turb	DO	TP	TN	NH	Ca	Mg	Cl
22.5	170	8.7	73.8	1.2	6.81	0.2	0.32	0.11	18.4	6.76	6.4

This report provides the first record on occurrence of *Paraboreochlus* in Missouri and adds to knowledge of the diversity of midge fauna inhabiting wadeable streams in the state. This report also adds to knowledge of the distribution and habitat of *Paraboreochlus* in North America. Additional macroinvertebrate community sampling in spring-influenced, wadeable streams in karst areas like the Ozark Highlands should add to knowledge of the distribution and habitat of *Paraboreochlus*.

Acknowledgments

We thank Broughton A. Caldwell and Bohdan Bilyj for confirming our *Paraboreochlus* identification. We also thank three anonymous reviewers for their reviews that helped improve the manuscript. Nick Girondo, Jennifer Girondo, and Chad Backes assisted with collection of samples in the field. Margie Mitchell prepared the map for the manuscript.

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Senior Division Abstracts

Agriculture

***Aide, C., M. Aide, D. Deere, K. Whitener, and M. Wood. Department of Agriculture, Southeast Missouri State University. BLACK CARBON IN SOILS.** Black carbon (BC), also called biochar or charcoal, has recently been proposed as a soil amendment to create a more favorable soil environment by improving the soil pH in acidic soils, raising the cation exchange capacity in poorly buffered soils and improving nutrient retention and availability in strongly weathered soils. We conducted a series of greenhouse experiments involving acid soil horizons from an Ultisol amended with various rates of BC. Common bean (*Phaseolus vulgaris* L. var 'contender') was grown in these amended soils using a completely randomized design and harvested when the untreated check had plants attaining two fully developed trifoliolate leaves. Plants grown in BC amended soil showed symptoms indicating boron toxicity. Plant tissue analysis and soil characterization showed elevated levels of boron. Black carbon amendments also show elevated soil and plant calcium concentrations. We conclude that boron threshold levels should be established for BC amended soils.

***Aide, M.T., W. Ellis, W. Mueller, I. Braden, N. Hermann. Department of Agriculture, Southeast Missouri State University. CORN AND SOYBEAN YIELD COMPONENTS GROWN ON A CONTROLLED DRAINAGE/IRRIGATION SYSTEM.** The influence of plant population density on controlled drainage/irrigated corn and soybeans was assessed to determine the optimum plant population for this emerging technology. Corn was planted on 30-inch rows and soybeans were planted on 15-inch rows. Main treatments consisted of irrigated corn having 25,000, 27,000, 29,000, 31,000, and 33,000 seeds /acre and irrigated soybeans having 110,000, 125,000, 140,000, 155,000, and 170,000 seeds per acre. Corn yields averaged 226 bu/acre and there were no significant differences among the plant density treatments or spatial distribution over or between the subsurface irrigation lines. Soybeans yields averaged 82 bu/acre and there were no significant differences because density treatments or placements with respect to the subsurface irrigation lines.

***Aide, M.T., W. Ellis, W. Mueller, I. Braden, N. Hermann. Department of Agriculture, Southeast Missouri State University. CORN AND SOYBEAN NUTRIENT ACCUMULATIONS GROWN ON A CONTROLLED DRAINAGE/IRRIGATION SYSTEM.** Corn and soybean nutrient accumulations were determined using tissue analysis and biomass estimates. Total corn nutrient uptake (lbs/acre) by element are N (290), P(55), K(158), Mg(27), Ca(72), S(24), Fe(1.1), Mn(1), B(0.1), Cu(0.2), Zn(0.6). Total soybean nutrient uptake (lbs/acre) by element are N (421), P(48), K(205), Mg(45), Ca(138), S(31), Fe(1), Mn(0.6), B(0.5), Cu(0.2), Zn(0.4). Based on total plant uptake, the percentages of each nutrient in the cob, stem, ear leaves, grain, tassel, shank and axial leaves are illustrated. Approximately 50% of the N is partitioned into the corn grain and 82% of the N is partitioned in the soybean grain.

Atmospheric Sciences

***Calvert, K.T.[1], C. Gravelle[2], J. Gagan[3], D. Gaede[3], A. Foster[3], D. Albert[3], and A.R. Lupo[1]. [1]Department of Soil, Environmental, and Atmospheric Sciences, University of Missouri, [2]Department of Earth and Atmospheric Sciences, Saint Louis University, [3]National Weather Service Forecast Office (WFO), Springfield, Missouri. INTERANNUAL VARIABILITY OF SNOWFALL EVENTS IN SOUTHWEST MISSOURI AND SNOWFALL TO LIQUID WATER EQUIVALENTS AT THE SPRINGFIELD WFO: A FOLLOW-UP STUDY.** Snowfall events in the Springfield, Missouri, WFO county warning area (CWA) from the winter of 2003 – 2004 to the present were examined in order to determine whether or not these events fit within the context of a previous study examining southwest Missouri winter events. The related liquid-to-snow ratio associated with the snowfall events were recorded and compared to the synoptic pattern associated with each event as well as the ENSO phase of each season. The primary data were acquired from the Springfield National Weather Service Office as well as the Department of Earth and Atmospheric Science at Saint Louis University and the Missouri CoCoRaHS network. Results from this updated study support those of a previously published study for the same region. Out of four storms that impacted Springfield, two were southwest lows and two were progressive troughs. These two synoptic patterns produced more than twice the number of snowfalls as northwest lows and bombs. This study also supported the conclusion that El Nino years are more prolific snowfall years in southwest Missouri than La Nina or neutral years.

***Dawson, N.W.[1], P.E. Guinan[2], and A.R. Lupo[1,2]. [1]Department of Soil, Environmental, and Atmospheric Sciences, University of Missouri, Columbia, Missouri, [2]Missouri Climate Center, University of Missouri, Columbia, Missouri. A LONG-TERM STUDY OF TROPICAL SYSTEMS IMPACTING MISSOURI.** Tropical storms and depressions were counted and evaluated to determine if climate change is behind the recent rise of hurricane remnants affecting Missouri. The data was acquired from the Unisys Weather archive of Atlantic Hurricane tracks from 1938-present. Information on the Pacific Decadal Oscillation cycles and ENSO periods were obtained for Atlantic hurricanes using a recent study. Tropical systems directly and indirectly affecting Missouri were observed.

Initial results show two periods of PDO cycle one (1938–1946) (1977–1998) resulted in 13 storms affecting Missouri with an average of 0.42 storms per year. PDO cycles two (1947–1976) (1999-present) have a combined result of 28 storms affecting Missouri with an average of 0.70 storms per year, which is nearly twice the number of storms per year than PDO cycle one. Also, the number of tropical systems affecting Missouri since 1938 was compared to the type of ENSO cycle. La Nina periods produced an average of 0.63 tropical storms per year, El Nino periods produced 0.53 tropical storms per year, and Neutral periods produced 0.54 tropical systems per year. This suggests that the number of storms per year that strike Missouri is largely influenced by the natural cycles rather than climate change. In Missouri there have been five tropical systems classified as tropical storm intensity, the most recent in 1949.

***Fritz, C., N. Fox and A. Lupo. Department of Soil, Environmental, and Atmospheric Sciences, University of Missouri, Columbia. FORMULATING A CORRECTION FACTOR FOR THE EFFECT OF SHELTERING ON WIND SPEED OBSERVATIONS.** Beginning 2006 ten tall tower wind observatories have been precisely stationed across the state of Missouri in the attempt to investigate the availability of wind power as an alternative energy source. To assess the enormity of wind speed in union with each wind tower location, anemometers are placed in pairs, one upwind and one downwind, at heights of up to 150 meters. Each tower contains 6 anemometers, extending horizontally 3 meters from each side of the tower. The tower structure, however, has engendered a negative effect, resulting in inaccurate wind speed measurements. The open lattice frame and support of the wind tower is found to reduce the true wind speed when the sensor is aligned parallel to the wind direction and the anemometer is downwind of the tower. On a number of occasions, there are periods for which only a one anemometer is working due to icing or equipment malfunction. Thus, a project has been proposed to formulate a correction factor that will ensure wind speed measurements are not underestimated in situations where a single operating anemometer becomes blocked. This work will show the angular range over which a correction is required, the variability of corrections required from one pair of anemometers to the next, and the impact on the monthly mean wind speed and power density of the correction.

***Fritz, C.L.[1], P.S. Market[1], N.I. Fox[1], S. Skibinski[2], and A.R. Lupo[1]. [1]Department of Soil, Environmental, and Atmospheric Science, University of Missouri, [2]International Met Systems, 4460 40th St. SE, Grand Rapids, Michigan, 49512. A RADIOSONDE SYSTEM FOR THE UNIVERSITY OF MISSOURI: AN INFORMAL STUDY OF A DECAYING THUNDERSTORM NEAR COLUMBIA, MISSOURI.** Recently, the University of Missouri purchased a mobile radiosonde weather balloon system from International Met Systems. Currently, only one WFO (SGF) launches balloons twice a day in Missouri, although there are several stations surrounding the state. Historically, balloons were launched from the Columbia Regional Airport and our station identifier was KCBI. After the purchase of this system and subsequent training, two test launches were done during the afternoon of 24 September 2008. During that afternoon, thunderstorms developed to the north of Columbia and moved in a south, southeasterly direction. A pre-frontal trough sparked this convection across the NW sector of Missouri in advance of a cold front. A surface analysis illustrates that there was a ridge of high pressure to the east with moderate warm south southeasterly flow. Furthermore, additional forcing is suggested by diffluent flow aloft at the base of an existing mid/upper level trough moving eastward across the northern plain states. Values of CAPE were around 1000J/KG for the morning hours with higher values to the east. During the afternoon (1945 UTC), a balloon was launched prior to the arrival of a line of thunderstorms. This sounding demonstrated that there was sufficient CAPE available for thunderstorm development. A second launch was done starting at 2137 UTC as the thunderstorm was moving in. An analysis of RADAR data indicated that the thunderstorm had clearly deteriorated. The sounding showed that as convection moved in to the region, and the atmospheric stability had adjusted toward moist neutral reducing the CAPE and other indicies. Finally, the faculty at the University of Missouri has discussed this acquisition with personnel at surrounding WFOs, and our newly acquired system may provide helpful information during special launches.

***Hawkins, C.L. and A.R. Lupo. Department of Soil, Environmental, and Atmospheric Science, University of Missouri, Columbia. A POTENTIAL VORTICITY DIAGNOSIS OF A SOUTHERN HEMISPERE BLOCKING EVENT.** Our study thus far had started with looking at a GrADS image from the NCEP Reanalysis Pressure Level data of the NOAA Earth System Research Laboratory website. These plots were gridded 500 hPa height fields at 500mb on a 2.5° by 2.5° lat/lon grid from 23 July 1999 at 12Z to 1 August 1999. From this we knew for future reference where our blocking system would propagate across the eastern Atlantic. The next step was to print out GrADS images for the 12Z of each day from July 21 through August 1, 1999. These images contained the same longitude and latitude range has our base image, however, they were plotted in pressure and temperature fields on the tropopause level. Our final step to this halfway mark was to analyze the trend of pressure and temperature through time. Overall, the blocking event showed higher temperatures and pressure than the surrounding environment. Results showed that the temperature and pressure seemed to be directly correlated with each other. As the blocking system strengthened, both temperature and pressure increased in the tropopause layer.

***Madden, J.M., J.T. Moon and A.R. Lupo. Department of Soil, Environmental, and Atmospheric Sciences, University of Missouri, Columbia. THE BATTLE OF WILSON'S**

CREEK 1861: HOW WEATHER MAY HAVE INFLUENCED THE OUTCOME. The Battle of Wilson's Creek, 10 August 1861, is called by some historians, the "Bull Run" of the west. It was the first major engagement between the forces of the Union and Confederacy in Missouri, and the outcome may very well have kept Missouri in the Union even though it was a nominal Confederate victory. Weather may have played a role in the outcome. Using quotations from those who participated, we know that the Confederate forces delayed their initial march on Union forces the night before due to rain. Further investigation reveals that light rain fell for approximately two hours the previous night, and that the day of the battle was at least warm to hot. Using climatological normals and analogue techniques, we speculate that light rain may have been the result of a weak cold frontal passage, and that the upper air pattern was likely dominated by a ridge across the northern tier of states and whose axis was located over the plains.

***Moon, III, J.T.[1,2], P.E. Guinan[1,2], and A.R. Lupo[1,2]. [1]Department of Soil, Environmental, and Atmospheric Sciences, University of Missouri, [2] Missouri Climate Center, University of Missouri. COCORAHS IN MISSOURI: THREE YEARS LATER, THE IMPORTANCE OF OBSERVATIONS.** On 1 March 2006, Missouri became the 13th state to join the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS). CoCoRaHS is a national volunteer network of individuals who have agreed to measure and report precipitation observations daily. This program was founded in Colorado where it is currently based. On 12 March, 2006, CoCoRaHs quickly demonstrated its usefulness during the severe weather events of that day when there were several reports of large hail. Since then, Missouri CoCoRaHS network regularly receives over 200 reports per day. This data can be used to study severe weather events such as the passage of tropical depressions Gustav and Ike through Missouri over a 10 day period bookended by 4 and 14 September 2008. Here we will compare the CoCoRaHS volunteer rainfall totals to RADAR derived estimates taken from the National Weather Service as well as the Cooperative Site measurements. CoCoRaHS data was even incorporated by the National Weather Service to summarize these events. CoCoRaHS data is currently used by all six National Weather Service offices and River Forecast Centers in the state of Missouri as well by as by other state and federal agencies and several television stations. The data has been used to dispatch flash flood information to the National Weather Service and to make flood and drought assessments for the Missouri Departments of Agriculture and Natural Resources. Public works departments, insurance companies, contractors and farmers have also used the data for documentation and management decisions.

***Smith, N.B., P.E. Guinan[1] and A.R. Lupo[1]. [1]Department of Soil, Environmental, and Atmospheric Sciences and [2]Missouri Climate Center, University of Missouri, Columbia, Missouri. A STUDY OF THE EFFECTS OF ENSO CYCLES ON MISSOURI DEW POINT LEVELS.** Dew point levels are evaluated to determine if El Nino, La Nina, and Neutral cycles have a significant effect on Mid-Western dew points levels. The dew point data was acquired from a recent study of Mid-Western weather patterns. Information on the Pacific Decadal Oscillation cycles and ENSO periods were from the NOAA Earth Systems Research Laboratory archive of isobar levels from 1948-present. The monthly average dew point levels affecting Missouri since 1948 was compared to the type of ENSO cycle. La Nina periods produced an average dew point of 23.671 in winter months, 42.927 in spring months, and 64.362 in summer months. El Nino periods produced an average dew point of 24.945 in winter months, 41.705 in spring months, and 63.707 in summer months. Neutral periods produced an average dew point of 22.703 in winter months, 42.207 in spring months, and 64.902 in summer months. This suggests that El Nino years produce the wetter winters, La Nina years produce the moist springs, and Neutral years produce the humid summers.

Biology

***Andersen, M.L. Department of Biology, Rockhurst University. MUSCLE DEVELOPMENT IN THE HINDLIMB OF XENOPUS LAEVIS.** My previous studies focused on the changes in patterns of cell densities in the developing hindlimb of Xenopus. The purpose of this study was to describe hindlimb muscle cleavage in several stages of early Xenopus embryos and to determine the sequence of cleavages. Approximately 100 Xenopus embryos were raised in the lab to various stages of development and preserved in formalin, Zenker's or Bouin's. The embryos were embedded in paraffin for sectioning. Selected stage 49–57 embryos were serially sectioned at either 6 μm or 10 μm and subsequently stained with hematoxylin and eosin or with toluidine blue or iron hematoxylin. Cell density was determined by using an ocular grid and counting cells at various locations throughout the limb section. 3-D reconstructions of the limb at each of stages 51–57 were completed using line drawings of selected serial sections. Maximum cell density of blast cells occurs during stage 50 and reaches approximately 75,000 cells/mm^3. Cleavage lines first appear at stage 51 in areas of maximum density. Early muscle condensations first appear at the end of stage 51 and the beginning of stage 52 in the mid-femur region adjacent to prechondrogenic blastemata. Prechondrogenic blastemata and adjacent muscle condensations in the pelvic region do not appear until stage 53. Prechondrogenic blastemata in the tibia also appear in stage 53 along with associated musculature. Most hindlimb musculature is represented by stage 53. Cleavage occurs in several planes and at several levels simultaneously and appears to be coordinated with chondrogenic condensations along a proximal-distal axis. The sequence of muscle condensations appearances is: proximal femur, pelvis, tibia/fibula, knee, tarsus. Sarcomeric organization appears in stage 54.

Creek, TC) especially below a large mall (BM) in comparison to above mall sites (AM) and a rural stream (Jones Creek, JC). Such invertebrate declines might affect leaf decomposition rates in these streams. In the fall of 2008, we estimated decomposition rates and macroinvertebrate community structures using freshly dried red elm leaf packs. Thirty-six leaf packs, housed in polyester mesh (1.5 by 4 mm) bags, were anchored in riffles at the three sites. Bags were recovered after 15 and 36 days, invertebrates were removed and identified, and leaf residue air dried. Decay rates at 15 days (TC AM 4.20%/day, TC BM 4.43, JC 4.45) and at 36 days (TC AM 2.14%/day, TC BM 2.15, JC 2.36) were not significantly different between sites (ANOVA, $P = 0.55$ at 15 days and $P = 0.23$ at 36 days). Shredders were primarily represented by the cranefly (*Tipula*) larvae in both TC sites and by *Tipula* and the isopod *Lirceus hoppinae* in JC. Collector-gatherers, primarily net-spinning caddisflies *Cheumatopsyche*, *Ceratopsyche*, and *Chimarra* as well as the Chironomidae numerically dominated leaf-packs, especially in TC. Leaf decomposition may be more related to physical fragmentation and microbial process than shredding in this urban stream. Dominance of collector-gatherers may indicate leaf packs serve primarily as habitat and not a direct energy source for many stream invertebrates.

***Vanderpool, S.S. Department of Life and Physical Sciences, Lincoln University. DISTRIBUTION AND SEX RATIO OF A LARGE POPULATION OF PONDBERRY (LINDERA MELISSIFOLIA) IN ARKANSAS.** Pondberry (*Lindera melissifolia*) was officially listed as endangered under the Endangered Species Act of 1973 in 1986. Historically pondberry occurred in 10 states in southeastern United States, but probably has been extirpated from three and is considered globally imperiled throughout its range. Pondberry was first observed in Arkansas in 1972, occurring in small, scattered, usually single sex colonies in isolated sand ponds west of Crowley's Ridge. In 2001 a large, reproductive population of pondberry was found east of Crowley's Ridge. Fieldwork established the existence of an extensive, sexually reproductive population extending along the St. Francis River. A multiyear project to map distribution, and determine sex and reproductive status of the population began in 2002. The number of isolated plants, size of clones, ratio of fruiting to non-fruiting stems, and population boundaries were determined. The overall population encompasses approximately 438 ha. A total of 282 clusters or clones were identified, of which 81 (28.7%) included at least one fruit-bearing plant. Estimates of fruit-bearing plants provided a conservative estimate of pistillate plants in the population. Our research indicates that the St. Francis Sunken Lands population may be the largest extant population. Results of the evaluation of fruiting conditions indicates that reproductive processes in this population of the dioecious shrub are intact, as compared to other small, isolated populations known from Arkansas. This study was supported by the Arkansas Natural Heritage Commission.

Engineering

Block, E., B. Bowen*, M. Jednachowski and J. Yusko. Parks College of Engineering, Aviation and Technology. Saint Louis University. OPTIMIZATION OF HUMAN PERFORMANCE ASSESSMENT IN A COMPLEX TRAINING ENVIRONMENT. This study assesses human performance in the latest complex simulation device in current domestic production. The Canadair Regional Jet Simulator was manufactured by Paradigm Solutions utilizing the concepts of elegant engineering for Parks College of Engineering, Aviation and Technology at Saint Louis University. It is suggested that elegant engineering will provide a more reliable platform for training pilots and support personnel in critical task management. In support of this assertion, baseline research in the area of cognitive performance will be tested in an experimental process using standardized measures. Subjects are presented a sequence of critical tasks in a simulation of a high-risk flight environment. Assessment of the subject's reaction and response to critical situations will be recorded for measurement and evaluation, as well as the impact of a training protocol based on a critical task management approach. Preliminary data is reported from this multi-phase research design with the purpose of enhancing training protocols and improving the reliability and validity of training performance assessment using a critical incidents technique.

Geography

Fox, D.P. and B.L. Hoffman*. Department of Natural and Physical Sciences, Park University. CHARACTERISTICS OF INFLUENZA FATALITIES IN SAINT JOSEPH, MISSOURI, DURING THE 1918–1919 PANDEMIC. Investigations into the demographics of influenza fatalities during the 1918–1919 epidemic in the United States indicated the population segments most impacted were the under 1-year, over 60-year, as well as young adults 20–44 years of age. This result is striking since young adults are typically killed by influenza at low levels. Also, males were typically more likely to die from influenza than females. Studies of eastern US cities have indicated immigrants and children of immigrants, especially those from Eastern Europe, were more likely to die from influenza than natural born US citizens whose parents were natural born US citizens. Saint Joseph, Missouri influenza fatalities during this period showed a different profile. Mortality was accelerated in the under 1-year, 1–5 year, and 20–44 year age groups. The death rate in the 45 and older age group was much lower than expected. Sex seemed to have no bearing on risk of death from influenza, since male and female death percentages mirrored those of the general population. Race and immigrant status played little to no role in risk for death from influenza. If anything, immigrant populations faired better than native-born US citizens. These results indicate the factors determining risk for death from Spanish influenza in 1918–1919 for Saint Joseph, Missouri are different from those that were at work in eastern US cities.

Geology/Geophysics

***Dudley, M. Department of Biology and Earth Science, University of Central Missouri. BANDED IRON FORMATIONS IN THE MESOPROTEROZOIC ST. FRANCOIS MOUNTAINS IGNEOUS TERRANE, SE MISSOURI. WHAT DO THEY TELL US ABOUT THE MIDDLE PROTEROZOIC WORLD?** Some of the earliest preserved rocks in the Earth's geologic record are represented by a unique group of chemical sedimentary rocks known as banded iron-formations (BIF), that are comprised of alternating iron- and silica-rich laminae generally in the form of iron oxides (hematite and/or magnetite) and microcrystalline quartz (jasper). Considerable debate still persists over the nature of these rocks, and one of these notable points is their apparent exclusivity to the Archean and Proterozoic rock record. This unusual characteristic is further deepened by an apparent hiatus of BIF deposition within the Proterozoic extending for nearly one billion years duration from 1.8 to 0.8 Ga. Leading hypotheses account for this absence to a fundamental change in ocean chemistry, i.e., the oceans became sulphidic (euxinic) in nature thus favoring sulphide precipitation over oxides. However, recent work by Dudley and Nold (2001–2006) within the St. Francois Mountains Iron district of southeast Missouri has uncovered a number of previously undescribed deposits that clearly represent BIF's, yet occur in a terrane that is 1.5–1.4 Ga in age. These Missouri deposits share many mineralogical and sedimentalogical similarities to the extensive and well-studied BIF occurrences found in the Labrador Trough (Canada) and Minnesota that characterized the end of BIF deposition worldwide around 1.9–1.8 Ga. The presence of the Missouri deposits indicate that the same conditions, mechanisms, or processes responsible for the creation of BIF in the Archean and early Proterozoic were still active in the middle Proterozoic and does raise questions on the validity of the prevailing dogma concerning the Proterozoic oceans.

***Hagni, R.D. Department of Geological Sciences and Engineering, Missouri University of Science and Technology. ORIGIN OF FLUORSPAR ORES AT OKORUSU, NAMIBIA.** Okorusu mines in North-Central Namibia are a world-class fluorspar producer at >130,000 tons fluorspar concentrate/year. The fluorspar ores are associated with the Okorusu alkaline igneous-carbonatite complex that is late Cretaceous in age (125 Ma), intrudes late Precambrian Damara Series metasedimentary rocks, and is crudely circular and about 8 km in diameter. The ores are currently mined from four open pits, A, B, C, and D. Exploration is currently progressing at two additional fluorite deposits, G and the Wishbone, and to extend the A orebody to a depth for possible underground mining.

The fluorspar ores were formed by fluorite replacement of carbonatite (83%) and marble (16%). Locally, some fluorite ores (1%) were formed by the cementation of fenite breccias. The ore fluids were acidic, oxidizing, and moderate in temperature. The ore fluids selectively replaced carbonatites and marbles because their calcite contents were readily dissolved by the introduced acidic ore fluids. Dissolution of calcite provided calcium that combined with introduced fluorine to form the calcium fluoride, fluorite. The ultimate source of the fluorine was from the carbonatite magma at depth in the Okorusu alkaline igneous-carbonatite complex. Carbonatites are known worldwide for their elevated quantities of fluorine. The oxidizing character of the ore fluids caused pyrrhotite, magnetite, and iron-rich diopside in the replaced carbonatites to be altered to goethite pseudomorphs that persist in the fluorite ores and attest to the replacement of carbonaite by the fluorite ores. Fluid inclusions in the fluorite indicate that the ore fluids ranged in temperature 166–128°C and were very low in salinity (1.5–5% NaCl equiv.).

***Hagni[1], R.D., O. Sikazwe[2], A.M. Hagni[3] and E. Mwelwa[4]. [1]Department of Geological Sciences and Engineering, Missouri University of Science and Technology, [2]Department of Geology, University of Zambia, [3]Geoscience Consultant, and [4]Mindola Mine, Zambia. ORE MICROSCOPY OF ZAMBIAN COPPERBELT ORES: REPLACEMENT OF PYRITE BY COPPER SULFIDES AT THE MINDOLA MINE, AND CHARACTER OF REFRACTORY COPPER ORES AT THE NCHANGA MINE.** Because copper shale-type deposits elsewhere in the world (e.g., Polish Kupferschiefer; Creta, Oklahoma) commonly exhibit prominent copper sulfide replacement of syngenetic-diagenetic pyrite forms such as fine-grained framboidal and colloform pyrite, ores from the Mindola copper-cobalt mine were examined by ore microscopy to search for such pyrite forms. The ores from the Mindola mine are the least metamorphosed in the Copperbelt, but unfortunately even those have been affected by sufficient metamorphism to destroy original syngenetic-diagenetic pyrite forms. Chalcopyrite, bornite, and covellite have veined and partially replaced Mindola pyrite (and cobaltite) crystals, but the pyrite crystals are large cubes with octahedral modifications that appear to have formed by recrystallization during metamorphism. Ore microscopy also was employed early in a study of refractory ores from the Nchanga mine in the Zambian Copperbelt. Early thoughts on possible causes for the refractory character of those ores included fine-grained copper sulfides and secondary copper minerals such as malachite. Ore microscopic study showed fine-grained sulfides were absent from those ores. Although secondary malachite was observed in certain of the refractory ores, those ores had been stockpiled in an open pit for about 40 years and the secondary malachite appears to have developed post-mine. Subsequent microprobe and automatic image analysis show that the copper resides within biotite crystals, either in solid solution or as submicroscopic sulfide inclusions.

***Hoffman, B.L., C.E. Hoffman and S.A. Hageman. Department of Natural and Physical Sciences, Park University. MICROICHTHYOLITHS AND CONODONTS FROM THE QUINDARO SHALE AND ARGENTINE LIMESTONE OF THE KANSAS CITY GROUP.** The Quindaro Shale (15 cm thickness) and Argentine Limestone (5.5 m thickness) Members (Wyandotte Limestone, Kansas City Group, Upper Pennsylvanian System) are marine regressive sediments prominently exposed at Park University, Parkville, Platte County, Missouri. Microremains from this locality were separated from Quindaro Shale soaked in water or from Argentine Limestone treated with 10% acetic acid. The sediments were then examined with a dissecting microscope and 3,128 specimens were isolated. Remains from several groups of fishes are evident, including chondrichthyans (sharks and acanthoid fishes), bony fishes and craniates (conodonts). "Teeth" from *Gunnellodus belistriatus*, *Gunnellodus cameratus* and *Gunnellodus trispinosus*, which resemble cephalic and branchial denticles from stethacanthid sharks are found throughout the two members and represent 11% of identified fish remains. "Teeth" similar to *Zangerlodus williamsi* (1%) and cladodont-style teeth (1%) are also found. *Listracanthus* denticle fragments account for another 1% of fish remains. Other shark remains include placoid scales (17%) previously referred to several form genera (*Cooleyella, Cooperella, Fortscottella, Hammondella, Kirkella, Moreyella*, and *Williamsella*). Scales and fin spines from acanthodian fishes are commonplace (20%). Isolated teeth, teeth in jaw fragments and scales of bony fishes are also numerous (15%). Present, but rare, are teeth from petalodonts and tooth plates similar to lungfish. Conodonts are common (34%), including *Idioprioniodus* and *Streptognathodus* from the Quindaro and *Streptognathodus*, *Idiognathodus*, *Hindeodus*, and *Adetognathus* from the Argentine. The conodont distribution also indicates a transition from open ocean to shallow nearshore paleoenvironments. This marine regression is likewise evident from examination of associated invertebrate fossils.

***Klawinski, P.D. Department of Biology, William Jewell College. ISLAND BIOGEOGRAPHY OF CARIBBEAN SPIDERS: EFFECT OF ISLAND SIZE AND TOPOGRAPHY.** Classical island biogeography posit that species richness on islands is determined by rates of colonization and extinction which are affected by island size and distance from the mainland, respectively (MacArthur and Wilson 1967). While this accounts for a great deal of variation in species richness among islands, other factors might be important (variation in habitat diversity, resistance to inundation during interglacial periods, etc.). Ackerman *et al.* (2007) examined orchid species richness in the Caribbean and found that species:area relationships were largely due to relationships among "montane" islands (> 300 m maximum elevation) and was driven by endemic species. I examined the relationship between log (spider species richness) and log (island size) (slope of this relationship = **z**) for Caribbean islands and examined this relationship for all combinations of island type and endemism. The species area relationship for all species and all islands was significant but the **z** value was low (**z** = 0.08). Removing nonendemc species led to an increase in **z** (0.63) while non-endemics alone produced a non-significant **z**. When examining the effect of island topography, montane islands had **z** significantly greater than zero and this relaionship increased when only endemic species were included (**z** = 0.67). Nonedemic species showed no significant relationship with island size regardless of the type of island examined. Calcareous islands had weak relationships between island size and species richness. I conclude that topography is crucial to understanding patterns of species richness across archipelagoes as higher islands have more species largely due to increases in topographic diversity and increases in levels of endemism due to *in situ* speciation.

***Laudon, R. C. Department of Geological Sciences & Engineering, Missouri University of Science and Technology. A GLOBAL SAND BUDGET—ARE WE RUNNING OUT OF SAND?** A compilation of data from the literature on rates of global sand and soil generation as compared against consumption by man and destruction by natural processes indicates sand and soil are being lost at rates that exceed generation. By assuming that sand comprises 30% of soils, 30% of sediment lost to the oceans and 30% of construction grade aggregate, it is possible to make very rough estimates of a global sand budget. Although global estimates require many assumptions that are highly debatable, this paper concludes: (1) sand is presently being generated from soils at rates that vary between 0.06 and 450 billion tons per year, with a best estimate at about 5 billion tons per year. (2) Sand, through erosion and transportation, is being lost to the oceans at about the same rate, about 5 billion tons per year. (3) Industrial grade sand is being consumed by man at rates estimated at 100 to 300 million tons per year. (4) Construction grade sand is being mined at rates estimated at 4.5 billion tons per year, and thus (5) total consumption by man is estimated at about 4.6 to 4.8 billion tons per year. Although definitions of the term "renewable natural resource" vary, and although estimates of rates of sand generation, destruction and use are very difficult to establish on a global basis, this paper concludes sand is being generated naturally from soils at rates that exceed industrial grade use and that industrial grade sand is a renewable natural resource.

***Nold, J. and M. Dudley. Department of Biology and Earth Science, University of Central Missouri. FURTHER TEXTURAL INDICATIONS OF IGNEOUS MAGMATIC ORIGIN OF THE PILOT KNOB MAGNETITE DEPOSIT, ST. FRANCOIS MOUNTAINS TERRANE, MISSOURI.** Textural indications that support an igneous/magmatic origin for the Pilot Knob Magnetite (subsurface) deposit have previously been reported by Nold and Dudley (2008) and include plagioclase as the most abundant matrix mineral, intercumulus poikilitic texture of some of the plagioclase, hypidiomorphic granular texture of the ores, porphyritic magnetite textures, zoned magnetite phenocrysts, 120 degree angle triple junction or foam texture between some magnetite crystals, layering in some of the ores which is interpreted to be rhythmic in origin from gravitational differentiation, euhedral volcanic quartz phenocrysts floating in the ores, and angular host rock breccia fragment inclusions that show a distinct lack of alteration or replacement. Additional textural indications of magmatic origin for these ores not previously described include dendritic growths of magnetite, and the observation that the orebody is finer grained near its contact with host rocks, which we interpret to be a magmatic chill zone. Most of the orebody appears to be of magmatic origin, but hydrothermal mineralization is present as late-stage veins and breccia fillings crosscutting the orebody. Additionally, there is a thin envelope of low grade magnetite ore adjacent to the main orebody, apparently having originated by hydrothermal impregnation of host rock rhyolite/trachyte by magnetite.

***Priesendorf, C.D. Department of Natural Sciences, Longview Community College, Lee's Summit, Missouri. PRELIMINARY INVESTIGATIONS ON THE OCCURRENCE OF THE PRIMITIVE VASCULAR PLANT, PSILOPHYTON AND ASSOCIATION WITH LEPERDITICOPID OSTRACODS AND GNATHOSTOME FISHES FROM THE MIDDLE DEVONIAN CEDAR VALLEY FORMATION OF CENTRAL MISSOURI.** Well-preserved plant fragments of the Genus *Psilophyton* are found in association with abundant Leperditicopid Ostracods and the remains of numerous disarticulated fish. The fossils are found in association with two thin shaley intervals in the lower portion of the mostly micritic Cooper Facies of the Cedar Valley Formation. Previous investigators have regarded *Psilophyton* as inhabiting shallow water marginal habitats that were subjected to environmental stress such as tidal flats, lagoons, embayments and estuaries. Leperditicopid Ostracods have also been found in sediments that have also been interpreted as shallow water "marginal habitats." Beneath the shaley intervals are borings within the micritic limesone that are indicative of a "Marine Firmground," likely of the *Glossifungites* Ichnofacies. The *Glossifungites* Ichnofacies is also an indicator of shallow water subtidal zones including salt marshes, mud bars or high intertidal flats. Nearby, within the same strata are brecciated Stromatoporoid and *Hexagonaria* fragments indicative of a high energy environment. The occurrence of *Psilophyton*, Leperditicopid Ostracods and fish remains found in the shaley interval is interpreted as a low-energy backreef lagoon environment. The abundant fish fragments have yet to be identified to the species level, however ,appear to be Acanthodian and Sarcopterygian. The disarticulated fish remains include well-preserved scales, spines, cheek plates, vertebrae, and possible cranial bones.

Physics

***Gibbons, P.C., A.P. McMahon*, and J.F. Wiegers*. Department of Physics and Science Outreach, Washington University. AN ASTRONOMY COURSE FOR K-8 TEACHERS.** We will describe the science and pedagogy content for an astronomy course for K-8 teachers. The science content addresses topics from the nature of science (scaling, operational definitions, and models), cycles of motion of objects (sun, moon, and stars) in the sky, frames of reference, and geocentric/heliocentric models. The pedagogical content addresses topics of inquiry, learning cycles and learning progressions. We will describe strategies for helping teachers become good observers and describers of motion, and developers and users of models to explain and to account for observations.

Science Education

***Haskins, M.F. Department of Biology, Rockhurst University. TEACHING ENZYME ACTIVITY WITH KREBS CYCLE REDOX REACTIONS.** Most of the general biology lab manuals promote the use of amylase, catalase, or catechol oxidase to teach enzyme activity. An interesting, but often-overlooked enzyme, is succinic acid dehydrogenase (SAD). SAD is a normal constituent in mitochondria and typically aids in the transfer of hydrogens from succinic acid to the coenzyme nicotinamide adenine dinucleotide (NAD^+) resulting in the formation of fumaric acid. However, in the lab "blue" methylene blue can serve as an alternate hydrogen receptor, and because the methylene blue loses color once it has been reduced, enzyme activity can be easily measured by simple color changes. Data will be presented using both yeast and beef liver as sources of enzymes along with the effects of various substrate concentrations. Methods for using SAD in general biology labs will be discussed, as well as methods for using SAD to help students develop their analytical skills. This novel lab reliably demonstrates enzymes are capable of catalyzing numerous reactions, is relatively inexpensive, and is a lab that students enjoy. In addition, the interaction between cellular respiration and photosynthesis is easily demonstrated if these experiments are conducted using plants as the enzyme source.

***Saha, G. Department of Education, Lincoln University of Missouri. DEVELOPING AND VALIDATING PERFORMANCE-BASED ASSESSMENT TASKS IN SCIENCE: A HOW-TO GUIDE.** The purpose of this research was to design a how-to-guide for developing and validating a set of three performance-based assessment tasks in science. This guide involves an iterative process of trial testing that calls for frequent reviews, revisions, modifications and changes from feedback at several stages. With the state and national emphasis on inquiry-based science instruction demanding performance-based assessment, it has become quite a challenge for teachers to generate reliable and valid assessment tasks (tests) to assess their students' proficiency credibly. This challenge has become more formidable when most science teachers do not have formal training in test (or assessment task) development. One big concern expressed by several educators and psychometricians about performance-based assessment task is the psychometric quality that affects the validity of inference made from such assessment tests. The authors used a variety of statistical data to address this concern. Inter-rater reliability was $r = 0.95$, Spearman-Brown r formula (internal consistency) was 0.70 across all the tasks and process skill categories, correlation coefficient across all the tasks and process skill categories showed a significant positive relationship, items of each task were highly positively correlated with the task itself – all demonstrate that these tasks are highly reliable to use. There was high agreement of polls among the science educators establishing the content/process validity of these tasks, descriptive statistics validly represents three categories of process skills. Item-wise data on three process skill categories indicate that students demonstrated proficiency in all the sub-skills, non-significant $F = .05$ (223, 1) $p = 0.82$ from ANOVA showed no gender difference among all skill categories. Factor analysis (PCA) was conducted to garner additional support for the validity that demonstrated that the items in these three tasks in fact are grouped into three components: Planning skills, Performance skills and the Content itself – supporting that items are consistent in explaining the relationship among them.

Social and Behavioral Science

***Smith, P.S. Independent Scholar. PRIMARY CULTURE, EXISTENTIAL ATHROPOLOGY AND THE EMERGENCE OF MAGIC.** Like many religious assumptions, magic can be nothing more then psychological reaction to and mental extrapolation about the physical environment. Magic in essence reflects the human condition of acute vulnerability to the environment, the awareness of which is expressed in a need to control circumstances beyond control thus enhancing chances at communal survival and physical comfort. One answer to the problem is an interaction with the sublime, but the social-scientific view simply cannot address that, but may look to the relevancy of the existential situation as the basis for much religious notion. In continuation from previous presentations incorporating the proposition behavior and social order systematically from psychological reaction to existence, the following study will seek to understand how magic plays a prominent role in religious assumption of primary peoples, what the circumstances were that engendered its emergence and the reasons for its ritualization. Two questions which will be asked are: is magic precursory to religion: 1.) did one evolve from the other or 2.) are they interrelating phenomena with similar definition and purpose, and relevant to this, is a Darwinian formulation best in understanding a perceived evolution from magic to religion to science?

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College Division Abstracts

Agriculture

***Magrowski, E.[1], A. Andrei[1] and L. Mechlin[2]. [1]Department of Agriculture and Environmental Sciences, Lincoln University and [2]Missouri Department of Conservation.** **INVERTEBRATE RESPONSE TO INITIAL PHASES OF WARM SEASON GRASSLAND RESTORATION.** Restored warm season grasslands provide habitats for a great diversity of invertebrates that serve as a source of protein for numerous grassland birds. We sampled invertebrates and vegetation in restored grasslands in central Missouri to investigate how vegetation structure and diversity influence invertebrate biomass, abundance, richness, and diversity. In 2007, we collected 71 families of arthropods. The most abundant invertebrate families were Acrididae (grasshoppers), Araneae (spiders), Chrysomelidae (leaf beetles), Cicadellidae (leafhoppers). Invertebrate dry mass was related to percent cover by forbs ($R^2 = 0.73$, $n = 16$, $F = 38.66$, $P < 0.001$). Invertebrate abundance, individuals/m^2, was correlated to percent cover by forbs and number of forb species/m^2 ($R^2 = 0.62$, $n = 16$, $F = 10.87$, $P = 0.0017$). Variations in invertebrate richness, number of families/m^2, were best explained by number of forbs species/m^2 and percent bare ground ($R^2 = 0.74$, $n = 16$, $F = 18.98$, $P < 0.001$). Invertebrate diversity (Shannon-Wiener) was related to number of forbs species/m^2 and percent cover by bare ground ($R^2 = 0.76$, $n = 16$, $F = 20.90$, $P < 0.001$).Our study reveals efforts and investments to restore warm season grasslands and to maintain high percent ground cover by forbs and bare ground, through plantings, prescribed fire, or otherwise, result in greater overall biodiversity and likely benefit all vertebrates that take invertebrate prey.

Biology

Stephan, K., E. Backes* and J. Yang. Department of Life and Physical Sciences, Lincoln University. **LONG-TERM EFFECTS OF PRESCRIBED BURNING ON SOIL CARBON AND NITROGEN CONCENTRATIONS.** Soil C and N are important indicators of soil fertility and have been shown to be highly susceptible to disturbance. We investigated the effects of spring prescribed burning on total C and N concentrations in a SE Missouri oak-hickory forest. Soil was collected from the organic horizon and at two depths of mineral soil from plots that had been burned annually, periodically (every four years), and no burns in the last 57 years. Analyses were performed with a TruSpec elemental determinator. Preliminary analyses indicate that both total C and N concentrations decrease with increasing soil depth ($P < 0.05$) with the sharpest decline occurring between the organic soil and top 10 cm of mineral soil. Concentrations declined from on average 7.2% and 0.4% in organic soil, to 1.2% and 0.08% in mineral soil at 0–10cm, to 0.5% and 0.03% in mineral soil at 70–80cm depth for total C and N, respectively. Preliminary analyses also indicate that prescribed burning may have a significant effect ($P < 0.05$) on C and N concentrations within the top 30 cm of mineral soil. C and N concentrations were lowest in annually burned soil (0.79% and 0.05%, respectively) but did not differ between periodically burned soil and controls (0.92% and 0.07%, respectively). Whereas the higher concentrations at lower soil depth are likely due to inputs from decomposing plant material, the decrease in annually burned plots can be explained by losses due to combustion. The implications of these preliminary findings will be investigated in future studies. This study was supported by US DOD grant W911Nf-05-2-0003.

***Bamber, A[1]., M. Eisterhold[1], N. Dudenhoeffer[1], K. Lee[1], F. Rindi[2], P. Nam[3]. [1]Bioenergy Research Laboratory, Department of Life and Physical Sciences, Lincoln University. [2]Marine Science Institute, National University of Ireland, Gallway. [3]Department of Chemistry, Missouri University of Science and Technology.** **CULTIVATION AND LIPID ANALYSIS OF ISOLATED MICROALGAE STRAINS FOR BIODIESEL PRODUCTION**. Energy consumption and its effects have far-reaching impacts both today and in the future, however, renewable biofuels such as biodiesel derived from microalgal lipids could provide a solution. Algae culture growth rates are influenced by climate, which is the determining factor for site-specific biodiesel production based on algae. A main focus of this research was to isolate samples of algae that can be grown in our local climate. Microalgae samples were collected from both Missouri and other US locations, and cultured and isolated in the laboratory. To date, we have isolated over 200 strains of microalgae, which have been identified based on morphology. Isolated strains include: *Scenedesmus*, *Chlorella*, *Ulothrix*, and *Monoraphidium*. Lipid analyses of selected algae strains revealed lipid contents as high as 47% lipid biomass / algal dry weight). One Missouri native strain was further studied for the purpose of manipulating culture conditions, such as media type and light intensity. We have successfully isolated and identified multiple microalgae strains that show potential for economical biodiesel production based on their capacity to grow rapidly under local climate conditions and to produce relatively high lipid contents. This study was supported by the USDA Evans-Allen Program and the Missouri Life Science Research Board.

***Dudenhoeffer, N.[1], K. Lee[1], P. Nam[2]. [1]Bioenergy Research Laboratory, Department of Life and Physical Sciences, Lincoln University. [2]Department of Chemistry, Missouri University of Science and Technology.** **OPTIMAL CULTIVATION AND HARVESTING CONDITIONS FOR LARGE-SCALE MICROALGAE CULTURES**. A local algae strain was chosen to be the focus of our investigation of the optimal growing and harvesting conditions that will yield the maximum amount of microalgae biomass. The economical production of microalgae biomass could lead to a new source feedstock for the renewable biofuels (biodiesel, ethanol, and syngas), and other valuable bioproducts. The different growing conditions evaluated were the amount and frequency of the growing media and carbon dioxide supplied to the algae culture. We measured optical density with a spectrophotometer to indirectly measure the amount of algal growth. Different types of media developed in our lab were also evaluated for their effect on the rate of growth. Harvesting tests were done by removing 10, 50, or 90 % of the culture volume when growth was maximum. The long-term cultivation and harvesting of this algal strain yielded the most biomass when the 90% batch harvesting strategy was employed. This study was supported by the USDA Evans-Allen Program and the Missouri Life Science Research Board.

***Koon, G., E. Brogdon, S. Tobin, D. Chong, B. Crosby, S. Magruder, and E.S. Critser. Department of Science, Columbia College. PARTIAL SEQUENCING OF THE GAPDH GENE OF *VIOLA X WITTROCKIANA*.** Glyceraldehyde-3-phosphate dehydrogenase (GAPDH) is a well characterized housekeeping enzyme in both glycolysis and the Calvin cycle. The purpose of this project was to isolate and sequence the GAPDH gene(s) in *Viola x Wittrockiana* using *Arabidopsis thaliana* as a reference. Genomic DNA was isolated from 6 separate plant samples and amplified using nested PCR, performed with degenerate primers targeted to the GAPDH gene of *Arabidopsis thaliana* (Biotechnology Explorer Series, Bio-Rad). PCR products were evaluated by electrophoresis to identify DNA for subsequent study, and blunt-end ligated into the pJet 1.2 cloning vector. Transformation of *E.coli* HB101 was performed followed by overnight culture with ampicillin selection. Two independent rounds of plasmid isolations were performed producing successful plasmid isolation from 45 bacterial clones. Purified plasmid DNA was used for DNA sequencing (DOE Joint Genome Institute, Walnut Creek, CA) using two primer sets targeted against the pJet 1.2 cloning vector and (2) a degenerate primer set targeted to the GapC region of GAPDH gene in *Arabidopisis thaliana*. One clone failed to provide any sequencing information. Sequencing data were analyzed using iFinch software (Geospiza, Inc.), CAP3[1], and BLASTn (NCBI). Sequences with a minimum Q20 score of 50 were included for subsequent analysis (n = 141 reactions). Three distinct contigs were identified, spanning more than 3500 nucleotide bases with sequence homology to regions of GAPCP-1, GAPCP-2 (Chromosome 1, *Arabidopsis thaliana*) and GACP (Chromosome 3, *Arabidopsis thaliana*). Current work is in progress to identify intron/exon boundaries and determine possible reading frames for protein translation.

***Warnck, J.C. and R. S. Orf*. Department of Biology, Westminster College. INFLUENCE OF PHYSICAL EXERCISE ON RAPID DECISION MAKING IN ATHLETES AND NON-ATHLETES.** This experiment was performed to test the effects of physical exertion, measured as heart rate, on rapid decision-making between athletes and non-athletes. This was tested by administering simple and choice reaction time tasks while subjects pedaled on an *Ergomedic 828E*. Athletes were considered to be individuals who were currently in their respective college sport at Westminster. Non-athletes were considered to be individuals who exercise equal to or less than once a week. Each subject was given a survey prior to experimentation detailing age, gender, sport or physical activity, heart or dehydration problems, concussion history, and color blindness. Upon arrival at the testing facility, subjects were administered a simple choice reaction time test at rest. Simple reaction time tests involved quick response to a dot appearing on a screen. Choice reaction time tests challenged the subject's rapid decision making skills (ie different stimuli presented required an appropriate, or correct, response from the subject). Then, subjects were asked to begin exercise on the *Ergomedic 828E*, wherein more simple and choice reaction time tasks were given at specific heart rates (ie 100 bpm, 120, 150).

***Roberts, J. and E.S. Critser. Science Department, Columbia College. WATER QUALITY ANALYSIS OF PERCHE CREEK USING DAPHNIA MAGNA AS A BIOLOGICAL ASSAY.** This project was designed to assess the water quality adjacent to an abandoned strip coal mine and test the hypothesis that water within the coal mine has reduced quality as assessed by biological parameters. Water samples from Perche Creek were taken from stream locations above (site 1), at (site 2), and below (site 3) in an abandoned strip mine during November 2008, and January and February 2009. We have so far assessed water quality with a fecundity assay of *Daphnia magna*, and an acute assessment of glutathione (GSH) concentration in *D. magna*. The long-term fecundity assay was run using individual specimens (n = 5) cultured in water samples (35 mls) from each site at three different times. Cultures were examined daily and neonates were counted and removed. Brood number and average brood size were analyzed by ANOVA (SAS®). Mean number of broods and mean brood sizes for *Daphnia magna* cultured in water samples collected in November (2.1 ± 0.97SE; 4.0 ± 1.6), January (4.1 ± 0.54; 4.07 ± 0.67) and February (5.13 ± 0.33; 5.9 ± 0.75) were significantly different ($P < 0.05$). However, there was no difference in number of broods or brood sizes amongst sites. A significant ($P < 0.05$) month x site interaction for both number of broods and brood size was obtained. Lifespan data (days) were analyzed by non-parametric analysis (CATMOD, SAS®). There was a significant ($P < 0.05$) effect of site, month, as well as a significant month x site interaction. Water obtained in November had lower mean lifespan, particularly in site 2 (2.6 ± 0.4se) and in site 1 (5.2 ± 1.2) as compared to other sites and times which were greater than 9.0 days. GSH is an essential compound to reduce oxidative stress and free radical exposure. *Daphnia magna* will be cultured for 96 hours in water from each site and month.

GSH content (as a ratio of total protein) will be determined by Ellman's spectophotometric assay. Total protein content will be measured using the Bradford assay. GSH content is expected to decline in response to oxidative stress.

Chemistry

***Sampson, A.D. and D. K. Howell. Department of Chemistry, Park University. PROBLEMS ASSOCIATED WITH THE REMOVAL OF SULFUR FROM HEAVY CRUDE.** Fused ring systems, such as anthracene, act as catalyst poisons to normal hydrodesulfurization catalysts. Heavy crude contains larger amounts of these fused ring systems, which act as competitive inhibitors to standard heterogeneous hydrodesulfurization catalysts used for light crude. The main class of sulfur contaminates in crude oil are benzothiophenes and dibenzothiophenes. These are very similar in structure to fused ring systems with the main difference the large sulfur atom in the central ring. Carbon only fused ring systems can only bond to the metal surface through the π system, η 6 (for a six membered central ring) rather than a single atom η 1. Our research is attempting to design and model a catalyst system bulky enough to block the η 5 or η 6 bonding mode for both fused ring and thiophenes, thereby forcing the catalyst to utilize the η 1 bonding mode only available to the sulfur containing thiophenes. In this way, the catalyst will be effective at removing sulfur from both light and heavy crude oil. Early investigations have shown several molybdenum-sulfide based complexes with possible activity to HDS.

Geosciences

***Aldieri, M.A. and A.W. Johnson. Department of Geology and Geography, Northwest Missouri State University. PETROLOGY OF THE NON-FELSIC ROCKS ASSOCIATED WITH THE SILVERMINES (MO) GRANITE.** We analyzed 16 thin sections from non-felsic dikes cross-cutting the Silvermines Granite to determine the mineralogic composition and petrology of the non-felsic rocks. We used standard point count analysis to determine the type and abundance of minerals in each thin section. Samples consist of carbonates, plagioclase, sericite, olivine, magnetite, and pyrite. The percentage of carbonate in the samples ranged from 8–48%. The approximate percentage of sericite in the samples ranged from 8–58%. Plagioclase composition varied widely. In five samples the percentage of sericite was greater than the percentage of plagioclase and in two of those samples the plagioclase had been nearly completely altered. Olivine was present in six samples, ranging from a trace to 10% of the rock. Opaque minerals were absent in two samples. In the remaining samples, opaque minerals accounted for 6–60% of rock composition. Opaque minerals appear to include mostly magnetite with a small amount of pyrite. Significantly, one sample consisted of 60% magnetite and appeared to include flow induced crystal alignment. This evidence implies a primary magmatic origin for magnetite in this dike. Nine samples included quartz crystals. Quartz made up as much as 50% of rock volume. This analysis reveals that the dikes of the Silvermines area are mafic, have been subsequently altered, perhaps by mineralizing fluids and, in some cases, magma may have encountered the proper conditions to evolve to a magnetite-rich composition. Quartz crystals present in these basalts likely represent xenocrysts liberated from granitic host rocks. This study was supported by the NWMSU Undergraduate Research Program.

***Hunsecker, T.T., J.F. Taulman, S.A. Hageman, and B.L. Hoffman. Department of Natural and Physical Sciences, Park University. COLD WEATHER EFFECTS OF PRECIPITATION, HUMIDITY, AND TEMPERATURE ON THE WATER QUALITY OF THE OSAGE AQUIFER IN LEAVENWORTH, KANSAS. R**ising pollutants in the air and soil, including crop fertilizers, can affect ground water quality. This study evaluates the water quality of a well located on the Osage aquifer by comparing effects of season, precipitation, humidity, and temperature on well water quality. During a six month period, beginning November, 2008, water was drawn from the well on a bi-monthly basis to test for dissolved oxygen, ammonia nitrogen, alkalinity, hardness, chloride, carbon dioxide, pH, and silica. These data will be compared to the average monthly precipitation, temperature, and humidity. Preliminary results indicate that during the winter months, particulate levels are increasing as much as 20 ppm over other seasons. This research will be valuable for many homeowners and farmers that rely on the use of well water for themselves and their livestock and will enable homeowners to know when to purchase water for potable reasons or store well water for low level times of the year.

***Riley, J.J. Department of Geography/Geology, Northwest Missouri State University. INVESTIGATION INTO THE WINDFLOW OF THE NORTHWEST MISSOURI STATE UNIVERSITY CAMPUS AND THE FEASIBILITY OF A MICRO-SCALE WIND FARM.** The purpose of this project is to compare wind flow in a rural and an urban area. These data are then analyzed using a geographic information system model to interpolate and determine if small-scale electricity-generating wind turbines are economically viable on the roofs of urban buildings using the Northwest Missouri State University Campus as a test site. This is done by analyzing the relationship between ground and rooftop wind rates and how their flow changes as they interact with the landscape. By using research on the cost of these turbines, their generating capacity, and current electrical usage and cost information from the University, it is then possible to assess if such a system would be economically viable on the Northwest Missouri State University campus. Also, by comparing different models of vertical axis wind turbines this study will be able to display the most effective model for this University's landscape. This study adds to the understanding of economic feasibility of small wind generators in small urban settings.

Physics

***Boutsabouabane[1], K., S. Mitra[1] and J. Conner[2]. [1]Department of Physics, Astronomy, and Materials Science, Missouri State University and [2]U.S. Photonics Inc. DEVELOPMENT OF A SOL GEL MATRIX FOR THE FABRICATION OF PH SENSORS.** The sol gel process is a chemical synthesis technique for preparing gels. In our study, we are fabricating pH sensors using the chemicals tetraethyl orthosilicate [$Si(OC_2H_5)_4$; TEOS] and bromothymol blue using the sol gel method. Using a previously developed model, we modified some of the chemicals to fit our experiment. Our initial results showed the addition of TEOS, methanol, and hydrochloric acid (HCL) leads to the formation of a gel that is crack free for at least seven days. The molarity of the acid plays a critical role in the development of cracks in the gel during the drying process that typically takes 5–10 days. Some modifications to the previous developed model included adding drying additives such as formamide and lowering the amount of TEOS and methanol. These modifications led to less cracking of gels. Preliminary tests were taken on bromothymol blue. The next phase of the study will be to fabricate a pH sensor by coating a thin glass fiber with the gel. Detecting the color of the emitted light as it is transmitted from the optic fiber through the gel is the first step in the fabrication of the pH sensor.

***Mangan, T.C. and S. Mitra. Department of Physics, Astronomy, and Materials Science, Missouri State University. EFFECT OF VARYING MATERIALS AND LAYERING MODELS ON PHOTOVOLTAIC DEVICE PROPERTIES.** With the many negative aspects of fossil-fuel energy sources, increasing the efficiency and lowering the cost of alternative sources is a vital area of research. Cost and efficiency of a photovoltaic (PV) device, along with all its other properties, are determined by its design and material composition. In this study, we simulated the performance of PV devices using the software Analysis of Microelectronic and Photonic Structures (AMPS-1D). Knowing device design and the layer material absorption coefficients as a function of wavelength in the AM1.5 spectrum, we computed the fill-factor (FF), open-circuit voltage (V_{oc}), short-circuit current (J_{sc}), and efficiency (η) of the device. We first examined the effect of stoichiometry on device properties for $CuIn_{(1-x)}Ga_xSe_2$ (CIGS). We engineered the bandgap of this alloy from 0.97 eV ($x = 0$, $CuInSe_2$) to 1.68 eV ($x = 1$, $CuGaSe_2$), thereby changing the wavelength at which the device is most efficient. We also controled the bandgap of the material by substituting Al for the In or Ga, or substituting S for the Se. Our initial studies indicate the efficiency of device with a 1500 nm thick $CuInSe_2$ (CIS) layer is $9.6 \pm 1\%$. We will present detailed results for devices of varying stoichiometric composition and design.

Social and Behavioral Sciences

***Reader, S.A., T.R. Nixon and M.S. Aruguete. Department of Social and Behavioral Sciences, Lincoln University. MEMORY OF SYLLABUS INFORMATION IN AN INTRODUCTORY COURSE.** Reviewing the syllabus on the first day of class is common, but how much do students remember about the class structure and policies? Our research tested student memory of information contained in the syllabus on two occasions: on the second and last day of class. Results indicated that although students believed the syllabus was very important, their syllabus retention scores only ranged from 48% to 73%. At the beginning of the semester, students remembered more about their instructor and the class policies than at the end of the semester. However, their knowledge of course requirements increased from the beginning to the end of the semester. Retention of syllabus information might be improved if instructors increase the uniformity of syllabi across campus or provide graded assessments of syllabus knowledge.