Louisiana Geological Survey

NewsInsightsonline

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Chip Groat Returns to Louisiana Geological Survey as Acting Director

The Center for Energy Studies, or CES, at Louisiana State University is pleased to announce that Charles "Chip" Groat, Ph.D., will serve as professor and acting director of the Louisiana Geological Survey, or LGS, or the Survey. Groat returns to LSU after many years in academia, government, independent research, and administrative positions. Groat's prior tenure at LSU includes serving as the LGS director and state geologist (1978-1990) and as the executive director for Coastal, Energy, and Environmental Resources (1992-1995). He will work as acting LGS director with CES Executive Director David E. Dismukes to explore new research and growth opportunities for LGS and for LSU's overall energy, coastal and environmental research initiatives.

"We are looking forward to having Chip return to LGS to help us expand its role as the state's center for geological research," said Dismukes. "His extensive research and public policy experience will help the University reach its ambitious energy and environmental research goals."

Groat is a nationally renowned educator and government scientist. Most recently, he retired as president and CEO from the Water Institute of the Gulf. He was professor and director of the Center for International Energy and Environmental Policy and associate director of the Energy Institute at the University of Texas at Austin. He was also director of the U.S. Geological Survey under Presidents Bill Clinton and George W. Bush.

"We are glad to see Dr. Groat re-establish his relationship with LSU and look forward to his contributions in making LGS a very important part of our natural resources exploration activities," said Kalliat T. Valsaraj, Ph. D., LSU vice president for Research & Economic Development.

"I am happy to be re-kindling my relationship with LSU and working on a part-time basis in academia again," Groat said.

The Louisiana Geological Survey (LGS) originated in 1869 and was later officially established by the Louisiana legislature in 1934 (Act 131). LGS is presently a research unit affiliated with Louisiana State University having been legislatively transferred in 1997 from the Louisiana Department of Natural Resources. LGS currently reports through the Executive Director of the Center for Energy Studies to the LSU Vice President of Research and Economic Development.

LGS currently has 13 full time and 4 part time staff including all categories of personnel.

lsu.edu/lgs/

In September of this year, the Louisiana Geological Survey launched a new and improved web site, http://www.lsu.edu/lgs/. The new site conforms to LSUs digital media standards. The LGS cartographic section developed the site emphasizing the importance of geology to our everyday lives. Educational resources are among the header items that are available from the LGS. The data resources page included lists of well logs and core samples collected throughout the state over many years. The core samples can be viewed by setting up a time with the publications expert, Pat O'Neill (poneil2@lsu.edu).

Downloadable data and maps are also available on the site. The Publications page contains a list of maps and publications that are available for a very modest price. Free pdf downloads are available for most 100,000 scale and some 24,000 scale surface geologic maps. The associated digital geologic data are uploaded to the site for public use as quality control is completed on each file.

Louisiana Geological Survey
Earth Science Serving Louisiana
1934

The Louisiana Geological Survey

LOUISIANA GEOLOGICAL SURVEY
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LGS Mission Statement

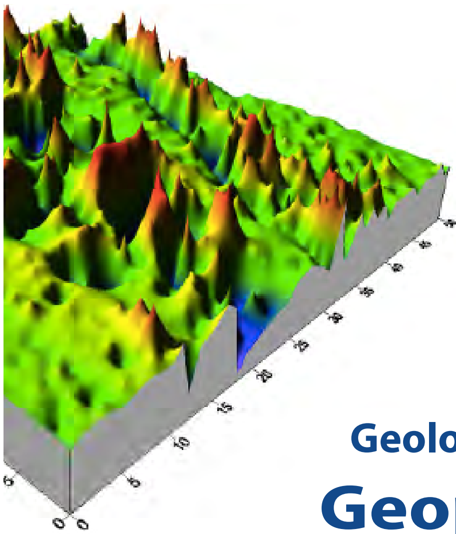
The goals of the Geological Survey are to perform geological investigations that benefit the state of Louisiana by:

(1) encouraging the economic development of the natural resources of the state (energy, mineral, water, and environmental);

(2) providing unbiased geologic information on natural and environmental hazards; and

(3) ensuring the effective transfer of geological information.

The Louisiana Geological Survey was created by Act 131 of the Louisiana Legislature in 1934 to investigate the geology and resources of the State. LGS is presently a research unit affiliated with the Louisiana State University and reports through the Executive Director of the Center for Energy Studies to the Vice Chancellor for Research and Graduate Studies.

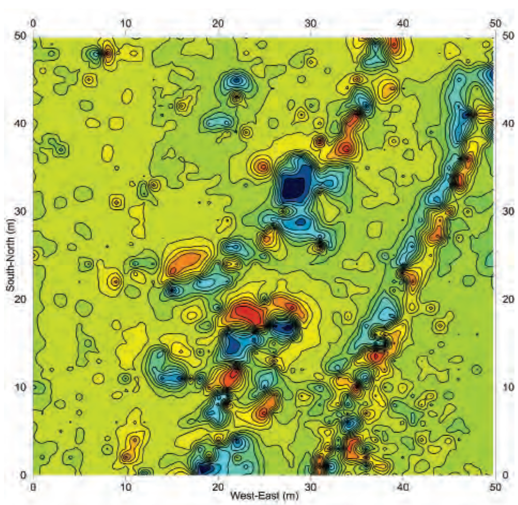


Louisiana Geological Survey Geophysics

Geophysics Section

The Louisiana Geological Survey develops and applies geophysical techniques to shallow subsurface conditions in civil engineering, archaeology, natural resources, and geologic investigations. Anthropogenic features, such as historic ruins, human burials, and buried utilities, are located and mapped based upon electrical resistivity and magnetic field data. Lithostratigraphic layering and its kin - concentrations of Earth materials, water table topology, and fault zone movement - are resolvable with electrical and seismic refraction methods. Natural hazards, such as slumping, creep, and fault displacement, and man-made hazards related to earthen structures, buried utilities, and buried waste are amenable to analysis using all three techniques.

These tools provide information that is vital to the management of natural and historic resources and assessment and mitigation of natural and man-made hazards in the unique geological setting of Louisiana and the greater Gulf Coast province. These techniques have proven successful in a variety of situations and, in collaboration with student and professional geologists, geophysicists, archaeologists, and forensic scientists, **LGS continues to expand its capability and applications.**



A pair of buried electrical conduits on LSU campus resolved as magnetic gradient anomalies.

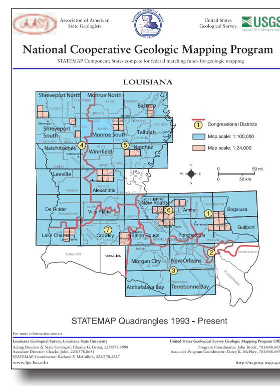
Contracts/Grants

Geologic Mapping

Surface-geologic mapping projects conducted by the Louisiana Geological Survey (LGS) during the past 20 years comprise 1:100,000-scale compilations of 30 × 60 minute geologic quadrangles and 1:24,000-scale field-mapped 7.5-minute geologic quadrangles. The vast majority of these mapping efforts were funded under the STATEMAP component of the National Cooperative Geologic Mapping Program (NCGMP), begun in 1993 and administered by the U.S. Geological Survey (USGS).

The principal goal of this program of geologic mapping for LGS initially was to prepare statewide surface geology coverage at 1:100,000 scale in 30 × 60 minute quadrangle format. This scale was emphasized because it is at the large end of the range of intermediate scales, and preserves abundant detail from source mapping done at larger scales (principally 1:62,500 and 1:24,000) while yet covering relatively large areas. By the close of FY 2013, LGS had completed 30 × 60 minute geologic quadrangle coverage of the entire state (30 sheets total) with a mix of published lithographs and draft open-file compilations.

Since the late 1990s LGS also has prepared 7.5-minute geologic quadrangles at 1:24,000 scale totaling 57 sheets. Forty-seven were prepared with STATEMAP support, and the other ten were prepared for the U.S. Army Corps of Engineers within the Fort Polk region, west-central Louisiana.



STATEMAP 2016–2017 deliverables completed and submitted included geological maps and pamphlets covering four 7.5-minute quadrangles in the greater Lafayette area.

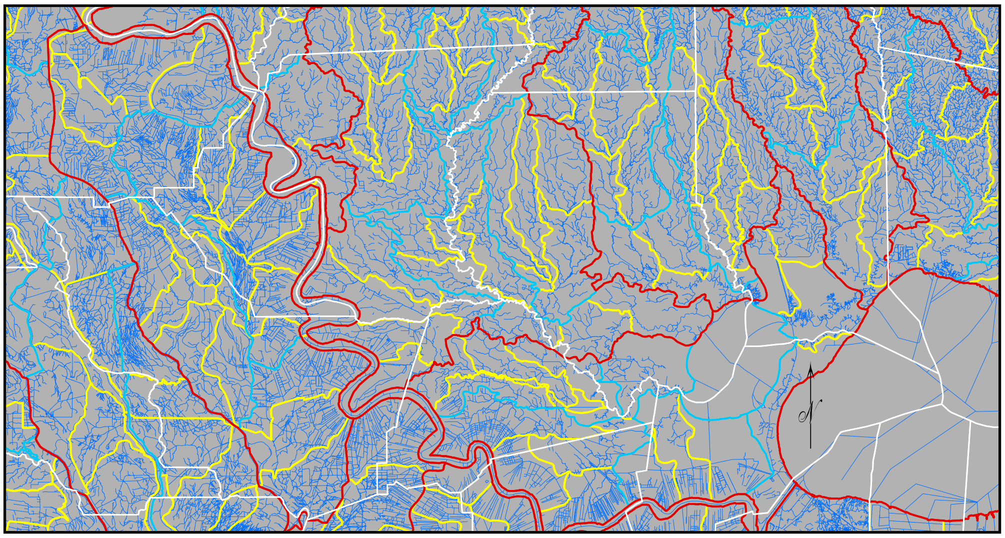
Integrated Carbon Capture and Storage in the Louisiana Chemical Corridor

This 18 month project which commenced in February 2017 is funded by the US Department of Energy and LGS researchers are participants in this project. David Dismukes, Executive Director of the Center for Energy Studies, is the Principal Investigator and LGS researchers are Chacko John and Brian Harder. Other research staff working on this project include Richard Hughes, Mehdi Zeidouni, Muhammad Zulqarnain (LSU Department of Engineering), Keith Hall (LSU Memorial Law Institute) and Juan Lorenzo (LSU Department of Geology and Geophysics) and Brian Snyder (LSU Department of Environmental Sciences).

The objectives of this project are (1) develop a multidisciplinary team of stakeholders with interest in carbon capture and storage in the Louisiana Chemical Corridor, (2) analyze the technical and economic feasibility of an integrated carbon capture and storage project that captures 50 million tons of CO_2 from one or more industrial sources, transport it via pipeline, and store it in underground reservoirs; and (3) provide a geologic evaluation of the potential for CO_2 storage in saline reservoirs found in depleted oil and gas fields in South Louisiana. The LGS role is to provide a geological evaluation of saline formations with requisite shale seals in Bayou Sorrel (Iberville Parish) and Paradis Fields (St. Charles Parish) along part of the Mississippi River Industrial corridor which has a concentration of petro-chemical industries that generate large volumes of CO_2 emissions.

National Hydrographic Dataset

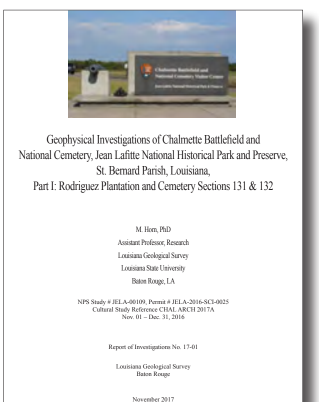
This year R. Hampton Peele was asked to become the new editor of the National Hydrographic Dataset for Louisiana (NHD). He will be performing the required research and data development as needed to correct existing errors and update the NHD as changes to Louisiana's hydrography occur. Due to the dynamic nature of water, the NHD is a "living dataset" that will always require maintenance. NHD data have been developed for the entire country through a joint effort by the U. S. Environmental Protection Agency and the U. S. Geological Survey. These data are used for a wide range of applications, from cartography, to water quality monitoring, to flood modelling and mapping. This research project is funded by Louisiana Department of Environmental Quality with an assistance grant from USGS.



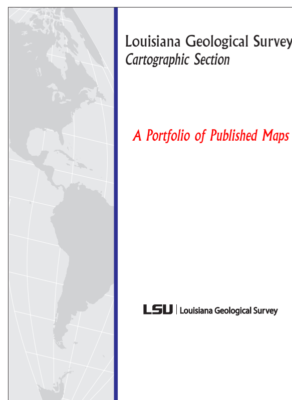
LGS Publications 2017

This years publications include:

- *Geophysical Investigations of Chalmette Battlefield and National Cemetery, Jean Lafitte National Historical Park and Preserve, St. Bernard Parish, Louisiana,* by M. Horn, 2017. View online.
- *Broussard 7.5 Minute Geologic Quadrangle* (Paul Heinrich, and Richard McCulloh)
- *Lafayette 7.5 Minute Geologic Quadrangle* (Paul Heinrich, and Richard McCulloh)
- *Milton 7.5 Minute Geologic Quadrangle* (Paul Heinrich, and Richard McCulloh)
- *Youngsville 7.5 Minute Geologic Quadrangle* (Paul Heinrich, and Richard McCulloh)



Map Lithographs



Louisiana Geological Survey has created A Portfolio of Published Maps, a 66-page example of maps produced by the Survey's Cartographic Services section since 1980. The full-color publication showcases the wide-ranging cartographic design technologies used by LGS in creating maps of Louisiana's offshore oil and gas structures, river basins, aquifers, estuarine basins and more.

To view the portfolio, log on to https://filestogeaux.lsu.edu/public/download.php?FILE=lgpond/74335IzsEZz

For more information, contact LGS at 225.578.5320.

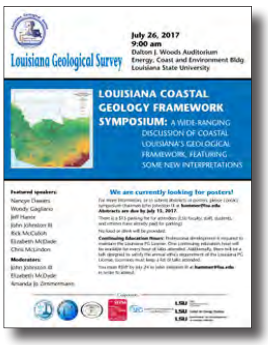
LGS Outreach Activities

Louisiana Governor John Bel Edwards

Earth Science Week: Sponsored Nationwide by the American Geoscience Institute (AGI) and at the request of LGS, Louisiana Governor John Bell Edwards issued a proclamation declaring October 9-15 as Earth Science Week 2016. This week's celebration placed emphasis on energy, paleontology, water quality, conservation and climate change.

As in previous years, LGS received 50 educational kits from AGI which were distributed to K-12 school earth science teachers with the assistance of the Louisiana Department of Natural Resources Office of the Public Information Director.

Louisiana Coastal Geology Framework Symposium: John Johnston III of the Louisiana Geological Survey hosted the Louisiana Coastal Geology Framework Symposium on July 26th, 2017, which was co-sponsored by both the Center for Energy Studies and the School of Coast and the Environment. The symposium was designed to showcase cutting-edge research into Louisiana's coastal geology which had not yet reached the publication stage. Presentations were made by Chris McLindon, Sherwood Gagliano, Jeff Hanor, Nancye Dawers, Rick McCulloh, John Lopez. Elizabeth McDade, and John Johnston III. A poster session featuring works by numerous graduate students and faculty of various Louisiana universities accompanied the presentations. After the presentations an enlightening joint question and answer session was held. The symposium was viewed as a great success and is likely to be reprised in 2018.



Rockin' the Swamp: LGS participated in "Rockin' the Swamp", a one-day educational outreach event for schools and the general public organized by Baton Rouge Parks and Recreation Bluebonnet Swamp Nature Center on Saturday March 9, 2017. The LGS exhibit booth displayed a poster of the Brushy Creek Meteorite Impact Crater in St. Helena Parish, rocks and minerals specimens found in Louisiana and other places, and thin sections of rocks and the Greenwell Springs Meteorite which was discovered in 1987 just northeast of Baton Rouge, LA in Livingston Parish. The LGS's Scope-on-a-Rope was set up to view rock and mineral specimens, or anything else attendees desired to view (i.e. skin, plant parts etc.) on a TV/monitor screen. Fossils specimens from Louisiana and around the world were also displayed. The LGS booth proved to be one of the star attractions for the hundreds of children and adults attending the event. The event also featured gem and mineral vendor booths and other natural science exhibits, including "Gold" mine, treasure trial, Stone Crafts, Fossil Quarry, Rock Climbing Wall, and Rockhound Market.

Earth As Art: Inspired by the success of last year's **Earth As Art** exhibit at the Galleries at Manship, in Baton Rouge's Shaw Center (see 2016 LGS newsletter), R. Hampton Peele of Louisiana Geological Survey teamed up with Dr. R. Eugene Turner of the Dept. of Oceanography and Coastal Sciences to design and install a mini display of four beautiful satellite images of our Earth from space. The images were originally produced by USGS and NASA through their joint project, *"Earth As Art"*. The project was designed to reach a broader constituency of supporters for their earth-imaging satellite programs. While the original intent for the *"Earth As Art"* project was to showcase the artistry of satellite images, Peele and Turner see these images as powerful educational resources for LSU students, faculty, and their guests.

An additional panel has been developed by Peele and DeWitt Braud of Coastal Studies Institute, with assistance from Lisa Pond (LGS) to explain the science and technology of satellite remote sensing. Four new satellite images will be rotated into the display regularly. This mini *Earth As Art* series is on display across the hall from Room 1209 in the Energy Coast and Environment building. Come by and view these spectacular, revealing images of our Earth.

LGS Resource Center

The LGS Resource Center consists of a core repository and log library. It is located behind the old Graphic Services building on River Road. Most of our cores are from the Smackover and Wilcox Formations. The core facility has more than 30,000 feet of core from wells mostly in Louisiana. The well log library contains over 50,000 well logs from various parishes in the state. The Core Lab is equipped with climate controlled layout area, microscopes, and a small trim saw. The core and log collections are included as part of the LSU Museum of Natural History as defined by the Louisiana Legislature and is the only one of its kind in Louisiana.The LGS Resource Center is available for use by industry, academia and government agencies, and others who may be interested. Viewing and sampling of cores can be arranged by calling Patrick O'Neill at 225-578-8590 or by email at poneil2@lsu.edu. Please arrange visits two weeks in advance. A list of available cores can be found at the LGS web site, lsu.edu/lgs/.

Conference Publications and Presentations

LGS research staff authored/co-authored publications and made presentations at various professional conferences at detailed below:

McCulloh, R. P., 2017, The challenge(s) of surface-geologic mapping in Louisiana; Presentation to the monthly meeting of the New Orleans Geological Society on 10 July, 2017, (recorded and now posted online by NOGS at https://www.youtube.com/watch?v=ygtVMdqT2VA).

McCulloh, R. P., 2017, Surface indicators of possible basement structure in Louisiana; Presented to the first Louisiana Coastal Geology Framework Symposium on 26 July, 2017 in the Dalton Woods auditorium.

Douglas Carlson and Marty Horn, 2017, What are the Impacts of a Dense Field of Septic Systems on Groundwater Quality?: Gulf Coast Association of Geological Societies Transactions, v. 67, p. 79-94

Douglas Carlson, 2017, A comparison of Holocene climatic optimum periods are they as warm post little ice period and are greenhouse gas concentrations similar?: Gulf Coast Association of Geological Societies Transactions, v. 67, p. 39-78.

Douglas Carlson, 2017, Influences on water quality of the Wilcox Aquifer in Northwest Louisiana: Louisiana Geological Survey & Louisiana Water Resources Research Institute's 11 th Annual Louisiana Groundwater, Surface Water, and Water Resources Symposium, April 11, 2017.

Douglas Carlson, 2017, Has initial development of Haynesville Gas Play impacted water quality of the overlying Wilcox Aquifer?: Louisiana Geological Survey & Louisiana Water Resources Research

Institute's 11 th Annual Louisiana Groundwater, Surface Water, and Water Resources Symposium, April 11, 2017.

Douglas Carlson, 2017, Influences on and Changes of Water Quality of the Wilcox Aquifer in Northwestern Louisiana: Baton Rouge Geological Society, Baton Rouge, Louisiana, April, 7, 2017.

Earth, Rocks, Minerals and Fossils

On September 8th, 2017, John Johnston and Riley Milner of the LGS made requested geological presentations at the Sunrise assisted living center on Siegen Lane in Baton Rouge. Johnston delivered a PowerPoint presentation about the fundamental processes of the Earth, and Milner delivered a hands-on presentation about the rocks, minerals, and fossils of the Earth. The presentations were well-received by the residents and the staff.

A Comparison of Holocene Climatic Optimum Periods: Are they as Warm as the Post–Little Ice Age Period and are Greenhouse Gas Concentrations Similar?

Douglas Carlson

There have been a number of studies that have observed that there is a variability of temperature as indicated from analysis of stable isotope data throughout the Holocene. The Holocene includes six warm periods (including the current one) and five cool peri-ods, some of which have been named. Named warm periods include Holocene Climate Optimum, first portion, 6200 to 7700 years before present (BP); Holocene Climate Opti-mum, second portion, 3500 to 4700 BP; Roman Climate-Optimum, 300 BC to 400 anno domini (AD); and Medieval Warm Period, 700 to 1300 AD. Named cool periods include Dark Age, 400 to 700 AD; and Little Ice Age, 1300 to 1850 AD. Another unnamed peri-od is a cool period that was between 750 and 300 BC. The question to consider is how similar is each of the periods to the current Modern Warm Period in terms of temperature and concentrations of greenhouse gas and other measured properties as recorded in either ice cores, cave formations, or fossils. This involved compiling records of greenhouse gas concentrations, temperature data from oxygen isotope data, sulfate, and total dust concentrations and comparing distribution of these concentrations among the different climate periods within the Holo-cene by two statistical tests: Mann-Whitney ranks and Wilcoxon rank sum used to de-termine the statistical confidence of the differences between climate periods. That is, is the current warm period similar to other warm periods? It appears that the current warm period has statiscally significant higher concentra-tions of greenhouse gases than earlier warm periods. However, the temperature data appear to be more equivocable. Overall, it appears that solar irradiance has had more of an effect on temperature than greenhouse gases.

What are the Impacts of a Dense Field of Septic Systems on Groundwater Quality?

Douglas A. Carlson and Marty Horn

This was initiated to address public concerns about the chemicals present within the fracturing solution to be used in development of an unconventional hydrocarbon deposit in southeastern Louisiana as a possible source of contamination of their drinking water. Establishment of baseline water quality by testing existing residential water wells was done prior to fracing and revealed significant variability of water quality. This variabil-ity maybe due to residential septic system density as apparent between areas with aver-age lot sizes of about 0.5 acres to those over 1.5 acres. Samples were collected from 100 domestic water supply wells mainly screened across a shallow sand that is less than 300 feet below the surface. Each sample was analyzed for the following ions and compounds: arsenic, benzene, boron, bromide, butane, cadmium, calcium, chloride, chromium, copper, ethane, ethylbenzene, fluoride, iron, lead, magnesium, manganese, methane, nickel, nitrate, nitrite, pentane, pH, phosphate, phosphorous, potassium, propane, silicon, sodium, specific conductance, strontium, sul-fate, toluene, xylenes, zinc, and total dissolved solids (TDS). Within the study area is a subdivision that can be split into residential developments of two different densities, which contained approximately half of all of the study's wells. The southern half of the development has lots typically between 1.5 and 2.5 acres. The northern half of the development has lots typically less than 0.5 acres. Results are such that the septic system density appears to influence ion concentrations. Ground water concentrations of aluminum, barium, bromide, calcium, chloride, copper, iron, magnesi-um, manganese, methane, nitrate, phosphorous, potassium, sodium, strontium ions, and TDS are significantly higher for the more-dense portion of the subdivision than for the lower density portion of the subdivision.

Surface Indicators of Possible Basement Structure in Louisiana[1]

Richard P. McCulloh

Overview

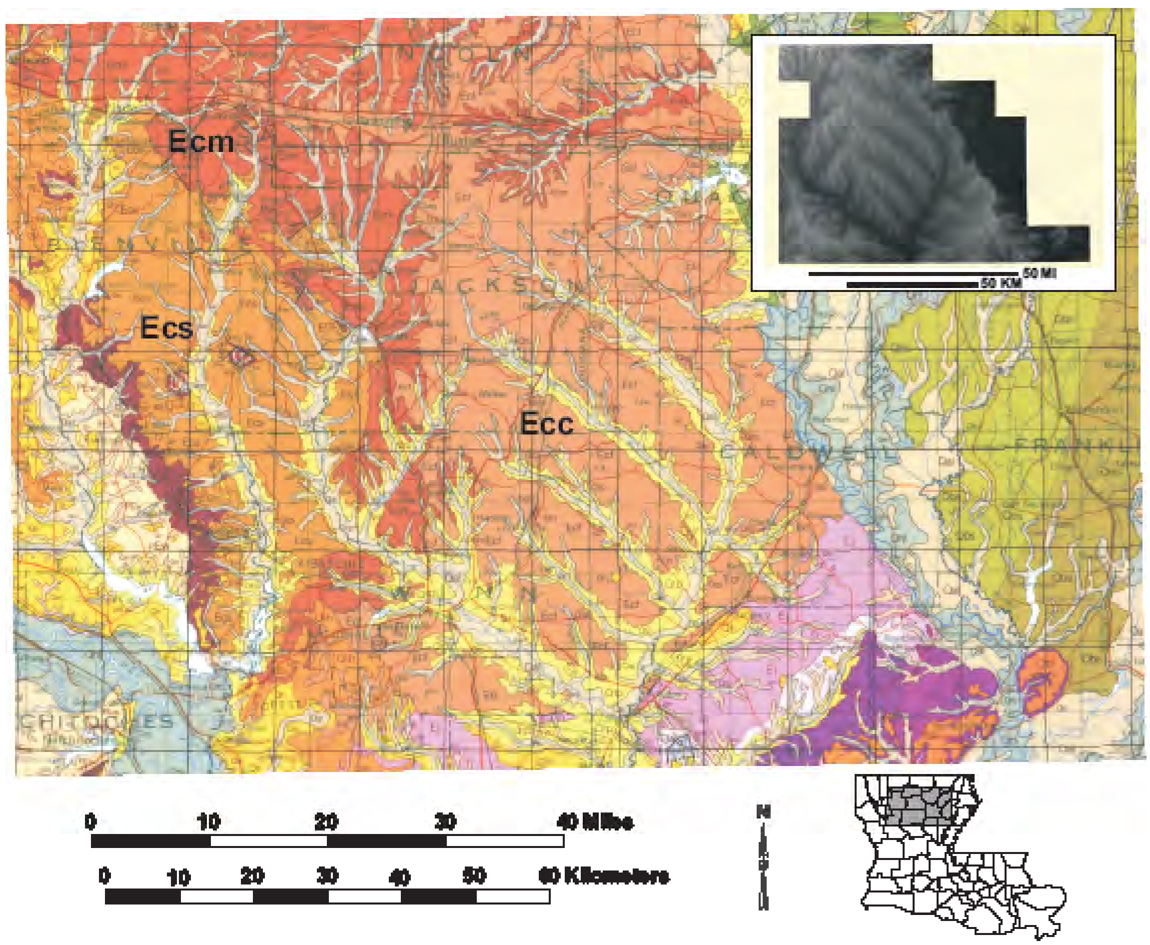
Linear surface features, broadly designated as lineaments, are collectively numerous in Louisiana, including a large proportion that are traceable in Pleistocene strata. They manifest primarily as straight aspects of river and stream courses, bottoms, and valley walls, and their resultant patterns. These features lack obvious correspondence with mapped surface faults and may reflect the effects of systematic jointing. Because they extend without obvious interference across the faulted Quaternary terrane of south Louisiana, where the stress regime since the early Pleistocene has reactivated subsurface Paleogene and Neogene growth faults and given them surface expression, the largely different lineament trends likely are unrelated to current regional stress conditions and represent propagation of older structural trends from depth. In at least one case a distinct surface lineament in Pleistocene sediment coincides with a specific structural trend previously inferred as a regional strike-slip fault zone related to Jurassic rifting and the opening of the Gulf of Mexico. Occurrence of lineaments in strata ranging in age from early Cenozoic to late Pleistocene suggests the possibility that eventually they also could appear in Holocene sediment of the chenier and delta plains in the Louisiana coastal zone.

[1]Adapted from a presentation given at the first annual Louisiana Coastal Geology Framework Symposium, 26 July 2017, Louisiana State University, Baton Rouge. The term *basement* as used in the title of this article refers to rocks and structures older than Upper Cretaceous, which is the age of the oldest rocks exposed at the surface in Louisiana.

Introduction

Natural linear surface features with potential geologic-structural significance are common in Louisiana despite the coastal-plain setting, humid subtropical climate, and consequent scarcity of exposures of "bedrock" geologic map units. These *lineaments* are map- and image-based, and as used here they are scale-independent. This definition is descriptive and geomorphologic, and appears essentially the same as that employed by Baumgardner (1987). In practice, Louisiana lineaments mostly comprise hydrographic features, typically consisting of drainage courses and their associated aspects and attributes, especially those relating to perceptible straightness. The Little River drainage system in north-central Louisiana is the first introduction to lineaments in our state for many geologists, because it is a large array that stands out on small-scale compilations of surface geology.

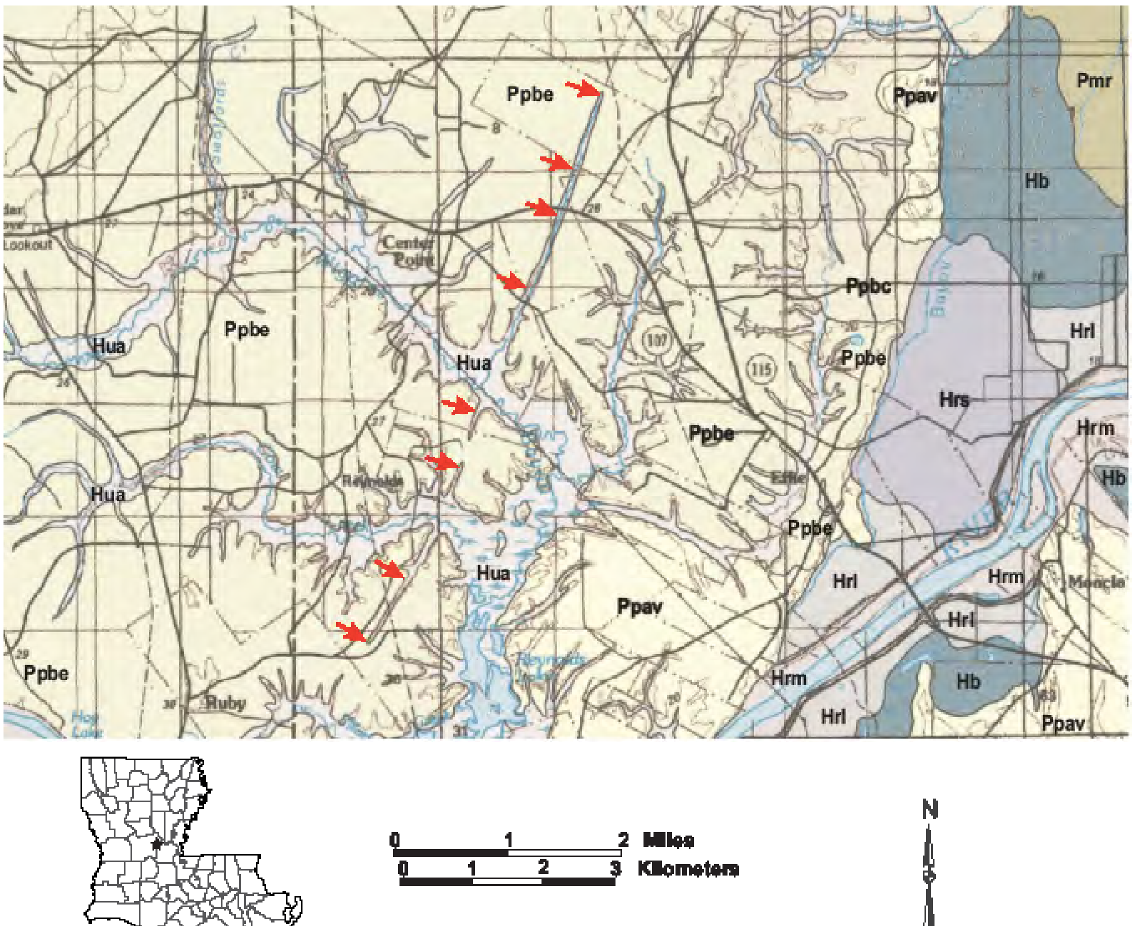
Fisk (1944) appears to have been the first geologist to interpret lineaments in Louisiana. He labeled his features "fault zones," though essentially they were photolineaments (straight trends interpreted from aerial photographs), and he adduced no independent evidence indicating they were faults. An influential author on lower Missis-



Lineaments developed in Eocene strata of the Claiborne Group, on a labeled excerpt from a 1:500,000-scale geologic map (Snead and McCulloh, 1984): the Little River drainage basin. Inset is an image prepared from a mosaic of 1:24,000-scale digital elevation models. Ecc, Cockfield Formation; Ecm, Cook Mountain Formation; Ecs, Sparta Formation.

sippi River valley geology after Fisk was R. T. Saucier, who initially accepted Fisk's lineaments (Saucier, 1963), but later dismissed them and was unreceptive to similar interpretations (Saucier 1974, 1994). Since the mid 1980s and especially the early 1990s, however, increasing numbers of investigators (e.g., Adams, 1993; Zimmerman, 1992, 1994, 1995, 1996; Milner, 2006; Stephens, 2009) have interpreted strike-slip fault zones traversing Louisiana that formed during Mesozoic rifting and the opening of the Gulf of Mexico, and such regional structures could create lineaments. One lineament on a draft surface-geologic map covering an area in northwestern Avoyelles Parish corresponds in position and orientation to one of the wrench faults interpreted by Zimmerman (1992, 1994, 1995, 1996) as associated with Jurassic rifting.

In recent decades, most newly revealed examples of rectilinear drainage and lineaments followed directly from geologic-mapping activities. In most of the years since 1989, the Louisiana Geological Survey has participated in annual cooperative agreements with the U.S. Geological Survey via programs created for the specific purpose of supporting new geologic mapping. Between 1989 and 1993, the COGEOMAP program emphasized 1 × 2 degree quadrangle areas at 1:250,000 scale. Beginning in 1993, the STATEMAP component of the congressionally authorized National Cooperative Geologic Mapping Program offered support to the states for new large-scale geologic mapping (7.5-minute quadrangles at 1:24,000 scale) and intermediate-scale map compilation efforts (30 × 60 minute quadrangles at 1:100,000 scale). These activities have led to the discovery of numerous lineaments on images and completed geologic maps at all scales of presentation. None of these features alone represents a conclusive indicator of structural control, however, the multitude of surface indicators collectively supports some likelihood of structural influence.



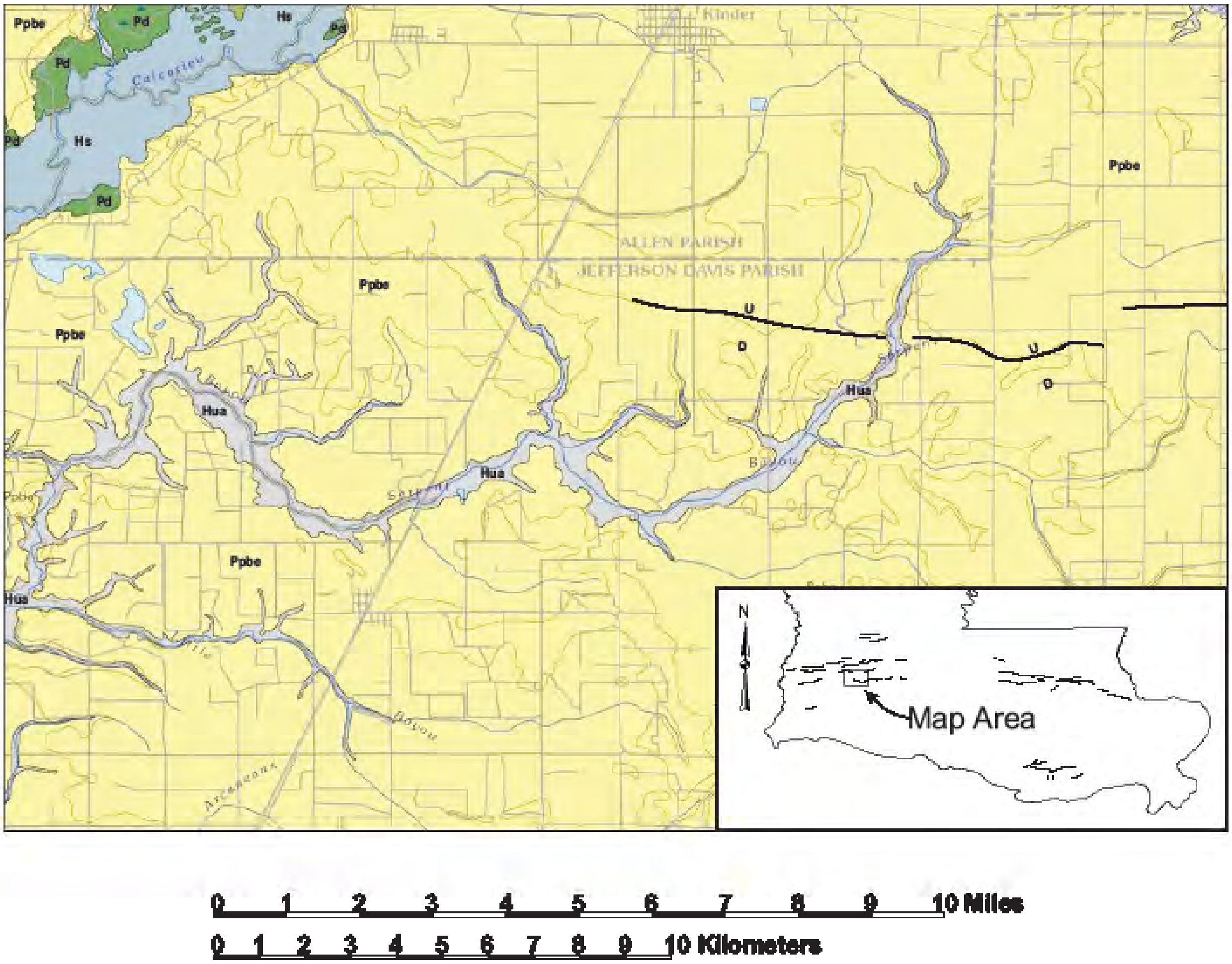
Lineament (red arrows) developed in Pleistocene strata, on a labeled excerpt from a 1:100,000-scale geologic map (McCulloh and Heinrich, 2004). Source mapping of the area figured, by John Snead at 1:24,000 scale, originally was part of a cooperative agreement with the U.S. Geological Survey to compile a draft 1:250,000-scale rendering of the surface geology of the Alexandria 1 × 2 degree quadrangle (Louisiana Geological Survey, 1993). The composite, curvilinear feature incorporates different tributary segments of both Cow Creek and Wiggins Bayou, lies within one of Zimmerman's (1992, 1994, 1995, 1996) interpreted wrench-fault zones, and has an average orientation of N 23° E, identical to the strike of the wrench-fault trend. It also appears very nearly parallel to the Pleistocene–Holocene contact lying approximately 3 miles (5 kilometers) to the east. **Ppbe**, *Beaumont Alloformation, Pleistocene Prairie Allogroup;* **Ppav**, *Avoyelles alloformation, Pleistocene Prairie Allogroup;* **Ppbc**, *Big Cane alloformation, Pleistocene Prairie Allogroup;* **Pmr**, *Macon Ridge alloformation, Pleistocene Braid Belts / Valley Trains;* **Hrm**, *Holocene Red River meander-belt deposits;* **Hrl**, *Holocene Red River natural levee deposits;* **Hrs**, *Holocene Red River crevasse splay deposits;* **Hb**, *Holocene backswamp deposits;* **Hua**, *Holocene undifferentiated alluvium.*

Because lineaments show no clear correspondence with mapped faults, the next most plausible control at the surface is *joints*, or fractures with no (or negligible) displacement. There is one area in the state where joint strikes (orientations at the surface) accord with nearby stream orientations—at Longleaf Vista, Red Dirt Wildlife Management Area, Kisatchie National Forest, southern Natchitoches Parish, in west-central Louisiana (McCulloh, 1995)—but this is an area with abundant hard sandstone of the Catahoula Formation, which is notably different from the unconsolidated to poorly consolidated sediments that dominate the surface in many other parts of the state. Among joint measurements from 15 localities in the Fort Polk region, also in west-central Louisiana, "[t]he particular joint sets expressed can differ greatly at nearby localities" and "no regional continuity of joint-strike trends appears visually traceable across the study area" (McCulloh and Heinrich, 2002, p. 53), suggesting the potential for variable/differential expression of joints in relation to material properties (e.g., bed thickness, grain size) of the substrate.

Recognition of Louisiana Lineaments

Systematic fractures (faults or joints or both) are those occurring in sets characterized by consistent strikes. Drainage patterns regarded as indicative of control by systematic fractures include rectangular drainage (where straight drainage segments show 90° junctures) and rectilinear drainage (where drainage segments show relative straightness and parallelism, but intersect at angles other than 90°). Rectilinear drainage is the more inclusive term and is emphasized here, with rectangular drainage recognized as a specific subset. In a rectilinear drainage network, any individual straight segment that may be perceived or interpreted on maps or imagery would qualify as a lineament according to the definition given above.

In practice, however, straightness and parallelism often are composite percepts (i.e., different straight and/or parallel aspects and attributes may link up to form a single composite linear feature with perceived straightness), and their perception by different observers may differ in detail, making them ultimately subjective. "Straightness" may refer to this attribute of a stream channel, of a relatively narrow zone in which a channel meanders, of an alluvial bottom of fairly constant width, or of valley walls. "Parallelism" refers to a finite number of recurring orientations of "straight" attributes. Louisiana drainage patterns manifest a spectrum of attributes ranging between

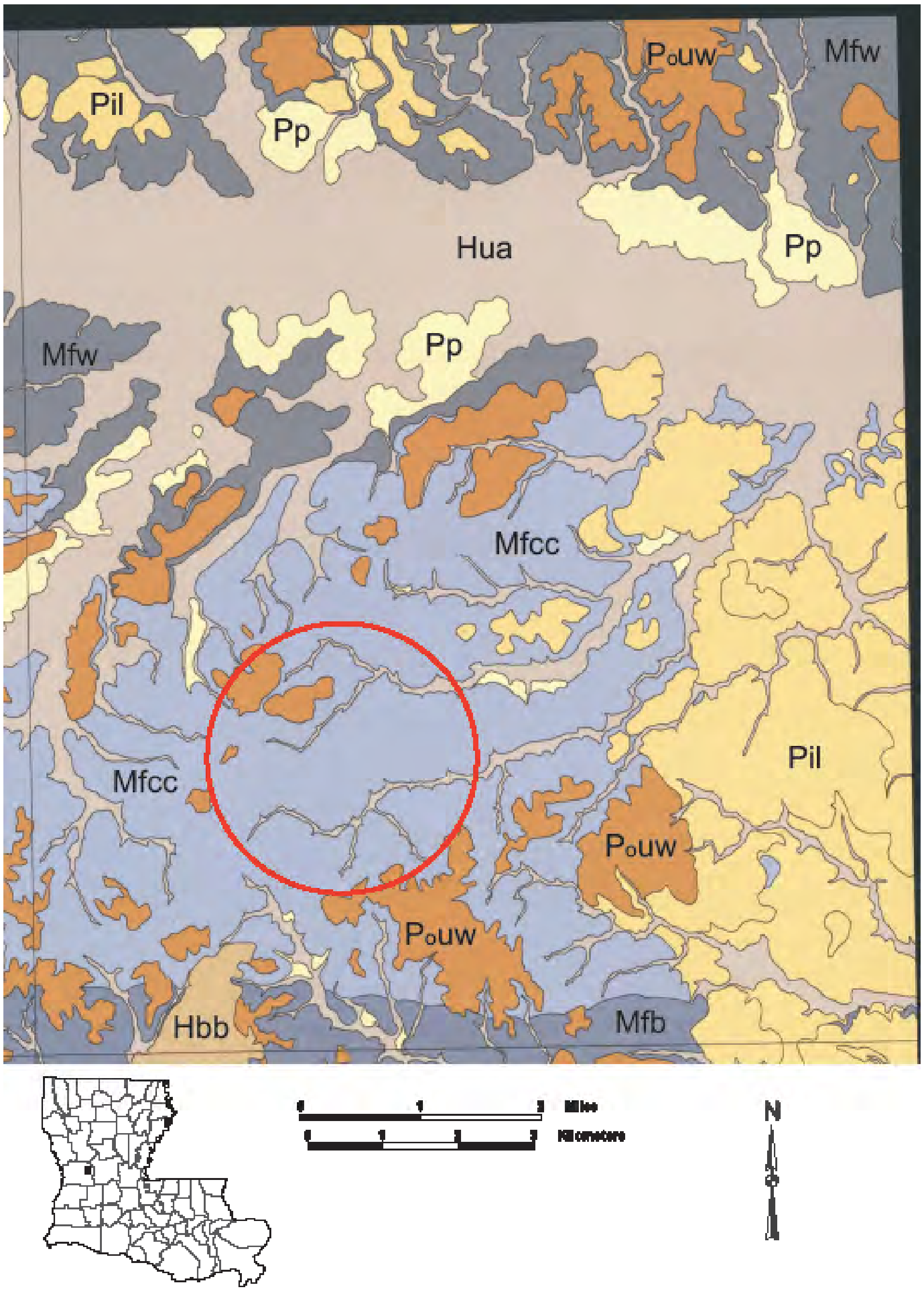


Lineaments developed in Pleistocene strata, on an excerpt from a 1:100,000-scale geologic map (Heinrich et al., 2003): Bayou Serpent and the Calcasieu River valley. The surface faults in the east-central portion of the image are reactivated growth faults of the Tepetate system; the index map shows the extent of the excerpted area on a generalized presentation of surface faults in south Louisiana. **Ppbe**, *Beaumont Alloformation, Pleistocene Prairie Allogroup;* **Pd**, *Pleistocene Deweyville Allogroup, undifferentiated;* **Hs**, *Holocene small river deposits, undifferentiated;* **Hua**, *Holocene undifferentiated alluvium.*

rectilinear and nearly dendritic. No two observers will perceive rectilinear attributes identically (or receive identical impressions of their meaning) if no compelling adjacent bedrock geology (faults, joints) is apparent from maps, images, or ground observations. At the very least, however, the map products resulting from federally funded geologic-mapping projects over the past 25+ years have indicated that areas with rectilinear drainage characteristics in our state are common outside the larger areas of Holocene deposits (the areas of coastal marsh and the Mississippi River flood plain).

Standardized/Automated Recognition of Surface Lineaments Using Stream-Net Data

Because of the inherent subjectivity in perception and interpretation of lineaments, it would be desirable to develop more objective statistical, automated, and standardized techniques for recognition of surface lineaments in a population of stream-net data. Truly dendritic drainage should generate an approximately random distribution of orientations (Morisawa, 1963; Scheidegger, 1980), but requires both an extremely flat (even and level) surface and a homogeneous substrate,



Lineaments (area within red circle) developed in Miocene strata and perceptible at 1:24,000 scale: Lacamp 7.5-minute quadrangle surface geology, excerpted from a ten-quadrangle geologic map of the Fort Polk region (McCulloh and Heinrich, 2002) and labeled. **Mfw**, *Williamson Creek Formation, Miocene Fleming Group;* **Mfcc**, *Castor Creek Formation, Miocene Fleming Group;* **Mfb**, *Blounts Creek Formation, Miocene Fleming Group;* **$P_o$uw**, *Willis Formation, Pliocene Upland allogroup;* **Pil**, *Lissie Formation, Pleistocene Intermediate allogroup;* **Pp**, *Pleistocene Prairie Allogroup, undifferentiated;* **Hbb**, *Holocene Big Brushy formation;* **Hua**, *Holocene undifferentiated alluvium.*

a combination that is relatively uncommon even in our state. Deviations from a random distribution should reflect deviations from either or both of these preconditions. Either type of deviation may reflect geological structure: a single trend could represent the regional dip of strata and overall drainage gradient; and drainage directions that cluster in a limited number of consistent orientation trends would be suggestive of substrate inhomogeneity, whether because of structure or rock fabric. A nonuniform, "spiky" orientation-frequency pattern with multiple maxima cannot be due to slope alone, and must entail some measure of inhomogeneity, the principal suspected geological cause of which in most terranes typically would be systematic fractures, although bedding could account for one trend.

To date, two attempts to extract a structural or lineament signature from Louisiana stream-net data using directional-analysis software, following the general procedure outlined by Scheidegger (1980), produced mixed results. One (McCulloh, 2003) indicated a strong north-south trend, a weaker N 20–30° W trend, and a faint N 80–90° W trend for a statewide dataset. The other used better-quality stream-net data for each of 10 hydrologic units (drainage subbasins) that collectively extend from north Louisiana to south Louisiana centered approximately between 93° and 92°30' west longitude. In this case each hydrologic unit generated orientation frequencies with strong cardinal (N-S and E-W) and weaker diagonal (NW-SE and NE-SW) maxima. The directional summaries, however suggestive (see below), showed observable peculiarities suggesting that these seemingly meaningful trends may have been influenced by data-processing artifacts that would make the data unsuitable for this type of exercise, and ultimately it was not possible to accept the results with confidence.

Inferred Genesis of Louisiana Lineaments

Lineaments occur in strata ranging in age from early Cenozoic to late Pleistocene, in all parts of the state where such strata lie at the surface. Those in south Louisiana are juxtaposed in places with the traces of reactivated Paleogene and Neogene growth faults originally known from the subsurface. The south Louisiana stress regime that reactivated these growth faults and gave them surface expression began in the early Pleistocene (Nunn, 1985). Thus, the largely different lineament trends likely are unrelated to current regional stress conditions, and if they reflect the influence of joints, it appears the joints likely were propagated from deep older structures into increasingly young overlying strata, as outlined by Blanchet (1957), Hodgson (1965), Gay (1973, 1995), Mollard (1988), and others.

The occurrence together at a given locality of cardinal (N-S – E-W) plus diagonal (NW-SE – NE-SW) lineament trends and/or joints has been observed in some parts of the world, and has been interpreted in places as reflecting propagation of older structural trends from depth (e.g., Katterfeld, 1976). This pattern also has been observed in Louisiana, both for lineaments and for joints, albeit sparingly.

Epilogue: Lineament Studies in Louisiana

Fisk's (1944) lineament interpretations appear to have been the first in Louisiana, and more than a half century later still receive intermittent corroboration (e.g., Kinsland et al., 2003, via mapping of gravity and magnetic data in west-central Louisiana). After Fisk's work, numerous authors since the 1980s have interpreted regional strike-slip fault zones, associated with Mesozoic rifting and opening of the Gulf of Mexico, traversing parts of Louisiana. Such structures could create lineaments, and one example of a lineament on a surface geologic map corresponding to such an interpreted wrench-fault trend is known from northwestern Avoyelles Parish.

Joints at the surface likely control drainage lineaments, possibly as zones in which fracture density increases (e.g., Blanchet, 1957, his figure 5). It seems plausible that joints may be exploited more readily in poorly consolidated strata, such as characterizes much of the surface of Louisiana, than in harder-rock terranes, but this remains speculative at present.

In south Louisiana, lineament patterns similar to those farther north are spatially juxtaposed with growth faults at the surface in places, yet the two seem not clearly related to each other, like different episodes of writing on a palimpsest scroll. The south Louisiana stress regime since the early Pleistocene has been reactivating the growth faults, which mostly have arcuate traces with dominantly east-west average strikes. Thus, if the juxtaposed lineaments reflect joints, it appears they are unrelated to the current stress regime in south Louisiana, and likely reflect propagation of older structural trends from depth.

Difficulties attending the investigation of Louisiana lineaments are that alluvial courses conceal any structures that may affect them, and that joints, which lack displacement, will be invisible in cross section and probably on most seismic records as well.

Louisiana lineaments occur in all surface pre-Holocene strata (except for the relatively small exposures of upper Cretaceous limestone on the crests of Prothro and Rayburns salt domes in Bienville Parish). Unambiguous lineaments are not yet known in the Holocene of the Louisiana Coastal Zone except for those attributable to reactivated growth faults that reach the surface in wetlands and are marked by sharp, broadly curvilinear land-loss patterns. After sufficient compaction, however, Holocene sediment will become capable of experiencing brittle fracture, following which there is reason to expect lineaments similar to those in older strata to appear in onshore Holocene terranes. In geologic terms, this would happen relatively soon. In human terms, it may not happen for millennia, and may be delayed somewhat further depending on potential acceleration of the rate of relative sea level rise in south Louisiana and reinundation of much of the coastal Holocene sediment that at present lies onshore.

Acknowledgments

A review of the abstract by Paul V. Heinrich led to its substantial improvement.

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Progress Report On Determination Of Chloride, Nitrate And Other Ion Concentrations In Mississippi Alluvial Aquifer In Northeast Louisiana

Douglas Carlson

Introduction

The Mississippi River Alluvial Aquifer is the principal to sole aquifer supplying groundwater in northeastern Louisiana (Figure 1). It accounts for over 90% of the groundwater supplied for all but Morehouse Parish. For the full study area the Mississippi River Alluvial Aquifer in 2000, 2005 and 2010 accounts for 94% of all groundwater used in the nine parish study area (Sargent, 2002, 2007 and 2011) and 100% of groundwater used in three parishes: Franklin, Madison and Tensas for 2000, 2005, and 2010 (Sargent, 2002, 2007, and 2011). In the past fifty years groundwater use has increased in terms of the number of gallons and percentage of all water used in the nine parish study area (Figures 2 and 3) which are largely being drive by a large increase in the number of acres of cropland irrigated within the study area (Figure 4). There has even been slight increase in the share of groundwater used that is drawn from the Mississippi River Alluvial Aquifer from 89% in 1990 (Lovelace, 1991) to 93% in 2010 (Sargent, 2012)

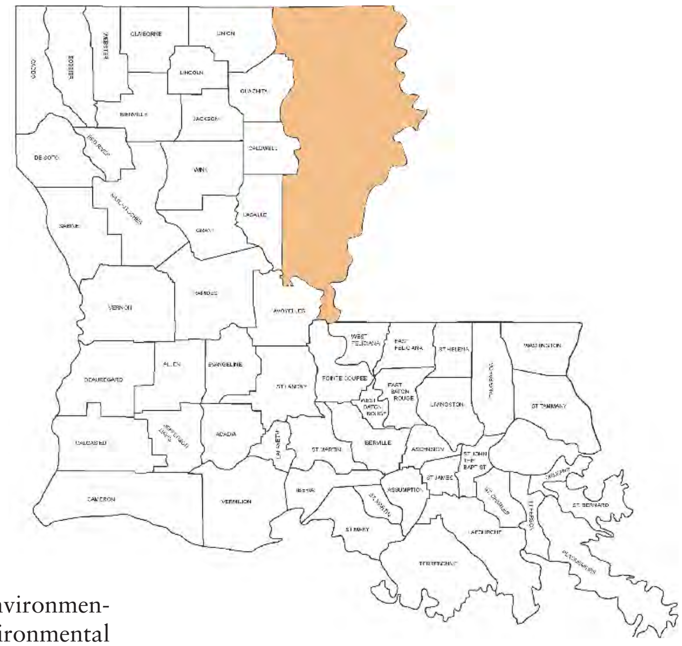

Figure 1. Location of study area.

Three reports have noted pockets of saltwater, as indicated by high chloride concentrations that lie in an axis from eastern Morehouse Parish to central Franklin Parish to central Concordia Parish (Whitfield, 1975; Huff and Bonck, 1993; and Louisiana Department of Environmental Quality, 2003). The Louisiana Department of Environmental Quality (2003) study displays larger areas of higher chloride concentrations than Whitfield's (1975) study. However, this is could be a result of a smaller data set of only 25 wells rather than Whitfield's (1975) study, which includes samples from approximately 125 wells. This study's larger data set when analyzed and mapped could reveal if the high chloride regions have expanded or not.

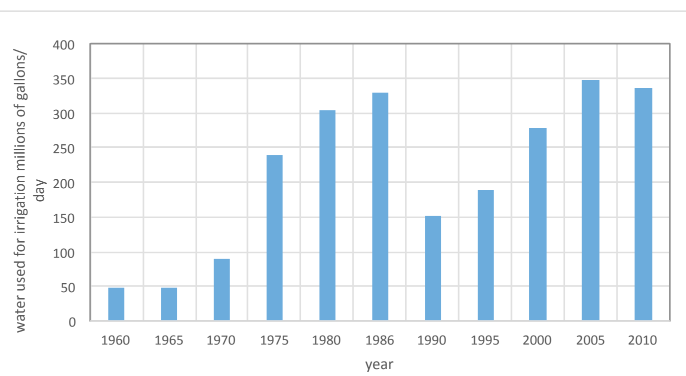

Figure 2. Daily groundwater use in study area between 1960 and 2010 (Snider, and Forbes, 1961; Bieber and Forbes, 1966; Dial, 1970; Cardwell and Walter, 1979; Walter, 1982; Lurry, 1987, Lovelace, 1991; Lovelace and Johnson, 1996; and Sargent, 2002, 2007 and 2012).

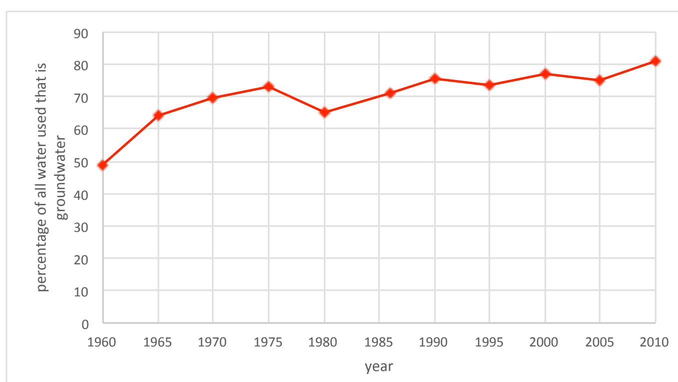

Figure 3. Fraction of water used in study area that groundwater supplies (Snider and Forbes, 1961; Bieber and Forbes, 1966; Dial, 1970; Cardwell and Walter, 1979; Walter, 1982; Lurry, 1987, Lovelace, 1991; Lovelace and Johnson, 1996; and Sargent, 2002, 2007 and 2012).

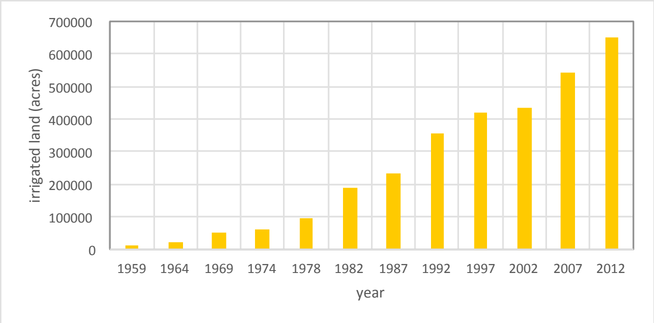

Figure 4. Area of irrigation for nine northeast Louisiana parishes: Catahoula, Concordia, East Carroll, Franklin, Madison, Morehouse, Richland, Tensas, and West Carroll, sources is: US Department of Agriculture (2016).

Three past studies that have focused on Mississippi River Alluvial aquifer water quality. The first and one of the largest studies is that of Whitfield (1975). His study includes 115 wells sampled for Ca, Cl, F, Fe, HCO_3, K, Mg, Mn. Na, NO_3, pH, SiO_2, SO_4, Total Dissolved Solids (TDS), and specific conductance. Whitfield's (1975) study reveals elevated chloride concentrations in Concordia, Franklin, Morehouse, and Tensas Parishes. The largest values are in Franklin Parish (Whitfield, 1975). Two other studies in the 1990s also sampled a large number of wells within the Mississippi River Alluvial Aquifer (Huff and Bonck, 1993; and McGee, 1997). McGee's (1997) study of nutrient concentrations included 137 wells sampled, but only 83 wells sampled are from the nine parishes included in this study. Huff and Bonck (1993) study included 42 wells from Concordia Parish and 35 wells from Morehouse Parish. At the same time another study considered water quality of the Mississippi River Alluvial within Louisiana, and neighboring Arkansas and Mississippi and western Tennessee and extreme southeast Missouri, the full Mississippi embayment area (Pettijohn, 1992). Huff's (1994) study considered the influence of which Eocene formation is under the Mississippi River Alluvial Aquifer and faults on location of chloride rich zones in the Mississippi River Alluvial Aquifer. As of 1990, the highly saline portion of the Mississippi River Alluvial aquifer lies in Franklin Parish. This area is also a potentiometric ridge where water flows east towards eastern parts of Franklin Parish and Tensas Parish and west towards western portion of Franklin Parish and toward the Boeuf River, which is a regional sink (Seanor, 1995). This means that the saline region could easily spread.

The Louisiana Department of Environmental Quality (1999, 2003, 2006, 2009, and 2012) completed series of triennial reports of Mississippi River Alluvial Aquifer water quality for samples collected between 1999 and 2011. There are many ions and parameters tested for during these studies. For example, the 2003 study include analysis of: Alkalinity, Ag, As, Be, Br, Cd, Cl, Cr, Cu, Fe, Hg, NH_3, Ni, NO_2 + NO_3, P, Pb, pH, Sb, Se, SO_4, TDS, Ti, TSS, and Zn (Louisiana Department of Environmental Quality, 2003). These studies include only a small number of wells were sampled within the study area 16 in 1999, 19 in 2003, 17 in 2005, 15 in 2008, and 18 in 2011 (Louisiana Department of Environmental Quality, 1999, 2003, 2006, 2009, and 2012). However, only seven of the wells were sampled during each of the five studies between 1999 and 2011. There appears to be some trends in ion concentrations. There is a slight trend upwards for chlorides concentrations between 2002 and 2011 (Figure 5). By contrast, there appears to be slight decrease in nitrate plus nitrite concentration over the same years (Figure 6). Lastly, it appears there are no significant trends in TDS concentrations (Figure 7).

A water quality concern for the Mississippi Alluvial Aquifer are con-

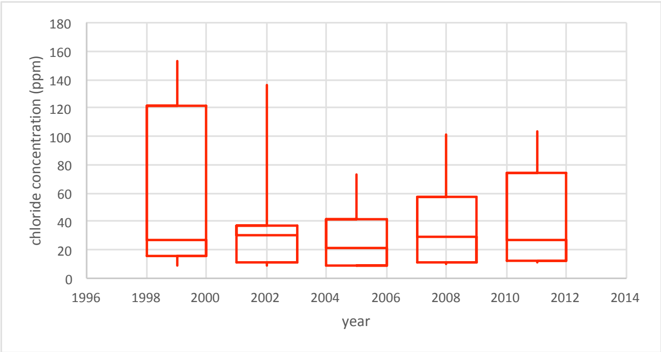

Figure 5. Distribution of chloride concentration for seven wells sampled in all five of the LA DEQ studies (1999, 2003, 2006, 2009, and 2012).

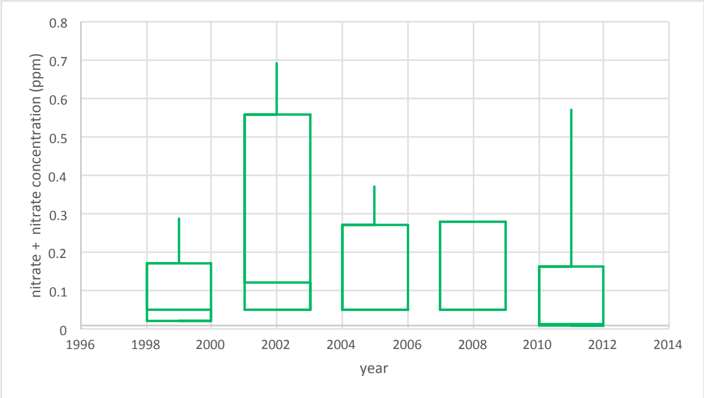

Figure 6. Distribution of nitrate + nitrite concentration for seven wells sampled in all five of the LA DEQ studies (1999, 2003, 2006, 2009, and 2012).

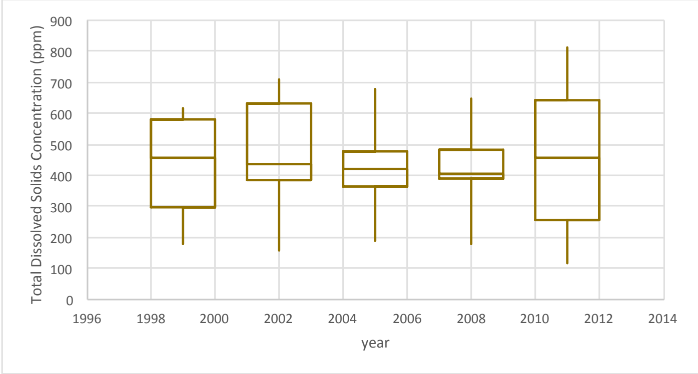

Figure 7. Distribution of TDS concentration for seven wells sampled in all five of the LA DEQ studies (1999, 2003, 2006, 2009, and 2012).

centrations of nutrients, in particular nitrate, which has a primary drinking water concentration standard of 10 mg/L (U.S. Environmental Protection Agency (EPA), 2017). In the early 1990s, a major study of nitrate and nitrite that included collection from 83 wells that draw water from the Mississippi River Alluvial aquifer (McGee, 1997). Only 2 of 83 wells have nitrate concentrations exceeding the US EPA primary drinking water standard. There were three major regional studies throughout the full extent of the Mississippi River Alluvial aquifer (Gonthier, 2003; Welch et al, 2009; and Kingbury et al., 2014). The Gonthier (2003) study included 54 wells, however only six of these were in Louisiana. The others were in Arkansas, Mississippi, Missouri, and Tennessee. The Welch et al (2009) study included 169 wells; however, only seven are in the Louisiana portion of the Mississippi River Alluvial aquifer. The most recent regional study include only seven wells in Louisiana's portion of the Mississippi River Alluvial Aquifer the majority of the 54 in Arkansas and Mississippi (Kingsbury et al., 2014).

Methods

Groundwater samples have been and will be collected throughout the study area (Figure 8). The water wells were purged as needed (approximately plumbing volume plus casing volume) prior to collection of the two samples. First sample collected is in 250 ml-bottle unpreserved. Second sampled collected in a 50 ml bottle is preserved with nitric acid. All samples are placed in a cooler with ice and kept at a temperature of approximately 4 °C in the field. Then transferred to a refrigerator until analytical analysis.

The unpreserved 50 ml samples analyzed for anions and nutrients. This analysis includes determination of concentrations of: bromide, chloride, fluoride, nitrate, nitrite, phosphate, sulfate This analysis is completed using Louisiana Geological Survey's (LGS's) Dionex ICS-1000 Ion Chromatography System (Figure 9) as described in Standard Method 9056A for the determination of anion concentrations by ion chromatography (U.S. Environmental Protection Agency, 2007). This technique is noted to have detections limit for these seven ions of 0.1 mg/L (NEMI, no date a) which is far below the US EPA primary drinking water standard for nitrate, 10 mg/L, and nitrite 1 mg/L. (U.S. Environmental Protection Agency, 2017).

The remaining portion of the sample in the 250 ml bottle was analyzed for TDS by gravimetric analysis, which involves using SM 160.1 gravimetric determination of TDS (caslab.com, 1971). For this study field measurements for specific conductance were done using LGS's Hanna Instruments HI-9033 Multi-range Conductivity meter; for pH using LGS's EcoSense pH100A meter; and iron, nitrate and phosphate concentrations using LGS's HACH Pocket Colorimeters.

Louisiana State University Wetland Biochemistry Service Laboratory completed analysis for metals and other cations using their Varian (ICP-OES model MPX) Inductively Coupled Plasma-Optical Emission Spectrometer. This analysis is completed by using EPA 200.7-SW 846- 6010B method for inductively coupled plasma-atomic emission spectrometry (caslab.com, 1996; and nelac-institute.org, 2008). Ions included in this analysis are: aluminum, barium, boron, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, nickel, phosphorous, potassium, silicon, sodium, strontium, vanadium, and zinc. This analysis has a detection limit of approximately 1 to 10 part per billion (ppb) depending on ion considered (caslab.com, 1996).

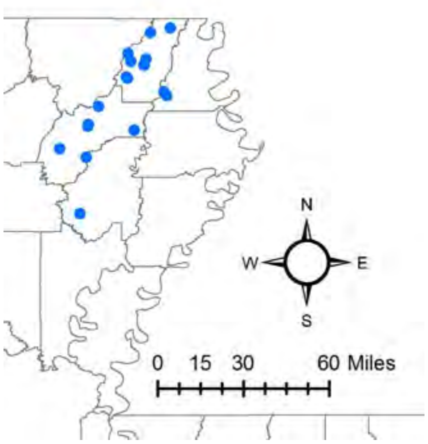

Figure 8. Location of wells already sampled, 21 as December 1, 2017. Blue dots are locations of wells already sampled.

Figure 9. Louisiana Geological Survey's chromatography.

Preliminary Results of this Study

At the time of this report samples have been collected and analyzed for wells in four of the nine parishes within the study area: East Carroll, Morehouse, Richland, and West Carroll Parishes. Results of this initial analysis are included in Table 1. The first phase of this study will be collection and analysis of domestic, irrigation, and stock wells, private systems. After the first phase is completed their be collection of a smaller number samples from public supply wells which tend to be the focus of previous studies such as: Whitefield, 1975, Seanor and Smoot, 1995; and Louisiana Department of Environmental Quality, 2003).

It is apparent even from this initial sample collection that West Carroll Parish samples have far higher concentrations of chloride and TDS than samples from elsewhere (Figure 10 and 11). Whitefield (1975) and Huff (1994) also noted this pattern earlier. The median concentration of chloride, 123 mg/L, significantly higher than median observed for the LA DEQ studies (1999, 2003, 2006, 2009, and 2012), less than 40 mg/L. This could be a result of this studies greater share of samples in West Carroll Parish. However, it appears that this study's set of West Carroll Parish has larger chloride concentrations than Whitefield's (1975) for their select samples collected in just West Carroll Parish (Table 2). This study's results are similar to Whitfield's (1975) in Richland Parish This indicates that chloride concentrations are rising in West Carroll which even the 1970s already had higher greater concentrations than elsewhere within the Mississippi River Alluvial Aquifer (Whitefield, 1975).

Table 1

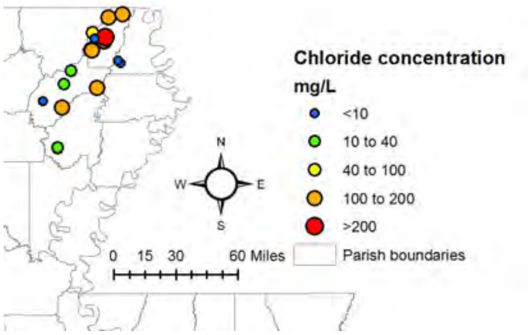

Figure 10. Initial observed values of chloride concentration within Mississippi River Alluvial Aquifer groundwater.

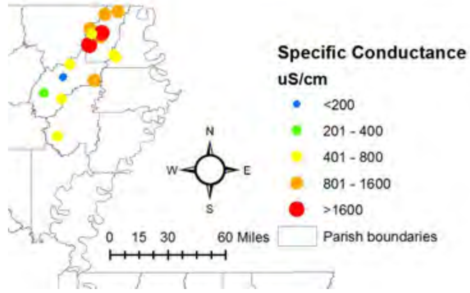

Figure 11. Initial observed values of TDS concentration within Mississippi River Alluvial Aquifer groundwater.

Initial results of analytical analysis. Means and Median are only for samples above detection limits.

Analyte	No. of obs.	Mean	Median	Range
Field results:				
Nitrate	15	1.0 mg/L	1.0 mg/L	<0.1 to 1.6 mg/L
pH	21	6.94	6.86	6.39 to 7.42
Phosphate	18	0.76 mg/L	0.63 mg/L	0.02 to 2.21 mg/L
Specific conductance	21	1030 µS/cm	1120 µS/cm	35 to 2320 µS/cm
temperature	19	21.2 C	21.1 C	19.8 to 24.9 C
Laboratory results:				
Aluminum	21	0.067 mg/L	0.028 mg/L	0.006 to 0.634 mg/L
Barium	21	0.345 mg/L	0.298 mg/L	0.040 to 1.81 mg/L
Boron	21	0.092 mg/L	0.079 mg/L	0.040 to 0.137 mg/L
Bromide	21	0.422 mg/L	0.356 mg/L	<0.02 to 0.946 mg/L
Calcium	21	95.8 mg/L	99.1 mg/L	7.08 to 181 mg/L
Chloride	21	94.3 mg/L	123 mg/L	1.84 to 228 mg/L
Chromium	21	all values non-detections		<0.009
Cobalt	21	all values non-detections		<0.008
Copper	21	0.027 mg/L	0.023 mg/L	<0.009 to 0.039 mg/L
Fluoride	21	0.252 mg/L	0.228 mg/L	0.168 to 0.567mg/L
Iron	21	4.06 mg/L	2.11 mg/L	<0.007 to 26.6 mg/L
Magnesium	21	39.4 mg/L	45.5 mg/L	2.22 to 74.4 mg/L
Manganese	21	0.322 mg/L	0.206 mg/L	<0.007 to 1.02 mg/L
Nickel	21	all values non-detections		<0.01 mg/L
Nitrate	21	2.65 mg/L	1.88 mg/L	<0.02 to 8.56 mg/L
Nitrite	21	all values non-detections		<0.02 mg/L
Phosphate	21	1.00 mg/L	0.630 mg/L	<0.02 to 3.67 mg/L
Phosphorous	21	0.293 mg/L	0.236 mg/L	0.110 to 0.770 mg/L
Potassium	21	3.40 mg/L	3.29 mg/L	1.60 to 6.11 mg/L
Silicon	21	18.8 mg/L	18.6 mg/L	15.7 to 22.4 mg/L
Sodium	21	53.7 mg/L	62.9 mg/L	7.13 to 99.6 mg/L
Strontium	21	0.352 mg/L	0.263 mg/L	0.080 to 1.15 mg/L
Sulfate	21	33.2 mg/L	21.9 mg/L	<0.02 to 176 mg/L
Vanadium	21	all values non-detections		<0.035 mg/L
Zinc	21	0.207 mg/L	0.056 mg/L	0.028 to 2.84 mg/L

Table 2

Chloride concentration for samples collected from wells in Richland and West Carroll Parishes for this study and Whitfield's (1975) study.

Study	No. of obs.	Mean	Median	Range
Richland Parish				
Whitfield (1975)	15	92.2 mg/L	24.0 mg/L	1.0 to 960 mg/L*
This study	10	54.0 mg/L	26.3 mg/L	1.84 to 160 mg/L
West Carroll Parish				
Whitfield (1975)	18	46.2 mg/L	26.5 mg/L	2.3 to 123 mg/L
This study	10	148 mg/L	161mg/L	9.43 to 228 mg/L

The * notes the second highest concentration is only 150 mg/L.

The specific conductance results for this study are similar to past studies of Whitfield (1975) and McGee (1997) in Richland Parish (Table 3). By contrast, for West Carroll Parish the specific conductance values of have increase between Whitfield (1975) and McGee studies. Likewise, there has been a continuing increase in specific conductance between McGee (1997) and this study over the past twenty years.

For this study the water concentrations in all samples so far, 21, meet U.S. EPA primary drinking water for barium, chromium, copper, fluoride, nitrate, and nitrite. By contrast, there are exceedances of U.S. EPA secondary drinking water standards. In particular five wells yield samples that have concentrations of aluminum above the secondary drinking water standard and 16 wells yield samples that have concentrations of iron and manganese about the secondary standard. For 8 wells the iron concentrations is over 10 times the secondary standard of 0.3 mg/L for iron and 4 wells the manganese concentrations is over 10 times the secondary standard of 0.05 mg/L.

Table 3

Specific conductance values for samples collected from wells in Richland and West Carroll Parishes for this study and two other large studies.

Study	No. of obs.	Mean	Median	Range
Richland Parish				
Whitfield (1975)	13	631 µS/cm	443 µS/cm	117 to 2630 µS/cm*
McGee (1997)	15	540 µS/cm	385 µS/cm	102 to 1130 µS/cm
This study	9	532 µS/cm	483 µS/cm	35 to 1340 µS/cm
West Carroll Parish				
Whitfield (1975)	17	740 µS/cm	678 µS/cm	123 to 1290 µS/cm
McGee (1997)	10	1170 µS/cm	1210 µS/cm	722 to 1700µS/cm
This study	10	1550 µS/cm	1550 µS/cm	741 to 2320 µS/cm

The * notes the second highest value is only 1130 µS/cm.

In terms of nitrate, this is the first study since McGee's (1997) study of nitrate values in 1993 that included 83 samples. For the initial 21 values, most of which are Richland and West Carroll Parishes the results are very similar to McGee's (1997), see Table 4. This study has yet to have any water samples with nitrate concentrations over U.S EPA standard, which is not surprising considering only 2 of the 83 wells sampled have nitrate values for the U.S. EPA standard.

Table 4

Nitrate concentration for samples collected from wells in Richland and West Carroll Parishes for this study and McGee's (1997) study.

Study	No. of obs.	Mean	Median	Range
Richland Parish				
McGee (1997)	15	2.91 mg/L	1.20 mg/L	<0.02 to 14.0 mg/L
This study	9	2.37 mg/L	1.59 mg/L	<0.02 to 8.56 mg/L
West Carroll Parish				
McGee (1997)	10	0.50 mg/L	<0.02 mg/L	<0.02 to 5.00 mg/L
This study	10	0.52 mg/L	<0.02 mg/L	<0.02 to 2.14 mg/L

Acknowledgements

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An Overview Of Trends Within Hydraulic Fracturing In Louisiana

Douglas Carlson

Introduction

Hydraulic fracturing is used to increase productivity of oil and gas fields. It has been referred to as hydrofracturing, hydrofracking, fracking or fracing (Suchy and Newell, 2012), Hydraulic fracturing (HF) is a four-step process. One, use fluid to pressure the reservoir rock creating fractures. Two, continue to pump fluids into fractures to grow them. Three, pump proppant mixture into fractures. Four, stop pumping and flowback to the well to recover fracture fluids while leaving proppant in place to keep fractures open (Canadian Society for Unconventional Resources, no date)

Enhancing the production of hydrocarbons by fracturing rocks started in the 1860s by explosives (Montgomery and Smith, 2010; Larkin, 2016; and Testa, 2017). Later in the 1930s acidizing treatments under pressure were used to increase rock permeability (Montgomery and Smith, 2010; Larkin, 2016; and Testa, 2017). Modern HF using a variety of chemicals has been used since 1947 in order to increase permeability and ultimate production of hydrocarbons deposits (Montgomery and Smith, 2010; Suchy and Newell, 2012; Larkin, 2016; and Testa, 2017). The first commercial application of HF occurred in 1949 (Khyade, 2016). By 1955, over 100,000 individual treatments of HF have been performed (Testa, 2017). Starting in 1973 massive HF involving 1.2 to 3.5 millions of gallons of water per well occurred in the western United States (Khyade, 2016). Approximately one million applications of HF by 1988 and more than 2.5 million applications were completed by 2016 (Testa, 2017). As of 2012, over 60% of all oil and gas wells drilled worldwide are fractured (Suchy and Newell, 2012). One benefit of HF is that it has increased estimated recoverable reserves of gas by 90% and oil by 30% (Montgomery and Smith, 2010; and Suchy and Newell, 2012).

In 1929, the first horizontal well was completed near Texon, Texas and few more wells that are horizontal were completed by 1957. However horizontal wells were not common into the early 1980s (Khyade, 2016; and Testa, 2017). First horizontal drilling for Barnett Shale west of Dallas, Texas occurred in 1991 (Khyade, 2016). In 2000, 6% of all wells drilled were horizontal wells. Just ten years later, 2010, 42% of all wells drilled were horizontal wells (Gallegos and Varela, 2014)

One of the concerns about HF is the volume of freshwater used for it (Gallegos et al., 2015). Well orientation, date of HF and geologic basin influence the volume of water used (Gallegos et al., 2015). One of the basins, which has among the highest average volumes of water used for HF is the Haynesville-Bossier of Louisiana-Texas. Typically HF uses between 2 and 10 million gallons (Mgal) per water per well (Larkin, 2016). Others noted similar average volume of water used for HF elsewhere, Table 1. These large withdrawals in drier climates or highly stressed hydraulic systems can caused significant local water shortages, degradations of water quality, and lowering of stream flow in even wet areas (Vengosh et al., 2014).

Table 1

Average water use per well for HF (Vengosh et al., 2014).

Basin	Water use per well millions of gallons (Mgal)
Horn River Basin, British Columbia, Canada	13.21
Marcellus Shale, Pennsylvania (<2010)	2.03 to 10.04
Haynesville, Texas	5.70
Eagle Ford, Texas	4.25
Woodford Shale, Oklahoma	4.23
Marcellus Shale, Pennsylvania (2008-2011)	3.04 to 5.02
Niobrara, Colorado (2012)	3.43
Barnett Shale, Texas	2.64

There have been observed trends of increasing volume of water used for HF for other unconventional shales. Between 2000 and 2014, median volume of water used for HF increased from 0.17 Mgal to 4.0 Mgal for oil and 5.1 Mgal for gas fields throughout the United States (Gallegos et al., 2015). This is a result of both increasing volume for median horizontal well fracturing and the increasing share of wells fracture that are horizontal. The share of wells fractured that are horizontal increased from approximately 5% in 2000 to approximately 58% in 2014 (Gallegos et al, 2015). Increase has occurred for a single basin. Nicot and Scanlon (2012) observed that per well use of water for fracturing of the Barnnet Shale increased from approximately 1.4 Mgal in 2000 to 2003 to approximately 2.0 Mgal in 2010 to 2011.

There have been changes in not only volume of water used per HF but the chemistry of HF fluid used. The first HF was treated with napalm in 1947 (Holditch, 2007). Through the decades, the chemistry of fracturing fluids has continued to change between the 1950s and 1990s. By the 1950s, fracturing involved the use of gelled oil and aterin, which progress to the 1960s use to linear gelled water. Cross-linked gelled water was used in fracturing by the 1970s. Foamed fluids and delayed cross-linkers were used for fracturing by the 1980s. In the 1990s, fracturing uses reduced polymer loading with advanced breaker technology (Holditch, 2007). In 1996, slickwater fluids were introduced (Khyade, 2016). The slickwater fluids include water-soluble gelling agents, for example guar gum, which increases efficiency of proppant intrusion into the formation rock that hosts oil and/or gas (Khyade, 2016). For modern fracturing solution, there are 11 different categories of compounds having different roles within the fracturing operation (Table 2). Many of these categories of compounds are used within other products that more familiar and used daily (Table 3).

The chemistry of fracturing fluids is one of the concerns about hydraulic fracturing, which could contaminate drinking water due to spills/leaks, stray gas migration, in adequate treatment of waste water or migration of hydraulic fracturing fluids or produced waters (Venosh et al., 2014; Gallegos et al. 2015; and Larkin, 2016). Typically, the HF solution is composed of 90% water and 9.5% sand/quartz (Khyade, 2016. Typically, there are 3 to 12 added compounds to the HF fluid for a single well HF job (Khyade, 2016). The other compounds are what creates public concern (Larkin, 2016). Concern is for a good reason, overall, approximately 2500 HF additives of which over 650 are possible human carcinogens under the safe drinking water act or listed as hazardous pollutants (Khyade, 2016). This concern about contamination of groundwater from leaks of fracturing solution based on what chemicals are in that solution (Table 2) such as petroleum distillates, methanol (wood alcohol), hydrochloric acid.

Table 2

HF solution as divided by category of purpose for chemicals and some examples of what chemicals are used (FracFocus, 2017a and 2017b).

Category of use	Purpose in fracing solution	Example compound(s)
Acid	Helps dissolve minerals to initiate cracks in the rock.	Hydrochloric acid
Acid/Corrosion Inhibitor	Protects casing from corrosion	Formic Acid, Methanol & Isopropanol
Biocide	Eliminates bacteria in water that can cause corrosive by products	Glutaraldehyde & Quaternary Ammonium Chloride
Breaker	Allows a delayed break down of gels when required	Sodium Chloride & Magnesium Oxide
Clay and Shale Stabilization/control	Permanent or temporary clay stabilizer to lock down clays in the shale	Sodium Chloride & Tetramethyl Ammonium Chloride
Crosslinker	Maintains viscosity as temperature increases	Petroleum Distillate, Boric Acid, Borate Salts, Ethylene Glycol & Methanol
Friction Reducer	Reduces solution friction compared to water on pipes	Petroleum Distillate & Methanol
Gel	Thickens water in order to suspend the proppant	Guar Gum, Petroleum Distillate & Methanol
Iron Control	Helps prevent precipitation of metal oxides	Citric Acid & Acetic Acid
Non-Emulsifier	Break or separate oil/water mixtures	Isopropanol & Ethylene Glycol
pH Adjusting agent/ Buffer	Maintains effectiveness of other additives such as crosslinkers	Sodium Hydroxide & Potassium Hydroxide
Scale Inhibitor	Prevents buildup of scale on pipes and formation	Phosphoric Acid Salt
Surfactant	Reduces surface tension of the treatment fluid in the formation and helps improve oil and/or gas recovery from the well after the frac is completed	Ethanol, Naphthalene & Methanol

Table 3

HF solution as divided by category of purpose for chemicals and some examples of other uses of these chemicals (Larkin, 2016)

Category of use	Share of Frac solution	Other Uses
Acid	0.123%	Household cleaner, and swimming pool cleaner
Friction Reducer	0.088%	Water treatment, candy, and makeup remover
Surfactant	0.085%	Glass cleaner, antiperspirant, and hair color
Potassium Chloride	0.06%	Low sodium table salt substitute
Gelling Agent	0.056%	Toothpaste, basking goods, ice cream, sauces and cosmetics
Scale Inhibitor	0.043%	Household cleaners and deicing agent
pH Adjusting Agent	0.011%	Detergents, washing soda, water softener and soap
Breaker	0.01%	Hair cosmetics and household plastics
Crosslinker	0.007%	Soaps and laundry detergent
Iron Control	0.004%	Food additive, lemon juice, and food & beverage flavoring
Corrosion Inhibitor	0.002%	Pharmaceuticals and Plastics
Antibacterial Agent	0.001%	Disinfect used to sterilize medical equipment

Method

Companies have voluntarily reported the chemical additives used for HF on a web-based registry FracFocus (Suchy and Newell, 2012). FracFocus reports the maximum concentration of a chemical compound, within each of the general categories of use of compounds. They listed concentrations as a percentage within each category of compounds used and for the total solution used. The total values are the ones of interest for this study. For this study, it was assumed that category of compounds were added separately and that maximum reported are not additive for the total maximum for the fracture solution.

Results

Volume of water used

For Haynesville shale gas play parishes (Bienville, Bossier, Caddo, De Soto, Natchitoches Red River, Sabine, and Webster) the median volume of water used for HF was approximately constant between 2008 and 2014, approximately 5 Mgal for each well (Figure 1). This is similar to the Texas side of the Haynesville where average volume of water used for HF during 2010-2011 is 5.7 Mgal (Nicot and Scanlon, 2012). After 2014 there has been a major increase of median volume of water used for fracturing jobs in northwest Louisiana up to approximately 15 Mgal (Figure 1). The rate of increase is larger but similar to what Nicot and Scanlon (2012) noted for the Barnett Shale for 2001-2003, 1.4 Mgal, and 2010-2011, 2.8 Mgal. They noted doubling of water used in nine years, which is similar to the tripling of water used for HF of the Haynesville in Louisiana between 2011 and 2016-2017 (Figure 1). This increase is partially caused by an increase in the median length of the producing lateral from 4,419 feet in 2011 to 7,441 feet in 2017 at 68% increase (Figure 2). The increasing length of horizontal laterals in Haynesville is similar to what occurred in the Barnett Shale where average lateral length increased from 1900 ft. in 2004 to 3800 ft in 2011 (Nicot et al., 2014). Increasing lateral length also occurred between 2005 and 2013 from approximately 7200 ft to 9500 ft in the Bakken Filed (Scanlon et al., 2014).

Outside the Haynesville parishes, the increase of median fracturing job is from less than 500 thousand gallons per well for 2011 to 2013 to approximately 5 to 10 million gallons for 2015 to 2016 depending on year (Figure 3). The results are more variable than for Haynesville parishes because the data sets are far smaller. The full years for Haynesville have between 143 fracture jobs in 2016 and 673 fracture jobs in 2011 (Figure 1). By comparison number of fracture jobs outside the Haynesville parishes for full year is between 21 in 2011 and 56 in 2015 (Figure 2), approximately an order of magnitude fewer individual fracturing jobs.

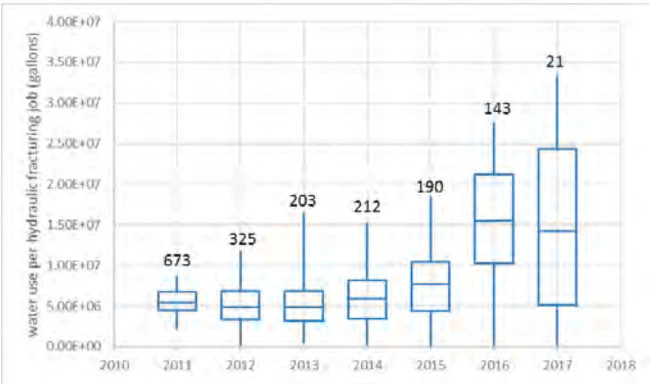

Figure 1. Distribution of the volume of water used for HF of wells within the Haynesville shale gas play parishes in Louisiana. Source of volumes is Frac Focus (2017c). Number above each box and whiskers is total observations for the distribution of values. The bottom whisker is the 5% rank, bottom of the box is the 25% rank, median value bisects the box, top of the box is the 75% rank and top whisker is the 95%. This convention holds for all box and whiskers plots that follow. The results for 2017 for this and following plots is for approximately first six months.

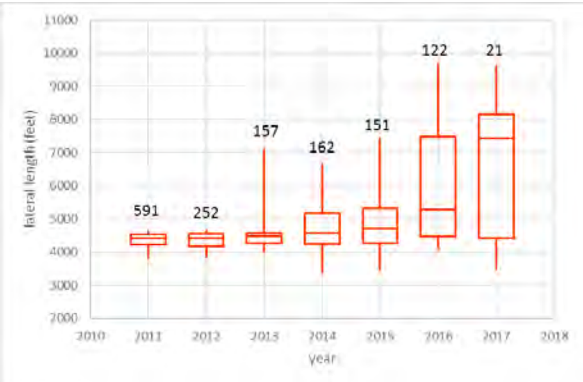

Figure 2. Length of horizontal lateral for Haynesville wells in Louisiana between 2009 and 2016. Source of lateral length data is Louisiana Department of Natural Resources (2017).

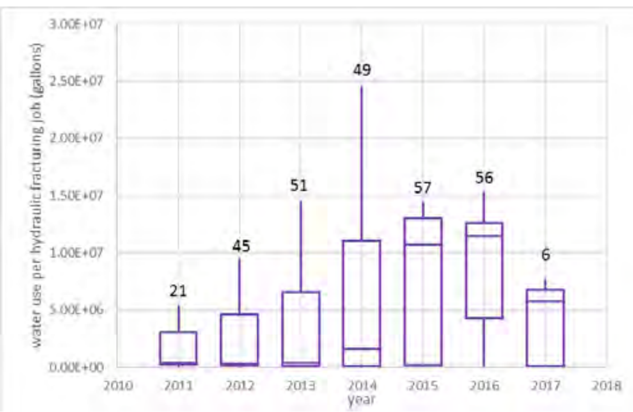

Figure 3. Distribution of the volume of water used for hydraulic fracturing of wells outside the Haynesville shale gas play. Source of volumes is Frac Focus (2017c)

Water chemistry of fracturing water

Many of the compounds added to the HF fluid are generally safe. The bulk is water and sand (quartz) which typically makeup over 98%-99.5% of the HF fluid. The other 0.5-2% of additives have created concern in the public. However, many of these are generally safe (Suchy and Newell, 2012), The list of compounds within a fracture fluid will variety greater as a result of reserve properties, rock and hydrocarbon type, pressure, temperature, and sensitivity of reservoir system to water (Gallegos and Varela, 2014).

Have there been trends in the used of various compounds in HF? Six of the over 200 compounds used for HF in Louisiana are considered. Others have reported that approximately 1000 chemicals have been used in HF fluids (Suchy and Newell, 2012). Among the six, considered quartz/sand, sodium chloride/salt, and guar gum are generally considered safe and two of these salt and guar gum are used in food. Two compounds, methanol/wood alcohol and petroleum distillates/kerosene, are commonly used in hydraulic HF and are considered occupational hazards, largely due to being flammable (New Jersey Department of Health, 2011, and 2016). Lastly, one of the compounds naphthalene is a greater concern by OSHA as indicated by lower permissible exposure limits (PEL) standards than either methanol or petroleum distillates. The PEL for naphthalene is 10 ppm, for methanol is 200 ppm and petroleum distillates is 3500 ppm (New Jersey Department of Health, 2011, 2012 and 2016). In addition, Naphthalene identified as a carcinogenic compound (Christopher et al., 2005; and New Jersey Department of Health, 2012).

Quartz/sand/silicon dioxide is a proppant within hydraulic fluid (Suchy and Newell, 2012). Sand has been used in approximately 99% of all HF solutions between 1947 and 2010 (Gallegos and Varela, 2014). It is the second most common compound in almost all of the approximately 1850 FracFocus compounds listed for Louisiana wells considered in this study. The concentration of quartz within hydraulic fracturing fluid has generally been increasing as indicated by the median concentration of quartz, proppant, nearly doubling between 2011 when concentration is 6.21% to 2017 when concentration is 11.91% (Figure 4). Increasing concentration of proppant was observed elsewhere. In the Eagle Ford there was a general increase over time between 2011 and early 2012 in the proppant loading/concentration (Scanlon et al., 2014).

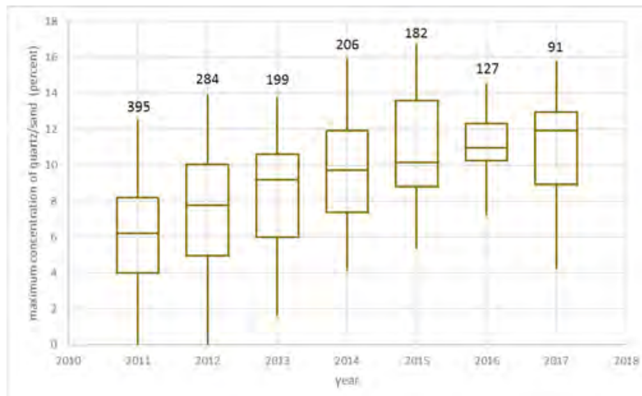

Figure 4. Maximum concentration of quartz/sand within the fracture solution used for a well. Source of concentrations is FracFocus (2017c).

Gallegos and Varela (2014) noted the general type of HF fluid throughout the United States for approximately 1.6 million fracturing treatments throughout approximately one million wells fractured included eleven classes: acid, crosslinked gel, fluid, foam, gel, fracturing, My-T Frac, oil, slick water, unknown, and water, Initially the most common type was unknown, 1947 to 1959. Water was the most common overall and for years of 1961 to 1970 and 1982 to 2008. My-T Frac was most common type between 1971 and 1980. Lastly, they noted that in last couple of years, 2009 and 2010 slick water was the most common type of fracture solution (Gallegos and Varela, 2014). Only approximately 19% of records note individual additive classes and almost no records prior to 1978 (Gallegos and Varela, 2014). Surfactants, for example petroleum distillates, came into common use only since 2005. It appears this study is the first examination of concentrations of individual fracturing compounds/additives.

The concentration of sodium chloride/salt has been approximately steady between 2011 and 2017 (Figure 5). The concentration has been modest, typically yield chloride concentrations less than the U.S. EPA secondary drinking water standard for chloride is 250 mg/L / 250 parts per million (ppm). Secondary drinking water standards are not health concerns but are concentrations that affect taste, smell or cause staining of fixtures and cloths (U.S. EPA, 2003). Sodium chloride, NaCl when it dissociates yields Na and Cl ions. Concentration of NaCl must be over 412 ppm to yield Cl concentrations over the U.S. EPA secondary drinking water standard. Less than 25% of HF fluids for all seven years has a concentration of sodium chloride that could yield a chloride concentration exceeding the EPA secondary drinking water standard (Figure 5).

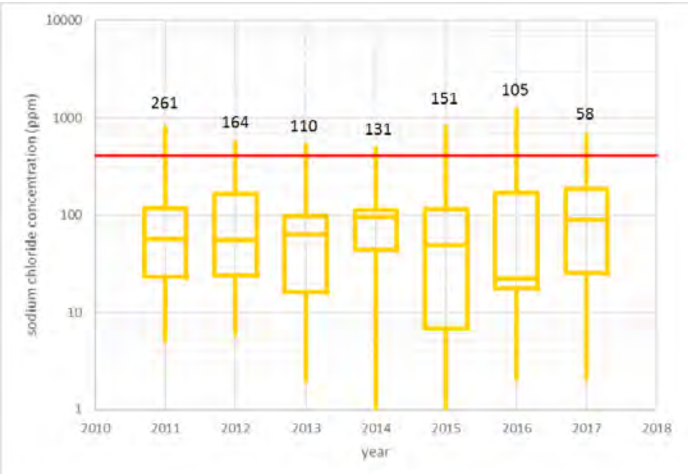

Figure 5. Maximum concentration of sodium chloride/table salt within the fracture solution used. Source of concentrations is FracFocus (2017c). Red line is a NaCl that would yield chloride concentration at U.S. EPA secondary drinking water standard

Guar gum is a thickening agent used in hydraulic fracturing fluid. It helps suspend the proppant. Guar gum is also used as a thickening agent for cosmetics, food and toothpaste (Suchy and Newell, 2012). For Louisiana wells, the concentrations of guar gum have generally been declining between 2011 and 2017 (Figure 6) as indicated by median concentration decreasing from 1510 ppm in 2011 to 445 ppm in 2017 a 71 % decline.

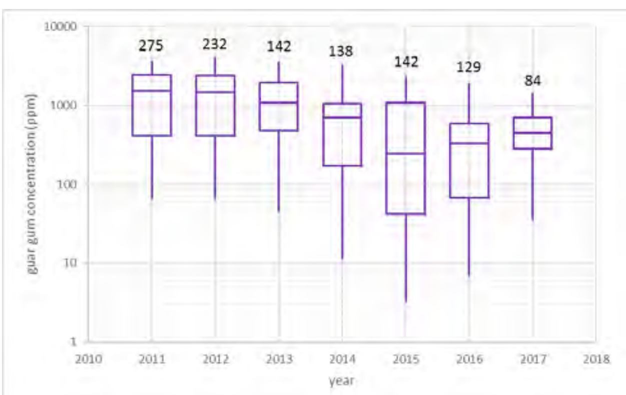

Figure 6. Maximum concentration of guar gum within the fracture solution used. Source of concentrations is FracFocus (2017c).

The concentration of the two compounds that are flammable but not carcinogenic generally have lower concentrations than more benign compounds previous noted. There was a decline of median methanol concentrations from 70 ppm in 2011 to less than 10 ppm in 2012 to 2015 then a rise in concentrations to medians of 17 ppm in 2016 and 300 ppm in 2017 (Figure 7).

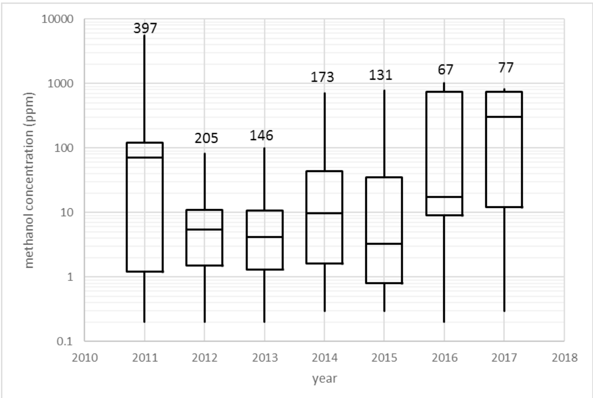

Figure 7. Maximum concentration of Methanol/methyl alcohol/wood alcohol within the fracture solution used. Source of concentrations is FracFocus (2017c).

Petroleum distillates/kerosene are the third most commonly used chemical in hydraulic fracturing fluid in Louisiana behind only water and sand/quartz, The median concentration is typically fourth behind only water, quartz, guar gum in most hydraulic fracturing fluids in Louisiana (Table 3). Petroleum distillates are used as a surfactant, which used to facilitate pumping of the fluids and proppant at higher rates and lower pressure than if water alone was used (Suchy and Newell, 2012). There are two trends for petroleum distillates concentrations. One, a weak trend of decreasing median concentrations. The decrease is from 292-377 ppm for 2011 to 2013 to 233-394 ppm from 2014 to 2017 (Figure 8). Two, a decrease in the scatter of results for concentration between 75% and 25% rank for the same set of years. This decrease is from 838-1381 ppm for 2011 to 2013 to 162-238 ppm from 2014-2017 (Figure 8).

Table 3

Top ten compounds other than water and quartz for frequency of use for hydraulic fracturing in Louisiana. A total of 1847 hydraulic fracturing reports are included in Louisiana set of data, through June of 2017. All concentrations in ppm.

Compound	number	Share of all fracs	25% rank	median	75% rank
Petroleum distillates	1588	86.0%	208	309	693
Methanol	1201	65.0%	1.3	7.6	68.5
Guar gum	1145	62.0%	258	780	1870
Sodium chloride	982	53.2%	1.99	56.7	135
Isopropanol	936	50.7%	0.9	3.2	13.7
Sodium hydroxide	911	49.3%	30.2	48.3	122
Potassium hydroxide	745	40.3%	4.1	13.9	65.3
Ethylene glycol	635	34.4%	13.3	40.6	125
Ethanol	627	33,9%	2	9	145
Sodium Chlorite	613	33.2%	7.6	16.8	47

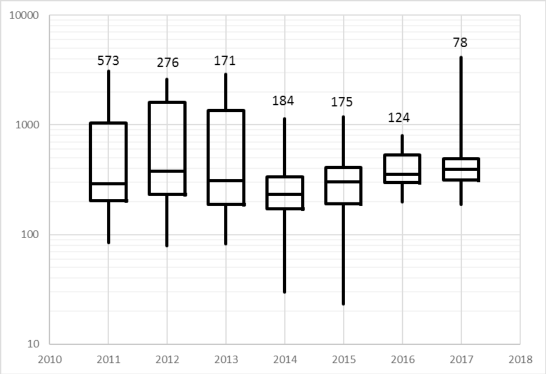

Figure 8. Maximum concentration of petroleum distillates/kerosene/mineral spirits within the fracture solution used. Source of concentrations is FracFocus (2017c).

Naphthalene is the only compound that is consider carcinogenic among the six consider for this inital study. For Louisiana wells fractured, both its median concentration between 2011 and 2017 and frequency of use are decreasing (Figures 9 and 10). The decrease in concentrations of naphthalene occurred first as median concentration decreased from 21.5 ppm in 2011 to 0.1 ppm in 2012, an over 99% decrease. Other years had higher median concentrations up to 0.4 ppm in 2016, which is still a 98% decrease from 2011 (Figure 9). After the concentration decrease came the decrease in frequency that naphthalene was included in the HF fluid from 26-36% in 2011 to 2012 to 14- 18% in 2014 to 2017 (Figure 10).

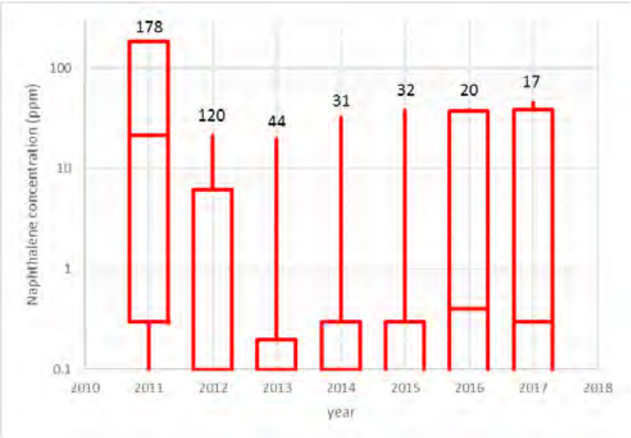

Figure 9. Maximum concentration of naphthalene/camphor tar/mothballs within the fracture solution used. Source of concentrations is FracFocus (2017c).

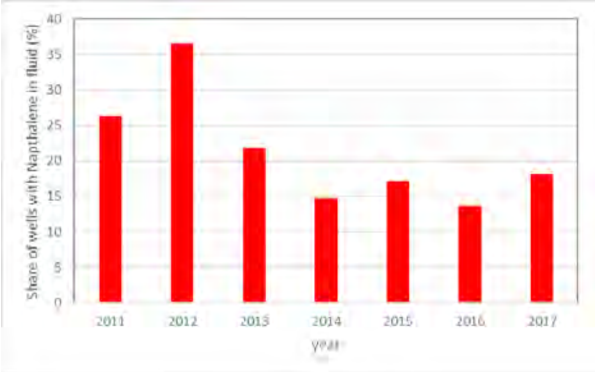

Figure 10. Share of hydraulic fracturing jobs that are included in the fluid mixture used. Source of concentrations is FracFocus (2017c).

In addition to the list of compounds noted by their chemical names there are ones listed as proprietary compounds, unknown or not available. These unknown compounds present a question in terms of the toxicity of HF fluid. Often in a FracFocus report there are compounds such as methanol or petroleum distillates that are listed more than ounce because they perform a variety of functions within the HF fluid. The assumption for this study's count of unknown compounds is that they are very specialized and tend to serve only one function within the HF fluid. The share of HF jobs with at least one unknown/proprietary/not available (UPNA) compound is over 83% every year. The lowest share is in 2016, 84% and highest in 2015, 98%. For the sum of 1846 HF reports, there is at least one UPNA compound for 90% of reports. Initially the number of UPNA compounds per FracFocus report increased from approximately four in 2011 to seven in 2014 to 2017 (Figure 11).

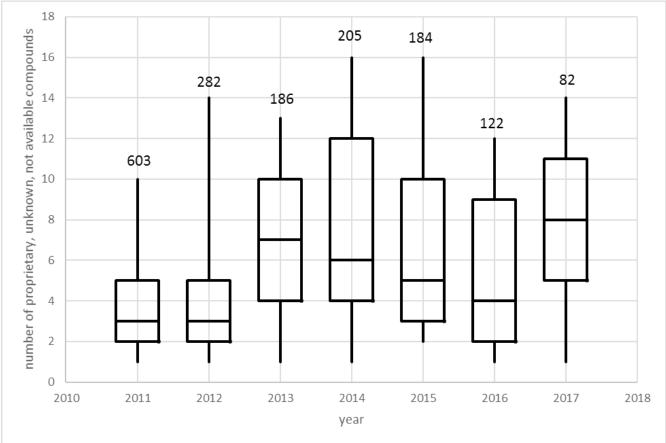

Figure 11. Number of proprietary, unknown or not available compounds listed with a FracFocus report for a well' HF report. Source of information is FracFocus (2017c).

Target of hydraulic fracturing

Within Louisiana the share of HF jobs as indicated by FracFocus occurring in the seven Haynesville parishes has been declining over the past six years from over 95% in 2011 to approximately 80% in 2017 (Figure 12). The majority of all wells fractured are of the Haynesville within both the seven-parish area (Figure 13) and all of Louisiana (Figure 14). The share of wells within the seven-parish area that are Haynesville wells decreases from 89% in 2011 to 78% to 80% in 2012-2014 (Figure 13). Later in 2016-2017 the share of wells in Haynesville increases back to 85% to 86%. As for the state as whole Haynesville shale always accounts for over 60% of all wells fractured. In 2011 87% of all wells fractured in Louisiana were Haynesville wells. In general, between 2013 and 2016 share of state wells that were fractured in Haynesville wells was between 61% and 63% (Figure 14).

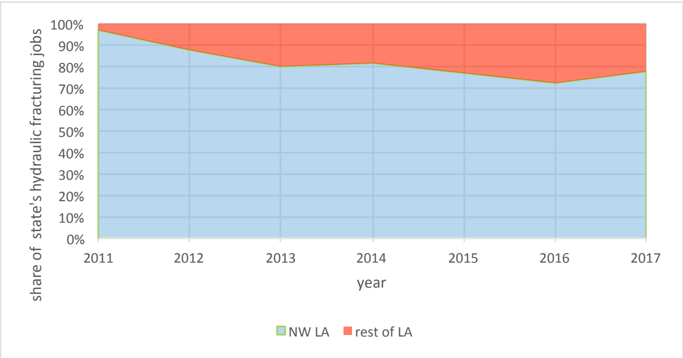

Figure 12. Share of wells fractured in northwest Louisiana parishes where the Haynesville shale gas play is versus in the rest of Louisiana. Source of data FracFocus (2017c).

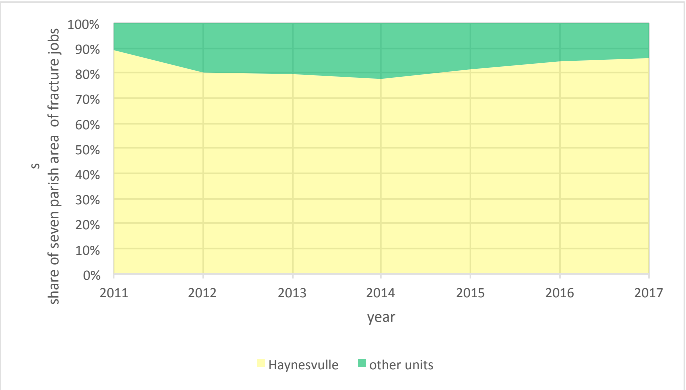

Figure 13. Share of wells fractured in northwest Louisiana parishes that are of Haynesville shale gas play is versus other units in the seven-parish area. Source of data FracFocus (2017c).

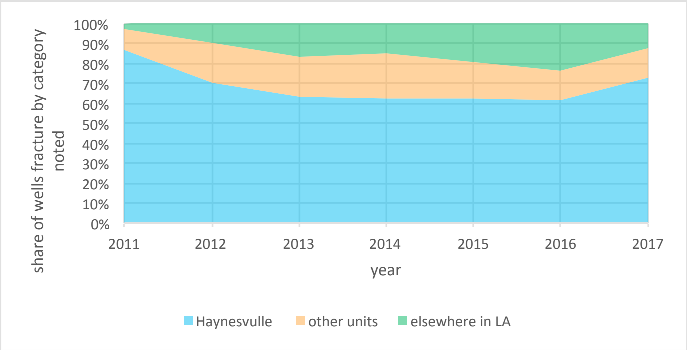

Figure 14. Share of wells fractured that are in Haynesville shale gas play, other units in Northwest Louisiana seven-parish area and elsewhere in Louisiana. Source of data FracFocus (2017c).

Conclusions

There have been a number of trends within hydraulic fracturing of Louisiana gas and oil wells:

There has been a significant increase in median volumes of water used for HF of wells that are both open to the Haynesville Gas Shale and other formations in Louisiana.

The increase for other units is larger than for Haynesville that had median volume of water increase from 5 Mgal in 2011 to 15 Mgal per well in 2017. Increase of median water volume used per well for other units is from <0.5 Mgal in 2011to 5 Mgal well in 2017. This is probably partly due to different mix of other units through time.

Part of the increasing volume used of HF water for Haynesville well is an increase in median length of horizontal laterals from approximately 4400 feet in 2011 to 7400 feet in 2017.

The median portion of hydraulic fracturing fluid that is proppant, quartz/sand, has increased from approximately 6% in 2011 to 12% in 2017. Increasing proppant share appears to be similar to what is occurring in other shale gas plays.

Median concentrations of other compounds in the HF fluid changes through the past six years.

For compounds such as sodium chloride, table salt, and guar gum that are used within food tend to have a fairly steady and larger median concentrations than other compounds that more hazardous.

Hydrocarbon compounds such as methanol/wood alcohol, and petroleum distillates/ kerosene, have median concentrations that are relatively steady with small increases in the case of methanol, or small decreases in the case of petroleum distillates.

More toxic compounds such as naphthalene tend to have major decreases in concentrations and are less frequently used between 2011 and 2017.

In summary, if present trends continue larger and larger volumes of water will be used for HF. The share of wells fractured that are in the Haynesville is likely to remain similar to the past six years unless there is a major change of the ratio of oil/gas price. As for water quality for the HF fluid there are some trends although not as clear. One, the concentration of proppant would likely to increase. Two, more-toxic compounds such a naphthalene are likely in the future to be less frequently used and at lower concentrations. As for other compounds that occupational hazards such as methanol/ wood alcohol and petroleum distillates the trends depend on what compound is considered and could be either be increases or decreases if current trends continue.

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