hydrology

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Rapid Development of Small Steep-Walled Sinkholes Associated with Forest Clearing and Later Water-Table Drawdown

Gregg Davidson [1,2,*] and Yung-Yu Chiu [3]

1 Gregg Davidson, LLC, 603 Thrasher Pt, Oxford, MS 38655, USA
2 Geology & Geological Engineering, University of Mississippi, University, MS 38677, USA
3 Independent Researcher, Taichung City 421006, Taiwan
* Correspondence: davidson@olemiss.edu

Abstract

More than 100 small sinkholes, 12 to 50 cm wide and 10 to 80 cm deep, developed rapidly in sandy-clay soils in two adjacent plots in south-central Mississippi, USA, following the installation and operation of a nearby high-capacity water well. The local area is not known for karst features, evaporite dissolution cavities, underground mining, soil erosion around manmade structures, or desiccation fractures of shallow clays. When studied several years after first appearing, the sinkholes had nearly vertical walls, with some cavities widening with depth. Some had tree stumps visible in the center. Further investigation found remnants of stumps or roots in and radiating outward from multiple sinkholes. Installation of piezometers along a transect revealed a continuous hydraulic gradient under the impacted property toward the production well and evidence of reduced overall water levels. The most plausible causes of rapid sinkhole formation are (1) initial partial preservation of tree stumps in soils saturated by a high water table and capillary action in fine-grained surface sediments, (2) lowering of the water table and aeration of near-surface sediments, and (3) accelerated decomposition of stumps faster than soil could creep or cave into the cavities. We propose designating the resulting features as "decomposition sinkholes."

Keywords: sinkholes; subsidence; water table; decomposition; land clearing

1. Introduction

In 1999, a property owner near Magee, MS, noted the rapid development of steep-walled sinkholes in two plots of cleared land separated by a forested hilltop. The sinkholes varied in size, with maximum dimensions of roughly 50 cm in width and 80 cm in depth. The timing of the first sinkholes was reported to be shortly after the installation and operation of a high-capacity water production well a short distance to the north on a neighboring property. (The property owners' names are intentionally left anonymous.) Sinkholes in the plot closest to the production well appeared first and were subsequently larger in number and size relative to the more distant plot. By 2009, the number of sinkholes had grown to over one hundred. No sinkholes appeared in the forested land surrounding the plots.

Globally, the most common cause of sinkhole formation is from subsurface dissolution of carbonate or evaporite rocks. Dissolution cavities, especially near the surface, are subject to the collapse of overlying rock or sediment, creating distinctive surficial depressions or open holes [1]. Lava tubes in volcanic terrain [2] and underground mining [3] also produce subsurface cavities that are subject to collapse and sinkhole formation. Groundwater pumping that lowers the water table below the ceiling of a shallow cave or shaft often

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Academic Editor: Dengfeng Liu

Received: 30 July 2026
Revised: 8 September 2026
Accepted: 10 September 2026
Published: 15 September 2026

accelerates cave collapse [4]. Sinkholes can also occur in highly weathered silicate rocks where incongruent dissolution leaves behind minerals that occupy a smaller volume [5].

Sinkholes created by voids within unconsolidated sediments are less common, associated with several different phenomena. Where shallow clay lies beneath surficial sands and soil, desiccation cracks in the clay can open pathways for the downward movement of surface sediments [6,7]. Erosive flow around or under manmade structures such as pipes and dams can create cavities and subsequent collapse of overlying material [8,9]. Piping along terraces, such as river cut banks, can open up steep-walled sinkholes [10]. Incongruent dissolution can also occur in unconsolidated sediments, such as the weathering of kaolinite to gibbsite, resulting in a decrease in the solid volume and subsidence [11], though this is less likely to produce steep-walled sinkholes. Two studies of particular interest for this paper followed after the sudden disappearance of a small boy into a vertical hole in a migrating sand dune along the southern coast of Lake Michigan (the boy was rescued). It was later determined that the dunes had migrated through a forest, with cylindrical voids forming as tree trunks decomposed [12,13].

The sinkholes near Magee, MS, did not initially seem to fit with any common or previously reported cause, though there was possible overlap with the decomposed trees in the dunes along Lake Michigan. Following a preliminary investigation in 2009, and given the timing and proximity of the nearby production well, a working hypothesis was formed that (1) a historically high natural water table partially preserved tree stumps from land clearing, (2) the production well lowered the water table beneath both plots, and (3) aeration resulted in rapid decomposition, faster than soil could creep or slump into the cavities, leaving small steep-walled sinkholes.

2. Methods

2.1. Study Site

The study site is located on the southwestern border of the town of Magee in Simpson County, Mississippi (Figure 1), in the Southern Pine Hills physiographic region [14]. The terrain is hilly, with a local topographic relief of 30 m. The impacted property consists of a northern mowed plot (~2500 m^2) and a southern mowed plot (~4500 m^2) separated by a forested ridge 60 m in width. Aerial images from 1994 show both plots with roughly the same open space as in 2009, meaning forest clearing had occurred at least 5 years prior to operation of the production well and, based on property owner records, the appearance of the first sinkhole. Upland forests in the region are dominated by loblolly (*Pinus taeda*) and other pine species (longleaf, shortleaf, slash, and spruce), with lesser numbers of hardwoods [14]. Pines are typically shallow rooted, with reports of roughly 80% of loblolly roots found within the upper 60 cm [15].

A small pond (~1000 m^2) sits at low elevation on the southern perimeter of the study site (Figure 2). A water production well sits at high elevation approximately 60 m north of the impacted property. A perennial spring, McNair Spring, is located approximately 100 m east of the northern plot (east of McNair Springs Road). For the purpose of this paper, “impacted property,” refers specifically to the two plots containing sinkholes plus the pond; “study site,” or “site,” refers to the larger area encompassing the production well, plots, pond, and McNair Spring.

The study site lies within the United States East Gulf Coastal Plain, where gently southward-dipping Cenozoic strata record a long history of marine, marginal marine, and fluvial deposition [16,17]. The near-surface geology (upper 100 m) of Simpson County consists of the Catahoula, Pascagoula, Hattiesburg, and Citronelle formations. The Catahoula Formation is an irregularly bedded, cross-stratified sequence of gray sands, sandstones, and clays with local gravel, interpreted as fluvial and fluvio-deltaic deposits laid down by braided and meandering river systems draining onto the coastal plain during the early-to-middle Miocene. The Pascagoula and Hattiesburg formations are composed of clays, sandy clays, and silty sands, deposited in marginal marine to lower coastal plain settings as the Gulf shoreline oscillated across the region. Uplands are capped in places by reworked Pliocene–Pleistocene gravel, sand, and white clay assigned to the Citronelle Formation or mapped as high-level terrace deposits. Dockery and Thompson [14] report that the ages and contacts between formations are questionable, as there are few marine units present in surface exposures of Miocene to recent clastic sequences. The modern land surface is shaped primarily by differential fluvial erosion of these gently dipping, interbedded sand and clay units, producing rolling, dissected uplands where resistant sandy Catahoula beds cap ridges and gentler, clay-floored lowlands where the Hattiesburg/Pascagoula clays are exposed [18].

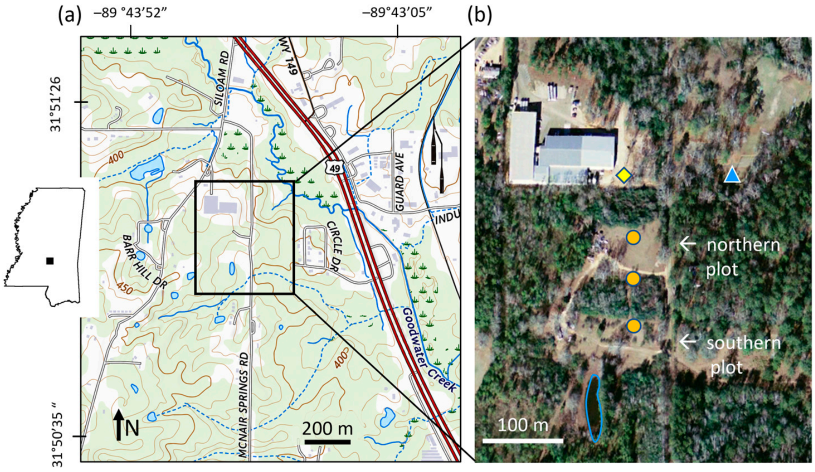

Figure 1. The study site. (**a**) The image is a cropped section of the USGS Magee South 7.5′ quadrangle map on the southwestern border of Magee, MS. The contour lines are in 10-ft intervals. (**b**) The expanded aerial image shows the relative locations of McNair Spring (the blue triangle), pond (the blue outline), production well (the yellow diamond), and piezometers (the orange circles; #1 at bottom and #3 at top).

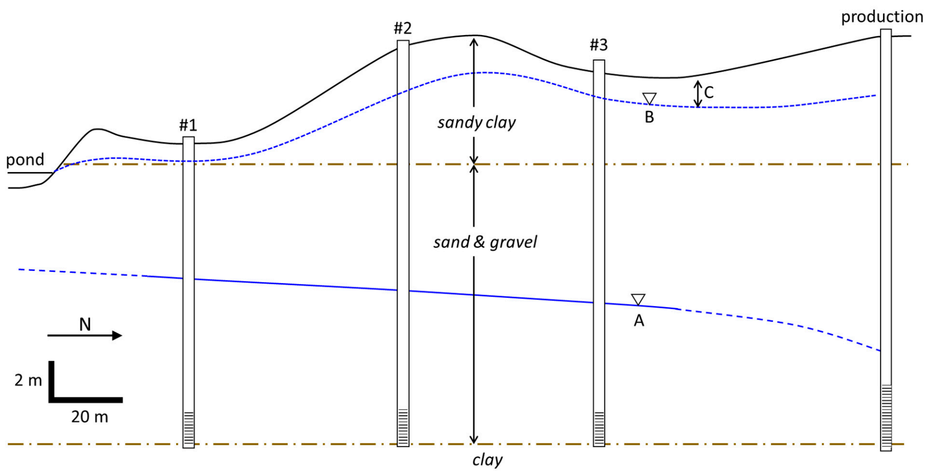

Figure 2. A cross-section of the study site from the pond to the production well with the relative position of the piezometers, surface topography, and sediment transitions. The letters mark (A) the measured position of the water table at the time of the study, (B) the hypothesized historical water-table elevation, and (C) the hypothesized position of a saturated capillary fringe. The vertical exaggeration is approximately 5×.

No agency or academic studies were found specifically for the hydrogeology of McNair Spring or the city of Magee, but a driller's log for the production well reported red sandy clay in the upper 6 m, then 37 m of sand and gravel before encountering clay at a depth of 43 m. Based on a USGS hydrogeology report for the neighboring towns of Mendenhall and D'Lo (northwest of Magee), the production well at the study site was likely completed in sands and gravels of the Hattiesburg Formation and separated by a clay layer from the underlying Catahoula Formation, which serves as the primary water source for municipal wells in Mendenhall and D'Lo [19].

2.2. Sinkholes

The sinkholes were measured for width, depth, shape, and distance from each other. Upon observation of highly decayed tree stumps cut off near ground level in the center of several holes, five sinkholes with no obvious stump were dug out to determine if stumps or radiating root remnants were present. A detailed map of sinkhole location was planned, but not completed before permission to access the property was rescinded.

2.3. Water Table Depth and Fluctuation

Three piezometer wells were installed on a north–south transect, approximately 70, 115, and 180 m from the production well (piezometers 3, 2, and 1, respectively). The piezometers were completed to depths similar to the production well (~43 m) (Figure 2). Piezometer #2 was placed at higher elevation along the forested hill, with piezometers #1 and #3 at lower elevation in the mowed plots where the sinkholes were found (Figures 1 and 2). The driller's logs for the piezometers were very approximate, but documented a similar profile as the production well. Each piezometer encountered sandy clay in the upper 3 to 6 m, followed by sand and gravel until reaching clay at a subsurface elevation similar to the production well. The bottom 3 m of each piezometer was screened. The production well was screened over the bottom 6 m.

Each piezometer was outfitted with a data-logging non-vented pressure transducer, recording measurements (water plus atmospheric pressure) every 30 min. A separate logger on site recorded barometric pressure to subtract atmospheric pressure from the well loggers. All water-level data were normalized to elevations relative to the base of a concrete channel where McNair Spring discharges.

2.4. Pond and Spring

Data-logging pressure transducers were deployed in the pond and in the outflow channel of McNair Spring, with measurements recorded every 30 min and corrected for barometric pressure. McNair Spring discharges into a manmade channel with uniform dimensions, such that any changes in discharge rate should be accompanied by corresponding changes in the depth of water in the channel.

2.5. Precipitation

Daily precipitation data were obtained from a NOAA weather station in D'Lo, MS, (USC00222385), 20 km northwest of the study site.

2.6. Property Owner Records

The timing of sinkhole appearance is based on the property owner's records, including a logbook of the dates of production-well installation and operation. Operation of the production pump could be heard from the property owner's home. According to those records, sinkholes began to appear in the northern plot in 1999, within weeks or months after the start of pumping from the production well. The holes grew in size and number over the following years, eventually extending into the southern plot.

The pond level was claimed to be stable for more than 50 years, only beginning to drain between precipitation events after the production well began operation in 1999. A personal log was kept when the production-well operation was audible, typically during business hours. Periodic shifts to a higher pitch, followed by shutting down operation, were interpreted to be times when the well was pumped dry (air intake in pump).

3. Results

3.1. Sinkholes

Over 100 sinkholes were documented on the impacted property, ranging from 12 to 50 cm in diameter, circular or semi-circular in shape. An exact number could not be determined as some had been filled in by the property owner and overgrown. Remaining sinkhole depths ranged from 10 to 80 cm. The walls were generally vertical, with some widening with depth. The northern plot, closer to the production well, contained roughly twice the number of sinkholes as the southern plot. The size range of sinkholes overlapped considerably between the two plots, though with a larger average size observable in the northern plot (exact averages were not quantified). Within each plot, the number and size of sinkholes did not vary systematically with distance from the production well.

Partially decayed tree stumps were visible at or above ground surface for approximately 10% of the sinkholes. Five sinkholes with no visible stumps were partially excavated to determine if stump remnants were present. In each case, wood remnants were found (Figure 3), including some with woody "root-like" material radiating outward from the center.

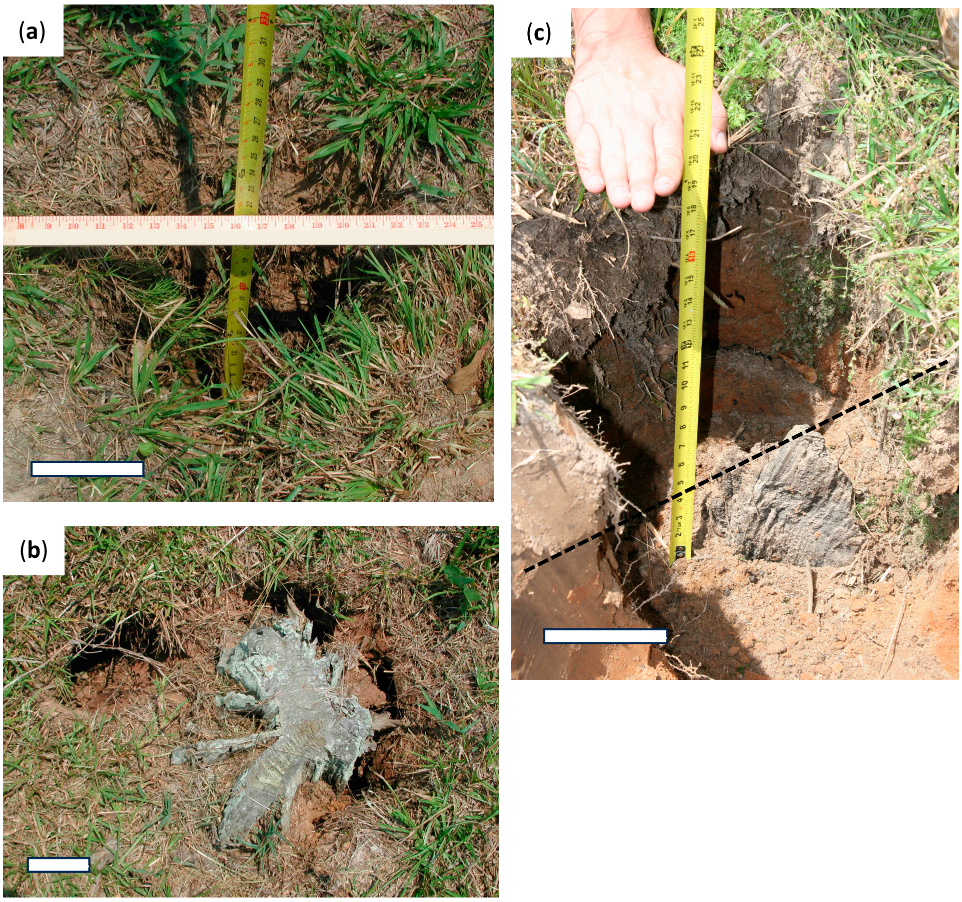

Figure 3. Photos: (**a**) sinkhole, (**b**) sinkhole forming around exposed stump, (**c**) sinkhole with wood remnant in center; excavated on one side (below dashed line) to see interior. Scale bar in each photo is 10 cm (tape measure and measuring stick are in inches).

In the northern plot, the distance between holes varied from roughly 1 to 4 m, with wider and more variable spacing in the southern plot. No sinkholes were found in the adjacent forested land where trees had not been cleared. Evaluation of longer-term changes in the development or evolution of the sinkholes beyond 2009 was not possible, as holes were later filled in by the property owner.

3.2. Hydrogeology

The piezometers documented a continuous gradient under the impacted property toward the production well (Figures 2 and 4) during the six months of observation. On Monday through Thursday or Friday of each week, the piezometers recorded periods of rapid drawdown and recovery during business hours, consistent with the property owner's log of pump operation which could be heard from inside the home. Drawdown typically began by 7 a.m. and recovered in the early afternoon. The magnitude of the daily drawdown and recovery was greatest in piezometer #3 (~20 cm), less in #2 (~9 cm), and smallest in #1 (~5 cm). Following several days of heavy precipitation in late March, the baseline (non-pumping) water level in all three piezometers increased by the same magnitude (15 to 17 cm). Gradients were consistently greater between piezometers 2 and 3 (closer to the production well) than between 1 and 2. Gradients ranged from 0.0078 to 0.0093 between 1 and 2, and from 0.0096 to 0.0142 between 2 and 3. The largest gradients occurred during the periods of greatest drawdown in each piezometer.

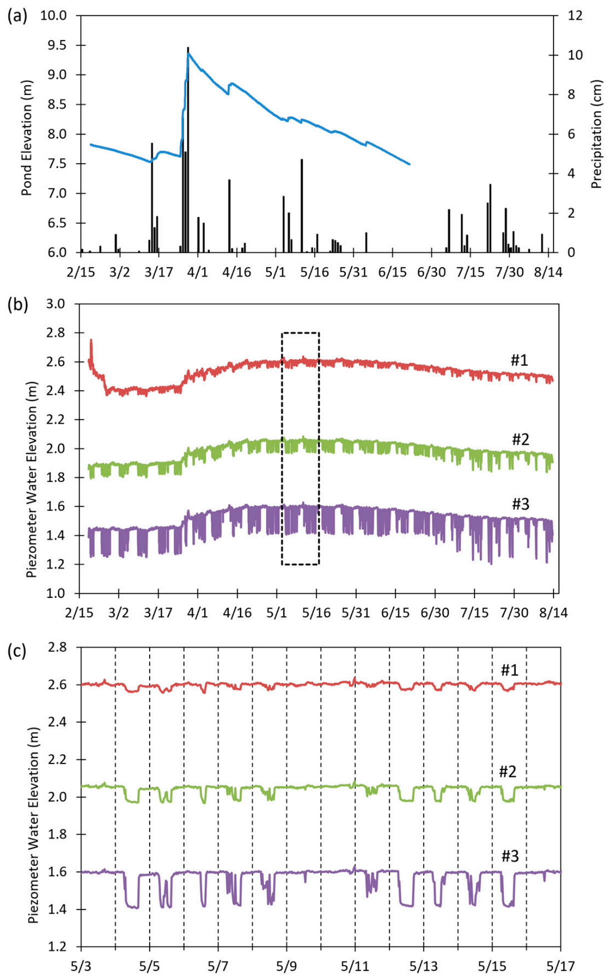

Figure 4. (**a**) The pond elevation (blue line) relative to McNair Spring and precipitation (black bars) during the six-month study (the pond transducer failed at the end of June). The x-axis labels are month/day in 2009. (**b**) Piezometer water elevations relative to McNair Spring over the six-month study, with a two-week interval outlined and expanded with daily grid-line divisions in (**c**). See Figure 2 for the piezometer locations.

A piezometer was not completed directly beneath the pond, but projecting the gradient recorded by the three piezometers indicated a water table approximately 6 m beneath the bottom of the pond. Fluctuations in pond elevation tracked with precipitation, with no observable change during times of production-well operation.

McNair Spring flowed at a relatively constant rate throughout the period of investigation. No reductions in the water level of the outflow from the spring were observed during periods of production-well operation.

4. Discussion

4.1. Sinkholes

The spacing of sinkholes (1 to 4 m), particularly in the northern plot where sinkholes are larger in number, is consistent with the spacing of mature trees in the surrounding forested land. The diameter of the larger holes (up to 50 cm) is similar to the diameter of trees and root systems where they first begin to radiate out from the trunk. A maximum depth (up to 80 cm) is also what is expected for the bulk of root mass for pine species such as loblolly (*Pinus taeda*) [15]. Many sinkholes contained remnants of stumps visible at the surface (Figure 3). Partial excavations of five sinkholes without visible stumps all encountered buried woody remains with the appearance of a central stump, some with tubular woody material extending laterally, interpreted to be what was left of larger roots radiating outward.

It is common for the decomposition of buried organic material, including the remains of trees, to result in localized subsidence, but typically over multiple seasons and producing gently sloped depressions as soil is washed inward. Exceptions include buried brush piles, with decomposition resulting in the isolated collapse of overlying sediment into void spaces [20]. Stumps left behind following deforestation do not typically produce sinkholes. For this investigation, the primary hypothesis for the cause of dozens of steep-walled, rapidly forming sinkholes was that a historically high natural water table slowed the decomposition of tree stumps, predisposing them to accelerated decay when aerated by a lowered water table. This requires first considering what is known regarding the nature of decomposition of wood during saturation and later aeration.

4.2. Decomposition of Saturated and Aerated Wood

Saturated wood can last for centuries or longer [21], but is not perfectly preserved. Prolonged waterlogging produces a slow and selective degradation of the cell-wall components. Cellulose and hemicellulose are progressively hydrolyzed or otherwise lost, with bacterial erosion causing substantial depletion of holocellulose and compromising the structural integrity of the secondary cell wall. As polysaccharides are removed, the remaining material becomes increasingly dominated by a lignin-rich framework of the middle lamella and residual secondary wall, which can persist with relatively minor structural alteration even after extensive bacterial decay. Lignin is nevertheless not completely resistant to degradation; archaeological waterlogged wood exhibits depolymerization and cleavage of lignin ether bonds, accompanied by an increase in free phenolic units. Thus, although the external form of waterlogged wood may remain intact, slow decay during prolonged saturation can substantially alter its chemical composition and microstructure through preferential loss of polysaccharides and more limited modification of lignin [22–28].

Decomposition leads to increased porosity which is filled with water under saturated conditions. Upon aeration, partial drying causes additional physical degradation as capillary forces cause shrinking and collapse of weakened residual cellular structures. Saturated archaeological wood can be significantly compromised within hours of excavation just because of drying [29]. Once aerated, decomposition of the chemically weakened lignin structures can occur much faster than in fresh wood [22]. At the study site, it is not known when the land was cleared, but aerial photography from 1994 documents that clearing took place at least five years prior to the production-well operation and first appearance of sinkholes.

4.3. Pre-Pumping Water Table

Saturation of ground-level stumps does not require the original water table to reach all the way to the surface. Capillary action in fine-grained near-surface sediments can keep pores mostly saturated as long as the water table is relatively shallow. Given that no historical data is available documenting the exact location of the water table prior to the sinkhole formation, testing this hypothesis was focused on current water levels and gradients, and how they compare to reasonable expectations of prior conditions.

In temperate climatic zones, an undisturbed water table in unconfined aquifers in unconsolidated sediments will generally reflect the surface topography, with discharge into topographic low spots appearing as ponds, streams, and springs [19,30]. This expectation is supported at the study site by a uniform response in the water table in all three piezometers following heavy rains in late March of 2009. Infiltration resulted in a consistent rise in the water table of 15 to 17 cm in all three locations, indicating relatively consistent infiltration rates across the impacted property. In contrast to the surface topography, the observed gradient at the time of the study sloped continuously to the north toward the production well. Further, the water-table gradient was consistently higher beneath the northern plot, consistent with expectations for a cone of depression terminating at the production well.

The relatively consistent pond-level prior to pumping, indicated by the property owner, is also consistent with a pre-pumping water table intersecting with and discharging water to the pond. The bottom of the pond extends below the surficial sandy-clay layer, making the pond prone to water loss between rains if perched higher than the water table. During the period of study, the water table was well below the bottom of the pond and pond levels fluctuated by up to 2 m over a matter of days (Figure 4a).

A steady hydraulic gradient to the north during the six months of observation, coupled with the increasing responses to pumping with increasing proximity to the pumping well, indicates that pumping has been drawing water from beneath the impacted property, resulting in an overall reduction in the water-table elevation.

4.4. McNair Spring

The lack of any observable response to pumping in spring discharge was unexpected, as the spring lies well within the radius of a circular cone of depression from the production well and the production well is completed and screened deeper than the discharge elevation of the spring. It is possible that the spring is fed primarily from the underlying Catahoula Formation, or possibly isolated from the production well by a low-permeability clay zone. Additional borings near the spring would be required to confirm.

4.5. Alternate Explanations

Oil and gas wells operate in the region, including some associated with a deep salt dome north of D'Lo, MS [31,32]. Oil and gas extraction can lead to the depressurization of hydrocarbon-bearing zones and subsequent subsidence, with notable examples in places like the San Joaquin Valley of California and the US Gulf Coast [33]. This typically results in regional subsidence rather than sinkhole formation. Smaller steep-walled sinkholes may form where salt is dissolved or drilling fluids carve out subsurface cavities. To our knowledge, there are no oil and gas wells in the immediate vicinity of the study site, and no previous reports were found of subsidence of any kind in Simpson County.

https://doi.org/10.3390/hydrology13090248

Other possible explanations considered include piping and mineral weathering. Piping occurs where groundwater flow erodes passages through a stream embankment or under a barrier such as a levee or dam [10,34]. The sinkholes at the study site are not associated with a stream embankment, dam, or levee. The only groundwater discharge point is a distant spring that appears to be hydraulically disconnected from the groundwater system beneath the impacted property.

Mineral weathering, resulting in a reduction in the volume of sediment, may be occurring to some degree in the area, though it does not explain why sinkholes would only form in plots cleared of trees. The adjacent wooded areas surrounding the site were explored, with no evidence of sinkholes. There are a number of ponds near the site (Figure 1), though much larger and more gently sloped than those observed on the impacted property. No obvious relationship was found between the sinkholes and the surrounding landforms or geomorphology.

4.6. Varied Forms of "Decomposition Sinkholes"

There are similarities and differences worth noting between the holes formed via burial of a forest by a migrating dune, such as those found near Lake Michigan [12,13], and the deforested plots in the current study. Migrating sands burying a stand of trees resulted in the creation of vertical cylindrical voids as tree trunks decomposed. While sharing trees and decomposition in common with the current study, the holes in the migrating dunes were not dependent on fluctuations in the water table or variable rates of decay. Isolated surface holes developed only when overlying sediments collapsed into an empty cast of a decayed tree trunk. In the current study, the stumps were never buried. Myriad holes appear to have developed as accelerated decomposition left steep-walled cavities open directly to the surface.

There does not appear to be an established term for sinkholes formed by these processes. Argyilan et al. [12] referred to holes created within migrating dunes as "decomposition chimneys." State agency reports of collapse features above buried brush piles refer to them by the more generic terms of subsidence or sinkhole features [20], with one agency fact sheet identifying them as "false sinkholes" [35]. We propose designating any steep-walled holes formed by the decay of organic material as "decomposition sinkholes."

5. Summary and Conclusions

The rapid formation of more than 100 small, steep-walled sinkholes in two plots cleared of trees began soon after a nearby water production well began operation in 1999. Based on property owner records, the sinkholes appeared first in the plot nearest the production well and later in the plot farther away. At the same time, a small pond on the site began to drain between rains. When examined in 2009, the sinkholes ranged in size from 12 to 50 cm in width and 10 to 80 cm in depth, most with near vertical walls and some widening with depth.

Typical causes of sinkholes, including carbonate or evaporite dissolution, incongruent weathering, underground mining, piping, or erosion around manmade structures, are not plausible explanations at this site. The presence of partially decayed tree stumps in several sinkholes in the surficial sandy-clay soil suggested a link between decomposing tree stumps and a lowering of the water table.

A set of piezometers placed in 2009, in and between the two plots, documented a water table at the time of measurement that did not reflect the surface topography or intersect with the pond as is commonly expected for an unconfined aquifer in unconsolidated sediments and temperate climate. The water table was below the pond and sloped continuously toward the production well. Daily drawdowns and recoveries in each piezometer coincided with operation of the production well, with a greater magnitude observed in the piezometer closest to the production well and diminishing responses with distance. These data are consistent with the hypothesis that the water table was historically much closer to the surface, with later development of a significant cone of depression beneath the impacted property.

Altogether, the data suggests a likely sequence of (1) partial preservation of tree stumps in saturated soils created by a historically high water table and capillary action for at least five years before sinkhole formation, (2) lowering of the water table and aeration of surface sediments due to pumping, and (3) accelerated decomposition of weathered stumps faster than soil could slump or wash into the cavities. However, with no physical records of the position of the water table prior to 1999, the explanation for rapid formation and character of the sinkholes at this site cannot be defended with certainty.

Author Contributions: G.D.: project oversight and writing initial draft; Y.-Y.C.: field work, sediment analyses, reviewing and editing final draft. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The pond, spring, and piezometer water-level data are available in the HydroShare data repository: http://www.hydroshare.org/resource/5211b4e175074817a3c39104e6036a2e, accessed on 8 September 2026.

Conflicts of Interest: The study was performed on behalf of the property owner, now deceased, seeking damages or mitigation for the sinkholes. The work was performed as a private consultant by Gregg Davidson LLC. The authors have no financial interest beyond remuneration for the work done at the time of the study.

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