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Historical changes of a major juncture: Lower Old River, Louisiana

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Old River is one of the most important river junctures in North America. It connects three large, navigable rivers – the Mississippi, Atchafalaya and Red – which support economies and environments critical to United States of America. Starting in the 1800s, the Atchafalaya River began receiving more flow through this juncture, and by the mid-1900s, an avulsion was likely so the Old River Control Project was authorized to prevent diversion of the Mississippi River to the Atchafalaya. This paper examines the historical changes of Lower Old River, the main juncture prior to 1963 before the flow became controlled by structures, including its flow changes, human modifications, and whether and how it was changing as the Atchafalaya received more flow. In contrast to some reports that suggest that bidirectional flow in Old River was just a few years in duration, occasional flow from the Red River is documented: starting in the 1880s and persisting for several decades through 1945. This paper identifies three transitions in the transformation from bidirectional to unidirectional flow, the first of unknown cause in the late 1910s, the second likely instigated by the flood of record in 1927, and the third immediately following a local artificial cut-off in 1944-1945. Also, changes in flow and geometry in Lower Old River are related to changes in the adjacent Mississippi and Atchafalaya Rivers.

Keywords: fluvial geomorphology; bidirectional flow; junction dynamics; Mississippi River; Atchafalaya River

Introduction and background

Old River is a short (10 km long), yet important juncture that connects the Mississippi, Atchafalaya, and Red Rivers, three rivers vital to the economy and environment of the nation. It is located near the 31st parallel in Louisiana and at the boundary between the Mississippi River alluvial valley and the delta plain, about 300 km upstream of New Orleans. Significant changes in the past century in these adjoining rivers, particularly the threat of diversion of the Mississippi River into the Atchafalaya River, are related to changes at this juncture. This paper examines the transformations at this juncture, including how natural changes and human interventions created the juncture, maintained it, altered the rivers that contribute flow and sediment to it, altered the rivers that received flow from it, altered flow angles through it, and then closed it so that flow could be regulated by structures through artificial channels to the north. The focus of this paper is on Lower Old River, which was bidirectional for some time, then became unidirectional, and later was closed as it began receiving more flow, which threatened diversion of the Mississippi into the Atchafalaya.

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The area near Old River has a complicated history due to natural changes associated with its location and to human interferences, and the quest to manage it as the link between these three important waterways (Fisk, 1952) (Figure 1 and Table 1). In the fourteenth century, the Mississippi River and Red River were separate systems, located within a few kilometers of each other at this location, but flowing in different directions toward the Gulf of Mexico. By the sixteenth century, a meander bend of the Mississippi migrated westward and captured part of the Red River flow. The Red River south of this juncture was abandoned, forming a new course, the Atchafalaya, which now carried the Red River flow but was also connected to the Mississippi (Figure 1).

Substantive human intervention began in 1831 when Captain Henry Miller Shreve brought in 159 men (Anonymous, 1987) to dig a ditch to cut off the meander neck to reduce the length of the Mississippi by approximately 30 km for navigation (Figure 1). The neck was approximately 1 km wide at the time of the cut-off, rather narrow for a river the size of the Mississippi. At the next high water, the Mississippi cut through the ditch, which caused the Red River to empty into the smaller Atchafalaya and left behind Old River, the former active channel of the Mississippi, which was still

Figure 1. Some of the major channel planform changes near the Old River juncture (modified from Fisk [1952]).
connected to the Mississippi, Atchafalaya, and Red Rivers. The cut-off created a northern arm, or Upper Old River; a western arm, consisting of the Red River, which turns into the Atchafalaya in the southwest; and a southern arm, or Lower Old River. Thus, this cut-off formed a unique tie channel (e.g., Rowland, Dietrich, Day, & Parker, 2009) with connections to the three large rivers.

Typically, the endpoints of a cut-off near the river fill in with coarse deposits from lateral accretion, forming an oxbow lake (Allen, 1965; Hooke, 1995). In smaller rivers, this may happen quickly, but in a river with the depth and width of the Mississippi, the connectivity can last for decades or more. Both arms of the cut-off were still connected in 1839; by 1854, Upper Old River was quite wide but the connection with Lower Old River was closing (Figure 1). An 1855 map, which Fisk (1952) attributed to State

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Inferred effect on Old River</th>
</tr>
</thead>
<tbody>
<tr>
<td>16th Century</td>
<td>Lateral migration of Mississippi River results in capture of Red, and creation of Atchafalaya below juncture</td>
<td>Old River not yet formed</td>
</tr>
<tr>
<td>1831</td>
<td>Shreve's Cut-off created</td>
<td>Forms Upper and Lower Old Rivers, reduced Mississippi length by appx. 30 km (&gt;95%)</td>
</tr>
<tr>
<td>1833 and 1870s</td>
<td>Removal of Red River log jam</td>
<td>Increased importance of Red River flow in network</td>
</tr>
<tr>
<td>1839–1855</td>
<td>Removal of Atchafalaya River log jam</td>
<td>Atchafalaya River increased in importance and more of the Mississippi River flow diverted through Old River</td>
</tr>
<tr>
<td>1878–1937</td>
<td>Dredging of canal connecting Lower Old and Mississippi Rivers. Flow apparently maintained juncture after 1937</td>
<td>Prevented cut-off from becoming an oxbow lake. Lower Old River maintained size instead of filling. Flow was bidirectional for several decades</td>
</tr>
<tr>
<td>1896–1897</td>
<td>Construction of two submerged sills across the Atchafalaya River near Simmesport to prevent its further enlargement</td>
<td>Uncertain. May or may not have slowed growth of Atchafalaya</td>
</tr>
<tr>
<td>1927</td>
<td>The largest flood of record on the Mississippi. Caused extensive flooding and several crevasses</td>
<td>Likely increased the size of Lower Old River, and resulted in increased flows from the Mississippi River</td>
</tr>
<tr>
<td>1929–1942</td>
<td>Creation of 14 artificial cut-offs on Mississippi along 600 valley km above Old River, shortening channel length by nearly 400 km (approximately 20%)</td>
<td>Increased slope and stream power of Mississippi upstream of Old River</td>
</tr>
<tr>
<td>1944–1945</td>
<td>Local cutoff at Carr Point shortens path between Mississippi and Lower Old River (local slope increased 400%)</td>
<td>Locally higher slope promoted increased flow to Mississippi</td>
</tr>
<tr>
<td>1961–1963</td>
<td>Completion of Old River control Structure, including Inflow/Outflow Channels, Low Sill and Overbank Structures and Lock and Dam</td>
<td>Abandonment of Lower Old River as juncture that brought flow from Mississippi to Atchafalaya. Flow now routed upstream through Inflow/Outflow Channels. Lower Old River used for navigation</td>
</tr>
</tbody>
</table>
Engineer Louis Hébert, shows that a canal was proposed to maintain this link with Lower Old River. Much later, the act of 18 June 1878 provided for maintaining a navigable channel during low water between the Mississippi, Red, and Atchafalaya by means of dredging and washing the channel with the wheels of steamboats (United States Army Corps of Engineers, 1920). An 1883 historical map (not shown) shows infilling of Upper Old River and the enlargement of Lower Old River, which became the path for flow exchange between the Mississippi with the Red and Atchafalaya Rivers. Later, in 1896–1997, the project was modified, resulting in the construction and maintenance of two low-relief brush and stone submerged dams across the Atchafalaya River near Simmesport to prevent its further enlargement. The canal across the bar at the mouth of Lower Old River was to be dredged to a width of 61 m (200 ft) and a depth of 1.8 m (6 ft) below the zero of the local gage during low water. Fisk’s notes on (1952) Hebert’s 1854–1855 map indicate that this canal between Lower Old River and Mississippi River was “maintained by dredging until 1937” (Figure 1).

Contemporaneous with much of this, Congress authorized Shreve to remove a gigantic series of logjams, the Great Raft of the Red River, with its lower end in northwest Louisiana near Natchitoches, approximately 260 km (160 mi) long (Reuss, 1998). This raft was natural; it had been observed by early explorers, and Torres and Harrelson (2012) suggest that it dated back over 2000 years, when the Mississippi avulsed and captured the course of the Red River.

In 1833, Shreve and 159 men supported by Shreve’s invention, the “snag steamboat,” removed logs from the raft. By 1836, they had cleared it. Because Congress ignored Shreve’s request for maintenance, the raft re-formed a few years later. In the following decades, other contractors were unsuccessful, but eventually in 1872 and 1873, Lt. E. A. Woodruff used Shreve’s snagboats, saws, cranes, and even nitroglycerine to again dismantle and remove the raft (Humphreys, 1971). Once the raft was cleared, the river was dredged. This time, Congress authorized monitoring and maintenance to prevent the raft from redeveloping. After many centuries of blockage, this change likely increased the magnitude of peak flows and sediment deliveries to the Old River by the Red River (Table 1).

Also affecting flow, sediment, and geometry in this system were a series of rafts on the Atchafalaya, beginning some 48 km (30 mi) south of the river’s head and extending 64 km (40 mi) towards the Gulf of Mexico. Reports suggest that the aggregate length in 1805 was a little over 16 km (10 mi) and that the raft dates back to the sixteenth century, but the accumulation intensified in the late 1700s (Comeaux, 1970; Reuss, 1998). The Atchafalaya rafts then might have become worse due to Shreve’s cut-off (Bragg, 1977) or the Red River raft removal (Morris, 2012). After unsuccessful efforts at gaining state support, local residents burned the surface portion of the Atchafalaya River logjam during a drought in 1839. Then, in 1840, the State began to use snagboats to remove timber, a difficult process which was not fully complete until 1855 (Latimer & Schweizer, 1951). Because the Atchafalaya River had an appreciably shorter, steeper course to the Gulf of Mexico, it began to enlarge and carry a higher percent of the Mississippi flow (Fisk, 1952).

The changes to fluvial processes stemming from raft removal and alteration of this juncture were not desirable to all. Dating back to the 1880s, riverboat personnel were concerned about the Atchafalaya (Anonymous, 1884), describing it as “the most dangerous and turbid stream in America.” There were repeated appeals to Congress (e.g., United States House of Representatives, 63rd Congress, 2nd session, 1914) for engineering intervention to maintain the juncture with the Red and the Mississippi but
“divorce” it from the Atchafalaya. Such a divorce would entail more drastic modification of this juncture.

Flooding, also an important driver of morphologic change, resulted in mitigation through the building of flood-control structures. The flood of 1927, the largest recorded flood on the Lower Mississippi River, inundated approximately 70,000 km² (27,000 mi²) (Reuss, 1998) by overtopping and crevassing levees in numerous places. This flood triggered legislative response, the Flood Control Act of 1928 (Reuss, 1998), authorizing the United States Army Corps of Engineers to raise and widen approximately 3000 km of artificial levees, and build new ones (Kesel, 2003). In the following decades, floodways were constructed, including the Bonnet Carré spillway, about 300 km downriver (near river mi 100 a distance upstream of the Head of Passes), completed in 1931. Levee building for the Morganza spillway, about 40 km downriver (near river mi 280), began in the late 1930s, and was completed in 1954. Artificial levees along much of the lower Mississippi River were later stabilized with concrete revetments along 1400 km of riverbank (Kesel, 2003).

Another major transformation was construction of multiple artificial cut-offs by the United States Army Corps of Engineers to improve navigation. Between river km 1091 (mi 678), and km 552 (mi 343), from 1929 to 1942, meander distances of 516.6 km (320.9 mi) were reduced to cut-off distances of 123 km (76.4 mi), shortening the river upstream of the study area by 393.6 km (Biedenharn & Watson, 1997; Winkley, 1977). A longitudinal profile shows that this zone comprises about one-third of the Mississippi below Cairo, Illinois (Harmar & Clifford, 2007). These rates of cut-off formation were several times the natural rates documented in prior studies (Winkley, 1977). Slopes increased in varied reaches from 5.7 to 36.1%, as did stream power (Biedenharn, Thorne, & Watson, 2000). These cut-offs had a major effect on the longitudinal profile of the Mississippi (Harmar & Clifford, 2007) and likely influenced changes in water and bed-surface elevations (Lane, 1947), complicated by the number and proximity of these to each other (Biedenharn & Watson, 1997). The juncture of the Mississippi with Lower Old River juncture was approximately at km 493 (mi 306), so the primary zone of shortening began 50 km upstream. Perhaps, the most important direct effect on Old River was a local cut-off known as Carr Point cut-off, made in 1944–1945, which shortened the path to Lower Old River locally from about a 5-km path to less than 1 km (Figure 1). Just downstream of Old River, the Mississippi channel-bed elevation increases, which Harmar and Clifford (2007) attribute to flow diversion into the Atchafalaya through Old River, which results in an abrupt reduction in stream power per unit width downstream on the Mississippi and thus a reduction in the energy expended in transporting bed material.

There was increasing awareness in the late 1940s regarding the potential for avulsion of the Mississippi to the Atchafalaya channel and its potential harm to the lowermost Mississippi, including the deep-water ports of New Orleans and Baton Rouge. Detailed studies (Fisk, 1952; Latimer & Schweizer, 1951) completed in the 1950s shed insight on the increasing flow and the enlarging geometry of the Atchafalaya River and its potential to capture the flow of the Mississippi River. Not long afterwards, on 3 September 1954, the Old River Control Project was authorized (Figure 2). The first group of structures, completed in 1963, but partly operational by 1961, included: (1) the Old River Inflow and Outflow Channel, a canal where the Mississippi flow would now be controlled; (2) the Low Sill Structure on the intake to the outflow channel, which was the primary structure controlling flow through the river; (3) a Lock and Dam near Lower Old River, where navigation occurs; and (4) an Overbank Structure,
which includes levees to keep the rivers apart, flood gates, and a spillway. This project helps regional and local flood management by controlling the amount of flow into the Atchafalaya and better using the floodplain during major floods, and it facilitates continuing navigation between the rivers near Lower Old River. These structures were built to send as much as 30% of the “latitudinal” flow (i.e., the sum of the Red River and Mississippi River flows at the latitude of the Old River complex) through the Atchafalaya to the Gulf.

Due, in part, to serious undermining induced by the 1973 flood, which affected the integrity and performance of the Low Sill Structure, the Old River Auxiliary Structure and an Auxiliary Inflow channel were built nearby to limit reliance on one structure and maintain better control of flow diversion. It went operational in 1987 and works in tandem with the Low Sill Structure (Figure 2). Subsequently, the Sidney A. Murray, Jr. Hydroelectric Plant, a dam and 192-MW power plant was emplaced about 3 km above the Low Sill Structure in 1990 to take advantage of the average 6-m head difference between the Mississippi and Atchafalaya rivers (Figure 2) (Holly & Spasojevic, 1999). Since that time, it has been operated successfully by Louisiana Hydroelectric

Figure 2. Topography from the National Elevation Dataset (http://ned.usgs.gov/) shows the current configuration near the Old River juncture, with three inflow channels at the Hydropower project (completed in 1990), Low Sill Structure (completed in 1963), and Auxiliary Structure (completed in 1987) controlling flow between the Mississippi and Atchafalaya rivers. All three bring flow from the Mississippi River through the Old River Outflow Channel to the Atchafalaya River. Lower Old River, the juncture featured in this paper which was once bidirectional, then unidirectional, then closed off, is now a navigation channel supported by the Old River lock. Gage stations mentioned in this paper and current flow directions are shown.
Corporation, in coordination with the United States Army Corps of Engineers and in concert with the Auxiliary and Low Sill structures, to achieve the 30–70% target flow distribution. The facility passes an average flow of 2800 m$^3$/s and is also capable of passing a significant sand and silt load without long-term damage (Holly & Spasojevic, 1999).

Despite this complicated history and its important position between two large rivers, little has been written about the changes in flow and channel geometry of the Old River juncture prior to completion of this project, and what exists is contradictory. For instance, Bragg (1977, p. 194) wrote:

In 1872, the Red River changed its course, abandoned its old mouth, broke through into the old riverbed, and joined itself to the head of the Atchafalaya. With the channel that had become known as Old River as the only connection with the Mississippi, the flow was either westerly or easterly, depending on the respective stages of the Red and the Mississippi. The changed conditions caused the Atchafalaya to enlarge rapidly near its head. In 1880 it was reported that water was no longer flowing into the Mississippi from either the Red or Atchafalaya. The current in Old River was flowing into the Atchafalaya at all stages of water.

This conclusion that the river was bidirectional only from 1872 to 1880 contradicts other reports discussing Old River in the context of adjoining rivers (Latimer & Schweizer, 1951; Meade & Moody, 2010; Mossa, 1996) and post-1935 data obtained from the Corps of Engineers (http://www.mvn.usace.army.mil/cgi-bin/). Others have noted that bidirectional flow occurred in the Old River according to hydrologic and hydraulic conditions in the adjacent river systems (Holly & Spasojevic, 1999). Old River was historically troublesome for engineers, boaters, and farmers who sought stability and predictability; either too much of the Red River flowed into the Mississippi, which left the Atchafalaya dry, or too much Red River flowed into the Atchafalaya,
which made riverboat passage between the Red and Mississippi difficult, or too much Mississippi flowed down the Atchafalaya, which threatened diversion along with abandonment of its route past Baton Rouge and New Orleans (Morris, 2012). This paper examines the historical geomorphology of Old River, integrating data from various sources, using both data and engineering publications of the United States Army Corps of Engineers not synthesized until present. Goals are to better understand the nature of flow through the Old River juncture, including the history of how the juncture changed from becoming bidirectional to unidirectional, how the timing of this related to the numerous human modifications of the juncture and adjoining rivers in the system, and how the flow and geometry was changing as the Atchafalaya was getting more flow. This understanding is relevant to studies of river engineering (e.g., Smith & Winkley, 1996), connectivity (Amoros & Bornette, 2002; Kondolf et al., 2006; Phillips, 2011), sediment dynamics (Mossa, 1996), and related areas.

Data and methodology
Data regarding the discharge and channel geometry of the Old River juncture are in a variety of historical and recent publications. Early data are dispersed in a variety of publications and reports. One source, for instance, included a few measurements from 1851 and 1858, then more frequent and regular measurements from 1880 through 1923 (Mississippi River Commission, 1948). The two 1851 measurements are outliers,
having large cross-sectional areas for their associated velocities and discharges. The
method by which these were collected is listed as SL (ship’s log) and differs from the
other measurements, which are $F$ (double floats), $M$ (velocity measurements with one
meter), or $MM$ (mean result of simultaneous measurements with two meters) in the
reports (Mississippi River Commission, 1948). Over the years, discharge measure-
ments have improved, particularly since 1931 when current meters were employed
(Dyhouse, 1985) and after 1998 when more advanced technologies (e.g., Doppler)
were adopted. Although historical float measurements are not as accurate as modern
current measurements, a detailed study of data from the middle Mississippi compared
historical float measurements with more recent current meter measurements and found
no significant difference, such as lower or higher means, between these methods
(Pinter, 2010).

Tabular data in the appendices of the Latimer and Schweizer (1951) report are an
important source of annual to multi-year changes in the system; these were entered in
spreadsheets and converted to metric units. Daily discharges and stages from 1928
onwards have been published in Mississippi River Commission pamphlets (1948, n.d.,
varied), and those from 1935 onwards are available online, posted by the New
Orleans District of the United States Army Corps of Engineers (http://www.mvn.
usace.army.mil/eng/edhd/wcontrol/miss.asp). Instantaneous measurements since 1928
were typically collected every 1–2 weeks, and more frequently during high flow peri-
ods, with intervening data derived through rating curves. Discharge values were
reported as positive or negative, depending on whether the flow through Lower Old
River was from the Mississippi (positive) or from the Red River (negative). Data were
mostly collected in the Lower Old River near Torras or the Texas & Paci
fi
fi
c Railway. Unlike the United States Geological Survey, which publishes by water year (starting 1
October), United States Corps of Engineers data are generally published and reported
by calendar year (starting 1 January); thus, the data are analyzed accordingly. Since
1963, flow has been routed through the artificial Old River Outflow Channel, located
parallel to and upstream of Lower Old River, through the three inflow channels asso-
ciated with the Low Sill Structure, the Auxiliary Structure, and the Hydroelectric Plant
(Figure 2).

Some of the earlier and more recent publications contain information on channel
geometry. In some instances, the instantaneous discharge measurements include width,
cross-sectional area, mean and maximum depth, and velocity. Such records were col-
lected before 1930 and started again in 1943, but are beyond the scope of this paper.
Some channel geometry data are included in reports, especially that by Latimer and
Schweizer (1951), which are helpful in discerning the changes near this juncture.

All available data were combined into a time series in spreadsheets and converted
into metric units. Stages were adjusted for gage datum changes. Data were evaluated
and corrected to remove inconsistencies in annual reports, for instance, where discharge
were reported as negative but where velocities were not. In these cases, the velocity
values were converted to negative to display the data appropriately.

Because the stage and discharge data were the most continuous and long-term, spe-
cific stage trends were helpful for inferring changes in channel geometry (Blench,
1969). This analysis examines the river stage (water surface elevation) over the period
of record, keeping discharge constant or within a specified, fairly narrow range. An
increase in stage suggests that aggradation or narrowing occurred, and a decrease in
stage indicates that the bed degraded or the cross-section widened.
Results

The flow near the Old River juncture can be expressed in different ways. The most common way is as “latitude flow,” the percentage of the flow that passes through the Atchafalaya River at Simmesport in comparison to the combined flow of the Atchafalaya River at Simmesport and the Mississippi River at Red River Landing below the Old River navigation channel. The aim described in numerous reports is to have the latitude flow percentage at 30–70%; that is, 30% down the Atchafalaya and the bulk of flow continuing down the Mississippi (e.g., Holly & Spasojevic, 1999). These percentages are always positive because none of the components are negative. Early data synthesized from Latimer and Schweizer (1951) were by calendar year and are updated with United States Army Corps of Engineers’ data through the construction of the Old River Control Project. Latimer and Schweizer showed that, around 1900, 12% of the latitudinal flow was in the Atchafalaya, and that this amount had increased to exceed 30% a few years prior to project completion in 1963 (Figure 3).

An alternative way to characterize the flow is to examine the percentage of flow through Old River by comparing the flow in Old River, positive or negative depending on direction (from the Red River or from the Mississippi, respectively), to the combined amount from Old River and the Mississippi River below the diversion. Latimer and Schweizer (1951) expressed this total as a net, not gross amount, for the calendar year and thus it is done similarly herein for purposes of comparison. The continuous data derived from the flow data reveal the bidirectional or unidirectional character of Old River and show that the annual average flow was bidirectional from 1880 through 1914, with a mixture of positive and negative values ranging between −10 and 22% (Figure 4). Since 1915, the net annual flow through Old River has come from the Mississippi, and the general trend has been toward increasing percentages, with the last several years mostly between 20 and 25% (Figure 4).

A third way in which Latimer and Schweizer (1951) evaluated flow was by tabulating the number of days with flow from the Red River to the Mississippi, with flow from the Mississippi to the Atchafalaya River, or with no flow. Because a few of the early years have incomplete records and others are leap years, these were converted to percentages. These data show considerable year-to-year variability, but the trend is evident. Flow through Old River was dominantly from the Mississippi, but mixed in direction through 1915; the flow to the Mississippi ranging from 0 to 56% of the days during this period (Figure 5). Since that time, the flow through Old River was toward the Atchafalaya River 80–100% of the days (Figure 5). Zero-flow days are typically less than 5% of the total, and there has been no flow towards the Mississippi River after 1945. Some zero-flow days have occurred since construction of the diversion in 1963.

When mean daily flow data are examined, the level of variability increases. The synthesized data-set of the daily Lower Old River discharge, which begins in 1880, includes more than six decades of documented bidirectional flow and its transformation to unidirectional flow in the 1940s (Figure 6). Some of the larger flows toward the Mississippi, during years for which data were found, occurred in 1917 and 1928 (Figure 6). The last measurement with flow towards the Mississippi was in February, 1945. Since then, flows have been at or near zero on occasion, but never negative or from the Red River. Besides changes in direction, there has also been a marked change in the magnitude of flow through Old River. During the early period, before 1935, discharge ranged between −7000 and 12000 m³/s, although this does not include the 1927 flood. After
Figure 5. The percentage of days per calendar year that flow through the Old River juncture was towards the Mississippi, towards the Atchafalaya, or zero. Data through 1951 are from Latimer and Schweizer (1951) and were updated to 1963, when the Control Project became operational, using more recent data from the United States Army Corps of Engineers, New Orleans district.

Figure 6. Hydrograph of Old River instantaneous (pre-1930) and mean daily flows (1930-present), combining intermittent and daily data near Torras with that at the Old River Outflow Channel. Discharges show a change from a bidirectional to unidirectional river. Unfortunately, no data were collected during the flood of 1927 and several other years before 1930 (Data Sources: Mississippi River Commission (1948), (varied), (n.d); United States Army Corps of Engineers, New Orleans District, http://www2.mvn.usace.army.mil/eng/edhd/wcontrol/miss.asp).
1940, discharge ranged between −1000 and 19,000 m³/s (Figure 6). Since 1963, when measurements began to be made on the Old River Outflow Channel, there have been two floods of even higher magnitude, including 1973 (17,274 m³/s) when the Low Sill Structure was undermined, and quite recently, in 2011, when the highest recorded flow of 19,001 m³/s passed through the Outflow Channel towards the Atchafalaya (Figure 6). The presence of three structures, instead of just the one that existed before 1987, allows larger flows to pass through the system, as each structure individually passes less flow than the original Low Sill Structure, which was undermined and overtasked in 1973.

As expressed in earlier graphs with annual data, the percentages of latitude flows were calculated using daily data to show the relative changes in this system, including the role of Old River. The latitude flow at Simmesport shows a range of 10–15% within any given year before the diversion was built and, since regulation, shows an even greater degree of variability in some years, even though the initial goal was to stabilize flows (Figure 7). The maximum daily percentage of Mississippi River flow through Old River has been 34% since completion of the project (Figure 8).

A few changes in channel geometry that accompanied discharge changes are discussed in this paper. The focus here is on changing cross-sectional areas in the Atchafalaya and Old River, which are well documented through detailed hydrographic surveys done approximately decadal intervals and are used to determine bankfull stage, or the stage above which the river will inundated the floodplain. The cross-sectional area of the Atchafalaya below fixed stage levels, which are tied to hydro-geomorphic levels such as bankfull stage, mean stage, and low-water stage, stayed within a range of 1000 m² from 1880 to 1920, but then areas increased until reaching maxima in 1945, at approximately two to three times the cross-sectional areas of around 1900 (Figure 9). At Torras, the Old River cross-sectional area below fixed stage levels labeled bankfull stage and low-water stage, steadily increased since 1903, and were largest at the end of the period in 1951, also approximately two to three times the areas of 1903 (Figure 10). Surveys spanning about a 9-km length of Old River, with more frequent sampling but

Figure 7. The flow of the Atchafalaya River at Simmesport as a percentage of the combined flow of the Atchafalaya River and the Mississippi below the Old River diversion (Data source: United States Army Corps of Engineers, New Orleans District from http://www2.mvn.usace.army.mil/eng/edhd/wcontrol/miss.asp).
also large data gaps, similarly show an increase in the area of this juncture from 1894 to 1951 (Figure 11).

Natural changes, human alterations, and morphologic adjustments in the adjoining systems created a change in the stage difference between the Mississippi and Atchafalaya rivers. Because floods are an important trigger of change, maximum stages of rivers near the juncture were contrasted using data from the Mississippi River Commission (1961). Annual maximum stages on Atchafalaya River at Simmesport were subtracted from the annual maximum stages of the Mississippi River near the juncture at Red River Landing and those at Old River near Torras (Figures 2 and 12). The early portion of the record shows less difference than the latter portion. The shift to a greater stage difference between these systems began in 1928, just after the largest flood of record in 1927, an event that enlarged the Atchafalaya more than events of prior years (Figure 12).

Stations on the Mississippi and Atchafalaya River in the proximity of Lower Old River show multi-decadal specific stage trends (scaled for $Q$; Figures 13 and 14). Using the web data since 1935, the long-term trend of Mississippi River stages increased 2 m at several fixed low discharge values, likely due to aggradation of the bed (Figure 13). Similarly, using different types of analysis, Winkley (1977) and Biedenharn and Watson (1997) observed rising stages and also inferred aggradation nearby on the Lower Mississippi. The Atchafalaya stages decreased approximately 4–6 m from 1935 to 1980 at several fixed low discharge values, likely due to degradation and also evident in the cross-sections (Figure 9); stages have stabilized since 1980 (Figure 14).

**Discussion**

The Old River has been through a transformation from a juncture with bidirectional flow to a juncture with unidirectional flow within the past century. To better interpret this transformation and possible causes, it is helpful to identify periods when conditions
shifted from one type to another. Three shifts seem to be integral in the transformation of the juncture from bidirectional to unidirectional flows.

The first shift occurred in the late 1910s, when the percentage of days when flow was directed towards the Mississippi decreased; before that time, flow toward the Mississippi ranged from 0 to 60%, whereas after that time the flow toward the Mississippi was consistently below 20% (Figure 5). Approximately a decade of low annual variability occurred ca. 1920, when the flow through Old River was consistently between 2 and 9%, as compared to the much wider ranges earlier and later (Figure 4). This transition period corresponded with a time when the Atchafalaya River started a period of channel enlargement (Figure 9), which may be partly responsible for the decrease in flow towards the Mississippi through an initial change in local water-surface slopes.

The second shift occurred during the late 1920s, when the percent of latitude flow at Simmesport increased over prior years, and began a generally increasing trend through completion of the Old River Control Project in 1963 (Figure 3). Similarly, the percentage of the Mississippi River flow through the Old River juncture began increasing into double digits after that time (Figure 4). The 1927 flood, the largest flood on the Lower Mississippi and the only event not properly depicted on the graphic because the flow was not confined, may have triggered this increasing trend by enlarging the Old River Outflow Channel as well as the channel of the Atchafalaya River. Shortly following this date, the percentages of Mississippi River flow through Old River started increasing (Figure 4) and total flows also increased (Figure 6). The below-bankfull cross-sectional area of the Atchafalaya River increased with the 1927 flood (Figure 9), likely due to scour, although it decreased again in the years shortly following. Cross-sectional area was not regularly measured, but there was clearly a big increase in area between the early 1920s and late 1930s, perhaps due in part to the 1927 flood (Figures 10 and 11).

The third shift occurred in 1945, the last year with negative discharge or flow from the Red River towards the Mississippi (Figure 6). The Carr Point cut-off, a local cut-off on the Mississippi at the Old River juncture, made in 1944–1945, perhaps in combination with cut-offs upstream on the Mississippi, likely made flow through this

Figure 9. Cross-sectional areas for the Atchafalaya River near Simmesport, 1880–1951 (Data source: Latimer and Schweizer [1951]).
juncture more efficient. Lower Old River continued to enlarge from the time of that local cut-off until the Control Project was completed.

These three periods all fall within times of consistent data-acquisition technologies, thus they likely represent true changes that occurred at the Old River juncture and its adjoining rivers, the Mississippi and Atchafalaya. However, long-term trends are not isolated to discrete years; thus, varied drivers of change probably interacted to affect long-term trends. For instance, the stage trends on the Mississippi River below the diversion show increasing stages for a given discharge level. These increases likely are due to bed aggradation, which in turn may have been influenced by local factors (e.g., the position just below the diversion and the drop in stream power) but also by changes upstream, such as the cluster of artificial cut-offs created between 1929 and 1942.
This study shows that the Old River juncture was bidirectional for several decades, contradicting some earlier reports (Bragg, 1977). Although this bidirectional character is documented for more than six decades, from 1880 through 1945, it is not known what flow was like in this juncture since its creation by Shreve in 1831. Probably, during flood years on either the Red or Mississippi, flows overtopped the bar forming at the cut-off. Removal of log jams in the Atchafalaya River from 1839 through 1855 and

Figure 12. Stage differences between annual maxima on the Mississippi River (MR) at Red River Landing and Lower at Old River near Torras (LOR) with the Atchafalaya River at Simmesport (AR). The flood of 1927 is one event that may have increased the stage difference between these systems (Data source: Mississippi River Commission [1961]).

Figure 13. Flow stage trends for the Mississippi River at Tarbert Landing over time for specific discharges (± 500 m³/s) at lower flows. Stage levels rose about 2 m since 1935, suggesting that this section is aggradational (Data source: United States Army Corps of Engineers, New Orleans District, http://www2.mvn.usace.army.mil/eng/edhd/wcontrol/miss.asp).
removal of the Red River raft, first in 1833 and later during the 1870s, increased the prominence of the western side of system by allowing flows to move more freely.

Humans helped maintain the juncture by keeping Lower Old River open with a canal that was dredged beginning in 1878 (United States Army Corps of Engineers, 1920) and continued to exist through 1937 (Fisk, 1952). The ends of the oxbow lake were filling, as often happens during cut-off formation (Allen, 1965; Hooke, 1995), as documented on historical maps of 1839 and 1854–1855 (Figure 1). Shreve’s cut-off would likely have stopped growth of the Atchafalaya or at least delayed it by several decades if left alone. The Atchafalaya’s growth and prominence was supported by maintaining this connection.

Thus, the causes of the transformation from bidirectional to unidirectional flow were diverse, show a strong human footprint, and are difficult to completely isolate. The continued dredging of the tie channel or canal at Old River was integral, and it is uncertain how quickly the increased flow through the juncture would have happened without the removal of log jams on the Red and Atchafalaya in the 1830s and 1870s. The channel size of Lower Old River increased from 1903 through completion of the Old River Control Project, possibly initially due to dredging, but it continued to increase after dredging stopped and after unidirectional flow was established. Moreover, the cross-sectional area of Lower Old River and the Atchafalaya were both increasing in the 1900s. Thus, further study of the absolute and relative timing and the drivers of changes in geometry is warranted.

Conclusions

In recent years, Lower Old River, the juncture between the Mississippi, Atchafalaya and Red Rivers, has had a myriad of natural and artificial changes. Human interventions helped create this juncture, altered the rivers that contribute flow and sediment to the juncture, altered the rivers that received flow from the juncture, maintained the
juncture, altered the flow angles through the juncture, and then closed the juncture so that flow could be regulated nearby. Natural changes, such as the lateral migration that first made the connection, and floods, particularly the flood of 1927, which increased flow through this connection, were also important.

Fluvial history could have unfolded quite differently without human intervention near Old River. Much importance is placed on the most recent interventions – the Old River Control Project and its subsequent additions – but very little attention is given to the earlier historical transformations that were integral in the development of this system. Without Shreve’s cut-off, there would be no Lower Old River. Removal of log jams on the Red and Atchafalaya Rivers increased flow in rivers that had been stagnant for centuries. Without decades of dredging, Lower Old River would have continued to fill with sediment and become an oxbow lake, perhaps with a tie channel active only during flood periods. Those who advocated for divorcing the Mississippi and Atchafalaya more than a century ago in 1884 might have had success if they had suggested curtailing dredging of the canal connecting Lower Old and Mississippi Rivers. Furthermore, without creation of a local cut-off at the entrance in 1945, flow angles into the juncture would have been less efficient. If left unaltered, flow through the system might have stabilized for some time and would not have increased so rapidly. Early studies of this system and the potential for diversion were authorized shortly afterwards.

Although Lower Old River is now inactive, its history is integral to recent transformations of flow, sediment and channel geometry in the Lower Mississippi River and the Atchafalaya Rivers. It is important to understand these changes for engineering and management of large rivers in general, but particularly for planning what comes next in this particular system. There is continuing controversy about how to regulate flow and sediment at this juncture, and whether the 30–70% split should be maintained, particularly in light of the serious coastal land loss problem in Louisiana. This study provides insights towards understanding complex changes at this juncture, specifically the role of human intervention in the changing nature of some of the largest rivers in North America, and highlights that further historical work is needed to better comprehend the varied drivers of this transformation.

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References


