Channel modification and evolution alter hydraulic connectivity in the Atchafalaya River basin increasing vulnerability to sea-level rise

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Abstract

Channel dredging and erosion in the Atchafalaya River basin have resulted in changes to the hydraulic connectivity of this floodplain swamp that have not been previously quantified. In this study, analyses were conducted to determine hydraulic and geomorphic factors that have changed since channel closure in 1962. Results indicated changes occurred in the Atchafalaya main channel cross-section between 1962 and 2010, and hydraulic and geomorphic changes were detected in portions of the interior eastern basin floodplain. Analyses of hydrographs in relation to floodplain elevations indicated that there was a lack of mineral sediment deposition sufficient to offset subsidence and rising sea level. This deficit has resulted in extended hydroperiods over the floodplain which could prevent tree regeneration and promote hypoxia.

Introduction

The Atchafalaya River (AR) basin (Figure 1) is the largest remaining forested wetland in the contiguous United States. Many changes have occurred in the basin since channel closure in 1962 and the end of channel dredging in 1968. Channel dredging and erosion have resulted in changes to the hydraulic connectivity of this floodplain swamp that have not been previously quantified. In portions of the East side, decreased tree regeneration has occurred (Faulkner et al. 2009) due to changes in the water level and hydroperiod over the floodplain. Numerous studies indicate widespread hypoxia (Sabo et al., 1999a; 1999b; Kaller et al., 2011; Pasco et al., 2015) and fish populations indicate worsening oxygen concentrations over time (Bennet and Kozak, 2016).

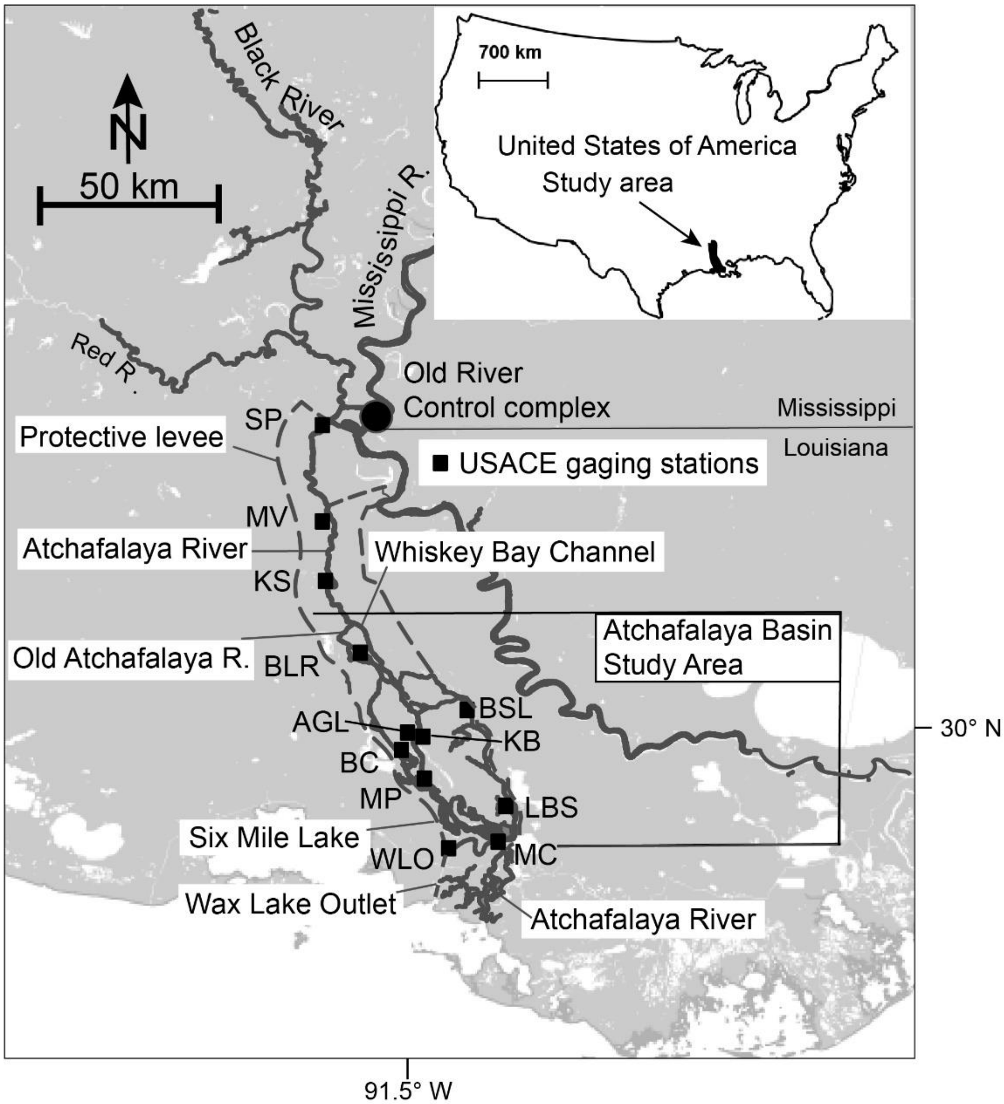

Figure 1. The Atchafalaya River basin study area is located within the Atchafalaya Basin Protective levees and extends from the head of the Whiskey Bay Channel to Morgan City. Squares show the location of the U.S. Army Corps of Engineers streamgage stations. See Table 1 for definitions of the station codes. Shaded base map created using ArcGIS software by ESRI, modified from Kroes et al., 2015. USA base map modified from Kroes and Brinson, 2004.

Table 1. U.S. Army Corps of Engineers (USACE) streamgage stations. [USGS, U.S. Geological Survey; --, no available data.

USACE station name (partial)	Station code (see Fig. 1)	USACE streamgage number	USACE period of record	USGS station number	USGS period of record
Simmesport	SP	03045	1930-	07381490	2009-
Melville	MV	03060	1911-	07381495	2015-
Krotz Springs	KS	03075	1934-	--	--
Butte La Rose	BLR	03120	1930-	07381515	1996-
Arm of Grand Lake	AGL	49197	1976-	300312091320000	2003-
Buffalo Cove	BC	49235	1976-	07381567	1996-
Keel Boat	KB	03615	1957-	--	--
Bayou Sorrel Lock	BSL	49630	1942-	--	--
Chicot Pass at Millet Point	MP	03540	1963	073815450	1996-
Little Bayou Sorrel	LBS	49725	1970-	--	--
Morgan City	MC	03780	1932-	07381600	1992-
Wax Lake Outlet	WLO	03720	1942-	07381590	1995-

We examined: 1) channel and bank hydrographic surveys from 1962, 1974, and 2010; 2) surface-water elevation/streamflow relationships from 1960-2015; 3) flow distribution to the swamp comparing synoptic streamflow measurements from 1958-1974 to 2001-2017; 4) total subsidence rates (preliminary) 5); sediment deposition rates (preliminary); and 6) the hydroperiod required for tree regeneration. These analyses were conducted to determine hydraulic and geomorphic factors that have changed since channel closure that may contribute to worsening oxygen and fisheries conditions. Once the changed factors are identified, ongoing restoration projects may capitalize on remediating the identified factors that degrade water quality.

Methods

Channel cross-sectional areas were analyzed using channel bed elevations from transects of hydrographic surveys conducted by, or for, the USACE for the main channel(s) of the AR. Hydrographic surveys used for this analysis were conducted from 1962-64 (hereafter 1962, USACE, 1967), 1974-76 (hereafter 1974, USACE, 1977) and 2010 (USACE, 2012). Bank morphology for the 2010 survey was determined using 2010 light detection and ranging (LiDAR). The top of the bank of the channel transect was defined as the mean of bank heights as determined by the surveyed topographic breaks or the tops of point bars.

Stage relative to streamflow was analyzed for an approximate 1.5-yr high, mean streamflow, and 1.5-yr low to approximate a range in stages that could be expected to occur. Flow distribution divergent from the main channel was calculated using streamflow measurements made by the Corp of Engineers for the period 1959-1968 (USACE, 1977) and from measurements made by the USGS for the period 2001-17 for a range of streamflows that could be considered normal: 2,700 m^3/sec to 11,500 m^3/sec (1.5-yr low to 1.5-yr high). Streamflow data collected by the USGS are available from the National Water Information System web interface (U.S. Geological Survey, 2019).

Rod-type surface elevation tables (SETs) were installed in 2010 and read yearly through 2017. SET rods were surveyed using real-time kinematic global positioning system surveying devices and optical levels to determine elevation in 2010 and 2017.

Deposition in the area previously identified as interior east and interior isolated east by Hupp et al. (2019) was measured using a ceramic tile marker horizon on the near permanently flooded floodplain surface. Samples of the semi-fluid deposition were collected above the marker horizon using a 51-mm diameter clear plastic tube, measured in-situ and in the tube, and the volume of sample was calculated. Samples were dried, and mass was determined. Deposition in mm/yr was calculated by dividing the mass of sample by the average density of deposition of 0.8 g/cm^3 from Hupp et al. (2008).

Hydroperiods were examined relative to the areas determined by Faulkner et al. (2009) to be non-regenerative for trees even if planted. The elevations of the areas found to be non-regenerative were determined and then compared with the closest gage hydrograph to calculate the percentage of the year that the floodplain was above water.

Results

From 1962 to 2010, the Atchafalaya River main channel doubled in cross-sectional area (Figure 2), half of the increase occurred (1962 – 1974) because of dredging and erosion, whereas the remaining increases (1974- 2010) resulted from erosion only. This increase in cross-sectional area lowered the surface-water elevation of a 1.5-yr flood (11,500 m^3/sec) at the Butte La Rose gaging station (USGS station no. 07381515) from 1 m above bank height to 2.4 m below the bank height (Figure 3). The bankfull streamflow increased from 6,400 m^3/sec (1960) to more than 17,500 m^3/sec (2011). Reduction in surface-water elevation and distributary blockage has reduced the volume of water leaving the main channel since 1968 when channel dredging was completed (USACE, 1979; Kroes, 2012; USGS 2019). Flow leaving the river does not indicate flow across the swamp floor as numerous spoil banks exist that inhibit or block flow through the forested portions while encouraging flow through the many over competent channels that exist on this floodplain.

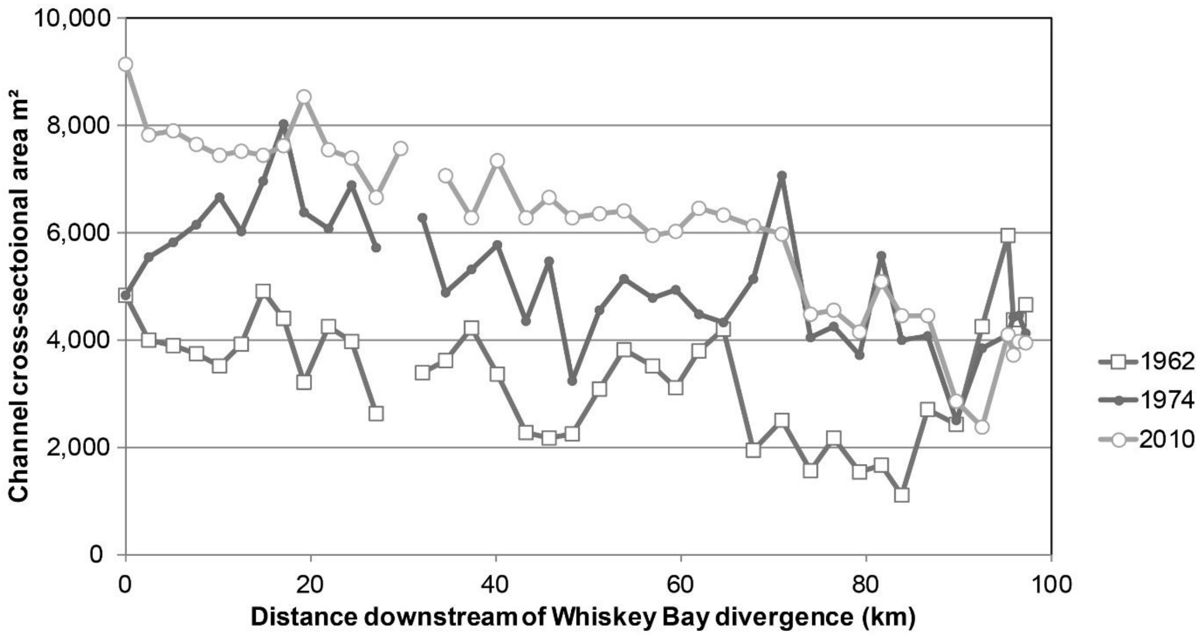

Figure 2. Atchafalaya River channel cross-sectional areas from the head of the Whiskey Bay Channel to Morgan City from 1962, 1974, and 2010 channel surveys. Gaps in the graph are where the Whiskey Bay and Old Atchafalaya River channels rejoin creating an abnormal scour feature. Mean bank height was determined from the surveyed topographic breaks and/or the tops of point bars.

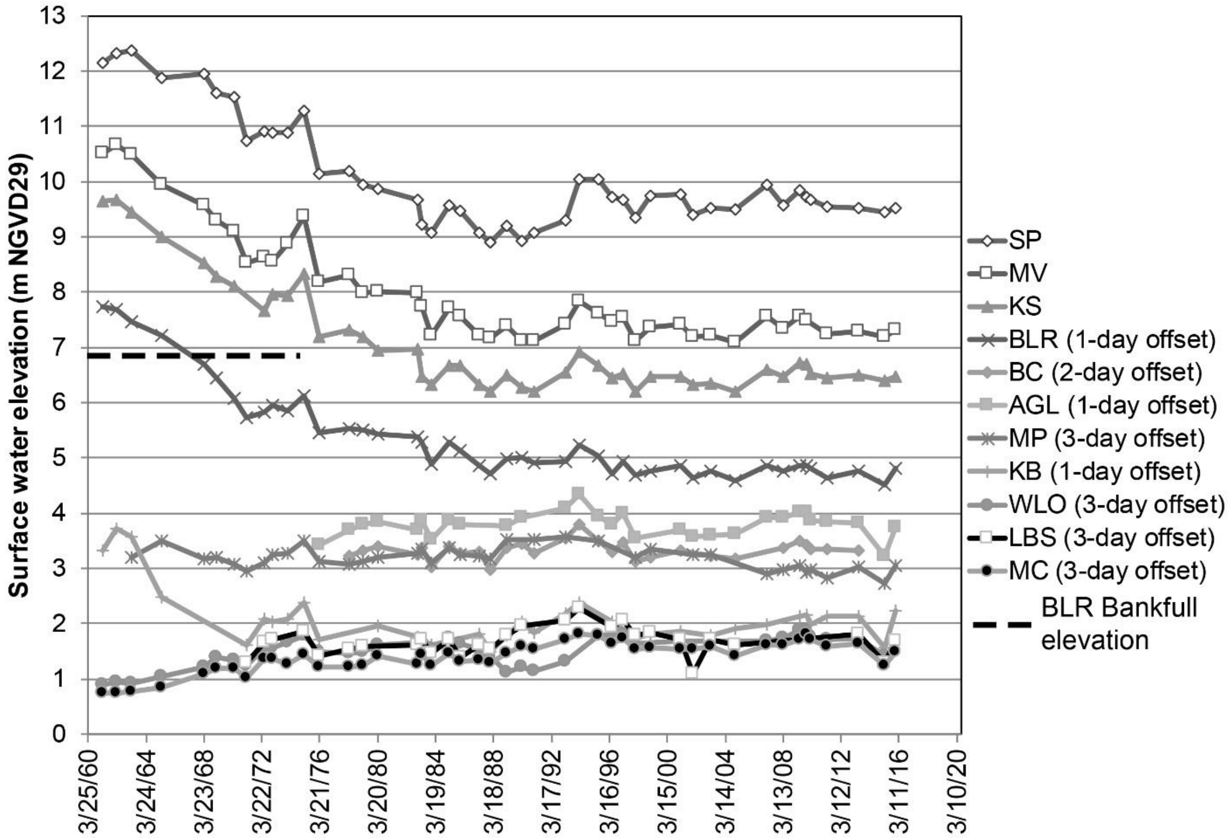

Figure 3. Changes in surface-water elevation of a 1.5-year flood at select streamgage stations in the Atchafalaya River basin study area. [NGVD, National Geodetic Vertical Datum of 1929; Station codes from Table 1].

Subsidence rates (shallow and deep) were monitored from 2010-17, indicating lower subsidence rates in the west part of the Basin (1 mm/yr) and the north part of the Basin (15 mm/yr, Figure 4). Greater subsidence rates (21 to 26 mm/yr) were observed on the east and southern portions of the Basin. Hupp et al. (2019) found hydraulic connectivity to be least in the area where subsidence was the greatest. The reduced connectivity was manifested in low sediment deposition rates in the interior east and isolated interior east side of the Basin (approximately at an average of 3.8 mm/yr assuming density of 0.8 g/cm^3).

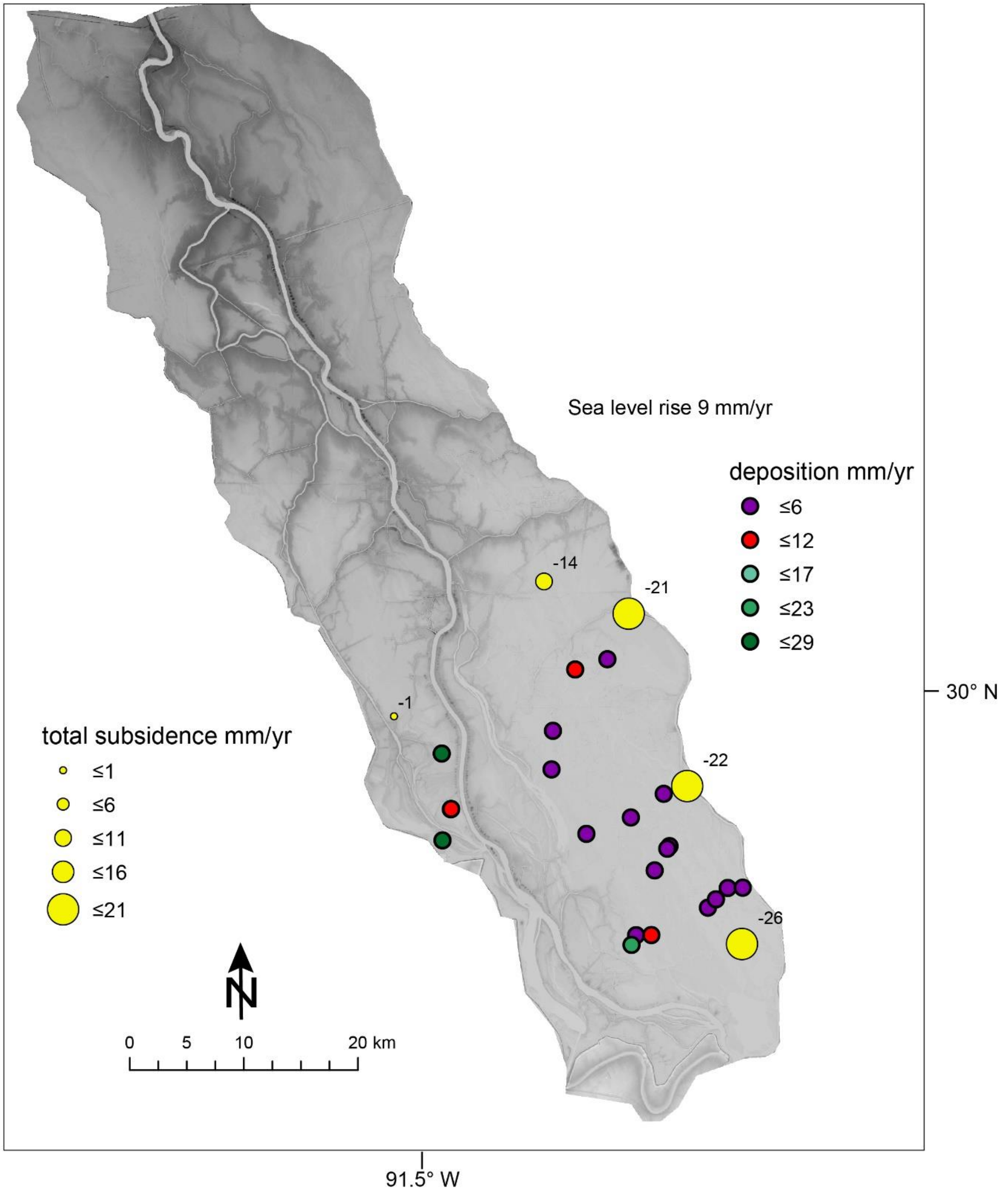

Figure 4. Subsidence and deposition measurements for the lower Atchafalaya River basin. Base map derived from 2010 LiDAR (USGS 2012) using ArcGIS software by ESRI.

The reduction of hydraulic connectivity between the Atchafalaya main channel and its floodplain swamp has resulted in several conditions. For large portions of the east side of the Basin, sediment deposition rates are insufficient to keep up with subsidence (preliminary, avg 21 mm/yr) and sea-level rise (9.7 mm/yr, National Oceanic Atmospheric Agency tide gage no. 8761724 NOAA, 2018). Our analyses indicated that in this system the floodplain requires an unflooded sediment surface for tree regeneration between 46 to 55 percent of the year. However, the estimated sediment deficit has resulted in a large area of floodplain (approx. 400 km^2) that either may soon lack or no longer has, sufficient dry time for woody plants to successfully regenerate.

Conclusions

Much of the swamp no longer receives headwater flow (upstream to downstream) or receives too little flow to alleviate backwater stagnancy and hypoxia at lower surface-water elevations because of blocked distributaries, increased channel cross-sectional area, and spoil banks. Interior areas of the swamp are lacking the sediment deposition rate required to keep up with subsidence and sea-level rise. Large portions of the Basin have low water levels that are now controlled by the Gulf of Mexico (Figure 5), resulting in extended inundation that inhibits or precludes tree regeneration and may eventually result in currently forested floodplain becoming open water.

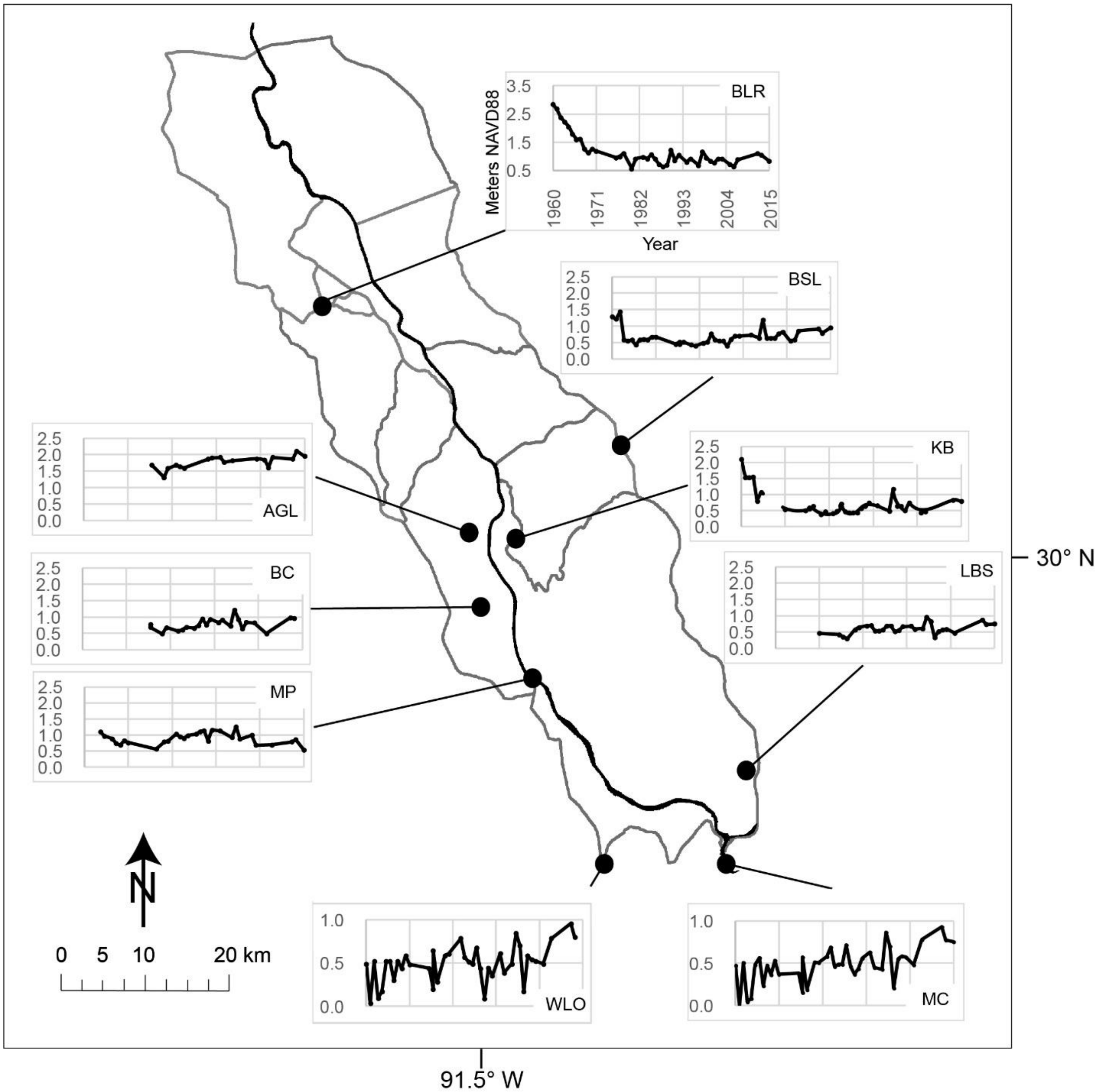

Figure 5. Surface-water elevation of a 1.5-year drought at select streamgage stations in the Atchafalaya River Basin study area. Gage datum for these observations were converted to North American Vertical Datum 1988 (NAVD88) because of the increased accuracy needed for comparison of observed small differences in elevation. Base map from Allen et al, 2008.

Disclaimer

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the US Government.

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