Restoration of Abandoned Channels

Neck Cutoffs
Green River in Wyoming

Report prepared for the:

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Table of Contents

List of Figures

List of Tables

Restoration of Abandoned Channels

1 Introduction

Abandoned channels are important elements of alluvial river systems. Abandoned channels are called oxbow lakes when sediment plugs cause the flow to change course. The oxbow lakes are formed from natural and engineered processes. Abandoned channels can provide habitat for wildlife and maintain biodiversity of aquatic habitat. However, there are problems associated with non-point source pollution and reduced water levels that can affect the quality and quantity of these channels. As a result, restoration is necessary to preserve abandoned channels.

Restoration can have many different meaning based on the context. In most cases restoration is defined as returning to a pre-disturbance physical state (Burchsted 2006). While, Wohl et al. (2004) define river restoration as assisting the recovery of ecological integrity in a degraded watershed system by reestablishing hydrologic, geomorphic, and ecological processes, and replacing lost, damages or compromised biological elements. This study focuses on looking at different case studies on the restoration of abandoned channels and the measures taken to provide ecological or engineered improvements. In cases that look at ecological improvements, water quality and quantity is improved in these abandoned channels through wetlands, best management practices and engineered solutions. The other cases are focused on improving the main channel for flood control and navigation as primary concern. However, the abandoned channels that have been created need to be restored due to failing water quality and quantity which were not considered at the time of channel construction.

1.1 <u>Objectives</u>

This study focuses on a literature review on restoration of abandoned channels with examples of oxbows within the United States and around the world. The statement of work includes three main objectives:

1. Provide a classification and analysis for abandoned channel restoration:
    - Classification of abandoned channel restoration cases based on examples within the United States and around the world.
    - Identification and analysis of key factors and parameters for the classification and analysis of abandoned channel restoration.
    - Analysis and evaluation of the strengths and weaknesses of each type of abandoned channel restoration.
2. Summarize long-term channel changes after restoration:
    - Review and analysis of examples with long term channel changes after abandoned channel restoration. Provide case studies with emphasis on morphological changes.
3. Technical review and consultation on the evaluation and stability of channel design *(No report required for this component).*

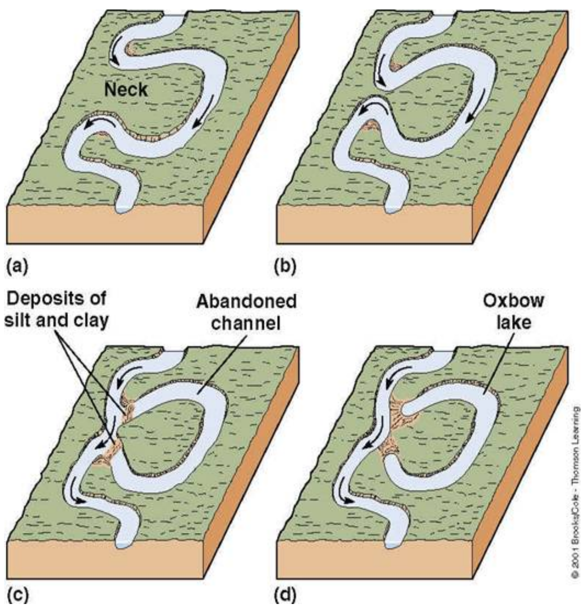
2 Classification of Abandoned Channels

This section looks at classification of abandoned channels and restoration plans developed for the improvement of water quality and quantity.

2.1 Abandoned Channel Processes

2.1.1 Natural Cutoffs

Rivers have a tendency to meander within their floodplains to balance the transport of water and sediment. There are two types of natural cutoffs that occur. The first natural cutoff is a neck cutoff. It is formed when river sediment is deposited continuously on the convex bank and sediment is eroded from the concave bend. This causes the sinuosity of the meander to increase and the formation of a narrow neck of land. Eventually the neck disappears and a straight channel is formed, thus creating an abandoned channel or cutoff. When the cutoff is sealed from the main channel by sediment deposition an oxbow lake is formed. Refer to Figure 2.1 for a schematic of a neck cutoff and an example of a neck cutoff located along Green River in Wyoming.

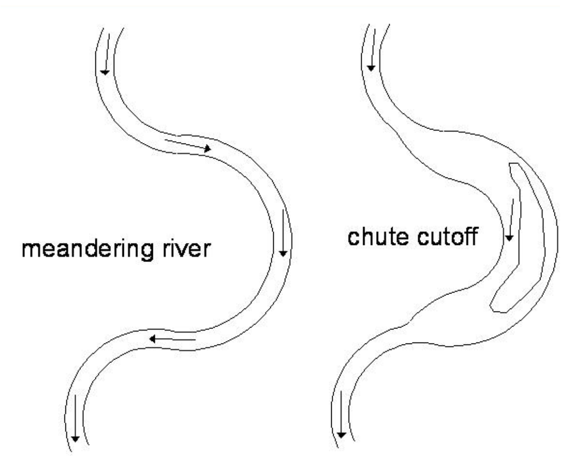


a. Neck Cutoff Process

b. Example of Neck Cutoff on Green River in Wyoming

Figure 2.1 – Natural Neck Cutoff

The second type is a chute cutoff. This usually occurs when successive high water flows develop a chute across the inside of a point bar, decreasing the sinuosity. The channel forms a middle bar. Refer to Figure 2.2 for a schematic of a chute cutoff and an example of a chute cutoff located along Williams River in Alaska. Rivers reduce sinuosity and increase slope and sediment transport capacity through chute and neck cutoffs.



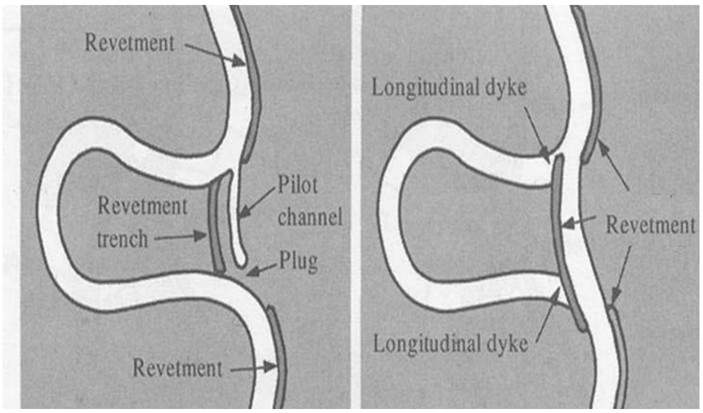
a. Chute Cutoff Process

b. Example of Chute Cutoff on William River in Alaska

Figure 2.2 – Natural Chute Cutoff

2.1.2 Engineered Cutoffs

Abandoned channels have also been formed by engineering a straight channel. Rivers are straightened to aid with navigation and flood control. It is important to provide bank stabilization when straightening a channel, if this is not provided the channel will have a tendency to meander. Figure 2.3 provides an illustration how a channel is engineered and an example of an abandoned channel along the Red River.



a. Engineered Cutoff

b. Example of an Engineered Cutoff on the Red River

Figure 2.3 – Engineered Abandoned Channel (Julien 2002)

When engineering a cutoff, it is important to construct revetments upstream and downstream of the concave side of the meander. In addition, a small revetment trench is need along the cut prior to the construction of the pilot channel. The excavation of the pilot channel should be from downstream to upstream with a minimum of 3 to 1 side slope, 15 to 60 meters wide and 2 to 4 meters below the low water reference plane (Julien 2002). This will allow for a straight channel that will be able to pass the flow with impairing navigation or flood control. Figure 2.4 shows the process of an engineered cutoff on the Mississippi River.

a. Earth Plug Separating Pilot Channel

b. Dynamite Blasting Earth Plug

c. One Hour opening cutoff

d. Ashbrook, Tarpley and Leland Cutoffs.

Figure 2.4 – Construction and Aerial View of Engineered Cutoffs

2.2 Identification and Analysis of Key Factors

Human impacts within a watershed can cause significant problems associated with water quality in abandoned channels or oxbows. Within the US, the natural landscape has been converted into agriculture and urban uses. The change in land uses has caused an increase in sediment and contaminants from entering the water bodies. One concern is the effects these non-point source pollutants have on abandoned channels. These channels are being used for recreation, while others function as wetlands. However, poor water quality is damaging these channels and thus restoration is required. In addition, as these channels have lost connectivity with the main channel due to sediment plugs and levee construction, there are periods when these abandoned channels are dry. As a result aquatic habitat cannot be supported.

One of the main problems associated with water quality is sedimentation. Moon Lake is a natural oxbow lake located in northwestern Mississippi. Prior to human settlement this area contained bottomland hardwood, but currently over 70% of the watershed is agriculture. Refer to Figure 2.5 to see the change in land use. In the 1920's a levee was constructed that blocked the Mississippi River from periodic flushing of the oxbow. As a result sediment accumulation has been dramatic. From 1954 to 1965 the rate of sediment accumulation was 2cm/yr. From 1965 to 1982 the rate of accumulation has dropped due to the change in cropping, from cotton to soy bean and rice (Cooper and McHenry 1989). Studies are being performed to develop management plans to reduce sediment accumulation (TetraTech 2003).

a. Bottom Hardwood b. Cotton c. Soybean

Figure 2.5 – Example of the Change in Land Use

2.3 Classification and Benefits for Abandoned Channel Restoration

Restoration of abandoned channels can be classified based on the different types of restoration efforts: Wetlands, Best Management Practices (BMPs) and Engineered Solutions. Table 2.1 provides a summary of the three main categories of restoration, the type of restoration and their benefits. In all cases, restoration provides some form of benefit for the abandoned channel. Table 2.2 is a detailed summary of the different case studies within the US and around the world. It identifies the abandoned channel and the river location, where the abandoned channel is located. In addition, it summarizes the formation and the problems associated with the abandoned channel. Finally, it provides a summary of the type of restoration and the benefit and effectives of the restoration effort.

Table 2.1 – Classification and Benefits of Restoration

	Type of Restoration	Benefits
Wetlands	Riparian Wetlands	Improved water quality Enhance wildlife habitat
BMPs	Agronomics	Reduced sediment, nitrogen and phosphorous
	Edge-of Field Practices	Reduced sediment
	Stream Buffer Strips	Reduced sediment, nitrogen and phosphorous
	Bank Stabilization	Reduced Sediment
Engineered Solution	Weir Construction	Increase flow interaction Improve water quality Improved navigation in main channel
	Dam and gate	Increase flow interaction Improve water quality
	Pump to divert flow out of lake	Improve water quality
	Dredging	Remove organics, nutrient rich sediment Deepen lake
	Adding Water from Power Plant	Increase flow depth
	Riparian Buffer	Prevent channel migration
	Lock and Dams	Improve navigation in main channel

Table 2.2 – Summary of Case Studies of Abandoned Channel Restoration

Abandoned Channel	River	Type	Problem	Restoration	Benefits	Effectiveness
Ashbrook Cutoff Tarpley Cutoff Leland Cutoff	Mississippi River Greenville, MS Mississippi River Greenville, MS Mississippi River Greenville, MS	Man-made for navigation and flood control	Prior to cutoff navigation and flood control was a problem	Dredging, dike construction	Provides necessary navigation and flood control	Yes, requires monitoring to assure river path has not changed
Choctaw Bar	Mississippi River North of Greenville, MS	Natural Chute Cutoff	Navigation Path	Weir Construction	Prevent flow into secondary channel	Yes, this area also has a nice wildlife habitat
Thompson Bend	Confluence of Mississippi and Ohio Rivers	Prevention of Abandoned Channel	Severe Erosion is causing a neck cutoff	Erosion Control 1985-1986 a riparian buffer along 20 miles	Prevention of Neck cut	The erosion control did not work, but the riparian buffer is working well
Thighman Lake Beasley Lake Deep Hollow Lake	Mississippi River	Natural	Sediment	BMP - Agronomic Methods BMP - Edge-of-Field Practice BMP - Agronomic and Edge of Field Practice	The BMP's sedimentation is reduced 34 to 59%. Increased chlorophyll, which suggest more aquatic plants.	Most effective site was Deep Hollow, followed by Thighman. Thus suggesting the Agronomic is quite successful.
Lake Whittington	Mississippi River (River Mile 926)	Man-made	Decline in Fisheries and Seasonal Dewatering	Engineered Weir Construction	Restoration of backwater by permitting water exchange during high river stage and pool water during low water stage	Not Available
Lake Chicot	Mississippi River Arkansas	Natural	Deterioration in water quality, fisheries and recreation	1968 (Construction of Water Level Control Structures on the major inflow and outflow and upstream diversion) 1985 (an upstream and downstream dam and gate and a pump to divert poor water quality into Mississippi River)	Suspended sediment declines and chlorophyll increased	Yes
Browns Lake	Missouri River Iowa	Natural	Excessive macrophytes and Frequent Winterkills	Adding Cooling Water from a Local Coal Fire Power Station	Increased lake depth	Slight improvement: Reduction in Phosphorous and Nitrogen concentration. No change in Sediment.
Collins Lake	Mohawk River New York	Man-made	Excessive macrophytes and algae	Hydraulic Dredging	Remove organics, nutrient rich sediment and deepen lake	Yes, 10 years after dredging biomass is low.
Cutoff on Morava River	Morava River Slovakia and Austria	Man-made for river regulation	Intensive sedimentation, dissolved oxygen depletion	Connectivity with main river. Rock filled weirs		Not effective
Former Channel of Rhone River	Rhone River France			Dredging and preserve banks, riparian forests and shorelines		Yes
Rouge River Oxbow Lake Restoration	Rouge River Dearborn, Michigan	Man-made	Poor Water Quality in Rouge River	Wetland Construction	Improved Water Quality and Used from Education	Yes. There have been diverse wildlife sightings throughout the area, including coyote, fox, raccoon, deer, raptors, owls, bats, ducks, herons, turtle, frogs, fish, etc. In addition the oxbow provides flood water storage.
Kachituli Oxbow	Sacramento River California	Man-made	Loss of Wetlands	Wetland Construction		Yes, but aggressive management is needed to mitigate site from weeds and rats
Cutoff on Sandusky River	Sandusky River Ohio	Natural	Reduced Fisheries and Sedimentation	BMP - Agriculture - Stream Buffers and bank Stabilization	Coarsening of Substrate	Unknown because BMP implementation and change in crop type occurred. It is unclear if the improve water quality is associated with the BMP or the crop planted.

2.4 Abandoned Channel Restoration Examples and Analysis

2.4.1 Wetlands

Kachituli Oxbow is the only constructed oxbow lake along the Sacramento River in Northern California. Constructed in 1991 to mitigate the destruction of wetlands, this oxbow is located outside of the flood control levees. The characteristics of this oxbow were determined by performing detailed field surveys of six naturally formed oxbows along the Sacramento and Feather Rivers. A sinuous meander channel was specified with a deep pool of approximately 5 feet at the southern end. Analysis of the site revealed groundwater, which would provide sustainable water supply. In addition, irrigation was provided to establish the diverse plant community. Though management is needed to insure the survival of this mitigation site from weeds and herbivory (rats) an aggressive action plan has been implemented for site survival (Hey and Philippi 1999). Figure 2.6 show Kachituli Oxbow during the dry season and an aerial view of the site.

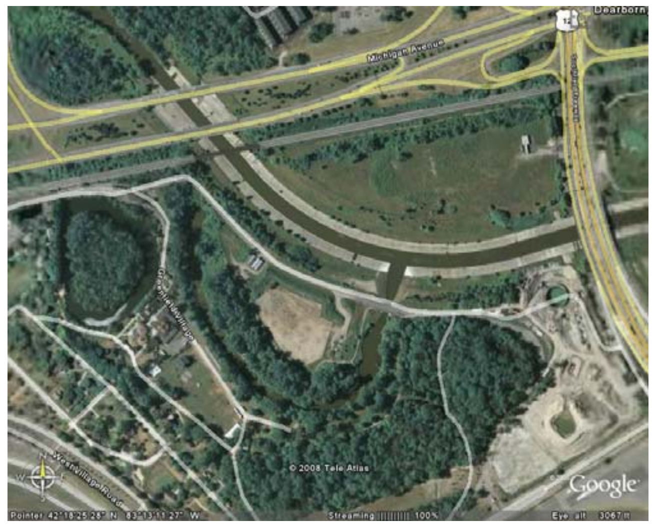
a. Dry Season Flow

b. Aerial View

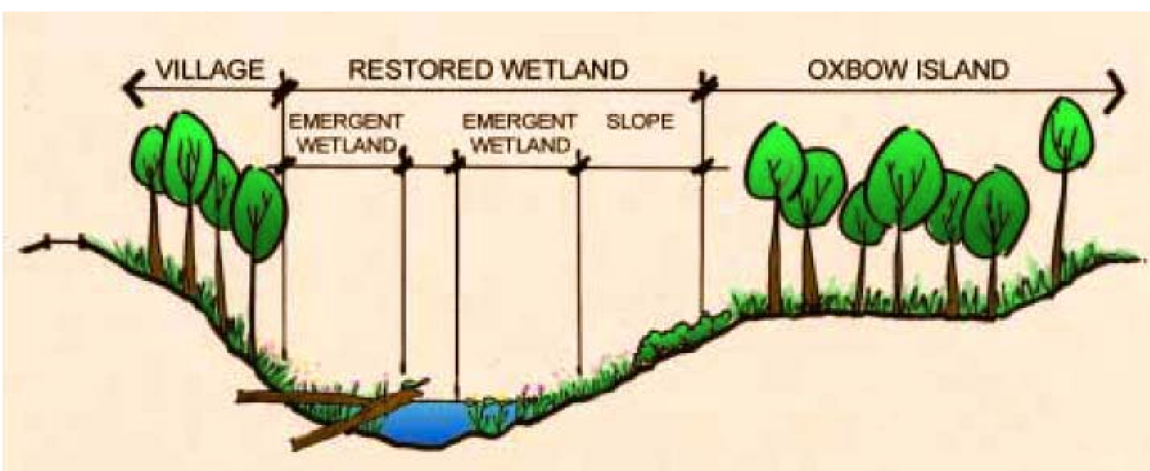
Figure 2.6 – Kachituli Oxbow along Sacramento River (Hey and Philippi 1999)

The water quality along the Rouge River in Dearborn, Michigan has been degraded due to pollutant loading from various sources. Due to channelization in the 1970’s, numerous oxbow lakes were formed. However, these oxbows have become forested wetlands with large deciduous trees and shrubby material. The little ground cover provides little food and shelter for the wildlife. The area has standing water in the spring and is vulnerable to drying out during the summer. This project restores the western-most oxbow, which will enhance the wildlife habitat, restore the riverine wetlands and improve water quality. This is accomplished by removing existing fill that was placed in the old oxbow. The new oxbow is 2,220 feet long, 15 to 105 feet wide and 3 to 6 feet deep. The area is surrounded by 3 acres of wetlands. Bioengineering techniques were used to stabilize slopes (O'Meara et al. 2002-2003). The project was completed in 2007. Prior to stocking the site with fish over 14 species were identified. The newly constructed oxbow will increase flood storage for the Rouge River. There have been diverse wildlife sightings throughout the area, including coyote, fox, raccoon, deer, raptors, owls, bats, ducks, herons, turtle, frogs, etc. Figure 2.7 provides an aerial views of per and post construction and a typical post construction cross section.

a. Aerial View Pre Construction (O'Meara et al. 2002-2003)



b. Aerial View Post Construction



c. Typical Cross Section Layout (O'Meara et al. 2002-2003)

Figure 2.7 – Rouge River Oxbow Lake Restoration

2.4.2 Best Management Practices

The use of Best Management Practices (BMPs) at sites can significantly improve water quality. A study was performed on three oxbow lakes within Mississippi (Thighman, Beasley and Deep Hollow Lake). The goal of the project was to implement edge-of-field practices (slotted pipes, slotted board inlets, grassed buffers and stiff grass hedges) and agronomic methods (conservation tillage and winter cover crops) to reduce non-point source pollutants from agricultural runoff (Cullum et al. 2006; Knight et al. 2002; Knight and Welch 2004). The Beasley Lake watershed was protected by edge-of-field practices (Refer to Figure 2.8 for examples), Thighman Lake watershed was protected by agronomic methods and Deep Hollow watershed was protected by a combination of the two prescribed BMPs.

a. Edge-of Field BMP (Cullum et al. 2006)

b. Riparian Buffer

c. Conservation tillage

d. Crop Cover to Prevent Erosion

Figure 2.8 – Examples of Best Management Practices

Table 2.3 summarizes the results from the three site pre and post BMP implementations. Prior to the implementation of the management practices the lake was damaged due to excessive sediment. The results indicated that there is significant reduction in sediment due to the implementation of the BMPs.

Table 2.3 – Average Pre- and Post-BMP Water Quality Results

Parameters	Beasley		Deep Hollow		Thighman	
	Pre BMP	Post BMP	Pre BMP	Post BMP	Pre BMP	Post BMP
Secchi (cm)	14	17	12	25	11	15
Total Solids (mg/L)	482	265	351	143	505	334
Suspended Solids (mg/L)	429	202	289	70	405	169
Dissolved Solids (mg/L)	58	65	52	75	115	166
Nitrate (mg/L)	0.534	0.553	0.393	0.387	1.157	0.85
Ammonium-Nitrogen (mg/L)	0.123	0.139	0.189	0.116	0.168	0.224
Total Phosphorous (mg/L)	0.496	0.344	0.522	0.233	0.437	0.299
Ortho Phosphorous (mg/L)	0.032	0.049	0.019	0.046	0.018	0.044
Chlorophyll (µ/L)	16.6	118.9	24.4	61	9.9	72.2

Source (Knight and Welch 2004)

An additional study was performed on the effectiveness of BMPs on a cutoff channel located 12 km east of Bucyrus along Sandusky River in Ohio. Agriculture has influenced this watershed since the later 1800's. As a result, in stream substrate has changed from gravel to sand. Thus to reduce the in stream sedimentation, crop rotation and contour plowing was implemented in 1987 (Murphy et al. 2007). However, it is important to consider high cover crops which result in minimal surface erosion.

2.4.3 Engineered Solutions

Dredging

Collins Lake is an oxbow lake created by the Mohawk River in Scotia, New York. This lake is used intensely for swimming, boating, and fishing. The lake is experiencing excessive macrophytes and algae growth, thus restoration strategy has been constructed to remove the organic, nutrient rich sediment and deepen the lake through hydraulic dredging in 1977 and 1978 (Snow et al. 1979). Due to the cost, environmental impacts, and the problem of disposal, dredging should not be performed for aquatic plant management alone. It is best used as a lake remediation technique. Figure 2.9 provides an aerial view of Collins Lake. A long term study has been conducted on the effects of dredging on Collins Lake and is summarized in Section 3.

Figure 2.9 – Mohawk River and Collins Lake (http://engineering.union.edu/~birds/)

Water Level Control Structures

Lake Chicot, located along the Mississippi River in Arkansas is the largest oxbow lake in North America. The lake was formed naturally over 600 years ago. In 1968 a water quality restoration project was implemented. The U.S. Army Corps of Engineers constructed water level control structures on the major inflow and outflow streams and upstream diversion system to reroute water into the Mississippi River (Ritchie et al. 1983). In addition, in 1985 the U.S. Army Corps of Engineers placed three additional structures into operation to help with the poor water quality. A downstream dam and gate regulates the lake level, an upstream dam and gate prevents poor quality water from entering the lake and a combination pump-gravity flow facility diverts poor quality water to the adjacent Mississippi River (USACE 1985).

Additional studies have been conducted on the Mississippi River to look implementing weirs and other water control structures to improve premature or excessive dewatering. Dewatering results in low water for spawning and rearing in the littoral zone, contributes to hypoxia and high temperatures in isolated pools which results in fish kill (Hoover et al. 2000). Lake Whittington is an oxbow lake located along the Mississippi River, refer to Figure 2.10. It was developed in 1937 when the US Army Corps of Engineers completed the Caulk Island Cutoff. The deepest portion of the lake is up to 20 feet deep. During bankfull the surface area of Lake Whittington is 3000 acres, but is reduced to three small pool totaling 1000 acres during the late summer. A weir constructed on Lake Beulah in 1955 helped restore backwater and the sample plan is being proposed on Lake Whittington. This will increase the habitat population.

Figure 2.10 – Change of Lake Whittington due to Caulk Island Cutoff, Mississippi River

Water Pumping

Browns Lake is 2 miles west of Salix, in Woodbury County, Iowa. Refer to Figure 2.11 for an aerial view of Browns Lake. The watershed contain 88.7% cropland, 4.9% pastures, 2.6% forests and 3.8% other land uses. Browns Lake is characterized by shallowness, a large population of macrophytes and frequent winter kills. Thus to increase the lake's recreational value the water level is being raised by adding cooling water effluent from a local coal fired power station (Bachmann et al. 1980).

Figure 2.11 – Aerial View of Browns Lake

Water quality measurements were made on Browns Lake in 1979 (pre) and 1992 (post) and are summarized in Table 2.4. The data indicates that levels of nitrogen and phosphorous have decreased however, there continue to be issues associated with sediment and turbidity. The reasons for the decrease in nitrogen and phosphorous and an increase in alkalinity and hardness is due to the pumping of cooling water from a local power plant to supplement the water supply from the Missouri River. In 1992 15% of the watershed was approved to participate in a soil conservation program. The area is recommended to practice the following BMPs: terracing, contouring and conservation tillage (Bachmann et al. 1994).

Table 2.4 – Water Quality Summary for Browns Lake

Parameters	1979[1] (average)	1992[2] (average)
Secchi Depth (m)	0.9	0.6
Turbidity (NTU)	9	8.1
Chlorophyll (mg/m3)	2.4	17.2
Total Phosphorus (mg/L)	43.1	0.074
Total Nitrogen (mg/L)	0.63	0.9
Ammonia Nitrogen (mg/L)	0.13	0.1
Nitrate-Nitrogen (mg/L)	0.09	0.07
Total Suspended Solids (mg/L)		10.66
Organic Suspended Solids (mg/L)		7
Total Hardness (mg/L ad $CaCO_3$)	152.7	245
Calcium Hardness (mg/L ad $CaCO_3$)	36.7	144
Total Alkalinity (mg/L ad $CaCO_3$)	190.7	172
DO (mg/L)	7.5	6

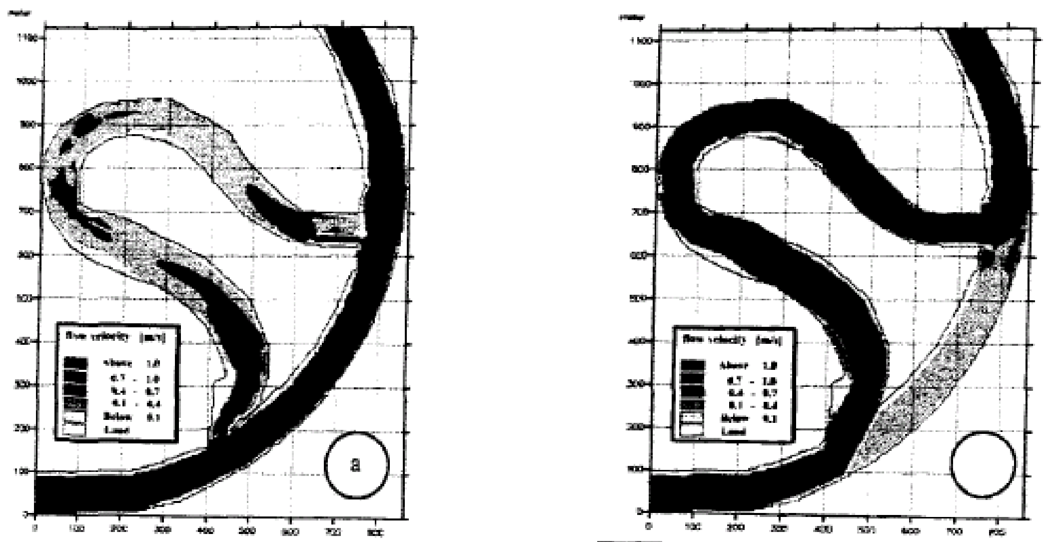
1. Source of 1979 data (Bachmann et al. 1980)
2. Source of 1992 data (Bachmann et al. 1994)

2.4.4 Preventing Abandoned Channel Formation and Restoring River Meanders

Thompson Bend on the Mississippi River is above the confluence of the Mississippi and Ohio rivers. Severe erosion has occurred causing the formation of a new channel across the peninsula, which threatens a levee and navigation (Figure 2.12). Costly erosion control methods have been implemented but failed. Thus beginning in 1985 and early 1986 revegetation of the area began. Today solution includes a riparian buffer strip of trees planted between the riverbank and floodplain. Due to the revegetation along 20 miles of shoreline the Great Flood of 1993 resulted in minimal erosion and prevented a neck cutoff from occurring.

Figure 2.12 – Thompson Bend on the Mississippi River

In the 1950's meanders of rivers were straightened for river regulation in current Slovakia and Austria along the Morava River. As a result abandoned channels were formed and there was limited flow interaction between the main channel and the abandoned channels. As a result sedimentation began to fill in these channels and dissolved oxygen levels were low. Thus restoration was needed to protect the oxbow system along the Morava River. Rock filled weirs were constructed at the entrance of these meanders. Thus the meanders acted as reservoirs connected with the main channel. Fish studies were performed to determine the role that restoration has but the results were inconclusive (Hohausova and Jurajda 1997). This proved to not work because the oxbows continued to fill with sediment. Thus alternative restoration plans have been proposed where the inflow and outflow of the meander would be restored to their original size and the sediment removed or blocking the main channel thus restoring the meander (Holubova and Lisicky 2001). Figure 2.13 provides a schematic of the flow velocity distribution with the proposed restoration.



a. Present state of reconnected channel with rock weir b. New Proposed condition with full diversion

Figure 2.13 – Flow Velocity Distribution for Bankfull (Holubova and Lisicky 2001)

2.5 Proposed Abandoned Channel Restoration

There are numerous abandoned channels located along this reach of the Sacramento River in Northern California. Three sites were selected to determine sedimentation rates and evolution scenarios by taking sediment core samples and analyzing aerial photos over time. Sixteen sites were selected to perform an assessment of the aquatic vegetation. Based on this study conservation strategies have been suggested to protect and restore the disappearing abandoned channels, as seen in Figure 2.14.

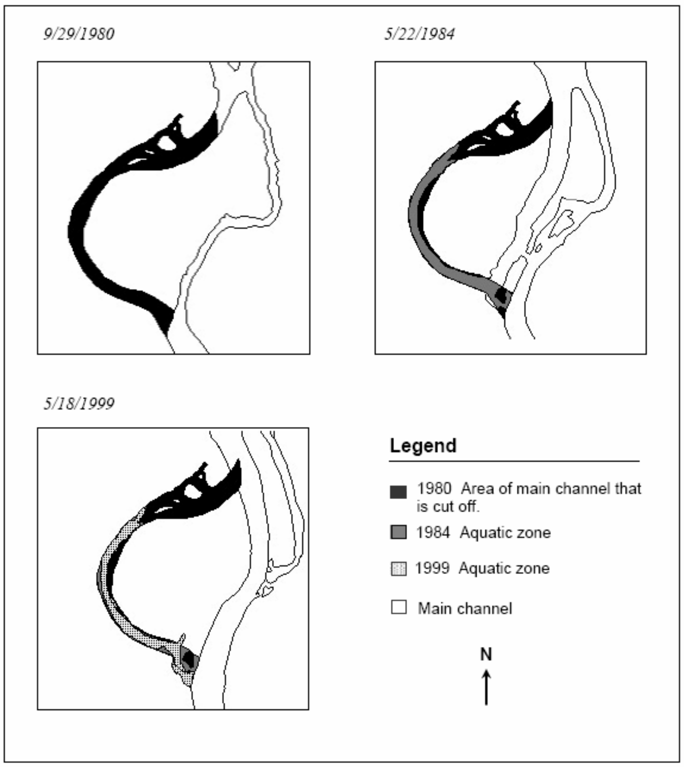


Figure 2.14 – Change in Aquatic Zone, Sacramento River (Morken and Kondolf 2003)

The study area is surrounded by agriculture, thus water quality monitoring is suggested to improve biodiversity within the oxbow lakes by identifying sources of pollution. Next, restoring the riparian forests adjacent to oxbow lakes will reduce sedimentation and provide a natural filter. In addition, a short term fix might be providing connection to the main channel by opening the upstream or downstream sediment plugs (Morken and Kondolf 2003).

Delaney Creek is located in Hillsborough County, Florida and drain 16 square miles of industrial, residential and agricultural area. An oxbow lake is being proposed to improve water quality and wildlife habitat. This oxbow will be inline with the main channel. The project includes a diversion structure located at the upstream section of the main channel. The top of the weir is set to allow low flows to be diverted into the wetland (oxbow) system to physical, chemically and biologically remove pollutants. An effluent weir control is placed on the downstream section to allow water to re-enter the main channel. It is estimated that the proposed system will remove 75% of the TSS, 25% of the nutrients and 50% of the heavy metal from the main stream (Hatoum 1998).

3 Long Term Channel Changes

3.1 Greenville Reach, Mississippi River

The Greenville Reach is located between Arkansas City, Arkansas, and Greenville, Mississippi. Revetment and dikes have been constructed along this reach to preventing natural cutoffs from occurring. By the 1930's it was necessary to construct three man-made cutoffs; Ashbrook, Tarpley and Leland Cutoffs. Table 3.1 summarizes the initial construction of each cutoff. Table 3.2 summarizes the construction requirements to maintain navigation.

Table 3.1 – Summary of the Greenville Reach Cutoffs

Location	Construction Date	Cutoff Length	Bend Length	Change in Slope	Initial Dimensions	Post construction activity
Ashbrook Cutoff	August-35	4530 ft	13.3 miles	15.5 Times Steeper	13 feet to 23 feet below low water	River Widened causing formation of bars which required dredging
Tarpley Cutoff	January-35	13,000 ft	12.2 miles	5 Times Steeper	Cutting ccurred from the down-stream to up-stream initially. The width was from 250 to 300 feet. The flow depth was 15 feet below low water level.	Soil was sandy and resulted in the development of bars which caused the river tendency to be braided. Dredging was needed for many years.
Leland Cutoff	July-33	4600 ft	11.2 miles	13 Times Steeper	Not Available	Dredging due to braiding of river and excessive sediment transported by the upstream cutoffs.

Source (Winkley 1977)

Table 3.2 - Construction Requirements to Maintain Navigation

	Prior to 1933	1934-1974
Number of times crossings were dredge to maintain navigation	0	135
Length of revetment to hold channels	76,350 ft	137,050 ft
Length of dikes in reach	3,377 ft	61,596 ft
length of river from upstream end of construction to lower end	51 miles	24 miles

Source (Winkley 1977)

Figure 3.1 shows how the alignment of the river changed prior to the construction of the cutoffs and the location of the revetment to align the river. Additional cutoffs were summarized by Winkley in regard to the work done in the 1930's. Appendix A contains photos of the site and how the area has changed over time and the current restoration plan (LMRCC 2003; Winkley 1977).

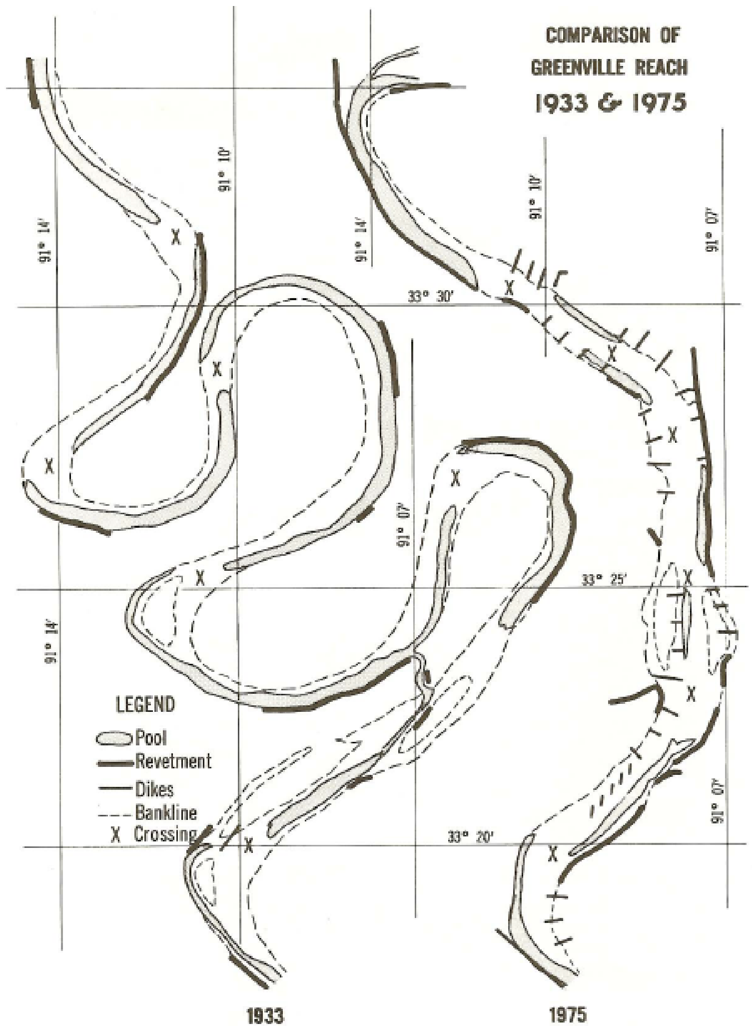
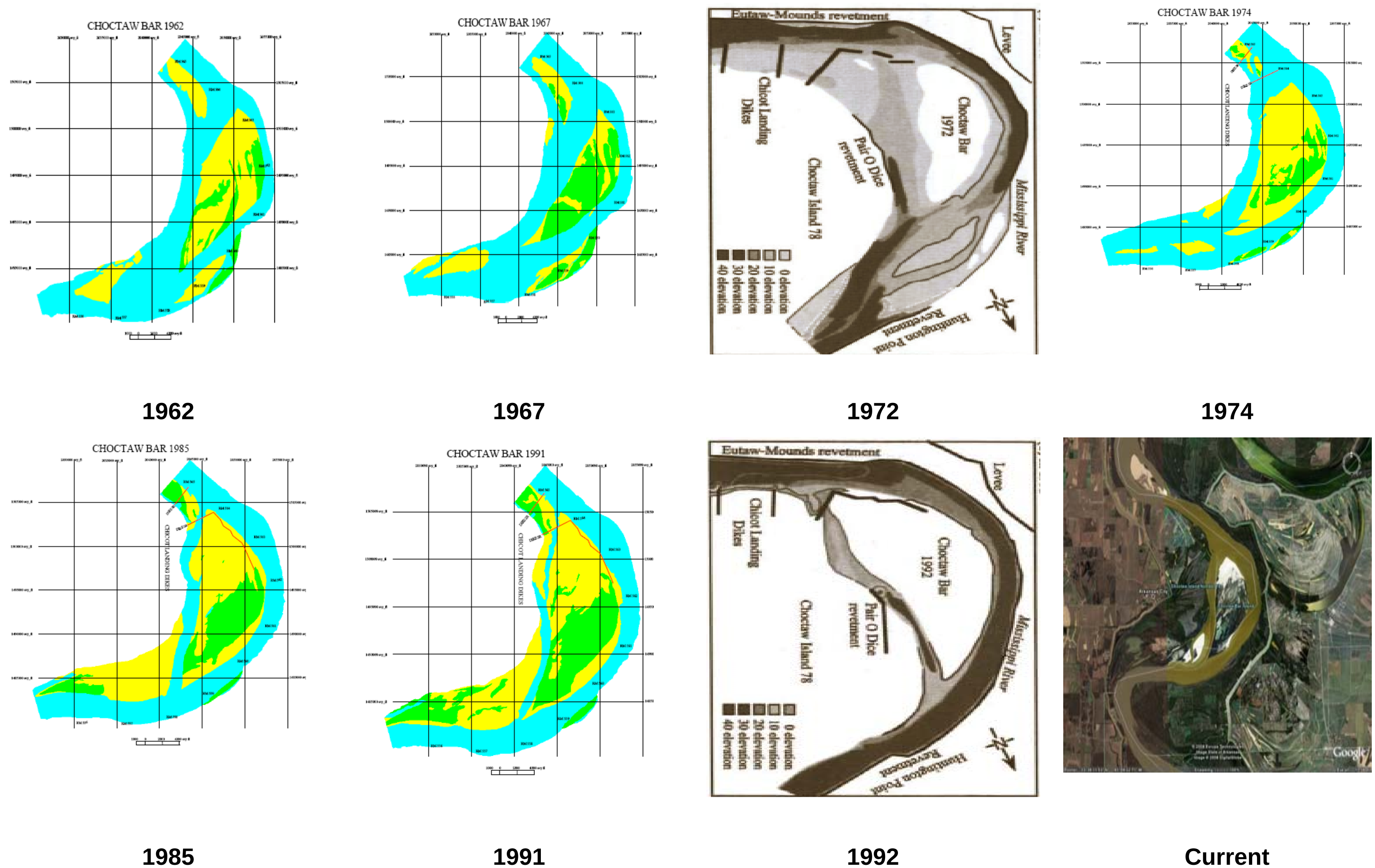


Figure 3.1 – Alignment of Greenville Reach due to man-made cutoffs (Winkley 1977)

3.2 Choctaw Bar, Mississippi River

Engineering efforts have been made at Choctaw Bar to stabilization the river for navigation and flood protection. Flow at the Choctaw Bar is divided with a secondary channel on the right bank and a main channel on the left bank (Figure 3.2). A stone dike system was constructed at the upstream entrance to the secondary channel in 1968 to reduce divided flow conditions and deepen the navigation channel. However during the 1973 flood, a large section of the main closure dike degraded, creating a weir, which allowed significant flow in the secondary channel and caused sedimentation within the main channel requiring dredging. Vegetation on the islands is natural and provides bar stabilization. Appendix A shows the current restoration plan for Choctaw Bar.



(red line = stone dikes, yellow = bare sandbar, blue = water and green = vegetation)

Figure 3.2 – Time Series of Choctaw Bar (USACE 1999)

3.3 Rhone River, France

A restoration effort was carried out on former channels along the Rhone River in France. Long-term monitoring of aquatic vegetation was conducted on two sites for 17 years located in Bregnier-Cordon plain in the Upper Rhone River. One was a reference site and one was a restored ecosystem. A hydroelectric plant was built in 1982 and 1984 and a weir in 1985 was constructed to maintain upstream water levels. This construction destroyed the downstream part of the Rossillon channel. The channel exhibited rapid eutrophication. Thus in 1993 construction began to restore this channel. The following measures were taken to restore the side channels: dredging was conducted, preservation of river banks and riparian forests which bordered the channel, and undamaged shorelines were preserved for rapid re-colonization of vegetation. Figure 3.3 is an example of a restored channel along the Rhone River. By 1997 the restoration was still successful as the channel stated to reach a mesotrophic (fertile) state (Henry et al. 2002).

Figure 3.3 – Restored Side Channel along Rhone River downstream of Pierre-Benite Dam (http://institutbeaumont.com/field-trips/)

3.4 Clackamas River, Oregon

A gravel mining site is located at river mile 15 on the Clackamas River in Oregon. Geomorphic assessment has been performed along Clackamas River from 1938 to 2000. Figure 3.4 shows the planform changes that the river has experienced. The figure shows that the channel plan form area and length have decreased (Wampler et al. 2006). The natural process of meander cutoff was prevented by dike construction and can be seen in the 1994 planform. However in 1996 a flood caused severe erosion of the meander bend. Within hours the river cut off at the meander, reducing the reach by 1100 meters. Within two days 3.5 hectares and 105,500 m^3 of gravel had been eroded. The reach slope increased from 0.0022 to 0.0035.

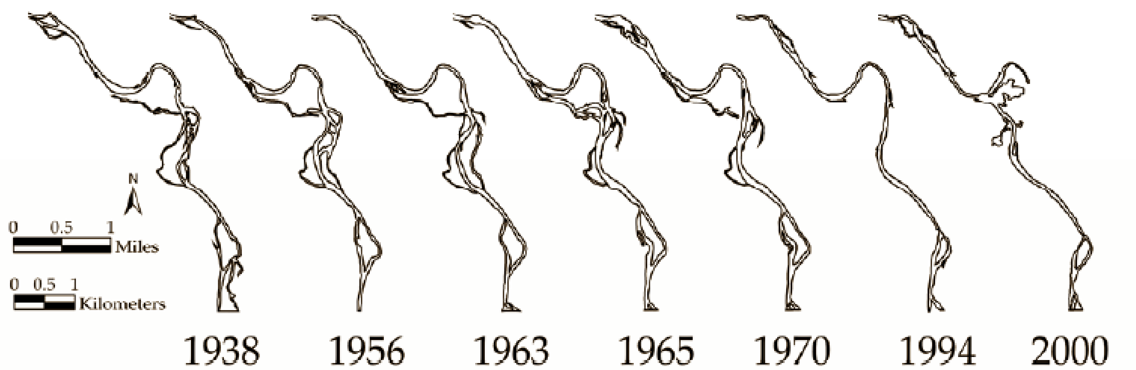


Figure 3.4 – Historical Channel Planform Changes (Wampler et al. 2006)

3.5 Collins Lake, New York

In 1977 and 1978 dredging was performed within Collins Lake to remove the pondweed. Additional information about the dredging is mentioned in Section 2.4.3. Table 3.3 provides a summary of biomass samples taken from the Collins Lake after dredging in 1979 and 1988. The results indicate that after 10 years the plants have grown back, but levels in the dredged area are still low and significantly less then the controlled area. The dredging did reduce the pondweed biomass in Collins Lake with few ecological consequences (George et al. 1982). However, dredging may not be economical in other locations due to depth of pondweed growth.

Table 3.3 – Pondweed Biomass in Collins Lake after Restoration

Sample Date	Control Area (Undredged)		Dredged Area	
	No. of Samples	stems/m^2 of Bio Mass	No. of Samples	stems/m^2 of Bio Mass
May 1979	3	183 ± 32	52	0.8 ± 0.3
May 1988	4	149 ± 17	8	5.8 ± 5
June 1988	3	126 ± 12	15	20 ± 13

Source (Tobiessen et al. 1992)

4 Summary

This study summarizes a literature review of abandoned channel restoration project with several examples from the United States and around the world. The first item of the scope of work emboldens a classification and analysis of abandoned channel restoration projects. This is accomplished by performing an analysis of the processes by which abandoned channels are formed. In addition, an identification and analysis of key factors which trigger restoration is defined. A classification of different restoration projects, their benefits and effectiveness is also presented in this report. In addition, an analysis and evaluation of wetlands, BMPs and engineered solutions for abandoned channel restoration is included. The second major item focuses on long-term examples of channel changes after restoration. This is accomplished through five distinct examples. All cases are not necessarily restoration project; however these studies illustrate the effects that abandoned channels experience over time.

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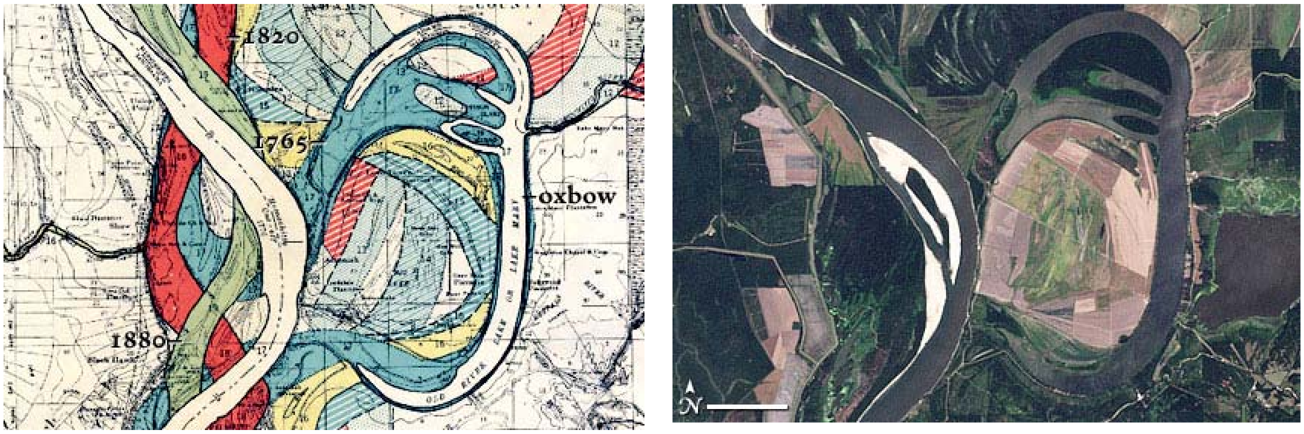
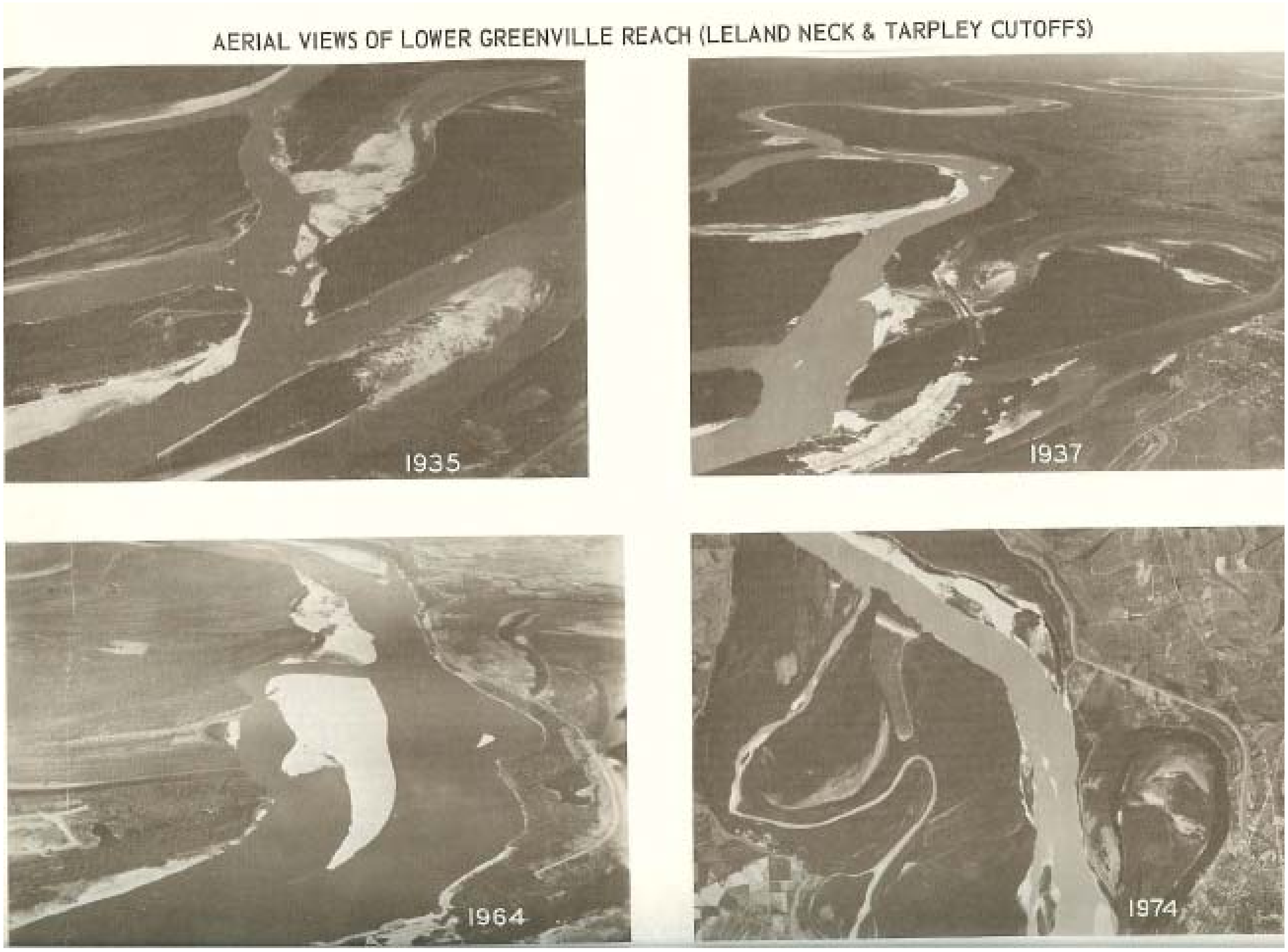
Appendix A – Additional Photos of Abandoned Channels

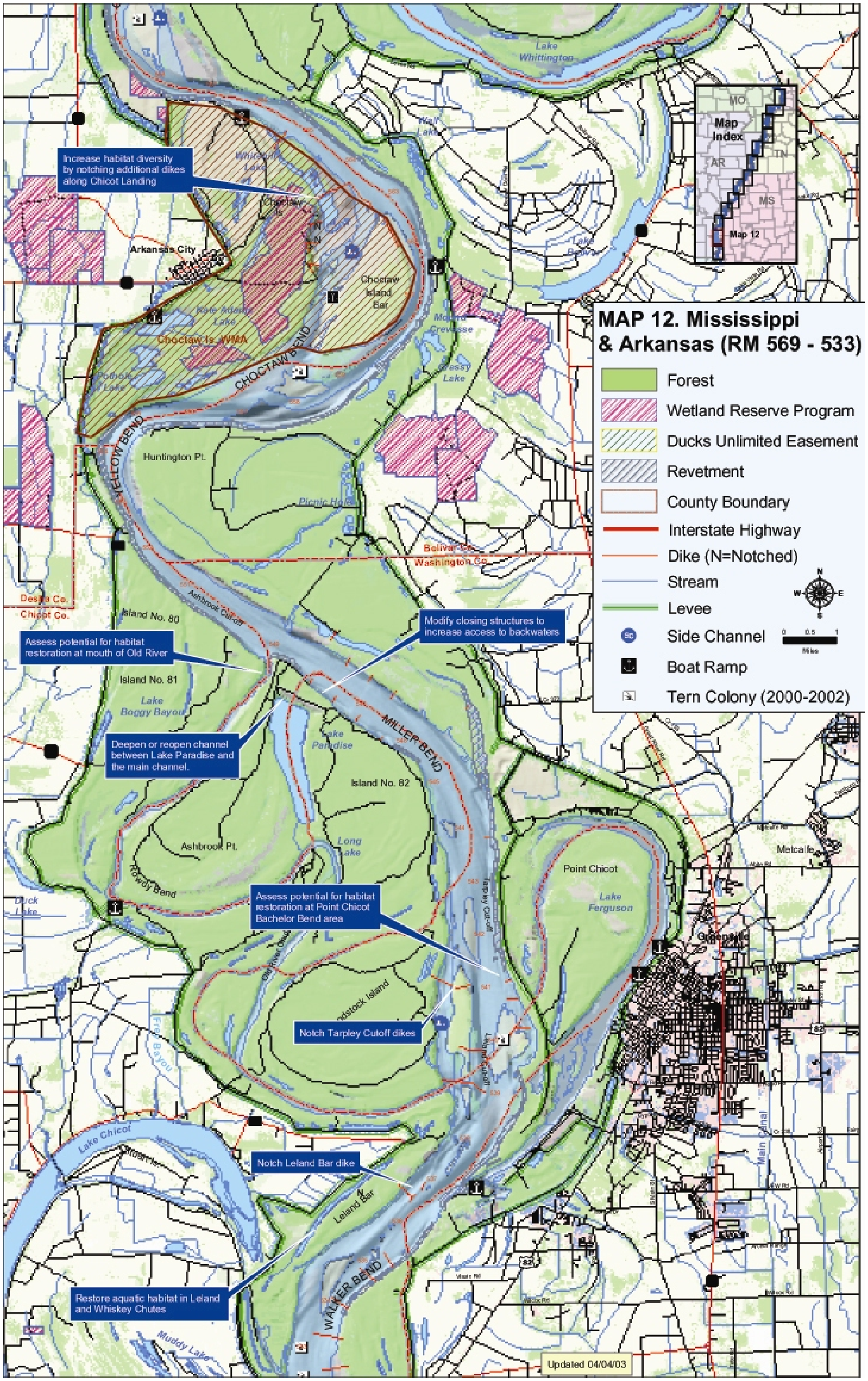


Historical Changes at Old River Lake (Simmon 2006)

Upper Greenville Reach of the Mississippi River (Winkley 1977)



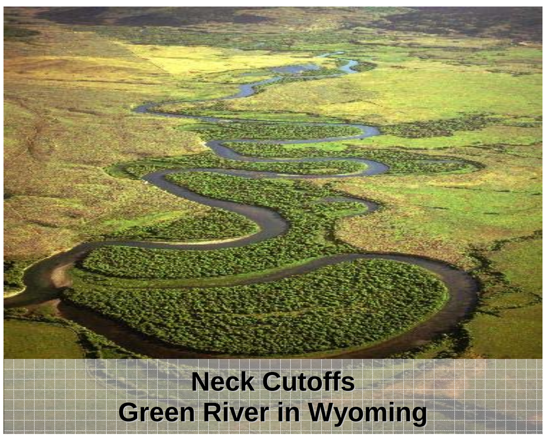
Lower Greenville Reach of the Mississippi River (Winkley 1977)



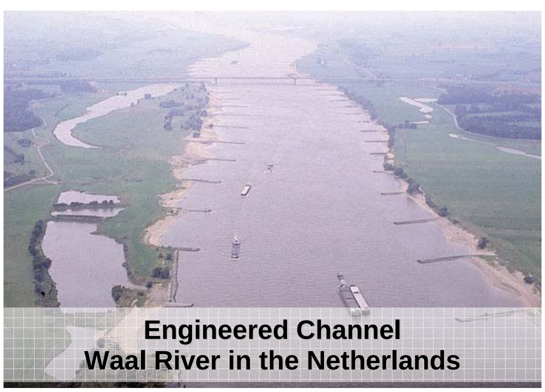
Current Restoration Plan of Choctaw Bar and Greenville Reach

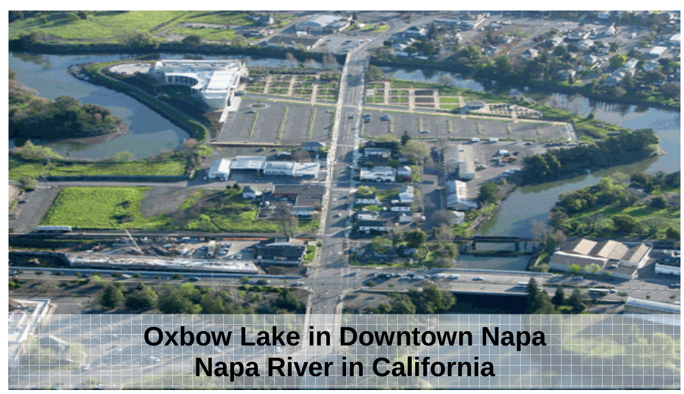

Neck Cutoffs
Red River in Minnesota


East Fork Des Moines River, Iowa


Neck Cutoffs
Green River in Wyoming


Abandoned Channel
Murrumbidgee River, Australia


Engineered Channel
Waal River in the Netherlands


Oxbow Lake in Downtown Napa
Napa River in California

Other Examples of Restoration Projects