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Historical Review: Long-Term Environmental and Human Health Impacts of Connecting the Great Lakes to the Mississippi River System through the Continental Drainage Divide

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Abstract

Starting in 1836, three canals, the Illinois and Michigan Canal, the Chicago Sanitary and Ship Canal and the Calumet-Sag canal were dug across the continental drainage divide. These canals permitted navigation from the Great Lakes to the Mississippi River and the transfer of Northern Civil War soldiers and supplies to Cairo, Illinois in the 1860s. Historically, the rivers like the Illinois were used as "roads" to connect inland settlements to river and coastal ports. The primary objective is to document the environmental and human health impacts of connecting the Great Lakes Basin to the Mississippi River Basin through the Continental Drainage Divide. The Chicago and Calumet rivers and connecting canals were used for navigation and waste disposal for stockyards, meat packing plants, and other industries. A large storm in 1885 dropped high levels of precipitation in a short period of time on the city and resulted in runoff that washed untreated sewage and debris far out into Lake Michigan. This put Chicago's drinking water supply at risk of typhoid and cholera epidemics, since the city water intakes were located only 3.2 km offshore. This paper examined policy issues, the interaction of governmental units, and economic, geographical, and technological constraints that accompanied the attempts to resolve the problem of sewage pollution control in the Chicago metropolitan area while maintaining navigation and shipping channel across the natural drainage divide. The US Army Corps of Engineers (USACE) reversed the direction of a portion of the Chicago River in 1892, and Chicago's sewage began to flow across the natural drainage divide and into the Illinois and Michigan Canal and away from Lake Michigan. The redirected wastewater and contaminated runoff flowed downstream into the Illinois

River where pollutants could be diluted and treated naturally as waters flowed to the Mississippi River. The record flooding on the Illinois River in Spring of 2013 was a result of Chicago River reversal and heavy rainfall in the watershed which raised the pool levels behind the dams along the Illinois River. Heavy rainfall and strong winds created river currents and conditions that resulted in runaway barges that damaged the locks and dams. Many federal, state and private relief agencies responded to help assess and cleanup the damage from flooding and USACE began repairing the damaged Marseilles Dam structure in Summer of 2013. This was done to open one of the most used shipping channels in the nation. The Illinois Waterway continues to be an essential transportation corridor for moving goods across the continental drainage divide and from the Great Lakes to the Mississippi River. This review was an attempt to learn from a historical Chicago lesson and provide recommendations for cities attempting to provide safe drinking water for their residents and to reduce the environmental and human health impacts of their waste disposal. In some cases, the waste can be moved across a drainage divide to separate it from the drinking water supply source.

Keywords

Chicago Canals, Illinois and Michigan Canal, Illinois Waterway, Chicago River Reversal, Continental Drainage Divide

1. Introduction

In the seventeenth century, the French built trading forts between the Illinois River and Lake Michigan in the Illinois territory [1]. The first known Europeans to travel through the area were Father Marquette and Louis Joliet who in 1673 went across the Chicago Portage on their return trip. Joliet remarked that with a canal they could remove the need to portage and the French could create an empire spanning the continent [2]. These explorers understood the importance of easily crossing of the continental divide between the Gulf of America (formerly the Gulf of Mexico) and Atlantic Ocean watersheds. A canal was never built by the French. The Valparaiso Moraine, a very broad moraine, is the largest in Will County and extends into Du Page and Cook counties. This 3.7 to 7.3 m high moraine formed the drainage divide between the Des Plaines, Illinois and Mississippi River system and the Great Lakes and St. Lawrence River system. At the end of the French and Indian War in 1763 the area was ceded to the British and was then awarded to the new United States (US) by the Treaty of Paris (1783).

The Illinois Waterway runs from the Calumet River in Chicago to Grafton, Illinois where the Illinois River flows into the Mississippi River connecting the Great Lakes to the Gulf of America (formerly the Gulf of Mexico). The construction in 1900 of the Chicago Sanitary and Ship Canal and the reversing of the Chicago River to flow out of rather than into Lake Michigan made this waterway a major route for shipping goods to flow to international markets from the Port of

New Orleans at the mouth of the Mississippi River. The Illinois Waterway drops from 176 m above sea level at Lake Michigan to 128 m at the mouth of the Illinois River as it flows southwest into the Mississippi River. A system of eight locks on the Illinois River managed by the USACE controls water flow along the 541 km system to assure a 2.7 m deep navigation channel. The Illinois Waterway and the Illinois River continue to be an essential transportation corridor for moving goods from the Great Lakes to Mississippi River.

Three canals, the Illinois and Michigan Canal, the Chicago Sanitary and Ship Canal and the Calumet-Sag Canal were dug across the continental drainage divide. These canals permitted navigation from the Great Lakes to the Mississippi River starting in 1836 and permitted the transfer of soldiers and supplies to Cairo, Illinois, during the American Civil War in the late 1860s [3]. Many kinds of boats and vessels are used on rivers to move people and products from one place to another. Navigation was extremely important for foreign and domestic trade and travel in the early days of the United States (US) before cars, trucks, trains, and airplanes were invented. Historically, the rivers, like the Illinois, were used as "roads" to connect inland settlements to river and coastal ports. The record flooding in the spring of 2013 on the Illinois River raised the pool levels behind the dams along the Illinois River [4]. Heavy rain and runoff from tributaries along with strong winds created river currents and conditions that made it difficult to secure the barges being moved in the shipping channel or anchored along the channel [5]. Seven unmoored barges were caught in the currents of the Marseilles pool and struck and damaged 5 of the 8 Tainter gates at the dam, leaving two gates with 5 to 6 m holes. Four of the seven barges partially sunk in front of the southern gates and the other three barges blocked the water flow through three middle gates on April 19, 2013.

More than 200 homes, a school and public buildings were flood-damaged [5]. In the weeks immediately after the barge accident, hundreds of relief workers, including FEMA, Lutheran Early Response and RUBICON teams, aided residents, helped remove the damaged appliances and household items or inspected the properties to assess the extent of the damage. The response teams helped clear out flooding debris, damaged appliances and furniture, removed walls, flooding and cabinetry and even treated the houses for mold. Dumpsters and port-a-potties were brought in for use by some residents and by relief workers. The damaged appliances were placed out on the streets, put in dumpsters or hauled to a public parking lot where relief workers sorted damaged property into categories and hauled the damaged household items away.

The Marseilles Elementary District 150, which serves 632 students, sued the Ingram Barge Company for $6.4 million for flood damages resulting from the barges blocking the dam. By June 30, 2013, forty Marseilles property owners also filed claims against Ingram, with more claims expected. The school's claim was filed in the Chicago federal court and lawyers argued the Nashville-based company" breached its duty" to safely secure the barges and is at fault for the massive flood-

ing of the city. The damage to the school was mostly covered by insurance from Illinois School District Agency, through a self-insured pool of several school districts, except for a $834,000 deductible. To hold Ingram legally and financially responsible, it was necessary for the school district to file a claim.

The USACE created a temporary rock dike dam during the four weeks after the accident to permit repairs to the three most severely damaged gates. The temporary U-shaped dike downstream from the three gates included a series of culverts to hold or release water from the pond as needed, substituting for the controlled spillway effect under normal conditions. Many federal, state and private relief agencies responded to help assess and cleanup the damage from flooding and USACE began repairing the damaged Marseilles Dam structure in summer of 2013. This was done to open the shipping channel, one of the most used in the nation.

2. Methodology

This study related to Chicago's 132-year attempt to provide safe drinking water to residents and to safely dispose of waste via rivers and streams that historically drained into Lake Michigan and contaminated the cities drinking water supply for more than a century ago. Initially, mitigation techniques, such as extending the intake pipes farther from the shore, failed during storm events and resulting in typhoid and cholera epidemics. Finally, the rivers (**Figure 1**) were blocked and the US Army Corps of Engineers reversed the river flows across the continental drainage divide and the sewage and river water was discharged into the Mississippi River system. The effects of Chicago waste disposal on downstream cities and towns became the subject of legal action, especially by the state of Missouri and the city of St. Louis. The case was presented to the US Supreme Court and eventually Illinois and Chicago won. This review was an attempt to learn from a historical Chicago lesson for cities attempting to provide safe drinking water for their residents and to reduce the environmental and human health impacts of their waste disposal.

3. Findings

3.1. Chicago and Calumet River Reversal and Sewage Transfer across the Continental Drainage Divide

In the early 1800s, the Valparaiso moraine, a 3.7 to 7.3 m high ridge of glacial outwash and glacial lake sediments, was the continental drainage divide (**Figure 1**) that separated the Great Lakes and the Mississippi River watersheds [1]. Three canals, the Illinois and Michigan Canal, the Chicago Sanitary and Ship Canal, and the Calumet-Sag canal were dug across the continental drainage divide. These canals permitted navigation from the Great Lakes to the Mississippi River starting in 1836 and permitted the transfer of soldiers and supplies to Cairo, Illinois during the American Civil War in the late 1860s. The Chicago and Calumet rivers and connecting canals were used for navigation and waste

disposal for stockyards, meat packing plants, and other industries [2]. The Great Chicago fire of 1871 destroyed stockyards, wooden industrial buildings and residential houses in much of Chicago. The growth of the city was not slowed, and rebuilding occurred rapidly along the Illinois and Michigan Canal, the Chicago River, and the shores of Lake Michigan. A large storm in 1885 dropped high levels of precipitation in a short period of time on the city and resulted in runoff that washed untreated sewage and debris far out into the lake. This put Chicago's drinking water supply at risk since the city water intakes were located only 3.2 km offshore. Although typhoid and cholera were risks, no epidemics occurred. However, this was a wakeup call, and in 1889 the Illinois legislature created the Chicago Sanitary District (currently the Metropolitan Water Reclamation District of Greater Chicago).

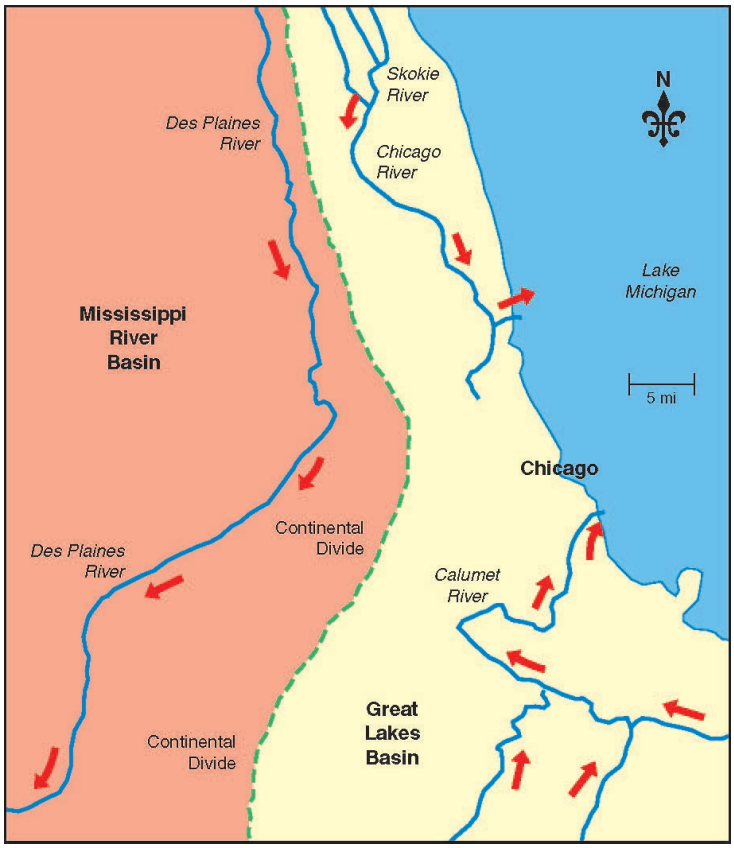

Figure 1. This map shows the water flow of the Chicago and Calumet rivers into Lake Michigan prior to 1900. The continental drainage divide separates Lake Michigan from the Des Plaines and Illinois rivers that flow south into the Mississippi River.

The US Army Corps of Engineers (USACE) reversed the direction of a portion of the Chicago River in 1892, and Chicago's sewage began to flow into the Illinois and Michigan Canal southward, instead of into Lake Michigan, and away from Lake Michigan. The redirect wastewater and contaminated runoff flowed downstream into the Illinois River where pollutants could be diluted and treated natu-

rally as waters flowed to the Mississippi River [4] [5]. However, this was a temporary fix, and the complete reversal of the Chicago River's flow was not accomplished until the Sanitary and Ship Canal was opened in 1900. The Chicago Sanitary District designed a plan to build a network of channels and canals that would reverse the flow of the Chicago and Calumet Rivers to transfer the untreated sewage and industrial debris and waste into the Des Plaines River in 1900. The Illinois and Michigan Canal was partially replaced by the Chicago Sanitary and Ship Canal in 1900, which was wider and deeper and later by the Illinois Waterway in 1933. The permanent reversal of the Chicago and Calumet rivers with the construction of the Chicago Sanitary and Ship Canal was an immense municipal public works achievement that became internationally known as one of the seven wonders of American engineering. It provided training for a generation of engineers, many of whom later went on to design and construct the Panama Canal and the Headwaters Diversion levee [6].

3.2. Environmental Impact of Chicago Waste Disposal Downstream

The origin idea of "reversing the Chicago River" came from a public health crisis in the late 19th century. Public officials and engineers in Chicago began planning what was known as Chicago Drainage Canal in the late 1880s. Chicago used the rivers and Lake Michigan as both sewers for the discharge of human waste and as a source of their drinking water [7]. After a series of cholera and typhoid outbreaks led to the deaths of thousands of Chicagoans, city and state officials began touting the Drainage Canal as the solution to the city's public health problems. Chicago relied on Lake Michigan for its drinking water, but sewage disposal into the river, which then flowed into the lake, contaminated the source, leading to rampant waterborne diseases like cholera and typhoid. The idea was to reverse the river's flow and to carry sewage away from the lake, thus safeguarding the city's water supply.

To fix the problem, officials and engineers turned to the idea of "self-purification". The term refers to the natural process of rivers cleansing impurities from their ecosystems. Rivers with a dissolved oxygen level below 5 mg/L tend to decline in health, and species die [8]. At the end of the 1900s, Edwin Oakes Jordan, a University of Chicago scientist and advocate of the Drainage Canal, insisted that self-purification would help Chicago solve its waste problem and improve public health. Dr. Jordan asserted that no significant levels of pollution were detected in water redirected downstream via the Illinois and Michigan Canal to the Des Plaines, Illinois, and Mississippi Rivers. Officials and engineers agreed to solve Chicago's waste problem with a progressive engineering feat. A 45 km canal, or "Condit," would connect the Chicago River (**Figure 2**) with the Des Plaines River. Instead of the Chicago River sewage and river water flowing into Lake Michigan, pumping stations would funnel water from Lake Michigan through the canal, and flush Chicago's waste downriver and towards the Des Plaines, Illinois, and Mississippi Rivers. The success of the Drainage Canal depended on the idea of Progressive Era science giving a helping hand to the engineers and scientists.

Figure 2. Illinois and Michigan sanitary canal used to reverse the flow of the Chicago River and to transfer sewage from the Great Lakes drainage basin to the Mississippi River drainage basin [7].

Many people living in downriver communities in Illinois and Missouri did not believe transferring raw sewage through a canal (**Figure 3**) would enhance the process of self-purification. Newspaper editors in the late 1800s and early 1900s lambasted engineers and argued that the proposal to reverse the flow of Chicago River was an experiment "*contrary to the laws of nature and contrary to the laws of gravity*". In 1901, the Chicago Eagle (an Illinois newspaper), argued that the proposal to reverse the flow of the Chicago River would contaminate the Des Plaines. Illinois, and Mississippi Rivers, which provided drinking water for thousands of Americans. None of the Illinois downriver communities sued Chicago and the State of Illinois. However, the city of St. Louis in Missouri, located more than 500 km downriver from Chicago, did sue Chicago and the State of Illinois. Three court cases captured national attention in the early 1900s as Missouri officials sued the state of Illinois and "duked it out" in the Supreme Court. The most consequential of these cases was Missouri v. Illinois, a trial that lasted from 1901 to 1906 [8]. The trial gave unprecedented visibility to American scientists at major universities in both Illinois and Missouri and provided new donor interest in funding their research.

The sanitary canal was opened in January 1900. Anticipating this event trustees of the Chicago drainage district, acting upon the advice and cooperation of Arthur R. Reynolds, M.D., Commissioner of Health of the City of Chicago, arranged in 1899 for an exhaustive chemical and bacteriological study of the stream from Bridgeport to St. Louis. To assure that this work might have all possible weight and that the results might be abundantly conclusive, Commissioner Reynolds was given authority to secure, under his own general direction, a prolonged series of independent examinations and analyses by several well-accredited experts. To fulfill this task, the Commissioner arranged for the work by the Municipal Laboratory of Chicago, by the laboratory of the University of Chicago, and by that of the University of Illinois. He endeavored also to secure the cooperation of Washing-

ton University or of the City Laboratory of St. Louis, but in this was not successful. The work as undertaken was put in charge of Dr. Adolph Gehrmann of the laboratory first named, of Professor E. O. Jordan of the second, of Professors A. W. Palmer and T. J. Burrill [8] of the third. In the latter case the bacteriological examinations were conducted by the present writer and his results alone are herein given, except that other general conclusions are mentioned. The work was commenced in May 1899 and continued uninterruptedly until October 1900. Further examinations, made during the latter part of the year 1901, did not significantly modify the earlier conclusions.

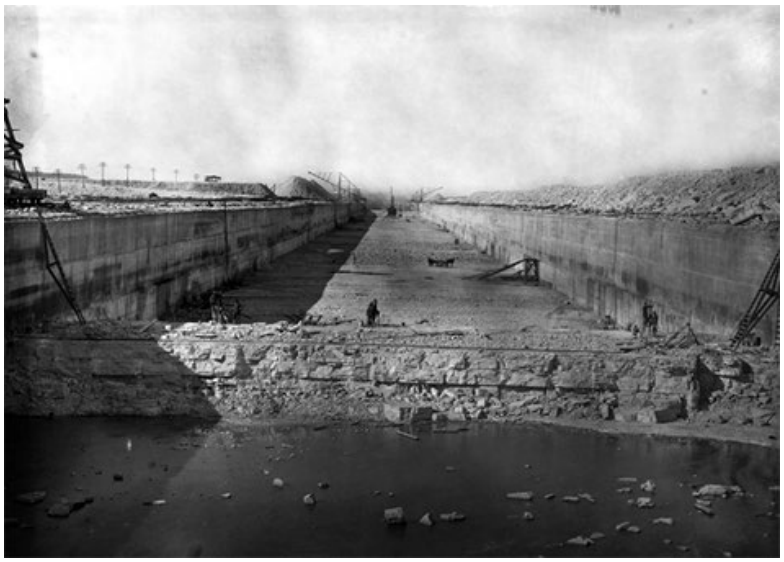

Figure 3. Chicago Sanitary Canal used to reverse the flow of the Chicago River and to transfer sewage from the Great Lakes drainage basin to the Mississippi River drainage basin [7].

Burrill [8] reported that "*Collections, usually one each week at each place, were made from* 38 *carefully located stations of the stream and tributaries, including the canals above named, the Des Plaines, Kankakee, Fox, Big Vermilion, Sangamon, Illinois, and Mississippi rivers and from Chicago and St. Louis tap waters. Comparative tests were also made of the Missouri River several miles above its mouth. During that period, the writer and his assistants received* 2,800 *samples, from which an aggregate of about* 30,000 *bacterial cultures were made. In all these two primary ends were sought*: (1) *To determine for each sample the number of bacteria in a cubic centimeter which could be made to develop colonies on a culture plate, and* (2) *to test the presence or absence in each sample of Bacillus coli-communis. In work of such magnitude, and upon waters generally so polluted, further refinements of analysis were impracticable or less important. The first was expected to indicate quantitative and the second to give the best obtainable knowledge of qualitative contamination, that is, whether such pathogenic species as Bacillus typhosus were present in the samples examined. In work of this kind, it is impossible directly to identify the latter, but since the two species just named*

gain access to such water from intestinal evacuations the presence of one of them must give a comparative indication of that of the other. There is no room for doubt as to the polluted character of the head waters of this stream. What becomes of the highly putrescible and often pathogenic germ-laden matter equal to 150 *tons of dry matter daily from Chicago and as much more from other sources that is persistently poured into the water*? *The question has been much discussed, and opinions have been exceedingly diverse upon what has been called the self-purification of running water. Somewhat misquoting an expression in a report of a British commission, it has recently been asserted before the American Medical Association that* '*biologists have about come to the conclusion that no river is long enough to purify itself.*' *In a recent book on sanitation, it is argued that the apparent purification in a river course is principally due to the dilution by pure water and not to any destruction of the organic matter with which the stream is originally polluted.* '*The theory of self-purification is now abandoned, or rather accepted only after so much modification that it is practically new.*' *Because of contentions of this kind and otherwise the authorities of St. Louis, Missouri, became alarmed that the Chicago contamination could reach the intake in the Mississippi River, from which St. Louis receives its water supply. An injunction has therefore been sought from the United States Supreme Court against the use of the sanitary canal, and the discharge into the Illinois River of Chicago sewage*" [8].

After the Supreme Court heard all the expert testimony, Justice Holmes, speaking for the majority, sided with Illinois and the tide of Progressive Era reform. Missouri wanted to halt the construction of the canal, and Holmes prefaced his rejection of that request by saying: it is a question of the first magnitude whether the destiny of the great rivers is to be the sewers of the cities along their banks or to be protected against everything which threatens their purity. To decide the whole matter at one blow, by an irrevocable fiat, would be at least premature.

Burrill [8] noted that "*Holmes unwillingness to act by* '*fiat*' *left the health of American rivers for another generation to solve. The court's decision allowed Illinois to complete the Drainage Canal and reverse the flow of the Chicago River. It was a spectacular feat of modern engineering… and it turned out that downriver residents were right: the Drainage Canal was too narrow, and the volume of human waste too large, to enable the Des Plaines and Mississippi Rivers to self-purify. Human waste continued to pollute America's inland rivers. In our current era of climate crisis, barely a day passes without local news outlets reporting on failed sewage systems or malfunctioning oil and gas pipelines polluting our rivers. The Indigenous elders were right: humans needed to work with the land and its waterways, not against it.*"

Missouri [9] filed its bill in Court to enjoin Illinois and the Sanitary District of Chicago from discharging sewage through an artificial channel connecting Lake Michigan with the Des Plaines River, a tributary of the Illinois, the latter of which empties via the Illinois River into the Mississippi River above St. Louis, claiming that such sewage so polluted the water of the Mississippi as to render it unfit to

drink and productive of typhoid fever and other diseases [10]. Illinois denied the jurisdiction of the Supreme Court, and the allegations of the bill, and alleged that, if the conditions complained of at St. Louis existed, they resulted from discharge of sewage into the Mississippi by cities of Missouri and from other causes for which Illinois was not responsible. A demurrer was overruled, with leave to answer, U. S. 180 U.S. 208; after answer and taking of proof, including much expert testimony as to effect of sewage on water and health, *held* that:

This Supreme Court [9] determined it "*has jurisdiction and authority to deal with a question of this nature between two states which, if it arose between two independent sovereignties, might lead to war. In such a case, while this Court cannot take the place of a legislature, it must determine whether there is any principle of law, and if any, what, on which the plaintiff state can recover.*"

"*Every matter which would be cognizable in equity if between private citizens in the same jurisdiction would not warrant this Court in interfering if such matter arose between states; this Court should only intervene to enjoin the action of one state at the instance of another when the case is of serious magnitude, clearly and fully proved, and in such a case, only such principles should be applied as this Court is prepared deliberately to maintain.*"

"*While a state may have relief in this Court against another state to prevent it from discharging sewage through an artificial channel into, and thereby polluting the waters of, a river flowing through both states and on which the complainant state relies for water supply, if the alleged facts as to such pollution are not fully proved, and it also appears that such pollution might result from the discharge of sewage by cities of the complainant state into the same river the bill should be dismissed, but in this case without prejudice.*"

"*The reasons on which prescription for a public nuisance is denied or granted to individuals against the sovereign power to which he is subject have no application to an independent state, but it would be contradicting a fundamental principle of human nature not to allow effect to the lapse of time. The fixing of a definite time, however, is usually for the legislature, and not for the courts. Page* 200 *U. S.* 497."

"*The mere fact that the drainage canal, constructed by authority of Illinois and also under authority of an act of Congress, brought water from the Lake Michigan watershed into the watershed of the Mississippi does not, in the absence of proof of the deleterious effects of such water, render the canal an unlawful structure the use whereof should be enjoined at the instance of another state in the Mississippi watershed. The facts, which involved the right of the defendants to discharge the sewage of Chicago through an artificial channel into the Desplaines River, which empties into a tributary of the Mississippi River, are stated in the opinion of the Court. Page* 200 *U. S.* 517" [9].

3.3. Illinois Waterway

The backbone of the Illinois Waterway is the Illinois River (**Figure 4**), which par-

tially runs through the ancient Mississippi River Valley toward St. Louis, Missouri. Historically, the ancient Mississippi River entered Illinois to the south of Davenport, Iowa, and flowed east into the valley where the Hennepin Canal is located. The Wisconsin glacier and end moraine blocked the flow of the ancient Mississippi River through the valley approximately 15,000 to 30,000 years ago. The upper Illinois River headwaters now start near Chicago, Illinois, and outlets to the Mississippi River are located at Grafton, Illinois [2]. Had the Wisconsin glacier advance not plugged the ancient Mississippi River Valley and caused the realignment to its current location, the land area south of Hennepin Canal, west of current Illinois River, and north of Alton, Illinois, would probably belong to the states of Iowa and Missouri. This assumes the Mississippi River would have remained the western boundary of Illinois. This area is approximately one-seventh of Illinois land area, or about 2,000,000 ha in size, and would have dramatically changed the shape of Illinois [3].

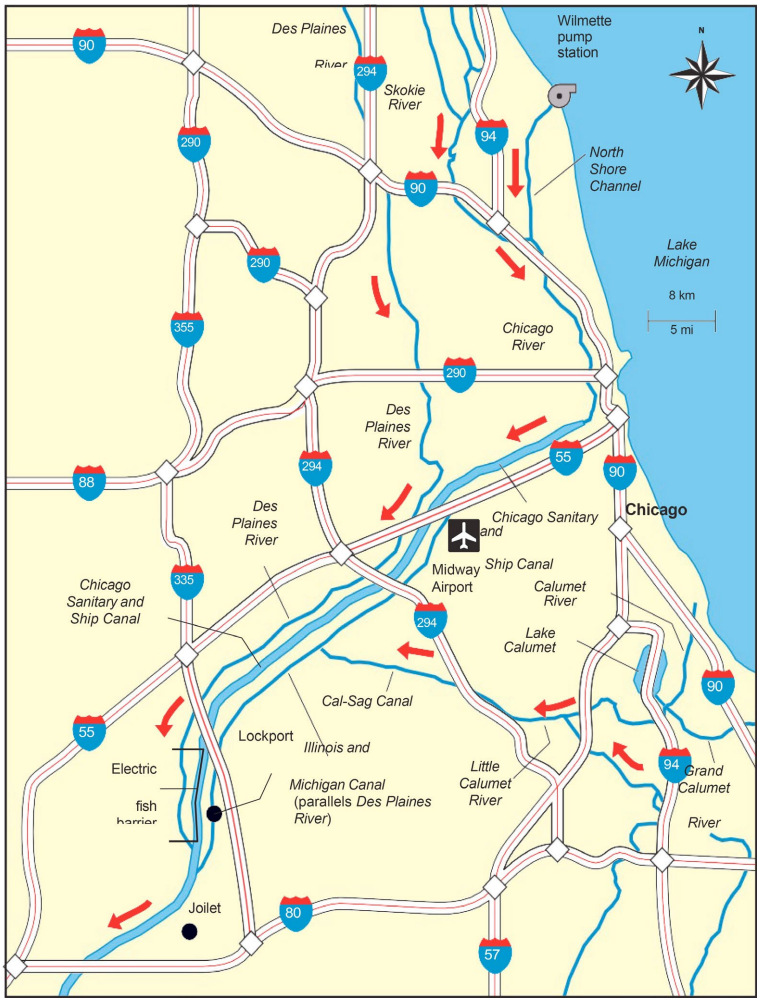

Figure 4. This 2015 map shows the direction of the water in the Chicago canals after the Chicago and Calumet rivers were reversed to carry wastewater away from Lake Michigan into the Chicago Sanitary and Ship Canal and south into the Illinois Waterway and the Mississippi River [2].

A string of eight locks and dams on the Illinois Waterway runs southwest from Lake Michigan (Chicago, Illinois USA) to Grafton on the Mississippi River connecting Great Lakes barge and boat traffic to the port of New Orleans. Record spring floodwaters in 2013 [11] [12] and three damaged Tainter gates at the Marseilles Dam at river mile marker 247 halted navigation on the Waterway [13]. On April 19, 2013, the currents and winds on the Marseilles pool caused seven barges to break free and crash into the Marseilles Dam. Four barges partially sank in front of the dam restricting the capacity of the eight spillway gates to manage water levels in the pool. Water backed-up and flooded portions of the Illinois River floodplain upstream including residential bottomlands in the city of Marseilles. There was an immediate and substantial federal disaster relief response as homes and businesses were flooded with damages in the millions of dollars. The greatest agricultural impact was the suspension of the shipping of fertilizers and grain. In this paper damages to the dam structure caused by the seven runaway barges and repair efforts are discussed as well as flooding impacts in the City of Marseilles and engineering efforts to maintain the 2.7 m navigation channel on the Illinois Waterway [13].

In spring of 2013 the highest floodwater levels in the last 70 years were recorded on the Illinois Waterway [11], a 541 km navigation system of rivers, lakes and canals running from Lake Michigan (Chicago, USA) to the mouth of the Illinois River at Grafton on the Mississippi River (**Figure 5**). River traffic, made possible

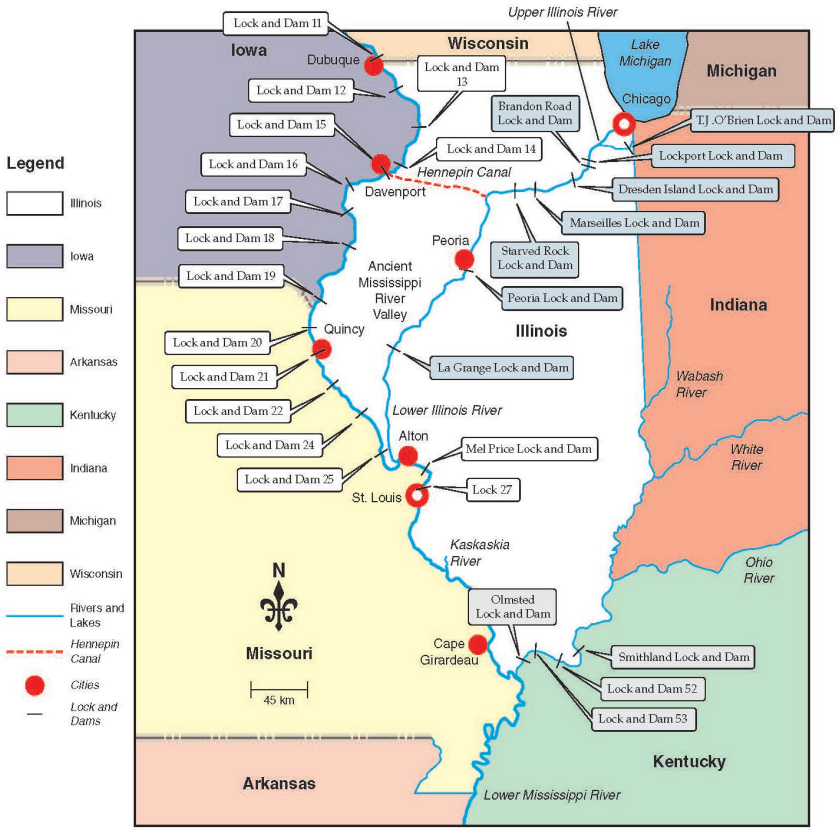

Figure 5. Map of Mississippi, Ohio, and Illinois River locks and dams. Created by Mic Greenberg [2].

by eight lock and dam structures on the Waterway, was halted when the dam at Marseilles, 247 river miles above the Mississippi River was damaged. On April 19, 2013, the currents and winds on the Marseilles pool above the dam caused seven barges to break free and crash into the Marseilles dam resulting in four of the barges sinking (Figure 6). These barges blocked the southern-most spillway submersible Tainter gates used to maintain the 2.7 m navigation channel and prevented gate adjustments to release excess water from the pool. Floodwaters backed-up for many kilometers and flooded adjacent Illinois River bottomlands including the town of Marseilles (Figure 7). Approximately 1500 residents were evacuated from the low-lying areas and more than a meter of floodwater surrounded 200 homes and building structures and destroyed at least 24 homes. Many other buildings required substantial repairs, and many appliances and household furnishings had to be discarded. When the rains stopped and upstream runoff slowed, flood waters in Marseilles drained out through a diversion channel previously used by a former hydroelectric plant.

There was an immediate and substantial federal disaster relief response including Federal Emergency Management Agency (FEMA), Lutheran Early Response and RUBICON team workers. Damages were in the millions of dollars and many residents and relief workers were housed in area hotels for weeks. The barge accident and 2013 flooding of Marseilles did some damage to parklands (Figure 8), sidewalks and roads. The greatest agricultural impact was the suspension of the shipping of fertilizers and grains. The primary objective of this study is to document the damages to the dam structure caused by seven runaway barges which reduced the capacity to manage the Marseilles water pool for navigation on the Illinois Waterway and to limit flooding in the town of Marseilles.

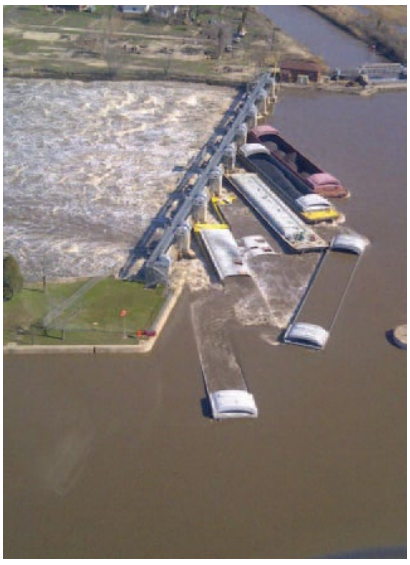

Figure 6. Seven partially sunken barges at the Marseilles lock and dam and deflectors. Courtesy of Major General John W. Peabody, Commander of the Mississippi Valley Division, United States Army Corps of Engineers and President of the Mississippi River Commission [2].

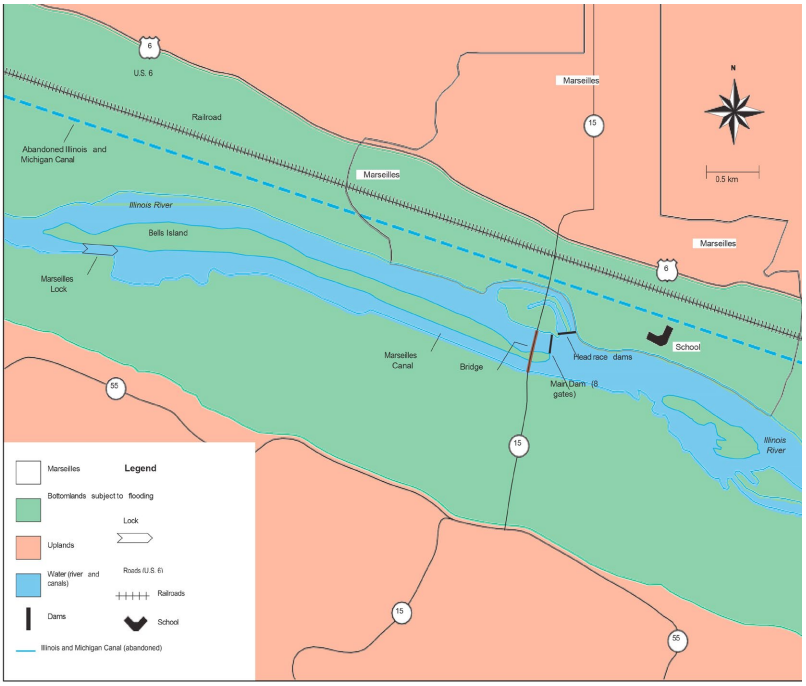

Figure 7. Map of the Illinois River bottomlands and adjacent upland between the Marseilles lock and the Marseilles dam. Created by Mic Greenberg [2].

Figure 8. Stream bank erosion at the Illini State Park [2].

3.4. Constructing the Illinois Waterway System

The US has more than 40,000 km of navigable inland waterways with the Mississippi River system accounting for almost 14,400 km. Many of these inland waterways are only navigable because of extensive lock and dam engineering. The map of the Upper Mississippi River Basin (**Figure 5**) shows the locks and dams on the sections of the Mississippi and Ohio rivers that border Illinois and those on the Illinois

River within the state of Illinois. The Illinois Waterway runs from the Calumet River in Chicago to Grafton, Illinois where the Illinois River flows into the Mississippi River and connecting the Great Lakes to the Gulf of America (formerly the Gulf of Mexico). The construction in 1900 of the Chicago Sanitary and Ship Canal and the reversing of the Chicago River to flow out of rather than into Lake Michigan made this waterway a major route for shipping goods to flow to international markets from the port of New Orleans at the mouth of the Mississippi River [12]. The Illinois Waterway drops from 176 m above sea level at Lake Michigan to 128 m at the mouth of the Illinois River as it flows southwest into the Mississippi River (**Figure 5**). A system of eight locks on the Illinois River managed by the USACE controls water flow along the 541 km system to assure a 2.7 m deep navigation channel.

A lock is an engineered structure used to raise and lower boats between stretches of water that are at different levels on canals or rivers or to bypass rapids or mill weirs using the water for hydroelectricity [10]. It is a chamber with water-tight doors or gates at each end that seal off the chamber from the stretch of water between the next upstream or downstream lock. The chamber holds one or more vessels and when full of water lifts the boats to the level of the upstream body of water; and when empty the gate is open to the downstream body of water. The lock and dam system is like a flight of stairs going up and down the river using gravity to move the water and maintain a minimum depth for boat traffic. Water drains from an open lock by gravity into a second lock until the water is level. Then barges and boats at the downstream lock can travel upstream to the next lock assured of sufficient water depth for navigation and without expending a great deal of energy against the flow of the river. Once the vessels reach the next lock, they are lifted the river in a repeating process.

Dams upstream from each lock control the amount of water released or held back to maintain the desired water depth for navigation (2.7 m in the case of the Illinois Waterway). Dam capacity to hold the pool of water within each lock to tight tolerances is critical to avoid the water levels becoming too low for navigation to occur or too high resulting in flooding along sections of the river that have low-lying bottomlands which have been built upon.

3.4.1. Navigation on the Illinois Waterway

Many kinds of boats and vessels are used on rivers to move people and products from one place to another. Navigation was extremely important for foreign and domestic trade and travel in the early days of the United States (US) before cars, trucks, trains, and airplanes were invented. Historically, rivers like the Illinois were used as "roads" to connect inland settlements to river and coastal ports [9].

Communities established at these commercial ports, such as Chicago, Illinois and St. Louis, Missouri became important economic, cultural, and social hubs in the development of the state of Illinois and were instrumental in unifying the US as a nation. Many food products and materials are still transported by vessels on the Illinois River and through the Hennepin Canal. Towboats push barges loaded with products such as grain, coal and petroleum up and down the Illinois River to

loading and unloading facilities.

The most common way of transporting products on rivers is by tow which consists of one towboat and one or more barges. There are four basic types of barges [13]. Covered dry cargo barges, such as the ones that crashed into the Marseilles Dam, that carry bulky solid cargo including dry cement, fertilizers and farm products such as corn, wheat and soybeans and need protection from the weather. Open hopper barges which hold bulky products, such as sand, gravel and coal and do not need protection from the weather. Liquid cargo (tank) barges carry liquid products such as chemicals, petroleum, oil and molasses. The fourth type is a deck barge, which carries almost any kind of equipment, materials or products that can be tied down and do not need protection from the weather.

3.4.2. Recreation on the River

The Illinois Waterway created water surfaces ideally suited for water-associated recreational activities. In addition to the deep navigation channel, the dams (**Figure 5**) on the Illinois River create a series of eight lakes or pools as well as extensive marshes, swamps, open sloughs, backwater sloughs, ponds, small lakes, and expanses of open water that provide a variety of natural habitats [13]. Many public and private recreational areas and marinas provide facilities for picnicking, swimming, boat launching and camping along the Illinois River. Wildlife-oriented recreation includes fishing and opportunit ies to observe nesting and hatching areas for waterfowl and breeding grounds for aquatic furbearing mammals [14]. The riparian floodplain forest [15] provides habitat for a wide variety of animals.

3.5. Marseilles Lock and Dam

The eight locks and dams on the Illinois River were designed by the USACE to function as a unit to maintain the shipping channel and other types of water traffic (**Figure 5**). The Marseilles Lock and Dam system is located upriver about 8 river miles from Starved Rock lock and dam. The Marseilles Lock at 244.6 mile marker is 4 km west and downstream from the Marseilles Dam located at the City of Marseilles (**Figure 7**). The dam at mile marker 247, constructed in 1933 to maintain the navigation pool between Marseilles and Dresden Island locks, lies adjacent to the upstream end of the Marseilles Canal which was created as a bypass to the rapids used to generate hydroelectric power [3]. Thus, the Illinois River at Marseilles splits into three channels (**Figure 7**). Marseilles Canal flows directly into the Lock; the rapids with water flow controlled by the dam; and the man-made channel on the Marseilles side of the river that runs through the former hydroelectric plant. The location of the abandon Illinois-Michigan canal is shown in **Figure 7.**

The dam at Marseilles is a gated structure with eight 18.3 m wide submersible Tainter gates (**Figure 6**) covering a total width of 168.2 m and a 14.2 m section containing an abandoned ice chute [4]. The main dam has a normal head about 4 m and maintains an upper pool at an elevation of 147.3 m. The submersible Tainter gates 4.9 m high with a radius of 7.6 m are used as a spillway and are frequently adjusted to maintain the 2.7 m navigation channel and to prevent

overtopping when the gates are fully closed. The gates are remotely operated (with manual capability) using a schedule that: 1) maintains a flat pool, 2) prevents excessive scouring (e.g. one gate wide open while remaining gates are closed), 3) varies to reduce vulnerability to floating ice and debris, 4) minimizes out-draft, and 5) assures approximate equal use of the gates [4]. During flooding conditions, the gate schedule attempts to manage the high discharge created from wide-open gates and the considerable turbulence below the spillway which has high potential for downstream scouring.

3.6. Flooding on the Illinois River

The record flooding on the Illinois River in spring of 2013 caused by the reversal of the Chicago River and heavy rains in the watershed raised the pool levels behind the dams along the Illinois River. Heavy rain and runoff along with strong winds created river currents and conditions that made it difficult to secure the barges being moved in the shipping channel or anchored along the channel. Seven unmoored barges were caught in the currents of the Marseilles pool and struck and damaged 5 of the 8 Tainter gates at the dam leaving two gates with 5 to 6 m holes [16]. Four of the seven barges partially sunk in front of the southern gates (**Figure 6**) and the other three barges blocked the water flow through three middle gates (**Figure 9**) on April 19, 2013. As a result, the blocked gates were unable to fully open to release the additional floodwaters. Water backed up into the Marseilles pool, topped riverbanks with and without a low levee protection and flooded the bottomlands with alluvial soils (Sawmill, Millesdale, DuPage, Lawson and Benton soils) in the town of Marseilles (**Figure 7**). Most of these poorly drained soils were developed under prairie and in alluvium over outwash or limestone. The floodwaters also flowed into the third channel running through Marseilles City, the old diversion previously used to generate hydroelectric power and then back into the Illinois River west of the Marseilles Dam.

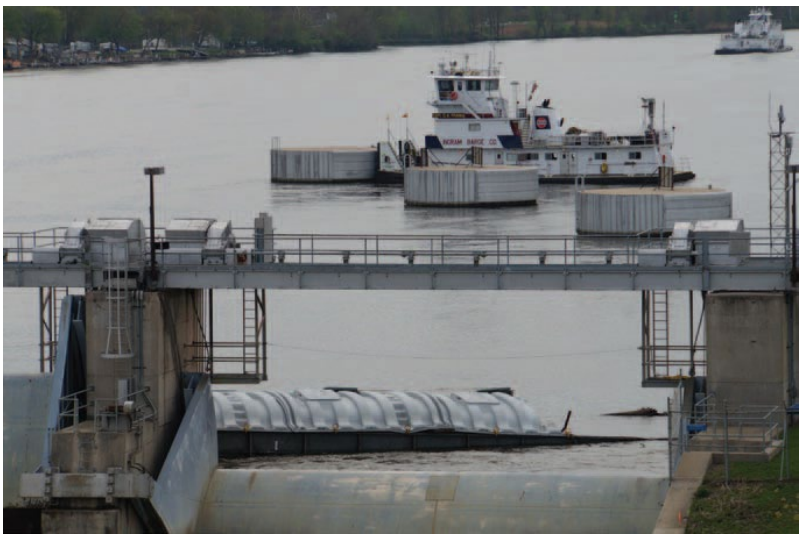

Figure 9. Partially sunken barge and damaged Tainter gates struck at different heights [2].

More than 200 homes, a school and public buildings were flood damaged. Floodwaters reached depths of 1 m in many buildings and the lower 1/3 of the walls had to be removed and replaced. In the weeks immediately after the barge accident, hundreds of relief workers (**Figure 10**), including FEMA, Lutheran Early Response and RUBICON teams, aided residents, helped remove the damaged appliances and household items or inspected the properties to assess the extent of the damage. The response teams helped clear out flooding debris, damaged appliances and furniture, removed walls, flooding and cabinetry and even treated the houses for mold. Dumpsters and port-a-potties were brought in for use by some residents and by relief workers. The damaged appliances were placed out on the streets, put in dumpsters or hauled to a public parking lot where relief workers sorted damaged property into categories and hauled the damaged household items away.

Figure 10. Relief workers removing damaged items from flooded homes [2].

The Marseilles Elementary District 150, which serves 632 students, sued the Ingram Barge Company for $6.4 million for flood damages resulting from the barges blocking the dam [17]. By June 30, 2013, forty Marseilles property owners also filed claims against Ingram with more claims expected. The school claim was filed in the Chicago federal court and lawyers argued the Nashville-based company" breached its duty" to safely secure the barges and is at fault for massive flooding of the city. The damage to the school was mostly covered by insurance from Illinois School District Agency, through a self-insured pool of several school districts, except for a $834,000 deductible. To hold Ingram legally and financially responsible it was necessary for the school district to fill the claim. The lawsuit claims Ingram "had a duty to operate its vessels safely and to secure its barges under tow to prevent against a break away." School district lawyers claimed that because of the breakaway and resulting crash, "the flow of the Illinois River was impeded and altered such that floodwater flowed ashore, causing extensive flood damages to

the Marseilles Elementary School" [17].

In anticipation of damage suits, Ingram filed for protection in federal court in May (2013), asking it be freed from liability for the flood damage, or at least, be restricted to the value of the seven barges and towboat, or $4.2 million. Ingram Senior Vice President Dan Mechlenborg said the company does not believe it was responsible for the flooding of Marseilles and the school district. The record flooding could have resulted in Marseilles being flooded on or after April 18th and evacuation notices were issued before the Marseilles Dam accident occurred. The USACE is investigating to determine if all or part of the flooding was because of the seven barges slamming into the Marseilles Dam **(Figure 6)**.

3.6.1. Who is Going to Pay for Damages to Residences and Elementary School?

When the record high flood peak was predicted to occur on the evening of April 18, 2013, police began notifying and evacuating 1500 residents from low-lying sections of Marseilles **(Figure 5).** The floodwaters entered Marseilles and damaged hundreds of homes and the elementary school. Often 1/3 to 1 m of water entered the first floor of buildings and filled the basements. Long-time residents including some that had lived there for 45 to 65 years reported they had never experienced this kind of flooding before. Some residents were disabled and bedridden and had to be moved along with medical equipment and many lost everything in homes that were touched by floodwaters.

3.6.2. Damages to Marseilles Lock and Damage and Barge Removal by USACE

The three barges that were floating in front of the dam were removed within a few days of the accident. The partially sunken barges were removed by cranes **(Figure 8)** after the Marseilles pool was lowered for dam repairs. Salvage operations were led by Unified Command and continued for weeks after the barge accident. An additional crane was brought in on April 26th to offload cargo from the sunken barges. The removed cargo was placed in a receiver barge during the next two days. After enough of the cargo was unloaded the barges were refloated and removed.

USACE monitored the dam the first few weeks after the barge incident to determine if significant damage to the dam had occurred. If there was serious damage, it would have posed a threat to the structure and to safety of the public. Due to high river levels and interference by sunken barges, the most critical public safety damage is souring of riverbed [18]. Abnormal or accelerated scouring could undercut the dam's foundation and result in catastrophic failure at some future point in time. In early June of 2013, heavy rains in the local watershed resulted in rapid discharge of floodwaters through the four gates on the north side of the river and had the potential of accelerated scouring on the bottom of the riverbed and on the north side of the riverbank which is partially protected by a cement floodwall. The USACE spent much of the spring of 2013 assessing the dam safety. If failure of the dam were to occur, many commercial vessels, recreational craft and

river-based structures could be damaged by the receding pool. In addition, river structures below the dam could be impacted by debris. However, dam failure would not have caused widespread downstream flooding since the Marseilles Dam is not a flood control structure and does not retain water like a reservoir.

3.6.3. Lock and Dam Repairs

The USACE created a temporary rock dike dam (Figure 11) during the four weeks after the accident to permit repairs to the three most severely damaged gates. The temporary U-shaped dike downstream from the three gates included a series of culverts to hold or release water from the pond as needed, substituting for the controlled spillway effect under normal conditions. The temporary dike was able to hold enough water to elevate the navigation pool by late May 15th to restore boat traffic. However, another storm system in late May and early June (2013) flooded the watershed and raised the discharge rate through the four open gates and complicated the dam repair. The Marseilles Phase 1 repair costs are $10 million. The current cost estimate to complete Phase II repairs in the range of $30 to $50 million or total of $40 to $60 million. The money comes from the Emergency Response or Disaster funds available to USACE.

Figure 11. Temporary dike and pond created below the 3 damaged gates on the Marseilles Dam [2].

3.6.4. Shutting Down of Shipping and Boating on Illinois River as a Result of Flooding

In addition to developing and maintaining structures that protect agricultural, residential, and commercial lands along the Illinois River as well as the Ohio and Mississippi rivers, the USACE is also charged with maintaining a river channel of at least 91 m wide and 2.7 m in depth for river barge traffic [19]. The decision to lower the Marseilles pool for dam repairs resulted in suspension of all use of the

pool for shipping and travel. The northern stretch of Illinois River, a main artery for shipping bulk commodities to terminals at the Gulf of America (formerly the Gulf of Mexico) was affected. Both agricultural inputs, such as fertilizer and lime material, and outputs, including grain, are shipped using the Illinois River shipping channel. The torrential rains that moved through the upper Midwest in April and May of 2013 resulted in the Coast Guard declaring the Illinois River unnavigable and if anyone wanted to move something it required coast guard permission. A safety zone was created to protect salvage operations from being impeded by the vessel traffic above the damaged Marseilles Dam. The safety zone extended between the Marseilles lock and dam and Seneca, Illinois. An additional section between Alcon, IL and Brendon Road lock at Joliet remained closed for weeks due to high water and excessive river debris. USACE maintained a 2.7 m navigational channel between Marseilles and the Dresden dams between April 27th and May 7th (2013). Heavy rains in late May extended the shipping restrictions.

4. Conclusions

Smithers [7] noted "*In* 1833, *the Odaawaa, Ojibwe, and Bodéwadmi signed the second Treaty of Chicago, transferring the lands and waterways that stretched from Lake Michigan to Lake Winnebago. Anglo-American settlers swarmed into the region. And then the city emerged as a major center of the American manufacturing, meatpacking, and shipping. From a settler population of* 4,470 *in* 1840, *Chicago became the second largest city in the United States by* 1900 *with a population of a little under* 1.7 *million. Chicago's rapid growth placed enormous strain on the region's natural resources. For over a millennia Native people had cared for the land and waterways of the Great Lakes in a system that preserved both the people and the waters. Spiritual traditions and scientific knowledge taught Indigenous people not to foul the waters one drank from, or to pollute with human excreta the rivers in which community members bathed. Instead, Native people constructed refuse pits and latrines to ensure the purity of Lake Michigan's waters.*"

"*They also faced several geographical and topographical challenges to changing their waste management. Most obviously, the city was built on thick clayey soil, a monotonously flat topography, and uncooperative river currents. As Chicago's population grew, local rivers and streams filled with human feces, while lakes abounded with the rotting carcasses of dead animals. Devastating cholera, typhoid, and diarrhea outbreaks were the result.*" [7].

This paper examined policy issues, the interaction of governmental units, and economic, geographical and technological constraints that accompanied the haphazard attempts to resolve the problem of sewage pollution control in the Chicago metropolitan area [20]. The focus was on activities of the Sanitary District of Chicago from its creation in 1889 until the issuance of a significant Supreme Court decree in 1930 [21]. Chicago had the same basic sewage disposal problem as any city located on a freshwater lake, how to dispose of its waste without contaminating it water supply [10]. Fortunately, Chicago was located near a very low point

on the continental drainage divide between the Great Lakes watershed and the Mississippi River watershed [22].

The Illinois Waterway continues to be an essential transportation corridor for moving goods across the continental drainage divide and from the Great Lakes to St. Louis, Missouri and the Port of New Orleans [23]. Chicago River reversal, unpredictable weather and extreme rain events can cause had to control flooding and river currents which can damage river vessels, waterway control structures and communities which lie along the river. Damage to the Marseilles Dam when seven unsecured Ingram barges crashed into the dam and damaged the Tainter gates affected navigation and put at-risk the adjacent community [24]. The USACE is still assessing whether the barge accident caused or enhanced the flooding in Marseilles and damaged the Elementary School and the local residences. Many federal, state and private relief agencies responded to help assess and cleanup the damage from flooding and USACE began repairing the damaged Marseilles Dam structure in summer of 2013. This was done to open the shipping channel which is one of the most used in the nation.

This review was an attempt to learn from a historical Chicago lesson and provide recommendations for cities attempting to provide safe drinking water for their residents and to reduce the environmental and human health impacts of their waste disposal. In some cases, the waste can be moved across a drainage divide to separate it from the drinking water supply source.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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