Quantifying Change in Channel Areas Following Impoundment Within Navigation Pool 5, Upper Mississippi River

Kristin Moe
Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, MN, 55987

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Abstract

The changes in channel areas induced by impoundment of Navigation Pool 5 of the Upper Mississippi River are widely recognized. This study seeks to describe and quantify channel activity, determining effects on the pool following impoundment. Three study periods are introduced in which changes in channel areas are described. Lateral channel migration proved to be a minimal factor in the study. Migrations rates varied between 1.06 and 1.89 m/year and may not be accurate for the first period of study. In the period from 1890 to 1975, water areas increased by 269% throughout the pool. Such a tremendous increase can largely be attributed to dam closure. This period was followed by a time of noticeable channel abandonment. Backwater areas in the upper pool began filling in with sediment. The final period, 1989 to 2000, indicated a trend toward channel stabilization. Rates of channel creation were nearly equal to those of channel abandonment.

Introduction

According to the National Inventory of Dams, there are over 79,000 large dams in the United States. Twenty-nine are lock and dam systems that operate on the Mississippi River. Dams provide numerous benefits including flood control, navigation, and recreation opportunities. The impoundment of a river system by a dam can significantly alter fluvial processes (Wang et al., 2007; Studley, n.d.). Major changes occur with decreased sediment load (Juracek, 1999) and alteration of the system's flow regime (Magilligan and Nislow, 2004; Garcia de Jalón et al., n.d.).

Changes in flow regime ultimately influence the rate of channel activity in the form of avulsion or migration (Wellmeyer et al., 2004; Grams and Schmidt, 2001). Raised pool elevation levels (Grubaugh and Anderson, 1988) and increased surface areas (Chen and Simons, 1986) are common among navigation pools of the Upper Mississippi River following impoundment. Understanding the changes and trends that have occurred since impoundment can help land managers and river engineers to better plan for the future.

Navigation Pool 5 of the Upper

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Mississippi River is currently under regulation by the operation of a lock and dam system. Since impoundment in 1935, acres of habitat have been lost and replaced by open water. Government agencies have attempted to rectify this problem by building islands and constructing closures to limit water action in certain backwaters and restore the areas to pre-dam conditions (U.S. Army Corps of Engineers, 1986).

The purpose of this study was to quantify changes in water areas or channels over periods of time using a geographic information system (GIS). The results were analyzed in conjunction with available discharge, precipitation, and pool elevation records in order to explore and offer possible explanations for any alarming shifts in water areas and channel migration trends.

The objectives of this study were to:

- Calculate rates of main channel migration
- Quantify rates of channel creation and abandonment
- Examine stability within the pool

Methods

Study Area

The study area is 15,706 acres within Navigation Pool 5 of the Mississippi River. The pool is bound to the north by Lock and Dam 4 at Alma, Wisconsin and to the south by Lock and Dam 5 at Minnesota City, Minnesota. Both lock and dams were constructed and put into operation in May of 1935. The pool spans 14.7 river miles from Lock and Dam 4 to Lock and Dam 5 and has a drainage area of 58,845 square miles. Pool 5 consists of a main and secondary channel and acres of backwater areas (Figure 1).

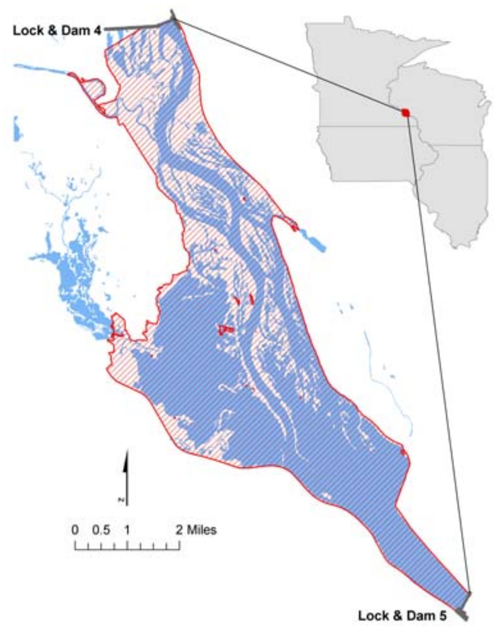

Figure 1. Location of Navigation Pool 5 Study Area.

Data

Four individual years of Land Cover and Land Cover/Use files were available for the entire study area: 1890, 1975, 1989, and 2000. These land classification files were obtained from the Upper Midwest Environmental Sciences Center on-line data library.

The 2000 Land Cover coverage was created by the Long Term Resource Monitoring Program. The dataset was automated from 1:24,000-scale color infrared aerial photos collected in 2000. Photo interpretation was performed using a 1-hectare minimum mapping unit. A stereoscope was used to transfer data from photo overlays to 1-meter ground resolution DOQ basemaps. The resultant product was then fed into a large format scanner (400 dpi) and digitized using ArcInfo.

The 1989 Land Cover/Use coverage was also created by the Long Term Resource Monitoring Program. The dataset was automated from 1:15,000-scale color infrared aerial photos collected in 1989 and photo-interpreted using a 0.1-acre minimum mapping unit. The aerial photo overlays were transferred to 1:15,000-scale mylar overlays that were registered to 7.5' USGS quadrangles. Transferred data was then converted to coverages using ArcInfo or a digitizing table (absolute accuracy 0.001 inch up to +/- 0.003 inch), or scanned and automated using ArcInfo's ArcScan.

The 1975 Land Cover/Use coverage was created by the Upper Midwest Environmental Sciences Center and the Great River Environmental Action Team I. The dataset was automated from 1:9,600-scale color infrared aerial photos collected in 1975. A minimum mapping unit of less than half an acre was used to delineate any features seen in the photos. The photo overlays were transferred onto 1:24,000-scale USGS quadrangles and automated using a GIS program. During this process the data was generalized to a 2.5 acres minimum mapping unit in accordance with guidelines established for the GREAT projects.

The 1890 Land Cover/Use coverage was created by the Mississippi River Commission and the Upper Midwest Environmental Sciences Center. The dataset was automated from late 1880's and early 1900's high-resolution survey maps created by the Mississippi River Commission. Mylar overlays were used to delineate boundaries from the commission maps. The information was then automated using ArcInfo and digitizing tables (absolute accuracy 0.001 inch up to +/- 0.003 inch).

Pool elevation data and daily discharge data used to construct an average annual discharge chart were obtained from the U.S. Army Corps of Engineers St. Paul District Water Control website. The Lock and Dam 5 gauging station is located at River Mile 738.1 above the Ohio River. The gauging station has been in operation since 1960 and has a near complete record of daily and peak flows.

Daily precipitation data were obtained from the NOAA National Climatic Data Center website. Cooperative Observer Network (COOP) station 470124 is located at Lock and Dam 4. COOP station 215488 is located at Lock and Dam 5. Both stations have been in operation since January 1, 1948. Precipitation data since 1960 has been used to construct an average annual precipitation chart for Pool 5 for comparison with discharge measurements and pool elevation.

Environmental Systems Research Institute (ESRI) software was used for this project. ESRI's ArcMap, ArcCatalog, Geoprocessing tools, and Spatial Analyst were utilized throughout the analysis.

Planform channel changes and the derived rates were obtained by comparing the four years, or 3 intervals, of the Land Cover and Land Cover/Use datasets. For each of the four years, areas of open water were merged and classified as water while all other values were merged and classified as land.

Channel activity was assessed using two methods. The first method considered the percentage of channel area occupying the same location between consecutive years of available data. To obtain this measure, the open water polygons were converted from vector to raster formats. The output cell size was 1 square meter. The cells of the raster sets were then assigned a unique number based on their classification as either land or water (Table 1).

Table 1. Code assigned to raster cells based on year and land classification of the cell.

YEAR	CLASS	CODE
1890	Land	1
	Water	2
1975	Land	3
	Water	4
1989	Land	5
	Water	6
2000	Land	7
	Water	8

The area of channel abandonment and channel creation were derived in a raster analysis. Raster sets for consecutive years of data were overlain and the corresponding cell values multiplied using Spatial Analyst's Raster Calculator. The result was four possible cell values for each interval or twelve values total. Depending on the value of the cell, four possible classifications were possible and are listed below.

- Channel occupied by land in consecutive years
- Channel occupied by water in consecutive years
- Channel abandoned
- Channel created

Channel abandonment area is calculated according to the number of cells containing water occupied only during the older dataset of the interval. This number is then converted to ground units to represent area. The area of channel creation is computed in the same manner except based on the number of cells containing water occupied only during the most recent dataset in the interval. Similar raster-based analysis was used by Downward et al. (1994), Leys and Werritty (1999), and Wellmeyer et al. (2004).

Channel centerlines were defined from the open water polygons of each dataset. For this portion of the analysis the main channel was used to measure stability in areas of high velocity flow. The attributes of the 1890 dataset identified the main channel. A query was performed to first select the main channel and then export those features to a new vector polygon layer. The features were then merged to form a single polygon. The same process was followed for the 1975 dataset.

The 1989 dataset did not identify the main channel in the attribute table. Sections of the main channel were selected individually and the features were exported to a new vector polygon layer. The features were then merged to form a single polygon. The same process was used to create a main channel polygon layer for the 2000 dataset (Figure 2).

Thiessen polygons were generated for each main channel polygon. From the Thiessen polygons a main channel centerline was derived (Figure 3). The length of the individual centerlines were computed and stored in each layer's attribute table.

The centerlines from consecutive time periods were superimposed to form a new single layer for each of the three intervals. The new layer was then converted from a line to a polygon layer.

To calculate total area of active migration, the area of each polygon was computed and stored in the layer's attribute table. The area was divided by the length of the main channel centerline from the earlier period in the interval. The resulting number was the linear measure of lateral migration (Table 2).

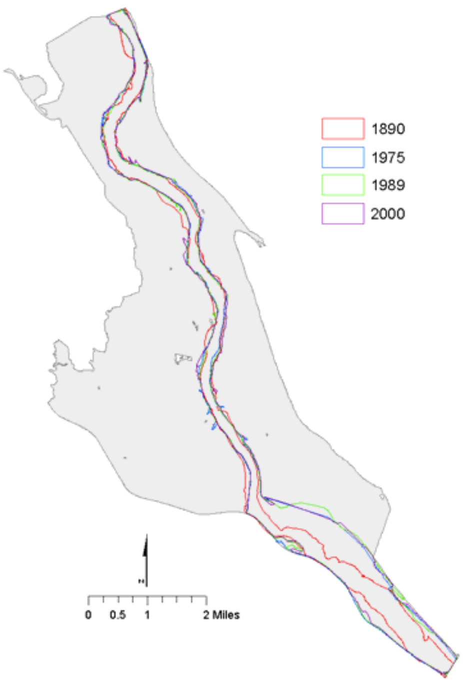

Figure 2. Channel locations by year.

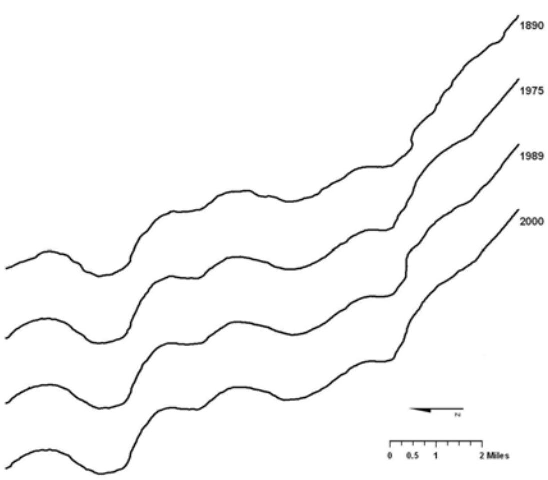

Figure 3. Sequential channel centerlines of each of the 4 years of data.

Results

Discharge, Precipitation, and Pool Elevation

Mean annual discharge for the Lock and Dam 5 gauging station are variable and years of above normal discharge are generally followed by proportional years of below normal discharge (Figure 4). Above normal precipitation totals normally do not affect average annual discharge (Figure 5). However, pool elevations (Figure 6) were elevated to flood stage during extreme precipitation events.

Table 2. The number of years in period, area of active migration, length of earlier centerline, and resulting rate of migration for each period of study. Lateral migrations rates for the period from 1890-1975 are not considered significant due to the impoundment of the river during this time.

Period	# of Years	Area (sq. meters)	Length (m)	Rate of Migration (m/yr)
1890-1975	85	2,083,854.28	23,141.96	1.06
1975-1989	14	612,234.99	23,125.66	1.89
1989-2000	11	444,454.77	23,153.68	1.75

Channel Planform Change

Period from 1890 to 1975

During the first period of study, 1890-1975, there was a great deal of change within the pool (Figure 7). As expected, after dam closure in 1935, the pool became inundated with water. Backwater areas that were once forests, marshes, and grasslands were flooded with waters deep enough to inhibit the growth of plant life.

Typical of Mississippi River pools following impoundment, the lower portion of Pool 5 was most affected by dam closure. The lower half of the pool was comprised of nearly all open water. The wide expanse of water extended north to meet the main channel and west to Weaver Bottoms.

Channel creation occurred over 3,302.4 hectares of Pool 5. Increased areas of channel reflect the raising of the pool elevation to accommodate navigation. In comparison, channel abandonment was significantly lower (210.3 hectares) and consisted mainly of downstream accretion at inner bends of the main channel. In general, water velocities at such locations are typically lower. One may speculate that lower velocities caused sediment and other materials to be deposited along the inner bends of the channels throughout Pool 5.

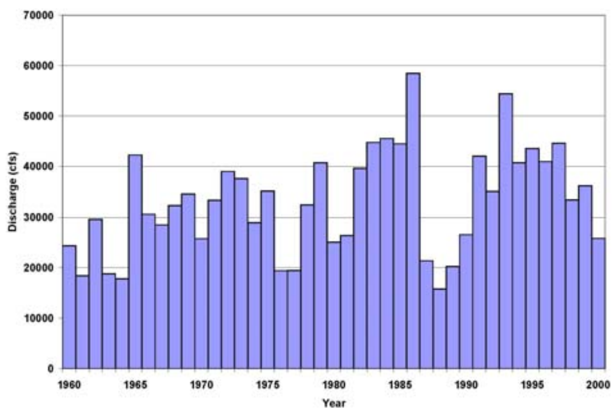

Figure 4. Mean annual discharge at Lock and Dam 5, 1960-2000.

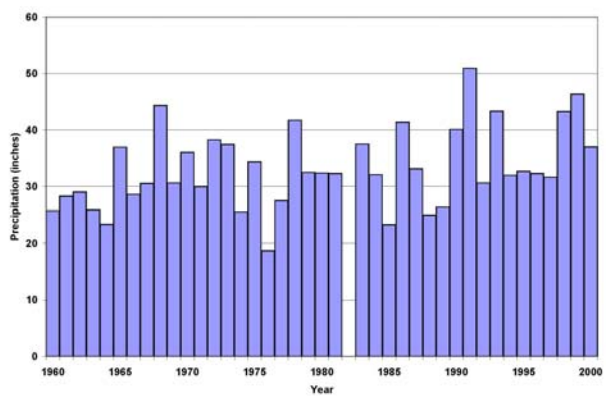

Figure 5. Mean annual precipitation for Navigation Pool 5, 1960-2000; complete 1982 data is unavailable and has been omitted.

The lateral channel migration rate over the 85 year period was 1.06 m/year. However, due to the spontaneous inundation of the pool during this period of study, the rate will not be considered in this analysis.

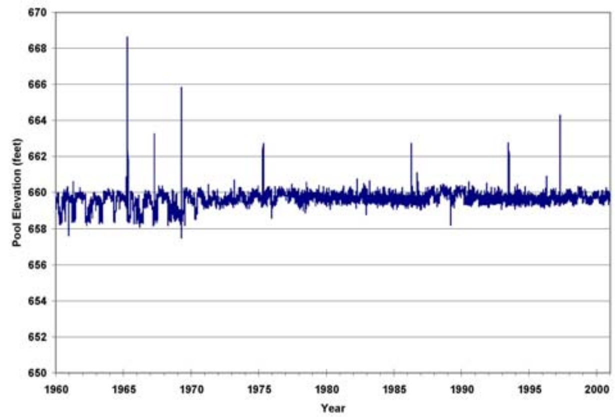

Figure 6. Pool elevation by year of record.

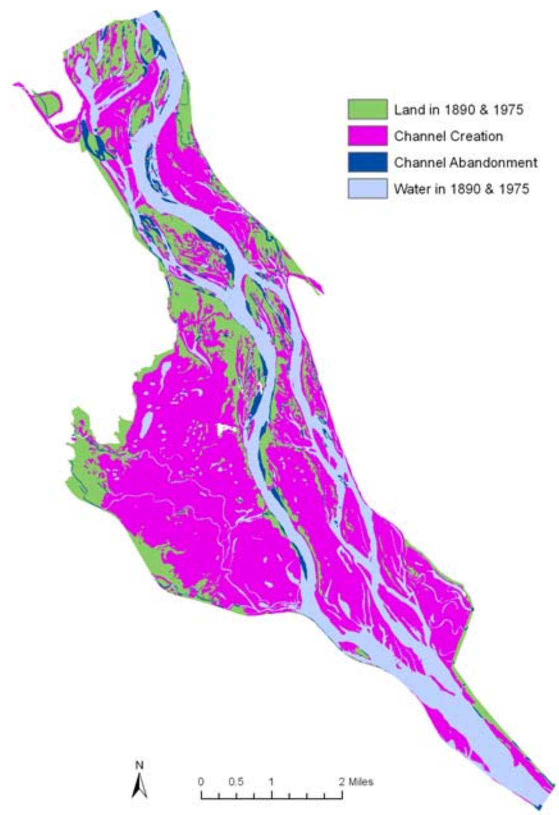

Figure 7. Changes in channel area from 1890 to 1975.

Pool elevations fluctuated a great deal in the period of record from 1960-1975. High flow events were recorded in 1952, 1965, 1967, and 1969. In 1952, lower pool levels were raised to 664.6 feet above sea level from a normal pool elevation of 651.0 feet. A flood in 1965 raised lower pool elevation to 669.0 feet above sea level. Levels were raised to 669.4 feet in 1967 and to 666.1 feet in 1969. Although impoundment is most likely the cause of the high rate of channel creation, these flood events cannot completely be ruled out as a contributor.

Concerns for this period of study are incomplete discharge and precipitation data. Comprehensive precipitation and discharge records are available beginning in 1960. This leaves 70 of the 85 years from this period with no supporting data of this kind.

Another concern is the lack of pre-dam data for comparison. The 1890 dataset was the only dataset available documenting pre-dam conditions for the study area. Therefore, although one can make assumptions concerning the stability of the channel, there are no statistics to assess the previously mentioned calculations against historic figures.

Period from 1975-1989

The period from 1975 to 1989 was the first span documenting Pool 5 following the closure of Lock and Dam 5. Precipitation totals were average and there were no high water events on record. Discharge is low compared with the data available for the previous period. Eight of the fourteen years report discharge levels well below the average.

The area of channel creation during this period (238.2 hectares) was much lower than in the previous period. Newly created channel areas were present along outer bends of the main channel where high velocity flows or wave action formed by boats may have played a factor through erosion. Weaver Bottoms also had a significant amount of newly created channel area along its western shoreline. Although there may be many causes of the created channel areas, shoreline erosion is a natural process of an alluvial river system and there is no evidence of any major events that may have impacted the areas of erosion.

Surprisingly, the areas of channel abandonment increased during this period (772.6 hectares). The most significant abandonment was in the upper portion of the pool below Lock and Dam 4. Channel abandonment was primarily isolated to backwaters where one may speculate that flow velocities were not sufficient to carry large amounts of sediment. Abandonment was present west of the main channel in and around the Finger Lakes area as well as east of the main channel. Less significant amounts of channel abandonment occurred in the backwaters of the lower pool.

Mallard Island and Swan Island were built in Weaver Bottoms by the U.S. Army Corps of Engineers as part of an on-going habitat restoration project (Figure 8). Together, the islands account for 13.7 of the 772.6 hectares of abandoned channel area.

Lateral channel migration occurred at a rate of 1.89 m/year. This rate is generally low compared with the rates of other impounded alluvial rivers during similar time periods (Wellmeyer et al., 2004). Visible areas of migration can be seen in the upper portion of the pool. As previously mentioned, there was a considerable amount of channel abandonment in the upper pool during this time period. This may be one possible factor in the migration of the channel.

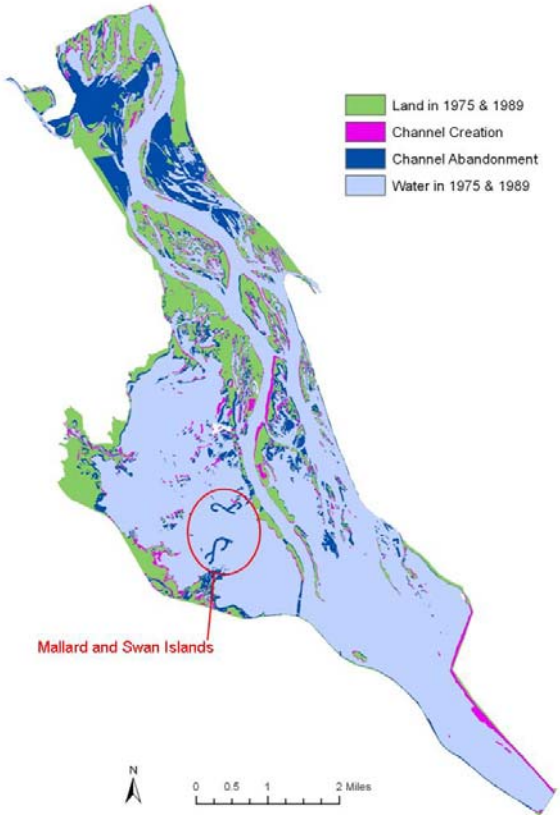

Figure 8. Changes in channel areas from 1975 to 1989, Mallard and Swan Islands were built during this period.

Period from 1989-2000

The final period, 1989 to 2000, may show a trend towards stabilization of the channel. Average annual precipitation yields were at or above normal levels for eight of the eleven years in the study period so this may make results difficult to interpret. Historic high water levels occurred in 1993, 1997, and 2000. Pool elevations during these events were raised from 651.0 feet above sea level to 662.8 in 1993, 666.2 in 1997, and 666.6 in 2003.

High water does not necessarily correlate to high average annual precipitation but rather can be attributed to single flooding events. The most significant event occurred in the summer of 1993 when precipitation, discharge, and water levels were unusually elevated and widespread flooding occurred throughout the Upper Mississippi Valley and among its tributaries.

Areas of channel creation (317.0 hectares) increased somewhat following the previous period. Evidence of this was widespread and mainly located in the backwaters of the pool as well as along the shorelines of a few large islands (Figure 9). The extreme precipitation and flooding events most likely caused some major erosion along shorelines. A number of small islands were washed away completely. This is especially true of small islands in Weaver Bottoms and the Spring Lake area.

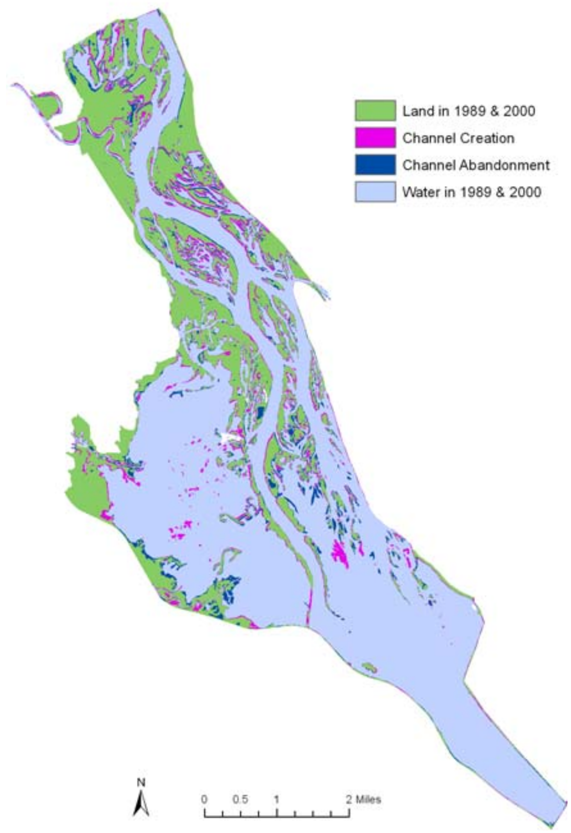

Figure 9. Changes in channel areas from 1989 to 2000.

The area of channel abandonment decreased drastically (259.4 hectares) during this period. Sediment was deposited along the inner bends of the main channel but also in the backwaters. One possible explanation is that sediment may have been sloughed off during times of extreme precipitation or flow and then re-deposited further down the pool as elevations and flow dropped.

Lateral channel migration lessened to some extent during this period (1.75 m/year) but this is not a significant indicator of channel stability. Visible migration was not connected to any considerable areas of channel creation or abandonment.

Discussion

On Navigation Pool 5 of the Mississippi River, channel areas have undoubtedly been altered drastically by the implementation of a lock and dam system. This system, in combination with wing dam construction and dredging activities along the main channel during pre- and post-impoundment periods, has transformed the area from a winding multi-channeled river to a large expansive pool.

Lateral channel migration rates for the first period of study, 1890-1975, are not thought to be accurate given that impoundment occurred during this time period and the pool underwent spontaneous change. For this study, migration rates are not a significant indicator of channel stability but rather provide a quantitative measure of channel activity over time (Figure 10). The amount of time covered in this study is not sufficient to determine channel stability using this technique. The period from 1975-1989 may serve as a baseline for post-impoundment conditions in the future.

Varying areas of channel creation following the period of impoundment may suggest that the channel has been undergoing a transition. Following the inundation of the pool, open water areas increased by 269% (Figure 11). Backwater areas were most affected as water entered previously vegetated areas and created riverine lakes as seen in the lower pool.

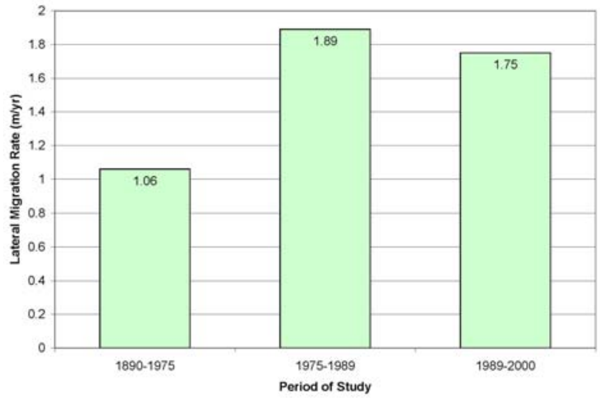

Figure 10. Rates of lateral channel migration for each period of study.

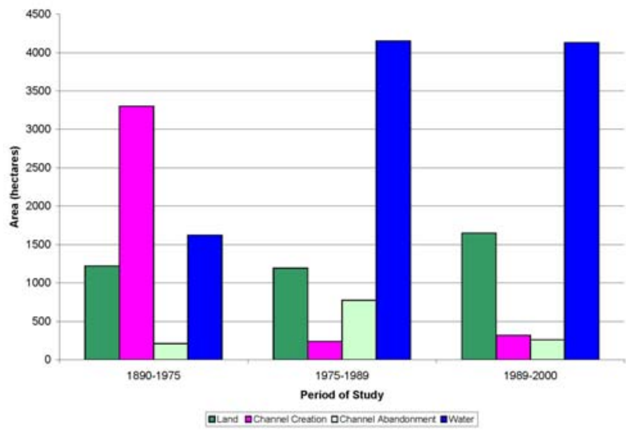

Figure 11. Total areas of consistent land, channel creation, channel abandonment, and consistent water for each period of study.

Pool 5 continued to undergo a great deal of change during the period from 1975 to 1989. In fact, some adjustments were made as the total area of channel abandonment was much higher than that of channel creation. Impoundment may have altered the sediment regime of the entire pool. As sediment-free water was released from Lock and Dam 4, scouring likely occurred beneath the dam and carried sediments into the backwaters as high-velocity flows traveled down the main channel. Evidence of this process may exist in the extreme northern end of the pool in areas that were considered open water during the previous period of study.

The final period, 1989 to 2000, may be interpreted as showing a trend towards stabilization. The total area of channel creation paralleled that of channel abandonment. Normal alluvial processes may explain the widespread transference of sediment throughout the pool. Extreme weather events or raised pool elevations during this time could also account for the disappearance of small islands and island chains in the lower pool.

Overall, Navigation Pool 5 appears to be adjusting to impoundment. The expected result of dam operations was seen as water levels were raised and the pool was inundated. Such inundation undoubtedly changed the habitat and ecosystem of the pool forever and can be seen in the loss of acres of land and vegetation. Some advancement has been made through natural processes as the upper pool is re-building land previously lost. Recent man-made attempts at rehabilitating the pool have been seen in the form of island-building in Weaver Bottoms and Spring Lake.

The theories that have been offered as possible explanations for documented pool changes are based on assumptions. It is known that impoundment led to drastic changes within the pool. However, many assumptions have been made to explain the changes in channel areas following the upset of initial impoundment. For example, this paper assumes that normal alluvial processes are still occurring in Pool 5. In fact, this argument could be made to explain all changes in channel areas following the raising of the pool by impoundment with the exception of man-made islands.

A second assumption may be that extreme weather events have an impact on the pool by raising water levels, contributing to erosion, and disrupting flow. This could also be a strong argument for change given the multitude of precipitation events that have occurred over the entire study period.

A third assumption is that human activities are disturbing the pool through dredging operations, artificial maintenance of pool levels, and even recreational boating.

It is unlikely that any one factor is responsible for the changes that have taken place in Pool 5. More probable is that all of the aforementioned factors, as well as others not discussed, have played a role in the transformation of Navigation Pool 5 since 1890.

Data Limitations

The data used for this project may have some discrepancies caused by inaccuracy of the available coverages. The datasets were created using different methods and minimum mapping scales. Therefore generalizations and thus accuracy of the data varies from coverage to coverage. This may have caused certain land areas to be classified as water when in fact they were land and vice versa.

The ‘Open Water’ classification was used for this study. All datasets contained this classification but due to the classification methods of the organizations involved, there may be some inconsistencies.

Certain portions of Navigation Pool 5 were eliminated from the study area due to lack of data for the year 1975.

Precipitation and discharge data was not available for the entire study period. Conclusions were not made based on this data but instead the data was made to complement analysis during periods for which it was available.

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References

Chen, Y.H. and Simons, D.B. 1986. Hydrology, Hydraulics, and Geomorphology of the Upper Mississippi River System. *Hydrobiologia*, *136*, 5-20.

Downward, S.R., Gurnell, A.M., and Brookes, A. 1994. A Methodology for Quantifying River Channel Planform Change Using GIS. Retrieved October 8, 2007 from EBSCOhost database.

Garcia de Jalón, D., Kondolf, G.M., Miller, P., & Vizcaíno, P. n.d. Changes in Channel Morphology and Floodplain in Clear Creek, California, in Response to Dam Constructions. Retrieved November 20, 2005 from http://www.montes.upm.es/Dptos/DptoIngForestal/Hidrobiolog%C3%ADa/Publicaciones/Changes%20in%20Channel%20Morphology%20ProcsEcohydraulics-VOL%20I%20362-366.pdf

Grams, P.E., & Schmidt, J.C. 2001. Streamflow Regulation and Multi-level Flood Plain Formation: Channel Narrowing on the Aggrading Green River in the Eastern Uinta Mountains, Colorado and Utah. *Geomorphology, 44,* 337-360. Retrieved November 21, 2005 from EBSCOhost database.

Grubaugh, J.W. and Anderson, R.V. 1988. Spatial and Temporal Availability of Floodplain Habitat; Long-term changes at Pool 19, Mississippi River. *American Midland Naturalis, 119*, 402-411.

Juracek, K.E. 1999. Channel Stability of the Neosho River Downstream from John Redmond Dam, Kansas. U.S. Geological Survey. Retrieved November 20, 2005 from http://kswater.usgs.gov/Kansas/pubs/fact_sheets/fs.088-99.pdf/

Leys, K.F. and Werritty, A. 1999. River Channel Planform Change: Software for Historical Analysis. G*eomorphology, 29,* 107-120. Retrieved October 2, 2007 from EBSCOhost database.

Magilligan, F. and Nislow, K. 2004. Changes in Hydrologic Regime by Dams. *Geomorphology, 71*, 61-78. Retrieved October 15, 2005 from EBSCOhost database.

Studley, S.E. n.d. Changes in High-Flow Frequency and Channel Geometry of the Neosho River Downstream from John Redmond Dam, Southeastern Kansas. U.S. Geological Survey. Retrieved November 25, 2005 from http://ks.water.usgs.gov/Kansas/pubs/reports/wrir.96-4243.html.

U.S. Army Corps of Engineers. 1986. Supporting Documents for Lower Pool 5 Channel Maintenance/Weaver

Bottoms Rehabilitation Plan on the Upper Mississippi River. Retrieved October 9, 2007 from http://stinet.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA170159

Wang, Z., Wu, B., and Wang, Z.. 2007. Fluvial Processes and Morphological Response in the Yellow and Weihe Rivers to Closure and Operation of Sanmenxia Dam. *Geomorphology*, *91*, 65-79. Retrieved October 9, 2007 from EBSCOhost database.

Wellmeyer, J.L., Slattery, M.C., and Phillips, J.D. 2004. Quantifying Downstream Impacts of Impoundment on Flow Regime and Channel Planform, Lower Trinity River, Texas. *Geomorphology*, *69*, 1-13. Retrieved November 21, 2005 from EBSCOhost database.