Long-Term Effects of Dredging Operations in the Lower Mississippi River

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Abstract

Dredging of the Mississippi River to maintain navigation is an important, ongoing effort which requires significant resource allocation each year. The objective of this effort was to assess the feasibility of using a one-dimensional numerical sedimentation model (HEC-6T) to test the effectiveness and efficiency of alternative dredging approaches to optimize the nation's resource allocation. The HEC-6T model used for this work had been calibrated and externally reviewed in previous studies. Currently, in the Lower Mississippi River above Venice, Louisiana, dredged material is returned back into the channel downstream from the dredging site. This study assessed the impact of removing the dredged material from the channel and disposing of it onto the overbank or over the levees. Over the 50-year simulation period it was determined that dredging quantities could be reduced by about 50 percent. These results suggest that targeting overbank disposal at a few key locations could optimize the dredging impacts. The model was also used to assess the effects that wet and dry hydrologic cycles could have of dredging requirements.

Introduction

Dredging is required to maintain an adequate navigation channel along the Mississippi River. This USACE mission is both necessary and expensive. A research project was conducted to assess the effectiveness and efficiency of alternative dredging approaches in an attempt to optimize resource allocations. The study approach was to utilize a validated and externally reviewed one-dimensional HEC-6T model that was developed for the Mississippi River and Tributaries Flowline Project.

The USACE developed a HEC-6T numerical model of the Mississippi River between East Jetty, at the end of Southwest Pass, and Cairo, Illinois, at the confluence of the Ohio River, to determine the effect of sedimentation on maximum water surface elevations 50 years into the future. The model included dredging activity for the lower portion of the river, below Venice, Louisiana, but it did not include the impacts of dredging activities further upstream. Dredging in the upstream reaches was considered to have a relatively minor influence on long-term sedimentation because dredged materials in upstream reaches are typically removed from the bed and pumped back into the flowing water downstream of the dredging site, a technique referred to as “in-channel disposal”.

The HEC-6T numerical model contains several dredging algorithms that are useful to evaluate alternative dredging operations. One option that can be evaluated is the location of dredge material disposal. Disposal location options include 1) back into the river immediately downstream at the next cross section, 2) back into the river downstream from the specific dredging site, 3) into a permanent holding site on the overbank, or 4) complete removal from the system. Another option that can be evaluated is timing of dredging operations with respect to the rise and fall of the annual hydrograph and the effects of high or low periods of annual runoff. This paper discusses how these dredging approaches were analyzed.

Methodology

The HEC-6T one-dimensional numerical model of the Mississippi River developed to determine the long-term effects of sedimentation on project flood water-surface elevations was used as a starting point for this study. That model had been calibrated using 1991-2013 geometry changes, water-surface elevations and hydrographs.

For this study, annual dredging operations were added at several sites and the numerical model dredging parameters were adjusted to reproduce reported dredging volumes, over the 23-year period between 1991 and 2013. It is recognized that actual dredging operations are subject to several constraints not necessarily simulated in the numerical model. These may include availability of dredges, dredging site priorities, and available funding among others. It is also recognized that uncertainty is associated with reported dredging quantities as with all field data. For purposes of this study, simulation of the actual dredging dates and dredging capacities was not attempted. Dredging volumes calculated in this study should be considered approximate. It was determined during the course of model calibration that detailed modeling would be required to obtain accurate dredging volumes at individual sites. This detailed modeling effort is beyond the scope of this research effort, which is intended to provide relative effects of dredging activities on a system-wide basis.

One of the most significant challenges associated with the dredging simulation was a lack of adequate channel geometry data. This was especially apparent for dredging sites where dikes had been constructed. In some cases, as-built top-of-dike elevations were not available. In all cases, existing top-of-dike elevations were unknown so that dike degradation could not be definitively simulated. There is also uncertainty associated with the actual dredging depth, the timing of dredging, and the capacity of the dredges involved.

In addition to Southwest Pass and upstream of Head of Passes to Venice, fifteen existing dredging sites were included in the numerical model, which were designated the most dredged sites for each district. Of these fifteen, eleven were located in the deep draft navigation channel between New Orleans and Baton Rouge.

Calibration to Reported Dredging Volumes

The HEC-6T numerical model used in this study had been previously calibrated to measured water-surface elevations, specific gage records, measured sediment transport at intermediate gages and dredging in Southwest Pass and between Head of Passes and Venice. The calibration is documented in multiple reports: Copeland and Thomas, 1992; Copeland et al., 2010; and Copeland, 2018. Water surface elevation calibration was accomplished by varying Manning's roughness coefficients with discharge. This was done for the initial hydrographic survey geometry. The model was then run for a 23-year calibration period and calculated water-surface elevations at the end of the calibration period were again compared to measured stages to evaluate the model's ability to predict specific gage changes. Intermediate gages at Union Point, Tarbert Landing, and Belle Chasse were used to evaluate the ability of the model to transport the appropriate volume of each size class through the study reach. Dredging records in Southwest Pass and between Head of Passes and Venice were used to evaluate the ability of the model to correctly account for sediment deposition in the lower reaches of the river where significant distributary flow reduces the sediment transport capacity. For this study the model was additionally calibrated to reported dredging volumes. Upstream from New Orleans, reported annual dredging volumes were available for the period 1991-2013 for the dredging sites used in this study. At and below New Orleans, dredging records were available for 1996-2013. The reported dredging volumes in Southwest Pass and between Head of Passes and Venice were combined in the available reported data. In addition, the reported dredging volumes for Southwest Pass included dredging downstream from the numerical model boundary. Consequently, reported dredging records downstream from Venice could not be used in the calibration study. Calibration parameters for fine sediment properties from previous model studies were therefore used for this study.

In the numerical model, dredging was simulated at the beginning of each year between 1991 and 2013. A dredging depth and advanced maintenance depth was specified at each dredging site. Except in reaches below Venice, dredged material was re-introduced back into the water column at the next downstream cross section, to represent the in-channel disposal method. This handling of the dredged material proved to be significant at dredging sites with more than one cross section. For calibration of the dredging volume, multiple options were used, which include:

1) Distance between dredged cross sections and cross sections upstream and downstream from the dredging reach - The numerical model calculates dredging volumes using a length equal to half the distance between cross sections (as opposed to the fixed-end method). Cross sections were added to the numerical model to achieve a better representation of dredging site lengths at several dredging sites.
2) Depth and width of the dredging template - These parameters naturally affect the calculated dredging volumes. Survey data, especially in the New Orleans District below Baton Rouge, were used to estimate reasonable limits within which these variables could be used as calibration parameters.
3) Width of movable bed - The movable bed width can be set equal to the dredging template width or it can extend beyond the limits of the dredging template in the numerical model. In most cases, the movable bed was confined to the dredging template. This

assignment precludes long-term deposition at the dredging site and assumes that the dredging operation will maintain a relatively constant cross-sectional area. The option to allow deposition outside the dredging template was only used in cases where the calculated dredging exceeded reported dredging.

4) Number of dredging cycles each year - The numerical model dredges cross-sections in the dredging reach to the designated dredging template at the beginning of each calendar year. In the model this occurs "instantaneously" i.e. during the first day. In cases where the dredging site consists of one cross-section or where dredging volumes are minimal, one dredging cycle per year is sufficient. However, in cases where there are more than one cross section and dredged material from an upstream cross section deposits in a downstream cross section, then more than one dredging cycle may be required to obtain appropriate dredging volumes.
5) Dredging capacity – not used in this study as a calibration parameter. Dredging capacity of 100,000 cubic yards per day was assigned to the Southwest Pass and Head of Passes dredging sites, which is consistent with previous studies.

Calibration parameters at each dredging site are shown in Table 1. Results of the calibration study are shown in Table 2 and Figure 1.

Table 1. Calibration Parameters used in Dredging Simulations

SITE	Model Cross Sections River Mile	Number of Cross-Sections	Dredging Template Elevation FT NGVD 29	Advance Maintenance FT	Number of cycles per year	Movable-Bed Width = Dredging Width
Southwest Pass	-18.0 to -0.01	14	-55 to -60	3	2	Yes
Head of Passes	0.72 - 5.5	6	-50	3	2	Yes
New Orleans Harbor	100.2	1	-45	3	1	No
Belmont	153.1 - 153.4	4	-45.5	3	8	Yes
Smoke Bend	175	1	-46	3	1	Yes
Philadelphia	183	1	-45	3	1	Yes
Alhambra	189.5 - 189.8	2	-45	3	90	Yes
Bayou Goula	197.9 - 198.2	2	-45	3	60	Yes
Granada	203.6 - 204.1	2	-45	3	60	Yes
Medora	211.6 - 212	2	-42	3	1	No
Sardine Point	218.9	1	-45	3	1	No
Red Eye	223.5 - 224.4	3	-45	3	80	Yes
Baton Rouge US	230.4 - 232.7	4	-44.5	3	1	Yes
Westover	652.5	1	107	2	1	No
Finley Bar	704.08	1	147	1	1	No
Redman Bar	740 - 741	2	160	3	1	No
Kate Aubrey	788.13	1	186	3	1	Yes

Table 2. Reported and Calculated Dredging between 1991 and 2013.

SITE	Model Cross Sections River Mile	Reported 1991-2013 Million Cubic Yards	Calculated 1991-2013 Million Cubic Yards
New Orleans Harbor	100.2	19.3	22.1
Belmont	153.1 - 153.4	52.1	53.0
Smoke Bend	175	11.2	11.3
Philadelphia	183	5.1	5.8
Alhambra	189.5 - 189.75	58.4	59.9
Bayou Goula	197.9 - 198.2	25.6	25.8
Granada	203.6 - 204.1	28.0	25.6
Medora	211.6 - 212	29.2	30.3
Sardine Point	218.9	23.2	21.4
Red Eye	223.5 - 224.4	114.7	114.3
Baton Rouge US	230.4 - 232.7	37.1	37.0
Westover	652.5	15.1	16.9
Finley Bar	704.08	14.4	14.9
Redman Bar	740 - 741	22.0	19.2
Kate Aubrey	788.13	9.8	9.5

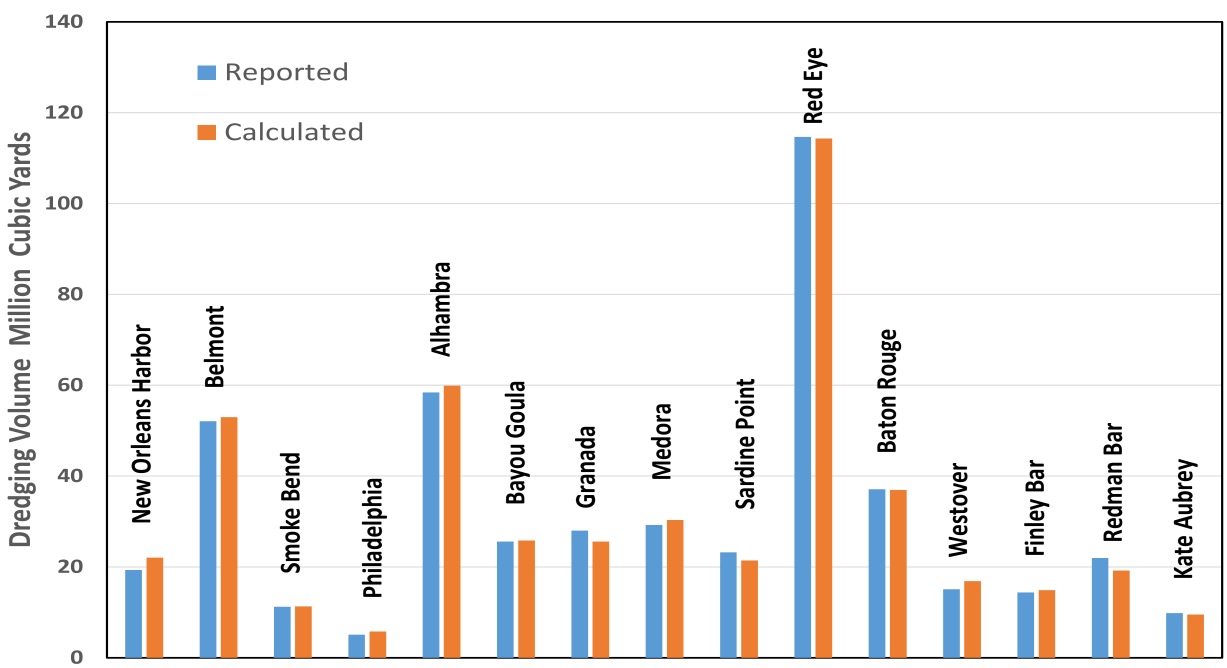

Figure 1. Calculated and Reported Dredging 1991-2013

Results and Discussion

Overbank Disposal

The current practice, in the Lower Mississippi River above Venice, is in-channel disposal. One option evaluated for this study was the disposal of dredged material over the levee (potentially into receding marsh lands). This alternative may be more expensive in terms of a specific dredging site, but could prove cost effective in terms of not having to re-dredge the same material over and over at downstream sites. There is also the potential advantage of marsh replenishment. Marsh replenishment is already being practiced in reaches of the Mississippi River downstream from Venice.

Dredging volumes over a 50-year period at several sites were first calculated by the model assuming current in-channel disposal of dredged material at dredging sites upstream from Venice. Then, dredging volumes over the same 50-year period at the same sites were calculated by the model assuming overbank disposal at all dredging sites. The 50-year dredging volumes at the sites evaluated in this study are shown in Table 3 and Figure 2. As expected, dredging requirements were reduced significantly at sites downstream from sites where in-channel disposal is currently practiced. The HEC-6T results show that overbank disposal would reduce dredging volumes above Venice by about 350 million cubic yards (almost 50 percent) over 50-years.

Table 3 shows little difference in dredging volumes in Southwest Pass and above Head of Passes. In these dredging reaches overbank disposal and physical removal are already practiced. This partially explains why dredging volume differences are insignificant below Venice. However, another factor is the significant distance between Head of Passes and the upstream dredging sites (100 miles to New Orleans Harbor and 150 miles to Belmont). Sediment can be eroded from the channel bed over these many miles to meet some of the sediment deficit created by the removal of sediment from the river by overbank disposal. The numerical model results suggest that the alluvial system response to upstream changes in sediment supply may take decades to affect downstream conditions.

There was no dredging calculated at the dredging sites upstream from River Mile 700 for either of the two disposal options. This is due to the dredging constraints established during the calibration phase of the study and to the degradation trend currently active in this reach of the river.

Table 3. Calculated 50-Year Dredging Volumes Comparing Current and Overbank Disposal Options

SITE	Model Cross Sections River Mile	Current Disposal Operations Million Cubic Yards	Overbank Disposal at All Dredging Sites Million Cubic Yards	Percent Reduction
Southwest Pass	-18.0 to -0.01	171.3	171.8	-0.3%
Head of Passes	0.72 - 5.5	651.3	632.3	2.9%
New Orleans Harbor	100.2	31.0	32.1	-3.4%
Belmont	153.1 - 154	68.2	24.1	64.7%
Smoke Bend	175	8.2	3.2	60.2%
Philadelphia	183	1.1	0.0	100.0%
Alhambra	189.5 - 189.75	78.6	12.9	83.5%
Bayou Goula	197.9 - 198.2	53.3	18.3	65.7%
Granada	203.6 - 204.1	41.4	11.3	72.6%
Medora	211.6 - 212	56.8	34.3	39.5%
Sardine Point	218.9	41.3	28.2	31.8%
Red Eye	223.5 - 224.4	236.1	120.5	49.0%
Baton Rouge US	230.4 - 232.7	78.5	61.2	22.0%
Westover	652.5	30.0	28.6	4.7%
Finley Bar	704.08	0.0	0.0	0.0%
Redman Bar	740 - 741	0.0	0.0	0.0%
Kate Aubrey	788.13	0.0	0.0	0.0%
Total		1547.0	1,178.8	23.8%
Above Venice		724.4	374.8	48.3%

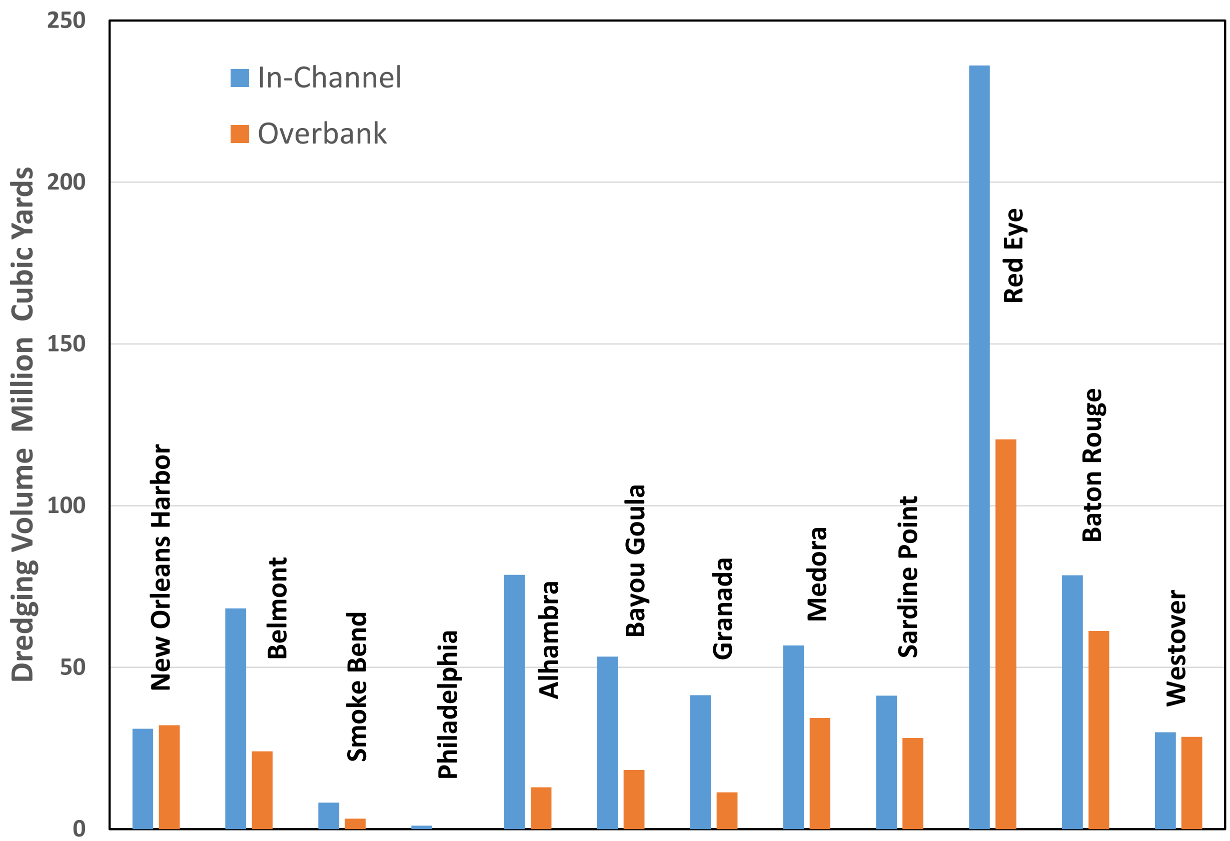

Figure 2. Calculated 50-Year Dredging Volumes Comparing Current and Overbank Disposal Options

Removing dredged sediment from the river also affects conditions upstream from the dredging sites. The numerical model calculated the quantity of sand passing each cross section every day during the 50-year simulation for both the in-channel and overbank disposal options. These daily quantities were accumulated as the simulation progressed. The difference between the sand transported past each cross section with in-channel and overbank disposal is shown in Figure 3. The differences were calculated by subtracting sand passing with overbank disposal from sand passing with in-channel disposal after 10, 30, and 50 years. Upstream differences with the disposal options are best demonstrated at the Westover dredging site (River Mile 652) where sand transport is not complicated by the proximity of other dredging sites. As expected, immediately downstream from the dredging site, sand transport is greater with in-water placement than with overbank disposal because sand is returned to the river. Somewhat surprisingly however, upstream from the dredging site, sand transport is less with in-channel disposal than with overbank disposal. This is attributed to an increase in upstream sediment transport potential that occurs as a result of permanent lowering of the bed downstream. This decrease in bed elevation occurs as a consequence of both the removal of dredged material and increased scour as the river bed seeks to restore the sediment deficit. Thus, it can be concluded that the natural river processes will dampen the expected benefit of reduced dredging requirements associated with overbank disposal (on the order of 50 percent).

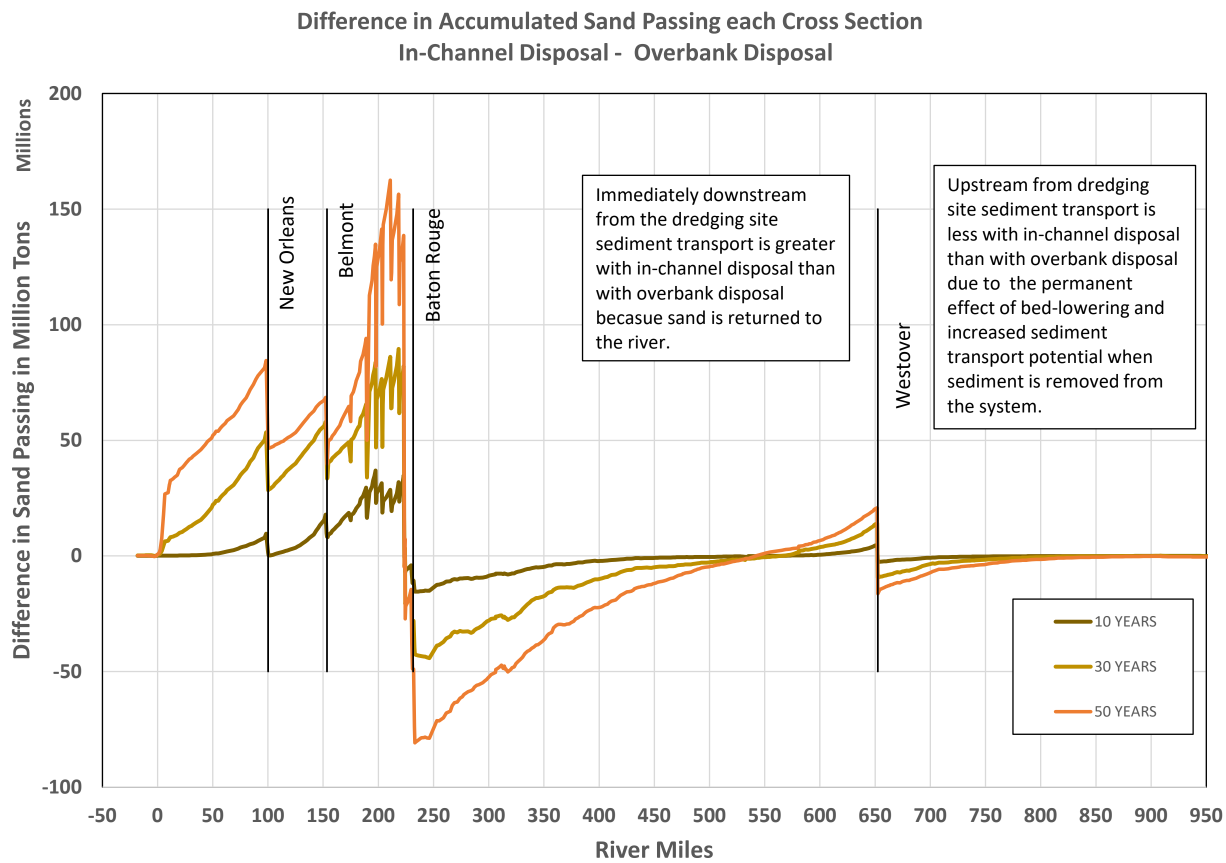

Figure 3. Difference in accumulated sand passing each cross section

It is unlikely that overbank disposal is feasible at all dredging sites along the Lower Mississippi River. Disposal site proximity and pumping costs are factors to be considered. Fifty years of overbank disposal was simulated at two sites while the current practice of dredging disposal was simulated at the other dredging sites. The two sites were Medora Crossing at River Mile 212 and Sardine Point at River Mile 219. These two sites are on opposite sides of Australia Point, which is currently an undeveloped area inside the mainline levee. This is not a proposal, only a demonstration of model capability.

The reduction in the downstream dredging quantities over 50 years with overbank disposal at Medora Crossing and Sardine Point is quantified in Table 4 and Figure 4. The overall reduction in dredging volume for the sites above Venice for the 50-year period was eleven percent or 82.6 million cubic yards. Erosion of channel bed material downstream from Medora Crossing accounts for the reduction in total calculated dredging being slightly less than the combined calculated dredging at Medora and Sardine, which was 89.0 million cubic yards.

Table 4. Calculated 50-Year Dredging Volumes comparing Current Disposal Operations and Overbank Disposal at Medora Crossing and Sardine Point

SITE	Model Cross Sections River Mile	Current Disposal Operations Million Cubic Yards	Overbank Disposal at Medora and Sardine Million Cubic Yards	Percent Reduction
Southwest Pass	-18.0 to -0.01	171.3	171.3	0.0%
Head of Passes	0.72 - 5.5	651.3	649.3	0.3%
New Orleans Harbor	100.2	31.0	31.2	-0.4%
Belmont	153.1 - 154	68.2	62.2	8.8%
Smoke Bend	175	8.2	6.5	20.5%
Philadelphia	183	1.1	0.0	100.0%
Alhambra	189.5 - 189.75	78.6	50.6	35.6%
Bayou Goula	197.9 - 198.2	53.3	34.7	35.0%
Granada	203.6 - 204.1	41.4	18.5	55.4%
Medora	211.6 - 212	56.8	46.4	18.3%
Sardine Point	218.9	41.3	42.6	-3.4%
Red Eye	223.5 - 224.4	236.1	238.3	-0.9%
Baton Rouge	230.4 - 232.7	78.5	80.9	-3.1%
Westover	652.5	30.0	30.0	0.0%
Finley Bar	704.08	0.0	0.0	0.0%
Redman Bar	740 - 741	0.0	0.0	0.0%
Kate Aubrey	788.13	0.0	0.0	0.0%
Total		1547.0	1,462.7	5.4%
Above Venice		724.4	641.8	11.4%

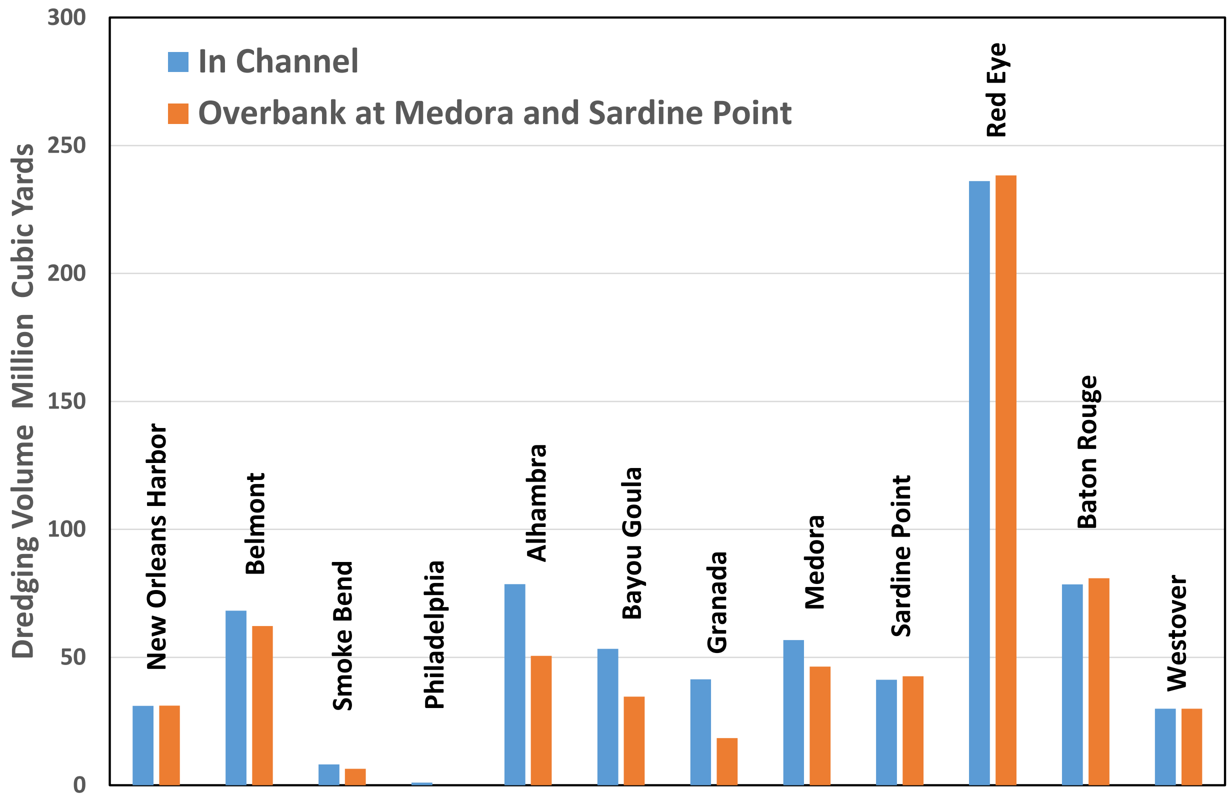

Figure 4. Calculated 50-Year Dredging Volumes comparing Current Disposal Operations and Overbank Disposal at Medora Crossing and Sardine Point Crossing

The calculated progression of downstream sedimentation with overbank disposal at Medora Crossing and Sardine Point is demonstrated by comparing the difference between calculated thalweg elevations for 50-year simulations with overbank disposal and in-channel deposition at the two dredging sites. Figure 5 shows this difference at three cross sections downstream where dredging does not occur. At River Mile 201, which is about eleven miles downstream from Medora Crossing, the effect of overbank disposal at Medora and Sardine is relatively quick and the current dredging practice results in about 2.3 feet more deposition at River Mile 201 after 50 years. At River Mile 188, which is about 24 miles downstream from Medora, the sedimentation effect of overbank disposal at Medora and Sardine is significantly less. At River Mile 188, the 50-year deposition difference is about 1.2 feet, but the effect doesn't get started until about 25 years have passed. At River Mile 169.2, which is about 43 miles downstream from Medora, sedimentation effects are even more muted. The downstream attenuation of sedimentation effects is attributed to erosion of the channel bed in response to the decrease in sediment supply from the overbank disposal. Of significance is the length of time required for the effects of sediment transport disruption to affect downstream reaches.

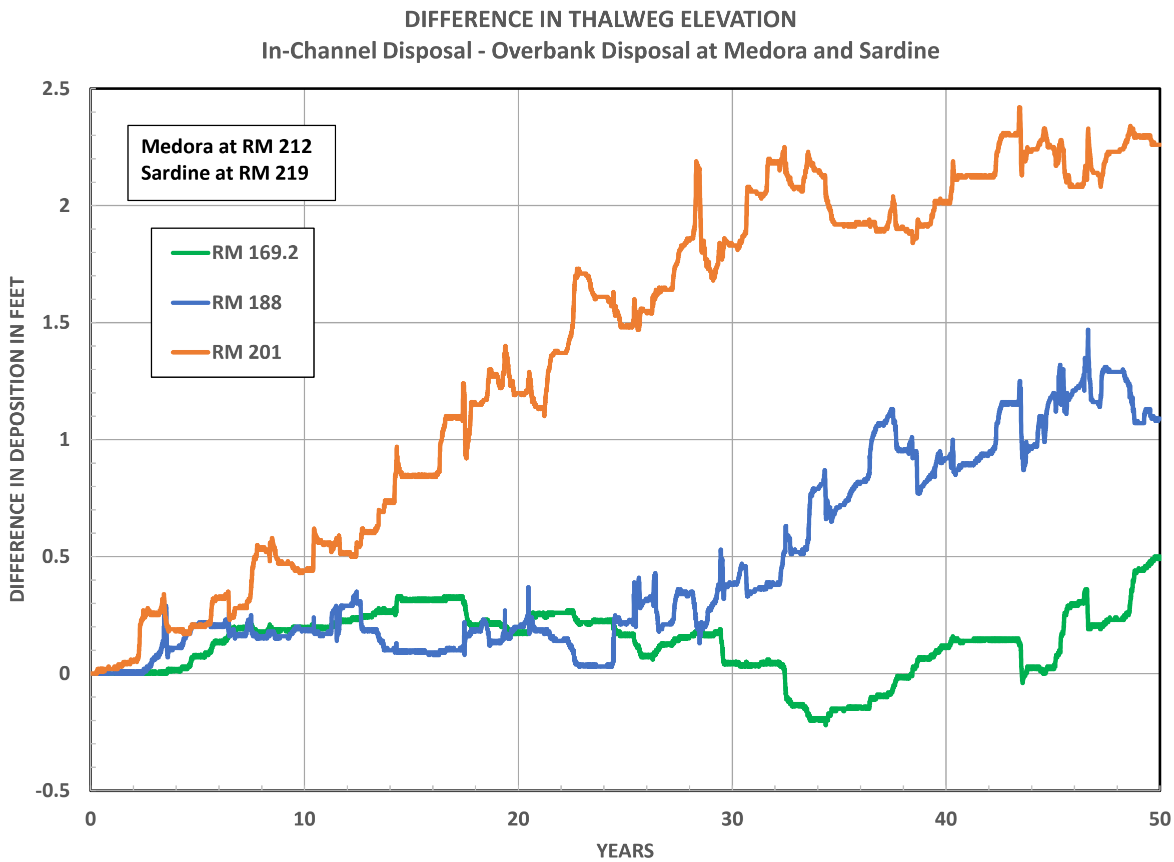

Figure 5. Difference in calculated thalweg elevations during a 50-year simulation with and without overbank disposal at Medora Crossing and Sardine Point

Effect of Wet and Dry Cycles

The model was used to evaluate the effects of long-term wet and dry runoff cycles on dredging quantities. Seven-year wet and dry cycles were extracted from the 1988-2014 hydrograph. The wettest water years during that period were: 1993, 1994, 1997, 1998, 2008, 2010 and 2011. The driest years were 1988, 1992, 2000, 2001, 2006, 2012 and 2014. The seven-year simulations were run using the in-channel deposition base test that models current dredging practice. The same dredging template elevations and dredging widths were used for both the wet and dry years. In actual practice, dredging depths may increase in dry years to insure that the authorized navigation depth is maintained. However, in this study, the same dredging parameters were used for the wet and dry hydrographs in order to isolate the actual effects of the high and low runoff. Calculated dredging quantities are shown in Table 5 and Figure 6. The results indicate significantly higher dredging requirements during wet years.

Table 5. Calculated dredging volumes for wet and dry cycles

SITE	Model Cross Sections River Mile	7 Years of Abundance Million Cubic Yards	7 Years of Drought Million Cubic Yards	Percent Difference (Wet-Dry) / Wet
Southwest Pass	-18.0 to -0.01	38.2	8.9	76.7%
Head of Passes	0.72 - 5.5	107.1	23.5	78.1%
New Orleans Harbor	100.2	8.2	2.1	74.4%
Belmont	153.1 - 154	24.8	2.5	89.7%
Smoke Bend	175	4.2	0.0	100.0%
Philadelphia	183	0.0	0.6	-100.0%
Alhambra	189.5 - 189.75	21.5	7.2	66.5%
Bayou Goula	197.9 - 198.2	10.7	6.4	40.3%
Granada	203.6 - 204.1	9.6	5.9	38.1%
Medora	211.6 - 212	8.9	5.7	36.2%
Sardine Point	218.9	6.9	3.8	45.2%
Red Eye	223.5 - 224.4	46.4	17.6	62.0%
Baton Rouge US	230.4 - 232.7	11.0	17.2	-56.7%
Westover	652.5	4.8	3.8	20.8%
Finley Bar	704.08	0.6	0.0	100.0%
Redman Bar	740 - 741	0.0	0.0	0.0%
Kate Aubrey	788.13	0.0	0.0	0.0%
Average Annual - Total		43.2	15.0	65.3%
Average Annual - Above Venice		22.5	10.4	53.8%

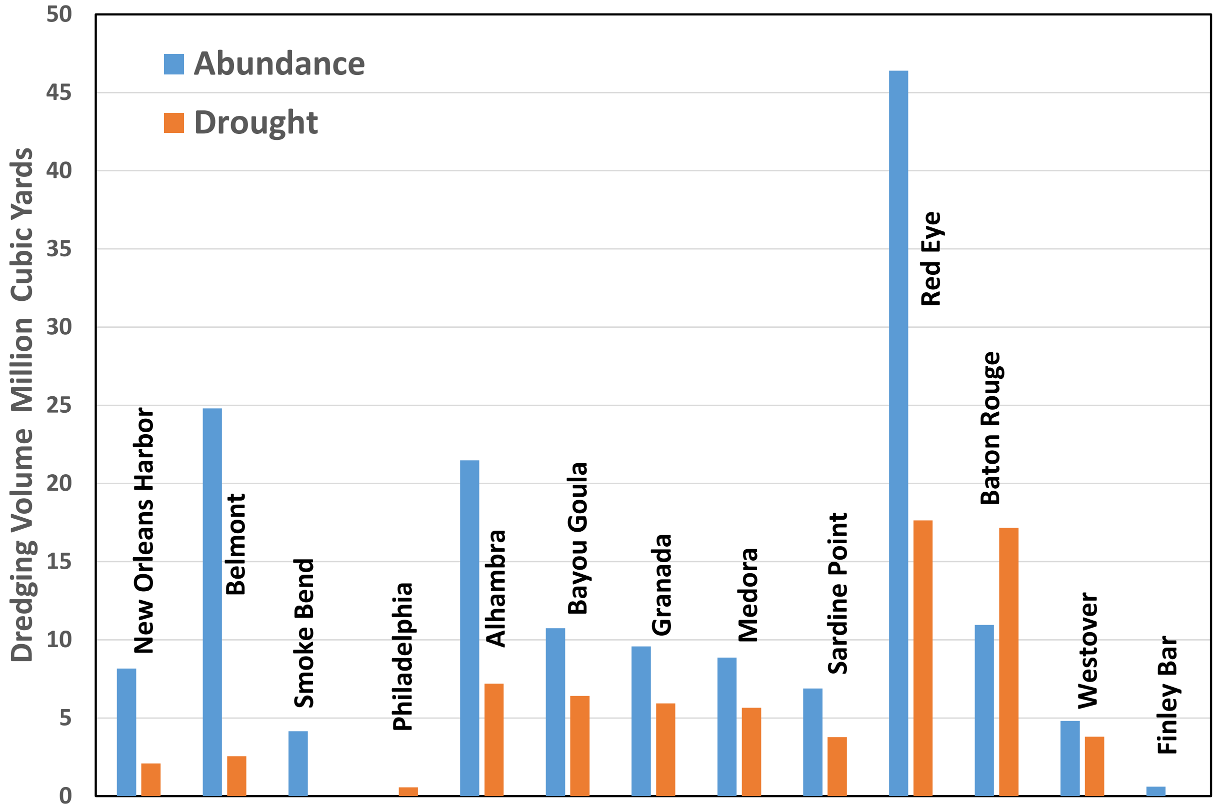

Figure 6. Calculated dredging with in-channel disposal for seven consecutive wet and dry years

Conclusion

The goal of this study was to assess various dredging alternatives to determine methods to optimize the dredging process. Use of the numerical model discussed in this study would supply only one factor, specifically the reduction in dredging volumes, to be considered in the economic feasibility and overall viability of altered dredging operations. Other factors include: disposal site availability and location, equipment required including different dredge types, pumps and transport piping, haul/barge logistics, utility pipelines in the river and navigation impacts. Two main areas were analyzed, disposal options and dredging during wet and dry cycles. The dredging options evaluated in the study have proved to have more impact than originally expected. As stated previously, values represented in this study are merely approximate due to the number of uncertainties dealing with sediment transport and dredging volumes. Regardless of the uncertainty involved, showing nearly 50% reduction (above Venice) between in-channel and overbank disposal is substantial. Also, understanding how wet and dry seasons impact dredging can be very helpful when planning future dredging operations. More studies may be used in the future to determine more long-term benefits for dredging practices.

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