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JND Thomas's 8-Inch DSC Dredge at Wilde Lake in Columbia, Maryland
(Photo Courtesy of Columbia Association)

IN THIS ISSUE

AIMS & SCOPE OF THE JOURNAL

The *Journal of Dredging* is published by the Western Dredging Association (WEDA) to provide dissemination of technical and project information on dredging engineering topics. The peer-reviewed papers in this practice-oriented journal will present engineering solutions to dredging and placement problems, which are not normally available from traditional journals. Topics of interest include, but are not limited to, dredging techniques, hydrographic surveys, dredge automation, dredge safety, instrumentation, design aspects of dredging projects, dredged material placement, environmental and beneficial uses, contaminated sediments, litigation, economic aspects, and case studies.

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CONSERVATION ACTIONS ALONG INTERIOR RIVERS OF THE UNITED STATES: CONTRIBUTIONS TO THE RECOVERY OF THE INTERIOR POPULATION OF LEAST TERN

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ABSTRACT

The U.S. Army Engineer Research and Development Center, in collaboration with American Bird Conservancy, is conducting research on how to improve engineering practices to reduce conflicts with federally listed bird species and to assist in species recovery. The U.S. Army Corps of Engineers (USACE) conducts coastal shoreline protection, beach nourishment, and maintenance/operation of interior waterways for multiple uses. Dredged material resulting from these activities has been used extensively for habitat creation and the conservation of coastal and inland bird species, several of which are federally listed as threatened or endangered. Least terns are colonial, fish-eating birds that nest on bare ground in a variety of open habitats on rivers and along coasts. The federally endangered interior population of least tern nests most frequently on sand accumulations behind dike fields on major rivers or, in the case of lock and dam navigation systems, where regular dredging to maintain navigation channels results in dredged material disposal to create habitat. We provide an overview of how the USACE and its partners are developing a comprehensive, range-wide conservation strategy to support recovery of an endangered species by: (1) using dredged material, river flows, and other engineering practices, within the framework of the USACE "Engineering with Nature" initiative, to create and maintain least tern habitat; (2) integrating least tern life-history information, along with dredging practices, river flow data, and habitat information, into regional and range-wide models; and (3) working with partners to develop regional collaborative conservation agreements. The ultimate objective is to bring these activities together in a coordinated fashion to promote long-term conservation and persistence of least terns, while simultaneously facilitating USACE authorized missions along navigable rivers.

Keywords: USACE, dredged material deposition, interior river systems, least tern, Engineering with Nature

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INTRODUCTION

All of the large interior rivers of the U.S. have been highly modified for infrastructure purposes, including navigation, flood control, power generation, and/or water supply. Major river engineering projects on these river systems generally were authorized, funded, and constructed prior to the enactment of strong environmental protection legislation now in force (e.g., Clean Water Act [CWA] of 1972, National Environmental Policy Act of 1969, Endangered Species Act [ESA] of 1973). Additionally, riverine infrastructure developments have been characterized by local and regional declines in habitat complexity and biodiversity within river channel ecosystems. Nowhere is this more evidenced than within the Federal List of Endangered and Threatened Wildlife and Plants, where the past and current threats to virtually all large river channel species on that list, including mussels, snails, fish, and birds, are directly tied to channel engineering and infrastructure development and maintenance. Major environmental protection legislation (e.g., CWA and ESA) has now been in effect for decades, and conflicts[4] between these laws and waterways maintenance and operation (e.g., dredging, dike construction, dredged-material disposal, variable dam discharge actions) occur frequently (Guilfoyle et al. 2006; Lott et al. 2013). Recovery of listed species inhabiting or dependent upon large river channels has been rare to nonexistent in the United States.

In an effort to better define roles and to minimize conflicts between infrastructure development, waterways operations, and ecosystem functions, the responsibilities of federal action agencies to ecosystem and species protections have been further addressed at multiple regulatory levels. For example, several authorities have been provided to the Secretary of the Army, acting through the Chief of Engineers under Water Resources Development Acts (1986, 1988, 1990, 1992, and 1996) to plan, design, and modify or construct projects for the purposes of restoring and protecting habitat. Executive Order (EO) 13186 (66 FR 3853-3856: Responsibilities of Federal Agencies to Protect Migratory Birds) requires all federal agencies to promote the conservation of migratory bird populations, including habitat restoration and enhancement. In order to address ecosystem mandates, the U.S. Army Corps of Engineers (USACE) developed the Civil Works Ecosystem Restoration Policy (CWERP; ER 1165-2-501) (USACE 1999), identifying ecosystem restoration as one of the primary missions of the USACE Civil Works program. Additionally, USACE has developed and implemented Environmental Operating Principles (EOP; www.usace.army.mil/Missions/Environmental/EnvironmentalOperatingPrinciples.aspx) to ensure that agency missions include totally integrated sustainable environmental practices.

Maintaining engineered river infrastructure requires consistent and continued construction and maintenance (e.g., dredging of navigation channels), which must undergo interagency review, and often modification, to minimize effects upon trust species (i.e., those species demanding extra time and resource commitments due to legal status, management need, vulnerability, or geographic areas of importance) and their habitat. However, these considerations generally apply only to the immediate project footprint and its vicinity, focusing on reducing (not eliminating) the effects of the project and the impacts to trust species within that footprint and

[4] These actions potentially conflict with federal, state, and interagency mandates to protect species, which can result in a lack of operational flexibility and increased costs for USACE projects.

rarely, if ever, improving the environmental baseline of the species under consideration. There are several reasons for this, including political and economic factors, lack of adequate knowledge of the species and/or the ecosystem, and insufficient interagency communication. However, a primary reason has been the failure to integrate project engineering with ecosystem resource values or trust species requirements at regional or range-wide scales.

USACE has recognized that recent advances in the fields of engineering and ecology provide opportunities to combine these fields of practice into a single collaborative and cost effective approach for infrastructure development and environmental management. Termed "Engineering With Nature" (EWN), this concept seeks to intentionally align both natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes (Banks and Gerhardt Smith, 2013; Banks et al. 2013; USACE 2012). There are four main concepts included in the EWN initiative (USACE 2012) as follows:

1. Using both science and engineering to produce operational efficiencies supporting sustainable delivery of project benefits
2. Using engineering techniques synergistically with natural processes to provide maximum environmental benefits
3. Broadening and extending the base of benefits provided by projects to include substantiated economic, social, and environmental benefits
4. Using science-based collaboration to organize and focus interests, stakeholders, and partners to reduce social friction, resistance, and project delays while producing more broadly acceptable projects

Herein, we demonstrate the successful application of the four EWN concepts to the lower Ohio River and Lower Mississippi River navigation systems to improve the population and habitat baseline of the federally endangered interior population of the least tern that nests within large river channels of the Interior Basin of the United States. We outline the benefits of the application of modeling approaches of this trust species, to multiple, unrelated engineering projects throughout the range of the species, as well as to USACE regulatory mandates and missions, apart from the ESA (i.e., EO 13186, CWERP, EOP). Finally, we provide detail on collaborative conservation agreements between the USACE and U.S. Fish and Wildlife Service (USFWS) to secure the interior population of least tern and its habitats as part of regular agency missions along regulated rivers.

BACKGROUND

Least terns (*Sternula antillarum*) are colonial, fish-eating birds that nest on bare ground in a variety of open habitats on rivers and along coasts (Thompson et al. 1997). The population of least terns that nest on large rivers in North America is known as the interior least tern, or ILT. Sandbars and sand accumulations in river channels are the primary habitat components used for ILT nesting. When sandbars become covered in vegetation, they are no longer suitable for tern nesting. New habitat is formed when high flows remove existing vegetation or deposit new sand.

The interior population was federally listed as an endangered species in 1985 because of suspected low numbers and concerns about breeding habitat loss and degradation due to impoundment and development of the large interior U.S. rivers (USFWS 1985). A recovery plan was published in 1990 that provided a summary of the known population size, identified suspected threats, and detailed delisting criteria (USFWS 1990). This plan also outlined recovery strategies to increase the ILT population to approximately 7,000 birds throughout its range and to maintain drainage-specific target populations for 10 years.

As a species, the least tern has a broad breeding distribution, with nesting records in 37 different U.S. states (Thompson et al. 1997; Pyle et al. 2001; Lott 2006; Marschalek 2010; Lott et al. 2013), along both coasts of Mexico and northern Central America (Howell and Webb 1995), and many islands throughout the Caribbean (Thompson et al. 1997, Bradley and Norton 2009). Two different geographically-defined populations of least tern are listed under the ESA as federally endangered: the “California least tern,” with breeding populations along the Pacific coast in California and western Mexico (USFWS 1985; Marschalek 2011), and the ILT. Despite these regulatory definitions, eastern least tern breeding populations are nearly continuously distributed (with a few exceptions) from the Missouri River in Montana south through the Mississippi Valley (and its large western tributaries) along the entire Gulf of Mexico coast, west to Belize and east to Florida, up the Atlantic coast from Florida to Maine, and throughout the Caribbean. Aside from California, coastal least terns are not federally listed under the ESA, although they are on several state lists of conservation concern (Thompson et al. 1997; Lott et al. 2013).

USACE is responsible for managing and maintaining navigable coastal and inland waterways of the United States. USACE protects coastlines and maintains inland waterways by dredging, constructing dikes, managing dam discharges, disposing of dredged-material, and conducting beach nourishment projects. The process of dredging typically involves removing sand, gravel, rock, mud, and clay from the bottom of inland and coastal waterways to maintain a sufficient depth for the purpose of navigation. Natural processes, including erosion and sedimentation, create conditions where maintenance dredging operations must be performed regularly along coastlines, major navigable inland river systems, and ports and harbors. Nearly 400 million cubic yards of material are dredged annually to maintain the navigational operations of the United States’ inland and coastal waterways (http://www.iwr.usace.army.mil/ndc/dredge/dredge.htm). Historically, vast quantities of materials were dredged and deposited during the creation of the Intracoastal Waterway system, and there was maintenance dredging in major inland rivers and coastal beaches, ports, and harbors. Many islands were created during this process as part of maintenance and deepening projects associated with these sites throughout the continental United States. During this time, USACE developed considerable technological expertise and experience creating such island habitat as part of its beneficial use of dredged materials program (http://el.erdc.usace.army.mil/dots/budm/budm.cfm). These islands are used seasonally by many birds, and extensive research on the distribution and abundance of birds nesting on these islands was conducted between 1973 and 1978 as part of the USACE's Dredged Material Research Program (Landin 1997; Guilfoyle et al. 2006, 2007).

Activities associated with waterways maintenance or shoreline protection, including dredging, dike construction, dredged material disposal, beach nourishment, and variable dam discharge actions, potentially conflict with federal, state, and interagency mandates to protect endangered species populations (Lott et al. 2013), including an array of birds (e.g., least tern and piping plover [*Charadrius melodus*]), fish (e.g., pallid sturgeon [*Scaphirhynchus albus*]), turtles (e.g., loggerhead sea turtle [*Caretta caretta*]), and invertebrates (e.g., fat pocketbook mussel [*Potamilus capax*]). In other cases, these activities can provide habitat and assist with maintaining local or regional populations of these species (Guilfoyle et al. 2006).

EWN CONCEPT 1: USING SCIENCE AND ENGINEERING TO SYNERGISTICALLY DELIVER PROJECT BENEFITS

A variety of options are available for managing ILT populations, including those for increasing productivity, such as conducting predator control or reducing human disturbance (e.g., all-terrain vehicles and unleashed dogs) and activities for enhancing habitat, such as modifying dam discharges to create downstream sandbars, creating or maintaining dike fields, and depositing dredged material to create mid-channel sandbars. Lock and dam navigation systems, such as on the Ohio, Arkansas, and Red Rivers, primarily have stable reservoir releases intended to facilitate consistent navigation. On these systems, ILT nesting occurs most frequently on dredged-material deposition sites because renewal of nesting areas from habitat-forming flows has decreased significantly.

Maintenance dredging along the lower Ohio River provides an excellent example of the beneficial use of dredged material to enhance nesting habitat for ILT. Hydrologic alterations in the Ohio River have significantly reduced or eliminated suitable sandbar nesting habitats for least terns. Most of the remaining natural sandbar areas are small, temporary, and typically accreted to the shore, providing access by predators during the nesting season. Dredged-material disposal provides an opportunity for placement of material where it can support the low unvegetated island conditions preferred by ILT. In 2002, USACE Louisville District and its dredging contractor were working on the Ohio River just upstream from Paducah, Kentucky when ILT were observed in the vicinity. USACE requested the contractor add an additional discharge pipe and use the dredged material to create five dry sand islands, each 0.2 to 0.4 hectares in size, outside of the navigation channel. This surface area was determined by the height necessary for an island to withstand the normal periodic pool increases that would inundate nests (0.5 to 1.0 meter). Terns began nesting the day after the dry islands were created. Within five days, there were 22 nest scrapes with 55 eggs. One month later, monitoring indicated that there were 64 active nests with 109 eggs and 29 chicks. This practice was informally adopted by USACE Louisville District and has been conducted each year that conditions allow. In essence, dredged-material as a byproduct of navigation dredging can be cost effectively used to create habitat, rather than being side cast onto the shore or within the channel without island creation (e.g., Van Hoff 2007; Fischer and VanHoff 2009; Fischer 2011).

In 2012, over 916,000 cubic yards of material were dredged in the lower Ohio River, and much of this material was placed on previous sand deposition areas to maintain ILT habitat. The Kentucky Department of Fish and Wildlife, in cooperation with USACE, established an aggressive monitoring program to minimize recreational impacts (e.g., fishing, camping, and other activities on dredged-material islands) that would disrupt ILT breeding and nesting. A comprehensive survey of exposed sand in mid-August with a low local river gage identified 26 sandbar islands with a total area of 71.1 acres. Sandbars ranged in size from 0.1 acres to 14.3 acres. Six islands were composed of mostly old (previous years) disposal materials. The 2012 dredged-material islands were all similar in composition (mostly sand with a small component of small gravel). These sandbars are generally oblong, parallel to, and approximately 1000 to 1400 feet from the thalweg. Older sandbars had a gradual sloping shoreline while new sandbars often had steeper banks with gradual sloping in some areas. These islands currently support 150 to 180 nesting adult least terns per year and provide the only successful tern production in the lower Ohio River (Fischer 2012).

By combining information on the breeding and nesting ecology of Least Terns with routine engineering practices (i.e., annual maintenance dredging) along the river, USACE is able to maintain nesting habitat along the lower river where the species has been unable to find suitable habitat for decades. USACE Louisville District continues to work annually with contractors to use dredge material to create and maintain nesting islands for ILT in the lower Ohio River, effectively raising both the ILT population and habitat baseline at little to no extra maintenance cost. The notion of providing habitat via dredged-material deposition in areas where habitat is needed and not sustainable through river flow processes clearly illustrate the first EWN Concept (USACE 2012).

EWN CONCEPT 2: USING NATURAL PROCESSES TO ENHANCE PROJECT BENEFITS

In order to develop the Lower Mississippi River (LMR) for barge navigation, USACE built nearly 400 linear miles of hard rock dikes extending from the riverbank into the main channel. These dikes typically are constructed in series as “dike fields” with multiple dikes spaced hundreds to thousands of meters apart, varying in length, and level-crested at an elevation low enough to allow normal river traffic to pass over unimpeded. The hydraulic effects of the dikes reduce erosion on the outer bank by reducing flow velocities and concentrations near the outer bank, redirect flow to the thalweg to maintain depths for navigation, and promote deposition of significant amounts of sediment behind the dike. On the LMR, the bulk of ILT nesting habitat occurs on these large sandy dike-fields that vary in size from less than 100 acres to more than 1000 acres. Although this process collectively creates an abundance of suitable habitat for ILT throughout the LMR, most of these dike fields naturally accrete to the shoreline, which provides mammalian predators direct access to nests, eggs, and chicks.

Current management in the LMR that significantly enhances ILT habitat on dike fields (as well as other federally listed species, such as pallid sturgeon and fat pocketbook mussel) includes "dike notching" and secondary channel restoration. "Notching" involves making a hole in the dike by simply removing enough rock to provide a path for river current between the dike and the riverbank. A properly designed notch restores depth and habitat complexity below the notch, providing substantial benefits to endangered species without any negative effect to the original engineering purpose of the dike. Notching creates flow in side-channels, separating sandbars from the mainland and making ILT nesting sandbars more difficult to access for all-terrain vehicles and mammalian predators. Notching also enhances important side-channel habitat for pallid sturgeon larvae and juveniles and increases the overall productivity of small fish species, which drive the river food chain. By 2013, about 30 percent of the nearly 1,000 dikes on the LMR had been notched, and new dikes are being constructed with this design feature. Dike notching reverses some of the formerly negative impacts of river engineering (e.g., increased predation of ILT and fisheries habitat loss around dike fields) into a primary mechanism for habitat restoration and maintenance. USACE has worked closely with USFWS to develop a formal Conservation Plan for the LMR that includes dike notching and side-channel maintenance that provides benefits for multiple trust species (see below). USACE also cost-shares actions with the Lower Mississippi River Conservation Committee to restore flow and aquatic habitat within secondary channels, which are particularly beneficial to sturgeon and mussels. Cumulatively, science on endangered species ecology and site-specific engineering actions that work synergistically with natural processes have cost effectively raised the habitat baselines of all three endangered species associated with the LMR channel.

EWN CONCEPT 3: BROADENING AND EXTENDING THE BASE OF PROJECT BENEFITS TO ECONOMIC, SOCIAL, AND ENVIRONMENTAL BENEFITS

To assist in enhancing environmental benefits of projects that also influence economic and social factors, we are developing a modeling approach that will allow us to test and better understand potential outcomes of the wide array of management approaches and techniques applied to both regulated rivers and endangered species habitat. While the model outputs directly address population ecology of terns, modeling outcomes can assist in better understanding relationships with economic and social benefits associated with these management approaches. For example, the development of a metapopulation model for the ILT, used in conjunction with a more robust range-wide monitoring plan, will assist in directly reducing overall monitoring costs by the various (and numerous) state and federal agencies involved in monitoring the species.

Regional and Range-wide Modeling Efforts to Evaluate River Management Effects on Least Terns

The 1990 ILT recovery plan (USFWS 1990) included three types of criteria for de-listing. Two of these are quantitative criteria related to population size and trend. The third criteria specified that chronic threats to terns on managed rivers, such as habitat loss, predator impacts, and human disturbance, must be addressed through adaptive management prior to delisting. A wide variety of management techniques are employed throughout the range of ILT, yet effective monitoring has not been undertaken on a scale large enough to understand how well these management programs have succeeded. Furthermore, there has been no analytical attempt to compare the importance of one threat versus another or to understand how management strategies may be designed to deal with a multitude of threats in a variable environment. Pervasive threats must be evaluated for their relative importance and considered relative to recent progress towards population size and trend targets.

Regional Individual-based Modeling

To assist in addressing concerns about pervasive threats to ILT, an individual-based population model of tern reproduction, called TernCOLONY (http://www.leasttern.org), was developed with empirical data on the Arkansas River during 2009 to 2011 (Lott et al. 2012a, 2012b, 2012c). This model was designed and is being used to test different hypotheses about which factors limit reproductive success for the regional population of ILT nesting below Keystone Dam (e.g., predators, flooding, and human disturbance). As a simulation model, TernCOLONY has been used to predict tern population response across a range of habitat restoration scenarios (e.g., building habitat with dredged material), management techniques (e.g., altered flow releases from dams and predator management), and to optimize a habitat restoration strategy relative to logistics, costs, and benefits to the birds. Further applications of this model to other river systems can be used to develop cost-effective management strategies that will promote species persistence, particularly on engineered rivers where multiple stakeholders compete for the water. This work now provides USACE a tool to: (a) understand the population consequences of alternative management strategies; (b) address chronic threats directly and develop reach-specific management strategies that will promote population persistence, with or without monitoring; and (c) develop effective adaptive management strategies that focus field observations on detecting specific aspects of the system behavior that would trigger effective case-specific management actions.

Range-wide Metapopulation Modeling

Populations of many species occupy patches of suitable nesting and/or foraging habitat and use the intervening habitat only for movement from one patch to another. These species exist in a number of populations that are either isolated from one another or have limited exchange of individuals. Such a collection of interacting populations of the same species is called a metapopulation. Each distinct population in a metapopulation may be referred to as a subpopulation, a local population, or simply as a population. For example, ILT that nest on the Arkansas River below Kaw Dam are a subpopulation within the larger Mississippi/Arkansas River population, which is part of the listed entity of “interior least tern,” which is then part of a larger least tern metapopulation that includes coastal breeding areas.

Most population models do not account for migration and/or dispersal among populated patches. Metapopulation models, on the other hand, account for dispersal among sub-populations. By accounting for the key population processes of immigration and emigration, metapopulation models allow for better predictions of how any type of local management action (because most management actions are local relative to the range of ILT) may affect local, regional, or range-wide population size or trend. Unfortunately, empirical data on ILT dispersal or movement rates between populations are scant and come from a relatively small number of biased studies. Past attempts at developing regional ILT population models have been published mostly in gray literature (National Research Council 2004). Currently, no metapopulation models exist that cover the entire ILT population. Akçakaya et al. (2003) developed a spatially-explicit demographic metapopulation viability model for California least terns using software called RAMAS-Metapop. Inferences from all least tern population models, including this one, have been limited by high demographic parameter uncertainty, which seems to be an acute problem for least terns (Thompson et al. 1997; Akçakaya et al. 2003). These models have also not accounted for dynamic habitat change. This may not be particularly important on the Pacific coast, where California least terns are confined to a small number of colonies that occur in the same location year after year. However, it is critical to incorporate habitat change into a population model for ILT because nesting habitat conditions on rivers are constantly changing in response to flow regimes and vegetation succession.

To promote a science-based collaborative approach for assembling stakeholders and partners, the U.S. Army Engineer Research and Development Center organized a range-wide ILT Research and Monitoring meeting in 2012. During this meeting, the highest research priority identified for future investigation was the construction of a range-wide metapopulation model capable of synthesizing past research and answering questions about local, regional, and range-wide population status. Objectives would be to bring together all existing sources of information on ILT to evaluate conservation status and to evaluate the effects of alternative management strategies within the framework of metapopulation dynamics. Subsequently, a collaborative effort was initiated between USACE, American Bird Conservancy (ABC), USFWS, U.S. Geological Survey, and Mississippi State University to construct a range-wide metapopulation model for ILT. Individuals from these organizations (which include ornithologists, modelers, hydrologists, geomorphologists, and computer programmers) constitute the Metapopulation Modeling Team. For many years, it has been recognized that demographic uncertainty, particularly uncertainty related to dispersal, can compromise the results of demographic spatially-explicit population models (Bessinger and Westphal 1998). Wiegand et al. (2003, 2004) proposed that much of this uncertainty could be resolved using pattern-oriented modeling (Grimm and Railsback 2005). This was the approach taken in the development of TernCOLONY (Lott et al. 2012a), and it is the approach being taken to extend TernCOLONY from a regional application to a range-wide metapopulation model. The results of this model will significantly inform management decisions made to assist in sustaining ILT into the future, provide critical input to a status determination by the USFWS, and provide economical approaches to both management and monitoring.

EWN CONCEPT 4: USING SCIENCE-BASED COLLABORATIVE PROCESSES TO ORGANIZE AND FOCUS INTERESTS, STAKEHOLDERS, AND PARTNERS TO REDUCE SOCIAL FRICTION, RESISTANCE, AND PROJECT DELAYS

A final key component in developing a comprehensive, range-wide conservation strategy to support recovery of ILT is the use of regional conservation planning as a means of bringing together the action and regulatory agencies that collectively make decisions about how to manage interior rivers for endangered species. Historically, interactions between action and regulatory agencies regarding endangered species have often been fraught with friction and resistance, primarily due to differing missions and oftentimes cost. The EWN process seeks to reduce "social friction," which is defined as a slowing of progress (and often includes "resistance to change") during interactions among stakeholders that results from complex differences in the perceptions, values, and capacities of interdependent stakeholders in the process. In the case of conservation planning for ILT, USACE and USFWS have worked closely in strong collaborative fashion with the objective of identifying those actions already being undertaken as part of agency missions (e.g., maintenance dredging and deposition of material for habitat and creation or modification of engineered in-river structures that promote sandbar and side-channel habitats), in this instance by USACE, that provide significant benefits to ILT and other listed species inhabiting the river system and then formalizing the implementation of those actions through a signed interagency plan. This process involves significant collaboration between USACE and USFWS, with coordination among stakeholders (e.g., state agencies and non-governmental organizations), all working together to implement effective conservation actions that benefit ILT and other trust species.

Section 7(a)(2) of the ESA requires lengthy, and often expensive, formal consultations on individual federal agency actions, which can be adversarial and result in an atmosphere of compliance rather than collaboration. As much of the breeding range of ILT is within USACE project areas subject to Section 7(a)(2) consultations, ILT have ranked in the top five bird species for federal expenditures under the ESA over the past decade. For the LMR, USFWS and USACE chose a different path, taking notice of a 1994 Memorandum of Understanding (MOU) that was signed by many federal agencies expressing a desire to work more frequently within the framework of Section 7(a)(1) of the ESA. Section 7(a)(1) is a powerful, but seldom-used tool, for proactive conservation in the ESA that requires all federal agencies to work collaboratively and within their agency authorities to understand the effects of agency actions on endangered species and to agree upon best management practices for their conservation (i.e., recovery), before embarking on the often confrontational path of formal ESA Section 7(a)(2) consultation.

USFWS and USACE have formally adopted the 7(a)(1) approach and incorporated the EWN objectives into a LMR Strategic Habitat Conservation Plan and partnership, where the primary ecosystem conservation tools are identified as USACE Channel Improvement and Channel Maintenance programs (USFWS 2012). This Plan identifies the three endangered species associated with the channel—ILT, pallid sturgeon, and the fat pocketbook mussel—as surrogate species to measure success. To formalize the agreement between the two agencies, USACE developed a more detailed LMR Conservation Plan to: (a) describe the full range of federal engineering actions on the LMR; and (b) identify the programmatic mechanisms by which the Channel Improvement and Channel Maintenance programs will continue to be utilized as conservation tools to maintain and improve habitat values within the LMR for recovery of endangered and other trust species inhabiting the river channel. For each proposed federal action by USACE, the plan analyzes the effects on ILT, pallid sturgeon, and fat pocketbook mussel and proposes best practices to avoid negative impacts and integrate positive habitat improvement activities into standard operating procedures. The LMR plan may represent the first large-scale application of Section 7(a)(1).

The 7(a)(1) approach used in the LMR is serving as the basis for similar conservation plans in other USACE divisions with ILT and other listed species. Furthermore, the approach now provides conservation benefits for a wide range of species in the LMR and contributes to reducing or preventing future listings of species and, thus, saving USACE and other federal agencies significant future expenditures while serving the public trust. USACE and USFWS are now working collaboratively to develop partnerships to extend the EWN approach into portions of the Red, Canadian, Cimarron, Arkansas, Missouri and Ohio Rivers utilized by ILT will collectively include more than 80 percent of the ILT range. This is requiring consideration of multiple USACE mission and project footprints, including navigation, dredging, hydropower, flood control, and water supply, under the ILT metapopulation model currently under development. As has been demonstrated in the LMR with dike notching, larger-scale application of EWN will continue to provide cost effective long-term management of ILT and its habitats, while reducing regulatory restrictions on USACE mission activities on interior rivers.

CONCLUSIONS

USACE, USFWS, and ABC are working cooperatively to develop and implement a comprehensive, range-wide conservation strategy for the recovery of ILT. There are three main focal areas being investigated to accomplish this goal. First, USACE is "Engineering with Nature," where feasible, by using dredged material, river flows and natural hydrologic processes, and other engineering practices to create and maintain ILT habitat. The beneficial use of dredged material for creation of ILT habitat along rivers (e.g., lower Ohio River), where habitat is not sustainable through riverine processes, and the use of "notched" dikes to restore riverine island habitat along the lower Mississippi River are two prime examples of EWN. Second, a Metapopulation Modeling Team has been assembled to integrate ILT life-history information, management practices, river flow data, and habitat information into regional and range-wide models that can be used to test the efficacy of a wide variety of management scenarios involving techniques that influence ILT productivity or serve to create riverine habitat. Finally, USACE and USFWS have collaborated to incorporate EWN principles into regional conservation planning that identifies and establishes standard operating practices for mission-related USACE activities, customized according to the opportunities present in different drainages that sustain or improve the habitats of federally endangered and other sensitive riverine species. USACE has worked with the USFWS and state conservation agencies for more than a decade to identify and resolve ecosystem management issues, including endangered species conservation associated with USACE civil works projects in the LMR to provide flood control infrastructure and to facilitate navigation. It is evident that the very programs that have most significantly affected the river are the most important and cost-effective tools to maintain and enhance its ecological functions. This is accomplished by considering and incorporating ecological engineering opportunities during the design phase of channel improvement and channel maintenance projects. Early consideration of conservation designs results in localized improvements in habitat function and value with little to no effect on flood control, navigation, or project cost.

The conservation strategy and partnership outlined in this article not only ensures full and measurable compliance with the conservation requirements of the ESA but also cost-effective compliance with EO 13186, CWERP, and USACE EOPs. However, the ultimate objective and benefit is coordination of USACE activities in a fashion that promotes long-term conservation and persistence of ILT and other trust species while simultaneously facilitating USACE authorized missions along navigable rivers.

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BEST PRACTICES FOR DREDGING AND SEDIMENT MANAGEMENT AT INLAND LAKES

Walter J. Dinicola, P.E.[1], Travis W. Merritts, P.E.[2], Christopher A. Hayward[3], Ram K. Mohan, Ph.D., P.E. [4], and Charles Grey[5]

ABSTRACT

Three privately maintained lakes located in close proximity were recently dredged within a 5 year period. The lake dredging was necessitated due to prolonged sedimentation that had decreased lake capacity and impacted lake aesthetics. The following is a summary of best practices utilized during the design and construction, as well as recommendations for future dredging work so that subsequent dredging work at the lakes may be conducted more efficiently. The following evaluation and conclusions were drawn specifically from work conducted on the three subject projects but are broad enough to be applied to other programs. This evaluation consisted of a review of all project files for the Lake Elkhorn, Lake Kittamaqundi, and Wilde Lake dredging projects and a review of the key project parameters that affected the methodology, contractor selection, execution, and completion of the projects. These reviews identified the benefits and potential areas of improvement for the lake dredging program, including dredging goals, dredging operations, material tracking, and contractor selection. Additionally, best practices utilized during design and construction were identified, and recommendations for future considerations were developed to maximize the efficiency of the dredging program based on the analysis.

INTRODUCTION

Columbia Association (CA) has expended significant resources during the 5 year period between 2008 and 2013 to perform maintenance dredging operations in Lake Elkhorn, Lake Kittamaqundi, and Wilde Lake. The magnitude and scale of these projects has prompted

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a to review the lessons learned and dredging implementation procedures in order to identify areas in which these dredging projects can be optimized for future projects.

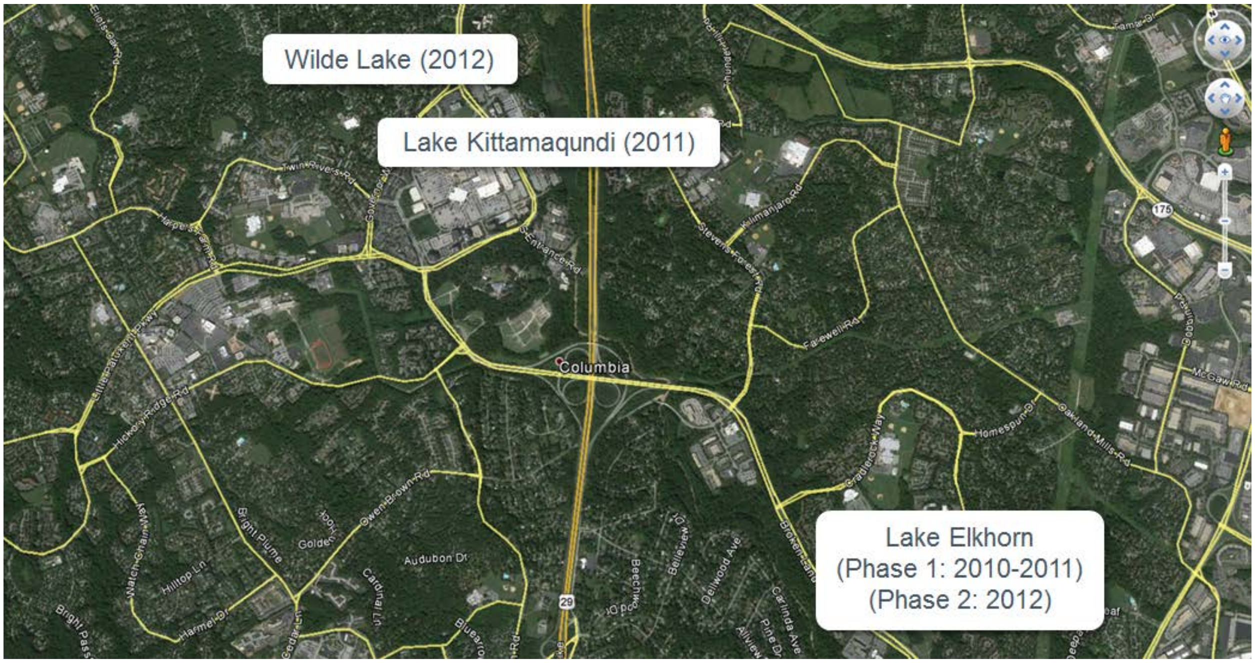

Figure 1. Map of Columbia Association Lakes

A review of these projects has been performed to evaluate lessons learned. The review consisted of the following steps:

- Review of project files for three recently completed lake dredging projects conducted by CA
- Review of key project parameters that affected the strategy, execution, and completion of the reviewed projects and identification of lessons learned
- Recommendations for future events based on lessons learned from review of the three projects

REVIEWED PROJECTS

A summary of the key aspects of the three dredging projects that were reviewed are provided in Figure 2 as a quick reference.

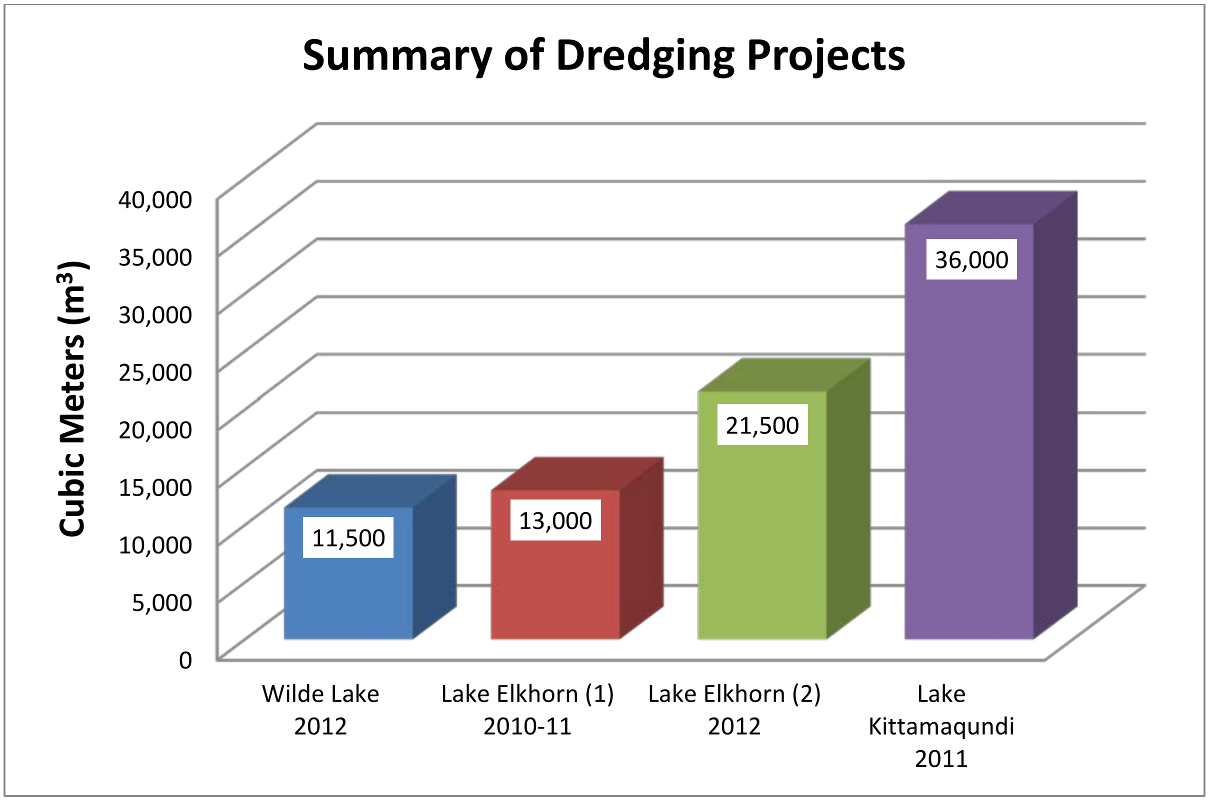

Figure 2. Summary of Reviewed Projects.

Wilde Lake

Construction on the Wilde Lake dredging project began in March 2012, and site operations were completed in August 2012. Approximately 11,500 cubic meters (m^3)—15,000 cubic yards (cy)—of sediment was removed from two distinct areas within the lake—the northwestern portion of the lake where the stream enters and at a cove area at the southern tip of the lake. Anchor QEA served as the engineer-in-charge for the dredging design and also managed the concurrent repair design for the lake dam, which is a Significant (Class 2) Hazard concrete dam structure. JND Thomas Company, Inc. (JND Thomas), based out of Riverdale, California, was selected as the dredging contractor following a competitive bidding process. Dredging operations were conducted utilizing a 203-milimeter (203-mm; 8-inch) Dredging Supply Company (DSC) hydraulic dredge. Sediment was dewatered using a mechanical dewatering plant that consisted of shaker screens, hydrocyclones, a clarifier tank, and three-belt filter presses, which were operated simultaneously during peak production. Dewatered sediments were loaded into dump trucks and hauled off site for disposal at approved landfill locations. The total cost of construction for the Wilde Lake dredging project was approximately $1,773,000. Project completion was documented in the final completion report submitted to the Maryland Department of the Environment in October 2012 (Anchor QEA 2012).

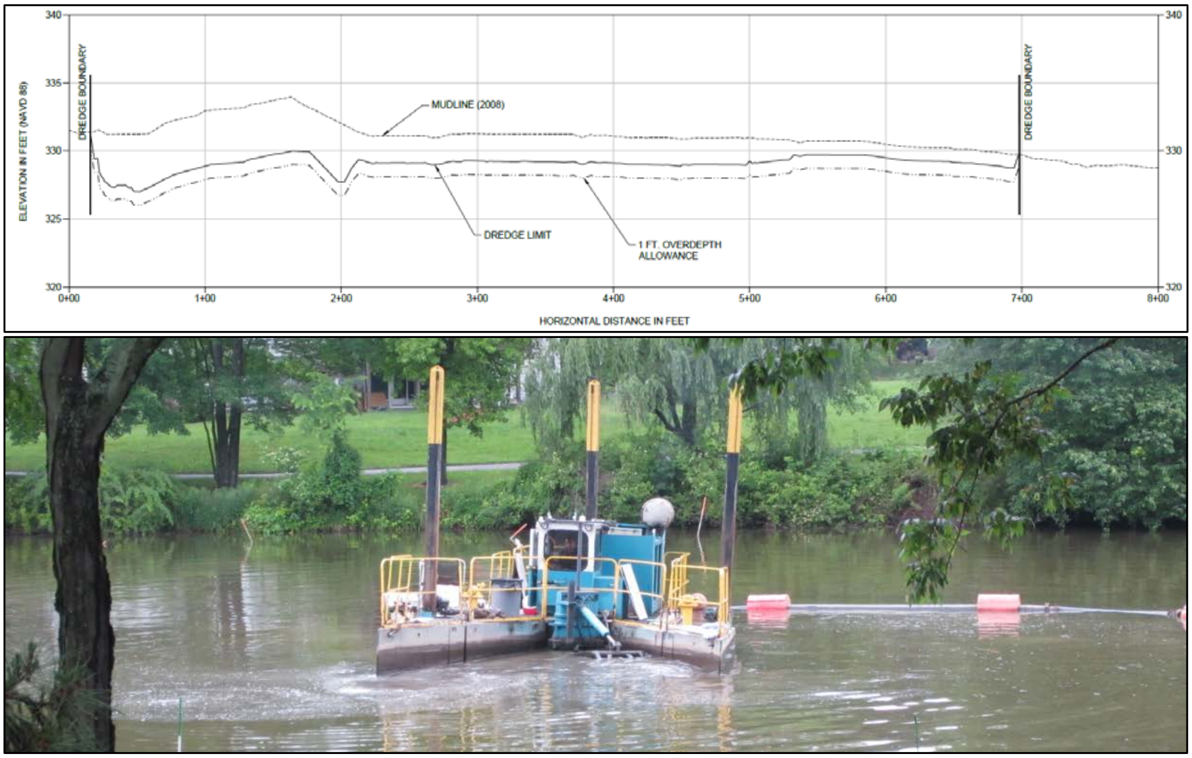

Figure 3. Wilde Lake Dredging Section and Construction Photo

This project was initially scheduled for dredging in 2010; however, the project was delayed when the contract with the first selected contractor expired. Following this delay, CA elected to re-open the project for re-bidding. JND Thomas was subsequently selected as the contractor, and they ultimately completed the work.

Figure 4. Wilde Lake Entrance Before and After Dredging

Lake Elkhorn

Lake Elkhorn dredging operations were completed as a combination of two separate dredging efforts involving two prime contractors and two engineering consultants. Work occurred from 2010 to 2012.

2010 to 2011 Dredging Operations

The 2010 to 2011 dredging activities at Lake Elkhorn were conducted by Mobile Dredging and Pumping Company (Mobile; Chester, Pennsylvania). These operations removed approximately 13,000 m^3 (17,000 cy). HDR, Inc. (HDR) served as the engineer for this initial effort. Mobile utilized a hydraulic dredge that transported sediment slurry via hydraulic pipeline to a mechanical dewatering system. Dewatered sediment was loaded to dump trucks and hauled off-site for disposal at approved landfill facilities. Information regarding the total construction cost to date for the 2010 to 2011 dredging activities at Lake Elkhorn was not available.

2012 to 2013 Dredging Operations

The 2012 to 2013 dredging activities at Lake Elkhorn began in July 2012 and were completed in January 2013. HDR performed the engineering design for this project, though CA ultimately requested Anchor QEA take on the responsibilities of the Engineer-in-Charge (EIC) for the project. JND Thomas was selected to perform the dredging operations following a competitive bidding process, and they were able to shift their operations to Lake Elkhorn following completion of the Wilde Lake dredging work in June 2012. A total of 21,500 m3 (28,000 cy) of material was removed from four discrete areas of the lake where significant sediment accumulation had been identified. The total cost of construction for 2012 to 2013 dredging activities at Lake Elkhorn was $3,200,000. Project completion was documented in the final completion report submitted to the Maryland Department of the Environment in June 2013 (Anchor QEA 2013).

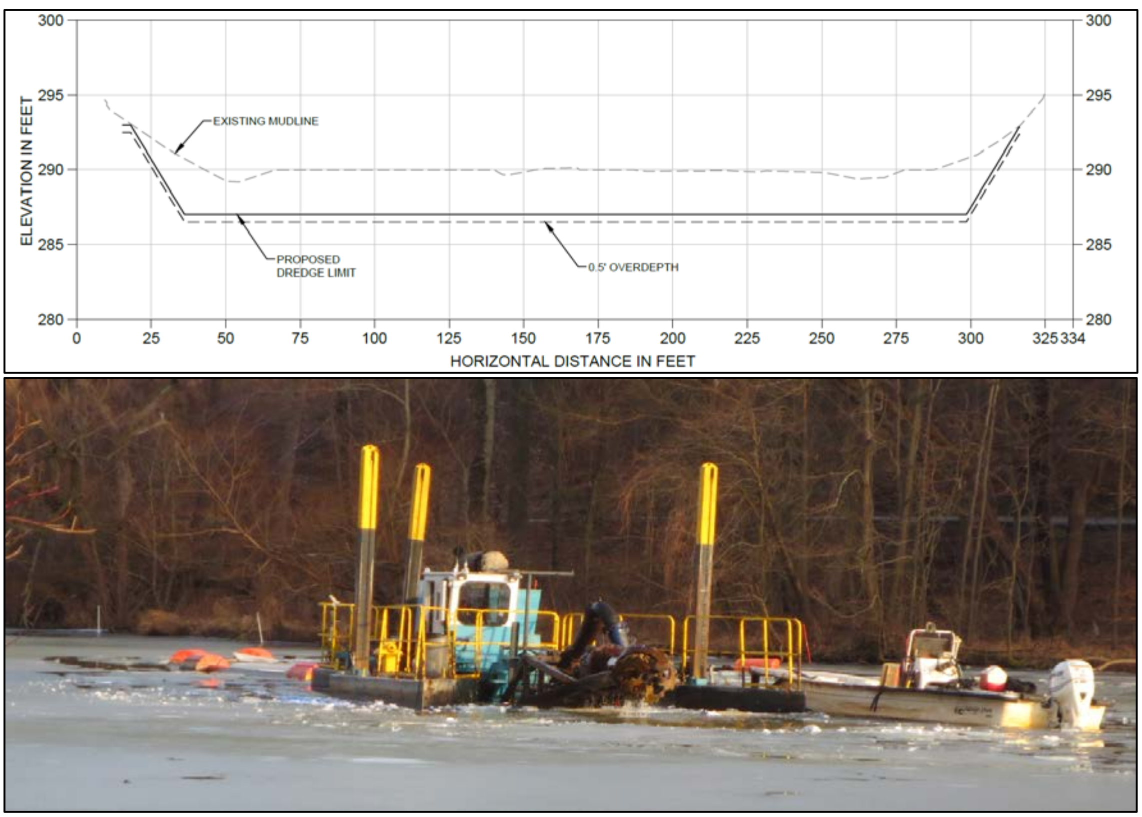

Figure 5. Lake Elkhorn Dredging Section and Construction Photo

Lake Kittamaqundi

Lake Kittamaqundi dredging operations occurred in 2011 and were conducted by Jay Cashman, Inc. (Cashman), located Quincy, Massachusetts. HDR served as the EIC for this project. Cashman utilized hydraulic dredging operations to remove sediment and initially utilized a DEL Corporation (DEL) Tank and Filtration System to perform the sediment dewatering. According to CA's field supervisor, as the dredged sediment transitioned from sand to finer silts and clays, issues with turbidity exceedances relative to the standards established by the regulatory agencies in the return water were encountered. Following work stoppages due to turbidity exceedances, Cashman transitioned to a geobag with flocculent log dewatering system.

Additionally, according to CA's field supervisor, a total design volume of approximately 43,000 m^3 (56,000 cy) was scheduled for removal and approximately 36,000 m^3 (47,000 cy) were actually removed. The total construction cost to date for the Lake Kittamaqundi dredging project was $5,000,000.

Figure 6. Lake Kittamaqundi Dredging

REVIEW OF THE COLUMBIA ASSOCIATION'S DREDGING PROGRAM ELEMENTS

The following sections review the key elements of CA's lake dredging projects and identify lessons learned.

Lake Maintenance Program Goals

The maintenance dredging events at the three lakes discussed in the Reviewed Projects section were triggered by visible sediment accumulation affecting lake aesthetics and the desire to restore lake water capacity. At certain locations within the lakes (e.g., forebays, creek mouths, and along shorelines), sediment accumulation had formed island features that developed into highly-vegetated areas, which were visually unappealing. Removal of these visible features, as well as restoration of diminished lake capacity, was the primary goal the dredging projects.

Figure 7. Lake Elkhorn Forebay Entrance Before and After Dredging

Design Consultant Selection Process

Similar to many corporations and associations, CA typically procures design consultants largely based on experience and lowest price bids in response to a select scope of services. These consultants were selected following an open-bid process, but selection was largely based on the lowest priced bids.

Selected Dredging Method

Dredging activities were conducted without draining or noticeably lowering the water surface elevation at the lakes. Each of the lake dredging projects was conducted utilizing a single, small hydraulic dredge, which transported sediment to an on-site dewatering area. Mechanical dewatering methods were implemented at Wilde Lake and Lake Elkhorn, whereas Lake Kittamaqundi utilized a DEL Tank and Filtration system before transitioning to a geobag with flocculent log dewatering system. The target dredging elevations were established to meet the removal goals of CA and to restore the lakes to near their originally constructed bottom elevations.

Figure 8. Hydraulic Dredging Operations

Contractor Selection Process

Again, similar to many corporations and associations, CA typically procures contractors largely based on the lowest price bids in response to a select scope of services. Separate contractors were selected to perform the dredging operations at each lake because all of the projects were bid individually. For dredging operations at Wilde Lake, bids were received from multiple contractors, who had previously participated in the site bid walk, and were evaluated based on cost, contractor qualifications, methodology and approach, and cover letter. A best-and-final-offer process was conducted, proposals were re-evaluated, and interviews were conducted with the top-ranked contractors. Similar procedures were followed for the bidding and selection process at Lake Elkhorn and Lake Kittamaqundi.

Cashman was selected following an open bid process, and they completed the dredging work at Lake Kittamaqundi. Mobile was selected to perform the dredging operations at Lake Elkhorn, and they performed dredging operations from 2010 to 2011. A separate bidding process was undertaken in 2012, through which JND Thomas was selected to perform the remaining dredging work. Part of the contractor selection process included the opportunity to complete Wilde Lake and Lake Elkhorn in one dredge season. Dredging operations were completed in January 2013, and the project was completed in May 2013.

Volume and Material Tracking

Bathymetric surveying methods were utilized to determine the design volume at all lakes and the removed volumes at Wilde Lake and Lake Kittamaqundi. Wilde Lake surveys were completed using dual-frequency, single-beam hydrographic survey techniques in combination with differential GPS (DGPS) positioning equipment. The surveys accurately mapped the lake bottom to determine available removal volume. By using the same methodology to conduct post-dredge surveys, a simple calculation was performed to compare the two surfaces and determine in situ removal volume.

According to CA's field supervisor, 2006 pre-design surveys conducted at Lake Elkhorn and Lake Kittamaqundi were performed using rod surveying methodology. The results of these surveys did not agree with the results of hydrographic surveys conducted prior to dredging operations (i.e., baseline construction surveys). The funding available to perform the dredging work was not sufficient to cover the additional volume. In order to move forward with the project, increased funds were secured and the dredge prism was adjusted to reduce the volume of material to be removed.

Bathymetric survey data was used to determine sediment removal volume for payment purposes at Lake Elkhorn during the initial phase of removal operations conducted by Mobile. Preliminary plans to use truck tickets/disposal tonnage as a method of determining dredged volume were rejected, as they were deemed imprecise.

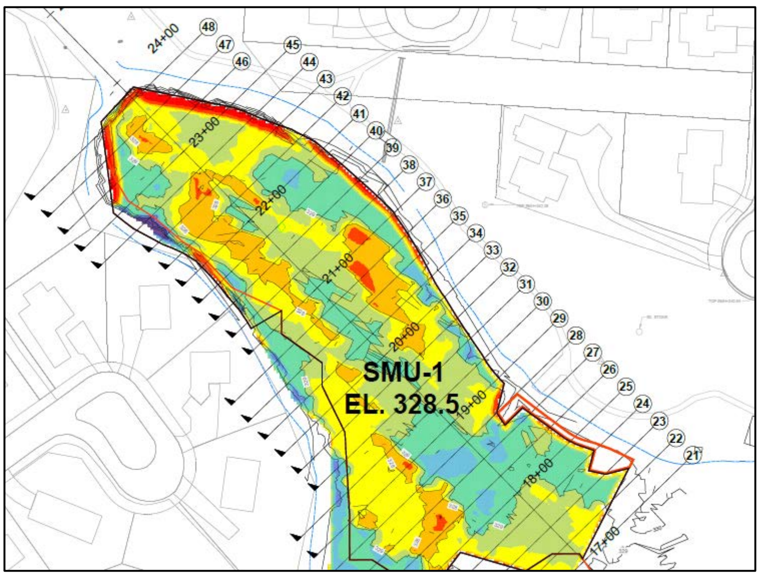

Figure 9. Typical Isopach Map from a Progress Survey at Wilde Lake SMU-1

FUTURE CONSIDERATIONS FOR IMPLEMENTING COLUMBIA ASSOCIATION DREDGING PROJECTS

The following section outlines suggestions for improving design and execution of CA's future dredging program, based on the review of the projects and lessons learned from the execution of these past dredging projects.

Figure 10. Key elements of a successful dredging project

Lake Maintenance Program Goals

Increased vigilance to forecast when a maintenance-dredging event is critical and can be monitored with regularly scheduled bathymetric surveys. In the three lakes that have been recently dredged, an accurate bathymetric survey to identify the baseline surface will exist in the form of the post-dredge survey. Regularly scheduled bathymetric surveys will allow CA to closely monitor sediment accumulation and accordingly adjust the maintenance dredging schedule and predicted budgetary needs. This may also facilitate utilization of an already mobilized dredging contractor for maintenance of a second project (where relevant), yielding potential cost savings such as the recent award of the 2012 Wilde Lake and Lake Elkhorn dredging work to JND Thomas.

Additionally, enhanced watershed management, such as the anticipated watershed-wide improvement evaluation and implementation program, will likely decrease the sediment loading to the lakes and increase the time between necessary maintenance events.

The ability to remove smaller volumes of sediments within easier accessible areas should be evaluated more frequently. This will limit the likelihood of a larger construction project, and possibly reduce the dredge design and permitting process.

In recognition of these goals, CA has developed lake-specific Sediment Management Plans (SMPs) to protect and sustain the recently restored functions of the lakes. To develop the SMPs, sedimentation rates were analyzed within the lakes, target dredge areas were identified, and future surveying, permitting, and dredging goals were set. Implementation of the SMPs will allow CA to realize cost savings, as it is anticipated the plans will prevent future large-scale dredging projects.

Recently, CA has initiated the process of obtaining the engineering and design services required to implement lake-specific SMPs. The services are anticipated to last several years and the SMPs will be reexamined and updated as necessary. The implementation program also requires investigation and assistance in acquiring a sediment disposal site to further reduce future dredging costs.

Design Consultant Selection Process

There are several factors for CA to consider when selecting a consultant for future support with their maintenance dredging programs. Overall, it can be observed from the three recent lake dredging projects that there are obvious benefits to retaining a single consultant to design and oversee similar lake dredging operations. The continuity that could be applied throughout project permitting and design and construction implementation, as well as established regulatory agency relationship, would provide many areas to streamline processes and reduce cost to CA. This continuity is seen at ports around the country.

Several corporations and associations have recently shifted their procurement approach to a joint qualifications and price-based approach, which gives due consideration to consultant qualifications and local experience, as well as price. This results in an initial design proposal with a more realistic cost that is likely to procure the best contractor prices in the end. Procurement of design consultants to achieve this objective of selecting the best qualified design firm will eventually yield much larger savings for the project (as the typical design fee is only 10% to 15% of the total projected construction cost on dredging projects). Thus, initial investment in a qualified engineering consultant would aid in the development of better design and procurement documents, which would yield more responsive and cost-effective bids and limit the potential for claims.

Experience

Future consultants should be able to provide documentation of inland lake dredging projects that they have previously completed. Inland lake maintenance dredging poses unique challenges that firms without previous experience in the area may not be able to properly identify and plan for appropriately. For example, firms that specialize in channel maintenance dredging may not fully grasp CA's goals for performing the lake maintenance dredging. Additionally, experience with sediment dewatering operations should be highly valued during the evaluation process. The consultant should understand the potential savings related to mechanical removal versus hydraulic removal.

Location

Hiring a consultant with a local presence has many inherent benefits. Primarily, a local consultant is more likely to have experience and relationships with key regulatory agencies than an out-of-area consultant. These relationships and knowledge of agency protocol are highly valuable and may make the difference between a project starting (and finishing) according to schedule, as opposed to one with delays (which will create unnecessary costs and risks). The ability for the consultant to be accessible to the client is important for communication and trust. Potential consultants should be able to demonstrate that local experienced staff will be available to attend site, progress, public, and/or agency meetings as necessary. Often these meetings will be scheduled in advance of the actual meeting date, but occasionally a quick-response presence will be required. During construction, it is important that consultants have staff of an appropriate level of expertise available for on-site monitoring and tracking of construction progress. Local personnel will also reduce travel time and expenses, thereby, yielding considerable savings during the project construction oversight phase in particular.

Cost

Although the cost of the consulting services must be within the available budget, this should not be used as the sole determining factor in consultant selection. Particularly, qualifications and experience should not be sacrificed when retaining a consultant because the cost savings may be lost due to project delays, change orders, and other factors that might have been avoided with a more experienced consultant.

Selected Dredging Method

During the three most recent lake dredging events, there were certain design elements that proved successful for implementation at these specific sites, and there were elements that need to be re-evaluated for future designs. Based on the recent dredging projects, hydraulic dredging with mechanical dewatering processes was generally more productive than other methods employed. However, all methods should be fully considered in the future design stages, as removal and dewatering technologies develop and continuously improve as developers pursue more advanced processing options.

On-site disposal would provide a significant cost savings to CA, and it has been a well-investigated option; however, it was determined that no viable on-site placement locations are locally available near CA lakes at the time of construction, nor was this desired by CA at the time. In the event that on-site placement is not available, dewatered sediment should be loaded on to trucks and hauled off-site to a permitted disposal location. Future options for beneficial re-use of the material should be investigated.

Contractor Selection Process

Similar to consultant procurement, contractor selection should not be based primarily on cost considerations. Although the selected contractor will need to perform the work within the available budget, the short-term cost savings of an inexperienced contractor may diminish as high-cost change orders, project delays, or overlooked project elements evolve into major issues during or following implementation.

Experience with inland lake dredging should be a prerequisite to consideration for selection on these projects. Additionally, it has been demonstrated the project runs more smoothly as the role of subcontractors is diminished. If possible, a contractor that performs the dredging and dewatering operations is preferable to a contractor planning to subcontract either part of the work. If subcontractors are proposed to perform a major component of the work, those subcontractors need to be identified and properly evaluated during the bid evaluation process. Experience working together between the contractor and the subcontractor needs to be evaluated during the interview process. In addition, prior working relationships among various vendors on a specific contracting team should be closely evaluated during bid award to avoid any coordination issues in the future post award.

In addition, similar to consultant selection, there are obvious benefits to the continuity that could be experienced by retaining a single dredging and dewatering contractor to perform work at multiple lakes, assuming the projects can be scheduled as such. Familiarity with state standards, the typical sediment dredging conditions, and ongoing refinements to the dewatering process could promote more efficient construction. Reduced mobilization/ demobilization durations and added incentive to complete work on schedule could lower the cost to CA.

Volumes and Material Tracking

The need for an accurate and properly executed baseline (pre-dredge) survey is critical to reducing the potential for disputes about payment volumes. Dredging projects that utilize sediment disposal tonnages or rely on poorly executed pre-dredge surveys are prone to disagreements on payment volumes due to the variability associated with those measurement methods. For example, a contractor being paid for sediment removal based on disposal tonnage, has an incentive to dewater the sediment to the minimum transport requirements, thereby, securing payment for water weight in the truckload. This leads to increased cost to CA and likely leads to increased road maintenance costs due to sediment displaced during transport. Performance of a pre-dredge survey that is agreed to by both parties prior to the start of sediment removal, in conjunction with clear survey-based pay conditions, will minimize the likelihood of payment volume disagreements between CA and the contractor. All pre-dredge, interim, and post-dredge surveys need to be consistent in terms of local control, equipment, and methodology. A single surveyor using the same control should be retained to perform all survey work if possible.

CONCLUSIONS AND SUMMARY OF RECOMMENDATIONS

Based on this evaluation, it is recommended that CA consider refinements to the following four key elements of their lake dredging programs: lake maintenance program goals, contractor and design consultant selection process, selected dredging method, volume and materials tracking procedures. Critical points of these key elements are presented below in Figure 11.

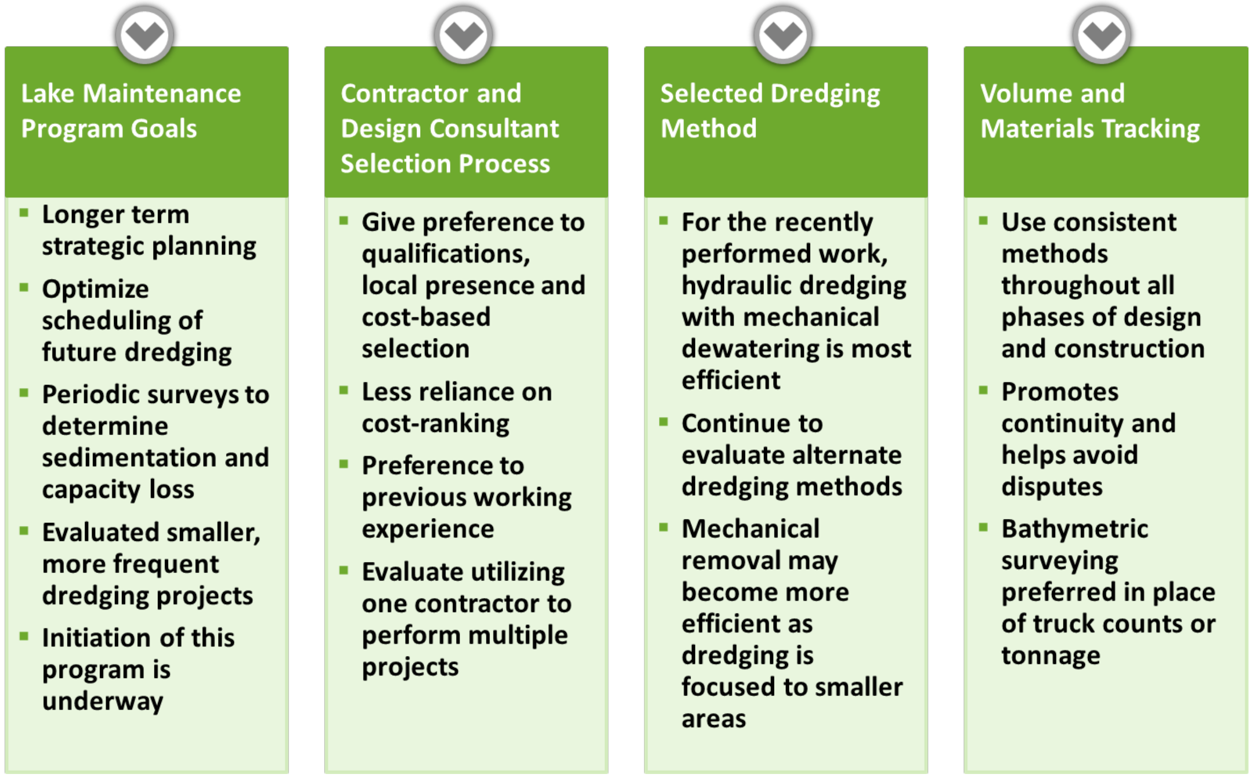

Figure 11. Recommendations for Key Elements of the CA Dredging Project Process

CITATION

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NOTES FOR CONTRIBUTORS

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The text should be submitted on unlined white 8½ x 11 inch paper with **single line spacing**, and top and side margins of 1 inch. Use full justification. **The image area or block of text will then be 6.5 x 9.0 inch.** The bottom margin should be 1½ inch. Page numbers should be marked in pencil and placed at the bottom center of each page. **Do not leave additional margins. Do not use company letterhead paper.**

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If possible, please use proportional, serif font such as Times New Roman 12 point. If such fonts are not available, use a 12 pitch typeface and work to the margins indicated above. Do not use headers or footers or draw a frame around your text. Use a letter quality or laser printer. **Do not use a dot matrix printer**. It may be possible for us to print your text directly from your disc. In this case, we shall still require hard copies of your text. The preferred word processing program is Microsoft Word 6.0 or Word 97. If using other programs please also save your text as ASCII files. Discs should be labeled with the file name in both word-processed and ASCII forms, the word processing package used, and the operating system.

Headings

Headings should be typed in bold capital letters centered and followed by a double space. Bold capitals and lower case letters should be used for subheadings, which should be preceded and followed by a single space as illustrated by these instructions. Sub-subheadings should use bold capitals and lower case letters and placed at the start of the paragraph.

Equations

All symbols must be defined in the nomenclature section that follows the conclusions. The SI system of units should be used. If units other than SI units are included, they should be given in parenthesis after the relevant SI unit. Equations should be successively numbered (in parenthesis) flush with the right-hand margin (see example below).

$$y = a + b + cx^2 \qquad (1)$$

References

References in the text should be given as follows: Smith (1988), (Smith 1988) or (Jones et al. 1986). References should be listed alphabetically in the References section at the end of the paper. Give the names and initials of all authors, followed by the title of the article and publication, the publisher and the year of publication. References to conference papers or proceedings should include the name of the organizers. References to articles published in journals should also include the name of the journal, the number of the issue and page numbers (see example below). References to publications in a foreign language should give all details in the original language followed by a translation of the title.

Hunt, J.B. (1995). *Environmental Dredging*. Smith & Son, Inc., New York, NY.

Donegan, T.M., and Dinicola, W.J. (1986). *Turbidity Associated With Dredging Operations. Technical* Report, XYZ Consultants, Inc., Baltimore, MD., 60 p.

Jones, F., Doe, A., Hart, E.J.E., and Next, J.P.J. (1986). *The Design of Dredged Material Disposal Sites.* Proceedings XIVth World Dredging Congress, CEDA, Amsterdam, The Netherlands, pp. 350-368.

White, F.K. and J.M. Jones (1991). *The Analysis of Flow Fields around Dragheads.* Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE, Vol. 121, No. 5, pp. 1-16.

Page Numbers

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Figures and Tables

High quality figures and tables should be incorporated into the body of the text. Figures must not be placed at the end of the paper. Leave spaces for photographs. Figure captions should be below the figure; table captions should be above the table.

Line Drawings

The lines and lettering on the figures should be clearly legible. If originals cannot be supplied, ONLY BLACK AND WHITE COPIES OF VERY HIGH QUALITY are suitable for reproduction. PENCIL AND PHOTOCOPIES OR COPIES WITH A BACKGROUND COLOR ARE NOT SUITABLE.

Photographs

Photographs must be sharp, high contrast, glossy prints. Please use a pencil to indicate the title of the paper, figure number and title and top edge on the back of each photograph. Paste in the photographs where they should appear in the final manuscript. Place captions under the photograph as part of the text.

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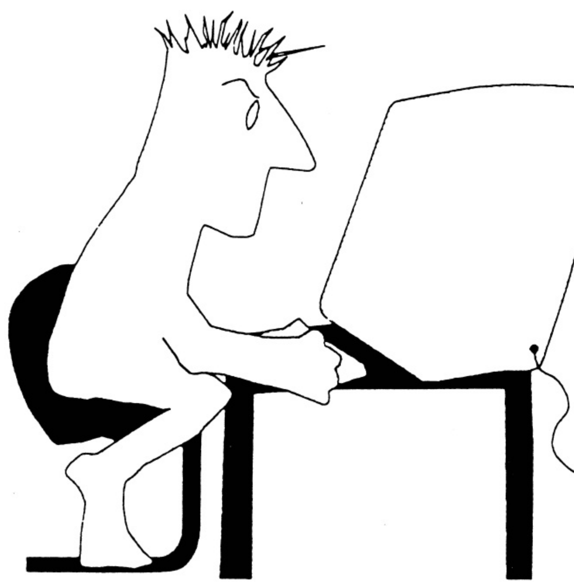

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