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Water Injection Dredging

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PURPOSE: This technical note describes water injection dredging (WID) and discusses the U.S. Army Corps of Engineers (USACE) and European experiences with WID. Key projects in the United States and Europe were analyzed in terms of the projects' states concerning WID use.

INTRODUCTION: WID is a dredging technique in which a dredge vessel pumps water into channel bottom sediments at low pressure and relatively high-volume flow rates. This dilutes and fluidizes the sediments, creating a near-bottom layer (density current) with higher density than the surrounding water. This layer is transported downslope by gravity to deeper water. In suitable conditions, this density current remains relatively close to the water body bottom. Thickness of the density current, or the height above the bottom that the fluidized sediment is lifted in the water column, is dependent upon grain size. The WID density current does not absolutely require a sloping bottom to flow, but a slope can assist the density current in a manner that can be likened to an underwater *avalanche*. WID also does not absolutely require ambient currents to transport the sediment out of the dredge cut because of the gravity-induced (density difference) component of flow of the density current. WID can be classified as a hydrodynamic dredging technique. These hydrodynamic dredging techniques have the common characteristic that the horizontal transport of the dredged material takes place in the water (PIANC 2013).

WID is a dredging technology that, in suitable site-specific conditions, can be used to achieve several USACE Engineering With Nature (EWN) objectives. EWN is the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes (*http://el.erdc.usace.army.mil/ewn/*). In alignment with these principles, WID uses the waterway and gravity to transport the sediment while retaining the sediment in the system for sediment management purposes. Since 1992, the USACE has contracted for dredging of approximately 3.95 million cubic yards (Myd^3) of material using WID. All of the WID has been done by Weeks Marine, Inc., and with the exception of a 1992 demonstration project in the upper Mississippi River, it has all been performed in the New Orleans and Houston areas.

THE WATER INJECTION DREDGING (WID) PROCESS: The Weeks Marine water injection dredge is illustrated in Figure 1. The Weeks Marine WID system is mounted on a standard marine barge measuring 32 feet (ft) in width and 120 ft in length. It has a draft of 5 to 6 ft. The dredge consists of a centrifugal pump powered by a diesel engine located amidships on the barge. Pipes running along each side of the barge deliver water from the pump, and a manifold with jets distribute the water along the top of and into the sediment. The diesel engine powering the water pump is rated at 900 horsepower. Water is pumped from directly below the barge (through a cylindrical pipe passing through the barge) to a header that supplies water to the two 28-inch (in.)-

diameter (diam) pipes running alongside the barge by means of two swing joints. The swing joints allow the two rigid steel pipes feeding the manifold to move up and down along the sides of the barge. The 30 in. diam, 38 ft long manifold is raised and lowered by means of a winch and steel cable at the front of the barge. Controls for the winch are located in both the tug pilothouse and the office area of the barge. Based on the current configuration, this WID has a minimum dredging depth of 5 ft and a maximum dredging depth of 70 ft. Water is jetted through holes in the manifold at a pump discharge water pressure of approximately 10 to 12 pounds per square inch.

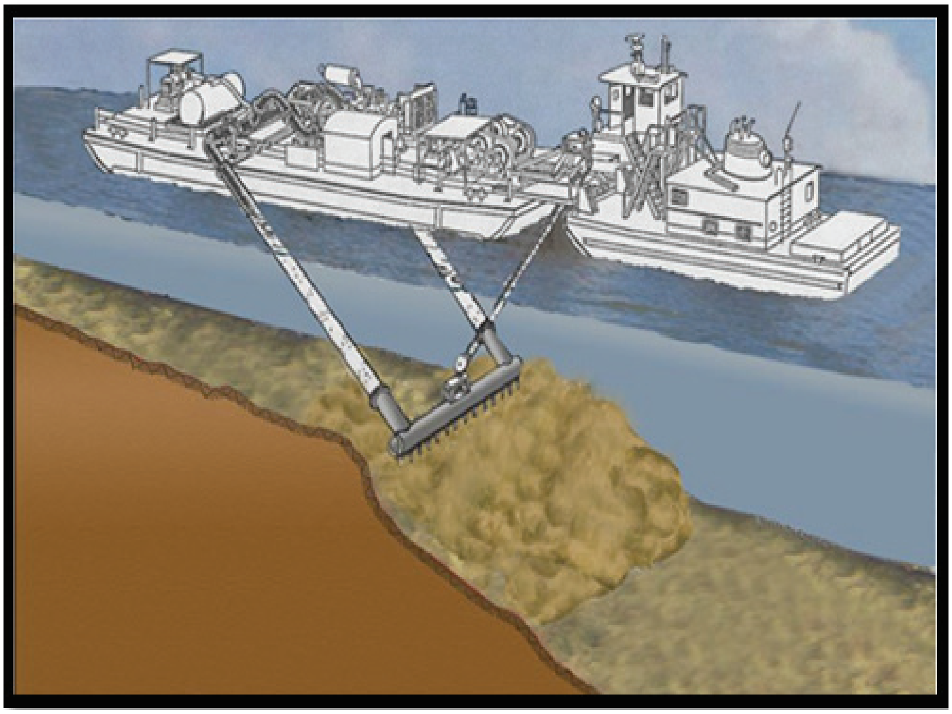

Figure 1. The Weeks Marine, Inc. water injection dredge.

The barge is also equipped with a diesel-powered electrical generator, a small water pump used to prime the main water pump, a small office, and a tool and supply shack. The barge is positioned and moved by means of a tug attached with steel cables to the back of the barge.

In operation, the barge is positioned over the shoaled area, the water pump engaged, and the manifold lowered to a depth within 1 to 2 ft above the surface of the sediment. The tug pushes the barge in both directions at speeds up to 4 to 6 knots in the area being worked, moving from one side of the area to the other with passes approximately 35 to 40 ft wide. The dredge generally initiates work in areas of highest sediment elevation or in the area nearest the desired location for deposition of the sediment. For maximum effectiveness, the dredge must maintain a gradient towards the deposition area to affect flow of the fluidized sediment. Weeks Marine personnel maintain that the direction of movement of the barge is not important since the jets in the manifold are directed downward perpendicular to the sediment surface and thus do not impart a directional thrust on the sediment. In long reaches, the dredge is operated using 400 to 800 ft passes. This helps maintain a gradient to the deposition area. The dredge works across and up and down the channel in increments until the full reach is covered. The length of time spent working in each increment is based on the characteristics of the sediment, the depth of sediment to be removed, and experience from previous projects.

Shoaled sediment elevation and distribution data needed for WID operations are collected using conventional hydrographic acoustic survey techniques. The project area is surveyed by means of a survey boat using established section lines and channel templates. This information is transferred to a computer program that develops an area contour plot showing channel stations, channel limits, and sediment height above the authorized depth. This contour plot is integrated with a navigation program that includes real-time Differential Global Positioning System (DGPS) signal input and a signal that provides a real-time depth reading on the manifold. The system output includes a visual image of the dredge location with respect to the channel boundaries, shoaled areas, elevation contours, and manifold depth and position relative to the top of the sediment. This output is displayed on computer monitors located in the tug pilothouse and the office area on the barge. This arrangement provides both the tug captain and barge personnel with a continuous display of the dredge location relative to the required area of operation. The survey data and resultant contour plot are generally updated once a day and more often if required by the specific project.

The tug captain, who also controls operation of the dredge, uses the contour plot to determine the area of operation for a particular shift or time period. The tug captain maneuvers the dredge within the defined area, moving back and forth and up and down over the area using the monitor display to determine and track relative position. The tug captain periodically lowers the manifold as the sediment elevation drops to maintain the manifold at a position immediately above the sediment surface. If the manifold is determined to be *dragging* the bottom, it is raised slightly and additional passes made until additional sediment is removed and the manifold can be lowered. In this manner, the tug captain can *feel* when the sediment has been removed to the desired depth. The data in the computer program is updated each time a new survey is completed, and a new area contour plot is generated. The whole process is completed when the shoal elevation is reduced to the required project depth.

USACE WID PROJECTS: Table 1 provides the locations and dates of all USACE WID projects since 1992.

Upper Mississippi River Demonstration Project. The first USACE WID project was in the Upper Mississippi River in June and July of 1992. It was a demonstration project conducted to meet several objectives as outlined in Clausner et al. (1993):

- verify the accuracy of the contractor's predictions on production rate, transport distance and direction, and sediment distribution in the water column
- determine if the technology worked in conditions found on the upper Mississippi River (moderate currents, medium-sized sand substrates, and two types of shoals typically found there [i.e., crossing and point bars])
- introduce the technology into an area with strong environmental concerns so that those concerns would be addressed during the demonstration.

In this demonstration, WID production rates were lower than the contractor's predictions. Two Upper Mississippi River sites were dredged. At one site, the contractor predicted approximately 250 cubic yards per hour (yd^3/hr) and achieved approximately 125 yd^3/hr. At the other site, the contractor predicted approximately 450 yd^3/hr and achieved approximately 250 yd^3/hr. According to Clausner et al. (1993), the distance and directions of the sediment transport “agreed well with contractor predictions, with the vast majority of the material staying within 200 to 400 ft of the limit of dredging.” It was found that the turbidity current remained within approximately 2 ft of the bottom and that the Iowa turbidity standard of 25 nephelometric turbidity units above background was not exceeded as specified (Clausner et al. 1993).

Table 1. USACE WID projects.

Project Name	Project Site	Cost ($)	Volume (yd^3)	Duration (hr)	Production Rate (yd^3/hr)
Upper Mississippi River 1992	WI and IL	NA	8,000	96	83
Calumet 1994	LA	41,438	15,644	24	652
New Orleans Harbor 1998	LA	731,975	650,482	1,368	476
New Orleans Harbor 2001	LA	794,260	334,530	849	394
Houston Ship Channel Emergency 2001	TX	335,810	113,200	96	1,179
Houston Ship Channel Bayport Flare 2001	TX	NA	116,671	48	2,431
Houston Ship Channel Carpenters to Green Bayou 2001	TX	NA	26,259	96	274
Houston Ship Channel Bayport Flare 2001	TX	NA	97,900	72	1,360
New Orleans Harbor 2002	LA	1,619,968	888,406	960	925
Michoud Canal 2002	LA	79,264	232,235	96	2,419
MRGO* 2003	LA	98,900	350,000	96	3,645
Houston Ship Channel Mid Bay 2004	TX	1,183,014	566,507	2,136	265
New Orleans Harbor 2005	TX	2,339,686	531,046	672	790
Calumet 2010	LA	260,436	22,406	24	934

* Mississippi River – Gulf Outlet (MRGO)

Michoud Canal. The U.S. Army Engineer District, New Orleans, contracted with Weeks Marine, Inc. to conduct WID in the Michoud Canal near New Orleans, LA, (Figure 2) in August 2002. The project was designed to remove a shoal in the canal and move 80,000 to 120,000 yd^3 of sediment from the canal into depressions in the channel bottom of the adjacent Mississippi River–Gulf Outlet (MRGO) (Figure 2). The WID area was approximately 5,200 ft long with a 1:1,000 slope toward the MRGO. A pre-dredge survey showed a maximum elevation of the shoal above the channel template of approximately 5 ft. The total volume of sediment moved out of the canal was determined to be 232,236 yd^3 over a 96 hr operating period, giving a production rate for the project of 2,419 yd^3/hr.

Figure 2. Site of the WID in Michoud Canal in August 2002.

Monitoring after the WID project was complete could not identify where the total volume of sediment removed from Michoud Canal was deposited. The fluidized sediment tends to flow down gradient and settle in thin layers in depressions. If the fluidized sediment spreads over a large area, the thickness of the deposits may be too small to be readily evident on traditional hydrographic surveys with an error band of +/-1 ft.

During the project, water quality and current velocity monitoring were conducted by personnel from the USACE Engineering Research and Development Center (ERDC), utilizing an acoustic Doppler current profiler (ADCP) and sampling equipment mounted on an ERDC survey boat. Data collection included current velocities and backscatter from the ADCP, suspended sediment samples using a Niskin tube, bottom samples, and near-bed samples using a ball valve sampler. Monitoring was conducted in front of and behind the dredge to document the extent and dispersion of any sediment plume generated by WID operations. Figure 3 shows a sample cross-channel plot of the ADCP acoustic backscatter data collected during the WID operation. Sediment suspended in the water column produces higher acoustic backscatter. Thus, the green area in Figure 3, near the bottom of the channel which represents higher backscatter than what was measured as being returned by the surrounding water (the blue and purple area), indicates an area of turbidity produced by the WID that extends up to 4 ft above the bottom. Water samples were collected and analyzed by ERDC. Analysis of the data indicated that most of the material moved by the WID remained within the bottom 3 to 5 ft of the water column and was not dispersed into the upper portion of the water column.

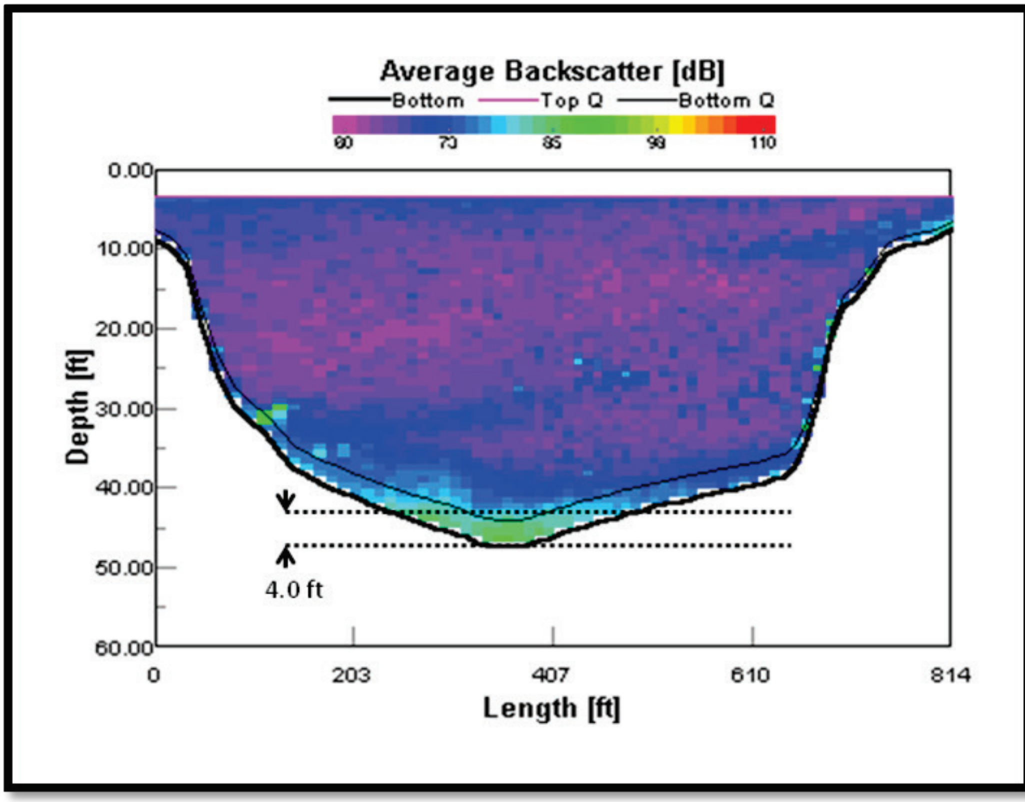

Figure 3. ADCP acoustic-backscatter, cross-channel plot in the Michoud Canal during WID.

ANALYSIS OF USACE WID PROJECTS: The Upper Mississippi River and the Michoud Canal WID projects were, respectively, one of the lowest production rates (Mississippi River) and one of the highest production rates (Michoud Canal) of the USACE's reviewed dredging projects. They demonstrated the important role that grain size plays in WID projects. The sediment dredged at the Upper Mississippi River site had a median grain size diameter (d_{50}) of 0.3 millimeters (mm) (0.01 in.) while the sediment in the Michoud Canal had a d_{50} grain size of 0.06 mm (0.002 in.). They resulted in very different production rates because the finer-grained material with its lesser fall velocity is easier to mobilize and keep suspended while it is transported downstream away from the dredge. Knox et al (1994) and Wilson (2007) recommend that WID not be used in areas with grain sizes greater than 0.2 mm (0.08 in.) unless site-specific conditions such as environmental concerns or the presence of very steep bottom slopes would make WID a viable option.

Wilson (2007) analyzed all USACE WID projects (Table 1) in terms of their Richardson Number as given by van Kessel and Kranenburg (1996) as

$$R_i = \left(\frac{\rho_m - \rho_f}{\rho_m}\right)\frac{gH\cos\theta}{U^2} \qquad (1)$$

where:

ρ_m = specific gravity of the turbidity current

ρ_f = specific gravity of the water
g = gravitational acceleration
H = turbidity current thickness
θ = bottom slope
U = average turbidity current speed.

The Richardson Number, R_i, includes considerations of how fast gravity-driven flow can transport sediment away from the dredge and the rate at which the dredge can supply sediment to the density current. These are functions of the bottom slope and the thickness of the density current. In Wilson's analysis, "high Richardson Numbers correspond to effective use of WID while low Richardson Numbers indicate other dredging methods would be more effective" (Wilson 2007). The Richardson number for the Michoud Canal Project was approximately 13 times greater than that for the Upper Mississippi River project.

Wilson's analysis also reveals the role of dredge-area confinement in WID production. Wilson (2007) found that "Long, clear channel stretches more effectively maintain a density current and production," while "confined areas will diminish WID production."

EUROPEAN WID EXPERIENCE

Elbe River. Maushake and Collins (2002) studied a 10-day WID project in the Elbe River in Germany in 1999. They conducted pre- and post-dredge acoustic surveys and collected bottom sediment samples. Figure 4 shows the grain-size distributions from samples taken before and after dredging. The d_{50} was 0.06 mm (0.002 in.) before dredging and 1.2 mm (0.047 in.) after dredging. Wilson (2007) also reviewed this study and notes that the plot presented in Figure 4 shows the grain size distributions begin to deviate around 0.2 mm (0.008 in.), supporting the advice of Knox et al. (1994) that, except under special circumstances, WID should not be used when the grain size exceeds 0.2 mm (0.008 in.).

Hellevoetsluis. Borst et al. (1994) described extensive data collected during a WID project to remove 157,300 yd^3 of material from an estuary near Hellevoetsluis, Netherlands. The area for the WID had a similar bottom slope (i.e., 1:1,000) to the Michoud WID site and similar sediment grain size (a silt/clay mixture). Measurements of the density current were made that allow the direct calculation of the Richardson Number (Equation 1) without having to estimate the flow rate, or the solids concentration, of the density current as was done in the Wilson (2007) analysis. In an example velocity and density profile provided by Borst et al. (1994, Figure 4 in their paper), the average density of the turbidity current is approximately 1,065 kilograms per cubic meter (kg/m^3) (66.49 pounds per cubic foot [lb/ft^3]), the average velocity is 0.20 m/second (s) (0.66 ft/s), and the thickness of the turbidity current is 0.70 m (2.30 ft). Substituting these values and a $\cos\theta \sim 1$ for the slope of 1:1,000 into Equation 1 gives a Richardson number of 10.47. This value is relative to that between the Richardson number for the New Orleans Harbor 1998 WID project (Table 1) that had a production rate of 476 yd^3/hr and the Houston Ship Channel Emergency 2001 WID project (Table 1) that had a production rate of 1,179 yd^3/hr. Borst et al. (1994) provide no information on the production rates for the Hellevoetsluis project; however, PIANC (2013) states that the production rate for this project was 624 yd^3/hr.

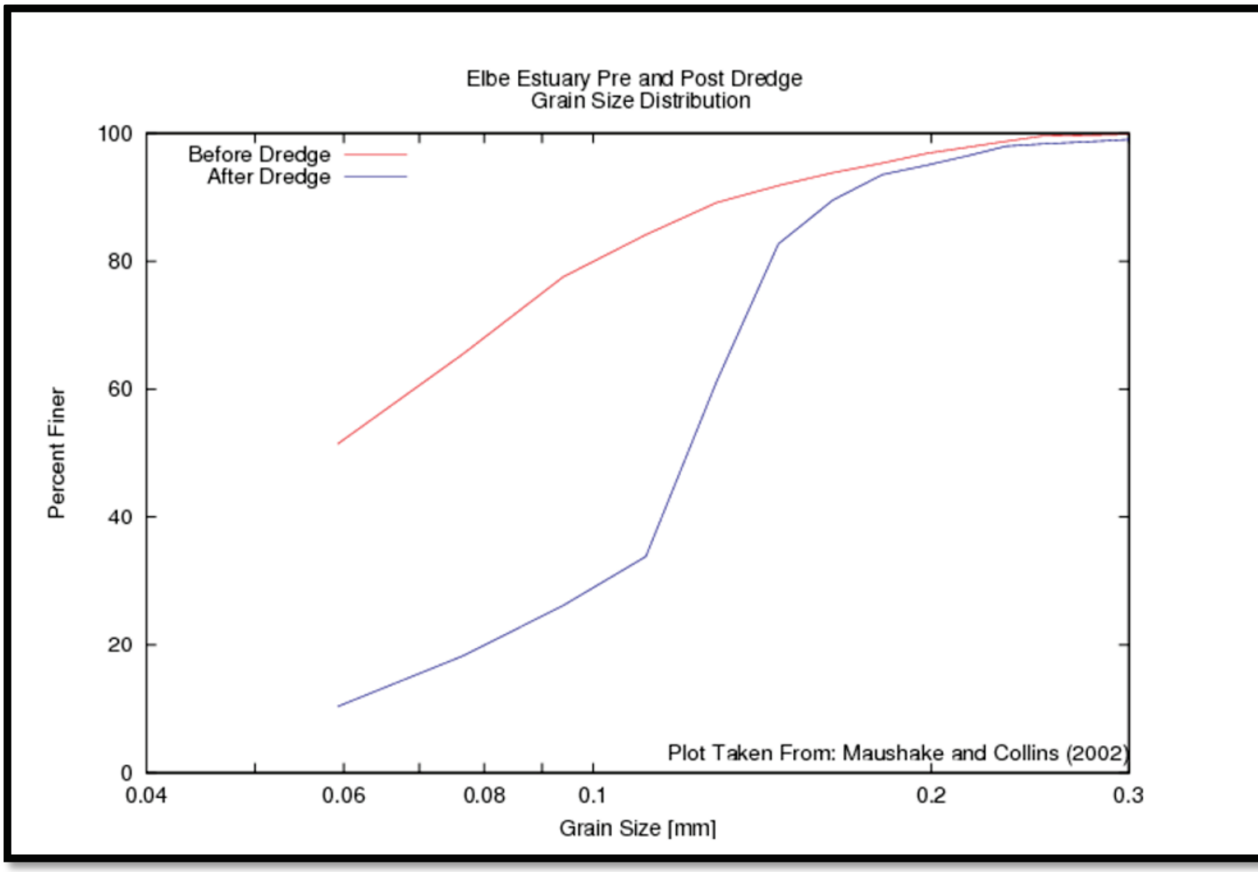

Figure 4. Elbe River pre- and post-dredge grain size distributions. (after Maushake and Collins 2002).

Wilson (2007) gives the production rates shown in Table 2 for other documented European WID projects.

Table 2. European WID projects.

Project Name	Soil Description	Volume (yd^3)	Duration (hr)	Production Rate (yd^3/hr)
Epon Harbor, Delfzigl, Netherlands	silt and fine sand 0.3 mm	209,600	192	1,092
Shipping Lane Boontjes, Waddenzee, Netherlands	N/A	19,620	19	1,033
Ferry Harbor and Entrance Channel, Den Burg, Texel, Netherlands	N/A	26,200	13	2,015
Wesbuitenhaven, Terneuzen, Netherlands	N/A	655,000	222	2,950
Crouch River, Great Britain	clayey silt	8,060	11	733

CONCLUSIONS: The Upper Mississippi River 1992 and the Elbe River 1999 projects demonstrated that, unless there are special site-specific conditions such as environmental concerns or the presence of very steep bottom slopes, WID should only be used to move fine-grained sediment. Knox et al. (1994) and Wilson (2007) recommend that WID not be used in areas with d_{50} grain sizes greater than 0.2 mm (0.08 in.).

Three of the WID projects presented here (two in the United States and one in Europe) stand out as having high production rates. They are the 2002 Michoud Canal project with a production rate of 2,419 yd^3/hr, the 2003 MRGO project with a production rate of 3,645 yd^3/hr, and the Wesbuitenhaven, Terneuzen, project with a production rate of 2,948 yd^3/hr (Tables 1 and 2). The grain size for the Michoud Canal and the MRGO projects is known to be classified as silt with a d_{50} of approximately 0.06 mm (0.002 in.). Presumably, the Wesbuitenhaven, Terneuzen, project also had fine-grained sediment. In addition to each of these projects having high production rates, another aspect connects them; all three locations have long channel reaches. The Michoud Canal and the Wesbuitenhaven, Terneuzen, projects were both along approximately 5,250 ft long channel reaches, and the MRGO was along an approximately 10,500 ft reach. In comparison, the Calumet projects (Table 1) were also in silt-size sediment. However, they were in a confined location, and their production rates were only 652 yd^3/hr (1994) and 934 yd^3/hr (2010). Most likely, one reason the three projects with the long reaches were able to achieve such high production rates, in comparison to other projects with similar sediments, is because in the long channels the dredge can stay parallel to the bottom slope while operating without time-consuming maneuvering. The longer channel reaches may also make it easier for the dredge to maintain an effective density current.

The Richardson number seems to be a reasonable indictor of WID efficiency, with projects having higher numbers as given by Equation 1 being more productive. Wilson (2007) presents a way to calculate a Richarson number for the project using an estimates of density current thickness. For a project near Hellevoetsluis, Netherlands (Borst et al. 1994), measurements were made that allowed for a direct calculation of the Richardson number. The calculated value compared reasonably well with the values calculated by Wilson (2007).

Monitoring of suspended sediment in the Michoud Canal and near Hellevoetsluis, Netherlands, has shown that, in the right conditions, the density current generated by WID can be confined to the near bottom. Confining the material to near the channel bottom can prevent sediment from being deposited in environmentally sensitive areas outside the channel. Also, keeping desirable sediment within the system and not transporting it to other sites aligns the dredging process with the natural sedimentation processes at the site. Keeping the sediment within the system can prevent erosion processes from altering the nature of channel that might, at some point, make the channel unsustainable for safe and efficient navigation. In this way, WID contributes significantly to the USACE EWN goals (*el.erdc.usace.army.mil/ewn/*).

POINTS OF CONTACT: For additional information on water injection dredging, contact Timothy Welp (601-634-2083, *Timothy.L.Welp@usace.army.mil*). This technical note should be cited as follows:

Welp, T. L., M. W. Tubman, D. A. Wilson, and C. E. Pollock. 2017. *Water injection dredging*. ERDC TN-DOER-T14. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *www.wes.army.mil/el/dots/doer*

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