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THE HISTORY OF DREDGING AT THE PORT OF HOUSTON: DITCHING HIGH AND LOW TO BUILD A PORT

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ABSTRACT

Today the Port of Houston is one of the largest and busiest ports in the United States and is internationally prominent for its petrochemical complex. Its story is remarkable considering that it began without the benefit of a natural harbor or a strong population base. The story of the Port is a story of dredging and associated tasks that resulted in a 67-mile ditch across a shallow estuary and through a bayou once barely suitable for a flat boat.

The history of dredging and channel development is a story of private and federal partnerships, forged by strong-willed entrepreneurs and civil servants and military engineering. Over forty years of mutual support resulted in the first ever federal cost-share agreement for dredging in 1914, and included federal dredges partially funded by the City of Houston.

Channels and tributaries were privately constructed and chained off from public use; were federalized, privatized, publically improved, and later federally maintained. Dredging was a huge challenge that has strained the capability for material disposal, and led to efforts to channelize the water way. Improvements straightened the tortious flow of the bayou, and have been balanced by commitments for beneficial use of dredge material for environmental purposes. Complicating the progress has been an evolution of Corps processes, policy, and interpretations of federal law regarding temporary occupation of projects, water quality, and real estate that have affected dredging and commerce. The history of the Port of Houston is ultimately a history of dredging to create and maintain channels for an irreplaceable port.

Keywords: Evolution of Dredge Technology, Dredge Material Disposal Challenges, Changes in Dredging Costs, Oyster Habitat, Government Contractor Defense

INTRODUCTION

The history of Houston and its ship channel have been often told. It is a story about ambition, politics, money, marketing, and development. The story line records advances in depths and widths, and then growth of industry enabled by the waterway. This paper looks at the dredging industry in Houston over the last 150 years and underscores the various construction, technology, innovation, decisions, and practices that created the channel and transformed the bay and riverine landscape.

The Early Years

The original water route from Houston to the Gulf of Mexico in the mid-1850's was a torturous route that is miles longer than today's channel. In technical terms, Houston's channel is a ditch dug through a bay, a river and a bayou. Early work consisted of never-ending removal of snags, logs, and trees that overhung the waterway, operation of a small dredge, and use of hand tools and clam shell buckets to remove oyster reefs and sand bars that were shallow enough to enable cattle to be herded across Galveston Bay. In 1867, the City of Houston organized and funded the Buffalo Bayou Ship Channel Company to make improvements to enable vessels to travel all the way to downtown—over 96 km (60 mi) inland. By 1873 the company had two dredges, two steam tugs, six dump boats, a steam derrick and three barges at work. Its goal was 1.8 m to 3.65 m (6 ft to 12 ft) of water that would be sufficient for steamboat

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service. The then U.S. Engineer Department (Corps) concurrently worked to link Galveston and Houston's channel through the bays and river, taking the natural 1.8 m to 2.4 m (6 ft to 8 ft) depth toward an authorized 3.65 m (12 ft) depth. In 1875 eight dredges worked simultaneously, day and night; Galveston Bay was described as "one blaze of light" at night because of dredging. (Sibley1968). In spite of the quantity of plant on station, the work was complicated by old sabotage; Lt. James B. Quinn wrote in 1875 that "obstructions placed in the river by Confederates during the late war to prevent Federal gunboats from ascending the river… prove at present to be a very great obstacle to commerce… Obstructions were flats and scows filled with shells and sunk, one upon another, and secured by piles." (Chief 1875).

In 1867, Charles Morgan, a shipping magnate, dredged an 8.7 km (5.4 mi) channel (Morgan Cut) partially through a peninsula but fashioned a chain across the canal and collected tolls. But in the 1880's dredging progress was dismal; sedimentation of the channel was so significant that in 1883 the mayor of Houston suggested leaving only a barge lane in service, and the Corps reported "the channel could not be made permanent at any cost." (Chief 1883).

In 1892 the government bought Morgan's canal for $92,316.85, which was the final piece of the channel plan for Houston. The government hired a watchman for the Cut for an annual salary of $360, with no pay raise for a decade--although one year the budget was increased to $360.40, so that the Corps could buy rubber stamps deemed necessary for the job.

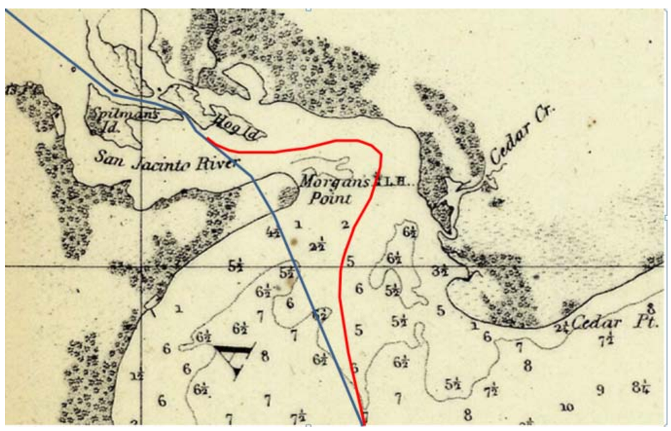

Figure 1. Morgan Cut (blue) vs U.S. channel (red).

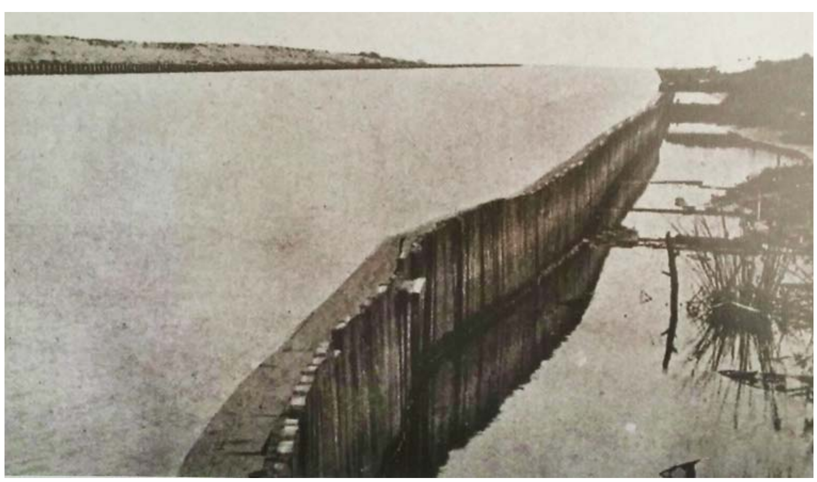

Figure 2. Morgan Cut channel and bulkhead.

In the next 15 years, government and contract dredges worked to complete a 5.64 m (18.5 ft) channel using stationary hydraulic dredges, and to maintain a shallow draft channel to the city, which quickly silted in because of bank wash and sewage. The shallow draft work used a city-owned dipper dredge with 1.91 m^3 (2.5 CY) bucket and scows that would dump at the deep draft turning basin for redredging and upland disposal. In 1909, the Corps commissioned the U.S. Dredge Galveston, a steel hulled, 92 m (304 ft) long, 15.5 m (51 ft) beam hopper dredge with 2100 m^3 (2,750 CY) capacity, which worked along the full length of the channel.

Figure 3. Future channel turning basin, 1898.

Figure 4. Dredge Washington, 1909 Turning Basin.

A $3,700,000 channel plan was developed between 1899 and 1905 for a 7.62 m (25 ft) deep, 45.7 m (150 ft) wide channel with side slopes from 1:3 in the bay to 1:2 in the bayou; 7925 m (26,000 ft) of dike revetment, and purchase of one hydraulic dredge for $150,000. The plan provided for ten channel cutoffs and one "shave", which together would reduce the channel length by four miles. With financing assistance from the city, Atlantic, Gulf, and Pacific Company (Atlantic) was awarded a contract by the Corps in 1912 to complete a full 52-mile, 25-foot deep channel in 3.5 years for a fixed price of $2,365,711; at the time, the estimated quantity of dredging was 16,802,000 m^3 (22,000,000 CY) of new work material. But by this time, the enemy of the project was siltation and the 18,288 m (60,000 linear ft) wooden sheet pile and brush silt wall constructed along the channel in the bay was inadequate to prevent an estimated 1,529,110 m^3 to 2,675,942 m^3 (2,000,000 CY to 3,500,000 CY) of infill of the channel annually. Atlantic and its subcontractors put six dredges on the project and completed the project a year early, absorbing the additional cost of dredging 765,000 m^3 (10,000,000 CY) of maintenance material. Because the contract required acceptance of the full channel at once, Atlantic had a dredge trail behind the acceptance survey party up the channel to perform remedial dredging in order to enable Corps acceptance. Atlantic continued to work on the Houston Ship Channel (HSC) for over 50 years, and by 1961 had dredged over 153,000,000 m^3 (200,000,000 CY) of material. (Atlantic 1961).

Figure 5. Atlantic, Gulf and Pacific Dredge Texas serving as booster pump for Dredge Pensacola, HSC Turning Basin circa 1928.

The Next Half Century

The next five decades, through 1965, were a period of incremental channel deepening by 0.6 m to 1.2 m (2 ft to 4 ft) about every 10 years. Advance maintenance was recognized as a key to commerce. In 1935, the upstream turning basin, which was historically clogged by runoff from development of the city six miles upstream, was approved for 14 feet of advance maintenance, with 0.6 m to 0.91 m (2 ft to 3 ft) of advance maintenance allowed elsewhere along the channel. Other exceptional advance maintenance permissions were not granted until the early 1990's, when necessary dredging to mine clay for placement area dike construction provided the opportunity. Silt fences in the bay were abandoned, in part because accretions from unconfined placement created a "barrier island" along the channel in the upper bay, which helped to lower siltation rates in nearby reaches. Part of the wood sheet pile wall constructed for Morgan's Cut burned in 1904, but the Cut was gradually widened so retaining structures were not needed. By the 1930's, dredges in Houston could move 229,000 m³ to 382,000 m³ (300,000 CY to 500,000 CY) per month under favorable conditions, but nothing approached the record 964,597 m³ (1,261,646 CY) of soft new work material dredged in one month by the dredge Texas in 1914. (Crotty 1933). The wooden-hulled Dredge Texas worked the HSC for over 50 years. (Atlantic 1961).

Much of the maintenance work in the HSC was performed by government dredges, but deepening work in the HSC was typically contracted. Dredging companies that worked the channel included Atlantic, Sternberg Dredging Company, St. Louis; Standard Dredging Company; and Lake Arthur Dredging Company.

Figure 6. Stern Wheel Dredge Delatour.

Houston-Galveston Navigation Channels Project (HSC Widening and Deepening) and Current Practice

Section 101(a) of the Water Resources Development Act of 1996 (WRDA 1996) specifically authorized a number of projects for water resources development and conservation to be carried out in accordance with the plans and subject to the conditions referenced in reports designated in the WRDA 1996. Among those projects was the Houston Ship Channel (HSC), which after over 15 years of planning and study, Congress authorized deepening 83.7km (52 mi) to 13.7 m (45 ft) and widening to 121 m to 161 m (400 ft to 530 ft) at a total cost of $298,334,000, of which $197, 237,000 would come from federal funds. Pursuant to Section 221 of the Flood Control Act of 1970, as amended, and Section 101 of the Water Resources Development Act of 1986 (WRDA 1986), as amended, the Corps must enter into a written cooperation agreement with its non-federal sponsor before any portion of the water resources project can commence. Accordingly, non-federal sponsors of water resources projects authorized by the Corps must take into account for scheduling purposes that projects cannot begin until a cooperation agreement has been agreed to and executed. This may be a long lead item; and schedules should be set accordingly.

In the case of the HSC, the project cooperation agreement with the Corps, the Port of Houston Authority (PHA), and the Port of Galveston (the latter had cost share responsibility for the entrance channel of the HSC) was completed within two years of authorization of the project, in 1998, and dredging began almost immediately. The project involved over 45,900,000 m³ (60,000,000 CY) of new work dredging, creation of approximately 1214 ha (3,000 ac) of marsh, restoration of islands in Galveston and San Jacinto Bay, and construction of over 48.6 ha (120 ac) of oyster habitat in mitigation. In 2000, Congress authorized construction of 3.65m by 71.6 m (12 ft by 235 ft) barge lanes along both sides of the HSC in the 40.2 km (25 mile) bay reach as part of the project. The 13.72 m (45 ft) channel was opened in 2005. The 1998 authorized cost was $298 million, and by 2015, over $700 million had been expended for construction, environmental mitigation, dredge material placement areas (including the new 242 ha (600 ac) Mid-bay placement area), and maintenance cycles during the construction period. Mid-bay marsh was converted to a placement area during the project. Mid-bay was completed using a 19.9 m³ (26 CY) clamshell dredge, two 3058 m³ (4,000 CY) hopper dredges, and two 762 mm (30 in) cutter suction dredges. Houston-Galveston Navigation Channels Project dredging contractors included Great Lakes Dredge & Dock, Weeks Marine, King Fisher Marine Services, T.W. LaQuay, Renda Marine, Mike Hooks, Bean Stuyvesant, and Manson Construction.

Tributary Channels of the HSC

While the federal government had a major role in the development of the main shipping channel, most of the tributaries of the HSC were developed or extensively maintained by non-federal interests. Jacintoport channel was constructed by the Corps to support a munitions depot at the beginning of WWII, and was eventually privatized in the 1980's; the Port of Houston Authority and private terminals assumed operation and maintenance. Although Congress authorized the Corps in 2007 to prepare for assumption of maintenance, assumption of maintenance of Jacintoport channel will not occur until mid-2015 at the earliest. Although federal maintenance will be at 12.19 m (40 ft) MLT, part of Jacintoport will be privately maintained at 13.7 2 m (45 ft). The channel and berths are typically hydraulically dredged as an option to the Corps HSC channel contract and pass-by individual contracts.

Morgan's Cut was a key element of the early main ship channel, and an adjoining tributary channel later became important to the region. The Port Authority constructed the 2133 m (7,000 ft) waterway and turning basin as a 91.4 m by 12.19 m (300 ft by 40 ft) channel beginning in the early 1970's to support the Gulf coast's first dedicated container terminal; new work dredging in 1972 cost $0.42 per CY. The Port Authority maintained the channel for over 20 years. Congress authorized assumption of maintenance in 1986, and the Corps assumed maintenance of the channel in 1993. The Corps clay-mined most of the channel and turning basin in the early 2000's to a depth of over 15.9 m (52 ft) to support construction of dikes in the adjoining placement area on Spilman Island, a significant beneficial use. As part of its channel modernization program in 2014-2015, the Port Authority relocated the deep draft ship channel 75 feet to the north in order to expand berthing areas for larger ships and bigger container cranes, and deepened the channel and berths to 13.72m (45 ft) to match the adjoining main ship channel depth. Prior clay mining by the Corps that produced dike material reduced the volume of new work material dredged in the PHA project to approximately 569,600 m³ (745, 000 CY), and 1,009,200 m³ (1,320,000 CY) total. The dredging was complicated by placement area dike revetment riprap having been displaced into the dredged area by Hurricane Ike in 2008, and by the need to extract remnants of old mooring dolphins "removed" in the early 1990's by cutting at the mud line. Orion Construction Company, the prime contractor, removed the main and batter piles by dredging along the line of the buried piles, which allowed the 132 piles to be accessed for mechanical removal.

Five miles south of Barbours Cut and connecting to the HSC across Galveston Bay, the Bayport Ship Channel was conceived in the 1950's and constructed in the mid-1960s as a barge channel to stimulate development of general cargo and liquid bulk terminals serving the growing chemical and refinery industry in Houston. The original barge lane was expanded in 1974 to a 6.4 km (4 mi) long, 91.4 m (300 ft) wide, 12.19 m (40 ft) deep channel across the bay and into the land cut. Non-federal maintenance of the channel was a financial burden to the Bayport companies, and dredging was generally scheduled when siltation resulted in draft restrictions of three feet or greater or potentially unsafe navigation conditions. Congress authorized federal assumption of maintenance in 1986, and turnover to the Corps occurred in 1994. The Bayport flare at the HSC has proven to be one of heaviest shoaling areas in the entire channel system, and requires the Corps to schedule maintenance dredging annually. As part of its 2014 self-funded channel modernization program, the Port Authority is widening the channel from 91.4 m (300 ft) to 121.9 m (400 ft) in the bay reach, to 106.7 m (350 ft) in the land cut, and deepening the channel to 13.72 m (45 ft).

Although part of the Bayport channel had been partially clay mined for dike construction in the early 2000's, the improvement project will dredge approximately 3,516,952 m^3 (4,600,000 CY) of new work and 764,555 m^3 (1,000,000 CY) of maintenance material. Most of the suitable new work material is being used to hydraulically raise dikes on an island placement area, providing approximately 4,587,329 m^3 (6,000,000 CY) of future capacity. This $60 million of work was part of the contract awarded to Orion Construction Company. Orion will use one dredge for channel widening and deepening, and will deploy its electric dredge for deepening adjacent container yard berths. Concurrently, one of the liquid bulk terminals at Bayport is developing a new berth. Because federal placement areas were not available, the berth is being dredged mechanically, and the dredge material is being placed on adjacent Port Authority property and formed into 6.1 m (20 ft) high sight and sound berms.

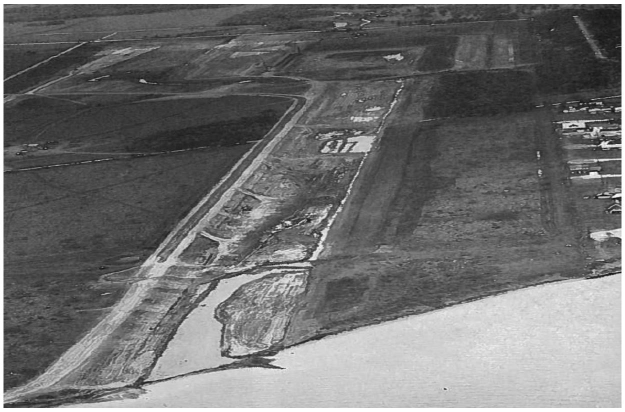

Figure 7. Initial Bayport Barge Channel, 1964.

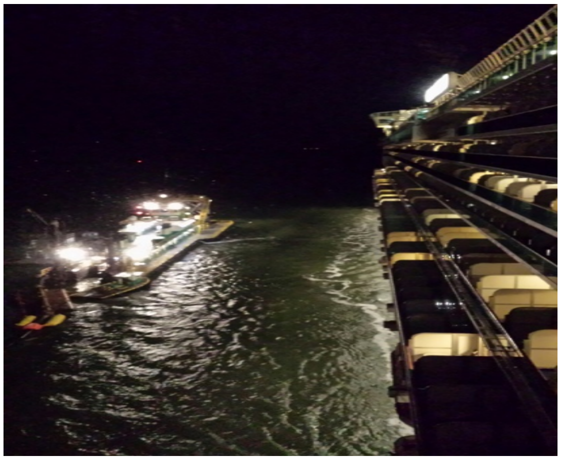

Figure 8. Cruise ship passing Dredge LaQuay deepening and widening Bayport Channel, 2015.

Schedule and Pace of Federal Projects.

Since the initial 3.65 m (12 ft) channel was constructed, Congress has authorized seven main Houston ship channel deepening projects:

- in 1899, to 5.64 m (18.5 ft);
- in 1905, to 6.62 m (25 ft);
- in 1919, to 9.14 m (30 ft), and later to 9.75 m (32 feet);
- in 1948, to 10.97 m (36 ft);
- in 1958, to 12.19 m (40 ft); and
- in 1998, to 13.72 m (45 ft).

Although the 7.62m (25 ft) project completed in 1914 was expedited with non-federal funds and involved up to seven dredges at once, subsequent federal projects were considerably slower paced because of limited federal funding. On average, overall project completion occurred 10.7 years after congressional authorization, and the completion of the upper bayou reach lagged seven years behind the bay reach and entrance channel work. The total volume of new work dredging for the HSC and tributaries since 1900 and the completion of the 3.65 m (12 ft) project is approximately 210,252,600 m^3 (275,000,000 CY).

Corps workload and the need to stretch operations and maintenance funds caused other activities to move at a very slow pace. Federal assumption of maintenance (AOM) of channels occurs only if the Secretary of the Army for Civil Works determines that such maintenance is economically justified and environmentally acceptable and that the channel was constructed in accordance with applicable permits and appropriate engineering and design standards. For example, Section 5001 of the Water Resources Development Act of 2007 (WRDA 2007) authorized the federal AOM for the Jacintoport Navigation Channel, a tributary channel of the HSC, provided that the Secretary made that determination. In August 2012, the Corps issued a draft AOM Decision Document for public comment which addressed: (1) environmental acceptability by reviewing environmental permitting of the project; (2) economic justification by demonstrating that project benefits, as defined by the Water Resources Council's Principles and Guidelines, exceed project operation and maintenance costs, and by evaluating lesser depth alternatives; (3) consistency with federal policy; and (4) a Dredged Material Management Plan demonstrating there is adequate disposal capacity for 20 years of operation and maintenance of the channel. In this draft AOM Decision Document, issued five years after the statutory authorization, the Corps recommended that the federal government assume maintenance of the channel.

As the Jacintoport Navigation Channel experience demonstrates, AOM approval can be a lengthy process. It has taken an average of over seven years for the Corps to complete and approve AOM for HSC tributaries. By contrast, the Port Authority prepared and funded the AOM report for the current Bayport and Barbours Cut channel improvements, which took one year for completion and approval, and assumption of maintenance is expected to occur immediately after18 months of construction. Because non-federal channel work has been accomplished as an option to Corps contracting for main channel work, the AOM will not reduce the number of contracting opportunities.

Non-Navigation Dredging

Although the public generally associates dredging with Houston's ship channels, other dredging operations have occurred for almost as long as the deep draft ship channel has existed.

In the days of the Houston area oil boom in the early 1920's and 1930's, pipeline crossings of the ship channel over a 40.2 km (25 mi) reach were traditionally laid in dredged trenches. Dike raises for placement areas in the bay have been facilitated by clay mining of channels and turning basins; the clay is either stockpiled within the placement area for mechanical construction of dikes, or is directly pumped to hydraulic form dikes.

Table of Contents

Figure 9. HSC Pipeline Crossing.

Figure 10. Hydraulic forming marsh levees, 2011.

Galveston Bay has historically been one of the most productive oyster habitats in the country. Because of the absence of rock and gravel in the region, oyster shell was mined as aggregate for construction, and even as a livestock feed supplement. From around 1900 to 1969, an estimated 183,493,200 m^3 (240,000,000 CY) of shell was removed from the bay, including the mining of reefs that first formed over 250,000 years ago. The first steam powered orange-peel bucket oyster dredge in Houston was constructed in 1905, and small hydraulic suction dredges operated continuously in the bay for over six decades. (POH Magazine 1980). The mining of ancient beds and reefs to depths of as much as 15.24 m (50 ft) in a bay that averages 1.8 m to 2.4 m (6 ft to 8 ft) deep later proved problematic when new placement area islands were being located to support ship channel improvements in the early 1990's. Additionally, the loss of oyster habitat has likely contributed to significant degradation of water quality and turbidity of the bay to the extent that return water from placement areas today is much clearer than the receiving waters of the channel or bay.

Indeed, the issue of oyster habitat degradation and its impact on the surrounding ecosystem has been central to a number of complaints and lawsuits in the region. For example, on June 29, 2012, the Commissioners Court of Chambers County adopted a resolution, at the request of a local seafood business, which identified proposed dredging at the Bayport Ship Channel as a "serious threat and danger" to "large-scale, viable oyster reefs [which] are essential to sustaining and improving the healthy habitat of essential fish and invertebrates, the water quality and clarity of Trinity Bay and [the] local economy." (Haynes 2012). The resolution encouraged the use of "core-sampling, side scan sonar, [and] first cut bottoms" to mitigate the effects of dredging and discouraged "the use of second and subsequent cuts, and the placement of shell, clutch and other materials on bottoms predominate with mud and sediment." (Haynes 2012).

Lawsuits brought by private citizens, businesses (including oyster farming operations) and environmental groups related to the impacts caused by dreding projects pose a unique problem for contractors. Namely, governmental entities and officials are for the most part protected from lawsuits by sovereign immunity. As a result, these lawsuits are typically brought against *only* the government contractors, or, if sued, the government entities are swiftly dismissed from the action leaving the contractors holding the bag. *See, e.g. Nat'l Audobon Society, Inc. v. Johnson*, 317 F. Supp.133 (1970) (declining to interfere with the official functions of officials in the Texas Parks and Wildlife Commission related to issuance of dredging permits such that the suit against the State must fail). Sovereign immunity effectively disallows lawsuits brought against governmental units and their agents, with respect to performance of their governmental functions, unless the State has consented to suit through legislative waiver of that immunity. *City of Highland Haven v. Taylor*, 2015 Tex. App. LEXIS 1366, at *5 (Tex. App. Feb. 12, 2015).

As one form of protection, government contractors should consider strong indemnification and contribution provisions in their contracts with government entities. *See, e.g., Fisherman's Harvest Inc. v. PBS&J*, 2008 U.S. Dist. LEXIS 58898 (S.D.Tex. Aug. 4, 2008) (where government contractor, a defendant in a lawsuit brought by oyster farmers alleging negligence in dredging, filed a third-party claim against the Corps alleging a contractual right to contribution and indemnification). Another potential protection against such lawsuits is to assert the government contractor defense. *Ackerson v. Bean Dredging LLC*, 589 F.3d 196 (5th Cir. 2009). The Fifth Circuit Court of Appeals, which is the Circuit Court with jurisdiction over Texas, recently affirmed a decision dismissing claims against the defendant contractors based on a broad construction of the government contractor defense, in which the court noted the work was a public works project and that the "actions causing the alleged harm were taken pursuant to contracts with the federal government that were for the purpose of furthering projects authorized by acts of Congress." *Id.* at 206-207. Because the plaintiffs had not alleged that the government contractors exceeded their authority in performing the dredging project or deviated from Congress's direction, the claims "attack[ed] Congress' policy . . . not any separate act of negligence by the contractor defendants." *Id.* As such, where the work was performed in "conformity with the terms [of the contract], no liability can be imposed upon it for any damages." *Id.* at 206 (citing *Yearsley v. W.A. Ross Constr. Co.*, 30 9U.S. 18 (1940)). To maximize the utility of this defense, it is integral to ensure that the specifications in the project contract are sufficiently detailed to demonstrate the government's direction on the project. Since deciding *Ackerson*, the Fifth Circuit decided in *In re Katrina Canal Breaches Litig.*, where, according to the Court, the contract specifications were not reasonably precise enough to afford the defendant contractor the protection of the government contractor defense. 620 F.3d 455 (5th Cir. 2010) (engaging in a fact-intensive analysis of the specifications and communications between the contractor and government entity prior to performance). Given the inevitability of these lawsuits, and the likelihood that the government and its officials will be dismissed from the action or not named at all, it is important to consider these precautions at the early stages of contract negotiation if the contractor has the power to so negotiate terms.

Figure 11. Oyster Shell Dredging from Texas Bays.

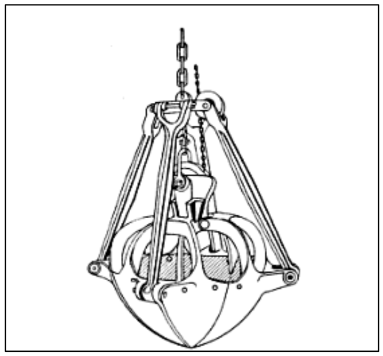

Figure 12. Orange peel bucket, 1912.

Dredging Technology in Houston's History

Routing a channel through Morgan Cut was an audacious move, and its construction was surprisingly sophisticated for the region. Excavation from 1866-1870 included use of an endless chain bucket excavator and a belt conveyor system for the material; 130 years later, a contractor's attempt at mechanical excavation of berths at Bayport and use of an electrical conveyor belt (both methods to minimize air emissions) failed.

In 1901, around the time oil was discovered in Texas, hydraulic dredges began to convert from coal to oil-fired boilers. The conversion could reduce a dredge operating cost by $1000 per month, which cut the cost of dredging per CY by half (or dramatically increased profits).

One of the most ambitious dredging projects in U.S. history was the post-1900 hurricane work to elevate the City of Galveston. All the structures in hundreds of city blocks were elevated, and dredges pumped millions of CY of sand and silt onto land under occupied houses to raise the height of the island by over 3.05 m (10 ft) in areas. A fleet of hopper dredges entered constructed canals to pump out material available off shore, while hydraulic pumps on a manifold system with up to 1066 mm (42 in) pipe distributed the dredge material around the island.

Figure 13. Dredge placement, Galveston.

As part of the 1902-1905 fleet of equipment, the dredge Atlantic appeared; she was a sea-going hydraulic dredge with a removable section of bow through which the ladder was projected for dredging; the bow was bolted in place during transit.[i]

The 1905 steam-powered orange peel dredge for oyster reefs was the first of its kind in the Gulf. In 1910, the Corps reported use of an "innovative" method to floating dredge pipelines on barges, instead of supporting pipe on pile trestles. In 1930, one dredge company used a quick-opening dredge line that would enable resumption of dredging within ten minutes after breaking for an approaching ship. While recent memories recall electric dredge use for federal and private work from the early 1990's to the present, Houston first had an electric dredge working on the main channel in 1912. (Crotty 1933).

By the early 1930's, dredges in Houston included steam-powered, steam turbine, diesel, diesel-electric, and all-electric dredges. Spuds were typically 762 mm to 914 mm (30 in to 36 in) timbers up to 21.3 m (70 ft) long. In 1932, the dredge Duplex began work in Houston, and was considered unique. She was a diesel powered, electrical engined self-propelled hydraulic dredge convertible to a swinging boom 4.6 m³ (6 CY) clam shell bucket dredge. Duplex performed new work dredging for 8.5 cents per CY. (POH Magazine 1932).

Hopper dredges were once used 64.4 km (40 mi) up channel from Galveston where "dumping grounds" were unavailable, and discharged to basins for rehandling by hydraulic suction dredges for final placement at upland sites. In 1927, the U.S. dredge Dan C. Kingman moved 276,000 m³ (362,000 CY) that way, or about 25% of the annual dredge volume of its companion hydraulic dredge. By the early 1930's, the Corps established booster pump stations on land as a more economical solution. In the early years of the channel, excessive maintenance material hindered progress. The bulkhead retaining walls first formed for Morgan's Cut were extended for up to twelve miles down the bay reach, in the form of king pile walls with brush infill for sediment management. When that wall proved inadequate, a second sheet pile wall was constructed offset 30.48 m (100 ft) from the first line of silt defense. While the pile walls were eventually abandoned, remnants of the wall are still charted as obstructions to boaters in Galveston Bay.

Bayport is notable for the container terminal permit that conditioned new construction to meet strict air emissions and noise limits. (Army 2004). As a result, new work berth dredging since the Bayport container terminal construction in 2006 has been performed by electric-powered hydraulic dredges. The sound level improvement standard imposed for the terminal eventually caused the Corps to specify similar sound attenuation requirements for federal maintenance dredges working in the land cut of the Bayport channel, an acceptable tradeoff of cost for good will among the residential neighborhoods adjacent to the ship channel. Since 2010, the Corps has completed maintenance dredging with diesel-powered dredges operating within 121 m (400 ft) of residential property with sound levels no higher than 10dBA (hourly average) over ambient levels of 50dBA to 55dBA at night. (Meyer 2011).

Losses of Dredges and Lives

The combination of wooden hulls and steam power was an early challenge for dredge fleets. In 1908, the U.S dredge Gen. Comstock blew up and was out of service for months. In 1909, the U.S. dredge Gen. H.M. Robert burned, and was replaced by the U.S. dredge Capt. C.W. Howell, which was lost at sea in 2011. In December 1904, the hopper dredge Texas, which was working the project to raise the ground elevation of Galveston, broke up and sank off shore. The U.S dredge Delatour, which worked in Houston in the 1930's, had previously sunk in Louisiana but was raised and put back into service.

While mechanical challenges were an everyday occurrence, coastal weather has always posed the biggest risk. In September 1874, a severe storm destroyed most of the dredge equipment working the inner bar of the entrance channel at Galveston, causing over $50,000 in damage to dredge plant. The sand dredge was swept 3.2 km (2 mi) inland, and eventually abandoned after salvage of key components. In the 1900 hurricane that destroyed Galveston, the dredge fleet was literally wiped from the water. Government and private dredges were driven as far as 17.7 km (11 mi) by wind and current, and carried up to 4.8 km (3 mi) inland; the loss of support boats and the need to recover dredges (often dredging a channel back to open water) delayed progress for months.

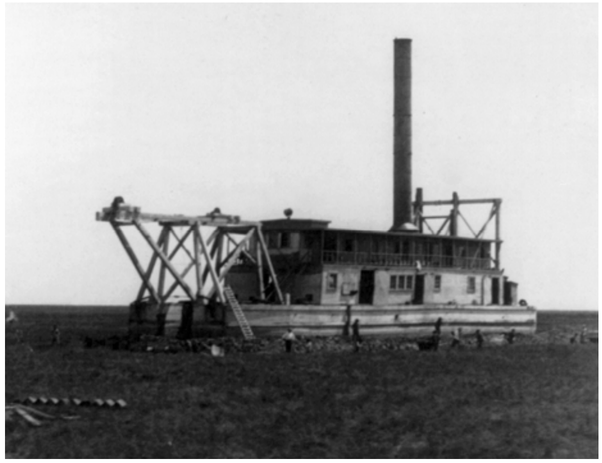

Figure 14. Dredge carried inland, 1900.

In 1915, another major storm capsized the U.S dredge Houston and two crewmen died. While storm forecasting and warnings had advanced by the 1930's, the cruelty of wartime was felt in Texas in 1943 when a major hurricane struck without warning because ships in the Gulf (which could have provided advance notice of the storm) were under radio silence as protection from German submarines. The U.S dredge Galveston, a mainstay for dredging in the Houston area for decades, sank in that storm with the loss of twelve of its crew.

In 1974, the Corps hopper dredge A. Mackenzie collided with a tanker in the Houston-Galveston entrance channel and sank; although the entire crew was saved, the sunken dredge partially blocked the ship channel for over two months. In support of the salvage operation, the Corps needed to survey the quantity of dredge material in the hull, and eventually had to "dredge" to remove over 54.4 tonnes (60 tons) of accumulated silt on the sunken hull to enable safe lift of the dismembered ship from Texas waters. (Navy 1975). Unfortunately, its namesake dredge Alexander Mackenzie sank under tow off the east coast in 1915 with the loss of five lives.

Figure 15. U.S. Dredge Galveston, 1937; lost in 1943.

Figure 16. U.S. Dredge A. Mackenzie.

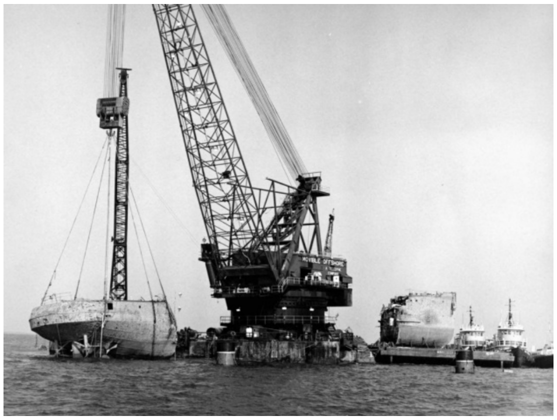

Figure 17. Dredge Mackenzie salvage, 1974.

Dredging Costs and Contracts

Oh, for the good old days. Early dredging records from 1900 reported new work dredging for as little as $0.09 to $0.20 per CY, and for as little as $0.03 to $0.06 per CY for maintenance material dredging in the main channel. Maintenance work by dipper dredges in the shallow draft areas near Houston were billed at up to $0.40 per CY. Costs were relatively stable for years, presumably because of strong demand for dredging in Houston and Texas and low fuel and labor costs, so by the early 1930's dredging was still $0.08 to $0.09 per CY. By the mid-1970's, non-federal new work costs had grown to $0.45 per CY. Enactment of the Clean Water Act in 1972 had a significant impact in costs: Galveston District unit costs increased from $0.37 to $0.93 per CY from FY 74 to FY 76, an increase of 151% over two years. (McCoy 1976).

Federally-owned dredges were prominent in the area for over 100 years, including use of hopper dredges for routine work into the mid-1970's. In 1901, the Corps would rent its dredges for public use at a rate of $50 per day, and for private purposes one cent per CY lower than current commercial rates. (Chief 1901). The Corps would routinely but reluctantly supplement federal plant with contract work because of federal dredge cost advantages. In the 1904 Report to the Chief of Engineers, an officer commented "if the United States had owned the dredge, the same work could have been done for one fifth the price." (Chief 1904). In 1908, the government bought and refurbished a private light draft dredge and added7.62 m (25 ft) to her ladder for $18,000, all to avoid excessive contract costs. For the milestone 67.62 m (25 ft) deep water channel completed in 1914, the Corps contracted to Atlantic, Gulf and Pacific for a turn-key, fixed price project—but the project cost sharing agreement that induced federal appropriations included joint City and federal government purchase of two government dredges for future maintenance work.

In 1905, Congress authorized the 7.63 m (25 ft) project for Houston, but for the first time in U.S. history Congress required (at the recommendation and enticement of Houston's leaders) non-federal cost sharing. Houston's first bill was $1.25 million for 50% of the estimated cost of government contracts that year, which included the $400,000 purchase of the two dredges and support equipment. (Crotty 1914). This "Houston Plan" has probably been the bain of ports since, but enabled Houston's great channel to be constructed for major ships. Federal dredge use for the Houston ship channel today is rare, and occurs for emergency purposes under special circumstances only. In spite of escalating unit costs in the area, Houston's dredging remains less costly than other major coastal ports on the East and Gulf coasts. (Cooley 2012).

Federal contracting in the early years was flexible, but cost conscious. Completion dates for work were often waived, but bids on solicitations were frequently rejected because prices were unacceptable. (Chief 1906) Rules were in place that clearly distinguished between maintenance and new construction; reports to the Chief of Engineers made clear that lack of progress was a result of the appropriation from Congress. Even in 1875 the Government required as many as three sets of construction progress photographs forwarded to Washington upon completion of construction. (Chief 1875). Through around 1915, it was common for dredges to double as snag boats, although use of a dredge for more than incidental debris removal caused the channel depth to continue to regress.

In 1910, the government combined the Galveston Bay and Buffalo Bayou channels into the single Houston Ship Channel. In 2014, the Houston Ship Channel and three tributary channels were combined as one channel system with a single line item for appropriations and work plans. Both of those actions served to provide flexibility in expending the scarce dredging resources provided by Congress.

The timing of federal appropriations impacted the continuity of dredging. In 1921, the Port Commissioners furnished $300,000 to the government in advance of appropriations in order that the government dredges might be kept employed prosecuting the 9.1 m (30 ft) channel project. The commission was nonplused when Congress failed to appropriate any funds for the project that year. (Port 1921). In 2013, dredging of the Houston Ship Channel turning basin was delayed until 2015 because of insufficient funds and delays in revising the standard agreement between the Corps and the non-federal sponsor. By 2015, the 10.97 m (36 ft) turning basin was draft restricted by 1.21 m (4 ft).

Today the cost for federal maintenance material is approximately $3 to $8 per CY for hydraulic pipeline dredging, and $4.50 to $5.00 per CY for hopper dredging of the lower channel. Dredging costs for private berth maintenance in Houston using a federal placement area average $20 per CY. Non-federal, new work dredging contract costs (2014 Bayport and Barbours Cut channel improvement contract) were $6 to $8 per CY for maintenance material and $9 to $13 for new work material, depending on the pump distance.

Dredge Material Disposal and Upland Ditching

In the early years of the channel, material from the gulf, the bay, and the river reaches was traditionally deposited in open water or unconfined placement areas. Captain Morgan's cut through the peninsula where the bay met the San Jacinto River formed an island, and the newly created Atkinson Island anchored accretions from channel dredging that now extends over five miles along the channel, with placement areas or adjacent constructed marshes over 2133 m (7,000 ft) wide. In early years, pipeline dredges would commonly be outfitted to pump 76.2 m (250 ft) from the channel, beyond the silt "fence" constructed in the bay. In the 1950's, discharge as unconfined placement occurred ever 457 m to 609 m (1,500 ft to 2,000 ft) along Atkinson Island. Today, new work material (including clay mining within the channels) is used beneficially for levee construction to the maximum extent. Channel maintenance material is also used to fill marsh cells developed as required environmental restoration and mitigation features.

In the upper channel approaching the City of Houston, dredge material placement was problematic in the early years. 12.19 m (40 ft) high banks and long pump distances strained the capability of many of the dredges. When banks were cleared of vegetation, bank erosion accelerated and created much more maintenance material that required disposal. Development of the city resulted in such significant quantities of siltation from runoff that the original plan for deep draft navigation to downtown was abandoned by 1905. By 1906, permissions were obtained for dredge material placement on private lands, but landowner expectations did not meet reality. In a letter to the Corps' district engineer, one landowner acknowledged his granting use, but complained he did not realize that the material would "kill all the timber upon the land", and that "cattle on these lands are mired every day, and people are compelled to dig them out". (Hunt 1906). In response, the Corps referred the complaint to the channel committee (precursor to the current Commission) as being responsible (as today) for acquiring land for disposal and all the community relations that come with that task. However, it wasn't until the state formed the navigation district (now

Port Authority) that the public channel committee had legal authority to acquire property through condemnation actions.

In 1908, the city dipper dredge loaded into scows that moved downstream for 9.65 km (6 mi) for dumping and red edging, because placement areas near the city were unavailable. During the 1920's, the Port Authority acquired over 404 ha (1,000 ac) of property for placement areas along the channel for about $500 per acre. (Navigation 1928). At that time, "dumping grounds" would be filled to a height of 3 m to 4.5 m (10 ft to15 ft), and afterward repurposed for tank farms or garden plots. Post-WWII, an estimated 5665 ha (14,000 ac) of total disposal areas have been used to support the HSC, including 4451 ha (11,000 ac) which displaced open water disposal. Today, the Port Authority has over 2428 ha (6,000 ac) of land, 1214 ha (3,000 acres along the Bayou) dedicated to dredge material placement with target dike elevations of 10.6 m to 13.7 m (35 ft to 45 ft). The Port Authority will also eventually manage 1214 ha (3,000 ac) of marsh or bird habitat created in Galveston Bay from dredge material.

As early channel construction made cuts and bend easings to straighten the channel for safe navigation, into the 1940's islands created by channel cuts were excavated and dredged, with much of that material reclaiming the original channel course for industrial use. Placement areas serving the upper channel since the late 1920's now are still used today, and may continue to be in use for 50 years. Those areas are surrounded by residences and industry. In 1913, "Many sight-seers have visited the Turning Basin and Magnolia Park to watch the operation of the dredge and its discharge." (Stone 1912). A current resident from the community of Galena Park remembers gleefully playing in the neighboring "lake" after channel dredging occurred in the 1940's.

Figure18. Bend Easing after 1913 Dredging.

Because of the shortage of land adjacent to the channels and the extraordinary cost of constructing new placement areas in the bay, crust management has been aggressively pursued in Houston since the late 1980's. Sites are dewatered after dredging as quickly as water quality requirements permit, and the site is ditched to facilitate drainage soon afterward. To maximize material drying time, channel and berth dredging and site use are tightly scheduled into narrow windows of time. This topside ditching is just as important to the viability of the channels as dredging of the "ditch" through the bay because dewatering and drying can reclaim up to 50% of the volume of material pumped by dredging. Use of a placement area at any time is limited to a single dredging company, and pumping into placement areas by multiple dredges concurrently is rare, and limited to only the largest placement areas. Standards for suspended solids in effluent from placement areas vary from 8 g/l for federal placement (measured against background) to 300 mg/l for non-federal placement projects—a standard that the Corps reports is unsupportable.

The issue of dredge material disposal in a November 1987 Environmental Impact Statement (EIS) prompted objections from state and federal resource agencies and environmental groups. As a result, a number of entities, including the Corps, the Environmental Protection Agency, the U.S. Fish and Wildlife Service, the Texas Parks and Wildlife Commission and the Port Authority of Houston, came together to establish the Interagency Coordination Team (ICT) in 1990. The ICT focused on the proposed dredge material disposal plan, which called for confined upland disposal in the inland reaches of the channel and continuation of open bay unconfined disposal for the Galveston Bay reach. The ICT was able to consider how to reduce environmental impacts, in part, due to the willingness of the Port Authority to spend up to $37,000,000 for development of beneficial uses of dredge material. In October 1992, the ICT approved a beneficial use plan for disposal of dredge material from the HSC project, which included creation of almost 6,000 acres of marsh, bird islands, and shoreline erosion protection. (Dietz 1994). While the collaboration was effective in developing a more acceptable environmental plan, it also lead to years of bureaucratic delays. (Jacobson 1999).

Beginning in 2014 in Houston, private terminal dredge material disposal into federal placement areas was virtually suspended after the Corps determined that it no longer had the authority to receive funds (tipping fees) required for use of those areas. So while channels were maintained, private terminals (including industrial service facilities with 13.72 m (45 ft) berths that were required to be dredged fully maintained to justify the 1998 channel deepening project) had no permitted placement areas available, and suffered from draft limitations for over a year or longer. New real estate and administrative procedures might not be standardized and implemented until 2016. Additionally, Federal tipping fees of $1.50 per CY might rise to a typical fee of $5 to $6 per CY when routine use of placement areas for berth maintenance resumes.

No-cost "Dredging" in Houston

Oil was discovered in the Houston area early in1907, and oil and gas extraction continues today with many active wells in and adjacent to Galveston Bay near the ship channel. The refineries and chemical plants that were established along the banks of the channel use millions of gallons of water daily, traditionally drawn from deep aquifers. The result of this resource extraction was subsidence of the land form in Houston, centered along parts of the ship channel-by as much as 3 km (10 ft) over 40 years. As a result, the hard bottom of the channel along over 24.1 km (15 mi) continued to gradually sink. As the Houston Ship Channel was deepened from 3.65 m to 7.62 m (25 ft to 36 ft), an estimated 15,291,100 m³ to 22,936,650 m³ (20,000,000 CY to 30,000,00 CY) of new work dredging was not required because of subsidence. That represents approximately 10% of the total new work dredging required to construct the original 7.6 2 m (25 ft) channel from Galveston to Houston.

While Congress required a conversion from the historic Mean Low Tide (MLT) datum that was in place in the 1900's to the Mean Lower Low Water (MLLW) datum in 1992, the Houston ship channel was initially exempted from conversion because of the pending 13.72 m (45 ft) project, which was finally authorized in 1996. When that datum conversion is made in 2015, the 13.7 m (45 ft) channel will be "deepened" on charts to 14.02 m (46 ft) MLLW, and the 12.12 m (40 ft) and 10.97 m (36 ft) channels will be maintained at 12.65 m (41.5 ft) MLLW and 11.43 m (37.5 ft) MLLW respectively.

Future Challenges

The Houston Ship Channel system remains one of the most maintenance-intensive harbors in the country. Although sediment inflow has likely slowed from the Trinity and San Jacinto rivers and the bayous, the huge quantity of loose sediment in Galveston Bay will necessitate continued dredging operation to sustain operations of the Houston Ship channel system. Today, the 13.72 m (45 ft) channel extends over 24 km (15 mi) into the Gulf of Mexico, and is subject to littoral drift of sand and sediments along the coast. However, the public's expected future deepening of the channel will require extension of the channel perhaps another 10 miles or more to a point where deeper water is available on the shallow continental shelf. A 1.52 m (5 ft) deeper channel that is also widened might involve over 76,455,490 m³ (100,000,00 CY) of new work material, with a first cost of over $2 billion.

Berth dredging and material disposal will continue to be a major challenge. The Port of Houston has over 400 ship and barge berths operated by over 70 private terminals and the Port Authority. While dredge material management plans include maintenance material from berth dredging, proposed terminal expansion in Houston could generate millions of CY of new work material over a period of several years; this material quantity could overwhelm the capacity of placement areas for which federal channel maintenance is a priority. In Houston (as well as other ports in Texas), private use of placement areas throttled down because funds required to be contributed could not be legally received by the Corps. While plans to develop procedures to legally receive private funds for placement area costs are progressing, the result is that Houston (and other Texas) waterways have been draft restricted for several years, from the edge of the federal channel to the dock.

While placement areas serving the upper 56 km (35 mi) of the channel have over 20 years of theoretical capacity today, thousands of acres of disposal sites may be out of service within one or two cycles of channel dredging. Real estate acquisition and environmental hurdles for possible new bay sites will be extraordinarily difficult and costly (the 242 ha (600 ac) Mid-bay placement area was constructed during the 13.72 m (45 ft) channel project around 2004 for approximately $100 million). Future dredging project environmental mitigation is likely to cost more than the channel construction itself and require decades of construction after future channels are operational, if the future project is environmentally acceptable at all. The opportunity to utilize hopper dredging further upstream with offshore material disposal may occur, but at greater cost than current pipeline dredging. Off shore disposal may be allowed, particularly for new work material, because environmental controls have resulted in huge improvements in sediment quality over the past 40 years. The result of environmental considerations, placement area demand, and other factors foretells strong increases in dredge project costs.

CONCLUSIONS

Houston created a port as a result of strong public and political will, perseverance of industry, and Congressional funding support. The length of the channels and the significant maintenance dredging requirement pose a significant challenge to navigation of high volumes of vessel traffic. Channel and berth dredging and oyster dredging combined have removed close to one billion cubic yards of material from the bay and channels through the cuts, rivers, and bayous that enable ships to travel upstream over 83.6 km (52 mi), enjoying safe haven from storms and access to over 80 km (50 mi) of industrial development along channel banks. The history of dredging in Houston is a story of achievement and success, loss of equipment and life, and a tale of a construction industry that ditched high and low to create a waterway that now leads to a great city.

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