Construction History Vol. 10. 1994

Science and the Grand Design: Origins of the U.S. Army Corps of Engineers

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The Corps in Context

The United States Army Corps of Engineers has been called America's pre-eminent engineering organisation, a nation builder, a bureaucratic superstar. Also a public enemy, a diligent destroyer, a military aristocracy, a lobby that can't be licked. Created in 1802, the engineering organisation began as a war academy and fort-building agency, but the idea of an army engineer corps stretched back more than a century to the time of Louis XIV when an elite and scientific force of government planners modernised the kingdom through highways, waterways, aqueducts and other spectacular projects. Americans have long since admired that French scientific tradition – and despised it as well. To the extent that American constitutional democracy remains a product of Great Britain – egalitarian, capitalistic, suspicious of government experts and peacetime armies – the Corps of Engineers has often worked outside the mainstream of American culture. Resisting the British and American example of the self-made builder-mechanic in a free-wheeling capitalist system, the Corps, historically, has advocated a planned economy where soldiers guided construction, and science was the methodical tool of rational, centralised state.[1]

Historians mostly applaud the Corps' contribution to science, but scholarly descriptions of that science-engineering connection are as varied as definitions of "science" itself. Today many writers point out that the goal of science ("understanding nature", said historian Melvin Kranzberg) is quite different from the goal of technology ("making useful things").[2] Yet the clarity of that distinction was lost in the nineteenth century army. Science in the language of army builders was order and classification. Rational and precise, it spelled out the theory or natural laws that reduced warfare and engineering to a regimen of standardised steps.

Engineering science was also politics in nineteenth century America. Before the opening of the Erie Canal in 1825, the frontier republic relied on field-trained artisans such as carpenters, masons and millwrights, yet few of these unschooled builders had experience with roads and canals. Few private companies, moreover, had the capital and technical know-how to build long-distance roads and canals across rugged frontier terrain. As nationalists pressed for a strong federal bureaucracy and the army searched for efficient ways to move troops and supplies, Congress in 1824 turned to the Corps' small force of academically trained fort builders and combat surveyors. Assisting private enterprise, the Corps became an advocate of massive and complex "scientific" projects: canals, dams, bridges, lighthouses, breakwaters, and ports -projects that would unite the far-flung republic, improvements that seemed extravagent to many frontier engineers. Corps science set a grandiose standard for public construction. It justified the cost and complexity of transportation programmes that were targets of the rising resistance to federal public works.

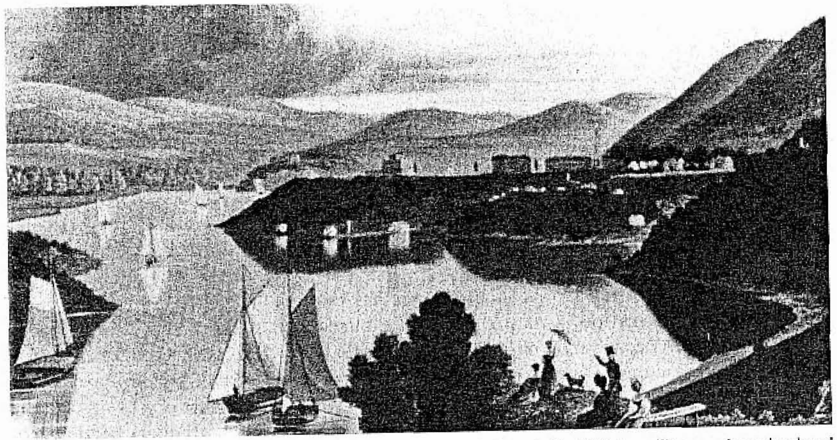

Fig 1: The United States Military Academy at West Point, New York. Founded in 1802, the military academy developed the nation's first formal course in engineering science (courtesy of the United States Military Academy).

Heirs to a French Tradition

The army science-engineering connection began with the French alliance during the American Revolution. Seeded by the French advisors to George Washington's army, the scientific tradition flourished at the U.S. Military Academy, a school for army builders at Fortress West Point (Figure 1). Corps faculty at West Point relied on Parisian textbooks. French became a prerequisite for the nation's first course on construction, formalized in 1817 by the Parisian graduate of Ecole Polytechnique, Claudius Crozet. Crozet students used algebra and trigonometry to calculate the optimal grade of the nation's first mountainous railroad, the Baltimore and Ohio. Others used French fortification theory to plan an impressive line of star-shaped coastal defences. French bridges, canals and breakwaters became models for American projects. And French ideas about standardisation drove the American army campaign for musket and rifle production through interchangeable parts.

Fig 2: Brigadier General Simon Bernard, the French army engineer who headed the U.S. Internal Improvement Board, 1824–1831. (Courtesy of the Casemate Museum, Fort Monroe).

France also sold the American army on the promise of science as national planning. In 1824, when the U.S. Congress launched a crash programme of river and harbour construction, the army placed Simon Bernard, a French engineer, at the head of the powerful United States Board of Engineers for internal improvements (Figure 2). Bernard was a baron of the French empire and a graduate of the Ecole Polytechnique who had served as an aide-de-camp to Napoleon before joining the American army a year after Waterloo. An

ardent nationalist, he imported a high-minded vision of militarised modernisation through monumental construction. "When a nation undertakes a work of great public utility", Bernard told the American Congress, "the revenue is not the essential object to take into consideration: its views are of a more elevated order – they are all, and, it may be said, exclusively, directed toward the great and general interests of the community."[3] Government, said Bernard, should build towering works for the ages. National glory outweighed fiscal concerns

An early test of that lofty position was the proposed waterway across Appalachia from Washington, D.C., to the heartland, the Chesapeake and Ohio Canal. Bernard, after a precise and scientific study of the canal route in 1826, advocated a wide and deep stone-lined canal built to the highest standards – a $22 million investment. It was a staggering sum and the estimate nearly destroyed the project, sending the investors into shock. Immediately the Chesapeake and Ohio company denounced Bernard and hired new engineers – not Frenchmen or schooled West Pointers but practical builders trained in the field.

Yet the subsequent history of the Chesapeake and Ohio Canal was a planning disaster that vindicated the Corps and Bernard (Figure 3). Technical problems, labour shortages, legal challenges, and bad management drove up the cost of construction until the company abandoned the venture far from its destination. Half-finished after an $11 million investment, the canal had proved every bit as costly as the army engineers had predicted, and the canal's board of directors were forced to admit their mistake. Bankruptcy had taught them a lesson about the false economy of practical engineering. Still, the goals and values of science also contributed to the fiasco. "We are planning a work for the nation", wrote Bernard, reflecting on his role as primary author of the original canal survey. "It did not belong to us to curtail the cost, in order to derive from the capital a greater interest ... to the detriment of durability and conveyancy."[4] Bernard had advocated long-term investments in permanent facilities. To the extent that the Americans followed the Frenchman's advice – deepening the Chesapeake and Ohio, paving the canal with stone and enlarging its locks – Bernard helped to deplete the canal company's meagre resources. Thinking big but failing to grasp the fiscal realities of private investment, Bernard helped to ensure that the great Appalachian canal would never reach the Ohio.[5]

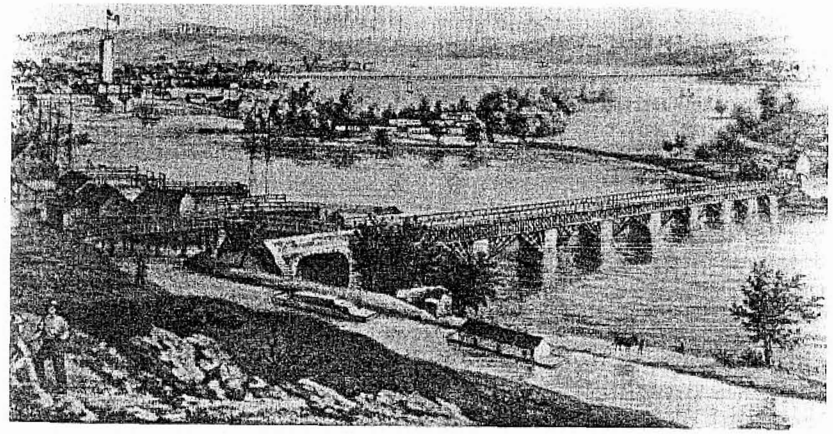

Fig 3: The Chesapeake and Ohio Canal and the army built Potomac Aqueduct at Georgetown in the District of Columbia, about 1865 (Courtesy of Library of Congress).

Science, then, was a grand approach that sometimes grated against capitalism, stretching the imagination at the expense of fiscal restraint. During the first era of federal aid to river and harbour construction, 1824 to 1838, the Corps frequently over-committed Congress, using elaborate scientific reports to justify towering projects, great objects of national pride. One of the most lavish of the nineteenth century projects was the doomed attempt to arrest Philadelphia's falling position as the hub of the maritime trade.

Geographically, the Quaker City was at a serious disadvantage. While Baltimore and New York enjoyed deep all-weather harbours, Philadelphia, dependent on the Delaware River, was shut down from December to late February by thick sheets of ice. Each year dozens of ships were crushed in the frozen river or forced out to sea. After studying the problem in the 1820s, the Corps recommended timber ice piers and a stone breakwater where the Delaware River met the Atlantic on the south lip of Delaware Bay. General Bernard believed a fine harbour could be built in a few years for $222,500. But when the last stone was in place more than seventy years later the Delaware Breakwater, already obsolete, had cost about $3 million.[6]

Bernard's plan called for a replica of the French breakwater at Cherbourg – a great wall of stones piled into the surf like a long, squat pyramid, its face slightly rounded to deflect violent swells. The challenge was to block ice and the crashing ocean yet permit the passage of useful currents that flushed mud and sand. Delaware Bay, however, refused to follow the plan. Instead of scouring the harbour, the disrupted tidal action brought in new deposits, and in 1834 the Corps reported the rapid approach of sand bars as shallow as 3 feet. Up-river the Corps' ice shelters were having the same effect. By 1839, when the funding expired, the gateway to America's second most populous city was shoaling and filling with sand.[7]

Big, expensive, and environmentally jinxed from the start, the Delaware Breakwater was the tempestuous future of scientific construction. Politically, it signalled the rise of the pork-barrel alliances that still bind port cities and public works organisations to powerful patrons in Congress. Technologically, the project showed that breakwaters were not simply ocean-proof forts, that every stone placed underwater changed the current and sedimentation of a delicate ecosystem. Delaware Bay was proof that West Pointers knew very little about what to expect from the seacoast. "A good theory of waves is still a desideratum in science," said West Pointer Dennis Hart Mahan, writing in his 1851 textbook.[8] The Delaware Breakwater was half-complete before Americans seriously studied the silt and sandy deposits that moved through harbours and bays.

Trouble at Presque Isle

Even before the breakwater fiasco the imperfect state of construction science made the Corps seem inept, even corrupt. Citing "extravagance" and "listlessness" in programme implementation, Congressman Francis O. Smith of Maine, a Democrat, spearheaded the early campaign for engineering reform. On 10 February 1836, Smith damned the Corps with the army's own list of troublesome water projects. Near the top was Oswego, New York, where the Corps had planned timber piers, a $33,000 proposal. Each summer for eight years the engineers anticipated success "beyond all doubt", each time asking for money. When Congress finally balked in 1836, the Oswego piers, still unfinshed, were $93,055 over the original budget. Meanwhile a dam in Ohio collapsed. A Florida dredge boat rusted. A jetty in the Genesee River opened one channel but silted another. Piers at Dunkirk, New York, allegedly completed "in a substantial and durable manner", could not survive the ice. "In none of these works," said Smith, "has the original estimate of cost, or of the probable effects of each expenditure, been verified by experience."[9] A House resolution calling for more precise estimates was followed by a heated Senate debate over the scientific methods of schooled engineers.[10]

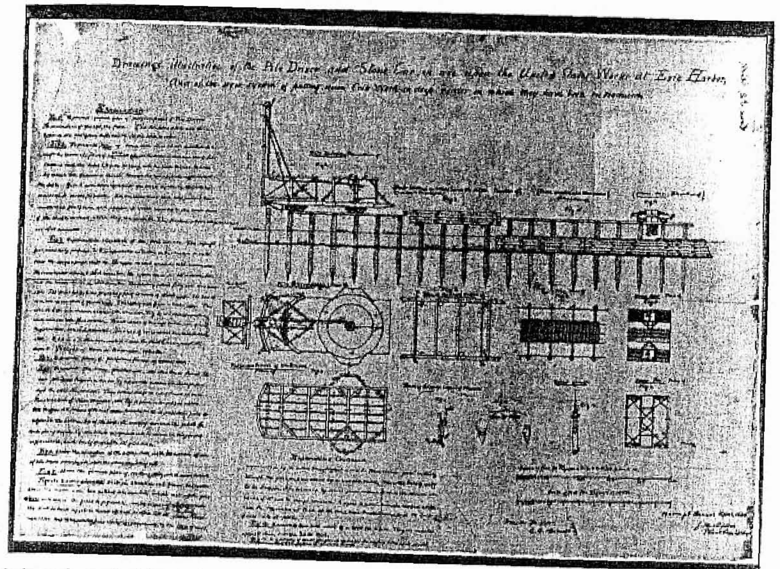

Fig 4: Plans for a pile driver and stone car used on the timber cribbing at Erie Harbor (Presque Isle) during the 1840s. (Courtesy of the National Archives Cartographic Division).

If a single project captured the mounting frustration, it was the deep bay at Erie, Pennsylvania. A grain emporium and a stop in the fur trade, it was reputedly "the best natural harbour on the Great Lakes."[11] Sailors still called the site by its French name, Presque Isle. Soldiers knew it as the thriving industrial town that had built a frontier navy for Captain Oliver Hazard Perry during the War of 1812. In early August 1813, as the British squadron prepared for a beach invasion, Perry's men, toiling at ropes and poles, had managed to drag two heavy brigs across the soft 4-foot bar that obstructed the mouth of the bay. Had either American brig not made it over the bar the battle of Lake Erie, a decisive victory for Perry, may have gone the other way. Soon after the war the townspeople lobbied hard for federal money to remove the sand bar. Pennsylvania financed a bar survey and Congress, in 1824, added $20,000 for experimental piers.[12]

Little did Congress realise that small Presque Isle would require a full-time supervisor, a clerk, four carpenters, up to 20 labourers, and an investment close to $200,000 by the time the army suspended work in 1861. The plan called for a double row of stone-filled cribbing to funnel the currents and tides that washed sand from the shipping channel (Figure 4). First completed in 1826, the piers broke apart in a gale. Meanwhile the crashing surf was severing a thin neck of land at the opposite end of the bay. Tides swept in from the west, eroding the beach. Damming failed and so did a hastily constructed breakwater along the outer beach. The bay now had two entrances, the second more navigable than the first. Soon the builders were hit with a frightening realisation. A large bar-like deposit was inching into the channel. Sand was filling the bay. "It would be useless now to attempt to estimate the ultimate expense", said an army inspector in 1833[13]. The Corps, nevertheless, requested $3,000 for another set of piers.

For years the engineers made no connection between shoaling, the breach, and the works at the eastern end of the isle. So foreign was the study of tides that the 1838 edition of West Point's engineering textbook cited only a single essay on waves, and that was in French. But in 1835 a veteran river engineer, Lieutenant Thomas S. Brown, had the skill and detachment to see the cause and effect. Brown confirmed that the timber piers had cut through the bar as promised. There was now about twenty feet of water at the entrance to Presque Isle. What was beneficial at one point, however, was disastrous at another, for the tide that washed through the channel changed the swirl of the current. Erosion now threatened to close the safest harbour of refuge on the vast stretch of northern coastline from Buffalo to Green Bay.[14]

Further Projects

The army's fascination with science did, nevertheless, open the engineering profession. Gradually, as civilian engineering schools appeared, the West Pointers broke down the parochialism that rooted pragmatic Yankees to the British craft tradition. Army engineers travelled freely in Europe with diplomatic papers and some had a line of government credit to buy books and scientific equipment. Their earliest contacts were primarily French. Later, chiefly through fact-finding missions by a group of army explorers and surveyors known as the U.S. topographical bureau, the engineer officers experimented with German, Italian, Dutch, and British technologies that exposed the provincial profession to a strange new world of ideas.

One mixed success of that technology transfer was the construction of dykes and dams that controlled floods and flushed river deposits, an Italian innovation (Figure 5). Since the time of Galileo and Guglielmini the Italian savants had experimented with structures that enlarged the carrying capacity of a channel by increasing the velocity of its current. By the 1770s the French students of Italian hydraulics were forcing sluggish, flood-prone rivers through rows of sunken piles. West Point textbooks referred to these experiments, and in

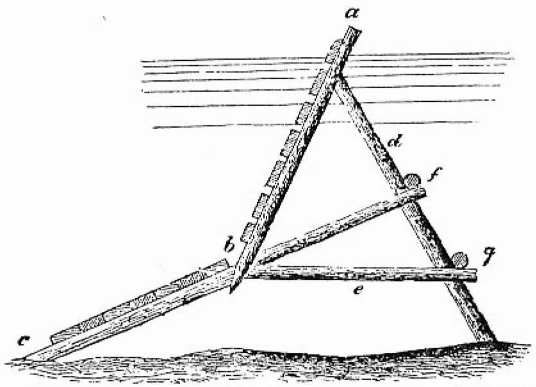

Fig. 174—Represents a section of the timber wing-dams on the Po, formed of plank nailed on the inclined pieces of the ribs.
ab and *bc*, inclined faces of the dam, the first making an angle of 63°, and the second of 23° with the horizon.
d and *e*, pieces of the rib.
f and *g*, horizontal pieces connecting the ribs.

Fig 5: Cross-section of an Italian wing dam from an 1851 West Point textbook. (Courtesy of the Office of History, US Army Corps of Engineers).

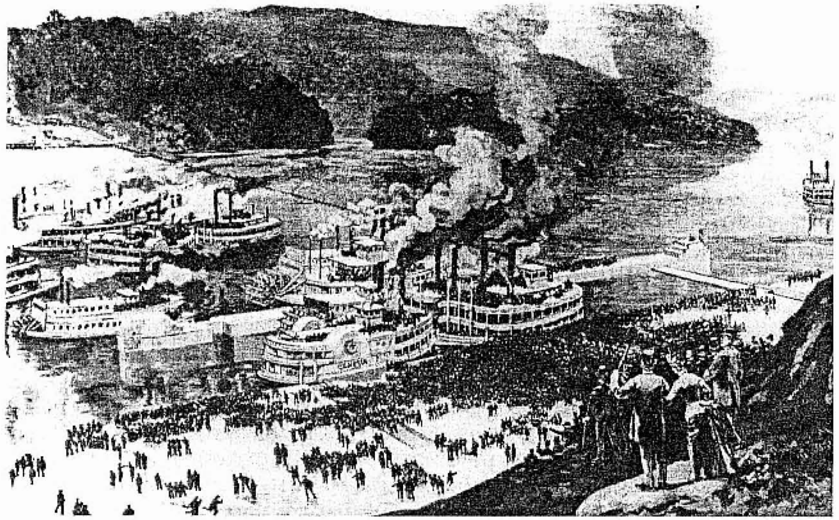

Fig 6: Lock and dam at Davis Island on the Ohio River, 1885. Adapted from a French design, the army project at Davis Island was the world's largest river lock. (Courtesy of the Office of History, US Army Corps of Engineers).

1821 the army engineers Bernard and Joseph Totten detailed the operation of low wooden "dykes" that worked by "diminishing the velocity of current above them, thereby economising (sic) the expense of water, at the same time constraining the current to rush with greater velocity through the narrow spaces to be deepened."[15] Noting the similarity between sand bars in the Ohio and those in the French Loire, the engineers identified 21 promising sites for dike experiments. Army topographer Stephen H. Long built the first experimental structure on a shallow sand bar at Henderson Island in the Ohio. Completed in 1826, he called it a "wing dam" – a double row of piles that slanted into the low-water channel at about 45 degrees. The dam scoured the bar and was "highly satisfactory" according to the Louisville Public Advisor.[16] An accumulation of gravel and sand held the structure in place until the army made repairs in 1872.[17]

The army also had some success with seawalls and sunken foundations held together with a kind of concrete the French called beton. Rubble concrete of various kinds had been studied by Europeans since the Romans made a mortar from limestone in about 200 B.C. John Smeaton improved the Roman mixture by adding English clay, and the New Yorker Cnavas White, recently returned from England in 1818, discovered an American clay that bonded underwater, a native cement. While canal building opened an American market for brand-name hydraulic cements – Portland Cement from England, Rosendale Cement from New York – their quality varied. Engineers still searched for a cheap, reliable compound that would withstand crashing surf. The West Pointer Mahan, reporting from Paris, followed French experiments with a beton mixture of burnt limestone and volcanic sand. Crushed into powder, limestone was burnt in a kiln, mixed into paste with water and gravel, and used as a mortar or cast into heavy blocks for breakwater construction. Corps engineer Totten, a talented chemist, found three kinds of American limestone suitable for beton. After twelve years of tests at Fort Adams in Newport, Rhode Island, Totten translated a French treatise on mortar chemistry, and in 1838 he introduced the scientific community to concrete in

Essays on Hydraulic and Common Mortars and on Lime-Burning. A year later the Corps used a concrete beton in an experimental seawall at Oswego, New York. At fort projects in Boston and elsewhere the Corps poured a cement-concrete mixture over broken stones.

Yet beton, like navigational dams, remained an experimental technology tested by the army but seldom used in river construction until after the Civil War. Not until 1878 did the Corps use beton as a mortar in a dam foundation, and the era of French domination had passed before the army found a way to build an entire lock chamber out of concrete near Hartford, Kentucky in 1895.[18]

Meanwhile the army elite so revered the French scientific tradition that British bombardment techniques and Prussian educational reform came to America slowly and chiefly through Paris. Thus the army-built tidal lock at the head of the Chesapeake and Ohio canal was adapted from a French design. So was America's first all-metal bridge, the world's longest masonry arch, and the world's largest river lock at Davis Island on the Ohio River – all army engineer projects (Figure 6). West Pointers also contributed to the Great Stone Dam at Lawrence, Massachusetts, the largest American hydropower dam of its time. As explorers and geographers, the West Pointers won wide acclaim for the scientific reconnaissance that mapped railroads to the Pacific. Meanwhile West Pointers like Andrew A. Humphreys and Henry L. Abbot were advancing the science of river hydraulics by rethinking the relationship between flooding and fluid resistance. Humphreys, Totten and fellow West Pointer Alexander D. Bache rose to leadership roles at the American Association for the Advancement of Science. During the 1840s the West Pointer Alfred Mordecai, an avid student of French engineering, founded an American strength-of-materials science with impressive experiments on gunpowder and cannon.[19]

In 1861 the American Civil War suspended internal improvements yet the French tradition survived. Soon after the war the Corps experimented with French-style moveable dams that closed to back up the river and opened to flush traffic downstream. One spectacular project was the Corps' 515 foot lock and dam that lifted ships into Lake Superior at Sault St. Marie.

French engineering helped the Corps make a political point about planning and centralisation. Only soldiers, the West Pointers maintained, had the training and scientific detachment to ensure that Congress invested in worthwhile projects. Although many civil engineers denounced the West Pointers, calling them incompetent and corrupt, the soaring demand for federal projects elevated the technological elite of the army and broadened its civil works jurisdiction. Gradually the Corps had become the nation's closest equivalent to an executive department of internal improvement, an American Corps des Ponts et Chaussees.

Science Pure and Applied

Triumphs of Corps engineering challenged the craft tradition and diversified federal projects, keeping the nation abreast of the latest European techniques. But did the West Pointer's cosmopolitan science radically alter civilian design? Did it seed civilian invention or revolutionise the way most American builders approached railroads, roads and canals? Probably not. Although engineer officers virtually monopolised the largest, most ambitious federal construction projects, the Corps was forced to rely on the same kind of building mechanics that served the nation at large. Many of these field-trained builders and craftsmen resisted scientific innovation. Even in the firearms industry a fear of militarism crippled the West Point attempt to modernise the factory system. As historian Merritt Roe Smith found in his study of the national armory at Harpers Ferry, army discipline and regimentation repulsed the civilian workforce, and French ideas about efficiency through standardisation were widely denounced as insults to the prideful independence of America's labouring class.[20]

Another limitation of the Corps' approach was that "science" was a slippery word that meant one thing to the laboratory researcher and something else to the engineer. Science, as many savants used the word, was a probe of the mystery of nature, a non-materialistic pursuit. But engineers were preoccupied with practical applications. As historian Edwin T. Layton, Jr., explained, most engineers shunned "idealisations" that allowed the physicist or true theoretician to describe something in nature that was hard to measure or test.[21] Wary of grand abstractions, fascinated by natural laws but finding them hard to apply, builders and inventors made do with the methods of science: the laboratory setting, the scale models, the precise instruments, the scientist's mode of communication through reports and technical journals.

Still the West Pointers had towering expectations for science. An important catchword in the nineteenth century army, science embodied disparate objectives and values; the love of order, the promise of technological progress through the conquest of nature, the romance of warfare as a Napoleonic chess game, a link to the world of Vauban. Science, in the language of army construction, was also rational planning. A yardstick of fairness in government, science measured the national interest against the rights of the states.

Effects of that political, technological science still ripple through America's public works. Corps emphasis on system and order still fuels the nationalistic conviction that state and local projects are chaotic and inconsequential. Corps ideas about scientific control still contribute to a bigger-is-better bias that fosters monumental construction but veils some of the cost. Only in the last generation have the engineers been forced to concede what their critics were beginning to see during the 1830s: economic progress has unplanned consequences, and even the most scientific attempts to turn rivers into technological systems tip a delicate balance between rushing water and earth. Thus piers that block floating ice silt with shallow deposits. Reservoirs cool the water and dramatically alter the food chain. Levees straighten and accelerate rivers, increasing erosion downstream. Dams rob the oceans of nutrients, block migrating salmon, and threaten important fisheries from Oregon to Chesapeake Bay. Today the Corps spends millions to mitigate the destruction unleashed by the great national projects of previous decades.

And so something about the Corps has stayed constant as the nation around it has evolved. An aging child of scientific professionalism, the civil works organisation has turned slowly in new directions without escaping the formative conflicts that anchor engineers to their past.

Editors' note

This article is an edited version of the paper presented by the author at the CHS 1993 Annual Seminar. The article is excerpted in part from Shallat's forthcoming book *Structures in the Stream: Water, Science, and the U.S. Army Corps of Engineers, 1680 – 1880.* University of Texas Press, Austin, 1994.

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