The Influence of Engineering Organization on Design and Construction Processes at Tennessee Valley Authority Dams of the 1930s

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ABSTRACT

This study examines engineering design processes and organization at the Tennessee Valley Authority in its early years from 1933 to 1936. During this time, Norris and Wheeler dams were constructed and plans and designs were begun for several additional dams. The TVA experience provides insights into how design processes evolved and were managed in this large engineering organization. A particularly innovative decision was the choice to build TVA dams by force account, i.e. by hiring their own employees, rather than by selecting contractors through a traditional bidding process. TVA engineers believed this approach would reduce overall design and construction costs, as well as reduce time to completion. Case studies of civil engineering history, like this one, provide an important tool for introducing students to design processes and engineering decision making.

DAM DESIGNERS

Unlike many of the landmark civil engineering works of the 20th century, which can largely be attributed to the engineering know-how and imagination of one individual, the construction of each of the massive federal dams during the 1930s and 1940s largely represents a collaboration of engineering design expertise among many individuals. This collaboration likely resulted from the unique challenges of dam design, which require integration of design of structures, water passage systems, turbines, transmission, and mechanical systems and involve all of the major branches of engineering. As a result, both the expertise and creativity of individual engineers and their interactions to integrate different aspects of the design are critical to the design process.

This study examines one major dam-building agency, the Tennessee Valley Authority (TVA), and its engineering design processes and organization. Much has been written about the TVA: the politics of its early proponents in the 1920s, its origins during the Great Depression, the controversy of creating a multi-state organization to manage a river basin, the conflict between its early board members, and the technical features of its concrete dams. However, little has been written about the development of the engineering organization within this unique and complex political instrument. The story of TVA engineering management during these early years provides an important case study of how an organization grew from nothing in 1933 to build major engineering works, including the planning, design and construction of six major dams by 1940.

THE TENNESSEE VALLEY AUTHORITY CONTEXT

President Franklin Roosevelt signed the act authorizing the Tennessee Valley Authority (TVA) on May 18, 1933, and chose Arthur Morgan as the organization's chairman. Morgan had gained renown as chief engineer of the Miami Conservancy District, for which he devised a flood control plan for the Miami Valley of the Ohio River (1915-1921), and administrative experience from his time as president of Antioch College (1921-1933). He also had experience designing earthen dams, but none with concrete dams or managing a large regional development project. Two others completed the Board of Directors: Harcourt Morgan, president of the University of Tennessee and David Lilienthal, lawyer for the Wisconsin Public Services Commission. In the summer of 1933, the government launched the new Authority with neither employees, technical expertise in the building of concrete dams, nor an organizational structure, but with three board members coming from diverse backgrounds and a desire to quickly begin construction of Norris Dam.

Decisions had to be made on how construction would be carried out, and how the TVA would be organized. Under Morgan's leadership, TVA began by removing the U.S. Army Corps of Engineers from the Tennessee River. The Corps had already begun plans for restructuring the valley, but both Roosevelt and Morgan felt that the duality of their engineering and social goals for the region could be better accomplished by a completely autonomous agency. The Corps of Engineers' legacy was a report that prioritized Norris Dam, on the Clinch River, and Wheeler Dam, on the Tennessee River, ahead of other proposed projects in the region.[1] In other areas, Arthur Morgan's previous experience at the Miami Conservancy clearly influenced early board decisions. Most importantly, the directors chose to build their dams by force account, hiring their own employees, as had been done at the Miami Conservancy. Morgan and other TVA engineers were strong proponents of this system, although little evidence existed as to its superiority and much of the engineering profession remained unconvinced as to its merits. Both the Bureau of Reclamation and the Army Corps of Engineers, for example, usually used the traditional contractor-bid method. Drawing on his connections with the engineering profession and previous employees, Morgan rapidly established a talented engineering staff, but he felt it was essential, too, to enlist the Bureau of Reclamation's assistance in the design of the first two dams.

TVA'S EARLY ENGINEERING ORGANIZATION

Since Morgan was chosen as TVA chairman prior[2,3] to the official authorization of the TVA by Congress, he influenced the writing of the legislation and the initial

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[1] United States Army Corps of Engineers. The Tennessee River and Tributaries: North Carolina, Tennessee, Alabama and Kentucky. Washington: Government Printing Office, 1930.

[2] Roosevelt announced that Morgan would lead TVA the day he signed the Act in May, 1933. By mid-April, 1933, Morgan and Roosevelt had begun communicating regarding plans for the TVA and Morgan had approval to confidentially begin inquiries about potential personnel.

[3] Talbert, Roy Jr., FDR's Utopian: Arthur Morgan of the TVA, Jackson: University Press of Mississippi, 1987. See also, Letter from Franklin Roosevelt to Arthur Morgan. April 18, 1933. *[Early TVA Correspondence. TVA Library. Knoxville, TN.]*

organization of the Authority. When the congressional committee asked Morgan how many members the Board of Directors should have, Morgan suggested three, a number he and Roosevelt had discussed. In addition, Morgan insisted that the three board members serve as equals and receive equal salaries.[4]

In an interview, Gordon Clapp, who began his time at TVA in July 1933 as assistant director of personnel and later became chairman of the TVA board in 1947, discussed the contradictory philosophies of organization that each of the original board members brought to the young corporation. Arthur Morgan, Clapp says, focused his efforts on hiring good people; armed with a superb staff, Morgan believed a suitable organization would develop without explicit planning. In the preface to a TVA organizational manual issued in March, 1935, Morgan wrote, "I personally detest regimentation, red tape, and bureaucracy, and am willing to endure a limited amount of confusion in order to give freer play to loyalty, initiative and enthusiasm."[5] Conversely, Harcourt Morgan, the lone member of the board with any experience in public administration, felt that a well-structured organization was essential.

Under the original organizational plan, Arthur Morgan became the general manager of the organization, responsible for coordinating and administrating the various activities of the organization, while the entire board would be responsible for general policies. However, this plan was abandoned only two months later, in August 1933, as Harcourt Morgan and David Lilienthal grew "dissatisfied with what they felt to be a lack of an adequate plan of administration or an effective overall method of control and review of the TVA program."[6] The new organization consisted of a tri-section of the board that continued until the 1936. Under this reorganization, the entire board maintained responsibility for general policy formulation. Arthur Morgan took responsibility for the engineering and construction programs, with Carl Bock as his assistant engineer. Within the engineering department, separate divisions were created for both of the major projects, Norris and Wheeler, as well as engineering services, maintenance and construction, and reservoir clearance.[7] Harcourt Morgan took charge of agriculture and fertilizer considerations, and David Lilienthal assumed jurisdiction over electric power issues.

DESIGN OF NORRIS DAM

Having obtained the Army Corps of Engineers' designs, the Board of Directors asked the Bureau of Reclamation, the federal dam-building agency with the greatest experience in large concrete dams, to do the design work for both Norris and Wheeler dams, their first projects.[8] The Bureau of Reclamation engineers, led by J.L. Savage, redesigned the dams and furnished TVA with complete designs and specifications. The decision to discard the Corps' designs seems to have been largely based in politics rather than engineering and, particularly, Morgan's well-documented dislike

[4] Arthur Morgan, Making of the TVA, Buffalo: Prometheus Books, 1974.
[5] C. Herman Pritchett. The Tennessee Valley Authority: A Study in Public Administration, Chapel Hill: The University of North Carolina Press, 1943, pg. 155.
[6] *Ibid*, pg. 154.
[7] *Ibid*, pg. 171.
[8] None of the archival materials available make it clear whether the decision to involve the Bureau of Reclamation was predominantly made by Morgan or by the entire board.

of the Corps of Engineers. Sherman Woodward, the TVA water resources engineer charged with reviewing the Corps of Engineers' designs, deemed them "naïve and in need of improvement."[9] However, careful evaluation of the two designs shows this negative assessment to be unjustified; the final Norris dam design had a lower reservoir elevation and removed the Corps' planned navigational lock, but the general shape of the dam remained similar to the Corps' original design and, certainly, the Bureau of Reclamation engineers had the Army Corps' design at their disposal. As well, there is some indication that the Bureau engineers utilized designs from recently completed Madden Dam on the upper Chagres River, in Panama, for the Norris design.[10] The Army Corps' preparation work, as well as the engineering expertise provided by the Bureau of Reclamation and mapping assistance from the United States Geological Survey, allowed TVA to begin construction of Norris and Wheeler Dams almost immediately. This quick start was imperative, in light of the politics of the Great Depression. TVA hired construction forces at the same time as the Bureau prepared the plans.

FORCE ACCOUNT CONSTRUCTION

TVA design plans and specifications were not put out to bid for contractors, but rather, were built by the organization's own construction employees, the so-called "force account" construction method. Arthur Morgan's experience at the Miami Conservancy District greatly influenced the decision to use the force account method for engineering and construction. Morgan originally had planned to use the traditional contract method for the Miami Conservancy dams. However, World War I led to fluctuations in materials and wages, and contracts included contingencies. Unwilling to accept these uncertainties, Morgan chose to hire his own workforce at the Miami Conservancy District. [11] Comparisons between his earlier years in private engineering practice and his years at the Miami Conservancy led Morgan to criticize the customary contract forms and specifications for their "ambiguity, repetition, [and] stereotyped phraseology."[12] Morgan viewed his plan for the Tennessee Valley as a scaling-up of the work he had done at the Miami Conservancy, and wanted to incorporate the same non-traditional construction methods. In his later writings, Morgan claimed that "the idea to take this course [the force account method] was mine."[13] Though the Bureau of Reclamation's construction work has always been done through the traditional bid-contracting system, Savage, the Bureau's chief design engineer, supported the choice of the force account method. The minutes of the July 29, 1933 board meeting read, "Mr. Savage believes the best and most economical results will come from the direct responsibility of the construction superintendent to the Authority, without the intervention of a contractor."[14]

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[9] Morgan, Making of the TVA.
[10] H.A. Sargent. "Memorandum to Barton M. Jones: Study of Design Costs" May 12, 1937. *[Carl Bock Papers. National Archives. East Point, GA.]*
[11] Morgan, Making the TVA, pg. 95.
[12] Arthur Morgan. The Miami Conservancy. New York: McGraw-Hill, 1951.
[13] Morgan, Making the TVA, pg. 95.
[14] "Minutes July 29, 1933 Meeting, Board of Directors." *[TVA Library. Knoxville, TN.]*

TVA leaders were convinced that the force account method shortened time to completion of the projects. At a July 29, 1933 board meeting, the directors acknowledged that plans for Norris Dam could not be finished for six months and that "it would be difficult to take bids until the plans are finished, but it is possible to begin work very soon by force account."[15] The extra time required to use the traditional contracting method was certainly unpopular in the midst of the Great Depression. Praising the original board's decision in retrospect, Gordon Clapp described the shortened construction time-line as the major advantage of TVA's force-account method: "Building a dam by contract, in fact, is to build a dam at least twice, once on the drawing boards before you move a cubic yard of dirt and building it again on the site."[16] There is, however, little empirical evidence that TVA's use of the force account method significantly reduced project completion time.

In addition, the TVA board believed that the interaction between construction and design teams facilitated the realization of improvements that could be made and added to the as yet unfinished plans, a concept Morgan referred to as "dynamic design". In describing the advantages of the force account method, Morgan wrote, "I had found [at Miami Conservancy] that in large outdoor constructions there would almost certainly be actual conditions that could not be anticipated at the start."[17] Ross White, construction superintendent at Norris Dam, advocated the force account construction method saying, "It may be necessary to change substantially the foundation plans when the excavation for the foundation has exposed the nature of the underlying rock."[18] Morgan later claimed that several changes at Norris Dam made late in the design process, including the decision to increase concrete density, thereby increasing the safe reservoir level by 10%, would have been impossible to make in a traditional contractor-bid system.[19]

The Board of Directors further justified doing their own construction because it would allow the Authority to provide good working conditions, a characteristic Morgan wanted to be a hallmark of the TVA organization. In particular, TVA employees worked a total of six 5.5 hour days per week, with three days spent on the construction site, the others in training programs. The board felt that the feasibility of this type of work schedule under the typical contractor-bid systems would have been very difficult, if not impossible: "the whole training program depends on the direct handling of the work by the authority."[20]

The implementation of the force account method meant that the final design of Norris dam was only a few weeks ahead of construction. However, the board members' criticism of the traditional contracting methods and promotion for the force account were unusual. Excepting those in the Tennessee Valley, all major federal American dams were built in the traditional method. TVA eventually utilized this force account method of construction for each of its major dams.

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[15] *Ibid.*
[16] Gordon Clapp. "Men and Management Rebuild a River." Six Lectures at the University of Chicago. (Chicago: University of Chicago Press), pg. 9.
[17] Morgan, Making of the TVA, pg. 95.
[18] "Minutes of July 29, 1933 Meeting, Board of Directors." *[TVA Library. Knoxville, TN.]*
[19] Morgan, pg. 95.
[20] "Minutes of July 29, 1933 Meeting, Board of Directors." *[TVA Library. Knoxville, TN.]*

TVA ENGINEERS

TVA engineers were chosen based on their previous engineering work and a particular ideology, including previous "progressive" work and a belief in "the feasibility of this [TVA] approach [for multi-purpose dams]."[21] During the summer of 1933, Arthur Morgan, and Bock, his assistant hired a team of respected engineers, drawing on Morgan's personal connections to quickly recruit technical staff.[22] Barton Jones, who eventually became TVA's chief design engineer, had worked with Morgan at Morgan's own firm, Morgan Engineering Company, the Miami Conservancy, and Antioch College. Morgan had also previously employed other high-level TVA engineers, including Bock, Woodward, Ross Riegel and Ned Sayford, James Bowman, and Emerson Chandler. In addition, Morgan recruited Dudley Dawson, head of training, from among the faculty at Antioch College. Morgan himself acknowledged the important legacy of Miami and his employees there, writing, "The general plan of the river control of the TVA and the dam building and administrative organization there was largely the work of men trained on the Miami Conservancy Project."[23]

The TVA also recruited a number of employees with previous dam-building experience with the U.S. Army Corps of Engineers or the Bureau of Reclamation. Theodore Parker, chief construction engineer, and Nicholls Bowden, hydraulic engineer, had both worked on large hydraulic projects with the Army Corps of Engineers. Byrum Steele and Robert Moore were former Bureau of Reclamation employees, Steele having worked on Hoover Dam.[24] Moore, who joined TVA in 1937 as assistant director of water control planning, had previously worked as the Senior Engineer in Charge of Structural and Hydraulic Design for the Bureau of Reclamation and played a major role in that organization's designs for Norris and Wheeler Dams.

ORGANIZATIONAL CHALLENGES

TVA Organization. The tri-section of the Board of Directors created the most fundamental organizational problem during TVA's first three years as it required the directors to split their time between leadership and general administration and oversight of the daily operation of the Authority. The TVA's organization at this time was unlike most private corporations, which tend to have a larger board of directors and a separate group of managers who direct the day-to-day operations of the organization.

Facing dual responsibilities, each director did not have adequate amount of time to address both the administrative and the operational issues. Although splitting their responsibilities was beneficial when initially conceived because it allowed each member of the board to focus especially on a particular aspect of the organization, the personal projects and personality clashes soon damaged the overall organization. John

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[21] Clapp, "Men and Management Rebuild a River", pg. 9

[22] Personnel decisions had to also be approved by President Roosevelt. *[Early TVA Correspondence.]*

[23] Morgan, The Miami Conservancy.

[24] Personal communication with Donald Jackson, Professor of History, Lafayette College.

Blandford, secretary to Arthur Morgan, and, later, TVA general manager, described the characteristics of the board between 1933 and 1936: "In reality, there was no board then in existence. Officials had to catch each director severally by his coat tails and get the necessary documents signed."[25] Separation between the three directors allowed each to hire based on personal relationships or convenient political appointments. This intense interest in specific projects and people, as well as personality clashes amongst the board members significantly decreased the effectiveness of the tri-section of the organization. F.X. Reynolds, an employee in the personnel department, reflected in an interview, "disagreement was not taken kindly, and irritations caused reprisals and hindrances, and, they tended to deny to each other the things to which each was entitled. It was this spirit rather than the mere organization that caused the trisection to operate worse than could be deduced merely from structure."[26] On an undated organizational chart, Carl Bock wrote, "Mature consideration indicates the desirability of having the Directors retire from the administration of those phases of the TVA program which they collectively delegated themselves as individual directors back in the fall of 1933."[27] However, no provision was made, and organizational remedies were not made until 1936.

Although much of the personal squabbling was limited to the Board of Directors, bureaucracy and "red tape" led to a loss of morale that permeated all levels of the organization. Those employees who reported directly to the Board of Directors complained of inadequacies in the service departments and of time wasted on bureaucratic and administrative decisions. The accounting department was described as both "unsatisfactory" and "inefficient" and the personnel department found to be unresponsive to engineering needs.[28] Carl Bock wrote, "These problems require more than half my own time and energy to combat... They are likewise sapping the energy of heads of our engineering departments, and this situation, coupled with failure to authorize some much needed assistance, creates a serious situation." The bureaucratic problems, Bock believed, were not a result of the people hired, but rather the organizational system that had developed.[29]

The morale problem extended beyond the existing organization as managers reported a difficulty in hiring as the public gained knowledge of the conflicts among the Board of Directors: "Recent contacts with high grade prospects for key position invariably elicit questions as to the probable effect of this split on the candidate's situation."[30] Concerns about morale at all levels also inhibited the adoption of suggestions for reorganization, as the administration believed they would further worsen the situation.[31]

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[25] "Interview with Clapp." *[Herman Finer Papers. National Archives. East Point, GA.]*
[26] " Interview with Reynolds." *[Herman Finer Papers.]*
[27] "Undated Organizational Chart." *[Carl Bock Papers.]*.
[28] "Suggestions for the Improvement of Administrative and Routine Procedures in the Engineering and Construction Departments by the Supervisory Staff of these Departments." *[Herman Finer Papers]*
[29] Mr. Woodward's Comments of October 15 on Red Tape. *[Carl Bock Papers.]*
[30] Carl Bock. "Engineering Organization and Administrative Problems of the Tennessee Valley Authority." April 26, 1937. *[Herman Finer Papers.]*
[31] " Correspondence regarding Architectural Design." 1937. *[Carl Bock Papers.*]

Engineering and Construction Organization. On an undated organizational chart from the mid-1930s, Carl Bock noted that "the authority is slowly changing from a planning and construction agency to a construction and operating agency."[32] He also acknowledged, "It was fundamentally impossible to design a suitable organization at the beginning because there had been no precedent for an enterprise such as the TVA. With the benefit of actual experience it should now be possible to introduce desirable forms of reorganization and this ought to be accomplished to the fullest extent possible."[33] In particular, the organization could learn from the design and construction experience at Norris and Wheeler dams. These changes in function of the authority required an alteration in the organization of the design and construction departments between 1933 and 1936.

Archival letters, interviews and other papers indicate a number of specific complaints regarding the engineering and construction organization. In particular, engineers frequently lamented the separation between electrical engineers, who were in the commercial electricity department, from the rest of the engineering division. This separation hampered communication between engineers and transmission power planners; while the engineers determined power capacity at dams, the electrical engineers designed the transmission lines, often without consulting each other, leading to repeated work once conflicts were discovered.[34] According to Reynolds, organizational difficulties increased costs: "in engineering, program money was lost because decisions were not agreed upon between the electrical engineers and the dam-building engineers."[35] The separation between the design department and the operating division also led to inefficiencies in TVA operation. Parker, Jones and Woodward, the three highest-ranking engineers, reported in October, 1936, that while they designed Norris to be operated by twelve people, twenty-eight men were on site, and, as a result, more facilities were needed.[36]

TVA engineers also found basic workplace amenities to be lacking.[37] The engineering design team reported that they had been moved from office to office often, and were not given enough space to work. The rapid increase in workforce from TVA's inception in May, 1933 to nearly 10,000 employees by July, 1934 exacerbated problems with workplace facilities. As TVA people and projects increased, difficulties emerged in employee training programs as well. The large number of isolated construction camps made it a necessity to provide a branch of training at each construction and operating center, requiring duplication of some training programs.[38]

Archival papers show that the organizational structure created animosity between the engineering department and other divisions, particularly the staff in the

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[32] "Suggested organizational charts." *[Carl Bock Papers.]*
[33] "Suggestions for reorganization of the TVA." *[Carl Bock Papers.]*
[34] "Memo". April 21, 1937. *[Carl Bock Papers.]*
[35] "Interview with Reynolds". *[Herman Finer papers.]*
[36] Theodore Parker, Barton Jones and Sherman Woodward. "Report on Operation and Maintenance of Navigation, Flood Control and Power Facilities. October 1936." *[Herman Finer Papers]*.
[37] "Suggestions for the Improvement of Administrative and Routine Procedures in the Engineering and Construction Departments by the Supervisory Staff of these Departments." Oct.1936. *[Herman Finer papers.]*
[38] "Interview with George F. Gant." April 22, 1936. *[Herman Finer papers.]*

personnel office. Steele discussed the barriers he found in hiring talented engineers: "past experience has shown that there were many difficulties in building up the design force to adequate strength to handle the work under consideration. These difficulties, however, have increased rather than decreased, due to the bureaucratic procedure established by the Personnel Department."[39] An unsolicited memo on suggestions for improvement written by members of the engineering staff described the personnel department as one of their most significant problems. Signatures on this memo included the head construction plant engineer (Ackerman), the chief engineer (Parker), the chief design engineer (Steele), the acting chief design engineer (Jones), the general construction superintendent (White), and several project and construction engineers.[40] Salary policy, developed by the personnel department, was another point of contention. Exit interviews conducted when engineers left the organization indicated that engineers felt that the aim of the new salary policy was to "throttle their opportunities with TVA."[41] The combination of the bureaucratic hiring process and unpopular salary policy made it difficult for the engineering organization to maintain and hire the staff necessary for their operations. A 1937 report in *Engineering News Record* that private engineering hires had increased further increased concern among TVA engineers about their ability to hire the best engineers.[42]

These organizational difficulties challenged the original fluid organizational strategy, proposed by Arthur Morgan. Personal animosities and the tri-section of the board hampered the productivity of the leadership of the organization; excess red tape and loss of morale decreased the effectiveness of the engineers and laborers. Though TVA successfully hired what Morgan considered to be "good people", organizational difficulties did not solve themselves, and, by 1936, a major restructuring of the organization, of the type originally advocated by Harcourt Morgan, was necessary. One of the critical changes was the institution of the office of general manager. The position was given to Blandford, who had joined the organization as Morgan's personal assistant in September, 1933.

ENGINEERING ECONOMY: TVA DESIGN COSTS

Despite the expectation that the force-account construction method would reduce the overall cost of TVA projects, A.J. Ackerman, the head construction plant engineer, acknowledged in 1937 that "design costs are way out of line," and that there were "possibilities here for introducing economies."[43] Though Ackerman's memo emphasized that he does not have enough data to make comparisons to other engineering organizations, the high design costs of the first TVA dams beg

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[39] Byrum Steele. "Report on Engineering Design in the Engineering and Construction Departments". October 1936. *[Carl Bock Papers]*.

[40] "Suggestions for the Improvement of Administrative and Routine Procedures in the Engineering and Construction Departments by the Supervisory Staff of these Departments." Oct.1936. *[Herman Finer Papers.]*

[41] "Salary Policy." From a preliminary report by Chairman Morgan on Organizational Problems of the TVA. 1936 – 1938. *[Arthur Morgan Papers. National Archives, East Point, GA.]*

[42] *Ibid.*

[43] Ackerman, A.J. "Memo to Carl Bock." Feb. 15, 1937. *[Carl Bock Papers.]*

comparison with dams built either by private sector or the other federal dam building organizations.

Total design costs at TVA dams, as a percentage of total structural cost, range from 2.2% at Wheeler to 6.8% at Hiwassee, as shown in Table 1. The two dams designed entirely by TVA forces (Pickwick Landing and Guntersville) had higher design costs than Norris and Wheeler, designed by the Bureau of Reclamation. Although Wheeler Dam probably had low design costs because the strong foundation material allowed the Bureau of Reclamation to use a particularly repetitive design, the total design cost for Pickwick Landing was twice that of Wheeler. Moreover, Hiwassee, the first tributary dam constructed after Norris, also had markedly higher design costs than either Norris Dam or Tygart Dam, constructed by the Army Corps of Engineers on the Monongahela River. However, overall structural costs among all the structures are similar.

Table 1. TVA dam design costs, in relation to total structural cost.

Dam	Year completed	Design cost	Total cost	Design costs as % of total structural cost
Norris[44]	1936	$561,248	$15,733,562	3.7%
Wheeler	1936	$507,927	$20,806,321	2.5%
Pickwick Landing	1938	$1,076,229	$21,902,776	5.1%
Guntersville	1939	$746,670	$17,837,168	4.5%
Hiwassee[45]	1940	$734,549	$10,764,624	6.8%
Tygart[46]	1938	$675,000	$18,400,000	3.8%

TVA engineers and administration attributed the large design costs in part to the TVA's young organization and lack of engineering experience. While other dam building organizations were able to reuse previous designs, TVA had no design experience to build on. By the 1930s, the Bureau had a standardized routine that lowered their design costs. Perhaps even more importantly, the force account method uniquely employed by TVA may have increased the design costs, while reducing the overall cost of construction, reflecting the mantra that, "With force account work, it is generally possible to apply the principle of spending another dollar to save two dollars."[47] While other dam building agencies were unable to make significant modifications in design after contractor bidding, the TVA design team worked with the field engineers and construction team to make modifications as the project progressed. Justifying the large design costs to the Board of Directors, Bock said, "it is our considered policy to scrap designs and make them over when by so doing a better construction will result or when substantial sums can be saved on construction

[44] Design costs for Norris, Wheeler, Pickwick Landing and Guntersville dams are given in the TVA memos: "Comparison of Design Costs of TVA Projects," dated May 12, 1937. *[Carl Bock Papers]*.

[45] The best estimate available for the design costs at Hiwassee is in TVA's technical report, The Hiwassee Project (Washington: Government Printing Office, 1946).

[46] The estimate of Tygart design costs is based on a letter from the Secretary of War, Harry Woodring, to West Virginia Senator Rush Holt on July 19, 1937. *[RG 77/111 Box 1682, Folder 5221. National Archives. College Park, MD.]*

[47] "Letter to Board of Directors." Feb. 15, 1937. *[Carl Bock Papers.]*

operation."[48] Cost engineer H.A. Sargent also acknowledged that some of the redesign was the result of having started the design before structural characteristics or equipment to be used were determined.[49]

To demonstrate these overall savings, the engineering department completed a detailed study of design changes and resulting economies for Norris Dam. As construction work progressed and more knowledge about the Norris site became available, TVA, together with the original Bureau design team, altered the diversion scheme to use spillway blocks rather than diversion tubes, eliminated the need for needle valve outlet conduits to regulate outflow, redesigned and moved the powerhouse, and removed a cutoff trench at the heel of the dam. Each of these changes increased the design costs, but resulted in estimated total savings of $980,335, a remarkable result considering the $561,248 total design price tag.[50] Similar TVA studies showed significant savings from redesign and the force account method at Pickwick Landing, Guntersville and Chickamauga Dams as well.[51]

CONCLUSIONS: THE IMPORTANCE OF STORIES IN ENGINEERING EDUCATION

In the words of the *American Society of Civil Engineers,* in civil engineering education we aim to prepare and inspire our students to,

> *serve competently, collaboratively, and ethically as master: planners, designers, constructors, and operators of society's economic and social engine, the built environment; stewards of the natural environment and its resources; innovators and integrators of ideas and technology across the public, private, and academic sectors; managers of risk and uncertainty caused by natural events, accidents, and other threats; and leaders in discussions and decisions shaping public environmental and infrastructure policy.*[52]

While ensuring that students gain the necessary technical expertise is essential to meeting these goals, it is insufficient. Case studies and stories of past civil engineering successes and failures provide a powerful tool for teaching students about the economic, societal and political impacts and considerations that affect any major engineering effort. In the early Tennessee Valley Authority described here, a group of political and engineering leaders set out to restructure the Tennessee River and the region's economy. Their story illustrates how one organization designed major civil engineering structures. Of particular importance are the insights into how the TVA went about building the human capital and technical expertise to design and construct the early dams. The early TVA engineering efforts also demonstrate the important role of engineering management and organization in facilitating or hindering design processes. In the mid-1930s, the organization's structure seems to have complicated

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[48] *Ibid.*
[49] H.A. Sargent. "Memorandum to Barton M. Jones: Study of Design Costs" May 12, 1937. *[Carl Bock Papers.]*
[50] "Major Design Changes and Resulting Economies, Norris Dam" May 12, 1937. *[Carl Bock Papers.]*
[51] "Pickwick Landing Project: Major Design Changes", "Guntersville Project: Major Design Changes", "Chickamauga Project: Major Design Changes". All dated May 12, 1937. *[Carl Bock Papers]*
[52] American Society of Civil Engineers (ASCE). Civil Engineering Body of Knowledge for the 21st Century Preparing the Civil Engineer for the Future (2nd Edition). Reston, VA, 2008.

efforts to collaborate across different branches of the organization and to integrate the different components of dam design (civil, mechanical, electrical and chemical). Even so, the TVA introduced a major innovation in design and construction, choosing to design and build the dams in-house. This design-build approach, which has gained more widespread use in recent years, probably facilitated the introduction of certain design changes and unique engineering features late in the dam design process and, in the process, provided design engineers with the flexibility to cope with some of the organizational and communication challenges they were faced with. These lessons – and others like them – can help our students better understand and navigate engineering design processes, including technical considerations of economy and efficiency and human considerations.

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