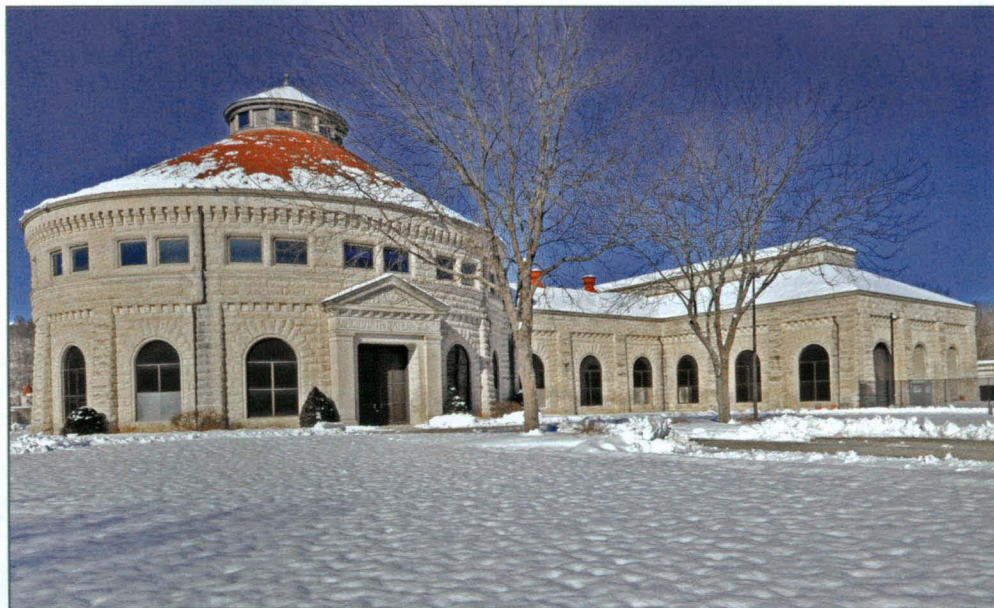


World's Largest Water Pumping Steam Engine

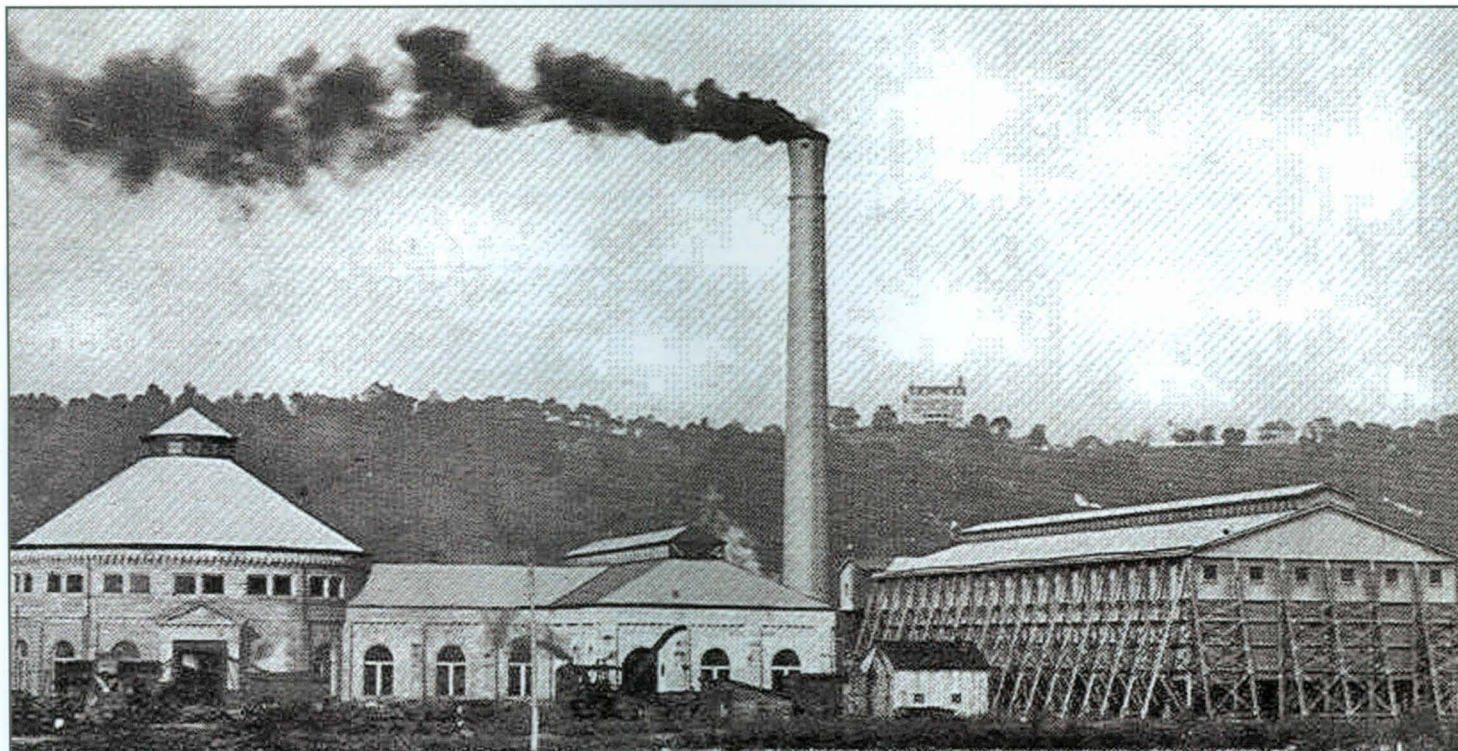
Leland L. Hite of Triple Steam based in Cincinnati, Ohio, tells the story of a capricious river that dictated the need for a pumping engine of gigantic proportions.*

Often called the world's largest, weighing in at over 1,400 tons with a height of 104 feet, the triple-expansion, crank and flywheel, water pumping steam engines at River Station for the Cincinnati Water Works ran reliably for 57 years. At 1,000 HP, they are not the most powerful as smaller engines with larger horsepower were used at Main Station in Cincinnati and elsewhere in the world. What caused the engines to become the largest ever built? Certainly, no one sat down and said, "Let's construct the largest engines we can erect."

Throughout most of the nineteenth century, faulty water works engines plagued Cincinnati because the superintendents designed some of them—and experience designing steam engines was not a job requirement! For nearly half of the 1800s, the average term of any superintendent was no longer than two years. Pumping stations in Cincinnati resembled mechanical curiosity shops.



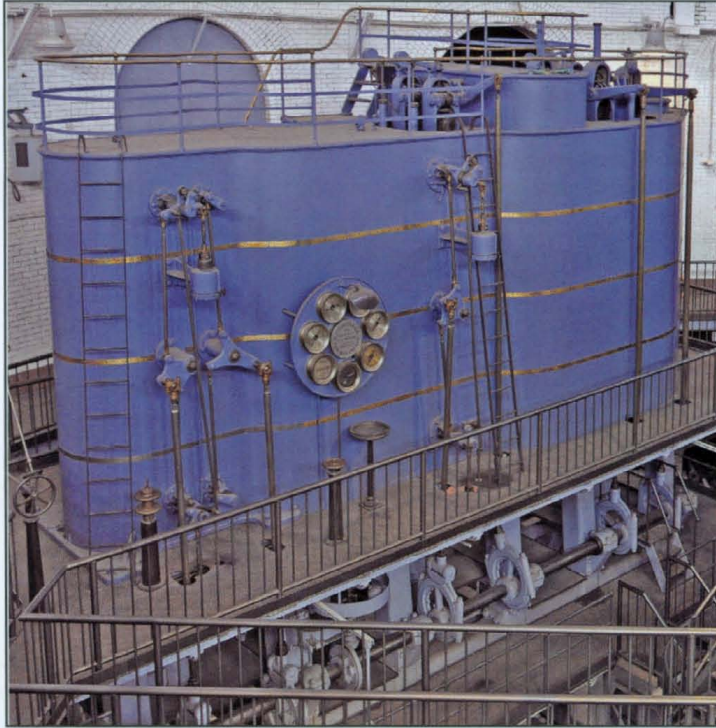
On the banks of the Ohio River, the Greater Cincinnati Water Works' River Station is an active pumping facility using electric pumps, but the impressive building also houses four extraordinary historical water pumps with colossal steam engines.



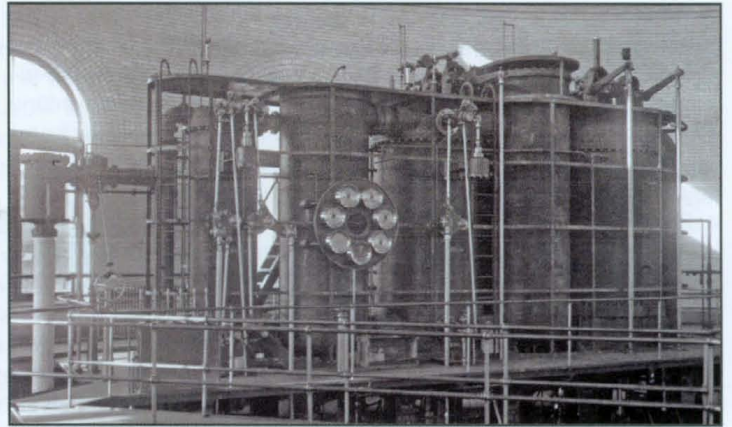
The nearly completed station of the Cincinnati Water Works (CWW) began pumping water in 1906. The coal storage building and the stack were dismantled soon after the pump house was decommissioned in 1963. Lovely architectural forms were suited to functions both inside and outside the buildings.

Engines were built by contract crews and day laborers, and no sooner were the machines set in motion than they were found defective and expensive to operate; they were as likely to get out of repair as the old machines they replaced.

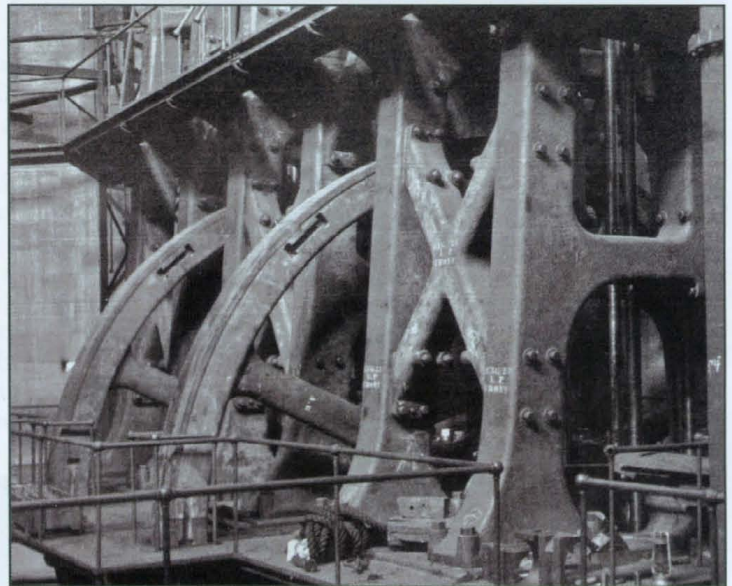
By 1890, Cincinnati was on the verge of a water shortage caused by the ever-changing water level of the Ohio River and aggravated



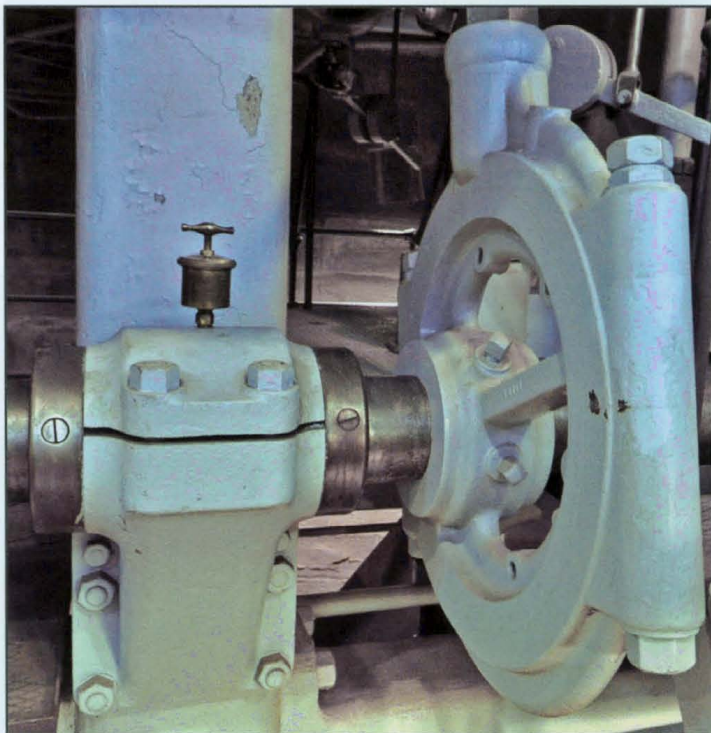
First online in 1906, the four triple-expansion, crank and flywheel, water pumping engines were arranged in a quadrangle inside a circular pump house at River Station.



An unforeseen and sudden need for maintenance in the older pumping stations caused one of the new engines to be set in motion shortly after installation, even before it had received its jacket!



Assembly of the 24-foot diameter 40-ton dual flywheels is shown prior to insertion of the dog bone locking keys.



On rare occasions, babbitt bearings were scraped and their oil grooves cleaned, but rebabbiting was never necessary.



Hook rods from the valving deck attach to the eccentric bearings on a 30-foot shaft.

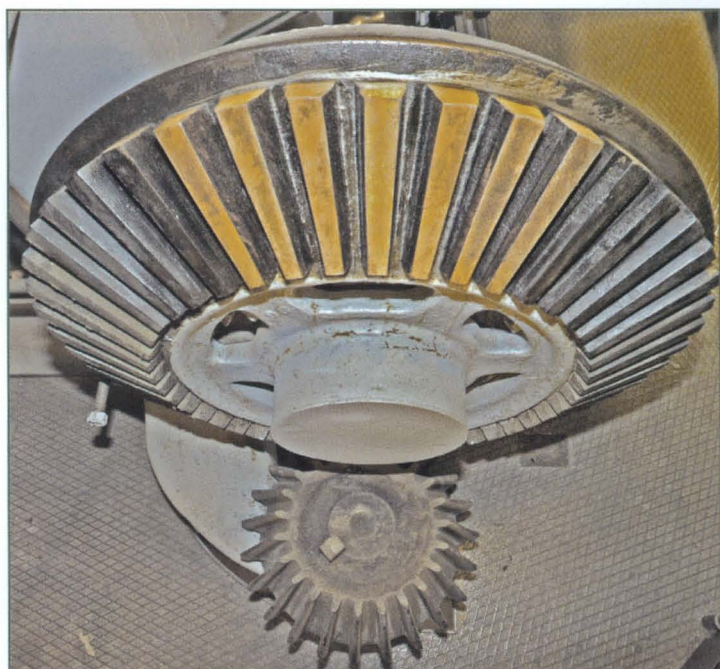
by unreliable pumping engines. Quickly added to the works was a pumping station that was located inside a movable building raised or lowered on three inclined tramways on the river bank to conform to the rise and fall of the river. This was a great aid in averting the crisis, but, within only a year, the facility, exacerbated by unreliable engines, flooded at high river levels. Next, a floating pump house solved the flooding issue, but winter ice on the Ohio River stalled the station, handicapped by all-too-frequent engine failure. When Cincinnati decided to build a new water works in the 1890s, officials insisted that the engines be purchased from—and designed by—an outside company.

Prior to the 1929, completion of navigation control locks and dams on the Ohio River that boosted minimum navigation depth to nine feet, the draft required by a coal barge tow, the river level often changed from under two feet to over 75 feet in the fall and spring. When the new water works facility began construction in

California, Ohio, during 1898, this large dynamic range for river level caused a challenging set of design considerations for pumping water to the City of Cincinnati.

The first question was how to guarantee air would not enter the pump chamber when the pump takes suction at low pool stage, causing dangerous pump cavitation and water hammering of the distribution system. Secondly, it was equally important to keep the steam cylinders dry during periods of high water, should the station become flooded, which happened after the first year of operation in 1907 with a river level of 80 feet and again in 1937.

Locating the base of the engine 5½ feet below the floor of the Ohio River, thereby allowing water to gravity feed the suction chamber and purge its air pockets, even at low pool stage, solved the first problem. Stretching the engine to 104 feet in height satis-



Dual bevel gear sets transfer power from the crankshaft to the eccentric shaft, use wooden teeth for the large gear to provide a small amount of shock absorption in the steel and cast iron engine, and help eliminate the whirling gear noise.



Pictured is one of two balanced poppet valves in the steam chest for the crank end on the exhaust side of the low pressure cylinder.



The bottom dial on the gauge panel is a CCW rotating piston position indicator (PPI), displaying the real time location for all three steam pistons and pump plungers. The starting procedure changed in response to the location of the piston in the high pressure cylinder.



Shown is the steam chest view of the 14-inch balanced poppet valves for the crank end on the exhaust side of the low pressure cylinder.

fied the dry head requirement and produced an engine with 11 working decks accessible by elevator and two spiral staircases.

While the design of triple-expansion water pumping engines was not new in the late 1800s, no one had ever built an engine this size. Facing a daunting challenge, the Cincinnati Water Works remained diligent in its quest for a successful design. Fifteen bids from eight manufacturers in December of 1897 resulted in a contract to the Lane & Bodley Co. of Cincinnati, Ohio, to furnish and erect four vertical triple-expansion pumping engines, each of 30,000,000 gallons daily capacity, the necessary boiler equipment, and a 30-ton circular traveling overhead electric crane. Two years passed when no plans entirely acceptable were ever submitted, and, with a ruling against the Lane & Bodley by the Ohio Supreme Court in January 1900, the firm's contract for \$514,000 was cancelled for failure to comply. Two successive attempts to acquire a successful proposal produced 14 responses from four companies, all rejected as unsatisfactory, causing considerable anxiety about the feasibility of the project.

Ultimately, one year later, reviewing 11 proposals from four companies revealed several bids that were close to meeting requirements. Most agreeable to making

design changes in real time and at no additional cost, the Camden Iron Works from Camden, New Jersey, was happy to be the chosen vendor. Contracted to supply four engines with appropriate boilers at a cost of \$807,500, the foundry began work in January 1901. The project proceeded quickly. Two and a half years later, with most of the foundry work finished, two-thirds of the castings were machined. The engines were erected and hand rotated at the Iron Works to ensure that moving parts functioned as designed. Steam was never applied while the engines were in Camden.

Subsequently, in June of 1903, after a long legal battle, Lane & Bodley had to pay back \$65,000 of the \$303,000 paid to them from their failed efforts to design and build the engines.

Limited navigation of the Ohio River affected fuel supply, causing a demand for the highest possible efficiency from the station to minimize coal consumption. Designed by John H. Lewis at the R. D. Wood & Co. in Philadelphia, and built by the Camden Iron Works, the four triple-expansion 1,000 HP engines sported a modern efficiency design. Each cylinder, 29 inches, 54 inches, and 82 inches, was encased with a steam jacket and both receivers supplied with reheaters. Efficient Corliss valves with dash pots were specified for the high-pressure cylinder and the

steam side of the intermediate pressure cylinder, while balanced poppet valves were used for the low-pressure cylinder and the exhaust side of the intermediate.

Initial startup found Engine 2 with a cracked head on the intermediate pressure cylinder, and, after replacement, no major



Levers to power all three steam indicators are normally attached to the connecting rods, but here they are shown in their resting position on the housing for the stabilization bearings. They extend upward to the operating deck at the rear of the engine.

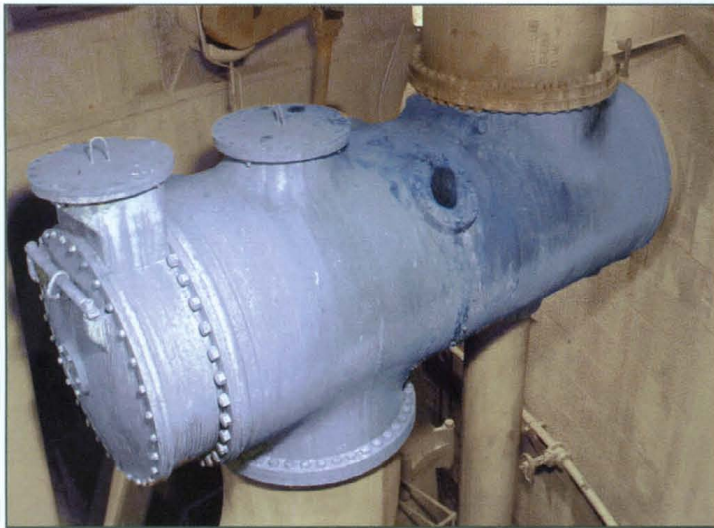


In the early 1900s, workers whose task was to oil the engines accessed various decks using this five-story spiral staircase accessible from the eccentric deck.

failures occurred to the four engines in 57 years of operation. Babbitt bearings were occasionally scraped and oil grooves cleaned, but none required rebabbiting.

Running quietly was a common characteristic for a triple-expansion condensing engine. R. D. Wood & Co. further enhanced the muted sound by incorporating wooden teeth in the two large gears for the dual bevel gear sets that transferred power from the crankshaft to the eccentric shaft. Only a minor clicking sound remained from the knock-off cams operating the Corliss valve as the engine ran at full speed, 15½ RPM. The wooden teeth also provided a small amount of shock absorption in an all-steel and cast iron engine.

Why the engines were never designed to start using a barring motor is a mystery. Most often, steam applied to the high pressure cylinder would roll the engine, but, occasionally, the engine would stop with the high pressure piston at top dead center for head end or crank end and require extra effort to start the pump. Under this condition, the first receiver was charged to 34 PSI in an effort to move the intermediate pressure piston. The procedure occasionally required the 139 foot head pressure to be removed from the pump plunger. On rare occasions, when all such attempts failed, a large rope was attached from the flywheel to the overhead crane to nudge the engine into rotation. When live steam was



Right: The 37½-inch plunger with a 96-inch stroke is outside packed with oakum. The quad connecting rods extend to the crosshead.

Left: All water pumped by an engine flowed through its surface condenser prior to leaving the station.



The quad connecting rods from the crosshead to the pump plunger straddle the crankshaft and the crank web.



The 36-foot high pump features an inlet port, the suction and discharge poppet valve compartment, a discharge port, and a force chamber. Note the wet air pump snuggled between the surface condenser (top right) and the pump chambers.

applied, two workers stood by with sharp axes to cut the rope immediately once the engine rotated.

Each engine drew 150 PSI of dry process steam from two four-drum Sterling water-tube boilers fitted with Foster superheaters and Green economizers, increasing boiler efficiency to over 78 percent. Firebox draft was forced from two 85-inch steam-powered Buffalo Forge fans into a 175-foot x 8-foot stack. Coal to water efficiency (duty) for two boilers and an engine was 156,315,000 foot-pounds of work per 100 pounds of Pittsburg Nut & Slack coal, or 1,883,000 gallons lifted one foot per 100 pounds of burnt coal.

Scale and unwanted chemicals were removed from the condensate flowing from the surface condenser using a large deaerating plant. Each engine housed its own wet air pump to evacuate air from the surface condenser, a doctor pump (also known as a boiler feed water pump), and a sump pump.

Collected in dual condensate storage tanks, boiler feed water originating in the hot well for the surface condenser was pumped through the deaerating plant, the exhaust heater, and the Green Economizer (preheating feed water using boiler flue gases) prior to entering the boiler at 210° F.

Each engine moved 30 million gallons per day into two holding reservoirs, providing a supply lasting several weeks in 1906, should pumping stop. The 96-inch stroke from each steam piston was directly connected to its nickel-iron pump plunger measuring 37½ inches in diameter and 14 feet long. The displacement type pump took suction on the up stroke and discharged 450 gallons on the down stroke, 1,350 gallons per engine per revolution. At 15 RPM, each engine moved six tons of water into its chambers every two seconds. Enormous forces resulted from starting and stopping six tons of water on each half rotation of the engine and caused the need for large force chambers (air chambers) on both the suction side and the discharge side to smooth pumping pulsations prior to distribution. Twenty-four tons of water moved through the station for every rotation of the dual 40-ton flywheels on each engine.

Poppet valves used a rubber disk against a brass seat for both the suction and discharge side of the pump. Fifty percent more valves were included on the suction and discharge side than required for the smooth flow of water, minimizing maintenance demands. Annually, each pump was dewatered, enabling a worker to crawl inside the pump chamber to inspect its 1,680 poppet valves, over 6,700 for the station. The brass seat often required refacing, using the station lathe to smooth its surface. Debris caught between the rubber and the brass seat would gouge the brass but not the flexible rubber.



Within the suction side of the pump chamber are seven valve cages, each housing 40 poppet valves. The 37½-inch plunger, at the top of the photo, moved 450 gallons out of the station for every rotation of the flywheel.

Components for one of the 6,700 poppet valves in the pumps at River Station include a brass seat, washer, and knob, but the spring is copper.



Removed from the engine for display purposes is one of 14 poppet valve cages in each pump.



An O. S. Kelly traction engine assisted a mule team to move a 3,600-pound Bedford limestone block to River Station after a heavy rain. Between 1890 and 1891, Oliver Kelly employed designing engineer Edward T. Wright, an Englishman who apprenticed at Aveling & Porter. Wright's influence may be detected in the design of the Kelly engine.

As with the engines, the Ohio River itself dictated coal storage designs at River Station. There was always a supply of pumping water, even at low pool stage, but year-round navigation was not possible. Because a coal carrying tow barge required a draft of nine feet, navigation from the fuel supply in Pittsburg was restricted to a few months each year, depending on low river level and ice. Good planning provided a 300-day supply (8,000 tons) of dry coal, stored seven feet above ground in 114 elevated pocket hoppers, accessible from a narrow gauge railway system traveling underneath. Even with navigation control dams and locks in place by 1929, low river levels over prolonged periods prevented

coal delivery, causing hoppers to be depleted. All coal burned in the last three months of 1930 was delivered by rail.

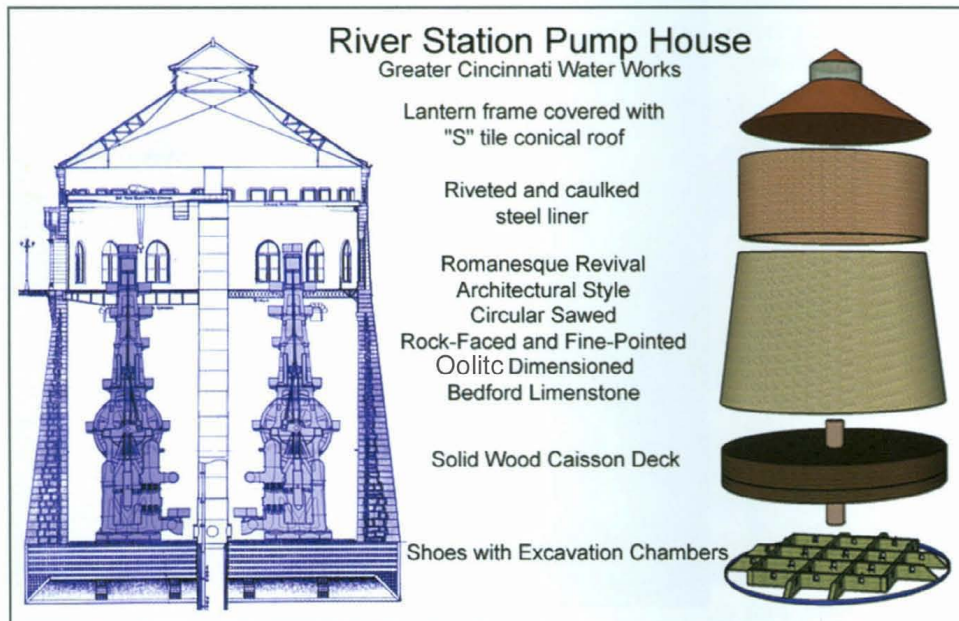
Daily usage averaged 26 tons of coal that was switched to the boiler house from the storage area using a narrow gauge rail system (19 inches) with two-ton boiler charging cars powered by an electric locomotive engine about the size of a golf cart called *Dinky*, which ran on Edison batteries. A coal passer dumped coal on the floor in front of each boiler. Shovelers moved the coal into the stoker hopper. Boiler ash cars were switched using the same locomotive.

Yet again, Ohio River dynamics influenced design decisions regarding the shape and size of the pump house. Because the

floor of the building was to rest 105 feet below grade in soil experiencing a high ground water level, a circular structure was best suited to withstand the 20,000 tons of hydraulic pressure pushing in and up on the building. The bottom of the pump pit wall, laid from Bedford limestone, is 15 feet thick and tapers to four feet in thickness at ground level, with the inside wall being plum and fine pointed. Fitted with a riveted and caulked steel liner resting two feet from the inside diameter, the cylinder provided for water-tight construction.

Because the extreme weight of the four engines was well over 6,000 tons, the pit floor required a high-strength design. A familiar construction technique employed to build wooden reservoirs at the water works in the 1800s used 12-inch square air-dried and machined white oak timbers that were closely spaced and bolted. Full of water, the wood expanded to seal the joints making an excellent storage container. Building a sturdy floor for the circular pump pit followed the same procedure but used crisscrossed timbers, bolted and closely spaced, to become a circular disk, 128 feet in diameter, 12 feet in thickness. Constructed in 12 months, this was a sizable chunk of wood.

Sinking the pit floor required 36 excavation chambers under the 12-foot caisson floor. Workers in each compartment removed sand and clay that was hoisted and stored on the floor surface to become ballast for lowering the center of the pit floor. As excavation progressed and the floor sank into the ground, limestone blocks were laid to form the outer wall, providing sufficient weight to lower the



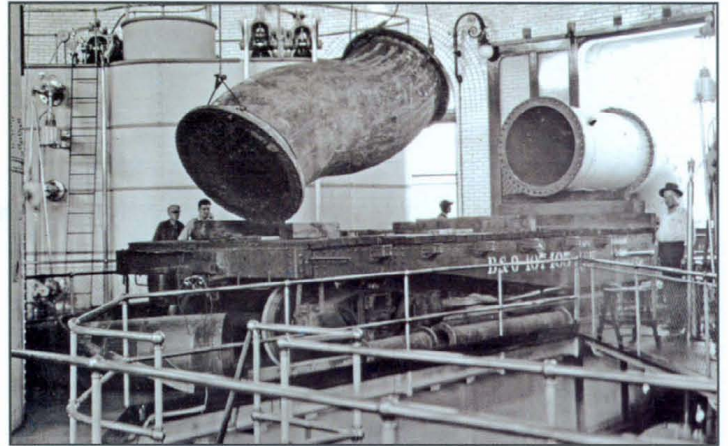
A cutaway view of the circular pump features structural components.

caisson. Most of the blocks were installed at ground level synchronically as the pit floor lowered. Six months passed while the caisson was lowered to 105 feet below grade and the wall reached to grade during a period of low ground water in 1899.

Becoming obvious from the movement of the caisson as the sinking operation progressed, the anticipated weight of the engine house and engines would not be sufficient to prevent shifting of the caisson. It did not prove feasible to rest the caisson on bedrock, and, as a result, the station had the undesirable potential to float during periods of high river levels from the 20,000 tons of hydraulic pressure caused by high groundwater.

With the caisson excavation complete, sand ballast was removed from the deck floor in December 1899. Shortly thereafter and prior to engine placement, the winter ground water level increased and the 12-foot thick wood caisson deck deformed taking the shape of an inverted ice-cream cone. The center rose 3½ inches as the wall edge fell 1½ inches, a catastrophic surprise to the engineering staff that prevented installation of the engines.

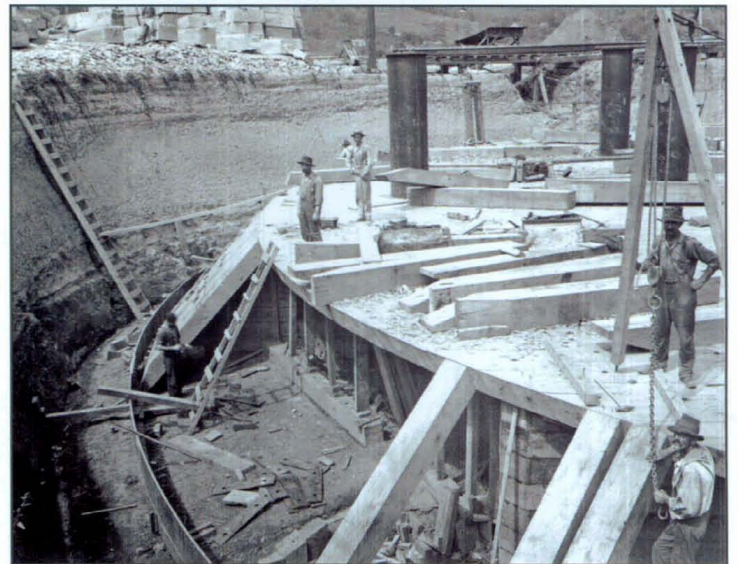
Without the engines installed, a disproportionate amount of weight (15,000 tons) from the limestone wall rested on the outermost 25 percent of the caisson deck. This imbalance had a ten-



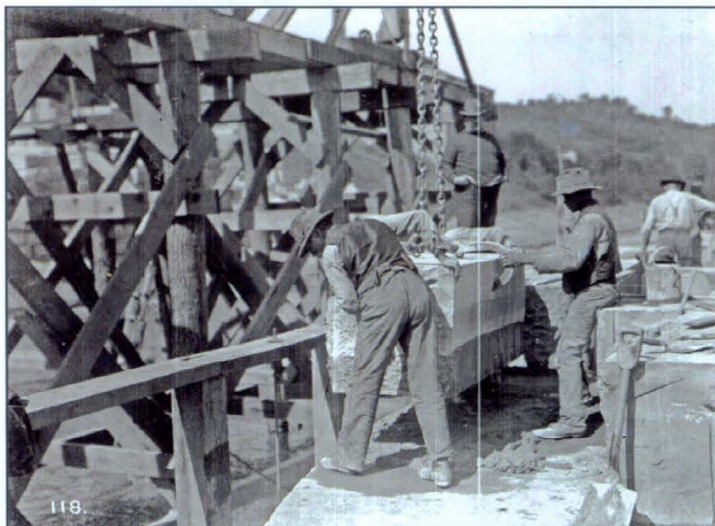
Delivering engine components, a full-sized railroad car was parked in the station on a steel plate railway girder that was riveted to the standpipe.



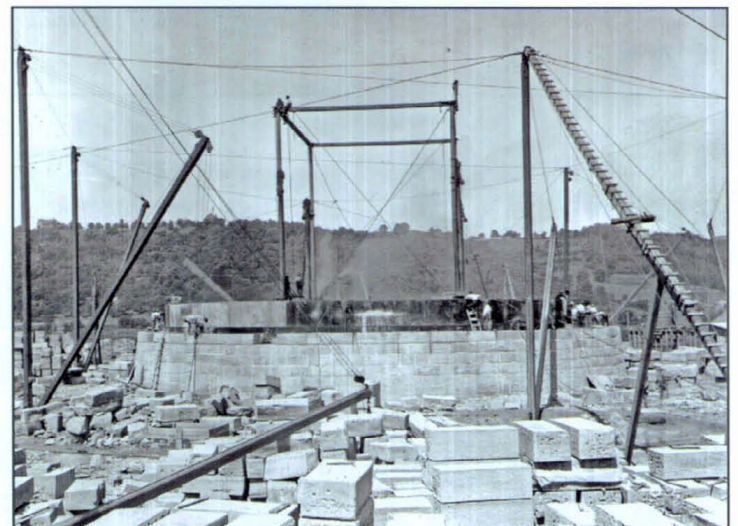
Low pool stage on the Ohio River restricted coal delivery to a few months each year.



Resting on 7-foot wooden shoes, the tapered edge for the caisson began being erected concurrently with the first layer of deck timbers.



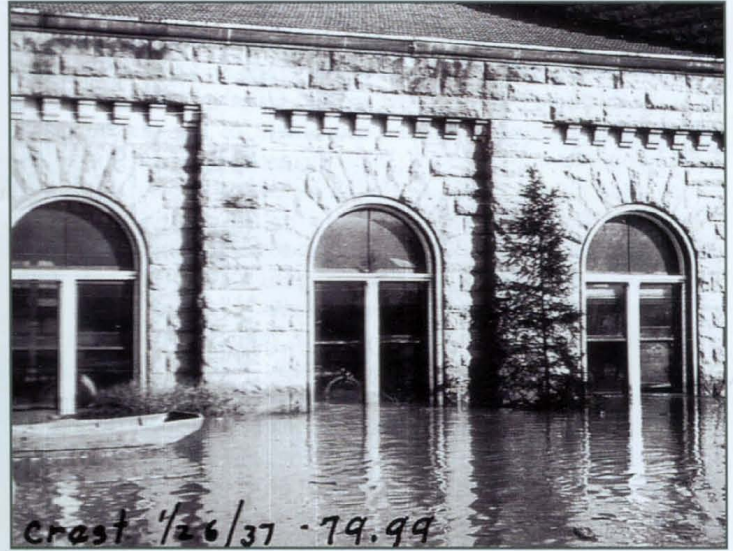
The pump pit wall was established at ground level from limestone blocks while the building sank into the ground.



Another section of the riveted and caulked steel liner was installed prior to forming the next row of masonry.



Six-ton pie-shaped cast iron segments formed a 4,200-ton ballast around the standpipe to assist holding the floor level and to prevent the building from floating during periods of high ground water.



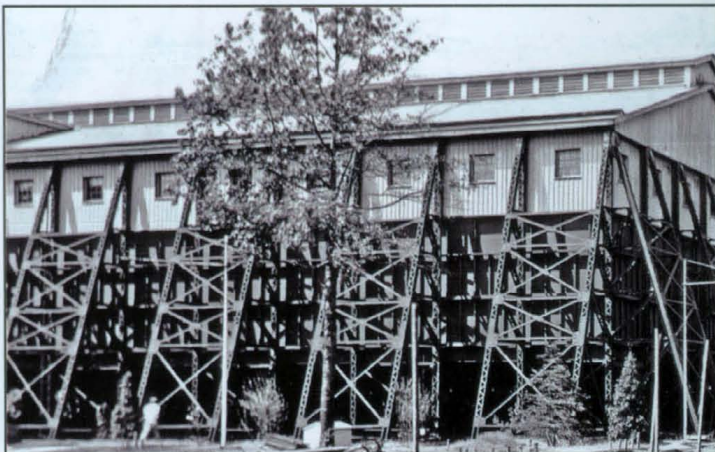
High water in 1937 flooded the station, disabling service for 11 days.



The 23-foot measuring gauge displays the water level when the pit floor is deliberately flooded at times of high ground water to prevent the building from floating.



Ground water seepage was anticipated from under the 15-foot thick pit wall resting on the wooden caisson deck. This circular trough around the circumference of the pit floor captures water to be pumped outside the station.



Shown is a third of the elevated coal storage building supported by steel bents holding a 300-day supply in 114 pocket hoppers.



Spouts for 114 pocket hoppers in the bent-steel-supported coal storage building, each holding 70 tons of coal, are elevated 7 feet from the ground.

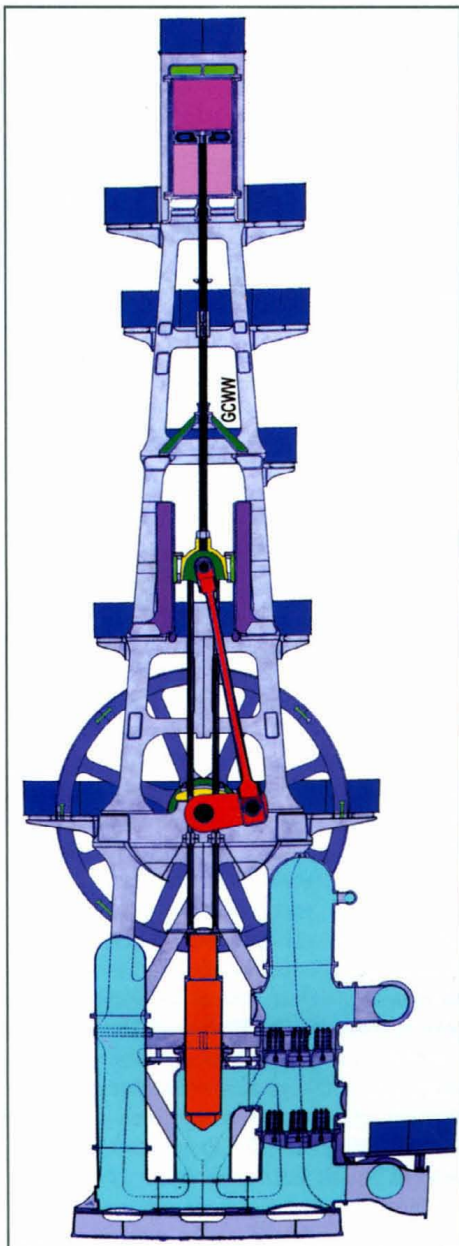
dency to cause the caisson to sink at the outermost edge and rise at the center. As the dry caisson absorbed water, extreme radial pressure toward the center from the expansion of the closely spaced and bolted timbers caused enormous forces. Dry white oak can easily expand 5 percent or more when saturated with water. The 10-foot diameter center hole for the standpipe acted to relieve inward pressure from the moisture-laden expanding wood. Hydraulic pressure from high river levels in December of 1899 then provided the necessary force to nudge the highly stressed caisson upward at the center.

Water works designers are not expected

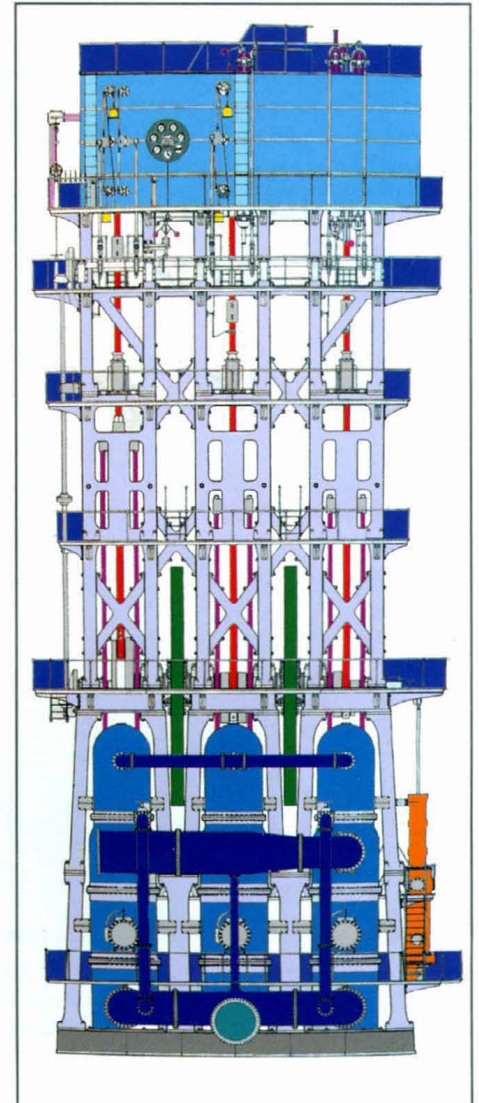
to be bridge builders. For example, when John A. Roebling designed cable suspension bridges for Cincinnati and for Brooklyn, New York, he avoided this dangerous swelling of the caisson by specifying its construction from loosely spaced lignum vitae, also known as pockholz or ironwood, from trees of the genus *Guaiacum*. Naturally sinking in water with a minimal coefficient of expansion, this was an ideal material for a stable caisson.

Five years passed before the floor of the Cincinnati pumping station returned to its original configuration. An unplanned 4,200-ton cast iron ballast wall was placed around the standpipe for additional center located weight, but even that did not push the center downward. Eventually, engine castings were randomly scattered about the floor and the pit flooded to 34 feet, causing an additional 12,440 tons to restore flatness to the floor. All four engines were rapidly assembled without regard to alignment or accuracy to place weight on the caisson. Then each engine was individually re-assembled for a precision fit.

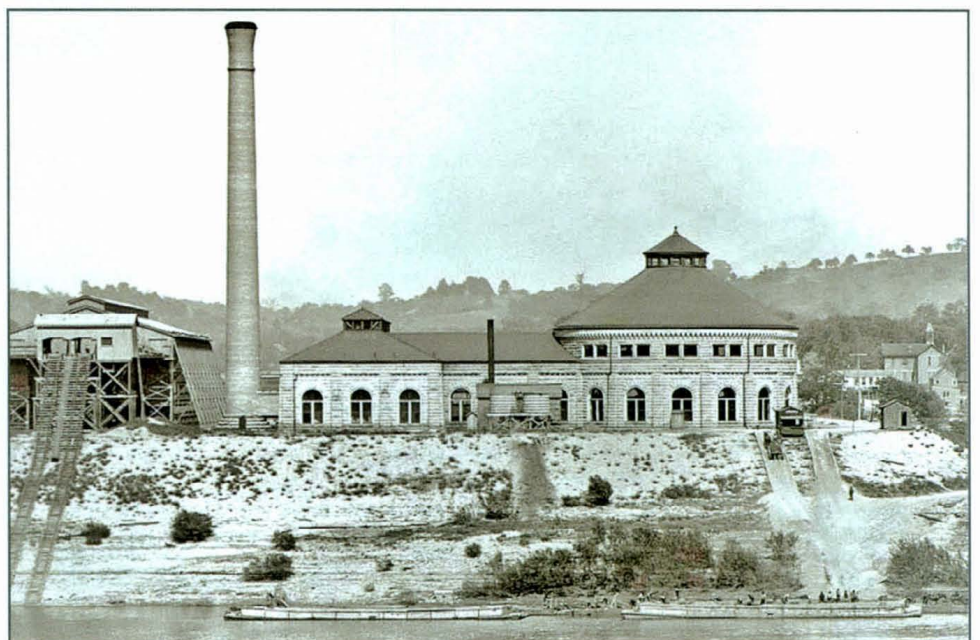
Today, the engines still help to preserve the flatness of the floor during periods of high water. Extreme river levels do cause deliberate flooding of the pump pit with one and half feet of water for every foot the



Of particular note in this side view is the arrangement of the pump plunger and the intake force chamber to the rear of the engine.



Right: In this front elevation view, we can see the arrangement of the headers connecting the intake and discharge ports for all three pumps, as well as the wet air pump at the lower right-hand side.



Dual narrow gauge railway tracks allowed one coal car to ascend to the hoisting house while another descended.

river rises. River Station is a wonder worth seeing. Tours are arranged through the Cincinnati Triple Steam website. Plans are underway to provide a power source to turn one of the engines again. If this goal can be achieved (and all signs look promising that it will be), visitors will have the rare opportunity to witness the dynamism of a mammoth engine.

* Virtually the same article was recently

published in *Old Glory*, British steam and vintage preservation magazine.

Acknowledgments

I thank Dr. Robert T. Rhode for his help in editing this document. Check his site (<http://www.roberttrhode.org>) where you will find many fascinating books and eBooks that he has authored, as well as

several complimentary documents of interest to readers of *Engineers and Engines Magazine*, and be sure to follow his weekly blog (<http://heartlandbooks.blogspot.com/>).

Leland Hite can be contacted at leland.hite@gmail.com

In Memory



Brian Vaughn

Brian Keith Vaughn, 51, a life long resident of North Vernon, IN, passed away Sept. 18, 2015.

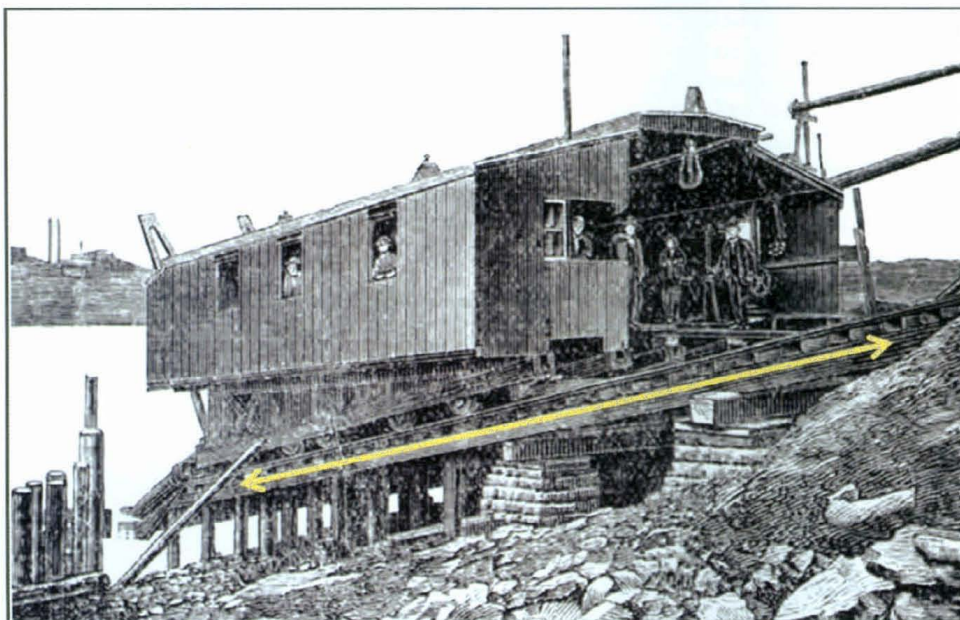
Brian was the son of Ray E. and Karen R. (Stout) Vaughn who both survive him.

Brian graduated from Jennings County High School in 1982, then entered the Navy one week after graduating. He served in the United States Navy for eight years, serving on nuclear submarines USS Houston, USS Dace and USS Philadelphia. He recently worked for Hartford Steam Boiler Inspection and Insurance Company as a boiler inspector. Brian currently has been serving as president, since 2003 of the Pioneer Engineers Club of Rushville, IN. He enjoyed classical music, playing chess, reading and was very passionate about steam engines. He purchased his first Keck Gonnerman Steam Engine in 1989, which he was extremely proud of. He was also very active with the Pawnee Steam School.

Other survivors include one brother, Jonathan L. (Stephanie) Vaughn of North Vernon, IN and two nephews, Austin Hunter Vaughn and Mason Cole Vaughn both of North Vernon, IN.

Memorial donations may be made to the Jennings County Hospice or Lymphoma Leukemia Foundation.

Submitted by Bob Crowell.



Self-contained and tramway mounted, this pump house featured coal storage, boilers, and three steam engines, each powering a water pump. The movable station was lowered or raised to allow suction from an ever-changing river level. Pumping over a wide dynamic range proved quite successful, but even this station flooded at high water levels.



Floating a self-contained pump house seemed like a good idea to deal with a capricious river, but challenges from winter ice, summer debris, and high water caused mooring to be a significant challenge.