Transforming Swampland into Nauvoo, the City Beautiful: A Civil Engineering Perspective

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The history of The Church of Jesus Christ of Latter-day Saints includes a number of significant engineering accomplishments. The Salt Lake Tabernacle was designated a national historic landmark by the American Society of Civil Engineers because of the innovative bridge truss system used to support its roof. Latter-day Saints also pioneered a technique known today as dynamic compaction in their efforts to improve the soil below the foundation of the St. George temple. A one-thousand-pound cannon was repeatedly dropped from a height of twenty to thirty feet to drive lava rock into the soil below the foundation level. One of the Saints’ most important accomplishments, however, was the transformation of hundreds of acres of disease-infested swampland into “Nauvoo, the City Beautiful.”

In the early nineteenth century, a major impediment to land development in the midwestern states was the presence of millions of acres of relatively flat swampland. Throughout much of the century, little progress was made in draining this land. As a result, Congress eventually passed the Swampland Act in 1850, which turned swamplands into public lands with the intent that they be reclaimed. Congress gave 65 million acres to fifteen states for reclamation, and Illinois received nearly 1.5 million acres. Illinois passed the lands on to the counties, but drainage benefits were slow in coming and generally were not realized until after the Civil War. Therefore, the drainage efforts in Nauvoo represent a rare early success story.

Although every account of the development of Nauvoo indicates that drainage was essential, few sources provide any detail regarding how this was done and the actual results of the work. A complicating factor is that over time ditches tend to fill in with silt and organic matter if they are not...
This project began with a conversation between two neighbors, Milton Backman, a former professor of Church history at BYU, and Kyle Rollins, a professor of civil and environmental engineering. After a visit to Nauvoo, Backman suggested that it would be useful for a civil engineer to investigate how the Saints had drained the Nauvoo swamp, since very little was known. With this encouragement, Rollins applied for a grant from the Religious Studies Center and undertook the study.

A study like this one, however, required a few different areas of expertise. Because Professor Rollins specializes in geotechnical (soil) engineering, he and one of his graduate students, Richard Smith, conducted the field investigations and the historical research. Professors Nelson and Borup specialize in hydrology and water resources. They were enlisted to work with Richard Smith in developing sophisticated computer models of the surface water runoff in Nauvoo, which helped explain the effects of the Saints’ drainage work.

When asked what the most difficult part of the project was, Rollins explains: “While the computer modeling was reasonably complicated, the physical effort associated with the fieldwork was probably the most challenging. We spent many long days drilling boreholes with a hand auger, surveying the drainage ditches, and slogging through muddy ground to obtain soil samples. Two large thunderstorms occurred during the fieldwork, and these gave us a firsthand understanding of the importance of drainage for Nauvoo.”

Were there any surprises as the project unfolded? “We were quite surprised,” explains Rollins, “at how effective the main interceptor drain was in lowering the groundwater level and at the amount of labor that was likely involved in digging this drainage ditch. While many other areas in the Midwest struggled with drainage problems over many years, the residents of Nauvoo worked together quickly to drain their swampland.”
maintained. This has happened to many ditches in Nauvoo. A system of shallow ditches on the sides of major roads still drains much of the surface water in Nauvoo today, but these ditches may not be the same ones the Latter-day Saints dug when they settled there. The objective of our study was to combine conventional historical research techniques with modern engineering analysis methods to explain the drainage of the swamplands in Nauvoo, Illinois.

**Historical Evidences Regarding Drainage**

Nauvoo (formerly Commerce), Illinois, is located in Hancock County on the east bank of the Mississippi River at the head of the Des Moines Rapids. The lowland section (or “flats”) is surrounded on the north, west, and south by the Mississippi, while bluffs rise about sixty feet to expansive prairie land on the east. Nauvoo is underlain by horizontally bedded limestone that is relatively impervious in the vertical direction but allows horizontal water flow. The overlying fine-grained soil tapers from a thickness of twelve to sixteen feet at the base of the bluffs to about two feet near the Mississippi River. Due to surface water runoff and groundwater flow, the volume of water increases as it moves westward on the flats; however, the impervious limestone layer traps the water in a progressively smaller volume of soil, leading to swampy conditions.

In spite of the obvious challenges this swampland presented, on May 1, 1839, Joseph Smith Jr. and a committee of Latter-day Saints bought 1.4 acres from Hugh White and 47.17 acres from Isaac Gal-land in the flatlands around Commerce, Illinois. Joseph and Emma Smith with their four children moved into a log cabin on the White property on May 10, 1839. Joseph Smith described the conditions in Commerce upon his arrival:

When I made the purchase of White and Galland, there were one stone house, three frame houses, and two block houses, which constituted the whole city of Commerce. Between Commerce and Mr. Davidson Hibbard’s, there was one stone house and three log houses, including the one that I live in, and these were all the houses in this vicinity, and the place was literally a wilderness. The land was mostly covered with trees and bushes, and much of it so wet that it was with the utmost difficulty a footman could get through, and totally impossible for teams. Commerce was so unhealthful, very few people could live there; but believing that it might become a healthful place by the blessing of heaven to the Saints, and no more eligible place presenting itself, I considered it wisdom to make an attempt to build up a city.
A map showing the locations of homesteads in the Nauvoo area prior to 1839 appears in figure 1 and, as Joseph Smith indicated, the population was extremely sparse.⁴

The Saints began arriving in Nauvoo throughout the summer of 1839, and the first official city plat was filed on August 30, 1839. Joseph Smith, in writing to the Saints abroad, expressed his vision for the new city of Nauvoo:

![Map of Nauvoo homesteads](image)

**Fig. 1.** Original Church land purchases and homes of early settlers prior to Mormon arrival. Courtesy Glen M. Leonard.
The name of our city (Nauvoo) is of Hebrew origin, and signifies a beautiful situation, or place, carrying with it also, the idea of rest; and is truly descriptive of the most delightful location. It is situated on the east bank of the Mississippi River, at the head of the Des Moines Rapids, in Hancock County, bounded on the east by an extensive prairie of surpassing beauty, and on the north, west, and south by the Mississippi.

To fulfill the Prophet’s vision for Nauvoo, considerable work awaited the Saints. Theodore Turley completed a home in Nauvoo in early June of 1839, but most of the Saints had inadequate housing upon their arrival. Having been forced to leave the state of Missouri under threat of government extermination, large numbers of refugees camped near the Mississippi River and sickness was rampant. The swampy conditions made ideal breeding grounds for mosquitoes, which transmitted malaria (known then as ague), although the source of the problem was not known at the time. Malaria produces attacks of chills and high fevers every two to three days as well as weakness and anemia between attacks. The experience of Jesse Wentworth Crosby, who arrived in Nauvoo on June 6, 1839, was likely typical of what the early settlers encountered:

Here, instead of meeting the Saints in comfortable circumstances as we had expected to find them in Missouri, they were, as many as had been able to get through, living in tents and wagons for want of houses, some 400 miles from the place whence they had been driven, many in straitened circumstances, some sick and overcome with hardships and fatigue. I walked about the place. The sight was beautiful. Though uncultivated and for the most part covered with timber, brush and grapevines, I concluded to stop and share with the people of the Lord while some of the company chose rather to go where they could fare better. I procured a lot and commenced to build a house for myself, Mother and Sister, who had journeyed with me, a short distance back from the Mississippi and near the residence of Joseph Smith. Here in the midst of these wilds with but little earthly substance, I toiled and assisted in opening some of the first streets in that part of the city, with my own hands by cutting down the timber and underbrush which was so interwoven with grapevines that it was difficult to get one tree to fall till several were cut off. However, the brush and encumbrances soon melted away before the persevering hand of Industry and Houses sprung into being on every hand. At length we were checked a little for the sickly season came on and many very many felt its withering influence. . . . I, myself, was taken sick in July and was laid up till late in September and the house which I commenced was not finished for the season.

Benjamin Brown also moved to Nauvoo in 1839 and commented on the conditions at the time and the prevailing opinion of the nearby residents regarding the place:

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Attempts had been made to build a city at this spot, previous to the entrance of the Saints, but all the inhabitants, with the exception of three or four families, had died, and the Saints used the deserted houses as far as they would go. It was a common saying among the inhabitants of the surrounding country that, if the “Mormons” could live there, they could live anywhere. It truly was a most unhealthy spot, filled with ponds and stagnant waters, left by the overflowing of the Mississippi river, afflicting all the neighbourhood with fevers and agues. From this condition I saw the city become, through the industry of the Saints, a healthy and prosperous place, being drained of these swamps.7

Although the Saints spent the early months in Nauvoo fighting sickness and providing the bare essentials necessary for survival, their focus soon turned to plans for making the area habitable and realizing Joseph Smith’s vision for the new city. Jesse Crosby noted, “As the winter [1839] approached the sickness disappeared and plans were laid for draining some parts of the land which lay low.”8 Little more regarding the planning for the drainage work is reported in the journals of the time. The decrease in disease was likely the result of the disappearance of mosquitoes in the winter.

The map of the city of Nauvoo shown in figure 2, prepared by Gustavus Hill between March 1841 and December 1842, shows the location of the bluffs and the two main drainage channels that flow into the flats.9 One drainage channel collects runoff from the bluffs on the northern side of the area and eventually flows north along Main Street and into the Mississippi River. A second drainage channel collects runoff from the bluffs on the southern side of the city and carries it to the Mississippi on the south. While no contemporary reports pinpoint the actual time and details of construction, it appears that early drainage efforts focused on digging a ditch to intercept the flow out of the southern drainage area.

An interceptor drain would provide two important benefits,
Transforming Swampland into Nauvoo as illustrated in figure. First, the drain would intercept surface runoff water that would normally flow from the bluffs onto the flats and instead channel it south towards the Mississippi. Second, the ditch would also intercept groundwater flowing west out of the limestone bedrock toward the flats and thereby depress the groundwater level west of the drain. The effect on the groundwater level would diminish with distance from the drain but would certainly have been important in the southeast quadrant of the flats.

A review of the Gustavus Hill map indicates a number of nearly linear drainage channels that were unlikely to be natural streams. These linear segments, highlighted in figure 2, followed roads and property boundaries and made ninety-degree bends. They were likely man-made ditches that carried water between existing natural drainage features. By the time Hill prepared his map, it appears that an interceptor drain had been constructed along the east side of Durphy Street (now State Highway 96) from Hotchkiss Street to Kimball Street. This ditch captures water flowing west out of the southern drainage area along White and Hotchkiss streets and immediately channels it south and away from the flats (figs. 4 and 5a). Subsequent efforts likely extended this main drain southward on Durphy Street to the present exit point at the south end of the street.

Although the stone bridge shown in figure 5b appears to have been constructed after the Mormons left the city, a report in the August 7, 1846, edition of the Hancock Eagle provides evidence of the drain’s construction during the Mormon period:

That big drain which runs along the base of the hill towards the south, should be bridged wherever it crosses by several streets. Parley is one of
Fig. 4. Drainage ditch on the east side of Durphy Street (State Highway 96) after it makes a ninety-degree bend off Hotchkiss Street.

Fig. 5. (a) Drainage ditch at the south end of Durphy Street and (b) water from the same ditch flowing under a stone arch bridge and into the Mississippi River.
the most traveled [streets] in the city, yet it is impassable at the big drain even for foot passengers without crossing several private lots.\textsuperscript{10}

Although the Saints may have developed drainage plans as early as the spring of 1840, it appears that they had made little progress in carrying out these plans at this point. Swamps and sloughs were still very much in evidence in Nauvoo. According to Mosiah Hancock:

When spring \([1840]\) started to draw near, father . . . made a hickory spade, and we piled up a brush fence and soon had a garden in. There were so many sloughs in Commerce, that the garden was sickly indeed! Our house was on the bank of a slough, and there was a spring about fifty yards down from the house.\textsuperscript{11}

Franklin Woolley also reported that sickness and swamps were common in the summer of 1840:

During the summer \([of 1840]\) my father’s family were nearly all sick with the fever and ague[.] I was the only one able to bring them medicine for some time and I remember going to Lyons’ Store for it, then, what was afterward Main Street, was a willow swamp.\textsuperscript{12}

John Butler’s autobiography also notes that “down in the bottom it was all swamp and low, wet places. The Saints went to work and drained it all off so that it became dry and a great deal more healthy.”\textsuperscript{13}

By the end of 1840, the drainage efforts had progressed sufficiently that the \textit{Times and Seasons} could report on November 15, 1840:

Nauvoo is still growing, great improvements have been made during the past season, the health of the place has been greatly facilitated during the season, by various improvements; such as the digging of excellent wells, draining off stagnant waters, etc. etc. The sickness of the place has generally subsided, and as a community we have great reason to thank a kind and merciful Providence for the bountiful blessings which he has seen fit to bestow upon us.\textsuperscript{14}

Again, on January 15, 1841, the \textit{Times and Seasons} reported:

The healthiness of the place during the past year had been greatly improved by the digging of wells and the draining off stagnant waters, and there was now but little or no sickness among the inhabitants. The saints were also blessed with an abundant harvest in the year 1840.\textsuperscript{15}

At the beginning of 1841, various assessments of the situation suggested that the greatest problems with drainage and swamps were now associated with the northwestern part of Nauvoo because earlier drainage efforts had focused on the southeastern part of the city. For example, on January 15, 1841, the \textit{Times and Seasons} reported:
This place has been objected to by some, on account of the sickness which has prevailed in the summer months, but it is the opinion of Doctor [John C.] Bennett, a physician of great experience and medical knowledge, that Hancock Co., and all the eastern and southern portions of the City of Nauvoo, are as healthy as any other portions of the western country, (or the world, to acclimated citizens) whilst the northwestern portion of the city has experienced affliction from ague and fever, which however, he thinks can be easily remedied by draining the sloughs on the adjacent islands in the Mississippi.¹⁶

In his inaugural address on February 3, 1841, Mayor John C. Bennett stated: “The public health requires that the low lands, bordering on the Mississippi, should be immediately drained, and the entire timber removed. This can and will be one of the most healthful cities in the west, provided you take prompt and decisive action in the premises.”¹⁷

Unfortunately, there is little evidence to suggest that the Saints ever fully carried out these drainage initiatives on the islands in Mississippi or bordering lowlands before they left Nauvoo. In fact, in 1843 Joseph Smith offered the following advice to settlers, which essentially reiterates the concerns expressed in 1841:

The lower part of the town is the most healthy. In the upper part of the town the Merchants will say I am partial &c. but The lower part of the town is much the most healthy. I tell you in the name of the Lord. I have been out in all parts of the city at all times of night to learn these things... . . .

There are many sloughs on the Islands from w[h]ere Miasma arises in the summer, and is blown over the upper part of the city, but it does not extend over the lower part of the city. All those persons who are not used to living on a river, or lake or large pond of water. I do not want you should stay on the banks of the river. get away to the lower part of the city.—

Back on the hill—where you can get good well water."¹⁸

Drainage in the Munson lands bordering the Mississippi on the west side of Nauvoo was a particular problem. Regarding this land, Hiram Kimball provides answers to questions posed to him in a court deposition given on October 7, 1842, in the case of Doyle v. Teas & Munson:

Q. Is the swampy land in the Teas tract [Munson Lands in figure 6] on the side next to the river or back from the river?
A. It is back from the river.
Q. How far back is it from the river?
A. About sixty rods [990 feet].
Q. Does it extend the whole length of said tract up and down the river? Or only a part of the distance, and if part only, state the distance?
A. It extends about two thirds across the tract up and down the river, and I should think from three to six rods wide [50 to 100 feet].

As a result of the high water levels in the Munson lands, by 1846 settlement in this area was limited to the eastern edge and a small section on the southwest corner near the river.

Despite the relatively hopeful assessments in January and February of 1841, evidence suggests that there was still more work to do in the summer of 1841. For example, Edward Hunter, in a letter from Nauvoo, dated May 6, 1841, said, “It is quite sickly here. Several have died within a few weeks with the winter fever and dysentery. Fever and ague is quite prevalent here.” Brigham Young returned to Nauvoo from a mission to England on July 1, 1841, and reported:

On my return from England I found my family living in a small unfinished log-cabin, situated on a low, wet lot, so swampy that when the first attempt was made to plow it the oxen mired; but after the city was drained it became a very valuable garden spot.

Brigham Young’s home, at the corner of Granger and Kimball streets (fig. 6), was relatively far west of the Durphy Street drain. Therefore, conditions at this location would probably not have been greatly improved until additional drainage ditches had been completed. Brigham Young’s statement also suggests that significant additional drainage work had yet to be completed in the summer of 1841. This idea is supported by a city council memo dated November 1, 1841, which directed that the “swamp west of Brigham Young’s home be drained as soon as circumstances will permit.” Apparently this drainage project was large enough that the city council organized a community effort.

Figure 6 presents a map showing the areas identified by journal writers as being swampy. Of course, the boundaries of these swampy areas are very poorly defined, and other swampy areas certainly may have

**Fig. 6.** Location of swampy (cross-hatched) areas, as indicated by historical accounts, overlaid on original plat for Nauvoo by Gustavus Hill.
existed besides those shown on the map. We have drawn on our experience with ponding during storms in present-day Nauvoo to provide some estimate of where the swampy areas may have existed.

Our hydrologic analysis, described later in this article, suggests that additional ditches, besides the Durphy Street ditch, would have been required to drain stagnant water and carry away surface runoff from rainfall on the flats. In contrast to the Durphy Street ditch, which extended to the bedrock to intercept groundwater flow, these ditches would have been smaller and shallower. The drainage work probably involved large community-wide projects requiring the combined efforts of many people as well as smaller ditching efforts undertaken by individuals and families on their own land. For example, ditches along the main streets may have been dug collectively. Joseph Smith gave notice in April of 1843 that “Bro Gardner wanted 2 or 300 hands ditching—a good job.”24 During this time period, drainage ditches and other excavations typically involved horse-drawn plows and scrapers as well as hand excavation.25

Evidence for another large drainage ditch is provided obliquely by an account of an accident in which Brigham Young’s horse team fell through a timber bridge on Parley Street on January 17, 1846. The horses had to be lowered six feet to the bottom of the gully.26 Since a bridge had not been built across the main ditch on Durphy Street where it crossed Parley Street, this bridge must have spanned another large drainage channel crossing Parley Street. In her autobiography, Sarah Carrel also describes a deep ditch located near the river to which John Sweat’s son ran from his home (see John Sweat home in fig. 6). Since the Sweat home was in the northern part of the city, this ditch would likely have flowed north into the Mississippi.

In contrast to these larger projects, a number of journals mention individual ditching efforts around homes and farms. Brigham Young noted that after his return from England in 1841 he spent much of his free time “draining, fencing and cultivating” the lot around his home, which was too damp for a proper root cellar28 (see fig. 6). Joseph Smith gave Bathsheba Smith and her husband a lot in Nauvoo in July of 1842. She reported that “by fencing and draining the lot, and putting much labor on it, we soon had a splendid garden with thrifty fruit trees &c.”29 Esaias Edwards built his house in the summer of 1842 on the northwest corner of the Garland Purchase on the banks of the Mississippi River (see fig. 6). He noted that he had a “living spring” on his lot and that he constructed a drain from the spring to the river.30 The historical records note that Joseph Smith spent part of a day (May 21, 1844) shoveling dirt out of a ditch.31
In spite of many difficulties, the population of Nauvoo grew rapidly. In July of 1841 Heber C. Kimball wrote to Parley P. Pratt in England and indicated that there were over 1,200 buildings in Nauvoo with hundreds more under construction. The map in figure 7 shows the location of occupied lots in Nauvoo based on an 1842 census, and the map in figure 8 shows the location and type of buildings in 1846. A comparison between figures 1, 7, and 8 demonstrates the rapid development of this city in just seven years. The location of the Durphy Street interceptor ditch and other possible ditches discussed subsequently are shown in figures 7 and 8 to highlight the importance of these drainage ditches relative to land development. Based on a detailed study of available records, Susan Easton Black has concluded that the population of Nauvoo was about 100 people in 1839 and increased to about 4,000 in 1842. The population peaked at about 12,000 in 1844 and was about 11,000 in 1845.

![Map of Nauvoo](image-url)

**Fig. 7.** Occupied lots in Nauvoo from 1842 census. Courtesy Glen M. Leonard.
While the northwest side of Nauvoo was largely uninhabited in 1842, by 1846 the Saints had constructed a number of homes in this region. In addition, homes had even been constructed on the east side and the southwest corner of the Munson lands. As new inhabitants dug drainage ditches on their individual properties and these drained toward the main ditches along the streets and into the Mississippi, the conditions in the city would have improved. Nevertheless, drainage of surface runoff during intense rainstorms would likely have remained a problem for the

**Fig. 8.** Map showing locations of various types of buildings throughout Nauvoo in 1846. Courtesy Glen M. Leonard.
Transforming Swampland into Nauvoo, the City Beautiful: A Civil E

Understanding Nauvoo’s Geology and Soil Conditions

The flats in Nauvoo lie on a limestone shelf that extends into the Mississippi River. This Mississippian age limestone underlies most of the surrounding region, and outcrops of limestone are common along the bluffs overlooking the river. (For more detailed information about the geologic profile of the region, see figure A on the BYU Studies website, byustudies.byu.edu.) Because the limestone is horizontally bedded, water moves along the bedding planes, creating numerous springs at outcrops in the limestone. Figure 9 shows a photograph of a limestone outcrop near Nauvoo, where water has frozen after flowing out of the horizontal beds in the limestone. These horizontal beds would transport water from the bluffs to the flats. Historically, limestone was quarried at a site near the north end of Main Street and used in building the original Nauvoo temple in the 1840s. A photo of the temple quarry is shown in figure 10. The construction of the Keokuk Dam downstream from Nauvoo increased the depth of the Mississippi by about twenty-two feet and raised the level of groundwater near the river so that the quarry is now filled with water. The limestone in the quarry is likely Keokuk limestone (see fig. A on BYU Studies website). Surface soils in the area consist of Holocene age alluvial materials derived from runoff from the bluffs as well as flooding from the Mississippi. In addition, some soil may be derived from weathering of the underlying limestone.

early settlers as it is in Nauvoo even today. For example, Josiah Quincy described the streets in Nauvoo as being “knee-deep in mud” after a severe rainstorm during his visit to Nauvoo on April 25, 1844.36

Despite the poverty, the sickness, and what must at times have seemed a never-ending process, the Saints’ efforts eventually transformed the swampland, in many respects, into “the City Beautiful” envisioned by Joseph Smith. In a letter to Wilford Woodruff in England, dated June 17, 1845, Brigham Young wrote:

There are many good buildings erecting in different parts of the city, there is not much sickness in this place, and there never was a more prosperous time, in general, amongst the saints, since the work commenced. Nauvoo, or, more properly, the “City of Joseph”, looks like a paradise. All the lots and land, which have heretofore been vacant and unoccupied, were enclosed in the spring, and planted with grain and vegetables, which makes it look more like a garden of gardens than a city; and the season has been so favorable, the prospect is, there will be enough raised within the limits of the corporation to supply the inhabitants with corn, potatoes, and other vegetables.37
**Fig. 9.** Photograph of frozen water from flow out of horizontally bedded limestone outcrop.

**Fig. 10.** Photograph in 1998 of limestone quarry used for the Nauvoo Temple in the 1840s.
To better define soil and water conditions in Nauvoo, we drilled nine hand-auger holes (2.5-inch diameter) in June 1998 along an east-west profile running from the base of the bluffs to the Mississippi River. The locations of the nine test holes, determined with a portable GPS unit, are presented in figure 11. (To review the actual boring logs for each test hole, see figure B on the BYU Studies website.) The cross-sectional profile was positioned between Hotchkiss and Munson streets. The test holes typically extended to the underlying limestone bedrock. We obtained soil samples from each hole to define the soil stratigraphy and the elevation of the ground water. In addition, we measured the permeability of the soil at two test hole locations. The permeability is proportional to the velocity at which groundwater moves through the soil. After walking 1,500 feet through water-saturated clay (muddy swampland) to drill test holes 7 and 8, we have a better appreciation for how difficult it would have been to walk across Nauvoo prior to drainage, as related above by Joseph Smith.

Typically, the soil profile contained a two-foot-thick surface layer consisting of dark brown or black clayey silt. This layer is consistent with

**Fig. 11.** Location of hand-auger test holes on a line from the bluffs on the east to the Mississippi River on the west between Munson and Hotchkiss streets.
deposition in a swampy environment. Below this surface layer the profile contained layers of brown clay, gray clay, and occasionally some sand layers. Some of the clay layers appear to be derived from weathering of the underlying limestone. A cross section through the test holes is presented in figure 12. This cross section shows the ground surface, the groundwater depth, and the depth of the limestone bedrock along the profile. The depth to bedrock generally decreased from up to sixteen feet on the east side of the flats to as little as two feet on the west side. During our drilling, the groundwater was eight to ten feet below ground level on the east side of the flats but was essentially at the ground surface on the west side in the Munson land area.

The silts and clays, which predominate in the soil samples, have low permeability that prevents rapid infiltration and increases surface water runoff. Water that does penetrate the soil reduces soil strength and requires a considerable time to move out of the soil. The horizontally bedded limestone bedrock tends to prevent vertical water flow, thereby trapping the groundwater in the soil layer, which becomes progressively thinner downstream. These conditions combine to produce a swampy environment in the flats of Nauvoo.

**Fig. 12.** East-west cross section through Nauvoo between Munson and Hotchkiss streets showing ground surface, groundwater location, and underlying bedrock.
APPRECIATING NAUVOO’S DRAINAGE FEATURES

Survey of Durphy Drainage Ditch

To better define the characteristics of the existing interceptor drain ditch on Durphy Street, we conducted an engineering survey in June 1998. Cross sections of the ditch were typically determined at 100- to 200-foot intervals along its length beginning at a point between Hotchkiss and Munson streets across from Wilford Woodruff’s home. North of Hotchkiss Street, the ditch has since been backfilled (presumably with gravel) and a drain pipe installed along the bottom. This shortens the length of the original ditch by about 425 feet. Table 1, found on the BYU Studies website, shows a summary of the cross section locations along with the characteristics of the ditch at each section. The existing ditch is approximately 2,500 feet long with an average slope of 1 percent. Three cross sections (sections 1, 5, and 11) along the length of the ditch are presented in figure 13. The depth of the drain is generally constrained by the location of the underlying bedrock and varies from about ten feet deep at the north end to about four feet deep on the south end. The width of the ditch measured from the top of the inside bank on each side varies from about thirty-five to fifty feet throughout most of its length. Computations indicate that the volume of excavation for this ditch would have been about 17,300 cubic yards. Based on data from the survey, the total excavation volume for the full-length ditch would have been approximately 22,100 cubic yards (about 2,200 dump truck loads). We estimate that hand excavation would have required at least 22,100 man-hours of effort to complete. This equates to approximately one hundred men working eight hours per day for about twenty-eight days.

![Fig. 13. Cross sections (looking downstream) of the existing Durphy Street drainage ditch.](image-url)
Flow Pattern within Current Drainage Ditches

Hydrological analyses, described subsequently, and experience during rainstorms in present-day Nauvoo clearly indicate that additional ditches besides the Durphy Street ditch would have been necessary to control surface water runoff. Without supplemental ditches, large areas on the flats would have remained in swampy conditions. In contrast to the interceptor ditch on Durphy, which extended down to bedrock, these ditches for surface water control would likely have been relatively shallow (one to two feet deep). The natural pattern for drainage ditches would be to follow streets and property boundaries. We assume that this would have been the case in Nauvoo. Drainage from individual lots would then flow into main drain lines and eventually into the Mississippi. To obtain some idea of the likely drainage patterns in 1840s Nauvoo, we investigated drainage patterns in present-day Nauvoo during a field survey in June 1998. Fortunately, during our visit two large thunderstorms provided ample evidence of water runoff patterns on the flats. During one storm, the Durphy ditch was flowing nearly three-quarters full, and flow volumes on other major street drains were also substantial. Figure 14 shows the flow pattern observed during storms in present-day Nauvoo and identifies areas where runoff water was ponding.

Consistent with Joseph Smith’s statement, drainage in the southern part of the city was better than elsewhere. Besides the southern flow in the Durphy ditch, substantial southward flows were observed on Partridge, Hyde, and Main streets. In addition, surface runoff still followed the drainage channel identified on the map by Gustavus Hill in 1842. A sizeable gully at the south end of Hyde Street, which serves as a natural drainage channel, would have provided a convenient outlet for water draining from the ditches in this area.

![Flow Pattern within Current Drainage Ditches](image)

**FIG. 14.** Surface water flow patterns in present-day Nauvoo.
Donald L. Enders indicates that Granger Street (see fig. 7) was a major road in Nauvoo during the Mormon period since it connected to the steamboat landing on the north side of the city. A natural drainage channel into the Mississippi at the south end of Granger Street would have provided an outlet for a drainage ditch on this street; however, in present-day Nauvoo, Granger Street terminates at Sidney Street and does not reach the river. This prevents drainage to the south, and water tends to pond between Kimball and Hotchkiss streets. Although a culvert has been extended to the west at Munson Street, ponding still occurs in this location after rainstorms.

Drainage is also relatively poor on Main Street between Mulholland and Munson streets. This region is the dividing line between northward and southward drainage, and the ground surface in this area is essentially flat. As a result, ponding occurs during storms, as shown in figure 16. This area was also identified as a swamp at the time the Mormon settlers arrived in Nauvoo. The installation of a culvert running west off Main Street at Ripley Street has not prevented ponding.

We also observed significant water flow in drainage ditches running west along Young, Mulholland, Munson, and Parley streets. However, three of these streets drain into the Munson lands where the slope is relatively flat and the soil is not very deep, so that drainage is far from optimal.

Historical data and our surface water analysis (discussed below) indicate that besides the Durphy Street interceptor drain, additional shallower ditches would have been necessary to deal with surface runoff in the flats. These ditches were likely constructed along main roads. North-south ditches would have paralleled Partridge, Hyde, Main, and Granger streets. East-west ditches would have followed Young, Mulholland, Munson, and Parley streets.
Numerical Analyses

Hydrology and Surface Water Flow Analysis

Two potential sources of water enter the Nauvoo flats: surface water and groundwater. Surface water may enter the area as the result of direct precipitation or runoff from the streams draining the bluffs. Our objectives in the surface water analysis were to determine the reduction in surface water flow onto the flats due to the Durphy Street drain and to evaluate the surface runoff on the flats due to direct precipitation. Historical precipitation data have not been recorded for Nauvoo, so we collected and analyzed data from surrounding areas. The four closest precipitation recording stations surrounding Nauvoo are La Harpe, Illinois; Keokuk, Iowa; Fort Madison, Iowa; and Donnellson, Iowa. Our analysis of the data from these stations revealed that we could approximate the precipitation in Nauvoo using the data from the Fort Madison station. Precipitation in this area is highest from May to September, with May being the month with the greatest precipitation. Average annual precipitation is about 5.5 inches.

Using these precipitation data, we estimated the relationships between storm intensity, duration, and frequency. Our analysis showed that intense storms of significant duration may occur regularly in Nauvoo.
(Storm intensity-duration-frequency curves are shown in figure C on the BYU Studies website.) These storms, combined with the relatively impermeable soils found close to the surface in the Nauvoo flats, result in significant amounts of standing water.

As discussed above, during a site visit in June 1998 we observed storm water pooling as the result of direct precipitation. Two storms during this visit resulted in significant accumulation of surface water in the flats.

We evaluated surface runoff by analyzing topographic data and developing a digital runoff model. We analyzed topographic data by obtaining digital information and applying several modeling and visualization techniques. The runoff model was developed using local hydrologic data and the Watershed Modeling System (WMS) software developed by the Environmental Modeling Research Laboratory at BYU. This software includes HEC-1, a surface runoff model developed by the U.S. Army Corps of Engineers.

We used a digital topographic map from the U.S. Geological Survey (USGS) to develop the surface water runoff model. The contours derived from the digital terrain model helped us visualize the topography of the area and the direction of flow. We then used WMS to process the digital terrain data, which produced the contours shown in figure 17. In this figure, twenty-five contour lines are evenly spaced between 510 and 690 feet of elevation (approximately seven feet of elevation difference between each contour). The three major drainage channels in the region, derived from the topographic data, appear as heavy black lines.

Another useful method of viewing the area topography is by shading contour changes. Figure 18 shows a shaded terrain model overlain by the USGS quadrangle maps for the area.

An examination of the details presented in figure 18 leads to the conclusion that surface water runoff from areas outside of the Nauvoo flats could produce a significant source of water in the flats. Prior to construction of the drainage ditches, precipitation...
falling on the bluffs would likely have run onto the flats below, where it would have collected as standing water.

To better understand this condition, we used WMS to generate flow paths that surface water runoff would take after a storm. We first employed this model assuming the Durphy Street ditch did not exist (as was the situation before the Saints arrived in the Nauvoo area). Results of this study are presented in figure 19. It is clear that without the drainage ditch, runoff from the bluffs would flow onto the southern flats and collect there or gradually flow out to the Mississippi River.

We then developed a model for the same area with the Durphy Street ditch in place. The results of this model are presented in figure 20. These results show that runoff from the bluffs is collected by the ditch and discharged directly to the Mississippi. None of the storm runoff reaches the flats. The Durphy Street ditch eliminates any upstream contribution to standing surface water in this area.

To assess the effect of the Durphy Street ditch, we developed a rainfall-runoff model to estimate the amount of surface water runoff from each drainage area during a typical storm. We used a rainfall-runoff simulation model, HEC-1, in combination with the WMS-delineated watersheds to simulate a storm and estimate runoff volumes from each drainage area.
Fig. 19. Runoff flow paths without drainage ditches in Nauvoo (runoff paths shown in black).

Fig. 20. Runoff flow paths after construction of the Durphy Street drainage ditch.
As an example, we used a storm with a twenty-four-hour precipitation depth of 4.06 inches for this analysis. A storm this size was measured at the Fort Madison station and would not be uncommon for the Nauvoo area. According to available statistical analyses of historical rainfall data, such a storm would be expected to occur about once every five years. By contrast, a storm with a depth of 2.5 inches would typically occur every year.43

Our analyses indicate that 4.06 inches of precipitation would produce 100 acre-feet of runoff in the flats. Without proper drainage, much of this water would collect in the area and contribute to the swampy conditions found there naturally. An additional 46 acre-feet of water would run off the area upstream from the Durphy Street ditch. Without the Durphy Street ditch, this water would also run onto the southern flats area and contribute to the swampy conditions. With the Durphy Street ditch in place, this water would be collected and diverted directly to the river, eliminating a significant source of water to the flats. Modeling storms of various sizes reveals that the construction of the Durphy Street ditch prevented about one-third of the storm runoff from flowing onto the flats.

Groundwater Flow Analysis

As indicated previously, in addition to surface water runoff, groundwater flow also contributed to the swampy conditions in the flats. The objective of the groundwater analyses was to determine what effect the ditch had on the elevation of the groundwater downslope from the drain, independent of surface water flow. Once we had defined the geologic cross section shown in figure 12, we constructed a numerical model to analyze groundwater flow through the cross section. We performed analyses with and without the interceptor ditch on Durphy Street using a two-dimensional finite element groundwater analysis program called SEEP2D developed by the U.S. Army Corps of Engineers.44 We used the Groundwater Modeling System (GMS), a computer program produced by the Environmental Modeling Research Laboratory (EMRL) at Brigham Young University, as a preprocessor to set up the finite element mesh and as a postprocessor to display the results of the analysis.

The SEEP2D model is composed of a two-dimensional mesh consisting of 4,229 triangular elements. Each element in the mesh represents a part of the cross section and can have different properties. For each element, soil properties were used to define the vertical and horizontal permeability of the soil or rock material. In addition, measured water table elevations were used to define groundwater levels at the upstream and
downstream boundaries of the model. We assumed the limestone to be essentially impervious at a depth fifty feet below the top of the limestone layer on the downstream boundary. The upper boundary of the model was free to move up and down to match the computed elevation of the groundwater level. We assumed water infiltration through the top boundary to be negligible for these analyses.

Although the nine test holes drilled across the flats defined the soil types and thicknesses, we were able to determine the permeability only approximately. Experience indicates that the permeability for a given soil type can vary significantly. Therefore, we initially calibrated the numerical model based on the measured groundwater elevations. We progressively modified estimates of the soil permeability in the model to improve the agreement between the measured and computed groundwater level across the model. For these calibration analyses, the water level at the upstream boundary was equal to the water level in the ditch (552.7 feet) and the water level at the downstream boundary was equal to the water level in the Mississippi at the time of our study (518 feet). To simplify the permeability adjustment process, we divided the soil cross section into eight zones, and the elements in each zone had the same permeability characteristics. These analyses justified a simplification of the model to only five zones with little additional error. The locations of the soil zones are shown in figure 21. The horizontal and vertical permeabilities can be found in table 2 on the

Fig. 21. East-west cross section through Nauvoo showing soil zones used to model groundwater flow.
BYU Studies website. The calibration results were reasonably good, with an average error between the measured and computed groundwater level of 0.75 feet.

Once we had determined that the model was a reasonable representation of the groundwater system, we modeled the flow in the cross section with and without the Durphy Street drainage ditch, but we assumed a water level in the Mississippi River twenty-two feet lower, where it would have been prior to the construction of the Keokuk Dam, which was completed in 1913. In all cases, the calibrated soil properties and soil zone locations remained the same. Therefore, for our model, both with and without the Durphy Street ditch, we decreased the water level at the downstream boundary to an elevation of 496 feet. Prior to construction of the ditch we

![Diagram of groundwater elevation](https://scholarsarchive.byu.edu/byusq/vol45/iss3/6)

**Fig. 22.** Computed groundwater elevation (dashed line) relative to the ground surface (a) before and (b) after construction of the Durphy Street drain but with the Mississippi River at its 1840s elevation of approximately 496 feet.
assumed that the water level was seven feet higher at the ditch location than after the ditch was constructed.

Cross sections showing the computed groundwater level relative to the ground surface are provided in figure 22 for conditions (a) before and (b) after construction of the Durphy Street drain and with the Mississippi water level typical of the 1840s. For the case without the drain, our analyses suggest that the groundwater would have intersected the ground surface at an elevation of 550 feet, or 15 feet higher than it did after the drain was in place. The maps in figure 23 show the zones where the water level would be at or above the ground surface both with and without the Durphy Street drain. Without the Durphy ditch, groundwater would have been at or above the ground surface for most of the land west of Hyde Street in the north, and south of Kimball Street. After construction of the main ditch, this boundary would have moved west a distance of about 1,500 feet to about Bain Street. These analyses show that the Durphy drain likely produced an important decrease in the groundwater level downstream from the drain by intercepting groundwater flow. When these results are coupled with those showing that the drain reduced surface water runoff by 33 percent, the value of the Durphy drain becomes very clear.

**Findings and Conclusions**

The Nauvoo Saints excavated the main interceptor drain ditch along the base of the bluffs on the east side of Durphy Street. The drain intercepted both groundwater flow and surface water runoff from the bluffs. Intercepting surface water would have decreased the total volume of surface water on the flats by about one-third. Intercepting groundwater would have moved the boundary where groundwater was at or above the ground surface west by a distance of about 1,500 feet.

This ditch was typically six to nine feet deep and thirty-five to fifty feet wide at the ground surface. It eventually extended for a length of approximately 3,000 feet. Its construction required excavation of approximately 22,100 cubic yards of clayey soils to the limestone bedrock. This project would have required at least 22,100 man-hours of effort to complete by hand.

Although efforts to drain off stagnant water commenced soon after the arrival of the Saints in 1839, the process of draining Nauvoo continued throughout their stay. The drainage system likely consisted of major ditches excavated by the community as a whole, as well as smaller ditches dug by individuals for their own private property.
Fig. 23. Map of the flats in Nauvoo showing the extent of the zone where the groundwater would equal or exceed the ground surface elevation (a) before and (b) after construction of the Durphy Steet drain.
Twenty-first-century engineering analysis methods shed much light on the great industry and wisdom of the nineteenth-century Mormon settlers in constructing the Durphy Street drain. Nevertheless, persistent work was still required to dig additional ditches and drain the land in the face of adverse geology and topography. Their communal and individual efforts to transform swampy land covered with dense underbrush into Nauvoo, the City Beautiful, stand as a monument to the extraordinary ingenuity of these people.

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This study was supported by a grant from the Religious Studies Center at Brigham Young University. This support is gratefully acknowledged. The views and opinions presented are those of the authors and do not necessarily reflect those of the Religious Studies Center or the Department of Church History and Doctrine at BYU.

We are particularly grateful to Professor Emeritus Milton V. Backman for providing access to journals from the Nauvoo period and to James Kimball for directing us to somewhat obscure references bearing on our topic. In addition, we thank Professors Emeriti Larry Porter and Milton Backman for reviewing the manuscript and offering helpful suggestions.

Finally, we thank Nauvoo Restoration, Inc., and the Illinois State Parks Department for allowing us to drill test holes on their property in Nauvoo.

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44. Norman L. Jones and Fred Tracy, SEEP2D Primer (Provo, Utah: Environmental Modeling Research Laboratory, Brigham Young University, 1999), 94.
Figure 14. Logs of hand-auger drill holes on east-west section through Nauvoo, Illinois.
Figure 23  Storm Intensity-Duration-Frequency Curves for Nauvoo, IL
Table 1. Location of cross sections and characteristics of each section.

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(17,300 yards³)
Table 2. Material properties used in for soil zones in groundwater analysis.

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Figure A (perhaps on CD, figure 10 in authors’ original copy)

Caption: Figure A. Stratigraphic profile showing rock types and geologic age for the Nauvoo area.


Figure B (perhaps on CD; figure 14 in authors’ original copy)

Caption: Figure B. Logs of hand-auger drill holes on east-west section through Nauvoo, Illinois.

Figure C (perhaps on CD; figure 23 in authors’ original copy)

Caption: Figure C. Storm intensity-duration-frequency curves for Nauvoo.
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