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Underground Water Problem at Chadron, Nebraska: Causes and Solution

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EARTH SCIENCES

UNDERGROUND WATER PROBLEM AT CHADRON, NEBRASKA: CAUSES AND SOLUTION

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Chadron, Nebraska and Chadron State College have experienced rising underground water levels and deteriorating streets and buildings in recent years. Groundwater levels have been measured monthly on the campus and in the City for a six-year period (1981–1986). Water levels on the measured parts of the campus show a rise of about two feet per year for the 1981–1984 period. In 1985, the water table started to decline, probably linked to the drought and decreased consumption of lawn–irrigation water. In 1986, a wastewater (desaturation) well was installed and the groundwater table continued its decline. On the other hand, a slower increase in groundwater levels was noted in certain parts of the City during the 1981–1984 period. During 1985 and 1986, only a slight or no increase in water levels was noted in certain parts of the City. Precipitation patterns, water consumption, and the geology of the area are examined in relation to their possible effects toward the rising underground water levels. Suggestions are made to reverse this trend.

† † †

INTRODUCTION

Chadron, in northwestern Nebraska, celebrated its centennial anniversary in 1985. In its development Chadron has not been without its problems (Dewing, 1986). Water is one of these.

For most of the last 100 years Chadron has experienced a shortage of water for domestic use. The early water supply was largely obtained from impounded water from Chadron Creek. As the City grew, it experienced a deficiency of water. In 1969 a deep–well system was installed to supplement the impounded water source from Chadron Creek. Since then, the City has had adequate water for domestic and lawn-garden use. Now, however, as a result of a rising water table, building and street failures are occurring in certain parts of Chadron and on the Chadron State College campus. This paper examines water consumption, precipitation patterns, geology of the area, types of building construction footings, and underground water levels which appear to relate to the structural failures of buildings and streets in Chadron. Suggestions are also made to reverse the rising water levels.

Water History

A review of the City Council minutes and news articles for the first century reveal that domestic water problems frequently prevailed and that numerous attempts to alleviate them were at times only temporarily successful. A reliable supply of water was a serious problem for the early settlers. An occasional well produced meager water but anything approaching an adequate supply was never obtained.

For the first few years, water was hauled into Chadron from creeks and springs and cost the consumer 25 cents per barrel. A well was soon drilled to 550 meters (1800 ft) in hopes of finding artesian flow, but efforts were fruitless; no water was obtained and the project was halted. Potential surface sources of water were Chadron Creek, located about 6 km (4 mi) west of Chadron, or Bordeaux Creek, located an equal distance east of Chadron. These north–trending streams flow year around and originate at the Pine Ridge escarpment about 15 km (9 mi) south of Chadron. Another potential source of water was the White River, which originates about 64 km (40 mi) west of Chadron. It flows within 6 km (4 mi) north of Chadron as the river proceeds northeasterly into South Dakota. Unfortunately, as the water descends towards Chadron, it becomes high in colloidal material and is unfit for human consumption.

As Chadron Creek appeared to be the best source of water, a reservoir was constructed in 1893 on Chadron Creek about 10 km (6 mi) south of the City, along with a gravity system to bring impounded water to Chadron. Unprecedented torrential rains in 1914 and 1916 created damage of varying degrees to the reservoir, spillway, and filter system on Chadron Creek. On July 1, 1922, the dam was destroyed by a flood, and the inhabitants were deprived of water.

The City grew rapidly in its early years (Table I), and the need to obtain water was amplified. Attempts to drill for water near or within the City were made. The City water minutes of January 7, 1929, indicate that " . . . there were eight wells put down in an effort to locate water in sufficient quantity, but showing that in each test that within less than 100 feet of the surface the underlying white chalk rock known as Butte Rock, is encountered. This Butte Rock is several hundred feet thick and to penetrate it would require a deep drilled hole and the results to be obtained would be problematical . . . " The City did not pursue drilling for water locally at this time.

TABLE I. Population of Chadron, Nebraska (from Dewing, 1985).

Year	Population
1886	1,172 (a private census)
1900	1,665
1910	2,686
1920	5,192
1930	4,606
1940	4,220
1950	4,687
1960	5,079
1970	5,853
1980	5,590

In 1930, the dam was once again destroyed by a flood (Fig. 1), and was again rebuilt. In 1960, another storage reservoir was constructed on Chadron Creek, doubling the water storage capacity. Bids later were let for a one–million–gallon steel reservoir, which was placed on C–Hill south of the College campus.

The minutes further indicate that water rationing was in effect and that water–stealing frequently occurred. Then, in 1964, a study was undertaken to obtain an additional source of water of three million gallons per day. This study resulted in a deep-well system of five wells located 29 km (18 mi) south of the City. Dedication of the system was made in August, 1969. Today, the combination of surface water from Chadron Creek and groundwater from the deep-well system supplies Chadron's needs. Water production from the well field is held to a minimum, and most of the water today still comes from impounded water fed by spring sources to Chadron Creek. Now, however, with an adequate supply of water, rising groundwater levels are causing damage to buildings and streets in parts of the City.

Geological Setting of Area

The need for Chadron to go 18 mi south of town for its deep–well water system is due to the geology of the area. Likewise, geological conditions are linked to the damaged buildings and streets in Chadron.

FIGURE 1. Destroyed Chadron reservoir dam on Chadron Creek, April 1930. (Photo by Billy J. Smith)

In Dawes County, the exposed rock that outcrops generally north of the White River is the Pierre Shale (~60 m.y. B.P.). The Pierre consists of marine shale and is often referred to as "gumbo" locally. It is not considered to be an aquifer.

Overlying the Pierre Shale in Dawes County is the Chadron Formation (~37 m.y. B.P.), which generally outcrops in various places in Dawes County but especially south of the White River in a strip one or two km (one mi) in width. The Chadron airport, located about 4 km (3 mi) west of Chadron, and the extreme northwest part of Chadron are both located on the Chadron Formation. The Chadron Formation is an aquifer in some localities, but when water is obtained it is highly mineralized and is of poor quality for drinking purposes.

The Brule Formation outcrops above the Chadron Formation. It is not a reliable aquifer, but a number of low–yield wells obtain water from the formation. Most of the City and the campus is located on the Brule Formation or its eroded rocks.

When the City sought additional water in the 1960's it went 29 km (18 mi) south and drilled five wells, averaging about 85 km (280 ft) deep in the younger Marsland Formation. The water from the aquifer is of good quality from a health point of view, as is also the spring fed source on Chadron Creek south of the City.

Forty test borings made on the Chadron State College campus in 1980 indicated an average of about 9 m (30 ft) of mainly silt material which has eroded from the higher lying Brule outcropping areas (engineering report for Chadron State College by Francis–Meador–Gallhaus, Inc., 1823 West Main, Rapid City, South Dakota, 57701, November, 1980). The depth varies from about 12 m (40 ft) in the north part of the campus to about 6 m (20 ft) towards the southeast. Sand and silt content of 40 test borings in the overlying material varied widely with test holes. All the soil above the weathered, impermeable bedrock, however, is highly compressible with low strength when wetted. This combination results in collapse of the soil structure to a smaller volume, especially when buildings are constructed on it. The surface drainage of the main part of the campus is good since the slope averages about 4 m per 100 m.

METHODOLOGY

This study collected and processed data for a number of parameters. From 1981 through 1986, groundwater levels have been monitored monthly, except for a few winter months, for a number of wells on the campus and at strategically located lawn–irrigation wells in the residential area of Chadron. Old photographs were obtained from various sources in an attempt to delineate the old drainageway through the campus and the City. Weather data and water consumption patterns were obtained. These and other parameters were evaluated in relation to the underlying causes of deteriorating buildings.

RESULTS AND DISCUSSION

Complete annual precipitation data since 1915 are shown in Figure 2. No complete annual records could be located for

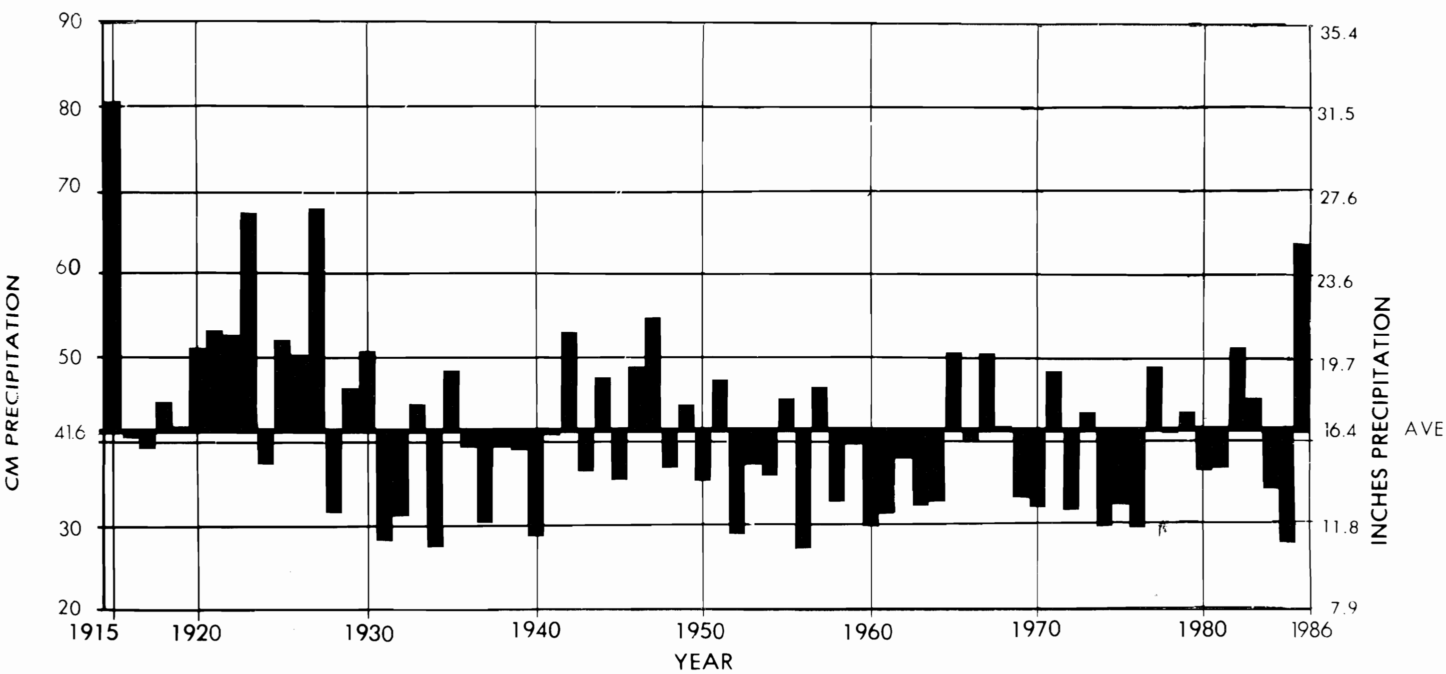


FIGURE 2. Annual precipitation at Chadron, Nebraska. Black areas indicate amounts of precipitation above or below the average of 41.6 cm (16.4 in) for the 72 year period.

years before 1915, although records go back to 1894. Prior to 1937, weather measurements were made at the College. After 1937 measurements were made at the Chadron airport (Anonymous, 1984). As the College is approximately 200 ft higher in elevation than the Chadron airport, a systematic error of increased precipitation may be reflected in the precipitation data prior to 1937. Any increase, however, would not have been a large amount.

The annual arithmetic mean for the 1915–1986 period is 41.57 cm (16.37 in). Greatest annual precipitation of 80.64 cm (31.75 in) was recorded in 1915; least precipitation was 27.02 cm (10.64 in) in 1956. A very small amount of 27.28 cm (10.74 in) was also reported in 1934. In 1985, Chadron and surrounding areas experienced a drought with the third lowest precipitation recorded in 72 years; only 27.66 cm (10.89 in) of precipitation was received. Of this total, only 15.75 cm (6.20 in) fell the first eight months of the 1985 season.

On the other hand, the period from 1915 to 1927 can be characterized as wet. The City minutes of July 7, 1913, indicate that " . . . the condition of the atmosphere is such that standing water will rapidly create fever conditions by germs and mosquitoes and we have within city limits ponds . . . " No wonder the long–time residents speak of a swamp area in the low–lying sections of Chadron and of the flowing springs, seeps, and standing water.

The dry period during the 1930's was not unique for the Chadron area, as drought conditions were widespread in the midwestern area. Wetter years prevailed in the 1940's and drier conditions existed between 1952 through 1964. After this time erratic precipitation patterns prevail.

An early photograph of Chadron (Figure 3) provides a clue of the surface drainage patterns. This photograph, taken about 1912 from C–Hill, and viewing north–northeast, shows the Chadron Congregational Academy in the foreground and the middle portion of the Administration Building, built in 1910–1911, behind it. A drainage pattern is shown in the middle–right of the photo and is assumed to be the drainage area near the present Armstrong Gymnasium.

Another photograph, an aerial photo taken in 1920 and viewing southeast, shows the drainage channels off C–Hill behind the present location of Armstrong Gymasium and between the present Kline Campus Center and the Armstrong Gymnasium (Agenbroad, 1979). The relative locations of the campus buildings today, along with their relationship to the City of Chadron today, are shown in Figure 4. The slashed

FIGURE 3. Looking north–northeast, about 1912, from C–Hill. The Chadron Congregational Academy is in the foreground and the middle section of the Administration Building in the left foreground. (Con Marshall photo)

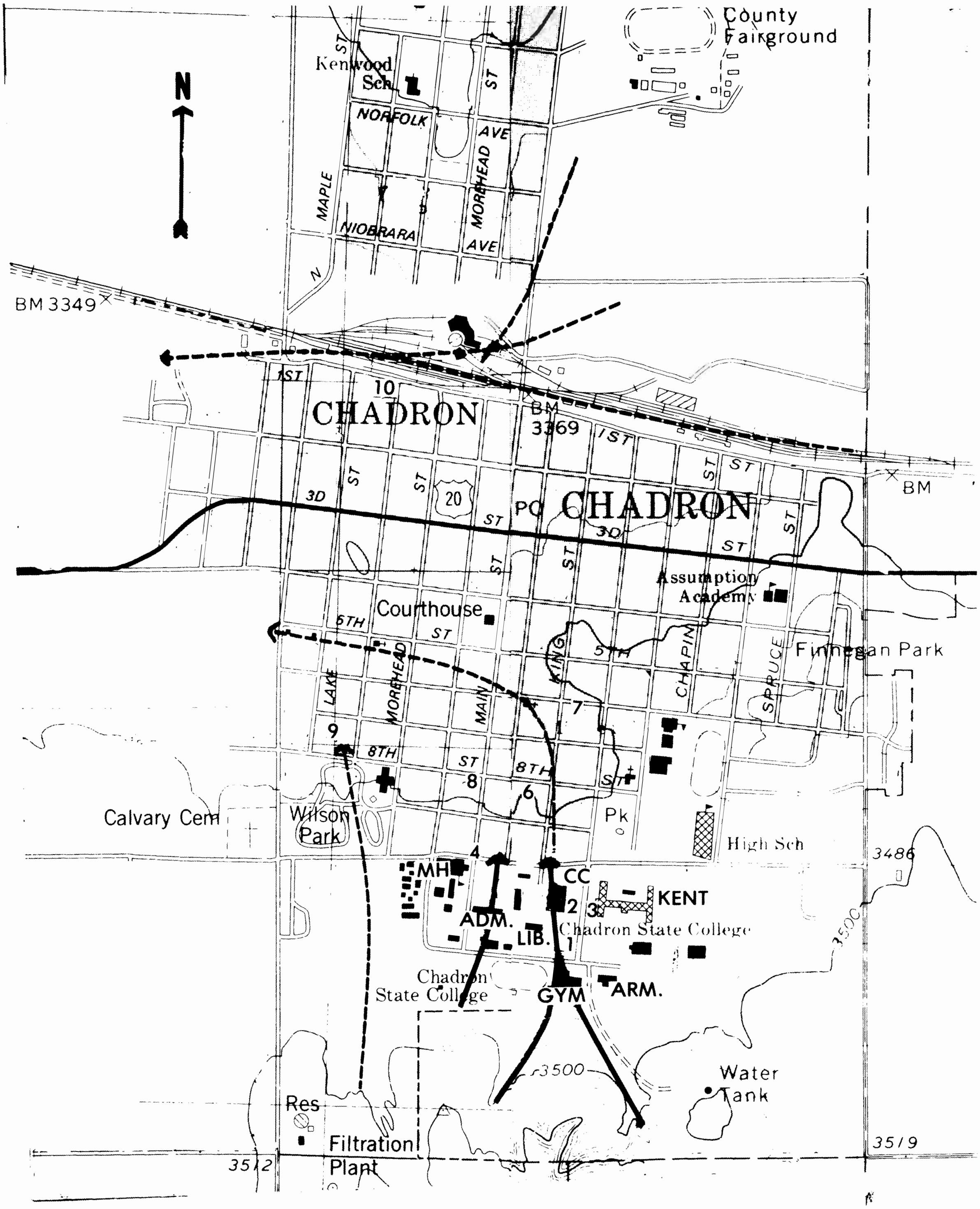


FIGURE 4. Modified U.S.G.S. topographic map of Dawes County, 7.5 series, of Chadron East (1970) and Chadron West (19
Solid lines indicate the buried drainageways based on test borings. The slashed lines indicate surface drainage patte
Caption: CC = Campus Center, ARM = Armory; GYM = Gymnasium; LIB = Library; ADM = Administra
Building; MH = Memorial Hall; KENT = Kent Hall.

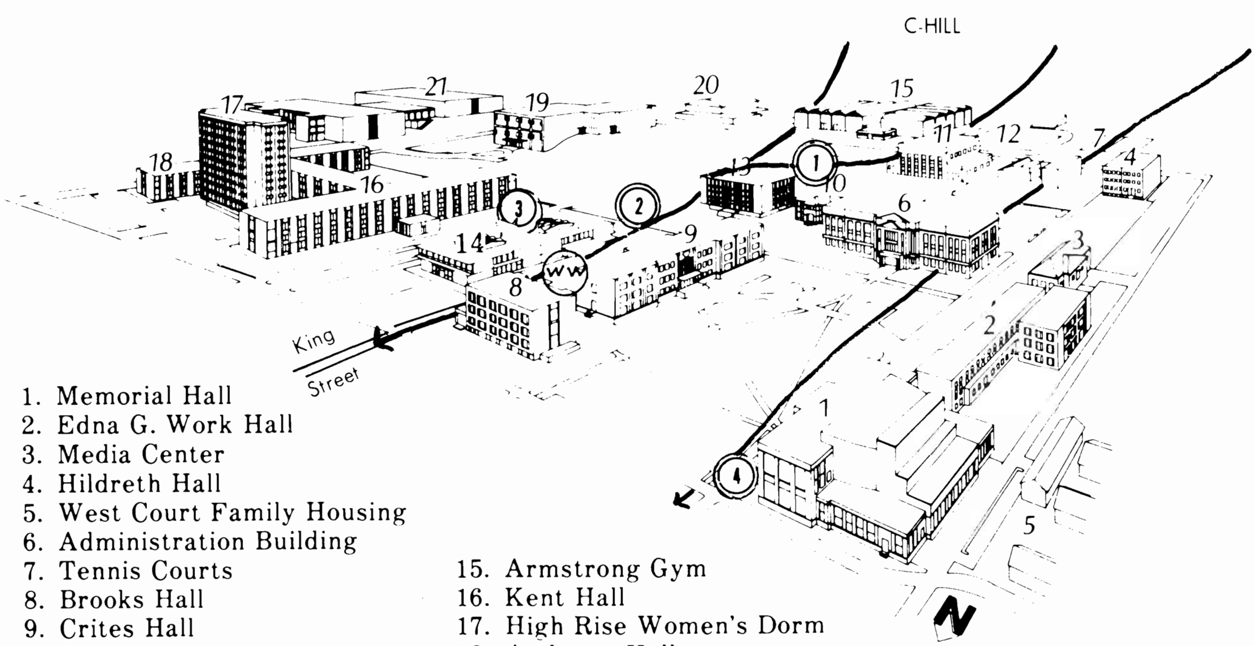
lines in Figure 4 indicate the surface drainage patterns. These drainage areas are reasonably certain and are mostly based on topographical maps. The solid lines show the buried drainageways as determined by photographs and test borings on the Chadron State College campus. Again, the locations of these lines are reasonably certain (engineering report prepared for Chadron State College by Francis–Meador–Gallhaus, Inc., 1823 West Main, Rapid City, South Dakota, 57701, November, 1980).

The greatest density of lawn–garden irrigation wells is found north of Wilson Park, along the railroad track, and in an area north of the campus, and all such wells are coincidental with the old drainage patterns (Agenbroad, 1979). No well is located in the higher areas in the southeast part of town. In 1981, 23 producing wells were located in Chadron. Most wells pump about 5 to 20 gallons per minute and are used solely for lawn–garden irrigation purposes.

Figure 5 shows a more detailed map of the assumed drainageways through the campus in relationship of the College's buildings. It also shows the locations of the four test wells and the waste (desaturation) well.

Settling problems of buildings on the Chadron State College campus were identified as early as 1964 (letter to F. Clark Elkins, President of Chadron State College, from E. Albin Larson, Secretary of the Board, regarding settling problems of the Kline Campus Center, dated December 22, 1964) and also in an engineering report for the College; the latter reported groundwater at 13.2 m (43.5 ft) below ground surface at the southwest side of the Campus Center (letter to Clark & Enersen, Olsson, Burroughs & Thomsen from Western Laboratory, Inc., 1630 Q Street, Lincoln, Nebraska, February 18, 1965). The settling problems now appear to be most pronounced on buildings constructed since 1960 on spread–footing foundations, and located on or near the assumed underground drainageway running down gradient (north) of the Armstrong Gymnasium. These include: (1) the north half of the Campus Center, constructed in 1967 and built on pier–type foundations, the main floor now showing settlement problems possibly related to the rising underground water levels, wetting, and compressibility of the soil; (2) Armstrong Gymnasium; (3) National Guard Armory; and (4) the south half of the Kline Campus Center, built in 1961, and condemned in 1979 because of structural differential sinking of 5 to 30 cm (2 to 12 in) (Fig. 6). Since 1971, many thousands of dollars have been spent on remedial repair of

Chadron State College . . . the campus



1. Memorial Hall
2. Edna G. Work Hall
3. Media Center
4. Hildreth Hall
5. West Court Family Housing
6. Administration Building
7. Tennis Courts
8. Brooks Hall
9. Crites Hall
10. Sparks Hall
11. Miller Hall
12. Elliott Field
13. Reta E. King Library
14. Kline Campus Center
15. Armstrong Gym
16. Kent Hall
17. High Rise Women's Dorm
18. Andrews Hall
19. Math and Science Building
20. National Guard Armory
21. Burkhiser Technology Complex

FIGURE 5. Location of wastewater (desaturation) well (WW) and test wells 1–4. Solid lines indicate underground drainageways.

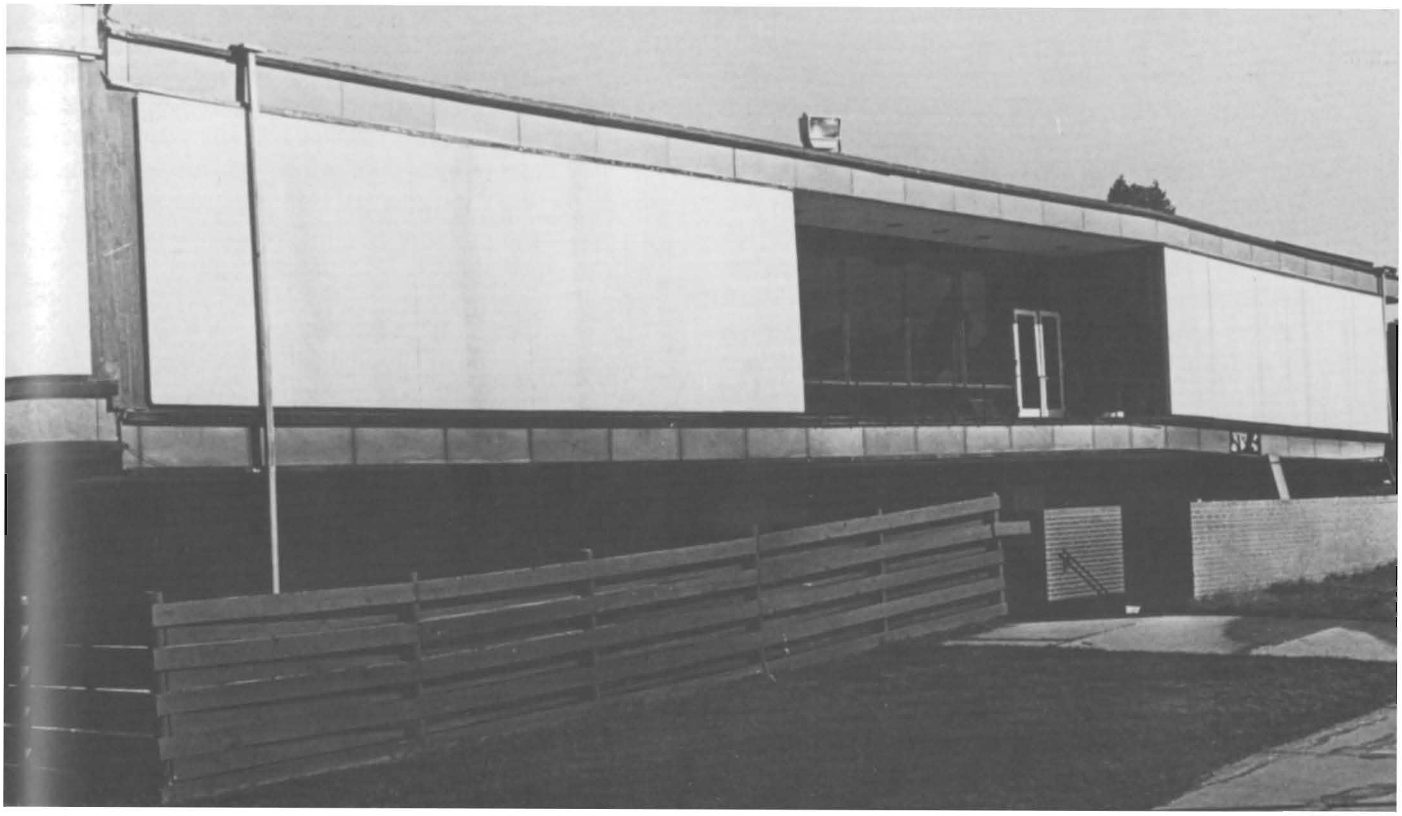


FIGURE 6. Differential cleavage of 10 inches between the north half of the campus center constructed on pier–type foundations (extreme left) and the south half of the campus center built on spread–type footings. (Photo by Con Marshall)

buildings (Agenbroad, 1979). At the time of this writing (September, 1987) the south half of the Campus Center is soon to be demolished at a cost of nearly $400,000.00.

Older buildings not located near the old drainageway, and recently showing settlement problems, include Crites Hall located about 30 m (100 ft) west off the Campus Center (Fig. 5); the Administration Building located about 60 m (200 ft) southwest of the Campus Center; and the east part of Brooks Hall.

Also, in recent years street deterioration and structural damage in homes are increasingly evident in an area north and northwest and down gradient from the campus. Damage appears to be most pronounced in an area down King Street following the assumed drainage area (slashed line) shown in Figure 4, then veering northwest and west along Sixth Street. Waste wells and pumps have or are being installed in many basements and outside locations to alleviate the rising water problems in basements.

The behavior of past underground-water levels provides a clue to future behavioral patterns. The campus test-wells measured for this parameter for a six–year period include wells 1 through 4 (Fig. 4, 5) and City producing wells 6 through 10 (Fig. 4). Well 1 is located north of the Armstrong Gymnasium, well 2 is south of the Campus Center, and well 3 is adjacent to the southwest corner of Kent Hall (east of the Campus Center). These three wells are in line with the old assumed drainageway. The underground water levels for wells 1–4 for years 1981–1986 are shown in Figure 7. Note the synchronous seasonal cyclic patterns of the wells for the 1981–1984 period. In each case, a buildup of water occurs in late summer, followed by a slight decrease in the spring months. The overall trend, however, is up. The rate of increase (slope) for wells 1, 2, and 3 is approximately 67 cm (2.2 ft) per year. These three wells are subject to upgradient supplemental campus lawn watering.

Test well 4 is located near the northeast corner of Memorial Hall, but is subject to only moderate upgradient lawn watering, and is assumed to be in a different drainageway system. Its water levels mimic the same patterns of the other wells, suggesting related contributary factors for the similar trends. No campus wells are pumped.

In the spring of 1986, a wastewater well was installed between the west side of the Campus Center and the southeast corner of Brooks Hall (Fig. 5), and the wastewater is discharged in the storm sewer. It has pumped continuously since its installation at the rate of 22 gallons per minute. As shown in

Figure 7, a notable decrease in groundwater levels is noted during the 1985–1986 period, especially for wells 1, 2, and 3. The double lines between the November 1985–February 1986 time period represent extrapolated data because the wells were not measured due to snow cover. Well 4 caved in during the summer of 1986 and its data are terminated at that point. The decline in groundwater during the 1985 season is probably due to the drought experienced in Chadron during the year (27.66 cm or 10.89 in). The continued decline during 1986 appears to be linked to the pumping influences of the wastewater well since 1986 was a wet year (63.65 cm or 25.06 in). Although not shown in Figure 7, this decline in water levels has continued into 1987 at the time of this writing (September, 1987), again probably linked to the discharge of saturated water into the storm sewer.

By contrast, the City wells are all lawn–irrigated wells and located in the residential area of Chadron. Wells 6, 7, and 8 are located in an area north and down slope from the campus (Fig. 4). Well 9 is located down gradient from Wilson Park. Well 10 is not part of the drainage patterns of the other wells. All wells are used for irrigation.

For the 1981–1984 period the underground water levels from all wells 6–10 follow the same seasonal synchronous and phase patterns (Fig. 8). During this period water levels tend to fall during the summer months and tend to increase slightly during the winter months, resulting in a slight net gain until 1984. In 1984, the water levels tended to remain static. The lowering of groundwater levels during the summer months appears to be related to the use of these wells for irrigation purposes. In 1985, a decline in groundwater levels is noted in all the wells, probably related to the drought and the need of increased pumping for lawn–irrigation purposes. The increase in water levels during 1986 may be related to the abundant rainfall during 1986.

City water records from before 1968 are scarce, but water usage for the City prior to 1968 approximated 260 million gallons annually. Following the installation of the deep-well system, approximately 365 million gallons have been used annually (or an average of 165 gallons per day per person). This represents a 40 percent increase in water consumption, yet the population of Chadron has remained approximately the same (Table I), and no significant increase in industrial demands have been placed on City water in recent years.

Chadron State College is the largest single user of water within the City. A view of the College's use of water for irrigation purposes on the campus is shown in Figure 9. Only taps serving irrigation purposes are used in the data. Two exceptions, however, are made: (1) water usage from the baseball field has been deleted because the field has not been used in recent years and is located away from the area of study; (2) water usage has been estimated for the area between the Gymnasium and Campus Center based on an equivalent area usage of the football field; this area is not on a tap supplying irrigation water only, yet it has been an important consumer of irrigation water. Unfortunately, complete data of campus usage could not be obtained for years before 1969, which would have added to a broader data base prior to the deep-well system. The data, however, indicate that on the average, for the last 18 years, approximately 12,300,000 gallons of water have been used by the College annually for lawn purposes from taps used exclu-

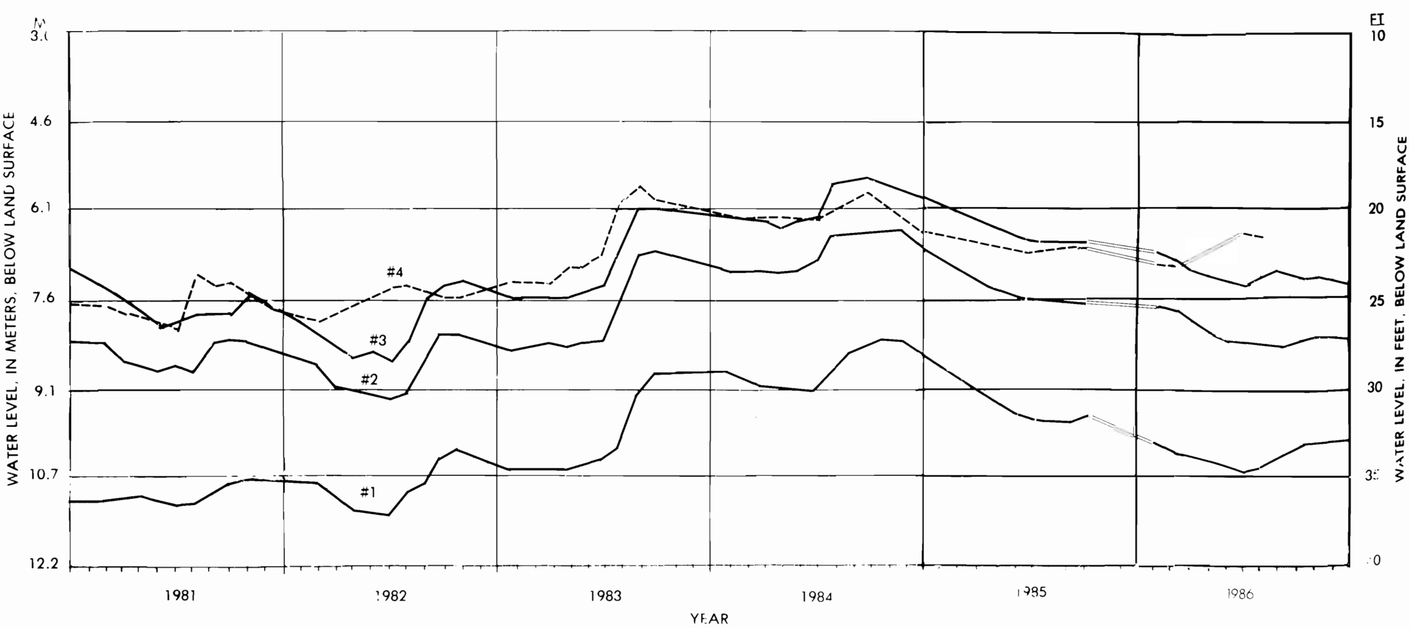


FIGURE 7. Depth in meters and feet to underground water on the campus.

sively for irrigation for an estimated area of 5.5 ha (13.6 acres). Generally, water consumption is inversely related to precipitation patterns; the exception is the 1985 season. It is noteworthy that a wastewater discharge of 22 gallons per minute equates to eleven million gallons of water in one year, or about the same volume applied for lawn purposes each year.

Seepage from the swimming pool has been suggested as a possible source of rising underground water. Figure 10 shows the usage of water from the Armstrong Gymnasium, where the pool is located, for a 18–year period. The data indicate increased water usage in 1976, 1977, and 1978, suggesting leakage. Perhaps as many as four million gallons of water may have leaked from the pool and entered the old drainage pattern. It was repaired in 1978, and water consumption in the Gymnasium has now been reduced.

Poor water management has also been suggested as a source of rising underground water. In several investigations concerning building deteriorations, recommendations have been made to better utilize irrigation water and reduce groundwater levels (letter to Edwin C. Nelson, President of Chadron State College from Don T. Pyle, representing Ketchum, Konkel, Barrett, Nickel, and Austin, Consulting Engineers, 730 Kalamath Street, Denver, Colorado 80204, May 20, 1971). Another investigator noted a lawn sprinkler setting of 18.5 hours applying 20.3 to 21.6 cm (8.0 to 8.5 in) of water in one setting (letter to Edwin C. Nelson, President, from Vincent H. Dreeszen, Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska, July 30, 1971). Since that time, lawn water–usage has not decreased except for 1982, and 1986, both wet seasons. This practice appears to have contributed to the rising underground levels.

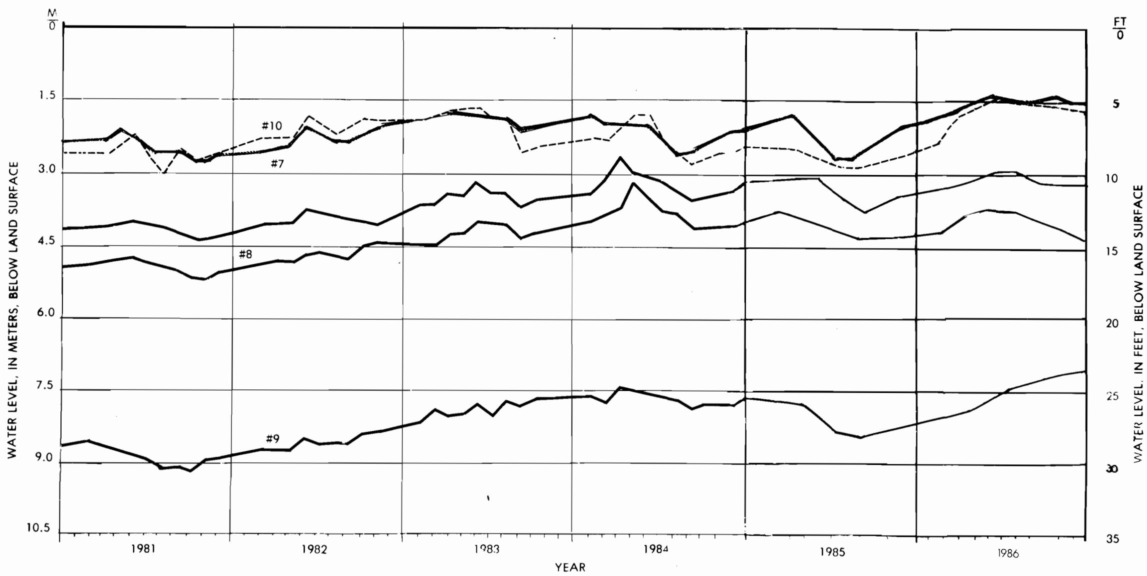


FIGURE 8. Depth in meters and feet to underground water in the city.

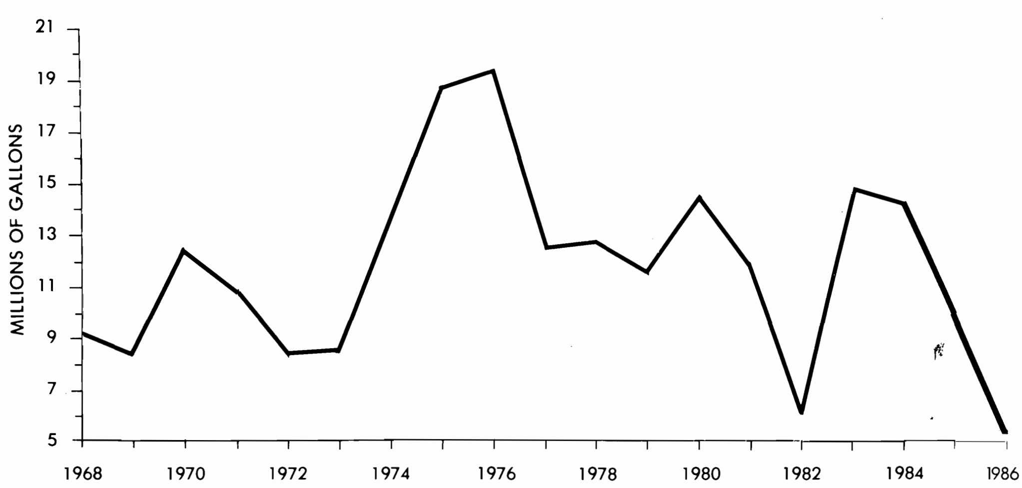


FIGURE 9. Water usage for lawn beautification at Chadron State College.

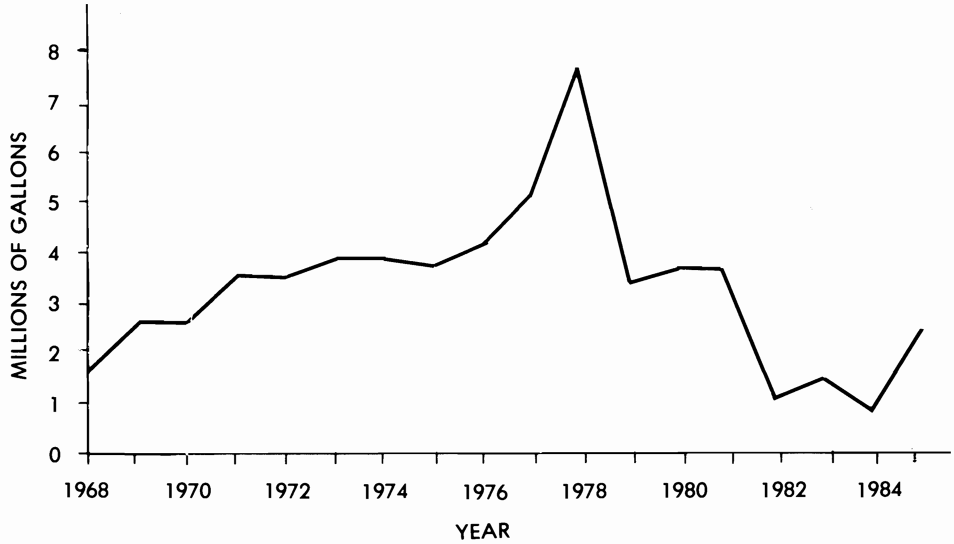


FIGURE 10. Water usage for Armstrong Gymnasium.

CONCLUSIONS

One aspect is obvious from this study, namely, that groundwater levels on parts of the campus have been rising at the rate of approximately two feet per year for the years 1981, 1982, 1983, and 1984. During this time period, no wastewater well was in operation.

In 1985, however, campus underground water levels started to decline at the rate of approximately two feet per year. This decline is probably linked to the drought and the decreased use of lawn–irrigation water. In 1986, a desaturation well was installed and this rate of decline continued.

Two quick calculations show the following: (1) Twelve million gallons of water deposited annually on 5.5 ha (13.6 acres) equates to about 83 cm (32.8 in) of rain. Add to this the mean annual precipitation of 39 cm (15.5 in) for a 19 year period (1968–1986), and a total of 122 cm (48.3 in) of water equivalent is applied annually. By contrast, the water equivalent (precipitation plus irrigation) for the 1985 season was 96 cm (37.6 in). Holding the supplemental watering to this level may maintain or even reverse the groundwater levels. (2) Water could be removed fairly rapidly from saturated material overlying the impermeable unweathered Brule. Assuming 3 m (10 ft) of material containing a porosity of 25 percent, one desaturation well delivering 25 gallons per minute could pump this water from an area of one city block in 47 days.

Even though Chadron State College has been singled out in its water consumption usage, it is not alone in this respect. The Chadron High School water pattern was not included in this study because meter readings used solely for irrigation were not obtainable. But it appears that its water usage patterns parallel those of the College. The City deep–well system likewise provides additional water for yard beautification in the City. The relative high cost of the water, however, restricts its consumption for domestic lawn and garden usage.

On the basis of the foregoing considerations, I suggest: (1) the College install a limited number of strategically located wastewater wells to further prevent structural damages to existing campus buildings; removal of campus underground water would also prevent its downward flow into the residential areas of the City; (2) concurrent with pumping, water levels be monitored for changing underground water levels; (3) the College and High School manage irrigation water so that the earth is not saturated below plant root depth.

ACKNOWLEDGMENTS

I am grateful to the many well owners who willingly cooperated over the years to permit their wells to be monitored and sampled and to various students who, over the years, have served in various capacities in the collection and analyses of water samples, measuring water levels, and the processing of data. They include: Steven Van Boening, Howard McCafferty, Mich Gehrig, Mark Brohman, and Steven Johnson. I also appreciate the records provided by City and College officials for review.

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