Seismic Qualification of the
Byron Deep Wells

**Report Prepared for
Commonwealth Edison Company**

SL-4492
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Revision 1

CONTENTS

CONTENTS, Cont.

CONTENTS, Cont.

TABLES

Table

EXHIBITS

Exhibit

EXECUTIVE SUMMARY

The Byron Station utilizes the Rock River as a source of cooling water makeup for the Ultimate Heat Sink. The current Technical Specification - Plant Systems 3/4.7.5, Ultimate Heat Sink, has a minimum water level of 670.6 feet Mean Sea Level (MSL) specified in the limiting condition requirements. This report has been prepared to provide technical data in support of changes to be made to the technical specifications by seismically qualifying the deep wells and thereby allowing greater station operation flexibility in operating the Ultimate Heat Sink.

The qualification data consist of two categories: a literature review of wells, pumps, and pipeline installations in areas of high seismicity and an analytical examination of the seismic rock-well interaction at the postulated levels of motions from the Byron Safe Shutdown Earthquake (SSE) event.

Wells may be damaged during seismic events by massive permanent ground movements, such as those occurring across faults and during ground rupture. Damage may also be caused by significant or large magnitude transient motions resulting from traveling surface waves with accompanying well system vibration.

The first three sections of this report describe the Byron wells and pumping data, geologic conditions, and seismological environment. Subsequent sections provide descriptions of facility damage following eight worldwide destructive earthquakes, all of which have a larger magnitude and shorter return interval than the Byron SSE. The seismic environment descriptions are intended to demonstrate the performance of deep water supply or oil wells during and following the various earthquake events. In addition, data relating to municipal well construction has been collected to show the long-term performance of municipal wells of communities neighboring the Byron site which have experienced local earthquakes.

Performance data from the earthquake literature was compared to the actual well construction at Byron and the postulated earthquake levels of the SSE. The performance data consisted of yield and content of the water, action of the pumps and any bacteriological contamination of the groundwater from the surface. The results indicate that wells have remained functional following earthquakes with larger magnitudes, higher accelerations, and longer duration motion created during multiple events. The literature also reported that wells have remained functional through repetitious large magnitude events in a 60-year history, and through the equivalent of six earthquakes equal to the Byron site SSE in a six and one-half hour duration.

The effects of earthquakes on ground water wells is shown to be dependent upon many factors that change with such variables as earthquake mechanism, wave propagation, geologic setting, soil and rock characteristics, and well construction. For this reason, the effects of earthquakes on groundwater wells near the Byron site have also been reviewed. Well records of the cities of Byron, Oregon, Rochelle, and Stillman Valley are reported in conjunction with the four earthquakes reported within 100 miles of the Byron site. The wells of these cities are still in service, and there has been no known permanent damage or impairment of pumpage of municipal groundwater wells in the Byron area as the result of earthquakes during the past 90 years.

A review was made of both the Water Well Standards: State of California Bulletin 74-81 and the AWWA Standard for Water Wells, ANSI/AWWA, A 100-84 for seismic design criteria. Neither standard provides guidance; however, they are used successfully for the installation of wells in areas of high seismicity. The Byron well exceeds the recommendations of these standards.

A seismic analysis was performed of the entire well system. The system consists of a 1500-ft-deep borehole through competent unsolutioned dolomites and sandstones with a 16-inch-diameter steel casing cement grouted into a segment of total rock depth. An eight-inch-diameter discharge pipe hangs within the casing and supports the pump at its lower end. A diagram of the well system is provided in Exhibit ES-1. The analysis conservatively used the acceleration time history developed for the station and its response spectra envelope for the site SSE. The analysis concluded that the stresses induced in each component of the well system during the safe shutdown earthquake are well within the code allowables.

In summary, both the review of literature which described the conditions of numerous water wells during and after earthquakes, and the seismic analysis which determined the well response and resulting stresses from the site SSE indicate that Byron site wells will remain functional after the design basis earthquake.

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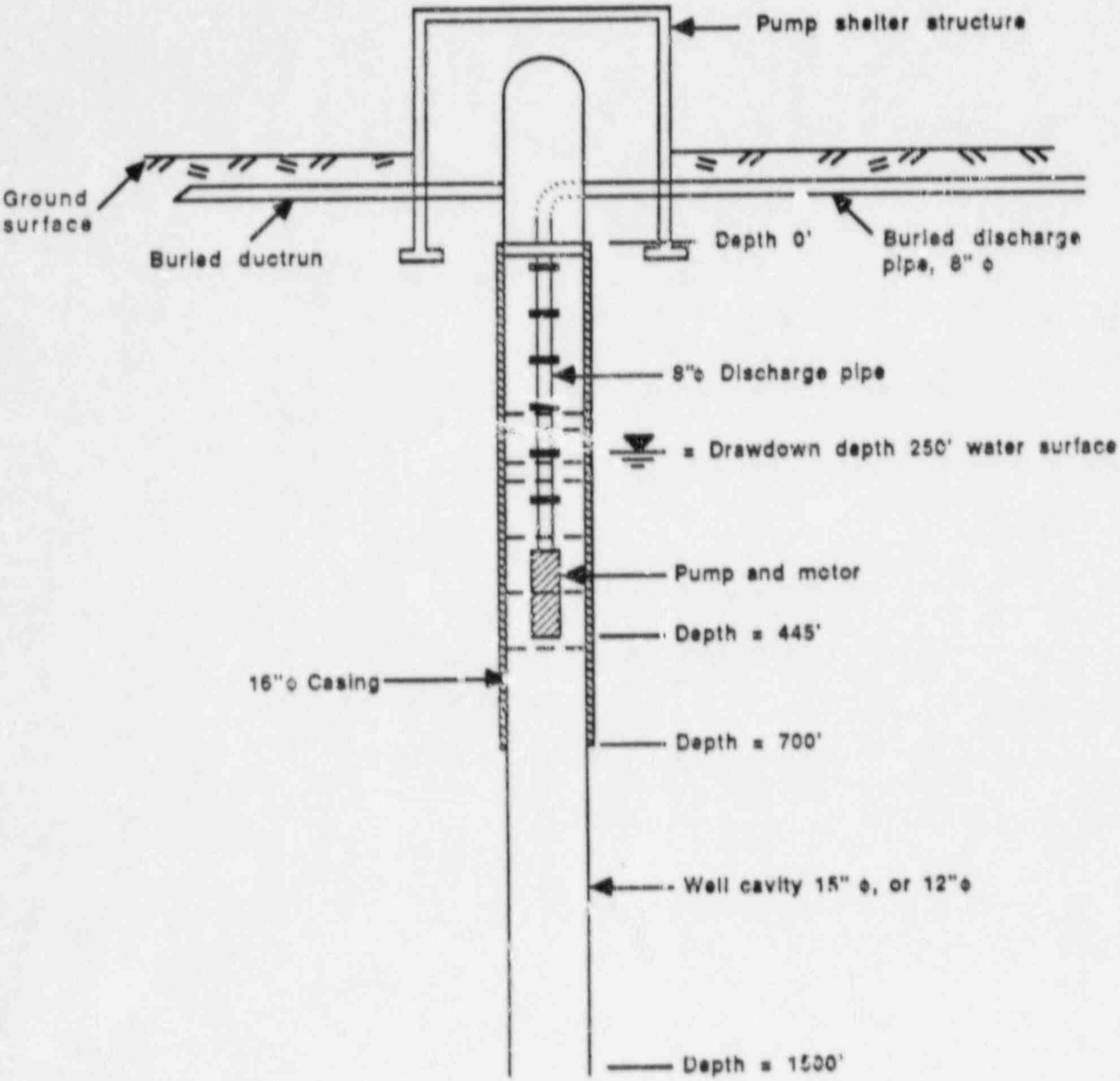
Deep Well System for Byron Station

Exhibit ES-1
SL-4492



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Section 1

INTRODUCTION

Byron Station Units 1 and 2 utilize the Rock River as a source of makeup for the Ultimate Heat Sink cooling towers. A minimum River Rock water level of 670.6 MSL is specified in the limiting condition requirements of Technical Specification - Plant Systems 3/4.7.5, Ultimate Heat Sink. This report has been prepared to provide technical data in support of changes to be made in the Technical Specifications by seismically qualifying the Byron deep wells. These changes will allow greater station operation flexibility by reducing operation restrictions that the Rock River low flow causes. The assessment is divided into two categories: a literature review of wells, pumps, and pipeline installations in areas of high seismicity and an analytical examination of the seismic rock-well interaction considering the in situ dynamic rock characteristics. The qualification of the deep wells also includes the ancillary equipment, electrical and structural components, and associated piping.

A review of the relevant literature indicates that the competency of the surrounding medium plays an important role in the assessment of the dynamic response of the entire well-pipe system. Parametric studies have been performed which accounted for the effects of dynamic interaction (Reference 1) when the surrounding medium is competent. From these studies it may be concluded that the effects of seismic interaction between buried pipelines and surrounding soil medium are small and would not be directly responsible for system failure. Seismic damage to wells and underground pipeline systems is caused primarily by soft ground movement and faulting, traveling seismic waves, liquefaction of loose sandy soil, or stiffness differences of two horizontally adjacent soil layers (Reference 2). Based on this, the founding conditions of the Byron well system are reviewed to demonstrate their performance.

The conclusions of the studies of earthquake hazard and seismic well-rock interaction demonstrate that the wells at Byron will remain functional after the postulated SSE event. Therefore, specific changes to the Technical Specification - Plant Systems 3/4.7.5, Ultimate Heat Sink are recommended.

Section 2

WELL QUALIFICATION

Seismic damage to underground wells [illegible] and vertical pumps is caused by permanent ground movements, such as those occurring across faults, at margins of landslides, zones of liquefaction, surface rifts, and ground ruptures. Damage is also caused by transient motions resulting from travelling waves. Pipelines, because of their lateral extent, can indicate the extent of damage. This is particularly true in regions of large and variable permanent ground movements which are manifest by the variation in pipeline movement and the relative displacement and rotation at joints. Damage is evident by rupture of pipe adjacent to a rigid wellhead joint, especially at a threaded root; and may be accompanied by lateral shear or fracture, axial buckling, or collapse of the supply pipe between joints.

Where ground shaking is dominated by wave effects, leakage at spots made thin by corrosion and disruption of caulking material in joints are more frequently the cause of failure.

The next section of the report describes the conditions at the Byron site, which includes the pump and well characteristics. After that, data are reviewed from various worldwide destructive earthquakes, which in all cases have a larger magnitude and shorter return interval than the Byron site SSE or Operating Basis Earthquake (OBE). Where damage to wells or piping has been noted or where the wells have been found to be operable following the worldwide earthquakes, a description is provided. Following each earthquake description, a short comparison is made to the Byron site well conditions to illustrate the superior conditions of the existing deep wells. The most comprehensive knowledge of structure performance was obtained from the assessments of earthquake damage by noted authors who provided descriptions of the damaged conditions but not necessarily the facilities which remained operational. Therefore, operational or functionally stable wells can be inferred from the damage reports.

A review was made of both the Water Well Standards: State of California Bulletin 74-81 and the AWWA Standard for Water Wells, ANSI/AWWA, A 100-84 for seismic design criteria. Neither standard provides specific guidance; however, each standard of practice has been used successfully in regions of the country where high levels of earthquake activity occur frequently. The Byron well construction exceeds the requirements of the AWWA and California standards.

Section 3

BYRON WELL SITE

WELL DESCRIPTION

The design basis for the Byron well site is based upon recognized American Water Works Association (AWWA) standards, A 100-66, governing the installation of the water wells. The two Byron Station deep wells (W-1 and W-2) were completed in the Ironton and Galesville Sandstones of the Cambrian-Ordovician Aquifer in 1974. The well as shown in Exhibit ES-1 was cased through the Galena-Platteville dolomites and open from the Ancell Group through the Ironton and Galesville Sandstones; the Ironton and Galesville Sandstone were the major producing zones. The groundwater resources in northern Illinois have been described in detail in numerous Illinois State Water Survey and State Geologic Survey reports. The geologic stratigraphic column and aquifer descriptions are shown in Exhibit 3-1. As shown in Exhibit 3-1, the deep sandstone aquifer contains, in descending order, the Galena-Platteville dolomite, Glenwood-St. Peter Sandstone, the Prairie du Chien series of Ordovician age; the Eminence-Potose dolomite, Franconia Formation, and Ironton-Galesville Sandstone of Cambrian age.

Cooling Tower Structure foundation grouting at Byron Station did not extend into the formations open to the site water wells; therefore, the specific capacities are unaffected by onsite grouting. The actual well construction consists of a submersible pump suspended 445 ft below the ground surface by an 8-inch-diameter supply pipe.

The specific capacities obtained in 1974 during well development pumping tests were 10.3 gpm/ft of drawdown at 620 gpm for 12 hours in well W-1 (east well) and 9.6 gpm/ft of drawdown at 1150 gpm for 24 hours in well W-2 (west well). The pumping rate for W-1 was relatively constant for the initial 12 hours, then was varied between 433 and 930 gpm during the last 12 hours of the test. The pumping rate for W-2 was relatively constant for the entire 24 hours.

A second aquifer pumping test was performed in November 1978 in order to demonstrate the ability of the station deep water wells to provide the design basis quantity of water makeup to the essential service water system during the 30-day period for safe shutdown. The specified pumping capability of 800 gpm per well or 1600 gpm for two wells exceeds the makeup needs for the worst 24-hour period following a Loss of Coolant Accident of 1545 gpm as documented in the FSAR Paragraph 9.2.5.3. The amount of makeup was conservatively calculated based on evaporation caused by the most extreme 24-hour weather period and conservatively includes 565 gpm blowdown for the 24-hour period. The aquifer pumping test consisted of pumping water W-1 at a continuous rate of 840 gpm while monitoring groundwater levels in water W-2 (Ironton-Galesville Sandstones), the grouting supply well TW-2 (St. Peter Sandstone), and an observation well TW-4 installed in the Ironton-Galesville Sandstone approximately 300 feet from water W-1 on the line connecting W-1, TW-2 and W-2. The aquifer pumping test consisted of a 22-hour pumping period followed by a recovery period of 1-1/2 hours.

The aquifer pumping test results demonstrated an adequate quantity of water; however, they also indicated that the aquifer transmissivity was 20,000 gpd/ft, the storage coefficient was 2.0×10^{-4}, and the specific capacity was 8.5 gpm/ft. These results indicated that in order to assure the necessary water supply during the station design life, the pump setting would have to be deepened because the specific capacity had decreased 15% since the well was first installed. On the basis of subsequent caliper logging and well depth measurements, the apparent decline in well productivity was attributed to movement of loose sand from the St. Peter Sandstone, with partial blockage of the more productive aquifer strata in the lower portion of the well.

Deep sandstone wells are commonly uncased through many of the deep aquifer formations similar to those that have been penetrated at the Byron well site because most of the bedrock encountered does not cave or swell. However, in order to ensure constant yields over time, hydrogeologists familiar to the area recommend casing off some of the lower geologic units that cause problems. This has been reported by the Illinois State Water Survey

(Reference 3). The lower shales and conglomerates of the Glenwood-St. Peter Sandstone and some weak shales of the upper beds of the Eau Claire Formation often experience well-wall deterioration and, therefore, require casing for long-term assurance of water supply.

The caving which occurred may be partially attributed to the local strata thickness, cementation, and lithologic character of medium-grain rock as well as the friable nature of the segment of St. Peter Sandstone penetrated. The loss of this portion of the aquifer does not have significant consequences because the caving units generally yield small amounts of water; therefore, additional casing and well deepening were undertaken.

Well modifications performed in W-1 and W-2 after the 1978 pumping test consisted of reaming and casing-off the caving St. Peter Sandstone, deepening the wells through the Ironton-Galesville Sandstones and into the upper portion of the Mt. Simon Sandstone, increasing the pumps' lift-capacity and lowering the pump settings by 100 feet. The modified water wells are open from the Franconia Formation, through the Ironton and Galesville Sandstones and into the Mt. Simon Sandstone. The Ironton and Galesville Sandstones and the Mt. Simon Aquifer are the major producing zones.

The specific capacities obtained during well development pumping tests in the modified wells were 12.3 gpm/ft of drawdown at 1330 gpm for 12 hours in W-1 and 12.2 gpm/ft of drawdown at 1210 gpm for 9 hours in W-2. Whereas the pumping rate for W-1 was relatively constant for the entire 12-hour test, the pumping rate for W-2 was relatively constant for only the initial 9 hours, then was varied between 1200 and 1600 gpm during the last 3 hours of the test. The available drawdown in the two wells is approximately 125 feet based on a static water level of 250 feet and a pumping level of 375 feet.

A third aquifer verification pumping test was performed in July 1980 after the well modifications were completed in order to demonstrate the ability of the modified station water wells to provide the required makeup to the essential service water system. The test consisted of pumping W-1 at 790 gpm for 24 hours. The test results indicated that the aquifer transmissivity is 40,000 gpd/ft, the storage coefficient is 2.5×10^{-4}, and the specific capacity is 13.2

gpm/ft. Based upon these aquifer characteristics and the equilibrium conditions achieved, it was concluded that the specified flow of 800 gpm/well could be sustained for 30 days.

SEISMIC WAVE TRANSMISSION CHARACTERISTICS OF THE SITE

The engineering properties of the soils and bedrock units at the site were evaluated using field geophysical measurements and laboratory testing; the properties were determined by laboratory testing.

Geophysical investigations were performed at the plant site. The velocity of compressional and shear wave propagation and other dynamic properties of the natural subsurface conditions were evaluated from these investigations, and the data were used in analyzing the response of the materials to earthquake loading.

Dynamic moduli for the subsurface soil and rock at the site were calculated based on measured properties. The in situ field measurements were compared with laboratory tests on the same materials.

Seismic wave velocities and densities for the deeper rock strata in the region have been measured by others (Reference 4). The data confirmed field measurements, and were used in the seismic analysis of site wells to predict dynamic behavior.

EARTHQUAKE EVENTS SIGNIFICANT TO THE SITE

The most significant earthquakes in the region can be determined by analyzing the tectonic association of earthquake events with structure, i.e., identifying the earthquake epicenter and known fault or geologic structure. The most significant earthquakes in the region are the 1909 Intensity VII Beloit earthquake, the 1972 Intensity VI northern Illinois earthquake, the 1912 Intensity VI northeastern Illinois earthquake, the 1804 Fort Dearborn earthquake, and the New Madrid earthquakes of 1811-1812. This evaluation is based on epicentral intensity, felt area, distance from the site, and tectonic association. Intensity is defined as the Modified Mercalli Intensity scale of 1931 as abridged and rewritten by C. F. Richter. The scale is a measure of the effect of the earthquake and is categorized by levels of I through XII. Level VII is defined by the following description: "Most people are frightened and run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving motor cars. Large bells ring."

MAXIMUM EARTHQUAKE POTENTIAL

The maximum earthquake which could be expected would be an Intensity VII event similar to the 1909 Beloit Intensity VII event near the site. This is equivalent also to the occurrence of the largest event which has ever been recorded within the Central Stable Region, and which cannot yet be associated with a specific structure or structural region; it is therefore described as random. The level of ground motion experienced from a near field VII event would envelop the motion expected from a recurrence of a New Madrid-type event at the closest approach of the Mississippi Embayment, a distance of 330 miles from the site.

The recommended safe shutdown earthquake was defined as the occurrence of an Intensity VII event near the site. This near field event would produce maximum horizontal ground accelerations of 0.13 g (Reference 5).

However, at the time of the review of the construction permit application, the NRC considered the occurrence of an earthquake of Intensity VIII to be equally probable (a low order or probability) at any place in the Eastern Central Stable Region. The NRC also took the position that, based on the postulated occurrence of an Intensity VIII at the site, a safe shutdown earthquake of 0.2 g at the bedrock-soil interface was adequately conservative for the Byron Station.

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Generalized Stratigraphy and Water-Yielding Properties of the Rocks in Northern Illinois

Exhibit 3-1
SL-4492

(after Suter, et al, 1959, and Hackett, 1960)

System	Series	Group or Formation	Geohydrologic Units	Log	Approximate range in thickness (feet)	Description	Drilling and Casing Conditions	Water-yielding properties
Quaternary	Pleistocene		Glacial Drift Aquifers		0-500	Unconsolidated clay, silt, sand, gravel, and boulders deposited as till, outwash, pond water deposits, and loess	Boulders, heaving sand locally; sand and gravel wells usually require screens and development; casing required in wells into bedrock.	Probabilities for ground-water development range from poor to excellent. Outwash sand and gravel yield more than 1000 gpm to wells at places. Large supplies generally obtained from permeable outwash in major valleys. Glacial aquifers used for many small water supplies because they are shallow.
Pennsylvanian		Carbondale Tradewater	Bedrock Aquifers		0-500	Shale; sandstones, fine-grained; limestone; coal; clay	Shale requires casing.	Jointed beds yield small supplies locally.
Mississippian	Kinderhook				0-350	Shale, green and brown, dolomitic; dolomite, silty		Limited areal extent; generally not used as aquifers.
Devonian					0-100	Shale, calcareous; limestone beds, thin		
Silurian	Niagaran	Port Byron Racine Waukesha Joliet	Shallow dolomite aquifers		0-500	Dolomite; silty at base, locally cherty	Upper part usually weathered and broken; extent of creviceing varies widely.	Not consistent; some wells yield more than 1000 gpm. Crevices and solution channels more abundant near surface.
	Alexandrian	Kankakee Edgewood						
Ordovician	Cincinnatian	Maquoketa			0-250	Shale, gray or brown; locally dolomite and/or limestone, argillaceous	Shale requires casing.	Shales, generally not water yielding, act as confining beds between shallow and deep aquifers. Crevices in dolomite yield small amounts of water.
	Mohawkian	Galena Decorah Platteville	Galena-Platteville Dolomite Cambrian-Ordovician Aquifer		0-350	Dolomite and/or limestone, cherty, sandy at base, shale partings	Creviceing common only where formations underlie drift. Top of Galena usually selected for hole reduction and seating of casing.	Where formation lies below shales, development and yields of crevices are small; where not capped by shales, dolomites are fairly permeable.
		Glenwood	Glenwood-St. Peter Sandstone		0-650	Sandstone, fine- and coarse-grained; little dolomite; shale at top	Lower cherty shales cave and are usually cased. Friable sand may slough.	Small to moderate quantities of water. Coefficient of transmissibility probably averages about 15 per cent of that of Cambrian-Ordovician Aquifer.
	Chazyan	St. Peter				Sandstone, fine- to medium-grained; locally cherty red shale at base		
	Prairie du Chien	Shakopee New Richmond Oneota			0-400	Dolomite, sandy, cherty; sandstone. Sandstone interbedded with dolomite, white to pink, coarse-grained, cherty, sandy	Crevices encountered locally in the dolomite, especially in Trempealeau. Casing generally not required.	Crevices in dolomite and sandstone generally yield small to moderate quantities of water. Trempealeau locally well creviced and partly responsible for exceptionally high yields of several deep wells. Coefficient of transmissibility probably averages about 35 per cent of that of Cambrian-Ordovician Aquifer.
Cambrian	St. Croixan	Trempealeau			0-225	Dolomite, white, fine-grained, geodic quartz, sandy at base		
		Franconia			45-175	Dolomite, sandstone, and shale, glauconitic, green to red, micaceous		
		Ironton	Ironton-Galesville Sandstone		105-270	Sandstone, fine- to medium-grained, well sorted, upper part dolomitic	Amount of cementation variable. Lower part more friable. Sometimes sloughs.	Most productive unit of Cambrian-Ordovician Aquifer. Coefficient of transmissibility probably averages about 50 per cent of that of Cambrian-Ordovician Aquifer.
		Galesville						
		Eau Claire	Eau Claire		215-450	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic	Casing not usually necessary. Locally weak shales may require casing.	Shales generally not water yielding. Act as confining bed between Ironton-Galesville and Mt. Simon
		Mt. Simon	Mt. Simon Aquifer		1000-2000±	Sandstone, coarse-grained, white, red in lower half; lenses of shale and siltstone, red, micaceous	Casing not required.	Moderate amounts of water; permeability intermediate between that of Glenwood-St. Peter and Ironton-Galesville.
Precambrian crystalline rocks								

Section 4

SEISMIC ENVIRONMENT COMPARISON

Researching a lifeline or system response to an earthquake was selected as a means of assessing the Byron well's ability to withstand comparable earthquakes; therefore, recent worldwide data were reviewed. For the comparison, water well and well pump performance of six recent worldwide earthquakes was examined in addition to four earthquakes reported within 100 miles of the Byron site. Worldwide data were selected which had much greater magnitudes than the Byron postulated SSE in order to demonstrate effects of earthquakes where ground rupture ($M_s \geq 6.0$) has occurred, while the Illinois data illustrate response in local areas. Worldwide earthquake data are presented in terms of magnitude M. The magnitude M represents a part of the frequency spectrum of seismic waves and therefore respresents a physical parameter of the earthquake. For earthquakes at very great distances from the recording station, seismic surface waves with a period around 20 seconds are often dominant on seismograms; the wavelength of these waves is about 60 km. Beno Gutenberg (Reference 6) used this characteristic by defining the amplitude of surface waves with a period of 20 seconds and calling them surface magnitude or M_s. It should be noted that magnitude scales use small numbers to express vast differences in earthquake size. In absolute terms of radiation of seismic energy, energy release increases about 32 times with each increase in magnitude unit. Because the amount of energy radiation reflected in the magnitude scale increases geometrically, small differences in magnitude are much more significant at the higher ends of the scales than they are at the lower ends. The difference in radiated energy between earthquake M=7.9 and 8.0, for example, is about one million times larger than the differences between earthquakes M=3.9 and 4.0.

Nuttli (Reference 7) reports that earthquakes east of the Rocky Mountains, in general, do not rupture the earth's surface, while the worldwide events do. Worldwide evidence from historical surface faulting events shows that nearly all ground ruptures have closely followed pre-existing fault traces. Displacements have occurred repeatedly along or near the same fault [illegible] and nearly always with the same sense of offset as that which can be inferred for the recent geologic past (Reference 8). As reported, and accepted by the NRC staff, there is no evidence of surface faulting near the Byron station. The absence of this condition suggests that the potential of damage could only be related to shaking or vibration. In the larger earthquakes, the stress drops are greater for the eastern earthquakes than for the worldwide events.

The worldwide seismic events selected for comparison with the Byron conditions are as follows:

- San Fernando Valley, California, 9 February 71
- Coalinga, California, 3 May 83
- Morgan Hill, California , 24 April 84
- Santiago, Chile, 3 March 85
- San Salvador, El Salvador, 10 October 86
- Edgecumbe, New Zealand, 2 March 87

The Illinois earthquakes within 100 miles of the Byron Station include:

• Beloit, Wisconsin	1909	MM VII
• N.E. Illinois	1912	MM VI
• Rock Island	1934	MM VI
• N. Illinois	1972	MM VI

The discussion of the Illinois earthquakes and their significance on local municipal wells is presented in Section 5 of this report.

SAN FERNANDO VALLEY EARTHQUAKE

Description of Event

The San Fernando Valley earthquake (M_s = 6.6) dramatically demonstrated that seismic design of major lifelines needed more attention. A detailed examination of pipeline leaks and eastern San Fernando Valley. The surface-faulting effects of the 1971 earthquake have been documented in detail (U.S. Geologic Survey Staff 1971). The zone of surface ruptures was 9.3 miles long extending from the western side of San Fernando to Big Tujunga canyon. Detailed mapping showed that five separate segments of the fault zone were activated at the surface during the earthquake. The character of ground deformation varied along each segment. The distal parts of the fault zone were marked by relatively simple rupture zones less than 15 feet wide. In contrast, fractures of the west central segment consisted of a main belt of thrusting about 250 to 650 feet wide with displacements of 7 feet. The earthquake was accompanied by permanent ground distortion, including uplift and horizontal displacements. The maximum uplift was about 7 feet, while horizontal displacements, locally of more than 7 feet, occurring over a broad area showed an abrupt discontinunity along the zone of surface faulting in the pattern and amount of horizontal distortion (Reference 9). The causes of approximately 90 leaks at 71 locations were determined from repair reports of the Los Angeles Department of Water and Power (Reference 10). The repair reports demonstrate the aerial extent of severe shaking and indicate the location, size, and type of pipe, type of damage, type of soil, and the presence of internal or external corrosion. Also, in the area where earthquake damage tends to occur, the depth to bedrock changes rapidly and, hence, changes in ground motion that affect pipes may be expected.

The performance of 21 water wells located in the epicentral area, particularly those in the city of San Fernando which were closest to the areas of maximum ground displacement and surface rupturing, was examined with the aid of television cameras. The postearthquake condition or performance of the wells was judged principally by comparing the yield and content of the water, the action of the pumps, and the results of bacteriological tests. The results of the study (Reference 7) indicated the following:

- A cased well can withstand severe ground uplifts and lateral shifting and compression of the surrounding soil short of actual rupturing, without irreparable damage to either the casing or the pump.
- The California cable-tool method of construction used for the water well was found to be satisfactory in resisting the ground motions experienced in the earthquake. The principal distress was cracking and lateral shifting of the concrete pads attached to the pumps.

It is significant that 20 of the 21 deep wells drilled in the unconsolidated sand, gravel, and finer sediments withstood the severe ground shaking and uplift without any appreciable damage. Only well No. 7, a 375-ft-deep well drilled in 1960, was distorted due to earth movements. The 18-in. ID double 8 gauge steel pipe casing with perforations below 88 ft was found distorted in shape and twisted by severe movements when photographed. There were no other reported well failures in the San Fernando Valley study. Table 4.1 indicates the data on wells in the San Fernando epicentral area that are pertinent to the Byron site. A more detailed description of three water wells selected for their age and past performance after the earthquake follows.

Well No. 1. The oldest in the system, Well No. 1 was drilled to a depth of 554 feet by cable tools in 1901. It was cased to an unknown depth with a 15-inch ID riveted steel casing with riveted joints. The pump is an electric-driven, deep-well turbine type supported on a concrete base. The pump house is constructed of corrugated metal with a concrete floor slab. This well was located south of the zone of tectonic rupturing and was operating at the time of the earthquake. The post-earthquake survey showed there was no structural damage to the well and well house, and the operation of the well had not been impaired.

Well No. 2. Drilled in 1910 to a depth of 250 feet using a cable-tool method, Well No. 2 was cased to full depth with a 15-inch ID riveted steel casing with riveted joints. The casing was perforated with a milling knife. The pump is an electric-driven, deep-well turbine pump set directly on a concrete pad. Well No. 2 is outside of the zone of rupture; however, the general ground around the well was raised over 5 feet. Photographs of the well, taken with a three-dimensional down-hole camera, both above and below the water surface, showed that the casing was in good shape considering its age. Joints of the casing were rough, the perforations were enlarged, and several deformations in the lower casing, where it was pushed in at the joint, were recorded. After remedial measures were taken near the surface to seal out contamination, the well resumed operation.

Well No. 7. Drilled in 1960 by a cable-tool method to a depth of 376 feet, Well No. 7 has an

18-inch ID double 8-gauge stovepipe casing with telescoping joints. The pump is an electric-driven submersible type with the well discharge housed in a 3-foot-deep concrete pit. The well is located in the west central zone of ground rupture, and the damage survey revealed that the electric cable had split open near the top of the well creating a short circuit. A calipher check was made of the 18-inch casing with the following results indicating the ovaling of the pipe to the following dimensions:

0-150 ft	17.625 inch
150-180 ft	17.250 inch
180-230 ft	17.0 inch
230-280 ft	15.375 inch
280-304 ft	14 inch
304-309 ft	7.75 inch

Because of the distortion and twisting of the casing, the well was considered beyond repair. The well was abandoned and filled with concrete; however, a new replacement well was installed 160 feet away from the abandoned well.

Byron Comparison

Table 4-1 indicates the data on wells in the San Fernando epicentral area that are pertinent to the the Byron site. The Byron deep well and associated piping are ASTM A53 welded steel casing and welded steel supply pipe covered under ANSI B39.1 pressure piping. The Byron well casing has a 3/8-inch wall thickness which exceeds the December 1981 Water Well Standards for the State of California Bulletin 74-81. Both the well and supply piping are grouted into the dolomite bedrock above the regional groundwater table. The highly active geologic conditions and loose soil conditions which greatly contributed to the damage in the San Fernando Valley simply do not exist at the Byron site. Yerkes (Reference 9) reports that an approximate measure of historical frequency of damaging earthquakes in the region where a majority of these wells are located is provided by the record since 1800. The record indicates that some part of the Los Angeles area has been shaken by a moderate or large event on the average of about once every 4 years. In terms of exposure to damaging earthquakes, the 1300 mi^2 miles of urbanized Los Angeles basin where the referenced wells in Table 4.1 are drilled, has been shaken at MM$\geq$VII (Byron SSE) at least once in the last 180 years. Approximately 91% of that area has been shaken twice or more; about 57% has been shaken 3 times or more; about 27% has been shaken 4 times or more; and about 9% has been shaken five times or more. A direct comparison cannot be made between the superior construction materials and competent fault-free founding conditions at the Byron site and the poorer quality materials and unconsolidated founding strata in California. However, given the more severe environment, it is noted that 20 of the 21 deep alluvial wells in the San Fernando Valley remained functional following the M_s = 6.6 earthquake and associated subsequent ground failure or differential soil movement generated failures.

The deep wells at Byron are expected to survive the Byron SSE (M_s = 5.3) because of the much lower magnitude of ground motion compared to San Fernando and because of the superior foundation material (competent bedrock) in which the wells are located.

COALINGA, CALIFORNIA EARTHQUAKE

Description of Event

The M_s = 6.2 earthquake sequence provides an opportunity to study damage in representative water distribution pipeline systems and major oil field deep wells. The main shock has been estimated as M_s = 6.5 and a large aftershock as magnitude M_L = 5.1. The distribution systems and oil field experienced ground surface motions of 0.4 to 0.6 g; with 0.5 g as a reasonable estimate for the entire network (Reference 11). The oil field wells are within 2 km of the earthquake epicenter and were reported to experience a ground surface acceleration of 0.6 g.

Where damage occurred to wells, the extent of damaged systems varied according to the use and type of construction used for the well. The various investigators who surveyed post-earthquake conditions described damage according to one of three categories of wells: water supply wells, irrigation wells, and oil wells. The irrigation wells suffered the greatest damage. This could be expected because these wells generally have the least controls placed on them by the state installation specifications. The most frequently reported damage was failure of the pump head as a result of being shaken out of alignment and knocked off its foundation. In addition, 2 of the 23 irrigation well reports indicated that light wall casings partially collapsed due to ground rupture (Reference 12). However, of the more than 1000 wells in the Shell Company oil field, where American Petroleum Institute (API) recommended practices are used, resulting in better constructed welded steel cased wells, none sustained losses of any consequence to subsurface equipment. Oil production had decreased for a short period, but returned to normal only days later.

Damage to oil field pumping jacks was reported with several jacks coming to rest at angles of up to 45° after the earthquakes subsided. In addition, observations were made indicating that ground separation occurred for distances of 1000 to 1300 feet, with evidence of both high-intensity and long-duration excitation in other oil field structures.

Byron Site Comparison

The two nearly simultaneous Coalinga earthquakes demonstrated that the quality of construction is an important factor in seismic design. In both the pipeline reports and well examination documentation, poorer quality materials; i.e., transite pipe and poorly mounted irrigation pumps suffered the greatest damage.

The AWWA specified Byron deep well construction and materials closely follow petroleum or API recommended practices for well construction utilizing 3/8-inch-thick welded ASTM A53 steel. The Byron type of construction is very similar to that used in the Shell Oil wells nearby to the Coalinga event which did not sustain significant subsurface damage, although the ground surface accelerations were between 0.4 and 0.6 g, and ground separation occurred in the highly variable sand and gravel deposits. The Byron deep wells are founded in competent rock and, if exposed to the much less severe 0.2 g ground acceleration due to the postulated SSE, will remain functional.

MORGAN HILL EARTHQUAKE

Description of Event

On April 24, 1984, a moderate earthquake of $M_s = 6.2$ occurred in the vicinity of Morgan Hill, California. Relatively strong and duration-significant shaking was experienced. The five closest strong motion accelergraphs registered peak accelerations of 0.31 g, 0.5 g, 0.63 g, 0.41 g, and 1.29 g which were recorded at the abutment of a dam. Because of the 72 accelergraph records obtained, observations from the earthquake are of engineering significance. The records taken for this event demonstrate the distinctive characteristic of this earthquake. The records give clear evidence of excitations from two sources with different characteristics. The first source provides a high frequency motion. A later event with a lower frequency content starts about 10 seconds after the first event (Reference 13).

The response of equipment at three local industrial installations is examined to show the lack of damage to well-engineered structures. The installations are IBM Santa Teresa Laboratories, United Technologies Chemical Systems (UTCS), and the Santa Clara Valley Water District (SCVWD). Free field peak ground accelerations were as follows:

- IBM measured at a distance of 100 yards from the building N-S 0.45 g, E-W 0.28 g and vertical 0.50 g;
- UTCS, estimated values 0.4 g to 0.5 g; and
- SCVWD estimated and variable 0.45 g to 0.60 g.

The results of inspections of these facilities and associated piping are reported by Swan (Reference 13). Because of the quality of seismic design and construction, the facilities experienced no significant damage despite the relatively high levels of seismic motion. It should be noted that the UTCS facility, which covers 5200 acres, did not report well damage but did suffer some piping damage. Major piping damage involved 37 breaks in underground lines. Pipe diameters ranged from 6 to 10 inches, depths from 60 to 120 inches. Buried lines included transite pipe, cast iron, ductile iron, and mortar or concrete-lined pipe. Most breaks occurred in the cast iron or the concrete-lined steel pipe primarily at connections and as a result of ground failure.

The Santa Clara Valley Water District's principal facilities consist of a wide variety of pump stations and hydraulic structures, located from 6 to 27 miles from the epicenter of the earthquakes, and varying in age from a few years to over 50 years. The equipment suffered either no damage or minor and functionally insignificant damage from the earthquake.

Byron Comparison

The well facilities at Byron are designed and constructed using methods and engineering standards of the American Water Works Association (AWWA) with materials specified by ASTM or API specifications, and like th facilities of the Morgan Hill earthquake should not suffer damage. The Byron water supply stem is not founded in materials which may realize ground failure or any lateral shift in rock strata during earthquake ground motion. In addition, the method of pipeline trench and backfill construction was closely monitored according to Quality Control and Quality Assurance procedures and documentation.

CHILE EARTHQUAKE, MARCH 3, 1985

Description of Event

A major earthquake of magnitude (M_L = 7.8) occurred off the coast of central Chile affecting the populated areas of Santiago and Valparaiso. A major network of strong motion instruments recorded the event. From the evaluation of these records, Saragoni (Reference 14) concluded that the event involved two successive shocks: the first of magnitude M_s = 5.3 with a duration of strong motion of 10 seconds, and the second, which occurred 10 seconds later, of magnitude M_L = 7.8 with a strong motion duration of 30 seconds. The duration of recorded motion was as much as 120 seconds. The peak ground accelerations measured for the earthquake at Milipilla were 0.67 g N-S direction and 0.60 g in the E-W direction. Post-earthquake reports described the performance of deep wells at the 24-year old Bata Shoe Factory located on the outskirts of Milipilla (Reference 14). The onsite well is located near the northeast corner of the facility with a nearby vertical storage tank. Steel plates welded to the base of each tank leg are embedded in the concrete foundation. The concrete foundation spalled and cracked; however, the tank was not damaged and the well was available for use following the earthquake. The well was a 150-mm-diameter cased hole through the overburden soils into a sandstone-like aquifer.

Water supply systems were damaged primarily due to soil foundation failure and liquefaction. The most notable occurrence of well performance occurred at the San Juan de Llolleo pumping plant. The pumping plant was constructed on poorly consolidated soils which had suffered considerable disturbance and settlements from previous earthquakes. At this station, peak ground accelerations were 0.67 g horizontal and 0.81 g vertical.

The main structures at the pumping plant are a two-story building and a basement concrete frame building with masonry infilled walls which house well pumps. The facility has six pumps and well casings 50 m (160 ft) deep. The plant has a maximum capacity of 460 l/s (7300 gpm). Damage to the pumphouse consisted of differential settlement of up to 200 mm (8 inches), a tilted second story and partial collapse of one wall. One of the pumps in the pumphouse suffered a crack to the vertical discharge tube casing at old weld repairs due to an earlier nonearthquake-related crack. After repairs to the cracked concrete and broken welds, the facility was operable in spite of the large differential settlement. More detailed descriptions of the Chile earthquake are available in Reference 14.

Byron Comparison

The postulated maximum vertical and horizontal acceleration of the Byron site is approximately one-sixth and one-fourth, respectively, of the accelerations measured at the Llolleo pumping plant. In addition, the founding conditions at Byron well site consist of competent Cambrian-Ordovician age sandstone and dolomites which are far superior to the unconsolidated soils of the pumping station described. It is, therefore, expected that the Byron cased well grouted in bedrock will perform better than the cased wells at the Llolleo pumping station and Bata shoe factory, which were subject to large liquefaction induced ground movements, but nevertheless remained functional.

SAN SALVADOR EARTHQUAKE

Description of Event

The October 10, 1986, San Salvador magnitude M_s = 5.6 was selected because this earthquake represents the latest in a series of damaging earthquakes to the city and also because the damage assessment provides a description of the effects of the earthquake on deep wells and pumping stations.

During the last 276 years, the interval between destructive upper-crusted earthquakes at San Salvador has ranged from 2 to 66 years and has averaged about 23 years. The last earthquake prior to the 1986 event occurred on May 3, 1965, and was recorded as magnitude $M_s = 6.0$ event which is typical for the area.

The descriptions prepared by the Earthquake Engineering Research Institute (EERI) inspection team, headed by S. W. Swan (Reference 15), has provided a complete description of well and pump performance: "The water pumping stations, which pumped from both groundwater and tanks, include vertical deep (150') well pumps (ranging from 100 hp to 300 hp). These pumps, for the most part, performed well. Some pumps have minor out-of-balance related vibration problems, and only one pump in the city's oldest pumping station (circ. 1925) burned out following restart after the earthquake." The failed pump was later examined and found to have had pre-earthquake severe cavitation and corrosion distress within the impeller casing; however, the distress was exacerbated due to the strong motion experienced.

Byron Site Comparison

As indicated, this particular event was selected for comparison because of the frequency of destructive earthquakes and the fact that the adequate pump and well system performance continued over 60 years at the San Salvador city site. At the Byron site, the NRC postulated SSE MM VIII event (magnitude $M_s = 5.3$), which has never occurred within two hundred miles of the site and has an estimated return interval in excess of the 2150 years calculated for the OBE event with a site intensity of VII. The expected performance of the Byron wells which are grouted into Silurian and portions of Ordovician aged bedrock will be superior to the existing San Salvador city wells installed without grouting into volcanic deposits and subjected to many earthquakes. The Byron wells should be better than the San Salvador wells, and they will remain functional even if the postulated Byron SSE should occur, because of the much less frequent seismic activities at Byron.

EDGECUMBE EARTHQUAKE

Description of Event

Modified Mercalli intensities of IX and X were reported as a result of the magnitude $M_L = 6.3$ earthquake located near the town of Edgecumbe in the North Island of New Zealand on March 2, 1987. Strong motion accelergraphs recorded peak ground accelerations of 0.33 g within 15 km (9.3 miles) of the epicenter. Of particular interest is accompanying seismic activity before and after the principal shock, each of which was greater than $M_L = 5.2$ magnitude. The foreshock and subsequent four aftershocks were within a 6-1/2-hour time period. The main shock produced a complex series of surface ground ruptures, the longest being 7 km (4.3 miles) long with a 1.3 m (4.3 ft) extension and 1.5 m (4.9 ft) downthrown surface. There was extensive evidence of level ground liquefaction and lateral spreading. Analysis of the strong motion accelergraphs indicated that the main shock response spectra was comparable to design levels of a 150-year return period.

The affected area geology consists of later Quaternary rhyoletic volcanics and Mesogoic greywacke with Quaternary alluvium consisting of alternating sequences of mainly pumice-derived alluvial sand and gravel, tephra sand, and marine silt and sand. The water table varies from 0 to 3 m (9.8 ft) below the ground surface with shallow wells as the primary source of water.

The behavior of existing functional wells is reported by Pender (Reference 16). Three types of responses were reported by local residents and were noted as:

- wells with water level below ground had flows above ground;
- wells capped, with a pressure gauge, indicated a rise in pressure after the earthquake amounted to several tens of kPa (1 kPa = 20.87 psf); and
- some well walls moved laterally and allowed water to flow between the casing and soil.

Damage to water supply piping was again used as a measure of the extent of damage. The damage was major because of the poor quality types of material and methods of construction. Water supply piping consisted of 100 mm (4 in.) diameter asbestos cement pipes with a glued socket. The pipes were buried about 750 mm (2.5 ft) below the ground surface. According to local reports, compression failures at pipe joints contributed to the shortening of one 11 km (6.8 miles) pipeline by 6 m (20 ft).

A natural gas pipeline consisting of a welded steel pipe, 200 mm (8 in.) diameter crossed the main fault trace at roughly right angles to the strike. The pipeline suffered very little damage. Deformation of the pipeline was confined to gentle warping over a relatively wide fault zone.

Byron Site Comparison

The Edgecumbe event was selected for comparison primarily because wells of poorer construction quality in an unconsolidated loose soil were subjected to six earthquakes equal or greater than the Byron SSE within seven hours. Although the Edgecumbe wells were subjected to liquefaction and increased pore water pressure, they remained functional as will the Byron wells should the postulated earthquake occur at the site. The Edgecumbe area wells consisted of alluvial soil wells drilled into sands and gravels and backfilled with graded gravel. The Byron wells are established in more competent rock material and are cement grouted into their location and are not anticipated to be subjected to high interstitial hydrodynamic pressures or hydroseisms which could cause damage to the rock, pump, or casing.

Table 4-1
SL-4492
Page 1 of 5

Pertinent Data on Wells near Earthquake Epicenters

Earthquake	Owner	Well No.	Aquifer Type	Year Drilled	Dia. (in)	Depth (ft)	Casing & Joint Type	Post-Earthquake Condition
Byron Site Wells postulated SSE M_s 5.3 Page 3-1 of text	Commonwealth Edison	1 & 2	Ordovician-Cambrian aged dolomites and sandstones	1978	15/12	1500	ASTM A53 steel, 5/8" wall thickness welded joints grouted into rock.	Local municipal wells with similar construction and depths remained functional following the 1909 MM VII event.
San Fernando Valley M_s = 6.6 9 Feb 71 Page 4-1 of text	City of San Fernando	1	Unconsolidated sands and gravels stratified across the entire valley	1901	15	554	Riveted steel with riveted joints. Stovepipe, 2-plys, 8-gauge (.162") steel.	No damage. Ground raised 5 feet, well #2 remained functional. Ground rose 4.5 feet, well #3 functional. Bacteriological contamination treated. Pump shifted in well #5. No damage in zone of rupture. Casing of well #7 collapsed.
		2		1910	15	250		
		3		pre 1920	18	309.5		
		4		1926	16	483		
		5		1950	14	612		
		6		1955	18	300		
		7		1960	18	376		
	City of Los Angeles	1	Los Angeles basin soils. Unconsolidated sands and gravels with fine sands.	1924	24	195	Stovepipe 2-plys, 8-gauge (.162") steel pipe. Welded stovepipe steel casing.	Outside the zone of rupture, no damage reported to the well pumps or casing. No bacteriological contamination reported; therefore, no damage to the casing is inferred.
		2		1926	20	209		
		4		1931	16	63		
		5		1960	20	450		
		6		1961	20	504		

Earthquake	Owner	Well No.	Aquifer Type	Year Drilled	Dia. (in)	Depth (ft)	Casing & Joint Type	Post-Earthquake Condition
San Fernando Valley (continued)	Sunland Wells	Bernard	Tujunga Valley soil primarily sand and gravels	1924	12	238	Stovepipe 8-gauge (.162") 2-plys riveted joints.	Located 1 mile south of zone of surface rupturing. No problems reported.
		Fenwick		1929	16	290		
		Foot-hill 1		1938	18	467		
		Foot-hill 2		1940	16	470		
		Lang Muir		1949	24/18	312		
		Woodward		1950	24/18	400		
	County of Los Angeles	1	Quatnary gravel deposits with little or no fines	1937	14	405	Stovepipe 2-plys, 8-gauge (.162") 1/4" welded casing.	0.2g to 0.3g ground acceleration experienced 3 to 4-foot horizontal and 1-1/2-foot vertical movement. No damage to wells.
		2		1937	48	84		
		5		1949	12	600		
	Dexter Park	1		unknown	10/8	313		

Earthquake	Owner	Well No.	Aquifer Type	Year Drilled	Estim. Dia. (in)	Depth (ft)	Casing & Joint Type	Post-Earthquake Condition
Coalinga California M_s = 6.7 & 5.6 aftershock 3 May 83 Page 4-6 of text	Shell Oil Company Oil Wells	1000 wells	Western part of San Joaquin Valley consisting of weakly cemented alluvium with high proportion of gravel and cobbles	1941 to present	8/24			No subsurface damage was reported to oil wells casing; however, pumping jacks were toppled because of surface movement.
	Pleasant Valley Water Dist. Irrigation Wells	NE920		1952	14/12	618	Unknown	Wells located in zone of ground rupture. Pump head shaken out of alignment.
		NW1621		1964	16	1000	Stovepipe casing	Pump damaged casing damaged at 4 locations to . depth within the zone of rupture of 606 feet.
		NW721		1958	16/12	800	Stovepipe casing	Well casing collapsed; unable to repair, well abandoned.
		SE421		1964	16	1250	Stovepipe casing	Pumping sand well damaged.

Earthquake	Owner	Well No.	Aquifer Type	Year Drilled	Estim. Dia. (in)	Depth (ft)	Casing & Joint Type	Post-Earthquake Condition
Morgan Hill California M_s = 6.2 24 April 84 Page 4-7 of text	Santa Clara Valley Water District	2 pumps	Compacted sand and Coyote Dam	1975	4	140	Plastic	No damage reported after experiencing 1.29g horizontal acceleration pressure.
	Vasona Pump Station	4 pumps	Dense sand and gravel	N/A	Pipe 48	30	Welded steel	No damage report.
	United Technologies Chemical Division	N/A	Sand and gravel	1955				No well damage reports.
San Salvador, El Salvador M_s = 6.2 10 Oct 86 Page 4-10 of test	National Water Co. ANDA Pumping Plant		Ancient lava flows pumic soils, known locally as tierra blanca, or fine sandy silt	1925 thru 1972	18 to 24	150 to 500	Cast iron asbestos cement steel welded	Pumps and wells remained functional. Only one circa 1925 pump burned out following the restart after the earthquake.
Valparaiso Chile M_s = 7.8 3 Mar 85 Vertical acceleration 0.81g	Bata Shoe Factory	1	Terrace Alluvial sands and gravels	1961	6			Well was available for use, foundation slab had cracked.
	Llolleo Pumping plant	1-6	River Alluvium of Maipo River		24 & 16	160	Welded steel	Llolleo pump house structure had differential settle-

Earthquake	Owner	Well No.	Aquifer Type	Year Drilled	Estim. Dia. (in)	Depth (ft)	Casing & Joint Type	Post-Earthquake Condition
Page 4-9 of text	Concon Pumping		Unconsolidated Alluvium of Aconcague River	N/A	24	33	Welded steel	ment of 8 inches due to liquefaction of foundation soils. Pumps remained functional at both plants except where wall collapsed on Liolleo pumps.
Edgecumbe New Zealand $M_L = 6.3$ 2 Mar 87 Five aftershocks	Rangitaiki Drainage Board	35 wells	Interlayered marine sediment and volcanic tephara sand size	N/A	16	33	Welded steel	Pumping equipment for irrigation and land drainage remained functional.
$M_s > 5.2$ Page 4-12 of text	Otakiri Orchards	N/A		N/A	6	45	Welded steel	Irrigation wells changed flow characteristics, remained functional.

Section 5

ILLINOIS E RTHQUAKE WITHIN 100 MILES

The effects of an earthquake on groundwater wells as noted in the previous section depend on many factors that change with such variables as the earthquake mechanism, wave propagation, felt intensity, geologic setting, engineering characteristics of soil and rock, aquifer systems, and well construction. For this reason, the effects of earthquakes on groundwater wells near the Byron site have been examined in light of the regional seismicity, geologic setting, and methods of well construction at that particular location.

The states of Missouri and Illinois were surveyed in order to include the highly seismic New Madrid, Missouri area; the epicentral locations of the November 9, 1968, and September 15, 1972, earthquakes; and the Byron site area.

The records of the Illinois State Geological and Water Surveys were used because data are complete and reliable from before the turn of the century. These records show no reports of damage to municipal groundwater wells in the Byron site area due to earthquakes. This time interval includes four of the five most important earthquakes with an epicentral location within 100 miles of the Byron site; the 1909, Beloit, Intensity VII; the 1912, northeastern Illinois, Intensity VI; the 1934, Rock Island, Intensity VI; and the 1972, northern Illinois, Intensity VI.

Available publications on recent earthquakes with epicentral locations in Illinois, November 9, 1968, in southern Illinois and September 15, 1972, in northern Illinois (References 17 and 18), provide the most-thorough records of the effects of earthquakes in Illinois. The publication on the 1968 earthquake included reports of cracked casing in an old, plugged gas well, increased productivity in several oil wells, increased turbidity of the groundwater, and a broken plastic nipple on an elbow coming off a well head. These reports generally covered an area within 50 miles of the epicentral location. The actual study of earthquake effects included a field reconnaisance within 100 miles of the epicentral location, letters of inquiry mailed throughout southern and central Illinois, and a review of newspaper accounts in Illinois and neighboring states. There were no effects of the 1972 (Reference 19) earthquake on groundwater wells in Illinois reported during a field reconnaisance, letter survey, and review of newspaper accounts.

Attached as Appendix A are records of wells dug in the vicinity of the Byron site. It is interesting to note from these records the following dates and depths of well construction when compared with dates of earthquakes within 100 miles of the Byron site.

Location	Depth	Date Dug	Flow
City of Byron Well #1	2000 ft	1900	100 gpm
City of Byron Well #2	673 ft	1929	300 gpm
City of Byron Well #3	715 ft	1969	975 gpm
City of Oregon Well #1	1690 ft	1897	450 gpm
City of Oregon Well #2	1200 ft	1948	736 gpm
City of Rochelle Well #1	1896 ft	1897	500 gpm
City of Rochelle Well #2	1026 ft	1907	250 gpm
City of Rochelle Well #3	1484 ft	1923	600 gpm
City of Rochelle Well #4	1450 ft	1929	660 gpm
Village of Stillman Valley	300 ft	1938	200 gpm

These wells are still in service, and there has been no known damage or impairment of pumpage of municipal groundwater wells in the Byron area as a result of any earthquake during the past 90 years or more. Reported effects on groundwater wells in these areas have included insignificant groundwater level fluctuations and temporary increases in turbidity of the groundwater; however, neither of these effects have damaged the wells or impaired pumpage.

Many data on the performance of deep dolomite sandstone wells in northern Illinois have been collected by the State Water Survey. The results of well production tests made on several hundred wells provide important information about the influence that location, depth, construction features, and age of a well have on its yield. Survey records indicate that deep sandstone wells such as the Byron deep wells have been prolific sources of water for nearly 100 years.

Section 6

WELL-AQUIFER RESPONSE TO SEISMIC WAVES

The response of well systems from seismic waves may be generally grouped into two classes, namely, faulting and shaking. Faulting includes the direct, primary shearing displacement of bedrock that may carry through the overburden to the ground surface. Such direct shearing of the rock or soil is limited to relatively narrow zones of seismically active faults that may be identified by geologic and seismological surveys. No active faults have been identified within 200 miles of the Byron site, and through previous comprehensive investigations the soil and rock of the site has been shown not to lose their integrity during an earthquake. Therefore, the response of the well system is limited to the general case of shaking. Underground shaking of a well casing and pump may respond to the various waves propagating through the surrounding soil. A rigorous dynamic analysis of the system response is described in Section 7. The following paragraphs provide observations of the seismic response of well water levels and the variation of acceleration with depth in deep wells.

In general, earthquakes have been reported to have affected groundwater wells in a variety of ways. The following have been observed: fluctuations of groundwater levels, increased turbidity of groundwater; extrusion of sand, mud, and water from alluvial wells; changes in productivity of wells; failure of the well system; and failure of associated structures. As a result of groundwater fluctuations, the U.S. Geological Survey (USGS) prediction experiment at Parkfield, California, along the San Andreas fault regularly monitors a network of water wells. This network consists of wells that are situated at seven sites that were drilled by the USGS for the express purpose of monitoring water levels. R. Vorhis (Reference 20) assembled data on 1450 wells in North America, along with other wells from around the world which had a response to the Alaskan Earthquake of 1964.

ALASKA EARTHQUAKE

Description of Event

The Alaska earthquake of 1964 was centered in Prince William Sound. The land vibrated for as long as six minutes from the main shock which had a magnitude $M_L = 8.4$. During the main shock and following aftershocks, more than 40,000 mi^2 of land was lowered as much as eight feet and more than 25,000 mi^2 was raised as much as 33 ft (Reference 20). The extent of the hydrologic effects was felt as far away as South Africa (Reference 20). Published reports (Reference 20) describing the conditions of 100 water wells during the intensity XI earthquake indicate that seven wells were destroyed because of earth displacement, and five failed due to liquefaction and sanding of the well.

In Illinois, a total of 21 hydroseisms were reported from local wells as a result of the Alaska earthquake. Only two aftershocks were recorded, and both were registered in well DuPage ANL-10.

Seismic seiches were recorded in Illinois at two lake stations: Wolf Lake at Chicago and Money Creek at Lake Bloomington. A well in Cook County (37N 14E-22.1b) from an uncased portion of the well which taps a Cambro-Ordovician sandstone has a depth of 1648 ft reportedly pumped sand following the earthquake, and two wells in Union County reportedly yielded muddy water after the event (Reference 20).

The response of water wells especially certain artesian wells which are in totally confined aquifers is remarkably great and is reported in Reference 21.

The mechanics of the volume change and corresponding water level change are described by Cooper (Reference 21) with the passage of seismically induced Rayliegh waves at the 8-to-30 second-period range. The requirements for a well to experience wide fluctuations in water level are a confined aquifer (artesian conditions), a highly permeable aquifer in which water readily moves in and out of the well, and a major earthquake energy.

Based upon these criteria and the mass of the water column at the Byron well, it has been estimated that the well would behave as an overdamped well and the water level oscillation would not occur; therefore, well or pump damage would not occur. A well located at and monitored continuously by the Illinois Geological Survey has experienced some water level change during major earthquakes. The well, located in the NE corner of Clark County, is used as a waste injection well with the fluids injected into a confined aquifer. The well is located in different geologic formations than the Byron site and responds to many distant large earthquakes without damage to the well system due to water level fluctuations.

Interestingly, the Illinois State Water Survey has no record of groundwater fluctuations in any observation well equipped with continuous recorders in response to any earthquake which had an epicentral location in Illinois. These observation wells equipped with continuous recorders are located in northeastern Illinois, the Champaign-Urbana area, Clark County, and the East St. Louis area.

TANG-SHAN EARTHQUAKE

Description of Event

The July 28, 1976, $M_s = 7.8$ earthquake in the People's Republic of China was most notable for determining how a strong earthquake affects underground facilities. In the area of Tang-Shan where the strongest shaking Intensity X and XI occurred, 80% to 90% of the surface structures collapsed (Reference 22). However, for the important engineered structures immediately below the surface, there was generally no serious damage regardless of the depth or size of the structure. It was reported that because underground structures are located within, and restrained by, rock or soil, damage is different from that to surface structures, and from measured response, it was found that earthquake damage decreased with increasing depth.

The Chinese National Earthquake Bureau (CNEB) installed seismographs in an inclined shaft through limestone bedrock into the 2100 ft deep Tang Shan coal mine following the main earthquake and recorded 80 aftershocks of varying magnitude. The results of the analysis of recorded ground motion were as follows from Reference 22:

- P-wave (compression) amplitudes at 25 m (80 ft) depth were about 50% to 80% of those at the surface;
- S-wave (shear) amplitudes at 25 m (80 ft) depth ranged from 60% to 120% of the surface values;
- the subsurface to surface P-wave and S-wave amplitudes at 83 m (270 ft) depth were 30% to 40% and 20% to 80%, respectively.

CNEB analysis of these records indicate that the ground displacement at 25 m (80 ft) depth is one-half the displacement at the surface and at 83 m (270 ft) is one-third the displacement at the surface.

It was also reported in the same paper that there was extensive damage to the shallow water supply wells and near surface underground piping. Damage was caused by sand liquefaction, infiltration into the wells, and separation of the bell and spigot piping joints due to the strong motion. The Bryon wells are founded in competent rock and the water piping has welded steel joints, therefore, they would not be subject to the types of failures occurring at Tang-Shan.

Section 7

SEISMIC ANALYSIS

This section presents the seismic analyses of the deep well system and evaluates the operation of the wells during and after the postulated safe shutdown earthquake. Exhibit ES-1 schematically shows the deep well system. It consists of a 1500-foot-deep borehole in competent rock formations. The top 700 feet of the borehole is cased with a 16-inch-diameter steel pipe. An eight-inch-diameter discharge pipe hangs within the cased portion of the well; it also supports the motor and the pump at its lower end. The length of the discharge pipe within the well is about 425 feet. The discharge pipe from the pump shelter structure to the station is also eight inches in diameter. This portion of the discharge pipe is buried in the same trench in which the safety-related essential service water pipeline is buried. There is also a buried reinforced concrete ductrun for the electrical cables from the station to the pump shelter structure. Each of these items is evaluated for the safe operation of the deep well system. The items include:

- Uncased well cavity
- 16-inch-diameter steel pipe casing
- 8-inch-diameter discharge pipe within the casing
- Motor and pump
- 8-inch-diameter buried discharge pipe between pump shelter structure and the station
- Buried reinforced concrete ductrun
- Pump shelter structure

UNCASED WELL CAVITY

The 15"-12" diameter uncased portion of the borehole runs through a competent rock strata which consists of Cambrian through Orodovician aged dolomites and sandstones. The measured average ultimate strength of Orodovician dolomite was 16,834 psi and of the sandstone was 10,050 psi. Also, information gathered from deep gas storage projects in Illinois indicates that the ultimate compressive strength of Ironton-Galesville Sandstone is in excess of 16,000 psi. Based on these data, an ultimate compressive strength of 10,000 psi and tensile strength of 1,000 psi are conservatively used in the seismic evaluation of the uncased cavity.

The state of strain and stress is determined in the rock formation during the postulated SSE and is then compared with the strength of the rock. The procedure given in Reference 23 is used to determine the state of stress in rock. The procedure is a simplified approach based on expressions derived by Newmark (Reference 24). It is considered conservative and is commonly used for buried structures. In the procedure, the maximum strain in the soil or rock is determined due to the passage of the seismic compression and shear waves. The direction of the particular wave propagation is selected to produce maximum strain in the structural element under consideration.

Maximum Strain and Stress due to Compression Waves

The maximum axial strain ε_a is given by:

$$\varepsilon_a = \pm \frac{v}{C_p}$$

Where v is the maximum particle velocity and C_p is the apparent wave velocity, which is the same as the compression wave velocity in the rock. Based on earthquake records, the maximum particle acceleration a, the particle velocity v and the particle displacement d are related by the following equation (Reference 24):

$$\frac{ad}{v^2} = 5 \text{ to } 15$$

In the above equation, $ad/v^2 = 5$ is used to conservatively derive the maximum particle velocity and thus yield a conservative large strain in the rock.

The above equation is based on data recorded at the ground surface. However, as discussed in Section 6 describing the Tang-Shan earthquake it has been observed that particle vibration amplitudes generally decrease as the depth increases (References 25 and 26). Hence, the use of the particle velocity corresponding to the ground surface is conservative.

The peak particle velocity corresponding to 0.20 g ground acceleration is 0.88 foot/sec (d = 0.6 ft per RG = 1.60).

The compression wave velocity for dolomite and sandstone is 18,300 feet/sec (Exhibit 7-1). Hence, the maximum strain in the rock is:

$$\epsilon_a = \pm \frac{.88}{18,300} = \pm 4.80 \times 10^{-5}$$

Maximum tensile stress = E ϵ_a
where the modulus of elasticity of the rock is given by:

$$E = \rho C_p^2 = \frac{.155}{32.2} (18,300)^2 \quad (\rho = \text{mass density})$$
$$= 1.61205 \times 10^6 \text{ ksf}$$

Maximum tensile stress: $= 1.61205 \times 10^6 \times 4.80 \times 10^{-5}$
$= 77.5$ k/sq ft
$= 538$ psi

Maximum Strain and Stress Due to Shear Waves

The maximum axial strain is given by:

$$\epsilon_a = \pm \frac{V}{2C_s}$$

Where C_s is the shear wave velocity.

Since, the shear wave velocity for the rock stratum under consideration is 9,500 feet per second which is greater than half the compression wave velocity, the compression wave velocity gives the larger strain in the rock at the cavity surface.

The above evaluation shows that the maximum tensile stress during SSE in the rock at the well cavity is 538 ksi as compared to the rock's tensile strength of 1,000 psi. Hence, the rock at the cavity surface will not scab or chip during the postulated SSE.

16-INCH-DIAMETER STEEL PIPE CASING

The casing is made of ASTM A53 Grade B steel pipe of outer diameter of 16.0" and wall thickness of 3/8". After the casing was put in place, the gap between the rock and casing was grouted with cement grout. Hence, during an earthquake, the relative motion of the casing is the same as the surrounding rock.

The lowest compression wave velocity and shear wave velocity in the upper layer of the rock formation are:

C_c = 7,500 ft/sec
C_s = 2,900 ft/sec

Maximum Strain and Stress Due to Compression Waves

Axial Strain $\varepsilon_a = \pm \frac{V}{C_p} = \pm \frac{.88}{7,500} = 1.17 \times 10^{-4}$

Bending Strain $\varepsilon_b = \frac{.385R\ a}{(C_p)^2}$

where R is the radius of the pipe and a is the particle acceleration. Hence,

$$\epsilon_b = .385 \times \frac{8.0}{12} \times \frac{6.44}{(7500)^2} = 2.94 \times 10^{-8}$$ (Negligible as compared to axial strain)

∴ Maximum axial stress $= 29{,}000 \times 1.17 \times 10^{-4}$

$= 3.4$ ksi

Maximum Strain and Stress Due to Shear Waves

$$\epsilon_a = \pm \frac{V}{2C_s} = \frac{.88}{2 \times 2{,}900} = 1.51 \times 10^{-4}$$

As shown previously, the maximum bending strain will be negligible as compared to the axial strain.

Maximum axial stress $= 29{,}000 \times 1.51 \times 10^{-4} = 4.4$ ksi

Hence, the maximum axial stress in the casing is 4.4 ksi as compared to the ASME allowable stress of 22.5 ksi (1.5 x 15 ksi). This gives a margin of safety of about 5.

8-INCH-DIAMETER DISCHARGE PIPE WITHIN THE CASING

The discharge pipe with the motor and pump attached to its lower end is supported by the well casing through a head fitting at the ground elevation. Part of the vertical hanging discharge pipe is submerged in water. This will cause hydrodynamic coupling between the discharge pipe (also the pump and motor) and the casing. This hydrodynamic coupling effect is taken into account by using the method developed by Fritz (Reference 27). The fluid reaction forces F_{f1} and F_{f2}, respectively, on the discharge pipe and the casing are given by:

$$F_{f1} = -M_H \ddot{x}_1 + (M_1 + M_H) \ddot{x}_2$$

$$F_{f2} = (M_1 + M_H)\ \ddot{x}_1 - (M_1 + M_2 + M_H)\ \ddot{x}_2$$

where M_1 = mass of water displaced by the discharge pipe as a solid

M_2 = mass of water that can fill the casing in the absence of the discharge pipe

$$M_H = M_1 \frac{b^2 + a^2}{b^2 - a^2}$$

where b is the inner radius of the casing and a is the outer radius of the discharge pipe.

$\ddot{x}_1$ and $\ddot{x}_2$ are the horizontal accelerations of the discharge pipe and the casing, respectively.

In the analysis, the effect of the above hydrodynamic forces is taken into account in addition to the inertial forces on the discharge pipe.

The analytical model for the system is shown in Exhibit 7-2. The discharge pipe is modeled by beam elements and the gaps between the discharge pipe (also the pump and motor) and the casing are modeled by nonlinear gap elements. Two cases have been considered in the analysis. One, earthquake occurs when the pump is not operating, and the second earthquake occurs when the pump is operating. In the first case, the 8-inch-diameter pipe does not have water in it up to a depth of 250' below ground. In the second case when the pump is operating, there is a drawdown of water in the well to a depth of 375 feet below the ground level and there is water in the discharge pipe. A nonlinear time-history analysis is performed using Sargent & Lundy NONLIN-2 program. The acceleration time-history used in the analysis is the same that was developed for the Byron Station and corresponds to the site safe shutdown earthquake response spectra. In the analysis, a 2% damping for the pipe has been used (RG 1.61).

Pipe Material and Geometry

Material. SA-106 Grade B carbon steel pipe
$F_y = 35$ ksi, $F_u = 60$ ksi

Geometry. 8"Ø schedule 40 pipe wall thickness = 0.322"
OD = 8.625"

Loads

Dead Load (DL) = 14.53 kips (Pump not operating)
Dead Load (DL) = 23.71 Kips (Pump operating)
Maximum Downthrust (DT) = 16.7 kips
Design Pressure (P) = 225 psi
Maximum Upthrust (UT) = 10 kips

Forces

Seismic Loads	Pump Not Operating	Pump Operating
Due to horizontal seismic (S_h)		
Maximum moment	11.83 Kft	16.25 Kft
Maximum shear	0.82 K	1.13 K
Due to vertical seismic (S_v)		
Axial force	11.77 K	19.2 K

Stresses and Allowables

Load Combination	Stress Pump Not Operating	Stress Pump Operating	Allowable Stress	Margin
Level A				
DL + (DT, UT or P)	3.72 ksi	4.16 ksi	15.0 ksi	3.6

Load Combination	Stress Pump Not Operating	 Pump Operating	Allowable Stress	Margin
Level C				
$DL + P + S_h + S_v$				
Membrane	3.13 ksi	6.44 ksi	22.5 ksi	3.5
Membrane + Bending*	10.73 ksi	16.67 ksi	27.0 ksi	1.6

(*$1.0\ S_h + 0.4\ S_v$ for simultaneous component of earthquake)

The above analysis shows that the stresses induced in the discharge pipe during safe shutdown earthquake are well within the code allowables.

MOTOR AND PUMP

The dynamic analysis performed for the discharge pipe with the pump and motor attached to its lower end shows that maximum stress in the 8-inch-diameter pipe is 16.67 ksi. Since the pump and motor are structurally rigid and of rugged construction, stresses in these components will be less than the pipe stresses during the safe shutdown earthquake. Also the experience with wells, discussed in the literature review section, shows that there was no failure of the pump or motor itself, even during much stronger earthquake events than the Byron SSE. Hence, the pumps and motor should perform well during and after the postulated safe shutdown earthquake.

8-INCH-DIAMETER BURIED DISCHARGE PIPE BETWEEN PUMP SHELTER STRUCTURE AND THE STATION

As mentioned before, the discharge pipe is buried in the trench which also has the seismic safety-related essential service water pipe. Exhibit 7-3 shows a typical section of the trench. The pipe is buried about 6 feet below the ground surface.

The seismic strains and stresses in the pipe are calculated using the procedure given in Reference 23 (similar to one described for 16-inch-diameter steel pipe casing).

The loads acting on the buried pipe are:

- Internal pressure, P (225 psi);
- Soil overburden and surcharge load, Lg;
- Thermal load, T_o ($\Delta T = 70° - 45° = 25°F$); and
- Seismic load, E_s.

For seismic stresses, a conservative, apparent wave velocity of 3000 feet/sec has been used for both shear and compression waves (Reference 23).

Pipe Material and Geometry

The pipe material and geometry are the same as the discharge pipe within the well casing.

Stresses and Allowables

Load Combination	Stress	Allowable	Margin
$1.0\ Lg + 1.0\ T_o + P + 1.0\ E_s$			
Membrane	13.95 ksi	22.5 ksi	1.6
Membrane and Bending	18.83 ksi	27.0 ksi	1.4

The above analysis shows that the stresses induced in the pipe during the safe shutdown earthquake are well below the code allowables.

BURIED REINFORCED CONCRETE DUCTRUN

Exhibit 7-4 shows a typical cross section of the ductrun with its reinforcements and conduits. The major loads on the ductrun are the seismic loads and the thermal load. The thermal stresses are calculated assuming an installation temperature of 70°F and a winter temperature of 45°F (a temperature drop of 25°F). The seismic loads are calculated using the same procedure as for the buried discharge pipe (as given in Reference 23).

Stresses in the Longitudinal Reinforcement

Stress due to temperature drop	= 4.71 ksi
Stress due to SSE	= 7.78 ksi
Total stress	= 12.49 ksi
Allowable	= .95 F_y = 57 ksi

Hence, the ductrun has a large safety margin against the safe shutdown earthquake.

PUMP SHELTER STRUCTURE

This is a small reinforced concrete box-like structure which houses the wellhead fittings, the junction box, and cables connected to the wellhead. The structure is already designed for tornado loads. For seismic evaluation of the structure, the seismic loads are compared with the corresponding tornado pressure loads, and it is concluded that the seismic loads are much smaller than the tornado loads.

The frequency calculation for the wall and roof of the structure shows that the structure is very rigid (frequencies greater than 33 Hz). Hence, peak ground acceleration of 0.2 g was applied to determine the horizontal and vertical seismic load.

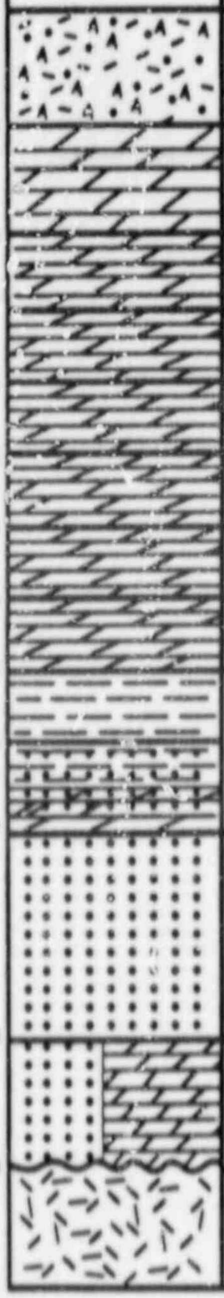
The 20-inch-thick walls are designed for a tornado wind pressure of 265 lb/ft^2. The 14-inch-thick roof slab is designed for a tornado wind pressure of 216 lb/ft^2. The equivalent accelerations corresponding to these loads are 1.06 g for the wall and 1.23 g for the roof, as compared to the peak seismic acceleration of 0.2 g. Hence, the pump shelter structure has a large safety margin against the safe shutdown earthquake.

SARGENT & LUNDY

Typical Geologic Profile Showing Geophysical Properties

Exhibit 7-1
SL-4492

(Figure 2.5-26 from Byron FSAR)

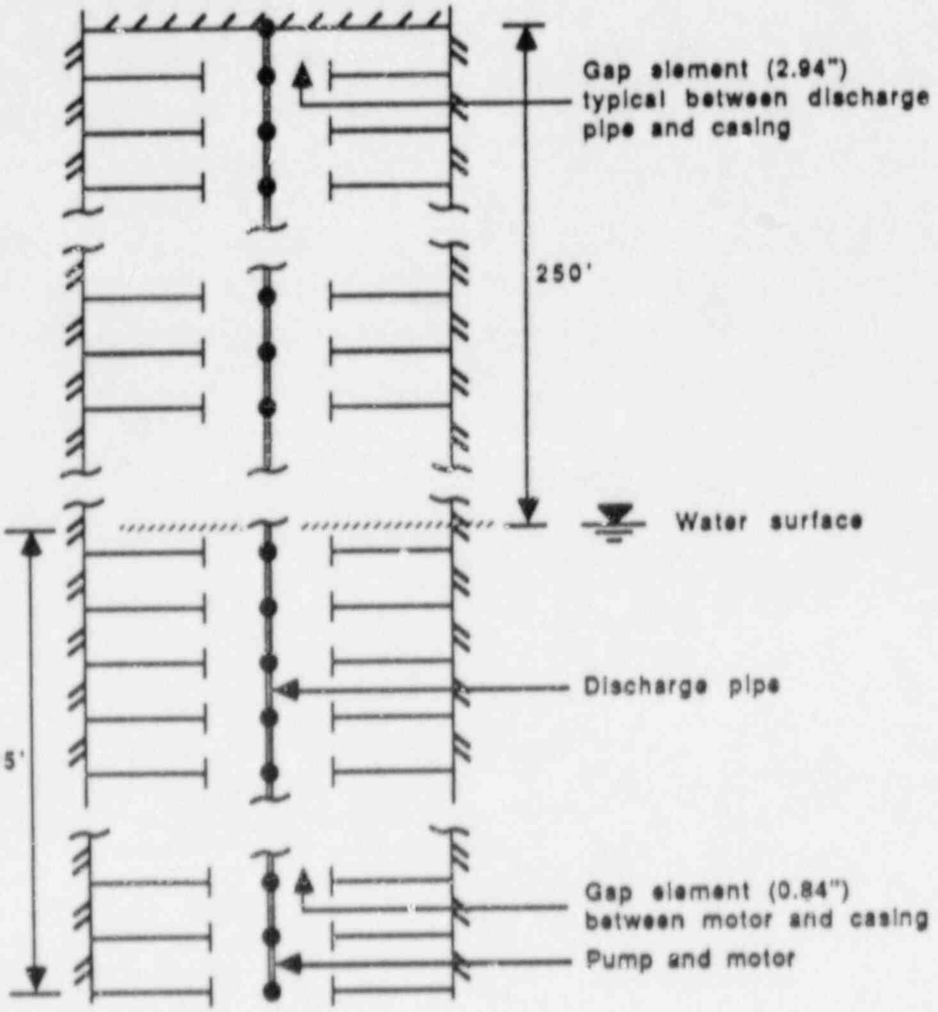
Depth in feet (not to scale)	Graphic Column	Unit Description	Compressional Wave Velocity (ft/sec)	Poissons Ratio	Shear Wave Velocity (ft/sec)	Unit Weight (lb/ft^3)
0		Overburden	1,000-2,200	(0.44)	(330)	110-130
15		Dunleith Dolomite	7,500-11,000	0.37-0.41	2,900-3,500	147-164
90		Guttenberg Dolomite	12,000-15,250	0.33-0.41	4,500-6,000	150-157
95		Quimbys Mill Dolomite				156-166
103		Nachusa Dolomite	15,000	0.19-0.23	9,500	162-168
125		Grand Detour Dolomite				156-177
163		Mifflin Dolomite				165-168
180		Pecatonica Dolomite				146-160
202		Glenwood Formation Harmony Hill Shale				116-129
205		Daysville Dolomite and Sandstone				155-167
227		St. Peter Sandstone	(15,000)	(0.19-0.23)	(9,500)	130-132
470		Cambrian through Ordovician Dolomite and Sandstone	(18,300)	(0.22)	(11,000)	(152-159)
2500		Precambrian Metamorphic and Igneous Basement Rocks	(19,000)	(0.18)	(12,000)	(162)

M2263.003 09-88

Note: Values in parentheses are estimated.

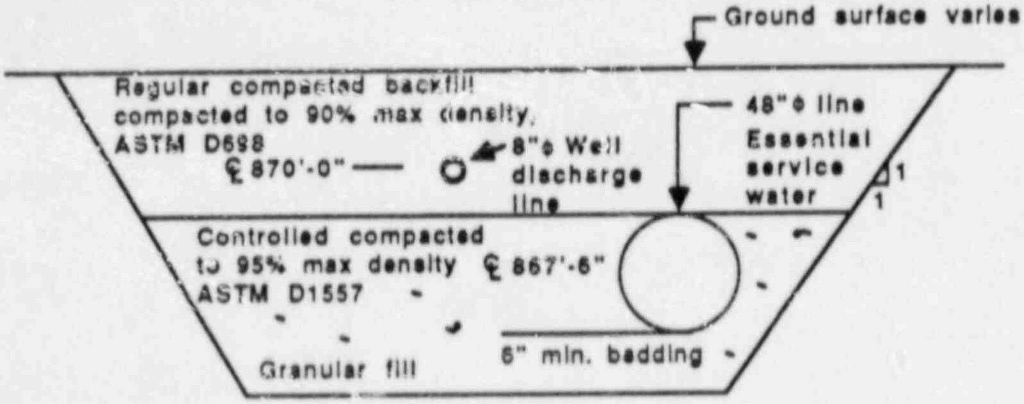
Analytical Model for the Discharge Pipe in the Casing

Exhibit 7-2
SL-4492



Circulating Makeup and Blowdown Piping—Typical Excavation and Backfill

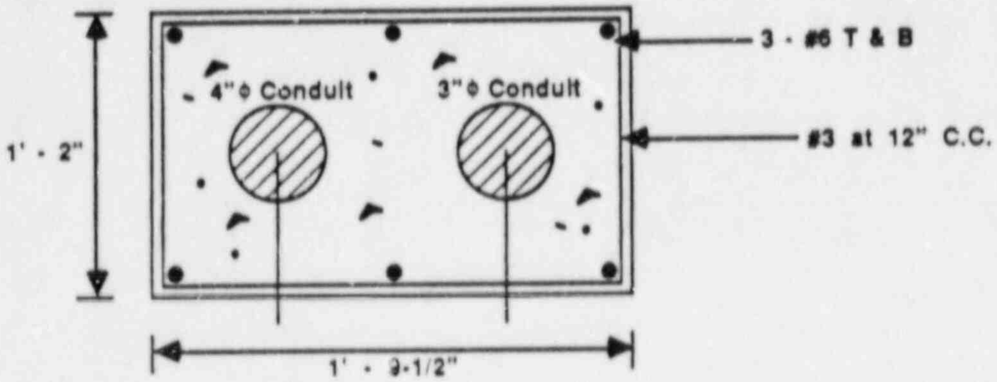
Exhibit 7-3
SL-4492



SARGENT & LUNDY

Typical Cross Section of the
Reinforced Concrete Ductrun

Exhibit 7-4
SL-4492



Section 8

CONCLUSIONS

The deep well system is one of two makeup sources for the Ultimate Heat Sink at the Byron Station. The ongoing drought has caused the level in the Rock River to drop below the limit specified in the limiting condition for operation of the Ultimate Heat Sink technical specification. That limit is 670.6 feet Mean Sea Level (MSL). As a result, Byron Station has entered technical specification action requirement 3.7.5e. This action requirement permits reactor operation to continue for an unlimited period of time as long as river flow remains greater than 700 cubic feet per second (cfs) and river level remains above 664.7 feet MSL. River flow must be verified every 12 hours under these conditions until the level exceeds 670.6 feet MSL.

In order to relieve or mitigate these operational restrictions, an examination of the deep wells' seismic response has been completed. The methodology of examination consisted of two parts: first, a literature review and second, an analytical evaluation of the well system when subjected to the maximum site seismicity.

EVALUATION BASED UPON LITERATURE REVIEW

In general, earthquakes have been reported in the literature to have affected groundwater levels in a variety of ways, most extensively by extrusion of sand, mud, and water from alluvial wells; fluctuations of groundwater levels; increased turbidity of groundwater; changes in productivity of wells in jointed rock; failure of alluvial wells due to silting of the pump column or due to differential movement of the well casing and the surrounding alluvial deposits; and, damage to or failure of associated pumping equipment (Reference 2).

The reported effects vary with a wide range of site-dependent parameters, such as the type of well construction; the geologic setting, the engineering characteristics of the soil and/or rock, and the felt ground motions. Six worldwide earthquakes have been described which illustrate the ways in which earthquakes may affect wells and their associated piping. Each earthquake selected for direct comparison produced magnitudes of strong motion which were 10 and as much as 150 times stronger than the postulated Byron SSE.

The selected earthquakes and reason for selection are as follows:

- **San Fernando Valley M_S = 6.6**

  Minor damage to cased alluvial wells in a high seismic area.

- **Coalinga M_S = 6.2**

  Very high (0.4 to 0.6 g) peak ground accelerations in an area of major oil field wells. Variable damage to wells of different construction.

- **Morgan Hill M_S = 6.2**

  Two simultaneous earthquakes affecting well-engineered buildings and water supply district facilities including wells, pumps, and reservoirs.

- **Chile M_S = 7.8**

  Two simultaneous earthquakes producing 120 seconds of strung motion with the effects of vertical peak ground accelerations of 0.8 g on wells of a water supply pumping station.

- **San Salvador M_S = 6.0**

  Repeated destructive earthquakes over a long time period (60 years) indicate well reliability when cased into foundation materials.

- **Edgecumbe M_S = 6.3**

  Six magnitude $M_S \geq 5.2$ earthquakes occurred within 7 hours and caused extensive liquefaction around alluvial wells and associated piping. Demonstrates variable effects of ground failure on wells.

- **Illinois Wells**

  Describes wells in the site area which have been in operation since the late 1800s and which have withstood local seismological events.

The Byron groundwater wells were constructed in accordance with AWWA standards of practice A 100-66 and, are cased with ASTM A53 steel casing through the soil and rock to a depth of 700 feet. Individual lengths of well casing were welded together when installed. The annular spaces between the boreholes and the well casings were grouted with concrete grout from the bottom upward in order to seat the casings into the bedrock and to provide seals preventing the movement of soil or surface contaminants into the wells. The production portion of the wells consisted of uncased, open borehole in the Ironton-Galesville and upper portion of the Mt. Simon sandstone, which have been reported as prolific sources of water for nearly 100 years by the Illinois Water Survey. The wells were overpumped after completion to remove any loose rock or drill cuttings. Subsequent pumping tests demonstrated the water yield for the Essential Service Cooling Tower makeup. The AWWA type of well construction, with the length of casing welded together and seated into the bedrock, provides the maximum strength for a groundwater well. Municipal or large-volume industrial wells in northern Illinois are generally of similar or lesser construction.

As noted in the literature review data presented, two conclusions may be drawn. First, worldwide experience indicates that deep, well-constructed, cased wells, either in alluvial soils or rock, have withstood a wide range of earthquake ground motions provided that the wells are not subjected to fault displacements, ground separation, landslide shear, or lateral spreading of liquefied soils. Based upon the extensive geologic and seismological investigations of the site, no active faulting has been found within 200 miles, therefore, fault shears and ground separations will not occur. Second, groundwater wells in Illinois of similar or lower quality construction than the Byron wells have experienced no impairment of production resulting from ground motions associated with earthquakes, and in particular, local events such as the November 9, 1968, earthquake in southern Illinois (epicentral Intensity VII) and the September 15, 1972, earthquake in northern Illinois (epicentral Intensity VI). Felt intensities in the vicinity of the Byron site for these earthquakes were Intensities IV and V at Byron. It is therefore concluded from the literature review that the deep wells at the Byron station would experience no damage or impairment of production as a result of felt ground motions of intensity VIII or less.

Well-Aquifer Response to Seismic Waves

Two additional earthquakes were researched to demonstrate the response of wells to earthquake motion. From the Tang-Shan, M_s = 7.8 event, measurements indicate that seismic displacements decrease with depth below the ground surface. Thus, the analyses of the Byron wells discussed in Section 7 which are based on acceleration at the ground surface, are conservative.

The Alaska, M_s = 8.4 earthquake was reviewed to demonstrate the effect of a great earthquake on water levels in distant wells. In addition, the U.S. Geological Survey prediction experiment at Packfield, California has a program that monitors water levels in water wells in an effort to predict earthquakes. A comparison of the Byron well conditions and the criteria used in the Parkfield experiment indicates that significant water level fluctuations caused by an earthquake would not occur in the Byron wells, therefore, well production would not be affected by such fluctuations.

EVALUATION BASED UPON DYNAMIC ANALYSES

Seismic analyses of the components of the deep well system have been performed based on technically conservative and acceptable procedures generally used for similar seismic safety-related components in the nuclear power industry. The items analyzed are: the uncased borehole cavity, the well casing, the discharge pipe within the casing, the motor and the pump, the buried discharge pipe between the pump shelter structure and the station, the buried concrete ductrun, and the pump shelter structure. The results of the analyses show that strains and stresses induced in these components, during the safe shutdown earthquake (including the other normal loads) are well within the corresponding allowables.

Based on both the literature review and the dynamic analysis, it is concluded that the deep well system at the Byron Station is seismically qualified for the safe shutdown earthquake and will remain functional after the postulated earthquake event.

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Section 9

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Appendix A

Well Records

OREGON
Ogle County
Mar. 18, 1948

The city of Oregon (2825) installed a public water supply in 1886.

Originally, water for fire protection was obtained from a shallow well. In 1897, the well was deepened to 1690 ft. This well is located close to the bank of the Rock River in the northeast part of town, near the intersection of 3rd and Illinois St. (or approximately 2300 ft. S. and 1500 ft. E. of the N.W. corner of Section 3, T. 23 N., R. 10 E.). The surface elevation is 672± ft. This well is 10 in. in diameter.

Originally, water flowed from the well into an excavated stone-curbed reservoir surrounding the well. In 1931, the reservoir was abandoned, and the well casing sealed. The suction side of each of the 2 Gould triplex pumps, which previously had pumped water from the reservoir, was connected to the well.

In Sept. 1947, the suction pumps were replaced by the existing pumping equipment: 90 ft. of 6-in. column pipe; 15-stage Fairbanks-Morse Pomona turbine, water lubricated pump, No. SH1260; the overall length of the pump is 10 ft.; 10 ft. of 6-in. suction pipe; 100 ft. of air line; 40-hp., 1745 rpm. General Electric motor, No. 5309746.

When the turbine was installed, water was pumped for 24 hr. at a rate of 450 gpm. On Dec. 2, 1947, the non-pumping water level was reported to be 5 ft. below the top of the well and when pumping at 466 gpm., the drawdown was 60 ft.

Analysis of a sample (Lab. No. 112,800) collected Dec. 2, 1947 after 1-hr. pumping at 466 gpm., showed this water to have a hardness of 17.0 gr. per gal., a residue of 286 ppm., and an iron content of 0.3 ppm.

The reservoir around the top of the well has been filled in and a pump house built over the well. The Gould pumps have not been removed from the pump house located 20 ft. south of the well, but the pumps are disconnected from the well.

Well No. 2 was completed at a depth of 1200 ft. in July, 1948 by Neely and Schimelpfenig, Batavia, and located 150 ft. east of Third St. and 150 ft. south of Franklin St. (or approximately 930 ft. S. and 1600 ft. E. of the N. W. corner of Section 3). The ground elevation is 707± ft.

Sample-study log of Well No. 2 furnished by the State Geological Survey:

Formation	Thickness ft.	Depth ft.
Pleistocene system		
"Clay, sandy"	12	12
"Gravel"	131	143
Granule gravel, clean	3	146
Ordovician system		
St. Peter sandstone, chert and clay	26	172
Cambrian system		
Trempealeau dolomite	100	272
Franconia sandstone, some dolomite	88	360
Galesville sandstone		
Sandstone, partly dolomitic	60	420
Sandstone, incoherent	73	493
Eau Claire shale and thin sandstone	447	940
Mt. Simon sandstone	260	1200

The hole and casing record is shown in Table 1.

TABLE 1

Hole Record

12 3/4-in. to 1200 ft.

Casing Record

20-in. od. from +1.0 to 145 ft.
below surface.
14-in. od. from +1.0 to 358 ft.
19-in. od. from 133 to 181 ft.

When the drilling had reached 962 ft. a production test was made by the State Water Survey on Apr. 23, 1948, using the following equipment for test purposes: 200 ft. of 7-in. id. column pipe; 11-stage turbine pump having an overall length of 12 ft.; 200 ft. of 1/4-in. air line; electric motor.

Before the test the water level was 31 ft. from the top of the 20-in. casing. After 3-hr. pumping at 385 gpm., the drawdown was 71 ft. and after an additional 7-hr. pumping at a final rate of 735 gpm., the drawdown was 149 ft. Thirty min. after stopping the pump, the water level was 53 ft. and 11 hr. later the water level as 34 ft.

Partial analysis of a sample (Lab. No. 15,403) collected July 16, 1948 after 5 1/4-hr. umping at 640 gpm., showed this water to have a hardness of 17.2 gr. per gal., a residue of 320 ppm., and an iron content of 1.1 ppm.

Pumpage is estimated to average 265,000 gpd.

LABORATORY NO. 112,800

		ppm.	epm.			ppm.	epm.
Iron (total)	Fe	0.3		Silica	SiO_2	11.9	
Manganese	Mn	0.0		Fluoride	F	2.0	
Calcium	Ca	60.0	3.00	Chloride	Cl	6.0	0.17
Magnesium	Mg	34.5	2.84	Nitrate	NO_3	Tr.	Tr.
Ammonium	NH_4	0.1	0.01	Sulfate	SO_4	15.2	0.32
Sodium	Na	0.0	0.00	Alkalinity	(as $CaCO_3$)	268.	5.36
Turbidity		Tr.		Hardness	(as $CaCO_3$)	292.	5.84
Color		0		Residue		286.	
Odor		Tr.		Temperature 57.3° F.			

ROCHELLE
Ogle County
Dec. 4, 1947

The city of Rochelle (4200) established a municipal water supply about 1876.

Water was first pumped from an old stone quarry near the south end of town by 2 duplex pumps.

About 1897, Well No. 1 was drilled to a depth of 1896 ft. by F. M. Gray, Chicago, and located near the quarry, on the west side of Eighth St. between Ave. "A" and Ave. "B", about 1000 ft. southwest of the pump station. The quarry supply was abandoned. The well is 8 in. in diameter at the top and was reported to be cased to about 70 ft. The well was abandoned about 1907 but was cleaned and put back into service in 1919, at which time the non-pumping water level was reported to be 12 ft. below the ground surface and the drawdown was 38 ft. when pumping at 500 gpm. In 1923, the water level was 30 ft.

This well is equipped with 150 ft. of 4-in. column pipe; 4-in., 4-stage A. D. Cook turbine pump; 10 ft. of 4-in. suction pipe; 169 ft. of air line which extends 19 ft. below the top of the bowls; 25-hp. U. S. electric motor. This pump discharges at a rate of 190 gpm. and is used to supply water to the swimming pool and is maintained as a standby for emergency use.

Analysis of a sample (Lab. No. 41220) collected in June 1919, showed water from Well No. 1 to have a hardness of 16.9 gr. per gal., a residue of 307 ppm., and no iron content.

Well No. 2 was drilled in 1907 to a depth of 1026 ft. by the J. P. Miller Artesian Well Co., Chicago, and is located just outside the power station (approximately 400 ft. N. and 1000 ft. E. of the S. W. corner of Section 24, T. 40 N., R. 1 E.). The ground elevation is 793± ft.

In 1940, the well was "shot" and then plugged at 800 ft. by Frank Gray. A 10-in. casing was set from the surface to 150 ft. Grout was placed outside the casing.

In 1930, the well was equipped with 145 ft. of column pipe; 8-in., 8-stage American Well Works turbine pump rated at 250 gpm.; 20-hp. U. S. Electric Manufacturing Co. motor operating at 1800 rpm.

In 1930, the non-pumping water level was reported to be 35 ft. below the ground surface, and in Dec., 1947, the non-pumping water level was estimated to be 35 ft., and when pumping at 250 gpm., the drawdown was 44 ft.

On Mar. 4, 1949, Mr. J. H. Russell, Water Superintendent, reported that the pumping equipment was replaced in 1948 by 190 ft. of column pipe and a 5-in., 7-stage American Well Works turbine pump rated at 350 gpm. When pumping in 1948 at 225 gpm. with this installation the drawdown was 145 ft.

Well No. 3 was drilled to a depth of 1484 ft. in 1923 by P. E. Millis and Co., Byron, and is located 150 ft. east of Well No. 2.

Hole Record

20-in. from surface to 131 ft.
15-in. from 170 to 301 ft.
12 1/2-in. from 301 to 1484 ft.

Casing Record

16-in. od. from surface to 131 ft.

The well is equipped with 140 ft. of 8-in. column pipe; 12-in., 6-stage American Well Works turbine pump rated at 600 gpm. at 1150 rpm.; 140 ft. of air line; 10 ft. of 8-in. suction pipe; 40-hp. General Electric motor operating at 1140 rpm. Air line is to the top of the bowls.

In 1930, it was reported that this well produced 680 gpm. with a drawdown of 77 ft. from a non-pumping water level of 35 ft. below the ground surface. On Dec. 4, 1947, the non-pumping water level was estimated to be 35 ft. below ground surface and the drawdown was 100 ft. when pumping at 680 gpm. Mr. Russell reported that on Mar. 4, 1949, when pumping at 560 gpm., the drawdown was 140 ft.

Analysis of a sample (Lab. No. 82732) collected Jan. 6, 1938, showed this water to have a hardness of 16.4 gr. per gal., a residue of 328 ppm., and an iron content of 0.07 ppm.

Well No. 4 was completed to a depth of 1450 ft. in Jan. 1929 by P. E. Millis and Co., and located 150 ft. east of Well No. 3.

Hole Record

20-in. from surface to 135 ft.
15-in. from 135 to 487 ft.
12-in. from 487 to 1450 ft.

Casing Record

16-in. casing from surface to 135 ft.
12-in. liner from 426 to 487 ft.

The well is equipped with 140 ft. of 8-in. column pipe; 12-in., 8-stage American Well Works turbine pump rated at 640 gpm.; 10 ft. of 8-in. suction pipe; 140 ft. of air line 30-hp., 1150 rpm. General Electric motor.

In 1930, it was reported that, when pumping at 680 gpm. the drawdown was 77 ft. from a non-pumping water level of 35 ft. below the ground surface. On Dec. 4, 1947, the non-pumping water level was estimated to be 35 ft. below the ground surface and the drawdown was 91 ft. when pumping at 640 gpm. Mr. Russell reported that on Mar. 4, 1949, when pumping at 660 gpm., the drawdown was 96 ft.

Analysis of a sample (Lab. No. 112,801) collected Dec. 4, 1947 after 2-hr. pumping at 640 gpm., showed this water to have a hardness of 19.1 gr. per gal., a residue of 325 ppm., and an iron content of 3.9 ppm. A previous analysis of a sample (Lab. No. 82,731) collected in 1938 showed the water to contain 2.0 ppm. iron. The temperature and quality indicates that little if any water is being obtained from the lower formations.

Water from Wells No. 1, 2, 3, and 4 is pumped to a reservoir.

Well No. 5 was drilled in 1938 to a depth of 502 ft. by W. L. Thorne Co., Des Plaines, and located on the north side of Sixth St., one-half block east of Fourteenth St., (or approximately 2000 ft. N. and 1100 ft. W. of the S. E. corner of Section 23). The elevation of the ground surface is 820± ft.

Hole Record

10-in. to bottom of well.

Casing Record

15-in. from +1 ft. to 43 ft.
10-in. from +1 ft. to 101 ft.

The 10-in. casing was sealed in with neat cement grout from the bottom to the top of the 15-in. casing.

A production test was made on Apr. 28, 1938 by the State Water Survey. A pump, furnished by the driller, was set at 200 ft. below the ground surface. After 12-hr. pumping at 700 gpm., the drawdown was 47 ft. from a non-pumping level of 36 ft. below the ground surface.

In 1947, one stage was added to the pump and the pump installation consists of 140 ft. of 8-in. column pipe; 6-stage American Well Works turbine pump, No. 61758, having a rated capacity of 650 gpm.; 140 ft. of air line; 10 ft. of 8-in. suction pipe; 40-hp. General Electric motor.

This pump discharges at a rate of 525 to 575 gpm., directly into the mains. In 1946, when pumping at 575 gpm., the drawdown was 92 ft. from a non-pumping water level of 36 ft. below the ground surface. The pump usually operates 24 hr. daily but at present time is being repaired.

Analysis of a sample (Lab. No. 83417) collected Apr. 28, 1938, after 12-hr. pumping at 700 gpm., showed the water to have a hardness of 16.3 gr. per gal., a residue of 278 ppm., and an iron content of 1.3 ppm.

Well No. 6 was drilled to a depth of 867 ft. in 1942 by the McCarthy Well Co., St. Paul, Minn. and located on the north side of Ave. "G" between South 3rd and South 4th St. (or approximately 1625 ft. S. and 1525 ft. W. of Section 25). The ground surface elevation is 800± ft.

Hole Record

19-in. from surface to 156 ft. 6 in.
12-in. from 156 ft. 6 in. to 783 ft. 8 in.
10-in. from 783 ft. 8 in. to 867 ft.

Casing Record

12-in. casing from surface to 156 ft. 6 in.
10-in. liner from 613 to 783 ft. 8 in.

In 1942, the non-pumping water level was 40 ft. below the ground surface.

The pump assembly consists of 150 ft. of 8-in. column pipe; 12-in., 8-stage American Well Works turbine pump, rated at 600 gpm.; 150 ft. of air line; 20 ft. of 8-in. suction pipe; 60-hp. General Electric motor.

This well has not been used for 2 years, but it is expected to be returned to service, upon installation of an iron removal plant about June, 1948.

Water from Wells 5 and 6 is pumped directly into the mains.

In 1947, municipal pumpage averaged 1 1/4 mgd.

Sample-study log of Well No. 4 furnished by the State Geological Survey:

Formation	Thickness ft.	Depth ft.
Pleistocene system		
Clay	4	4
Ordovician system		
Platteville dolomite	87	91
Glenwood sandstone, dolomite, and thin shale beds	49	140
St. Peter formation		
Sandstone, incoherent	300	440
Sandstone, chert and shale	70	510
Cambrian system		
Trempealeau dolomite, thin sandstone and shale beds	100	610
Franconia dolomite and sandstone	95	705
Galesville sandstone		
Sandstone, partly dolomitic	75	780
Sandstone, incoherent	75	855
Eau Claire formation		
Sandstone, shale, and thin dolomite beds	265	1120
Sandstone, incoherent	180	1300
Cambrian and Pre-Cambrian systems		
Mt. Simon and Fond du Lac sandstones and thin shale beds	150	1450

LABORATORY NO. 112,801

		ppm.	epm.			ppm.	epm.
Iron (total)	Fe	3.9		Silica	SiO_2	14.9	
Manganese	Mn	0.0		Fluoride	F	0.1	
Calcium	Ca	73.3	3.67	Chloride	Cl	2.0	0.06
Magnesium	Mg	34.8	2.86	Nitrate	NO_3	0.1	Tr.
Ammonium	NH_4	0.2	0.01	Sulfate	SO_4	11.3	0.24
Sodium	Na	3.7	0.16	Alkalinity	(as $CaCO_3$)	320.	6.40
Turbidity		35		Hardness	(as $CaCO_3$)	327.	6.53
Color		0		Residue		325.	
Odor		Tr.		Temperature 51.5° F.			

. Illinois State Geological Survey
Urbana, Illinois
City of Rochelle #8

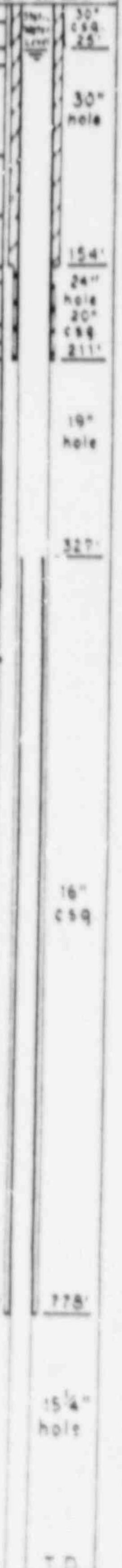
T 40 N, R 2 E, Sec. 30

Ogle Co.

Elevation: 785 E.T.M.
Drilled: 1960 by Wehling Well Works

Sample Set No. 41502,
Studied 3/63 by J.E. Rocke

System	Formation	Thickness	Bed thickness	Depth	Description
	Pleistocene	36	5	5	Till, dark brown
			20	25	Sand and gravel
			11	36	Till, sandy, light gray
ORDOVICIAN SYSTEM	Platteville	119	54	90	Dolomite, yellowish-buff, finely crystalline
			35	125	Dolomite, light gray; limestone, light gray
			30	155	Dolomite, light buff
	Glenwood	55	10	165	Sandstone, fine, coarse
			25	190	Sandstone, white, fine to coarse
			5	195	Sandstone and dolomite
			15	210	Sandstone, fine to coarse
	St. Peter	145	135	345	Sandstone, partly argillaceous, fine to medium
			10	355	Shale, light buff; sandstone
	Shakopee	25	25	380	Dolomite, light brown, finely crystalline
	New Richmond	20	20	400	Sandstone, fine to medium; dolomite; chert
	Oneota	140	80	480	Dolomite, cherty, light grayish-buff, finely crystalline
			60	540	Dolomite, light grayish-brown to light pinkish-brown, finely crystalline
	Gunter - Jordan	30	30	570	Sandstone, fine to medium; dolomite, cherty, light brown
CAMBRIAN SYSTEM	Trempealeau	105	65	635	Dolomite, light buff, sublithographic
			40	675	Dolomite, glauconitic, buff to light grayish-buff
	Franconia	85	45	720	Dolomite, glauconitic, light pinkish-gray; sandstone, glauconitic, very fine
			40	760	Sandstone, glauconitic, dolomitic, very fine to fine; little dolomite and shale
	Ironton - Galesville	170	30	790	Sandstone, slightly glauconitic, dolomitic, fine to coarse
			35	825	Sandstone, silty, fine to medium, little coarse
			30	855	Sandstone, fine to medium, little coarse; dolomite, pink
			75	930	Sandstone, white, very fine to medium, incoherent
	Eau Claire	5	5	935	Shale, sandy, light greenish-buff



DGL

WELL TEST DATA SHEET

Layne-Western Company, Inc.

WATER SUPPLY CONTRACTORS

221 West Illinois Avenue • Aurora, Illinois 60507 • Phone 312/897-6041

Job Village of Rochelle C-1925G Well No. 8
Date Tested 10/10/75
Location Rochelle
Tested By B. Aachauer
Dia. of Well 15¼ x 19¼
Driver 250 H.P., B.J.
Depth of Well 935'
Pump Used
Column and Shaft 10"
Length of Airline 233'
Bowls 14"GM - 4 Stage
Non Pumping Level 107'
Manufacturer Byron Jackson
Orifice Size 10 x 7
Serial No. 380443

Time	Manometer Reading (in.)	G.P.M.	Air Gauge Reading (feet)	Pumping Level	Drawdown	Disch. Pressure		Total Pumping Head	Remarks
						Lbs.	Feet		
1:20	Start								
1:25	69.5	1720	38	195	88	80			Sand 240-240-240
1:35	66	1680	37	196	89	80			Sand 238-239-240
1:45	64.5	1650	31	202	98	80			Sand - Dirty 235-235-235
5	56.5	1554	31	202	95	70			Sand - Dirty 230-230-230
2:05	58	1574	32	201	94	70			Sand - Dirty 230-231-231
2:15	58	1574	32	201	94	70			Sand - Dirty 230-230-231
2:25	71	1760	22	211	104	60			Less Sand - Clearing 235-233-235
2:35	69	1740	22	211	104	60			Clear 235-235-235
2:45	68.5	1735	22	211	104	60			Little Sand - Clear 235-235-235
2:55	41	1326	44	189	82	90			Little sand - Clear- 220-220-221
3:00	Shut Down								

Illinois State Geological Survey
Urbana, Illinois
City of Rochelle Well #9

R 1 E
T 40 N
Sec. 25
Ogle Co.

Elevation: 785 E.T.M.
Drilled: 1960 by Wehling Well Works

Sample Set No. 41503
Studied 4/1963 by J.E. Roche

Pleistocene		15	15	15	Soil, till, sandy, yellow
ORDOVICIAN SYSTEM	Platteville	84	45	60	Dolomite, yellow, finely crystalline, till, slumped
			10	70	Shale, light green to light buff, weak
			29	99	Dolomite, orange, light buff, finely crystalline
	Glenwood	71	31	130	Sandstone, light buffish-gray, medium, incoherent
			15	145	Shale, very sandy, light green, weak
			25	170	Sandstone, light buff, fine to coarse, incoherent
	St. Peter	295	50	220	Sandstone, white, fine to medium, incoherent
			15	235	Sandstone, white, fine to coarse
			45	280	Sandstone, white, medium to fine, incoherent
			10	290	Sandstone, white, coarse to fine
			120	410	Sandstone, light grayish buff to white, fine to medium, incoherent
			30	440	Sandstone, white, medium, incoherent
			15	455	Sandstone, white, coarse to fine
			10	465	Sandstone, reddish-gray, fine; siltstone
	Oneota	30	30	495	Dolomite, light buff, finely crystalline
	Gunter - Jordan	35	25	520	Sandstone, cherty, pinkish, incoherent
			10	530	Chert
CAMBRIAN SYSTEM	Trempealeau	95	15	545	Dolomite, grayish-buff, finely crystalline
			10	555	Sandstone, white, coarse to fine
			30	585	Dolomite, pinkish-brown, finely crystalline; sandstone, white medium, incoherent
			40	625	Dolomite, light brown to pinkish buff, finely crystalline
	Franconia	75	25	650	Dolomite, pink to red, finely crystalline, grading to siltstone at bottom
			5	655	Shale, reddish-gray, weak
			20	675	Sandstone, grayish-green, very fine, siltstone
			25	700	Dolomite, light green, finely crystalline, siltstone, light green, sandstone, fine
	Ironton - Galesville	177	40	740	Sandstone, dolomitic, light gray to light grayish-buff, fine to coarse, incoherent
			35	775	Sandstone, light buffish-gray, fine to medium, incoherent
			20	795	Sandstone, grayish-orange, fine to coarse; dolomite, orange
			15	810	Sandstone, white, fine to coarse, incoherent
			40	850	Sandstone, white, fine to medium, incoherent
			27	877	Sandstone, light grayish-orange, fine to coarse, incoherent
	Eau Claire	11	11	888	Shale, light brown, weak

DGL

F/L Motor = 310 Amps

WELL TEST DATA SHEET

Layne-Western Company, Inc.

WATER SUPPLY CONTRACTORS

721 West Illinois Avenue • Aurora, Illinois 60506 • Phone 312-897-6041

Job City of Rochelle

Well No. 9

Date Tested February 4, 1980

Location Park Well

Tested By W. Whisenant

Dia. of Well 18 x 16 x 12

Driver 250 H.P., 480 V, Type U

Depth of Well 869'6"

Pump Used:

Column ~~xxxxx~~ 10" T&C R/L

Length of Airline 318'

Bowls 12"MQL - 10 stage CIBF

Non Pumping Level 63'

Manufacture: Byron Jackson

Orifice Size 10 x 7

Serial No. C-380443 (721-C-0051)

Time	Piezometer Reading (in.)	G.P.M.	Air Gauge Reading (feet)	Pumping Level	Drawdown	Disch. Pressure Lbs.	Disch. Pressure Feet	Total Pumping Head	Remarks
:15	43.5	1364	70	248	185	80	185	433	H2O dirty
:20	43.5	1364	75	243	180	80	185	428	218-220-220 Amp
:25	40.0	1311	55	263	200	80	185	448	H2O dirty
:	40.0	1311	50	268	205	80	185	453	
:40	37.5	1274	48	270	207	85	196	466	220-220-222 Amp
:50	33	1200	45	273	210	100	231	504	H2O rusty
:00	34	1218	45	273	210	110	254	527	Cloudy
:10	34	1218	45	273	210	110	254	527	
:20	34	1218	45	274	210	110	254	527	Cloudy
:40	34	1218	45	273	210	110	254	527	No sand
:00	34	1218	45	273	210	110	254	527	Clear
:10	34	1218	45	273	210	110	254	527	
:20	34	1218	45	273	210	110	254	527	220-220-222 Amp
									Shut Down

Specific Well Capacity = $\frac{1218 \text{ GPM}}{210 \text{ ft/DD}}$ = 5.86 GPM/Ft/D.D.

STILLMAN VALLEY

Ogle County
Dec. 3, 1947

The village of Stillman Valley (333) installed a public water supply in 1938.

Water is obtained from a well drilled to a depth of 300 ft. in Aug., 1938 by C. W. Varner, Dubuque, Iowa, and located 300 ft. south of Roosevelt St. and 160 ft. east of Spruce St. (or approximately 1100 ft. N. and 1300 ft. E. of the S. W. corner of Section 1, T. 24 N., R. 11 E.). The surface elevation is 725± ft.

Correlated driller's log of well drilled in 1938 furnished by the State Geological Survey:

Formation	Thickness ft.	Depth ft.
Pleistocene system		
Sand and gravel	55	55
Ordovician system		
Platteville formation		
Limestone, yellow and blue	60	115
Glenwood formation		
Shale and lime	38	153
St. Peter formation		
Sandstone	147	300

The pumping equipment consists of 150 ft. of 4-in. od. column pipe; 6-in., 20-stage Fairbanks-Morse and Co. oil-lubricated turbine pump, No. 35200, rated at 200 gpm. against 250 ft. of head at 1750 rpm.; the overall length of the pump is 7 ft. 7 3/4 in.; 20 ft. of 5-in. od. suction pipe; 10-hp. Fairbanks-Morse hollow shaft motor operating at 1750 rpm.

Hole Record

12-in. from surface to 160 ft.
8-in. from 160 to 300 ft.

Casing Record

15-in. from surface to 10 ft.
12-in. from surface to 59 ft. 3 in.
8-in. from surface to 161 ft. 4 in.

The driller reported a production test immediately after completion. After pumping 9 hr. at 203 gpm., the drawdown was 55 ft. from a non-pumping water level of 30 ft.

Analysis of a sample (Lab. No. 112,797) collected Dec. 3, 1947 after 9-hr. pumping at 203 gpm. showed this water to have a hardness of 17.7 gr. per gal., a residue of 310 ppm., and an iron content of 1.1 ppm.

Pumpage is estimated to average 20,000 gpd.

LABORATORY NO. 112,797

		ppm.	epm.			ppm.	epm.
Iron (total)	Fe	1.1		Silica	SiO_2	17.8	
Manganese	Mn	Tr.		Fluoride	F	0.1	
Calcium	Ca	70.6	3.53	Chloride	Cl	1.0	0.03
Magnesium	Mg	30.7	2.52	Nitrate	NO_3	0.1	Tr.
Ammonium	NH_4	Tr.	Tr.	Sulfate	SO_4	8.4	0.18
Sodium	Na	0.0	0.00	Alkalinity	(as $CaCO_3$)	292.	5.84
Turbidity		20		Hardness	(as $CaCO_3$)	303.	6.05
Color		0		Residue		310.	
Odor		Tr.		Temperature 56° F.			

STILLMAN VALLEY
Ogle County
October 10, 1960

Two wells furnish water to the public supply of Stillman Valley (598).

WELL NO. 1, described in Bulletin 40, was completely rehabilitated and the pump repaired in 1957 or 1958. The well now is maintained for emergency service.

WELL NO. 2 was completed in Sept. 1954 to a depth of 445 ft. by Allabaugh Well Co., Rockford, and located adjacent to the elevated tank, or approximately 300 ft. N. and 750 ft. E. of the S. W. corner of Section 1, T24N, R11E. The ground elevation at the well is 740. The well was cased with 159 ft. 6 in. of 12-in. pipe and with 8-in. pipe from the surface to 179 ft. 6 in., below which the hole was finished 8 in. in diameter to the bottom. The annulus between the two casings and between the 8-in. casing and the wall of the 12-in. hole was pressure grouted.

During the drilling of the well, water levels were observed as shown in Table A.

The pumping equipment includes a Fairbanks-Morse Pomona turbine pump, No. 175987, rated at 280 gpm. and connected to a 25-hp. electric motor.

A mineral analysis of a sample (Lab. No. 153360) collected Oct. 6, 1960 showed the water in Well No. 2 to have a hardness of 16.5 gr. per gal., total dissolved minerals of 294 ppm., and an iron content of 0.9 ppm.

There are 150 services. Pumpage is reported to average 40,000 gpd.

TABLE A

Water Level		Depth
from	to	ft.
0	164	0
164	190	60
190	235	58
235	290	53
290	430	50
430	460	38

LABORATORY NO. 153360

		ppm.	epm.			ppm.	epm.
Iron (total)	Fe	0.9		Silica	SiO_2	10.8	
Manganese	Mn	Tr.		Fluoride	F	0.2	
Calcium	Ca	63.0	3.15	Boron	B	0.0	
Magnesium	Mg	30.3	2.49	Chloride	Cl	0.	.00
Ammonium	NH_4	Tr.	Tr.	Nitrate	NO_3	0.6	.01
Sodium	Na	4.	.17	Sulfate	SO_4	6.0	.12
				Alkalinity (as	$CaCO_3$)	284.	5.68
Turbidity		5		Hardness (as	$CaCO_3$)	282.	5.64
Color		0					
Odor		0		Total Dissolved Minerals		294.	

BYRON

Preliminary Draft - Bulletin 60 Series

To be Published in 1989 by Illinois Geologic Survey.

The city of Byron (2035) installed a public water supply in 1900. Three wells are in use. In 1950 there were 375 services, 370 metered; the average and maximum pumpages were 115,000 and 140,000 gpd, respectively. In 1984 there were 871 services, all metered; the average and maximum pumpages were 460,000 and 620,000 gpd, respectively. The water is chlorinated and fluoridated.

WELL NO. 1, finished in sandstone, was completed in __________ 1900 to a depth of 2000 ft (cleaned out to ~~[illegible]~~ 1325 ft in 1948) by W. H. Gray and Bros., Chicago. This well is pumped in conjunction with Well No. 2. The well is located south of Main St. between Union and Walnut Sts. in the main room of the pumphouse, approximately 2200 ft S and 700 ft E of the NW corner of Section 32, T25N, R11E. The land surface elevation at the well is approximately 720 ft.

A drillers log of Well No. 1 follows:

Strata	Thickness (ft)	Depth (ft)

Originally, a 12-in. diameter hole was drilled to a depth of 213 ft, reduced to 10 in. between 213 and 1000 ft, reduced to 8 in. between 1000 and 1600 ft, and finished 5 in. in diameter from 1600 to 2000 ft. The well was originally cased with 12-in. pipe from land surface to a depth of 213 ft. In 1948, the well was reamed out and the hole was then reported to be 10 in. in diameter from land surface to a depth of 246 ft, 8 in. from 246 to 850 ft, and 6 in. from 850 to 1280 ft. The well was then cased with 12-in. pipe from land surface to a depth of 213 ft and 10-in. pipe from about 1.5 ft above land surface to a depth of 40 ft (cemented in).

Upon completion, the well reportedly flowed.

In November 1947, the well reportedly produced 350 gpm with a drawdown of 62 ft from a nonpumping water level of 32 ft below the pump base.

In 1948, C. W. Varner, Dubuque, Iowa, reamed out the hole, installed new casing, and shot the well with 200 lb each at depths of 395, 680, 1150, and 1240 ft. The well was then cleaned out to a depth of 1250 ft. On August 23, 1948, the nonpumping water level was reported to be 50 ft below the pumphouse floor (Well No. 2 idle).

The pumping equipment presently installed is a ________ __________ pump set at ___ ft, rated at 600 gpm, and powered by a 30-hp 1775 rpm General Electric motor (Model No. 12K-1690, Serial No. KLJ6789744).

A mineral analysis made by the Illinois Environmental Protection Agency (Lab. No. B37330) of a sample collected February 27, 1980, after pumping for 1 hr at 600 gpm, showed the water to have a hardness of 262 mg/l, total dissolved minerals of 271 mg/l, and an iron content of 0.15 mg/l.

WELL NO. 2, finished in sandstone, was completed in __________

1929 to a depth of 673 ft (cleaned out to 675 ft in 1948) by P. E. Millis, Byron. This well is always pumped in conjunction with Well No. 1 because of high chromium content. The well is located in a small room south of the main room in the pumphouse about 14 ft southeast of Well No. 1, approximately 2612 ft S and 706 ft E of the NW corner of Section 32, T25N, R11E. The land surface elevation at the well is approximately 720 ft.

A sample study log of Well No. 2 furnished by the State Geological Survey follows:

Strata	Thickness (ft)	Depth (ft)
PLEISTOCENE SERIES		
Soil	15	15
Sand and gravel	185	200
ORDOVICIAN SYSTEM		
St. Peter Formation		
Sandstone, incoherent	160	360
Sandstone, chert and thin shale beds	80	440
CAMBRIAN SYSTEM		
Trempealeau dolomite and chert	55	495
Franconia sandstone, shale, and some dolomite	85	580
Galesville Sandstone		
Sandstone, partly dolomitic	50	630
Sandstone, incoherent	43	673

An 8-in. diameter hole was drilled to a depth of 673 ft. The well is cased with 8-in. drive pipe from above [illegible] above land surface to a depth of 212 ft.

In 1948, C. W. Varner, Dubuque, Iowa, shot the well with 400 lb of 100 percent nitrogel (200 lb per shot) at 640 and 600 ft. The nonpumping water level was reported to be 63 ft below land surface before shooting and 57 ft below land surface after shooting. The hole was then cleaned out to 675 ft. After this work, the well reportedly produced 300 gpm with a drawdown of 26 ft from a nonpumping water level of 39 ft below the pumphouse floor.

The pumping equipment presently installed consists of a 15-hp 1775 rpm General Electric motor (Model No. 12P4510, Serial No. 6528129), a 10-in., 8-stage Peerless turbine pump (Serial No. 62902) set at 100 ft, rated at 300 gpm, and has 100 ft of 6-in. column pipe. A 10-ft section of 8-in. suction pipe is attached to the pump intake.

A mineral analysis made by the Illinois Environmental Protection Agency (Lab. No. B28879) of a sample collected January 3, 1980, after pumping for 1 hr at 300 gpm, showed the water to have a hardness of 359 mg/l, total dissolved minerals of 414 mg/l, and an iron content of 0.089 mg/l.

A 5-in. diameter test hole was constructed in April 1964 to a depth of 140 ft by the Layne-Western Co., Aurora. It was located approximately 2650 ft S and 700 ft E of the NW corner of Section 32, T25N, R11E. A temporary 2-in. casing was installed and the nonpumping water level on April 8, 1964, was reported to be 52 ft below land surface.

WELL NO. 3, finished in sandstone, was completed in September 1959 to a depth of 715 ft by the Layne-Western Co., Aurora. This well was placed in service in 1973. The well is located about 150 ft east of Market St. and 250 ft north of Second St. under the elevated tank, approximately 1310 ft S and 1820 ft E of the NW corner of Section 32, T25N, R11E. The land surface elevation at the well is approximately 720 ft.

A drillers log of Well No. 3 follows:

Strata	Thickness (ft)	Depth (ft)
Black soil	1	1
Brown clay	5	6
Sand, gravel, few boulders	74	80
Boulders, drilled very rough	3	83
Sand, gravel, clay streaks, few boulders	92	175
Sand, gravel, clay	53	228
Sandstone	12	240
Sandstone, white shale cuttings	23	263
St. Peter sandstone	107	370
St. Peter sandstone, limestone lenses	20	390
White limestone	40	430
Brown limestone, some chert, hard	29	459
Sandstone, limestone and chert, hard	17	476
Light brown limestone, some chert, hard	19	495
Green and brownish red sandstone	88	583
Limestone and chert	4	587
Sandstone	13	600
Limestone	5	605
Sandstone with limestone lenses	35	640
White sandstone	54	694

Green shale and brown limestone	8	702
Green and red shale	13	715

A 22-in. diameter hole was drilled to a depth of 20 ft, reduced to 19 in. between 20 and 250 ft, and finished 15 in. in diameter from 250 to 715 ft. The well is cased with 20-in. pipe from land surface to a depth of 20 ft and 16-in. pipe from land surface to a depth of 249 ft (cemented in).

A production test was conducted on September 11-12, 1969, by representatives of the driller and Millett, Hofmann & Associates, Consulting Engineers. After 24 hr of pumping at rates of 1012 to 1268 gpm, the final drawdown was 50 ft from a nonpumping water level of 59 ft below land surface.

In May 1980, the well reportedly produced 975 gpm with a drawdown of 40 ft from a nonpumping water level of 55 ft.

The pumping equipment presently installed consists of a 75-hp 1775 rpm U. S. electric motor (Model No. TJ, Serial No. [illegible]2047196), a 12-in., 4-stage Crane Deming turbine pump (Model No. 470), Serial No. T71376), set at 150 ft, rated at 1000 gpm at about 221 ft TDH, and has 150 ft of 8-in. column pipe. A 10-ft section of 8-in. suction pipe is attached to the pump intake.

The following mineral analysis made by the Illinois Environmental Protection Agency (Lab. No B034294) is for a water sample from the well collected January 26, 1982, after 1.5 hr of pumping at 1000 gpm.

WELL NO. 3, LABORATORY NO. B034294

		mg/l	me/l
Iron	Fe	<0.005	
Manganese	Mn	0.018	
Ammonium	NH4	<0.1	
Sodium	Na	3	0.13
Potassium	K	3.2	0.08
Calcium	Ca	63	3.14
Magnesium	Mg	35.0	2.88
Strontium	Sr	0.105	
Arsenic	As	<0.001	
Barium	Ba	0.085	
Beryllium	Be	<0.0005	
Cadmium	Cd	<0.003	
Chromium	Cr	<0.005	
Cobalt	Co	<0.005	
Copper	Cu	<0.003	
Lead	Pb	<0.005	
Mercury	Hg	<0.00005	
Nickel	Ni	<0.003	
Selenium	Se	<0.001	
Silver	Ag	<0.005	
Vanadium	V	<0.004	
Zinc	Zn	<0.002	

		mg/l	me/l
Silica	SiO2	9.5	
Fluoride	F	0.29	0.02
Boron	B	0.02	
Cyanide	CN	<0.005	
Nitrate	NO3	5.3	0.09
Chloride	Cl	2.2	0.06
Sulfate	SO4	30	0.62
Alkalinity (as CaCO3)		285	5.70
Hardness (as CaCO3)		299	5.98
Total dissolved minerals		347	

pH (as rec'd) 7.4