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STATE ENGINEER

THE CHAMPOEG PARK DEMONSTRATION WELL

WITH A SECTION ON

THE DESIGN AND TESTING OF WATER WELLS

BY
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THE CHAMPOEG PARK DEMONSTRATION WELL

by

Jack E. Sceva

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INTRODUCTION

Water, which is the key to economic growth, will play an ever increasing role in the development of Oregon. The operating costs of ground-water projects in many parts of Oregon have been excessive owing to inefficient wells and the presence of sand in the water supply. Sand problems are particularly costly as they restrict the pumping capacity of wells and cause excessive wear on pumps, sprinkler equipment, industrial equipment, and the plugging of distribution systems. The Champoeg Park Demonstration Well was constructed with modern methods and materials to show that it is feasible to construct sand-free wells in the Northern Willamette Valley. This report presents the story of the construction of the Champoeg Park Demonstration Well and of the many problems that developed before its successful completion. The well construction and development, which was also for the purpose of testing the feasibility of using plastic well casing, was scheduled as a two day operation. Problems that developed in utilizing the plastic casing stretched the operation into a twelve day project that involved 900 feet of drilling. More than 300 well drillers, well owners, representatives from State, Federal, and municipal agencies, and representatives from engineering firms and private industries showed up to watch various phases of the demonstration.

INITIATION OF PROJECT

It has been the desire of many ground-water specialists who have worked in Oregon and who are familiar with the problems of well operation to show what could be accomplished with a screened well in the Northern Willamette Valley. The use of well screens is not common to well construction in Oregon and practically non-existent in the sand troubled areas lying between Salem and Portland.

Mr. Chris L. Wheeler, Oregon State Engineer, who is charged with the administration of Oregon's Ground Water Act and the licensing of water well contractors, was contacted in December, 1962 by Mr. E. J. "Dutch" Jungmann of the Bucyrus-Erie Company of Evansville, Indiana, and Mr. Howard Berry of the Stardrill Company of Portland. They set forth their desire to participate in a demonstration well and to seek additional help from other manufacturers and suppliers. As this appeared to be a desirable program, a meeting was immediately scheduled in Salem to discuss the feasibility of the project. Those in attendance were "Dutch" Jungmann, Howard Berry, Bruce Foxworthy, District Geologist United States Geological Survey, Don Price, United States Geological Survey, Chris L. Wheeler, State Engineer, and the writer. Mr. Jungmann and Mr. Berry informed the group that they had determined that sufficient participation could be obtained to carry out the project. The selection of a site for the demonstration presented somewhat of a problem. It was decided that it should be in the heart of this sand-problem area, reasonably accessible with adequate parking facilities for the public and on public owned land so that any benefit derived from the subsequent use of the well would be of benefit to the public. Mr. Alfred Shirley, Assistant State Parks Superintendent, was called to the meeting. He informed the group that Champoeg State Park could be made available for the demonstration and that the park is troubled by sand problems in their two existing wells. Since many of those present were familiar with the site and the sand problems common to the area, it was decided that Champoeg State Park would meet all the requirements for the well construction demonstration.

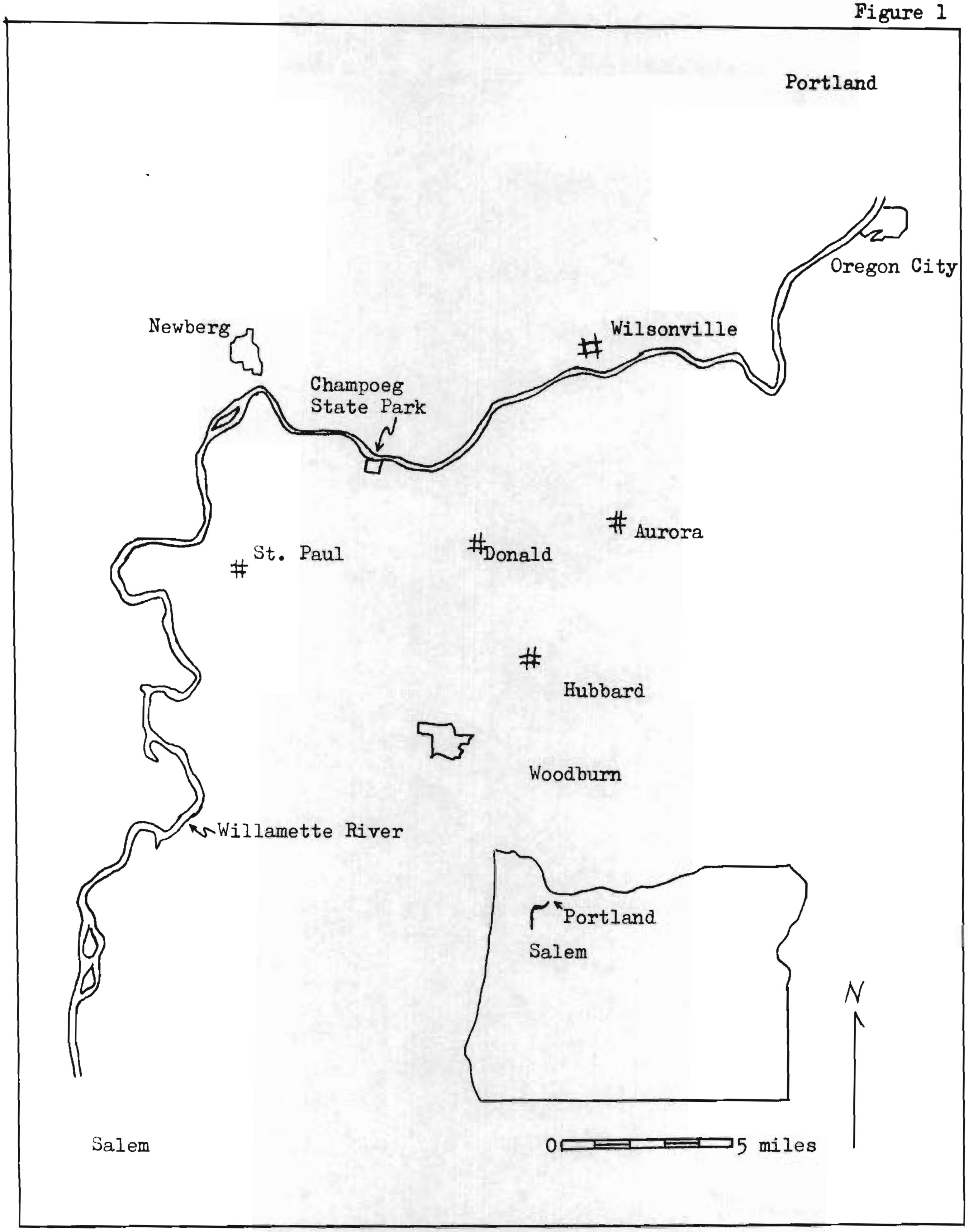
ACKNOWLEDGEMENTS

Many individuals and suppliers expended large amounts of time and materials to carry this demonstration to a successful completion. These individuals and suppliers included Howard Berry of the Stardrill Company of Portland, "Dutch" Jungmann of Bucyrus-Erie Company of Evansville, Indiana, Sam Grubb of Portco Corporation of Vancouver, Washington, Ray Schreurs of Edward E. Johnson, Inc. of St. Paul, Minnesota, Rex Ireton, Marvin Sample, and Joe Hansen of Hansen Drilling Company of Vancouver, Washington, and Tom Cunningham of the Baroid Division of the National Lead Company, Houston, Texas. Especial thanks is also given to the personnel at the Oregon State Parks Department who aided materially in making the demonstration a success.

SETTING OF CHAMPOEG PARK

Champoeg Park lies adjacent to the Willamette River some twenty miles southwest from Portland (Figure 1). It was an early trading post of the Hudson's Bay Company, and was the site of the first

Figure 1

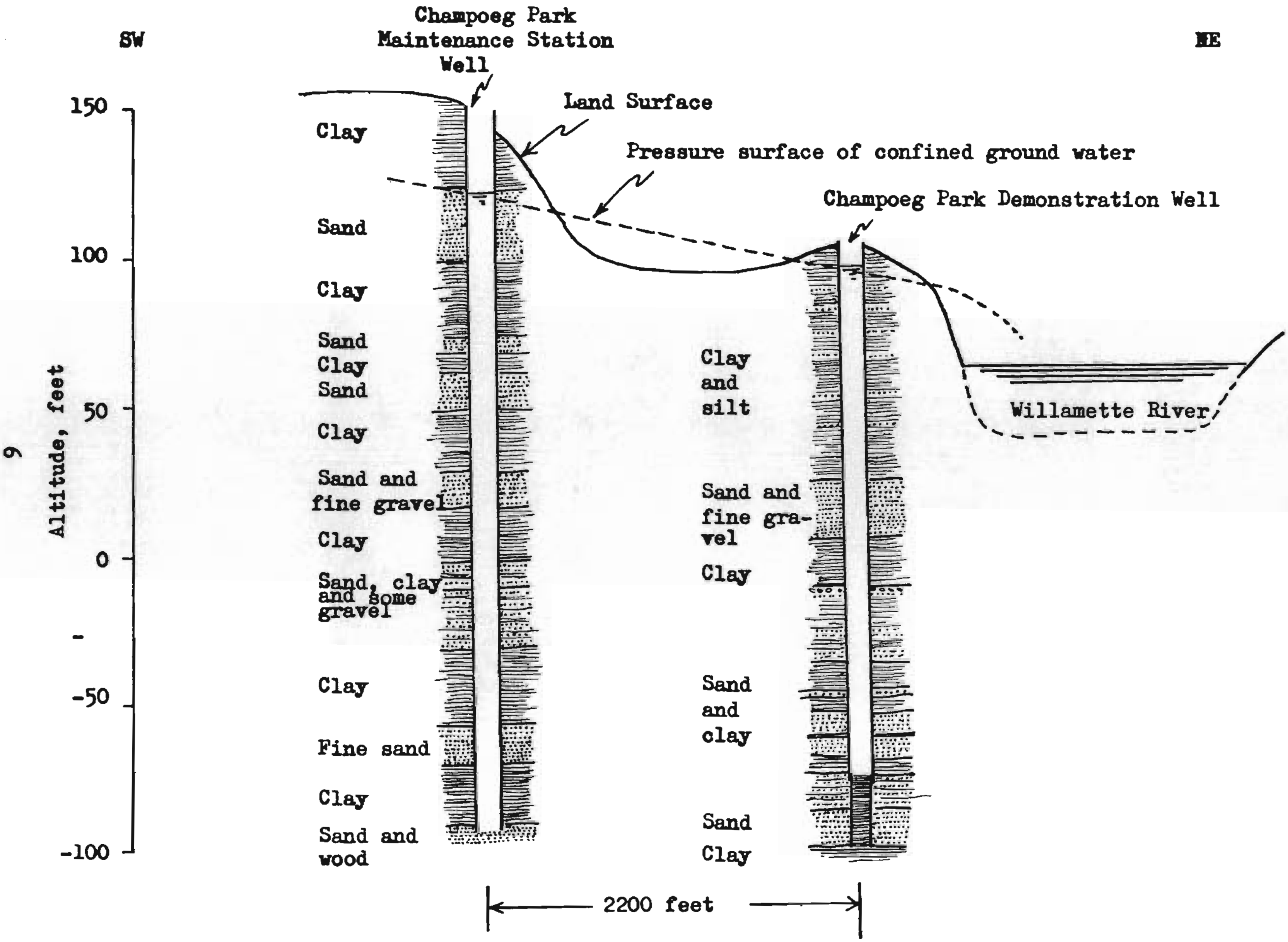


Map showing the location of Champoeg State Park meeting to consider the formation of a provisional government. The community that grew up at this river port was essentially destroyed in the flood of 1894 and was never rebuilt. The park occupies the site of this pioneer community.

Champoeg Park is near the Northern or downstream end of a large broad basin in the Willamette Valley that has been partially filled with stream and lake deposits. These sediments are generally coarser in the southern part of this basin near Salem and become progressively finer grained in a northerly direction. In the Champoeg Park area they are essentially sands, silts, and clays with a few discontinuous lenses of pebble gravel (Figure 2). These sediments at places exceed several hundred feet in thickness and are underlain at depth by a series of basaltic lava flows called the Columbia River Basalt Formation.

CONSTRUCTION OF THE TEST WELL

Mr. Jungmann, along with well drillers Marvin Sample, Rex Ireton, and Joe Hansen, moved a Bucyrus-Erie 10-R rotary drilling machine and other equipment to Champoeg Park on December 27, 1962 to construct a test well to aid in the design of the demonstration well. As the project also had the purpose of testing the use of plastic casing in well construction, special standards to Oregon's code of general standards for the construction of water wells were issued to allow the use of plastic casing in the test well and the demonstration well. The plastic casing used was high-impact styrene rubber (Kralon No. 235).



Cross section through Champoeg State Park

Figure 2

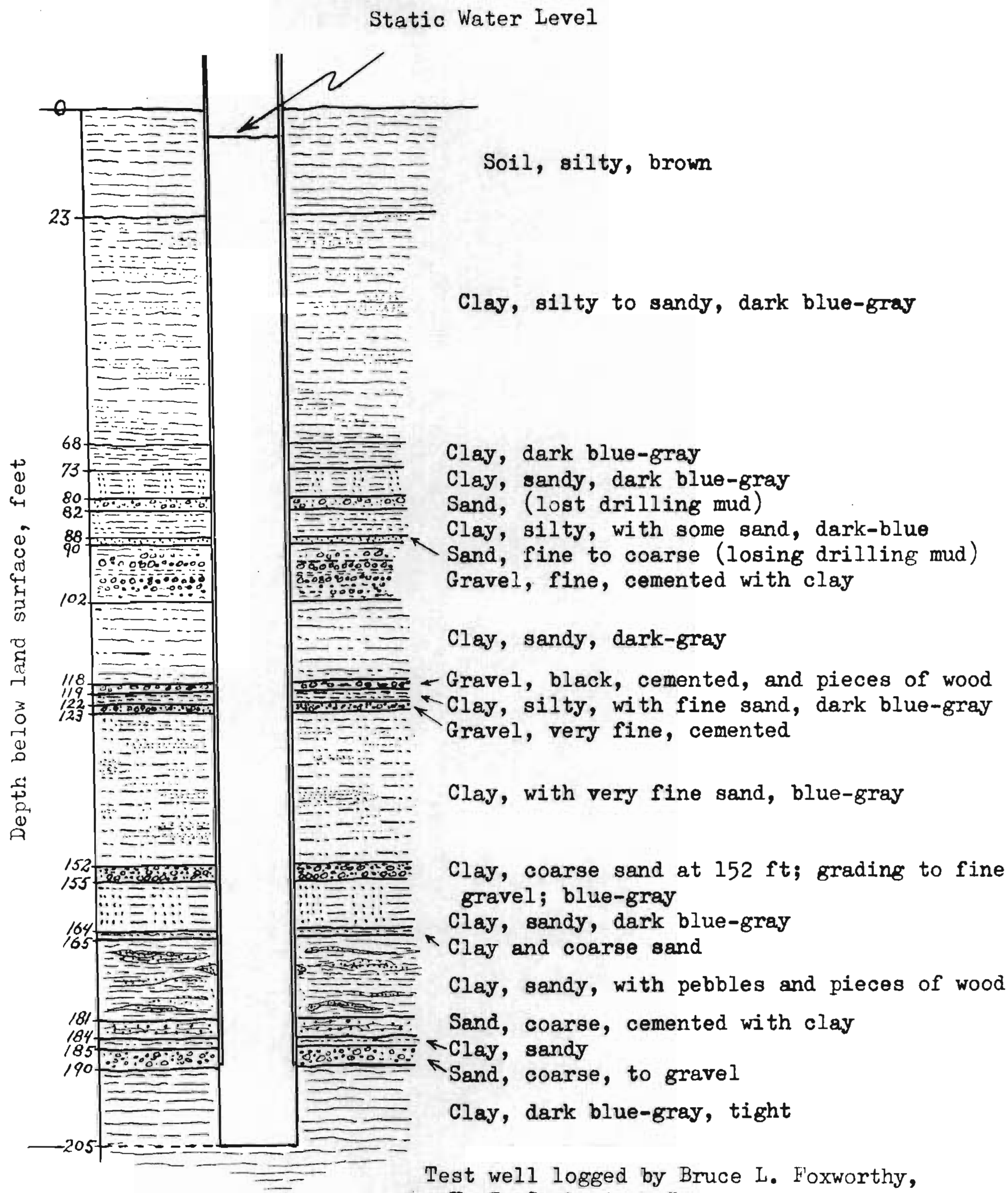
The test well was drilled to a depth of 205 feet and was cased without incident. Small holes had been drilled in the bottom section of the casing to allow the well to be developed as a source of drilling water for the demonstration well. The well was logged by Bruce Foxworthy of the Geological Survey and the log is shown on Figure 3. Representative samples of the water-bearing formation were obtained and sent to the Edward E. Johnson, Inc. laboratory at St. Paul, Minnesota, for a determination of the proper slot opening for the well screen. The results of the sieve analyses of these samples are given on Figure 4.

The program for the demonstration well was scheduled as follows:

> Drilling operations with a rotary drilling machine will commence at 9:00 a. m. on January 11, 1963. The well bore to a depth of 18 feet, will be 9-7/8 inches in diameter to provide an annular space for sealing the casing in compliance with the State Standards for water well construction. The well bore will then be reduced to 7-7/8 inches and the drilling will proceed to a depth of 160 feet.
>
> The drilling operations will resume at 9:00 a. m. on January 12, 1963, and the well will be drilled to 190 feet. Six-inch plastic casing utilizing solvent weld external couplings, will be set to 190 feet. A 15-foot section of Johnson Telescoping well screen (Everdur, 16-slot) will be placed from 175 to 190 feet and the casing will be pulled back to expose the screen. The well will then be developed utilizing high velocity water jets. Final steps of the demonstration will consist of pumping the well with air or with a centrifugal pump.

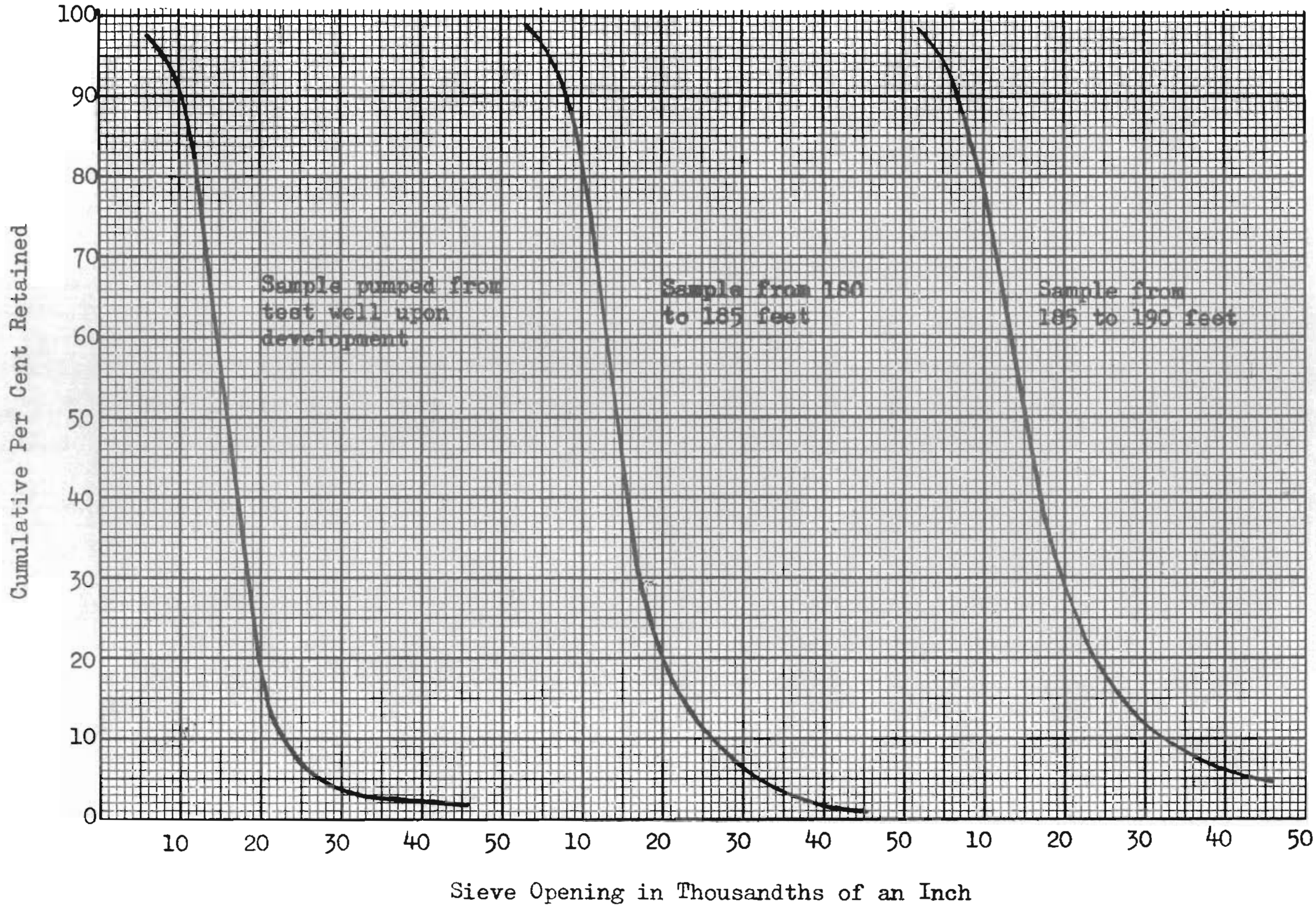
CONSTRUCTION OF WELL NUMBER 1

On January 10, 1963 the rotary drilling machine which had been used to construct the test well was moved back to Champoeg Park



Test well logged by Bruce L. Foxworthy,
U. S. Geological Survey

LOG OF CHAMPOEG PARK TEST WELL



Sieve analyses of sand samples from the test well.
(Analyses by Edward E. Johnson, Inc.)

Figure 4

and set up at the drill site. The mud pits were dug and equipment set up for the demonstration. The night of January 10 was an unusually cold night for the Willamette Valley, with temperatures dropping to 10 to 15 degrees F. Upon arriving at the site on the morning of the demonstration, it was found that some water had been left in the hose leading from the mud pump to the water swivel and considerable difficulty was encountered in thawing the hose.

Drilling mud was mixed under the direction of Mr. Tom Cunningham of the Bariod Division of the National Lead Company (Figure 5A). In describing the operation to the group, he stressed the importance of mud control to successful rotary drilling (Figure 5B). Actual drilling operations began about noon. The well was drilled with a 9-7/8-inch bit to 23 feet to insure proper sealing of the well casing and an 8-1/2-inch Tri-cone bit was used below 23 feet. The hole was drilled to 155 feet in approximately five hours time without problems.

January 12, 1963 was another cold, clear day. Drilling operations did not commence until 11:30 a. m. and the well was deepened from 155 feet to 197 feet in approximately one hour.

Six-inch diameter plastic casing was then installed without problems, except it was necessary to push the casing down as it didn't have sufficient weight to readily sink through the drilling mud that filled the well. The casing was jointed with solvent weld couplings. About five minutes curing time was allowed for each joint before it was lowered into the well. At 4:30 p. m. the 15-foot section of well screen was dropped into the well, (Figure 6A). The screen had a closed bottom and was equipped with a self-sealing neoprene packer at the top. This

Figure 5

A. Mixing drilling mud. The test well, which is behind the mud pit, has been equipped with a submersible pump and is being used as a water supply.

B. Explanation of drilling procedures being given to interested observers.

A. Well screen about to be installed in Demonstration Well No. 1. Ray Schreurs of Edward E. Johnson, Inc. shown with screen.

B. Well screen about to be removed from Demonstration Well No. 1. "Dutch" Jungmann of Bucyrus-Erie Company is operating the drilling machine.

was the beginning of the many problems that were to follow in the days to come.

The well screen with a solid bottom and a self-sealing packer acted as a piston in a cylinder. The screen had to be pushed down the casing with a drill pipe and it was necessary to add water above the screen to equalize the pressure. When the screen had been pushed down to approximately 165 feet, the driller raised the casing about one foot by pulling on a coupling attached to the top so as to allow an easier passage of the drilling mud up around the outside of the casing. This allowed the screen to quickly settle to the bottom of the well. A few minutes after raising the casing, mud from the pit began flowing toward the well and cascading down along the outside of the well casing and water began flowing out of the top of the well casing which stood several feet above land surface. It was estimated that approximately 200 gallons of mud flowed down around the casing and an equivalent amount of water flowed out over the top of the casing. It was not immediately realized what had caused the exchange of mud and water in the well and at 5:30 p. m. the driller pulled up the casing to expose the screen. The casing was raised approximately 12 feet with very little effort. The drill pipe with a jetting nozzle attached to the bottom had been used to push the screen down the casing and was used to hold the screen down as the casing was pulled back. As it was getting late and as it was not realized that we were in serious trouble, it was decided that it would save time to begin developing the well with air rather than with the water jet as originally planned. Air was turned on with the jet at the bottom of the screen and the well was surged gently for about five minutes. Large amounts of sand and drilling mud were removed from the well during this period. As water and drilling mud began spraying onto the drilling machine, the air was turned off so that a deflector could be placed on the top of the casing.

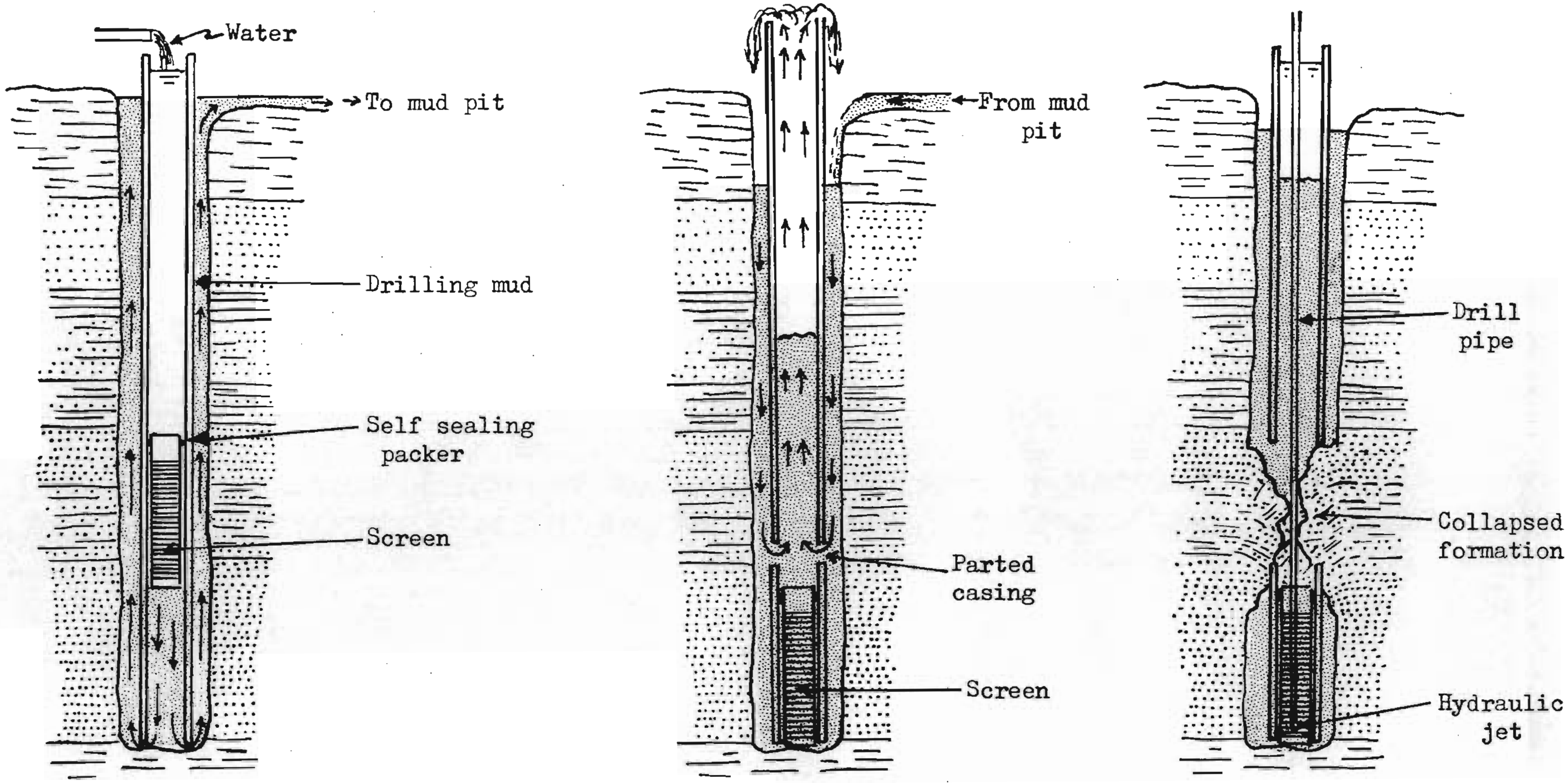
When the air was turned on it was found that the drill pipe was blocked and circulation could not be regained. High pressure water was also utilized to clear the drill pipe without success. It was then attempted to pull the drill pipe out of the well to remove the plug. The drill pipe could be pulled back approximately 12 feet with little effort to where it suddenly would tighten up and could be pulled back only with great difficulty. By pulling, pushing and rotating, it was possible to slowly raise the drill pipe. As the plastic casing also tended to move up, it was held down by blocking it against the drilling machine. The drill pipe was raised approximately 100 feet by 9 p. m. when it was decided to postpone operations until the following day.

During the night, those concerned with the construction of the well had time to recount the events of the previous day. By the morning of January 13, it was generally concluded that when the casing was raised the one foot to facilitate the lowering of the screen, a casing joint had parted. There was sufficient circulation around the bottom section of casing so that the screen could drop to the bottom of the well. The sudden cascading of drilling mud down around the outside of the well was caused by the difference in density between the drilling mud and the water that had been placed in the well and the drilling mud had free access into the well through the small opening created where the joint had parted. When the casing was pulled back to expose the screen, the upper section of casing was merely pulled away from the lower section, leaving approximately 12 feet of uncased well above the screen. The development with air brought in considerable sand which immediately settled down into the screen and blocked the drill pipe when the air was shut off. It was further concluded that the drill pipe was sand locked in the well screen and when it was pulled up 12 feet it encountered the bottom of the upper section of casing and was slightly offset. The tremendous effort required to raise the drill pipe more than 12 feet was due to the splitting and breaking up of the upper section of the well casing. The steps that led to the failure of this well are depicted on Figure 7.

With these conclusions in mind, it was decided that the best solution would be to remove the blocks that had been used to hold the upper section of casing in the ground, and pull the casing along with the drill pipe. It was found, however, that the hole had caved in around the casing during the night and that it was impossible to pull the drill pipe any higher.

It was decided that if the upper section of casing could be freed there would be no problem in pulling the screen and casing. We were all somewhat disappointed that we hadn't realized our situation the night before and had pulled the casing when it was free. It was then attempted to free the upper section of casing by jetting down around the outside with a 3/4-inch jet pipe (Figure 8A). It was found impossible to jet below 67 feet and the jetting operations which were continued throughout the day were unsuccessful.

On the morning of January 15, it was decided that the



Steps leading to the failure of Demonstration Well No. 1

A. Screen being pushed to bottom of casing. Water is added inside the casing to help equalize the pressure. Drilling mud is forced up around the casing.

B. When the casing was raised slightly to allow for the easier passage of drilling mud around the bottom of the casing, the casing parted above the screen. Heavy drilling mud began cascading down around the casing and water was forced over the top of the casing.

C. Formation exposed when upper section of casing was raised supposedly to expose the screen. Formation caved when development started.

Figure 7

Figure 8

A. Jetting operations on Demonstration Well No. 1.

B. Development of Demonstration Well No. 3 with a high pressure water jet.

quickest method of removing the screen would be to side-drill down along the casing. The drilling machine was moved back about 8 inches and a hole was quickly drilled to 100 feet. It was then found quite easy to pull the drill pipe and casing. It was a relief to find that the screen was indeed sand locked on the drill pipe and was apparently undamaged (Figure 6B). On a closer examination it was found that the neoprene self-sealing packer was damaged and that the bottom of the screen had been rotated about 90 degrees. This twist which was confined to the lower two feet of screen did not damage the screen and did not prevent the removal of the threaded bottom of the screen. We were all pleasantly surprised at the good condition of the screen considering the tremendous strain it had withstood during its removal. It was also found that the bottom of the drill pipe was within three inches of the bottom of the screen which attests to the tremendous strength of a sand-hitch.

CONSTRUCTION OF WELL NUMBER 2

After the screen had been removed from Well No. 1, the drilling machine was moved about 15 feet, and a new hole was drilled to a depth of 172 feet on the afternoon of January 15. On the morning of January 16, the hole was deepened to 198 feet. Plastic casing, identical to that used in the test well and in Well No. 1, was carefully jointed and installed. Two couplings, separated by a few inches of casing were placed on the bottom of the first section of casing and lowered into the well. Two heavy wire lines were attached to the casing between these couplings. These lines extended to the surface on the outside of the casing and were strapped to the casing at each joint as the casing was lowered into the well. These lines were to be used to pull the casing from the bottom to expose the screen so as to eliminate the threat of a joint separation. The casing was installed without incident and the well screen, which had been used in Well No. 1, was equipped with a partially preswedged lead packer, and was dropped to the bottom of the well. The screen was held down with the drill pipe and the casing was pulled back by the wire lines to expose the screen. The lead packer was then gently swedged so as to create a seal between the screen and the casing.

The drill pipe with a 20-foot length of 1-1/2-inch pipe on the bottom was lowered to the bottom of the well and clear water was pumped to flush out the drilling mud. The 1-1/2-inch pipe was used to eliminate the possibility of sand locking the larger diameter drill pipe in the screen. After the drilling mud had been removed from inside the casing and clear water was flowing over the top of the casing, the drill pipe was raised about 40 feet off the bottom and the well was pumped gently with air. Everything appeared to be proceeding as planned and the well was yielding water and find sand. Suddenly the well began to surge violently and water sprayed out the top of the casing and half way up the mast of the drilling machine. The air pressure was immediately turned off and the connections were changed so that circulation with water could be resumed. Upon starting the pump, it was found that the drill pipe was blocked and we could not gain circulation. As the drill pipe was being removed from the well, the plug broke loose and the pipe was cleared. As it was about 9:00 p. m., operations were stopped for the night.

On the morning of January 17 when the drill pipe was being lowered back down the well, it was discovered that there was a plug in the casing some 27 feet off the bottom. Clear water was again pumped down the drill pipe and water began flowing up on the outside of the casing rather than spilling over the top of the casing which was approximately 1-1/2 feet above land surface. The well was then gently pumped with air and large quantities of sand were removed from the well. As little headway could be made in removing the plug by pumping, a bailer was utilized in an attempt to remove the plug. It was soon found that the materials bailed from the well were too large to have passed through the well screen. It was immediately assumed that the swedging operations had split the casing and allowed the formation to pass into the well. The afternoon of the 17th and most of the 18th were spent in attempting to bail out the plug so that the screen could be retrieved. As little headway could be made, it was concluded that the break in the casing was some 10 to 13 feet above the top of the screen. It was then decided that a five-inch steel casing would be run down inside the plastic casing and pushed into the packer on the screen by use of an adaptor on the bottom of the casing. Arrangements were immediately made for the delivery of the five-inch casing so that operations could be started the following morning.

In recounting the events that led up to the failure of this well, it is concluded by the writer that the swedging operation was not responsible for the splitting of the casing. Subsequent swedging tests in a short section of identical casing failed to split the casing.

It was found, however, that this particular type of casing would split open receiving a sharp blow with a hammer. It is believed by the writer that the failure of the casing in the well resulted from a weakening of the casing by the swedging and a water hammer effect produced during the period of violent surging when most of the water had been exhausted from the well. A slug of water dropping a hundred feet or more in the casing and hitting the column of water standing in the bottom of the well is believed to have produced sufficient pressure to have ruptured the casing. Subsequent surging opened up the casing and allowed the formation to move into the well.

On the morning of January 19 after considering the numerous problems that could develop in attempting to telescope a 5-inch casing inside the plastic casing and the problems that might be involved in setting the casing into the well screen in case of an offset, it was decided that it would be quicker to drill a new six-inch well and utilize steel casing so as to eliminate the problems that had developed with the use of the plastic casing.

CONSTRUCTION OF WELL NUMBER 3

The drilling machine was pulled off Well No. 2 and moved approximately 20 feet. The screen was abandoned in Well No. 2 as time was not available for its recovery. Well No. 3 was drilled to 173 feet during the afternoon of January 19. On January 20 it was deepened to 203 feet and standard 6-inch welded-joint steel casing was installed. Three five-foot sections of 6-inch screen were provided by the Edward E. Johnson Company, Inc. These sections were welded together with a 20-slot screen on the bottom and two 18-slot sections on the top. A short section of steel pipe and a lead packer were attached to the top of the screen to reduce the possibility of pulling the casing out of the screen.

The screen was dropped into the well late in the afternoon on January 20. The screen bottomed at 202 feet and the casing was pulled back 16-1/2 feet without incident. The lead packer was swedged out to provide a seal between the casing and the screen. Clear water was circulated to remove the drilling mud from inside the casing. A high pressure water jet was then utilized to develop the well (Figure 8B). The jet, which shoots water out through the slots in the screen to break up the mud cake, worked well in removing large amounts of drilling mud and sand.

Development with the water jet was continued throughout the morning of January 21. In the afternoon the well was tested with a 5 HP submersible pump. The results of this initial test showed the water to be sand free and the well to have a specific capacity of 1.4 gallons per minute per foot of drawdown while being pumped 117 gallons per minute.

DEVELOPMENT OF WELL NUMBER 3

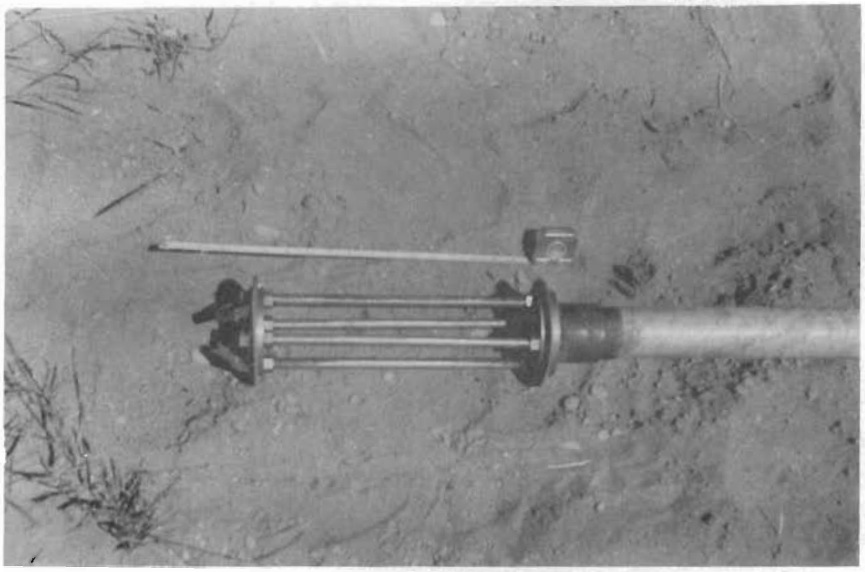
Well No. 3 was again developed during the Spring of 1963 by personnel of the Geological Survey, the State Park Department and the Oregon State Engineer. It was believed that the initial development with the high pressure jet produced very high water velocities out through the slots in the well screen, however, no method was employed to create higher entrance velocities in through the screen. Entrance velocities into the well through the screen during development should be greater than water velocities out through the screen.

In order to create high entrance velocities in through the screen it was decided to attempt further development of the screen by developing a shorter section at a time. To accomplish this, a packer was fabricated (Figure 9A) that could be telescoped inside the well screen. Neoprene gaskets were installed at the top and bottom of the packer assembly, which was about one foot in length, to prevent leakage around the ends of the packer. The packer assembly was attached to a 1-1/2-inch pipe and was lowered into the well screen. A centrifugal pump was attached to the 1-1/2-inch pipe and was used in development operations. It was found that this particular pump required the use of a check valve on the suction side of the pump which prevented any surging action during development. The pump capacity through the packer during development was approximately 30 gallons per minute, which gives an entrance velocity of approximately .6 foot per second (Figure 9B). This velocity was not sufficient to adequately develop the well, however, appreciable quantities of silt, fine sand, and drilling mud were removed.

Development started at the top of the well screen and the packer was periodically lowered a foot at a time with approximately 1/2 hour's pumping at each setting. After this operation, the packer was removed and the well was pumped at approximately 45 gallons per minute and produced clear sand-free water.

Five-hundred gallons of polyphosphate solution was prepared and poured in the well. After setting overnight, the pump was started and muddy water was pumped for approximately two hours. The well was again developed by use of the packer assembly as on the previous day

Figure 9



A. Packer assembly used in well development.

B. Well being developed through packer assembly and substantial quantities of drilling mud were removed. As sufficient pump capacity was not available, it was decided that further development with available equipment would not be effective. In comparing the short test made prior to the development with a similar test made after development, we calculated that there was about a 13 per cent increase in the specific capacity.

It is the writer's opinion that further development could have been accomplished if higher entrance velocity and some surging action could have been obtained. The use of the packer assembly on a turbine pump would have been a more effective method.

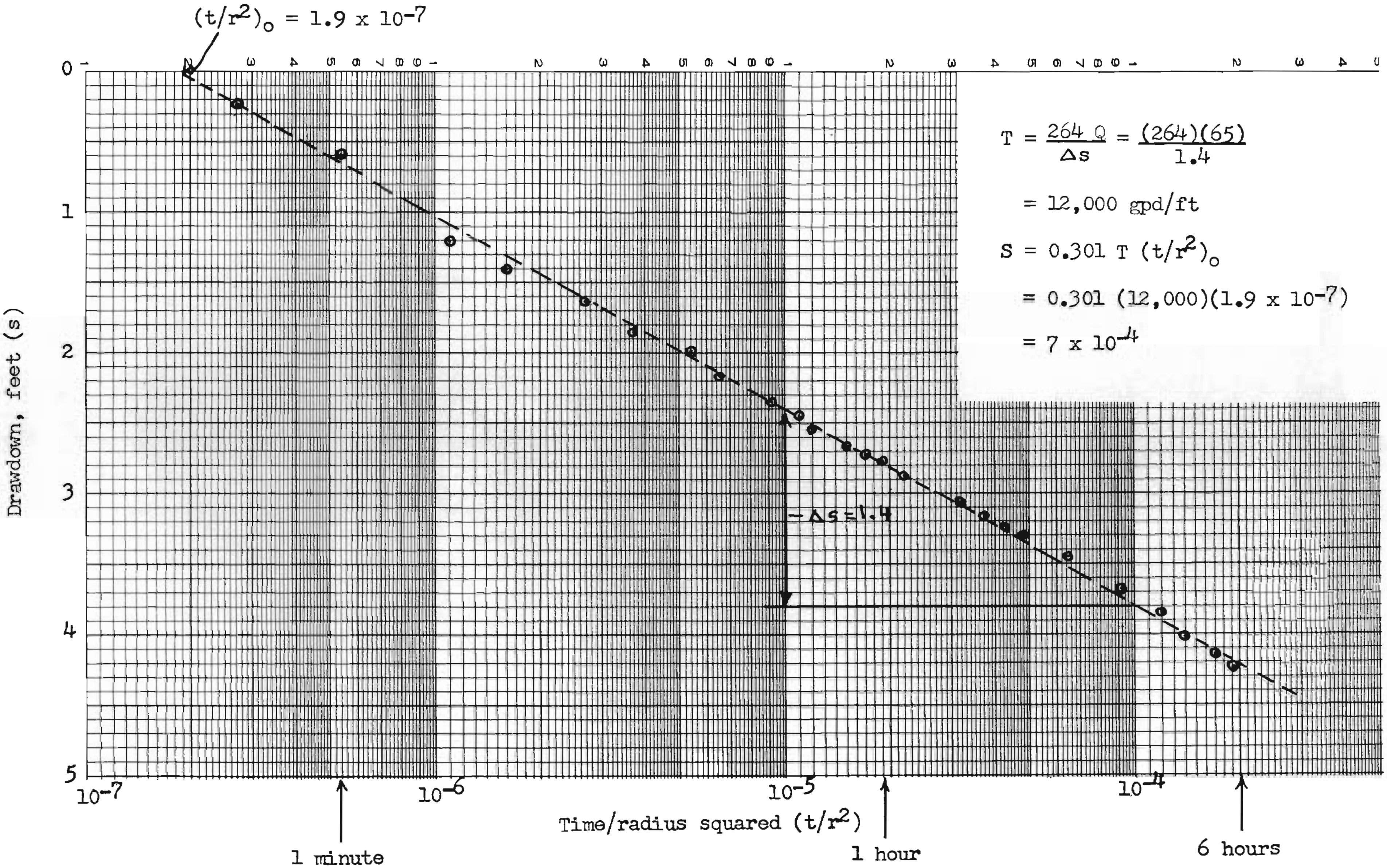
AQUIFER TEST

The demonstration well was equipped with a 3 HP line shaft turbine pump during the summer of 1963 for park use. A six hour pumping test was run on August 7, 1963, to determine the aquifer properties. An automatic water-stage recorder was installed on the original test well to record the water level adjacent to the demonstration well. Water level measurements in the pumped well and in Demonstration Well No. 2 were obtained by the use of an electric tape.

The pump was started at 10:00 a. m. and the pumping rate was maintained at 65 gallons per minute. The drawdown data for the observation well are given in Table 1. These data have been plotted on semi-log paper (Figure 10) and the aquifer properties have been calculated. The transmissibility (T) is 12,000 gpd/foot and the coefficient of storage (S) is 7 x 10 - 4. There were no aquifer boundaries apparent on the drawdown curve, and the proximity of the Willamette River has no effect on the yield of the well.

Drawdown in the observation well during the aquifer test on Well No. 3. Distance from pumped well to the observation well (r) is 36 feet.

Time since pump started (minutes)	Time since pump started (days) (t)	t/r^2	Drawdown, feet (s)
.5	.000347	2.7×10^{-7}	.24
1	.000694	5.4	.60
2	.00139	1.1×10^{-6}	1.21
3	.00208	1.6	1.40
5	.00347	2.7	1.64
7	.00486	3.7	1.85
10	.00694	5.4	1.99
12	.00833	6.5	2.17
17	.0118	9.2	2.35
20	.0139	1.1×10^{-5}	2.45
23	.0160	1.2	2.54
29	.0201	1.5	2.67
31	.0215	1.7	2.71
35	.0243	1.9	2.78
41	.0285	2.2	2.88
60	.0416	3.2	3.07
70	.0486	3.7	3.17
80	.0556	4.3	3.24
90	.0625	4.8	3.30
120	.0833	6.5	3.45
172	.119	9.2	3.96
217	.151	1.2×10^{-4}	3.86
270	.187	1.4	4.02
316	.219	1.7	4.15
352	.244	1.9	4.23



Drawdown in Observation Well During Aquifer Test

Figure 10

The specific capacity of the pumped well during this test was 2.3 gallons per minute per foot of drawdown. The drawdown in the pumped well is appreciably more than the theoretical drawdown. This is attributed to incomplete development. The use of a large capacity pump utilizing a surging action would probably increase the specific capacity and reduce the drawdown. It is the writer's opinion, however, that appreciable quantities of woody material occur in the water-bearing zone and that the woody or fiberous material has tended to block some of the openings in the well screen and has reduced the entrance area.

RECOMMENDATIONS

The Champoeg Park Demonstration well resulted in a number of conclusions that are recommended to the well drilling industry so as to prevent serious problems from developing in their well drilling operations. These recommendations are summarized below:

1. Never attempt to pull long strings of plastic casing from the top.

2. In selecting the slot size for a well screen, representative samples of the water bearing formation should, if possible, be obtained with a drive sampler, core barrel, or other sampling device rather than utilizing samples brought up in the drilling mud.

3. If an air lift pump is utilized in the development of deep wells, extreme care must be practiced so as to prevent the evacuation of the well which may cause violent surging and a water hammer effect.

4. When developing a deep well with air, never turn the air off with the air line pipe at or near the bottom of the well. Suspended materials will quickly settle to the bottom and can sand lock the air line pipe inside the well casing.

5. The use of a polyphosphate is recommended for use in all wells constructed with a hydraulic rotary machine utilizing drilling mud.

6. In constructing a well with a hydraulic rotary drilling machine, which in this demonstration resulted in 900 feet of drilling in 40 hours of drilling time, requires constant vigilance and sampling in order to adequately log the well.

SOME FACTORS TO CONSIDER IN THE DESIGN OF WELLS DEVELOPING WATER FROM SAND OR SAND AND GRAVEL

A well is a subsurface hydraulic structure designed and constructed so as to allow the passage of ground water from an aquifer into a chamber where it can be withdrawn for use. An understanding of the following terms is important to an understanding of well hydraulics.

Static Water Level - The depth to the water surface in a well when it is not being pumped. It is generally given as feet below land surface.

Pumping Level - The depth of the water surface in a well when it is being pumped. It is generally given as feet below land surface.

Drawdown - The amount the water surface in a well is lowered below the static level when the well is being pumped.

Cone of Depression - The surface of the water table or artesian pressure surface around a pumped or flowing well. Its shape is similar to an inverted cone and it produces the gradient or slope necessary to cause water to flow toward the pumped well.

Specific Capacity - The yield of a well in gallons per minute per foot of drawdown.

WELL DIAMETER

In wells developing ground water from a thick aquifer, the well diameter is not a large factor in the yield of the well. In general, the diameter should be approximately two inches greater than the diameter of the pump bowls to be installed. The well diameter and the amount of penetration into the water-bearing zone determines the surface area of the well casing that is in contact with the water-bearing formation that is available for perforating or screening. The following table gives the surface area per foot of well casing for casing of various diameters.

Casing Diameter Nominal Size	Surface Area Per Foot of Casing (Square Inches)
4	152
6	231
8	306
10	386
12	462
14	509
16	584
20	735
24	886

WELL PENETRATION INTO THE WATER-BEARING ZONE

In many ground water reservoirs there is a marked seasonal fluctuation of ground water levels. A well constructed and tested during a season of high ground-water levels may have a yield and specific capacity considerably different during seasons of low water levels. In order to obtain the maximum yield at any well site, the well should penetrate the entire thickness of the water-bearing zone. Such construction places more surface area of the well casing in contact with the water-bearing materials for development by perforating or screening and results in less head loss in the formation when the well is being pumped.

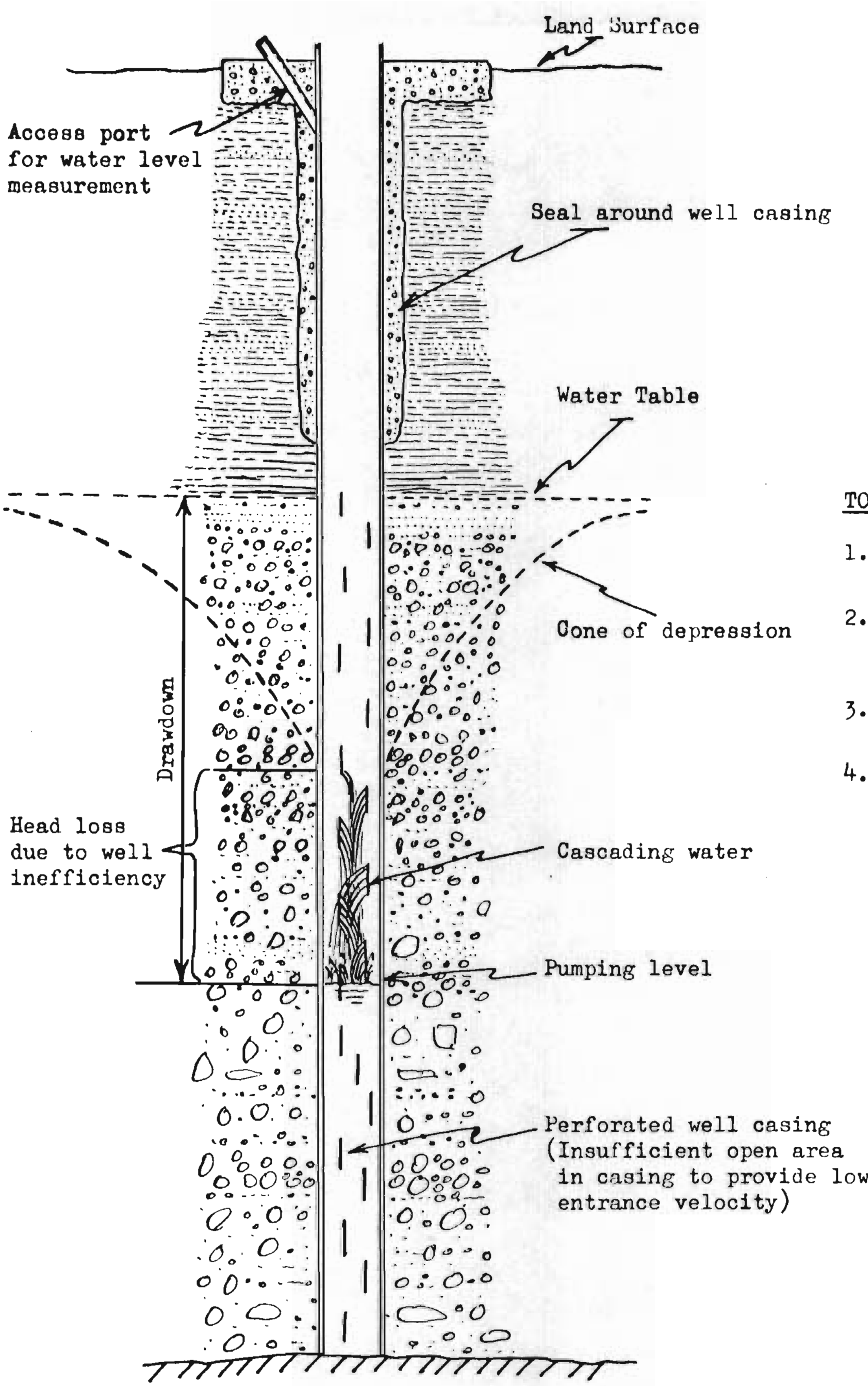
ENTRANCE VELOCITY

An efficient well is one where there is little head loss as water moves through the perforations or openings in the casing or well screen to gain entry into a well (Figures 11 and 12). High entrance velocities create water turbulence, which consumes energy, and can result in pumping levels appreciably lower than could be obtained in an efficient well. Well efficiency is generally not material in small capacity wells, however, it can be very costly in the operation of large capacity wells. For example, in an irrigation well pumping 1,000 gallons per minute, we'll assume it has an additional pumping lift of 50 feet owing to well inefficiency. If we further assume the power cost per KWH is $.01, the pump efficiency is 70%, the motor efficiency is 90%, and the pumping season is 100 days, the additional power cost due to well inefficiency would amount to $360.00 per irrigation season.

In general, an efficient well will have sufficient open area in the well casing or well screen to allow an entrance velocity of less than 0.3 foot per second. The number of square inches of open area leading into a well that is required to obtain an entrance velocity in the order of 0.3 foot per second can be closely approximated by multiplying the pumping rate in gallons per minute by two. For example, a well that is to be pumped 500 gallons per minute should have approximately 1,000 square inches of open area for the passage of water into the well. It is assumed that one-half of the open area is blocked with rock particles and is not available for the passage of water. The entrance velocity of a well can be calculated by the following equation:

$$\text{Entrance velocity} = \frac{\text{Gallons per minute } (0.64)}{\text{Open area in well casing or well screen in square inches}}$$

Figure 11



PROBLEMS COMMON
TO INEFFICIENT WELLS

1. Excessive pumping lift.
2. High entrance velocities causing sand problems
3. Restricted yield or production
4. Cascading water may result in air entrainment

Diagram depicting an inefficient well. Pump is not shown.

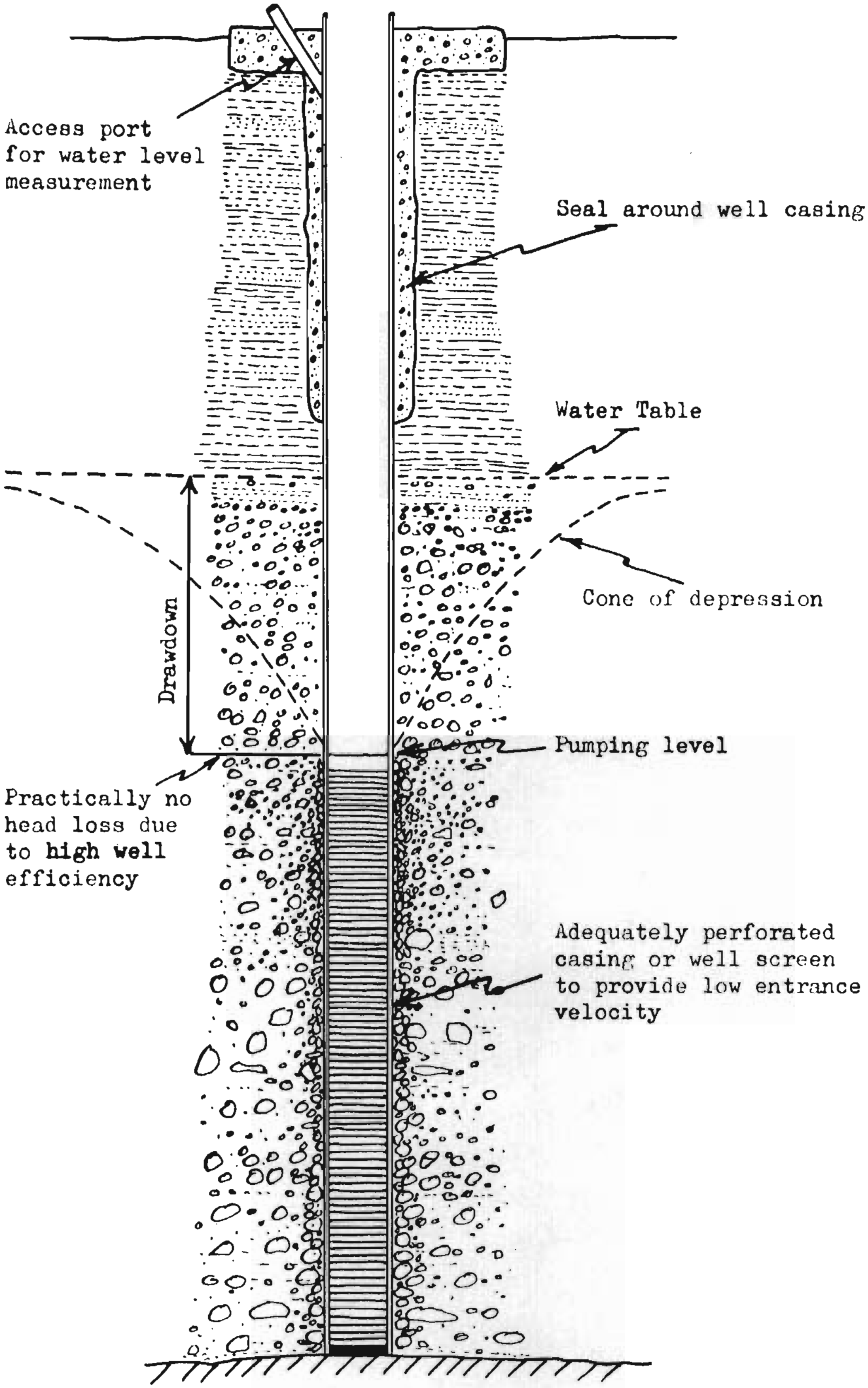


Diagram depicting an efficient well. Pump is not shown.

In the example given above, the calculated entrance velocity of the well pumping 500 gallons per minute with 1,000 square inches of open area would be computed as follows:

$$\text{Entrance velocity} = \frac{(500)\ (0.64)}{1{,}000} = .32 \text{ foot per second}$$

An examination of the records of 100 irrigation wells in the Northern Willamette Valley that have been completed with perforated casing shows that the open area in the perforated section of casing ranges from less than 0.2% to 16% and averages 3.3%. The acetylene torch cut perforation averaged slightly higher than the knife cut perforations with 5.4% open area. The calculated entrance velocities in some of these wells exceeds five feet per second.

Well screens generally range between 10% and 50% open area, being dependent largely upon the size of the slot opening. One advantage of well screens is that they will allow a large open area leading to the well to be placed opposite a water-bearing zone. Perforation or screens placed opposite tight or dewatered materials add little or nothing to well efficiency. The use of a well screen is particularly advantageous when the water-bearing zone is relatively thin.

If a commercial screen is not employed, a perforated liner with a high per cent of open area can be fabricated and installed like a well screen. Such construction will generally not be as efficient as a commercial screen, but would be substantially more efficient than the knife cut perforations.

A TEST TO DETERMINE WHETHER A WELL IS INEFFICIENT

When the pump in an inefficient well is turned off, partial recovery of the water level in the well will be very rapid as it is only necessary that the well casing be refilled to take care of the drawdown caused by well inefficiency. An easy test for determining whether a well that is developing water from sand and gravel is inefficient can be made by measuring the rate of water level recovery after a well has been operated for one hour. If over 90% of the drawdown produced by pumping is recovered within five minutes after the pump is shut off, it can be concluded that in most cases the well is inefficient.

For example, let us assume a well has a static water level of thirty feet below land surface prior to starting the pump. The pump is started and operated for one hour, and the pumping level is measured and found to be 120 feet below land surface, which is a drawdown of 90 feet. Ninety per cent of the drawdown then is 81 feet. A water level recovery of 81 feet would bring the water level up to 39 feet below land surface. The pump is shut off and if the water level in the well recovers to or above the 39 foot depth within 5 minutes, the well is inefficient, and an appreciable amount of the drawdown can be attributed to well inefficiency. The amount of water in the pump column that may drain back into the well during recovery will have a negligible effect in this test as a productive aquifer would readily absorb this quantity of water. The water level in the well 5 minutes after the pump has stopped would be representative of the water level in the aquifer.

An air line provides an easy method of measuring both static and pumping water levels. In wells where the drawdown is large, one air line may not be suitable for making both measurements. Two air lines may be necessary, one to measure pumping levels and one to measure static levels. An air line generally consists of a quarter-inch pipe that extends down the well between the pump column and the well casing. The amount of air pressure that can be built up inside the air line before air starts bubbling out the bottom will be indicative of the depth of water standing above the bottom of the air line. The exact depth to the bottom of the air line must be known to obtain an accurate measurement of the water level. A pressure of one pound per square inch in the air line is equal to 2.31 feet of water. The pressure is generally measured by a gage attached to the top of the air line and the air pressure is supplied by a tire pump.

If a well is found to be inefficient and the pumping cost and drawdown are appreciable, the owner may wish to repair his well so as to improve its efficiency. This can often be done by placing additional perforations in the well casing, installing a well screen or drilling the well deeper to obtain fuller penetration of the water-bearing zone.

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