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PAPER 67-56

FLOW CONTROL PROGRAM, COLDSTREAM RANCH WELL, VERNON, BRITISH COLUMBIA

(Report and 16 figures)

J. S. Scott

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ABSTRACT

This report describes the procedures undertaken in order to confine a high pressure artesian aquifer which, because it was flowing through an uncased exploratory drill-hole, had immediately attained an uncontrolled state. Eight conclusions, which should be of interest to anyone undertaking drilling programs in similar terrain, are drawn from the study.

FLOW CONTROL PROGRAM, COLDSTREAM RANCH WELL, VERNON, BRITISH COLUMBIA

INTRODUCTION

In June 1965 a field party of the Geological Survey of Canada carried out a contract drilling program to assist in a study of the Pleistocene deposits of the Vernon map-area in south-central British Columbia. One of the drill-holes, located on the property of the Coldstream Ranch about 5 miles south of Vernon, British Columbia (Fig. 1) encountered a previously unknown high pressure artesian aquifer at a depth of about 200 feet (Fulton, 1966).

The initial flow from the 6 1/2-inch diameter rotary-drilled hole was estimated at 500 Imperial gallons-per-minute with a surface pressure of between 30 and 50 p.s.i. Because the hole was uncased and the volume and pressure of the flow was such that it could not be contained by weighted drilling mud, the flow immediately attained an uncontrolled state. In view of the location of the artesian flow (in a populated area) control was necessary to eliminate property damage. This report describes the various phases of the work done to bring the flow under control.

The well-site, at an elevation of 1,550 feet above sea-level, is centred in the valley drained by Coldstream Creek which flows westward to empty into Kalamalka Lake. To the north and south the valley is bounded by mountains that rise to elevations of 4,600 feet, 4 miles from the valley.

According to Jones (1959) granitoid gneiss and other Precambrian (Archaean) rocks of the Shuswap Terrane form the mountains and underlie Coldstream Valley.

Beneath the floor of the valley Pleistocene deposits, at least 200 feet thick, were encountered during the drilling (Fig. 2). In descending order these comprise fine- to medium-grained sand, stratified soil and clay, sand and gravel, sandy till and coarse gravel. These deposits indicate that during the Pleistocene Epoch the valley was the site of deposition resulting from glacial outwash, direct glaciation and lacustrine and fluvial sedimentation.

The presence of relatively impermeable layers of till and silty clay overlying layers of coarse gravel, and the high relief surrounding the valley, have combined to produce an ideal hydro-geological setting for an artesian aquifer. Although the mean annual total precipitation in the area is only about 15 inches, the behaviour of the flow during the period following its initiation suggests that the aquifer is extensive and that the drawdown cone has expanded to a position where the discharge is being replaced by recharge. Consequently, the well is in a state of dynamic equilibrium.

Attempts to control the flow from the well were made at various times between June, 1965 and April, 1967, when the flow-control project was completed. The description of the flow-control program which follows is presented in chronological order according to the various phases of the work.

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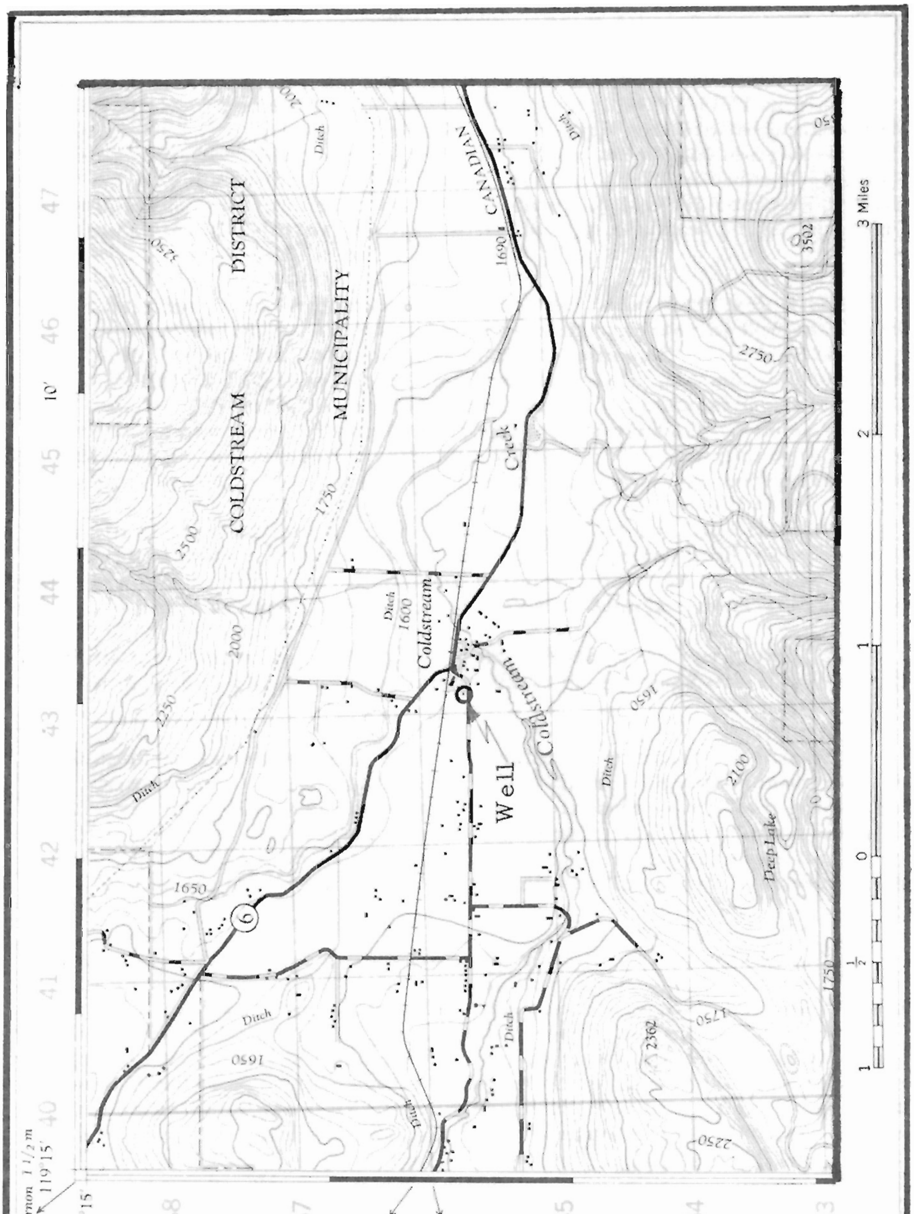

Figure 1. Location map

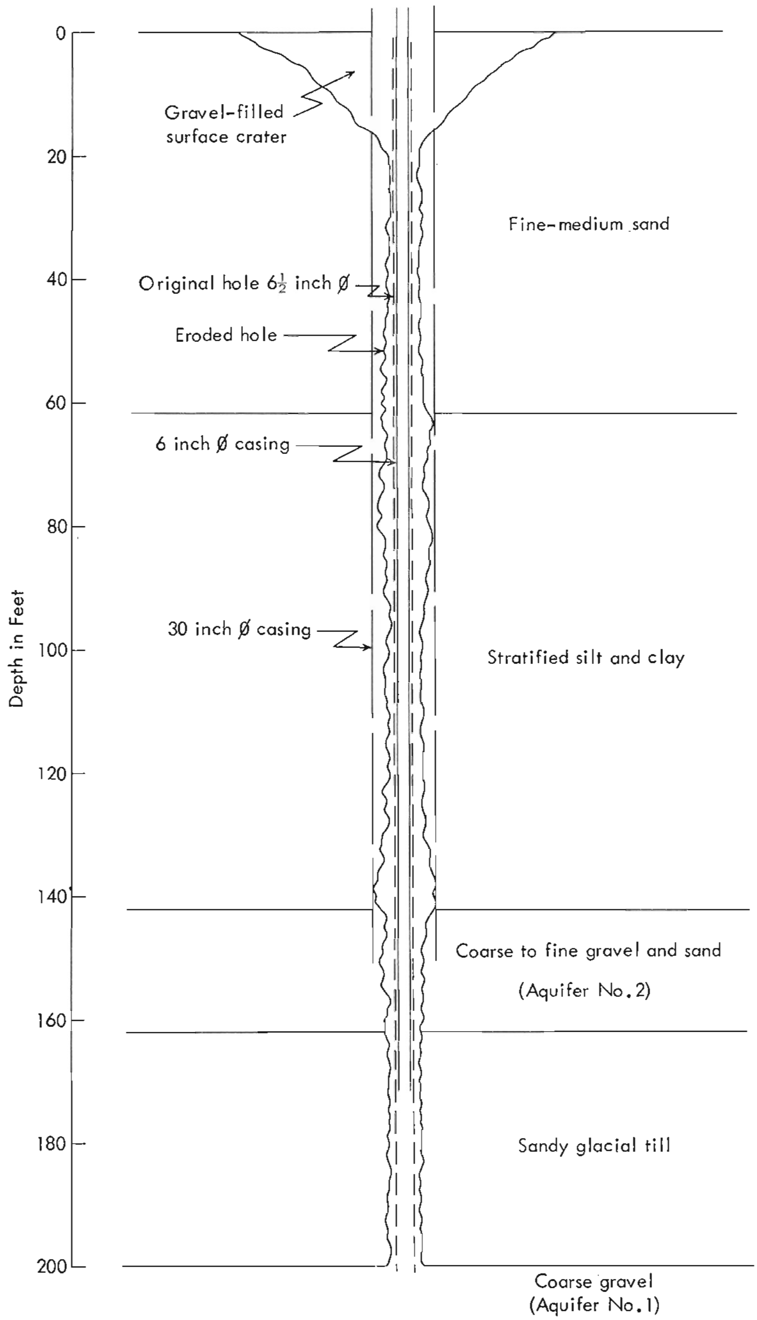

Figure 2. Stratigraphy at the well site.

PHASE I

The intensity of the initial flow from the hole was such that difficulty was experienced in removing the drill-stems from the hole as the large quantities of sand and gravel carried with the flow tended to wedge the bit. In addition, the surface sand was eroded rapidly by the flow and the upper layers of sand assumed a quick condition. However, the drill-stem was removed from the hole and the drilling rig moved from the site only a short time before a crater about 25 feet in diameter developed in the unstable surface soil surrounding the hole.

The first attempt at shutting off the flow was made one week after flow began and involved pumping 300 sacks of calcium-chloride-activated portland cement in slurry form through two 2-inch pipes jetted to depths of about 150 feet at the centre of the crater. This attempt effected a temporary reduction in discharge quantities but the original flow quantity resumed about one hour after grouting ceased. Further grouting was not attempted at this stage.

It was then decided to attempt to place a casing in the hole through which cement-grout could be pumped. In preparation for this work, the cratered area was back-filled with pit-run gravel and bridging across the site was provided by two long timbers. After considerable difficulty 6-inch diameter insert joint casing was forced into the hole to a depth of 170 feet where it met refusal.

Although the casing provided access for grout to the lower strata, it aided very little in confining the flow as the original hole had been considerably increased through erosion. Upon completion of the casing installation, about 80 per cent of the flow was discharged through the annulus between the casing and the hole (Fig. 3).

PHASE II

The first attempt at grouting showed that the drilling pumps used were inadequate to inject the volume of grout that would be required to shut off the flow. An oil field type cement-pumper was therefore obtained for use on the project.

In a preliminary trial a batch of 8 barrels of heavy drilling mud and sawdust followed by 100 sacks of portland cement in slurry form, were pumped through the 6-inch casing. It was expected that this material, or at least part of it, would be returned to surface through the annulus. However, no mud or cement returns were observed until several hours after the grout input and then only in trace amounts. The input trial also produced no flow reduction.

Figure 3.

Discharge of groundwater from 6 inch casing and from crater around well. July 1965. GSC 118628

At the time these facts seemed to indicate that the grout had been pumped below the main aquifer and that the main flow was being derived from aquifer No. 2 (Fig. 2) at a depth of 150 feet which was above the bottom of the casing. Although the exact flow-path of the grout is not known, it is possible that the lack of surface returns may have been caused either by discharge of the grout into the lateral flow through aquifer No. 1 at 200 feet, or partial return up the annulus and then lateral flow through aquifer No. 2, or a combination of both. In any event it was decided not to attempt further grouting through the 6-inch casing and that the grout input should be at the 150-foot level.

As timber bridging provided the only safe access over the site, the location of additional grout-pipes was confined to a line between the timbers. Four 2-inch diameter grout-pipe locations were selected at distances of about 3 feet and 6 feet on either side of the 6-inch casing. Although an attempt was made to fit these pipes to a depth of 150 feet with the use of a rotary drilling rig, none of the pipes attained that depth. One of those closest to the 6-inch casing met refusal at 132 feet and the other at 80 feet and both of the pipes farthest from the casing met refusal at a depth of 50 feet. All of the 2-inch pipes produced substantial flows of water both through and around the pipe prior to the injection of cement.

Small batches of quick-setting gypsum cement-grout were pumped down each of these pipes. Almost all of the grout injected through these pipes was returned to surface either by flow around the grout-pipe itself or by flow issuing from around the 6-inch casing. It was then apparent that further attempts at portland cement grouting would have to be done with the aid of relief wells to effect aquifer pressure reduction and thereby reduce the surface return of the cement grout. In addition it was apparent that both relief wells and grout-pipes would require surface casing to be cemented in place before any casing could be installed at greater depths. The second attempt at grouting was then abandoned until relief well supplies could be obtained.

PHASE III

In preparation for the third attempt at grouting, two 2-inch diameter grout-pipes were installed 8 feet apart at a distance of 25 feet to the south-southeast of the 6-inch casing. These installations were constructed by first cementing 30 feet of 4 1/2-inch surface casing in place and then drilling through the casing and on to a depth of 155 feet with heavy mud (11.2 pounds per U.S. gallon). The 2-inch diameter pipes were sealed in the surface casing by a rubber packer constructed from a casing wiper-plug as shown in Figure 4.

Figure 4. Initial stage of collapse at well site. August 1966. Note wiper plug used as casing seal on 2 inch pipe. GSC 118665.

During the drilling to a depth of 155 feet it was found that 11.2 pounds per gallon mud would contain the flow but upon removing 30 feet of drill-stems from the hole the mud columns became unbalanced and upward flow began. It was thus apparent that the mud-sump of the dried rig would be insufficient to provide adequate quantities of mud for drilling of the larger diameter holes required for the relief wells. To provide adequate quantities of drilling mud, a plywood-lined dug-sump of about 50 barrels capacity was constructed and the drilling mud was premixed in the sump by use of the cement-pumper (Fig. 5).

Figure 5. Mud sump and grout pipe installations, July 1965. GSC 118631.

Two relief wells, numbers 1 and 2, located as shown in Figure 6, were constructed at the site. Relief Well No. 1 penetrated aquifer No. 1 at depth of 210 feet and Relief Well No. 2 extended into aquifer No. 2 at 155 feet.

Each well consists of 32 feet of 13 3/8-inch flush joint surface casing cemented in place prior to the installation of 125 feet of 8 5/8-inch T. and C. intermediate casing also cemented in place by the displacement method. No difficulty was experienced in containing the flow with heavy mud during the drilling to a depth of 125 feet. It was necessary, however, during the drilling of holes for the relief wells, to circulate the weighted mud through the drill-stems by means of the cement-pumper as the rig pump was inadequate to handle the volume of mud required.

A 6 1/4-inch hole was then drilled through the intermediate casing in each relief well to the depth necessary to reach the required aquifer. The 4 1/2-inch production casing fitted at the lower end with 12 feet of No. 15 slot Johnson well-screen, was then placed to complete the relief wells. The top of the production casing in each well was at a depth of about 80 feet and a seal between the 4 1/2-inch casing and the 8 5/8-inch casing was made by a casing wiper-plug.

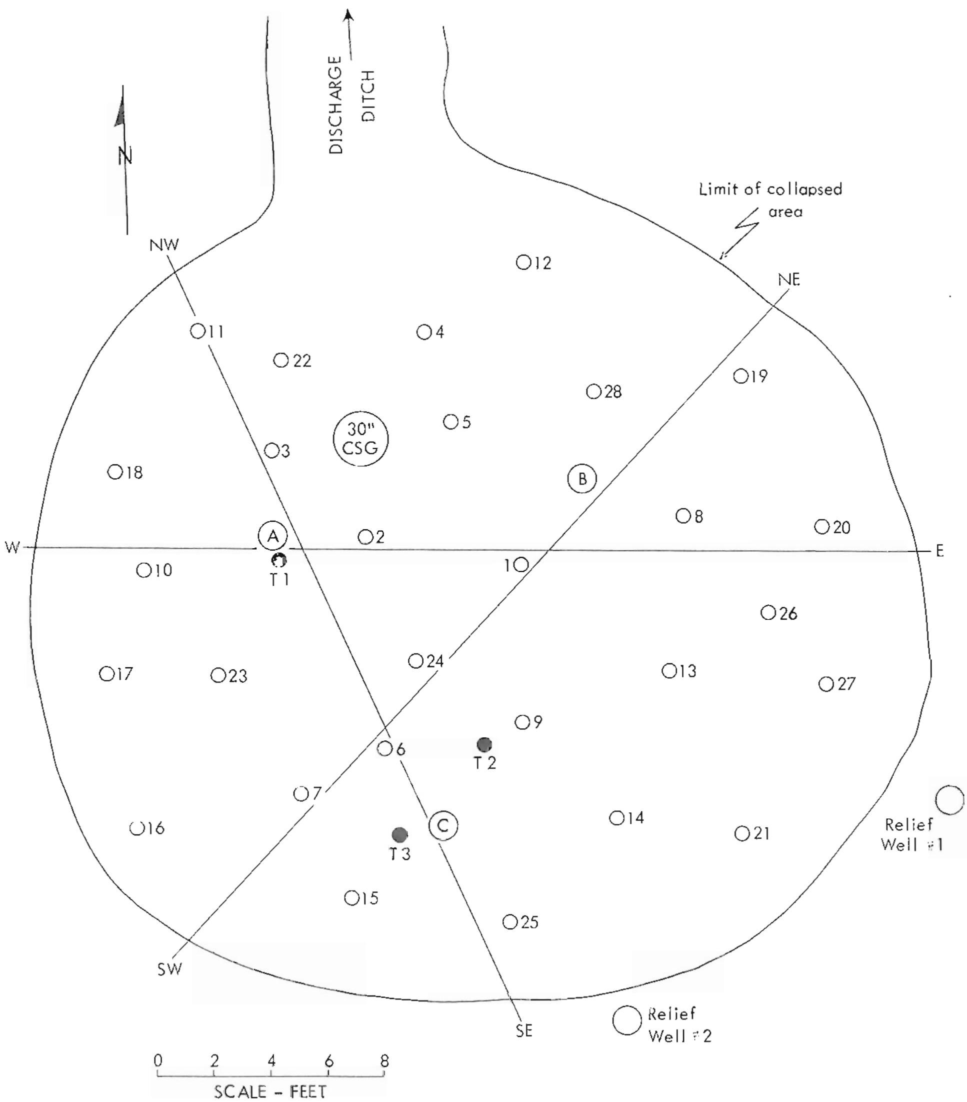

Figure 6. Plans of grout, observation and test-holes in crushed-rock fill.

Drilling to the final depth of the hole was done with mud having a weight of 13.2 pounds per gallon. Although the mud was of sufficient density to control the groundwater pressure, the constant migration of the mud columns to the flow zone around the original hole required continual replacement of the drilling fluid. Under the conditions of groundwater flow that existed at the site, it was almost impossible to maintain a balance between the mud column and the hydrostatic pressure. If the mud density was too low, the mud column was ejected from the hole by groundwater flow and if overweighted, the mud column migrated through aquifer No. 2 and was lost to the upward flow at the original hole.

Upon completion of Relief Well No. 1, an 8-inch turbine pump was run in the well with the pump bowls set at a depth of 70 feet. The pump had a capacity of about 600 gallons-per-minute but it was found that the well-screen would not produce a sufficient volume of water to allow the pump to run at full capacity. As a result, insufficient pressure relief at the crater was obtained. A similar experience occurred with Relief Well No. 2.

In order to increase the flow from Relief Well No. 2, the screen was perforated with a primacord shot and an airlift pump was installed. The well then produced about 1,000 gallons-per-minute accompanied by an abundance of silt and clay fragments. Even this flow quantity failed to provide sufficient pressure relief to reduce the flow from the crater to a level that would permit portland cement grouting.

The lack of success of the relief wells was due primarily to the selection of a screen-slot size that was too small to permit the entry of a sufficient volume of water. The effectiveness of the relief wells could probably have been increased by the use of 80 or 100 slot-screen and airlift rather than turbine pumps. However, from the experience of airlift pumping at Relief Well No. 2, a discharge of about 1,000 gallons-per-minute from each relief well would have been required in order to obtain the necessary pressure relief.

At this stage in the program it was apparent that further portland cement grouting would not be effective in the absence of high capacity relief wells. Before suspending the program, an attempt at flow-control was made by pumping Relief Well No. 1 at its maximum capacity and simultaneously injecting a 90-barrel batch of lost circulation gum containing 170 cubic feet of sawdust into a 2-inch grout-pipe, at a depth of 50 feet, located 8 feet west of the original hole. This material had the effect of temporarily stopping the flow but the material was unable to form a permanent seal in the upper sand and flow resumed unabated.

In view of these failures and of the costs involved in constructing additional relief wells of the capacity required to permit a successful grouting operation, the flow-control project was suspended and consideration was given to alternative methods of control.

PHASE IV

During the fall of 1965 a firm of consulting engineers was engaged to examine the site and to present a proposal for such surface structures as would be necessary for the filtration, collection and discharge of the artesian flow. A suitable design was prepared by the consultants but they pointed out that no guarantee of ground stability could be given under the conditions of flow that existed at the site and that continued high maintenance costs of the surface structures could be expected. The consultants also recommended that sealing off of the flow by grouting offered the only permanent solution to the problem.

An indication of the unstable character of the ground around the well was given by the fact that sediment continued to be discharged with the flow and that gravel had to be added to the site at numerous occasions throughout the fall and winter of 1965-66 to fill small craters that developed (Fig. 7).

In view of the previous unsuccessful attempts at portland-cement-grouting it was recognized that this type of work would be costly and could only be done if sufficient pressure and flow reduction could be obtained through the use of relief wells. Consideration was given, therefore, to the use of chemical-grout which had the advantage of being able to penetrate fine grained materials and of being a material that would set quickly and perhaps thereby eliminate loss by dilution.

Figure 7. Cratered area in gravel fill at well site, July 1966. GSC 125295

Enquiries were made to various United States government organizations and to the manufacturer of the chemical-grout to determine whether or not this material could be used under the flow conditions that existed at the well. It was learned that although chemical-grout had been used to seal the flow from bore-holes, there was very little experience in the use of the material under the severe conditions of pressure and flow that existed at the site. During the course of these enquiries a firm of grouting consultants, familiar with both chemical- and cement-grout techniques, was recommended. An engineer of the firm was then engaged to review the work that had been done and to prepare a proposal for a flow-control program.

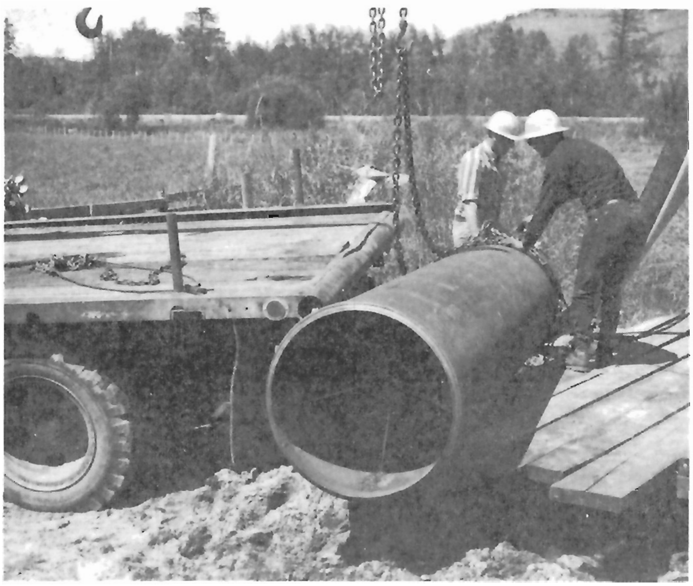

Figure 8. Guide shoe on initial length of 30 inch casing. GSC 125288.

The flow-control program as presented by the consultant consisted of three main elements:

1. the installation, by driving rather than drilling, of a 30-inch diameter casing centred about the 6-inch casing in the original drill-hole; this casing was to be firmly seated in the clay strata at a depth of about 100 feet with the intention of confining all of the flow within the casing;

2. excavation of the surface material in the cratered area around the 6-inch casing following installation of the large diameter casing and the pouring of a concrete plug into the excavated area;

3. consolidation of the upper sand strata with the use of chemical-grout by injecting the grout through a ring of holes located in the concrete pad. It was considered possible that relief wells might have to be used during this part of the operation.

The first requirements of the program, therefore, were to locate a contractor with equipment capable of driving the casing and to obtain the casing in approximately 10-foot lengths yet fabricated in such a manner that the lengths could be joined in the field by welding under conditions of flow inside the casing. After considerable investigation by the grouting consultant, it was found that the equipment requirements could be met by the Canadian-designed and built Becker model BDT-250 Hammer Drill which was equipped with an 8,000 ft. lb./p.s.i. diesel pile-driver. The drilling contractor also designed the casing with insert joints formed by steel bands welded to the inside and outside of the casing at one end of each casing-length. The initial length of casing was fitted with a drive-shoe at the bottom and a guide-ring on the inside of the casing to keep it centred about the 6-inch casing in the original hole (Fig. 8).

PHASE V

Before the flow-control program using the 30-inch casing could be put into operation, it was necessary to have all of the required materials and equipment ordered and delivered to the site. The equipment ordered for the project consisted of the Hammer Drill, an hydraulic hoist-equipped, flat-deck truck for handling materials at the site, an electric welder, cement-grout-pump and mixing plant, chemical-grout-pump and mixing equipment, and a portable air compressor for operating the pumping equipment. The materials consisted of the lengths of 30-inch casing and driving-head, casing and screens for the relief wells, and 5,000 pounds of chemical-grout and associated chemicals; portland cement was locally available in the quantities anticipated for its use.

The equipment and materials were assembled and delivered to the site in time for work on the project to begin in July, 1966. The site was first levelled by a front-end loader and a work-platform was constructed using logs and rough timbers.

In preparation for driving the casing, the driving-head, containing a discharge port in the side, was first connected to the pile driver by a connecting knob welded to the top of the head. The initial length of 30-inch casing containing the guide-shoe was then hoisted into place over the 6-inch casing and the driving-head was fitted into the insert joint at the top of the casing-length. As each length of casing was driven to the limit of travel of the pile driver, the head was disconnected, a plastic O-ring was inserted into the joint followed by the insertion of the next casing-length and the joint was completed by welding (Fig. 9). As flow occurred inside the casing (Fig. 10) it was necessary to replace the driving-head on the top of the casing-length being welded in order to keep a flow of water away from the welding operation. At times when leakage of water from the joint at the driving-head occurred, the water running down the outside of the casing could be kept away from the welding operation by diverting the flow with a stream of compressed air.

Figure 9. Welding 30 inch casing joint. Driving head in position on casing in preparation for driving casing with the diesel hammer. GSC 125293.

The time required to drive the casing varied from 11 minutes to 57 minutes per length (Fig. 11). The time of driving per length increased rapidly during the driving of the first four lengths as the casing was being driven through gravel fill that had been partly grouted during the previous operations and during the driving of length No. 4, the guide-shoe sheared off the 6-inch casing which was apparently not plumb. From length No. 5 to length No. 7 the driving rate decreased and the remainder of the casing was driven down at a rate of about 20 minutes per length.

During the driving of the 30-inch casing, minor collapse of the surface soil occurred at various times due to soil disturbance and the cratered areas were back-filled with pit run gravel. A further cause of collapse resulted from strong groundwater flow around the casing when the flow inside the casing became blocked by compacted silt and clay during the driving. Thereafter after each casing-length was driven, the casing was cleaned out by loosening the material by rotary drilling inside the casing and by evacuating the loosened material with an airlift pump.

When the 30-inch casing had been driven and cleaned out to the originally intended depth of 100 feet, the flow outside the casing essentially ceased and it was apparent that the 30-inch casing was capable of containing

Figure 10. Full flow over the top of a 10 foot length of 30 inch casing. GSC 118661.

the flow. In view of the reduction in driving rates with depth, however, it was felt that the 30-inch casing may have been seated in disturbed material and that it would be desirable to seat the casing in the gravel of aquifer No. 2 at 150 feet.

Five additional 10-foot lengths of casing were ordered and shipped to the site. During the driving of these additional lengths, the incidence of surface collapse increased as flow became plugged-off inside the casing. Although the flow had been restored on several occasions by cleaning out the 30-inch casing, considerable difficulty was experienced in restoring the flow following the driving of the last length of casing.

During the attempt to clean out the casing by rotary drilling, cratering at the edge of the work-platform was observed. As the crater was being rapidly enlarged the rotary drill-head was promptly disconnected from

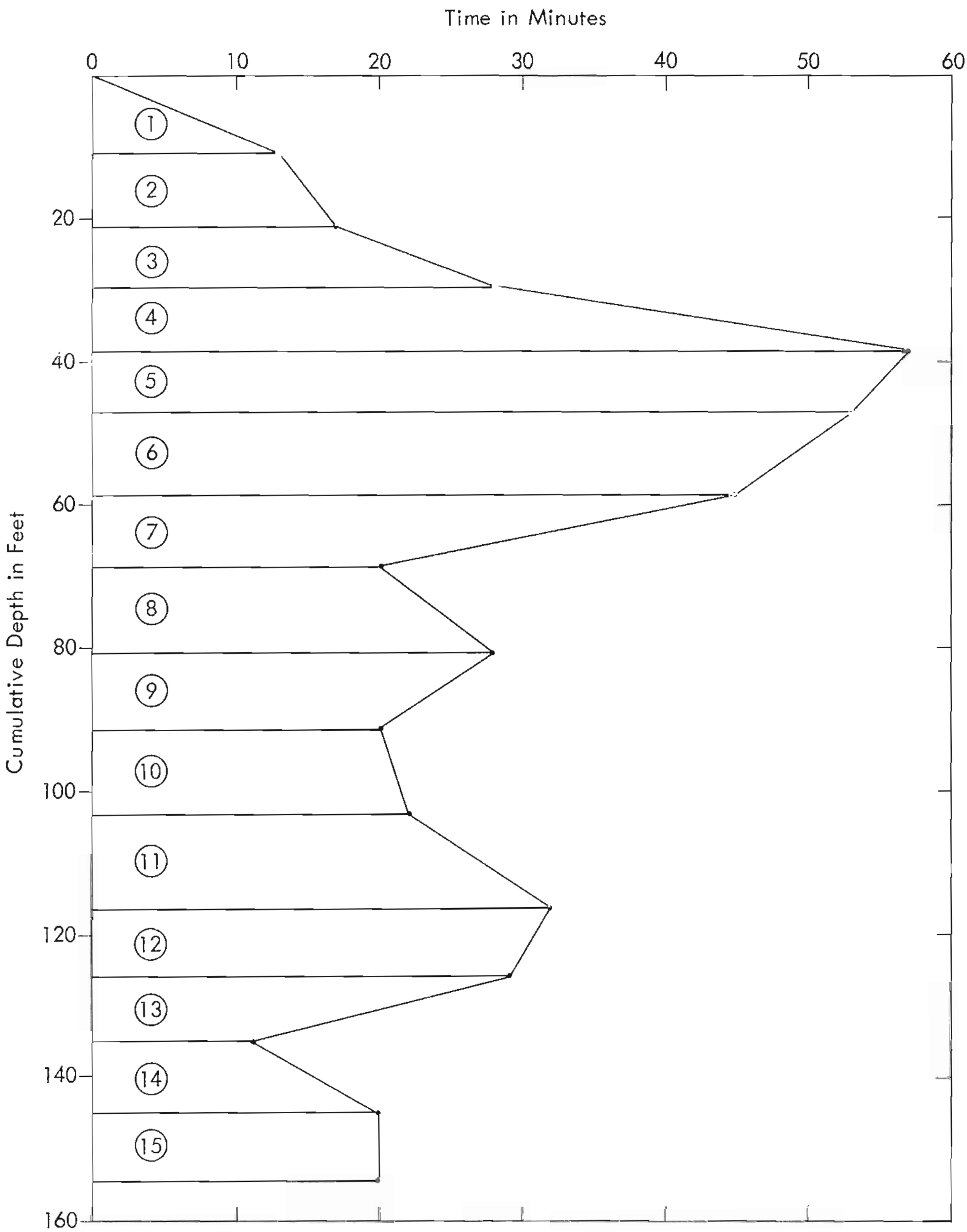

Figure 11. Variation in driving time with depth during installation of the 30-inch casing.

the drilling and left on top of the 30-inch casing, the drill-rod was left in the casing and the rig was removed from the platform. Disconnecting of the rotary drilling equipment in this case was a simple matter of disconnecting the hydraulic lines to the rotary drill-head and hydraulic pullers in which the rotary drill was mounted. Within 30 seconds of removal of the rig from the platform, the ground beneath the platform collapsed into a crater that expanded to a diameter of 35 feet (Fig. 4) and which was probed to a depth of 80 feet along the side of the 30-inch casing. The collapse of the ground was accompanied by an extreme turbulence of muddy water and at several stages during the collapse all flow from the crater ceased - flow from the crater resumed in force at the conclusion of the turbulence. Fortunately no injuries or loss of equipment were sustained during the collapse, but a stock of 6-inch and 8-inch well-casing disappeared into the crater along with the surface-cased 2-inch grout-pipes that had been installed previously at the south side of the site (Fig. 4).

The edge of the crater extended almost to the relief wells but the surface casing around these was not disturbed. During the entire period of turbulence that occurred with the collapse, no vertical or lateral movement was observed in the 30-inch casing which attested to its being firmly seated in the gravel at 150 feet. It is almost certain that the 30-inch casing would have either settled or tilted or both to a point beyond recovery had it been seated at the originally planned depth of 100 feet.

In the morning following the collapse it was found that the crater had not expanded beyond the maximum dimensions of the previous night. The task of filling the crater with crushed-rock then began and before completion 480 cubic yards of crushed-rock were end-dumped into the crater.

When the site had been restored by the crushed-rock fill, a new work platform was constructed and the clean-out of the 30-inch casing was resumed by both rotary drilling and airlift pumping. After several days of the clean-out operation, the clay plug that had blocked the flow was removed and flow resumed in the 30-inch casing. At the conclusion of the clean-out operation, a flow of only a few gallons per minute was issuing from the granular fill, the remainder of the flow being confined to the 30-inch casing.

The extensive soil collapse required a complete change in the remainder of the plan for flow-control. It was now necessary to consolidate the crushed-rock fill with cement-grout and it was estimated that between 2,000 and 3,000 sacks of cement would be required for this purpose. It was also decided that before grouting the fill should be allowed to settle for about one month in order to reduce excess voidage and consequently the operation was suspended to permit settling and to prepare a program for grouting.

Although the collapse caused an extensive set-back in the progress of the flow-control program, it was fortuitous that it occurred before an attempt had been made at chemical grouting as originally planned. It would not have been possible adequately to grout the extensive voidage that must have existed at the site prior to the collapse and it could have been disastrous if the collapse occurred either during or following the grouting.

The soil disturbance and disruption of flow caused by driving the casing undoubtedly triggered the collapse. However, the conditions for collapse were present as a result of the voidage created by the continual removal of material with the groundwater discharge from the time that flow was first encountered plus the disturbance at depth caused by the installation of grout-pipes and relief wells.

PHASE VI

Work on the flow-control project resumed in early October, 1966 following the completion of arrangements for the equipment and materials required for the consolidation grouting of the crushed-rock fill.

A plan of grout-holes was prepared (Fig. 6) such that the 1 1/2-inch pipes, through which the cement-grout was to be injected, were located at about 4-foot centres. The plan also provided for 3 observation pipes consisting of perforated casing so that the level of grout could be checked during the course of grouting. The location of the observation pipes are shown as A, B, and C on Figure 6.

The depths of the grout-holes were estimated during the planning stage to allow for adequate supplies of pipe but the actual depths were determined by the thickness of the gravel fill encountered during drilling. Ideally the grout-pipes should have been placed before the crushed-rock fill was added to the crater but to do so was impractical. In view of the difficulties that would be encountered in rotary drilling through the loose crushed-rock fill, the best method for installing the pipes was by use of the Hammer Drill.

The Hammer Drill uses a double-walled drive stem with a pilot bit that is driven into the ground with the diesel hammer. The drilling fluid (either compressed air or fluid) is pumped down the outer annulus and then jetted up the 3-inch diameter opening in the centre of the stem, thus carrying cuttings to the surface. For the purpose of installing the grout-pipes, the drive-stem was driven down until the soil below the gravel fill was encountered. The grout-pipe, fitted with a plastic slip-on cap at the lower end, was

Figure 12. 1 1/2 inch diameter grout pipes installed in the crushed rock fill.

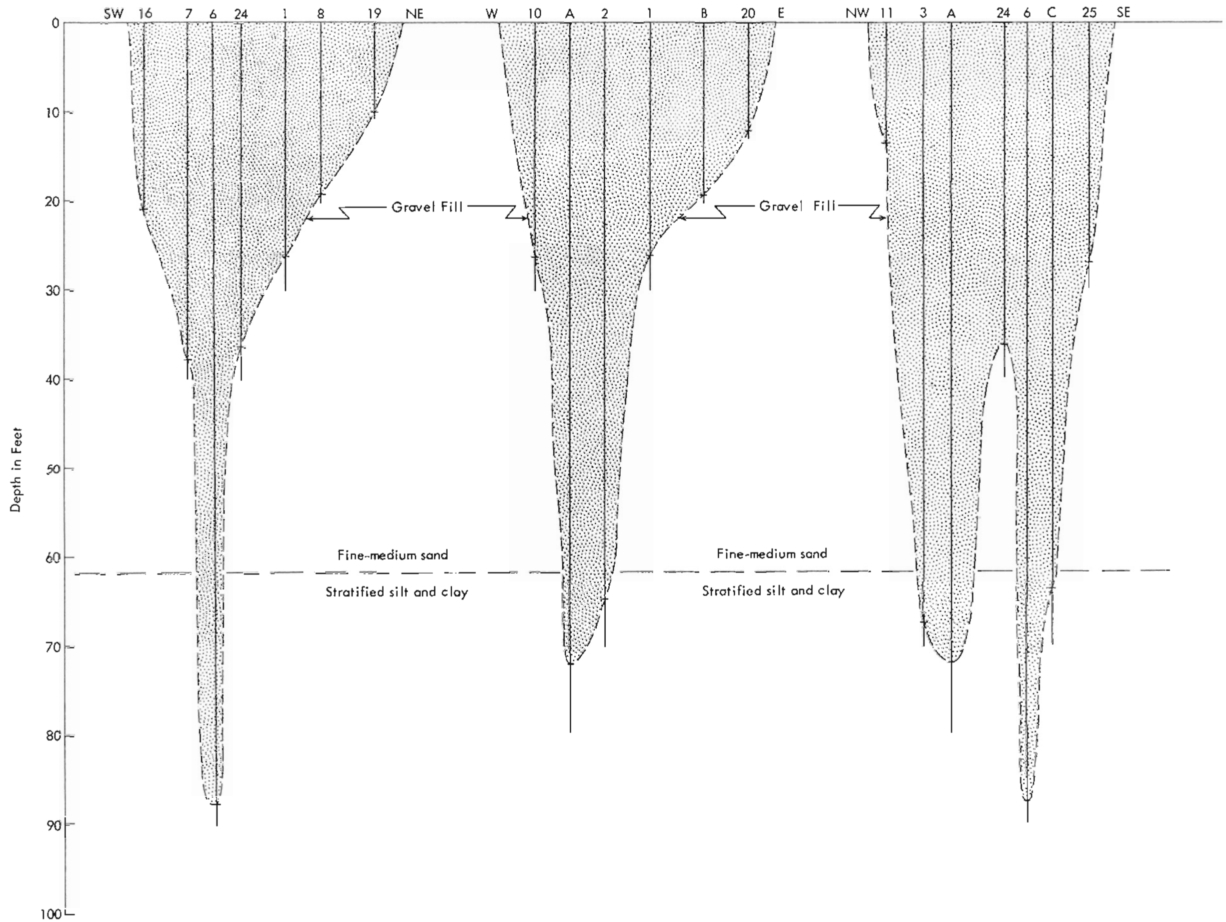

Figure 13. Cross-sections through the crushed-rock fill (horizontal and vertical scales are the same).

then placed inside the drive stem which acted as a casing. The drive-stem was then removed and the hole collapsed about the grout-pipe. Twenty-eight pipes, with a total length of 1, 200 feet, were installed in this manner by the Hammer Drill in 4 days (Fig. 12).

The drilling for the grout-pipes provided data from which the cross-sectional dimensions of the crushed-rock fill could be determined (Fig. 13). It is apparent from the cross-sections that the crushed-rock fill was in the form of a very steep-sided cone and that the deepest parts of the cone were centred about two separate areas; one around holes 3 and A and the other around holes 6 and C.

In order to bring the level of grout from the deepest levels to surface in a uniform manner, a 16-outlet grout-manifold was constructed (Fig. 14). The manifold was equipped with a central pressure to check input pressures and with quick-opening plug valves ahead of the flexible discharge lines. The manifold could, therefore, be used with from 1 to 16 outlets and the flow in the discharge lines could be simply checked by bending the hose by hand and feeling for flow. The pressure gauge was separated from the cement slurry flow by a diaphragm that transmitted pressure to the gauge through an oil-filled reservoir. During flushing of the manifold the diaphragm was ruptured by excess pressure and was replaced by an oil-filled circular tube as shown in Figure 14.

The cement-grout mixing and pumping equipment that had been originally ordered for work on the project was inadequate to handle the volume of cement slurry required for the consolidation grouting. An oil field

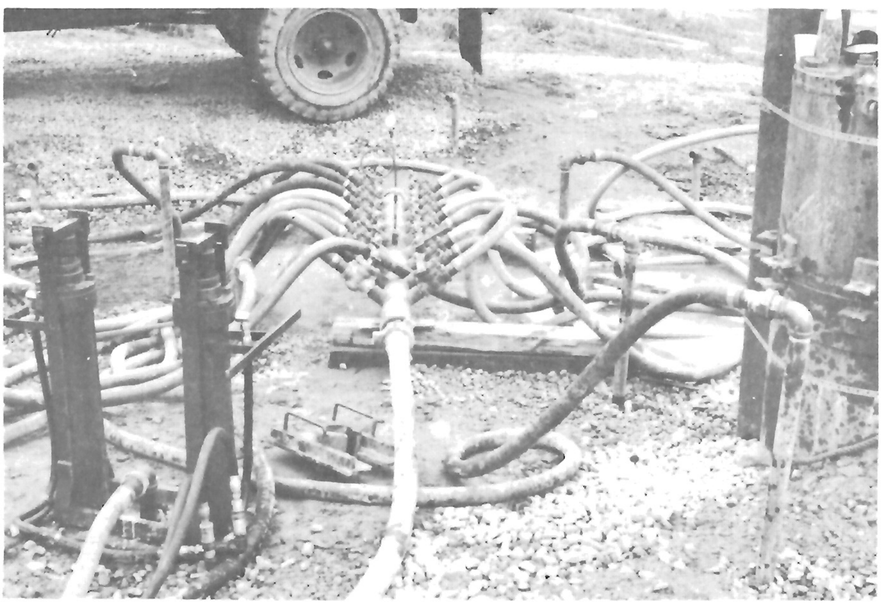

Figure 14. Multiple outlet grout manifold and hydraulic pullers. GSC 118688.

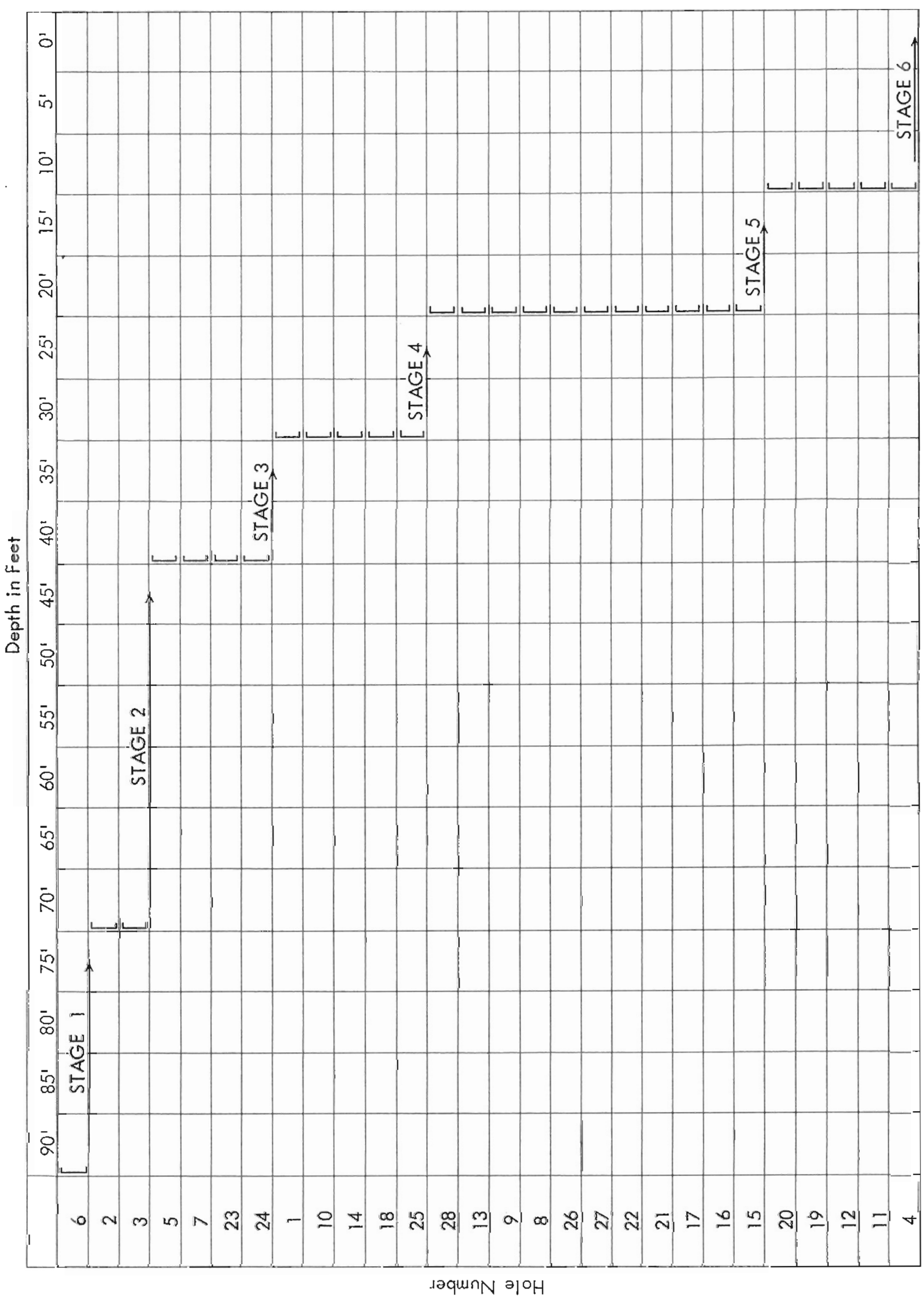

Figure 15. Grout-hole depths and stages in grouting of crushed-rock fill.

type cement pumper was obtained, therefore, along with a trailer mounted mixing tank of 1,000 gallons capacity in which the cement slurry could be batch-mixed to ensure a slurry weight of about 15 pounds per U.S. gallon and uniformity between batches which could not have been achieved by discharge of slurry directly from a jet mixer. Arrangements were also made to have the cement shipped to the site in 500-sack lots on pallets to facilitate handling at the site.

Prior to starting the grouting program, 20 barrels of water containing Rhodamine B (red) dye were pumped into Relief Well No. 2 to determine the extent of connection between this well and the 30-inch casing. Although the bottom of the well and the 30-inch casing are at essentially the same elevation in the No. 2 aquifer, no return of dye was observed in the flow from the 30-inch casing. A small batch of dye was also injected in grout-pipe No. 3 at a depth of 70 feet but no dye return was observed in the discharge through the gravel fill. The dye tests indicated that the grout could be injected through the No. 2 well without loss to the 30-inch casing and that the flow in the crushed-rock fill was of a magnitude such that cement-grout losses through dilution of the slurry would not be encountered.

Grouting of the crushed-rock fill was carried out on a continuous basis over a period of 36 hours, requiring flood lighting of the site to permit operations at night. Before the grout was injected, the end-caps on all of the pipes were pumped off by water injection and a feed-rate through the pipes was established. Some of the pipes became plugged with sand and had to be jet-washed with a 1/2-inch pipe before they would accept grout.

The grouting was carried out in stages as shown in Figure 15 with the deepest pipes being first connected to the manifold. The pipes were pulled in 5-foot stages by use of the hydraulic pullers as shown in Figure 14; as the depth of the pipes decreased many of them could be lifted by hand. As all of the grout-pipes were coupled in 10-foot lengths, the hose connections were never more than 5 feet above ground and thus could be easily handled.

As the pipes were pulled to the level of the next higher stage (Fig. 15) the additional pipes were connected to the manifold and grouting resumed. It was not until the 20-foot level that all 16 outlets of the manifold were in use at one time.

The total amount of cement pumped into the crushed-rock fill was 1,940 sacks and throughout the course of slurry injection, the manifold pressure was kept at 20 p.s.i. or less in order to prevent disturbance of the fill.

Upon completion of grouting of the crushed-rock fill, all of the grout-pipes were removed from the fill and cleaned of slurry for salvage purposes. The final stage of cement grouting was the injection of 560 sacks of cement into Relief Well No. 2 to consolidate the voidage created around the screen of this well during the airlift pumping in 1965. During the initial stage of grout injection into the well, no appreciable pressure build-up was encountered but in the latter stages of injection the pressure increased to 40 p.s.i.

At the conclusion of the grouting operations no flow could be detected from the grouted plug around the 30-inch casing and the discharge from the 30-inch casing was at a rate of 330 Imperial gallons-per-minute and was entirely sediment-free.

No attempt at chemical grouting of the soil surrounding the grouted plug was made at this stage as it was felt that the grouted plug should be permitted to set completely before any other work was attempted.

PHASE VII

The plan for the final phase of the flow-control program consisted of drilling a pattern of test-holes through the concrete plug with the use of an air-track-drill to determine: a) the magnitude of hydrostatic pressure at varying depths in the plug; b) the quality of the concrete in the plug; and c) the requirements for additional grouting. Work on this phase of the project was carried out in late April, 1967.

Three test holes No. T1, T2 and T3 (Fig. 6) were drilled to depths of 50, 30 and 10 feet respectively and were subsequently plugged with a heavy cement slurry. In all 3 holes it was found that the static water level in the plug was 8 feet below surface and was thus below both the level of the surface discharge from the 30-inch casing and the water table in the surface sand surrounding the plug. Holes T1 and T2 penetrated the contact of the plug with the surrounding soil to depths of 50 feet and 30 feet. Artesian pressure was not encountered in either of these holes. The drilling also indicated that the plug was composed of alternating layers of concrete of varying hardness containing lenses and pockets of water-saturated fine material that had not accepted grout.

It was also observed that the flow from the 30-inch casing was entirely sediment-free and was being discharged at a measured rate of 290 Imperial gallons-per-minute, a reduction from the flow of 330 Imperial gallons-per-minute measured at the conclusion of the grouting operation in October, 1966. Relief Well No. 2 was opened for inspection and no flow from it was found although at the conclusion of the cement slurry injection into the well in October, 1966 all of the slurry in the casing had been displaced through the bottom of the well by water injection and the well shut in. The shut-in pressure of the No. 1 Relief Well was 28 p.s.i. which was an increase of about 6 p.s.i. over pressures measured on this well during the installation of the 30-inch casing.

On the basis of the information obtained from the test borings and other observations at the site, it was concluded the grouted plug had effectively contained upward leakage of groundwater to a depth of at least 50 feet under the condition of open discharge from the 30-inch casing. The relation of the static water level in the plug to the ambient water table indicated that groundwater was not being discharged through the plug nor was discharge from the 30-inch casing entering the plug.

Although layers of unconsolidated material were encountered in the plug which could be consolidated by the use of chemical-grout, it was felt that this would not appreciably increase the competence of the plug.

Figure 16. Well site upon completion of grouting crushed rock fill (April 1967). GSC 125296.

At this stage the entire flow-control program was reviewed and it was decided that the primary purposes of confining the flow to a single outlet, the 30-inch casing, and obtaining a condition of ground stability at the well site, had been achieved (Fig. 16). Although it was possible that the flow from the 30-inch casing could be shut off by a valve, it was felt that there could be no guarantee of ground stability if the well were to be shut in. In addition, if flow did break out beyond the plug with the well shut in, there could be no assurance that reopening the valve on the 30-inch casing would recapture all of the flow. In order to ensure ground stability with the well shut in, further extensive grouting at the 150-foot and perhaps deeper levels would be required which would involve extremely high costs.

Under these circumstances, therefore, the decision was made to maintain the well in a condition of open flow and to convey the discharge to Coldstream Creek through a buried pipeline. The pipeline was to be constructed in such a manner that no back pressure would be experienced at the well.

CONCLUSIONS

A number of conclusions which relate both to exploratory drilling techniques and to methods of artesian flow control may be drawn from the flow-control program carried out at the well on the Coldstream Ranch.

1. In intermontane valleys or other areas bounded by high relief and containing perennial streams and about which little is known concerning the hydrogeological conditions, the use of cemented-in-place surface casings to a depth equal to at least 10 per cent of the anticipated depth of the exploratory holes is advisable. Such casings should have a threaded end at the surface to which control fittings may be attached if necessary.

2. If the use of a surface casing is impractical, exploratory drilling should proceed with the use of weight-controlled drilling fluid. Adequate supplies of weight material and drilling mud should be on the site before drilling begins and the rig pumps should be capable of circulating the fluid throughout the entire hole depth.

3. For purposes of flow-control in the event that drilling fluid is lost in permeable formations, a packer that could be inserted in the hole by the drill-stem, inflated by use of the rig pumps, and left in the hole by breaking the connection between the packer and drill-stem by rotating the drill-stem, would be a useful device. The packer should be included with the materials before drilling begins.

4. Any casing used to control flow from a previously uncased hole should be driven into place rather than drilled-in and should be of a diameter sufficient to encompass the original hole.

5. If equipment for driving large diameter casing is not available then casing with a diameter of from one-half to two-thirds the diameter of the original hole should be inserted in the hole. Flow-control could then be achieved by pumping a heavy cement slurry down the inside of the casing and the annular space provided by the smaller diameter casing would permit turbulent flow of the cement returns which is required for a proper job of cementing the casing in place. Adequate volumes of cement would be required in this type of operation to overcome slurry dilation and losses to permeable zones and to maintain sufficient density of the slurry to control the flow. The use of calcium chlorite in an amount equivalent to two or three per cent of the weight of cement per batch is useful to advance the set-time of cement slurry.

6. The following are prerequisites before attempting any flow control programs:

(a) Knowledge of the stratigraphy at the site with particular reference to the location of aquifer and the thickness and type of material forming the confining layers.

(b) A work program with definite objectives and provisions for alternative courses of action.

(c) Adequate equipment, materials and supervision to carry out the program.

(d) Initiation of the program as soon as possible after flow is encountered particularly if sediment is being discharged with the flow. Continued erosion can only aggravate the situation.

7. With respect to the early work carried out during Phase II of the program, it is probable that a misinterpretation was made of the results of pumping the initial batch of mud, sawdust and cement into the 6-inch casing. The absence of returns might have been treated as a lost circulation problem and an attempt made to restore circulation by the continued injection of heavy mud and bridging materials. If circulation could have been established at this stage the 6-inch casing could probably have been cemented in place by a large volume of heavy cement slurry and the flow consequently shut off.

8. The use of a portable roller-type conveyor would have greatly facilitated the handling of cement sacks during the period that large volumes of cement slurry were being pumped.

REFERENCES

Fulton, R.J.
1966: Quaternary studies, Vernon (West Half) map-area; in Jenness, S.E. (edited) Report of Activities, May to October, 1965, Geol. Surv. Can., Paper 66-1, p. 56-57.

Jones, A.G.
1959: Vernon map-area, British Columbia; Geol. Surv. Can., Mem. 296.

APPENDIX

List of contractors and consultants who participated in the flow control program at the Coldstream Ranch Well.

Okanagan Rotary Well Drillers	Vernon, B.C.
G and B Shot Hole Cementers	Calgary, Alta.
Halliburton Oil Well Cementing Co.	Calgary, Alta.
Big Indian Drilling Co.	Calgary, Alta.
Ripley, Klohn and Leonoff (Consulting Engineers)	Vancouver, B.C.
Grouting Consultants and Contractors	Toronto, Ont.
Becker Drilling (Alberta) Ltd.	Calgary, Alta.
B J Service of Canada, Ltd.	Calgary, Alta.
J.M. Donovan, Drilling, Mining and Blasting Ltd.	Vernon, B.C.
R.E. Postill and Sons	Vernon, B.C.
G.C. Tassie, P. Eng. (Consulting Engineer)	Vernon, B.C.