PAP-534

Sectional Well Research Program

H. W. Peck

October 13, 1988

PAP-534

D-3751
(PAP file)
PAP534

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27
(O/P 4-65) 5010-107

UNITED STATES GOVERNMENT

Memorandum

Memorandum
Denver, Colorado

TO : Chief, Ground Water Branch
DATE: October 13, 1988

THROUGH: Chief, Research and Laboratory Services Division
Chief, Earth Sciences Division

FROM : Chief, Hydraulics Branch

SUBJECT: Sectional Well Research Program (Hydraulic Research)

A report is enclosed summarizing the research completed to date on the sectional well model and outlining the study approach worked out in cooperation with you and your staff for the next phase of the research program.

Considering the present workload and staffing levels in the Hydraulics Branch, we will not be able to proceed with Phase I until the second or third quarter of FY89. Also, PRESS budget levels are reduced in FY89.

The research outlined for this program would cost about $120,000 over a 2-year period. Partial funding from your organization to supplement PRESS funds would make it possible to proceed with this work. We would be glad to meet with you to discuss the subject.

Enclosure

cc: D-3700B
(w/encl)
D-3750
(w/encl)
D-3750A
(w/encl)
D-3751 (PAP file)
(w/encl)
D-3752
(w/encl)
D-3752 (Peck)
(w/encl)
D-5740
(w/encl)

WBR:HWPeck/CAPugh:flh:10/6/88:236-6152
(Peck:009)

SECTIONAL WELL RESEARCH PROGRAM

INTRODUCTION

Clark Buyalski (D-3751) has been the principal investigator for the well research program during the last several years. Clark Buyalski recently retired from the Bureau of Reclamation and Hilaire Peck (D-3752) was appointed new principal investigator. The emphasis of the research program for the last 5 years has been on the well sectional model. The sectional model is well suited for investigation of several high priority research items. It is expected the emphasis of the research program will continue to be on the well sectional model until research is completed on these high priority items.

To ensure a methodical and effective research program, Peck has reviewed the work accomplished to date and presented in this summary report a proposal for further study in the well sectional model.

RESULTS TO DATE

Gravel Pack Thickness

In REC-ERC-86-7 titled "Gravel Pack Thickness For Ground-Water Wells - Report No. 1," Buyalski presents his findings on gravel pack thickness. The major findings are reprinted below.

1. The effective destruction of the rigid wall cake formation at the perimeter of the drill hole is a major factor that determines the prototype ground-water well pumping capacity.

2. The wall cake formed during the drilling operation has characteristics similar to the impervious core used in earth dams, i.e., it causes a significant head loss in the ground-water flow approaching the well screen.

3. The effect of the wall cake must be erased completely before the optimum specific capacity of the well can be achieved. The efficiency of the well is proportional to the effective elimination of the wall cake formation.

4. The practical gravel pack thickness should range from a minimum of 3 inches to a maximum of about 6 inches.

5. The high-velocity horizontal water jetting well development method from inside the well screen is an effective technique to physically destroy the wall cake and in the process to expand the gravel pack. However, a large amount of fines from the aquifer are mixed into the gravel pack as a result of the whirling action of the water jets. The expanded gravel pack is a major factor in the recovery of the well specific capacity to within 3 percent of ideal conditions. The high-velocity horizontal water

jetting method is not an efficient technique to remove the mixed-in fines that occur during the first jetting pass. About five to seven passes are required to attain an optimum well specific capacity.

6. Special test runs conducted without the wall cake formation verified that thicker gravel packs could essentially increase the effective diameter of the well and thereby increase the specific capacity. The test results indicate that the specific capacity of the well would increase about 27 percent when the gravel pack thickness is increased by 3 inches. Therefore, if the wall cake formation is ideally erased, the average specific capacity should increase by about 27 percent. The high-velocity horizontal water jetting from inside the well screen does not consolidate the gravel pack material enough to cause a significant reduction in the well specific capacity.

7. Well development procedures should not be used if the wall cake formation does not exist at the perimeter of the drill hole.

8. The water jet nozzle velocity is very critical. The wall cake cannot be destroyed if the water jet velocity is too low. However, if the jet velocity is too high, the water jet penetrates farther into the aquifer formation and mixes a larger percentage of fines into the gravel pack.

9. A larger percentage of aquifer material could be mixed into gravel packs having high P/A (pack-aquifer) ratios; i.e., for P/A ratios greater than 6 higher head losses could occur, rendering the gravel pack ineffective.

10. A PVC well screen requires a higher velocity (greater than 15 percent) water jet to penetrate the same distance as a wire-wound-cage type well screen having the same aquifer configuration. The mixing action of the water jet outside the PVC well screen was slightly more efficient in cleaning out the fines. This left the gravel pack material slightly coarser. The degree of clogging of the slots by the high-velocity horizontal water jetting method of well development for both the PVC and wire-wound-cage well screens was about the same. Overall, the effectiveness of the high-velocity horizontal water jetting through the PVC well screen was not significantly different from the wire-wound-cage well screen.

Well Development - Surging Versus Jetting

Buyalski also performed 10 tests for the purpose of investigating the relative merits of well development by high-velocity horizontal water jetting and surging. The following results were reported in a memorandum dated August 18, 1987:

1. Fine sand aquifers should use coarse gravel packs having a P/A ratio up to 10.

2. Horizontal water jetting should not be used as a method of well development in fine sand aquifers with high P/A ratios.

3. Surging is an effective method for natural well development and for development of fine sand aquifers that have coarse gravel packs.

4. Low-velocity horizontal water jetting for natural well development should be limited to one or two jet passes to quickly remove a large volume of the surrounding sand material and then again after surging, to stabilize the natural gravel pack.

5. High-velocity horizontal water jetting must be used, and it is the only method of well development known to develop the well when the fine sand aquifer uses an artificially graded fine gravel pack with a P/A = 4.

STUDY PROPOSAL

Introduction

Present standards limit the amount of gravel pack allowed to pass the screen to 10 to 15 percent. A much lower percentage of the gravel pack actually passes the screen due to bridging of particles next to the screen. These standards were developed at a time when corrosion resistant materials were not commonly used in the construction of well screens. Restrictive standards were appropriate due to the possibility of screen openings becoming enlarged from the corrosive action of ground water. These standards may now be overly restrictive due to the common usage of corrosion resistant materials such as stainless steel and PVC plastic for well screens.

This 10 to 15 percent standard applies to all gravel packs. However, the adverse impact is greatest on smaller pack materials. The screens used with these materials have smaller slot widths. Smaller screen slot width decreases the efficiency of high-velocity horizontal water jetting for well development.

Knowledge of the optimum percent of gravel pack that should be allowed to pass the screen will help to establish the relationship between well screen open area and well yield and efficiency. This will enable easier and more thorough development of wells resulting in higher yields and greater efficiencies.

There are two P/A ratios that are critical for successful well design. At low P/A ratios, no aquifer material will enter the gravel pack regardless of the velocity of the water entering the well. As the P/A ratio is increased a critical ratio will be reached at which the aquifer material will invade the gravel pack during the production phase if the velocity of water entering the well is great enough. The aquifer material decreases the permeability of the gravel pack and therefore decreases the yield of the well. This critical P/A ratio is believed to be greater than 6 for a uniform fine sand aquifer and a uniform gravel pack. As the P/A ratio is increased further, a second critical P/A ratio will be reached at which material from the aquifer migrates through the gravel pack and into the well. If this material passes through the pump, the abrasive action may remove enough metal from the impellers and bowls to reduce pumping efficiency and shorten the useful life of the pump. The pumped sand may be deposited in pipes or ditches resulting in additional maintenance expense. In some cases enough material may be removed from the aquifer to cause the collapse of the well. Identification of the first critical P/A ratio will enable the design of gravel packs for which the well will have its greatest yield. Identification of the second critical P/A ratio will ensure gravel pack designs that prevent sand pumping.

Another benefit of this study will be the knowledge gained about the jetting velocity required to penetrate the gravel pack as a function of screen slot width and gravel pack particle size at which 50 percent of the material is finer by weight (D_{50}).

These studies also present an opportunity to evaluate an alternative method of well development. High-velocity horizontal water jetting will be used as the standard method of well development. Selected runs will be repeated using a combination of high-velocity horizontal water jetting and surging.

In summary, the purpose of this study is to:

1. Determine optimum screen size as a function of the gravel pack design.

2. Determine the P/A ratio at which the aquifer material invades the gravel pack to the degree that well yield is adversely affected and the P/A ratio at which the well begins to pump sand.

3. Determine optimum velocity of the water jet required to penetrate the gravel pack.

4. Evaluate the relative merits of well development by high-velocity horizontal water jetting and high-velocity horizontal water jetting combined with surging.

A 4-inch-thick gravel pack will be used in this study. Therefore, the above results will apply only to a 4-inch-thick gravel pack.

Study Plan

Some of the factors influencing well development in approximate order of importance are listed below.

1. Slot size of the well screen.

2. Method used to develop the well.

3. Gravel pack thickness.

4. D_{50} size of the gravel pack. - Larger gravel packs will have greater porosity. During high-velocity horizontal water jetting, less velocity and, therefore, less energy will be required to penetrate the gravel pack to the wall cake. This will result in less mixing of the gravel pack and therefore a lower percentage of pack material actually passing the screen for a given design.

5. P/A ratio of the gravel pack D_{50} size to the aquifer D_{50} size. - Studies have shown that a gravel pack designed to certain specifications needs to be only a fraction of an inch thick to prevent migration of the aquifer material. However, for a given aquifer material, the gravel pack thickness must be increased to prevent migration of aquifer material as the P/A ratio is increased. To retain pack material of sufficient thickness, a smaller percentage of the gravel pack can be allowed to pass the screen as the P/A ratio is increased.

6. Uniformity coefficient (C_u) of the gravel pack. - A less uniform pack will have a lower porosity. Greater nozzle velocity and more energy will be required to penetrate to the wall cake. Greater mixing of the pack and therefore a larger percentage of the aquifer material actually passing the screen will result. However, a less uniform pack has better filtering capabilities and less pack thickness is required to prevent migration of aquifer material. From this standpoint a larger percentage of the gravel pack could be allowed to pass the screen.

7. D_{50} size of the aquifer material. - As the aquifer material increases in size it becomes less subject to movement by flow from the aquifer. Thickness and relative gradation characteristics required of the pack material to retain the aquifer material are therefore changed. A larger percentage of pack material allowed to pass the screen can probably be allowed.

8. Uniformity coefficient (C_u) of the aquifer material. - A less uniform aquifer is more capable of acting as its own filter; therefore, less gravel pack thickness is needed and more of the gravel pack can be allowed to pass the screen. On the other hand, for the same gravel pack more material is likely to migrate from the less uniform aquifer because it probably has a larger percentage of fines.

9. Hydraulic gradient in the vicinity of the well. - The velocity of the water entering the well increases as the hydraulic gradient is increased. For a given aquifer there is a P/A ratio at which aquifer material will invade the gravel pack if the velocity of the water entering the well is great enough. As the velocity of the water is increased, larger aquifer particles will migrate into the gravel pack if the interstitial spaces in the gravel pack permit.

Of the nine factors listed above it was decided to vary the screen slot size (1), P/A ratio (5) and the D_{50} particle size of the aquifer material (7). For the same aquifer material, the D_{50} particle size of the pack (4) is indirectly varied when the P/A ratio is varied.

The method used to develop the well (2) will be the commonly used method of high-velocity horizontal water jetting. Selected tests will be repeated with an alternative development method consisting of high-velocity horizontal water jetting combined with surging.

Gravel pack thickness (3) will be kept constant at 4 inches. In REC-ERC-86-7 Buyalski stated that "the practical gravel pack thickness should range from a minimum of 3 inches to a maximum of about 6 inches." The lower limit is to ensure that an envelope of gravel will surround the entire screen. Above the upper limit well development is adversely effected to a significant degree. A 4-inch gravel pack should be entirely sufficient in most cases.

In the field it is extremely difficult to place nonuniform gravel packs without incurring considerable segregation of the material. Therefore, only uniform gravel packs will be studied and the uniformity coefficient of the gravel pack (6) will not be varied. It is not possible to simulate the wide range of hydraulic gradients encountered in the field with the sectional model. Therefore, the hydraulic gradient in the vicinity of the well (9) will not be varied.

The aquifer C_u (8) will be kept as close as possible to 2.5. Present restrictive standards for percent of gravel pack allowed to pass the screen have the greatest adverse impact on uniform sand aquifers. The P/A ratio can be increased for less uniform (higher C_u) fine sand aquifers. This results in larger screen openings that are less subject to encrustation. However, before the study is concluded a decision will be made on whether or not to conduct additional tests using aquifer material with a higher C_u.

Table 1 indicates the preliminary testing procedure for Phases I and II. This procedure will require approximately 28 tests. In REC-ERC-86-7, Buyalski reports each test requires 8 days. At 8 days per test, testing will require 224 staff days or approximately 11 months. It is estimated that analyzing the data and writing a report will require 60 days. Therefore, the total time to complete this study is estimated at 1 year and 2 months. Allowing 208 working days per year this will require 1 year and 4 months. Other high priority research would probably prevent the principal investigator from spending 100 percent of his time on this study; therefore, it is expected the total time to complete this study would be between 2 and 3 calendar years. Therefore, after each phase is completed the relative worth of the next phase and the overall direction of the study will be reevaluated and the future testing schedule readjusted accordingly.

Table 1. - Testing procedures

Phase I - Aquifer material fine sand with $C_u \simeq 2.5$ (screen size # 200 to # 70)				Phase II - Aquifer material fine-medium sand with $C_u \simeq 2.5$ (screen size # 200 to # 30)			
Gravel pack $C_u \leq 2.0$				Gravel pack $C_u \leq 2.0$			
P/A ≃ 6	P/A ≃ 9	P/A ≃ 12	P/A ≃ 15	P/A ≃ 6	P/A ≃ 9	P/A ≃ 12	P/A ≃ 15
Test various well screen sizes.							

At each P/A ratio, successively larger well screen slot sizes will be tested until well performance becomes unacceptable. An alternative method of well development will be tested using fine sand as the aquifer material and a gravel pack with C_u of 2.0 or less.

Approximately 16 tests will be required to complete Phase I and 12 tests to complete Phase II. This estimate assumes an average of three screen sizes tested for each P/A ratio when the standard method of well development is utilized and two screen sizes tested for each of the tests repeated utilizing the alternative method of well development.

It is not expected the study will rigidly follow the progression of P/A's outlined in Table 1. At each step selection of the next P/A to be studied will depend on the results to date. Table 1 is useful for obtaining a rough estimate of time and costs.

Table 2 outlines the testing procedure for additional testing to determine the effect of aquifer C_u. At this time no additional testing is planned. If, in the future, the decision is made to conduct additional testing approximately 3 to 9 more tests will be required. This would require between 24 to 72 staff days.

Table 2. - Testing procedure to determine effect of aquifer C_u.

Phase III - Aquifer material fine-medium sand with $C_u \simeq 10$ (screen sizes #200 to #30)
*Gravel pack $C_u \leq 2.0$, P/A ≃. - **This pack will be identical to the corresponding pack in table 1 for a fine-medium sand aquifer.

*If three screen slot sizes are tested, three tests will result. If results from these tests warrant, other P/A ratios will be tested.
**The optimum P/A ratio as found in Phase II will be used.

Testing Procedure

Basically the same testing procedure will be followed as outlined by Buyalski in REC-ERC-86-7 (pages 9-17). During the first several runs minor modifications may be necessary to develop the most efficient procedure.

For each test essentially the same data will be obtained as in the previous studies by Buyalski. This data will include:

1. Specific capacity of the aquifer under steady state conditions before well development. This will be determined from piezometer tap and well discharge data.

2. Specific capacity of the aquifer under steady state conditions after each jet tool pass.

3. Mechanical analysis on material siphoned from the bottom of the well after each jet tool pass.

4. At the beginning of the first jet tool pass performed on each aquifer configuration the velocity of the jet issuing from the jet tool will be adjusted until it just penetrates the wall cake. This velocity will be recorded and used for all subsequent jet tool passes on the aquifer configuration.

5. After all jet tool passes have been completed, measurements of the deformation on the window of the aquifer, wall cake, and gravel pack.

6. Contour measurements of the sinkhole that develops under the concrete blocks at the surface of the aquifer.

7. As the aquifer is excavated measurements of the deformed wall cake and gravel pack boundaries.

8. Soil samples at several levels for mechanical analysis to be compared to "before" well development gradations.

9. Judgement of whether or not the well has "failed." If at any place along the length of the screen the entire thickness of the gravel pack has become so mixed with aquifer material that it has lost its original gradation, the well will be considered failed. If during pumping the well produces any appreciable amount of sand, failure will be assumed.

Time And Cost Estimates

Phase I

	Staff days	Cost
Familiarization with data acquisition programs	8	1,920.00
Familiarization with model operation	8	1,920.00
Calibration of jet tool	2	480.00
Construction of concrete blocks (shops)	3	720.00
Conduct testing (1 engineer, 1 technician part time)	192	46,080.00
Analyze data and write report	20	4,800.00
Sand and gravel material		914.00
Well screens		11,680.00
	Total	$68,514.00

Phase II

	Staff days	Cost
Conduct testing (1 engineer, 1 technician	144	34,560.00
Analyze data and write report	20	480.00
Sand and gravel material		914.00
Well screens		2,920.00
	Total	$38,874.00

Phase III

	Staff days	Cost
Conduct testing (1 engineer, 1 technician	48	11,520.00
Analyze data and write report	15	3,600.00
Aquifer material		914.00
	Total	$16,034.00

Additional Work Planned

Concurrently with the study outlined earlier in this paper work will be performed on the following items.

1. Assemble and edit the video coverage of the sectional model testing with the goal of producing a video training tape on gravel packs and development procedures. Video coverage of future tests may also be a part of the video training tape.

2. Assemble and evaluate data from the large well model and from any peripheral studies.