2

**IMPELLER FLOW-METER LOGGING
OF VERTICAL CROSS FLOW
BETWEEN BASALT AQUIFERS THROUGH WELLS
AT THE IDAHO NATIONAL ENGINEERING LABORATORY
EASTERN SNAKE RIVER PLAIN, IDAHO**

A PROGRESS REPORT: JUNE 22, 1992

**BY
WILLIAM M. BENNECKE
AND
SPENCER H. WOOD**

BOREHOLE GEOPHYSICS RESEARCH PROGRAM

**DEPARTMENT OF GEOSCIENCES
BOISE STATE UNIVERSITY
BOISE, IDAHO 83725**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**Funded by the State of Idaho - Division of Environmental Quality - INEL
Oversight Program**

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ABSTRACT

An impeller flowmeter was used with a COLOG digital acquisition system to determine existing borehole flows, to compare with previous logging results, and to acquire flow measurements of vertical cross-flow of water in the wells between permeable zones in the open-hole intervals. A 1964 study used Tracejector Sondes to measure flow velocities and directions. The direction of flow found was predominantly downward with velocities ranging from 0-30 ft/min. Some flow reversals were noted and attributed to nearby pumping wells.

USGS wells 44 and 46 were studied in September, 1991 near the Idaho Chemical Processing Plant (ICPP). The results showed a usual overall flow direction downward with flow entering the wells at around 510 to 600 ft. below the land surface. Water exited these wells at lower levels around 550 to 580 ft. Flow velocities ranged up to 24 ft/min. A flow reversal occurred during logging of well number 46. This reversal is thought to be caused by turning on a pump at 3100 gpm.

Using published aquifer parameters the rate of propagation of a pressure change in an aquifer was calculated for the well CPP-2 turning on and off, at 3100 gpm (2 hour on and 3 hour off cycle). The finite-element program MODFLOW was run to simulate these conditions. The computations indicated that within two hours of pumping from CPP-2, only 5×10^{-5} ft of drawdown would occur at

wells 44 & 46. We do not believe that a 10^{-5} ft head difference induces flow reversals in the wells. These computations suggest that the reported transmissivity values commonly used are too small or unconfined storativity too large to simulate the situation of flow reversals. We suspect that a value for storativity considerably less than 0.08 used in computation may be more appropriate.

INDEX

Abstract	i
Index	iii
List of Figures	iv
Introduction	1
Background	2
General Hydrogeology At The INEL	4
Methods Of Measuring Flow In Static Wells	4
Previous Work Done On Borehole Flow At INEL	6
Work Done In This Study	7
Cross Flow In Well No. 44	8
Cross Flow In Well No. 46	9
Causes Of Flow Reversals	10
Flowmeter Sensitivity Calibration	10
Rate Of Propagation Of A Pressure Pulse Caused By Turning On a Pump	11
Consideration Of Hydraulic Diffusivity In Other Studies	17
Computer Model Computation Of Drawdown Pressure	18
Conclusions And Future Research	19
References	21

LIST OF FIGURES

- Figure 1. Map showing the location of the Idaho National Engineering Laboratory (INEL)
- Figure 2. Map showing the location of the Idaho Chemical Processing Plant (ICPP) and the Test Reactors Area (TRA).
- Figure 3. Map showing the location of the CPP DISP well and the TRA DISP well.
- Figure 4. Map showing contours on the regional water table and the inferred directions of ground-water movement
- Figure 5. Showing a Heat-Pulse Flowmeter Probe
- Figure 6. Showing direction and velocity of flow in Site 17 well
- Figure 7. Showing direction and velocity of flow in MTR Test well
- Figure 8. Showing direction and velocity of flow in USGS 4 well
- Figure 9. Showing direction and velocity of flow in USGS 28 well
- Figure 10. Map showing the wells logged by Morris et al 1964
- Figure 11. Map of the ICPP area showing the locations of the wells surveyed by the Tracejector and directions of flow
- Figure 12. Graph of six wells in the ICPP area showing lithology, directions of flow, hole diameter and velocity of flow
- Figure 13. Geophysical Logs on wells USGS 44 & 46
- Figure 14. Illustration of a Mineral Logging Systems, Inc. 17/16 Impeller-flowmeter
- Figure 15. Calibration curves from USGS well #44 & 46

Figure 16. Logging results showing Impeller-flowmeter runs, flow velocity, hole diameter, and temperature log for USGS well #44

Figure 17. Logging results showing Impeller-flowmeter runs, flow velocity, and hole diameter for USGS well #46

Figure 18. Geologic section E-E' at the ICPP & TRA area showing the I basalt flow group, and location of production well CPP-2 (500 ft west of CPP-1), and wells 44 and 46, west of well 47

Figure 19. Altitude of the top of basalt-flow group I at the ICPP & TRA area

Figure 20. Showing where the transmissivity value from well CPP-2. Gamma logs of the zone to well USGS 44 is also shown. Flow zones in USGS 44 occurs between 500 and 550 ft.

INTRODUCTION

At the Idaho National Engineering Laboratory (INEL) there is great concern about the potential for migration of radioactive and chemical wastes from the various facilities there to the underlying Snake River Plain Aquifer (SRPA). More than forty wells at the INEL have large open intervals, typically their wells have cemented casing to the water level, and have 100 to 300 feet of uncased borehole in the saturated zone. These open intervals have numerous fracture zones of varying aperture, overall thickness, and lateral extent. There is the high likelihood for movement of contaminants across aquitards owing to connection by wells. A better understanding of flow in these wells would help to estimate the effects of contaminant movement and their impacts on the SRPA.

Studies and projects have tried to address these issues, but the projects were done 25 years ago and overall effects of these well interconnections were never studied in detail. This study is using impeller flow-meter techniques (Hess, 1986), to measure vertical cross-flows of water in the wells between permeable zones in the open-hole intervals. This will allow a better understanding of fluid flow within wells that is needed to understand contamination routes. In this preliminary study, the 25-year old data are reviewed, and preliminary results reported of flow-meter logging in September, 1991 by Boise State University-borehole geophysics research program.

BACKGROUND

The INEL was established in 1949 by the U.S. Atomic Energy Commission as an area to build, test and operate various nuclear reactors and to have fuel processing plants and support facilities with maximum safety and isolation. Administered by the U.S. Department of Energy, the site is comprised of seven major facilities operated by government contractors. The site covers 890 square miles of semi-arid land in the north eastern part of the eastern Snake River Plain (Fig. 1). The INEL is thirty-nine miles long from north to south and thirty-six miles wide at its broadest point.

The two facilities that will be discussed in this report are the Idaho Chemical Processing Plant (ICPP) and the test Reactor Area (TRA) (Fig. 2). The ICPP complex houses reprocessing facilities for governmental defense, and research on spent nuclear fuel. Facilities at the ICPP include spent fuel storage and reprocessing areas, a waste solidification facility and related waste storage bins, remote analytical laboratories, and a coal-fired steam generating plant. The ICPP is 8 miles north of the southern boundary of the INEL and covers about 0.15 square miles. The ICPP has discharged radioactive and chemical wastes to a disposal well and unlined percolation ponds for several decades. From 1953 to 1984 the ICPP discharged low-level radioactive and chemical wastewater directly to the Snake River Plain Aquifer through well CPP DISP (Fig. 3), a 600 ft. deep disposal well. From 1974-1985, 445 million gal/year of waste water containing an

average of 287 Ci/year of strontium 90 also was discharged to percolation ponds at the ICPP from 1982 to 1985 (Pittman from Anderson, 1991). The ICPP no longer discharges wastes down the disposal well, but percolation ponds are still in operation.

The TRA is a sophisticated materials testing complex housing extensive facilities for studying the effects of radiation on materials, fuel, and equipment. The Advanced Test Reactor (ATR) located at TRA produces a neutron flux that allows simulation of long duration radioactive isotopes used in medicine, research, and industry. The TRA is 2 miles northwest of the ICPP and covers about 0.10 square miles. Some knowledge of amounts of radioactive and non-radioactive wastes discharged to a deep well and to percolation ponds has been compiled by Pittman and Anderson (1991) and is summarized here: A 1,275 foot deep well located there is called the TRA DISP (Fig. 3), it was used to dispose of about 250 million gal/year of nonradioactive wastewater from 1964 to 1982. From 1959 to 1985, discharge of radioactive wastes to percolation ponds at the TRA averaged about 189 million gal/year. Nonradioactive liquid waste consisting mainly of sulfate and sodium has been discharged to a percolation pond at TRA since 1962. From 1974 to 1979, aqueous radioactive waste contained about 2,250 Ci/year of activation and fission products. This amount was reduced to about 288 Ci/year from 1980 to 1985. Tritium, which comprised about 10 percent of the radioactive waste discharged to ponds at the TRA from 1974 to 1975, comprised about 90 percent of the total radioactive discharged there from 1981 to 1985.

GENERAL HYDROGEOLOGY AT THE INEL

The regional direction of water flow in the SRPA is northeast to southwest (Fig. 4). The major area of recharge is from the Big Lost River which flows onto the eastern Snake River Plain near Arco. This river drains about 1,500 square miles of Butte and Custer Counties, including the northeastern flanks of the Pioneer Mountains and the southwestern flanks of the Lost River Range. Transmissivity of the aquifer generally ranges from 134,000 to 13,400,000 square feet/day (Bennett, 1990). In a static well, any flow produced will be due to the regional trend of the area which is quite large compared to other aquifer systems, but small compared to flow induced by a nearby pumping well.

Vertical flow velocities in a non-pumping well may be influenced by vertical head gradients, the diameters of the opening that water flows through, temperature, roughness of the borehole walls, and initial turbulence that may be present.

METHODS OF MEASURING FLOW IN STATIC WELLS

A method of finding the vertical flow velocity in a static well is by the use of impeller flowmeters (commonly called spinners). The impeller flowmeter is made up of a propeller that can range in sizes. These propellers spin when acted on by flowing water. The method of measurement is either to lower the flow-meter into the well and record flow at a stationary position or to tow the flow-meter up or down measuring flow. This later method is done because the propeller has an initial stall speed that must be

overcome to spin it. When the spinner is towed, the movement of water past it generates spin which overcomes its initial stall speed. Variations on the spin velocity is taken for flow in the well. The spinner's propeller makes revolutions which act on an electrical circuit in the instrument. The circuit sends a signal in counts/seconds which can be converted into feet/minute once the flow-meter is calibrated. Spinner flowmeters are available that can measure borehole water velocities of 2 meters/minute and greater (Hess, 1985).

Flow in a static well can be also measured in other ways. One such method is the use of tracers which may be salt, radioactive materials, dyes, and others items. These tracers are used in a Tracejector Sonde. The Tracejector Sonde using radioactive material is a combination of a gamma-ray unit and an ejector unit. The position of the two units is interchangeable and can be assembled for measuring either upward or downward circulation of borehole fluids. The procedure for operating the sonde is to lower the sonde into a borehole, to a particular depth of interest, which is hypothesized to be the flow area. A minute amount of tracer then is discharged from the ejector portion of the probe. The tracer travels from the ejector to the detector point and the travel time is calculated from a stopwatch. Very slow borehole-fluid velocities of a few meters per day have been measured by using tracer techniques (Hess, 1985). However, the use of radioactive solutions in groundwater is now subject to strict regulations, brine solutions are useful only in fresh water, and

both techniques are subject to considerable measurement errors caused by the differences in density between the trace solution and the borehole fluid (Hess, 1985).

Another such method to measure flow velocity in a static well, that has a similar theory and methodology as the Tracejector Sonde, is the heat-pulse flowmeter. The heat-pulse flowmeter is a combination of temperature sensors and a heating grid. The two temperature sensors are set 20 mm from either side of a heating grid (Fig. 5). The operation of the heat-pulse flowmeter is to lower it into a well, to a particular spot of interest, and then discharge a small pulse of heat which either travels up or down to the temperature sensors. The time it takes to travel to either sensor is used to calculate the velocity. The heat-pulse flowmeter has a useful flow-measuring range of 0.06 to 10 meters/minute (Hess, 1985).

PREVIOUS WORK DONE ON BOREHOLE FLOW AT INEL

Preliminary studies defining the velocity and direction of flow in static wells at INEL were reported about 25 years ago. The significance of the data were never evaluated, nor was the research continued. D.A. Morris and coworkers in 1964 noted work done with a Tracejector Sonde containing an Iodine 131 tracer. This work was done on over 20 wells at various places in the INEL area. A downward flow was determined in the wells with velocities ranging to 30 feet/minute. Illustrations from Morris and others (1964) are reproduced in this report (Fig. 6-9). The location of these wells

are shown in figure 10. J.T. Barraclough and coworkers (1965) also did Tracejector Sonde work with an Iodine 131 tracer. This work was done on wells in the ICCP, area on well numbers 42, 43, 48, 49, 51, 52, 59 (Fig. 11). Direction of flow was more variable than that measured by Morris and others. The velocities ranged up to 30 feet/minute (Fig. 12). Reversals of flows were also noted and attributed to nearby pumping wells. The reversals were evident over relatively short periods of time, in some instances less than an hour.

WORK DONE IN THIS STUDY

Flowmeter, caliper, natural gamma, and temperature logs were obtained in September, 1991 on USGS wells no. 44 and 46. The wells are located adjacent to the west boundary of the ICCP (Fig. 13). Pumps were pulled from these wells in September so that the U.S. Geological Survey Borehole Geophysics group from Denver and the BSU unit could make measurements. A report is currently being prepared on the U.S. Geological Survey work by Roger Morin (review, 1992).

Logs were run to determine existing borehole conditions, to calibrate other logs needing accurate borehole diameters in order to quantify their results, and to compare with previous logging results. The logs were run from Boise State University's logging truck Mt. Sopris 3000 geophysical logging unit, 1200-meter capacity 4-conductor downhole cable, and necessary logging sondes. All data are acquired on a COLOG digital acquisition system and are output as ASCII files to PC floppy disks that can be played back at any

scale. Depth precision is about 0.05 feet. This system has been in use for 2 years in aquifer studies in southwest Idaho. The various logging devices ran on USGS wells 44 and 46 were run repeatedly to check reproducibility of the sonde measurements.

An impeller flowmeter was used on the wells to acquire flow measurements of vertical cross-flow of water in the wells, between permeable zones in the wells' open-hole intervals. The impeller-flowmeter is a Mineral Logging Systems, Inc 1-7/16-inch-diameter (36.5mm) flowmeter with a voltage inhibitor (Fig. 14). The device is filled with Wesson vegetable oil to allow operation at varying pressures. For this report the propeller was a 2-3/16-inch (55.5 mm) blade. The device sends voltage pulses (4 per revolution) to a pulse-counting digital-data acquisition system and raw data is recorded as total and average number of counts per unit time.

A typical run would consist of sending the flowmeter down the hole at about 30 ft/min stopping at the bottom, and then preceding to tow up at a comparable speed. Varying towing speeds in cased portions of the well (where there was no flow present) were used to calibrate the pulse rate to vertical flow velocity. This procedure was done for each well studied (Fig. 15).

CROSS FLOW IN WELL NO. 44

In USGS well no. 44 major vertical cross flow was determined to be between fracture zones at 512 ± 2 feet and 549 ± 2 feet. These zones correspond with fracture zones detected by the caliper log from 510-516 feet and 540-546. There is also a suggestion on

the flowmeter record of low flow into fracture of 574-578. This is corroborated by the isothermal zone on the temperature log (Fig. 16). Four trolls of the flow meter tool were made in well no. 44 between 11:40 and 12:15, on October 2, 1991. Flow was consistently down the well from fracture zones at 512 feet and into fracture at about 540 ft. and minor flow into fractures at about 574 to 578.

CROSS FLOW IN WELL NO. 46

In well no. 46, the flow direction actually reversed while we were making logging runs between 14:40 and 15:20, October 2, 1991 (Fig. 17). Minor flows are coming into and out of fractures at the base of the casing and down to 429 ± 2 ft. A major flow goes in and out of the fractures at 514 ± 2 ft. The flow-velocity fluctuation at 542-549 is caused by the enlarged hole diameter in a fracture zone and not on account of the fracture zone accepting a yielding flow. Major flow does go in and out of fractures between 571 and 580. The vertical-flow velocity from 514 to 574 was downward at about 23 feet per minute from 14:29 to 14:55. It apparently reversed and was flowing upward about 16 ft/min. entering and exiting from the same fracture involved in the downward flow. This upward flow was consistent for the trolls from 15:05-15:10 and 15:10-15:20 on October 2, 1991. We did not run a temperature log on USGS no. 46, but the Denver USGS unit's temperature log run on September 1991 corroborated the flow zone shown by the interval of isothermal water. Flows are determined to be coming from openings at 510 ft. and 550 ft for USGS well #44 and

510 ft and 580 ft, with a smaller flows from 600-630 ft, 480-500 ft, and 637-Bottom of well for USGS well #46 (Fig. 16).

CAUSES OF FLOW REVERSALS

The change in flow direction may be the result of well pumpage in a nearby well CPP-2 (Cpp-671 (west)), 2400 feet away (Fig. 3) which was turned on and off at various times during this study. Unfortunately the record of the exact times the pump was on during our flowmeter runs were not recorded due to a malfunctioning recorder at the pumping well. The well has a pumpage of about 3100 gallons/minute. This well appears to be producing from what Anderson (1991) described as the I basalt flow group (Fig. 18). Figure 19 shows the extent of basalt flow group I in the ICPP and TRA area. Figure 20 shows tentative correlation of gamma logs between USGS 44 and the production well CPP-2. Flow zones are identified by fracture zones on the USGS 44 caliper log. No caliper log is available for CPP-2, but we suggest a correlation of gamma log character on Fig. 20.

FLOWMETER SENSITIVITY - CALIBRATION

The flowmeter records have considerable noise, (3 to 12 ft/min) and we are presently working on instrumentation to reduce the noise level and possibly increase the sensitivity of the meter. Sensitivity of the flowmeter appears to be about 5 ft/minute. We are also acquiring a new Gearhart Flowmeter with reported sensitivity of about 2 ft/min. and are adapting it to work with our

logging system. A flowmeter test calibration facility has been constructed at Boise State University.

RATE OF PROPAGATION OF A PRESSURE PULSE CAUSED BY TURNING ON A PUMP

To explore the idea that a nearby pumping well could have an effect on the flow measurements over relatively short periods of time, a look at the hydraulic diffusivity coefficient equation was used to find the rate of propagation of a pressure change in an aquifer.

From Domenico (1972, p. 319) after Theis (1935), the equation for the change of head caused by turning a pump on at time $t = 0$, at the point, $r = 0$, at a rate of Q , in a tabular confined aquifer of thickness b , uniform aquifer properties, and radial symmetry, is given by:

$$h - h_0 = Q \cdot W(u)/(4\pi T)$$

where h_0 = the initial head, extending from the well to infinite distance.

Q = pump rate, in gallons/day (1 gpm = 1440 gpd).

T = aquifer transmissivity, which is the thickness, b multiplied by the hydraulic conductivity, K .

$W(u)$ = the well function, with an argument of u , the tabulated

values of which are given in most texts on hydrogeology.

u = argument of the well function.

$$= r^2/4Dt$$

r = distance from well

t = time

D = hydraulic diffusivity

$$D = T/S$$

T = aquifer transmissivity

S = aquifer storativity (dimensionless)

$$= \sigma_w gb(\alpha + n\beta_w)$$

σ_w = density of water

g = acceleration of gravity

b = aquifer thickness

β_w = compressibility of water

n = aquifer porosity

α = compressibility of aquifer rock (elastic and inelastic combined)

Calculation of time at which a discernable pressure change is detected at a distant observation well: We would like to know how quickly the drawdown of head induced by pumping propagates through the aquifer. It is important to know when a perceptible change in head will occur at a distant observation well, after the pump at $r = 0$, is turned on. These estimations help in conceptualizing

aquifer dynamics and in planning well tests.

Using a well tape or a pressure transducer in an observation well, 0.01 feet is about the limit of resolution of a discernable change in head.

If the pump is turned on at $t = 0$, at a rate Q , how long (t) will it take to produce a head change of 0.01 feet, at a distance r ? To solve this, we set $h - h_0 = 0.01$ feet., and find the value of $W(u)$ and hence the value of $u = r^2/4Dt$ for which that value occurs. Since the equation also involves Q , and T outside the argument for the well function, we will have to prescribe those values first in order to find the relationship between r and t , meeting those conditions.

In practical engineering units (pressure head in feet, time in days, and pumpage in gallons/day),

$$0.01 = (Q/4\pi T) \cdot W(u)$$

$$W(u) = [4\pi T/Q] \cdot (0.01)$$

Example:

Take this situation where: $Q = 3100 \text{ gpm} = 4.46 \times 10^6 \text{ g/day}$

$$T = 1,465,000 \text{ g/day} \cdot \text{ft}$$

$$S = 0.08$$

values for T and S are from well CPP-2 (Stewart, 1951) (Fig. 20).

Calculate $T/Q = 1.47 \times 10^6 / 4.46 \times 10^6 \text{ (ft}^{-1}\text{)} = 0.328 \text{ (ft}^{-1}\text{)}$, and then calculate:

$$W(u) = 4\pi \cdot (0.328 \text{ ft}^{-1}) \cdot (0.01 \text{ ft}) = 0.0412$$

Now look up the value of u for which $W(u) = 0.0412$. The well function $W(u)$ is tabulated in most textbooks on hydrogeology [see for example Domenico (1975, p. 320), Freeze and Cherry (1979), or Domenico and Schwartz (1990, p. 147)].

The corresponding value of u is 2.213, therefore

$$u = 2.213 = r^2/4Dt$$

$$r^2 = 2.213 \cdot 4Dt \quad \text{and} \quad t = r^2 / 8.852 D$$

From this we can calculate the time at which a 0.01 ft head drop will occur at any distance r, using values from Stewart (1951) derived from well tests on April 21-22 and June 29-30, 1951 on well CPP-2, $S = 0.08$, $T = 1,465,000 \text{ g/day ft}$.

$T = 1,465,000 \text{ g/d} \cdot \text{ft}$ gives D, the diffusivity. We have a problem with units using gallons. T is in gallons/day·ft, and diffusivity

should be entirely in length and time units. To do this, we must convert T to length and time units. 1 gallon = 0.134 ft³, so that T = 1,465,000 gallons/day · ft = 196,310 ft³/day · ft = 196,310 ft²/day.

$$D = T/S = [196,310 \text{ ft}^2/\text{day}] / .08 = 2.45 \times 10^6 \text{ ft}^2/\text{day}$$

Now to calculate the time t, when a pressure pulse of 0.01 feet reaches a distance of 2400 ft from the pumped well.

$$t = r^2 / 8.852 D = [2400 \text{ ft}]^2 / [8.852 \times 2.45 \times 10^6 \text{ ft}^2/\text{day}]$$

$$= 0.2652 \text{ days} = 382 \text{ minutes}$$

So that according to calculations using the aquifer parameter of S=0.08, T=1,465,00 g/day/ft we should see a detectable (0.01 ft) drawdown at 2400 ft in about 6.5 hours. this seems a long, time in that we suspect effects are occurring more quickly to produce significant flow reversals of vertical flows of 20 to 30 ft/min. in wells. If S were decreased to 0.008, a factor of ten less, the effect propagates in about 0.6 hours which is more like the suspected situation. This suggests that a storativity more typical of a confined aquifer (<0.005) may be more appropriate.

One can plot a curve of the relationship for t and r, for the appearance of a discernable head change of 0.01 feet, by plotting the parabola:

$$t = r^2 / 2.17 \times 10^7 \quad \dots \text{units of days and feet.}$$

The slope of the straight part of this curve, and hence the rate at which the discernable signal propagates, can be calculated by differentiating the equation:

$$r^2 = 8.852 D \cdot t$$

$$2r dr = 8.852 D dt$$

$$dr/dt = 8.852 D/2r = 4.426 D/r$$

so that at a distance of 2400 feet, the signal would propagate at a rate of

$$dr/dt = 4.426 [2.45 \times 10^6 \text{ ft}^2/\text{day}] / [2400 \text{ ft}] = 4.53 \times 10^3$$

ft/day

= 3.14 ft/minute, for $S=0.08$

If $S=0.008$, the rate would increase to 31.4 ft/min.

CONSIDERATION OF HYDRAULIC DIFFUSIVITY IN OTHER STUDIES

The concept of hydraulic diffusivity, as a measure of the propagation rate of a pressure disturbance in an aquifer is rarely discussed in hydrogeology textbooks. Domenico and Schwartz (1990, p. 145) show through dimensional analysis that the value of $u = r^2/4Dt = \text{constant}$, is useful for estimating the time at which head changes occur in a basin from pumpage at a distance. However, their discussion is difficult to apply. It is hoped that the above discussion, and example shows the utility and the method of the calculation.

Hydraulic diffusivity has been considered on a larger scale in the study of earthquakes, and in particular earthquakes induced by pore pressure changes that result from the filling large reservoirs and also as a result of fluid injection into the ground (Li, 1984/85; Talwani and Acree, 1984; Rice and Cleary, 1976).

Li (1984/85) gives the expression for the half-space solution for the pressure at a point at a radial distance r away from the pressure source and at time t , due to a constant well pressure P_0 exerted on the wall of a sphere of radius a , beginning at time $= 0$. The equation is valid for a pressure disturbance and measuring point at considerable depth below the free surface.

$$P(r,t) = P_0 a [1/r \cdot \operatorname{erfc} (r/\sqrt{4Dt})]$$

where erfc is the complementary error function.

Note here that the argument of the error function is the same as that for the well function $W(u)$ considered above - and a similar kind of calculation can be made, in which Q nor T have to be assumed. One only needs a value of D , the hydraulic diffusivity, and for any detectable pressure ratio $P(r,t) / P_0$, the relationship between r , t , and D can be calculated.

Li (1984/85) has compiled values for the hydraulic diffusivity of large rock masses from a variety of sources. The values vary from 5×10^3 to 10^5 cm^2/sec . The value of 2.45×10^6 ft^2/day , used above converts to 2.6×10^4 cm^2/sec (using $S=0.08$) - so that the value used in the above example is reasonable. If S is more like that of a confined aquifer (0.008) then the value of D would be 2.6×10^4 cm^2/sec . and somewhat larger than those reported for large rock masses.

COMPUTER MODEL COMPUTATION OF DRAWDOWN PRESSURE

Computer modeling programs can also be used to study the time at which turning on a nearby well produces a disturbance effect in a observation well. The program MODFLOW (McDonald and Harbaugh, 1988) is a numerical solution for aquifer pressure variation similar to the Theis (1935) analytical solution, but which allows for irregular aquifer properties. MODFLOW was employed to calculate pressure disturbances using the same transmissivity and

storativity value used in the previous equations. The model was run with well CPP-2 turned on at 3100 gpm for 2 hours and pressure variations observed at a well 2400 ft away such as USGS no. 44. The computation indicated that within two hours of pumping from CPP-2, only 5×10^{-5} ft. of drawdown would occur at wells 44 and 46. All of these factors would indicate the transmissivity value used is too small and or storativity is too large to simulate the situation of flow reversals caused by head fluctuation in one fracture zone. Other hydraulic parameters and geometry of the transmitting zones are being estimated to see what combination could describe the flow reversals.

CONCLUSIONS AND FUTURE RESEARCH

Various chemical and nuclear wastes reside and are moving with the groundwater beneath the INEL site. It is important to track the movement of the contaminants and to determine if any of the contaminants pose a hazard and are sufficiently concentrated to be recovered. Cross-flow across separate aquitards in the aquifer system occurs artificially and may also occur through natural connections. A better understanding of this transport is needed. Vertical cross-flows of water in open-hole intervals were studied by previous workers with varying results. An Impeller flowmeter was used in this report to quantify and compare results of flow measurements. The cross flow velocities were comparable to previous workers ranging up to 24 ft/min. A flow reversal was also noted which would indicate that a nearby pumping well could have an important control on fluid flow direction, tracking of contaminant

plumes, and recovery of contaminants if necessary.

Our future research plan is to develop more precise flowmeter measurements, and to monitor corssflow over a several day period to detect exact timing of variation and reversals. We will also closely monitor timing of pumpage at nearby wells rather than rely totally on monitoring data provided by INEL personnel. Information on fluid flows and propagation of pressure variation should provided useful and detailed understanding of fluid movement near the ICPP and elsewhere on site.

In a parallel effort we intend to refine our understanding of the geometry and geologic nature of fracture zone interconnections through study of logs and cores.

Finally we will review whether S and T values used are appropriate to these aquifers, by computer calculation using varying combinations of T and S, and a pumpage of 3100 gpm. Present values used in this report do not produce a measurable head change 2400 ft away, within 2 hours. Since we believe cross-hole flows are reversed by pumping, the assumed values of T may be too small and S may be too large. Also the rate of propagation in fractured media needs to be examined.

REFERENCES

- Anderson, S.R., 1991. Stratigraphy of the Unsaturated zone and Uppermost part of the Snake River Plain Aquifer at the Idaho Chemical Processing Plant and Test area, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey, Water-Resources Division Investigations Report 91-4010, p. 2-6.
- Barracough, J.T., Teasdale, W.E., and Jensen, R.G., 1967, Hydrology of the National Reactor Testing Station, Idaho: Annual Progress Report, 1965: U.S. Geological Survey, Open-File Report, issued February, 1967, p. 2.
- Barracough, J.T., Teasdale, W.E., Robertson, R.G., and Jensen, R.G., 1966, Hydrology of the National Reactor Testing Station Idaho: U.S. Geological Survey, Water-Resources Division, Open-File Report, issued October, 1967, p. 2.
- Bartholomay, R.C., 1990, Digitized Geophysical Logs for Selected Wells on or Near The Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey, Water-Resources Division, Open-File Report 90-366, p. 225.
- Bennett, C.M., 1990, Streamflow Losses and Ground-Water Level Changes along the Big Lost River at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey, Water-Resources Division, Investigations Report 90-4067, issued April, 1990, p. 2.

Domenico, P.A., 1972, Concepts and models in groundwater hydrology: McGraw-Hill Book Co., New York.

Domenico, P.A., and Schwartz, F., 1990, Chemical and Physical Hydrogeology,

Freeze, A., and Cherry, J., 1979, Groundwater, Prentice-Hall Books, Englewood, New Jersey.

Hess, A.E., 1986, Identifying Hydraulically Conductive Fractures with a Slow-velocity Borehole Flowmeter: Canadian Geotechnical Journal, v. 23, p. 69-78.

Li, V.C., 1984/85, Estimation of in-situ hydraulic diffusivity of rock masses: Pure and Applied Geophysics, v. 122, p. 544 - 559.

McDonald, M.G., Harbaugh, A.W., 1988, Techniques of Water-Resources Investigations of the United States Geological Survey chapter A1: A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Book 6 Modeling Techniques: U.S Geological Survey, p. 1.1-14.39.

Morin, R., Barrash, W, Paillet, F., and Taylor, T., 1992 (in review), Geophysical Logging in the Snake River Plain Aquifer at the Idaho National Engineering Laboratory: INEL Wells No. 44, 45, 46: submitted for U.S.G.S. Water Resources Investigations Report (4/20/92). p. 41, manuscript.

Morris, D.A., Hogenson, G.M., Shuter, E., Teasdale, W.E., 1963, Hydrology of Waste Disposal National Reactor Testing Station Idaho: Annual Progress Report, 1962: U.S. Geological Survey, Water-Resources Division, p. 80-83.

Morris, D.A., Barraclough, J.T., Chase, G.H., Teasdale, W.E., Jensen, R.G., 1964, Hydrology of Subsurface Waste Disposal National Reactor Testing Station, Idaho: Annual Progress Report, 1963: U.S. Geological Survey, Water-Resources Division, p. 40-46.

Rice, J.R., and Cleary, M.C., 1976, Some basic stress diffusion solutions for fluid-saturated elastic porous media with compressible constituents: Review of Geophysics and Space Physics, v. 14, p. 227-241.

Stewart, J.W., 1951, Results of Tests on Wells at Site 3 and 7, Reactor Testing Station, Idaho: U.S. Geological Survey, Water-Resources Division, p. 1-25.

Talwani, P., and Acree, S., 1984/85, Pore-pressure diffusion and the mechanism of reservoir-induced seismicity: Pure and Applied Geophysics, v. 122, p. 947-965.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of a well using ground-water storage: American Geophysical Union Transactions, Pt. 2, p. 519-525.

*Figure 1. Map showing the location of the Idaho National Engineering Laboratory (INEL)
(Barracough, 1965).*

Figure 2. Map showing the location of the Idaho Chemical Processing Plant (ICPP) and the Test Reactors Area (TRA) (Anderson, 1991).

Figure 3, Map showing the location of the CPP DISP well and the TRA DISP well (Anderson, 1991).

Figure 4, Map showing contours on the regional water table and the inferred directions of ground-water movement (Barracough, 1966).

Figure 5, Showing a Heat-Pulse Flowmeter Probe (Hess, 1985).

Figure 6, Showing direction and velocity of flow in Site 17 well (Morris, 1964).

Figure 7, Showing direction and velocity of flow in MTR Test well (Morris, 1964).

Figure 8, Showing direction and velocity of flow in USGS 4 well (Morris, 1964).

Figure 9, Showing direction and velocity of flow in USGS 28 well (Morris, 1964).

Figure 10, Map showing the wells logged by Morris et al 1964.

Figure 11, Map of the ICPP area showing the locations of the wells surveyed by the Tracejector and directions of flow (Barracough, 1965).

Figure 12. Graph of six wells in the ICPP area showing lithology, directions of flow, hole diameter, and velocity of flow (Barraclough, 1965).

Figure 13, Geophysical Logs ran on wells USGS 44 & 46.

USGS 44:

Caliper resolution about .2 inches (5 mm)

Casing-collar locator .10 feet (30 mm)

Thermistor .5 F (.2 C)

Natural Gamma tool

Impeller Flowmeter

USGS 46:

Caliper

Impeller Flowmeter

- 1: CENTRALIZER BASKET ASSY.
- 2: TOP SUB ASSY.
- 3: BLADE ASSY.
- 5: SPINNER HEAD BODY
- 6: LOWER BEARING RETAINER
- 10: SHAFT
- 11: HOUSING 1 7/16x7 VOLTAGE INHIBITOR
- 23: THREAD PLUG GASKET
- 27: THREAD PLUG

Figure 14, Showing a Mineral Logging Systems, Inc. 1 7/16 Impeller-flowmeter with a voltage inhibitor.

Figure 15. Calibration curves for USGS well #44 & 46. cable speed — C*counts/sec = flow velocity.

**DATE
FILMED**

8 / 17 / 93

END