HYDROGEOLOGIC IMPACT ANALYSIS OF NEW
WATER USES IN SECTION 7, T. 10 N., R. 28 EWM., OF
THE HANFORD RESERVATION

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ABSTRACT

An evaluation was made of the hydrologic impact upon the Hanford ground water regime of removing 1.7 million gallons per day, MGD (6.4 million liters per day, MLD) from the unconfined aquifer in the north half of Section 7, T. 10 N., R. 28 EWM., and recharging to the aquifer within the same area 1.0 MGD (3.8 MLD). The hydrogeology of the specific area was characterized by examining data obtained from nearby wells. A preliminary well yield analysis was performed which verified that one well could supply 6.4 MLD at the study site. Several reasonable, simplifying assumptions were made which permitted the determination by means of an analytical equation of the water table changes resulting from projected water uses. The results of the analysis show minimal impact upon the water table as a result of either the withdrawal or recharge of water. The estimated size of a pond for recharging the used water would be about three to six acres. If the proposed groundwater use activity is implemented, one step-drawdown and one pump test are recommended to verify the withdrawal well water yield.

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INTRODUCTION

New activities within the Hanford Reservation requiring withdrawal of water from the underlying aquifers or discharging water to these aquifers may affect the transport of radionuclides already present in the ground water flow system. If a significant withdrawal of water is made, the hydraulic gradient may be sufficiently increased so as to cause a more rapid movement of radionuclides toward the Columbia River. Additions of waste water to the subsurface can create water mounds and alter the ground water flow path. Hydrologic impact studies should be conducted prior to any new withdrawals of ground water or prior to adding water to the aquifers so as to be sure that such uses would not adversely affect the existing flow system underlying the Hanford Reservation.

PURPOSE

The present report documents the results of an evaluation of the hydrologic impact of withdrawing 1.7×10^6 gallons/day (6.4×10^6 liters/day) and discharging 1.0×10^6 gallons/day (3.8×10^6 liters/day) in the north half of Section 7, T. 10 N., R. 28 EWM. The water would be withdrawn from the unconfined aquifer and the discharges would infiltrate into the same aquifer. Figure 1 shows the location of the study area.

FIGURE 1
HANFORD AREA MAP SHOWING STUDY AREA

HYDROGEOLOGY

The geology of the Hanford Reservation has been extensively studied and documented.^[1] The essential hydrogeologic features of the area of interest include several distinct sedimentary horizons. The Columbia River Basalt is overlain by two or three members of the Ringold Formation which in turn is overlain by a layer of glaciofluvial deposits. The glaciofluvial material consists primarily of unconsolidated gravels, sands, and silts. The Upper Ringold Formation is made up of intergraded layers of fine sandstone and siltstone. The Middle Ringold is composed of well sorted, compact, variably cemented sands and gravels. The Lower Ringold consists mostly of silts and clays with interbedded gravels and sands. Figure 2 details the stratigraphy of these horizons at Hanford as well as their general hydrologic character.

From a hydrologic standpoint the most permeable horizons are the sands and gravels of the Upper Ringold Formation and the overlying glaciofluvial sediment. In the study area the water table lies at or just above the Ringold-glaciofluvial contact.

The topmost water-bearing horizon lies between the water table and the silts and clays of the Middle and Lower Ringold Formation. Groundwater in these unconsolidated and semiconsolidated sediments occurs under unconfined or water-table conditions.

Data from driller logs at three well sites (699-S19-11, 699-S18-E2 and 699-S31-1) near the study area were used to reconstruct the local stratigraphy. Two cross sections (Figure 3) were drawn and the results are shown in Figures 4 and 5. Water table readings shown in these figures were taken in July 1975.^[2]

GEOLOGIC TIME SCALE			GEOLOGIC CHARACTERISTICS					HYDROGEOLOGY		
ERA	PERIOD	EPOCH	RADIOGENIC DATE YEARS B P	STRATIGRAPHIC	BED OR FLOW UNIT	LITHOLOGIC CHARACTER	THICKNESS IN METERS	HYDROLOGIC CHARACTER	AQUIFER	
CENOZOIC	QUATERNARY	HOLOCENE		ALLUVIUM COLLUVIUM & EOLIAN SEDIMENTS		SANDS SILTS GRAVELS & CLAYS MODIFIED BY WIND EROSION	DUNES TO 20	OCCUR EVERYWHERE ABOVE THE WATER TABLE	DRY	
			6 600 --		MAZAMA ASH	ASH FALL CRATER LAKE OREGON	2 3			
			10 000 -- 12 500 --		GLACIER PEAK ASH	ASH FALL GLACIER PEAK WASHINGTON	05			
		> 12 000 -- < 18 000 --	ST HELENS ASH	ASH FALL MT ST HELENS WASHINGTON	05	OCCUR ABOVE THE WATER TABLE EXCEPT BETWEEN THE HIGH TERRACE PLATEAUS & THE COLUMBIA RIVER HAS VERY HIGH TRANSMISSIVITY & STORAGE	OCCASIONALLY AN UNCONFINED AQUIFER OR DRY			
		GLACIOFLUVIATILE SANDS & GRAVELS	TOUCHE T SILTS	FINE GRAINED FACIES OF THE GLACIOFLUVIATILE DEPOSITS BEDDED IN QUIET WATER						
			PASCO GRAVELS	PREDOMINANTLY COARSE GRAINED GRAVELS COBBLES & SANDS WITH CUT & FILL STRUCTURE	0 120					
			40 000 --	PALOUSE SOIL	CALCAREOUS SAND & SILT EOLIAN DEPOSIT MAINLY DERIVED FROM RINGOLD FM	0 25	OCCUR EVERYWHERE ABOVE THE WATER TABLE	DRY		
		PLEISTOCENE	RINGOLD FORMATION	UPPER RINGOLD	LOCALLY CAPPED BY CALICHE MOSTLY WELL BEDDED FLUVIAL SILTS & SANDS WITH SOME GRAVELS	0 125	SAND & GRAVEL BEDS HAVE VERY HIGH HYDRAULIC CONDUCTIVITY & STORAGE SOME BEDS OF SILTY CLAY OR CLAY ARE ESSENTIALLY IMPERMEABLE	UNCONFINED AQUIFER		
				MIDDLE RINGOLD	SANDS & GRAVELS WELL SORTED COMPACT BUT VARIABLY CEMENTED	0 120				
				1 000 000 -- 1 500 000 --	LOWER RINGOLD	SILTS & CLAYS WITH INTERBEDDED GRAVELS & SANDS CLAY IS CHARACTERISTICALLY BLUE BUT MAY BE GREEN BROWN OR TAN			0 125	AQUICLUDE
	TERTIARY			PLOCENE	COLUMBIA RIVER BASALT GROUP	UPPER AND MIDDLE YAKIMA	BASALT FLOWS AND INTERBEDS TUFF & TUFFACEOUS SANDSTONE	0 700	FLOWS ARE DENSE VERTICAL HYDRAULIC CONDUCTIVITY IN THE FLOW IS MODERATE DUE TO SHRINKAGE CRACKS HORIZONTAL HYDRAULIC CONDUCTIVITY & TRANSMISSIVITY OF INTERBEDDED SEDIMENTS IS MODERATE	CONFINED SYSTEMS AQUIFER AQUITARD AQUIFER AQUITARD AQUIFER
						VANTAGE SANDSTONE	WEAKLY CEMENTED SANDSTONE	0 10		
		11 000 000 -- 15 000 000 --	LOWER YAKIMA			BASALT FLOWS & INTERBEDS	0 500			
MIOCENE										

V 504 R

FIGURE 2
STRATIGRAPHIC CHARACTERISTICS OF ROCKS IN THE HANFORD RESERVATION

FIGURE 3

CROSS SECTION LOCATIONS AND STUDY AREA

FIGURE 4
CROSS SECTION A - A'

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FIGURE 5
CROSS SECTION A - A''

From the cross sections one can see that the water table slopes down about five feet per mile in an easterly direction. Groundwater flow takes place in an easterly direction from the Yakima River to the Columbia River.

Deju and Summers^[3] estimated the mean hydraulic conductivities of the unconfined aquifer at wells 699-S19-11, 699-S18-E2, and 699-S31-1. Their estimates are 200, 150, and 120 feet/day (61, 46, 37 meters/day), respectively. These values represent the hydraulic conductivities over the entire aquifer thickness. The highest hydraulic conductivities will be found in the glaciofluvial material with a drastically smaller value in the Upper Ringold.

Recent pumping tests at well 699-S6-E4 (3 miles [4.8 kilometers] NE of the study area) reveal that the hydraulic conductivity of the glaciofluvial sediment locally averages 400 feet/day (122 meters/day) and the Upper Ringold is an order of magnitude less (40 feet/day [12.2 meters/day]). Thus, at the study area one can estimate the mean hydraulic conductivity by the equation:

$$\bar{K} = \frac{\sum_{i=1}^n b_i K_i}{b} = \frac{b_1 K_1 + b_2 K_2}{b} \quad (1)$$

where,

$\bar{K}$ = mean hydraulic conductivity (feet/day)

b_1 = thickness of saturated glaciofluvial sediment (feet)

b_2 = thickness of saturated Upper Ringold sediment (feet)

K_1 = average hydraulic conductivity of glaciofluvial sediment (feet/day)

K_2 = average hydraulic conductivity of Upper Ringold sediment (feet/day)

b = total aquifer thickness = $b_1 + b_2$ (feet)

From the cross sections we estimate that at the study site $b_1 = 46$ feet, $b_2 = 45$ feet, $b = 91$ feet (14, 13.7, and 27.7 meters respectively). Thus, using equation (1) we obtain $\bar{K} = 222$ feet/day (67.7 meters/day).

Cearlock, et al.[⁴] using hydraulic conductivity values from pumping tests throughout the Hanford Reservation, have generated a map of mean hydraulic conductivity values for the unconfined aquifer. The study area lies between the 100 and 500 feet/day (30.5 and 152 meters/day) hydraulic conductivity map contour lines.

On the basis of all the above information the authors will represent the aquifer in the study area as a 90-foot (27.4 meter) thick layer of homogeneous material with an average hydraulic conductivity of 225 feet/day (68.6 meters/day). The assumption of homogeneity is obviously a simplification since we have just noted that the upper half of the aquifer is an order of magnitude more permeable than the lower half. However, the aquifer behaves as a unit and over an extended period of time treating it as a homogeneous unit using the mean hydraulic conductivity values is a valid assumption.

WATER YIELD

Before continuing the analysis it is important to determine whether the thickness of the unconfined aquifer is sufficient to supply 1.7 MGD (6.4 MLD) at the study site with a single well. The optimum casing and screen size for the specified flow rate would be 16-inch OD and 12-inch nominal, respectively.[⁵] A conservative well screen slot opening based upon Hanford experience would be Number 20 slot which yields an intake area of 77 square inches per linear foot for a 12-inch screen.[⁵] Assuming an entrance velocity of 0.1 feet/second (.03 meter/second), the transmitting capacity of such a well screen is $(0.1 \text{ ft/sec}) (\text{ft}^2/144 \text{ in}^2)(7.48 \text{ gal/ft}^3)$ $(60 \text{ sec/min})(\text{intake area, in}^2/\text{linear foot of screen, feet})$ or $(0.31)(77) = 24 \text{ gpm/foot}$ (298 lpm/ meter) of screen. The requirement of 1.7 MGD or 1180 gpm from the pumped well combined with the above value for the flow per linear foot of well screen yields a value of 49 feet (15 meters) of required total screened interval. Since this is less than the average aquifer thickness in the study area one pumped well should suffice to produce the needed 1.7 MGD of groundwater.

LIMITATIONS

The following assumptions will be made in our analysis:

1. The aquifer is homogeneous and can be mathematically defined as infinite in areal extent.
2. No radiocontamination of the water will take place as a result of the proposed water use at the study area.
3. The aquifer is isotropic and of uniform thickness.
4. The aquifer is pumped at a constant rate $Q = 1.7 \times 10^6$ gallons/day [6.4×10^6 liters/day] under steady state conditions.
5. The pumped well penetrates the entire aquifer and thus receives water from the entire thickness of the aquifer by horizontal flow.
6. The withdrawal of water is from a well at the aquifer and the disposal of water eventually infiltrates the aquifer at a point or in an area not closer than the sum of the radii of influence of the pumped and discharge wells.*

ANALYSIS

The radionuclide plumes from the 200 Areas^[6] are rather far from the area under study. Unless a drastic change in the water table configuration extending miles away from the study area takes place, the plumes will be unaffected.

To analyze the extent of change in the water table as a result of the proposed operation one needs to solve the equation of flow in an unconfined aquifer under steady state conditions:

*This last assumption gives the worst possible case since if the withdrawal well is close to the infiltration area the cone of depression interacts with the cone of recharge, thus minimizing the impact of the entire operation.

$$\frac{\partial^2 h^2}{\partial r^2} + \frac{1}{r} \frac{\partial h^2}{\partial r} = 0 \quad (2)$$

where, h = head and r = radial distance from the well.

Assuming radial symmetry about the pumped well and with the assumptions noted in the preceding section one can calculate the head at any point using the solution to equation (2):

$$h^2 - H^2 = \frac{Q \ln r/r_0}{\pi K} \quad (3)$$

where,

H = initial water level (assumed to be 380 feet or 116 meters)

h = water level at any point

Q = discharge or recharge flow rate

r = distance from well to any point

r_0 = radius of influence

K = mean hydraulic conductivity (assumed to be 225 feet/day)

Thus, for the discharge well the head h at any point is given by the equation:

$$h = \left[\frac{2.27 \times 10^5 \text{ ft}^3/\text{day}}{(3.1416)(225 \text{ ft}/\text{day})} [\ln r - \ln r_0] + 144,400 \text{ ft}^2 \right]^{(1/2)} \quad (4)$$

The head h was obtained as a function of distance r away from the pumped well and is plotted in Figure 6. The radius of influence was initially assumed to be 1,500 feet (457 meters) which is a safe value based on pumping tests at Hanford.

Under these circumstances the maximum drawdown at the well face is just over 3 feet (0.9 meter) and the drawdown is less than 1 foot (0.3 meter) at distances greater than 150 feet (46 meters) away from the well.

The radius of influence is not as critical a parameter since its effect is inside a logarithmic term. If we assume that the effect of the well is felt all the way to the Yakima River (r_0 = 10,000 feet or 3,048 meters)

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FIGURE 6
DRAWDOWN RESULTING FROM A 1.7 MILLION
GALLONS PER DAY WITHDRAWAL ($r_0 = 1,500$ ft)

the resulting drawdown pattern is as shown in Figure 7. Such an assumption also implies that the effect of the drawdown extends to the 300 Area. As shown in Figure 7 under this assumption the effect of the withdrawal will be less than 1 foot (0.3 meter) at distances greater than 1,000 feet (305 meters) away from the pumped well.

The effect of building up a mound as a result of recharge of water to the subsurface can be calculated by using equation (3). Water withdrawn will be partly consumed and lost. However, one million gallons per day of water must be disposed. This disposal can be accomplished either in a pond or by a recharge well (assuming that the water is of adequate chemical quality). The maximum mound will be built in the case of a recharge well located at a minimum distance from the discharge well equal to the sum of the two radii of influence. To calculate the size of the resulting mound under these circumstances and assuming a constant recharge of one million gallons per day one uses equation (3) which becomes:

$$h = \left[\frac{(-1.337 \times 10^5 \text{ ft}^3/\text{day})}{(3.1416)(225 \text{ ft}/\text{day})} [\ln r - \ln r_0] + 144,400 \text{ ft}^2 \right]^{(1/2)} \quad (5)$$

Using equation (5) we can then plot the mound resulting from recharge assuming a radius of influence of 1,500 feet (45 meters) and a radius of influence of 10,000 feet (Figures 8 and 9 respectively). The maximum buildup (at the recharge face) is less than 2.5 feet in either case.

The buildup resulting from pond infiltration would be less than that from a recharge well due to evaporative losses and saturation of the area underlying the pond and above the water table.

If the distance between the pumped well and injection well is less than the sum of the two radii of influence, the effect would be less than calculated above.

In no case does it appear that the projected water usage will affect in a detrimental way the existing water table (assuming no radiocontamination will be put into the aquifer at the study area).

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FIGURE 7

DRAWDOWN RESULTING FROM A 1.7 MILLION GALLONS PER DAY WITHDRAWAL ($r_0 = 10,000$ ft)

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FIGURE 2
BUILDUP RESULTING FROM A 1.0 MILLION GALLONS PER DAY INJECTION ($r_0 = 1,500$ ft)

V7601-5.2

FIGURE 9
BUILDUP RESULTING FROM A 1.0 MILLION GALLONS PER DAY INJECTION ($r_0 = 10,000$ ft)

SIZE OF POND NEEDED FOR DISPOSAL

If a pond is selected for disposal, the size of such a pond would be a function of disposed water flow rate, infiltration rate, and evaporation rate at the pond surface. Infiltration rate near the Cold Creek Boundary of the Reservation has been calculated to be $5.3 \times 10^{-3} \frac{\text{gal/min}}{\text{ft}^2}$ or 1.0 feet/day (0.3 meters/day).^[7] Annual evaporation on the Hanford Reservation is estimated at about 50 inches/year or an average of 0.14 inches/day (0.36 cm/day). From these data it can be seen that evaporation is quite likely to be a very small fraction of infiltration and can be ignored in our analysis. Based upon an infiltration rate in the study area of 1.0 feet/day the pond surface area can be calculated as follows:

$$\begin{aligned} \text{Pond Area} &= \frac{\text{Disposed water flow rate}}{\text{infiltration rate}} \\ &= \text{approximately 3.1 acres (1.25 hectares)} \end{aligned}$$

The diameter of such a pond would be about 413 feet (109 meters).

If the infiltration rate were 0.5 feet/day (0.15 meters/day) the pond surface area would be about 6.1 acres (2.48 hectares) and the pond diameter would be about 583 feet (154 meters).

CONCLUSIONS

Based upon presently available data, the hydrologic impact upon the Hanford ground water regime of removing groundwater at the rate of 1.7 million gallons/day (6.4 MLD) and recharging 1.0 million gallons/day (3.8 MLD) back into the groundwater flow system in the north half of Section 7, T. 10 N., R. 28 EWM., will be insignificant. If the water to be recharged is chemically or radiologically contaminated, the impact of such contamination will require additional study.

RECOMMENDATION

If the proposed groundwater use activity is implemented, one step-drawdown, and one pump test should be conducted on the withdrawal well to verify the estimated water yield and verify the analysis results calculated herein.

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