'KAFB Bulk

ENTERED

From: Kent Friesen [mailto:kent.friesen@wyoming.com]
Sent: Friday, February 11, 2011 4:20 PM
To: Moats, William, NMENV
Cc: 'Paige Walton'; Brandwein, Sid, NMENV; McDonald, William, NMENV
Subject: RE: Kirtland AFB drawdown calculations - finished

Will – I completed a calculation of predicted drawdown using Neuman's (1975) method for unconfined aquifers. Attached is the calculation and predicted drawdown curve using 1) Shaw's assumptions in the IM LNAPL work plan; 2) what I consider more realistic assumptions based on the nitrate plume pump test (using the references Sid provided); and 3) a more optimized design assuming an additional well located 100 ft from the extraction well and increasing the extraction flow rate from 50 to 100 gpm. In addition to the full calculation brief, attached is a .pdf with just the predicted drawdown curves, and then the same drawdown curve in a .jpeg format in case someone wanted to drop it into a Word document. I don't mind others looking through the calculation brief, although it's obviously hand done and so not exactly cosmetic enough for publishing.

By the way, you were correct, the Theis equation seems to overestimate the drawdown compared to the Neuman approach, by about a factor of 2. Good call.

In this evaluation, it appears that there would be enough drawdown (over 1 foot) at the nearest monitor well using Shaw's assumptions. However, based on the aquifer test results at the Kirtland nitrate plume, it appears that the horizontal hydraulic conductivity and storativity values used by Shaw were too large. Using values from the pump test and other reasonable assumptions (provided in the calculation brief), I calculated drawdown on the order of 0.1 foot at the nearest monitor well, which is about 250 feet away from the extraction well. In my opinion that is too little to measure; the "noise" during the pump test would wash out that little of drawdown.

Then, I re-calculated the drawdown assuming two changes: increasing the flow rate to 100 gpm, and providing the monitoring point 100 feet away. That results in expected drawdown of about 0.4 feet, which I expect would be observable in the new observation well. Also, if the hydraulic conductivity at the Bulk Fuel Farm plume is actually less than obtained during the pump test (and it reasonably could be), then that would also help show more drawdown in an observation well.

Based on this analysis, here are my recommendations:

- Require Kirtland/Shaw to model the pump test as part of the next Work Plan version submittal, to verify well placement, flow rate, aquifer parameters, etc. However, suggest that we do not "require" they use a certain hydraulic conductivity, or flow rate, etc. These parameters all have an effect on each other, and they should think about what would be optimum, and then make their own recommendations. I don't think we should constrain them too much, because then if something goes wrong they could say "but we used your pump rate…", etc.
- Require Kirtland/Shaw to install another monitor well about 100 feet away. It just seems too risky to rely on the existing wells.
- Ask them how they plan on obtaining good data to determine specific yield, which requires extended pumping time to get a good curve match (probably longer than 72 hours). They could either extend the pump test, or alternatively I think they could provide extended transducer monitoring in an observation well during initial full-scale groundwater extraction; that would help with providing this type of data after system start-up.
- Next time I or NMED do this type of evaluation, it would really be beneficial to get a commercial program for pump test analysis; I think it would save a lot of time. Something like Aqtesolve or WinTest. Cost is about $500.

That's all for now, I hope this helps. Please keep me informed how this all comes out – Kent

Kent A. Friesen, P.E., P.G.
WYOMING ENVIRONMENTAL CONSULTING LLC
3712 Horse Creek Road
Cheyenne, WY 82009
(307) 637-0286
Fax (307) 778-7473
kent.friesen@wyoming.com

From: Kent Friesen [mailto:kent.friesen@wyoming.com]
Sent: Monday, February 07, 2011 11:38 AM
To: 'Brandwein, Sid, NMENV'; 'Moats, William, NMENV'; 'McDonald, William, NMENV'
Cc: 'Paige Walton'
Subject: RE: Kirtland AFB drawdown calculations - debrief on aquifer test

OK, I've reviewed the aquifer test report for Extraction Well KAFB-ST105-EX01 that Sid sent me this morning, and I've downloaded the pertinent Neuman 1975 journal article that includes the analytical technique for drawdown in an unconfined aquifer. I'm anticipating the new drawdown calculation to take me a little while due to complexity, the years since college, etc. However, here is something you can use sooner if needed:

"The aquifer test was performed in January 2009 at a location approximately 3000 feet southeast of the BFF area. Three observation wells were monitored during the pump test; however, only one monitoring well (KAFB-0508) had measurable drawdown during the 72-hour pump test. This monitoring well was located 70 feet away from the extraction well, and a total drawdown of 0.3 ft was noted in this well at the end of the pump test. No observable drawdown was noted in the two other monitoring wells located 1200 ft and 926 ft away from the extraction well. Since only 0.3 ft of drawdown was observed in a well 70 ft away, it seems highly improbable that any drawdown will be observed during the proposed BFF pumping tests from monitor wells that are over 200 ft away from the extraction well. Note also that the January 2009 pump test resulted in a hydraulic conductivity of 246 ft/day, and a storativity of 0.05, both of which are significantly higher than the parameters used for modeling in the current work plan."

I'll plan on looking through the Neuman method after lunch, unless you think the above analysis is sufficient for now. – Kent Friesen

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From: Kent Friesen [mailto:kent.friesen@wyoming.com]
Sent: Monday, February 07, 2011 8:50 AM
To: 'Brandwein, Sid, NMENV'; 'Moats, William, NMENV'; 'McDonald, William, NMENV'
Cc: 'Paige Walton'
Subject: RE: Kirtland AFB drawdown calculations

Capture zone goes from 400 ft either side of extraction well (using Shaw's numbers) to 50 ft using these pump test results. Big difference. – Kent Friesen

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From: Kent Friesen [mailto:kent.friesen@wyoming.com]
Sent: Monday, February 07, 2011 8:44 AM
To: 'Brandwein, Sid, NMENV'
Subject: RE: Kirtland AFB drawdown calculations - Question for Sid

Thanks Sid, I got it. Looks like Shaw's 30 ft/day hydraulic conductivity, vs. 246 ft/day in this report (almost a factor of 10). Storativity is 50 times higher than Shaw's (not sure how that plays in, yet). And the location is not too far from our interests. I'll work with this and get back with you'all, thanks! - Kent

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From: prvs=4019ba0d55=Sid.Brandwein@state.nm.us [mailto:prvs=4019ba0d55=Sid.Brandwein@state.nm.us] **On Behalf Of** Brandwein, Sid, NMENV
Sent: Monday, February 07, 2011 8:28 AM
To: kent.friesen@wyoming.com
Subject: RE: Kirtland AFB drawdown calculations - Question for Sid

Kent,
Here's the aquifer test report I was talking about. I ran across it last Wednesday - it was done under another bureau's bailiwick.
Sid

From: kent.friesen@wyoming.com [mailto:kent.friesen@wyoming.com]
Sent: Friday, February 04, 2011 10:41 AM
To: Brandwein, Sid, NMENV
Cc: Moats, William, NMENV; paigewalton@msn.com
Subject: RE: Kirtland AFB drawdown calculations - Question for Sid

Thanks Sid, stay warm down there. I can relate to the cold and am glad our cold spell is over now.

Yes, I would appreciate a copy of the report from the KAF pump test; I'd like to use those parameters for the unconfined drawdown evaluation. Regards - Kent Friesen

--- Sid.Brandwein@state.nm.us wrote:

From: "Brandwein, Sid, NMENV" <Sid.Brandwein@state.nm.us>
To: Kent Friesen <kent.friesen@wyoming.com>
CC: "Moats, William, NMENV" <Williams.Moats@state.nm.us>
Subject: RE: Kirtland AFB drawdown calculations - Question for Sid
Date: Fri, 4 Feb 2011 17:20:03 +0000

Kent,
I'm sending this to you from home because NMED closed its offices from about 2:30 yesterday through all day today due to gas shortages and frigid weather.
So I don't have the reference here, but, yes, KAFB did a constant draw down about 3000 feet southeast of the BFF and they did a 53 gallon/min pump test for 72 hours. The results said a drawdown of about 6-7 feet at the well, a drawdown on about .3 feet at a well 70 feet away, and the next closest well was about 1000 feet away, with no discernible effect. I think they came up with something like a conductivity of 100+ feet /day for the pump well and 200+ ft/day for the observation well. This seems very high compared to other wells in the area. Wells about 1-2 miles north of the site seem to have conductivity values around 30 feet/day but the nearest one (~1mile) has a value of 80 feet/day. I can't remember off hand what the storativity value they calculated, but it might have been 0.05 (but maybe I'm off). I'll have to check when I get back to the office (remind me if you need the number. (Actually, we have the report on disc and I can get you an electronic version next week when the office opens up again.

Sid

From: Kent Friesen [kent.friesen@wyoming.com]
Sent: Thursday, February 03, 2011 2:27 PM
To: Brandwein, Sid, NMENV
Subject: RE: Kirtland AFB drawdown calculations - Question for Sid

Hi Sid – were there any calculated parameters (transmissivity or hydraulic conductivity) for this test that Will is referring to? So far I haven't done anything about comparing Shaw's assumed aquifer parameters with anything else from Albuquerque (nor do I have any good resources on hand for this) – Kent Friesen

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From: Kent Friesen [mailto:kent.friesen@wyoming.com]
Sent: Thursday, February 03, 2011 2:19 PM
To: 'Moats, William, NMENV'
Cc: 'Kieling, John, NMENV'; 'Paige Walton'; 'Brandwein, Sid, NMENV'; 'McDonald, William, NMENV'
Subject: RE: Kirtland AFB drawdown calculations

Thanks Will. I can look into the Neuman method, after clearing some things off my desk. But in my opinion there is not much better than previous documented observations. - Kent

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From: prvs=8015c45733=Williams.Moats@state.nm.us [mailto:prvs=8015c45733=Williams.Moats@state.nm.us] **On Behalf Of** Moats, William, NMENV
Sent: Thursday, February 03, 2011 1:23 PM
To: Kent Friesen
Cc: Kieling, John, NMENV; 'Paige Walton'; Brandwein, Sid, NMENV; McDonald, William, NMENV
Subject: RE: Kirtland AFB drawdown calculations

Hi All,

We here at NMED are looking at applying the Neuman solution to this problem, which assumes a fully penetrating well (which isn't true for this case) and an unconfined aquifer. We are concerned that the Theis equation would overestimate drawdown because it doesn't take into account dewatering of the aquifer.

Sid found the results of a pumping test done at KAFB south of the Bulk Fuels Facility. Correct me if I'm wrong Sid, but KAFB pumped 50 gpm for 66 hours and saw 0.25 ft of drawdown at an observation well located 70 ft away. This would call into question whether one could see any drawdown at several hundred feet if hydraulic conditions to the north are similar.

Kent - do you want to try the Neuman method (or something else if there is anything that deals with unconfined aquifers)? If so, I would suggest using a specific yield of 0.2.

-- Will

From: Kent Friesen [mailto:kent.friesen@wyoming.com]
Sent: Thursday, February 03, 2011 11:19 AM
To: Moats, William, NMENV
Cc: Kieling, John, NMENV; 'Paige Walton'
Subject: Kirtland AFB drawdown calculations

Will - Paige found a resource on line that works well with this; it is based on the Cooper-Jacob straight-line approximation of the Theis equation. Basically it generates a drawdown without going through Theis curve matching, so that is quite convenient. I spent some time validating the approach and then applying site-specific parameters from the LNAPL IM Work Plan. The attached file shows the parameters used and conversions to common units (feet and minutes).

You can plug these numbers into the calculator, which shows that an observation well 300 feet away (about the distance from one proposed extraction well to monitoring well KAFB-10618) will have a drawdown of 1.9 feet after 24 hours. That is definitely measurable.

So I would conclude (which we did not intuitively think would happen) that the existing monitoring wells should be adequate to measure drawdown in the proposed pump tests, unless aquifer parameters and pump rates, etc. are drastically different than what is presented in the LNAPL IM Work Plan. Sid could check these input numbers if he has some other local-specific resources.

I'm out for an hour or two but then back this afternoon if we need to discuss – Kent

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Kent A. Friesen, P.E., P.G.

WYOMING ENVIRONMENTAL CONSULTING LLC

3712 Horse Creek Road

Cheyenne, WY 82009

(307) 637-0286

Fax (307) 778-7473

kent.friesen@wyoming.com

From: Paige Walton [mailto:paigewalton@msn.com]
Sent: Thursday, January 27, 2011 7:04 PM
To: Kent Friesen
Subject: drawdown calcs

Hi Kent,

This may help with the KAFB stuff...it is an on-line calculator for estimating drawdown.

http://www.groundwatersoftware.com/calculator_7_time_drawdown.htm

Paige

Paige Walton, PG, CHMM

Senior Scientist and Program Manager

AQS, Inc.

801.451.2864 office

435.830.7730 cell

pwalton@aqsnet.com

AQS
Environmental

Rev	Date	By	Ck	Title
				DRAWDOWN ESTIMATE USING NEUMAN 1975 METHOD, KIRTLAND AFB, NEW MEXICO
				-Kent Friesen 2/11/2011

REFERENCE: SHLOMO P. NEUMAN, 1975. "ANALYSIS OF PUMPING TEST DATA FROM ANISOTROPIC UNCONFINED AQUIFERS CONSIDERING DELAYED GRAVITY RESPONSE." WATER RESOURCES RESEARCH, VOL 11, NO. 2. APRIL. PGS. 329-342.

APPROACH: USE "TYPE CURVE METHOD" ON PG. 330-331, AND WORK BACKWARDS TO FINE DRAWDOWN AT 250 FT. AWAY FROM PUMP TEST.
USE FOLLOWING AQUIFER PARAMETERS, FROM "STAGE 2 ABATEMENT PLAN, EXTRACTION WELL KAFB-37105-EX01 AQUIFER TEST REPORT FOR NITRATE CONTAMINATED GROUNDWATER AT KIRTLAND AIR FORCE BASE, NEW MEXICO," APRIL 2009, PG 3-6

Transmissivity $T = 16,450\ ft^2/day$ (SHAW: $30\ ft/day \times 50\ ft = 1500\ ft^2/day$)

K_r (horizontal) $= (16,450\ ft^2/day)(1/67\ ft) = 246\ ft/day$

$K_z / K_r = 1/1000$, BASED ON WRIR 02-4200 RANGE.

$K_z = (1/1000)(246\ ft/day) = 0.2\ ft/day$

$Q = 50$ gpm (shaw assumption)

$b = 50$ ft (SHAW SCREEN DEPTH)

$r = 250$ ft (distance btwn. extraction well and KAFB-10618)

S_y specific yield $= 0.2$ (FROM WRIR 02-4200 range).

$S = 2 \times 10^{-6}$ / ft, assume $b = 100$ ft, S_e elastic storativity $= .0002$ (SHAW ASSUMED 0.001)

FOR EACH CALCULATION:

1) Find type curve from $\beta = \dfrac{r^2 K_z}{K_r b^2}$

2) FIND POINTS ON TYPE CURVE, (S_D, t_y) and (S_D, t_s)

3) Calculate drawdown (s) and time (t), and plot on log-log graph.

Calculation Sheet	Job Number	WBS Number	Page Number	Sheet 2 of 8

Rev	Date	By	Ck	Title

FIRST CASE: SHAW'S ASSUMPTIONS

1) FIND TYPE CURVE $\beta = \frac{r^2 K_z}{K_r b^2} = \frac{(250\ ft)^2 (0.03\ ft/day)}{(30\ ft/day)(50\ ft)^2} = 0.025$; USE 0.03 CURVE.

2) FIND POINT ON "TYPE B" LATE SIDE OF TYPE CURVE:
$S_D = 2.7 \quad t_y = 1.0$ (SEE ATTACHED)

3) CALCULATE DRAWDOWN + CORRESPONDING TIME:

$S_D = \frac{4\pi T}{Q} s \rightarrow s = \frac{S_D Q}{4\pi T} = \frac{(2.7)(50\ gal/min)(60\ \frac{min}{hr})(24\ \frac{hr}{day})}{4\pi(1500\ ft^2/day)(7.48\ \frac{gal}{ft^3})}$

$s = 1.38$ FT.

$t_y = \frac{Tt}{S_y r^2} \rightarrow t = \frac{t_y S_y r^2}{T} = \frac{(1.0)(0.2)(250\ ft)^2}{(1500\ ft^2/day)} = 8.3$ days

4) REPEAT FOR POINT ON "TYPE A" EARLY SIDE OF TYPE CURVE:

$S_D = 2.2, \quad t_s = 10.0$ (SEE ATTACHED)

$S_D = \frac{4\pi T}{Q} s \rightarrow s = \frac{S_D Q}{4\pi T} = \frac{(2.2)(50\ gal/min)(60)(24)}{4\pi(1500\ ft^2/day)(7.48)} = 1.12$ ft

$t_s = \frac{Tt}{S r^2} \rightarrow t = \frac{t_s S r^2}{T} = \frac{(10.0)(0.001)(250\ ft)^2}{1500\ ft^2/day} = 0.42$ DAY

PLOT ON LOG-LOG GRAPH PAPER + TRACE $\beta = 0.03$ TYPE CURVE.

SECOND CASE: NMED ASSUMPTIONS

1) FIND TYPE CURVE: $\beta = \frac{r^2 K_z}{K_r b^2} = \frac{(250\ ft)^2 (0.2\ ft/day)}{(246\ ft/day)(50\ ft)^2} = 0.020$, USE 0.03 CURVE

2) FIND POINT ON "TYPE B" LATE SIDE OF TYPE CURVE:
$S_D = 2.7 \quad t_y = 1.0$ (SAME AS BEFORE; OK).

3) CALCULATE DRAWDOWN + TIME: $s = \frac{S_D Q}{4\pi T} = \frac{(2.7)(50\ gpm)(60)(24)}{4\pi(16{,}450\ ft^2/day)(7.48)} = 0.13$ FT

$t = \frac{t_y S_y r^2}{T} = \frac{(1.0)(0.2)(250\ ft)^2}{16{,}450\ ft^2/day} = 0.76$ day

Calculation Sheet	Job Number	WBS Number	Page Number	Sheet of
				3/8

Rev	Date	By	Ck	Title

4) REPEAT FOR POINT ON "TYPE A" EARLY SIDE OF CURVE:

$S_D = 2.2, \quad t_S = 10$

$$S_D = \frac{4\pi T s}{Q} \rightarrow s = \frac{S_D Q}{4\pi T} = \frac{(2.2)(50\ \text{gal/min})(60\ \frac{\text{min}}{\text{hr}})(24\ \frac{\text{hr}}{\text{day}})}{4\pi(16{,}450\ \text{ft}^2/\text{day})(7.48\ \text{gal/ft}^3)} = 0.10\ \text{ft}$$

$$t_S = \frac{Tt}{Sr^2} \rightarrow t = \frac{t_S S r^2}{T} = \frac{(10)(0.0002)(250\ \text{ft})^2}{16{,}450\ \text{ft}^2/\text{day}} = 0.008\ \text{day}$$

THIRD CASE: MORE OPTIMUM DESIGN

ASSUMPTIONS: KEEP SAME AQUIFER PARAMETERS USED W/ "NMED ASSUMPTIONS", BUT DECREASE $r = 100$ ft, INCREASE $Q = 100$ gpm.

1) TYPE CURVE: $$\beta = \frac{r^2 K_z}{K_r b^2} = \frac{(100\ \text{ft})^2 (0.2\ \text{ft/sec})}{(246\ \text{ft/sec})(50\ \text{ft})^2} = 0.0033, \text{ USE } 0.004 \text{ CURVE.}$$

2) MATCH POINT ON "TYPE B" CURVE: $S_D = 4.6, \quad t_y = 1.0$

$$S_D = \frac{4\pi T}{Q} s \rightarrow s = \frac{S_D Q}{4\pi T} = \frac{(4.6)(100\ \text{gpm})(24)(60)}{4\pi(16{,}450\ \text{ft}^2/\text{day})(7.48)} = 0.43\ \text{FT}$$

$$t_y = \frac{Tt}{S_y r^2} \rightarrow t = \frac{t_y S_y r^2}{T} = \frac{(1.0)(0.2)(100\ \text{ft})^2}{(16{,}450\ \text{ft}^2/\text{day})} = 0.12\ \text{DAY}$$

3) MATCH POINT ON "TYPE A" CURVE: $S_D = 3.0, \quad t_S = 10.0$

$$S_D = \frac{4\pi T s}{Q} \rightarrow s = \frac{S_D Q}{4\pi T} = \frac{(3.0)(100\ \text{gal/min})(24)(60)}{4\pi(16{,}450\ \text{ft}^2/\text{day})(7.48\ \text{gal/ft}^3)} = 0.28\ \text{FT}$$

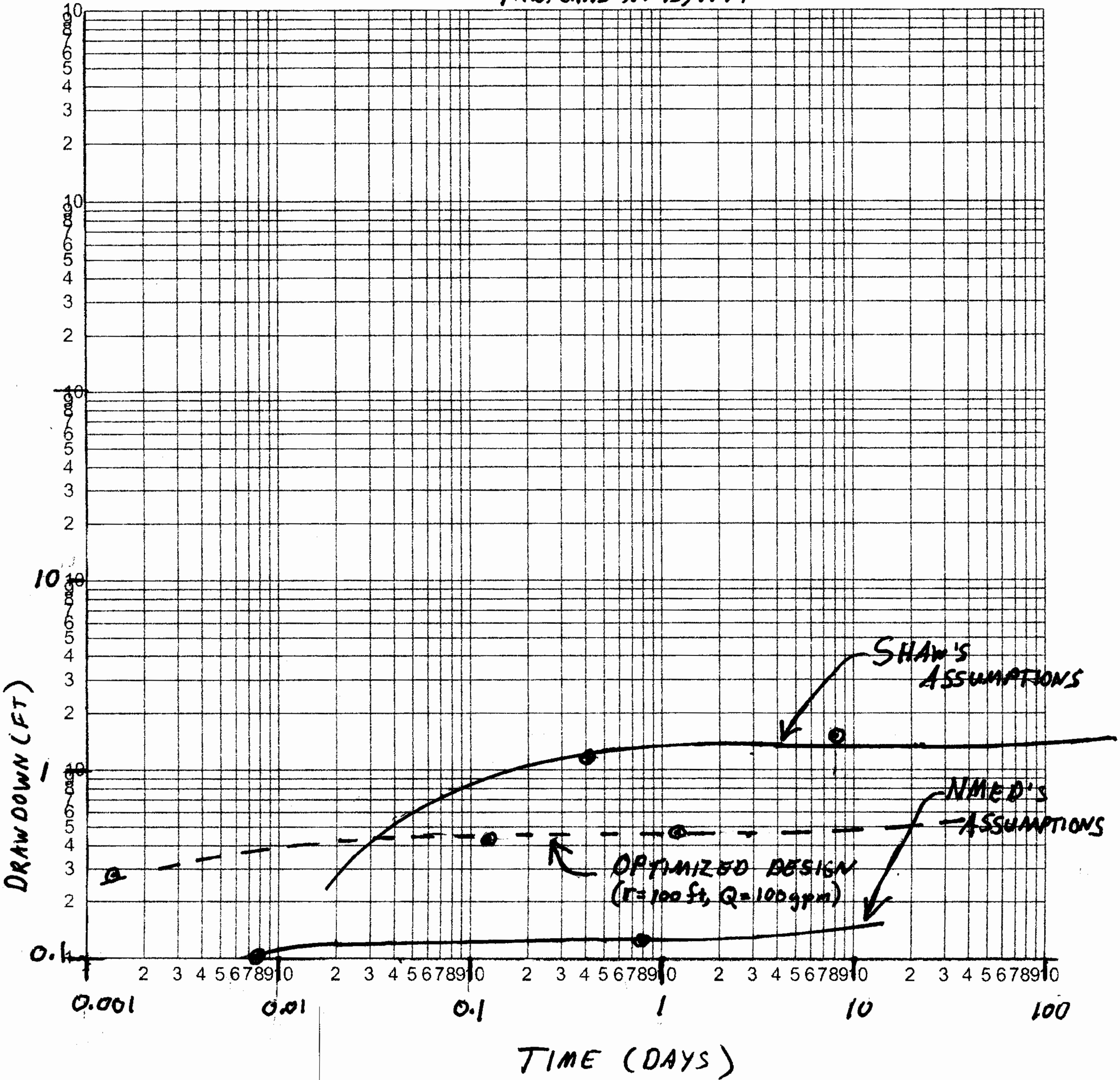
$$t_S = \frac{Tt}{Sr^2} \rightarrow t = \frac{t_S S r^2}{T} = \frac{(10.0)(0.0002)(100\ \text{ft})^2}{(16{,}450\ \text{ft}^2/\text{day})} = 0.0012\ \text{DAY}$$

4) ANOTHER "LATE" POINT: $S_D = 5.0, \quad t_y = 10$

$$s = \frac{S_D Q}{4\pi T} = \frac{(5.0)(100\ \text{gpm})(24)(60)}{4\pi(16{,}450\ \text{ft}^2/\text{day})(7.48\ \text{gal/ft}^3)} = 0.47\ \text{FT}$$

$$t = \frac{t_y S_y r^2}{T} = \frac{(10)(0.2)(100\ \text{ft})^2}{(16{,}450\ \text{ft}^2/\text{day})} = 1.21\ \text{DAY}$$

RESULTS OF DRAWDOWN CALCULATIONS
KIRTLAND AFB, NM



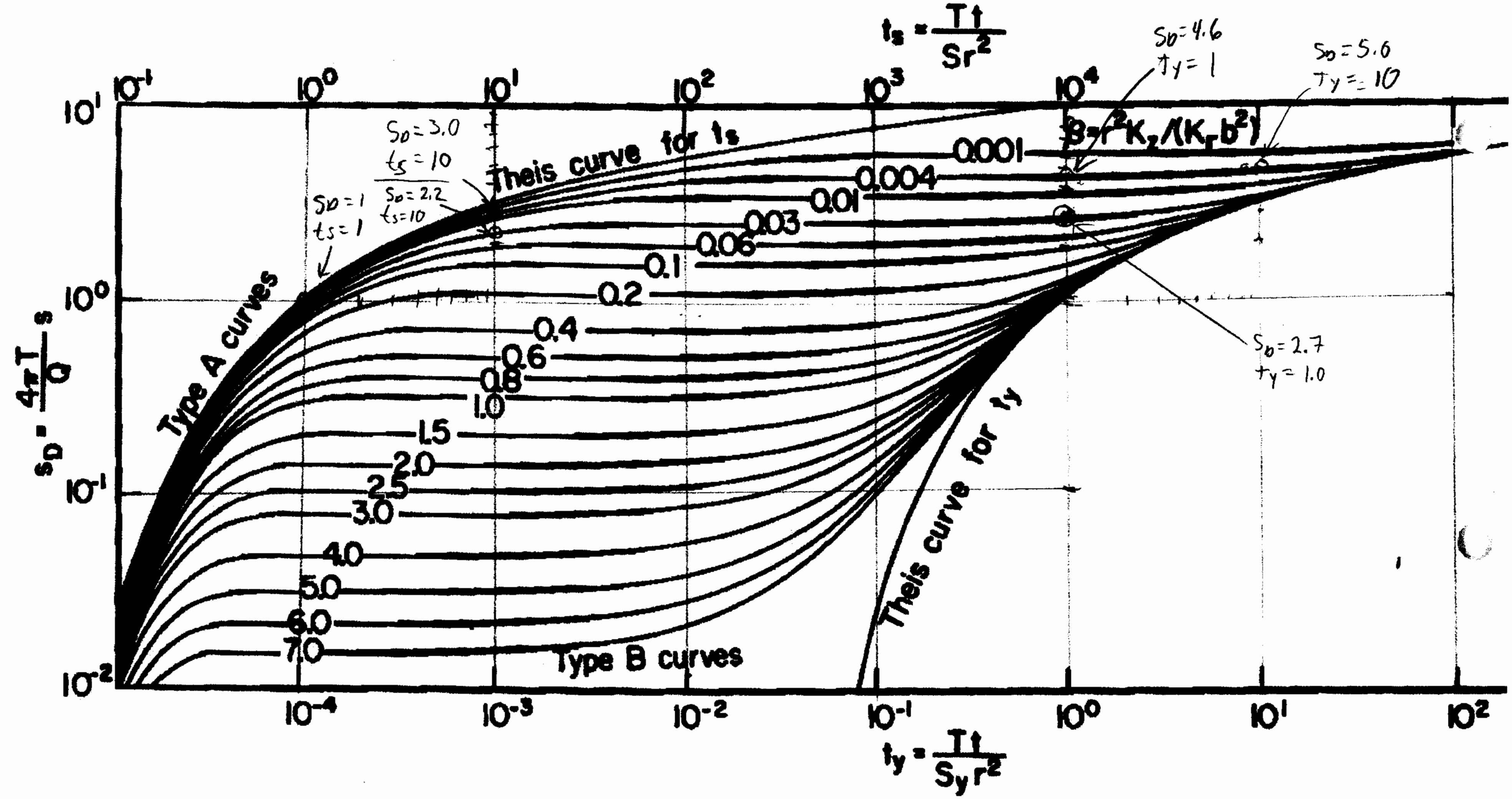


Fig. 1. Type curves for fully penetrating wells.

USGS, WRIR 02-4200

stage (5,390-5,410 feet above NGVD 29), the losses unaccounted for are about 15,000 acre-feet per month (250 cubic feet per second).

Seepage has been investigated along the Jemez River. Fischer and Borland (1983) reported that the results of seepage investigations conducted in 1981 were inconclusive. Craigg (1992) conducted two seepage investigation in 1984, one in March and one in August. The winter results indicated a gain in flow between Jemez Pueblo and Zia Reservoir of about 18 cubic feet per second, a possible loss of flow between Zia Reservoir and Zia Pueblo of about 5 cubic feet per second, and a gain in flow between Zia and Santa Ana Pueblos of about 8 cubic feet per second. The possible uncertainty of these estimates, based on streamflow measurement errors (Craigg, 1992, table 3), is +/- 6 to 7 cubic feet per second. The summer results indicated that the upper reach of the Jemez River gained flow but that the reach between Zia and Santa Ana Pueblos lost about 11 (+/- 4) cubic feet per second of flow. Craigg (1992) concluded that the loss in the lower reach was likely due to evapotranspiration by phreatophytes.

Data that would allow estimation of seepage from Jemez Canyon Reservoir were not available for this study. Prior to 1979, when the reservoir began permanently storing water, the reservoir operated to desilt flows above 30 cubic feet per second by a 1-day detention and to provide flood protection. Although water would have seeped from the reservoir during temporary-storage periods, the seepage likely was relatively small compared with the amount of seepage that occurred during permanent storage.

Hydrologic Properties

The post-Santa Fe Group inner-valley alluvium consists of channel and flood-plain deposits associated with the modern Rio Grande and Jemez River. The alluvium forms a band under and along each river, several miles wide and as much as 120 feet thick (Hawley and Haase, 1992). The unit is variable in composition, consisting of highly permeable sands and gravels interbedded with less permeable silts and clays that in some areas constitute a substantial part of the unit (Thorn and others, 1993). Hydraulic-conductivity estimates for these deposits vary widely. The Bureau of Reclamation (1997c) estimated values ranging from 90 to 350 feet per day using an auger-hole method. Willis (1993) estimated 0.2 foot per day for silty clays and 65 feet per day for gravelly coarse sands in these deposits. Recent testing by the City of Albuquerque resulted in hydraulic conductivities ranging from 5 to 325 feet per day (CH2MHill, 1999). McAda (2001) found that a value of 45 feet per day performed well in a simulation of a lengthy aquifer test in the Albuquerque area.

Aquifer-test data for the Santa Fe Group aquifer system typically come from wells that are screened over several hundred feet. Analyses of many of these tests are summarized in Thorn and others (1993, table 2) in terms of transmissivity and in estimated hydraulic conductivity (calculated using the screened interval as the saturated thickness term). Hydraulic-conductivity estimates for wells that penetrate the upper part of the Santa Fe Group range from 4 to 150 feet per day (Thorn and others, 1993, table 2). The most highly permeable zone of the upper part of the Santa Fe Group consists of the axial deposits of the ancestral Rio Grande; the largest hydraulic-conductivity estimates (as much as 150 feet per day for individual well tests; Thorn and others, 1993, table 2) come from wells located on Albuquerque's east side. A widespread, but less transmissive subunit of the upper part of the Santa Fe Group consists of alluvial-fan and piedmont-slope facies (Hawley and Haase, 1992). The hydraulic conductivity of this subunit, 12-15 feet per day, is fairly well constrained in the Albuquerque area by aquifer testing (Thorn and others, 1993; McAda, 2001).

Hydraulic conductivities estimated from aquifer tests in wells penetrating the middle and lower parts of the Santa Fe Group tend to be systematically lower than those in the upper part. McAda (2001) estimated hydraulic conductivities for Middle Santa Fe Group deposits in the Albuquerque area to be 4 to 11 feet per day, based on work by Hawley and Haase (1992). For their regional ground-water model, Kernodle and others (1995) and Kernodle (1998b) estimated hydraulic conductivities to be 0.5 to 40 feet per day for river-valley alluvium, 10 to 70 feet per day for the upper part of the Santa Fe Group, 4 feet per day for the middle part of the Santa Fe Group, and 2 to 10 feet per day for the lower part of the Santa Fe Group.

The stratigraphy of post-Santa Fe and Santa Fe Group units is dominated by interlayering of more and less permeable subunits, suggesting significant vertical anisotropy. This is supported by piezometer data that demonstrate the existence of substantial vertical hydraulic gradients within the aquifer system (discussed later in this report). Previous calibrated ground-water models of the basin have used horizontal to vertical anisotropy ratios of 450:1 to 3,500:1

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(Tiedeman and others, 1998) and 200:1 (Kernodle and others, 1995). McAda's (2001) intensive analysis of an aquifer test near the Rio Grande in Albuquerque yielded an anisotropy value of 82:1.

The numerous north-south striking faults within the basin probably impede ground-water flow across the fault planes, either by the juxtaposition of more permeable beds with less permeable beds and (or) by cemented sediments or fault gouge within the fault plane itself. The multitude of these faults suggests the likelihood that flow parallel to the strike of these faults (north-south) may be considerably less impeded than flow across the strike of these faults (east-west), so horizontal anisotropy may be a significant factor within the aquifer. Horizontal anisotropy through much of the basin is supported by several sources of information. Plummer and others (2001) identified 12 hydrochemical recharge zones in the Middle Rio Grande Basin. These zones show a distinct north to south pattern (Plummer and others, 2001, fig. C-1). In addition, the pattern of sedimentation in the basin is generally oriented north-south (Hawley and others, 1995, fig. 2), contributing to enhanced permeability north-south relative to east-west. Greg Ruskauff (INTERA, Longmont, Colo., written commun., June 2001) found that hydrologic data for the Kirtland Air Force Base (fig. 2) area were best explained by horizontal anisotropy.

Use S_y = 0.2

Specific yields in basin fill, such as in the Santa Fe Group aquifer system, typically range from about 0.1 to 0.25 (Johnson, 1967, p. 1). Ground-water-flow models of the aquifer system have used specific yields of 0.15 to 0.20 (Kernodle and others, 1995; Tiedeman and others, 1998; Barroll, 2001). Heywood (1998; 2001) calculated elastic specific storage of the basin sediments to be 2×10^{-6} per foot from extensometer data. McAda's (2001) analysis of an aquifer test near the Rio Grande in Albuquerque yielded a specific-storage value of 1.2×10^{-6} per foot.

$S_e = S b$
assume $b = 100$ ft
$S_e = (2\times10^{-6}/\text{ft})(100\ \text{ft})$
Use: $S_e = 0.0002$

MODEL DESCRIPTION

Movement of water through an aquifer can be expressed by differential equations (Pinder and Bredehoeft, 1968). However, solving these equations analytically generally is not possible because of the complexity of hydrologic boundaries and the heterogeneity and anisotropy of aquifer materials. A digital ground-water-flow model can be used to solve the ground-water-flow equation numerically through the use of a computer. A solution using this method is not unique in that any number of reasonable variations in representation of the aquifer system in the model may produce equally acceptable results. Nevertheless, the model is a tool that can be used to help understand an aquifer system and project aquifer responses to assumed stresses. Assumptions and simplifications are made in the formulation and solution of the mathematical equations; therefore, a ground-water-flow model is only an approximation of the aquifer system, and simulation results need to be interpreted with this in mind.

Numerical Method

Ground-water flow in the Middle Rio Grande Basin was simulated using the modular, three-dimensional, finite-difference, ground-water-flow model MODFLOW-2000 (Harbaugh and others, 2000). By assuming that Cartesian coordinate axes x, y, and z are aligned with the principal components of hydraulic conductivity, three-dimensional ground-water flow through porous medium can be expressed as (McDonald and Harbaugh, 1988, p. 2-1):

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W = S_s\frac{\partial h}{\partial t} \quad (1)$$

where K_{xx}, K_{yy}, and K_{zz} = values of hydraulic conductivity along the x, y, and z coordinate axes (LT^{-1});
h = potentiometric head (L);
W = volumetric flux per unit volume and represents sources and (or) sinks of water (T^{-1});
S_s = specific storage of the porous medium (L^{-1}); and
t = time (T).

The partial-differential flow equation (eq. 1) can be approximated by replacing the derivatives with finite differences. MODFLOW-2000 represents the aquifer system with cells using a sequence of layers and a series of rows and columns extending through each layer. Aquifer properties are assumed to be uniform within each model cell, and hydraulic heads are assumed to be at the center of each cell. For a model with N cells, N simultaneous equations are formulated geophysical data become available. This model will allow for ready analysis of geologic data, construction of scaled representations of site conditions (e.g., cross-sections), and the development of model layers for hydrogeologic modeling. RockWorks™ model results will be incorporated into the project geographical information system (GIS) for analysis and mapping.

5.2.4 Updated Capture-Zone and NAPL-Migration Modeling (Data Gap 5)

The analytical element groundwater modeling software WINFLOW was used to perform the preliminary NAPL system well location analysis used for the pre-design presented in this work plan. The following hydrogeologic parameters were used as model input values:

SHAW'S ASSUMPTIONS

- Hydraulic conductivity: 30 ft/day, based primarily on boring log lithologic descriptions
- Screened aquifer thickness: 50 ft = b
- Storage coefficient: 0.001 fraction
- Porosity: 0.25 fraction
- Hydraulic gradient: 0.004 ft/ft, N 20° E, groundwater elevation 4900 used as reference head from measured water table elevations
- Extraction well pumping rate: 50 gpm for each containment well
- Injection well rate: 100 gpm

The model simulations were run with these parameters with calibration other than the hydraulic gradient. Calibration was not viable because of lack of site-specific measurements of hydraulic conductivity at the time the modeling was performed. Therefore the necessary hydraulic parameters were estimated based on available boring logs and values used in regional hydrogeologic modeling performed by the U.S. Geological Survey (2002, 2003).

Because of the uncertainly in site conditions, simulations were made using a range of possible flow rate/hydraulic conductivity simulations, ranging from 10 ft per day to 50 ft per day. For each change in hydraulic conductivity, the containment well flow rates were adjusted up or down until the horizontal extents of the dissolved and NAPL plumes were contained. The lowest flow rate was 25 gpm for each

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