BETA

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RADIOCARBON DATING OF GROUND WATER

You're the expert; how would you interpret these results?

Hint: don't try to use the absolute dates. Compare the dating results on each well from year to year to see tendencies.

OUR OWN INTERPRETATIONS ARE ON THE LAST PAGE.

Ground Water Radiocarbon Dating of Wells along a Transect in the Aquifer Region

Abstract

Our aquifer is an unconfined aquifer which is the sole source of drinking water for the local population. Models suggest a slow recharge rate and predict the aquifer would provide adequate supply for a maximum of 150 years at its present exploitation rate. The Phase I study used radiocarbon dating to show that the water was old, confirming model calculations of a long mean residence time. This was done by dating 20 wells along a west/east transect. However, the easternmost wells unexpectedly showed younger dates than the others, but still old. This was not in agreement with our models and led to a Phase II study which consisted of yearly monitoring. Results showed progressively declining radiocarbon dates in wells at the easternmost end of the transect. Starting in 1995, we reduced the pumping rates of 5 wells which showed declining dates. By 1998, the radiocarbon dates of those wells had increased to their 1993 levels suggesting new maximum sustainable yields for those wells. The progression of wells with declining dates over the 5 year period allows us to postulate a flow direction of southeast to northwest for the region.

Theory

Hydrological modeling suggests that our aquifer is an unconfined, stratified aquifer believed to have a very long residence time. By radiocarbon dating our wells, the accuracy of our models can be examined. If the ages are old, the slow recharge rate will be confirmed.

By radiocarbon dating wells each year, changes can be observed and addressed. In doing this, we can address the subject of vulnerability since vulnerability of a well to contamination from surface water can be inferred using radiocarbon dating.

Radiocarbon dating uses the amount of naturally occurring carbon-14 in the water, in association with its half life (5730 years) to derive the age. This age gives the approximate time that has past since the water entered the aquifer. In our stratified aquifer, overlying waters will be younger than those below. Increased draw-down or coning can be observed by measuring the age of the water over time. The data provides empirical evidence of aquifer dynamics surrounding the exploitation of our well field.

Method

One liter of water was collected at 20 wells over a two day period in June 1993. The water was collected in one liter polyethylene bottles containing 0.5 grams sodium hydroxide. The bottles were then sent to Beta Analytic Inc. for radiocarbon dating .

Radiocarbon dating was performed using accelerator mass spectrometry (AMS) counting. First, the dissolved inorganic carbon (DIC) was precipitated as strontium carbonate ($SrCO_3$) using 1.2 grams of strontium chloride ($SrCl_2$) per liter of water. This was rinsed to neutrality and dried. The precipitate was then acidified using 0.5 N H_3PO_4 and the carbon collected as CO_2 gas. The collected gas was then mixed with hydrogen over a cobalt catalyst and heated to 600° C, reducing the carbon to graphite on the cobalt. The graphite was then placed in an AMS and measured for its radiocarbon age.

This process was repeated at yearly intervals between 1993 and 1998.

1993: Radiocarbon Date the Water and Establish a Baseline for Monitoring

Water was collected from 20 wells over a two day period in June 1993. The water was sent to Beta Analytic Inc. for radiocarbon dating. The following results were returned.

Date	Well #	Depth (meters)	Radiocarbon Date
6/15/93	1	92	38000
6/15/93	2	86	37500
6/15/93	3	62	34980
6/15/93	4	77	35500
6/15/93	5	80	36770
6/15/93	6	61	34890
6/15/93	7	57	33500
6/15/93	8	48	32100
6/15/93	9	77	35750
6/15/93	10	68	35300
6/16/93	11	82	36900
6/16/93	12	65	35400
6/16/93	13	71	35590
6/16/93	14	88	37900
6/16/93	15	65	35390
6/16/93	16	88	37810
6/16/93	17	75	35690
6/16/93	18	81	36850
6/16/93	19	75	18000
6/16/93	20	66	19500

Question No. 1

These 18 wells are all showing old radiocarbon dates

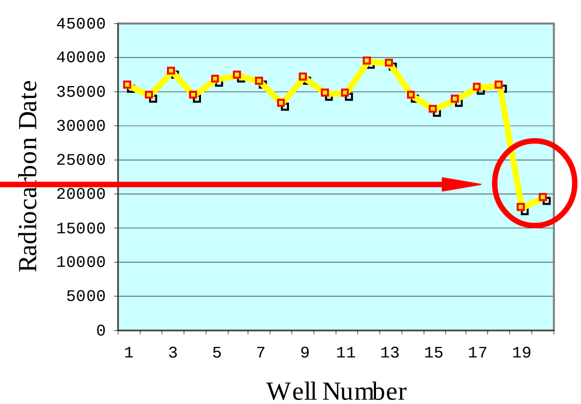
Why?

Question No. 2

The water dates in these 2 wells are younger than the others.

Why?

Radiocarbon Ages of 20 wells
In June 1993



1993 to 1995: Well Field Monitoring

Water was collected from the same 20 wells and radiocarbon dated each year over a 3 year period. Changes in radiocarbon dates were used to interpret dynamic changes, and their causes, within the aquifer.

Well #	Depth (meters)	Radiocarbon Dates		
		Jun-93	Jun-94	Jun-95
1	92	38000	37890	38270
2	86	37500	37450	37580
3	62	34980	34890	35010
4	77	35500	35600	35450
5	80	36770	36660	36710
6	61	34890	34810	34920
7	57	33500	33390	33590
8	48	32100	32050	32150
9	77	35750	35720	35850
10	68	35300	35210	35420
11	82	36900	36810	36790
12	65	35400	35380	35410
13	71	35590	35640	35510
14	88	37900	37910	37870
15	65	35390	35360	35280
16	88	37810	37780	29000
17	75	35690	35640	24000
18	81	36850	36880	18000
19	75	18000	12000	7000
20	66	19500	11700	8200

Question No. 3

No significant change was observed in these 15 wells over 3 years.

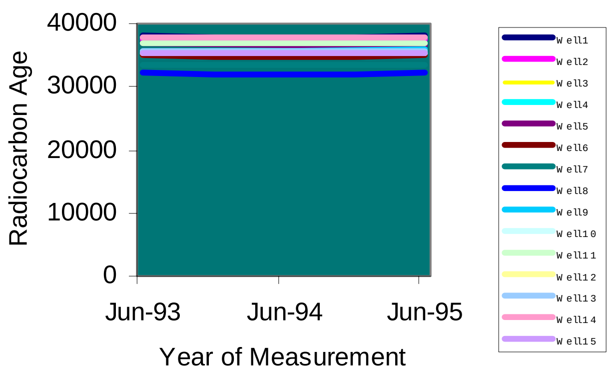
Why?

Question No. 4

Over a 3 year period, 5 wells showed decreasing radiocarbon dates.

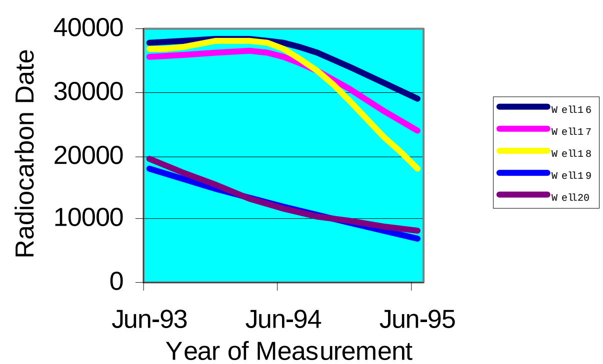
Why?

15 Wells Showed No Change Over 3 Years



15 wells showed consistent radiocarbon dates over 3 years

5 Wells Showed Changes Over 3 Years



Wells 19 and 20 continued to decrease from their previous lower values. Wells 16, 17 and 18 started showing declining dates in 1995.

1993 to 1998: Monitoring and Remediation

Between 1993 and 1998, 10 of 20 wells showed changing radiocarbon dates. Of these 10, the pumping rate was decreased on 5 of them after 1995 in an attempt to re-stabilize the wells.

Well #	Depth (meters)	Radiocarbon Dates					
		Jun-93	Jun-94	Jun-95	Jun-96	Jun-97	Jun-98
1	92	38000	37890	38270	38100	37910	37980
2	86	37500	37450	37580	37550	37290	37650
3	62	34980	34890	35010	35100	34950	35110
4	77	35500	35600	35450	35700	35470	35610
5	80	36770	36660	36710	36690	36710	36680
6	61	34890	34810	34920	34860	35000	34990
7	57	33500	33390	33590	33610	33490	33460
8	48	32100	32050	32150	32210	32010	32180
9	77	35750	35720	35850	35690	35850	35670
10	68	35300	35210	35420	35350	35430	35380
11	82	36900	36810	36790	36950	36740	24000
12	65	35400	35380	35410	35290	35510	22000
13	71	35590	35640	35510	35610	24000	17500
14	88	37900	37910	37870	37900	27980	18000
15	65	35390	35360	35280	35340	22900	14000
16	88	37810	37780	29000	18500	26660	36670
17	75	35690	35640	24000	16000	27980	35700
18	81	36850	36880	18000	10000	19340	36750
19	75	18000	12000	7000	17750	29770	35200
20	66	19500	11700	8200	19400	31660	35430

Question No. 5

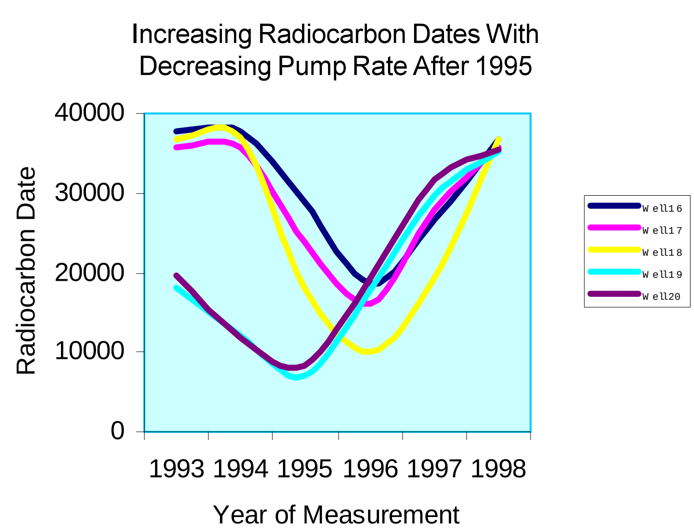
Between 1993 and 1998, 10 of the 20 wells showed changing radiocarbon dates.

Why?

Question No. 6

An engineer decided that the pumping should be reduced in wells 16 to 20 after the 1995 indication of possible draw-down of younger waters from above. The radiocarbon dates became older.

Why?



OUR ANSWERS

Question No. 1: Why do 18 of 20 wells in the same aquifer region show old radiocarbon dates?

1) The recharge rate is very slow or 2) perhaps the aquifer is unexpectedly confined.

Question No. 2: Why are waters from 2 wells much younger than 18 others in the same aquifer region?

1) They could be part of a different aquifer, or 2) they could be the same aquifer showing signs of higher draw-down of younger overlying waters (suggesting eventual contamination from surface waters), or 3) the casings could be cracking.

Question No. 3: Why do 15 wells in the same aquifer region maintain the same radiocarbon age over 3 years?

1) The aquifer is stable in this geographic region, or 2) perhaps the aquifer is confined, or 3) exploitation is not exceeding maximum sustainable yield in this region.

Question No. 4: Why do 5 of 20 wells in the same aquifer region show decreasing ages while the other 15 do not?

Younger waters from above are being drawn down, indicating eventual contamination from surface water. This could be due to over exploitation due to population growth, construction of too many new wells upstream, new upstream exploitation measures, recent geological phenomena, or cracked casings.

Question No. 5: Why do 10 of 20 wells show decreasing radiocarbon ages over a 5 year period?

Upstream exploitation is causing unsustainable yields in downstream wells at their present pump rates. Younger waters are being drawn down, suggesting imminent surface water contamination. As time passes, the situation gets worse, causing more and more downstream wells to be affected. The dates suggest that wells 19 and 20 will be the first to be contaminated from surface waters. The rest will follow in time, unless pump rates are reduced.

Question No. 6: Why do the radiocarbon ages of 5 wells get older when pumping is reduced?

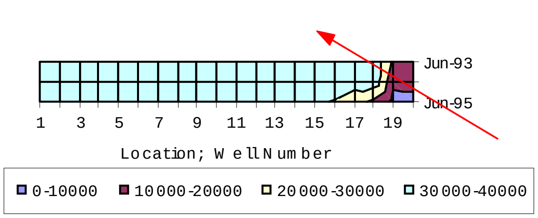
Reducing the pumping rate returned each cone of influence back to its 1993 level. The radiocarbon dates showed that the downstream wells could not maintain their prior pump rates without increased draw-down from above.

Of particular interest is the fact that radiocarbon dates over the 5 year monitoring period 1) suggest a flow direction for the aquifer and 2) offer a mechanism to quantify maximum sustainable yield.

The arrow is pointing in the probable direction of flow path based on expanding reduction in radiocarbon dates. Contamination is likely to follow this path if pumping is not reduced.

After decreasing the pump rates on wells 16 to 20, wells 16 to 18 returned to their 1993 values, and wells 19 and 20 exceeded their 1993 values. This implies the previous pump rates were exceeding maximum sustainable yield.

Surface View; Radiocarbon Ages vs. Location vs. Year;1993-1995



Surface View; Radiocarbon Age vs. Location vs. Yr; 1993 to 1998