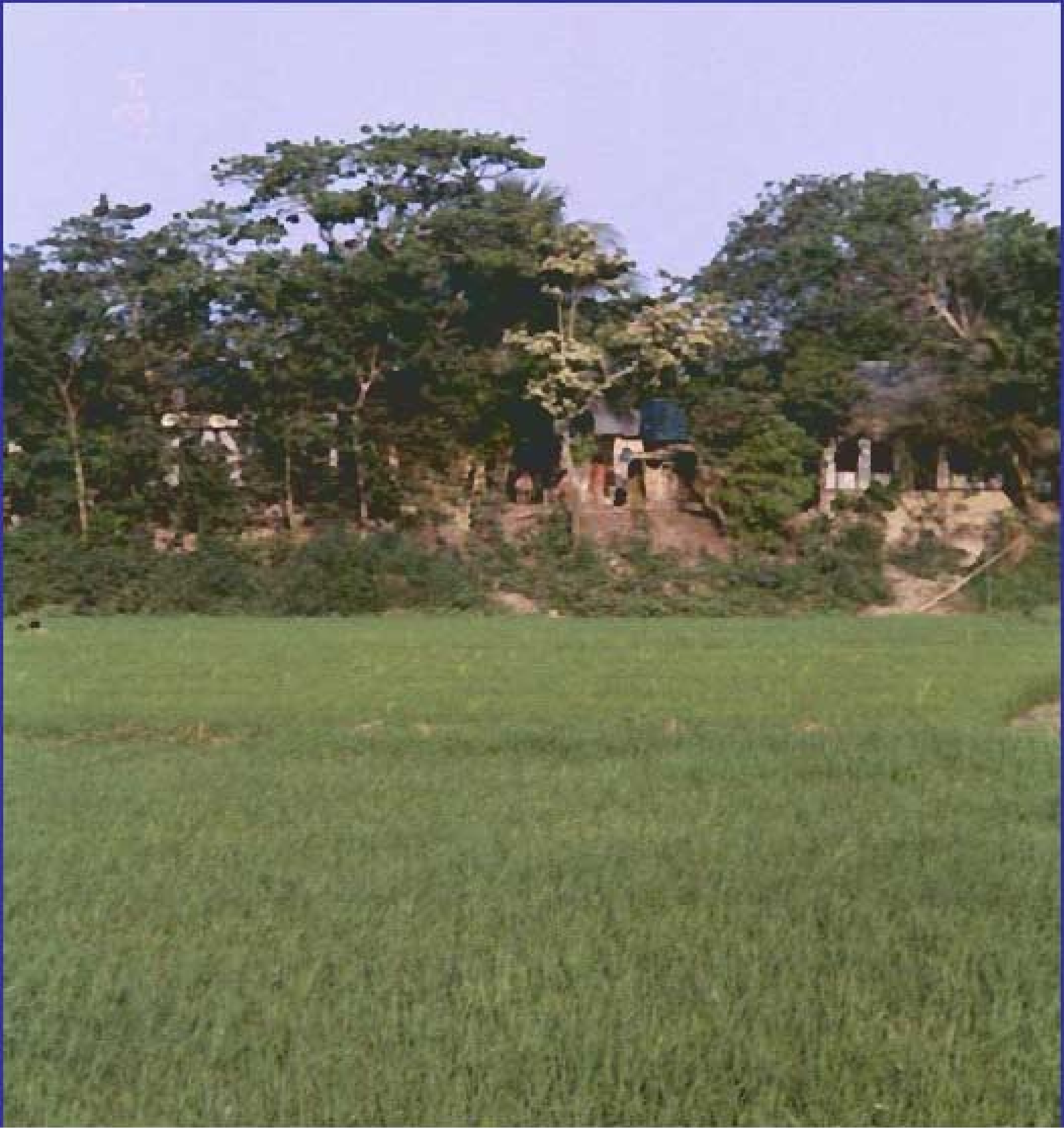
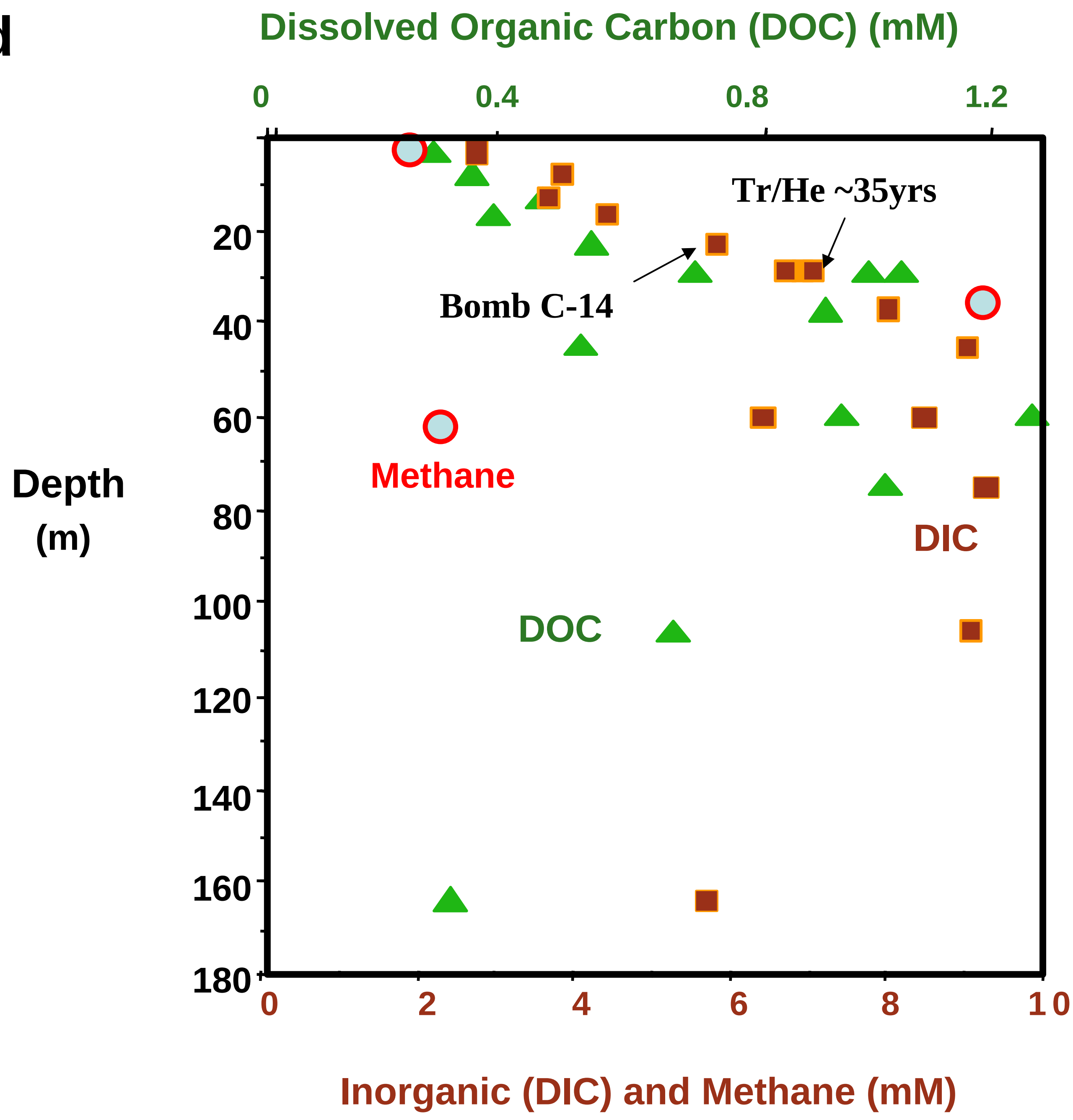
Hydrology



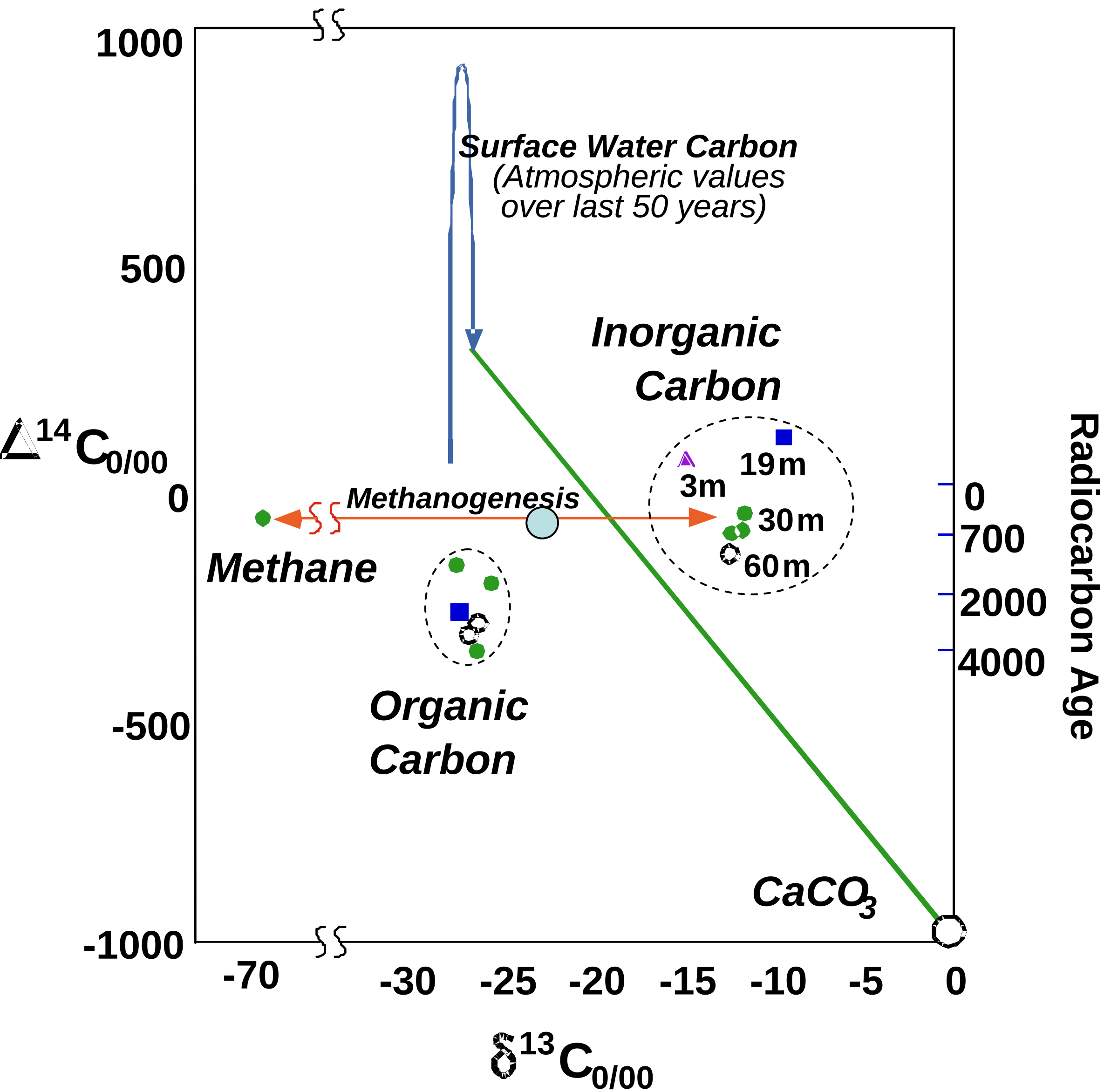

28 11:56 AM


28 11:58 AM

Dissolved Carbon

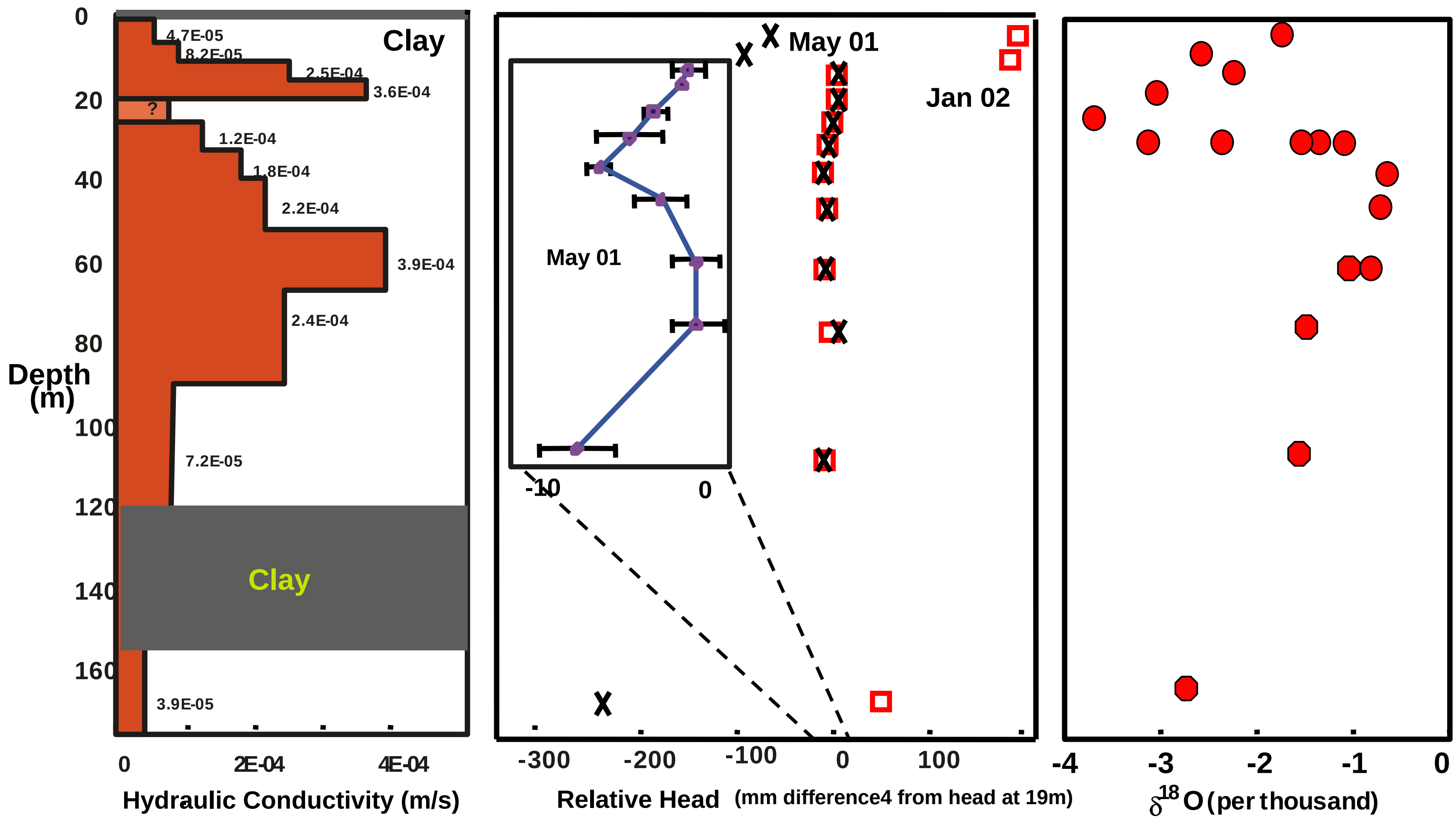


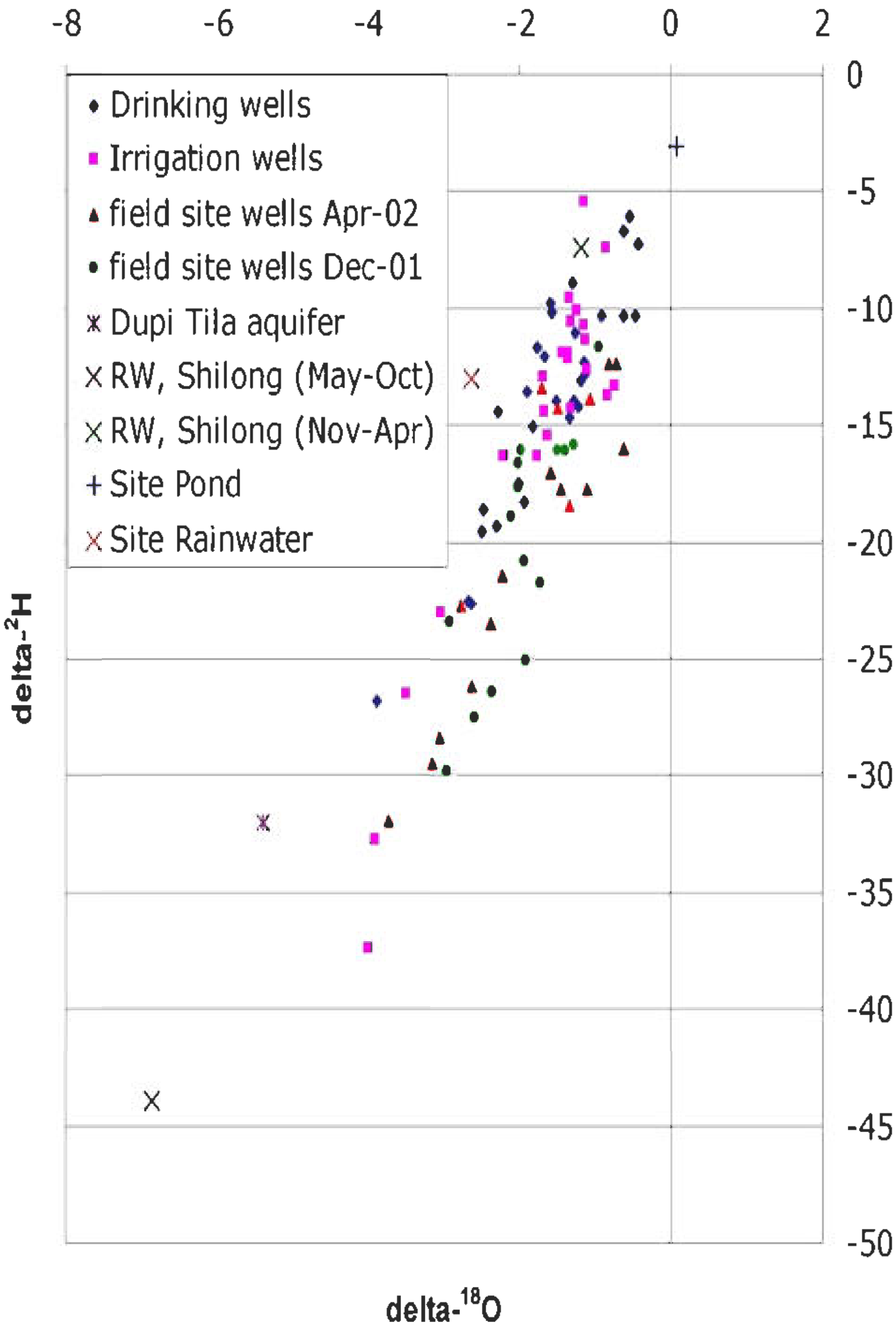
Carbon Isotopes

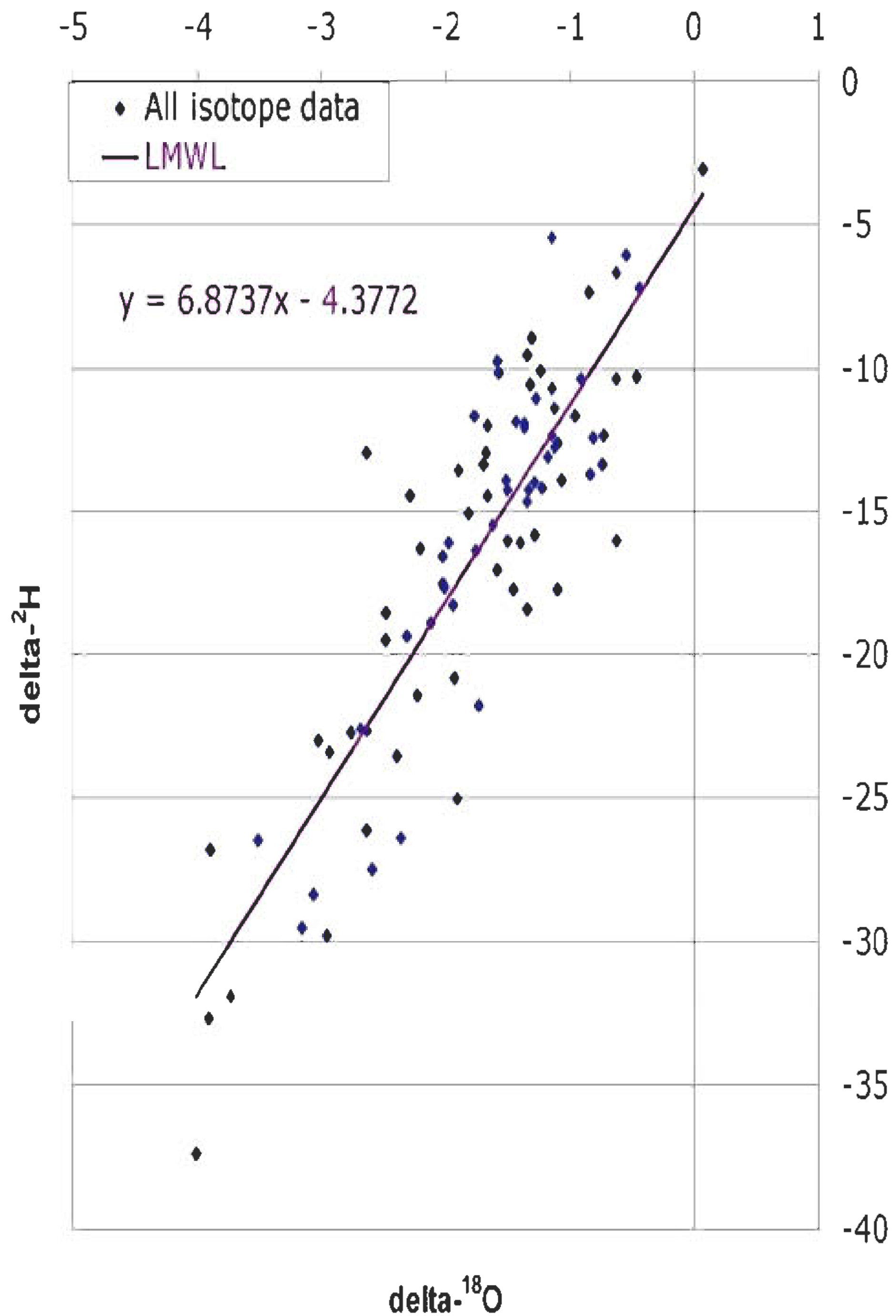


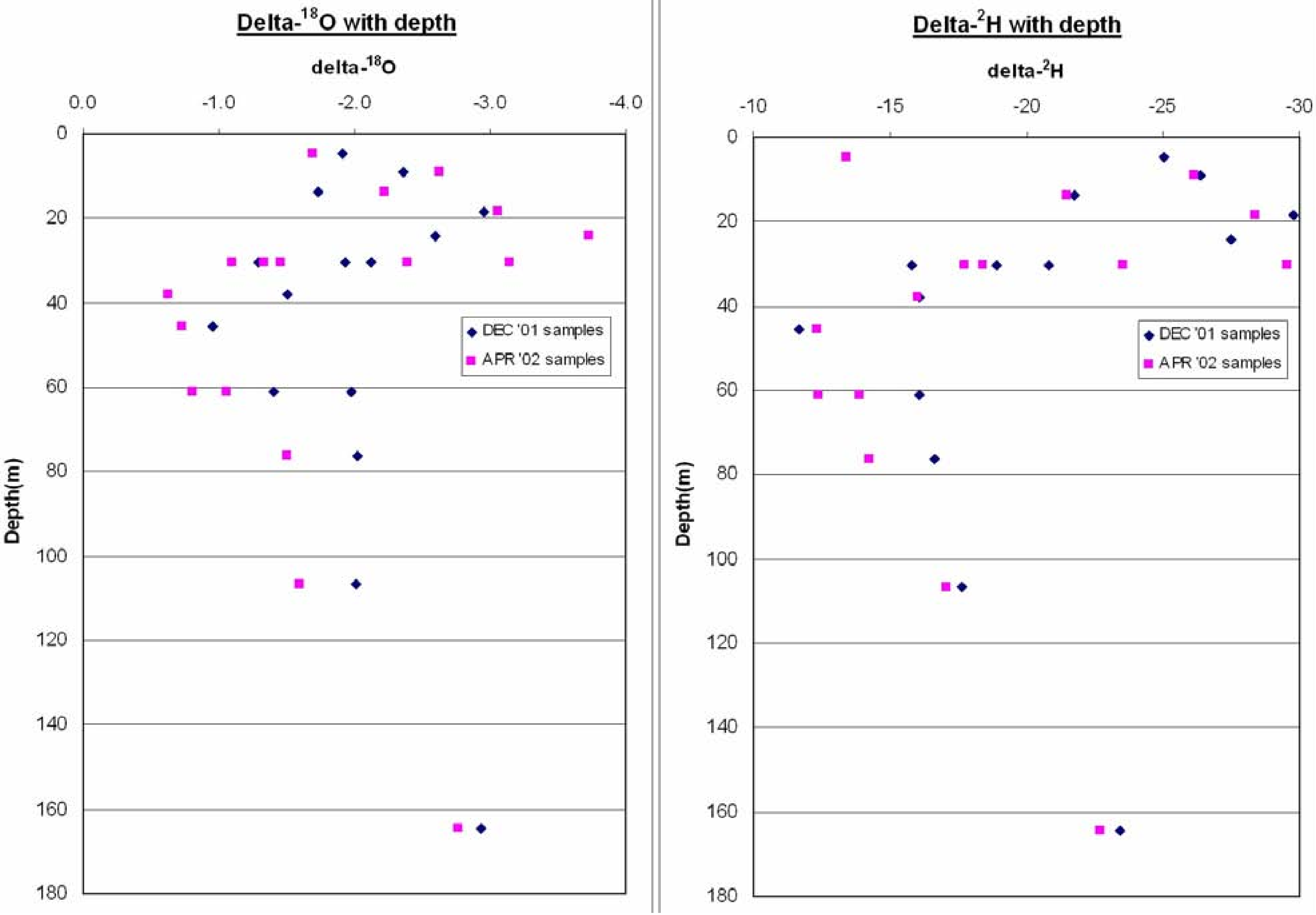
- Inflow of young carbon
- Young carbon drives biochemistry
- Mixture of young and old carbon is not the result of pore water mixing, but mobilization of old organic carbon

Hydraulic Characteristics at Intensive Site

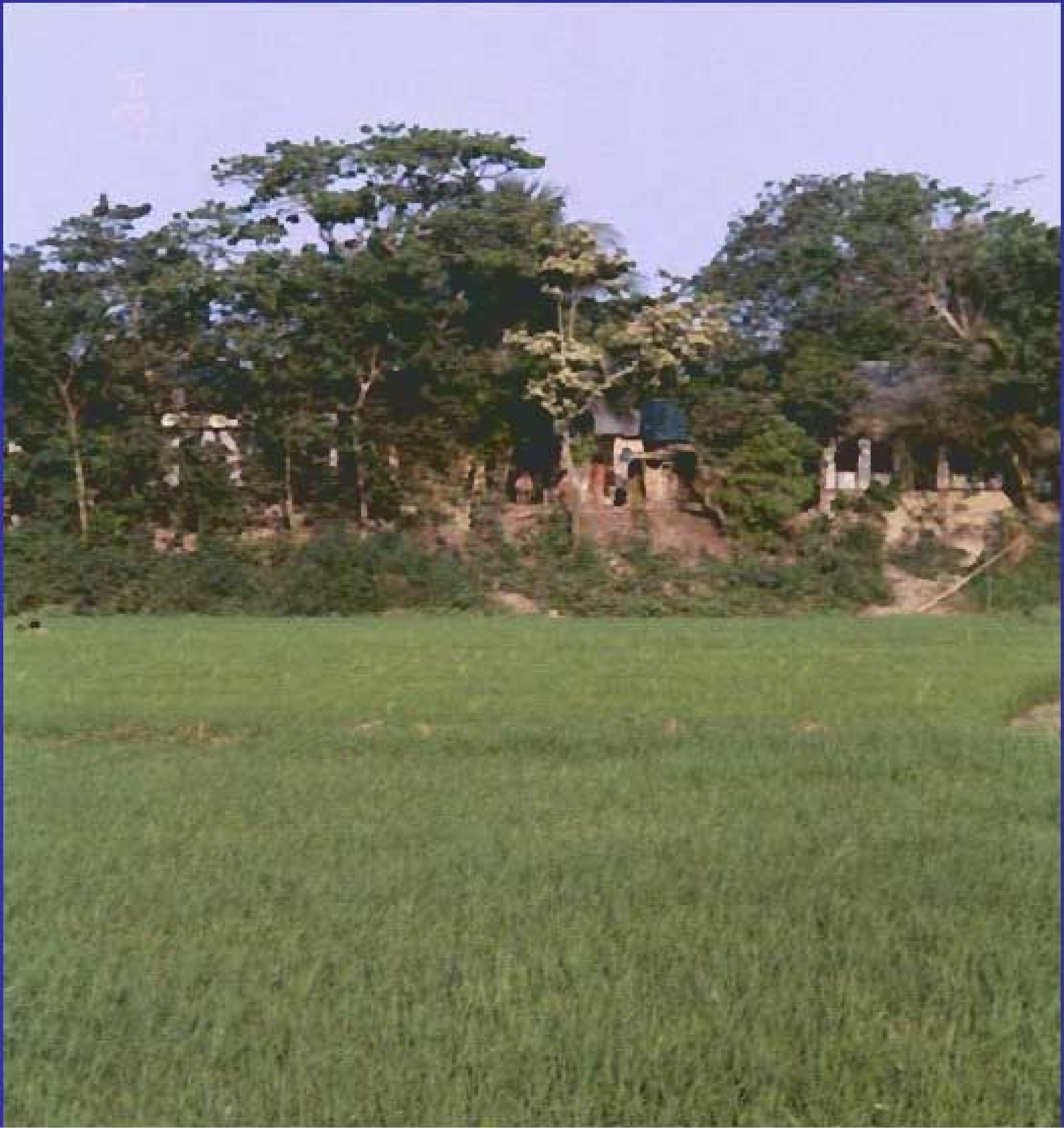


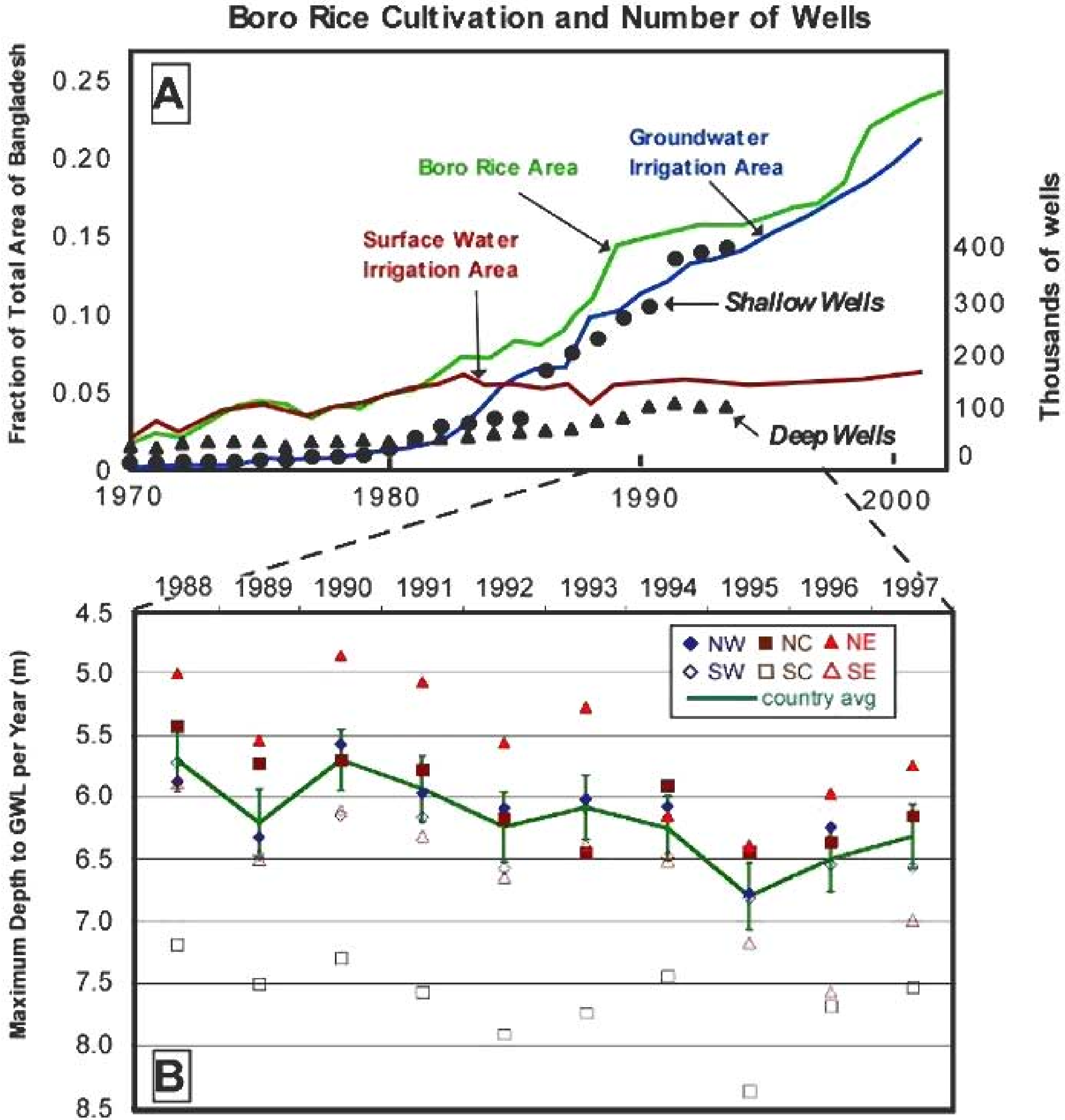

Drinking wells
Irrigation wells
field site wells Apr-02
field site wells Dec-01
Dupi Tila aquifer
RW, Shilong (May-Oct)
RW, Shilong (Nov-Apr)
Site Pond
Site Rainwater
delta-^{2}H
delta-^{18}O


All isotope data
LMWL
y = 6.8737x - 4.3772
delta-^{2}H
delta-^{18}O

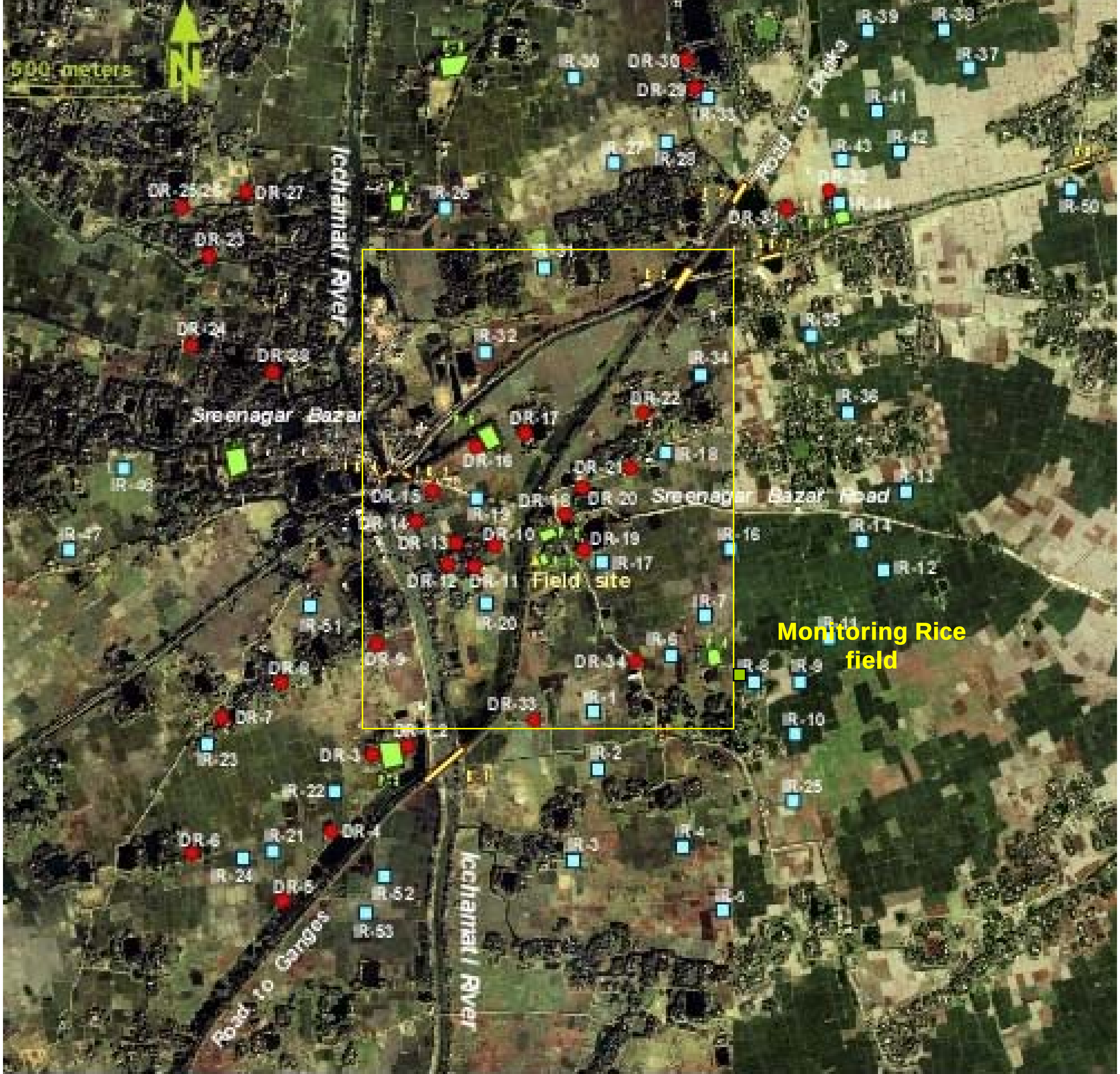


Depth-wise variation of stable water isotopic values at the filed site

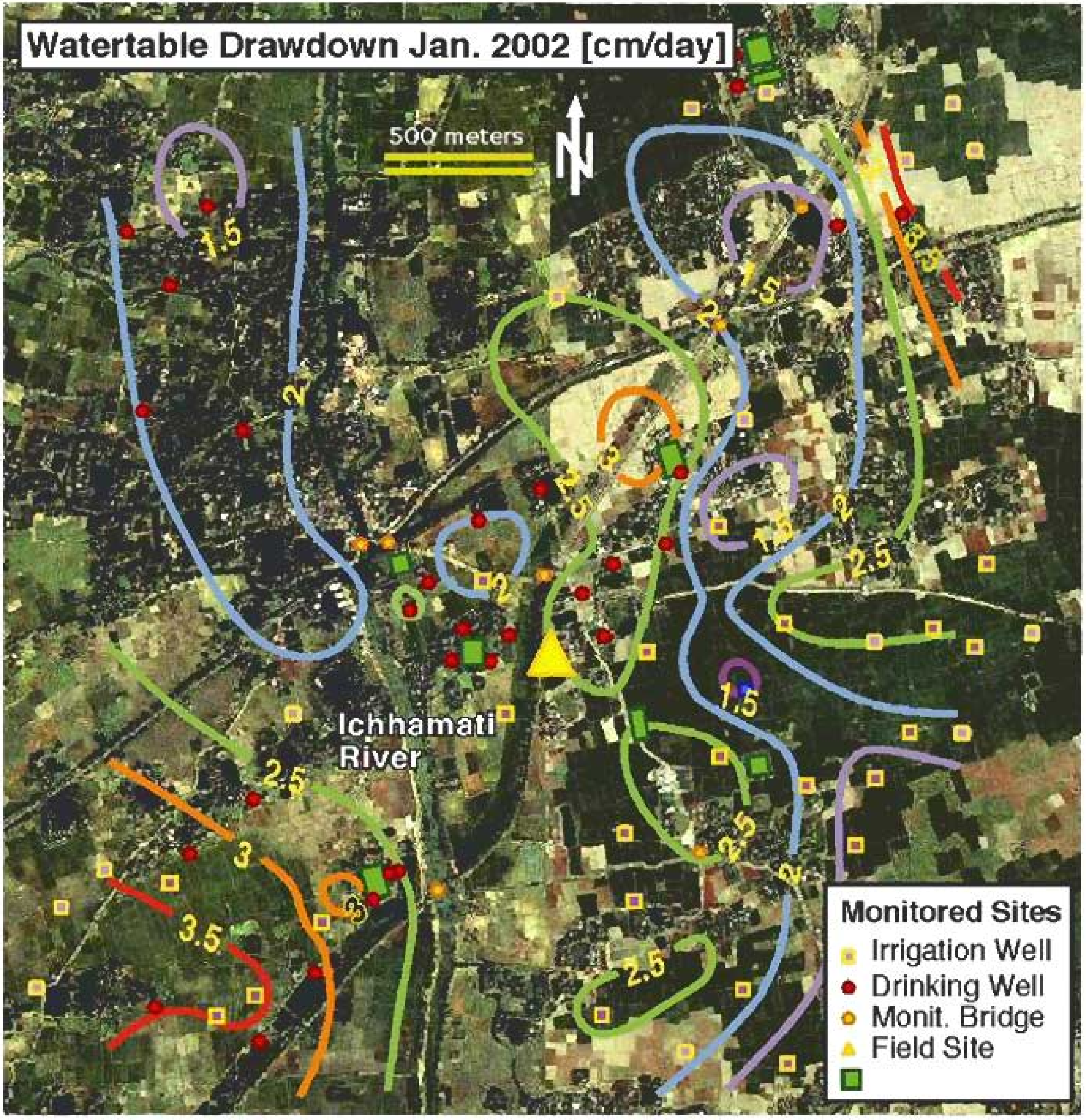




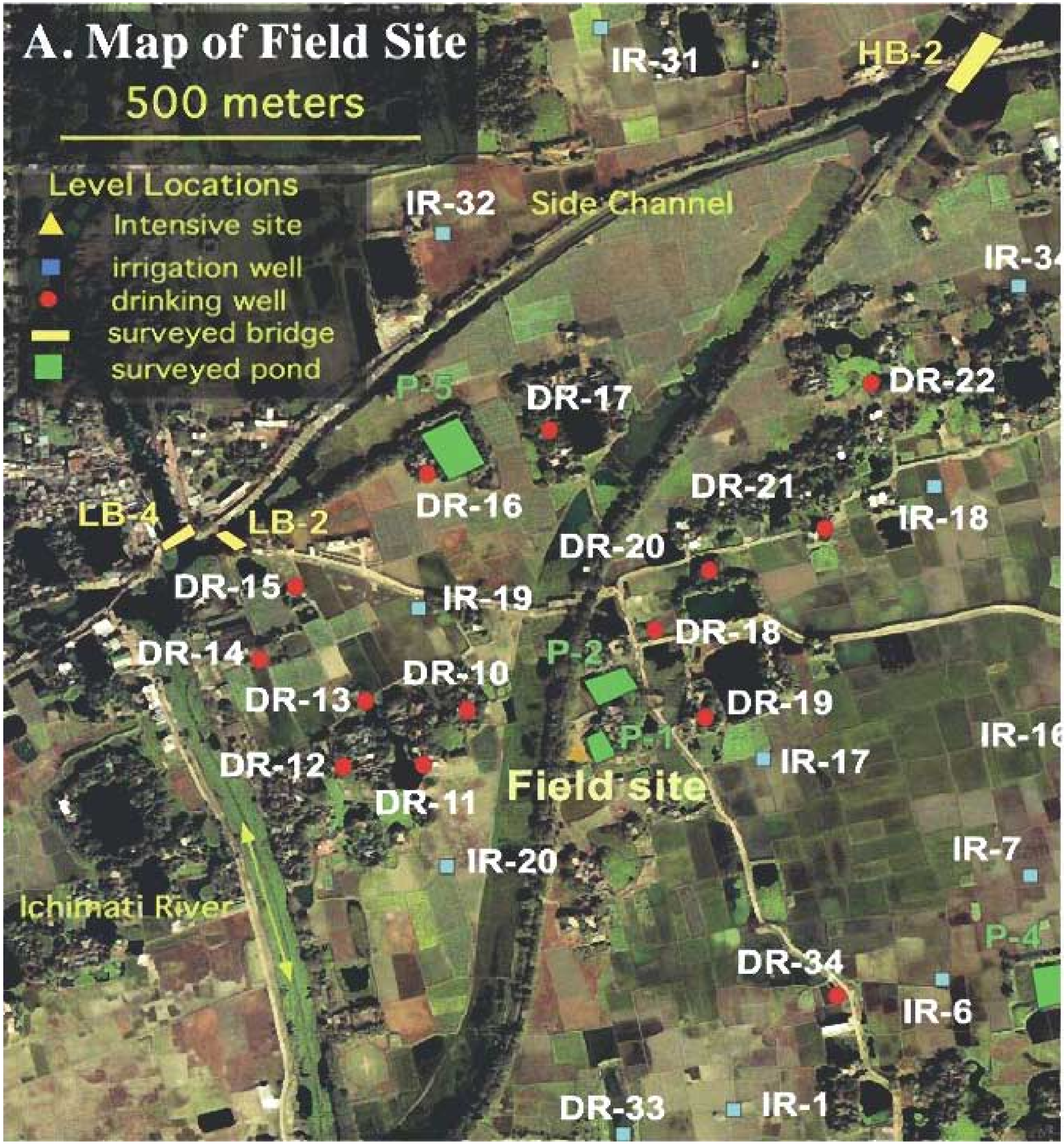
Boro Rice Cultivation and Number of Wells
A
Fraction of Total Area of Bangladesh
Thousands of wells
Boro Rice Area
Groundwater Irrigation Area
Surface Water Irrigation Area
Shallow Wells
Deep Wells
B
Maximum Depth to GWL per Year (m)
NW NC NE
SW SC SE
country avg

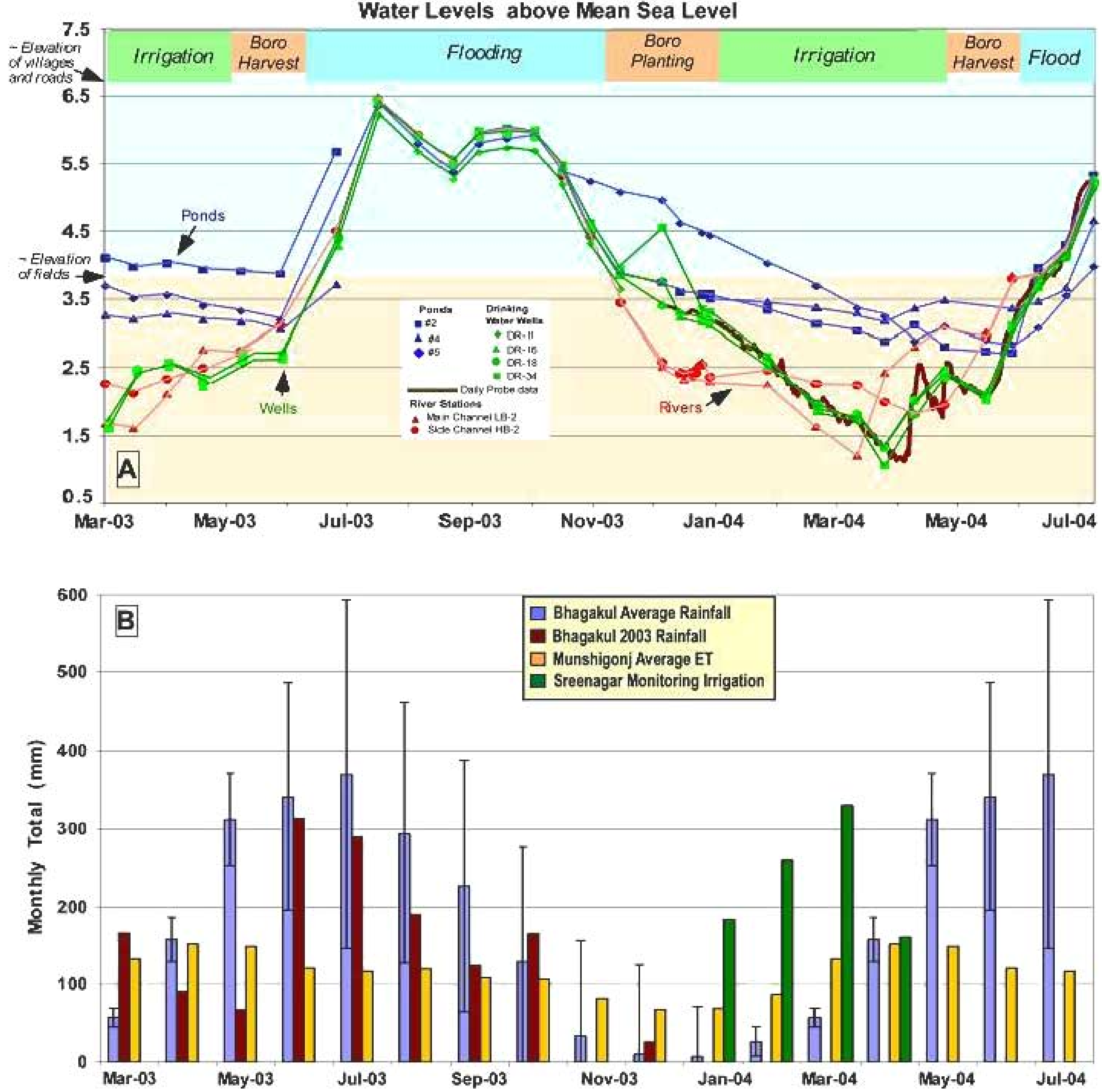


500 meters
N
Icchamati River
Sreenagar Bazar
Sreenagar Bazar Road
Field site
Monitoring Rice field
Road to Dhaka
Road to Ganges
Icchamati River

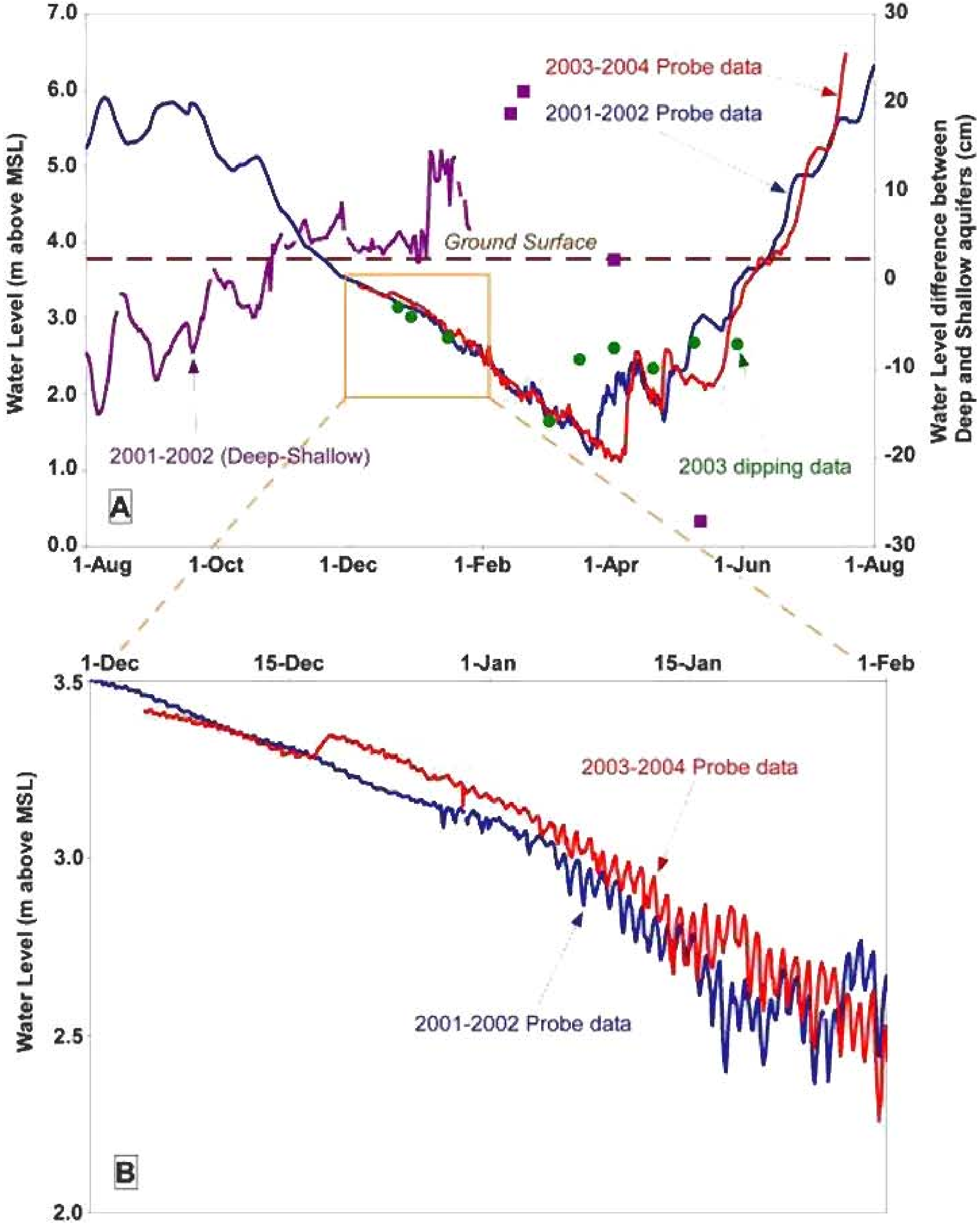


Watertable Drawdown Jan. 2002 [cm/day]
500 meters
N
Ichhamati River
1.5
2
2.5
3
3.5
Monitored Sites
Irrigation Well
Drinking Well
Monit. Bridge
Field Site


A. Map of Field Site
500 meters
Level Locations
Intensive site
irrigation well
drinking well
surveyed bridge
surveyed pond
IR-31
HB-2
IR-32
Side Channel
IR-34
DR-22
P-5
DR-17
DR-16
DR-21
IR-18
LB-4
LB-2
DR-20
DR-15
IR-19
DR-18
P-2
DR-14
DR-10
DR-13
DR-19
IR-16
P-1
IR-17
DR-12
DR-11
Field site
IR-20
IR-7
Ichimati River
P-4
DR-34
IR-6
DR-33
IR-1

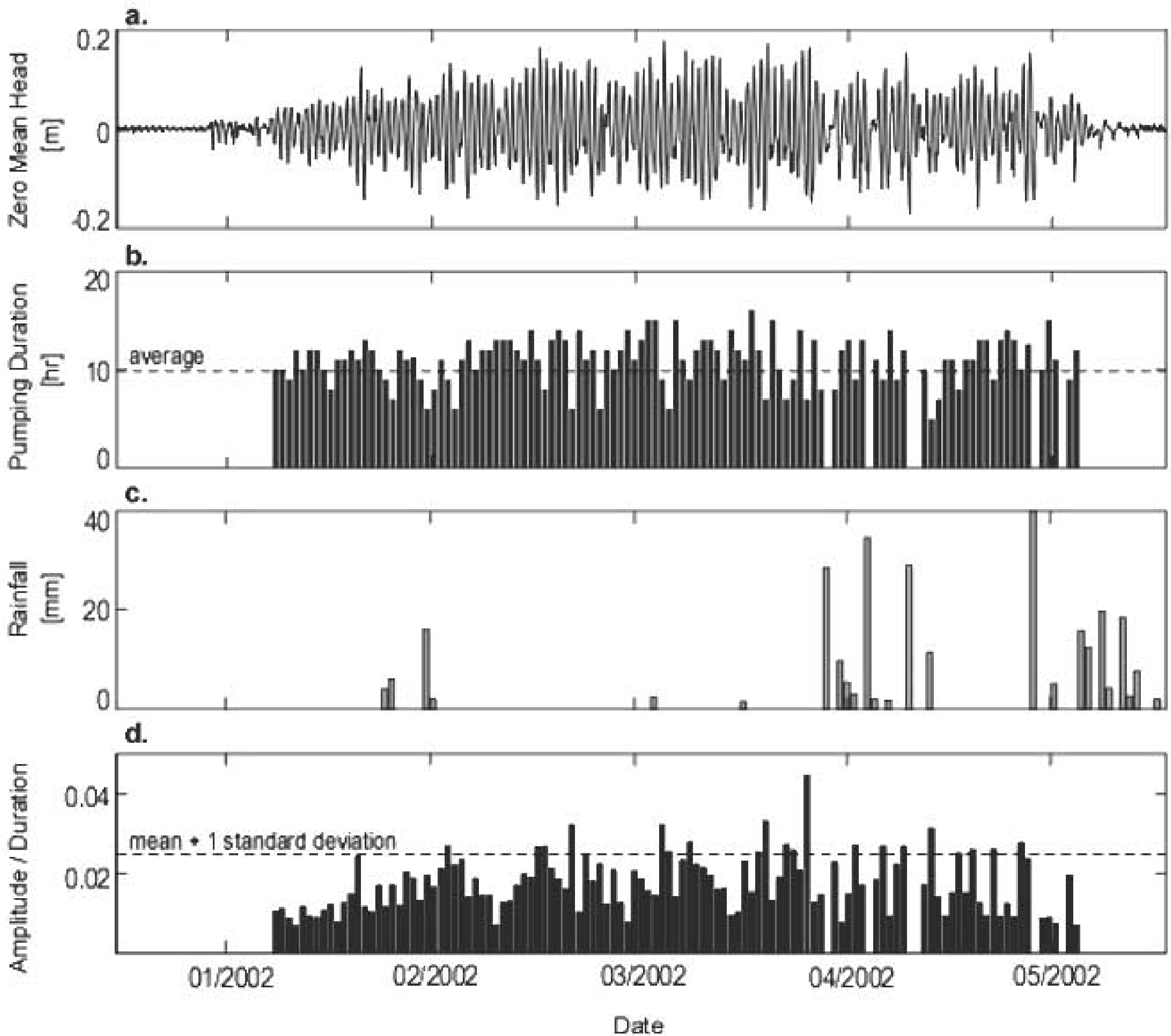


Water Levels above Mean Sea Level
Irrigation
Boro Harvest
Flooding
Boro Planting
Irrigation
Boro Harvest
Flood
~ Elevation of villages and roads
~ Elevation of fields
Ponds
Wells
Rivers
Ponds
#2
#4
#5
Drinking Water Wells
DR-11
DR-16
DR-18
DR-34
Daily Probe data
River Stations
Main Channel LB-2
Side Channel HB-2
A
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04
B
Bhagakul Average Rainfall
Bhagakul 2003 Rainfall
Munshigonj Average ET
Sreenagar Monitoring Irrigation
Monthly Total (mm)
600
500
400
300
200
100
0
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04

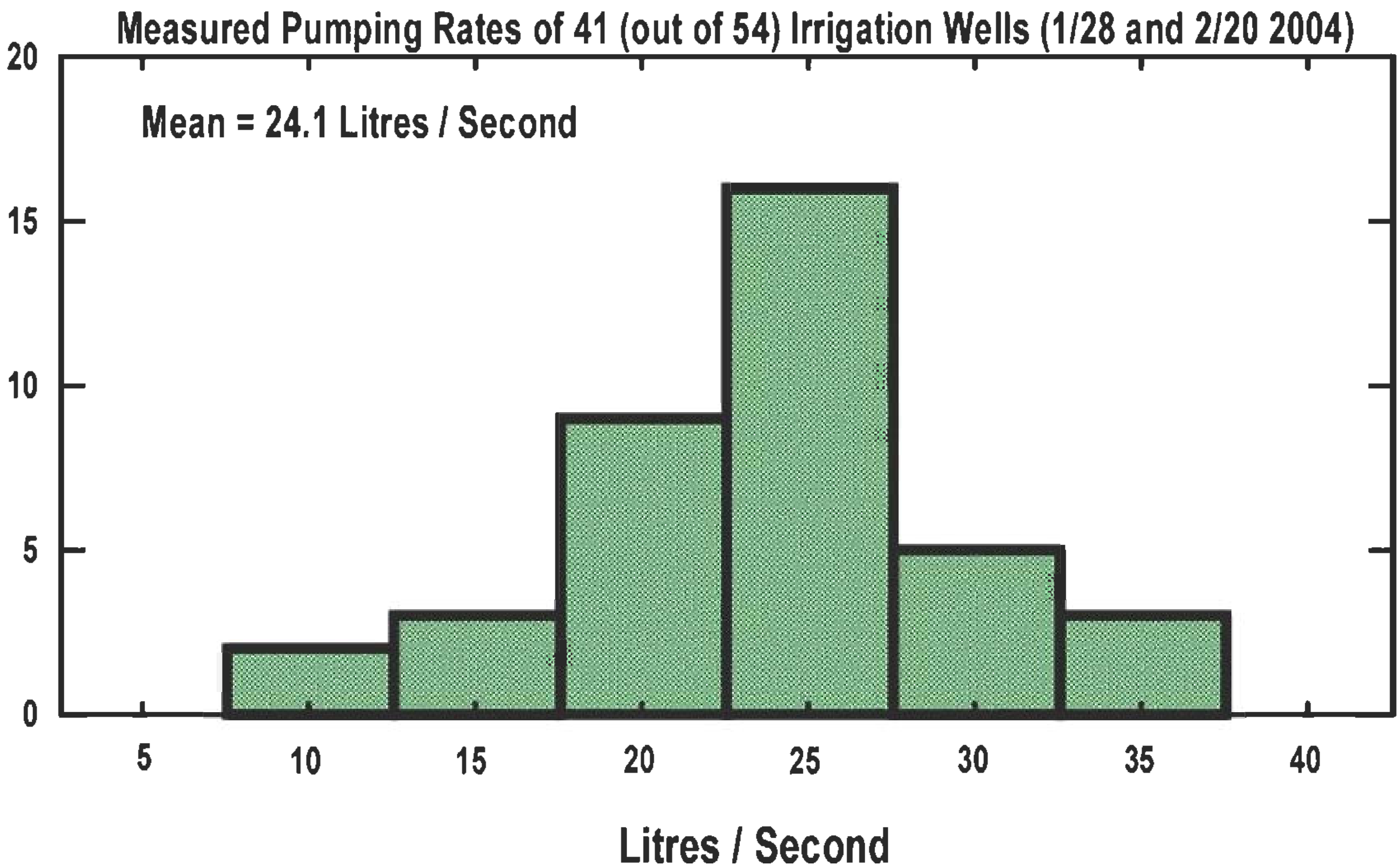


7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Water Level (m above MSL)
30
20
10
0
-10
-20
-30
Water Level difference between Deep and Shallow aquifers (cm)
2003-2004 Probe data
2001-2002 Probe data
Ground Surface
2001-2002 (Deep-Shallow)
2003 dipping data
A
1-Aug
1-Oct
1-Dec
1-Feb
1-Apr
1-Jun
1-Aug
1-Dec
15-Dec
1-Jan
15-Jan
1-Feb
3.5
3.0
2.5
2.0
Water Level (m above MSL)
2003-2004 Probe data
2001-2002 Probe data
B

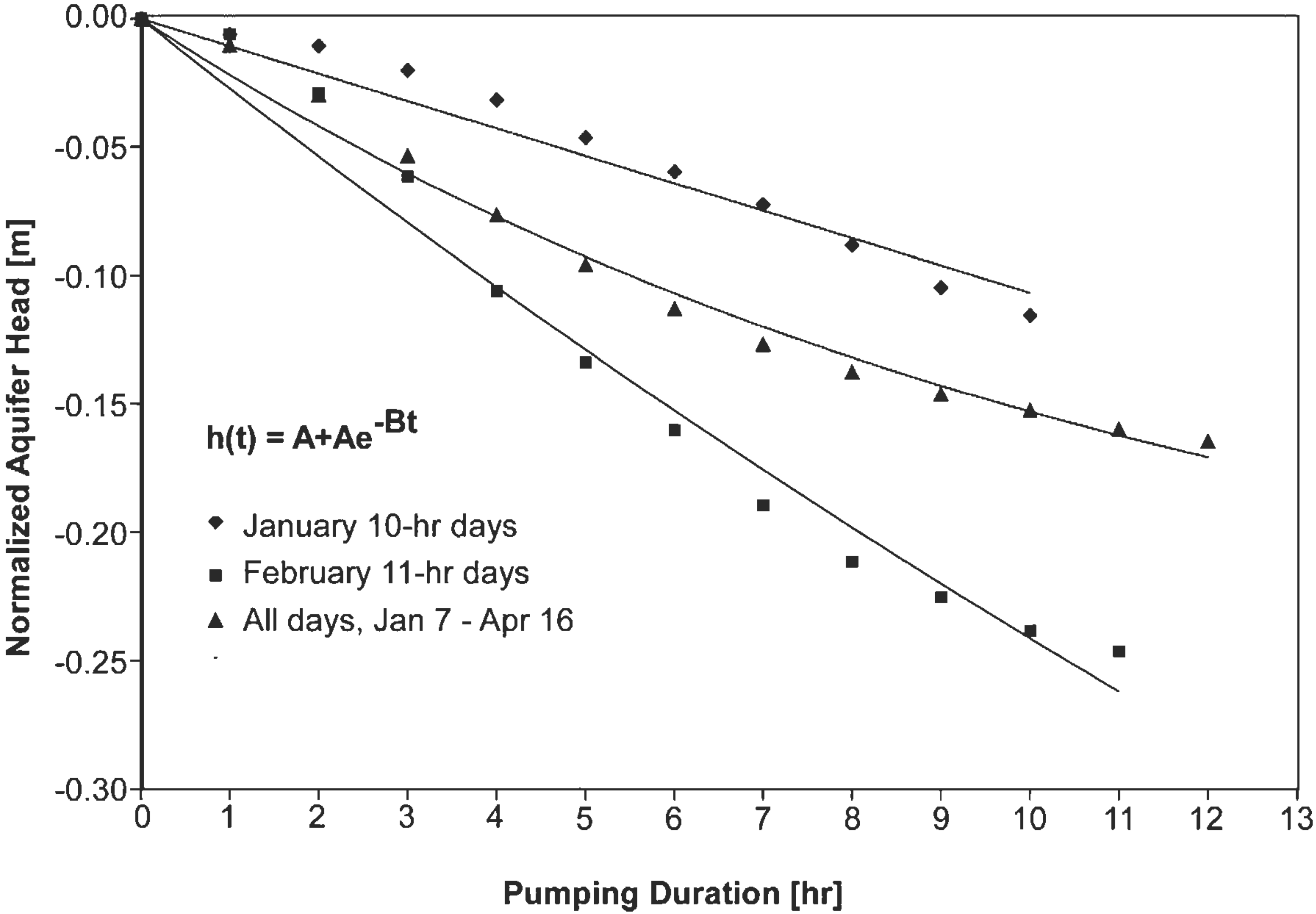
Pumping



a.
Zero Mean Head [m]
0.2
0
-0.2
b.
Pumping Duration [hr]
20
10
0
average
c.
Rainfall [mm]
40
20
0
d.
Amplitude / Duration
0.04
0.02
mean + 1 standard deviation
01/2002
02/2002
03/2002
04/2002
05/2002
Date



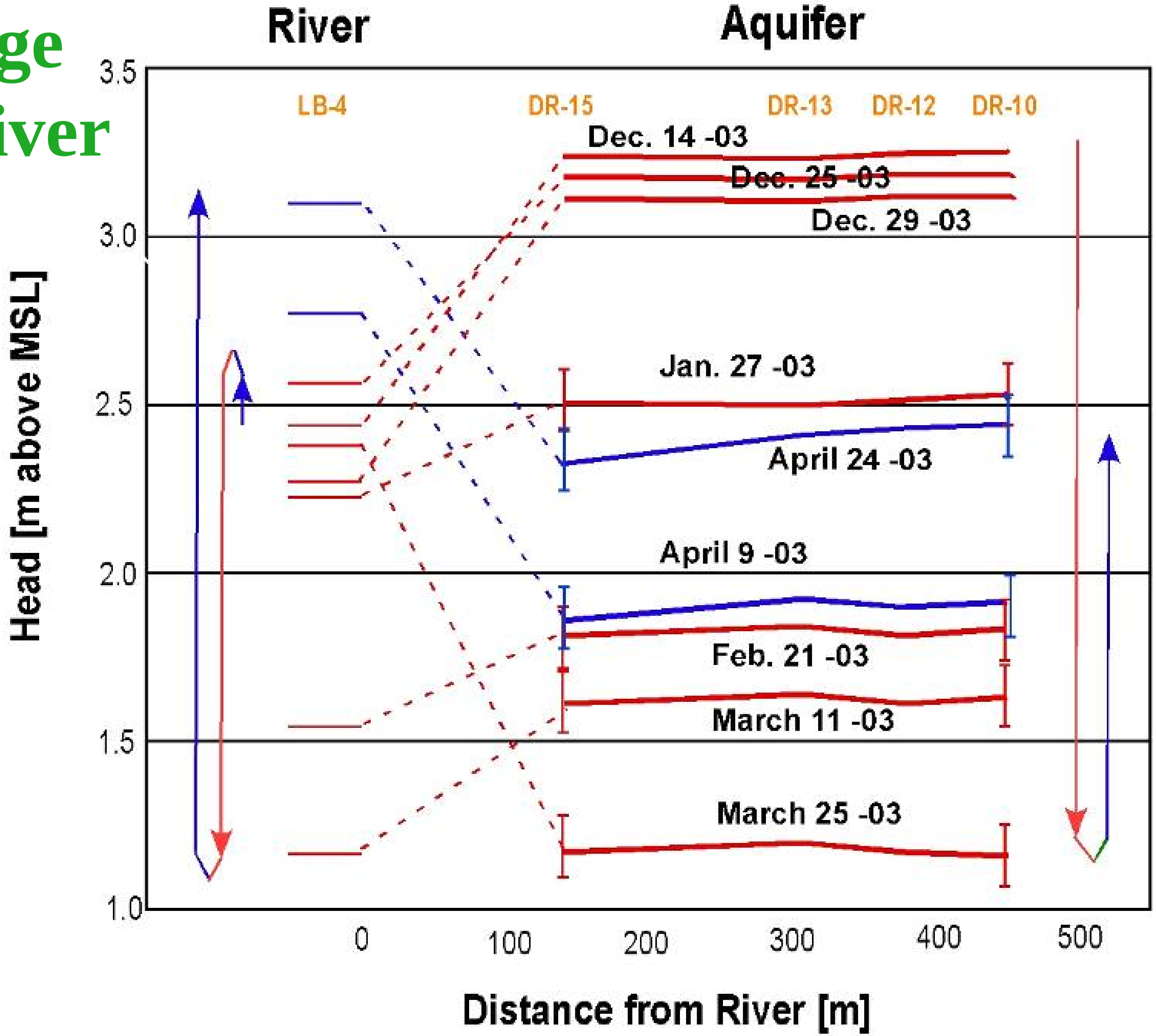
Measured Pumping Rates of 41 (out of 54) Irrigation Wells (1/28 and 2/20 2004)
Mean = 24.1 Litres / Second
20
15
10
5
0
5
10
15
20
25
30
35
40
Litres / Second

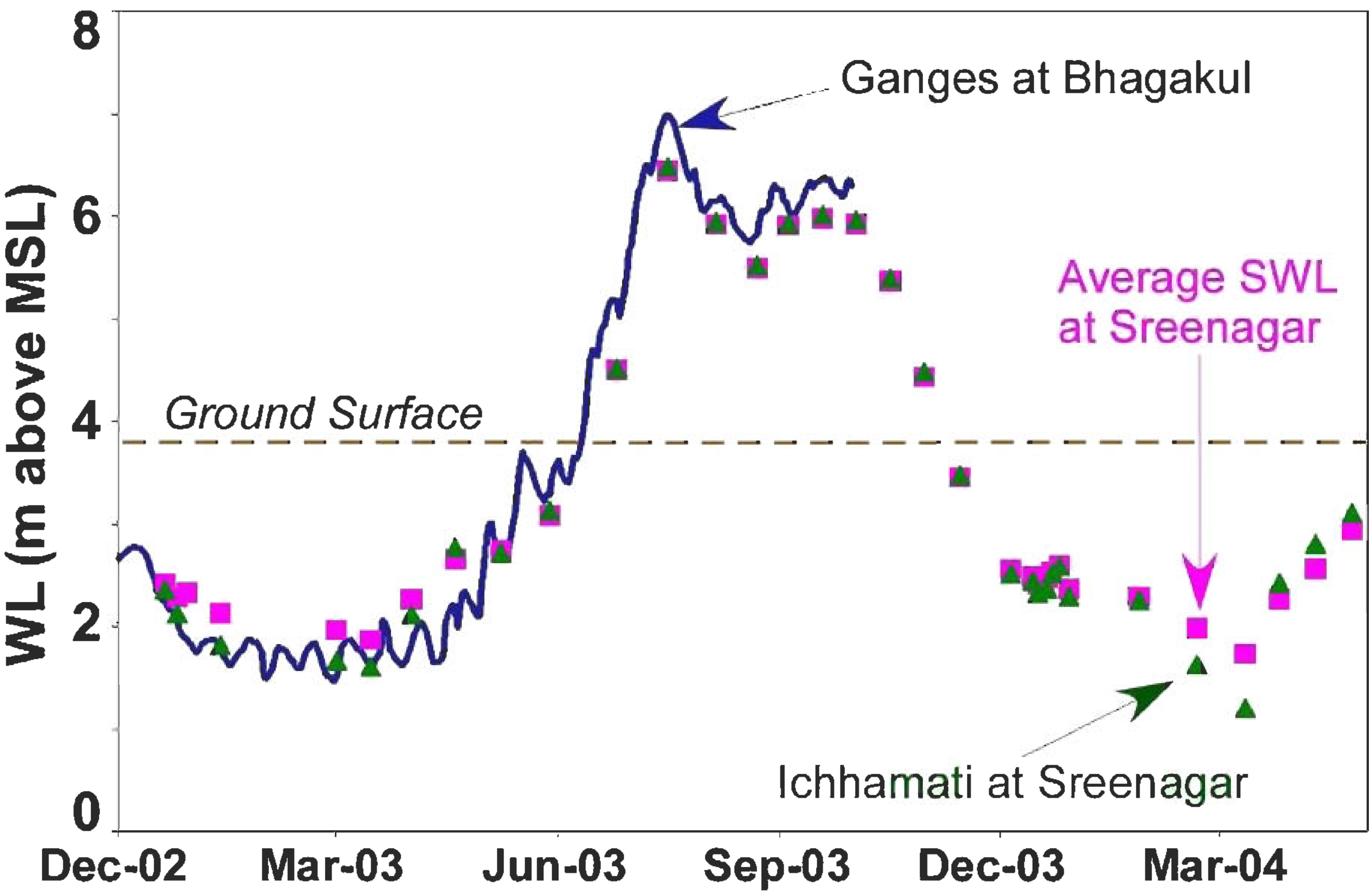


Normalized Aquifer Head [m]
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Pumping Duration [hr]
$h(t) = A+Ae^{-Bt}$
January 10-hr days
February 11-hr days
All days, Jan 7 - Apr 16

River Exchange

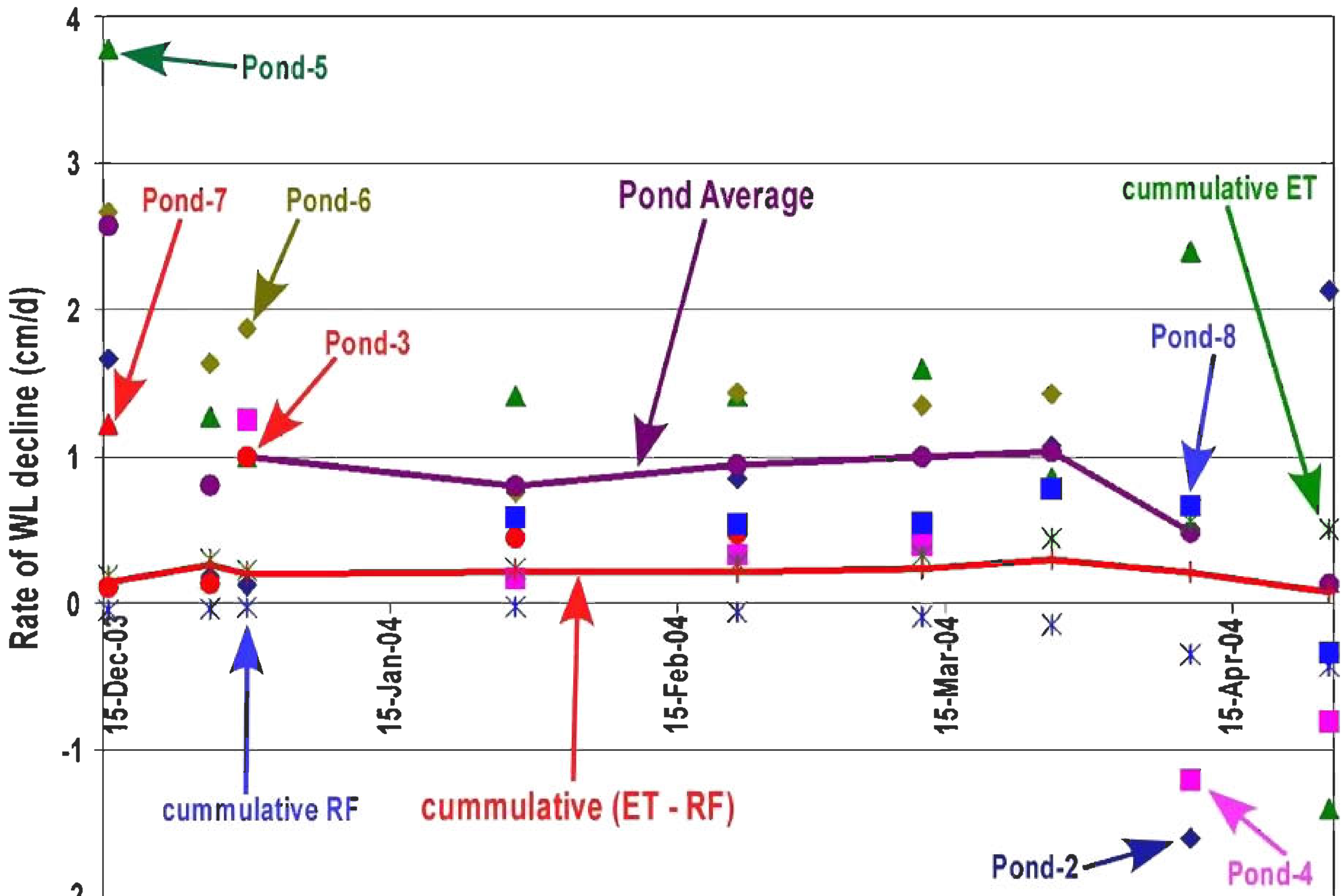
Exchange With River





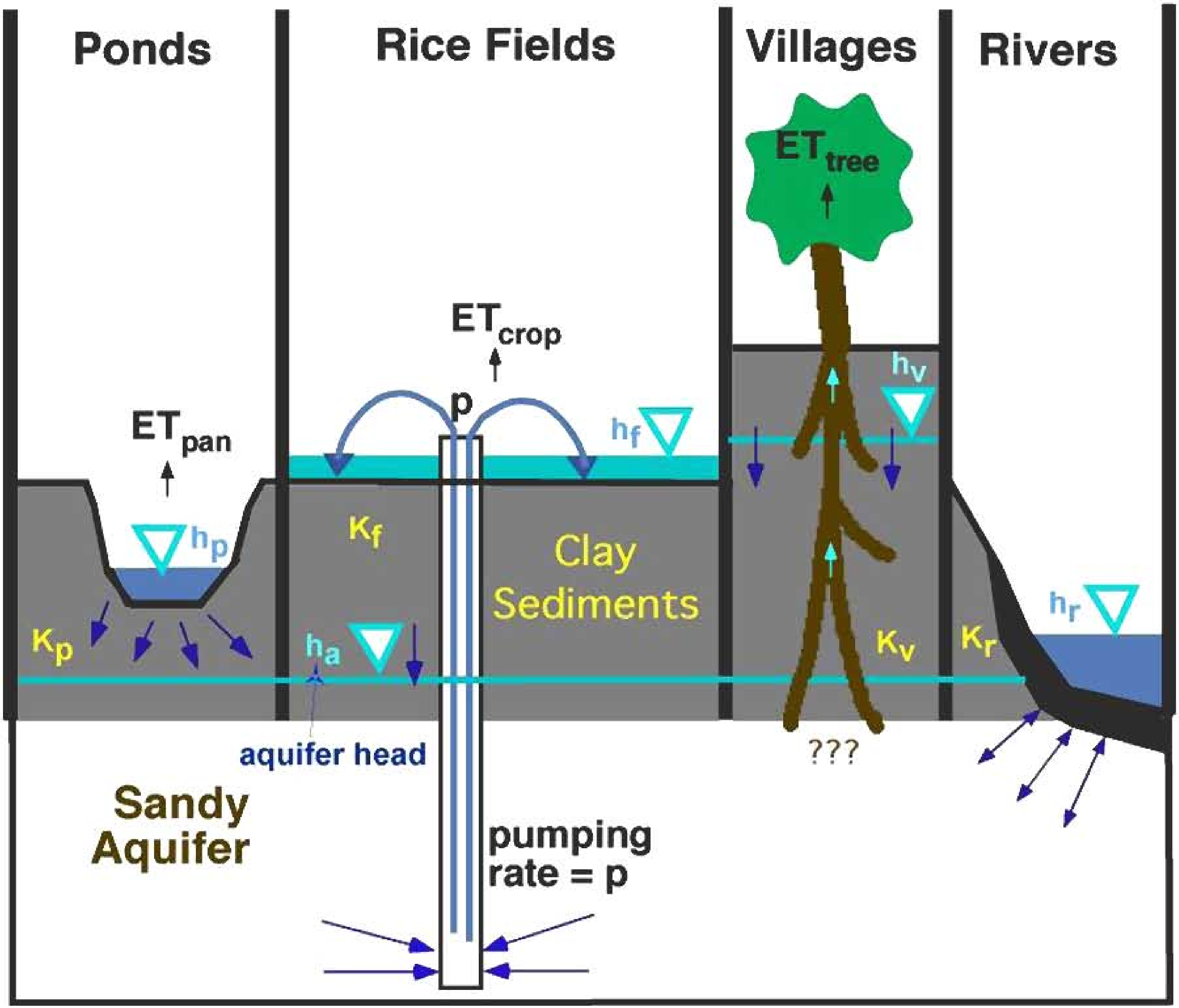
Ganges at Bhagakul
Average SWL
at Sreenagar
Ground Surface
Ichhamati at Sreenagar
WL (m above MSL)
8
6
4
2
0
Dec-02
Mar-03
Jun-03
Sep-03
Dec-03
Mar-04

Ponds



Rate of WL decline (cm/d)
4
3
2
1
0
-1
-2
15-Dec-03
15-Jan-04
15-Feb-04
15-Mar-04
15-Apr-04
Pond-5
Pond-7
Pond-6
Pond Average
cummulative ET
Pond-3
Pond-8
cummulative RF
cummulative (ET - RF)
Pond-2
Pond-4

Model



Ponds
Rice Fields
Villages
Rivers
ET_{tree}
ET_{crop}
p
ET_{pan}
h_f
h_v
h_p
K_f
Clay
Sediments
h_r
K_p
h_a
K_v
K_r
aquifer head
???
Sandy
Aquifer
pumping
rate = p

Aquifer:

$$S\frac{dh_a}{dt} = \left(h_f - h_a\right)K_f f_f + \left(h_p - h_a\right)K_p f_p + \left(h_r - h_a\right)K_r f_r + \left(h_v - h_a\right)K_v f_v - q_I - f_{av}\alpha_v ET_0$$

Village:

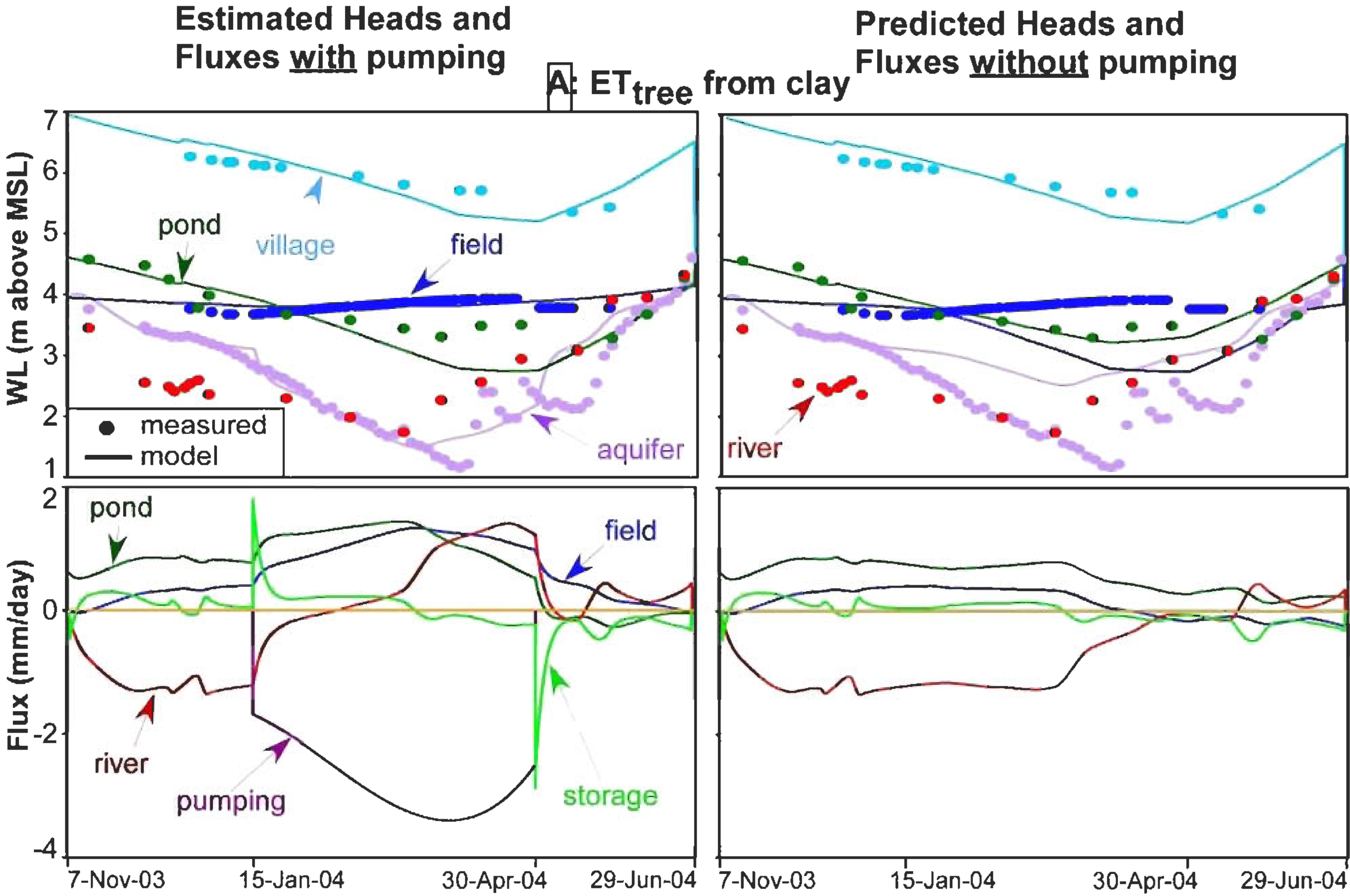
$$S_y \frac{dh_v}{dt} = \left(h_a - h_v\right)K_v - \left(1 - f_{av}\right)\alpha_v ET_0 + R$$

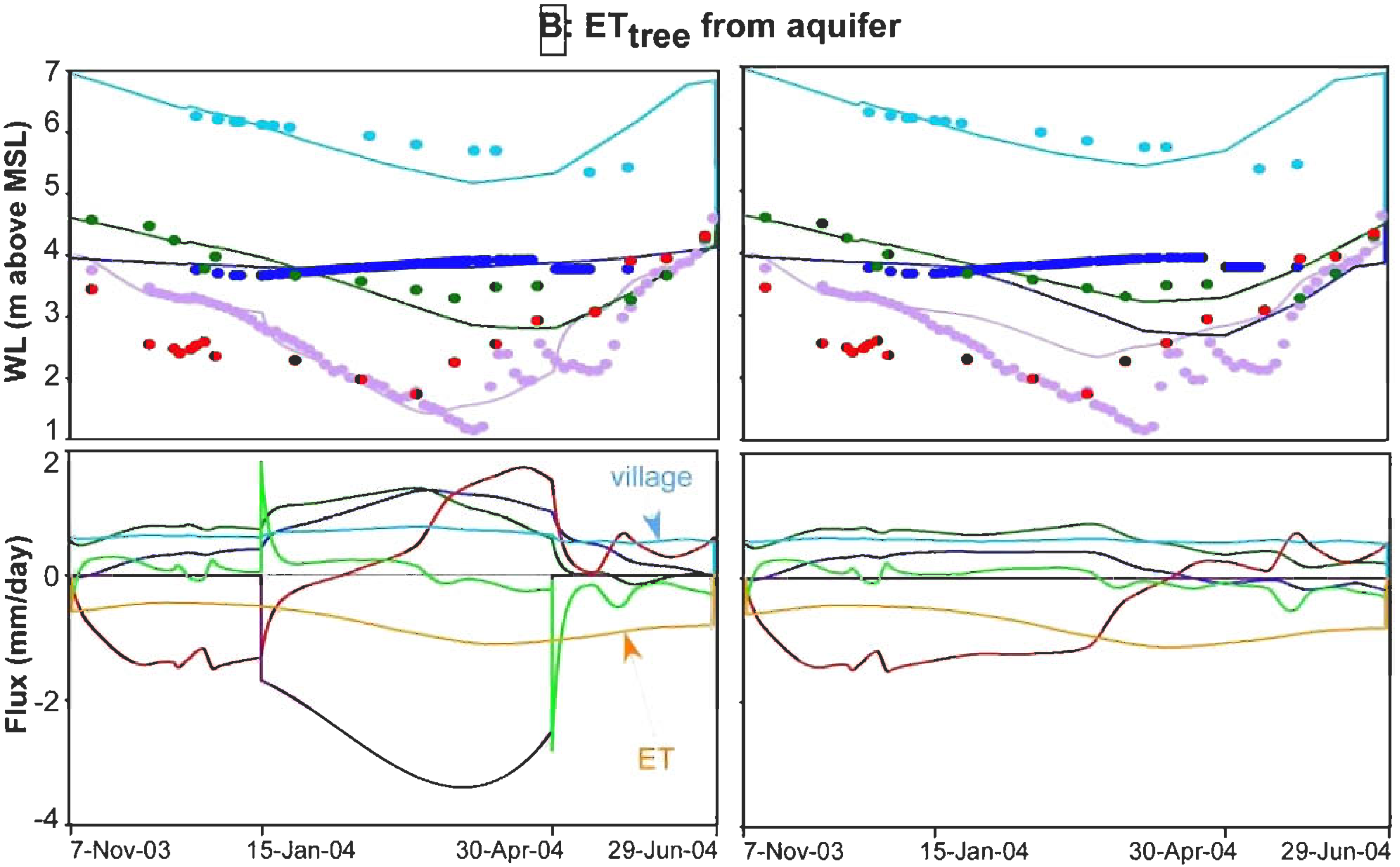
Field:

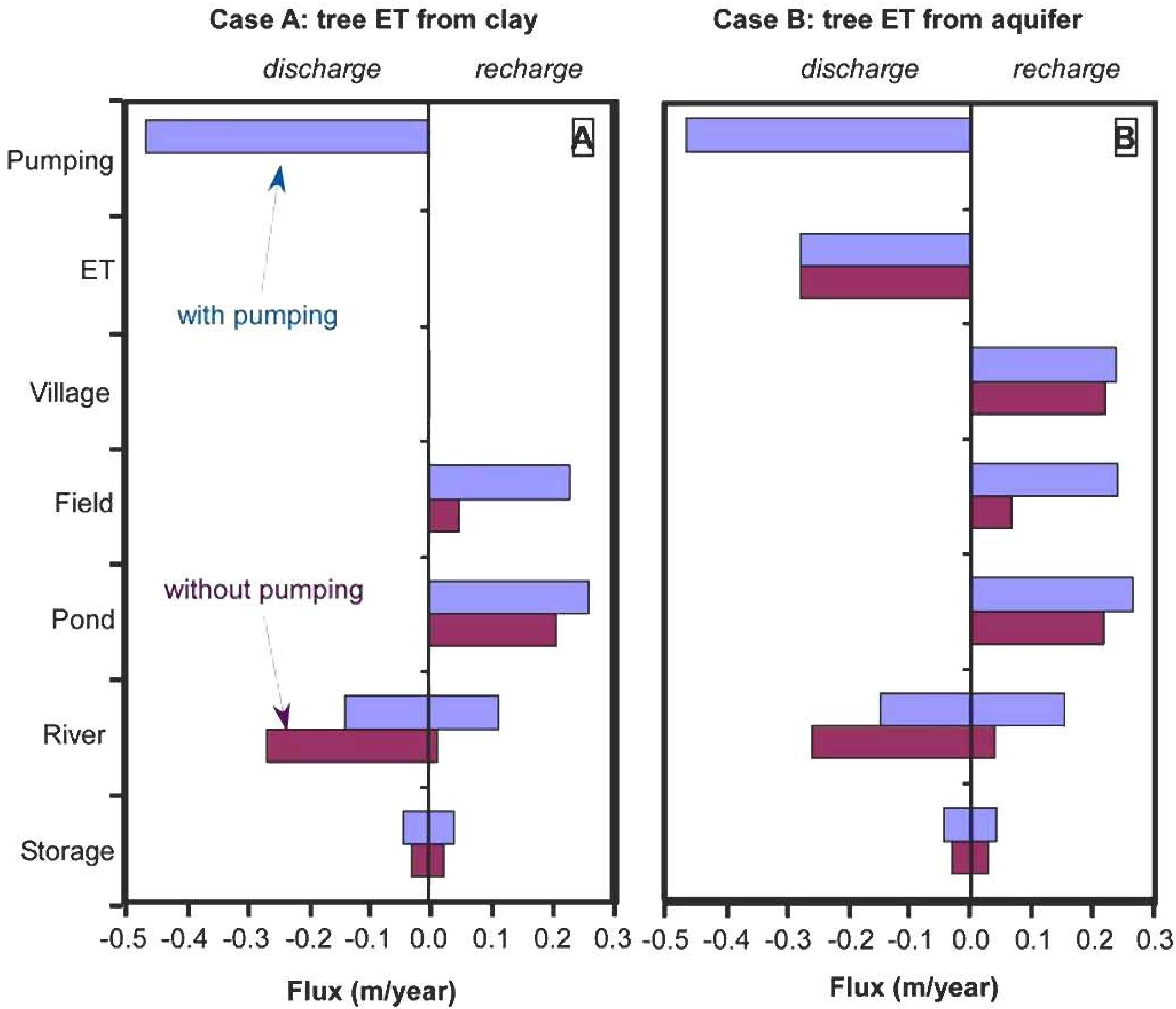
$$S_y \frac{dh_f}{dt} = \left(h_a - h_f\right)K_f - \alpha_f ET_0 + R + \frac{q_I}{f_f}$$

Pond:

$$\frac{dh_p}{dt} = \left(h_a - h_p\right)K_p - \alpha_p ET_0 + R$$


Estimated Heads and Fluxes with pumping
A: ETtree from clay
Predicted Heads and Fluxes without pumping
WL (m above MSL)
pond
village
field
measured
model
aquifer
river
Flux (mm/day)
pond
field
river
pumping
storage
7-Nov-03
15-Jan-04
30-Apr-04
29-Jun-04
7-Nov-03
15-Jan-04
30-Apr-04
29-Jun-04


B: ET_{tree} from aquifer
WL (m above MSL)
Flux (mm/day)
village
ET
7-Nov-03
15-Jan-04
30-Apr-04
29-Jun-04
7-Nov-03
15-Jan-04
30-Apr-04
29-Jun-04



Case A: tree ET from clay
Case B: tree ET from aquifer
discharge
recharge
discharge
recharge
A
B
Pumping
ET
Village
Field
Pond
River
Storage
with pumping
without pumping
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3
Flux (m/year)
Flux (m/year)

		Case-A	Case-B
Village ET_{tree} from		clay	aquifer
K_f (1/d) [conductance for field]		8.9x10-4	8.9x10-4
K_v (1/d) [conductance for village]		6.3x10-6	9.1x10-4
K_p (1/d) [conductance for pond]		9.3x10-3	8.3x10-3
K_r (1/d) [conductance for river]		7.7x10-2	8.7x10-2
Objective Function *w/ pumping*		5.9x10-1	5.7x10-1
Residence Time (yrs)	***w/ pumping***	19	13
	w/o pumping	42	22

Table 1. The estimated conductance parameter values when the storage coefficients are fixed, the respective objective functions (sum of square errors), and modeled residence times for the aquifer.

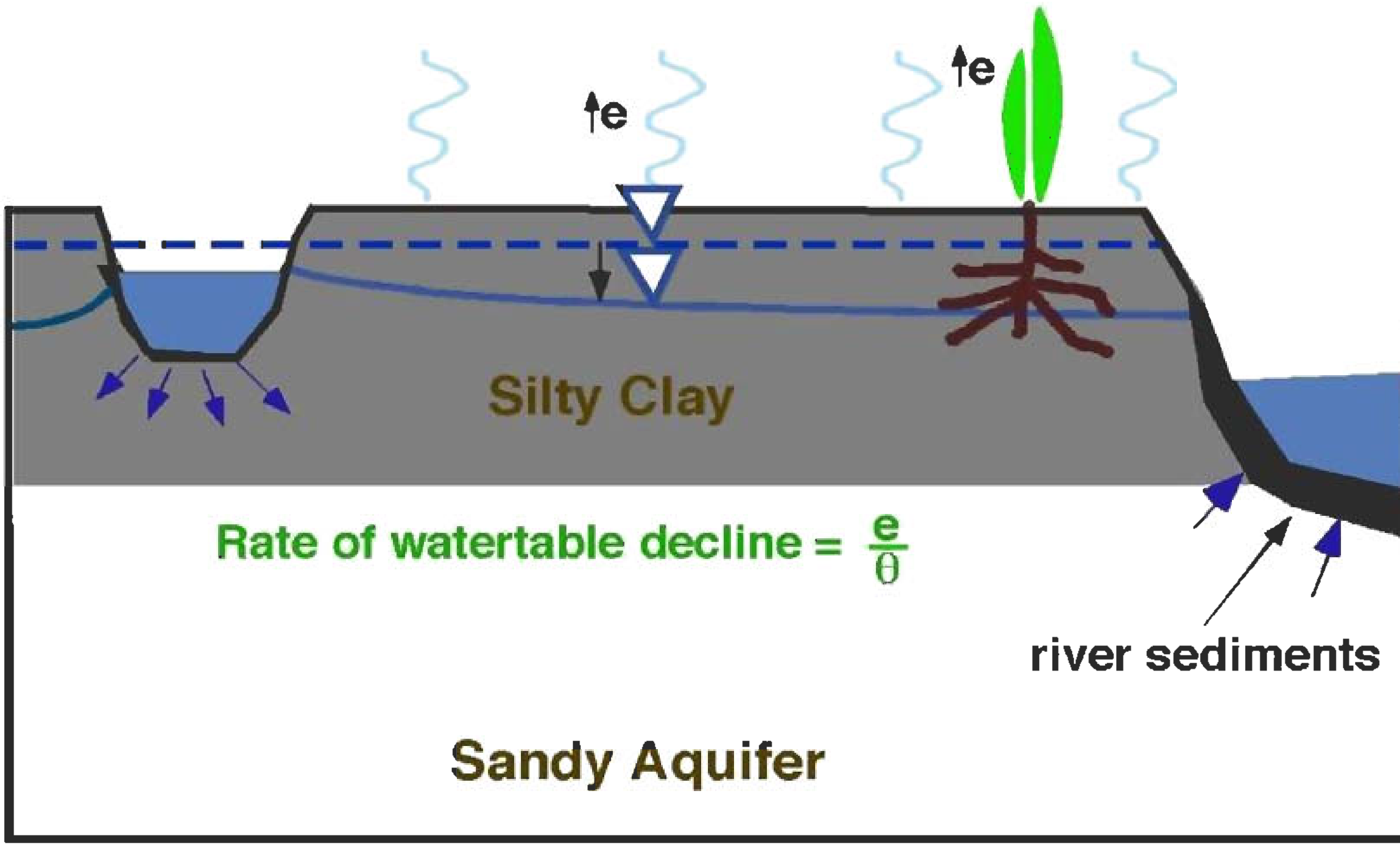
Case A: Village ET out of Clay						
	K_f	K_p	K_r	K_v		CV
K_f	1					0.11
K_p	-0.18	1				0.10
K_r	-0.28	0.29	1			0.11
K_v	-0.30	0.01	0.09	1		5.45

Case B: Village ET out of Aquifer						
	K_f	K_p	K_r	K_v		CV
K_f	1					0.10
K_p	-0.21	1				0.10
K_r	-0.31	0.23	1			0.10
K_v	-0.11	0.05	0.00	1		0.06

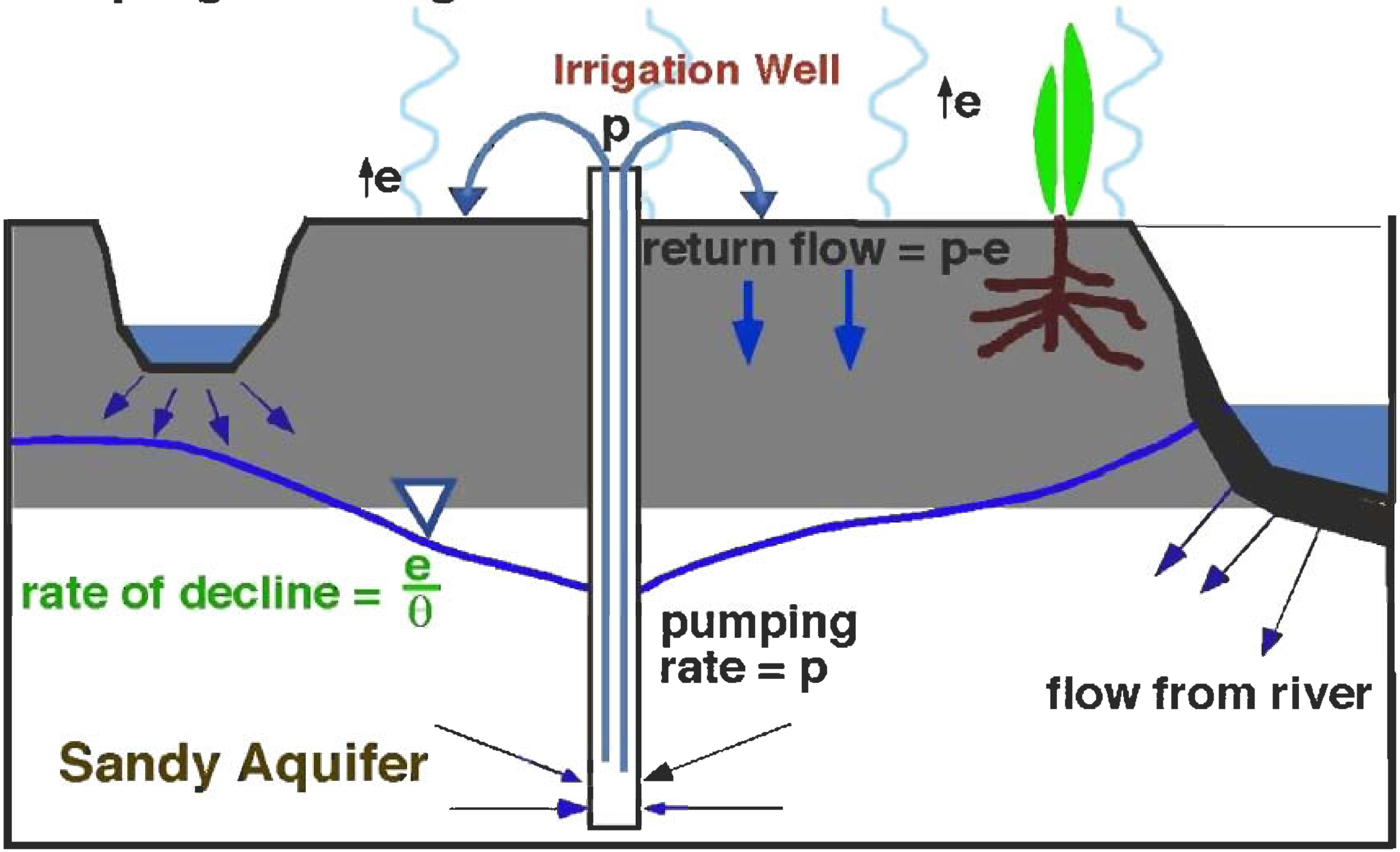
Case A: Village ET out of Clay								
	K_f	K_p	K_r	K_v	S_y	S		CV
K_f	1							0.15
K_p	-0.17	1						0.09
K_r	-0.31	0.04	1					0.10
K_v	-0.34	0.02	-0.22	1				0.77
S_y	-0.26	0.02	-0.29	0.92	1			0.14
S	-0.24	-0.07	0.81	-0.15	-0.19	1		0.13

Case B: Village ET out of Aquifer								
	K_f	K_p	K_r	K_v	S_y	S		CV
K_f	1							0.18
K_p	-0.11	1						0.09
K_r	-0.39	-0.06	1					0.11
K_v	-0.36	0.10	-0.07	1				0.08
S_y	-0.36	0.11	-0.10	0.79	1			0.09
S	-0.26	-0.14	0.83	-0.16	-0.22	1		0.15

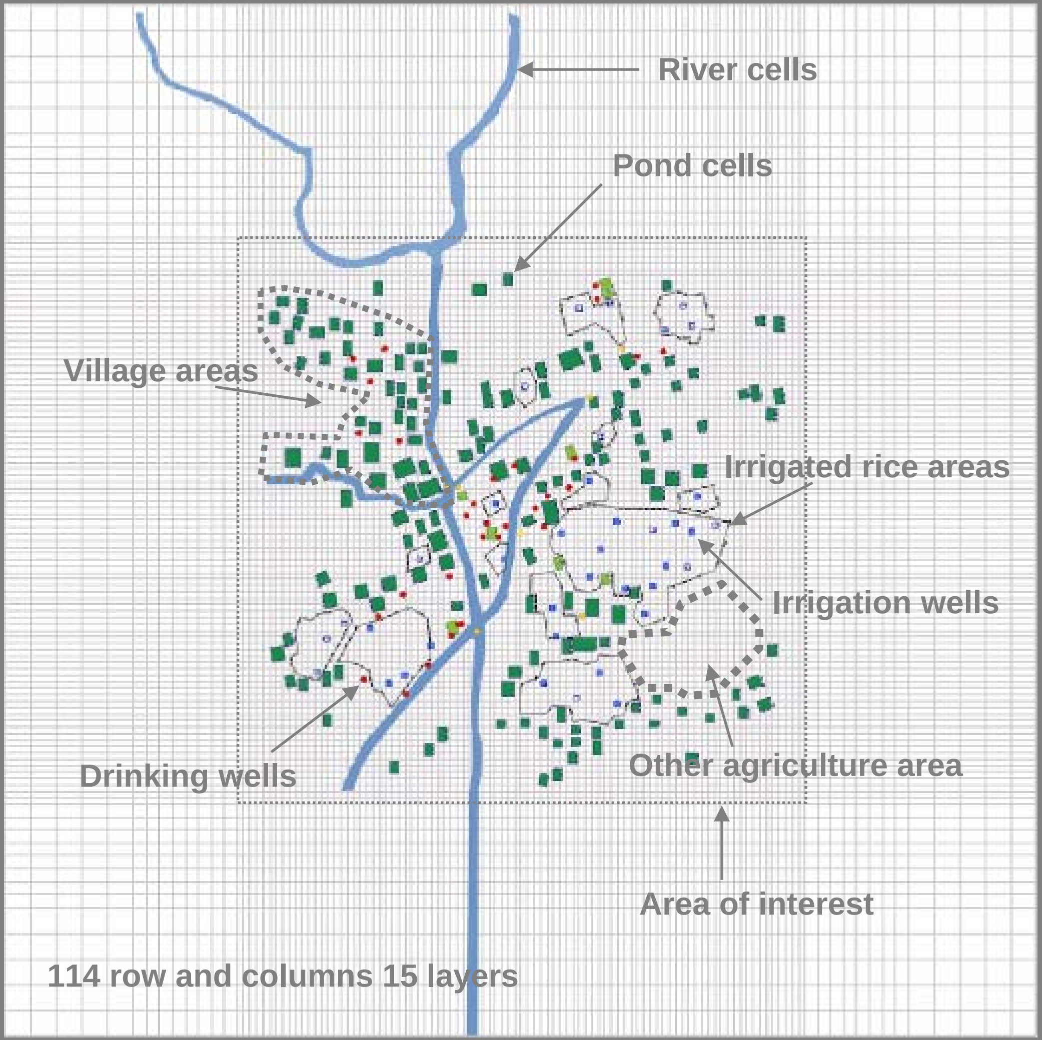
A. Planting Season (Nov-Dec, prior to pumping)



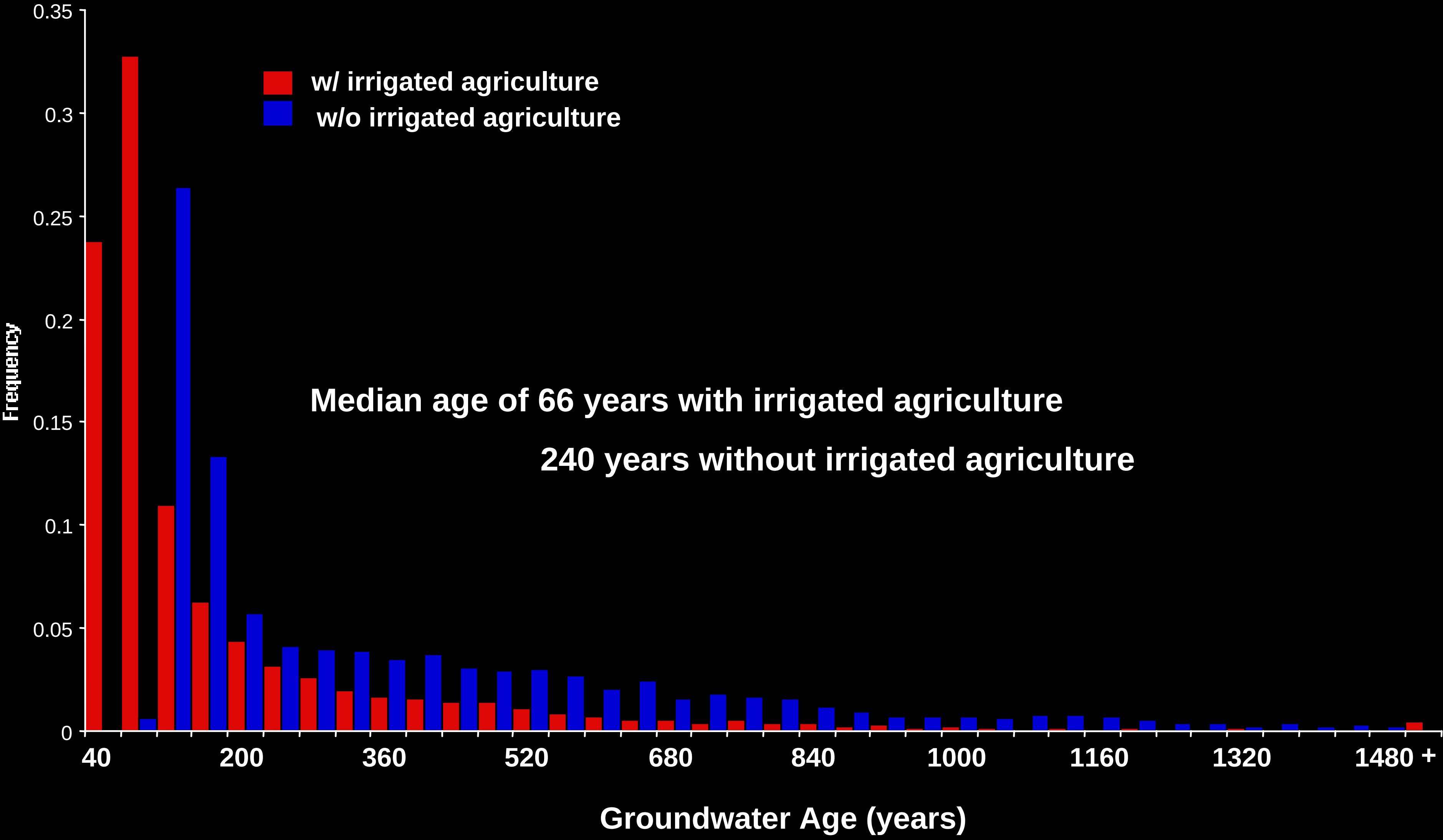
B. Pumping and Irrigation



Transient Three-Dimensional Flow Model



Estimated Groundwater Age Distribution at 30-m



Conclusions

- Arsenic concentrations are subject to change and irrigation pumping is sufficient to have significantly changed flow paths, drawing young water and chemicals into the aquifer.

- Geochemical parameters at our site are consistent with a scenario of concomitant arsenic release and organic carbon oxidation.

- Deeper wells have the potential to alleviate the problem, but could also become contaminated.

Tremendous disparity with US groundwater contamination problems

- In the developed world people don't drink seriously contaminated groundwater when contamination is known.

- Relative to US, efforts to understand the physical and chemical processes are not funded.

Need a serious scientific/engineering program

People

MIT

Chris Swartz
Nicole Keon
Winston Yu
Jenny Jay
Dan Brabander
Peter Oates
Harry Hemond

BUET

Borhan Badruzzaman
Ashraf Ali
Feroze Ahmed
Khandaker Ashfaque

U. Cincinatti

Shafik Islam

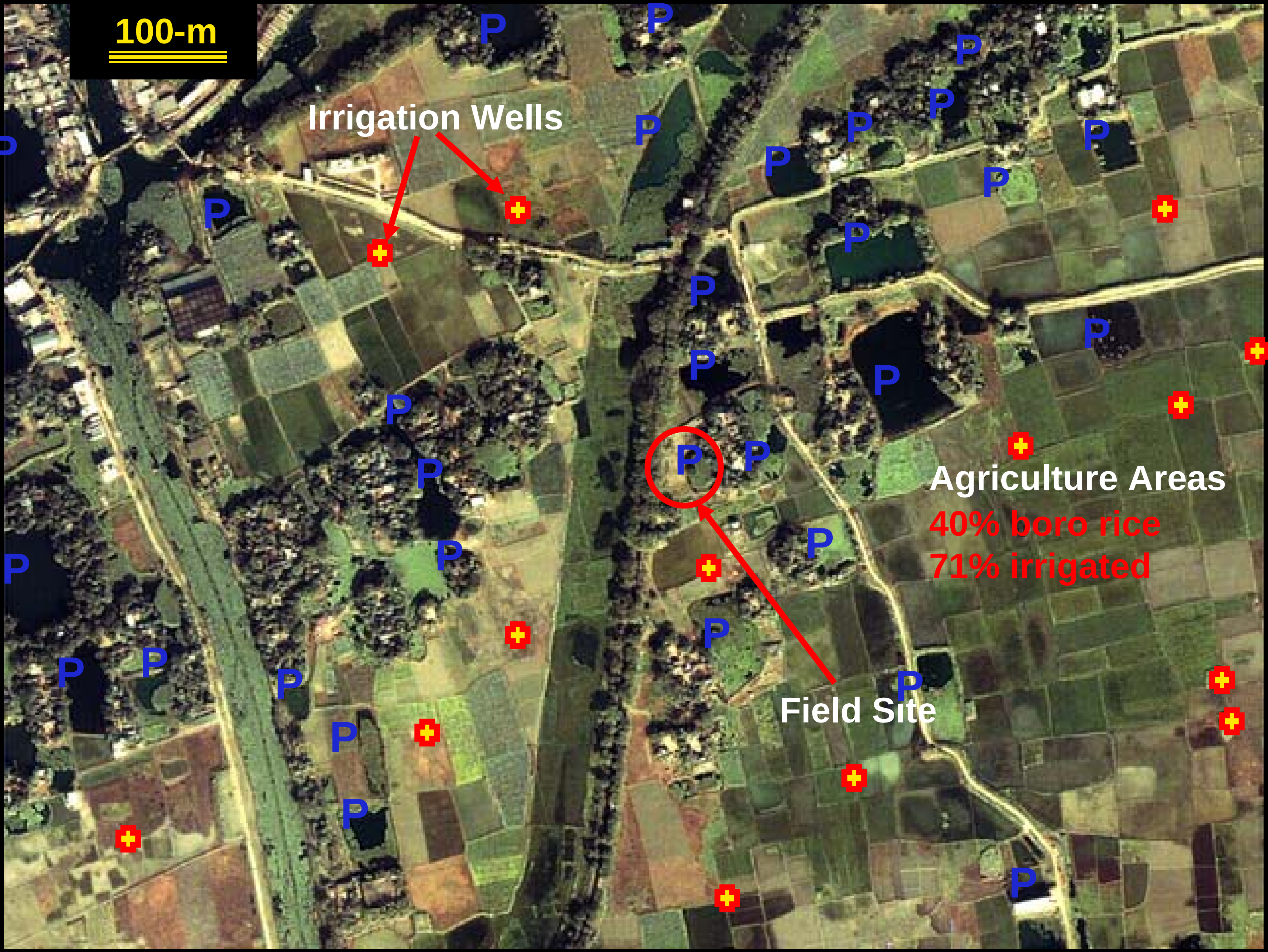
Roger Beckie
Volker Niedan

Future directions

- Arsenic in other regions in Asia
  Does Bangladesh indicate the future?

- Arsenic in agriculture and food chain
- Combined surface-water groundwater management pathogens vs. arsenic

Can these be done without a detailed hydro-bio-geo-chemical model?


100-m
Irrigation Wells
Agriculture Areas
40% boro rice
71% irrigated
Field Site
P

MIT/BUET/NSF Arsenic Project

Small N_2 glove bag at night