Karst Hydrogeology in South Africa

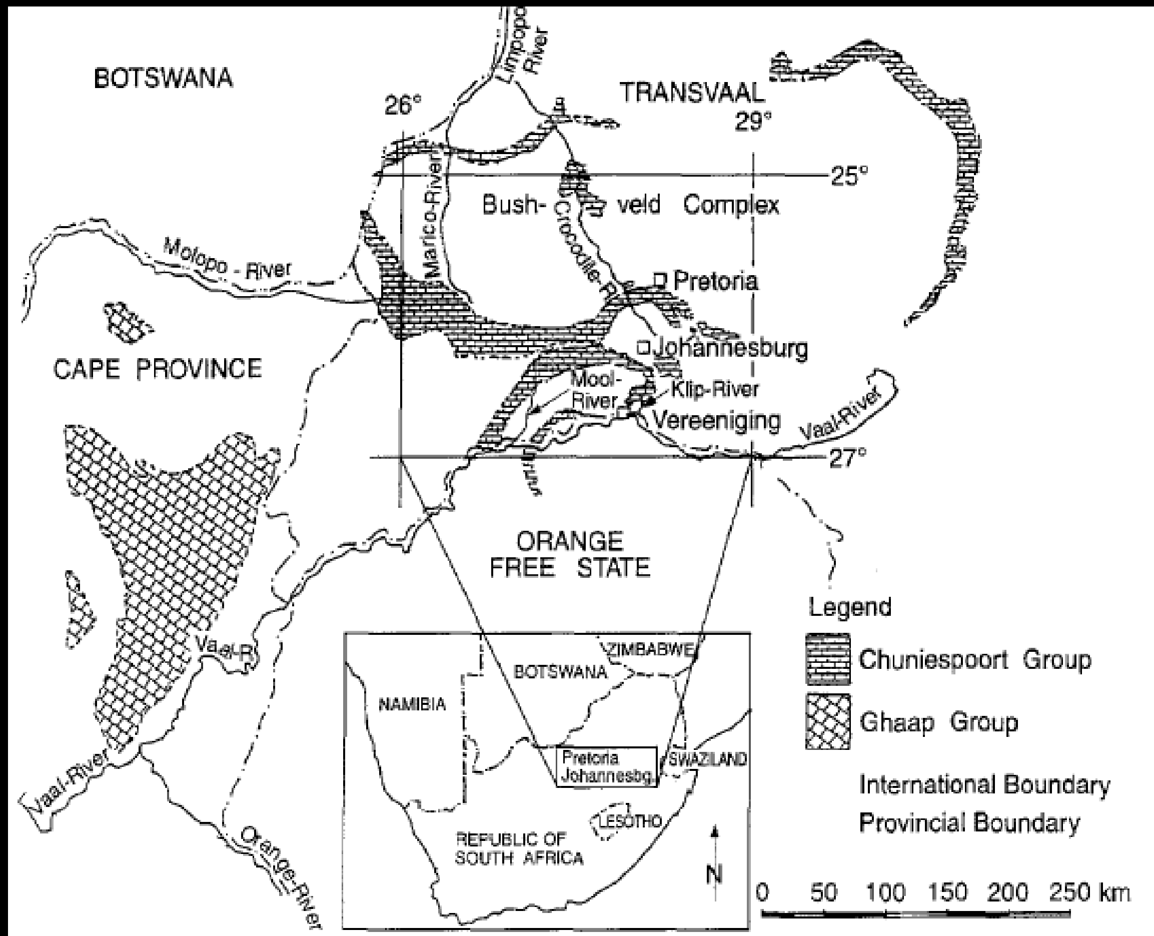
David Whitaker, Arup

ENGINEERING HYDROGEOLOGY

PREDICTIONS, MANAGEMENT, DEWATERING AND LEGISLATION
Wednesday 14 January 2009

ARUP

Location

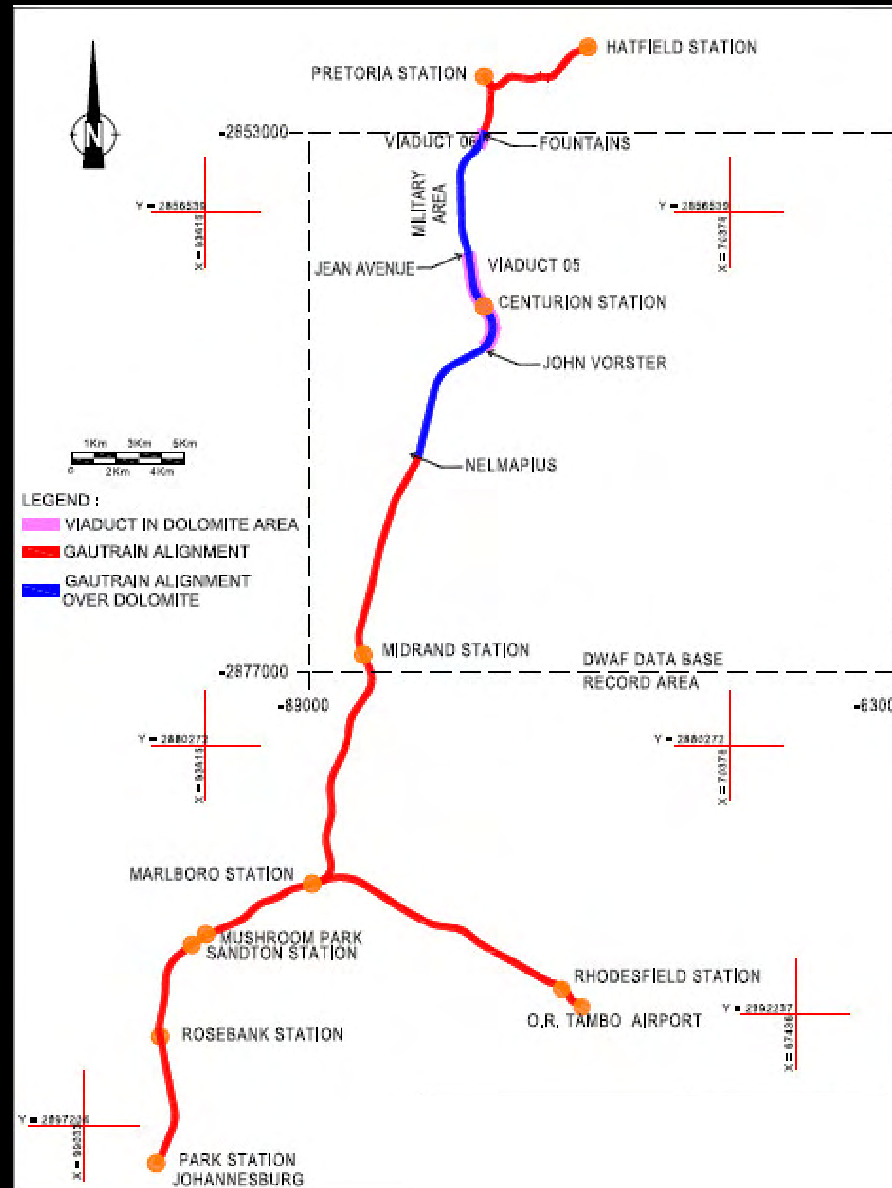


ARUP

Gautrain project

- VIADUCT IN DOLOMITE AREA
- GAUTRAIN ALIGNMENT
- GAUTRAIN ALIGNMENT OVER DOLOMITE

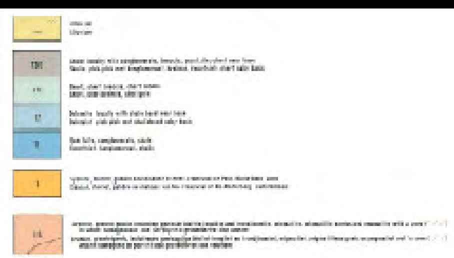
- **Gautrain is an 80-kilometre mass rapid transit railway system under construction in Gauteng Province, South Africa**
- **It will link Johannesburg, Pretoria, and OR Tambo International Airport.**



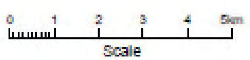
Geology

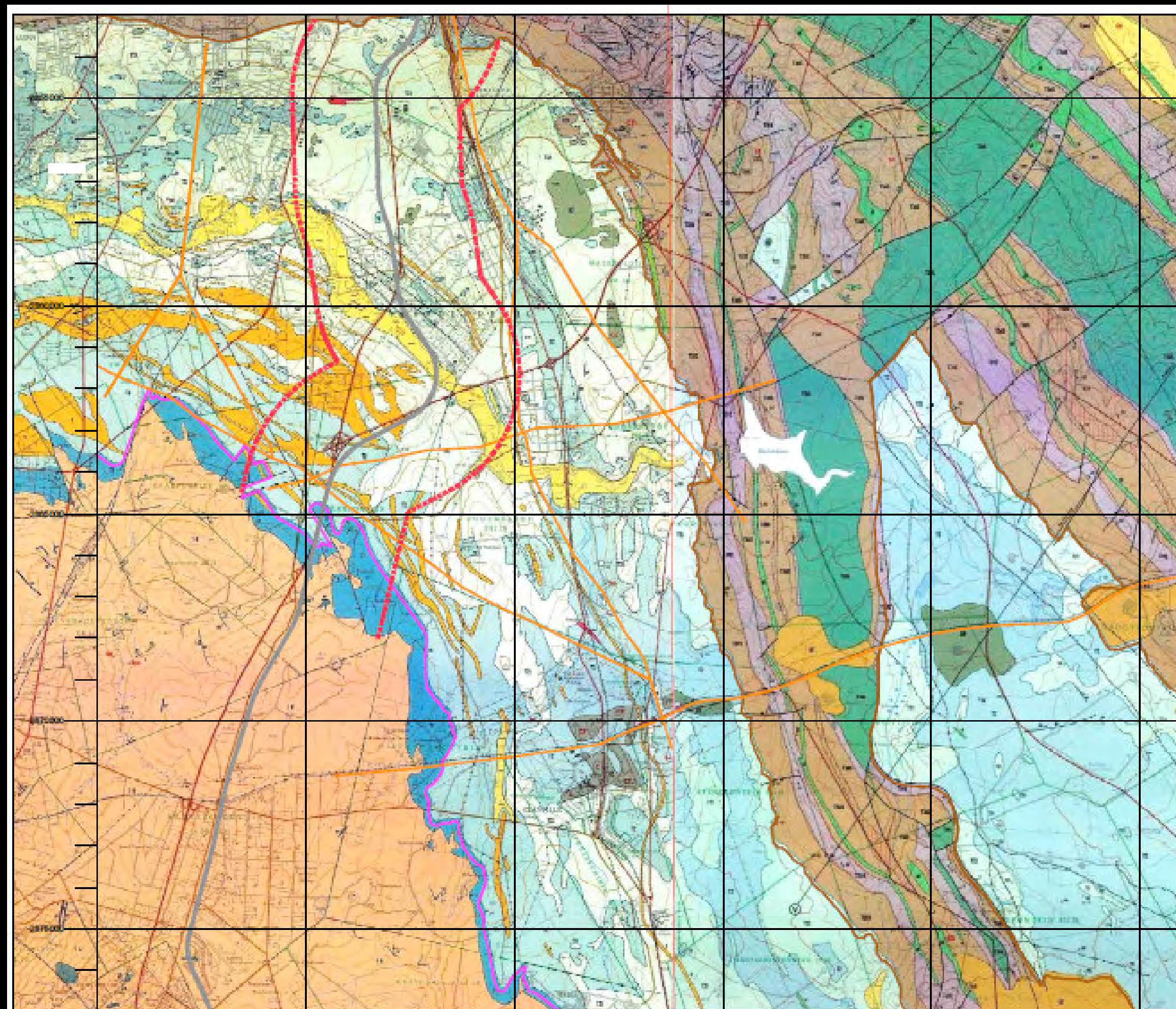
- Dolomite
- Granite
- Shale
- Syenite

Karst

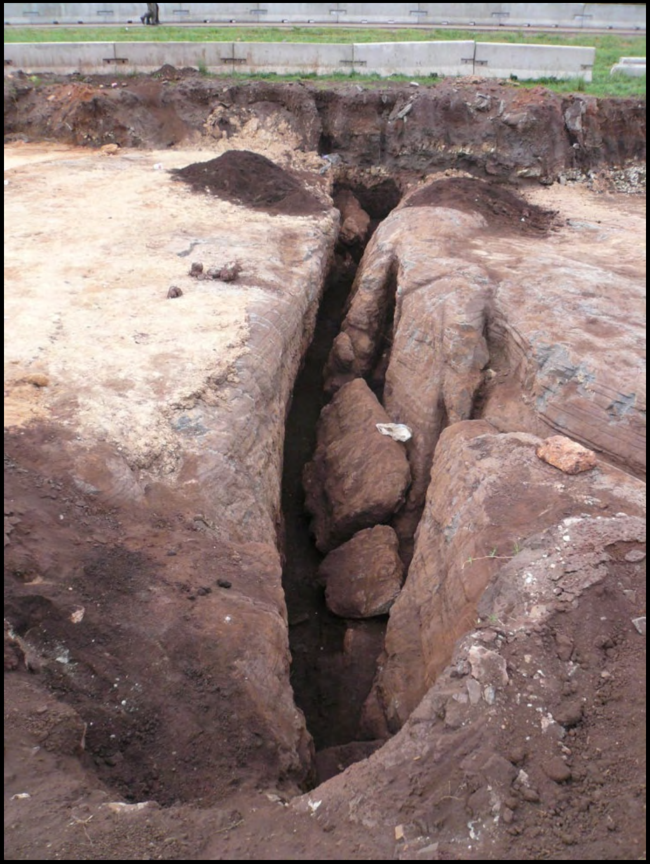


Selected information from map legend





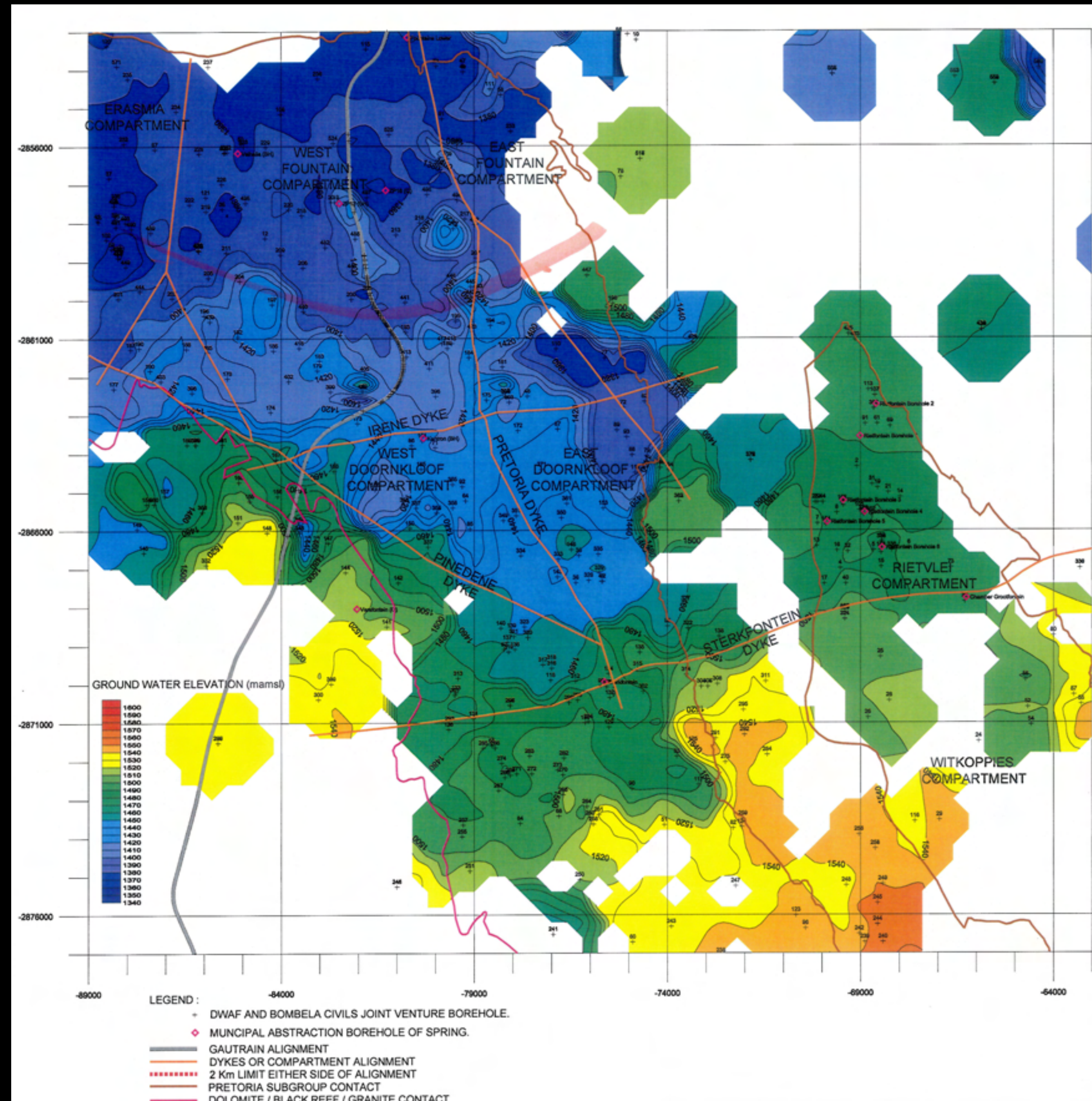
Karstic dolomite aquifer



ARUP

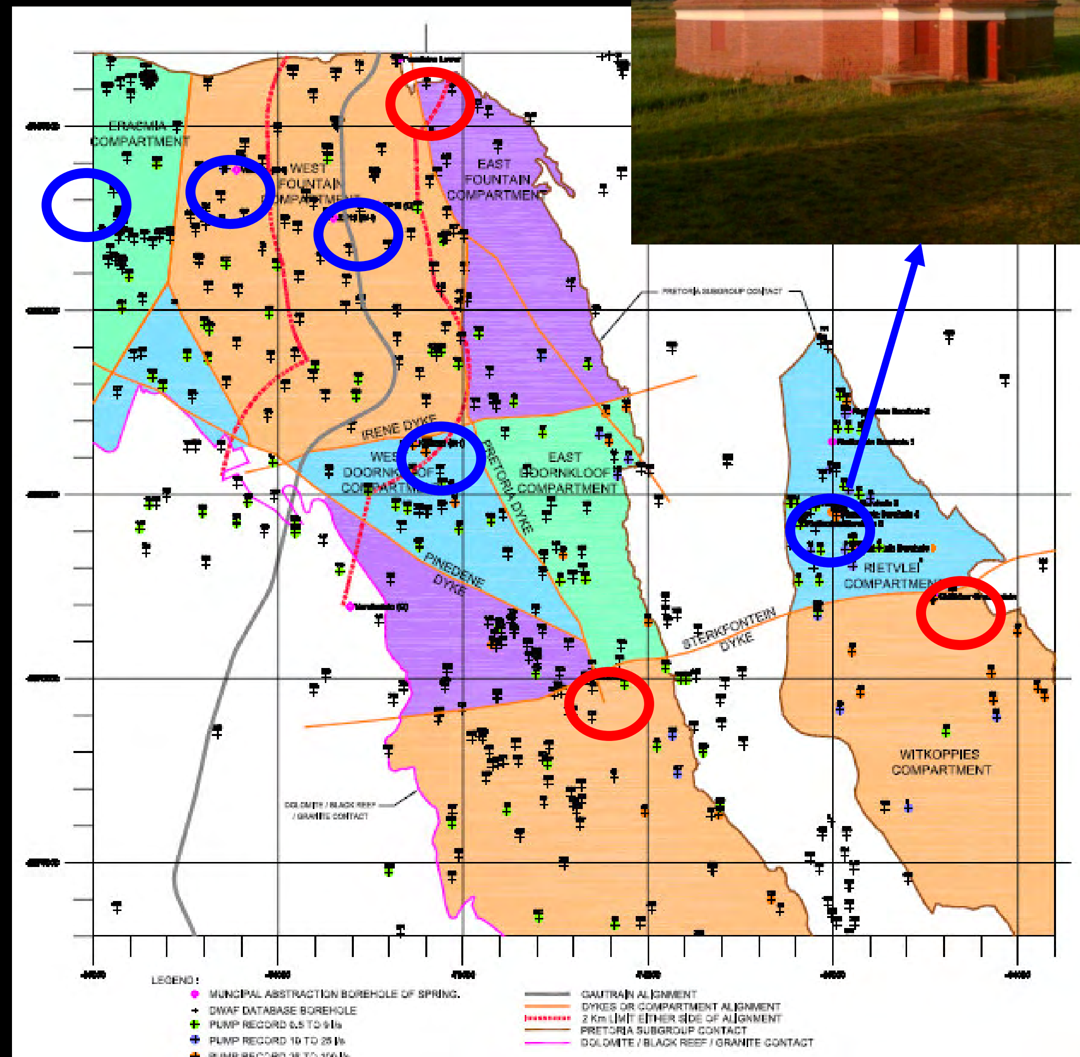
Groundwater Levels

- South – north direction of flow
- Controlled by springs
- Steeper gradients on margins
- Influence of dykes
- Natural fluctuation 2 - 4m



Water balance - outflow

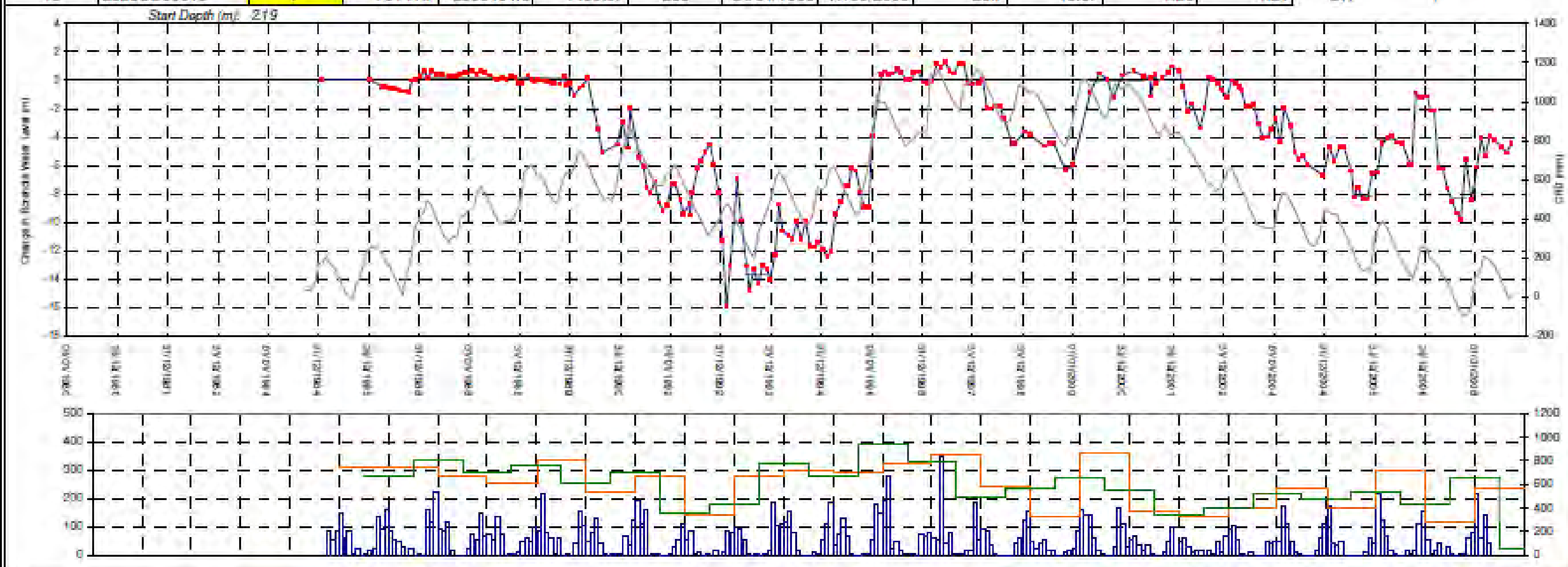
- Pretoria Fountains
- Sterkfontein spring
- Grootfontein spring
- ZP13 borehole
- ZP16 borehole
- Kentron borehole
- Rietvlei boreholes
- Erasmia borehole
- Valhalla borehole
- All from late 1980's



ARUP

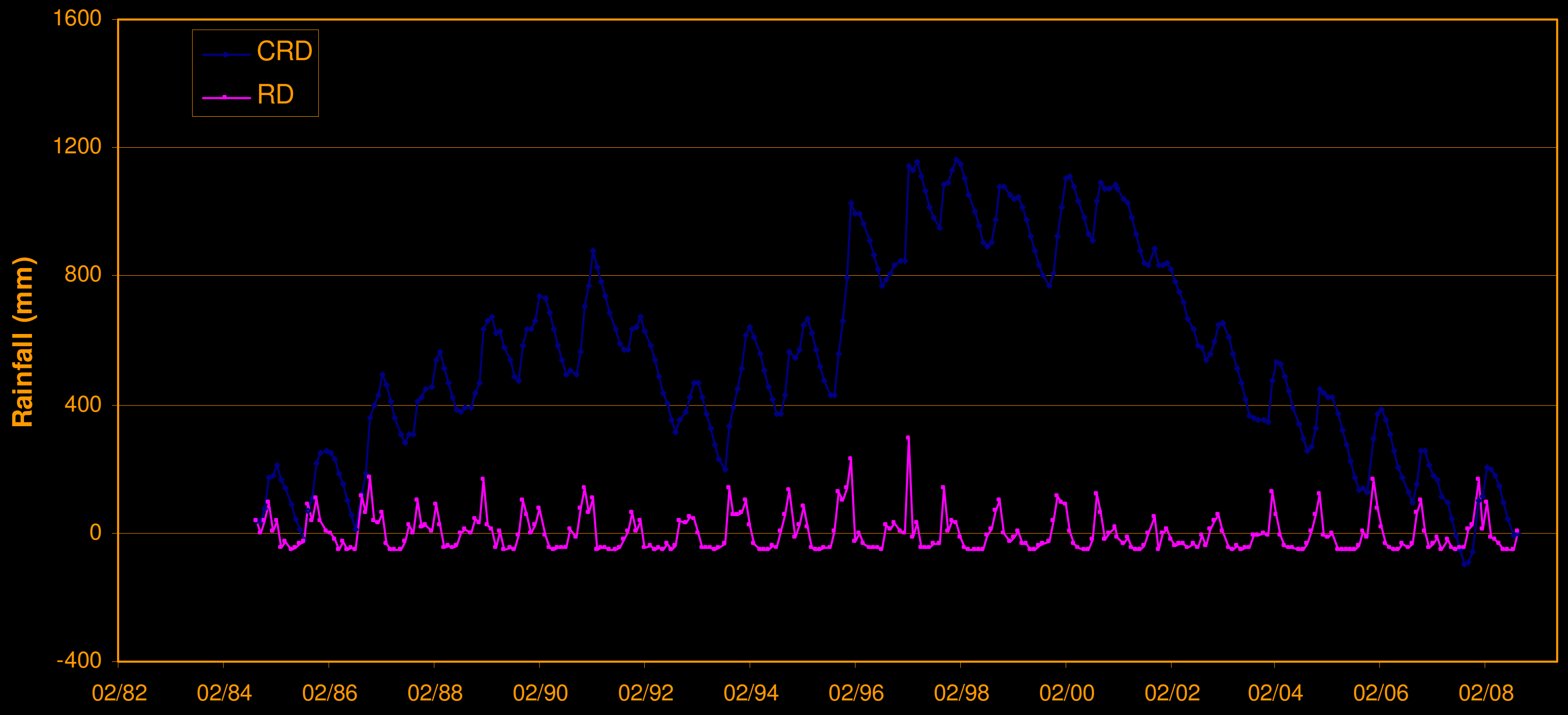
Example well hydrograph (13)

	Asbuilt					Readings								
Geotech Ref	Site ID	Area	X	Y	Z bh	No. Readings	Min Date	Max Date	Monitoring Period (Years)	Min Gnd Water Depth (m)	Max Gnd Water Depth (m)	Standard Deviation		
13	2528CD00013	F	-70141.7	-2866404.5	1490.97	238	24/01/1985	17/09/2008	23.7	-15.87	1.26	4.21	OK	1



- Up to 15m of water table lowering;
- Some relationship to rainfall – July to June (orange columns), CRD (grey line);
- Seven distinct periods of groundwater level change since the late 1980's.

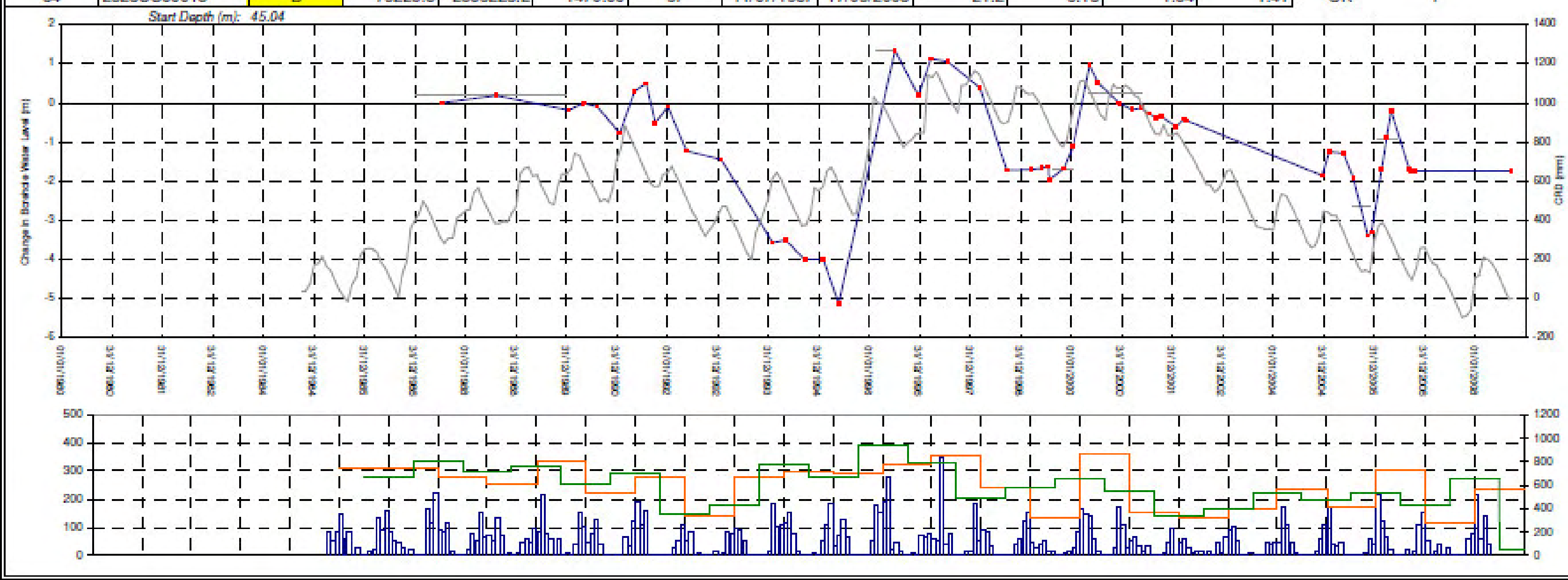
Cumulative Rainfall Departure (CRD)



ARUP

Example well hydrograph (64)

	Asbuilt					Readings								
Geotech Ref	Site ID	Area	X	Y	Z bh	No. Readings	Min Date	Max Date	Monitoring Period (Years)	Min Gnd Water Depth (m)	Max Gnd Water Depth (m)	Standard Deviation		
64	2528CC00018	D	-79223.8	-2865225.2	1470.00	57	11/07/1987	17/09/2008	21.2	-5.15	1.34	1.41	OK	1

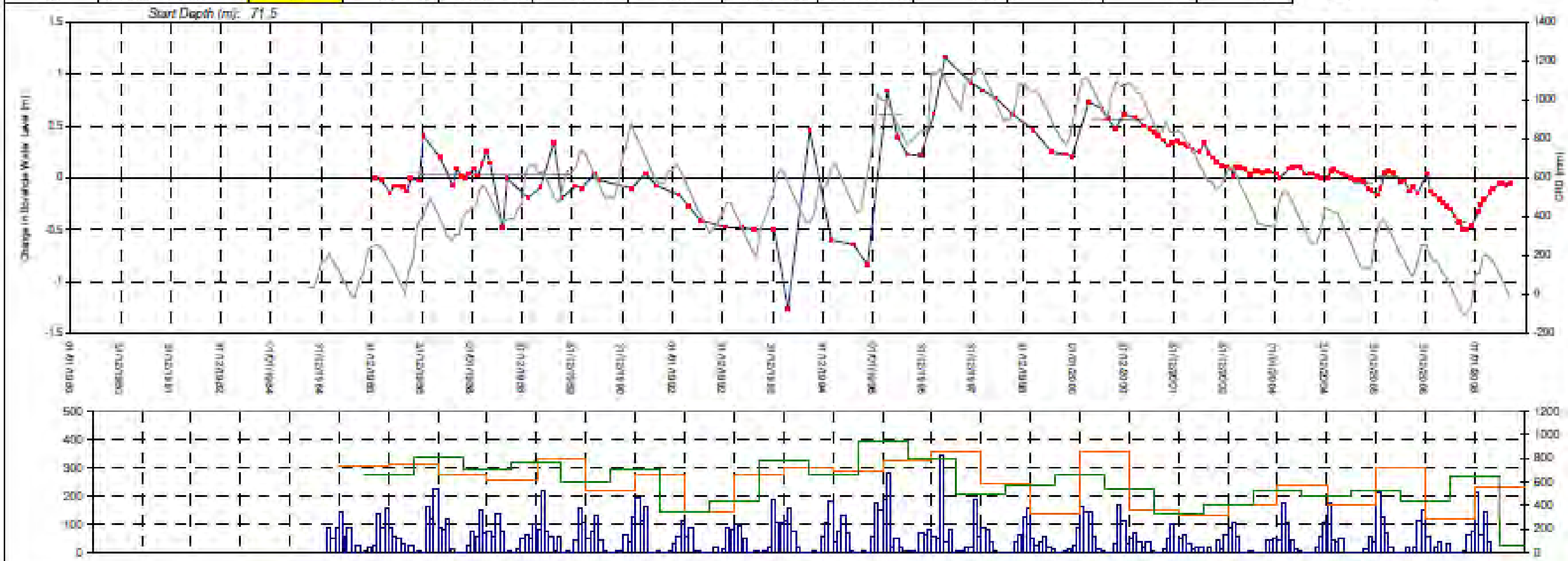


- **Similar changes in monitoring boreholes across the dolomite aquifer;**
- **Superimposed on the longer term fluctuations are fluctuations with shorter duration and smaller amplitude;**
- **Same overall sequence of rising and falling water levels.**

ARUP

Example well hydrograph (24)

	Asbuilt					Readings								
Geotech Ref	Site ID	Area	X	Y	Z bh	No. Readings	Min Date	Max Date	Monitoring Period (Years)	Min Gnd Water Depth (m)	Max Gnd Water Depth (m)	Standard Deviation		
24	2528CD00050	H	-65941.6	-2871479.0	1580.00	153	29/01/1986	11/09/2008	22.6	-1.26	1.16	0.33	OK	1



- Differences mainly in the amplitude or range rather than timing;
- Drawdown phases longer than the recovery periods;
- Levels generally recover fully following a drawdown phase.

Sinkholes

- One mechanism for sinkhole formation is lowered water table in karst
- We wanted to understand the causes of observed fluctuations in the water table and determine the risk of lowered water table

Water balance

$$Q_{Ri} = Q_{pi} + Q_{outi} + \Delta h_i AS \quad (i = 1, 2, 3 \ldots N)$$

- where Q_{Ri} is recharge from rainfall in $\boldsymbol{i}$-th month over aquifer area A;
- Q_{Pi} is the abstraction rate from pumped boreholes;
- Q_{outi} is natural outflow rate;
- Δh_i is water level change;
- S is storativity (specific yield).

Water level adjusts to changes in balance between recharge and outflow or to changes in pumping rate.

Bredenkamp formula for recharge

$$ {}_{av}^{\;1}CRD_i = \sum_{n=1}^{i} R_n - k \sum_{n=1}^{i} R_{av} \quad (i = 0, 1, 2, 3, \ldots N) $$

- where ***CRD*** is the Cumulative Rainfall Departure;
- ***R*** is rainfall in ***i***-th month and "*av*" the average;
- ***K*** is

$$ K = 1 + \frac{\left(Q_p + Q_{out}\right)}{A \cdot R_{av}} $$

- if ***K*** = 1 there is no pumping and/or outflow;
- if ***K*** > 1 there is pumping and/or outflow.

Bredenkamp formula relating recharge and storativity

$$\Delta h_i = (r / S) \cdot ({}^{i}_{av}CRD_i) \ (i = 0, 1, 2, 3, \ldots N)$$

- where Δh_i is the change in water level in the i-th month;
- r is a percentage of the CRD which results in recharge from rainfall;
- S is aquifer storativity.

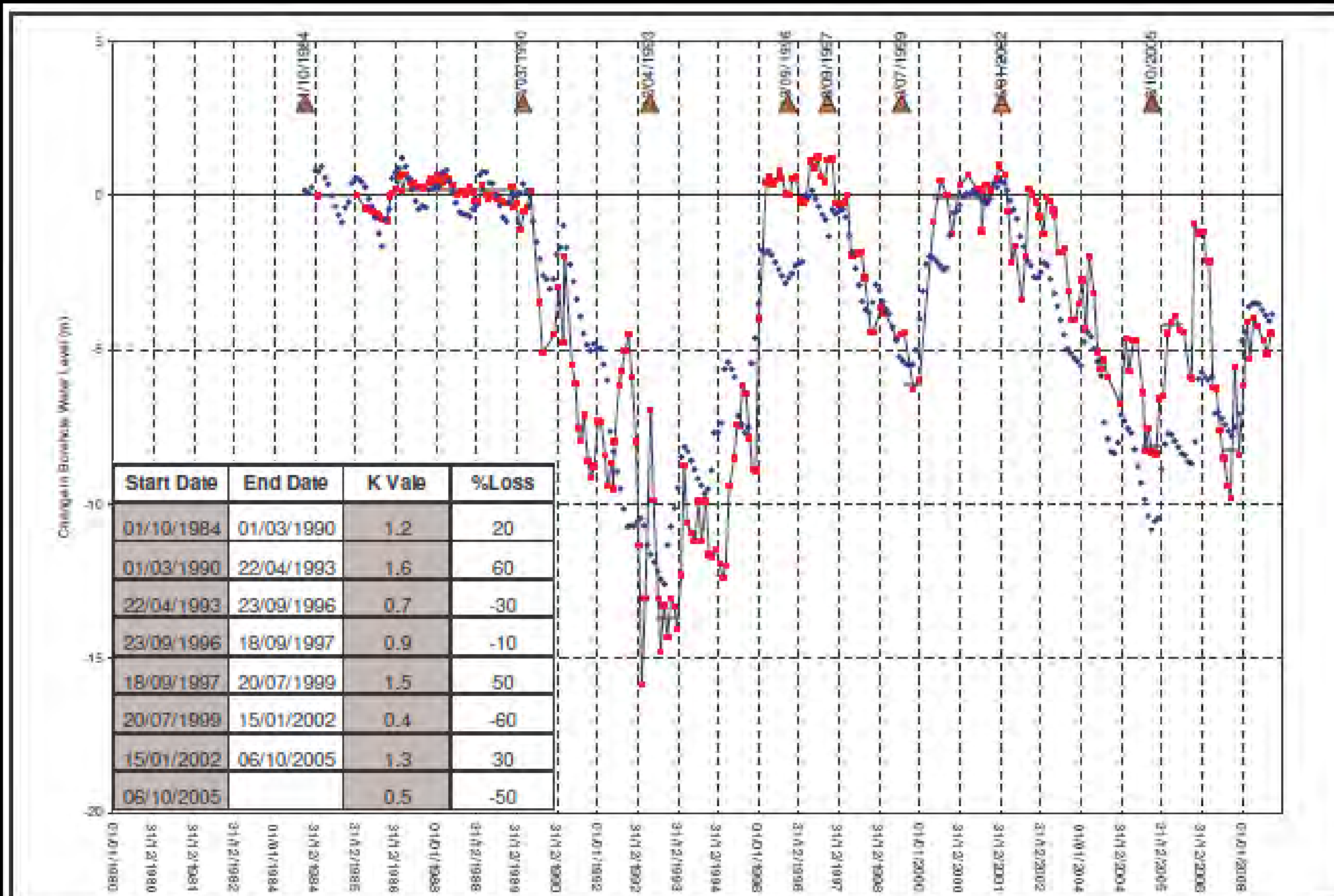
Combining and rearranging:

$$\Delta h_i = \left(\frac{r}{S}\right) \cdot \left[\sum_{n=1}^{i} R_n - K \sum_{n=1}^{i} R_{av}\right]$$

We have a relationship between water level and rainfall which includes ***K***

ARUP

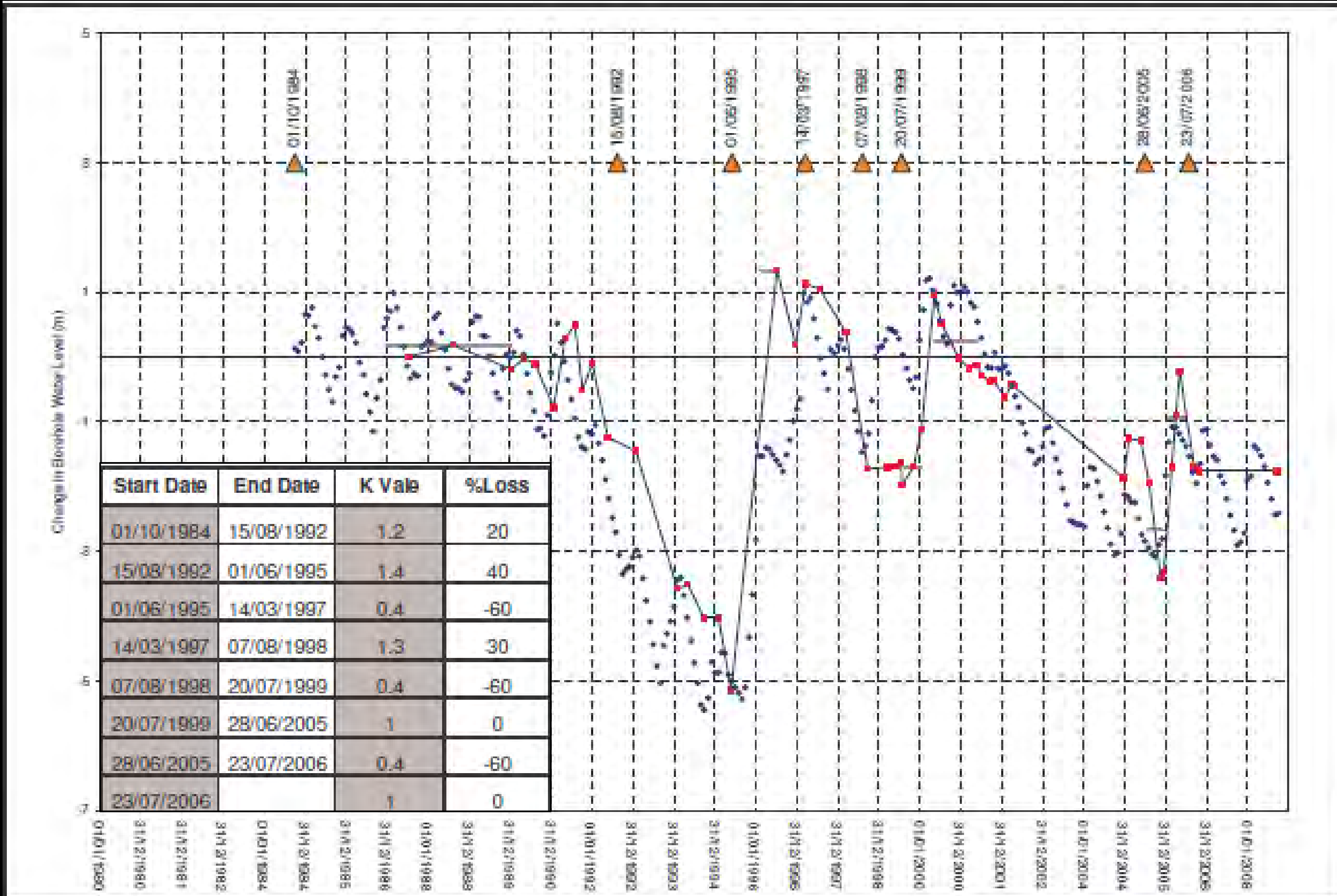
Well 13 – water levels generated by CRD



Start Date	End Date	K Vale	%Loss
01/10/1984	01/03/1990	1.2	20
01/03/1990	22/04/1993	1.6	60
22/04/1993	23/09/1996	0.7	-30
23/09/1996	18/09/1997	0.9	-10
18/09/1997	20/07/1999	1.5	50
20/07/1999	15/01/2002	0.4	-60
15/01/2002	06/10/2005	1.3	30
06/10/2005		0.5	-50

ARUP

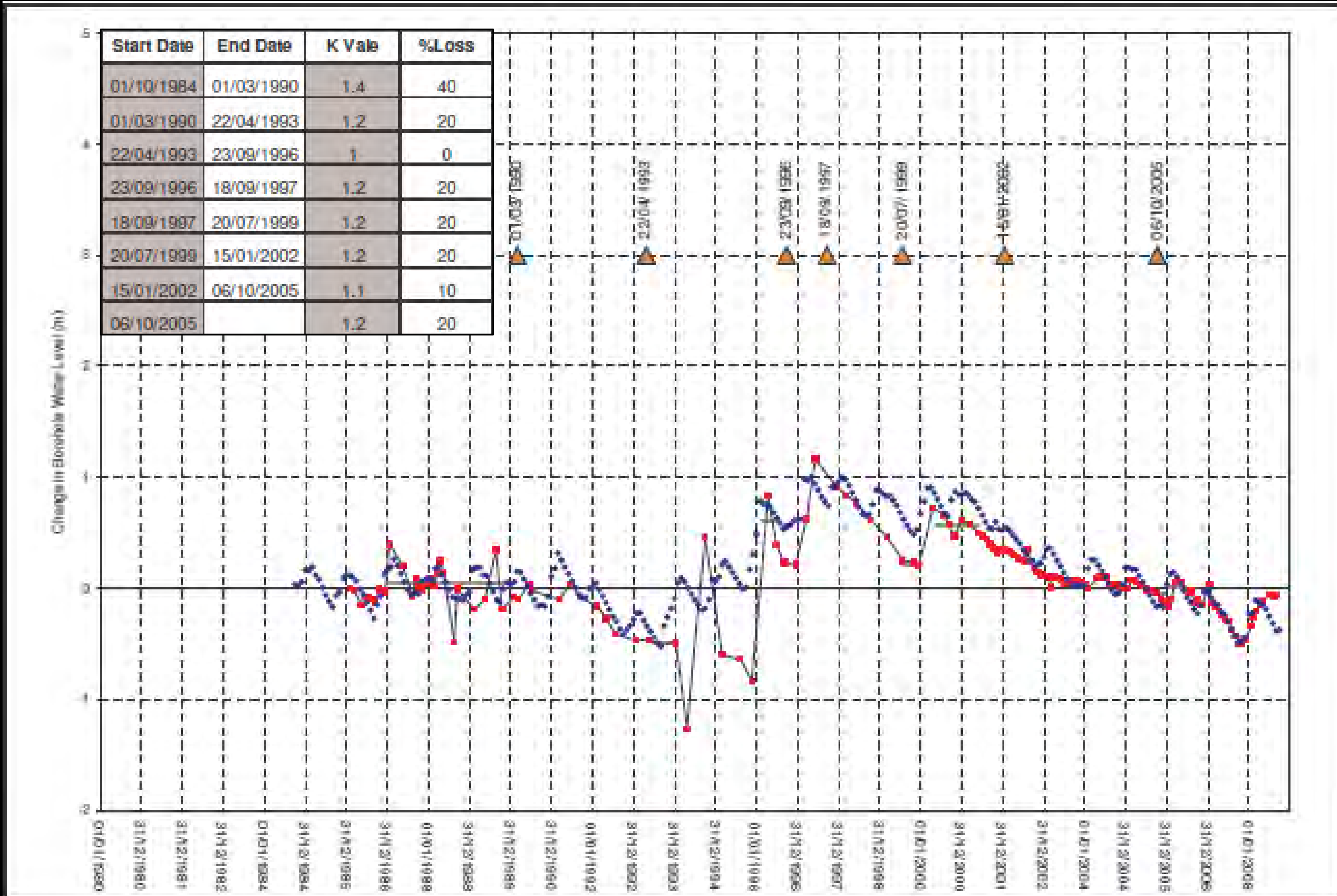
Well 64 – water levels generated by CRD



Start Date	End Date	K Vale	%Loss
01/10/1984	15/08/1992	1.2	20
15/08/1992	01/06/1995	1.4	40
01/06/1995	14/03/1997	0.4	-60
14/03/1997	07/08/1998	1.3	30
07/08/1998	20/07/1999	0.4	-60
20/07/1999	28/06/2005	1	0
28/06/2005	23/07/2006	0.4	-60
23/07/2006		1	0

ARUP

Well 24 – water levels generated by CRD



Start Date	End Date	K Vale	%Loss
01/10/1984	01/03/1990	1.4	40
01/03/1990	22/04/1993	1.2	20
22/04/1993	23/09/1996	1	0
23/09/1996	18/09/1997	1.2	20
18/09/1997	20/07/1999	1.2	20
20/07/1999	15/01/2002	1.2	20
15/01/2002	06/10/2005	1.1	10
06/10/2005		1.2	20

ARUP

Results

BH No.	Storativity %	Steady State K	Recharge as % of Rainfall	Pumping Max K	Pumping as % of Rainfall	Recovery Max K	Recovery as % of Rainfall
13	Varies with depth 10 to 6%	1.2	20%	1.6	200%	0.7	300%
64	10	1.2	20%	1.4	100%	0.4	600%
24	40	1.2 - 1.4	20 to 40%				

- Estimates of storativity and its variation with depth
- Steady state K value gives recharge estimate as a proportion of rainfall
- Pumping phase K gives estimate of pumping as a proportion of recharge
- Not sure what recovery phase K indicates – proximity to pumping?

ARUP

Conclusions

The results indicate that the:

- **aquifer storativity is in the range 5 to 40% which may be uniform or decrease with depth.**
- **Recharge is approximately 20% of the monthly average rainfall (50mm/month).**
- **Pumping takes place at a rate in excess of 2 to 3 times the recharge**

Thank you