Ground-water response to interannual and interdecadal climate variability, High Plains aquifer

science for a changing world

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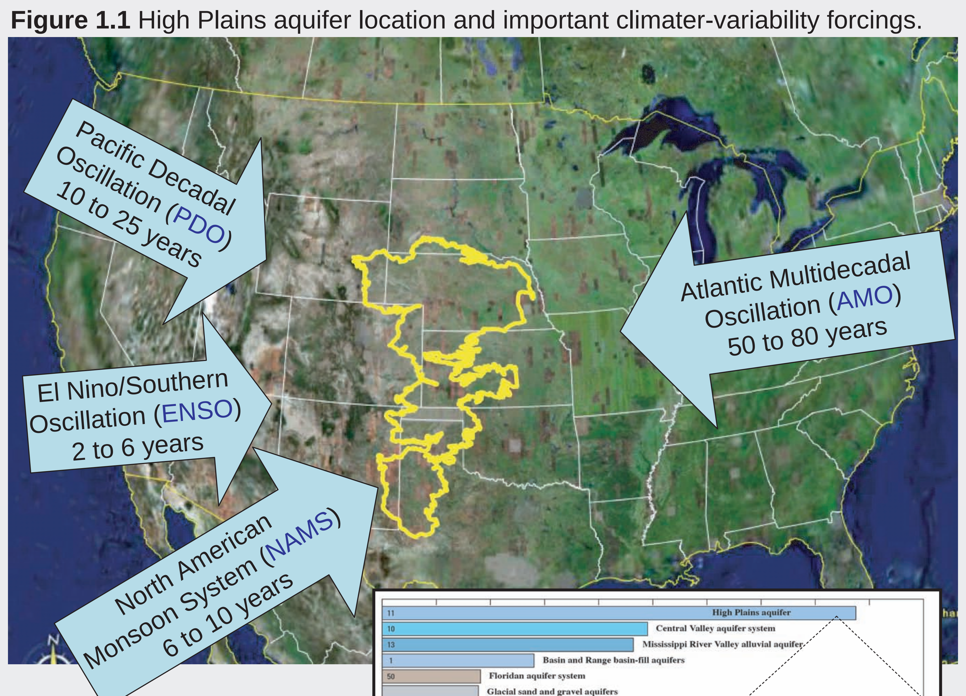
1.0 Introduction - Motivation and Study Objectives

The High Plains aquifer is an important regional system that supports approximately 30% of irrigated agriculture in the U.S. Sustainability of the aquifer is in question because of ground-water mining and limited recharge in this semi-arid climate. Natural climate variability on interannual to interdecadeal time scales can play a crucial role in the quantity and quality of ground-water, and thus, successful management of this ground-water resource. Recent research has identified interactions between interannual and interdecadal climate cycles that produce a cumulative climate variability that directly affects the distribution of precipitation and, in turn, stream discharge. Ground water can respond dramatically when climate variability cycles lie coincident in a positive (wet) or negative (dry) phase of variability. Preliminary results indicate variability in the ground-water level records attributed to the primary interannual to interdecadal climate cycles of the western US. These cycles include El Nino/southern Oscillation (ENSO) (2 to 6 years), North American Monsoon System (NAMS) (6 to 10 years), Pacific Decadal Oscillation (PDO) (10 to 25 years), and Atlantic Multidecadal Oscillation (AMO) (50 to 80 years). The study objectives are to better understand past linkages between climate variability and responses in the unsaturated zone and ground-water levels using available hydrologic time-series. This understanding is the foundation for realistic predictions of aquifer response under future climate variability and improved projections of the consequences of resource decisions on ground-water availability and quality.

Figure 1.1 High Plains aquifer location and important climater-variability forcings.



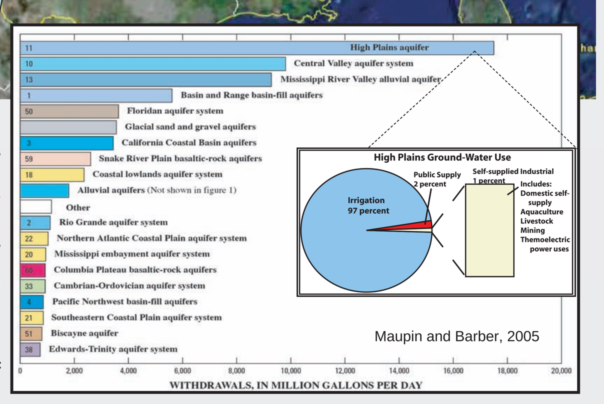


Figure 1.2 Ground-water response to complex climate variability has particular relevance for aquifers close to the limits of sustainability, because even marginal changes in supply and demand are of great importance.

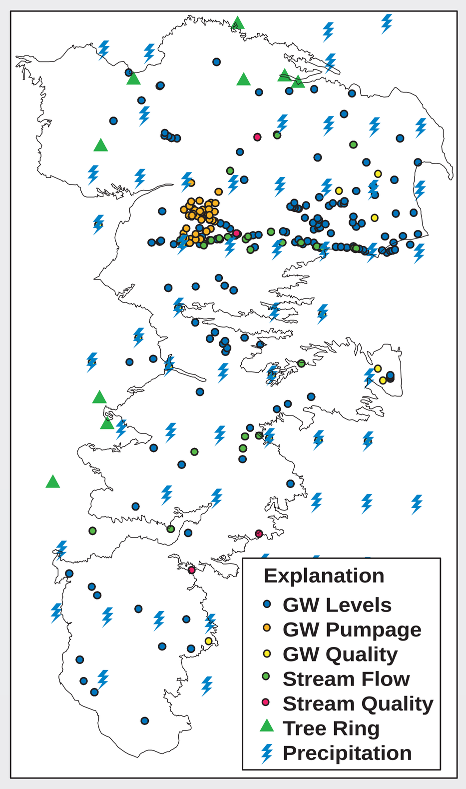


Figure 1.3 Location of long-term hydrologic time-series used during climate variability analysis.

2.0 Unsaturated Zone Response to Natural Climate Variability

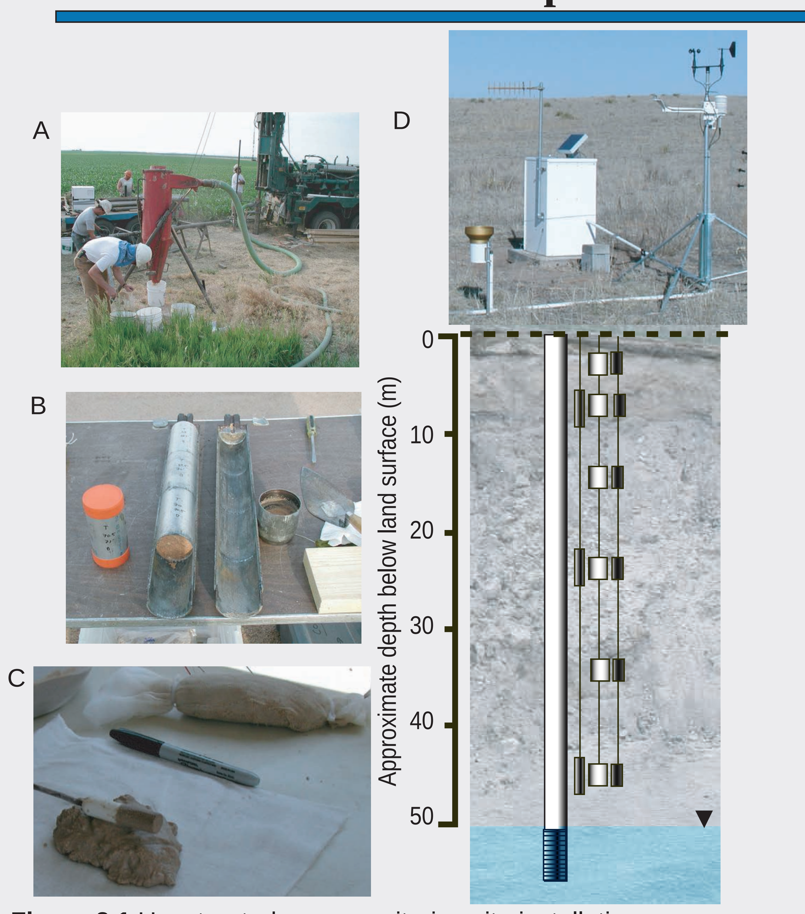


Figure 2.1 Unsaturated zone monitoring site installation:
A. Casing-advance, dry-drilling technology.
B. Collect cores for water content, chemical, and physical analyses.
C. Heat dissipation probe (HDP) preparation.
D. Final installation, includes HDP, lysimeters, gas sampling ports, monitoring well, weather stations, and remote data storage and transmission to office.

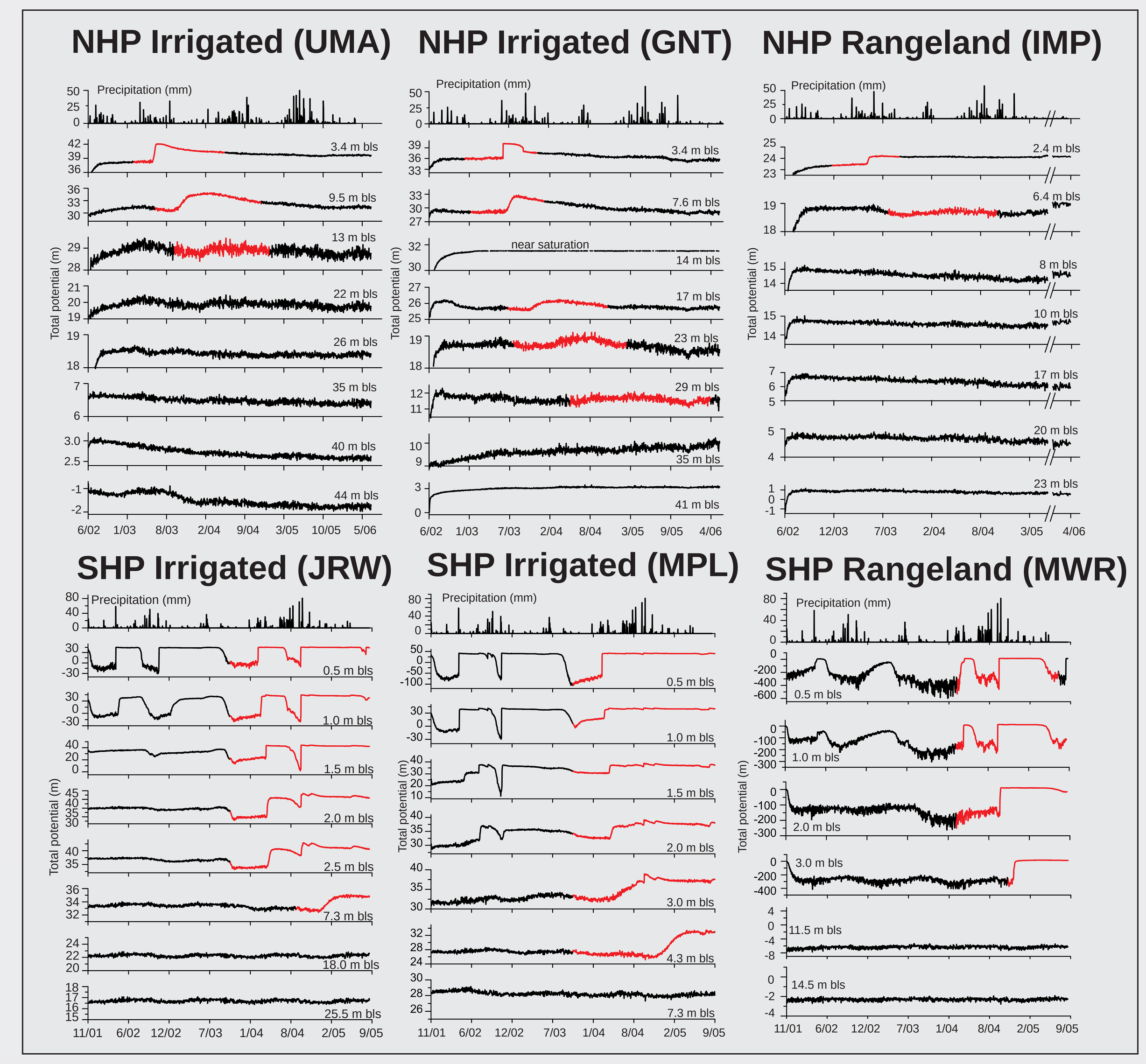


Figure 2.2 Daily precipitation and total potential profiles indicate deep percolation events beneath NHP sites in 2003 and beneath SHP sites in 2004.

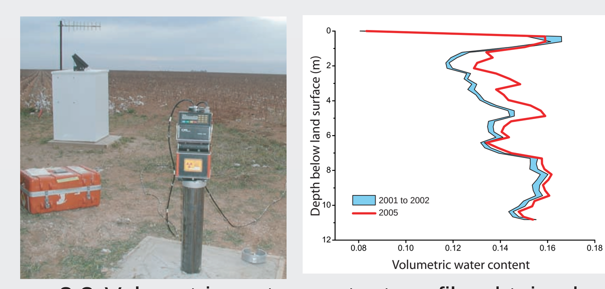


Figure 2.3 Volumetric water content profile obtained using neutron moisture meter indicates a 75-mm increase in water storage in 2005 compared to 2001-2002 range in volumetric water content at the SHP Rangeland site.

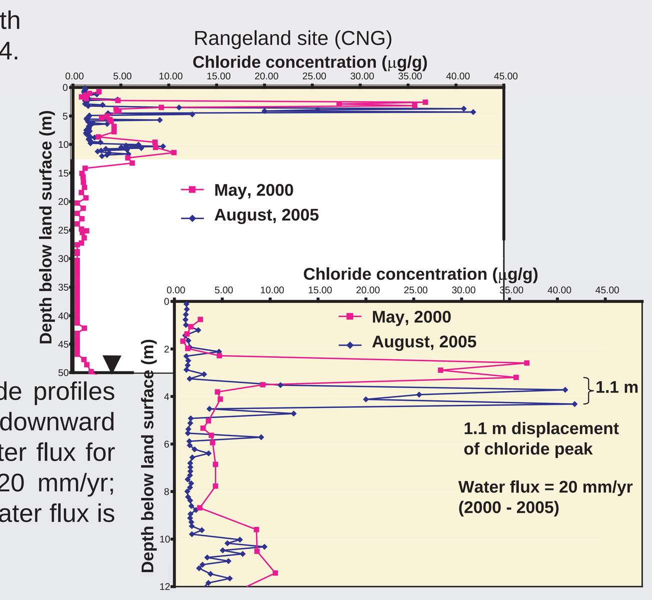


Figure 2.4 Chloride profiles indicate a 1.1 m downward displacement. Water flux for 2000 to 2005 is 20 mm/yr; long-term mean water flux is 5 mm/yr.

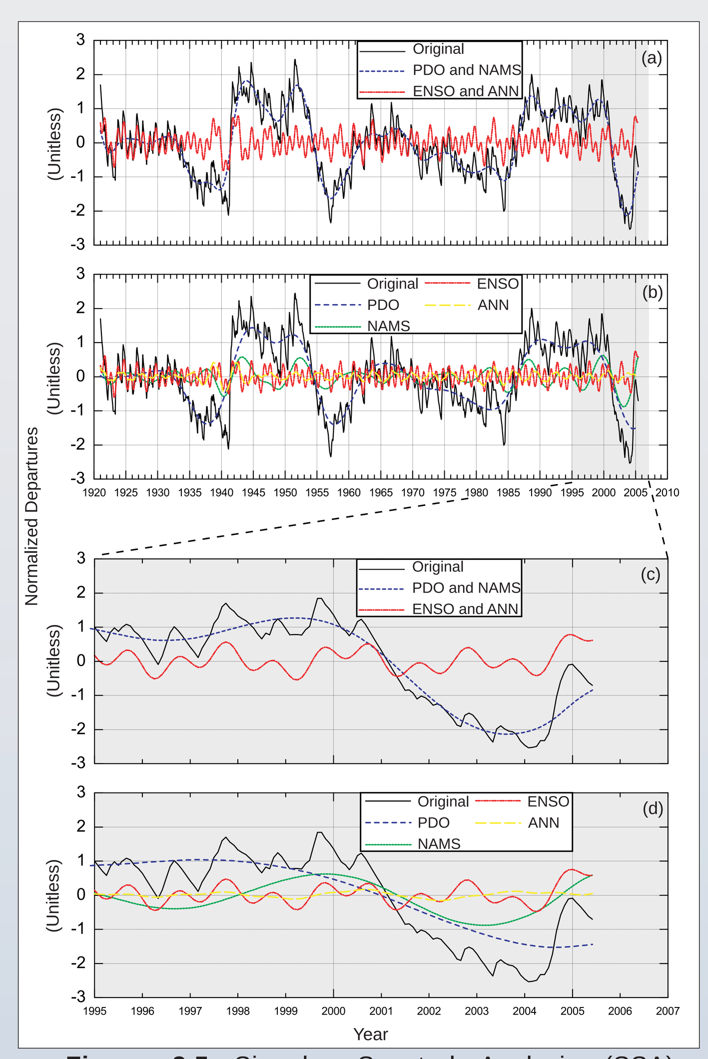


Figure 2.5 Singular Spectral Analysis (SSA) reconstructed components for long-term precipitation time series at SHP rangeland unsaturated zone

Conceptual Model of Water and Chemical Flux

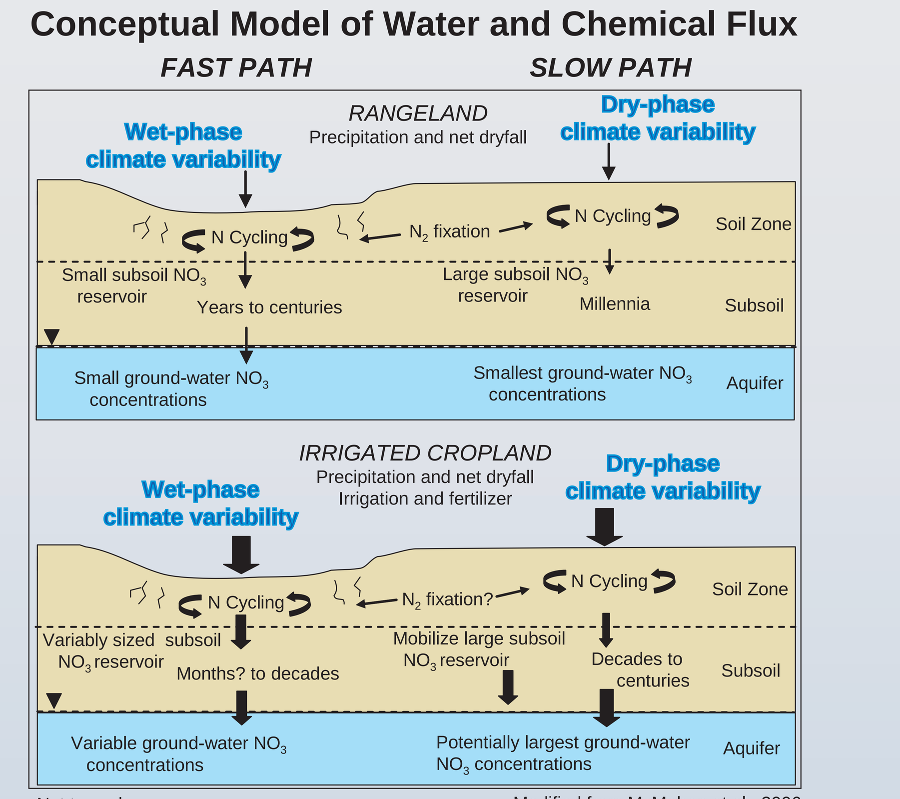


Figure 2.6 Climate variability represents another important component of the conceptual model for recharge and advective chemical transport to the water table of the High Plains aquifer.

3.0 Ground-Water Response to Natural Climate Variability

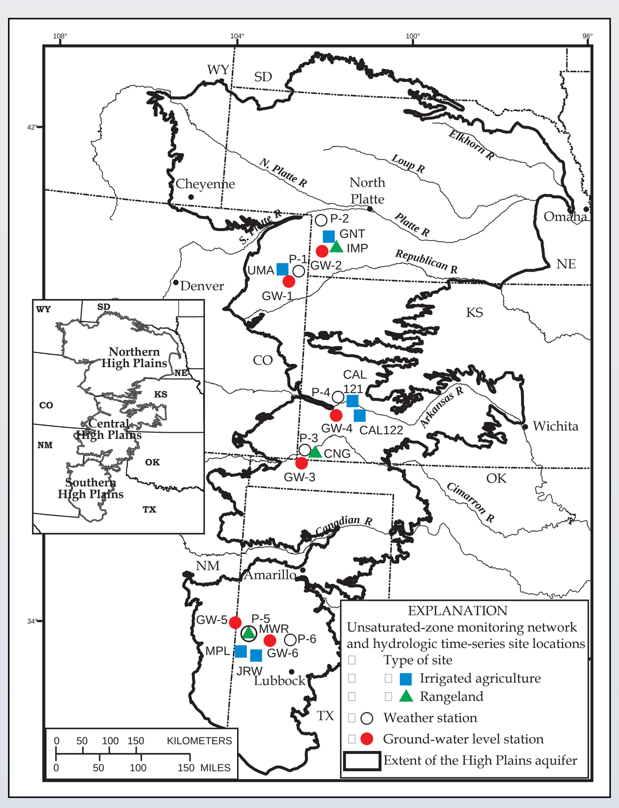


Figure 3.1 Site locations.

Dependent Hydrologic Time-Series	Subregion	PDO cycles (10-25 yrs) Lag Correlation	PDO cycles Phase lag (years)	NAMS cycles (6-10 yrs) Lag Correlation	NAMS cycles Phase lag (years)	ENSO cycles (2-6 yrs) Lag Correlation	ENSO cycles Phase lag (years)	Annual (ANN) (<2 yrs) Lag Correlation	Annual (ANN) Phase lag (years)
		(1) PDO index	(1) PDO index			(1) MEI	(1) MEI		
		(2) P-1	(2) P-1	(2) P-1	(2) P-1	(2) P-1	(2) P-1	(2) P-1	(2) P-1
		(3) P-2	(3) P-2	(3) P-2	(3) P-2	(3) P-2	(3) P-2	(3) P-2	(3) P-2
		(4) P-3	(4) P-3	(4) P-3	(4) P-3	(4) P-3	(4) P-3	(4) P-3	(4) P-3
		(5) P-4	(5) P-4	(5) P-4	(5) P-4	(5) P-4	(5) P-4	(5) P-4	(5) P-4
		(6) P-5	(6) P-5	(6) P-5	(6) P-5	(6) P-5	(6) P-5	(6) P-5	(6) P-5
		(7) P-6	(7) P-6	(7) P-6	(7) P-6	(7) P-6	(7) P-6	(7) P-6	(7) P-6
						(10) Pump	(10) Pump	(10) Pump	(10) Pump
Precipitation									
P-1	NHP	(1) 0.34	(1) 4.2			(1) 0.77	(1) -25		
P-2	NHP	(1) 0.27	(1) 3.6			(1) 0.41	(1) -21		
P-3	CHP	(1) 0.67	(1) 5.0			(1) 0.41	(1) -18		
P-4	CHP	(1) 0.41	(1) 4.6			(1) 0.64	(1) -29		
P-5	SHP	(1) 0.83	(1) -11			(1) 0.37	(1) -5.8		
P-6	SHP	(1) 0.82	(1) 1.8			(1) 0.36	(1) 15		
Ground-Water Levels									
GW-1	NHP	(1) 0.90	(1) -25			(1) 0.85	(1) 29		
		(2) 0.92	(2) -25	(2) 0.84	(2) -29	(2) 0.58	(2) 29	(2) 0.43	(2) -28
GW-2	NHP	(1) 0.82	(1) -24			(1) 0.47	(1) -21		
		(3) 0.67	(3) 23			(3) 0.32	(3) 15	(3) 0.28	(3) -28
						(10) 0.99	(10) -23	(10) 0.95	(10) -23
GW-3	CHP	(1) 0.51	(1) -10			(1) 0.71	(1) -28		
		(4) 0.32	(4) 1.6	(4) 0.63	(4) -21	(4) 0.53	(4) 17	(4) 0.04	(4) -16
GW-4	CHP	(1) 0.31	(1) 14			(1) 0.51	(1) 18		
		(5) 0.58	(5) -20	(5) 0.02	(5) 29	(5) 0.44	(5) 18	(5) 0.70	(5) -25
GW-5	SHP	(1) 0.93	(1) -23			(1) 0.41	(1) -10		
		(6) 0.87	(6) -26			(6) 0.40	(6) -30	(6) 0.15	(6) 18
GW-6	SHP	(1) 0.90	(1) 29			(1) 0.47	(1) -28		
		(7) 0.99	(7) 27			(7) 0.37	(7) 26	(7) 0.34	(7) 27
Ground-Water Pumpage									
Pump	NHP					(1) 0.99	(1) -22		
				(2) 0.99	(2) 22	(2) 0.99	(2) 23	(2) 0.98	(2) 22

Figure 3.3 Strong correlations observed for paired ground-water level and precipitation stations across the High Plains aquifer. Phase-lags may approximate unsaturated-zone traveltimes.

Data Type	Northern High Plains P-1	GW-1	P-2	GW-2	Pump	Central High Plains P-3	GW-3	P-4	GW-4	Southern High Plains P-5	GW-5	P-6	GW-6
Reconstructed Component	Period, in years (Percent Variance)												
1	38.0 (64.2)	12.8 (67.0)	32.6 (51.4)	20.8 (64.2)	6.7 (48.8)	20.8 (53.6)	11.1 (35.3)	28.8 (51.6)	18.5 (23.3)	21.1 (40.0)	20.8 (78.4)	38.3 (53.5)	18.5 (73.8)
2	22.8 (24.5)	6.4 (27.3)	16.3 (28.1)	11.1 (22.8)	3.5 (37.2)	15.2 (29.9)	8.3 (32.0)	17.7 (31.0)	6.9 (12.6)	13.0 (28.6	11.1 (17.2)	19.2 (28.9)	11.9 (19.8)
3	10.4 (4.52)	3.3 (4.04)	9.9 (7.78)	5.4 (4.04)	2.0 (10.5)	7.2 (6.79)	4.3 (13.2)	10.5 (8.35)	4.5 (9.23)	7.0 (10.7)	4.6 (1.70)	11.0 (6.77)	4.4 (1.71)
4	7.6 (1.75)	2.4 (1.23)	7.1 (2.76)	3.6 (2.64)	1.4 (2.71)	5.2 (1.91)	3.6 (9.12)	7.7 (1.85)	3.2 (7.23)	5.5 (4.89)	3.4 (0.82)	7.7 (2.09)	3.2 (0.62)
5	5.7 (0.84)	1.8 (0.28)	5.7 (1.75)	2.8 (2.39)	1.1 (0.61)	1.0 (1.36)	2.7 (2.86)	1.0 (1.11)	2.6 (5.46)	1.0 (2.37)	2.4 (0.42)	6.1 (1.65)	2.3 (0.43)
6	1.0 (0.71)	1.5 (0.11)	1.0 (1.69)	2.3 (1.55)	0.9 (0.14)	1.0 (1.34)	2.2 (1.35)	1.0 (1.10)	1.0 (4.78)	1.0 (2.22)	2.0 (0.34)	4.9 (1.26)	1.9 (0.35)
7	1.0 (0.70)	1.2 (0.04)	1.0 (1.41)	2.0 (0.46)	0.7 (0.03)	3.8 (1.04)	2.0 (1.11)	5.9 (0.80)	1.0 (4.74)	3.3 (2.08)	1.6 (0.25)	4.1 (0.83)	1.0 (0.19)
8	4.6 (0.60)	1.0 (<0.01)	4.5 (1.00)	1.7 (0.27)	0.6 (<0.01)	3.1 (0.84)	1.3 (0.75)	4.7 (0.51)	2.0 (4.14)	3.1 (1.90)	1.4 (0.19)	1.0 (0.79)	1.0 (0.18)
9	3.7 (0.40)	0.9 (<0.01)	3.8 (0.84)	1.1 (0.26)	0.6 (<0.01)	2.6 (0.67)	1.5 (0.73)	2.6 (0.48)	1.7 (3.81)	2.5 (1.71)	1.2 (0.14)	1.0 (0.71)	0.7 (0.17)
10	3.2 (0.32)	0.8 (<0.01)	3.2 (0.56)	1.1 (0.25)	0.5 (<0.01)	2.2 (0.42)	1.7 (0.55)	2.6 (0.41)	1.5 (3.45)	2.3 (1.09)	1.1 (0.09)	3.6 (0.51)	0.7 (0.17)

Figure 3.2 Summary of frequency and variance for ground-water level and precipitation stations. >PDO = darker shaded cells; PDO = lighter shaded cells; NAMS cycle = thicker bounded cells; ENSO = thinner bounded cells, and annual variability (ANN) = white cells.

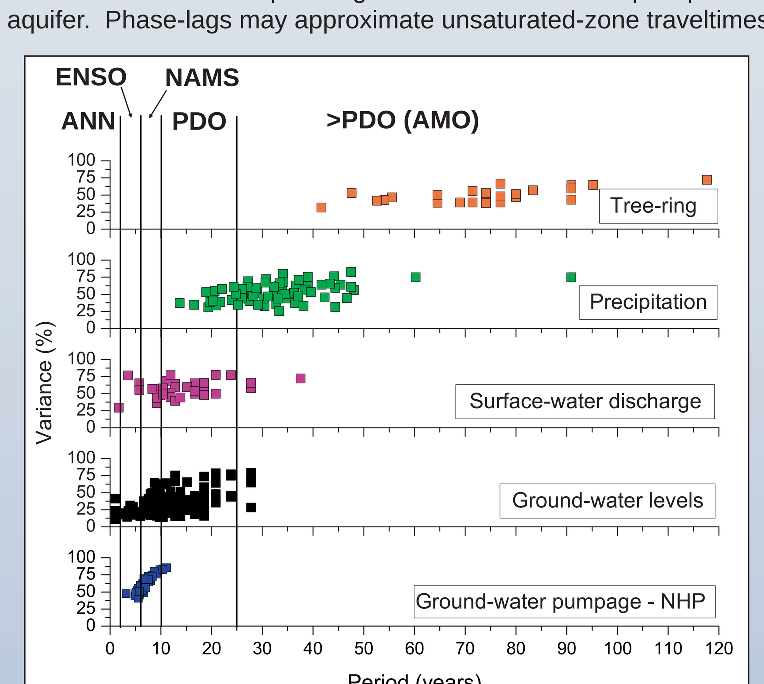
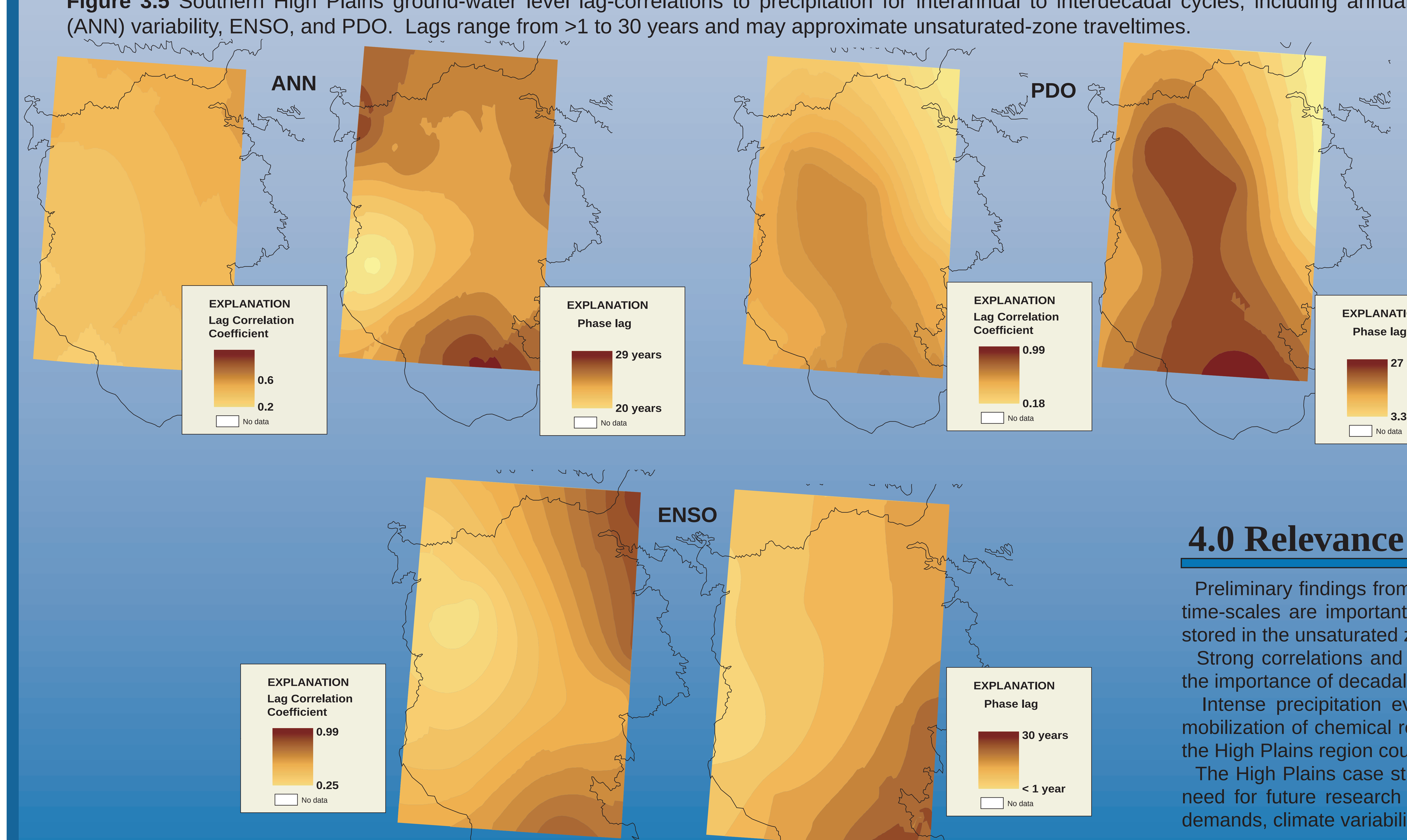


Figure 3.4 Frequency and variance trends observed across all hydrologic time-series.

Figure 3.5 Southern High Plains ground-water level lag-correlations to precipitation for interannual to interdecadal cycles, including annual (ANN) variability, ENSO, and PDO. Lags range from >1 to 30 years and may approximate unsaturated-zone traveltimes.



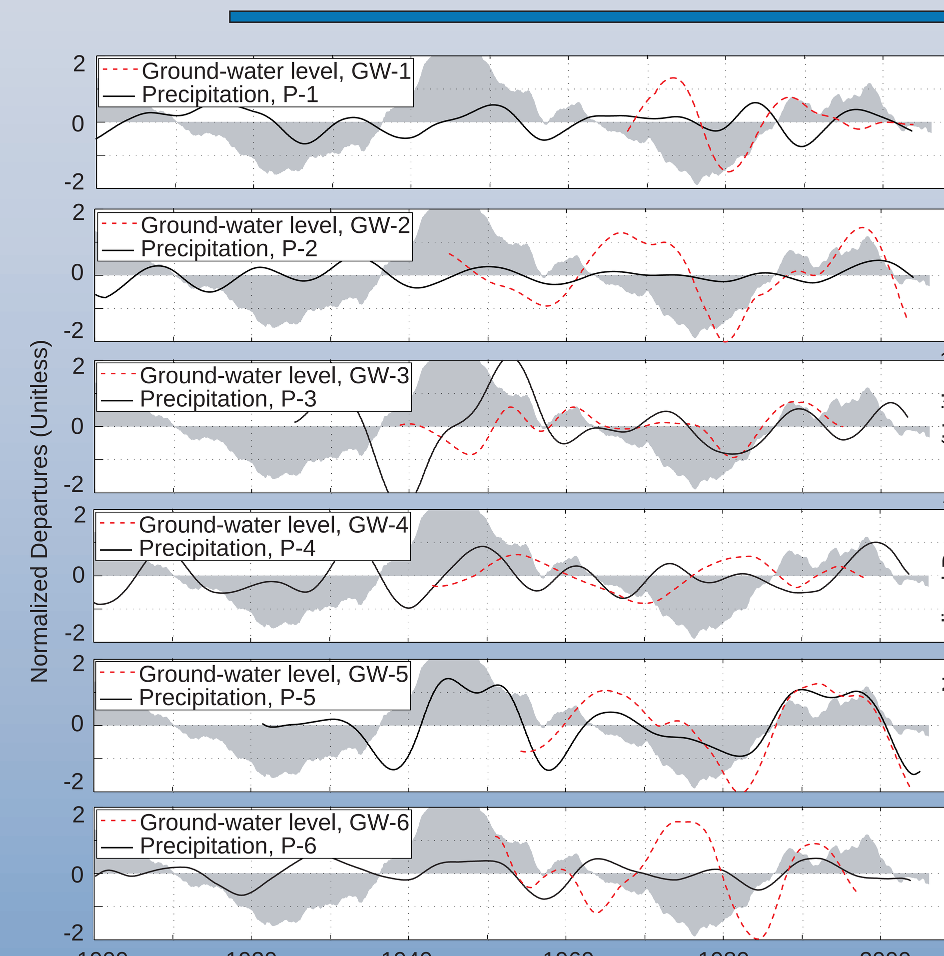


Figure 3.6 Reconstructed components for paired ground-water level and precipitation sites for PDO-range cycles (10- 25 years) for the High Plains.

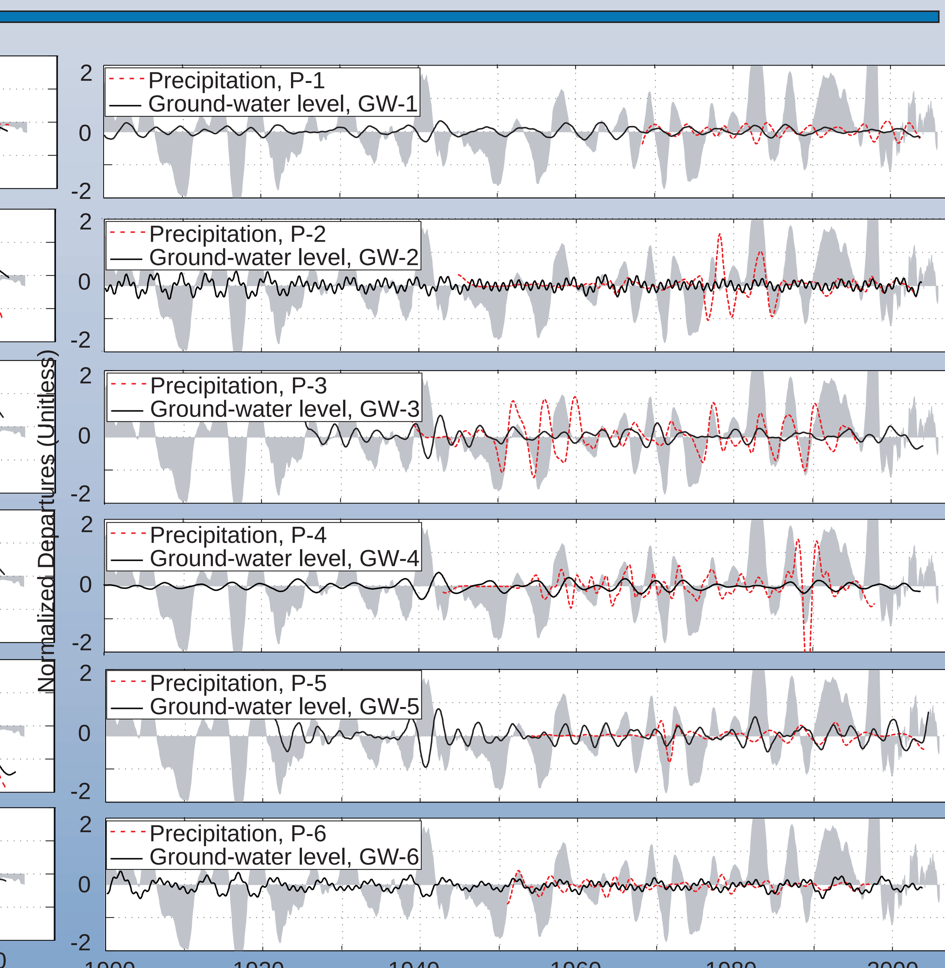


Figure 3.7 Reconstructed components for paired ground-water level and precipitation sites for ENSO-range cycles (2-6 years) for the High Plains.

4.0 Relevance and Benefits

Preliminary findings from this work-in-progress indicate that climate variability on interannaual to interdecadal time-scales are important forcings on ground-water levels, recharge, and mobilization of chemical reservoirs stored in the unsaturated zone of the High Plains aquifer.

Strong correlations and large variation in the ground-water level records due to PDO-like variability indicate the importance of decadal-long climate perspective on ground-water resource management.

Intense precipitation events, linked to annual climate variability, are important controls on recharge and mobilization of chemical reservoirs. Global climate change predictions of more intense precipitation events for the High Plains region could results in these episodic recharge and chemical mobilization events.

The High Plains case study illustrates the relevance of climate variability on ground-water resources and the need for future research aimed at better understanding and predicting ground-water response under future demands, climate variability, and possible climate change.

Questions

For additional information, please visit our homepage at
http://co.water.usgs.gov/nawqa/hpgw/index.html

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