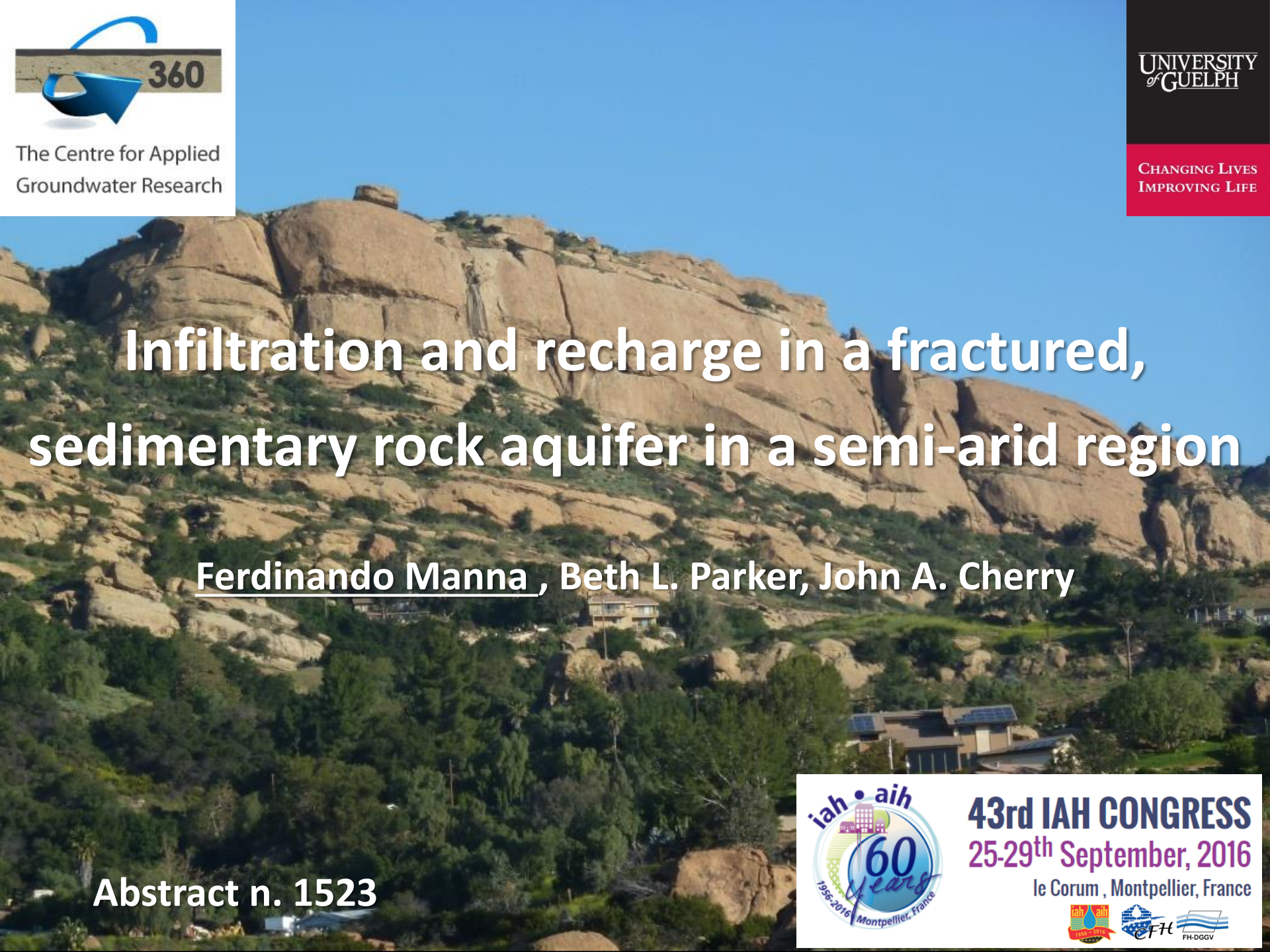

The Centre for Applied Groundwater Research

UNIVERSITY of GUELPH

CHANGING LIVES IMPROVING LIFE

Infiltration and recharge in a fractured, sedimentary rock aquifer in a semi-arid region

Ferdinando Manna , Beth L. Parker, John A. Cherry

Abstract n. 1523

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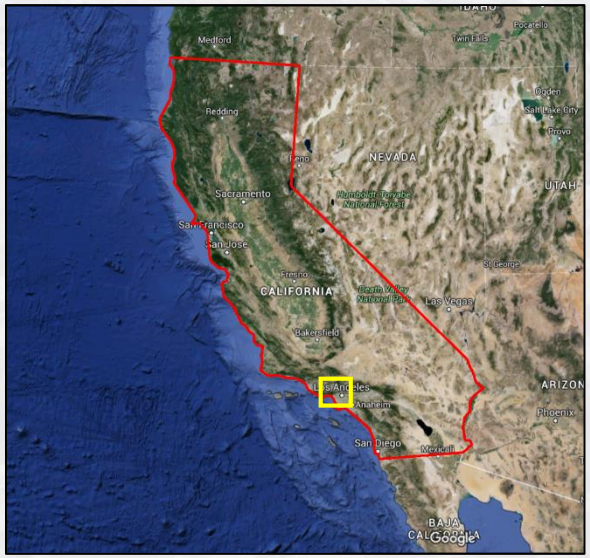
Study area

Santa Susana Field Laboratory (SSFL)

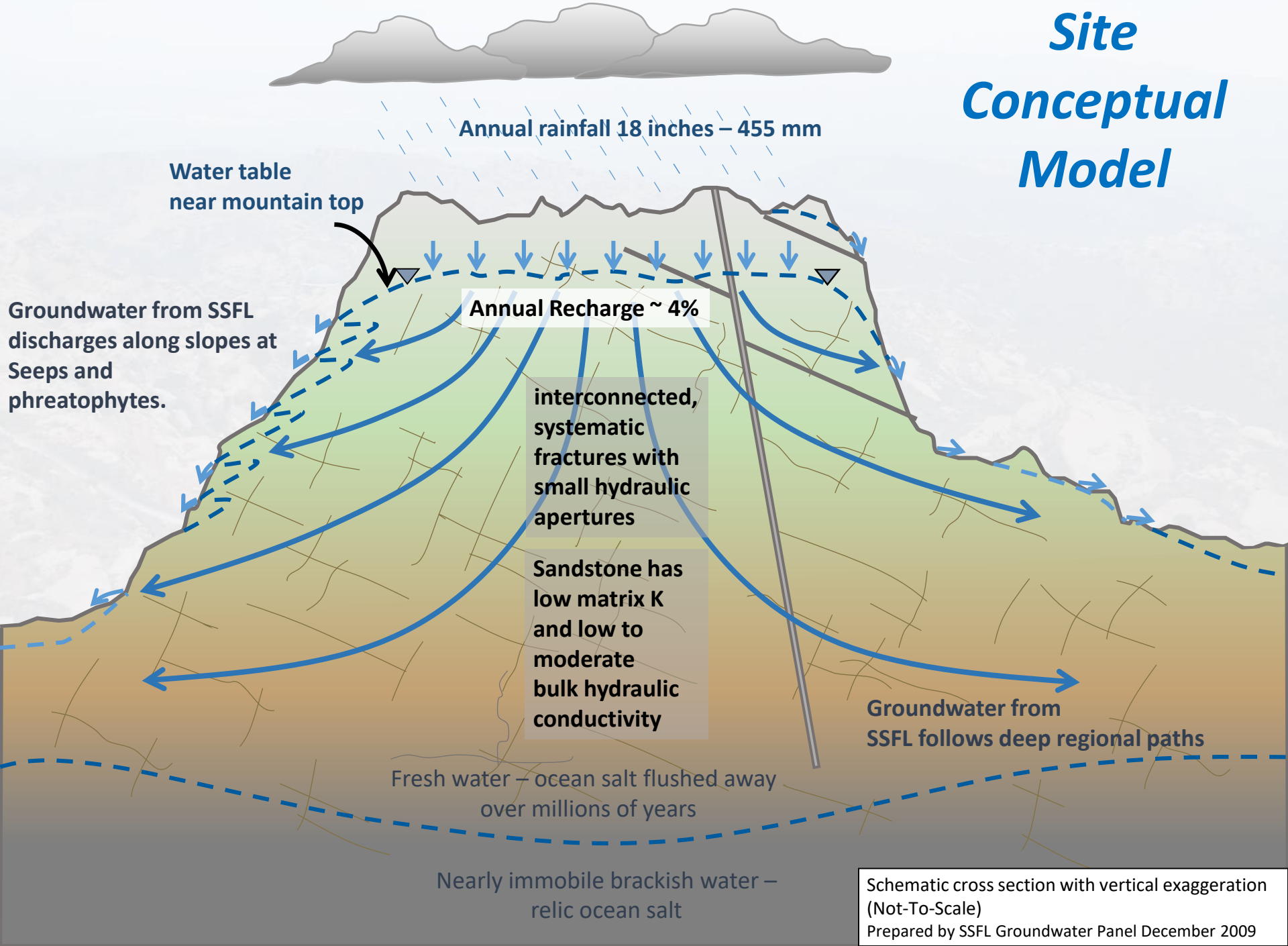


Located on an upland flat-topped ridge in a semi-arid region where PET (1500 mm) >> P (455 mm)

The Chatsworth formation

- It is a sequence of coarser- (sandstone) and finer (siltstone and shale)-grained units
- It is the result of a turbidite deposition on a sub-marine fan (*Link et al., 1981*)
- It is densely fractured with bedding-parallel fractures as well as vertical or near-vertical joints and faults

Site Conceptual Model



Schematic cross section with vertical exaggeration (Not-To-Scale)
Prepared by SSFL Groundwater Panel December 2009

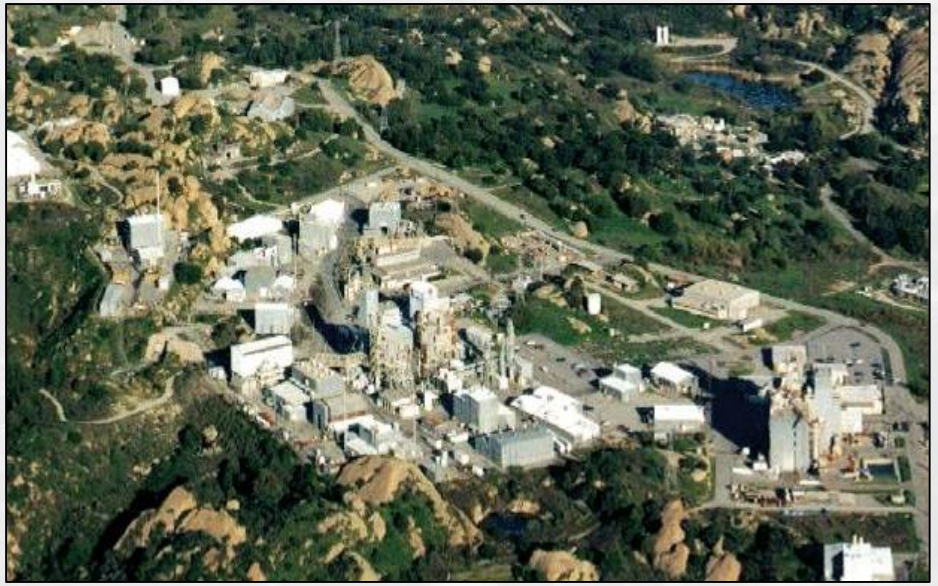
Two Primary Functions at SSFL

Rocket Engine Testing for NASA

- 1949-2006
- Six Test Stands – 17,000 Rocket Engine & Component Tests
- Last test March 3, 2006

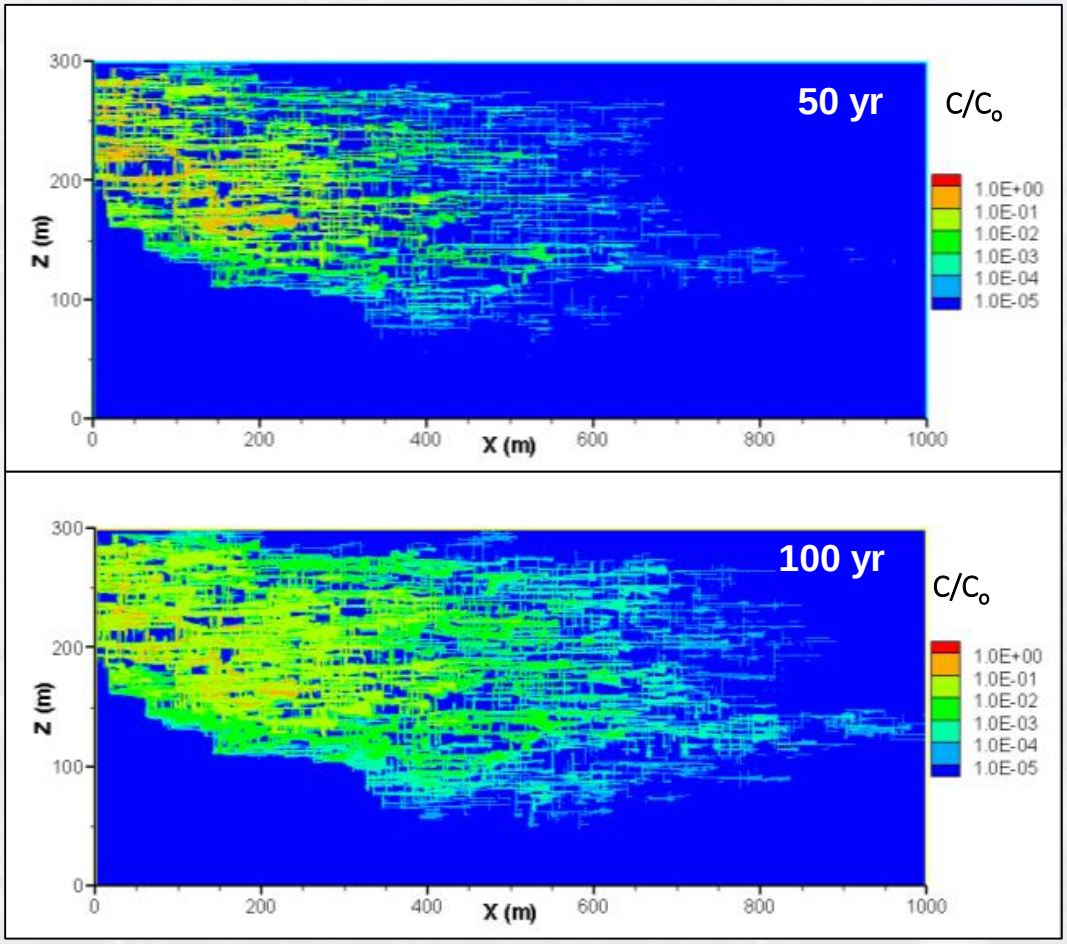
Nuclear Research & Liquid Metal Research for DOE

- Nuclear Power Research: 1956-1983
- Ten reactors
- Sodium component test facilities
- DOE Program ends 1988



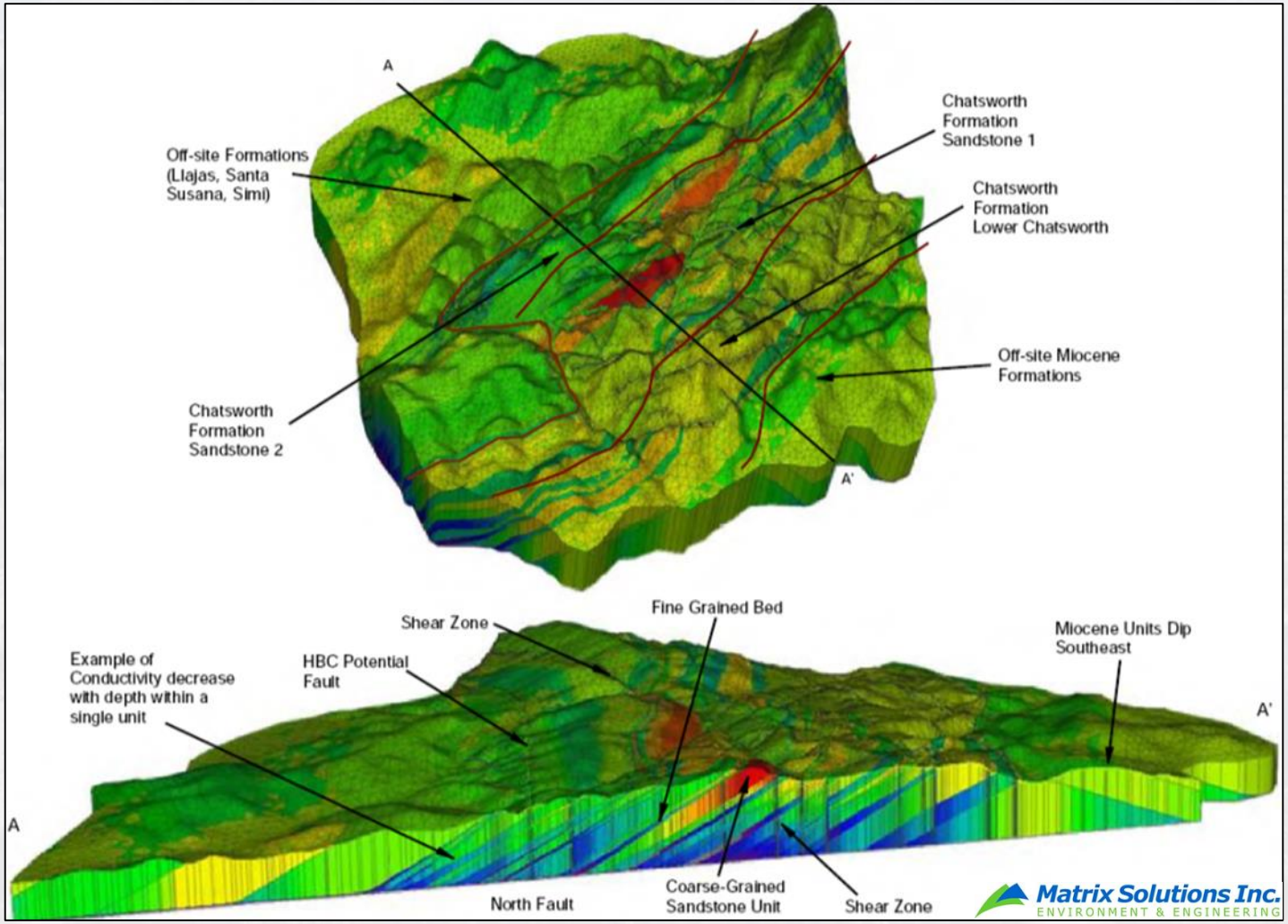
Why do we study groundwater recharge?

1. Recharge rate in the area of contaminants input, governs the flux of groundwater available to transport contaminants in plumes from the site to off-site receptors



Why do we study groundwater recharge?

2. Recharge values across the site are required as a boundary condition on the upper surface of the 3-D groundwater flow model domain



Objectives of the study

1) Estimate the groundwater recharge

2) Analyze the spatial and temporal variability of the recharge

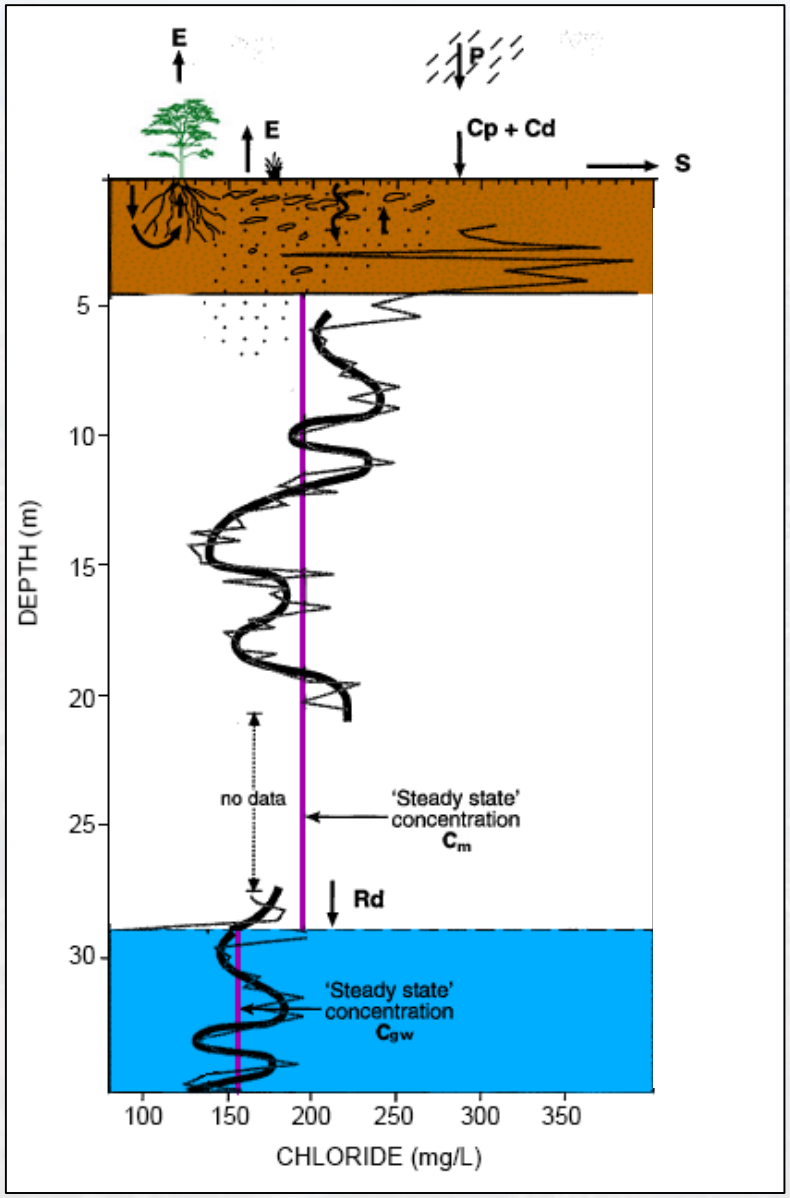
3) Understand the mechanisms of recharge

4) Analyze the effect of past environmental changes on the recharge

5) Estimate the travel times in the unsaturated zone

Chloride Mass Balance

(mod. from Edmunds, 1994)



Recharge estimation

$$R = \frac{C_a}{C_{gw}} \times P$$

Contribution of the two flow components

$$R_m = \frac{C_m}{C_{gw}} \qquad R_{pr} = 1 - R_m = \frac{\left(C_m - C_{gw}\right)}{C_m}$$

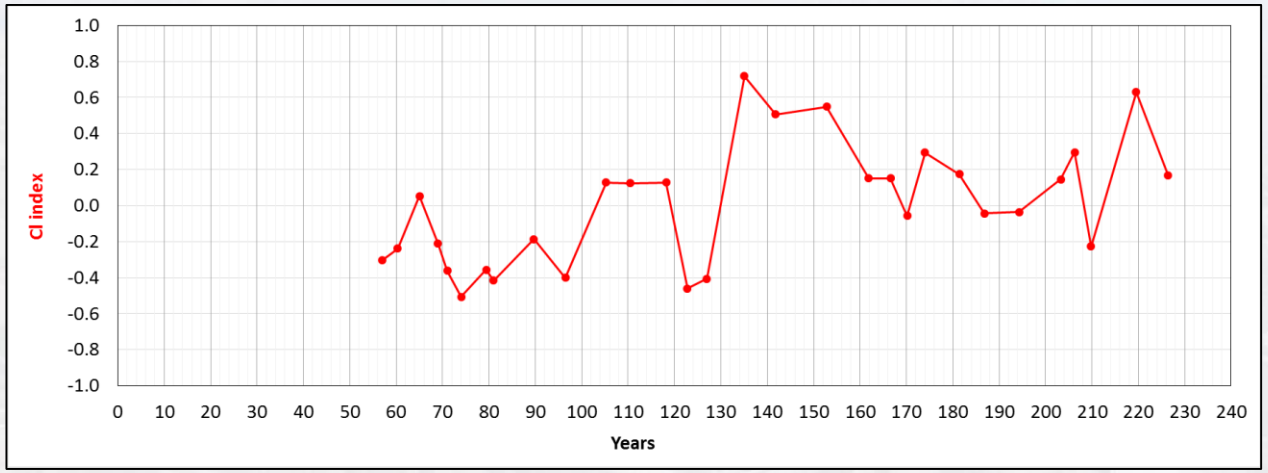
Time needed to accumulate Cl

$$t_z = \frac{\sum_{0}^{z} C_m \times \Theta}{\left(C_a \times P\right)} \times R_m$$

Vertical displacement rate

$$D = \frac{t_z}{z}$$

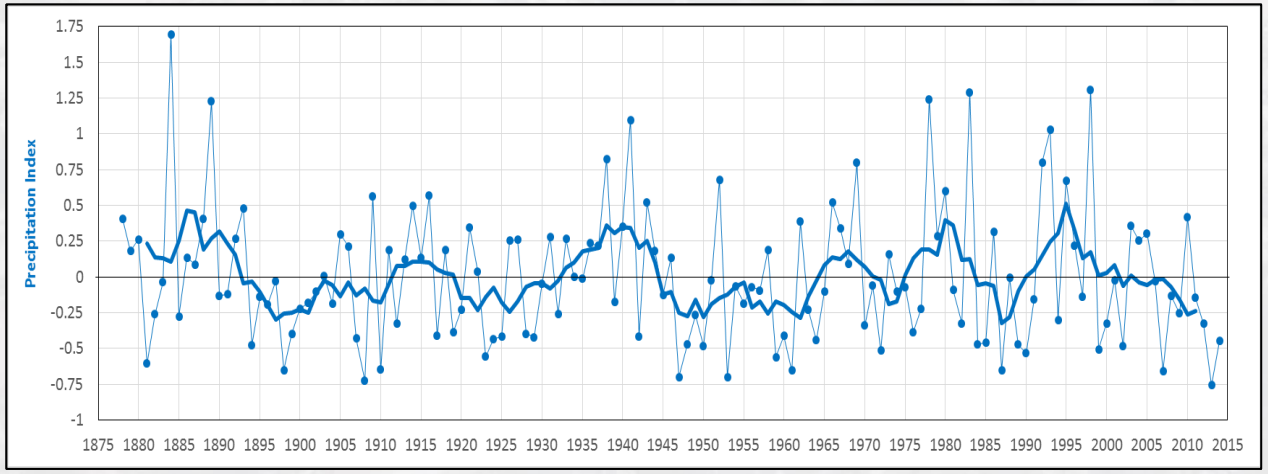
Cl Index and precipitation index



$$I_C = \frac{C_z - C}{C}$$

C_z: chloride concentration at the z depth

C: average Cl concentration in the unsaturated zone

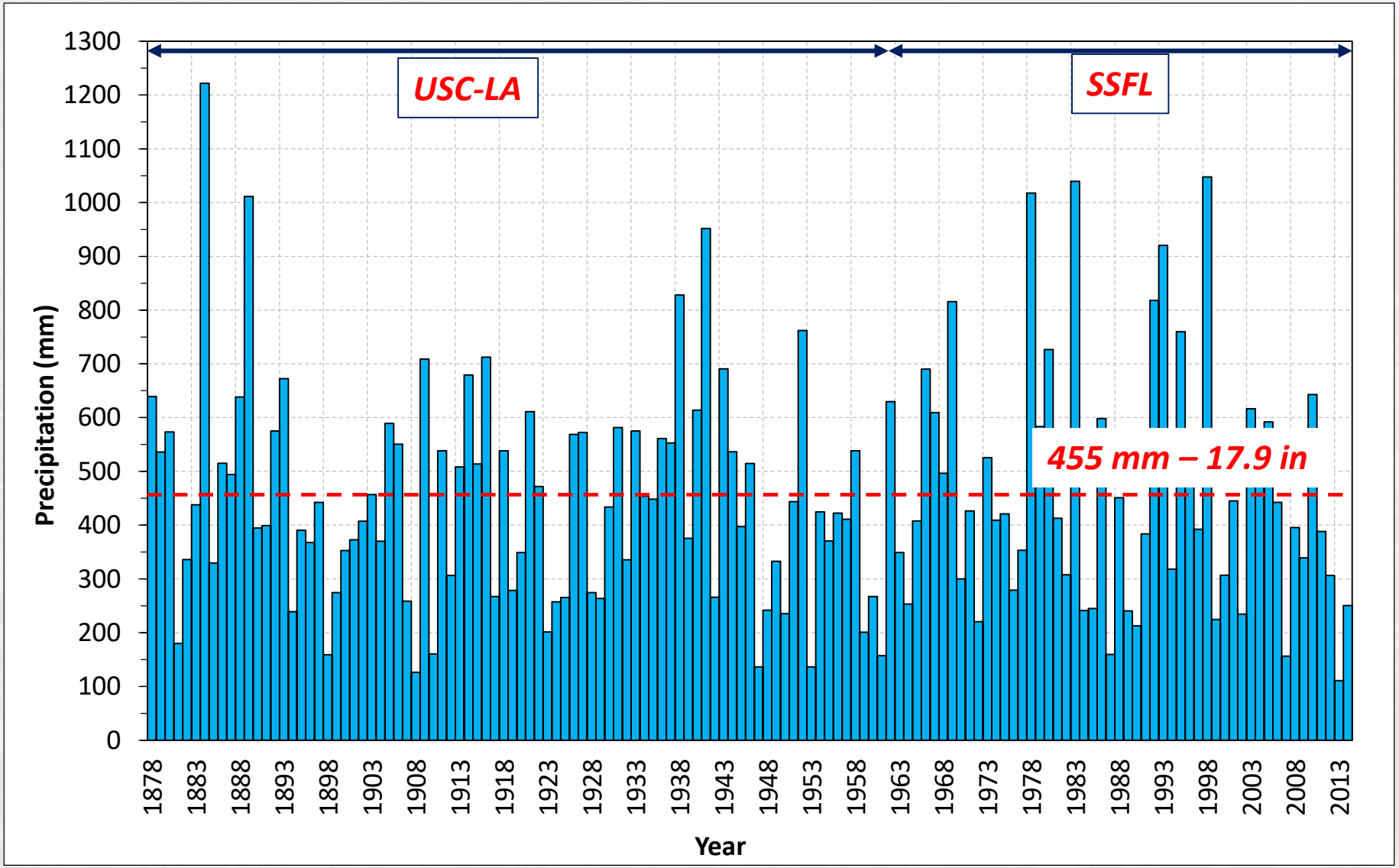


$$I_P = \frac{P_j - P}{P}$$

P_i: precipitation in the *j* year

P: long-term average precipitation

Annual precipitation



Atmospheric Chloride

(MWH, 2006)

Dry fall deposited in the collection funnel is periodically flushed down into the storage bottle by rainfall

$$D = \frac{C \times V}{A \times t}$$

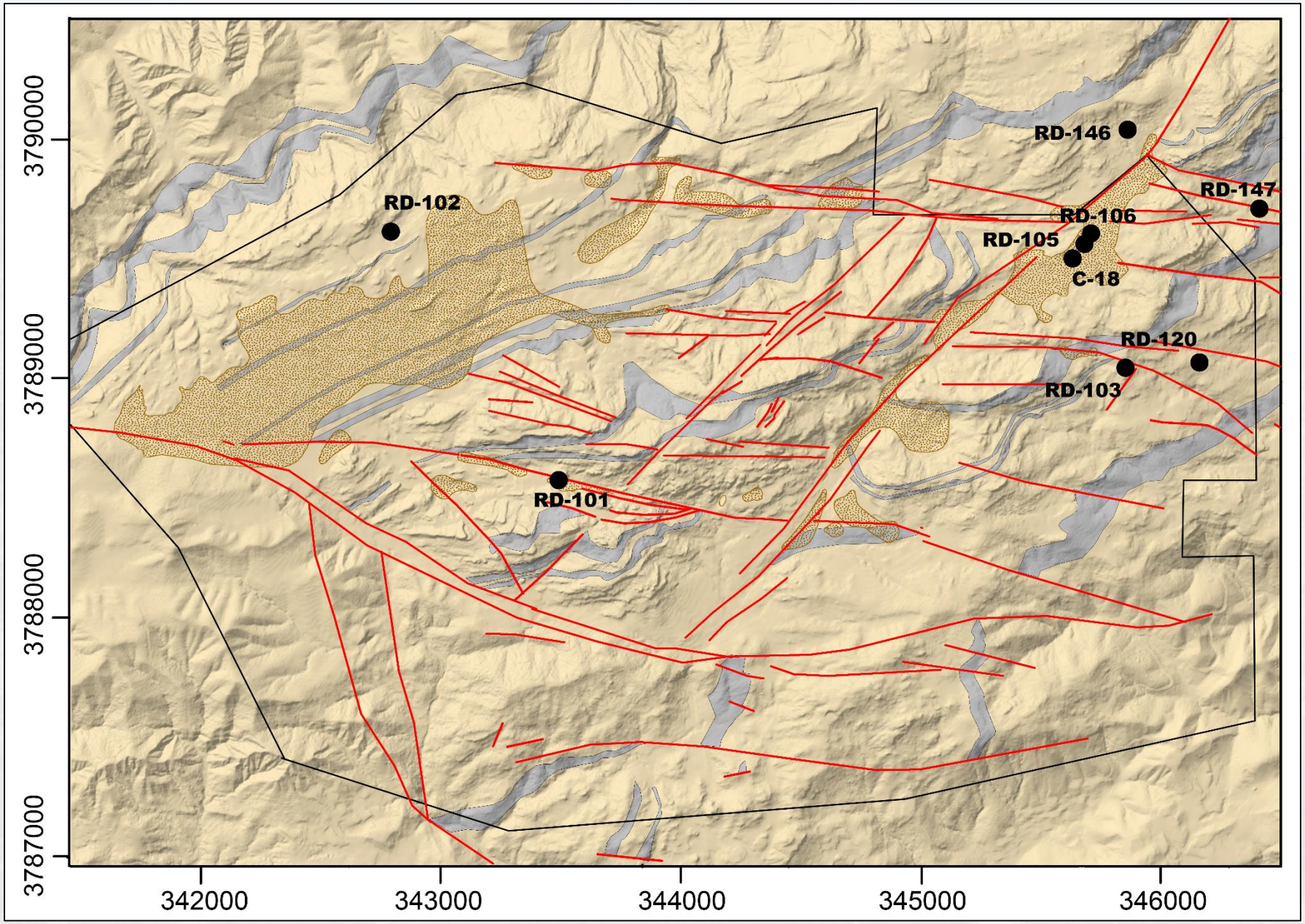
D = chloride deposition rate (mg/m^2/day)
C = chloride concentration in sample (mg/L)
V = volume of water collected during the sampling interval (L)
A = area of the funnel cup opening (m^2)
t = duration of the sampling interval (days)

Average deposition rate is 3.22 mg/m^2/day, equivalent to 2.6 mg/l

A number of rainfall samples have been collected and analyzed for wet chloride (**average = 0.49 mg/l**).

Therefore the dry deposition, when expressed as concentration in rainfall, is about **4 times the wet deposition**.

Cored holes location

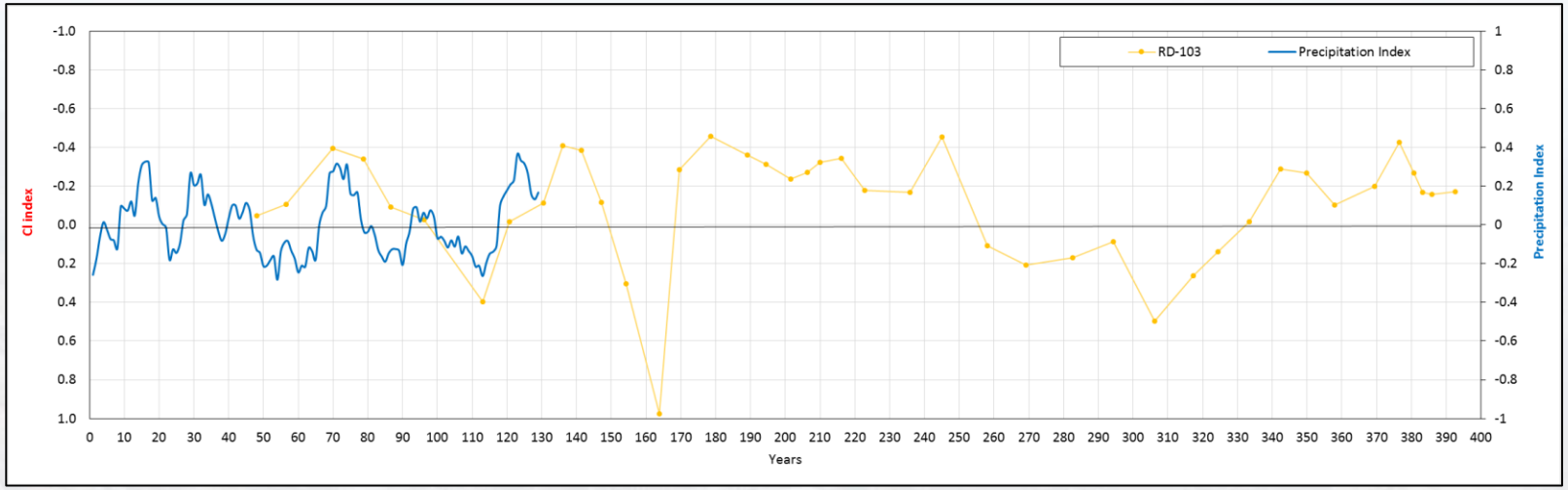


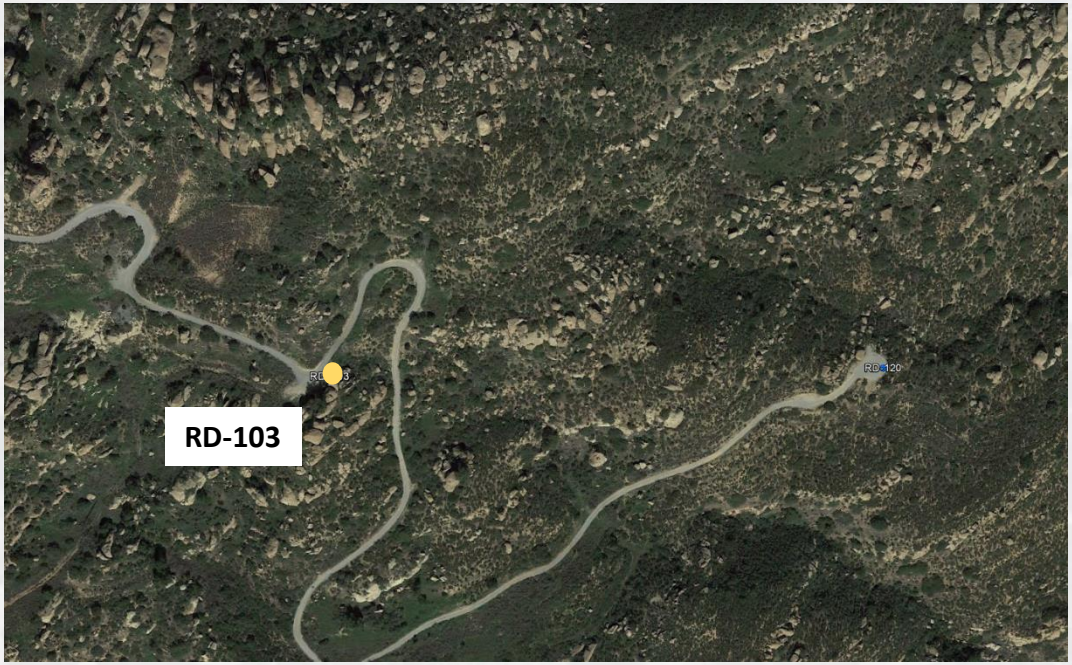
Results

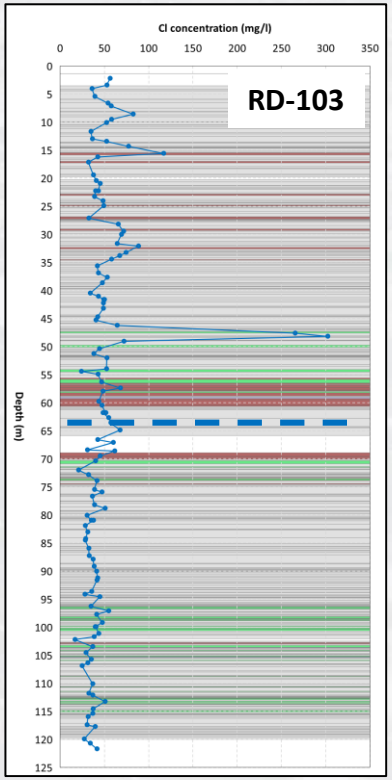
Core ID	Top profile (m)	Gw depth (m)	Analyzed depth (m)	Time to accumulate Cl (years)	Average Cl - UZ (mg/l)	Average Cl -GW (mg/l)	Downward flux (m/y)	R (mm)	R (%)	R_{pr} (%)	R_m (%)
RD-101	7	16	10	186	106.4	68.5	0.10	17	3.7	36	64
RD-102	3	21	17	161	64.9	55.0	0.14	21	4.7	15	85
RD-103	2	62	60	530	67.0	44.9	0.13	26	5.7	33	67
RD-105	10	27	18	154	60.3	55.2	0.14	21	4.7	8	92
RD-106	9	27	18	173	70.6	71.1	0.12	16	3.6	0	100
RD-120	15	45	30	347	80.6	52.3	0.11	22	4.9	35	65
C-18	10	27	18	295	97.0	82.6	0.07	14	3.1	15	85
RD-146	4	49	45	2138	407.0	334.4	0.03	3	0.8	18	82
RD-147	0	15	15	368	109.0	78.9	0.14	15	3.3	28	72

- The analyzed depth varies from 10 to 60 m, corresponding to a time scale spanning from centuries to millennia.
- The average recharge is 17 mm (3.8% of the average annual precipitation).
- An evidence of a bimodal flow regime is the difference average Cl concentration in the unsaturated and in the saturated zone
- Matrix flow is the main mechanism of flow. On average the 80% of the total recharge occurs through matrix flow.
- The vertical displacement rates range from 0.03 to 0.14 m/y.

Interpretation of Cl distribution

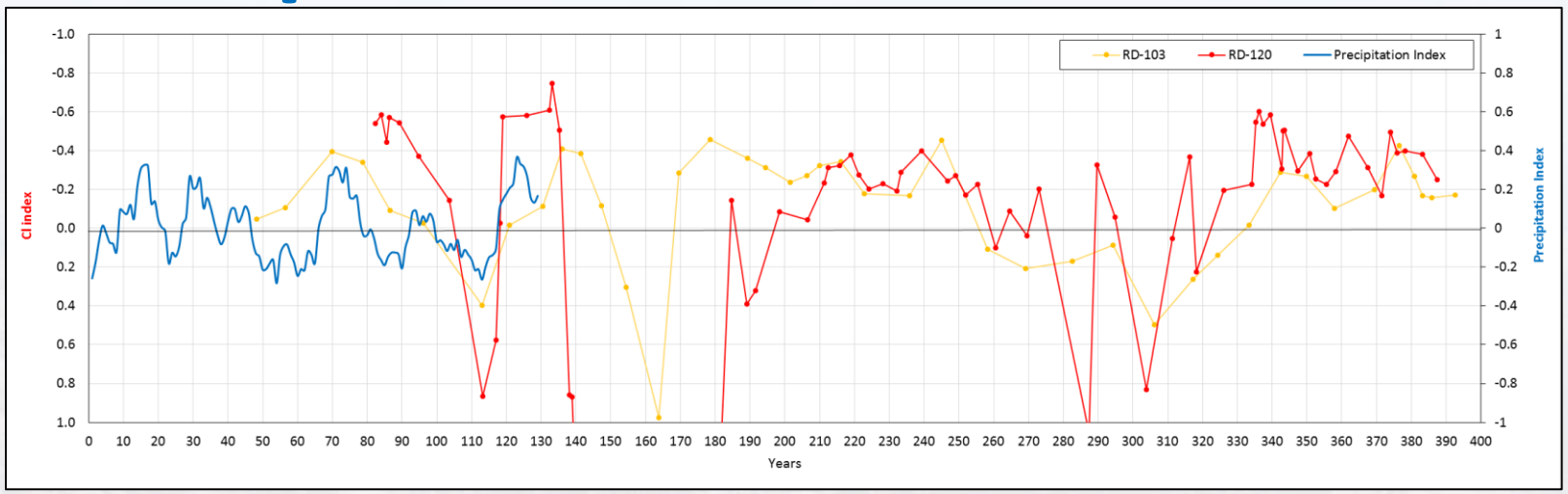


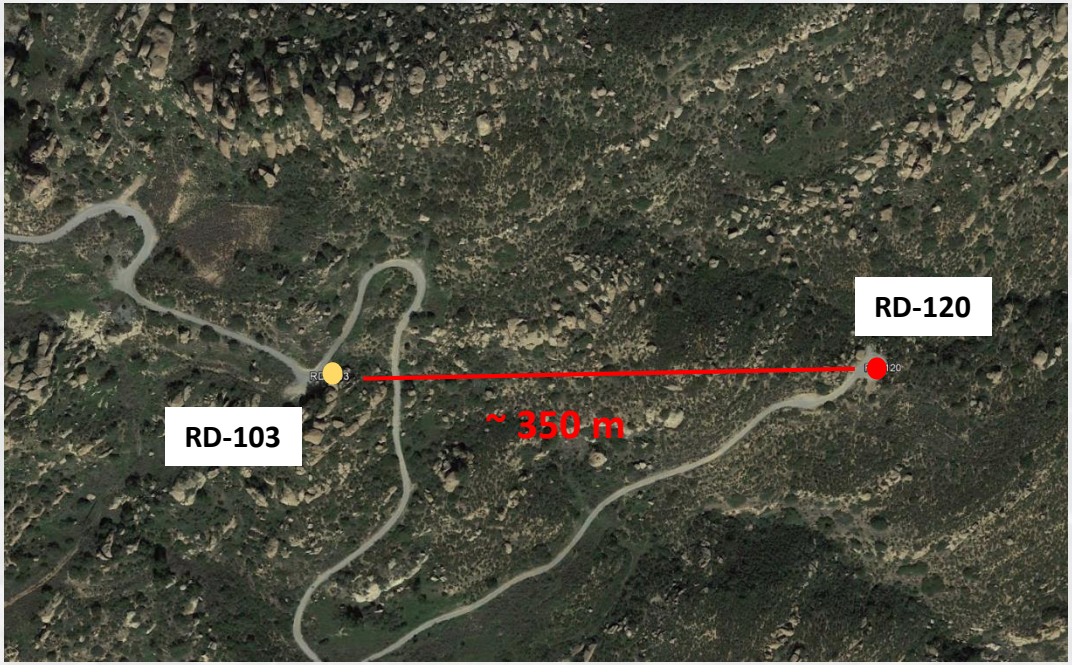


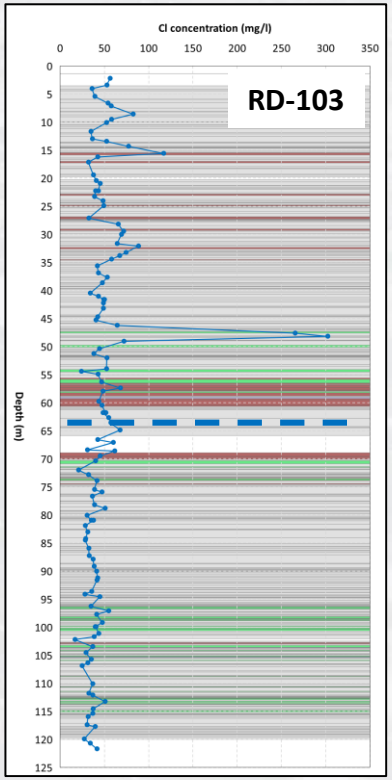


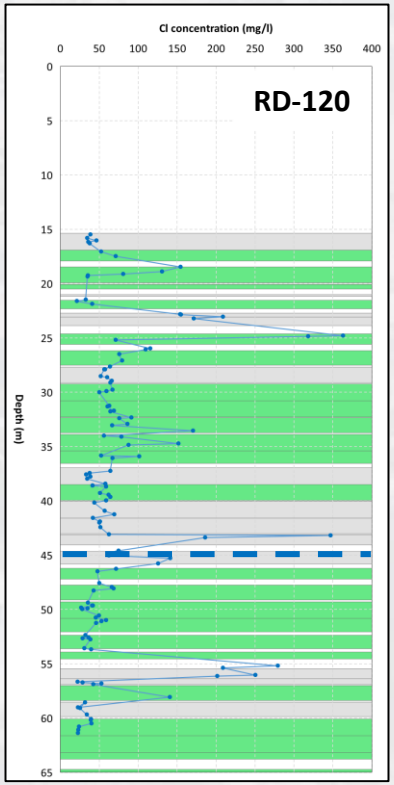
Siltstone | Sandstone | Interbedded | No Recovery

Interpretation of Cl distribution

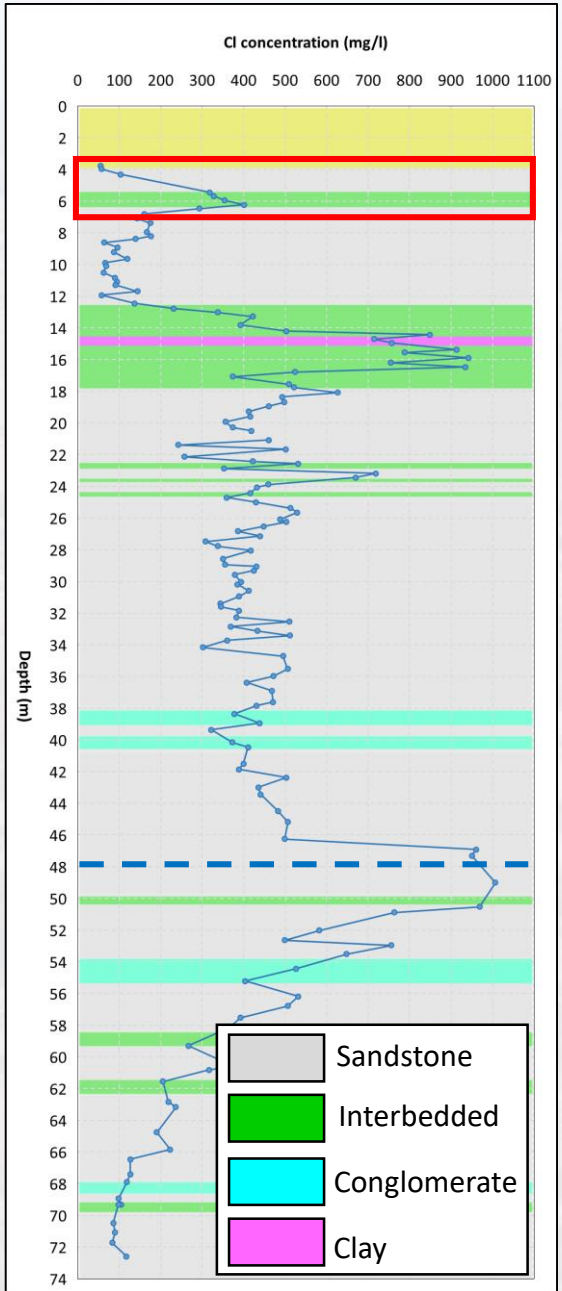


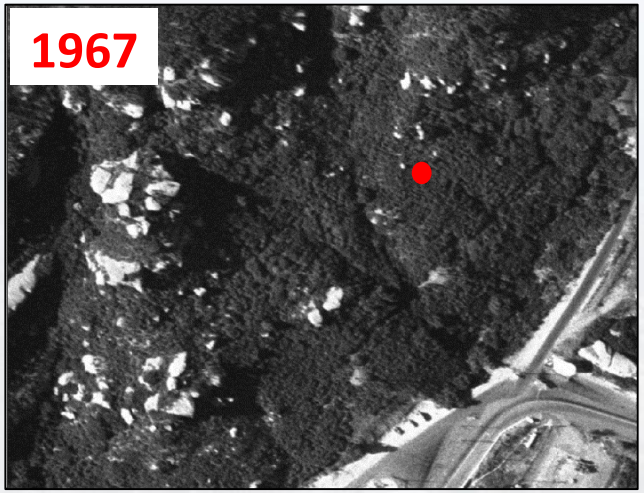


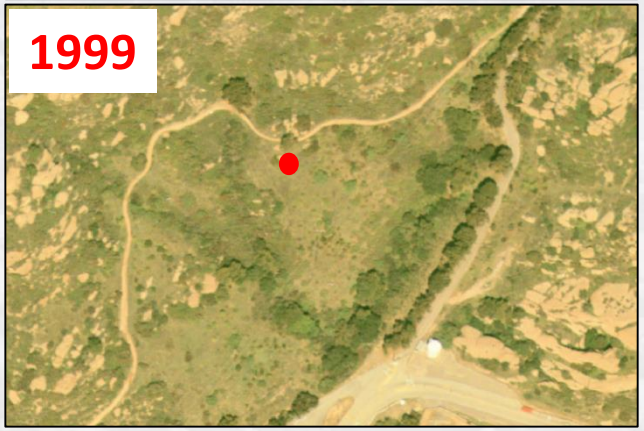


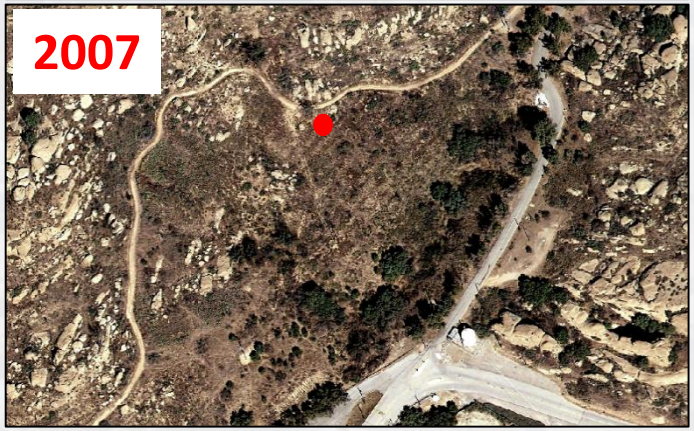


Interpretation of Cl distribution









Depth (m)	Cl concentration (mg/l)	Age (years)	Vertical displacement (m/y)	Volumetric water content (%)	Recharge (%)
3.8	55.6	10	0.25	0.07	3.8
4.0	58.2	11	0.20	0.08	3.6
4.3	104.1	17	0.12	0.07	2.0
5.4	318.4	44	0.03	0.12	0.7
5.7	328.4	53	0.03	0.10	0.6

Preliminary conclusions

- Average recharge is 17 mm (3.8% of the average annual precipitation).
- The average recharge values range spatially from <1 to 5.7% and temporally from <1 to 10%.
- This range of variation is mainly due to different land use condition.
- Even in a highly heterogeneous fractured media, Cl profiles in the unsaturated are archive of past recharge conditions.
- Recharge occurs mainly (~80%) through matrix flow.
- The average displacement rate is 11 cm/y. The unsaturated zone is a contaminant mass reservoir, with recharge moving the water phase slowly toward the water table.

Next steps

- Model the transport of Cl in the unsaturated zone to test our hypothesis.
- Analysis of isotopes (^{3}H, ^{18}O and D) to better understand mechanisms of recharge.
- Build a distributed hydrological model for recharge that will be included in the 3-D groundwater flow model of the site.

THANK YOU!