DIFFERENTIATION OF WATER SOURCES USING ANALYTICAL WATER CHEMISTRY DATA

PRESENTED TO

FOUNDATION PERFORMANCE ASSOCIATION

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BY

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GOAL

For many soil-structure interaction problems (such as foundation movement or slope stability problems), it is desirable to be able to identify the source of the sub-surface water.

(may also be desirable from a legal point-of-view to help determine liability issues)

Structural and foundation movement will very often be caused by differences in moisture in many cases exacerbated by “groundwater” (particularly for shallow foundations on expansive clay)

Groundwater origin analysis is also critically important in the assessment of soil-structure interaction problems

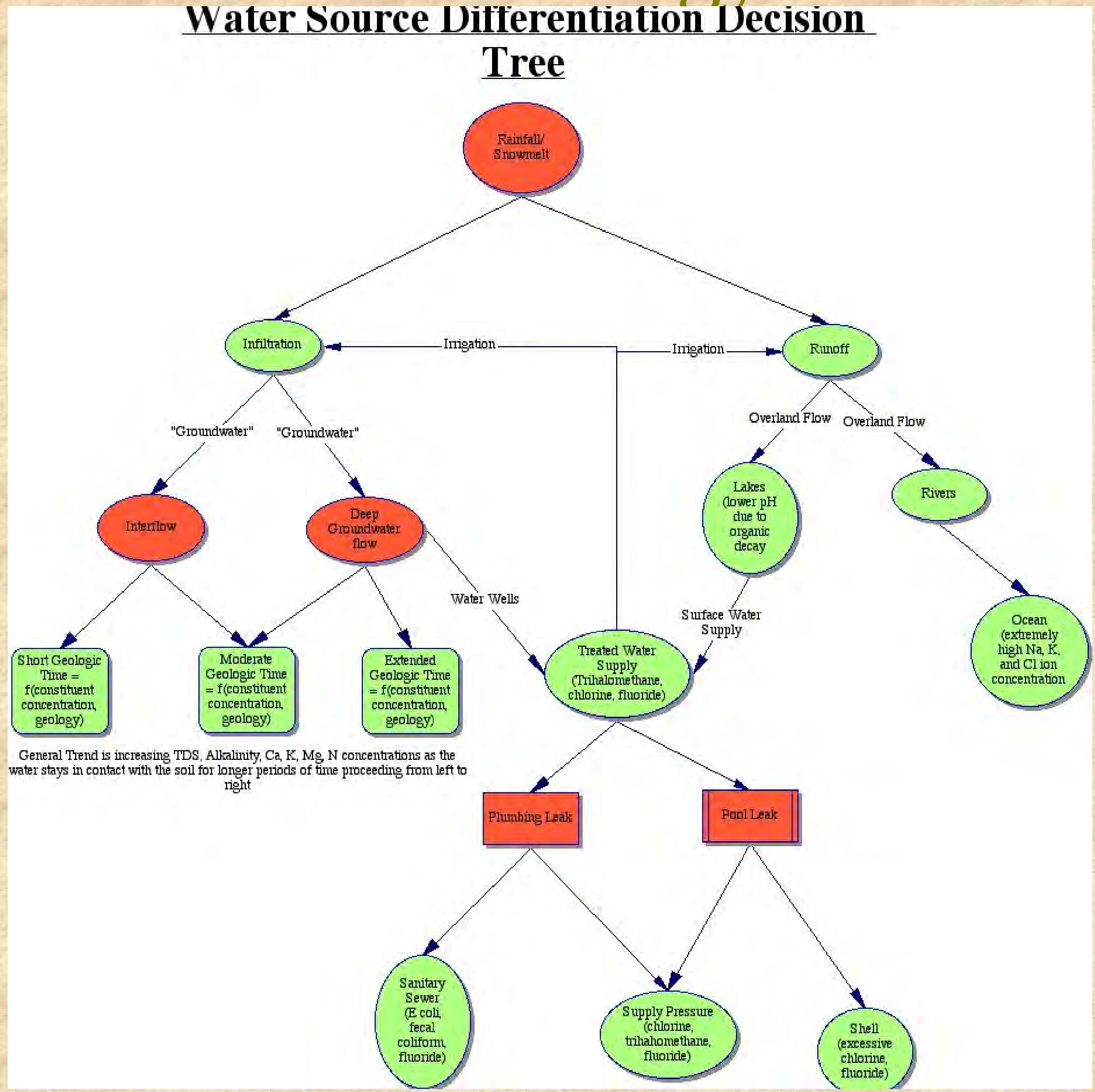
Possible Sources:

- I. Poor Surface Water Drainage (e.g. bad guttering)
- II. Pipe Leak (pipe break, corroded/leaky pipes)
- III. Subterranean Geologic Feature (filled-in gully)
- IV. Leaky Outdoor Faucet
- V. Cracked Pool

What is Groundwater

Strictly speaking groundwater is subsurface water that occurs beneath the water table in fully saturated soils and geologic conditions---but, in a broad sense It includes any subsurface water And we will use the broader definition for our purposes today

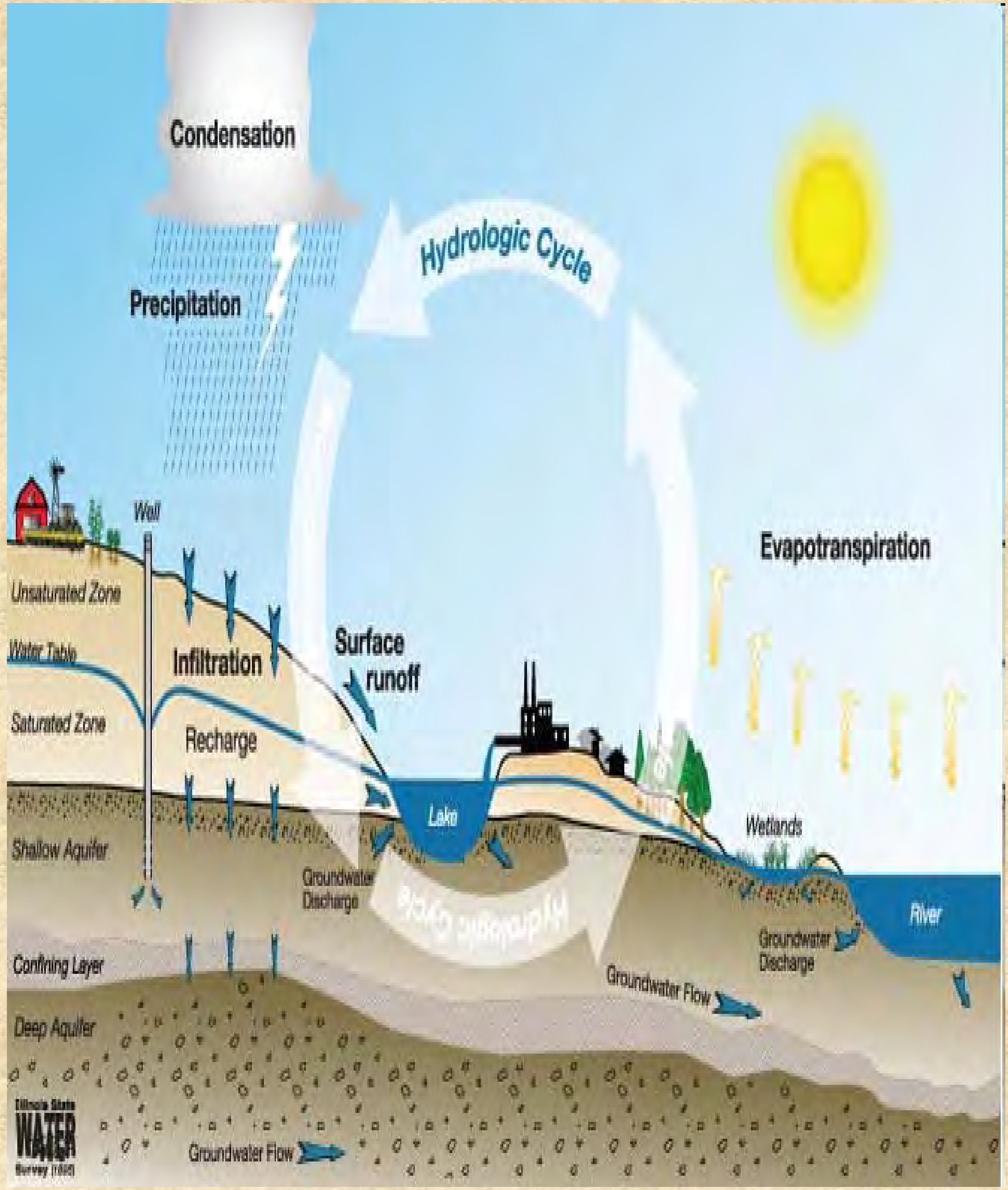
Origin Differentiation Methodology



Outline

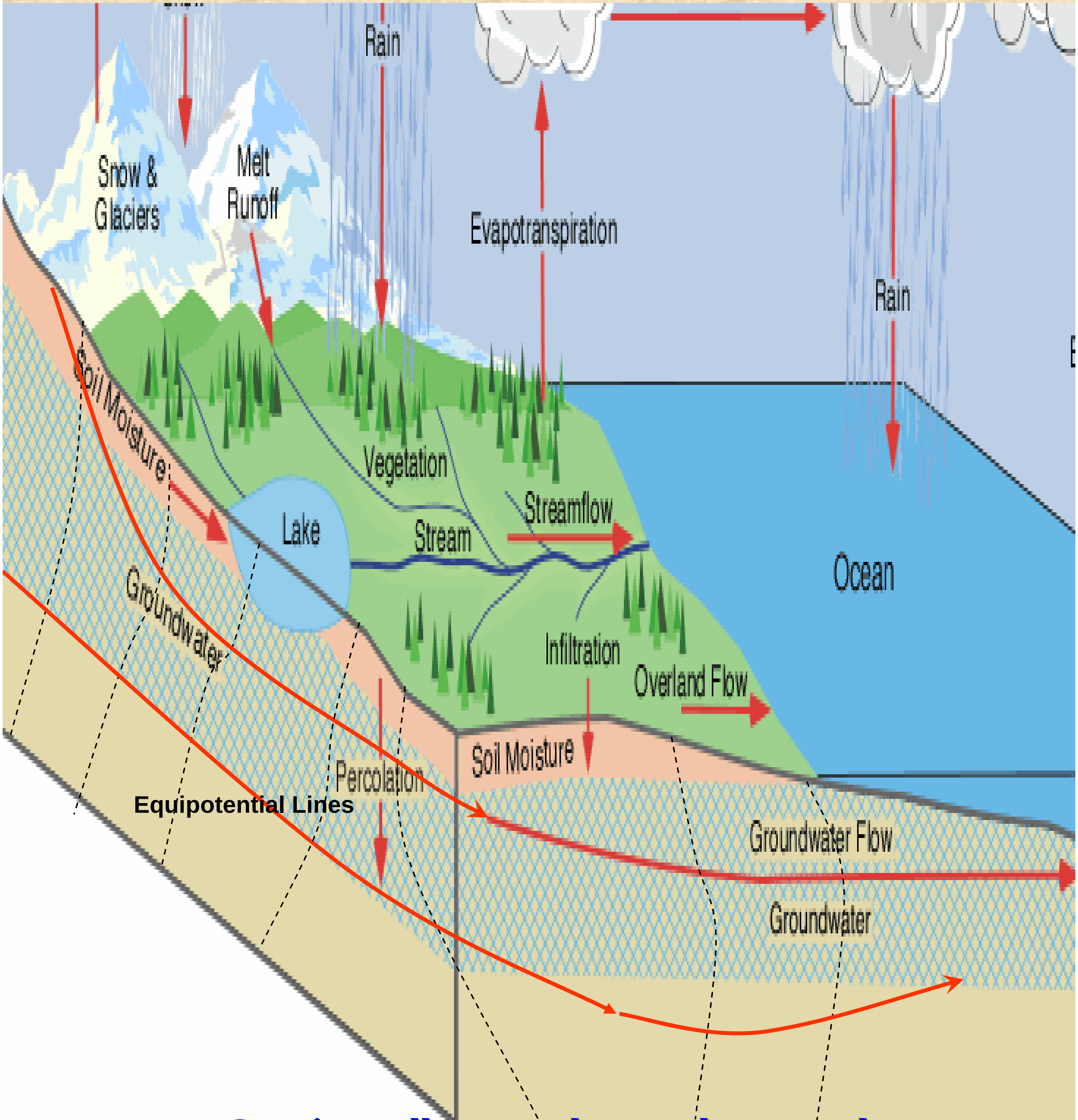
1. Hydrologic Cycle
2. General Theory
    - Flow
    - Geochemistry
3. Case Studies
4. Questions?

The Water (Hydrologic) Cycle



Source:
http://www.isws.illinois.edu/docs/watercycle/

How Does the Groundwater Flow?



- Gravity pulls groundwater downward
- Groundwater moves from one region to another region to eliminate energy differentials.

Flow Theory

Bernoulli's Equation

$$h = v^2/2g + z + P/\rho g = \text{constant}$$

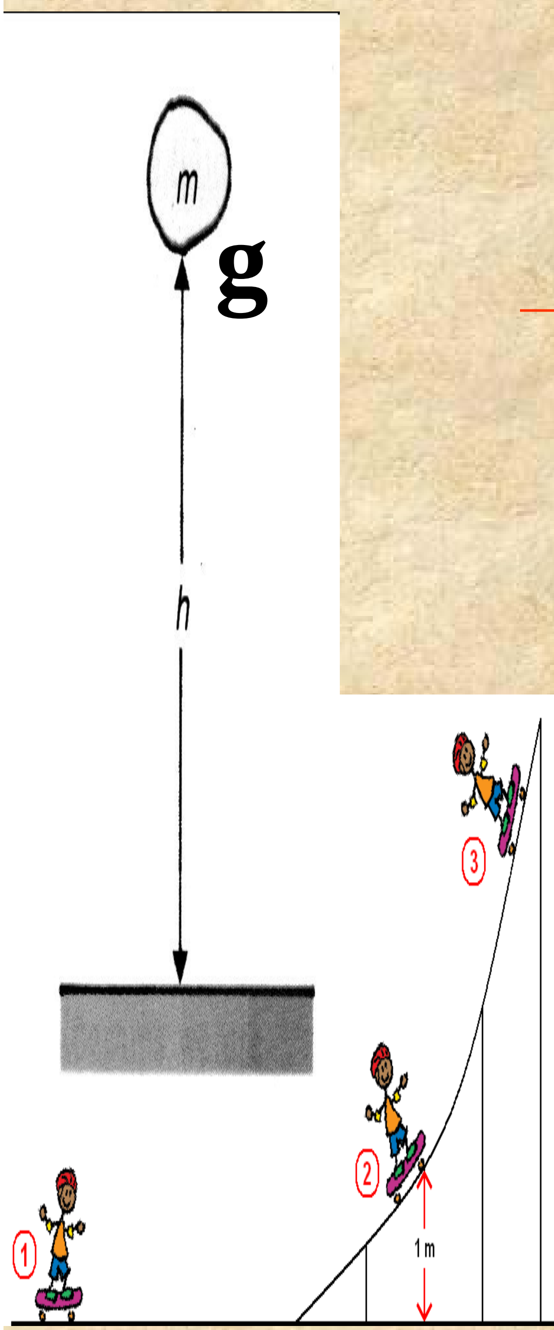
$h \rightarrow$ hydraulic head

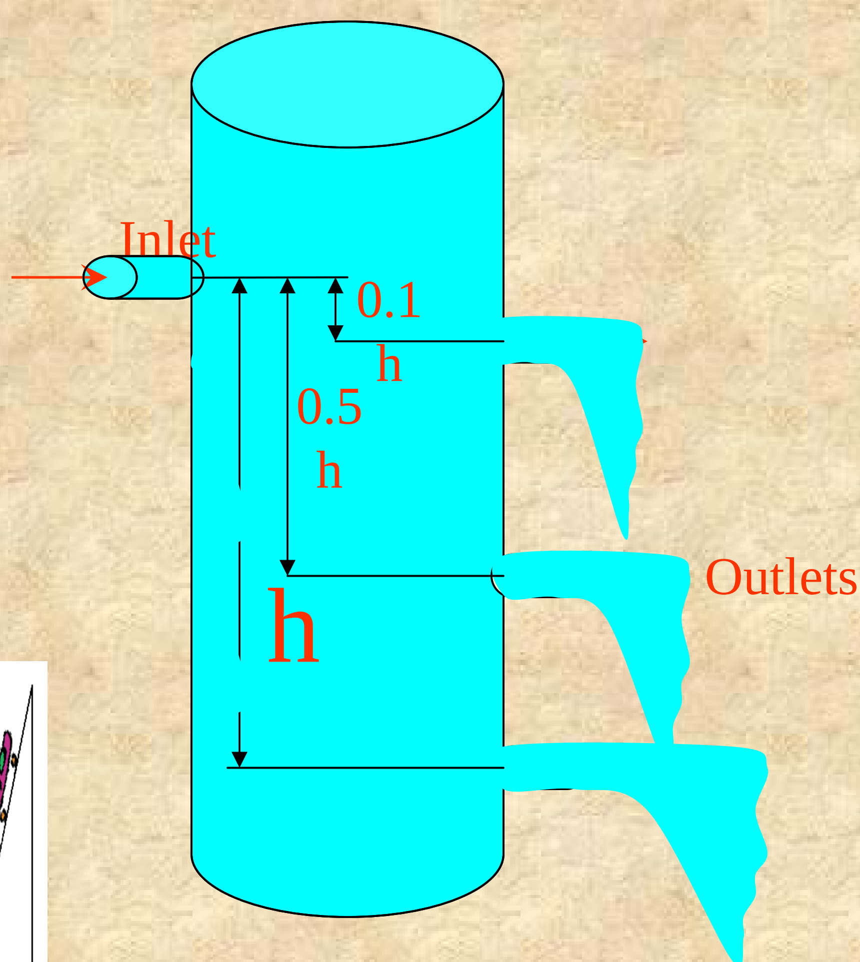
$v^2/2g \rightarrow$ velocity head (ignored in groundwater flow)

$z \rightarrow$ elevation head

$P/\rho g \rightarrow$ pressure head

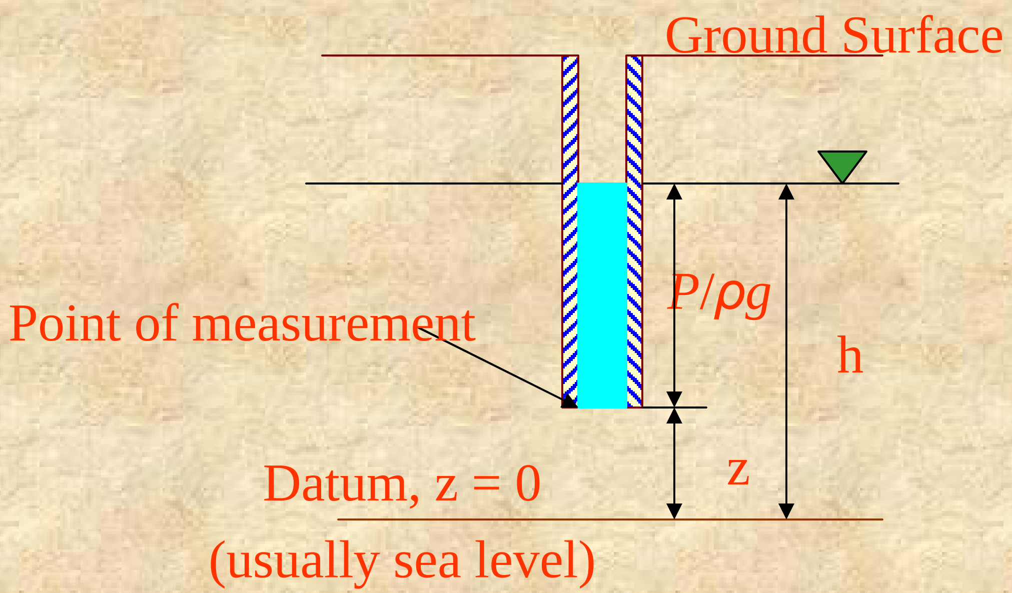
Flow due to Pressure Head





Hydraulic Head

Hydraulic head, h = z + $P/\rho g$



D'Arcy's Law

Q = kia/n

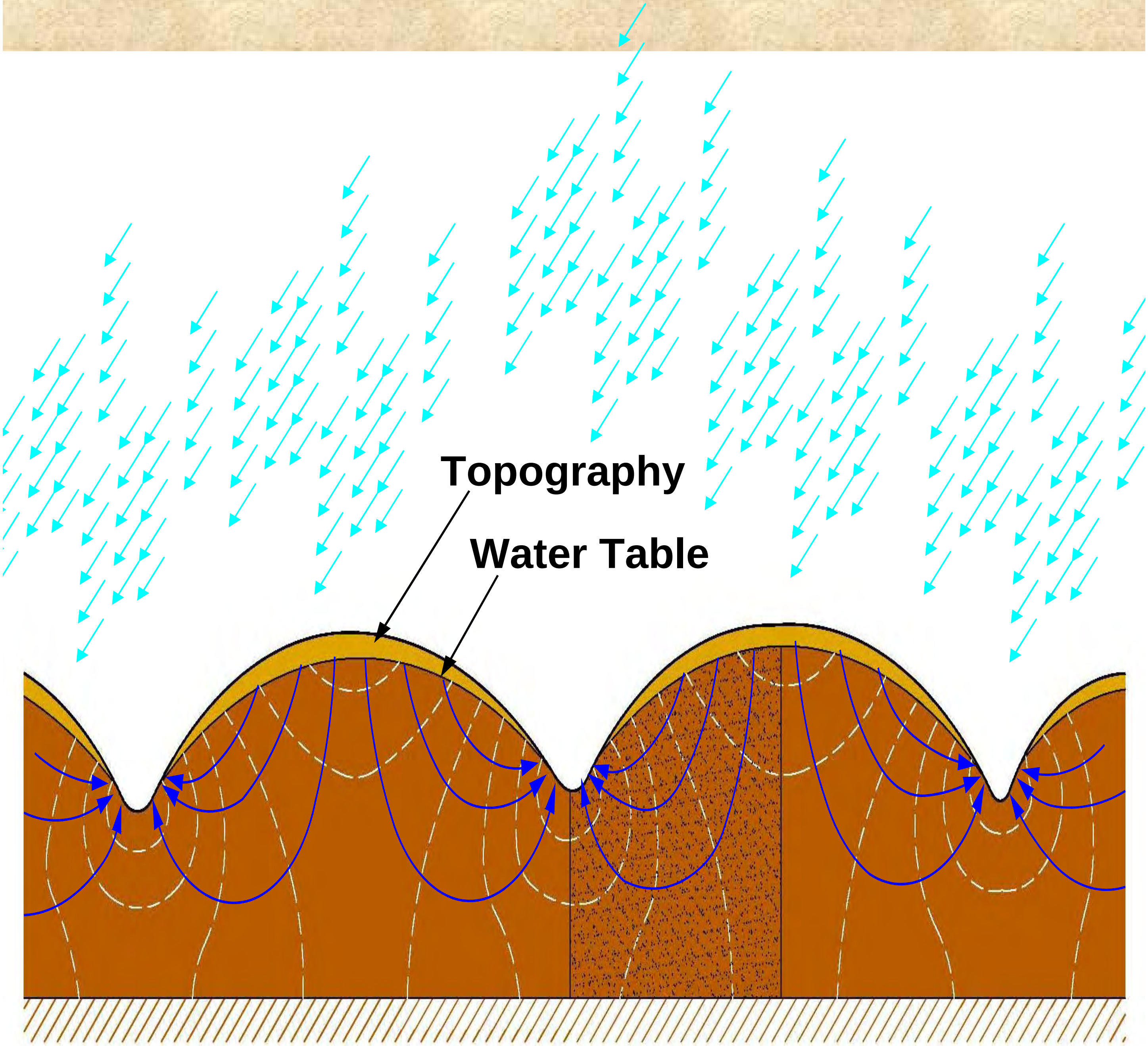
Q=flow volume

k = permeability

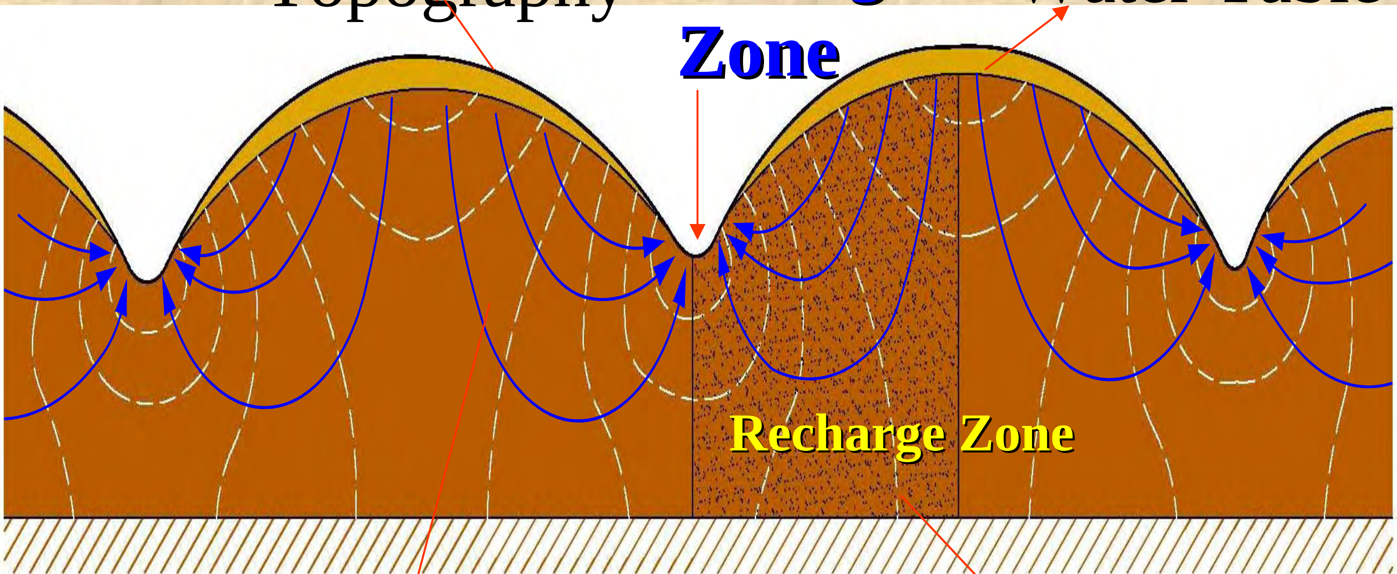
i = dh/dl=differential head gradient

n = soil porosity

Groundwater Flow



Groundwater Flow Net



Recharge Zone:

•Groundwater is directed away from the water table.

Discharge Zone:

•Groundwater is directed towards water table

Flow lines

•imaginary lines that trace the path of a groundwater.

Flow Net:

•visual solution of a groundwater flow system

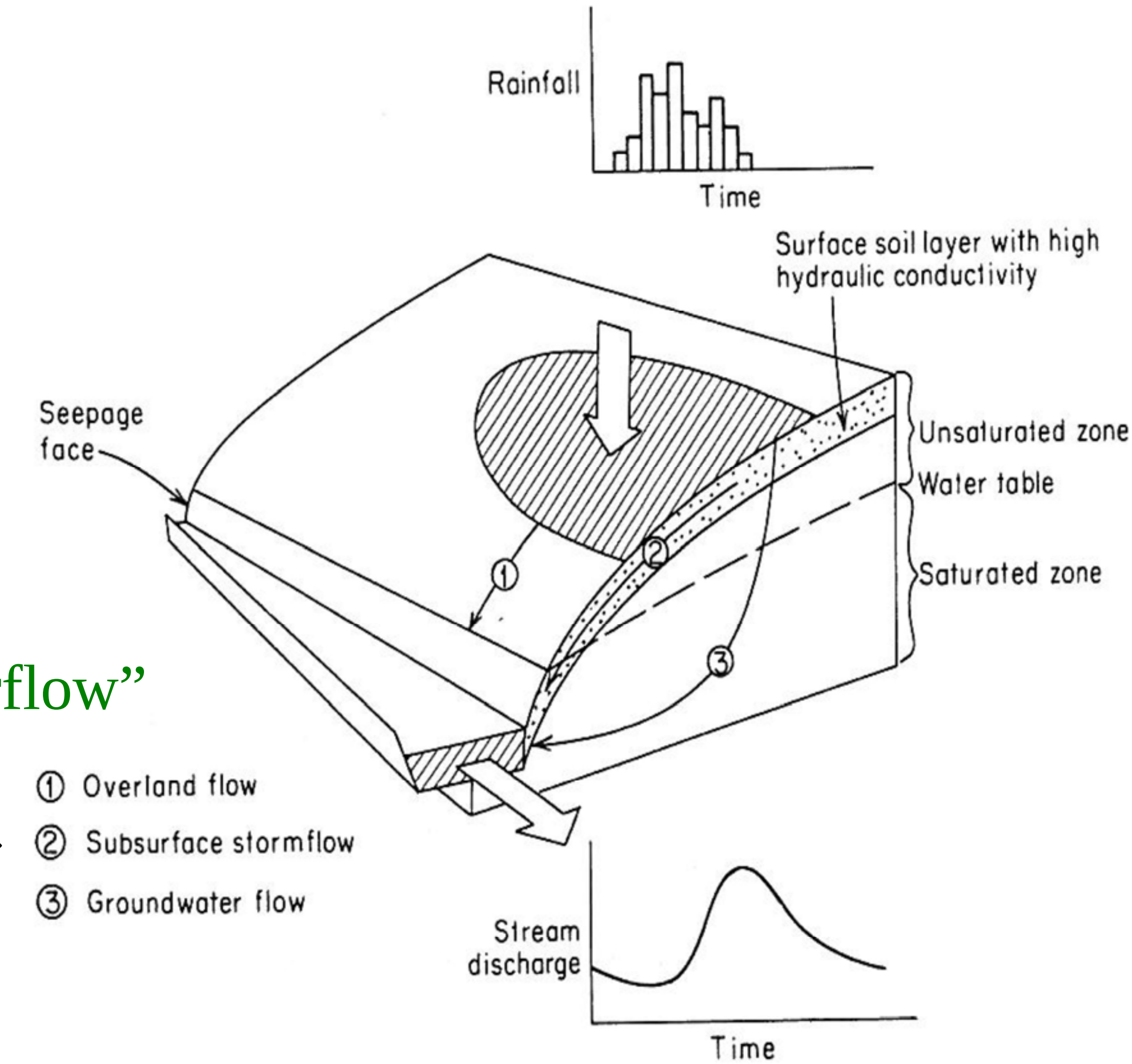
•comprised of **equipotential lines** and **flow lines**.

Equipotential Lines:

•often referred to as water table contour lines

•connect points of equal hydraulic head.

“Interflow”


Rainfall
Time
Surface soil layer with high hydraulic conductivity
Seepage face
Unsaturated zone
Water table
Saturated zone
① Overland flow
② Subsurface stormflow
③ Groundwater flow
Stream discharge
Time

What may have caused a crack like this ?

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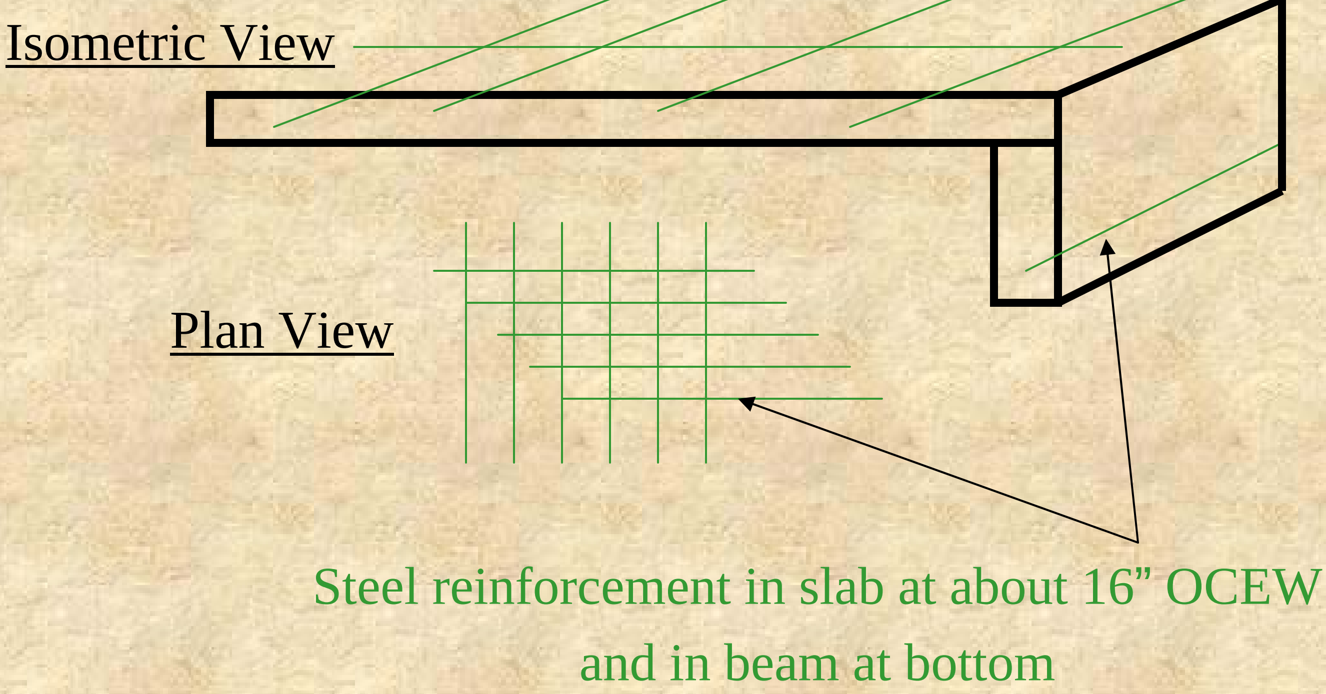
Such problems have become much more prevalent since the wide-spread adoption of "slab-on-grade" foundation types….

Conventional Reinforcement-steel reinforcement bars

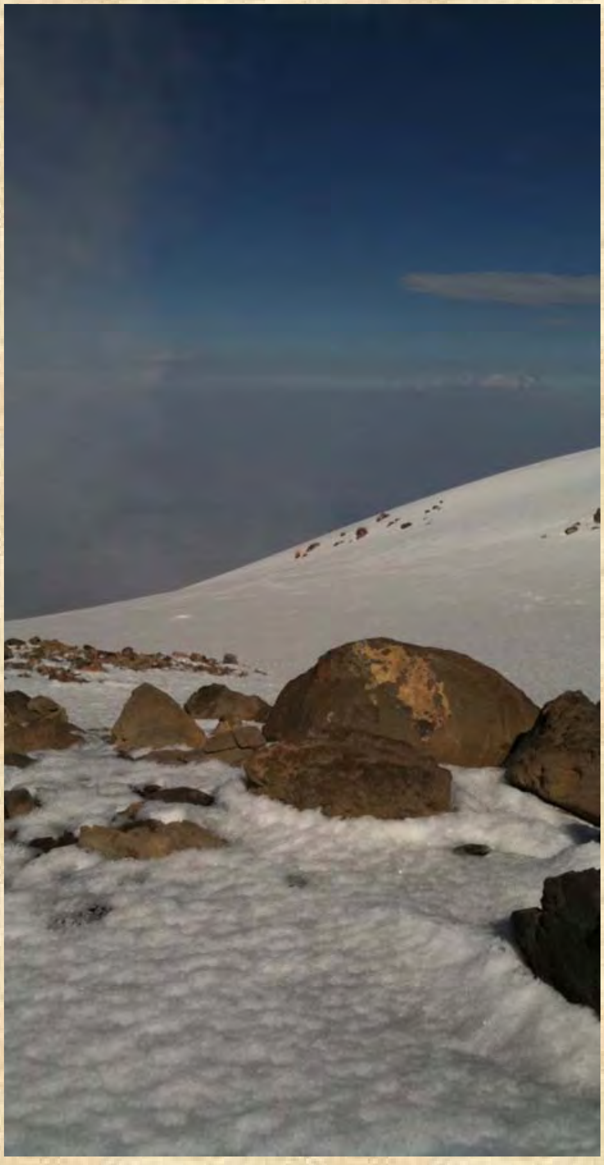


Geochemistry Theory

Chemical Evolution of Natural Groundwater

- Nearly all groundwater begins as rain or snowmelt that infiltrates through soil into flow systems in the subsurface geologic materials.

General Theory



- Snow at 17,000 feet is NOT exactly pure but it has very few ions

General Theory

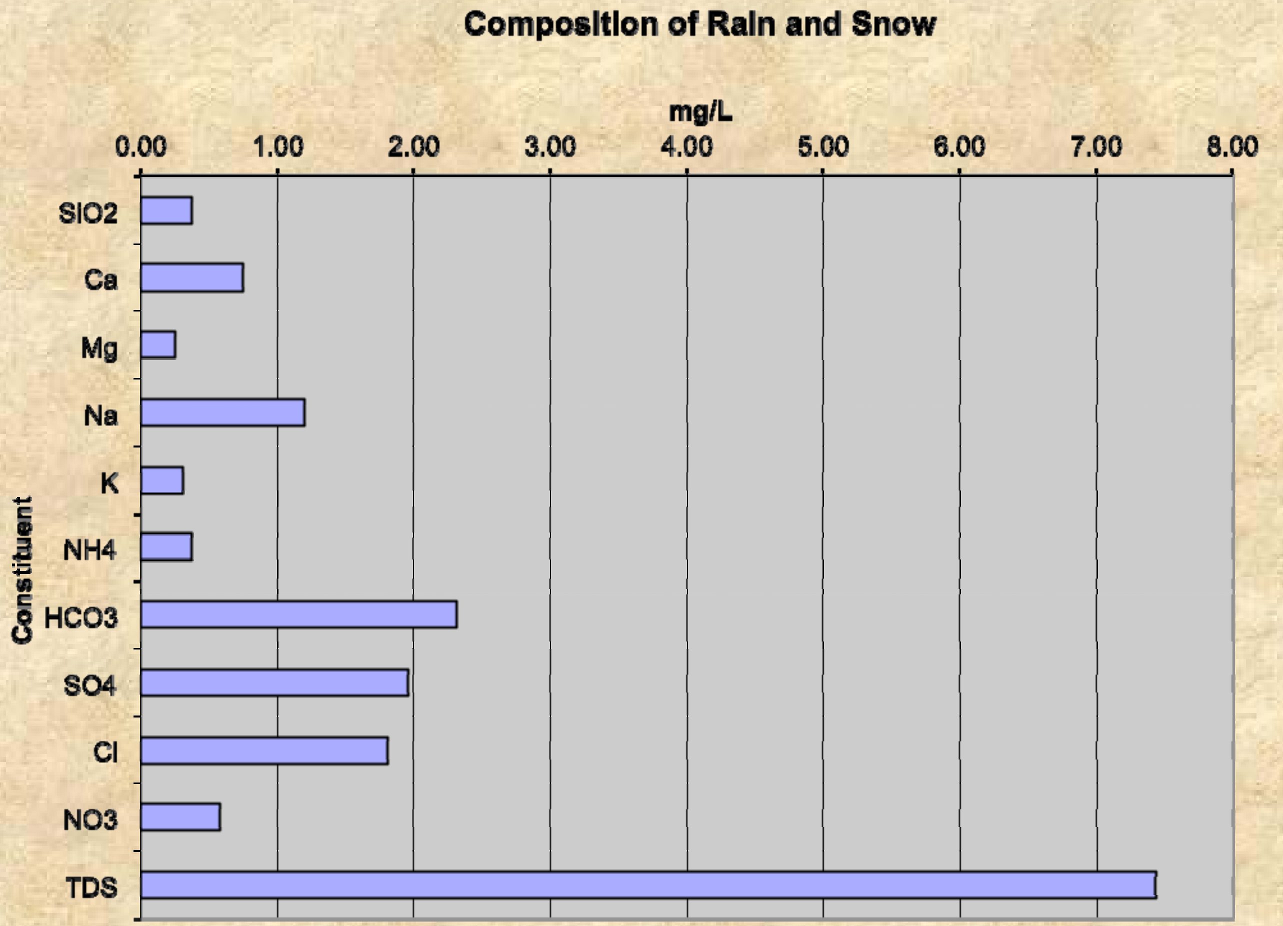
Table 7.1 Composition of Rain and Snow (mg/ℓ)*

Constituent	1	2	3	4	5	6	7
SiO_2	0.0	0.1	—	0.29	0.6	—	0.9
Ca	0.0	0.9	1.20	0.77	0.53	1.42	0.42
Mg	0.2	0.0	0.50	0.43	0.15	0.39	0.09
Na	0.6	0.4	2.46	2.24	0.35	2.05	0.26
K	0.6	0.2	0.37	0.35	0.14	0.35	0.13
NH_4	0.0	—	—	—	0.6	0.41	0.48
HCO_3	3	2.0	—	1.95	—	—	—
SO_4	1.6	2.0	—	1.76	0.45	2.19	3.74
Cl	0.2	0.2	4.43	3.75	0.22	3.47	0.38
NO_3	0.1	—	—	0.15	0.41	0.27	1.96
TDS	4.8	5.1	—	12.4	—	—	—
pH	5.6	—	—	5.9	5.3	5.5	4.1

*(1) Snow, Sponer Summit, U.S. Highway 50, Nevada (east of Lake Tahoe), altitude 7100 ft., Nov. 20, 1958; (2) rain, at eight sites in western North Carolina, average of 33 events, 1962–1963; (3) rain in southeastern Australia, 28 sites over 36 months, 1956–1957; (4) rain at Menlo Park, Calif., winters of 1957–1958; (5) rain, near Lake of the Woods, NW Ontario, average of 40 rain events, 1972; (6) rain and snow, northern Europe, 60 sites over 30 months, 1955–1956; (7) rain and snow at a site 20 km north of Baltimore, Maryland, average for 1970–1971.

SOURCE: Feth et al., 1964 (1); Laney, 1965 (2); Carroll, 1962 (3); Whitehead and Feth, 1964 (4); Bottomley, 1974 (5); Carroll, 1962 (6); and Cleaves et al., 1974 (7).

Graphic Representation of Rainfall/Snowmelt

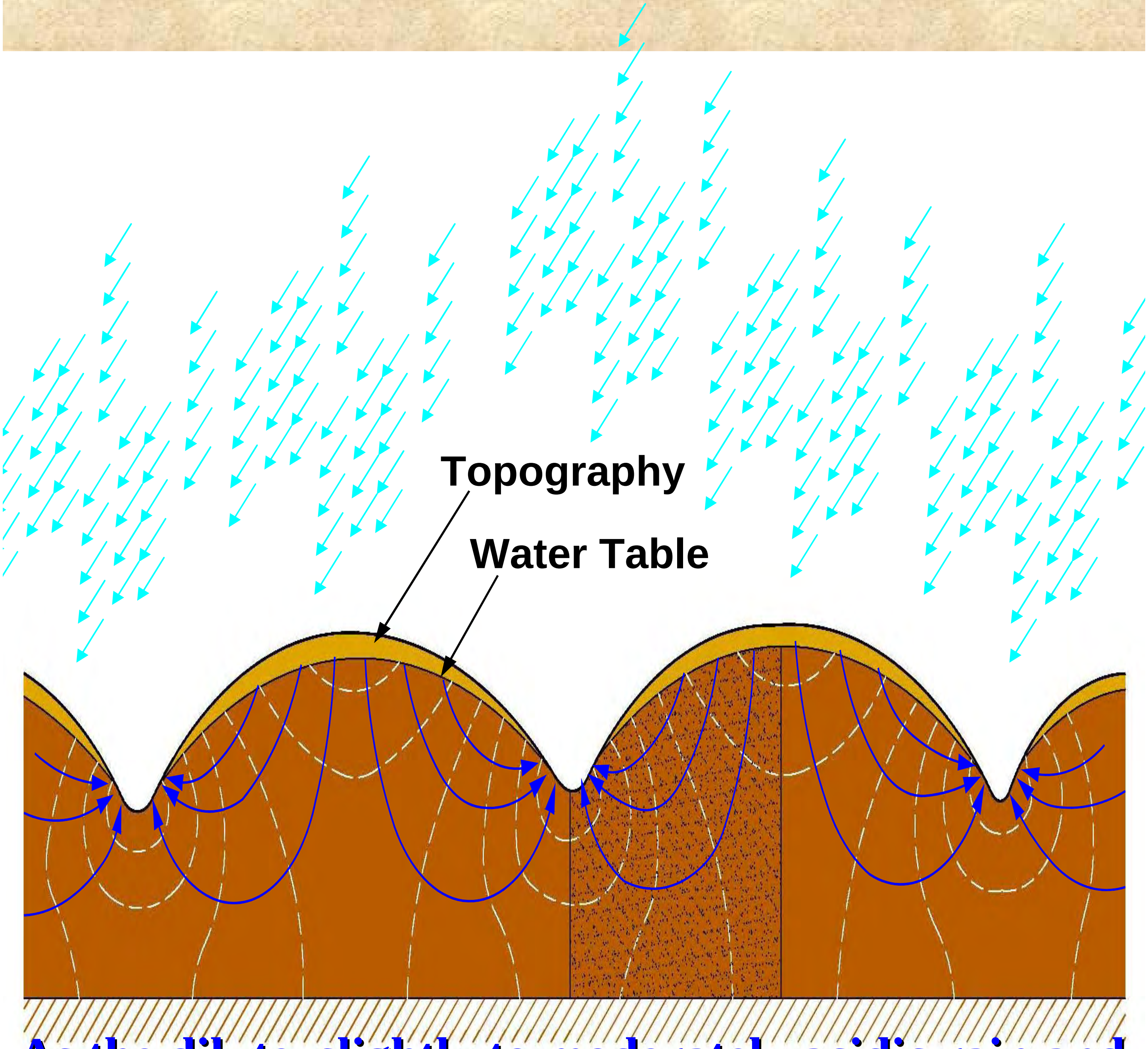


	TDS	NO3	Cl	SO4	HCO3	NH4	K	Na	Mg	Ca	SIO2
Average	7.43	0.58	1.81	1.96	2.32	0.37	0.31	1.19	0.25	0.75	0.38

General Theory

- Rainfall becomes influenced by ionic species that dissolve into water to achieve chemical equilibrium

General Theory



As the dilute, slightly to moderately acidic rain and snowmelt migrate down into the soil they become powerful oxidizing solutions that can quickly cause alterations to soils or geologic materials into which they infiltrate

General Theory

- Major ionic constituents are calcium, chlorides, magnesium, sodium, sulfates and carbonic acid = 90% of TDS in water

General Theory

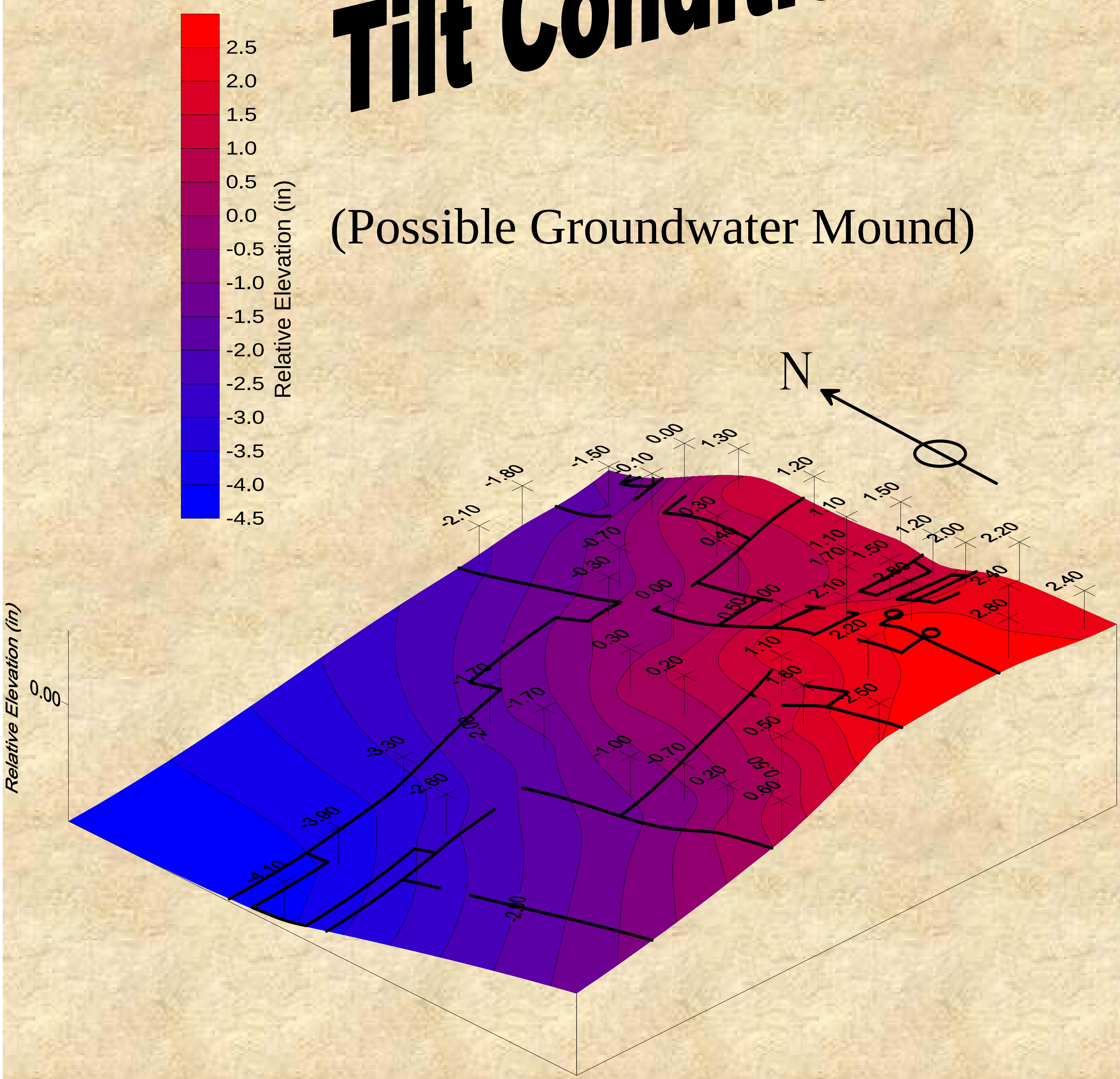
Table 1: North Texas Tap Water Averages				
Chemical	Average	Range	Maximum Allowed	Possible Source
Total hardness	131 ppm.	108 -179		Natural (calcium)
Total alkalinity	77 ppm.	48 - 106		Natural (CO_3 & HCO_3)
Sodium	28 ppm.	8 – 39		Natural
Chlorine residual	3.15 ppm.	2.8 – 3.6	0.5 - 4	Water treatment
Fluoride	0.67 ppm.	0.2 - 1	4	Public health additive
Nitrate	0.6 ppm.	0.12– 0.80	10	Fertilizer/septic tanks
Barium	30 ppb.	14 - 46	2000	Drilling additive
Copper	7 ppb.	0 - 21	1300	Plumbing corrosion
Lead	4 ppb.	3 - 51	15	Older plumbing

Case Study 1

Pool Leak or“Groundwater”

Tilt Condition

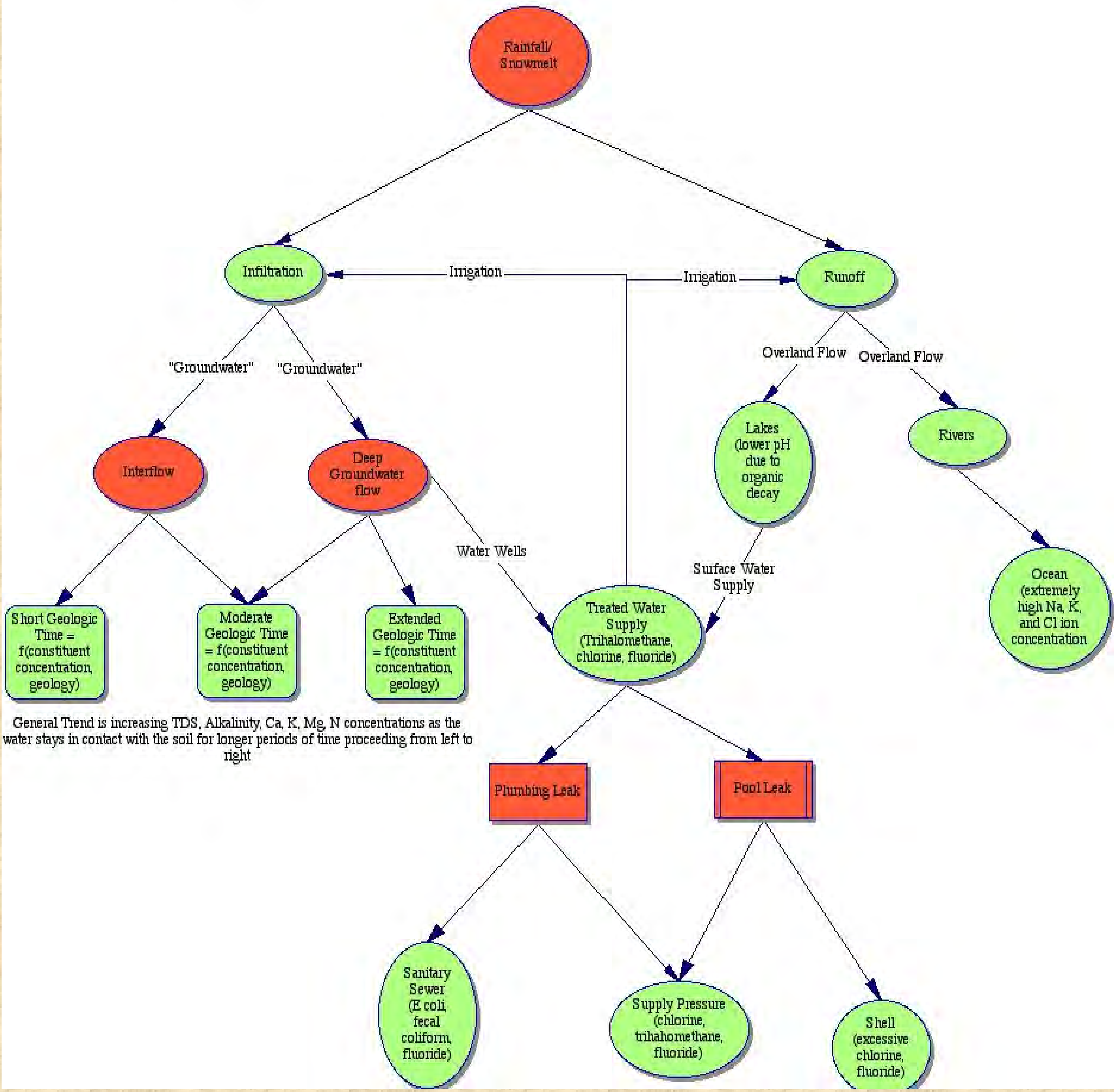
(Possible Groundwater Mound)



Possible Cause of such a Foundation Problem

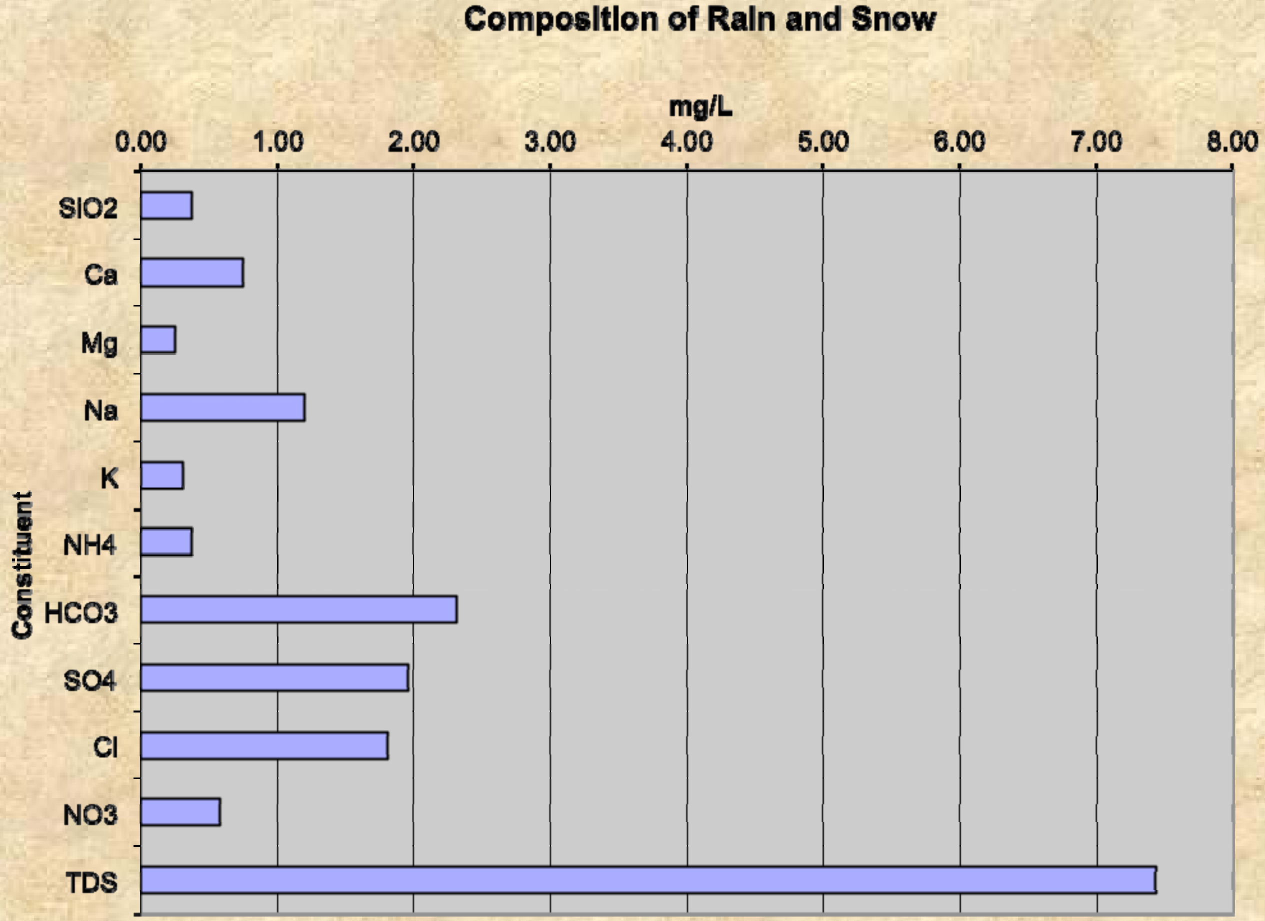
- Was it a pool leak?

Water Source Differentiation Decision Tree



General Trend is increasing TDS, Alkalinity, Ca, K, Mg, N concentrations as the water stays in contact with the soil for longer periods of time proceeding from left to right

Graphic Representation of Rainfall/Snowmelt



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Comparison of Some Representative Analytical Water Sample Results.

Test Item	Tap Water	Front Yard Hole	Pool Holes	Storm Drain	Swimming Pool	Piezometer
Fluoride	0.67-0.72	1.01	0.65-0.87	--	0.42 – 1.03	0.81
Total Chlorine Residual (mg/l)	1.6 - 3.13	<0.01	<0.01	0.02	2.5 - 18.0	<0.01
Total Dissolved Solids (mg/l)	264.0-288.0	684.0	384.0 - 400.0	--	599.0 - 720.0	944.0-1152.0
Chlorides (mg/l)	46	--	73.5-68.5	--	123.5-134.5	122.5-194.5
Electrical Resistivity (ohm-m)	22.2-22.7	12.2	15.4 – 15.9	--	9.3 – 10.9	5.05 -5.34
Alkalinity (mg/l)	176.2	--	117.6-162.6	--	50.6 – 85	703.6-710.0
pH	7.85-8.02	7.50	8.53 - 9.21	7.03	7.78 - 7.81	7.16-8.35

Observations in piezometer:

Significant fluorides – not rain water,

Negligible chlorine – not pool water,

High dissolved solids, chlorides and alkalinity – probably leached from soil,

Resistivity low – leaching through soil likely,

pH between tapwater & storm drain – some mixing of irrigation water and runoff likely

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Case Study 1

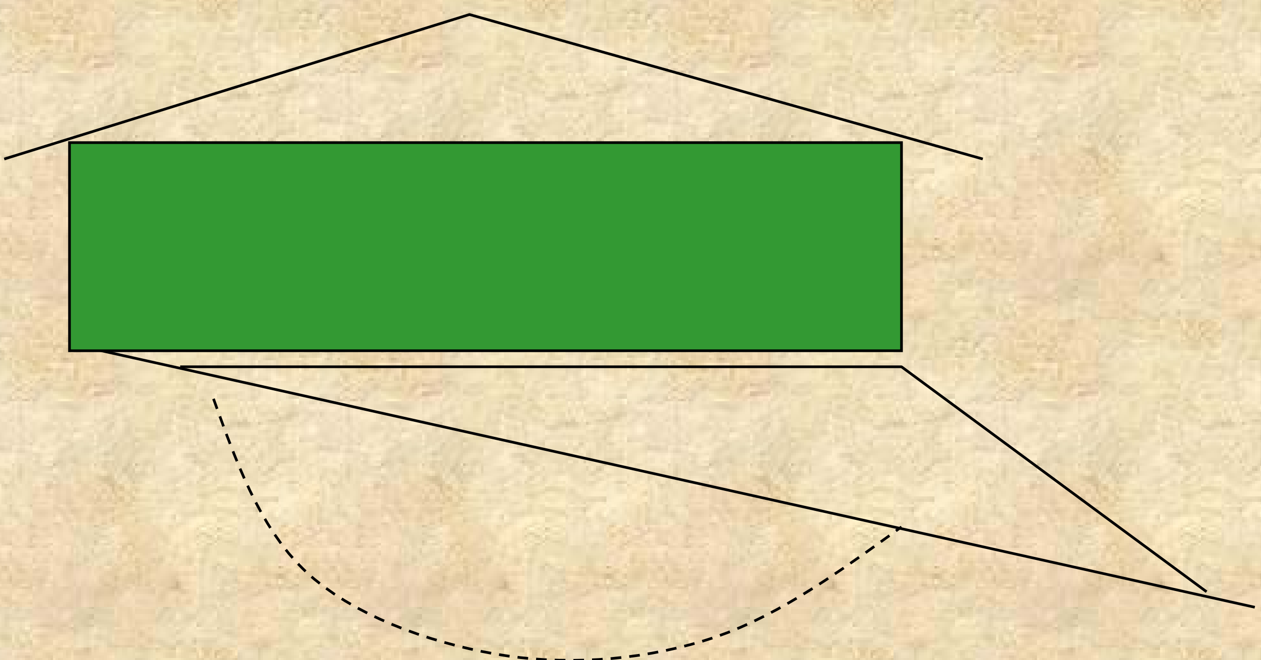
Pool Leak or“Groundwater”

Likely irrigation water and “groundwater” not pool leak.

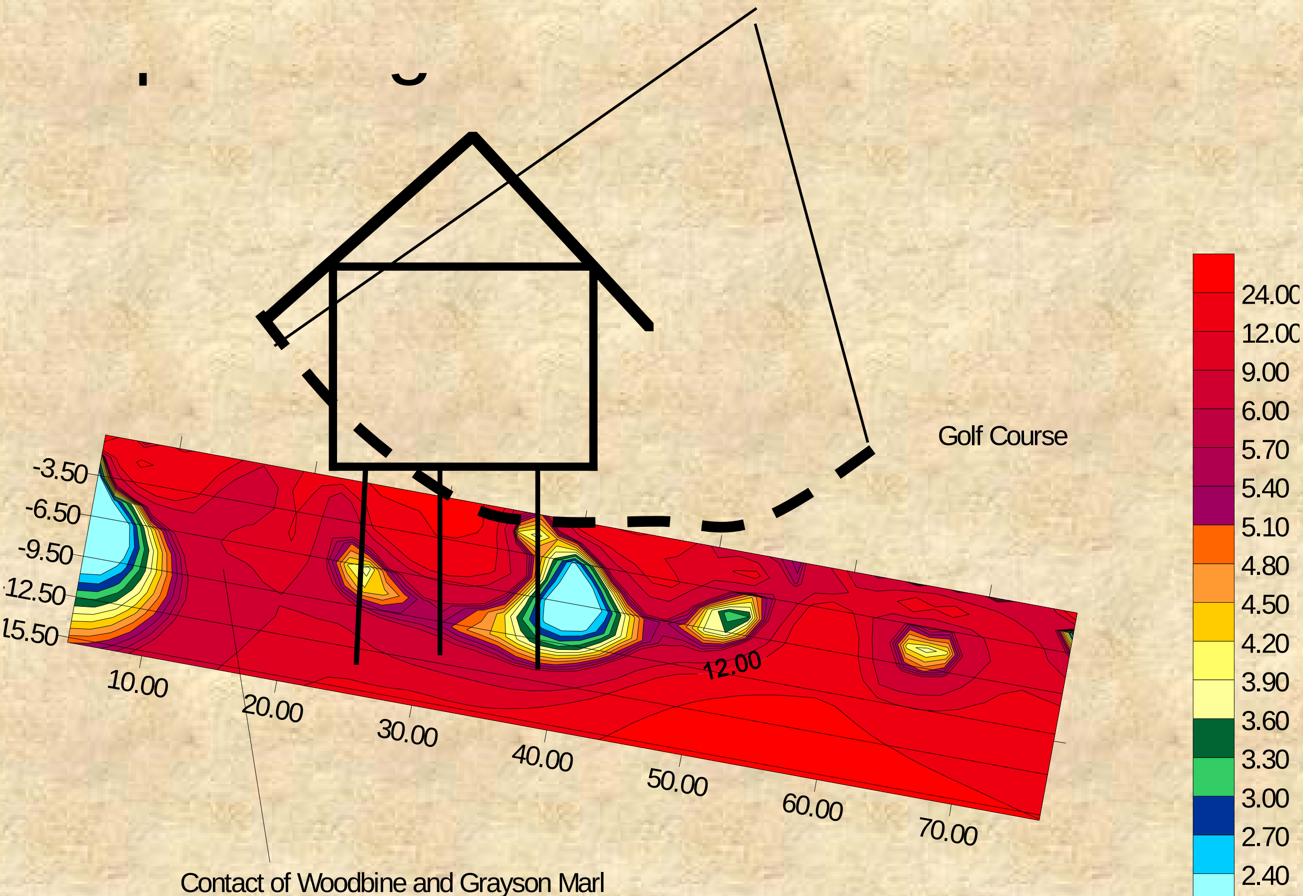
Case Study 2

Slope Failure

Slope Stability Example



SLOPE FAILURE
NOT A PLUMBING LEAK



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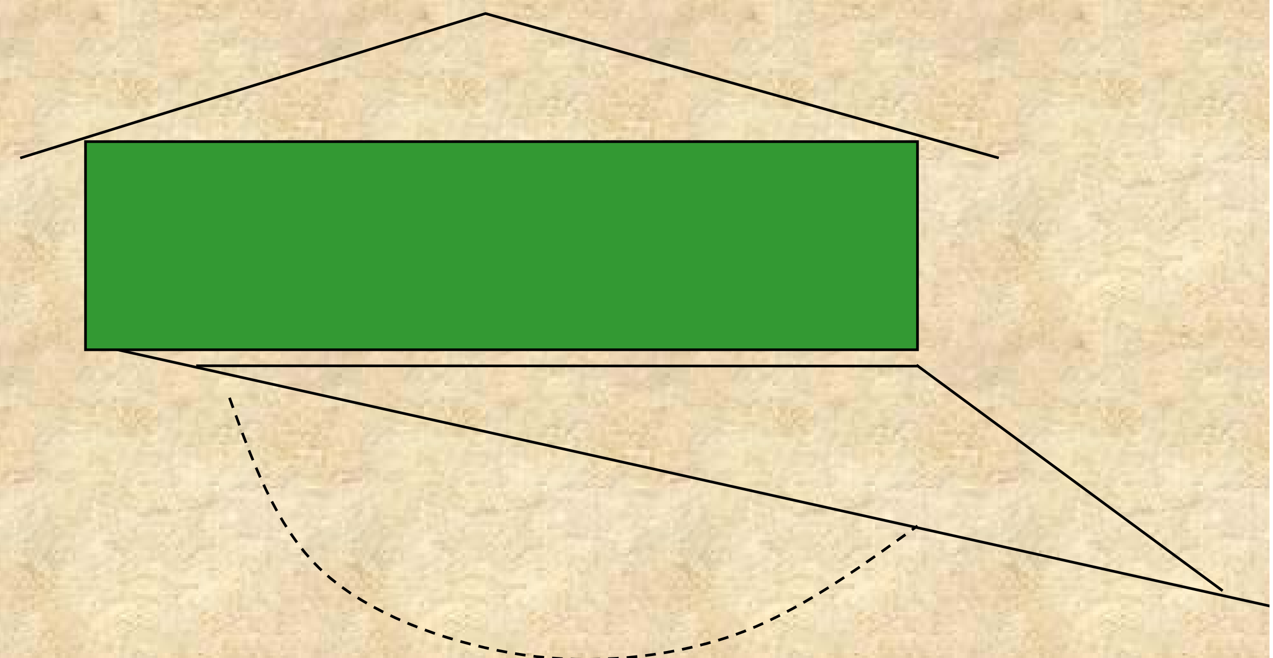

- A house severely impacted by a slope movement – what caused it ?

- Soil movement and damage not restricted to sloping ground – water also caused massive foundation erosion (fortunately the house was piered) …….

- Not to mention retaining wall problems….

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and pool problems……

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- *Piezometers and inclinometers to the rescue…….*

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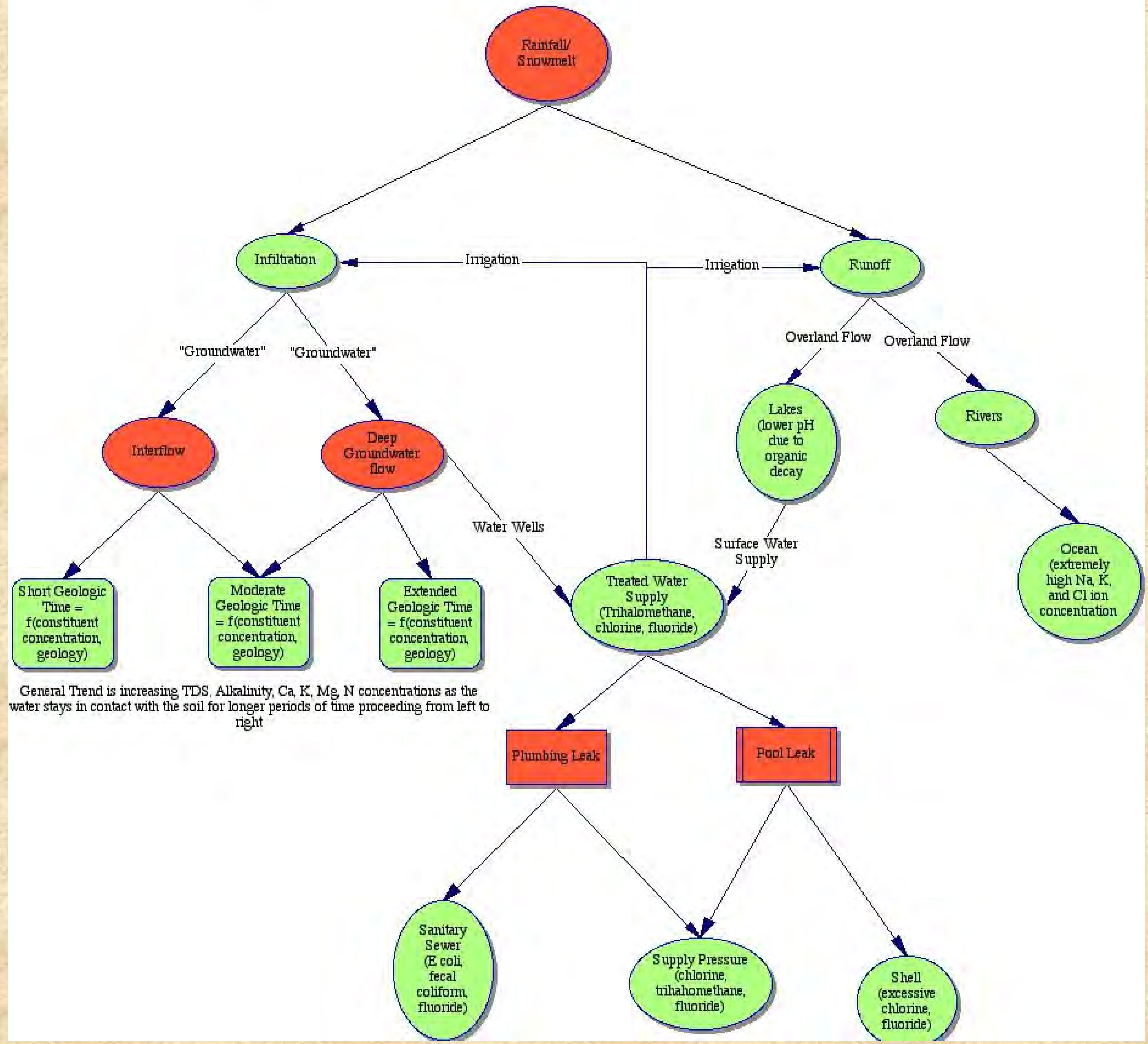
Water Source Differentiation Decision Tree



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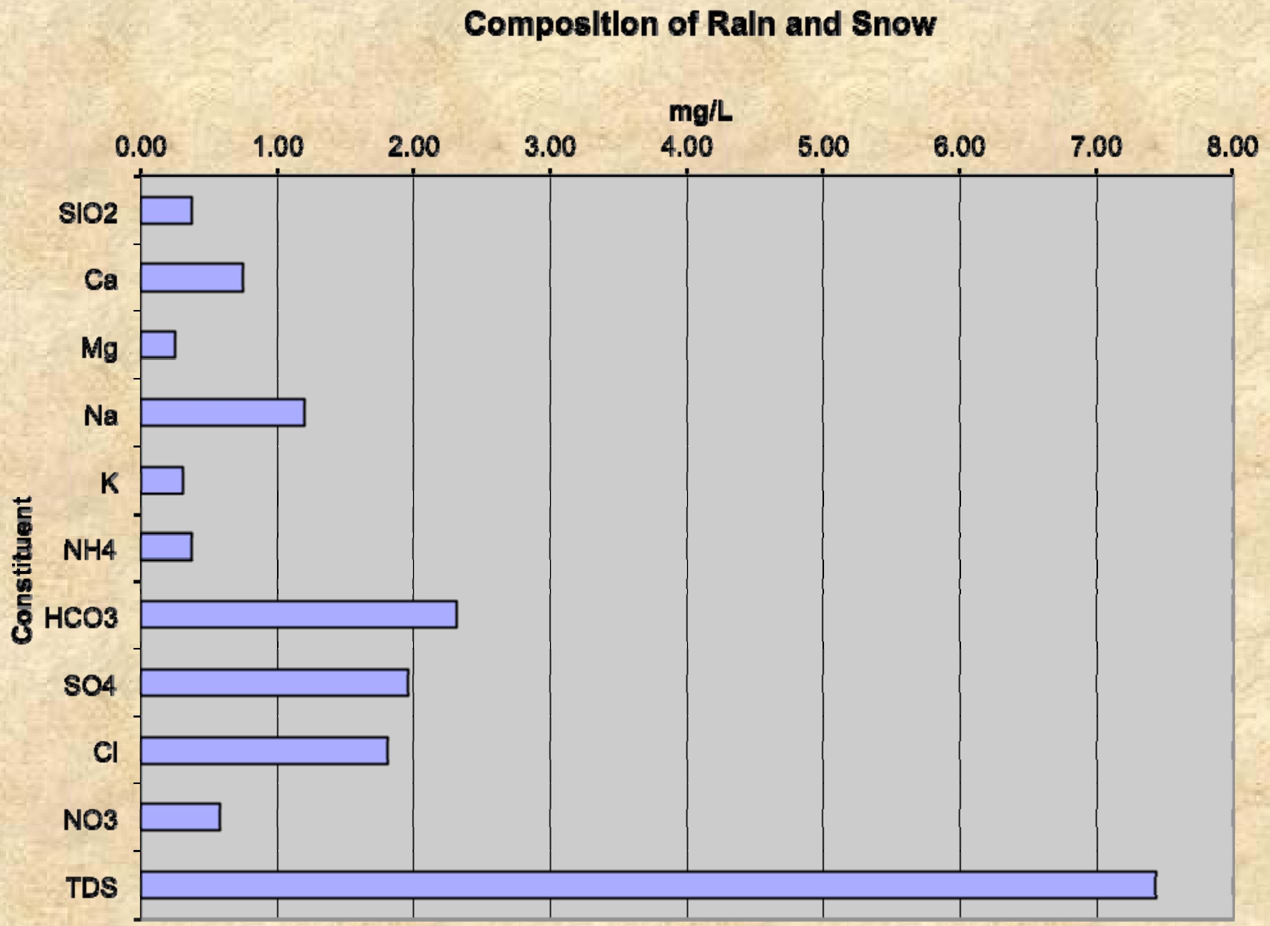

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Observations from boreholes:

Calcium much higher than water supply values,

Sodium and Chloride lower than water supply,

Fluorides present, but below tap water,

Alkalinity much higher than water supply values

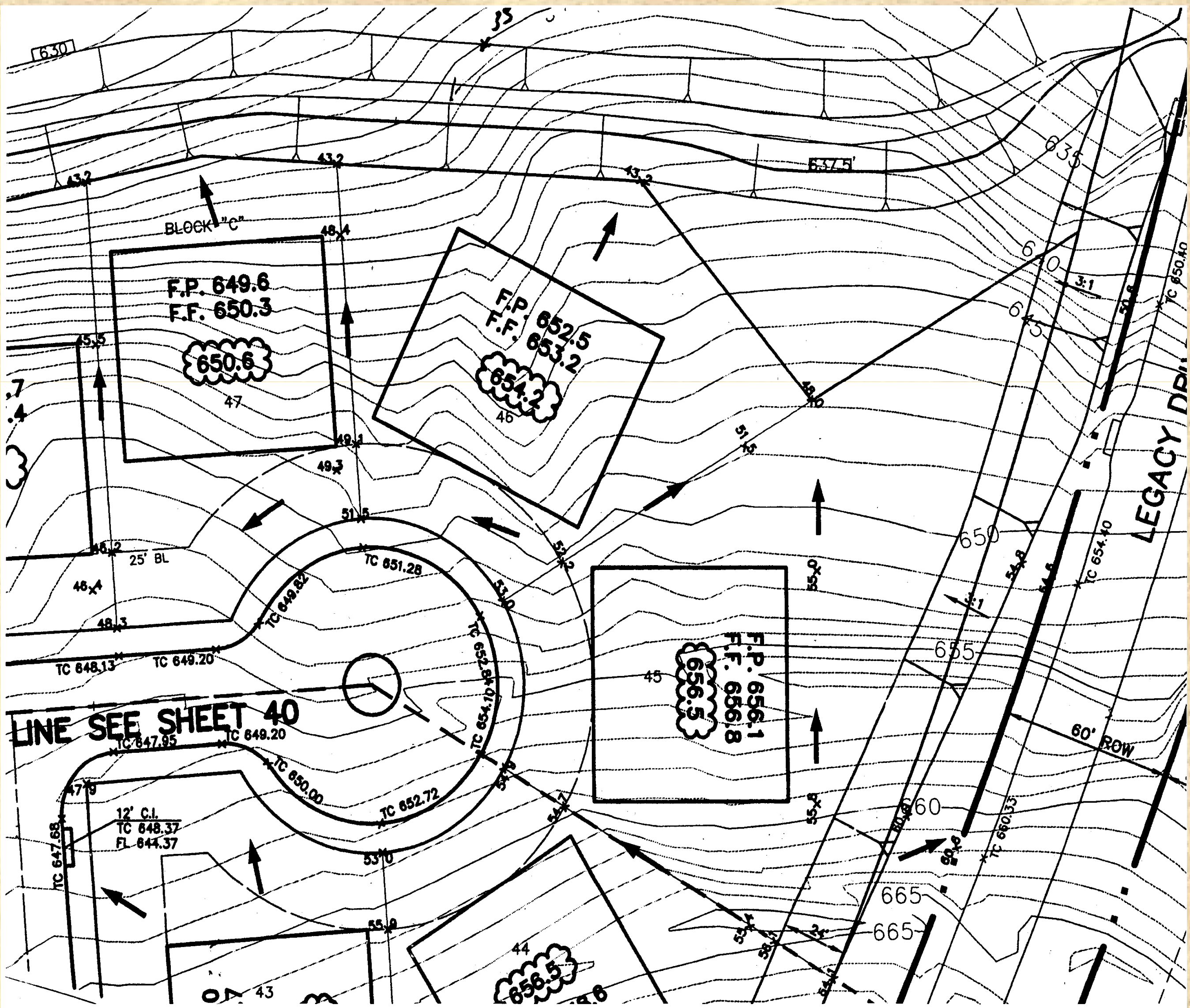
No detectable chlorine – no nearby tap water

Hardness and Dissolved Solids much higher than tap

pH a little low, but inconclusive

Parameter Measured (ppm)	**Borehole 1**	**Borehole 2**	**Denton Tap Water**	**Coppell Tap Water**	(Drinking Water Maximum)	(Detection Limits)
Calcium	163	3260	33	25	40	2.5
Sodium	61	82	144	-	275	10
Chloride	59	77	435	--	500	5
Fluoride	0.14	0.16	0.26	0.24	2	0.01
Total Alkalinity	342	328	124	84	150	2
Chlorine	below 1	below 1	1	2	5	1
Hardness	280	346	90	94	200	5
Dissolved Solids	634	664	234	182	500	10
pH (no units)	6.8	6.8	8.2	6.8	6.5 – 8.5	0.1

Study of original ground contours reveals presence of a historic drainage gully through the site.



Case Study 2

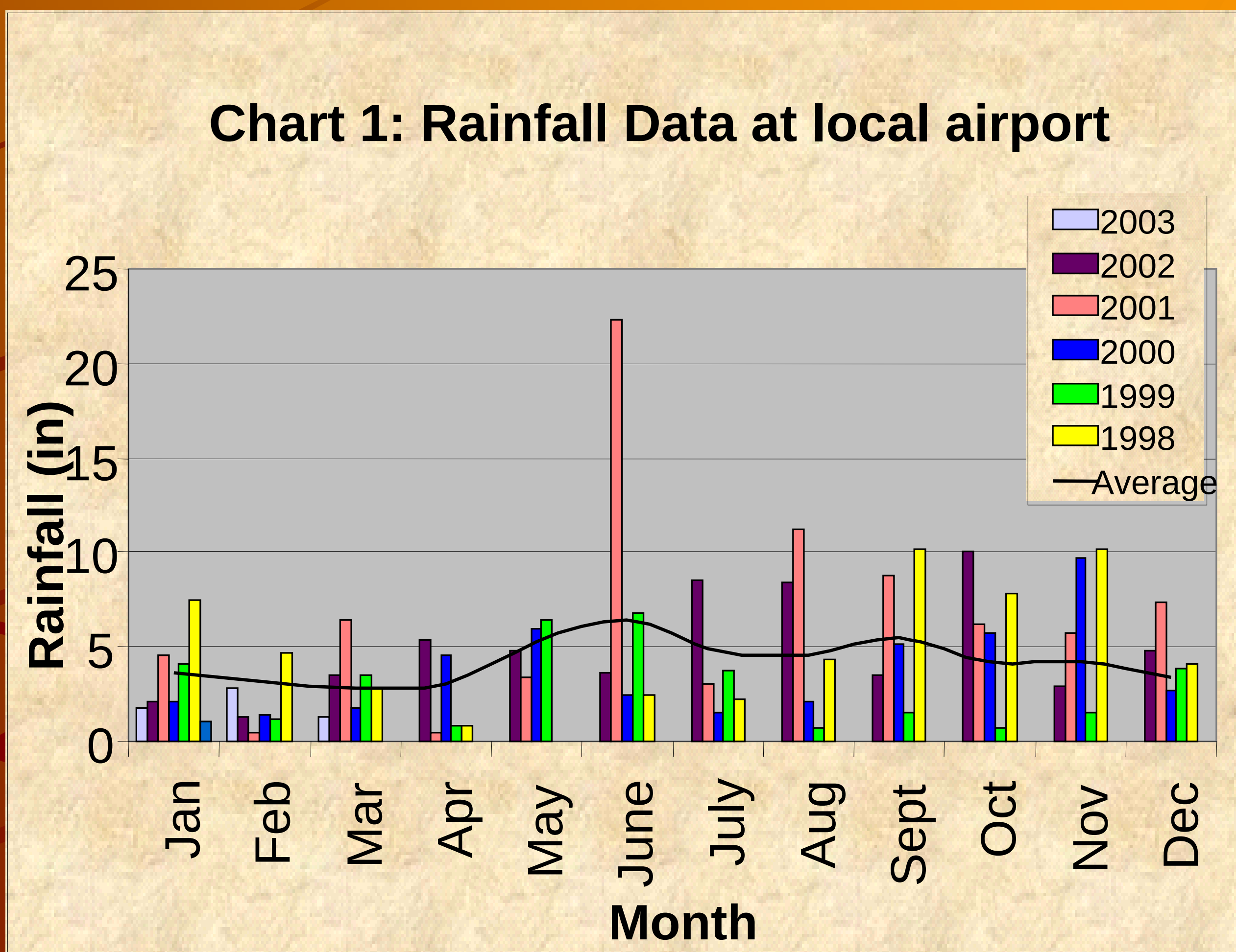
Slope Failure

Likely due to interflow and short to moderate contact with soil, some possible deeper groundwater recharge—Also at the geologic contact between Austin Chalk limestone (basically calcium) and Eagleford Shale

Case Study 3

Apparently trivial problem – why was this trench so frequently wet ?

Question – was this simply an unusual rainfall event….



Possible Sources of Water

RAINWATER/
ROOF
GUTTERING

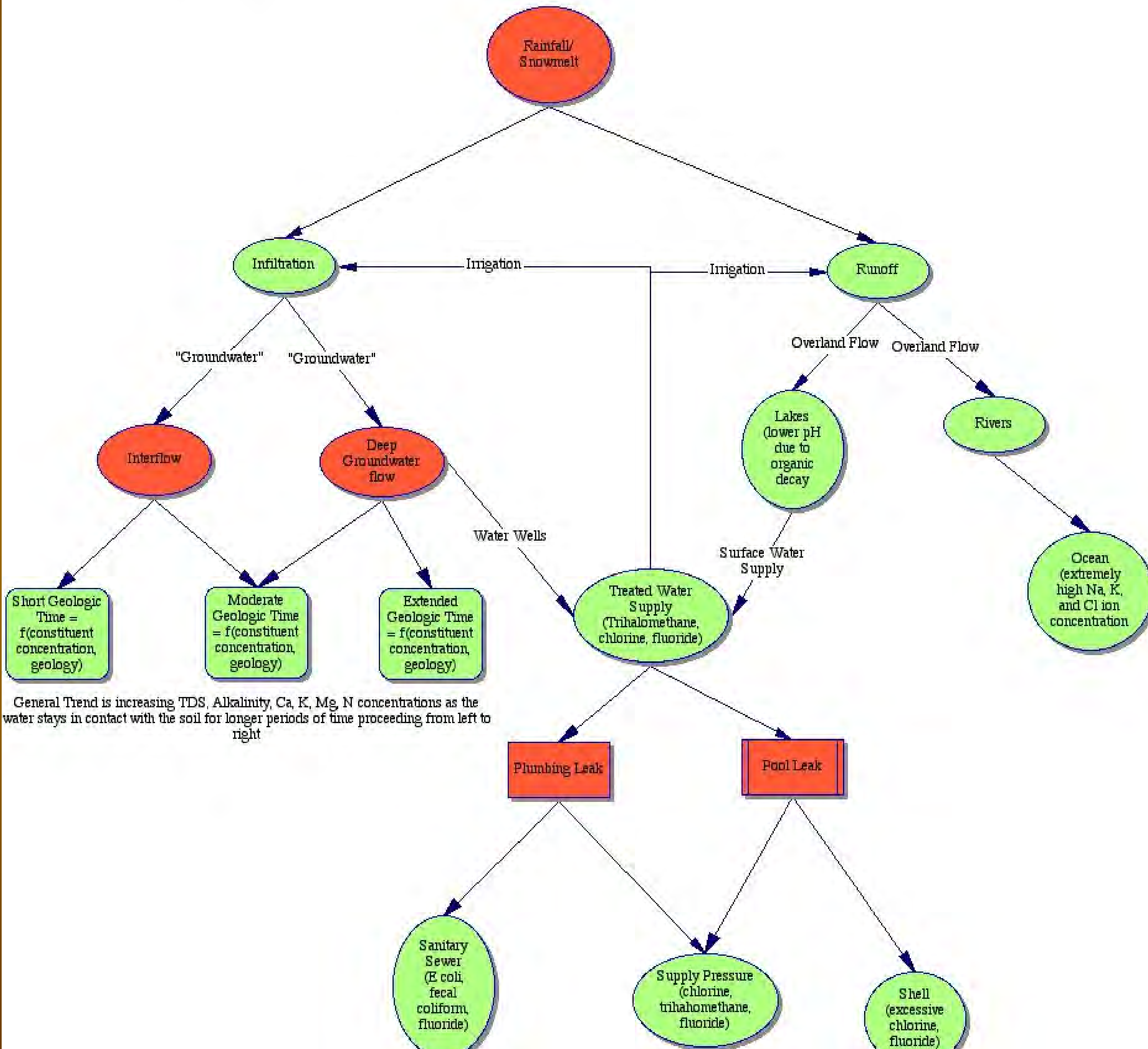
WATER
SUPPLY PIPE

GROUND
WATER

RUNOFF
FROM
SURFACE
DRAINAGE

(no pool in
this case)

Water Source Differentiation Decision Tree



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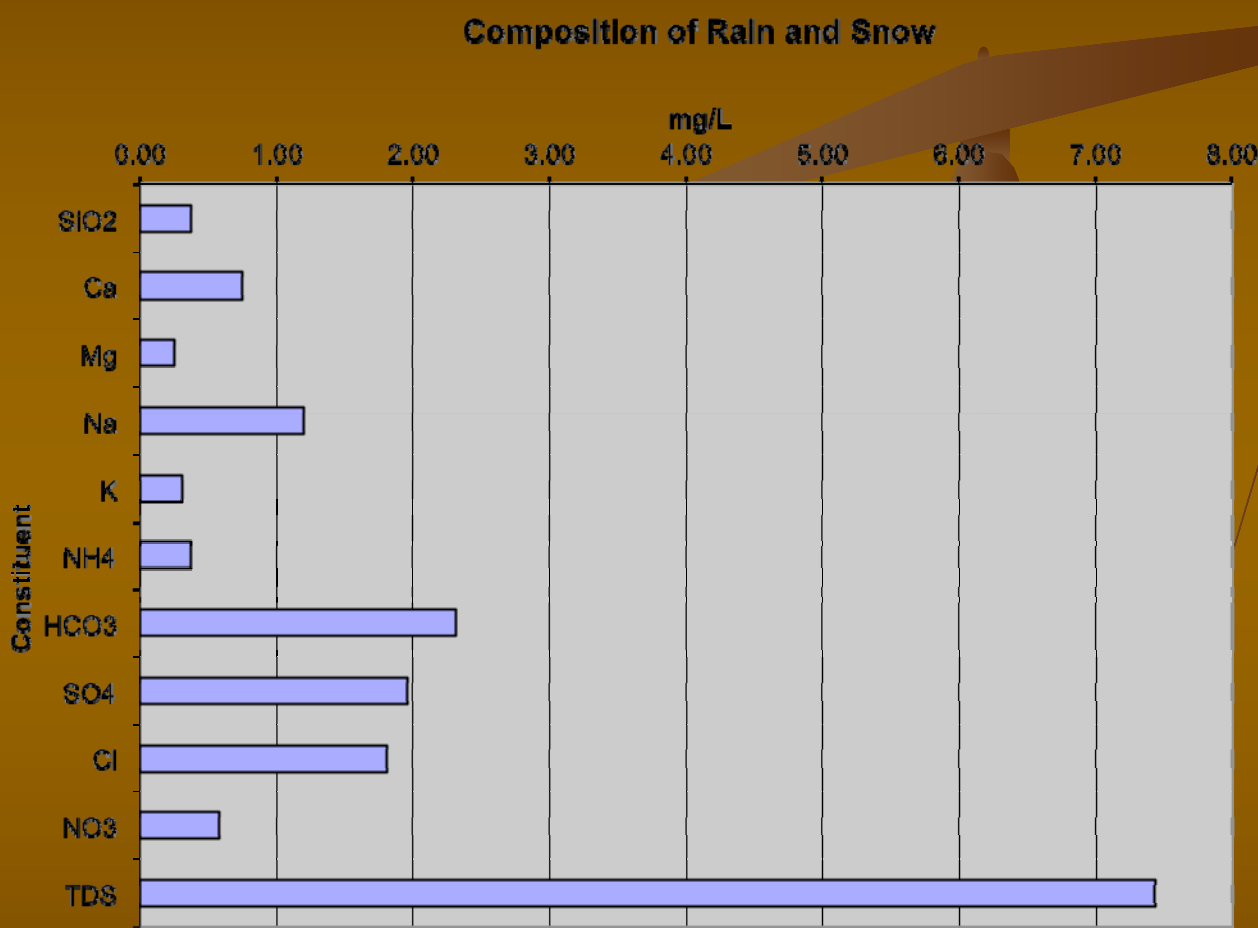

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Or something more ?

Calcium, iron, sodium, chloride & fluoride all higher than tap water – probably from soil,

Hardness, dissolved solids, and alkalinity – implies leaching through rather than run-off over soil,

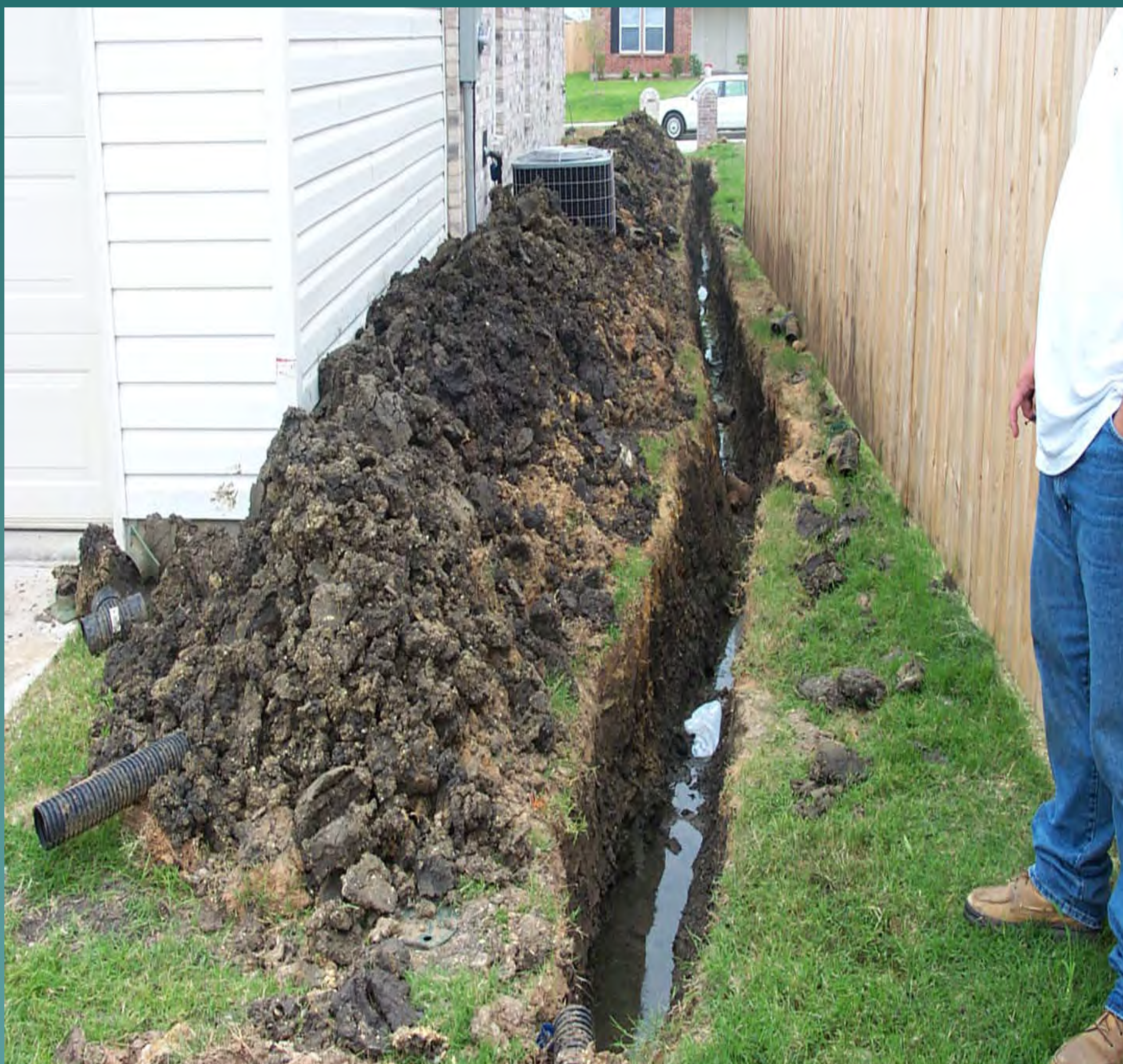
Chlorine inconclusive in this case – no pool anyway,

Conductivity much higher (resistivity lower) consistent with considerable transport through permeable media,

pH slightly higher than tapwater – unlikely to be rainwater

Test Item (ppm)	TapWater	Piezometer
Calcium	27	130
Iron	< 0.10	1.5
Sodium	12	310
Chloride	15.2	110
Fluoride	0.65	2.15
Hardness	80	560
Dissolved Solids	180	1700
Alkalinity	20	330
Chlorine	< 0.05	< 0.05
Conductivity	260	2400
Resistivity (ohm.m)	38.5	4.2
pH	7.0	7.3

Explanation – perched water seepage



Case Study 3

Likely due to deeper groundwater flow and some interflow

Conclusions

- **Water Chemistry measurements can be a significant help in identifying groundwater sources;**
- **The method is generally not expensive for the most commonly encountered chemical components;**
- **Care must be taken to allow for possible changes in the geo-chemical composition, based on travel path and time;**
- **The technique is significantly underrated in current practice.**

??QUESTIONS??