Differentiation of Water Sources using Analytical Water Chemistry Data

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Abstract

Assessment of the groundwater regime at a site can often be at the heart of determining subsurface conditions, especially those related to geotechnical and geological problems. Furthermore the sources of such groundwater can be more complex than is generally thought, particularly in an urban setting, where additional sources can also be present from manmade construction and water leaks of various kinds. A simple and relatively cost-effective tool for analyzing such problems, can be to analyze the water and ground-water chemistry around a site. Three case histories are presented where this procedure has been utilized.

Introduction

In the standard hydrologic cycle assumed by most textbooks (e.g. Wurbs & James, 2002) rainfall and its concentration into surface water is generally assumed to be the source of most groundwater. However in the modern constructed environment, human activity generates additional complications. Furthermore, the movement of the groundwater can also affect the water quality characteristics, even for short travel paths. In areas of the South-West where moderately expansive clays are present, further problems can arise with residential houses built on slab-on-grade foundations. Quite small non-uniformities in groundwater in expansive soil can cause foundation and structural distress, since the standard maximum allowable foundation differential movement is 40 mm. (1.5 in.) for the entire slab length (Ballast, 1994).

The complex nature of groundwater chemistry has been known for some time (Freeze & Cherry, 1979), although initial study in this area was driven by contamination studies, rather than by geological engineering considerations. However the percentage amount of any chemical present in water samples collected from groundwater, tapwater, pools and storm drains will have measurable amounts of minerals, which can sometimes differentiate the source, especially as certain amounts of trace elements are usually added to tap water for public health reasons.

Chemical Analysis

Groundwater can be viewed as an electrolyte solution because nearly all its dissolved constituents are present in ionic form. The major constituents are calcium, chlorides, magnesium, sodium, sulfates and carbonic acid. The total concentration of these six major ions normally comprises more than 90% of the total dissolved solids in the water.

The primary reference source of water used for comparison purposes is usually the local drinking tap water. Indeed in many cases the approximate percentage of the various constituents may already be known. For instance in the Dallas metropolitan area, the table below lists the levels of trace chemicals detected in 2000, compared with the amounts allowed by state and federal law, where applicable.

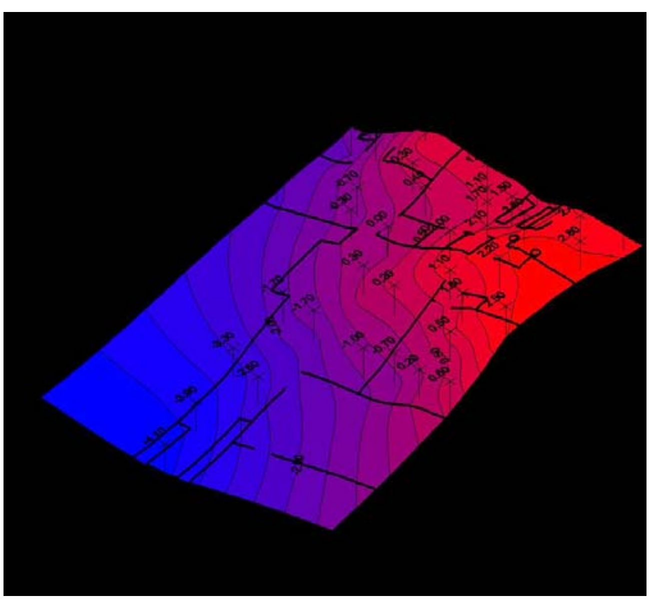
Chemical	Average	Range	Maximum	Possible Source
Total hardness	131 ppm.	108 -179		Natural (calcium)
Total alkalinity	77 ppm.	48 - 106		Natural (CO_3 & HCO_3)
Sodium	28 ppm.	8 – 39		Natural
Chlorine residual	3.15 ppm.	2.8 – 3.6	0.5 - 4	Water treatment
Fluoride	0.67 ppm.	0.2 - 1	4	Public health additive
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

Table 1: North Texas Tap Water Averages

However, at a particular site, tap water may be totally absent as a source of groundwater. Also the concentrations of the constituents are liable to be modified by the geology through which the water has passed, as well as possible mixing of water from various sources.

Analysis of a Groundwater Mound under a Residential Structure

The first case history shows a house that had developed diagonal cracking, as shown in Figure 1, to an extent that remedial repairs were being contemplated. The foundation was being adversely affected by a noticeable heave in one corner of the slab foundation, as shown on Figure 2. A number of things could have been responsible for this problem. From a legal point of view, the most important of these was the possibility of an underground water line leak, which state law would require the home-owner’s insurance to cover, and also a pool leak which would be covered by the appropriate warranty.



In order to address the possible causality, some simple water sampling holes were drilled around the property, to obtain water samples for comparative analysis. Table 2 below shows the results:

Parameter	**Tap Water**	**Pool**	**Downspout**	**Monitoring Hole**	**Yard Hole**	**Pool Hole**
Fluoride(mg/l)	0.67-0.72	0.42 – 1.03	< 0.3	0.81	1.01	0.65-0.87
Chlorine (mg/l)	1.6 - 3.13	2.5 - 18.0	0.02	<0.01	<0.01	<0.01
Dissolved Solids (mg/l)	264.0-288.0	599.0 - 720.0	--	944.0-1152.0	684.0	384.0 - 400.0
Chlorides (mg/l)	46	123.5-134.5	--	122.5-194.5	--	73.5-68.5
Resistivity (ohm-m)	22.2-22.7	9.3 – 10.9	--	5.05 -5.34	12.2	15.4 – 15.9
Alkalinity (mg/l)	176.2	50.6 – 85	--	703.6-710.0	--	117.6-162.6
pH	7.85-8.02	7.78 - 7.81	7.03	7.16-8.35	7.50	8.53 - 9.21

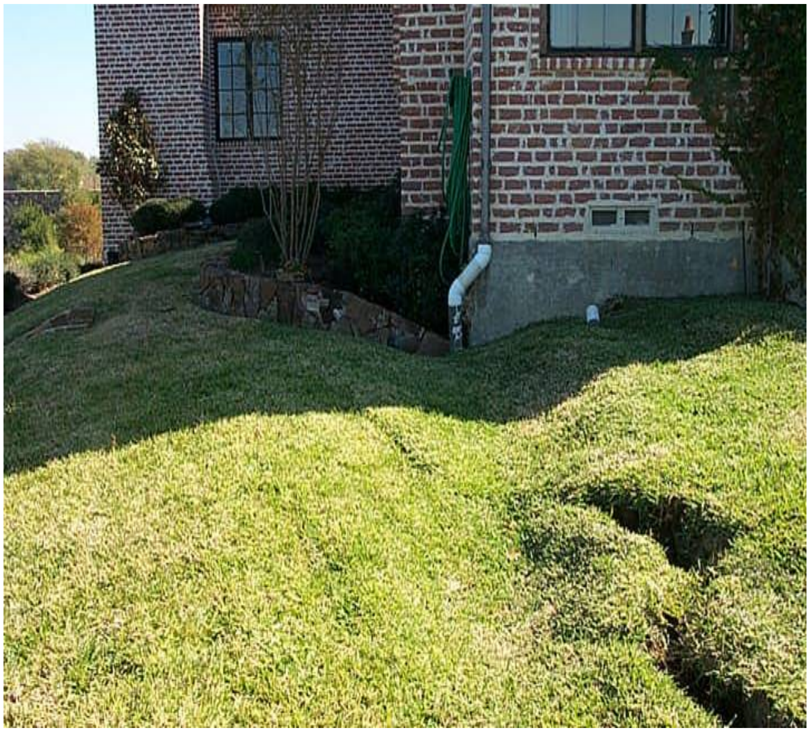
Table 2: Trace Element Observations, Case 1

In this locality, drinking water was artificially fluoridated, so that the presence of fluorides, the naturally occurring form of fluorine, excludes rainwater as the sole source of the ground water mound. Likewise the very low levels of chlorine largely excluded a leak in the pool liner (although chlorine levels will dissipate with time and therefore distance, so that this observation is less conclusive at large distances from a pool). Total dissolved solids were reasonably high, as were chlorides and alkalinity (higher than the water supply), which would be consistent with either groundwater or a substantial travel path of mains water through soils. Resistivity was also lower than either pool or tap water, indicating prolonged contact with fine-grained soils; and the pH was a little less than mains water, indicating some possible mixing with rainwater (which is almost always more acid than groundwater).

In this case, it was recommended that the domestic water lines be tested, and a slow leak was found a short distance away, but linked to the ground water mound by the plumbing trench. Expansive clay soils were also found to be present under the relevant corner of the house, which had evidently been activated by the additional water. Since this eventuality was covered by the homeowner’s insurance policy (including the cost of foundation and structural repairs), the client was unusually pleased with the outcome of this investigation.

Significant Slope Instability Threatening a Foundation

In this example, a multi-million dollar house was being threatened by a landslide that intersected the front part of the foundations. This property faced a lake that had been privately constructed, and shortly after construction an incipient slope failure had started to develop, essentially consisting of a rotational failure surface sliding into the lake. Figure 3 shows one side of this, extending underneath the side of the house facing the lake. At this time, cumulative movements were about 0.3 m (1 ft.), and inclinometer measurements showed that the displacements were increasing at the rate of several mm. per month, accelerating during wet periods. Because the house was actually supported on substantial concrete piers, the structure appeared intact, with no evident distress in the form of cracking or floor slab dis-elevations. There was also a pool present, although this had been constructed separately and the shell appeared intact. Water chemistry data from two boreholes drilled on the site gave the following results:

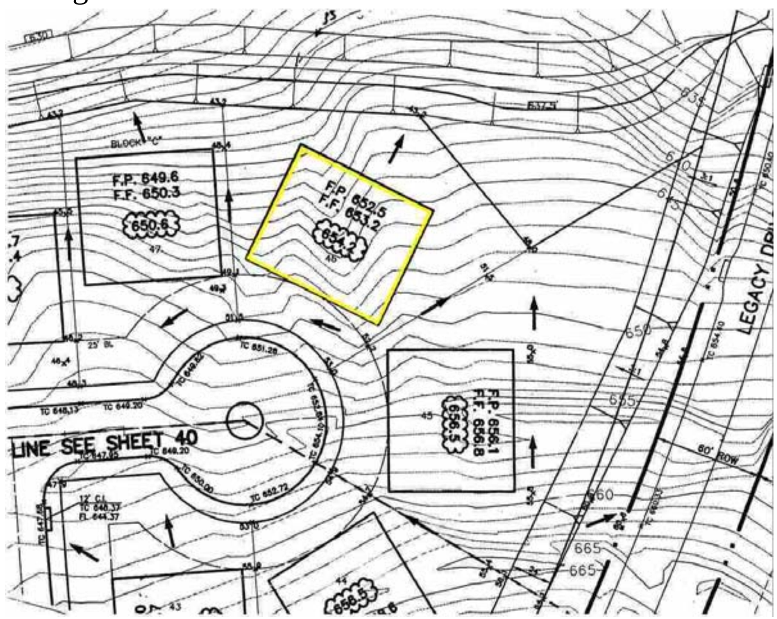


Parameter (ppm)	Borehole 1	Borehole 2	Denton Tapwater	Coppell Tapwater
Calcium	163	3260	33	25
Sodium	61	82	144	-
Chloride	59	77	435	--
Fluoride	0.14	0.16	0.26	0.24
Chlorine	below 1	below 1	1	2
Hardness	280	346	90	94
Dissolved Solids	634	664	234	182
pH	6.8	6.8	8.2	6.8

Table 3: Trace Element Observations, Case 2

Sampled groundwater showed calcium concentrations much higher than water supply values, which tended to exclude a rainwater source. Sodium and chloride levels were lower than the water supply, which probably excluded line leaks, but implies that any groundwater would be freely flowing without spending considerable residual time in the ground. Fluorides were present, but again below tap water values, and were therefore probably picked up primarily from the soil mineralogy. No chlorine was detected, therefore no nearby tap water. Hardness and Dissolved Solids much higher than reference, also implying a groundwater source. The pH was low, which would normally correlate to a rainwater source, but in this case one of the local water supplies also provided somewhat acidic water, so that this observation was inconclusive - however it did imply that any detention times in the ground must have been reasonably short.

Overall, these results indicated a groundwater source, but one that originated not very far away, and was reasonably freely flowing with short transit times in the subsoil. Subsequent study of the original ground contours from the grading plans revealed a historic drainage gully through the site, as shown on the adjacent Figure 4. This almost certainly acted as a short underground aquifer conducting a certain proportion of the uphill runoff underneath the property. The significance of this observation in this case, was that the responsibility then transferred from the homebuilder to the site developer, who had been responsible for the infilling of the original site contours (probably with poor quality fill from the site of the present-day lakebed), and the matter was then referred to legal counsel for adjudication.



Perpetually High Standing Water

The third case history involved a developer that had a problem with recurring wetness in a new development. This was evident every time utility trenches were laid out, as can be seen from Figure 5. The question was whether this was simply due to unusual rainfall, or something more, like a water supply pipe, adverse roof guttering directing rainwater to the wrong places, groundwater or runoff from surface drainage. Again trace element concentration measurements were taken from the water in question, and the following results obtained:

Parameter (ppm)	Local TapWater	Seepage Water
Calcium	27	130
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
pH	7.0	7.3

Table 4: Trace Element Observations, Case 3

In this instance, chlorine levels were below detection in both cases, so this parameter was inconclusive (there was no pool on the property anyway, so this could be excluded as a source). The pH measurements showed it to be significantly more alkaline than rainwater or even local tapwater, thereby excluding local rainwater as a possible source. Concentrations of calcium, sodium, chloride & fluoride were all higher than tap water, so these could really only have come from the soil mineralogy. Likewise levels of hardness, dissolved solids, and alkalinity were also significantly above either tap water or rainfall levels, which again implies substantial leaching through long distances in the soil, rather than short transport distances from surface run-off or water leaks. Further substantiation was shown by the conductivity which was much higher in the sampled water, consistent with considerable transport through permeable media

As a result, it appeared likely that the explanation was perched water seepage at this site, from subterranean sources. This was later addressed by further hydrogeological studies, which confirmed this assessment. As a result, responsibility could not be placed upon any individual homeowner or builder, and it became necessary to accept that subground seepage resulting in a high water table was simply a generic problem here.

Conclusions

Water chemistry measurements can be a significant help in identifying groundwater sources, both from a geologic point of view, and from an engineering point of view in terms of decision making. In the view of the authors, the technique is significantly under-rated in current practice, as the method is generally not expensive for the most commonly encountered chemical components, particularly if carried out on a routine basis by laboratories that might more usually be carrying out chemical analysis for other purposes. Of course, there are dangers on overly simplistic interpretation of the results - in particular care must be taken to allow for possible changes in the geo-chemical composition, based on travel path and time. However such analysis can represents a very cost-effective way of addressing questions that might otherwise require a much greater level of exploration.

References

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