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Groundwater notes

by Nick Doe with Norm Windecker

Gabriola receives, on average, about 35 inches of rain every year (900 mm), seventy-five percent of which falls in winter. That's a lot of water. It means that in most seasons, you could easily fill a medium-sized cistern (2000 gallons) with rain collected from one small, 12 by 12-foot area.

A quick, back-of-an-envelope calculation shows that, in theory, enough water falls on Gabriola to sustain a year-round flow of 1.4 cubic metre per second (19000 gallons a minute). That's not enough for a river you could paddle a canoe on—the Nanaimo River, for example, is in the 10–20 cubic metres per second range—but it would be enough for a substantial fast-flowing stream; one you'd hesitate to jump or wade across.

However, in spite of all this water, Gabriola is not noticeably endowed with waterways, nor is flooding a serious problem. What creeks there are, are mostly ephemeral. To be sure, there is one small lake, a few ponds, and in winter, the seldom-visited sandstone beaches become unpleasantly slick with the algae that flourish in the seeps of freshwater trickling down to the sea. But for the most part, the island seems to soak it all up.

At our latitude, most precipitation is returned to the atmosphere through evaporation or through the "breathing" of plants and trees (*transpiration*). On Gabriola—we have to use figures from elsewhere here—probably about 60% of the return flow in the hydrological cycle is by evapotranspiration. We can surmise that of the remaining 40%, somewhere in the vicinity of 20–30% is runoff, and 10–20% infiltrates into the ground. This is one of those ratios that is influenced in non-simple ways by the nature of the vegetation (clear-cuts, farmland, mature forests); the kind of human development (how much runoff-enhancing "blacktop" and ditching); and the opinion of experts without hard facts.

So, the bottom line is… we have, if these "guesstimates" are right, the equivalent of one modest creek putting water into the ground, year-round, at around 0.2 cubic metres (one bathtub) per second. It's a lot; but, as Gabriolans know, it's a far cry from being an unlimited supply.

The other day, out of interest, after a week of heavy rain, I took home a couple of fist-sized rocks, dried them off with a paper towel, and then stuck them in a warm oven.[1] One was sandstone. As it dried out, its weight dropped from 269 g to 263 g, a modest loss of only 2% or so, but the other, a piece of weathered mudrock (shale) about the same size, lost almost 10% of its weight as it dried out.[2, 3]

It is probably no surprise to anyone that sandstone does retain *some* water—it looks very porous, even though it's not. Most beach-going Gabriolans also know that

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[1] Never put rock in a microwave oven. It is very dangerous.

[2] The "sandstone" on Gabriola is greywacke. "Shale" is the word used by islanders, including myself, to describe any kind of mudrock, although, technically, not all the mudrock on Gabriola is shale.

[3] A day or two later, the mudrock had regained about 3% of the lost weight—some of the minerals within it must be hygroscopic.

towels dry out faster when laid out on granite boulders than they do when laid out on sandstone ones, and that lighting a fire on sandstone can be dangerous because the rock may explode and scatter burning debris as the water within it turns to steam.

Scientists have, of course, measured the rate at which water flows through Gabriola's unfractured sandstone.[4] Plugging their numbers into the appropriate hydraulic equations gives a velocity for water sinking down under its own weight of between one and thirty millimetres per week (just over an inch at most). This is at the low end of the "textbook range" for sandstones; however, judging by the way that water is retained in the holes in the millstone quarry throughout even the driest of summers, whatever the correct number is, it cannot be much more than this.

If you think even an inch per week is slow by the way, you're not thinking geologically. At that rate, it would take water less than twenty years to pass through a hundred feet of "solid rock"—and that's no time at all on a geological scale. That groundwater does indeed seep between the grains of sandstone is evidenced by white deposits of minerals (*efflorescence*) left behind by evaporating water on the undersurfaces of boulders and overhangs where the rain never reaches. Rock "transpiration" is also the cause of honeycombing (tafoni).[5]

However, interesting though that may be, water moving at a few millimetres per week (or a few litres per hour per acre) is obviously not how most of it gets into our wells. Rainwater takes only a week or two to trickle into the ground at the end of the dry season, and it can only move so quickly from the surface by flowing through cracks in the bedrock. Although many fractures are faulted, crushed, or mineralized and conduct no water, others make good water-conduits.

That mudrock retains more water than sandstone is also not such a surprise, even though unfractured mudrock is even less permeable than unfractured sandstone. You can see the water if you squeeze a wet piece between your fingers—the water shimmers on the surface all the while you squeeze, just as it does on the surface of newly-poured cement that has not yet set. The instant you let go, the water disappears back into hairline cracks.[6]

Mudrock underlying sandstone frequently retains water because the hairline cracks in mudrock are tighter, more numerous, and more tortuous than are the cracks in sandstone. Beds of mudrock act like clay soil; they don't stop the downward flow of water, but by forcing it to trickle to-and-fro, they slow it right down, creating reservoirs of backed-up water. It is likely too that this process is enhanced by the thin "pavements" of (locally) impermeable siltstone or fine-sandstone that the mudrock-dominant formations commonly contain.

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[4] The hydraulic conductivity of Nanaimo Group sandstone has been measured to be 10^{-10} to 3×10^{-9} metres per second, and its porosity is about 6% (Henderson, 1962). Data cited in (Hornberger, 1998, p.130) puts this at the low end of the range for sandstones, i.e. 10^{-10}–10^{-6} metres per second.

[5] *SHALE* 9, pp.12–40, 2004.

[6] A response to capillary forces. Unfractured mudrock has a hydraulic conductivity in the range 10^{-13}–10^{-9} metres per second, but in practice, mudrock (as shale) is always fractured. Breaking open lumps of mudrock reveals surfaces covered in an, often-blue, but sometimes earthy yellow-brown, veneer of weathered minerals that are clearly the result of the infiltration of air and water. Weathering by exposure to the atmosphere slowly crumbles cliffs of shale to piles of clitter.

This mudrock cliff on False Narrows below the cemetery illustrates the importance of fractures in determining how groundwater flows beneath Gabriola. The dark area, just to the right of the dog, is where groundwater seeps from the face of the cliff and is probably the exposed plane of a fracture. Minor bedding-perpendicular fractures that run in a N45ºW to N75ºW direction are common along this stretch of coast, and are why there is a cliff, a path parallel to the cliff down from the cemetery, and, come-to-that, a False Narrows here in the first place.

The thin white lines mark exposures of cross fractures or joints that have developed into minor faults. These appear to be conduits for the water. Note the differing heights (A, B, and C) of the thin sandstone interbed. Block A, for example, has slipped down to the *left* relative to block B, and block C has slipped slightly down to the *right* relative to block B. This type of so-called "normal faulting" is characteristic of rock formations that have been stretched horizontally as a result of region-wide folding by tectonic forces, in this case, tens of millions of years ago.

Mudrock also seems to play a major groundwater role in sandstone formations where it is present in *interbeds* often only an inch or two thick. Such interbeds are common in all the Nanaimo Group formations. Once an interbed is saturated with water, water moves through it laterally (along the bedding plane) fairly freely. This weathers the interbed, which perhaps in turn supplies silt and minerals to plug and "heal" sandstone fractures below it. Well-diggers often have to drill down through more than one of these interbeds to ensure an adequate supply of water in a sandstone well.

Fractured rocks depend for their existence as aquifers on a constant supply of water, and although many are able to survive a normal year's 100-day dry season, it has yet to be seen what happens if we get a multi-year drought such as we had in the 1930s.

Picture taken on Gabriola near the end of a very dry dry-season. The water is seeping from mudrock (Spray formation) underlying sandstone (Gabriola formation). Geological contacts like this are often where water collects, and wells in the interior go down a long way to reach "ground" water like this. The ditch is lined with clay.

Two of the more poorly understood aspects of groundwater on Gabriola are the flow paths and flow rates deep below the island. A 400-foot well may sound deep enough to avoid being contaminated for example, but the lack of water nearer the surface may simply be an indication that the rock contains large open fractures that rapidly carry surface water to great depths. Although there are techniques using "tracers", including "natural tracers", to see how fast and how far groundwater travels, these have (as far as I know) never been used in any systematic study of all of Gabriola's groundwater. Standard tests on wells—drawdown, recovery, slug—plus water analysis, characterize aquifers within a short distance of the well (its *radius of influence*) over a period of weeks, but tell little of groundwater flow (if any) over greater distances, depths, and over longer times. All the information on regional flows we have comes from a few shallow, unpumped, observation wells that are used to monitor water-quality and the level of the water-table in various parts of the island.

Both sandstone and mudrock soaked in oxygen-rich water ultimately weather to quartz and clay (*montmorillonite,* less often *kaolinite).* Clay, which often expands when it's wet, collects to form completely impervious beds, and presumably, it's beds like these that kept coal mines beneath Nanaimo Harbour manageably dry. Groundwater is (Norm tells me) never found below a bed of clay. Surficial deposits of clay host year-round swamps and wetlands on the island.

The high secondary (fractured) permeability of the upper Nanaimo Group formations ensures that most aquifers under Gabriola are of the open or *unconfined* variety. Wells are shallow; saltwater intrusion is possible; and water is derived entirely from meteoric water on the island and not from any fabled distant source like Mount Baker. Some wells on Gabriola near the coast do however tap into aquifers that are sufficiently confined for the water pressure to be high enough to drive the water to the surface without pumping. Norm likes to tell the tale of how one day when he was drilling in a small hollow in the landscape, he hit such an aquifer, which promptly sent him scrambling up the slope away from the rapidly rising water in the hollow.

Fortunately, the flow subsided before his rig was completely drowned.

Such *flowing wells* occur in locations where sandstone, or perhaps an interbed, acts as an impermeable cap (*aquitard*) overlaying the bed that actually contains and transmits the water. The water from mudrock interbeds in sandstone commonly squirts, rather than trickles, into well shafts, so such water must be *confined* and coming from an uphill source. According to Snunéymux^{w} elders, there used to be a spring in the reefs in False Narrows below the high-tide mark.

Although, in general, drilling into the major shale formations—the Northumberland and Spray Formations—is a good way to find groundwater, success is not guaranteed. Wells just a few tens of metres apart can have very different depths and flow rates—there's seldom "a big lake" down there. Inclined bedding planes, together with the local dispositions of fractures feeding water into and out of the formation may create topologically complex pools of sub-surface water, groundwater flows, and dry zones. Also to be expected in heterogeneous shale are unconfined aquifers above deeper, semiconfined ones, so well-production rates locally may vary greatly with depth.

The dominant cation in Gabriola groundwater is calcium (Ca^{++}), which is gradually replaced at depth by sodium (Na^{+}) released from sodium-rich feldspar (*albite*) as it weathers, and from former-marine mudrock. The dominant anion is usually bicarbonate (HCO_3^{-}), which is derived from the atmosphere and from dissolved *calcite*, but if saltwater intrusion is a problem then it becomes chloride (Cl^{-}). The acidity (pH) is usually close to neutral.[7]

Water flows down through mudrock more slowly than through sandstone for several reasons. One is that fractures in mudrock are less open than they are in sandstone. The picture illustrates another reason.

The small vertical fracture in the mudrock (Gabriola-Spray intertongue) (*centre of the picture*) makes a water conduit, but it is interrupted here by an interbed of sandstone an inch or two thick (*top of picture*). Although not shown in the photograph, the fracture continues on up through the mudrock for several metres once above the sandstone. In winter, groundwater pours off the top of this sandstone interbed in sheets, indicating that the sandstone is, as it looks, quite impermeable, and not extensively fractured.

This sandstone, which is very-fine-grained, is probably not a true sedimentary interbed, but was originally injected into the mudrock as slurry under immense pressure generated by a major earthquake. Such structures are reported to be common (Clapp, 1912) in the Nanaimo Group formations.

At or near the surface, glacial till that has been compacted beneath a glacier until it is rock-hard (*tillite*) often forms similarly impermeable beds that keep the water-table locally high (*perched*) in winter, thereby creating creeks and other seasonal wetlands.

[7] Earle & Krogh, *Geochemistry of Gabriola's groundwater*, *SHALE* 7, pp.35–42, December 2003. The authors report that "sandstone" wells have a consistently higher than average pH, which is an indication that the water from such wells has been in longer-than-normal contact with the bedrock. Prolonged contact of groundwater with the bedrock may raise the concentration of trace elements like boron and fluorine to undesirably high levels.

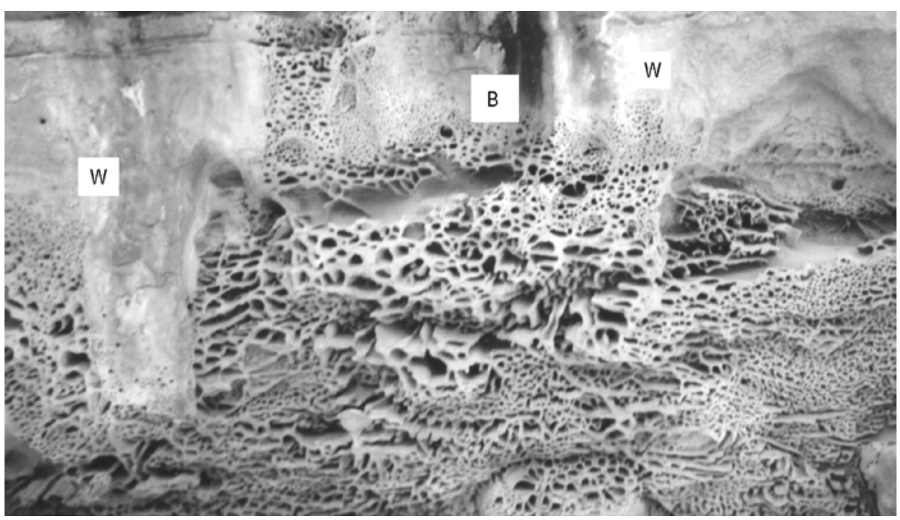
Iron, manganese, and sometimes aluminium are present in higher than average amounts.

The salinity (*total* dissolved solid content, not just “table salt”) of the water, which can be estimated from its electrical conductivity, varies widely both with location and time of year. Salinity levels in wells in the recharge zones often drop in winter due to the influx of freshwater. Levels of salinity in wells further down the groundwater path, where the water is more mixed, are usually higher, but more stable, even though the dominant cation in the water may be changing as it matures. However, even very low levels of saltwater intrusion (less than can be tasted) will cause salinity to spike.

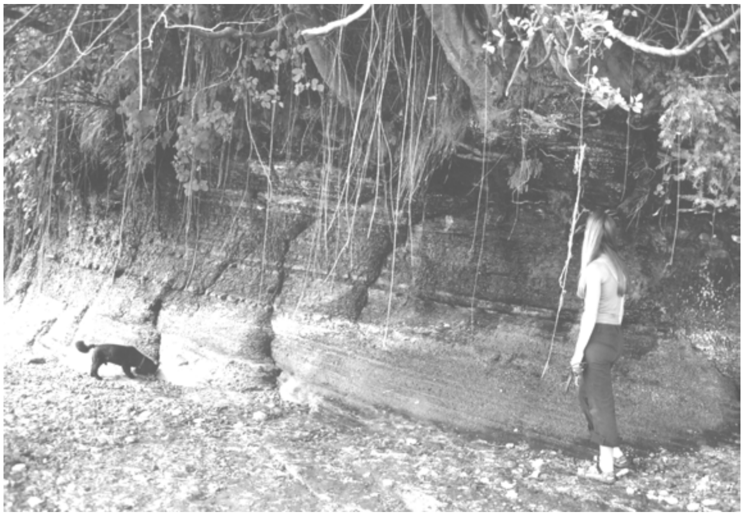
All wells on Gabriola show seasonal fluctuations in water level, even those that are not pumped. This, together with only modest mineralization of the water, indicates that aquifers are constantly being replenished and do not contain fossil (*connate*) water. Well-diggers do sometimes come across pockets of foul water, presumably trapped in the sandstone by a lack of exit fractures. This water, at a guess, might be many decades old, but the fact that it is not salty means that it is not of ice-age origin.

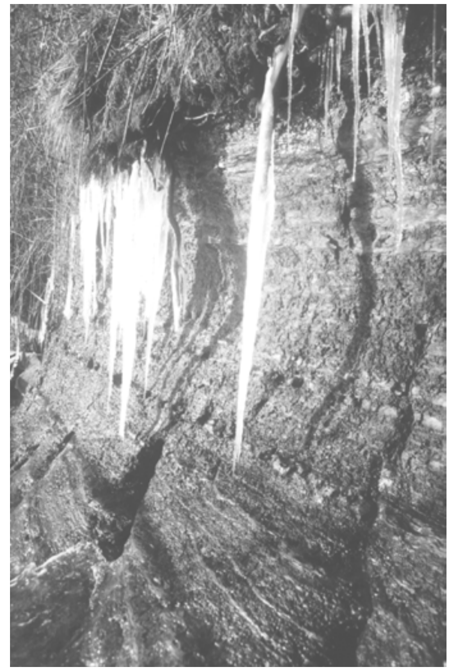
Minor discharges of groundwater from cliffs in the rainy season are often seen. In summer these are variously marked by white evaporite that contains various carbonates and sulphates; black lichen; green algae; or, if the flow is high enough, moss, ferns, and slime. The Maples on the Northumberland Formation, and at the end of a significant strike-slip fault, is one of those few points on the Gabriolan shoreline where there is a year-round seepage of freshwater, no matter how dry the season. This same fault runs by the gravel pit at the end of Dorby Road, where there is also always surface water.

One of the notions about groundwater that it’s very easy to unwittingly adopt is that human beings “consume” water. They don’t of course—they only re-direct it. If your house has a pipe carrying water into it, and there isn’t exactly the same amount of water leaving it, then it must be getting pretty damp inside. Not all the used water returns to become groundwater, for the same reason that not all rainwater does, but nevertheless, when you think about it, the notion that there aren’t many year-round creeks on Gabriola is not entirely correct. It’s just that our creeks don’t flow across the surface to



Groundwater seepage from rockfaces is common. Some leave white evaporite (W), others are black from lichen (B). The lichen appears to prefer seepages that flow freely in winter; while the white evaporite accumulates where seepage is slower and persists into the summer season. Both seepages inhibit honeycombing, likely because visible surface flows keep the rock free of salt. It is salt that causes honeycombing and creates galleries, not the “wind and the waves”.





A spring at the south end of the strike-slip fault that crosses the island from the Maples to the Dragon's Keep (N48ºE). The cliff face here is perpendicular to the nearby cliff face at the cemetery, and so may be a cross fracture exposed by the strike-slip faulting. Always good for a drink; lush, tropical-like greenery throughout the summer (*above*) and showy icicles in winter (*right*).

the sea; they flow down through the ground to it. Beneath our feet, there must be ponds and pools; "wetlands" and deserts; streams and networks of rivulets—a mysterious, mostly-unseen world, every bit as varied as the landscape at the surface. It will take time to get to know and understand it.

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Definitions

aquiclude: porous, but not permeable rock

aquifer: formation that contains and transmits useable quantities of water

aquifuge: rock that is neither porous nor permeable

aquitard: relatively impermeable rock

catchment: an area bounded by a divide across which surface water does not flow in

confined aquifer: aquifer in which the water is under pressure that is contained by an overlay of relatively impermeable rock

drawdown: withdrawing water from a well by pumping. The rate of fall of water level gives information about the aquifer

fracture: any kind of crack in a rock including joints and all kinds of faults

hydrological cycle: the never-ending global circulation of water involving oceans, rivers, and the atmosphere

interbed: a thin bed of sedimentary rock different from the host sedimentary rock

permeable: able to transmit water

porous: containing voids that may contain water. The degree to which the voids are interconnected determines the permeability

radius of influence: for an unconfined aquifer, the smallest distance from the head of a pumped well where there is no observable change in the level of the water-table. For a confined aquifer, the distance from the head where there is no observable change in the pressure in the aquifer

recovery: the restoration of a well to its equilibrium state after drawdown or slug testing. Recovery data gives further information about the nature of the aquifer

slug test: in principle like drawdown except that water is put into the well; however, in practice, there are several kinds of test

unconfined aquifer: aquifer in which the contained water is not under pressure

water-table: the level below which the rock or soil is saturated with water.