Flowing Artesian Wells

Cross border comparisons and notes from experience

British Columbia Groundwater Association

2018 Convention

Objectives

- Basic geology and hydrogeologic definitions
- Explain what an “artesian“ well is
- Explain the types of artesian wells
- Identify where they’re most common
- Explain why it pays to be prepared
- Comparison of Washington and B.C. Regulations
- Open discussion about what more can be done

Fundamentals

- Aquifers
- Confining Units
- Pumping/Flow Rate
- Water Level / Shut-in head

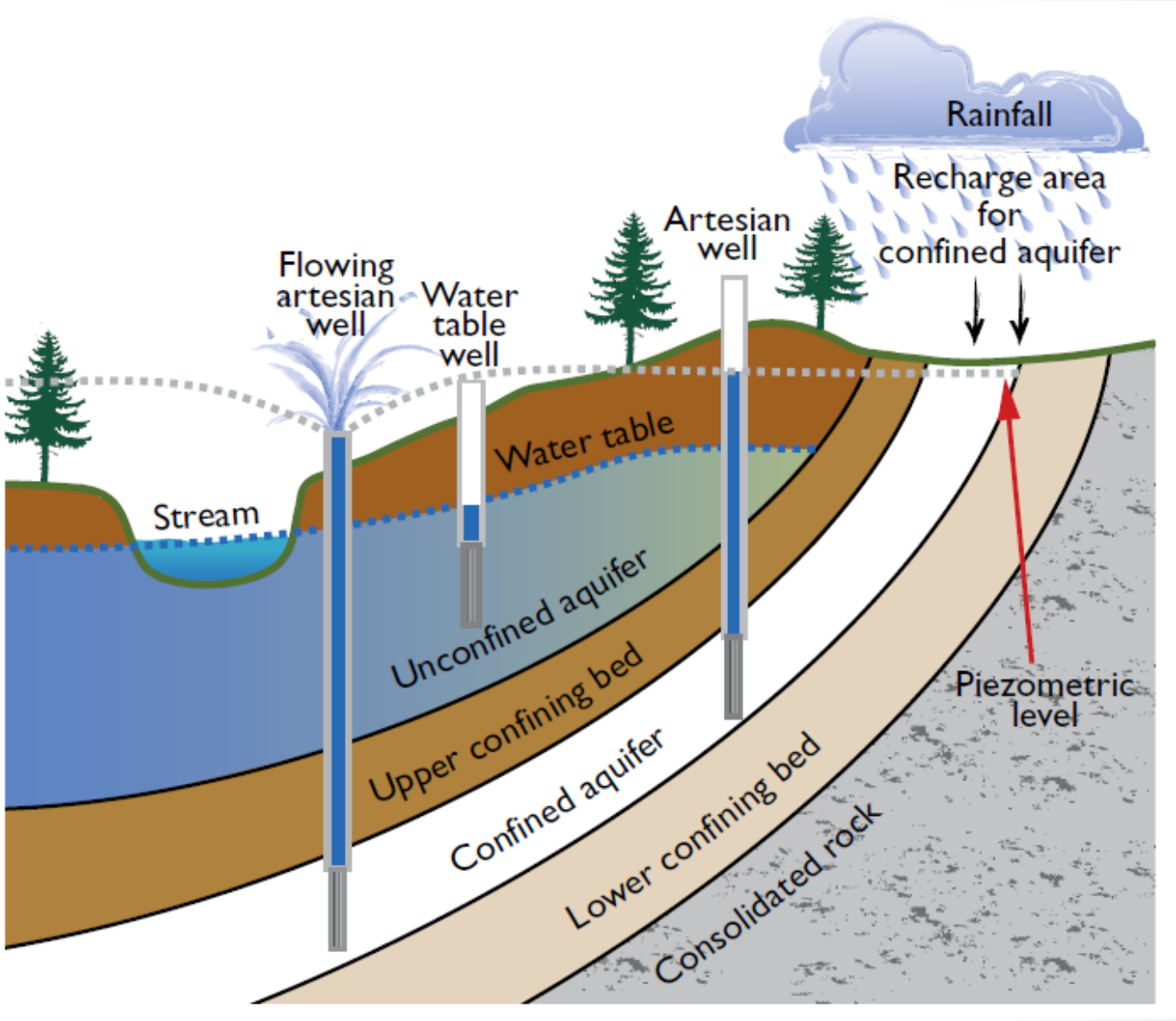


Image from: http://www.env.gov.bc.ca

Confined vs. Unconfined Aquifer

- Confined = Water rises above the upper boundary of the aquifer
- Unconfined = Any time the formation above the aquifer is unsaturated (dry)
- All confined aquifers are artesian aquifers
- Not all wells in artesian aquifers flow
- Not all unconfined aquifers are shallow
- Aquifers can transition from confined to unconfined, and vice versa

Artesian

Though it has a specific geological meaning, we see the word “artesian” used all over the place

Commonly used in marketing bottled water

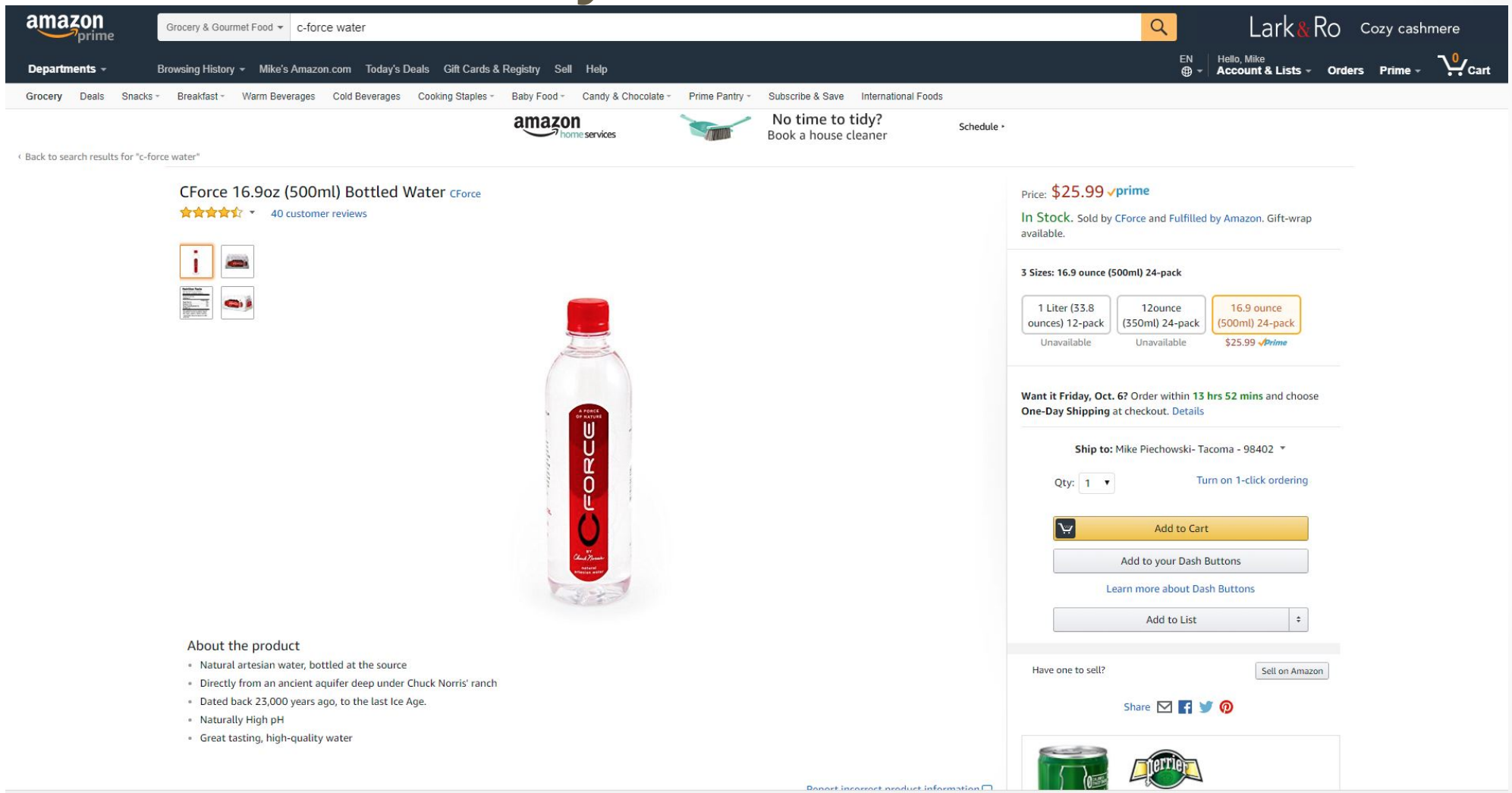
> "Artesian water" is water produced from an artesian well. To be an artesian well, the water in the aquifer (a subsurface rock unit that holds and transmits water) must be under enough pressure to force it up the well to a level that is higher than the top of the aquifer. Although this is an interesting geological situation, artesian water has no special chemical or medicinal qualities.
>
> – geology.com

Even Chuck Norris is in on the game

Cforce - Seriously

- Even though the former “Walker, Texas Ranger” star isn’t fighting crime on the small screen anymore, Chuck Norris is flexing his muscle in the business world.
- The famous martial artist, actor, and frequent subject of jokes regarding superhuman strength is tossing his cowboy hat into the bottled water industry. Norris and his wife Gena are heading up CForce, a line of bottled water sourced from the Norris Lone Wolf Ranch in Navasota, just southeast of College Station.
- According to the company’s website, CForce “bursts from an artesian spring with the same unharnessed power and intensity you’d expect from Chuck Norris’ roundhouse kick.”
- Bottles are completely recyclable, and a sales portion goes toward helping the environment and supporting Norris’ charity KICKSTART KIDS, which teaches karate to at-risk youth.
- The company recently had a launch party at its Texas headquarters and writes on its Facebook page that the bottled water is currently sold in limited stores in Texas and Louisiana.

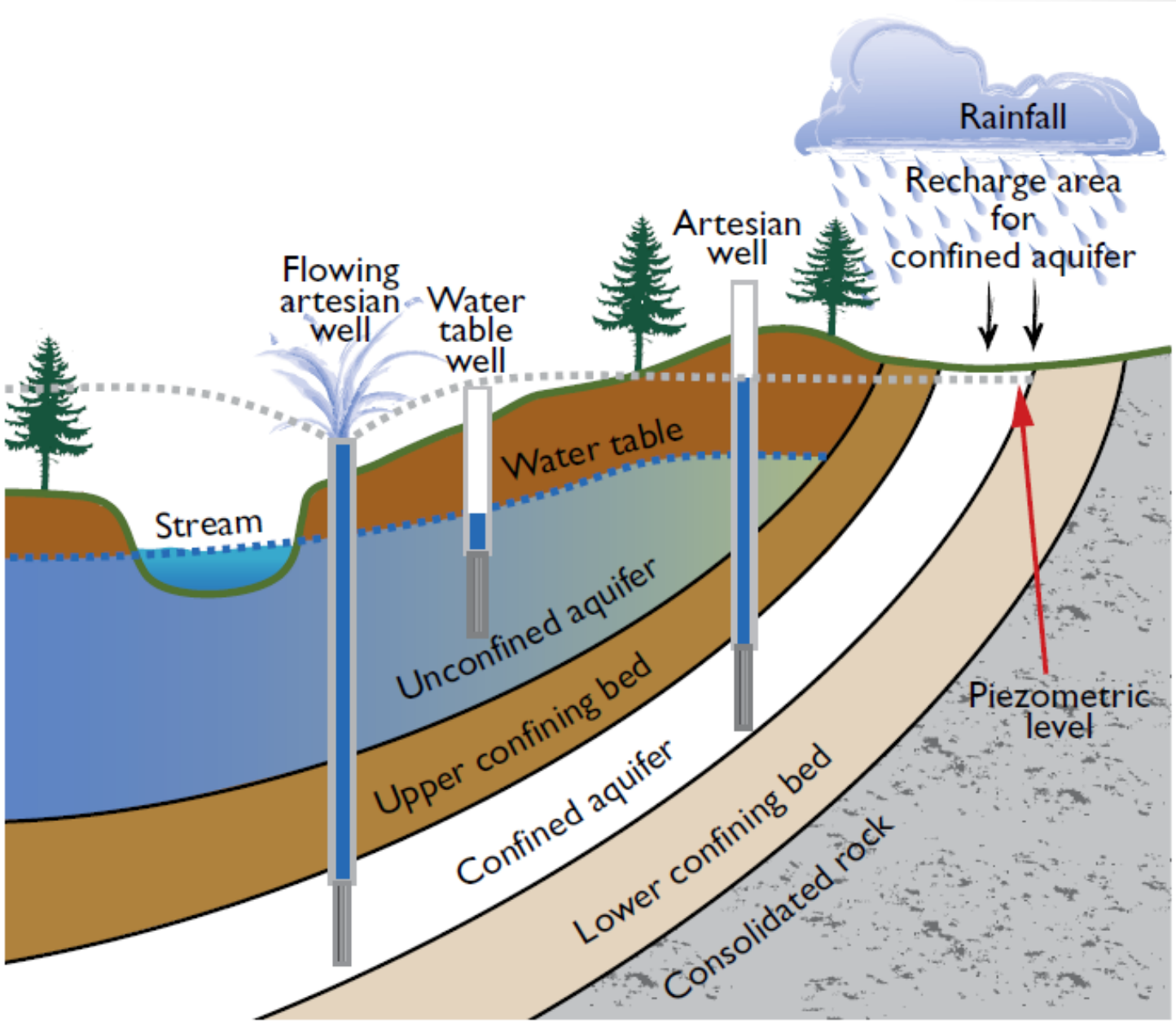
It's available today on Amazon



12 liters for $25.99 is $8.20/gallon or $2.17/liter! We're all in the wrong line of work…

Artesian Well

"Artesian well" is a well tapping an aquifer bounded above and below by confining or impermeable rock or soil layers, or rock or soil layers of distinctly lower permeability than the aquifer itself. The water will rise in the well above the point of initial penetration (above the bottom of the confining or impermeable layer overlying the aquifer). This term includes both flowing and nonflowing wells.



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Flowing vs. Non-Flowing

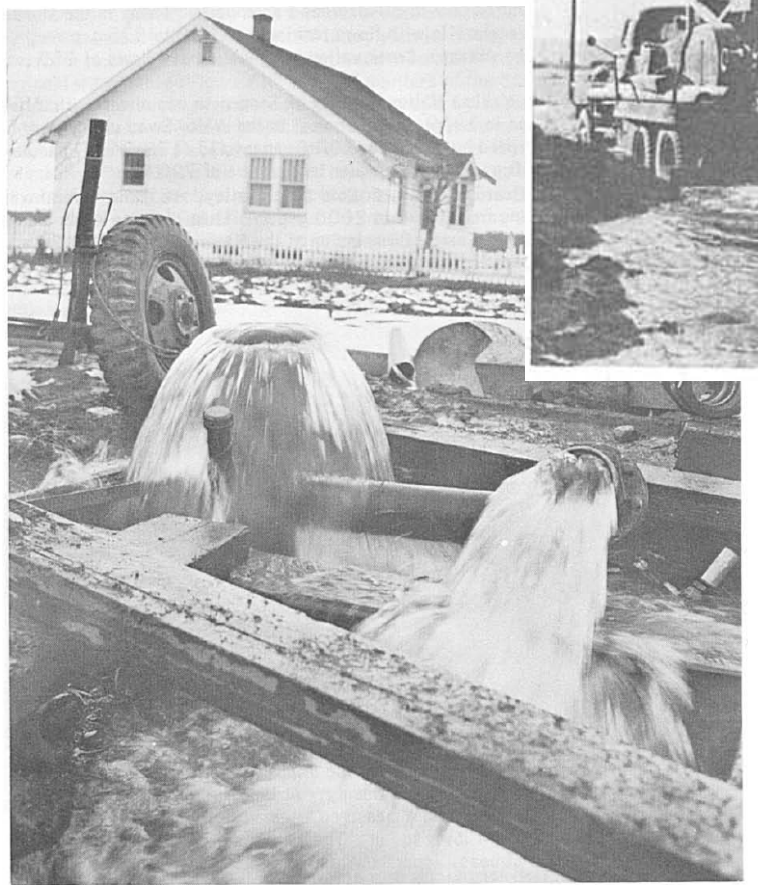
- Not all artesian wells flow
- Flow has to do with the relationship between the static water level (head) and the top of the well casing
- If the head is higher than the top of the well casing, the well flows
- Uncontrolled Free Flow = Not allowed per WAC and RCW in Washington, also prohibited in B.C. per the Groundwater Protection Regulation
- Chapter 90.36 RCW – Irrigation – seasonal valving required
- WAC 173-160-251 – Sealing standards: "If the well flows at land surface, it must be equipped with a control valve so that flow can be completely stopped."
- Groundwater Protection Regulation: Part 8, Section 66

Except…

And those are the good ones…

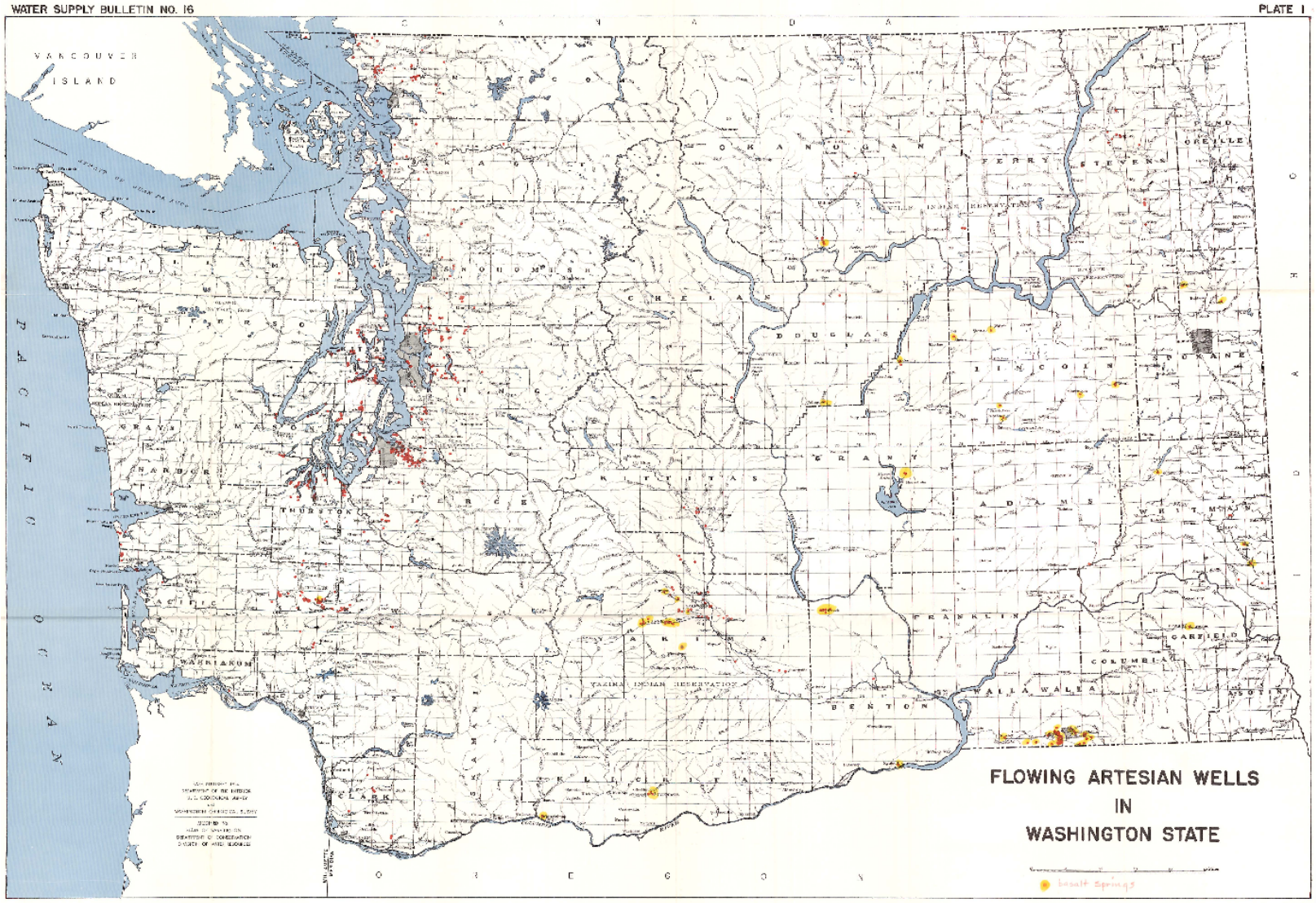
So, where do flowing artesian wells happen??

- Everywhere…
- Olympia – 96 mapped in downtown area
- Tacoma- Many existing in basements of old downtown buildings, I have measured several
- Shelton – Some in manufacturing facilities near the Port, I've seen a few
- Many of these are free-flowing and unused
- Bedrock geology too, not just unconsolidated formations
- Just need the right conditions



Images from: Molenaar, WSB 16, 1961

Where should you worry (WA)?



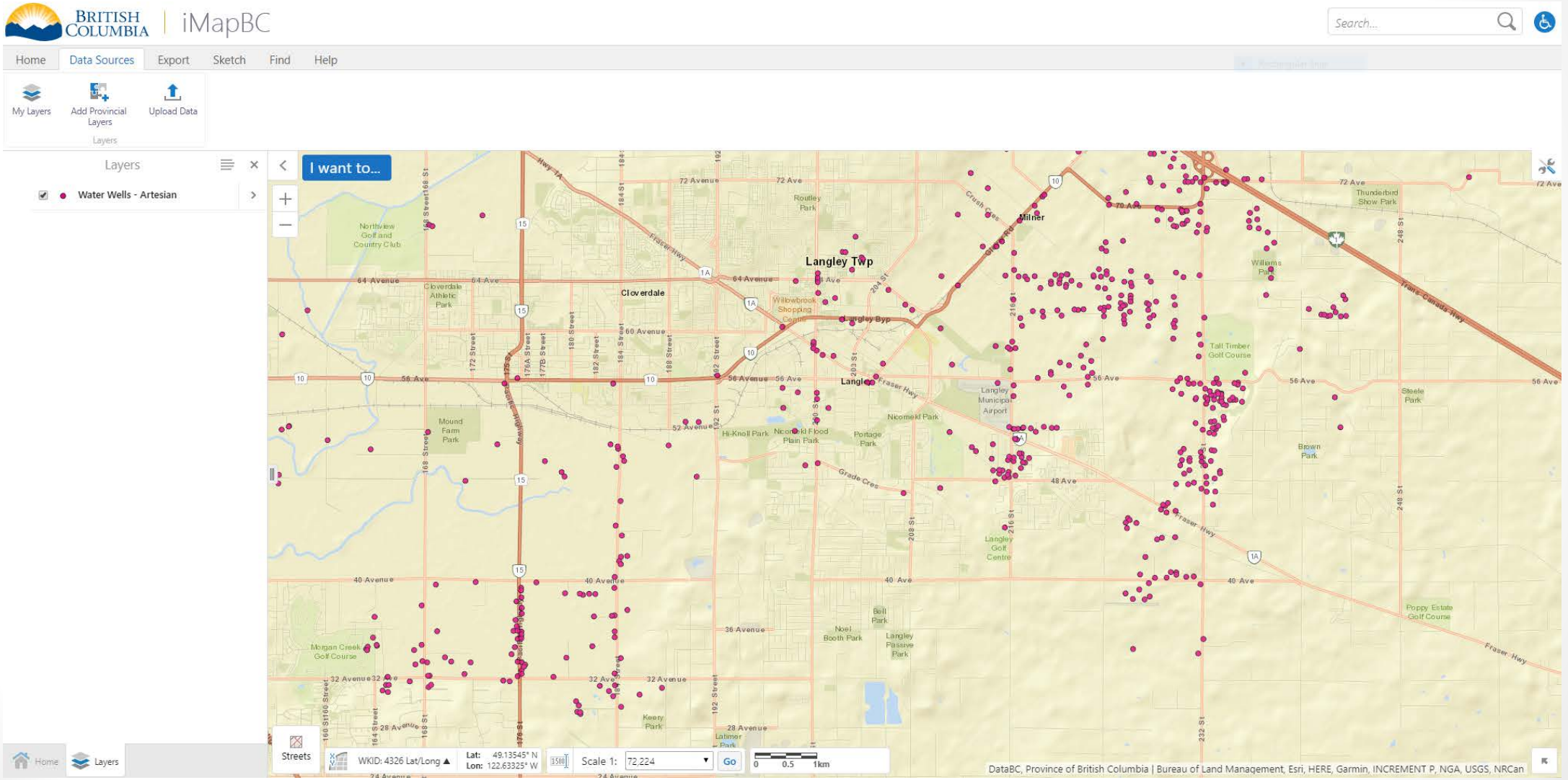
Where should you worry (WA)?

- Yeah, it is a paper publication that is older than I am
- While it was comprehensive for its day, it has not been updated since
- There is no online database exclusive to flowing artesian wells
- With approximately 10,000 wells drilled per year in Washington state, I think there could be a few more datapoints on that map
- It really comes down to institutional knowledge

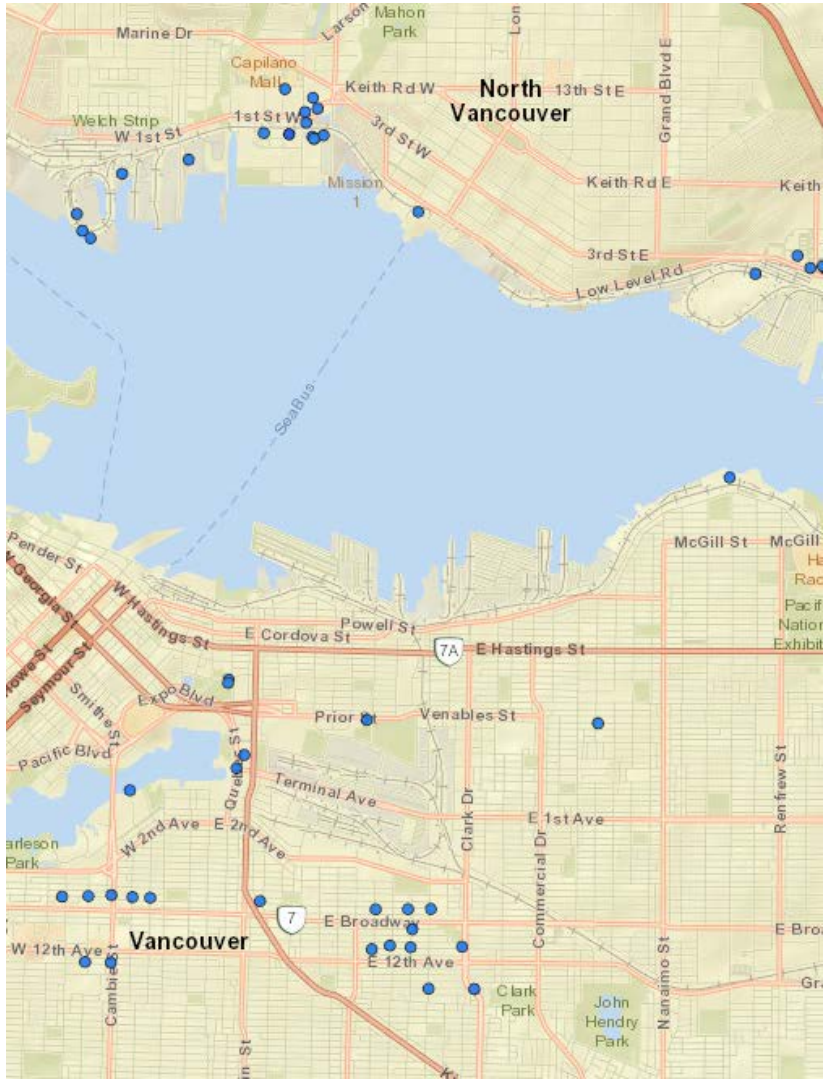
Where should you worry? (B.C.)

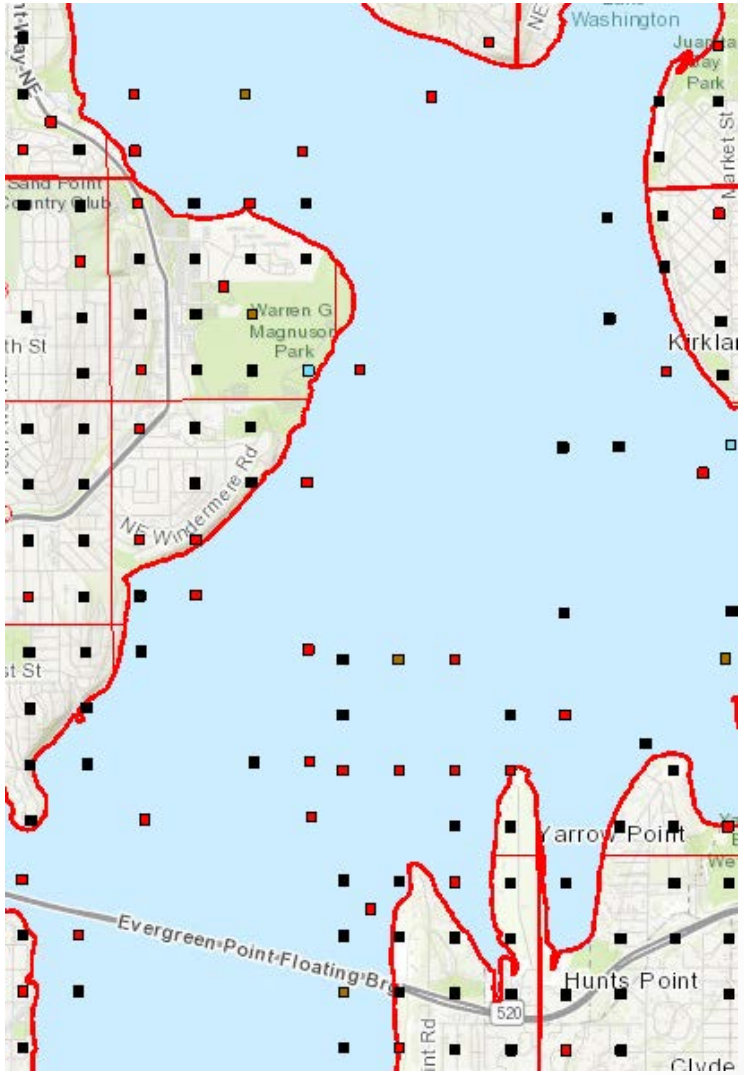
- Areas within Flowing Artesian Advisories
  - Lower Mission Creek area of Kelowna, B.C.
  - Vancouver, Burnaby, and New Westminster, B.C.
  - Chetwynd, B.C.
- Areas where artesian wells are mapped - iMapBC
- Use the tools available online
  - https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp
  - https://www2.gov.bc.ca/gov/content/data/geographic-data-services/web-based-mapping/imapbc

Where should you worry? (B.C.)



Mapping comparison:





Where should you worry?

- What about the rest of the region?
- Valleys
- Plains at the base of the foothills
- Anywhere with elevation change and potentially layered geology

so… this includes pretty much most of B.C.

What does it mean to drillers?

- Honest, accurate well logs are critical!
- Everyone is potentially at risk, not just water well drillers
- Be prepared, know what you're getting in to, look for clues
- Check well logs, maps, check Artesian Advisories and other publications
- Unexpected artesian flows can mean an "interesting", if not a downright "bad" day
- Fixing it after the fact is a LOT harder to do

What does it mean to drillers?

- ~400-foot deep fluid-rotary test drilling, exploring below a hole where cable-tool drilling reached casing refusal
- Encountered strong artesian flow (30 PSI)
- Not unexpected, but higher head than anticipated
- Lost all of the drilling mud, which overflowed into a nearby stream
- Controlled flow with weighted mud, continued to 650', successfully completed well

What does it mean to drillers?

- 35-foot deep geotech piezometer at a construction site in Federal Way
- 10 PSI shut-in
- Awful hard to control flow when drilling with hollow-stem augers
- Sealed, for now

What does it mean to drillers?

- Unlicensed driller installing geothermal loops in the Beechwood neighborhood of Vancouver, B.C. in September of 2015
- Encountered artesian flow at 60’, driller evidently panicked, pulled the rod, folded the rig, and left
- Initial flow was 200,000 gallons/day (130 gpm), increased to over 500,000 gallons/day (350 gpm)
- Neighborhood of multi-million dollar homes, up to a dozen potentially impacted

What does it mean to drillers?

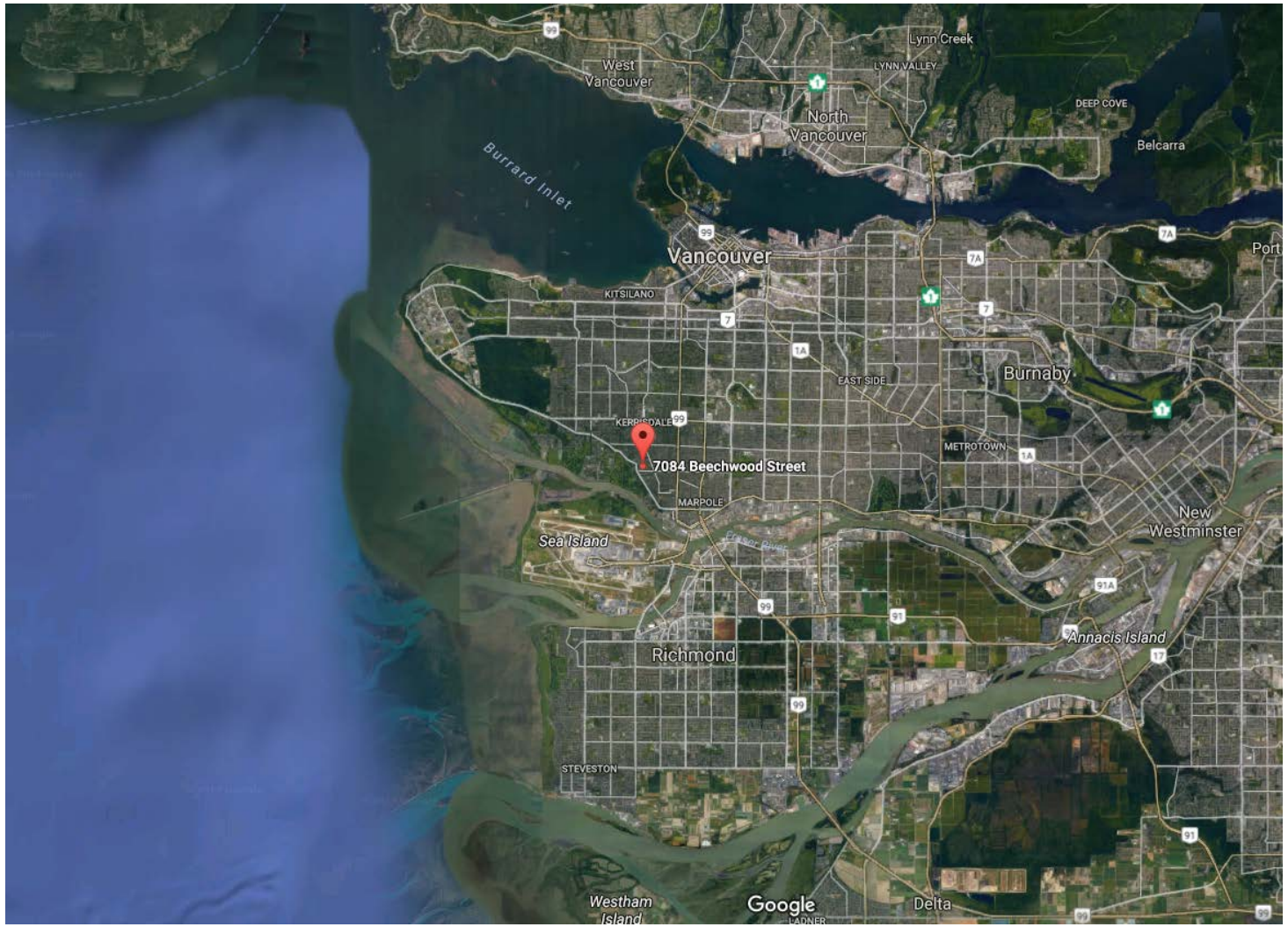


Image from: google.com

What does it mean to drillers?

Image from: google.com

What does it mean to Drillers?

A lot of that depends on which side you're on…

Nearly two million litres of water spill each day from an accidental breach of an aquifer at a house under construction at 7084 Beechwood St. in Vancouver. *JASON PAYNE, PNG / VANCOUVER SUN*

Crews continue to work on the property at 7084 Beechwood Street in Vancouver. *MARK VAN MANEN / PNG*

What does it mean to drillers?

More than one billion litres of water have spurted from a $3 million residential lot on the west side of Vancouver since inexperienced drillers breached an aquifer under the site then fled the country 15 months ago. JASON PAYNE / VANCOUVER SUN

What does it mean to drillers?

- Homeowner has apparently defaulted, driller is evidently long gone…
- Approximately $10 million spent
- Flowed for nearly 2 years
- Sealed, for now.

Not just a “new” problem

- Another Canadian well
- Okanogan, Vernon, B.C. area, Coldstream Ranch
- Drilled in 1965, by the B.C. government
- Pleistocene glacial deposits
- Lost control at 200’, free-flowing at 500 gpm/ 50 PSI shut-in, lots of erosion, created a 35-foot diameter crater around the casing
- Multiple attempts to get the well sealed over the years, 1965-67, 1979, and again in 2009
- 50 years so far, and nearly $4,000,000 Canadian for the last “fix”
- 2009 “fix” was a new well, which is valved, but still free-flowing, old well was grouted a few years ago and seems to be holding.
- Recently sealed successfully

Not just a Canadian problem…

- Baring: “lost” flowing well is now a lake
- Spokane: Similar situation
- Monroe: Gravel mining breached a confining unit, still flowing
- Shelton: Industrial well flowing outside casing
- “Jumbo” in Belle Plaine, Iowa (1886)
  - 2,000 gpm plus, 13 months to cap
- I’m certain there are others…people don’t often talk about them
- Once you open a hole into an aquifer and lose control of it, you can’t exactly close the hole and put the water back in

A bit of science…

- Hydrogeologists describe aquifers with Transmissivity and wells with Specific Capacity
- Transmissivity = The ability of an aquifer to yield water to a well

$$T = K \cdot b$$

- Specific Capacity = yield of a well per unit of drawdown

$$SC = Q / s$$

- Fundamental rule of hydrogeology: **Water flows down hill**

EVEN IN FLOWING ARTESIAN WELLS

Applied to a flowing well

- Shut-in head is another way to measure drawdown
- That 50 PSI of head? That means 50*2.31 = 115.5 feet of drawdown at the top of the casing
- 500 gpm with 115 feet of drawdown is a specific capacity of 500/115 = 4.35 gpm/ft-dd
- Not all that great of a well, a low specific capacity implies a low-T aquifer or poor efficiency

Applied to a flowing well

- For T, we need to measure discharge and time, just like a pumping test
- Valve to control discharge
- Orifice weir or meter to measure discharge
- Gauge or transducer to measure head
- Can do a step test by opening valve in stages
- Tests are valid if the well is small relative to the aquifer and Q remains constant (+/- 5%) for the test duration

Why do I say that flowing artesian wells aren't great?

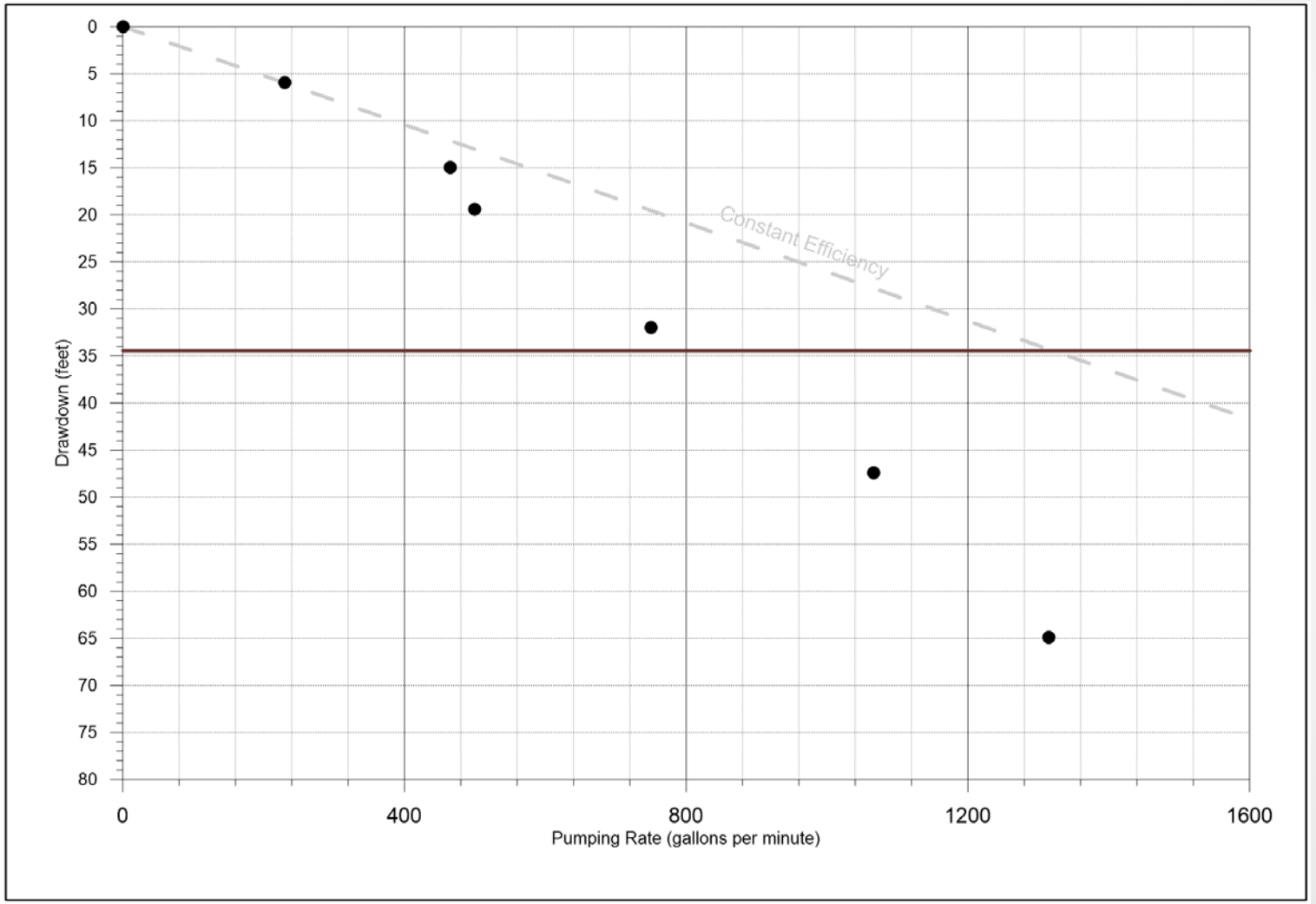
- The amount of drawdown is typically very high for the amount of water being produced
- Consider Coldstream: 115 feet of drawdown is a lot for 500 gpm, especially in unconsolidated glacial sediments (Q/s = 4.35 gpm/ft-dd)
- Implies a low transmissivity aquifer, one that does not yield water readily (estimated ~8,700 gpd/ft)
- Remember, drawdown starts from the static water level (shut in pressure), not the top of the casing

Why do I say that, continued?

- Since $T = K \cdot b$, and T is generally low, K must be on the lower side if b is significant
- Lower K means a steeper gradient
- Lower K implies the water can't flow through the aquifer
- Lower K plus a high head means challenges for drillers:
  - Heave
  - Overexcavation
- Specific capacity tends to decline over time, yield drops
- They're just a pain to deal with, the water will always find its way out

Real-world example

- Deep well near Puget Sound
- 34’ shut-in
- 1015 feet deep
- Flowed 750 gpm, pumped 1,300 gpm
- T only 46,000 gpd/ft, 300’ thick aquifer
- K=~20 ft/day



So – What to do?

- Be ready, know before you go
- Not just a good idea, it is the law in both Washington and B.C.
  - Artesian sealing requirements are spelled out in WAC 173-160-251
    - a bit more prescriptive than B.C.
  - B.C. has suggestions in the Flowing Artesian Wells booklet and requirements in the GWPR
  - B.C. has serious penalties for offences
- A lot depends on the type of drilling you're doing
- Less options on the table with probe or auger than with other techniques, but there are still options

Proactive vs. Reactive approach

- Washington – Artesian sealing plan required when flowing conditions are known or suspected
- B.C. – Artesian Advisories, specific registration and qualifications for drillers, sealing and flow control required, excellent mapping resource
- Only as good as the data that is available

…but far better than nothing

Proactive = over-protective

Artesian Seal
WAC 173-160-251 (1)

- When flowing artesian conditions are known or suspected, the operator shall have a written sealing plan prepared prior to initiation of construction. The plan shall identify the type of sealing material that will be used and the method for sealing. The plan shall also contain at least one alternative construction method for sealing and an emergency contingency section which will identify steps to be taken if the groundwater flow cannot be controlled.

Artesian Seal
WAC 173-160-251 (2)

- When artesian water is encountered in the well, an unperforated well casing shall extend into the confining stratum overlying the artesian zone. The casing shall be sealed into the confining stratum to prevent surface and subsurface leakage from the artesian zone. If the well flows at land surface, it must be equipped with a control valve so that flow can be completely stopped.

Artesian Seal
WAC 173-160-251 (3)

- The well shall be completed with seals, packers or grout that eliminates leakage around the well casing. The driller shall not move the drilling rig from the well site until leakage is completely stopped, unless authority for temporary removal is granted by the department, or when loss of life or property is imminent.

B.C. Rules and Regulations

Groundwater Protection Regulation, a part of the Water Sustainability Act

- Adopted in 2016
- Ticketable offences, significant penalties

Previously:

- “Best Practices”, but no teeth per se
- pre-2004 there was nothing

What can be done?

Best option?

Control the flow.

Simplest way?

Raise the top of the casing

Sometimes a foot or two is all you need.

Pump a nearby well to lower the head.

Other times…

Controlling flow

- Well casing was extended to ~14’ above grade after drilling
- Allowed monitoring of shut-in with a conventional datalogger
- Controlled flow
- Cheap and effective, but a bit awkward for measurements

Controlling Flow

- Valves are effective, and required
- Can’t really be used during drilling, but can shut things down overnight
- Valves have to be anchored. 50 PSI on a 12-inch valve is almost 3 tons of force, which can move things around
- Remember - the tide may change the head

Controlling Flow

- During drilling, there are options too, depends on the drilling technique used
- Run a plug, pull rods back and partially fill the casing with heave or sediment
- Drive the casing ahead
- Use a weighted mud with barite
- Weight the well with brine
- What's your backup plan?

While drilling

- Flow control approach depends where the flow is
- “Artesian” seal: WAC 173-160-251
- Much harder to do “after the fact”

So, what to do when you get unexpected flowing conditions?

- Slow the flow to the degree you can – allow it to choke itself with formation, drive the pipe ahead through the aquifer
- Control erosion and manage flow
- Phone a friend
  - Seriously, if you're in trouble and don't know what to do, call for help
- A quick response can make the difference, but the decision has to be the right one

Downhole Hydrostatic Head Pressure

- The formation's fluid pressure must be balanced by the drilling fluid weight to stop the well flow at the well head
- Basically, we are making a shorter column of a heavier fluid weigh as much as the column of water required to shut the well in
- Shallow flowing conditions are harder to control than deeper
  - Less column height to place weighted fluid means heavier fluid required
- If fluid is too heavy (> 15 lb/gallon), cement grout will float

Downhole Hydrostatic Head Pressure

Shut-in head

Land surface

Depth to flow

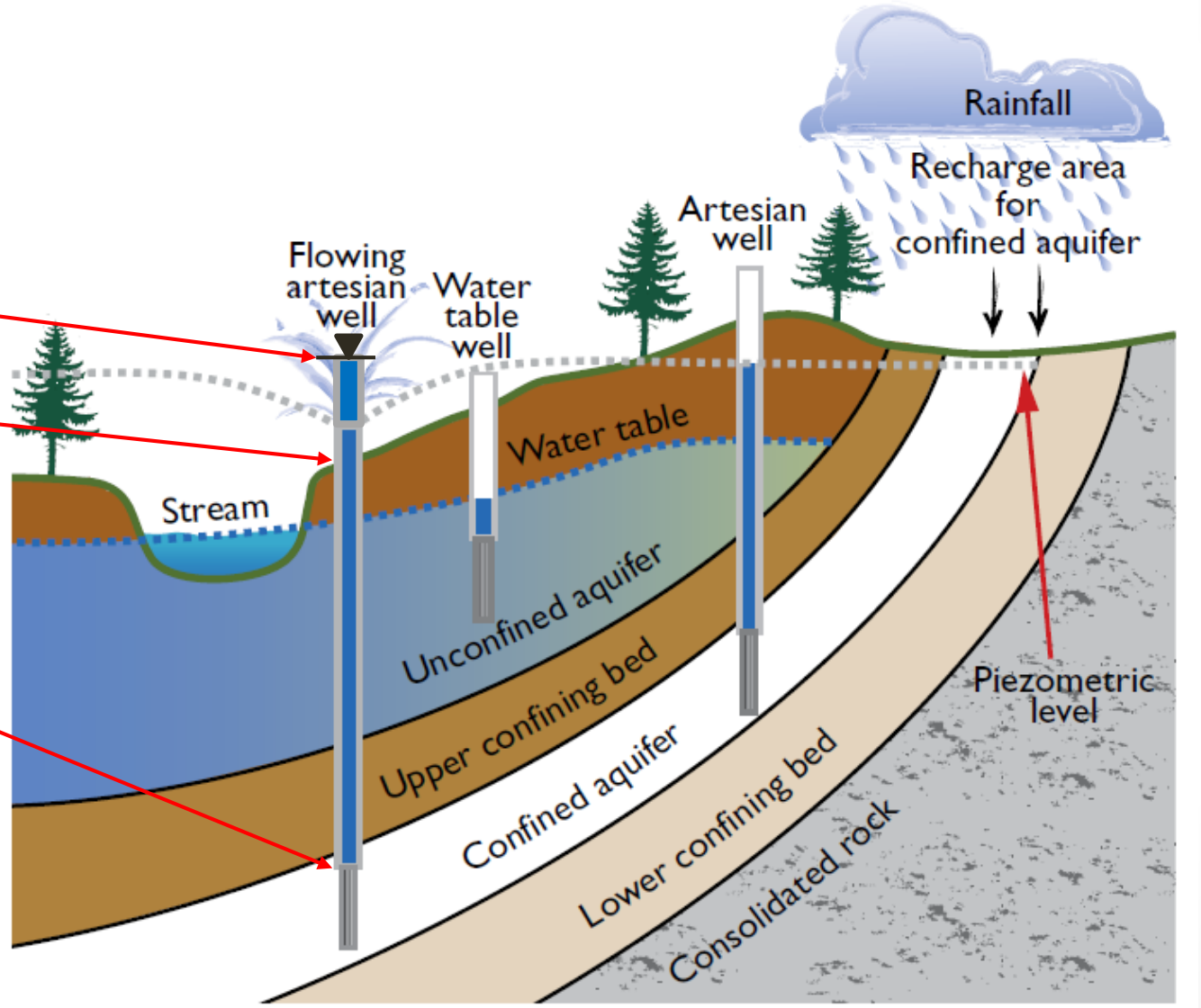


Image modified from: http://www.env.gov.bc.ca

Kill Calculations

- Need to know the following (at a minimum):
  - Depth to flow
  - Shut in head
  - Type of fluid
- Are you killing the flow, or are you continuing to drill?
- Assumes ALL flow is inside the casing!
- Flow outside casing is a whole different talk

Example Calculation

- Bentonite mud, 8.5 lb/gallon
- Using barite as a weighting agent
- Shut-in 20 PSI
- Flowing at 300 feet
- 1,000 gallons of mud
- 0.4 lb/gallon safety factor

Weight-Up Calculation with Barite

$$\text{Lbs. of Barite Required (B)} = \left[\frac{35.05 \times (W_f - W_l)}{35.05 - W_f}\right] \times V_l$$

Where:
- B = Amount of Barite to Add, lbs.
- V_l = Starting Volume of Mud, gallons
- W_f = Desired Mud Weight, lb/gal
- W_l = Starting Mud Weight, lb/gal

Rule of Thumb: For Weighted Drilling Fluids up to 12 lbs./gal using Barite.
For every 140 pounds of Barite added to 100 gallons (U.S.) the weight will rise 1 lb/gal
Prior to weighting up fluid the Funnel Viscosity must be raised with AQUAGEL® or QUIK-GEL® to four times the final mud weight.

Image from Baroid IDP

Example Calculation

- Shut-in head = 20 PSI * 2.31 feet = 46.2 feet
- Weight $= \frac{8.5 \times 46.2}{300} + 0.4$ = 1.7 lb/gallon additional
- Initial mud weight = 8.5 lb/gal, desired weight = 10.2 lb/gal

$$B = \left[\frac{35.05 \times (w_F - w_I)}{35.05 - w_F}\right] \times v_I$$

$$B = \left[\frac{35.05 \times (1.7)}{35.05 - 10.2}\right] \times 1000$$

B = 2,400 lb, requires 41-second mud

Example Calculation 2

- Fresh water, 8.34 lb/gallon
- Using salt as a weighting agent
- Shut-in 10 PSI (23.1 feet)
- Flowing at 400 feet
- 12-inch well, 6 gallons per foot
- Killing flow for rework
- 0.2 lb/gallon safety factor

$$\text{Weight} = \frac{8.34 \times Height}{Depth} + 0.2$$

$$\frac{8.34 \times 23.1}{400} + 0.2 = 0.68 \text{ lb/gallon}$$

6 gallons per foot, 400 feet means 1,650 lb. of salt are required per well volume for a brine of sufficient weight

Practical maximum for brine is 10 lb/gallon

Example Calculation 3

- Permanent sealing of a flowing artesian well with cement grout
- Shut-in 15 PSI (34.65 feet)
- Flowing at 300 feet
- 12-inch well, 6 gallons per foot

1. Enter depth to top of flowing artesian aquifer _____feet
2. Enter artesian head above ground surface _____feet
3. Add steps 1 & 2 to find total feet of hydrostatic head _____feet
4. Convert feet of hydrostatic head to downhole hydrostatic head pressure (DHHP) in pounds per square inch by dividing answer to step 3 by 2.31 ft/psi _____psi

   This is the DHHP that must be overcome using a column of grout from the top of the flowing aquifer to the ground surface.

5. Enter the grout weight (or density) _____lb/gal
6. Determine the pressure per foot of grout by multiplying the the grout weight by 0.052.

   Multiply the answer to #5 by 0.052 _____psi/ft

7. To find the downhole grout pressure (DGP), multiply the answer to #6 by the answer to # 1 _____psi

   If the answer to #7 DGP is higher than the answer to #4 DHHP - the flow can be controlled by the grout weight.

   If the answer to #7 DGP is lower than the answer to #4 - DHHP - the flow cannot be controlled unless weight of grout is increased.

From the Michigan Flowing Well Handbook

Example Calculation 3

1. Enter depth to top of flowing artesian aquifer	_____feet	300
2. Enter artesian head above ground surface	_____feet	34.65
3. Add steps 1 & 2 to find total feet of hydrostatic head	_____feet	334.65
4. Convert feet of hydrostatic head to downhole hydrostatic head pressure (DHHP) in pounds per square inch by dividing answer to step 3 by 2.31 ft/psi	_____psi	144.9
This is the DHHP that must be overcome using a column of grout from the top of the flowing aquifer to the ground surface.		
5. Enter the grout weight (or density)	_____lb/gal	15
6. Determine the pressure per foot of grout by multiplying the the grout weight by 0.052.		
Multiply the answer to #5 by 0.052	_____psi/ft	0.78
7. To find the downhole grout pressure (DGP), multiply the answer to #6 by the answer to # 1	_____psi	234
If the answer to #7 DGP is higher than the answer to #4 DHHP - the flow can be controlled by the grout weight.		
If the answer to #7 DGP is lower than the answer to #4 - DHHP - the flow cannot be controlled unless weight of grout is increased.		

From the Michigan Flowing Well Handbook

Since 234 PSI is higher than 144.9 PSI, a 15 lb/gallon grout will be sufficient to seal this well

One could successfully grout this well with a 9.5 lb/gallon grout, but that is too thin to set without shrinking

Plan on a minimum of 2 well volumes, so 3,600 gallons, or approximately 18 cubic yards

15 lb/gallon is a “6-sack” mix, 6 94-pound bags, each mixed with 5.75 gallons of water

Now what?

https://www.ontario.ca/document/water-supply-wells-requirements-and-best-practices/flowing-wells

Pulling the drill rod and casing may not be the best idea

More than one billion litres of water have spurted from a $3 million residential lot on the west side of Vancouver since inexperienced drillers breached an aquifer under the site then fled the country 15 months ago. JASON PAYNE / VANCOUVER SUN

Moving the rig off the hole might be a really good idea

Questions?

Jumbo Well, Belle Plaine Iowa 1886, https://www.youtube.com/watch?v=rySTICRcXl8