GROUNDWATER ISSUES IN THE GEORGIA AGGREGATE MINING INDUSTRY

Topic 32

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Moderator / Speaker

Nils Thompson, P.G.

Speaker

Adria Reimer, P.G.

INTRODUCTION

- Leggette, Brashears & Graham, Inc. (LBG) provides planning & environmental advice to the quarrying sector. The information contained in this presentation is based on our experience from numerous quarry projects.
- Together with water & oil, aggregates are the most exploited natural resources on Earth.
- The natural resources extracted by industry include clay (e.g., kaolin), sand & gravel, & rock.
- This presentation deals with extraction of rock from the surface & does not consider the environmental impacts from underground mining; however some issues are similar.

AGGREGATE MINING – BILLION DOLLAR DEALS

2008	$0.2	Martin Marietta acquires 6 sites from Vulcan
2007	$15.8	Heidelberg Cement acquires Hanson
2007	$15.3	Cemex acquires Rinker Group
2007	$4.6	Vulcan acquires Florida Rock
2006	$3.0	Lafarge Group acquires Lafarge NA
2006	$1.3	OldCastle acquires APAC
2005	$3.3	Holcim acquires Aggregate Ind.
2005	$5.8	Cemex acquires RMC Group
2001	$3.6	Lafarge Group acquires Blue Circle
2000	$1.2	Dyckerhoff acquires Lone Star
2000	$2.8	Cemex acquires Southdown
2000	$2.5	Hanson acquires Pioneer

GEORGIA GEOLOGY

Valley and Ridge & Appalachian Plateau Provinces

Sedimentary Bedrock:

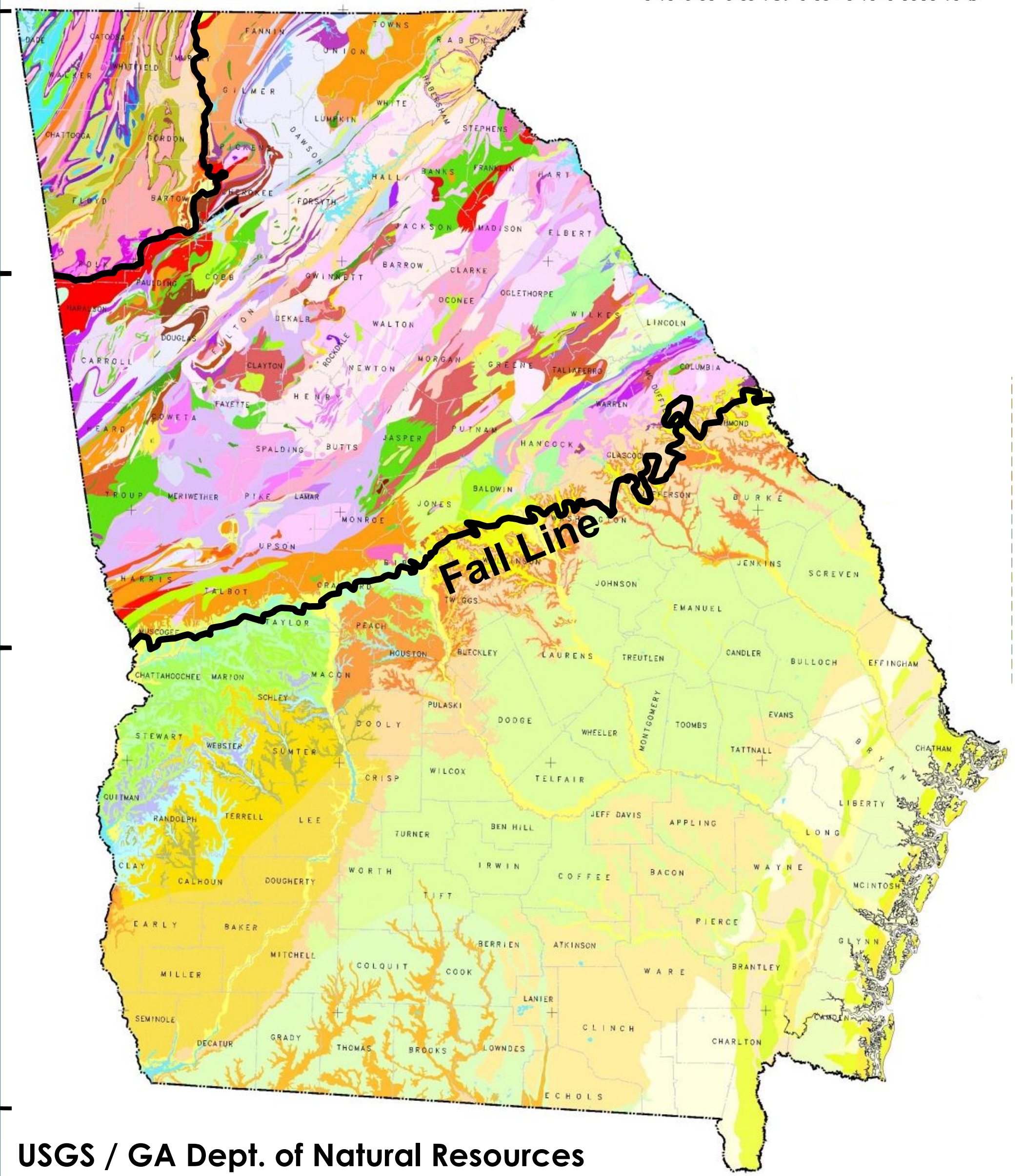
- Limestone / Dolostone
- Sandstone
- Shale
- Conglomerate

Piedmont & Blue Ridge Provinces

Crystalline Bedrock:

- Granite
- Gneiss
- Schist
- Amphibolite

Costal Plain Province



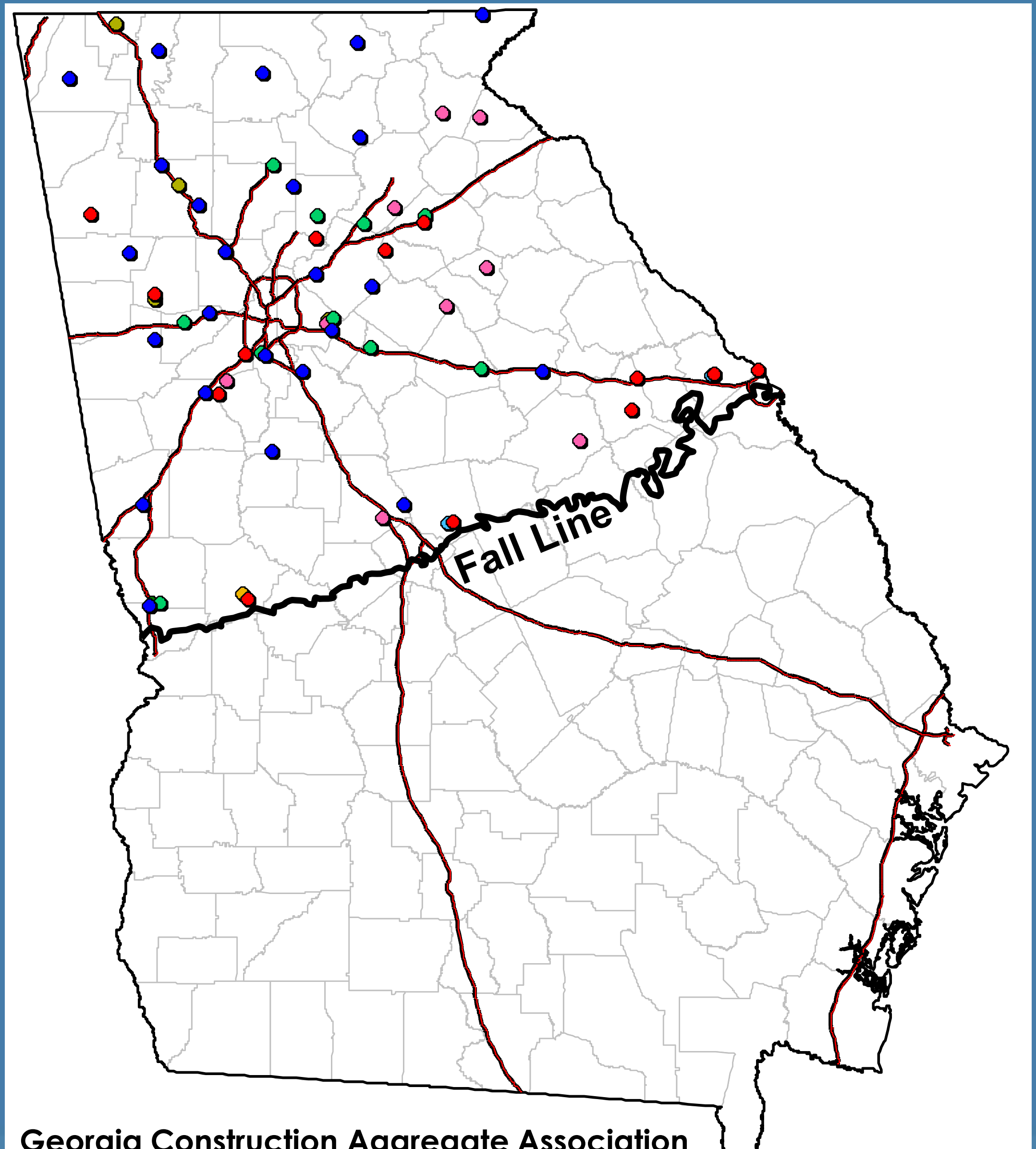
USGS / GA Dept. of Natural Resources

GEORGIA'S AGGREGATE MINING INDUSTRY

- Includes sand & gravel, & rock.
- Focus on the 2 principle types of rock quarries in Georgia:
  1. Limestone – sedimentary rock
  2. Granite – crystalline rock
- Various groundwater issues / problems faced by stone quarries:
  - Mining / dewatering influences off-site
  - Quarry pit failure
- We'll look at the following case studies:
  1. Limestone aggregate quarry dewatering issues
  2. Limestone aggregate quarry flooding & sinkholes
  3. Granite aggregate quarry potential flooding
  4. Granite aggregate quarry influences on neighboring wells
  5. Aggregate quarries as reservoirs

GEORGIA CRUSHED STONE AGGREGATE QUARRIES

- Vulcan
- Martin Marietta
- Lafarge
- Hanson
- Aggregates USA
- APAC Mid-South
- Columbus Quarry
- Junction City Mining



- Criteria for siting a quarry:
  1. Quality of stone.
  2. Little overburden.
  3. Sufficient volume to maintain a profit.

LIMESTONE QUARRY – Sedimentary Bedrock

GRANITE QUARRY – Crystalline Bedrock

SURFACE MINING IN GEORGIA

- Quarry development is regulated by Georgia EPD:
  - Land Protection Branch
    - Solid Waste Management Program
      - Surface Mining Unit
- Regulations enforced by Georgia EPD:
  - Georgia Surface Mining Act, O.C.G.A. 12-4-1, et seq., as amended.
  - Rules & Regulations for Surface Mining, Chp. 391-3-3, as amended.
- Some EPD policies:
  - Limestone quarrying below an established “permanent high water table” is prohibited to a minimum of 5 ft. above an established
    - ”Seasonal high” groundwater level, or a
    - “Synthetic” elevation.
  - If a new or expansion limestone quarry wants to go deeper with dewatering, then a hydrogeologic assessment must be performed.

QUARRY DESIGN

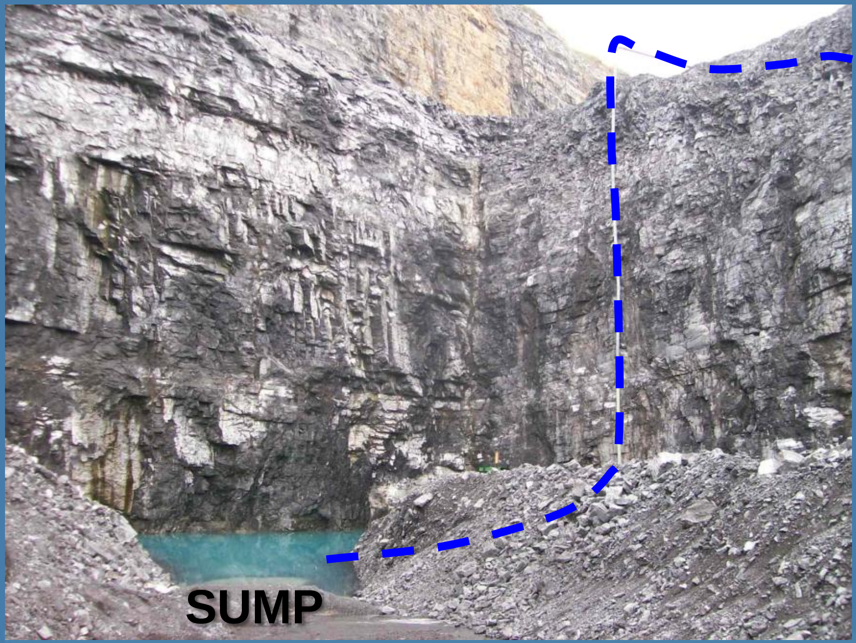
- By its nature, aggregate quarrying has a major potential impact on the geological environment.
- The Surface Mining Land Use Plan includes information on the extraction method, phases of the extraction, & the different pit elevations during & at termination of quarrying.
- Geotechnical & hydrogeological assessment of the quarry design should be included to ensure activities are proposed in a manner to ensure ground stability & no impact to the surrounding environment. For example:
  - Vibration
  - Noise
  - Dust
  - Water run-off
  - Dropping groundwater levels
  - Reduction of stream flows
  - Subsidence or sinkhole collapse
  - Saltwater intrusion

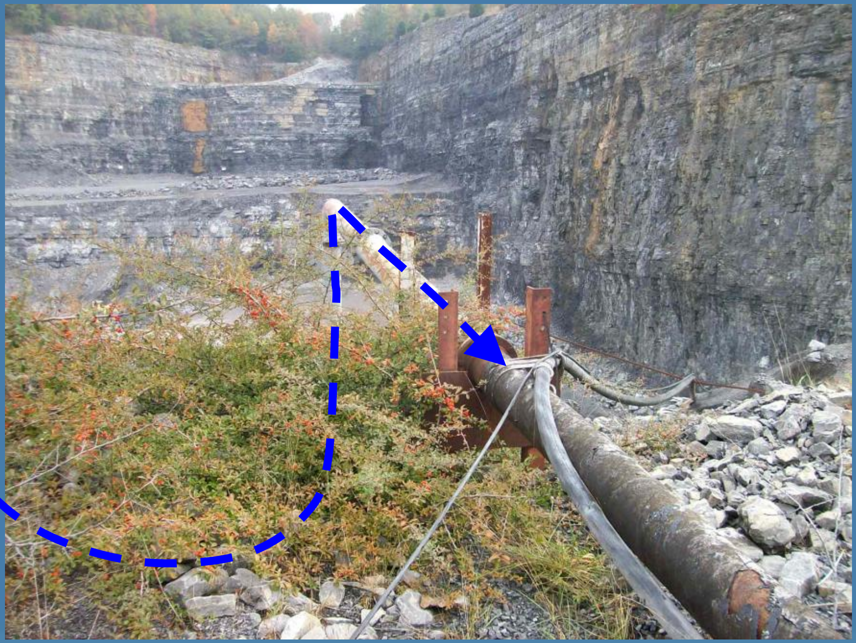
WATER HANDLING AT QUARRIES

- Quarry activities where there can be a significant amount of water handling include:
  - Quarry pit dewatering
  - Aggregate washing
  - Dust suppression
- Hydrogeological studies are often needed to address the effects of these activities on groundwater & surface water.

QUARRY PIT DEWATERING

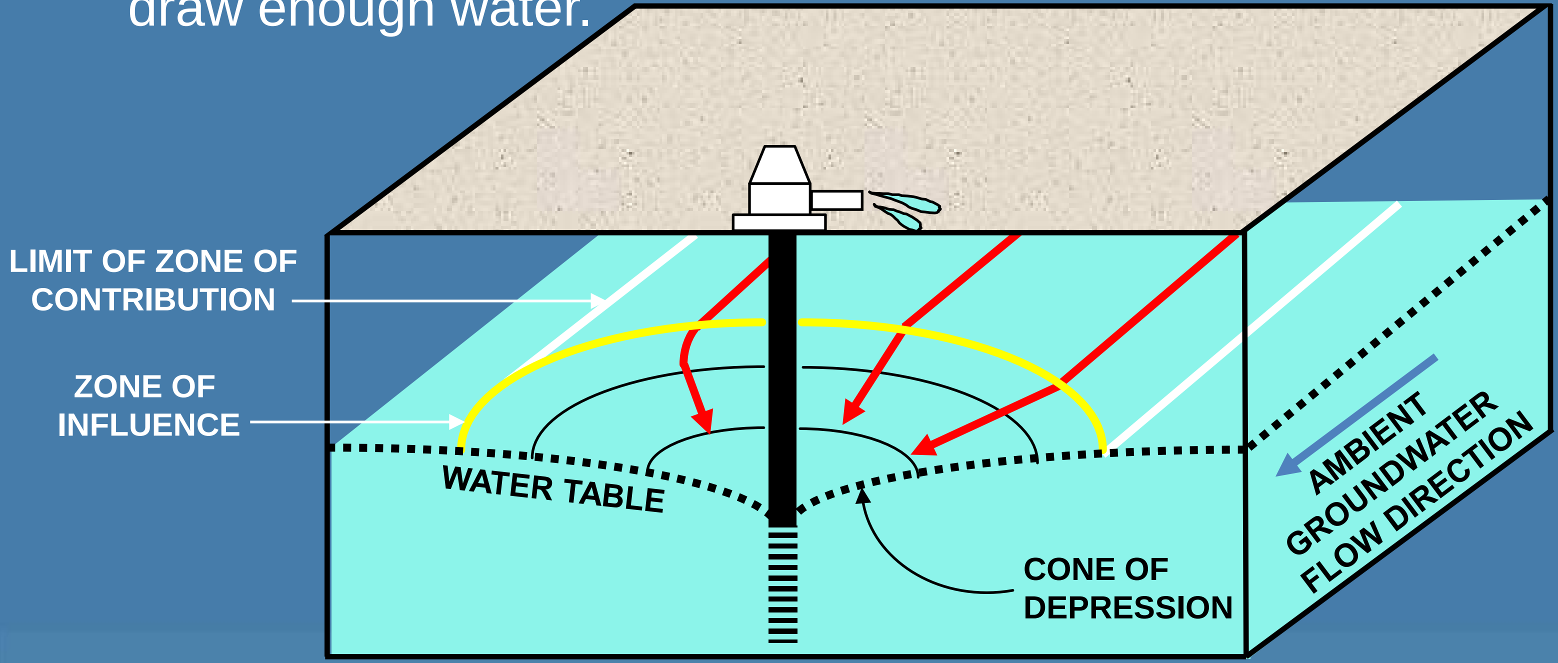
- Quarries have to pump out precipitation (rain & snow) & any groundwater seepage so that the rock can be extracted & processed on a dry floor.
- Dewatering is accomplished by pumping water from a sump in the deepest part of the quarry, up to a discharge point (e.g., ditch or drain).
- The water is then used for washing aggregate in the plant (& often recycled) &/or dust suppression in the pit & on roadways.





LIMESTONE QUARRY PIT DEWATERING

- Groundwater around the quarry responds much like a large well & becomes depressed around the edge of the quarry.
- The drawdown zone of influence is curved: greatest effect is nearest the quarry; diminishes with distance.
- If groundwater levels &/or water-bearing conduits or fractures are reduced too much, then neighboring water wells might not be able to draw enough water.



AGGREGATE WASHING & DUST SUPPRESSION

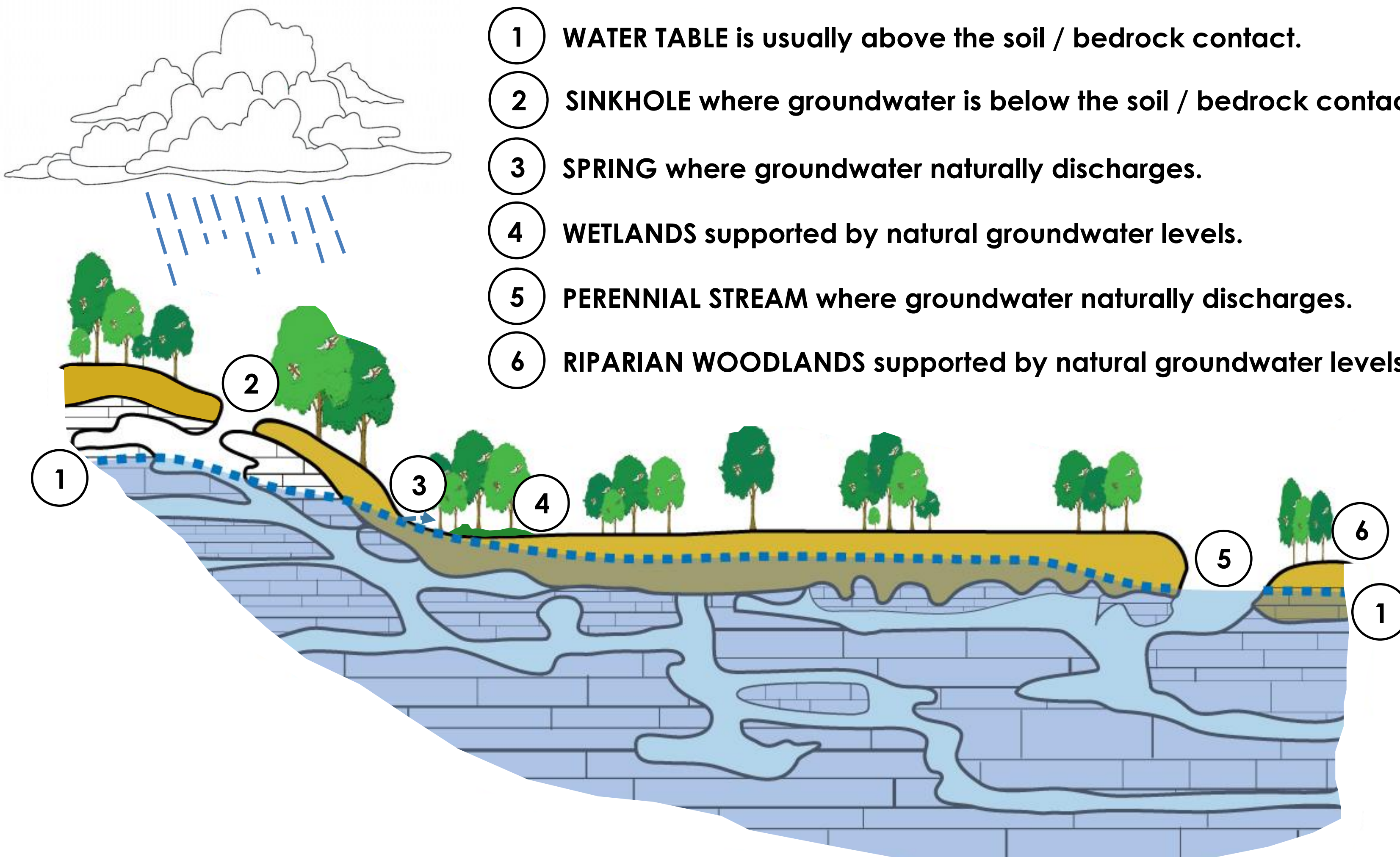
CASE STUDY #1:

LIMESTONE AGGREGATE QUARRY DEWATERING ISSUES

Speaker
Nils Thompson, P.G.

LIMESTONE CONDITIONS PRIOR TO PIT DEWATERING

1. WATER TABLE is usually above the soil / bedrock contact.
2. SINKHOLE where groundwater is below the soil / bedrock contact.
3. SPRING where groundwater naturally discharges.
4. WETLANDS supported by natural groundwater levels.
5. PERENNIAL STREAM where groundwater naturally discharges.
6. RIPARIAN WOODLANDS supported by natural groundwater levels.



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Natural

LIMESTONE CONDITIONS PRIOR TO PIT DEWATERING

Natural

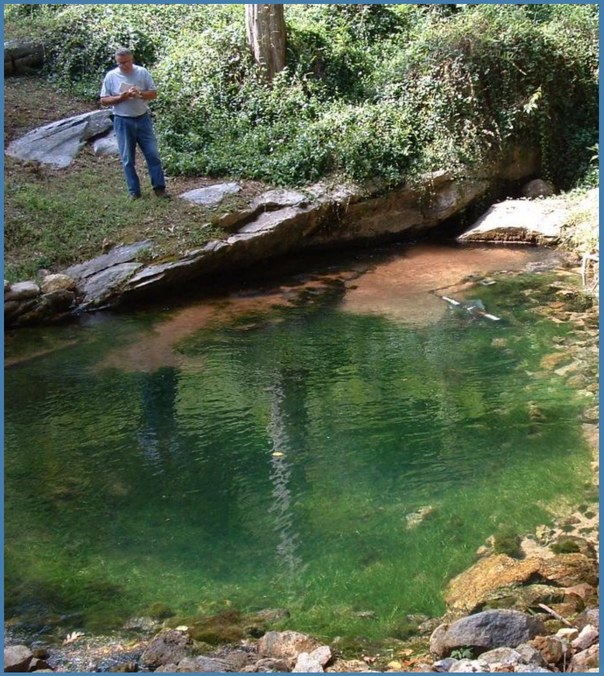
(2) Sinkholes.

LIMESTONE CONDITIONS PRIOR TO PIT DEWATERING

Natural

2 Sinkholes.

3 Springs.



LIMESTONE CONDITIONS PRIOR TO PIT DEWATERING

Natural

2 Sinkholes.

3 Springs.

4 Wetlands.

LIMESTONE CONDITIONS PRIOR TO PIT DEWATERING

Natural

2. Sinkholes.
3. Springs.
4. Wetlands.
5. Perennial streams.

LIMESTONE CONDITIONS PRIOR TO PIT DEWATERING

Natural

2 Sinkholes.

3 Springs.

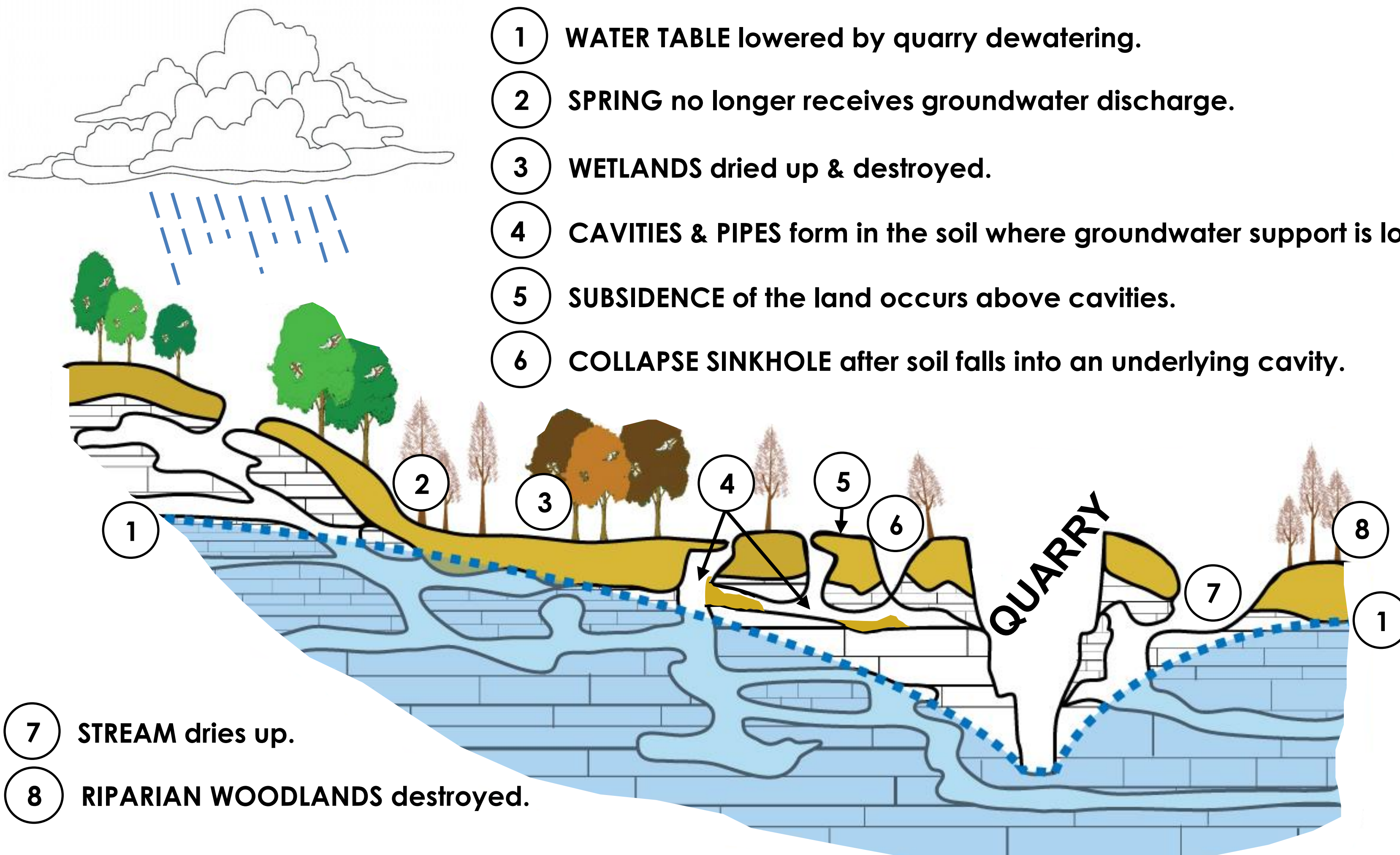
4 Wetlands.

5 Perennial streams.

6 Riparian woodlands.

LIMESTONE CONDITIONS WITH PIT DEWATERING

1. **WATER TABLE** lowered by quarry dewatering.
2. **SPRING** no longer receives groundwater discharge.
3. **WETLANDS** dried up & destroyed.
4. **CAVITIES & PIPES** form in the soil where groundwater support is lost.
5. **SUBSIDENCE** of the land occurs above cavities.
6. **COLLAPSE SINKHOLE** after soil falls into an underlying cavity.



7. **STREAM** dries up.
8. **RIPARIAN WOODLANDS** destroyed.

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Worst-Case

LIMESTONE CONDITIONS WITH PIT DEWATERING
Worst-Case

2 Dried-up springs.

LIMESTONE CONDITIONS WITH PIT DEWATERING

Worst-Case

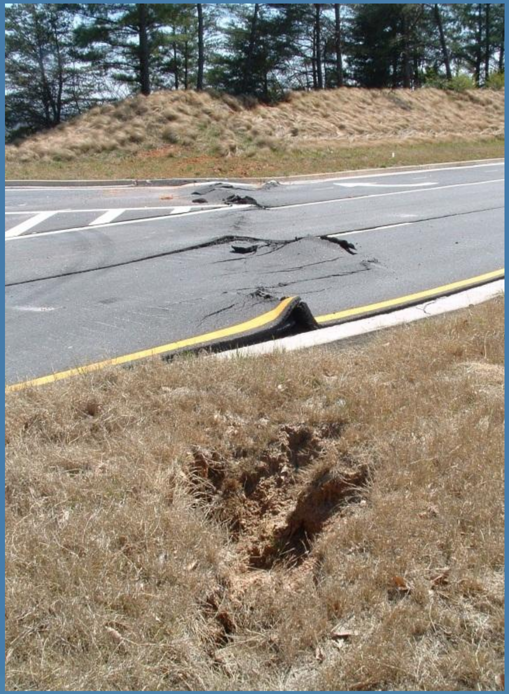
2 Dried-up springs.

3 Dried-up wetlands.

LIMESTONE CONDITIONS WITH PIT DEWATERING

Worst-Case

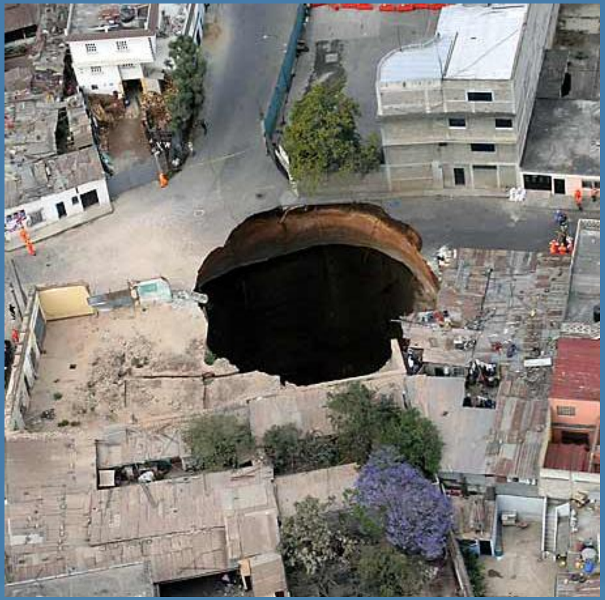
- (2) Dried-up springs.
- (3) Dried-up wetlands.
- (5) Cavities & subsidence.



LIMESTONE CONDITIONS WITH PIT DEWATERING

Worst-Case

- (2) Dried-up springs.
- (3) Dried-up wetlands.
- (5) Cavities & subsidence.
- (6) Collapse sinkholes.



LIMESTONE CONDITIONS WITH PIT DEWATERING
Worst-Case

- (2) Dried-up springs.
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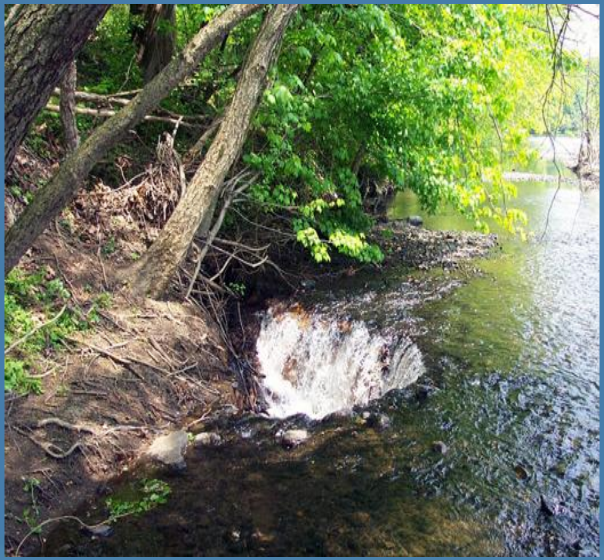
- (7) Dried-up streams.



LIMESTONE CONDITIONS WITH PIT DEWATERING
Worst-Case

- (2) Dried-up springs.
- (3) Dried-up wetlands.
- (5) Cavities & subsidence.
- (6) Collapse sinkholes.
- (7) Dried-up streams.
- (8) Dried-up riparian woodlands.

LIMESTONE QUARRY
Hydrogeologic Study to Assess Negative Impacts

- Existing geologic & hydrogeologic information reviewed.
- Geologic & karst features mapped.

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- Long-term (72-hr.) pumping test of wells.

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Hydrogeologic Study to Assess Negative Impacts

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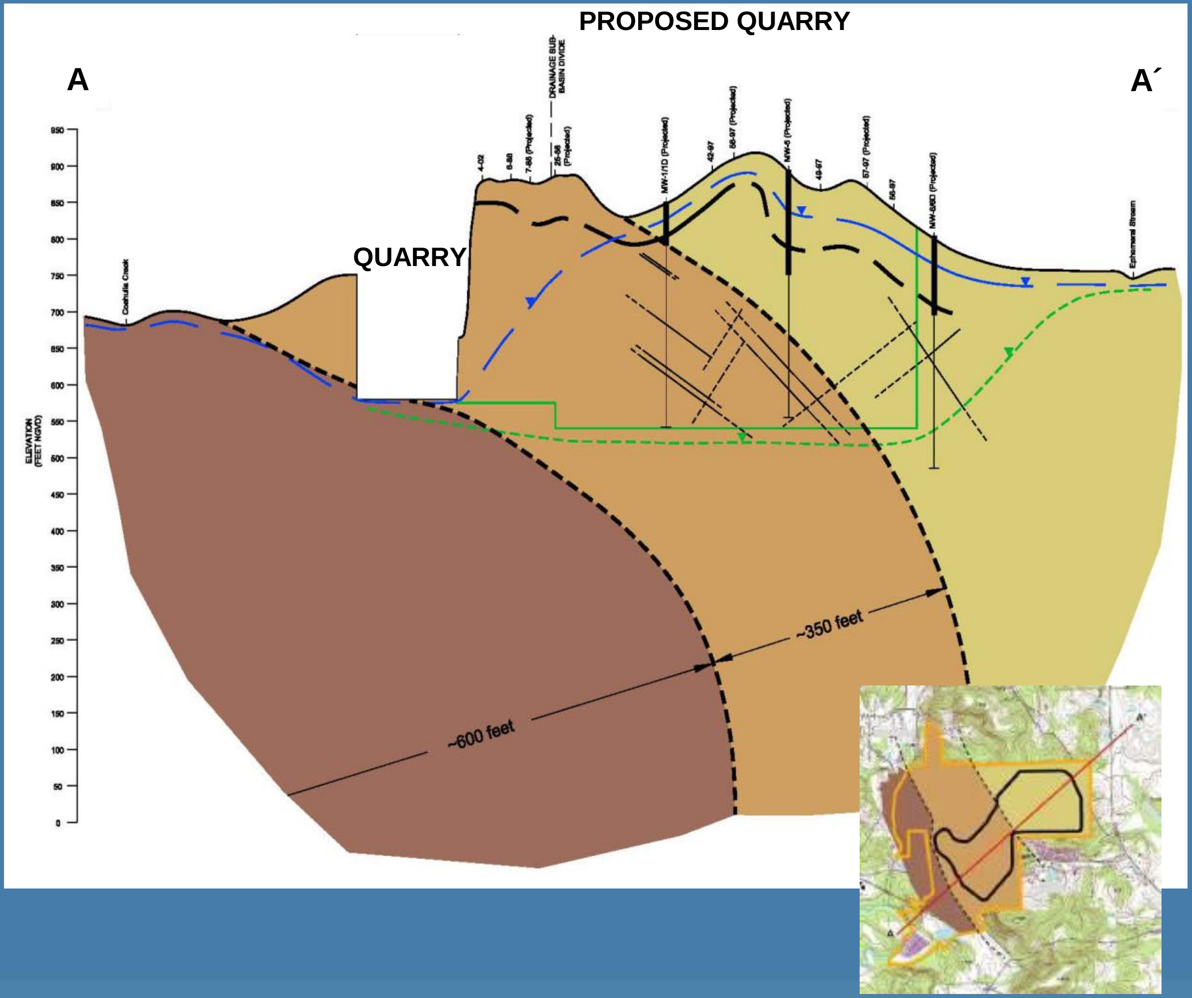
- Geologic & karst features mapped.
- Bedrock wells drilled, logged & installed.
- Coreholes inspected using down-hole video camera.
- Long-term (72-hr.) pumping test of wells.
- Long-term monitoring of groundwater levels & precipitation.

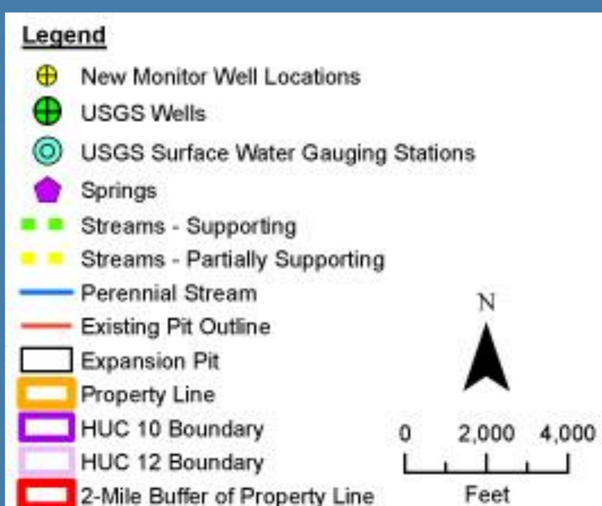
LIMESTONE QUARRY
Hydrogeologic Assessment Report

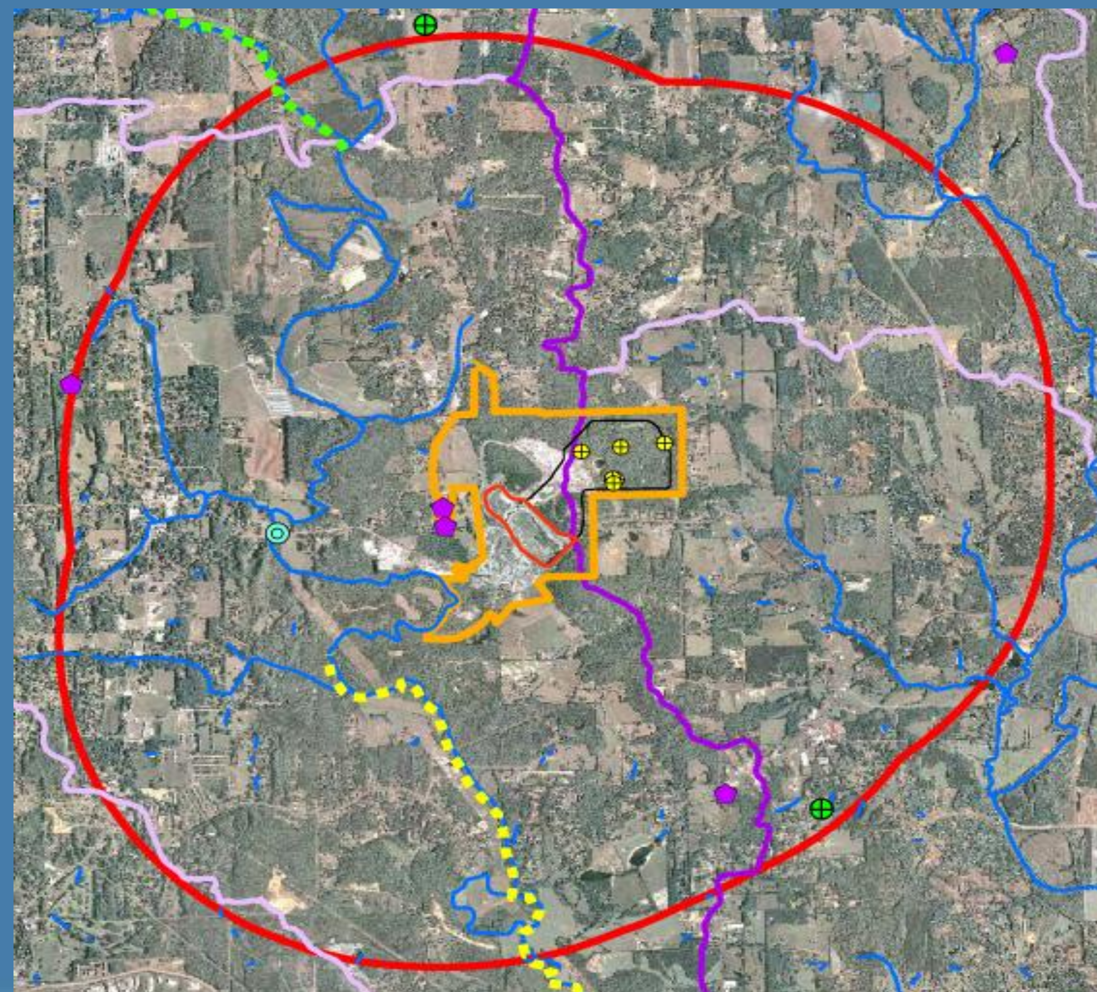
- Existing limestone quarry located on a ridge at the top of a drainage-basin divide.
- Routine pit dewatering with no history of groundwater infiltration.
- The proposed quarry will expand to the northeast.
- Geology dips to the east-northeast & limestone plunges 100s of ft.



LIMESTONE QUARRY
Hydrogeologic Assessment Report

- Diffuse flow along fractures, joints & bedding planes in all directions.
- No cavities or pipe flow.
- Dewatering radius of influence ± 2,540-ft.





LIMESTONE QUARRY
Conclusions

The study concluded that, in part due to the upland position of the quarry & the orientation of fractures, joints & bedding planes:

- The quarry would have a limited effect on groundwater recharge within the drainage basin.
- As the quarry is developed the initial source area of groundwater recharge would be removed (i.e., the area within the quarry footprint).
- The groundwater surface within a conservatively estimated 2,540-ft. boundary of influence around the quarry would descend in a radial pattern in concert with the removal of this local source of recharge.
- The potential for negative impacts due to quarry pit dewatering on-site and off-site within the predicted boundary of influence is minor.
- Natural resources such as springs, wetlands, streams & threatened & endangered species within a 2-mile radius of the pit are either located outside the boundary of influence or are predicted to not be affected by quarry activities.

CASE STUDY #2:

LIMESTONE AGGREGATE QUARRY FLOODING & SINKHOLES

Speaker

Adria Reimer, P.G.

LIMESTONE QUARRY FLOODING & SINKHOLES

- Typical limestone quarry located in the sedimentary rocks of Northwest Georgia.
- Quarry pit bottom is much lower than the creek bed.

LIMESTONE QUARRY FLOODING & SINKHOLES

Limestone Quarry – NW Georgia

- Routine pit dewatering with no history of groundwater infiltration.

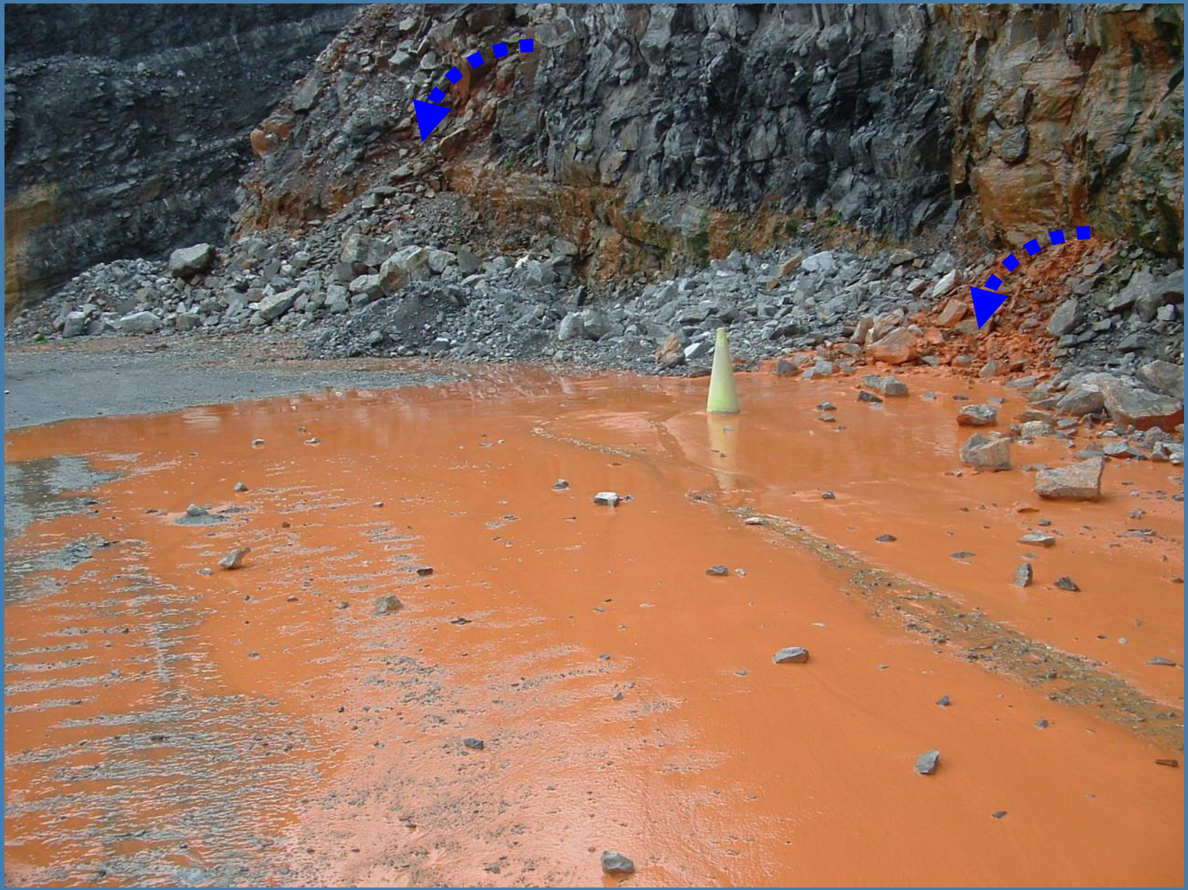
LIMESTONE QUARRY FLOODING & SINKHOLES

Limestone Quarry – NW Georgia

- Routine pit dewatering with no history of groundwater infiltration.
- Dry clay seam exposed during blast in June ‘08.

LIMESTONE QUARRY FLOODING & SINKHOLES

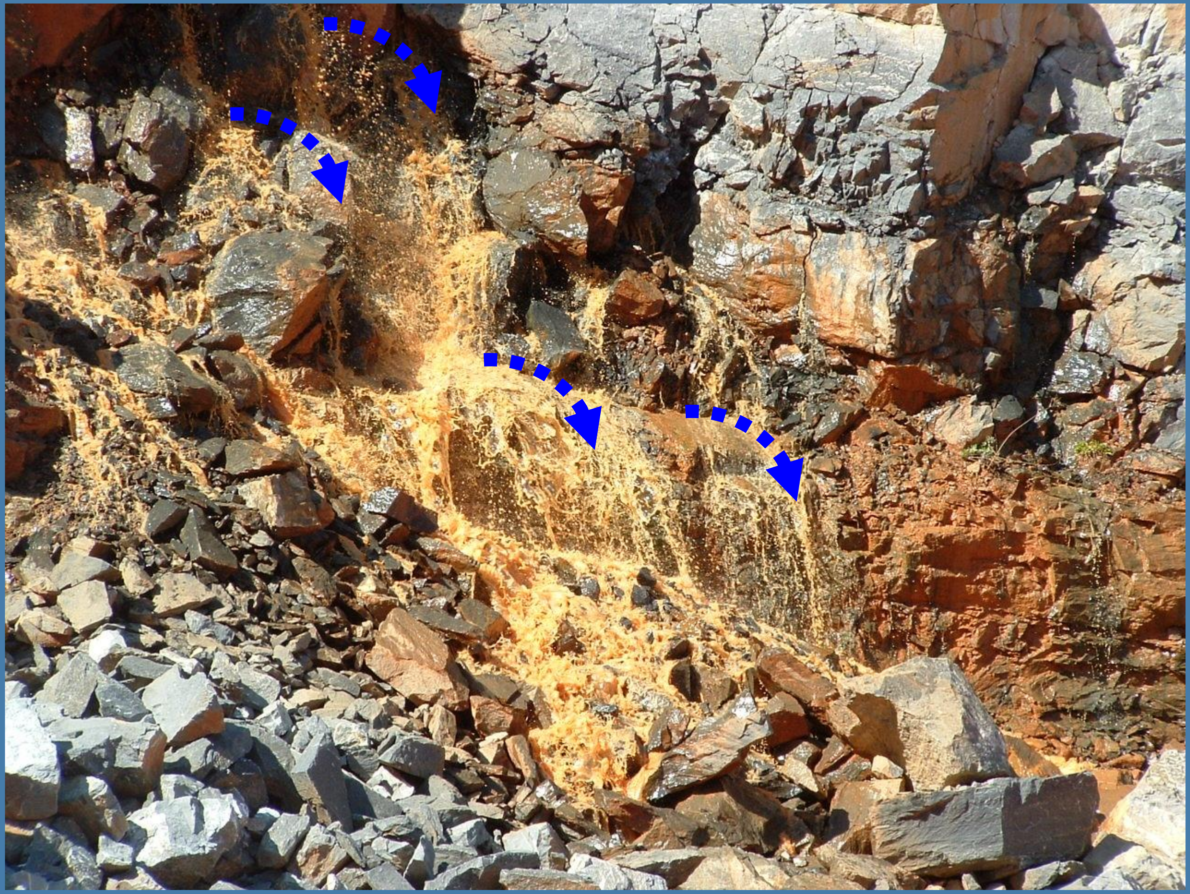
Limestone Quarry – NW Georgia



- Routine pit dewatering with no history of groundwater infiltration.
- Dry clay seam exposed during blast in June ‘08.
- Mud & water oozed from clay seam in Dec. ‘08.

LIMESTONE QUARRY FLOODING & SINKHOLES

Limestone Quarry – NW Georgia



- Routine pit dewatering with no history of groundwater infiltration.
- Dry clay seam exposed during blast in June ‘08.
- Mud & water oozed from clay seam in Dec. ‘08.
- Muddy trickle flowed from clay seam in Feb. ‘09.

LIMESTONE QUARRY FLOODING & SINKHOLES

Limestone Quarry – NW Georgia

- Routine pit dewatering with no history of groundwater infiltration.
- Dry clay seam exposed during blast in June ‘08.
- Mud & water oozed from clay seam in Dec. ‘08.
- Muddy trickle flowed from clay seam in Feb. ‘09.
- Sinkholes collapsed & creek went dry later that day (575 ft. away).

LIMESTONE QUARRY FLOODING & SINKHOLES
More Sinkholes Collapse

- Some of the sinkholes grew…

LIMESTONE QUARRY FLOODING & SINKHOLES
More Sinkholes Collapse

- Some of the sinkholes grew…
- and grew.

LIMESTONE QUARRY FLOODING & SINKHOLES
More Sinkholes Collapse

- Some of the sinkholes grew…
- and grew.
- Other sinkholes opened days later…

LIMESTONE QUARRY FLOODING & SINKHOLES
More Sinkholes Collapse

- Some of the sinkholes grew…
- and grew.
- Other sinkholes opened days later…
- or weeks later.

LIMESTONE QUARRY FLOODING & SINKHOLES
Creek Water Continued to Flow into the Quarry Pit

- Torrential flow washed the clay seam out of the rock.

LIMESTONE QUARRY FLOODING & SINKHOLES

Creek Water Continued to Flow into the Quarry Pit

- Torrential flow washed the clay seam out of the rock.
- Lower 85 ft. of quarry pit filled in <5 days.

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LIMESTONE QUARRY FLOODING & SINKHOLES

Creek Water Continued to Flow into the Quarry Pit

- Torrential flow washed the clay seam out of the rock.
- Lower 85 ft. of quarry pit filled in <5 days.
- Additional 95 ft. of quarry pit filled in <1 mo. (≈ 800-MG) & reached static conditions with the creek.

LIMESTONE QUARRY FLOODING & SINKHOLES

Creek Water Continued to Flow into the Quarry Pit

- Torrential flow washed the clay seam out of the rock.
- Lower 85 ft. of quarry pit filled in <5 days.
- Additional 95 ft. of quarry pit filled in <1 mo. (≈ 800M gal.) & reached static conditions with the creek.
- Creek had started flowing <3 days after the blowout.

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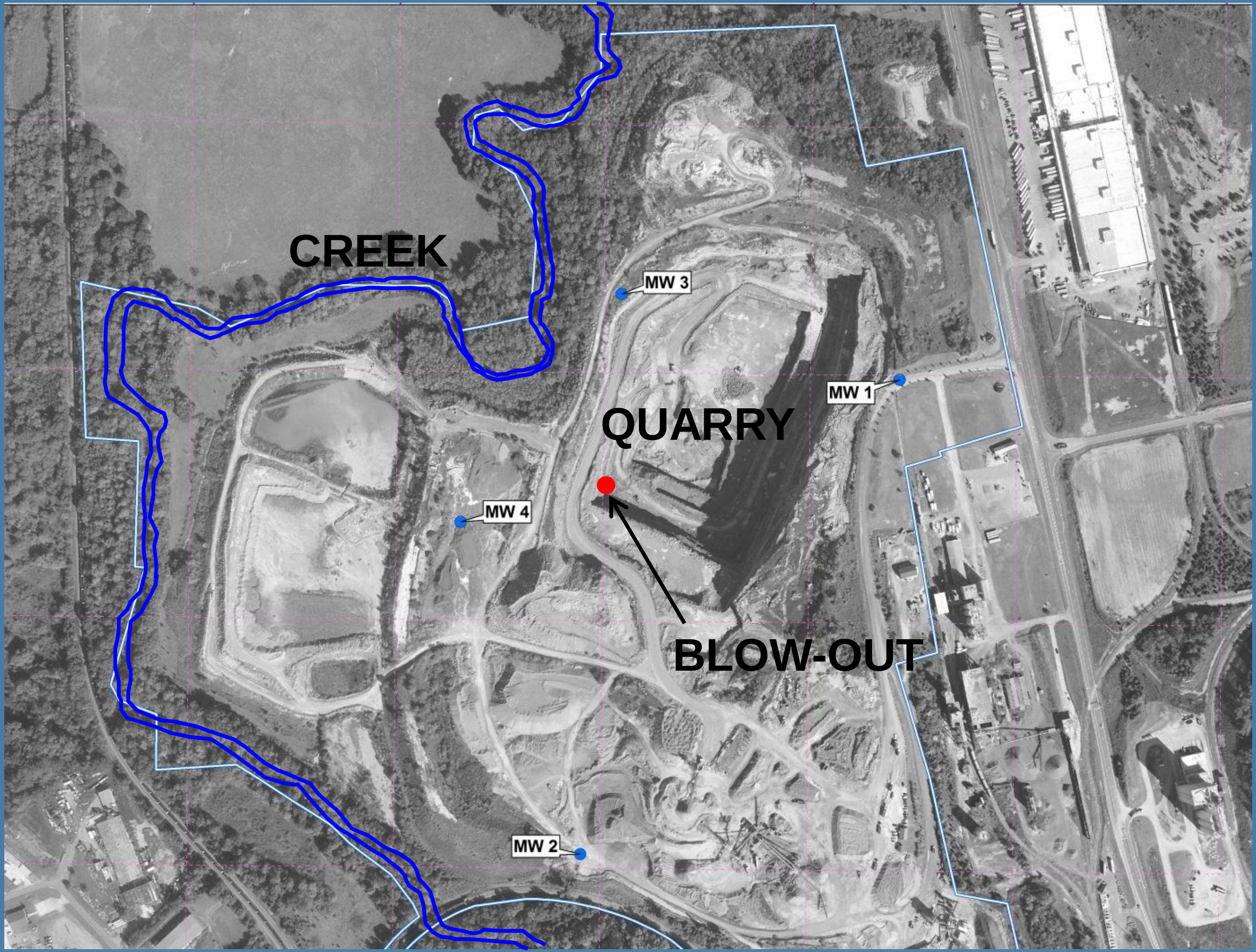
LIMESTONE QUARRY FLOODING & SINKHOLES
Hydrogeologic Study to Assess the Flooding



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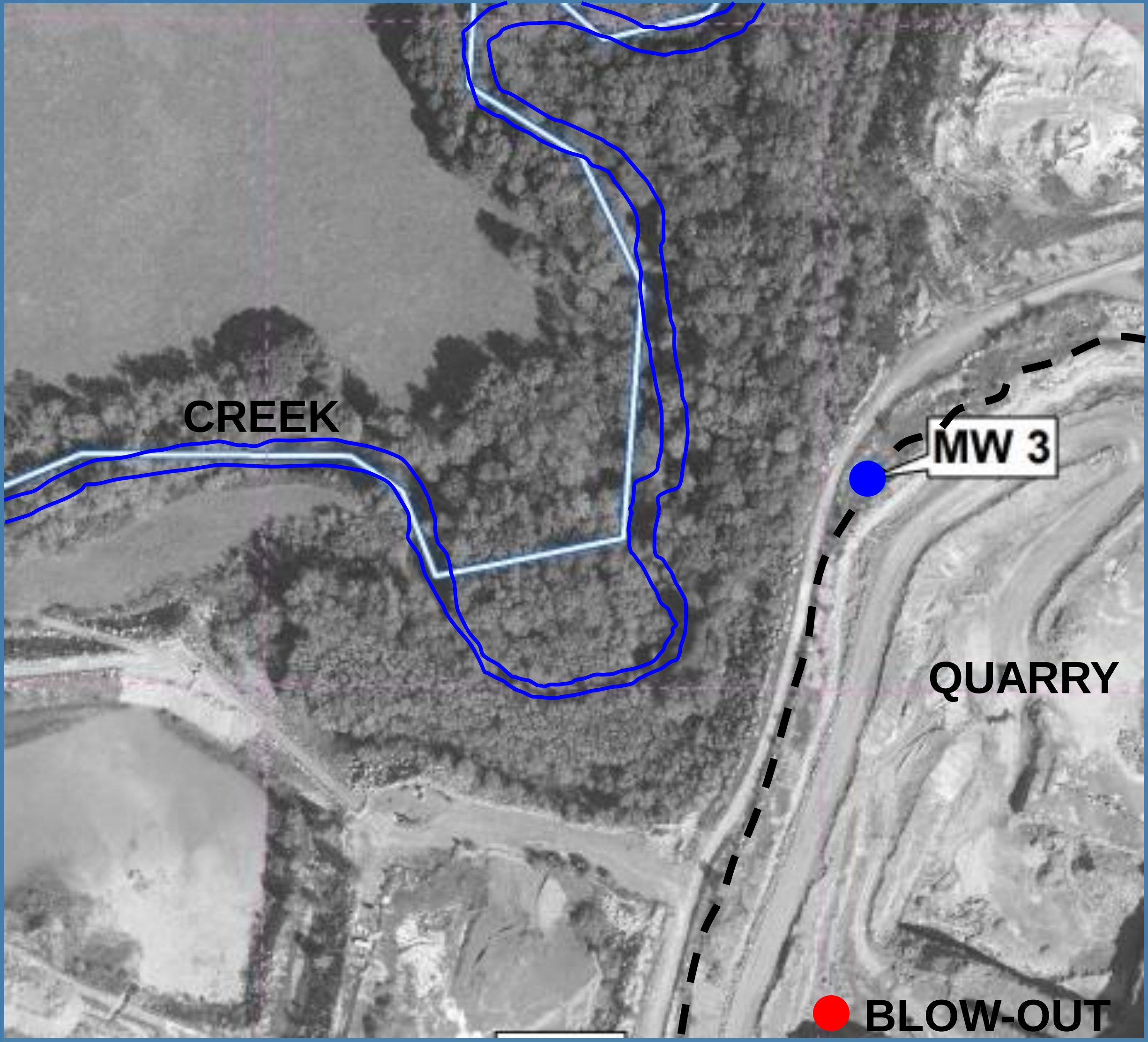
LIMESTONE QUARRY FLOODING & SINKHOLES



- Groundwater level ↑ 40 ft. in well closest to creek days before the blowout.

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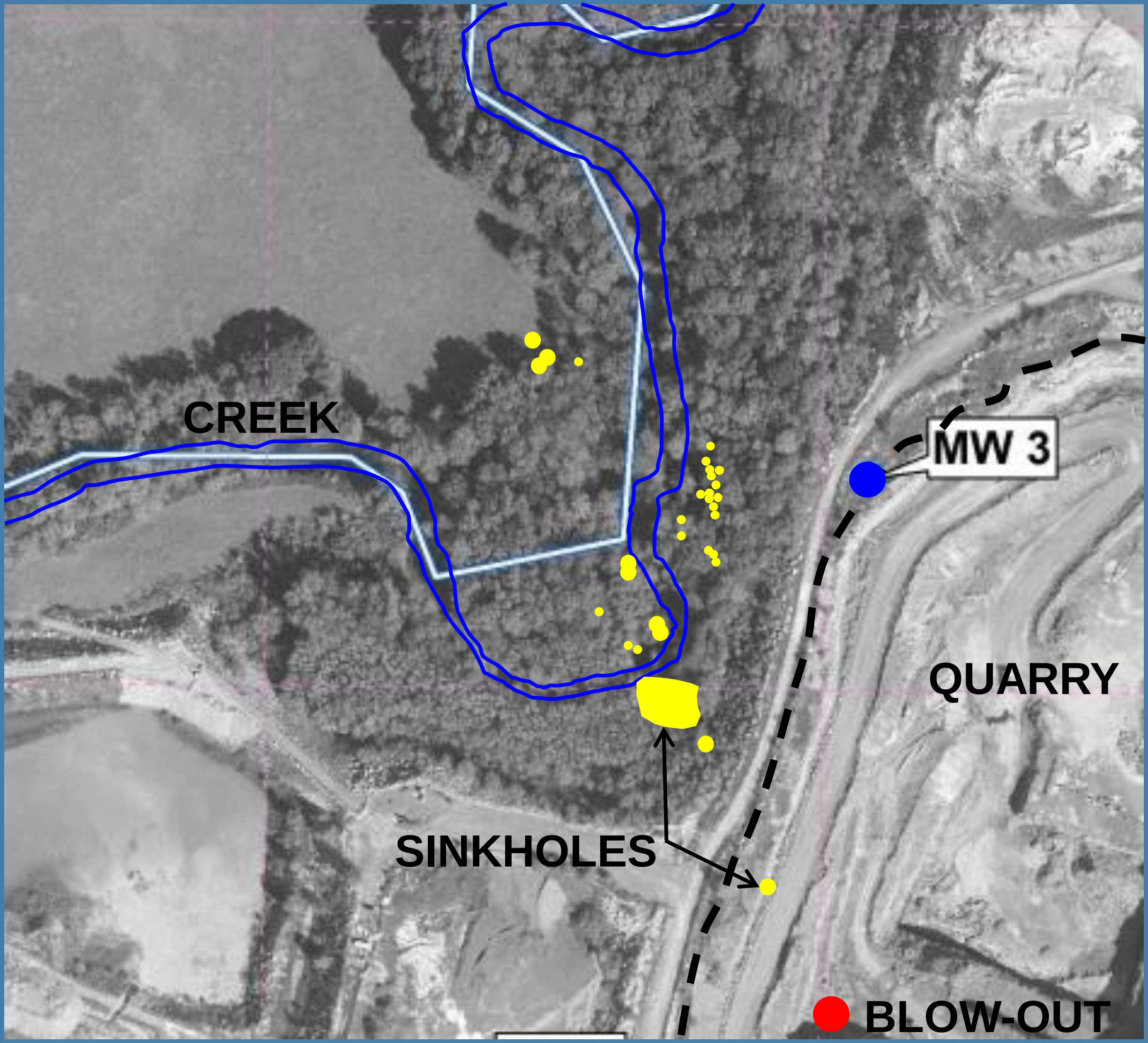
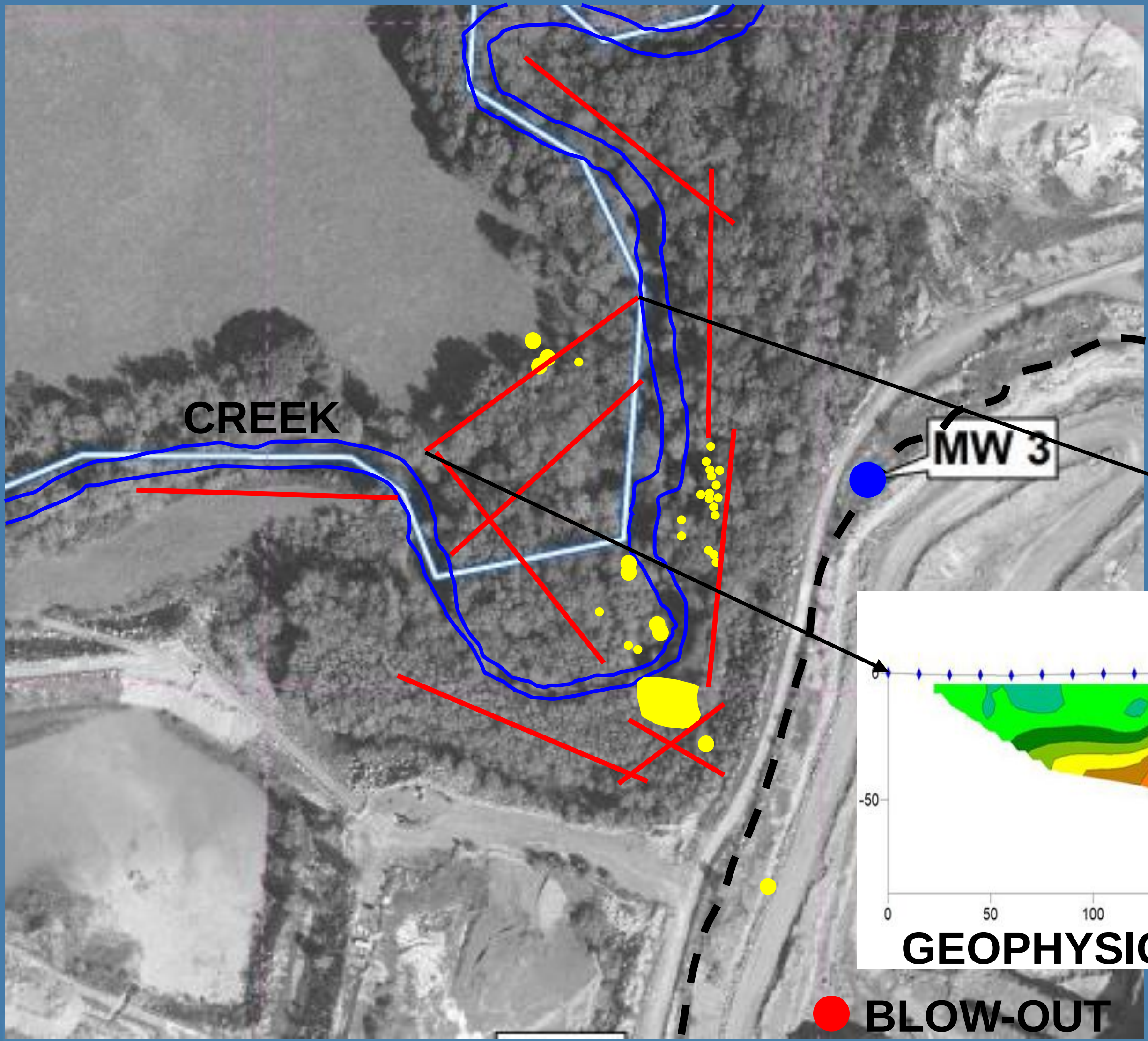
LIMESTONE QUARRY FLOODING & SINKHOLES

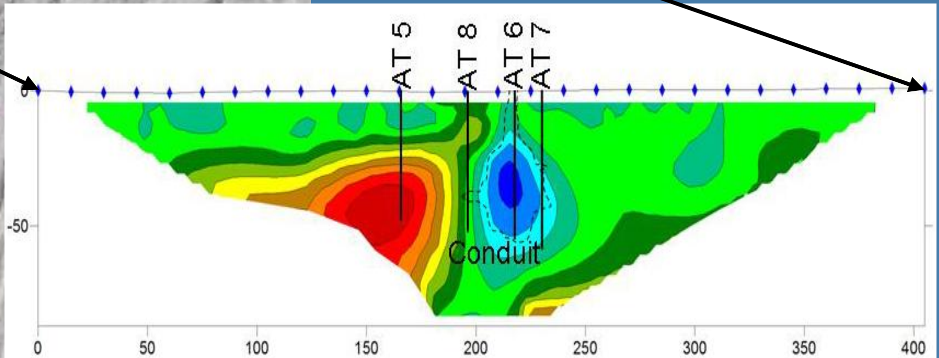


- Groundwater level ↑ 40 ft. in well closest to creek days before the blowout.
- Sinkholes mapped.

LIMESTONE QUARRY FLOODING & SINKHOLES

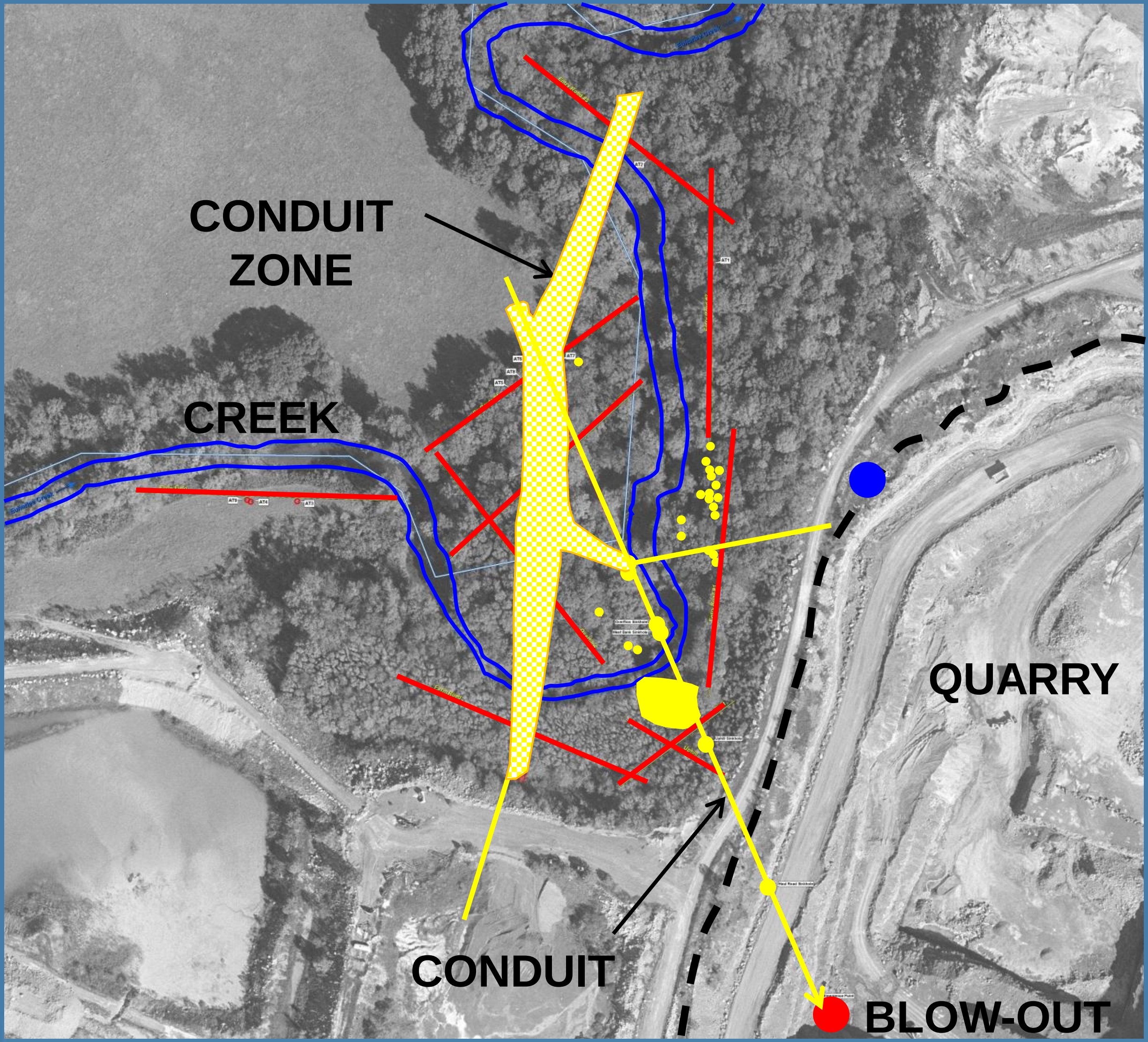


- Groundwater level ↑ 40 ft. in well closest to creek days before the blowout.
- Sinkholes mapped.
- Surface geophysics & confirmation drilling.



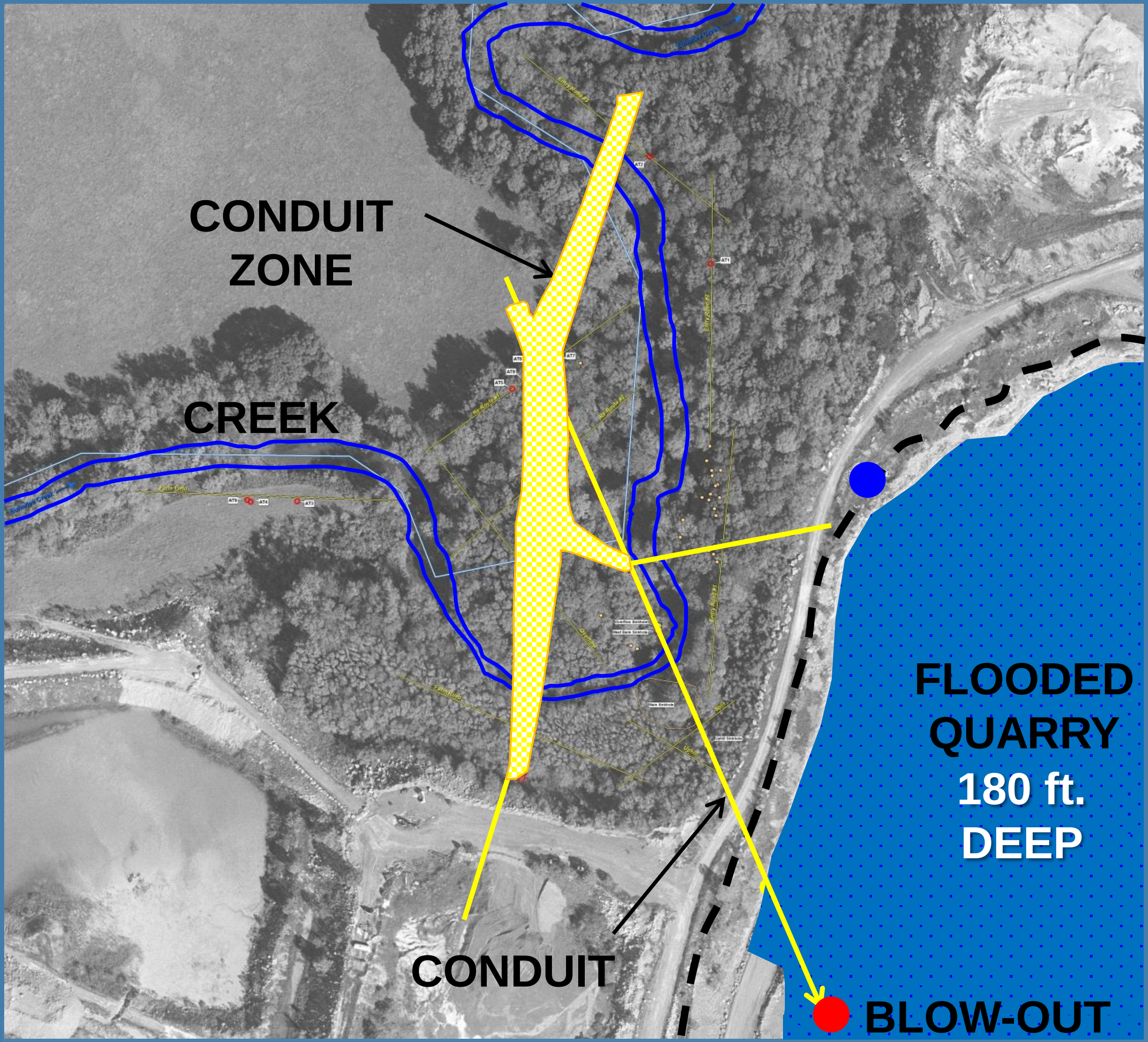
GEOPHYSICAL SURVEY X-SECTION

LIMESTONE QUARRY FLOODING & SINKHOLES



- Groundwater level ↑ 40 ft. in well closest to creek days before the blowout.
- Sinkholes mapped.
- Surface geophysics & confirmation drilling.
- Water-bearing conduits & conduit zones mapped.

LIMESTONE QUARRY FLOODING & SINKHOLES



- Groundwater level ↑ 40 ft. in well closest to creek days before the blowout.
- Sinkholes mapped.
- Surface geophysics & confirmation drilling.
- Water-bearing conduits & conduit zones mapped.
- Conduits packed with clay were flushed clear under head pressure from the creek & opened a flow path to the blow-out point.

LIMESTONE QUARRY FLOODING & SINKHOLES
Conclusions

- Only 1 conduit connection between the creek & quarry pit.
- Limestone aquifer does not contribute ground-water to the pit.
- No new sinkhole collapses anticipated.
- Possible solutions: Pump pit down & either:
  - relocate the creek & line its channel, or
  - drill & hydraulic grout the conduit.

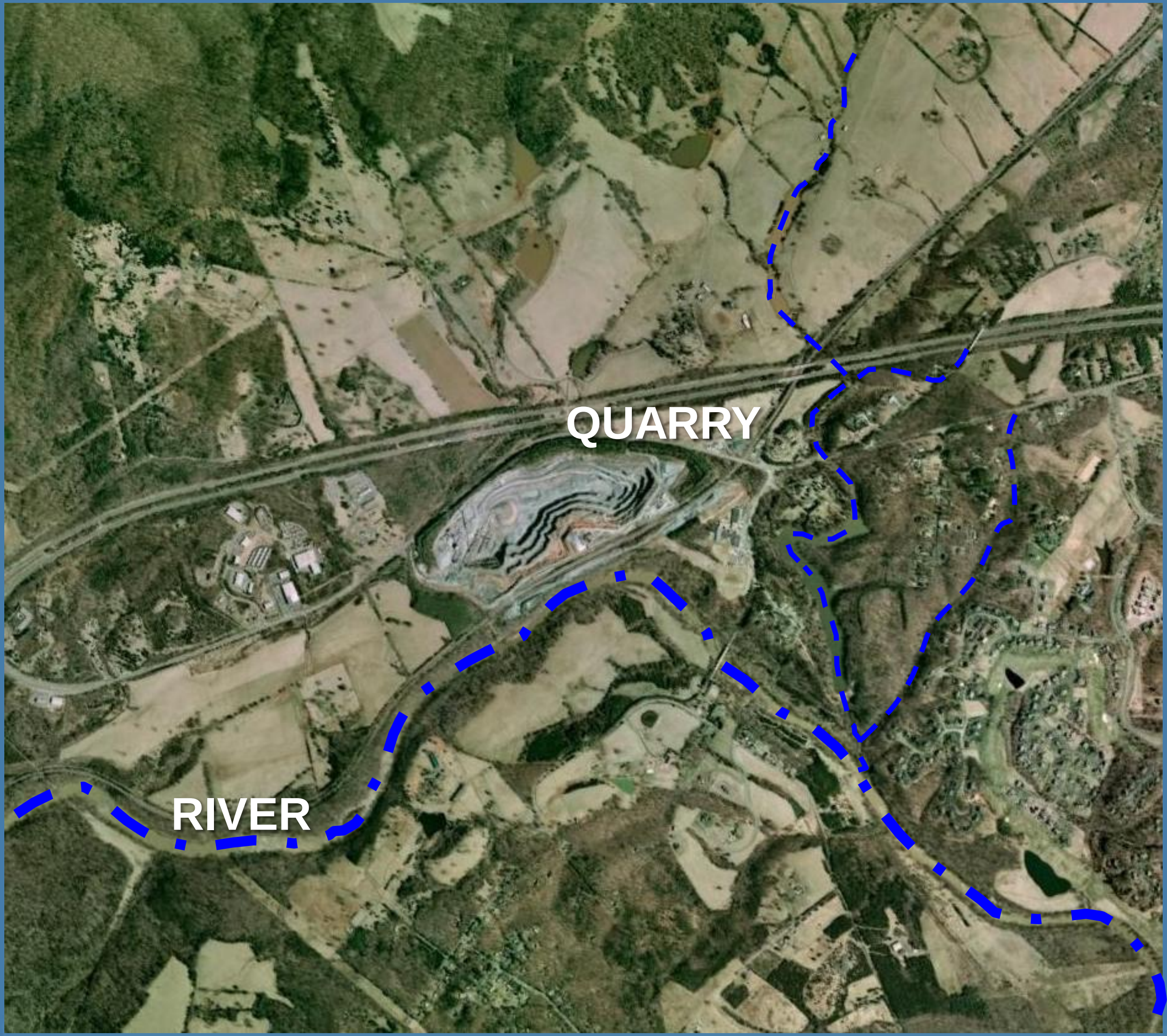
CASE STUDY #3:

GRANITE AGGREGATE QUARRY POTENTIAL FLOODING

Speaker

Nils Thompson, P.G.

GRANITE QUARRY POTENTIAL FLOODING



- Typical granite quarry located between a major highway & river.
- Quarry pit bottom is much lower than the river bed.
- Like most granite quarries, there is no significant recharge from ground-water.

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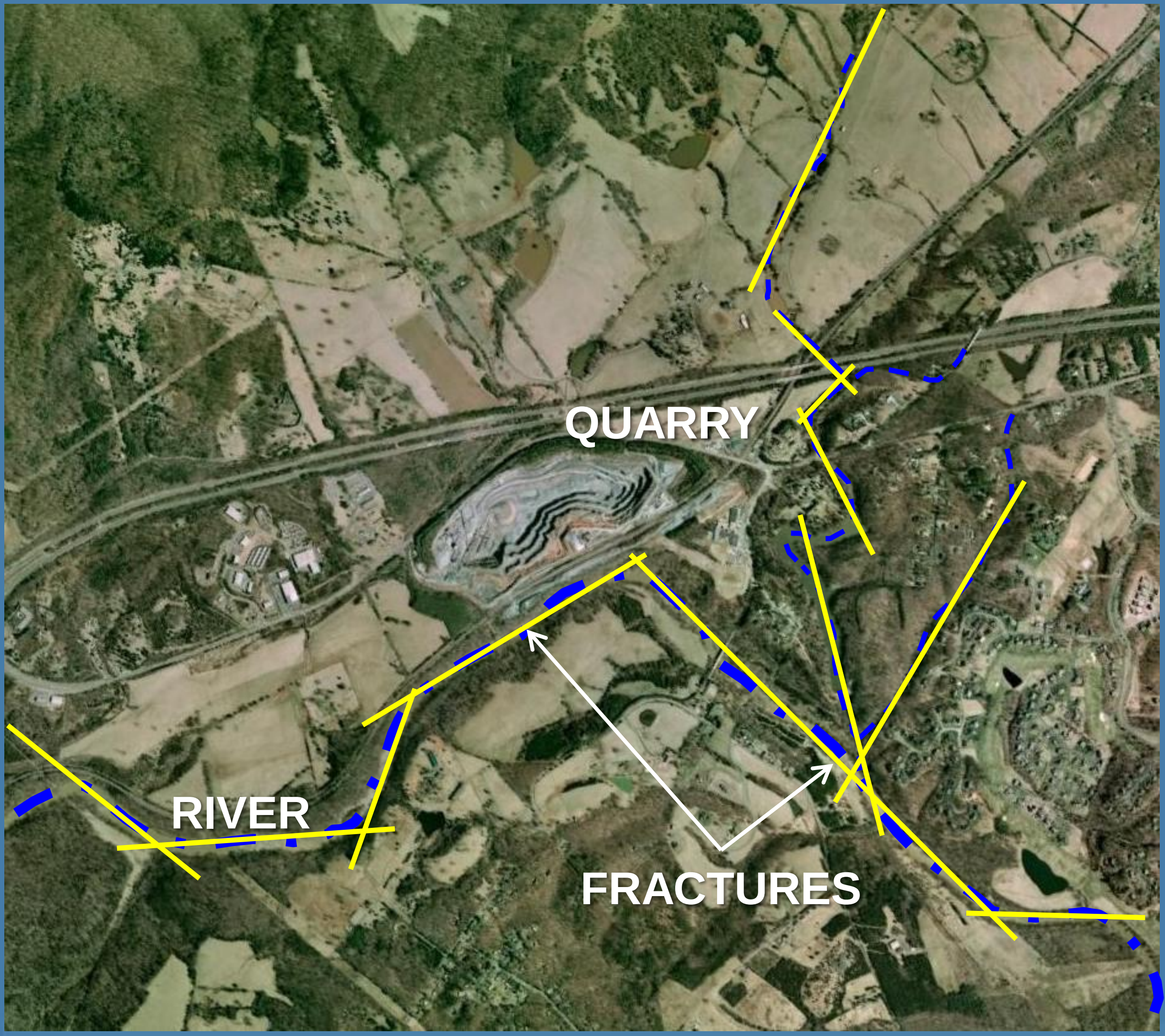
GRANITE QUARRY POTENTIAL FLOODING

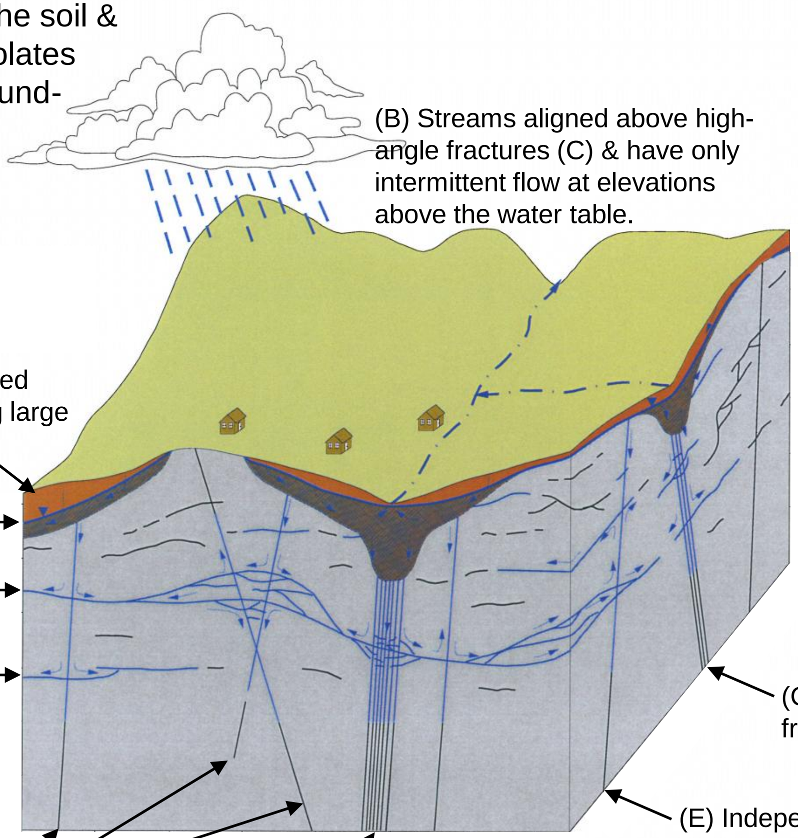


- Notice the natural straight-line sections of the river & streams.
- These lines (lineaments) often result from concentrations of high-angle fractures or joints.
- What exactly are fractures & joints?

FRACTURES & JOINTS IN GRANITE

1. Rainfall infiltrates into the soil & weathered rock and percolates downward to become ground-water.

2. Groundwater is stored in a soil "sponge" (A). Much of the recharge water moves downhill through the soil (A) & dis-charges to streams (B) during or shortly after a rainfall event.

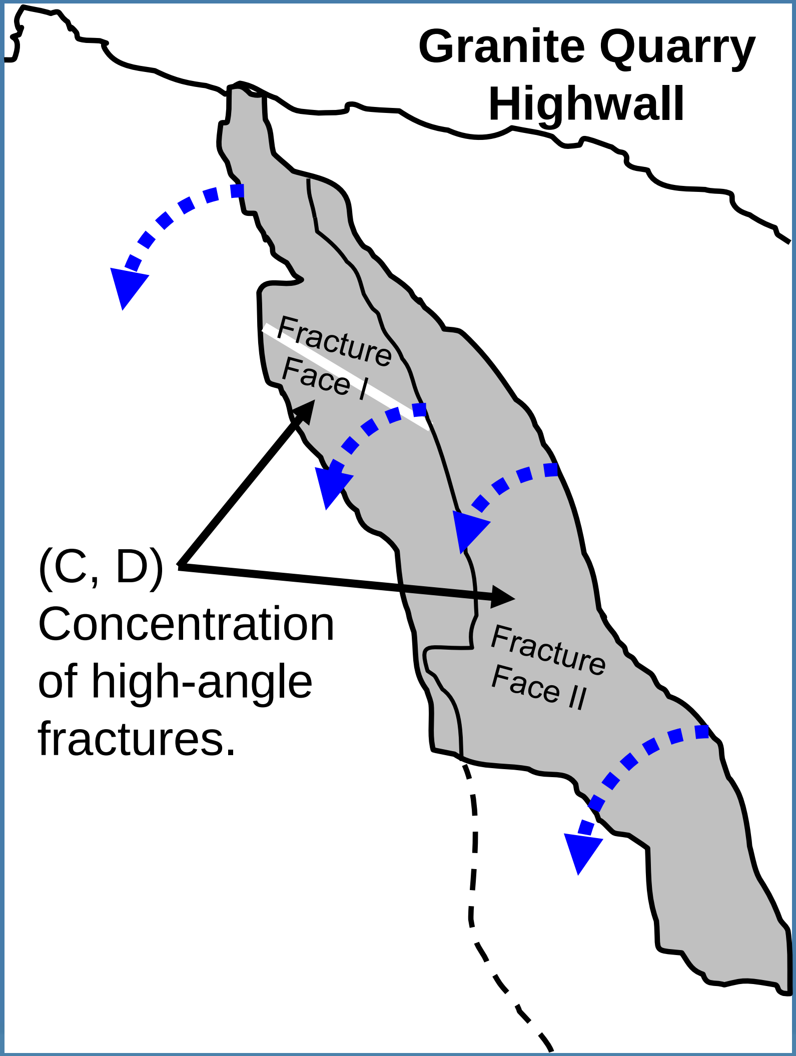


3. A smaller percentage of the groundwater moves downward along zones of weakness such as near-vertical fractures (C, D, and E) & along horizontal fractures (F).

4. Open fractures are scarce below about 400 ft.

Georgia Geologic Survey Guidebook 23

FRACTURES & JOINTS IN GRANITE

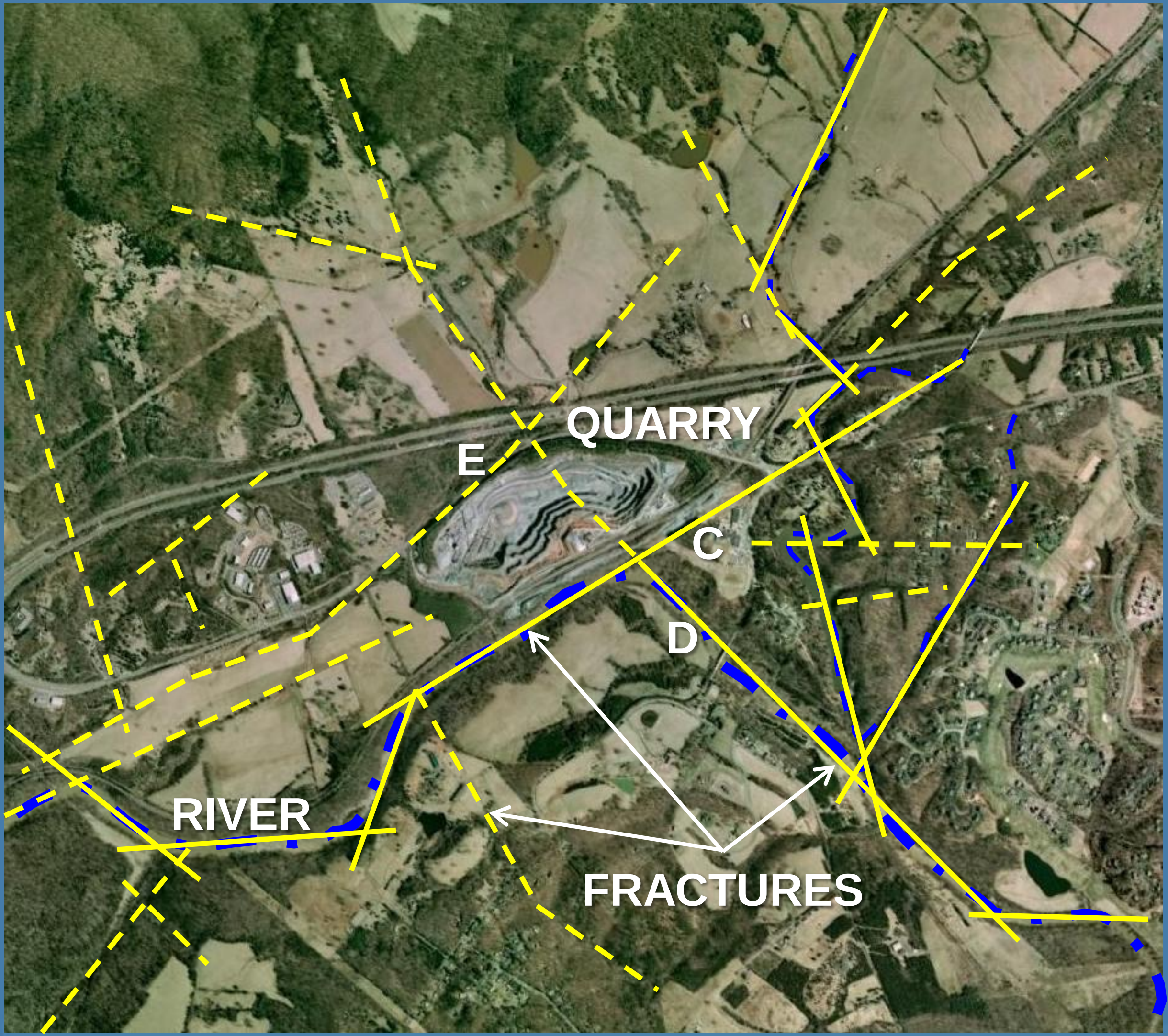


FRACTURES & JOINTS IN GRANITE

(E) Independent high-angle fractures (joints).

(F) Low-angle pressure release fractures.

GRANITE QUARRY POTENTIAL FLOODING

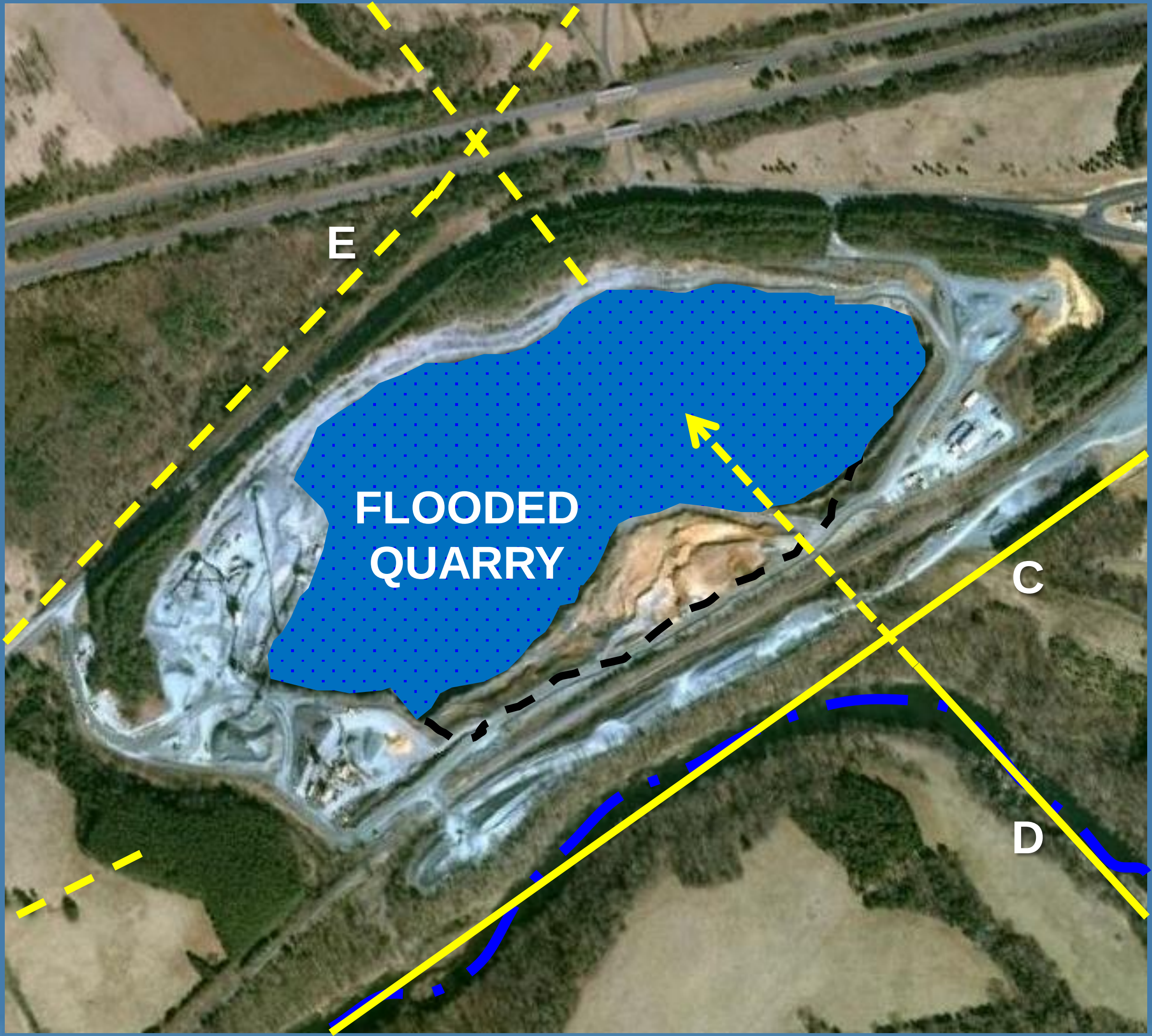


- (C, D) These lineaments often result from concentrations of high-angle fractures.
- (E) Smaller independent lineaments can be mapped along ditches.
- Note that the fractures existed long before the ground surface eroded to its current condition & the rivers, streams & ditches cut down to their current levels.

GRANITE QUARRY POTENTIAL FLOODING

- In order to produce more aggregate, the quarry needs to expand.
- Since the quarry can't expand north toward the highway, it makes sense to expand south toward the river.

GRANITE QUARRY POTENTIAL FLOODING



- Recall that fractures represent narrow, near vertical zones that are often preferred pathways for water movement & increased permeability.
- Expanding the quarry toward the river will shorten the preferred pathway for groundwater / surface water movement along the concentration of high-angle fractures & joints (D; with contribution from C), possibly resulting in a flooded quarry.

CASE STUDY #4:

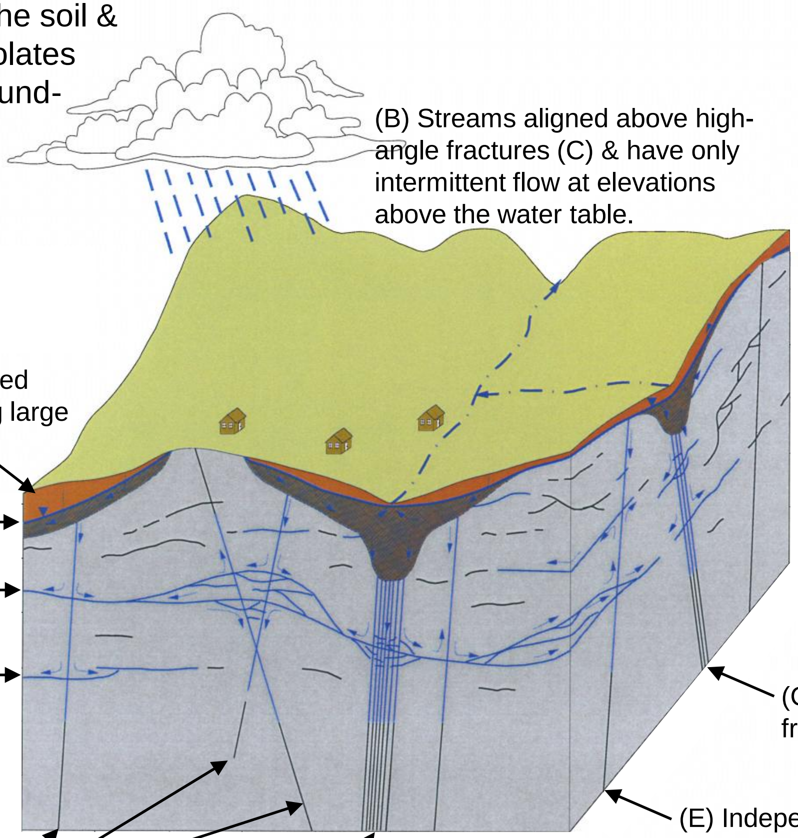
GRANITE AGGREGATE QUARRY INFLUENCES ON NEIGHBORING WELLS

Speaker

Nils Thompson, P.G.

GROUNDWATER OCCURS IN SOIL & FRACTURES

1. Rainfall infiltrates into the soil & weathered rock and percolates downward to become groundwater.



2. Groundwater is stored in a soil “sponge” (A). Much of the recharge water moves downhill through the soil (A) & discharges to streams (B) during or shortly after a rainfall event.

3. A smaller percentage of the groundwater moves downward along zones of weakness such as near-vertical fractures (C, D, and E) & along horizontal fractures (F).

4. Open fractures are scarce below about 400 ft.

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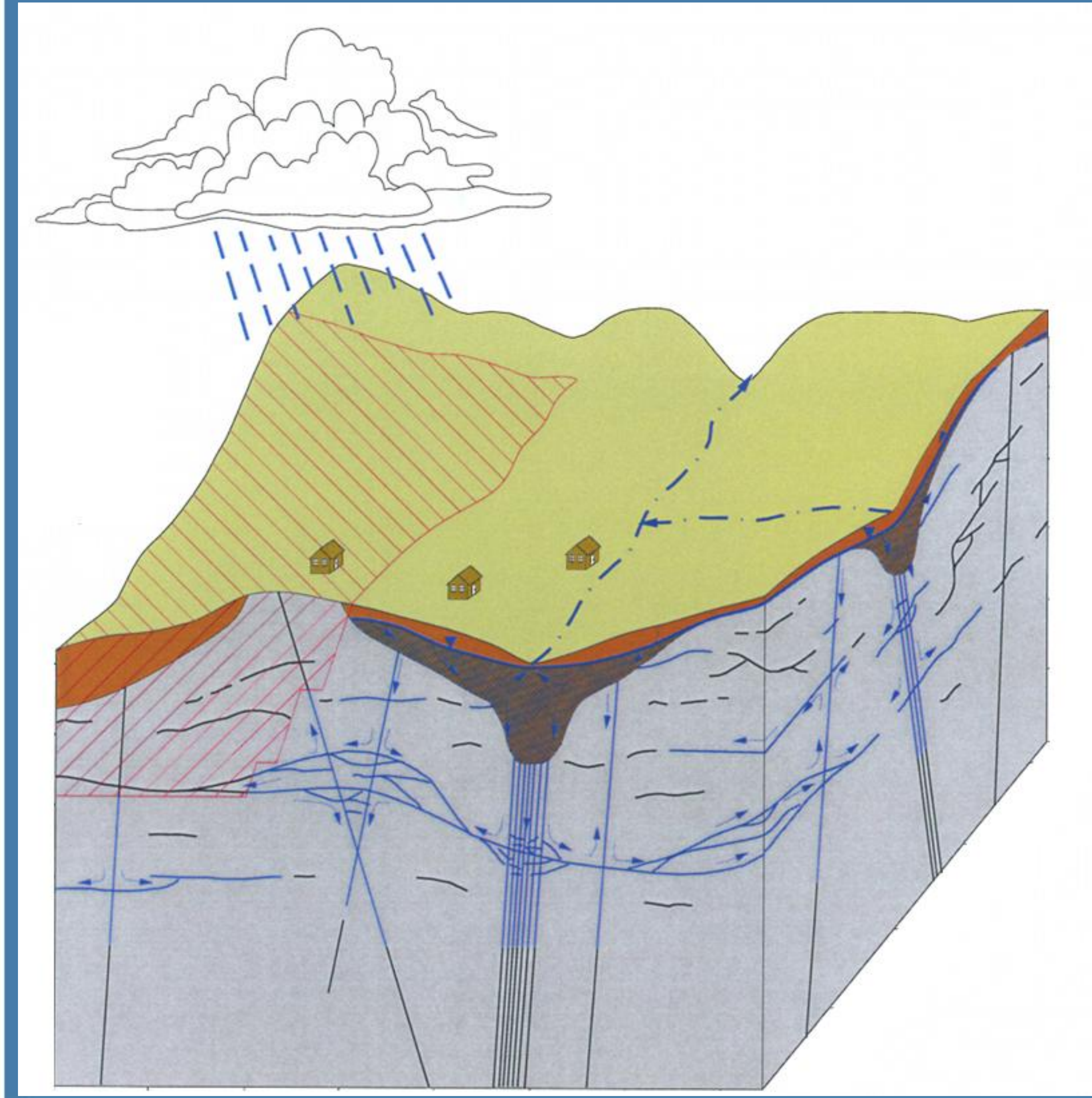
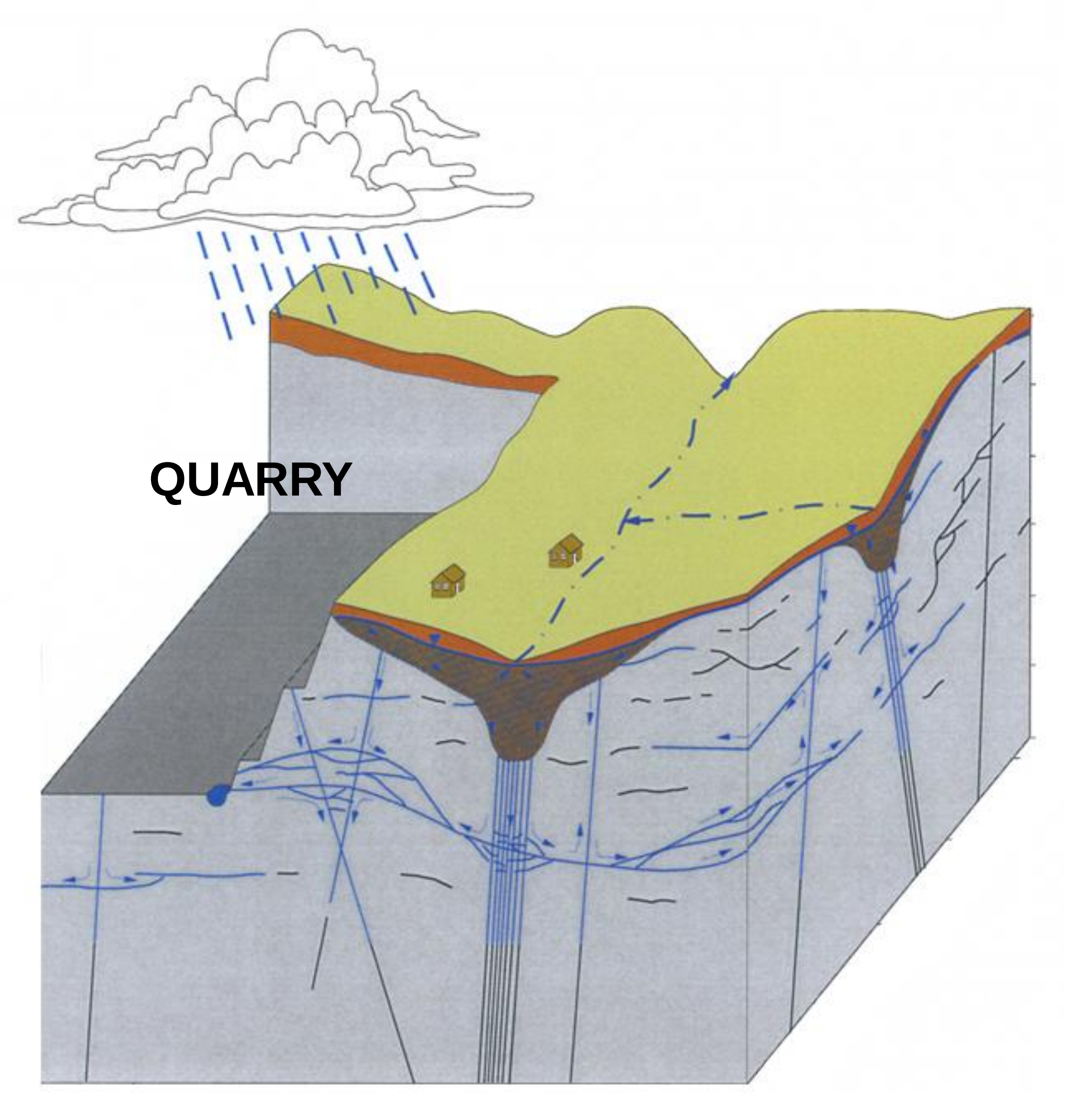
GROUNDWATER OCCURS IN SOIL & FRACTURES



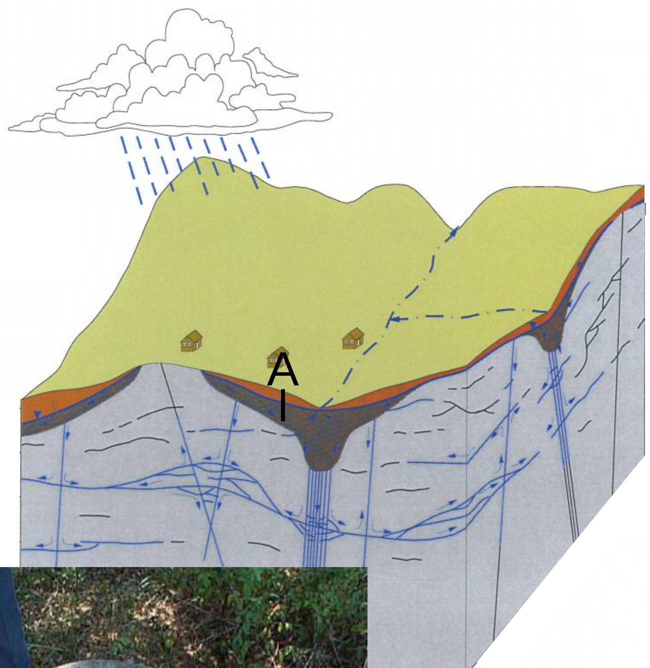
- Typical granite quarry located in the crystalline rocks of North-east Georgia. Mined since ‘53.
- Existing quarry pit bottom is much lower than nearby ditches with seasonal flow.
- Routine pit dewatering with no history of groundwater infiltration.
- There are plans on expanding the pit onto newly acquired, adjacent property.

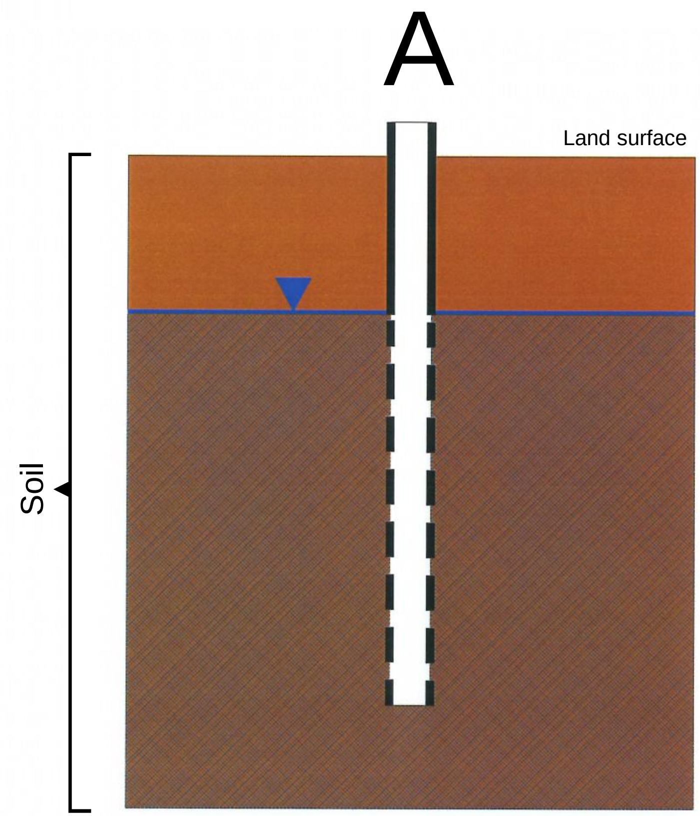
GROUNDWATER OCCURS IN SOIL & FRACTURES



- Neighbors are concerned that their domestic water-supply wells will be impacted.
- Neighbors don't understand that groundwater in crystalline rock is only available in fractures.
- The granite is tight with no conduits or aquifers that can be affected by quarry pit dewatering.
- How do supply wells in the Piedmont & Blue Ridge provinces get water?

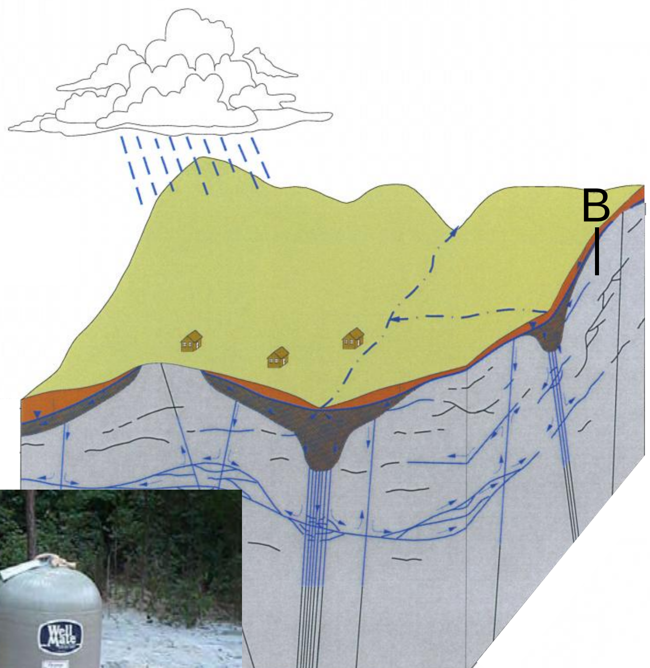
CRYSTALLINE ROCK – BORED WELL ONLY DRILLED INTO THE SOIL

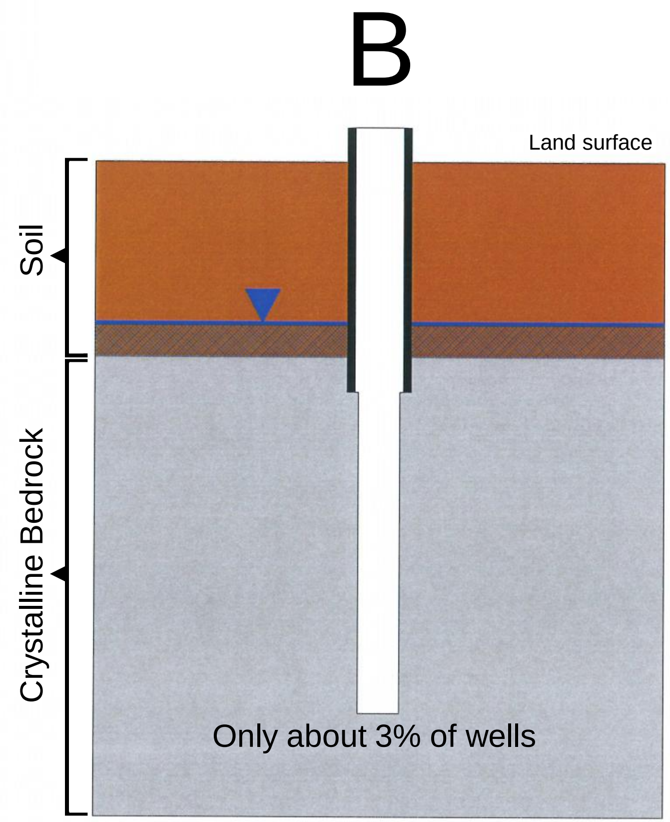




Wells bored into the soil can store large quantities of groundwater. The thicker the soil, the better the available yield.

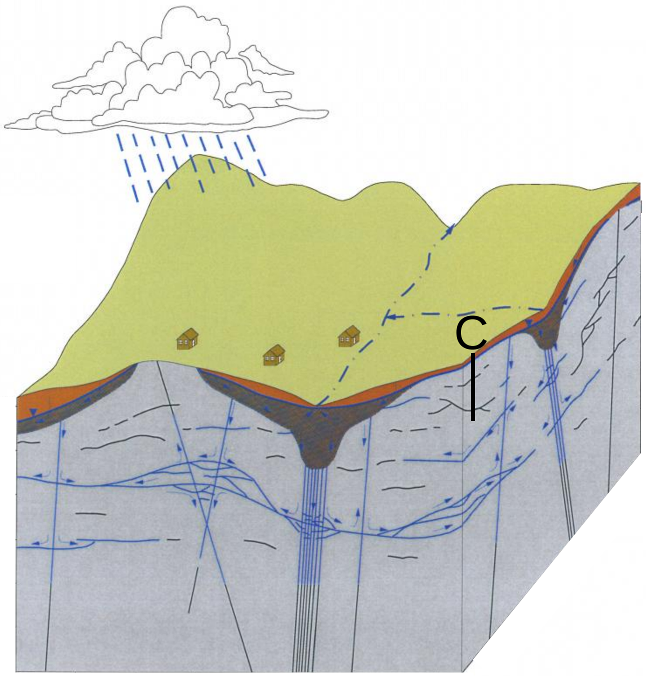
CRYSTALLINE ROCK – DRILLED WELL
NO FRACTURES ENCOUNTERED

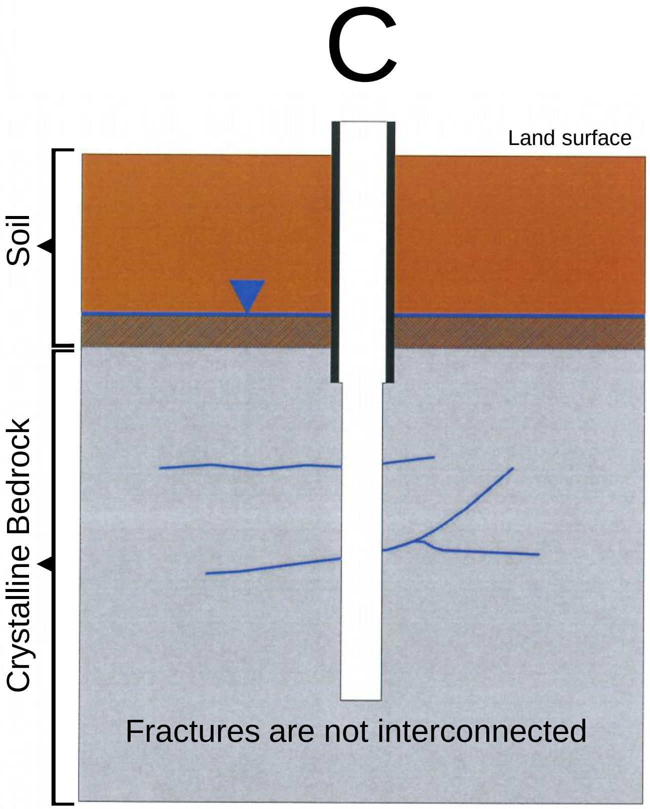




Wells drilled into bedrock, but miss any fractures below the casing will probably be dry or have no sustained yield.

CRYSTALLINE ROCK – DRILLED WELL YIELDS SUDDENLY DECLINE

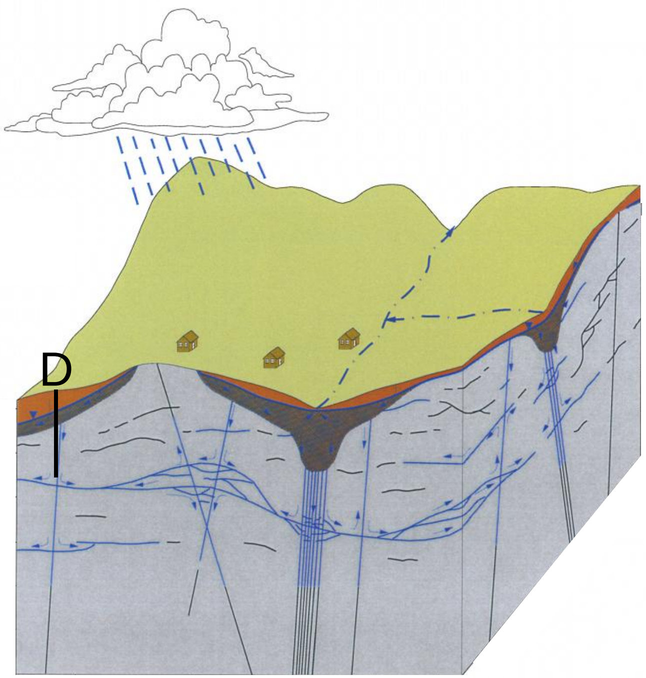


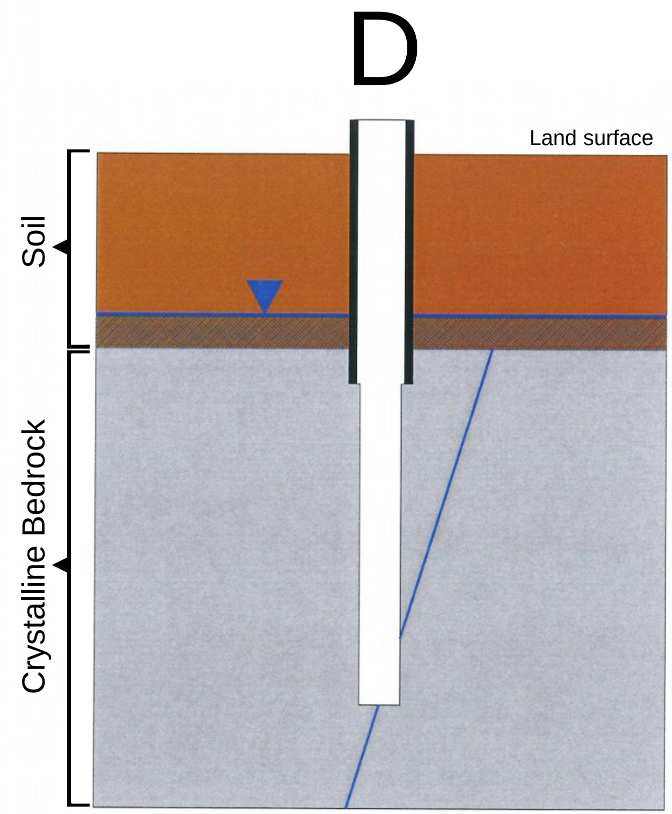


Wells drilled into bedrock that encounter a few fractures might briefly yield as much as 20 gpm until the fractures are drained.

LEGGETTE, BRASHEARS & GRAHAM, INC.
PROFESSIONAL GROUNDWATER AND ENVIRONMENTAL ENGINEERING SERVICES

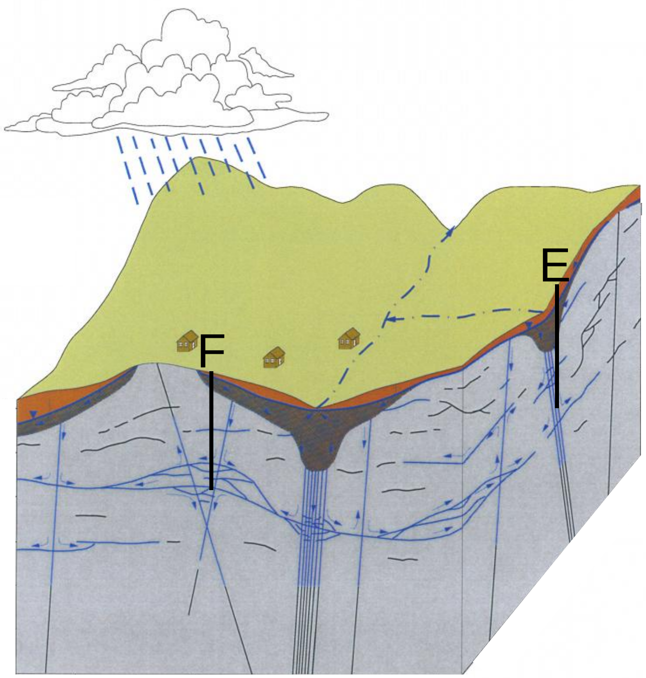
CRYSTALLINE ROCK – DRILLED WELL LOW SUSTAINED YIELDS

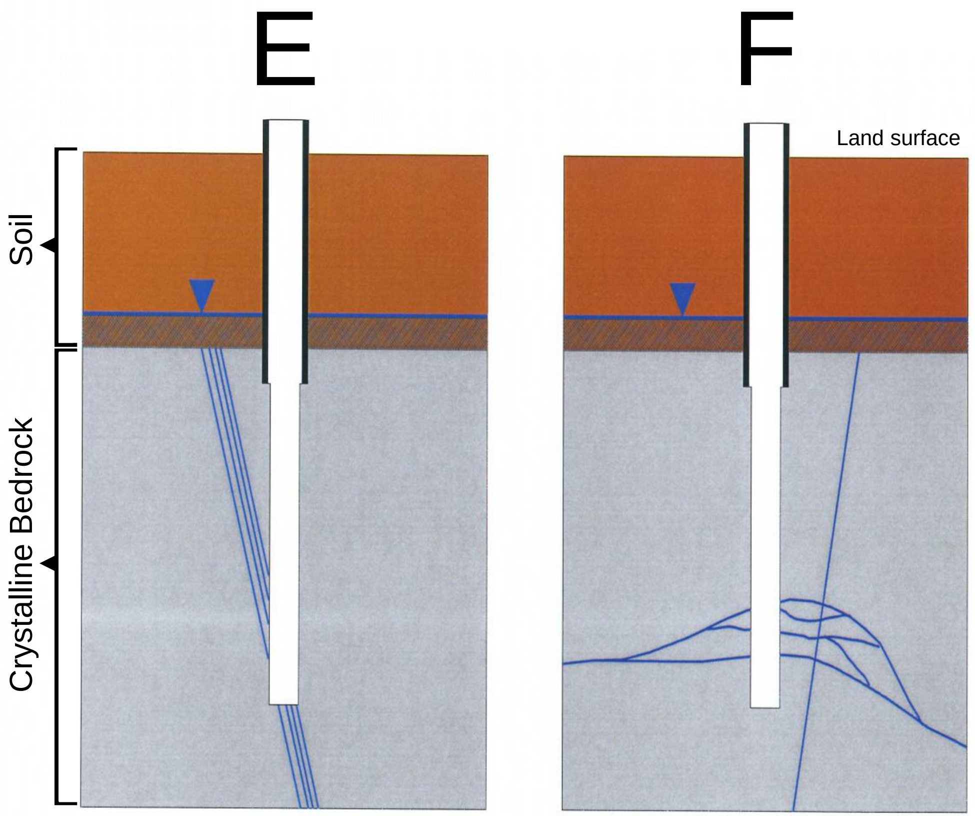




Wells drilled into bedrock that encounter only a single large fracture will have low sustained yields.

CRYSTALLINE ROCK – DRILLED WELL HIGHEST SUSTAINED YIELDS





Wells drilled into bedrock that encounter several fractures (E) or a large number of interconnected fractures (F) have the highest sustained yields.

GROUNDWATER OCCURS IN SOIL & FRACTURES

Conclusions

- Soil holds rainfall like a sponge = the source of groundwater:
  - Thicker soil = more water available to recharge any bedrock fractures.
  - Soil is thickest in the valleys & thin to non-existence on the ridges.
- Quarry expansion is located on top of a ridge:
  - Thin soils contain little to no water.
  - Any water will tend to drain away from the ridge (not towards it).
  - No fracture clusters lead to or away from the ridge.
- Existing quarry:
  - Mined for almost 60 years & a deep pit for the past 40 years.
  - No impact to wells historically & no impacts anticipated by expansion.

Dewatering the quarry will result in no negative impacts to domestic wells.

ADDITIONAL DISCUSSION:

AGGREGATE QUARRIES AS RESERVOIRS

Speaker

Nils Thompson, P.G.

QUARRIES AS RESERVOIRS

- Inactive or abandoned quarries containing water may represent a source of emergency water supply for municipalities.*
- During periods of drought, this water could be pumped into nearby streams to supplement base flow.*
- Active quarries are capable of containing water in the future when they are abandoned (e.g., Bellwood quarry in Atlanta).
- Keep in mind that many quarries are located on leased land & following reclamation, the quarry operation has no further interest.

* **Georgia Geologic Survey Open-File Report 92-2**

QUARRIES vs. RESERVOIRS

- A quarry can be thought of as an “in-ground tank” with a U-shaped profile:
  - A quarry with the same surface area of a reservoir has ↑ vol. than a V-shaped reservoir.
  - Generic site reservoirs typically have a much ↑ surface area than any quarry.
- Efficiency ↑ if the quarry doesn’t leak.
  - Limestone or granite quarries with ↓ historic groundwater infiltration are viable.
  - Must be assessed on a case-by-case basis.
- Obviously, both benefit from being near a stream with ample flow.
  - Although you wouldn’t necessarily find a quarry “on-stream.”
- Yield of available water from a quarry is much less than a constructed reservoir with a much larger footprint.

QUARRIES AS RESERVOIRS

- Pump surface water from nearby streams during periods of excess (i.e., wet season).
- During periods of drought:
  - Pump water back into the stream to supplement base flow.
  - Pump water directly to a WTP.
- "Small" quarries (≈3-BG) + pumped storage from any sizable nearby stream may help augment localized water storage needs* (e.g., Nixon's quarry in Rossville).
- "Large" quarries (≈15-BG) + pumped storage from any sizable ≤ 10 mi. away stream may provide significant storage needs.*
- Any quarry historically inundated with groundwater (not surface water) could impact the aquifer.
- Treatment will always be an issue.

* Technical Advisory Panel 144200-01 TF App. II

QUESTIONS?