MODELING RAPID FILLING PROCESSES IN STORMWATER TUNNELS

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COMBINED SEWER OVERFLOWS

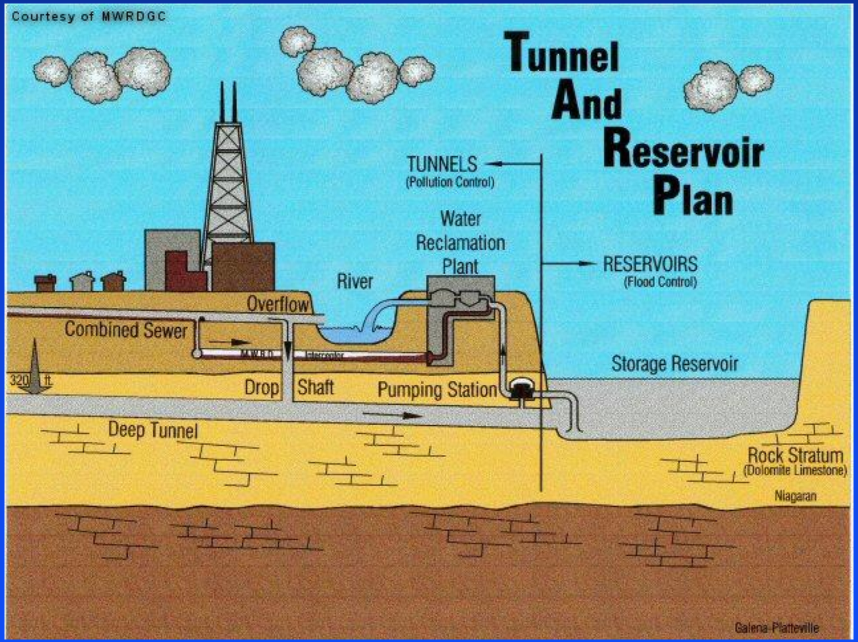
- Many large cities have combined storm and sanitary sewer system
- During heavy rainfall, stormwater overwhelms the system, requiring overflows (discharge to surface water)
- Starting in 1970’s, increasingly strict regulations to limit frequency and volume of overflows

CHICAGO EARLY ADOPTION OF CSO CONTROL SCHEMES

CSO control, Chicago

- Deep storage tunnel to receive stormwater peaks, later to pump back to sanitary system after flows subside
- > 170 km of tunnel up to 10 m diameter
- Project initiated 1975, scheduled for completion in 2029

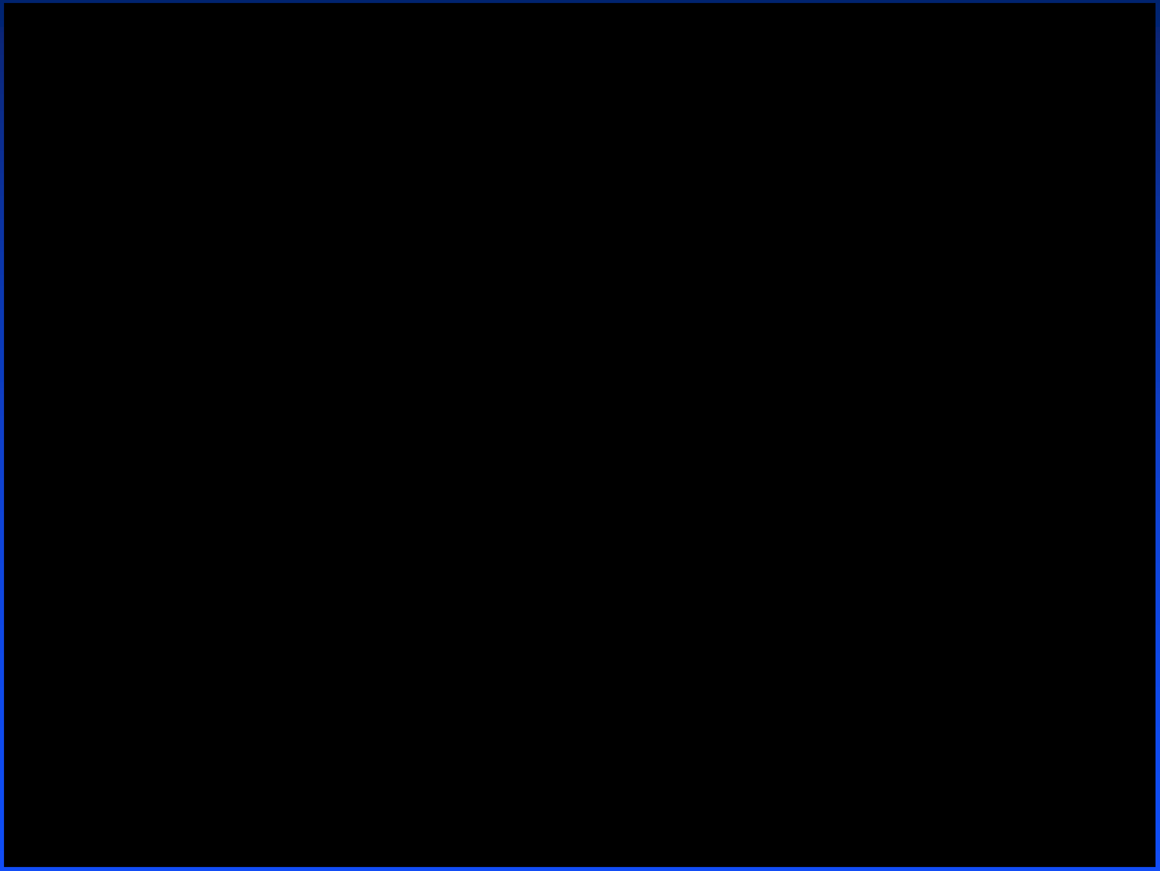
TARP schematic



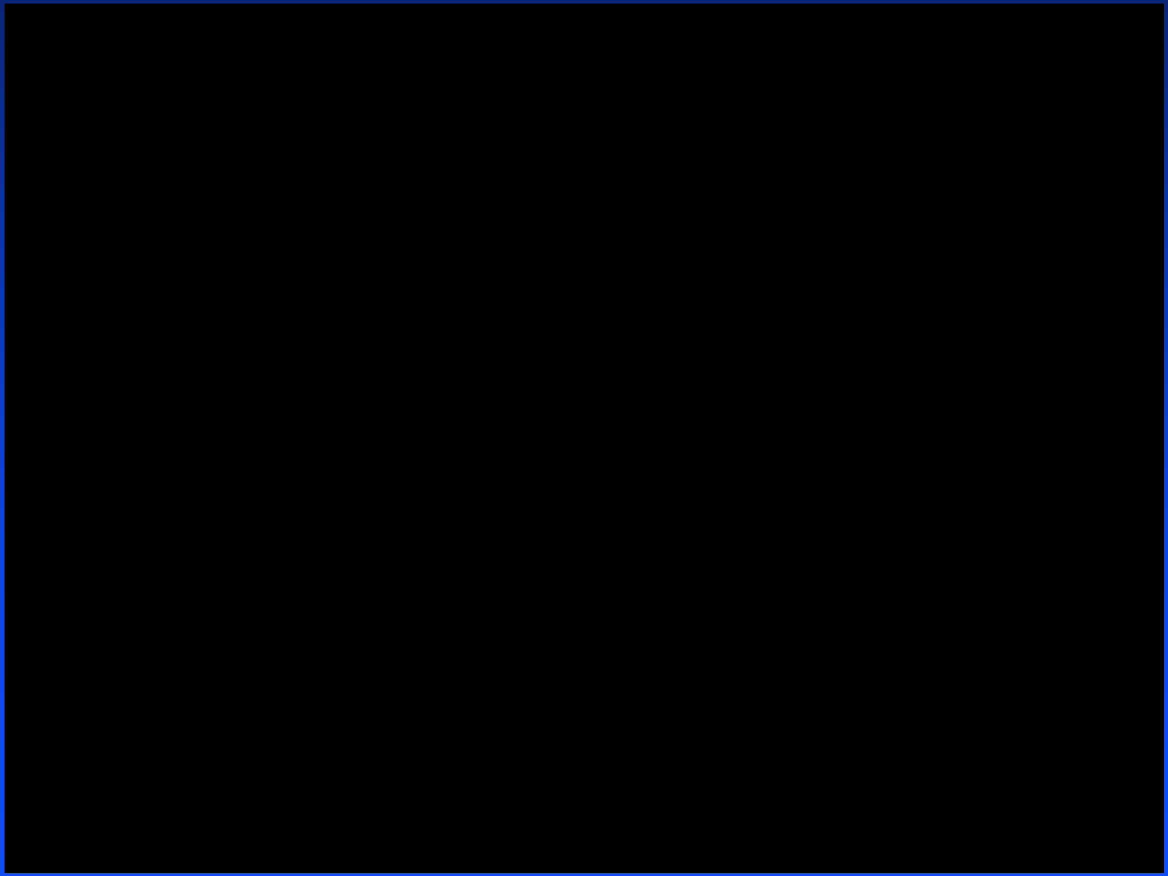
Major Issue Identified in Chicago TARP system

- “Geysers” reported at a number of located during rainfall event from 1986 or earlier
  - **Large jets of water/air from manholes**
  - **Manhole covers being ejected**
  - **Street flooding**
  - **“Solved” by closing tunnel gates once storage tunnel is about half full**

June 23, 2011 Storm



Montreal, etc.



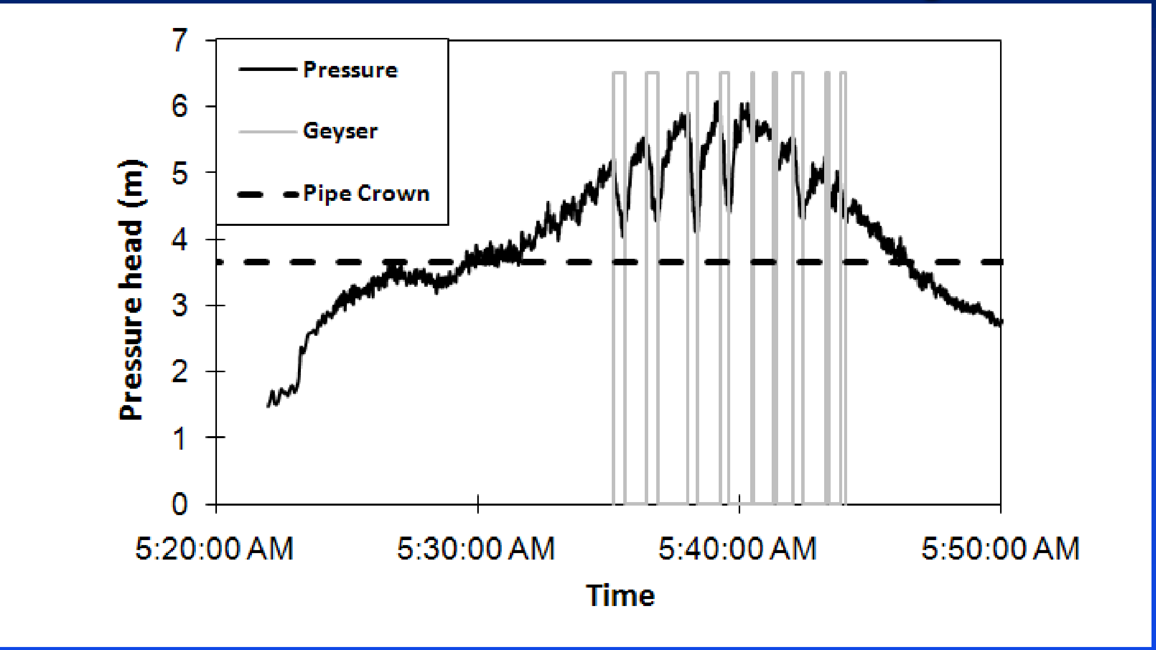
Other Systems

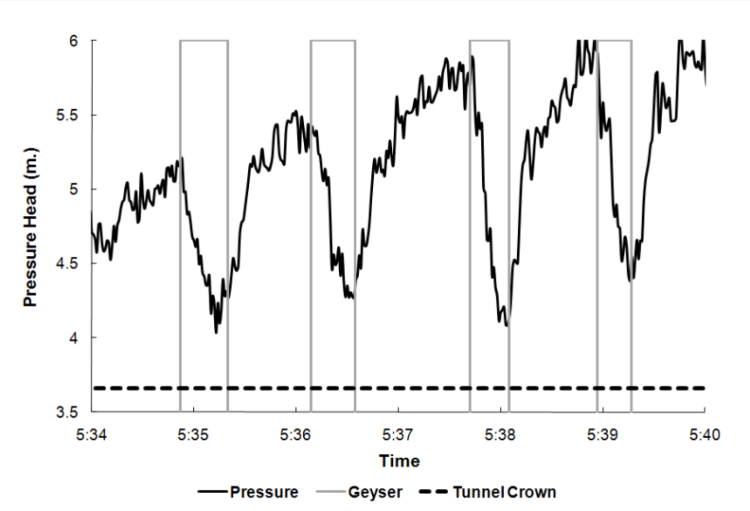
WHAT IS A GEYSER?

- Early work to solve Chicago problem analyzed the filling process as water flow only (surge). Is this reasonable?
- Mathematics is easier if we only consider one fluid phase (neglect air)
- What if the air is important?

Minneapolis, MN

Measured Pressures, Minnesota by SAFL



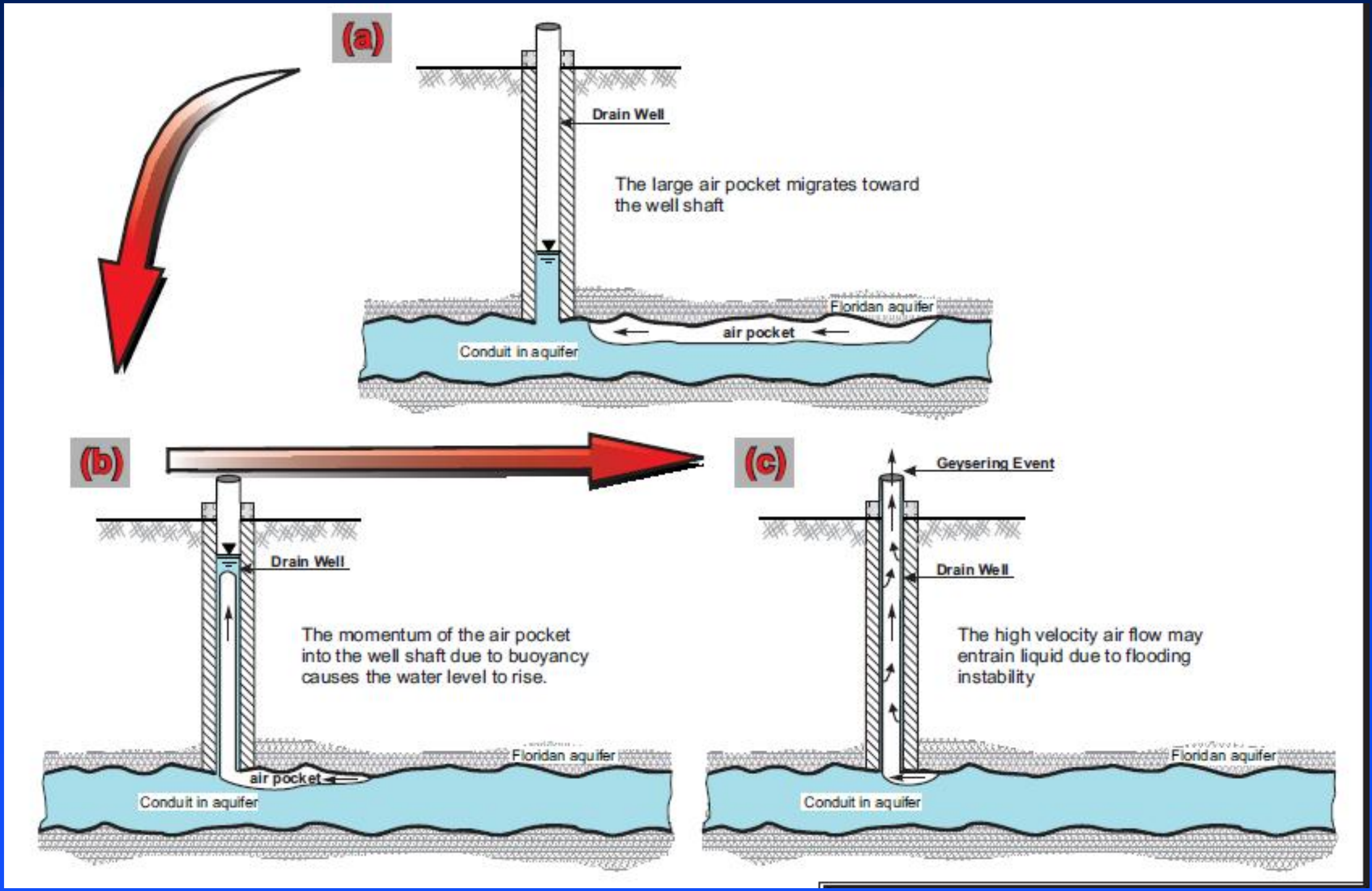


Lab Scale Studies

DEFINITION OF GEYSER IS IMPORTANT

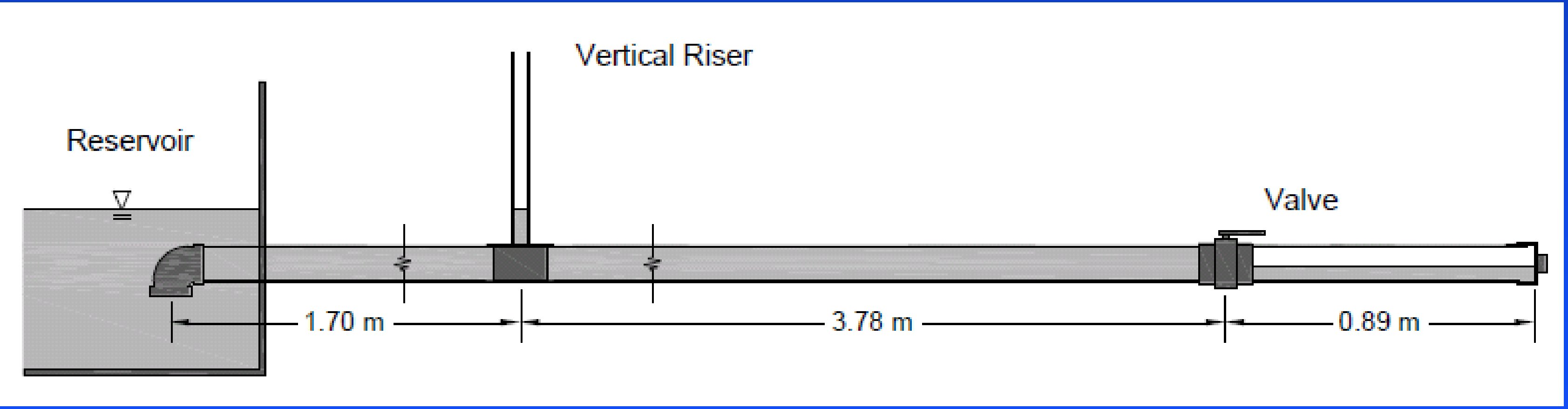
- Filling process could involve surcharging of sewer. Is that a geyser?
- Air pocket entrapment can result in some types of surges that could be interpreted as geysers. Small scale lab experiments – all processes do not scale so hard to conclude

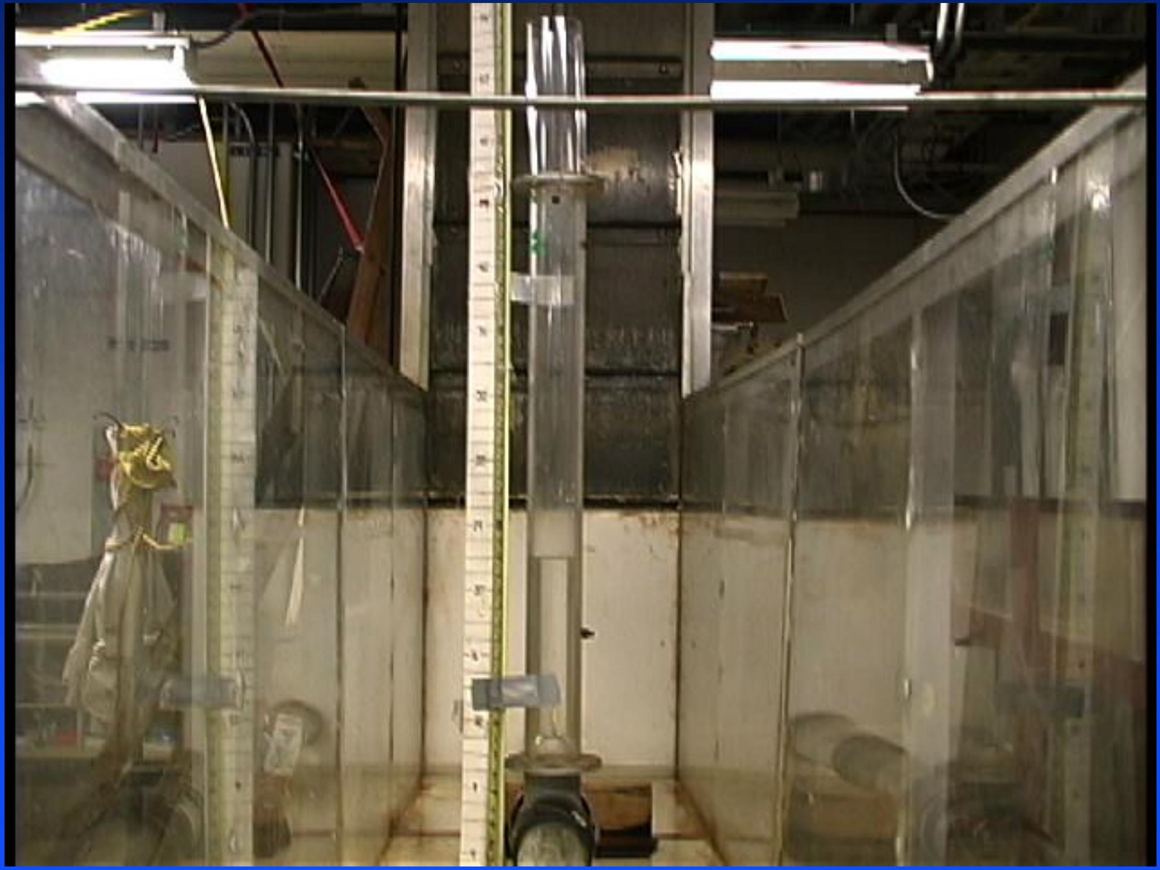
Hypothesis of Geyser Formation

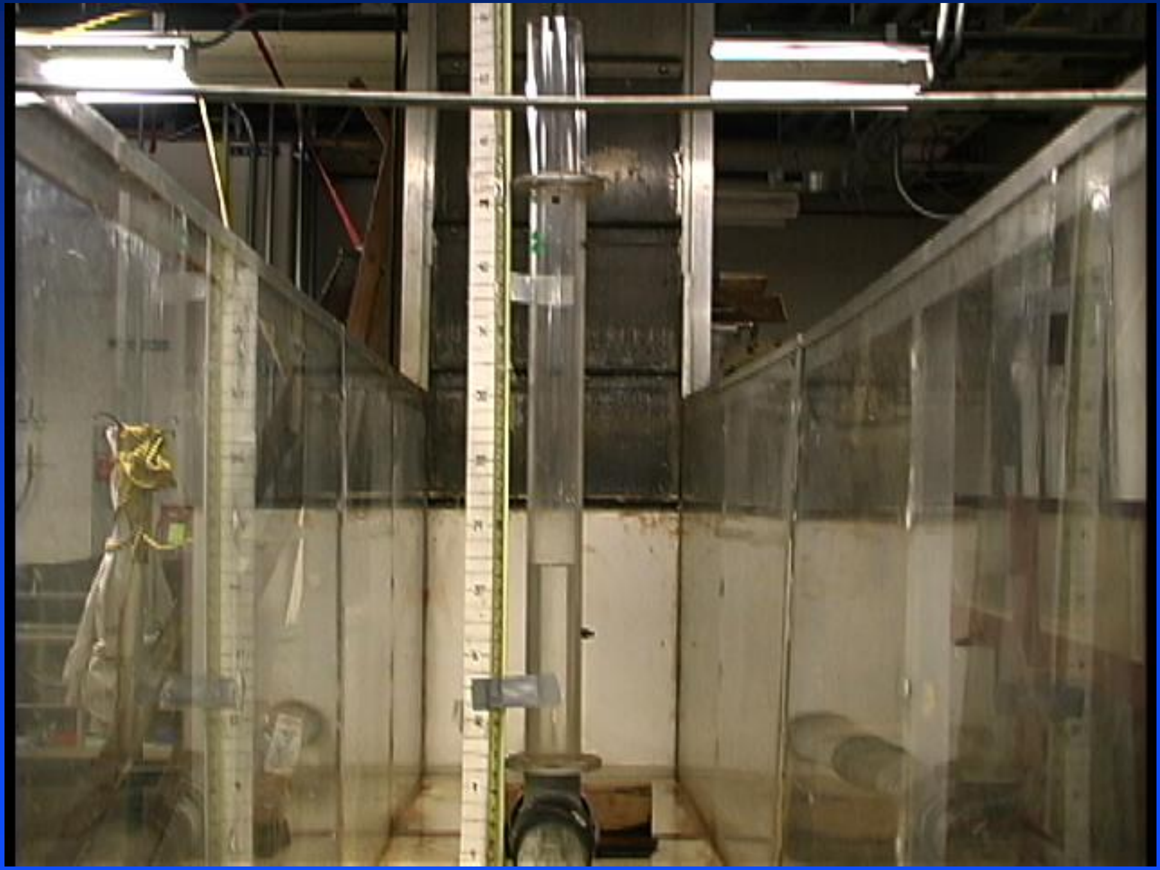


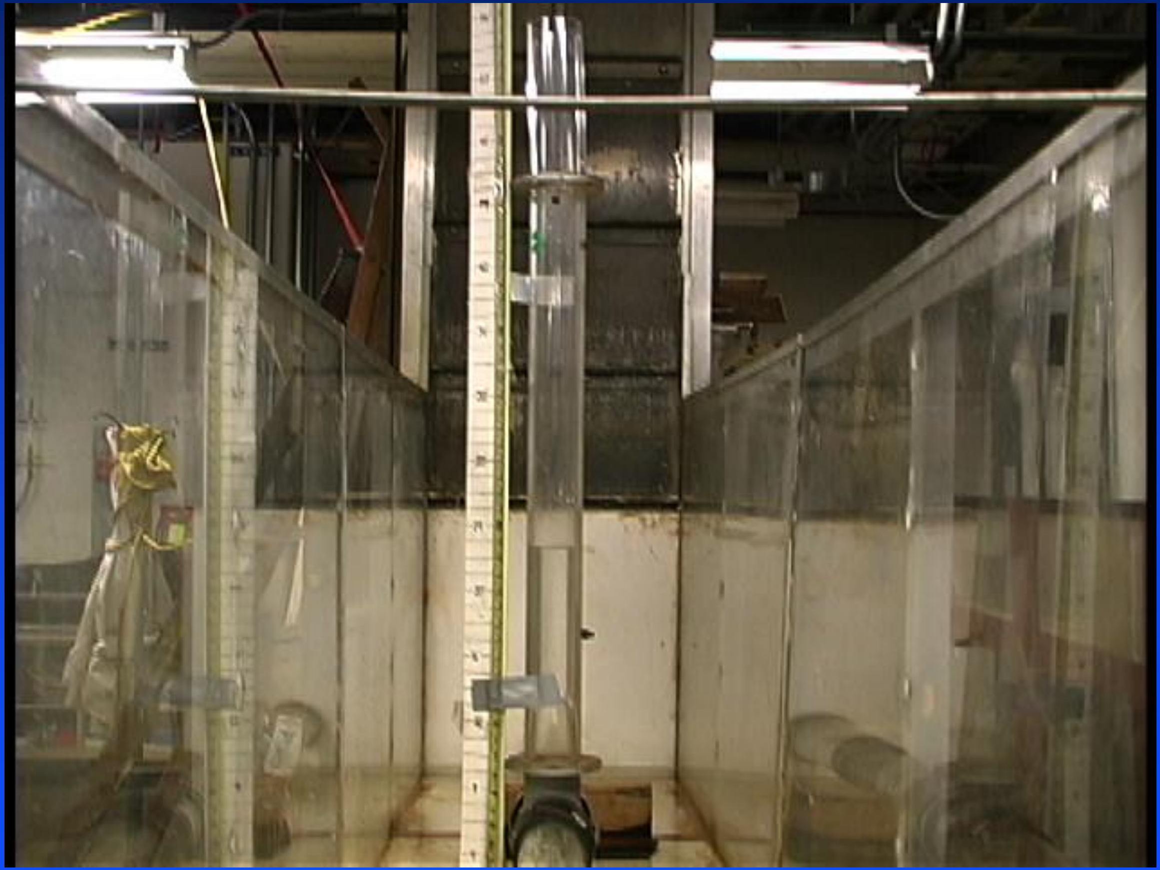
Laboratory Experiments

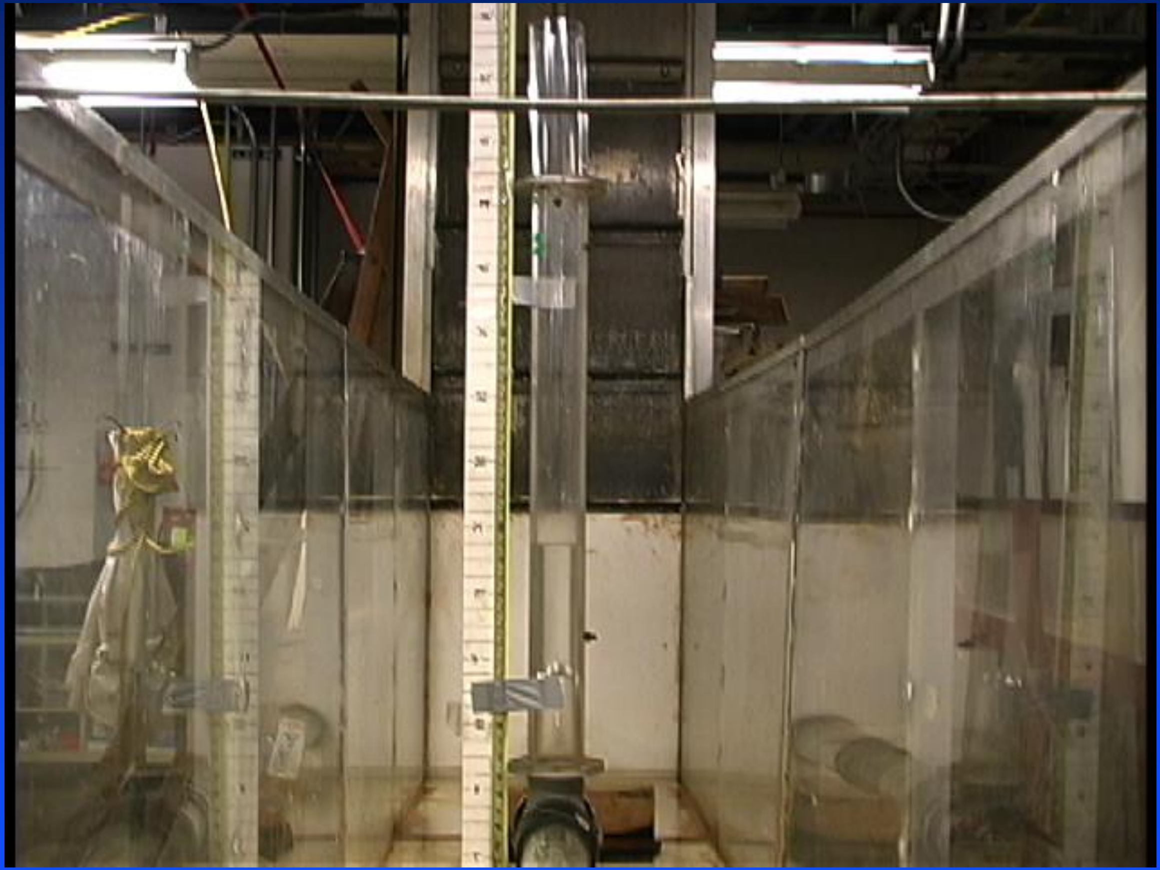
- Impose pressure with constant head reservoir, no surge
- Vary air volume and riser diameter

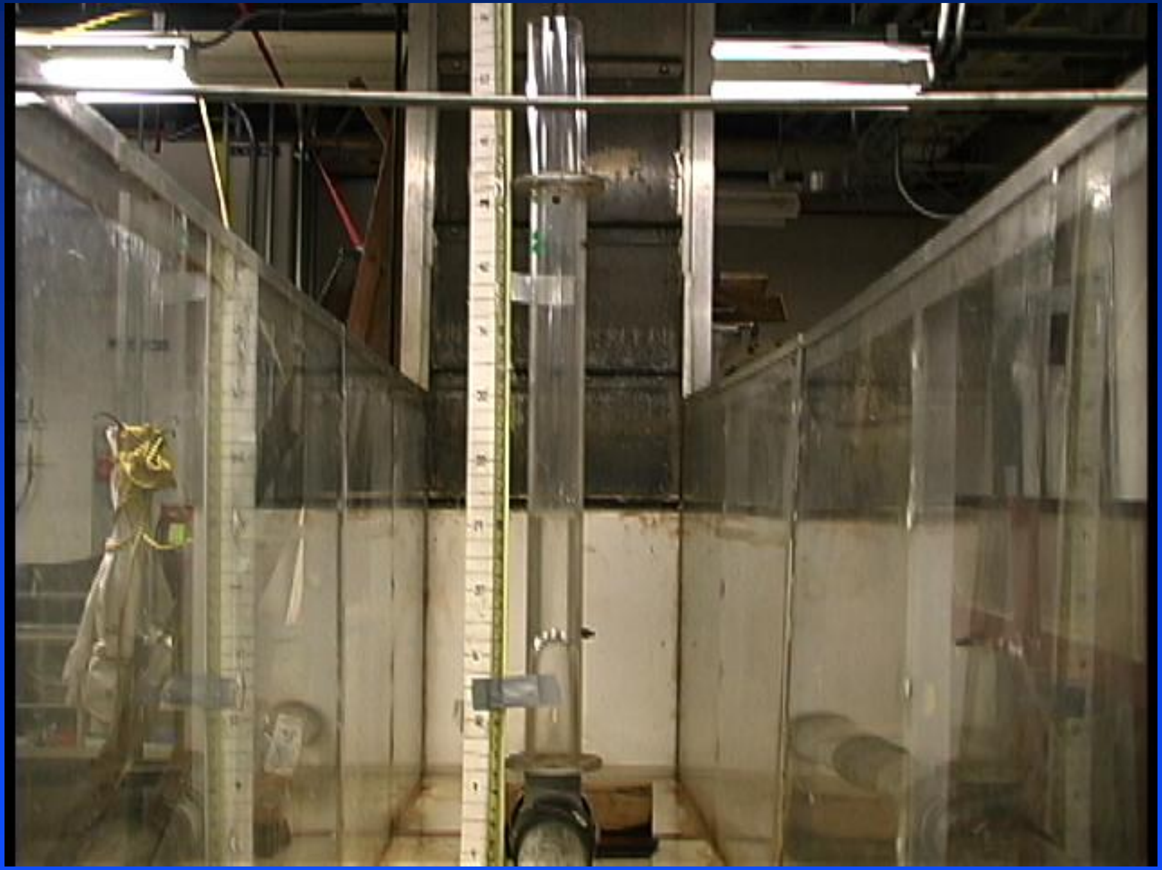


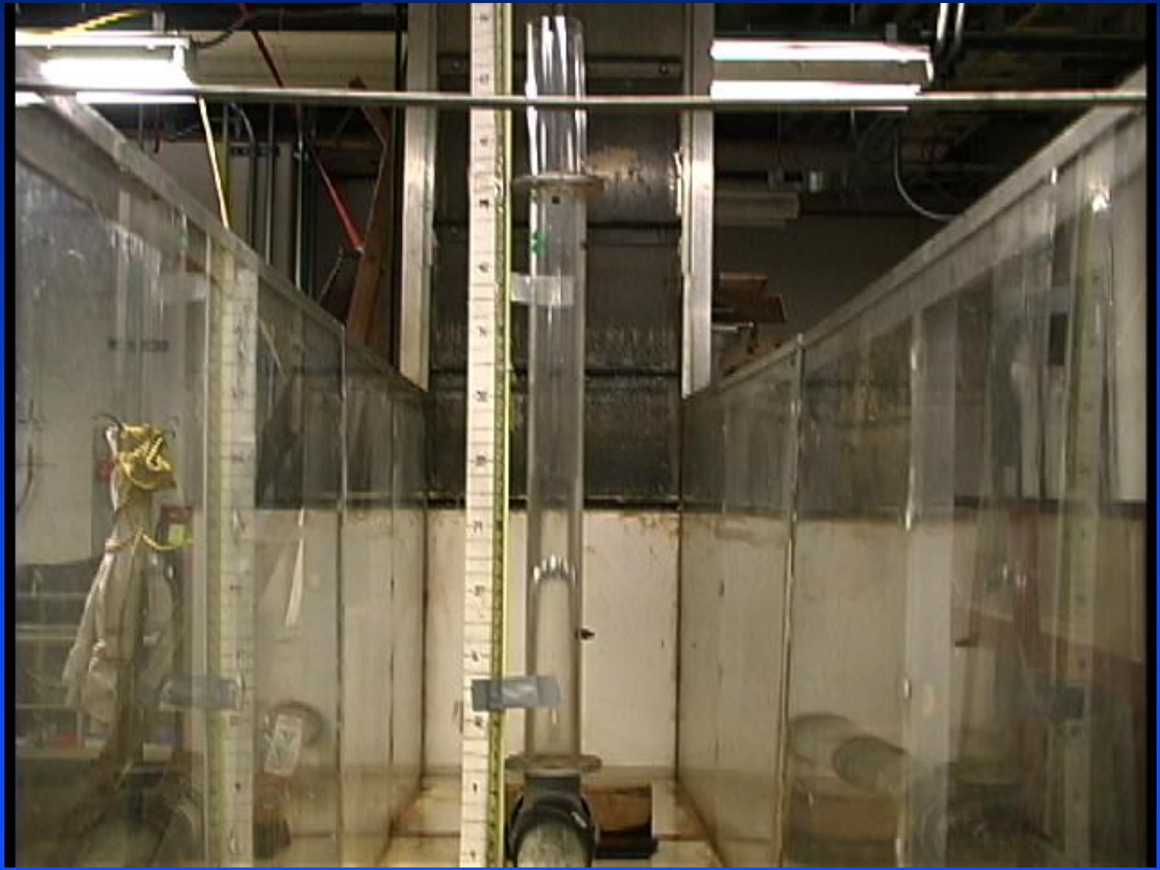


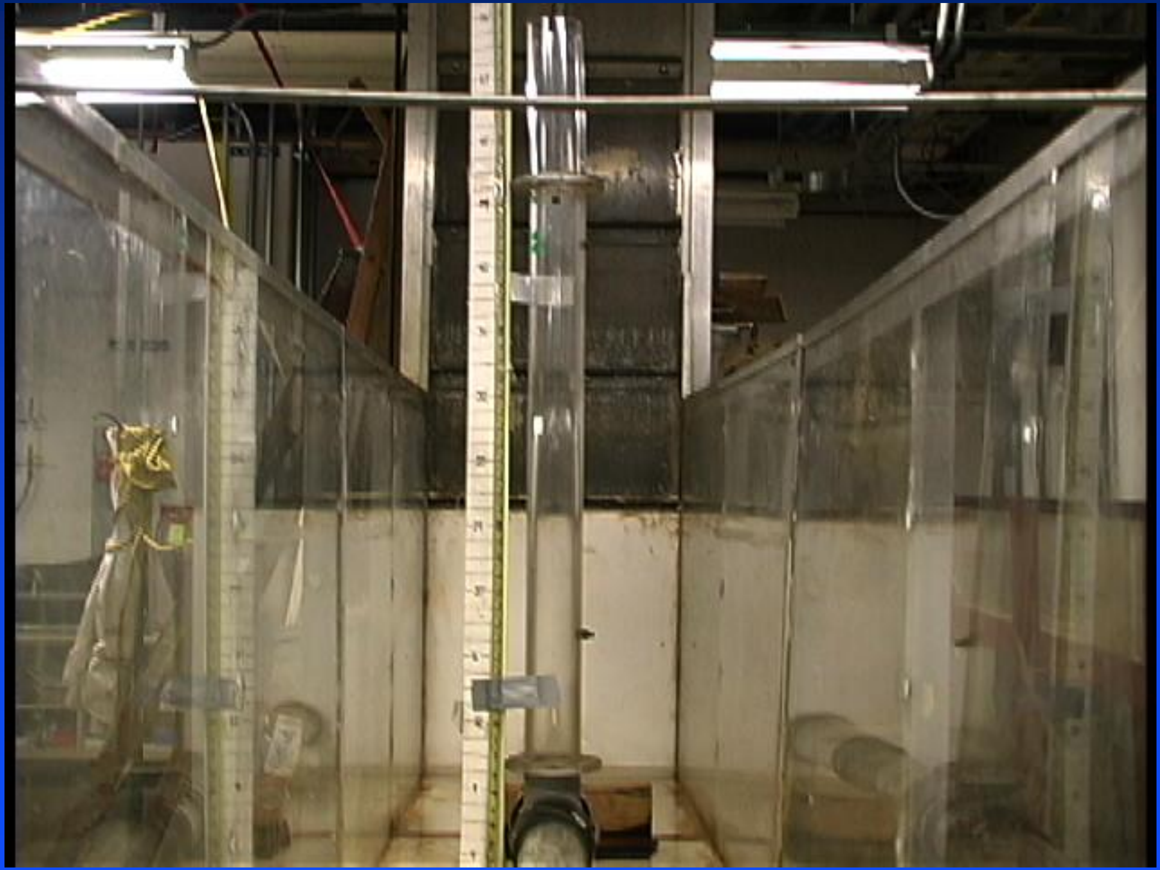


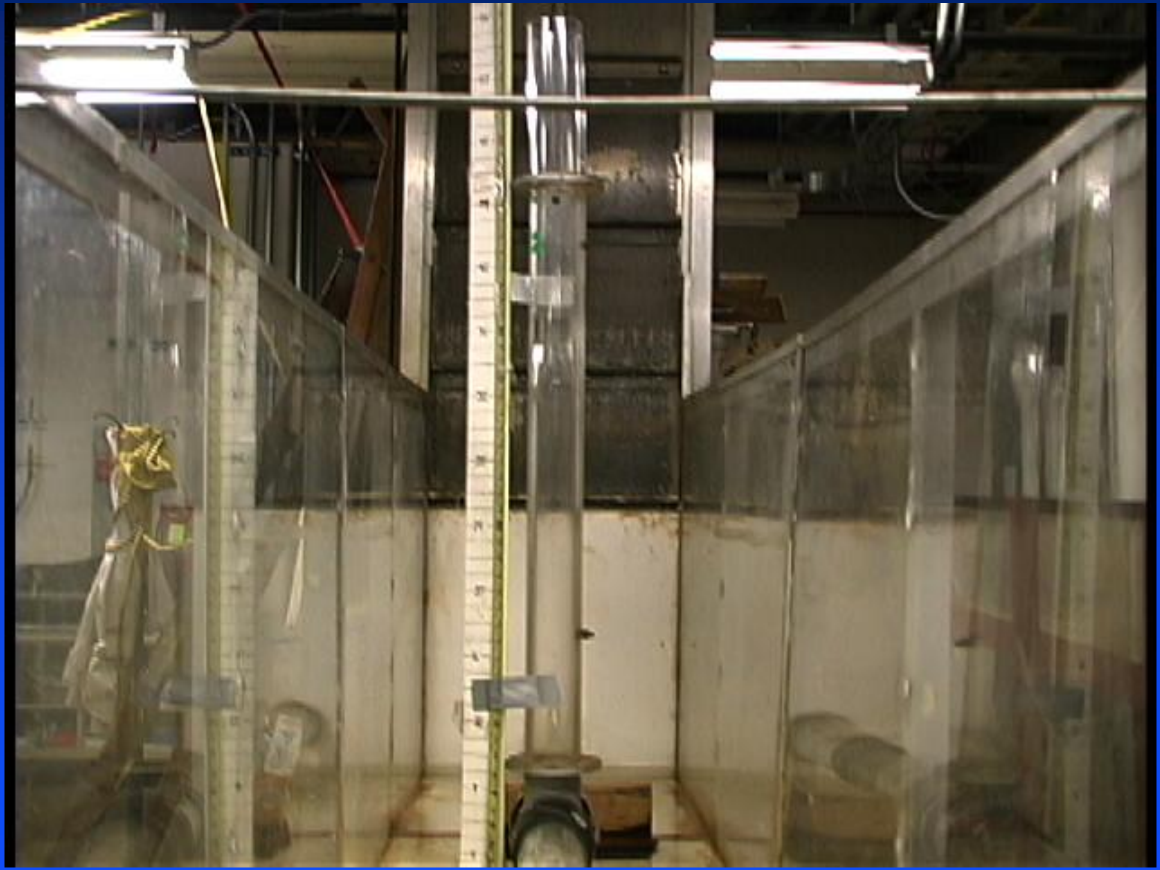


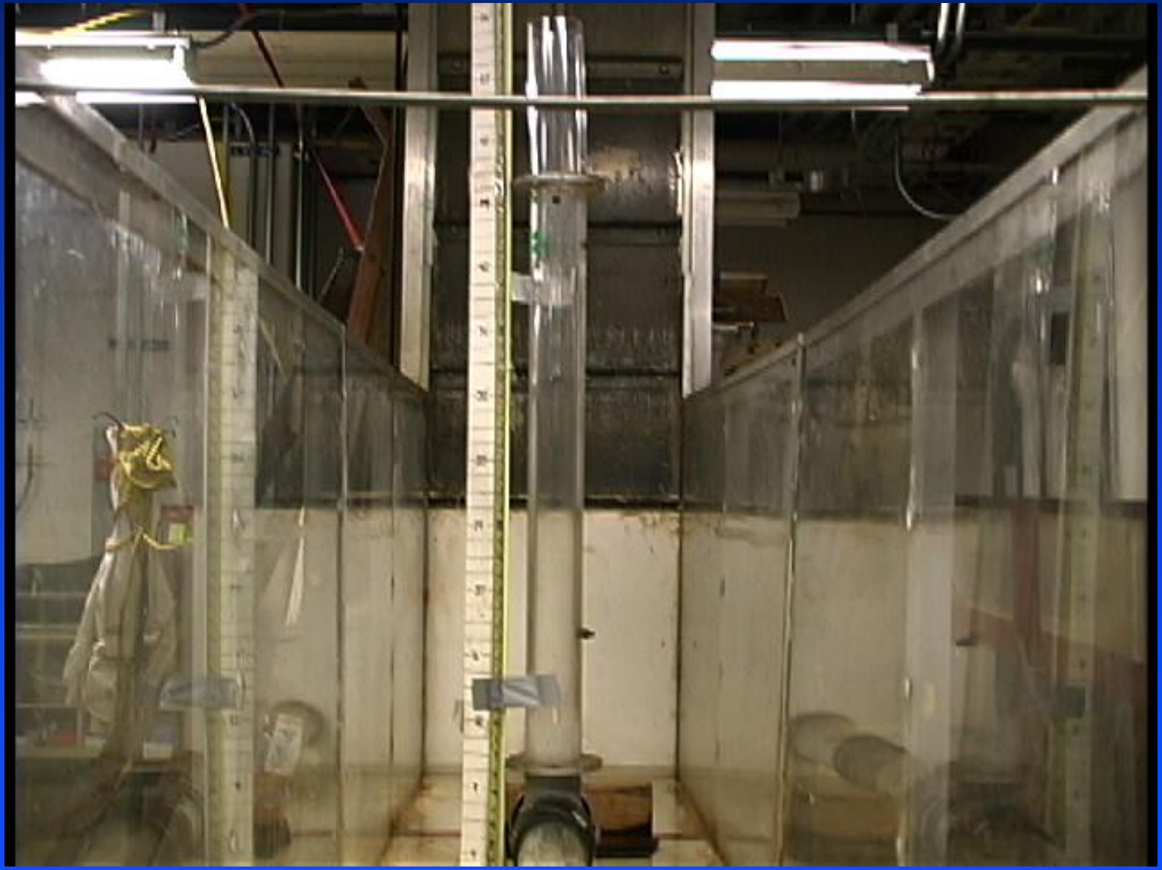


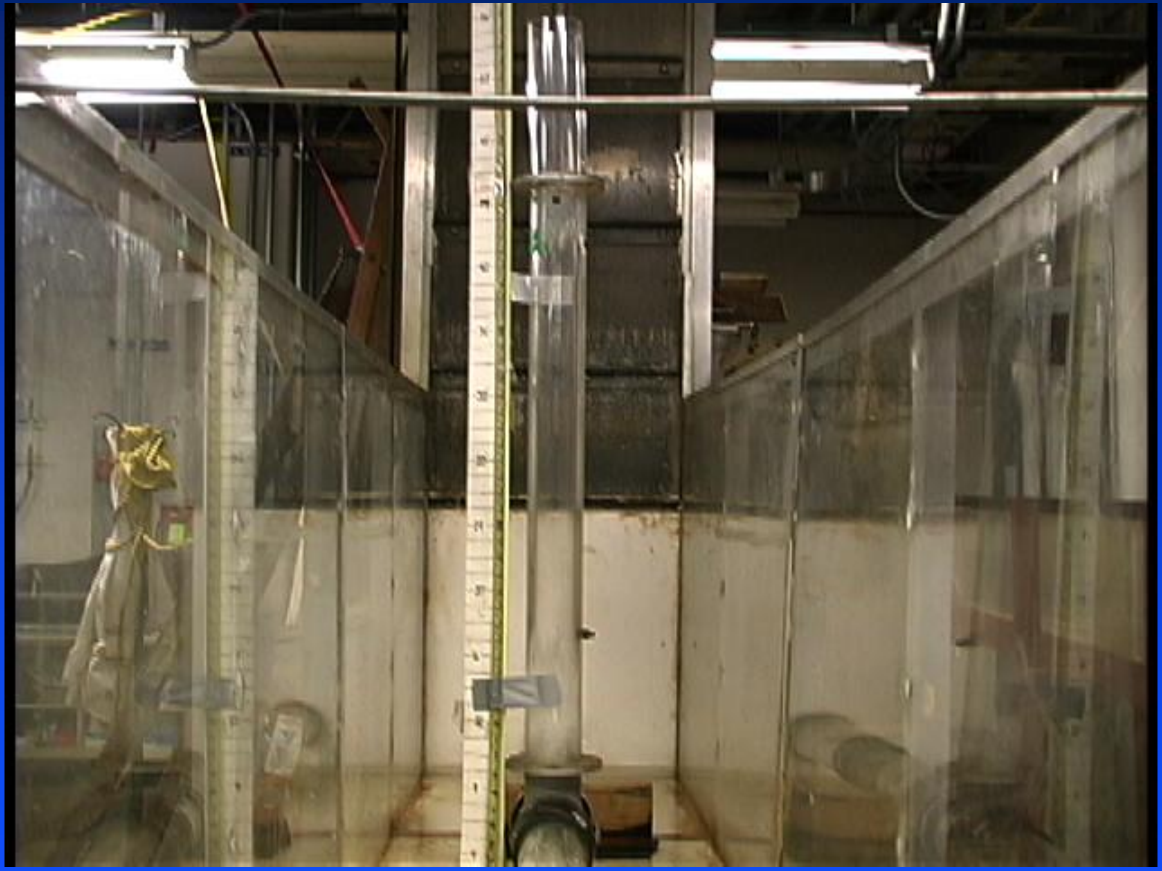




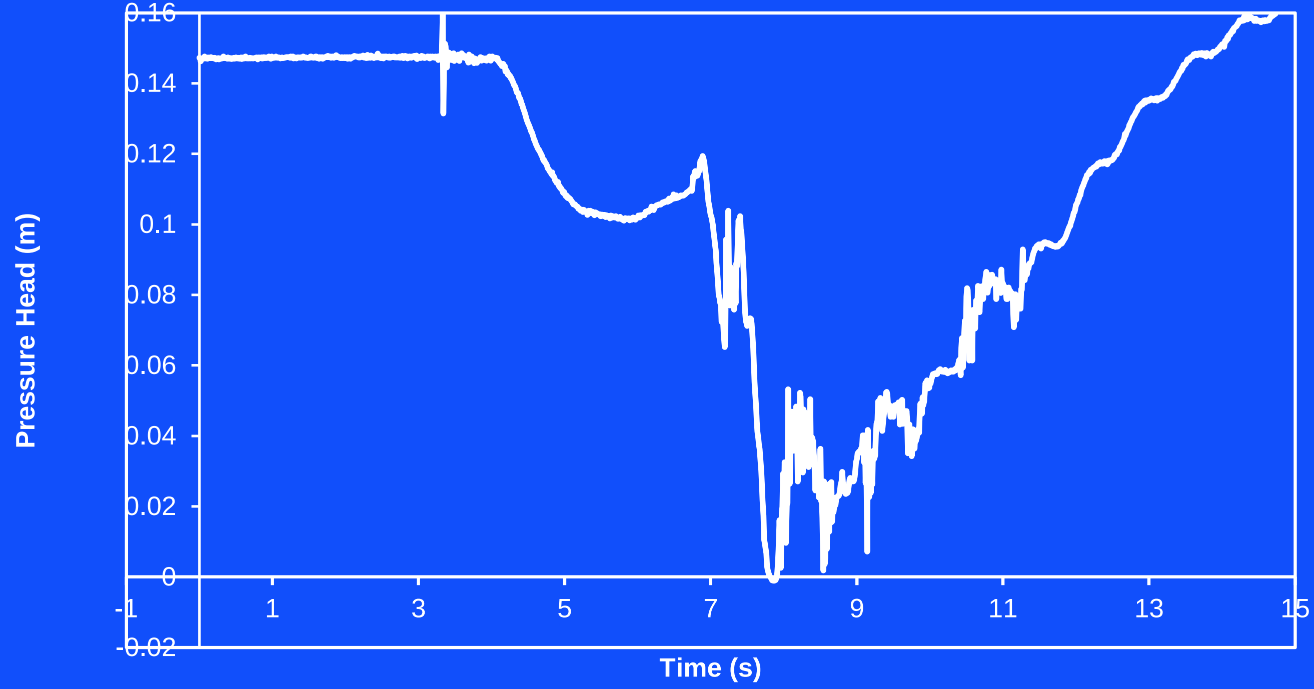


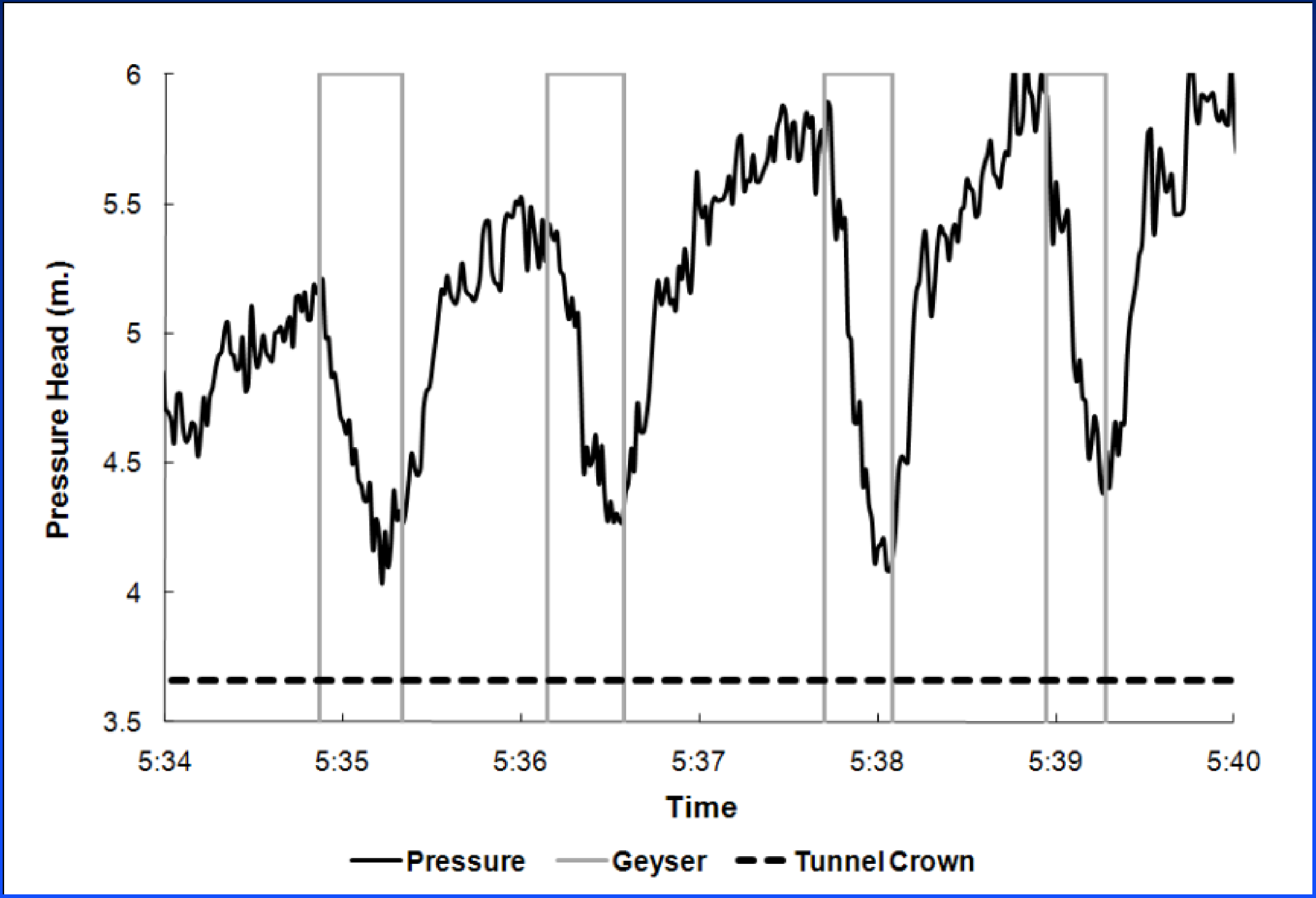






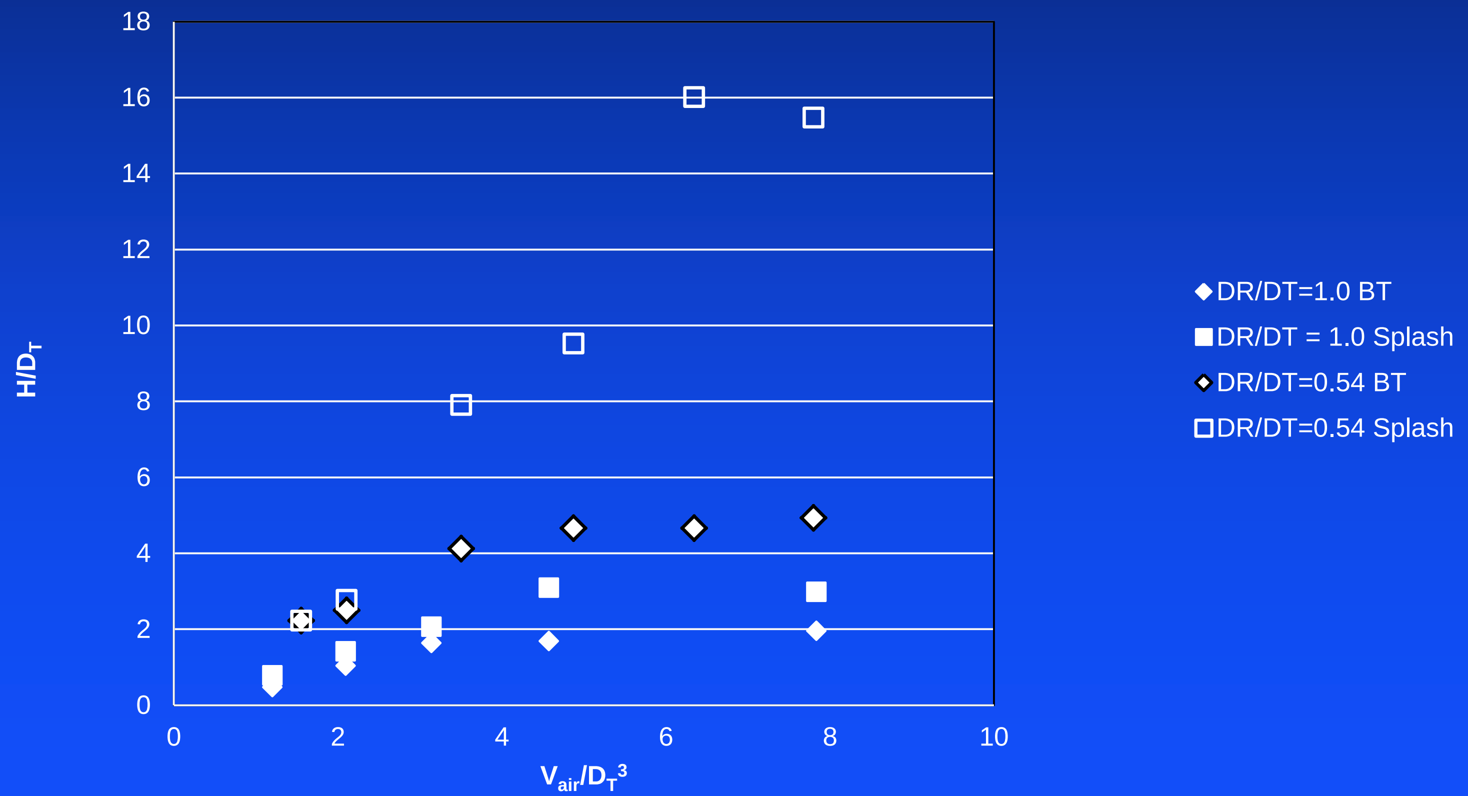
Pressure Trace at Rise Bottom



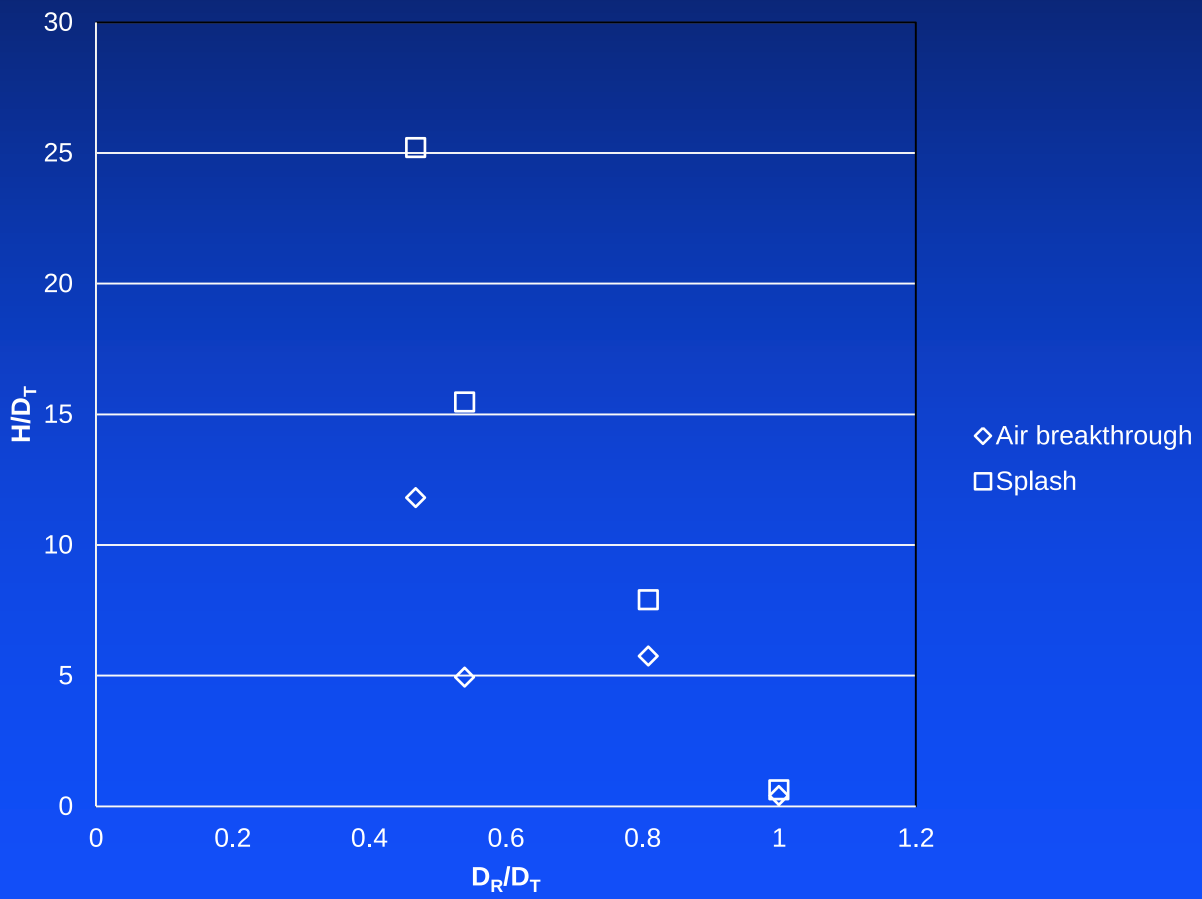


Pressure Head (m.)
6
5.5
5
4.5
4
3.5
5:34
5:35
5:36
5:37
5:38
5:39
5:40
Time
Pressure
Geyser
Tunnel Crown

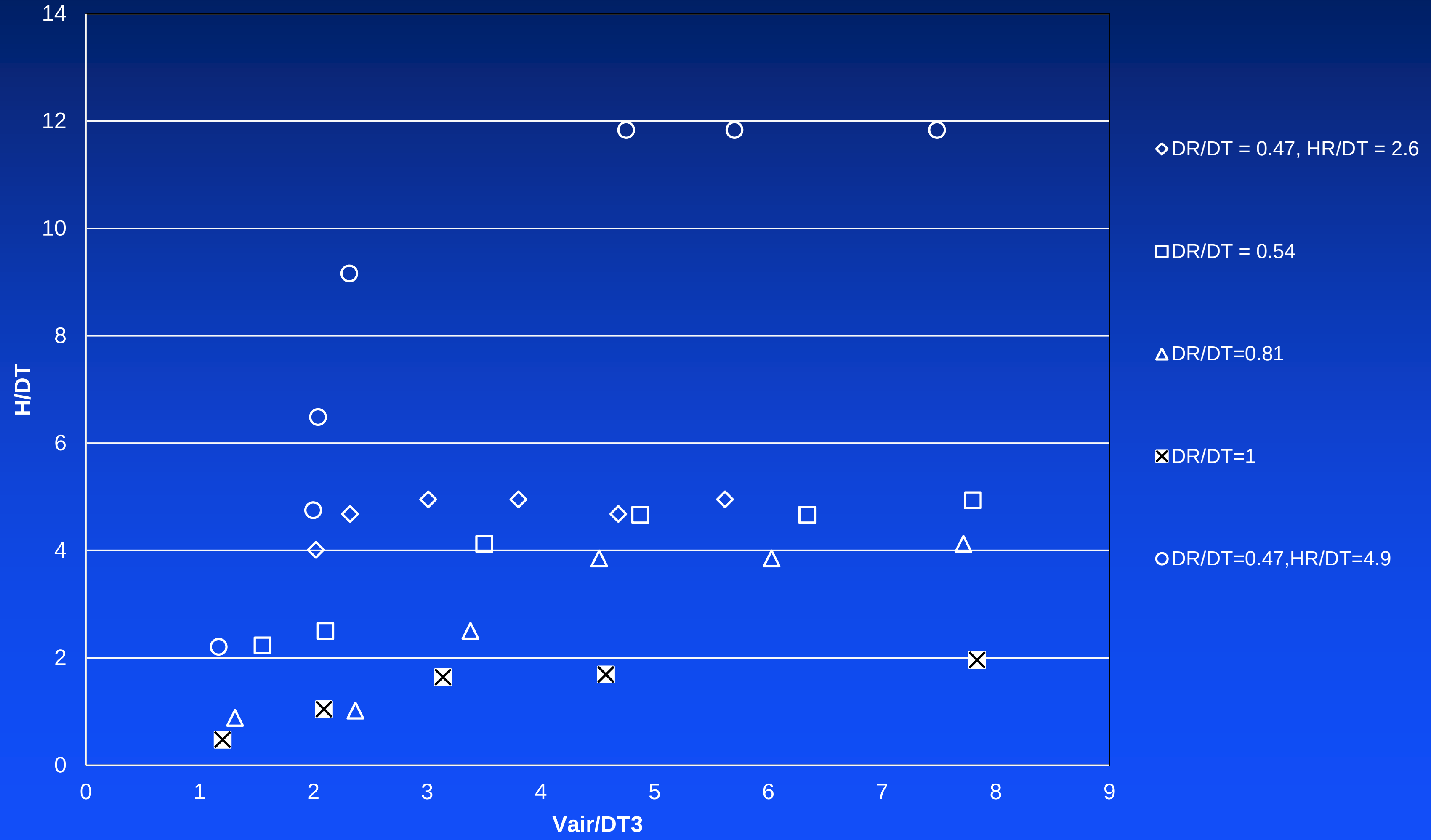
Two Different Diameters



Maximum Splash Heights



Effect of Air Volume



Limitations of Numerical Modeling

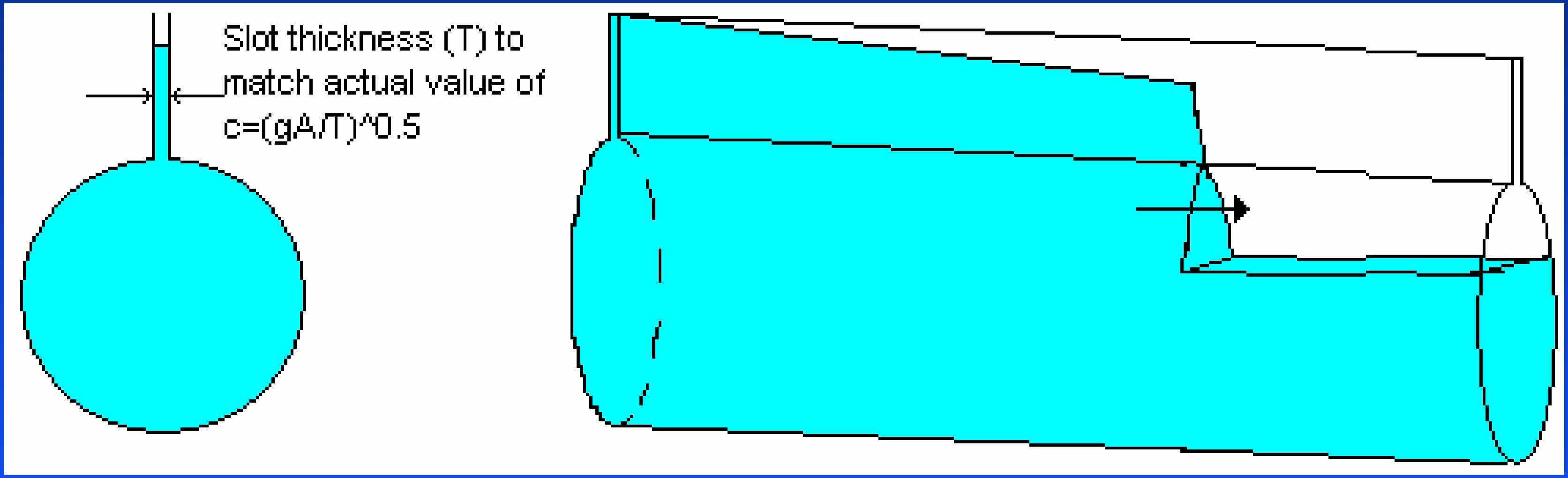
- Need 3-D two-phase flow models to solve for air transport
- Too computationally intensive in large scale systems
- Need for practical solution methods that can be used for design

Numerical Model Development

- Need - ability to simultaneously model free surface and pressurized flow in conduit with transition between, often in form of hydraulic bore
- Include air phase dynamics in model?
- Separate framework for vertical dynamics in ventilation shafts.

Historical Model for Flow Regime Transition

Preissman Slot Concept



Two-component Pressure Apprpoach (TPA)

- Another solution is to separate the hydrostatic-like pressure from the surcharge pressure, expected only in full pipe flows:
- Structural identity between the open-channel and pressurized mass and momentum equations with water incompressibility assumption

$$\vec{U}_t + \mathbf{A}\vec{U}_x = \vec{S}$$

$$\mathbf{A} = \begin{bmatrix} 0 & 1 \\ \frac{-Q^2}{A^2} + \frac{A}{\rho}\frac{\partial P}{\partial A} & \frac{2Q}{A} \end{bmatrix}$$

- Saint-Venant equations are modified to add a term that represents the surcharge head h_s:

$$\vec{U}_t + \vec{F}_x(\vec{U}) = \vec{S}(\vec{U})$$

$$\vec{U} = \begin{bmatrix} A \\ Q \end{bmatrix}, \vec{F}(\vec{U}) = \begin{bmatrix} Q \\ \frac{Q^2}{A} + gA(h_c + h_s) \end{bmatrix}, \vec{S}(\vec{U}) = \begin{bmatrix} 0 \\ gA(S_o - S_f) \end{bmatrix}$$

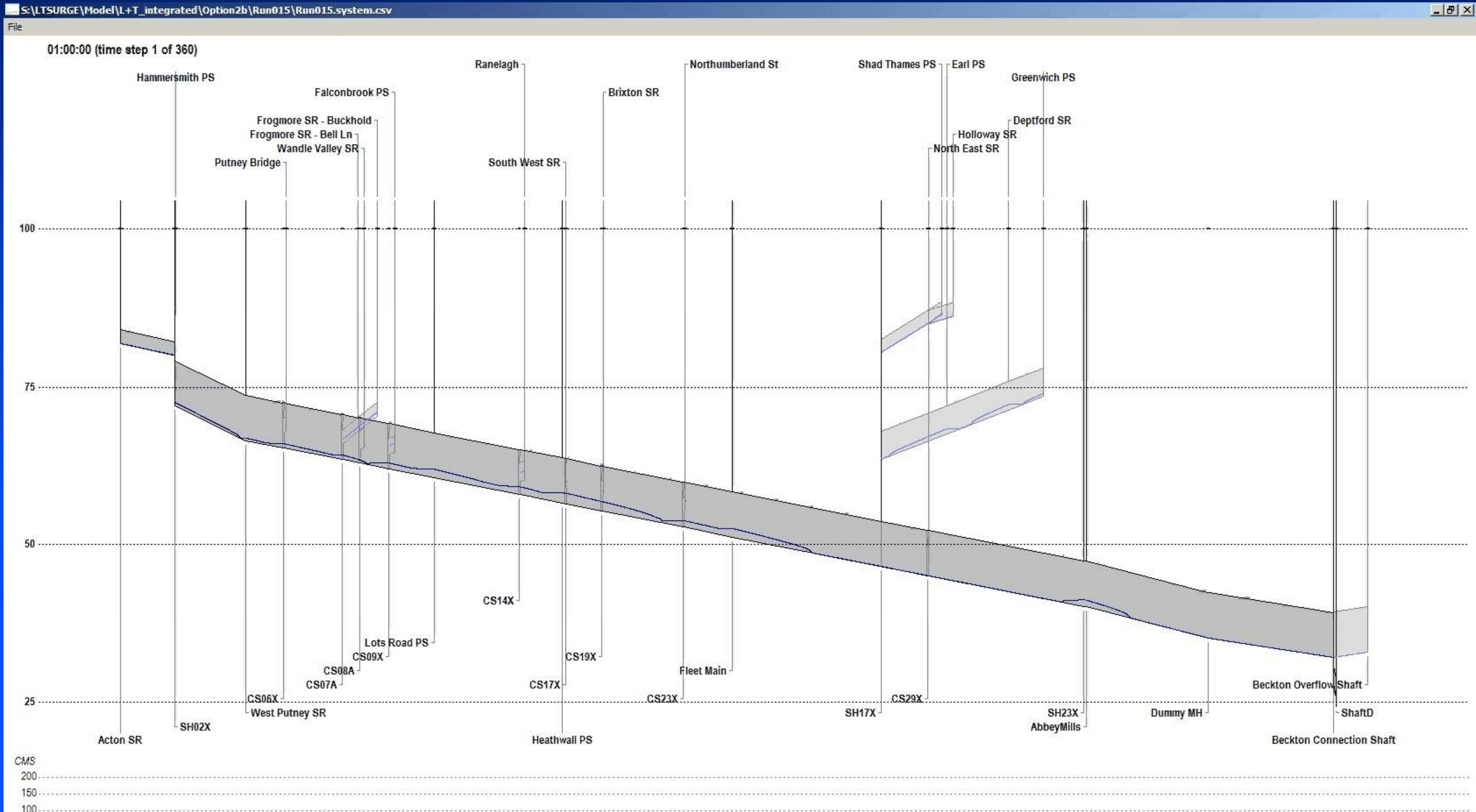
$$h_s = \frac{a^2}{g}\frac{\Delta A}{A_{pipe}}$$

- Conceptually similar to Preissmann slot approach except that storage provided by pipe wall elasticity rather than slot
- Easier to handle sub-atmospheric pressures in simulation as well as general implementation
- Use Roe first order upwind finite volume scheme as computational algorithm

Air Issues

- Do not explicitly model air, but simulation scheme can predict locations and volumes where air will be trapped
- Model predicts a “void” that subsequently vanishes, resulting in waterhammerlike prediction – not physically realistic

Air Pocket Entrapment Can be Predicted



Considerations

- Although water hammer pressures are not expected with trapped air, compression of (especially small) air pockets can also lead to significant pressure oscillations, discussed in manuscript
- Experience with structural damage in sewer systems where interactions of flow compressing air pockets is indicated
- Necessary to consider geometry and filling scenarios carefully, simple filling scenarios may not be troublesome

Conclusions

- Although surge can potentially be a problem in filling stormwater tunnels, interactions with entrapped air are probably the cause of the more significant geysering problems
- Small riser diameters present the conditions where significant geysering can occur
- Numerical modeling framework has been developed to predict general filling conditions and potential for trapping air pockets without explicitly modeling air phase
- Further model developments are in progress to better handle the air interactions