Assessment of Plume Diving

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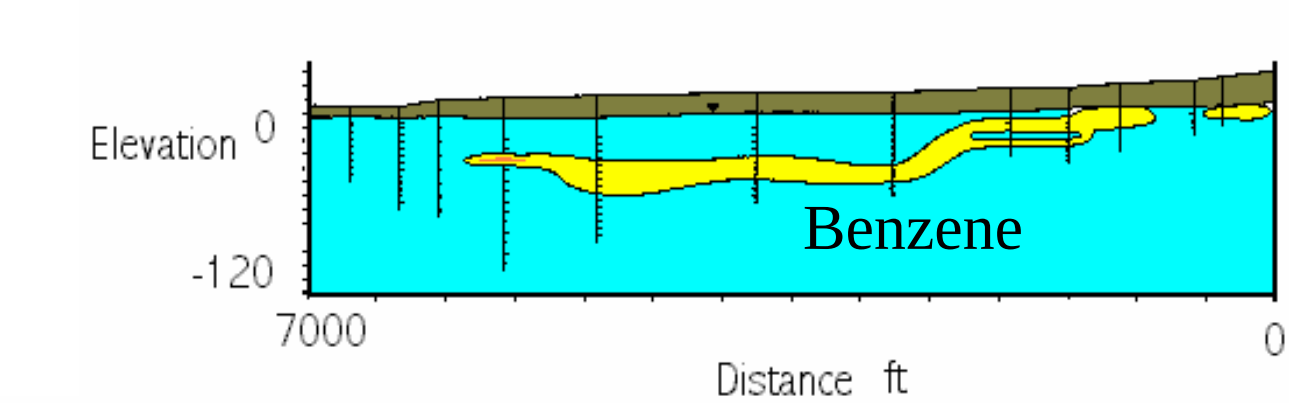
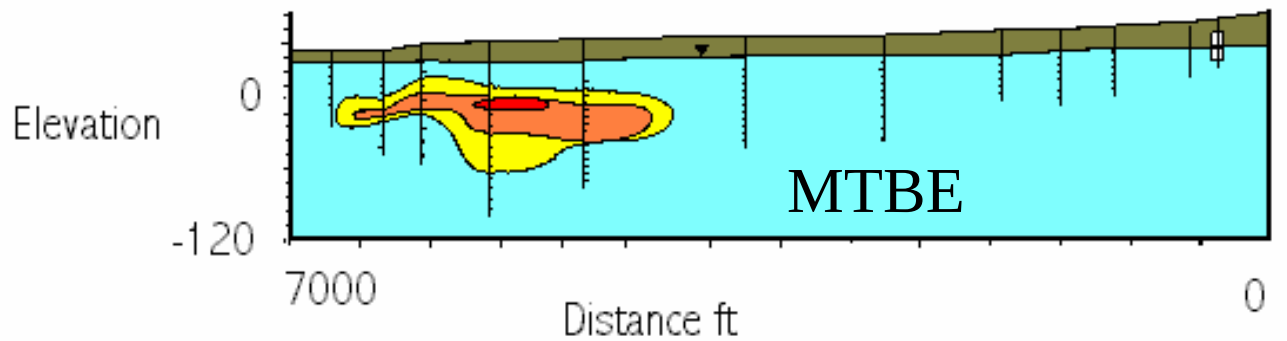
Observations

- Vertical plume delineation at East Patchogue, NY showed BTEX and MTBE plumes dropping on either side of a gravel pit.
- Lake Druid TCE plume dropped beneath unlined drainage ditch.
- Aquifer recharge/discharge areas drive ground water flow.

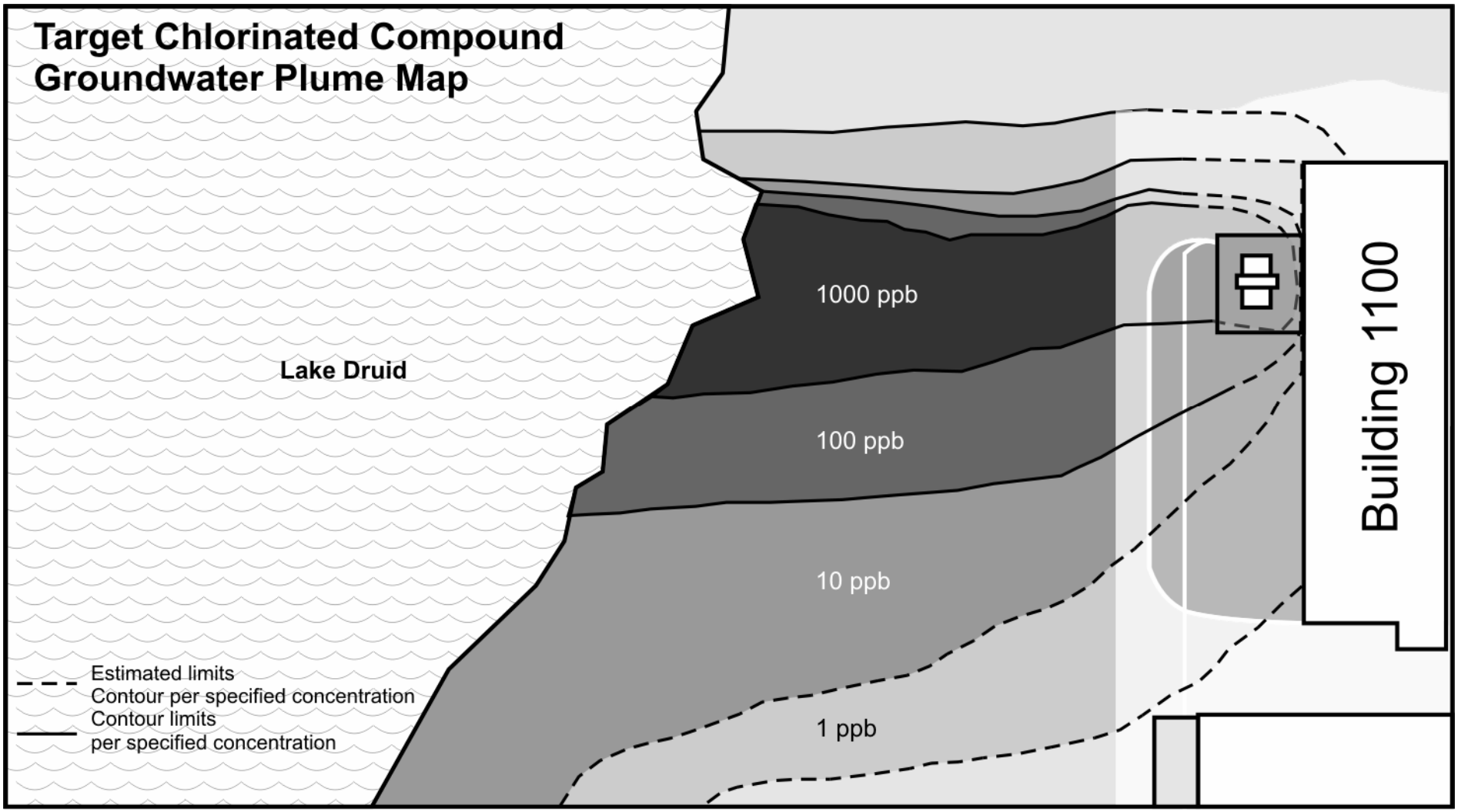
East Patchogue

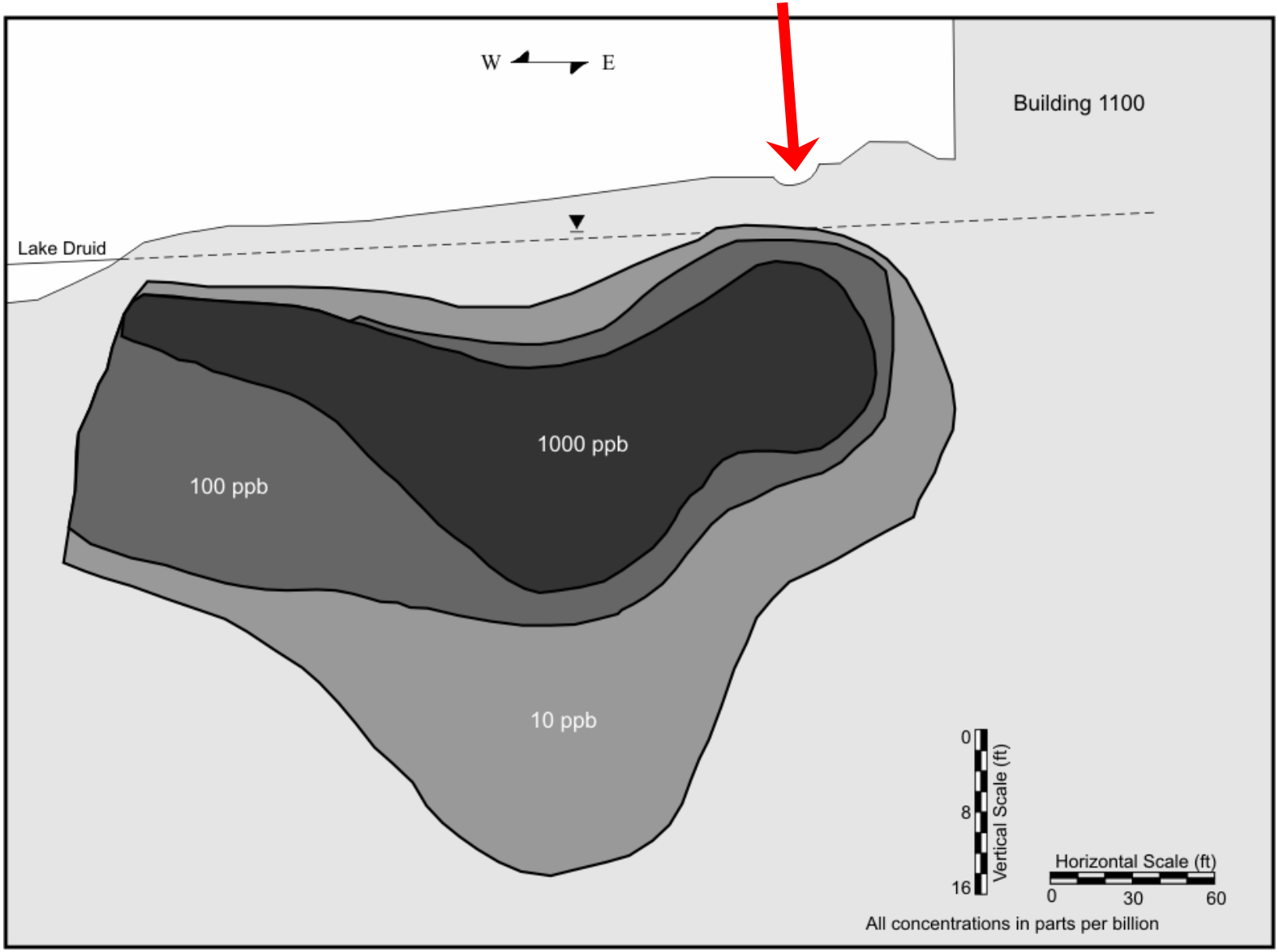
East Patchogue, NY



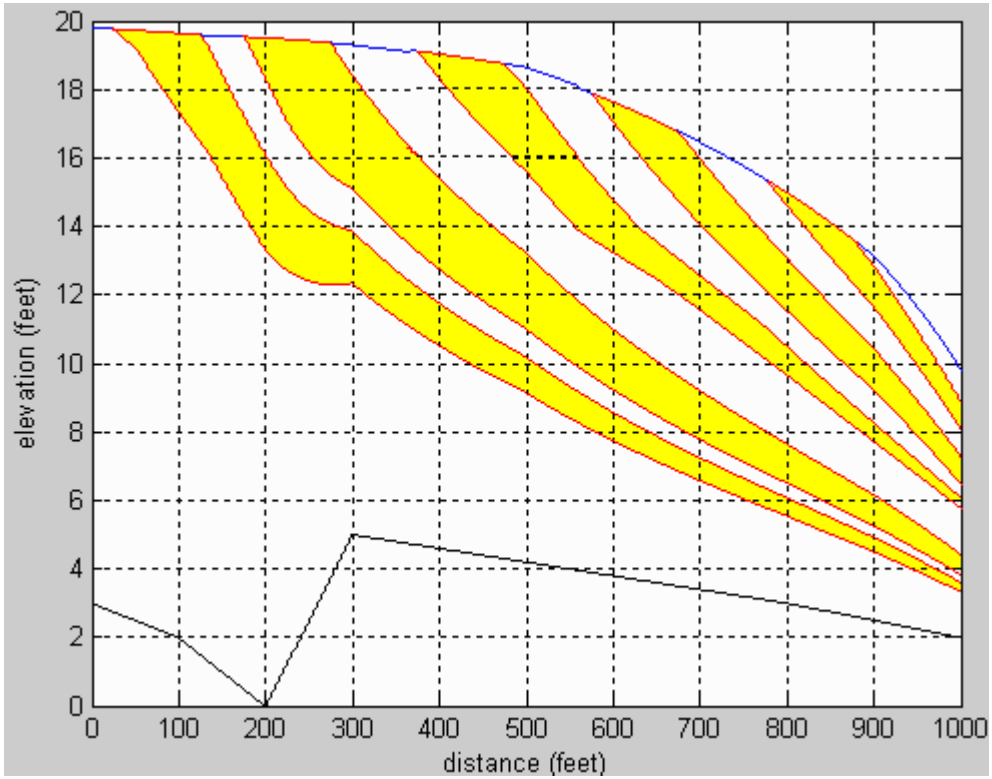


Lake Druid


Target Chlorinated Compound
Groundwater Plume Map
Lake Druid
1000 ppb
100 ppb
10 ppb
1 ppb
Building 1100
Estimated limits
Contour per specified concentration
Contour limits
per specified concentration

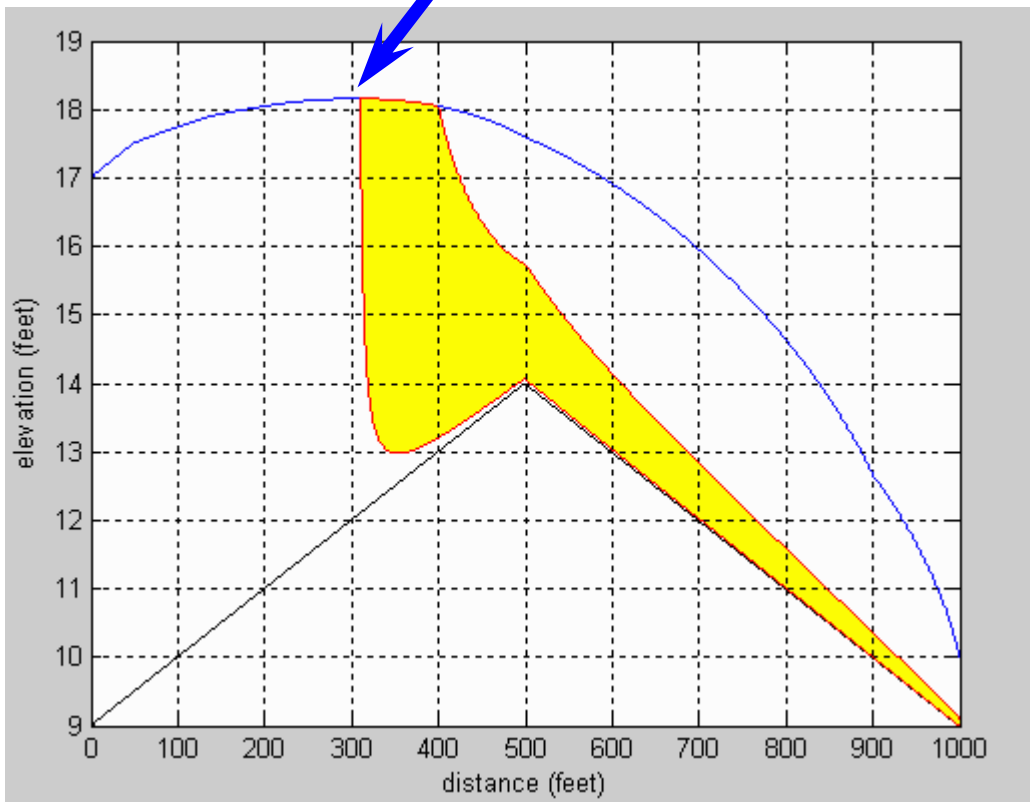

Unlined ditch
W
E
Building 1100
Lake Druid
1000 ppb
100 ppb
10 ppb
0
8
16
Vertical Scale (ft)
Horizontal Scale (ft)
0
30
60
All concentrations in parts per billion

Extreme Diving in aquifer recharge zones



Courtesy Vikenti Gorokhovski, S.E.E, EPA, Athens, GA

Ground water divide



Courtesy Vikenti Gorokhovski, S.E.E, EPA, Athens, GA

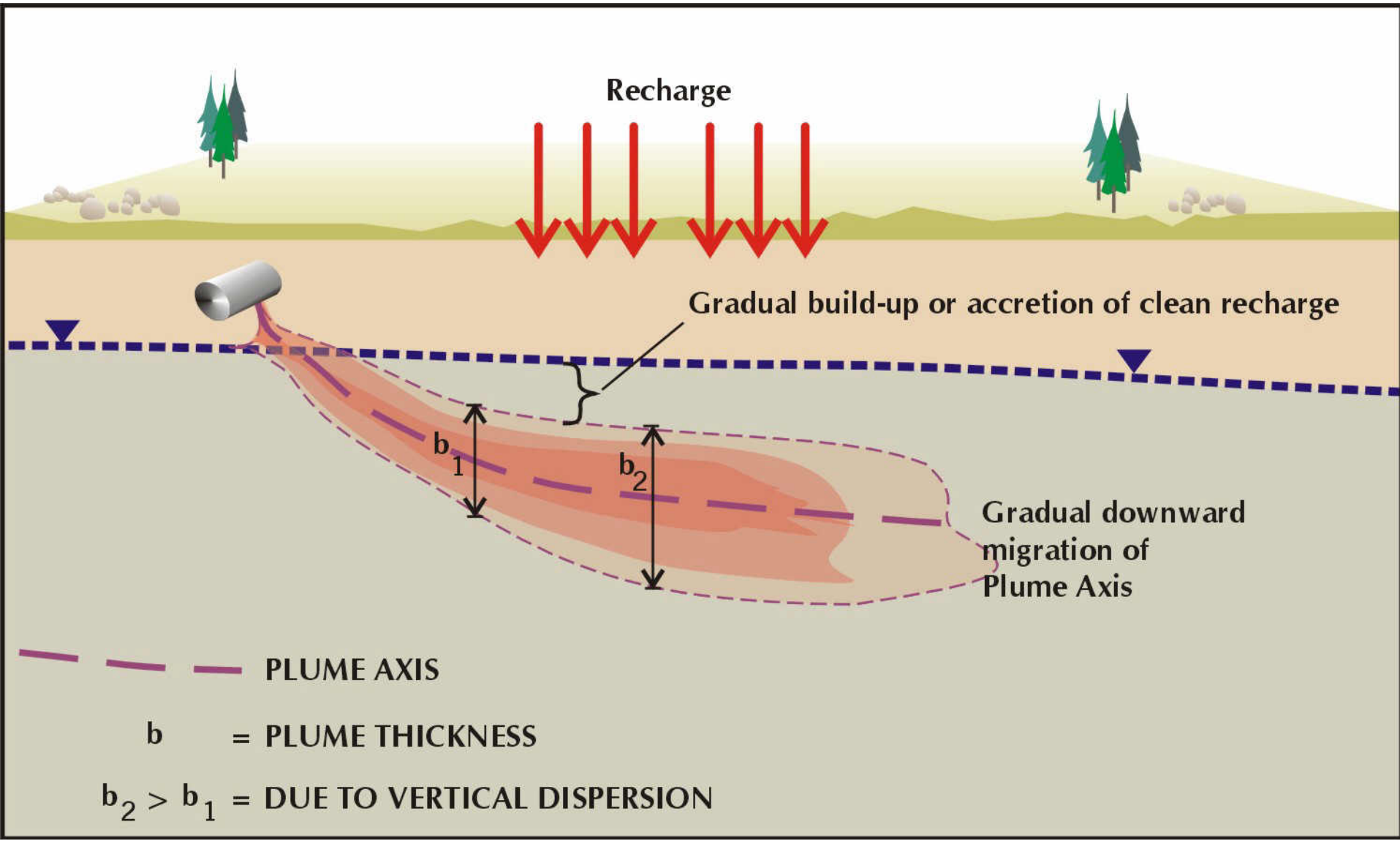
Recharge-Driven Plume Diving Look for:

- 1) Local Landscape features
  - Gravel pit, unlined ditches, public water + septic tanks
- 2) Average recharge rate over large areas
- 3) Recharge and Discharge Areas of aquifers

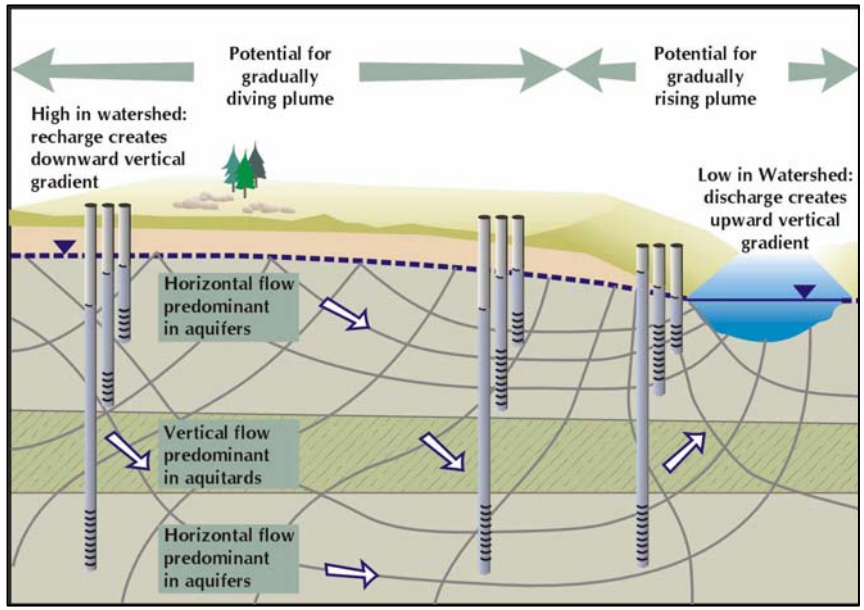
Plume Diving

- Why do plumes move downward?
  - Water pushes plume into aquifer
    - Aquifer recharge, leaking pipes, irrigation, focused recharge around paved areas
  - Preferential flow path following stratigraphy
  - “Deep” pumping pulls plume downward
  - Selective biodegradation from recharge of oxygenated water
- Why do plumes move upward?
  - Stratigraphic control
  - Discharge of water to surface water body

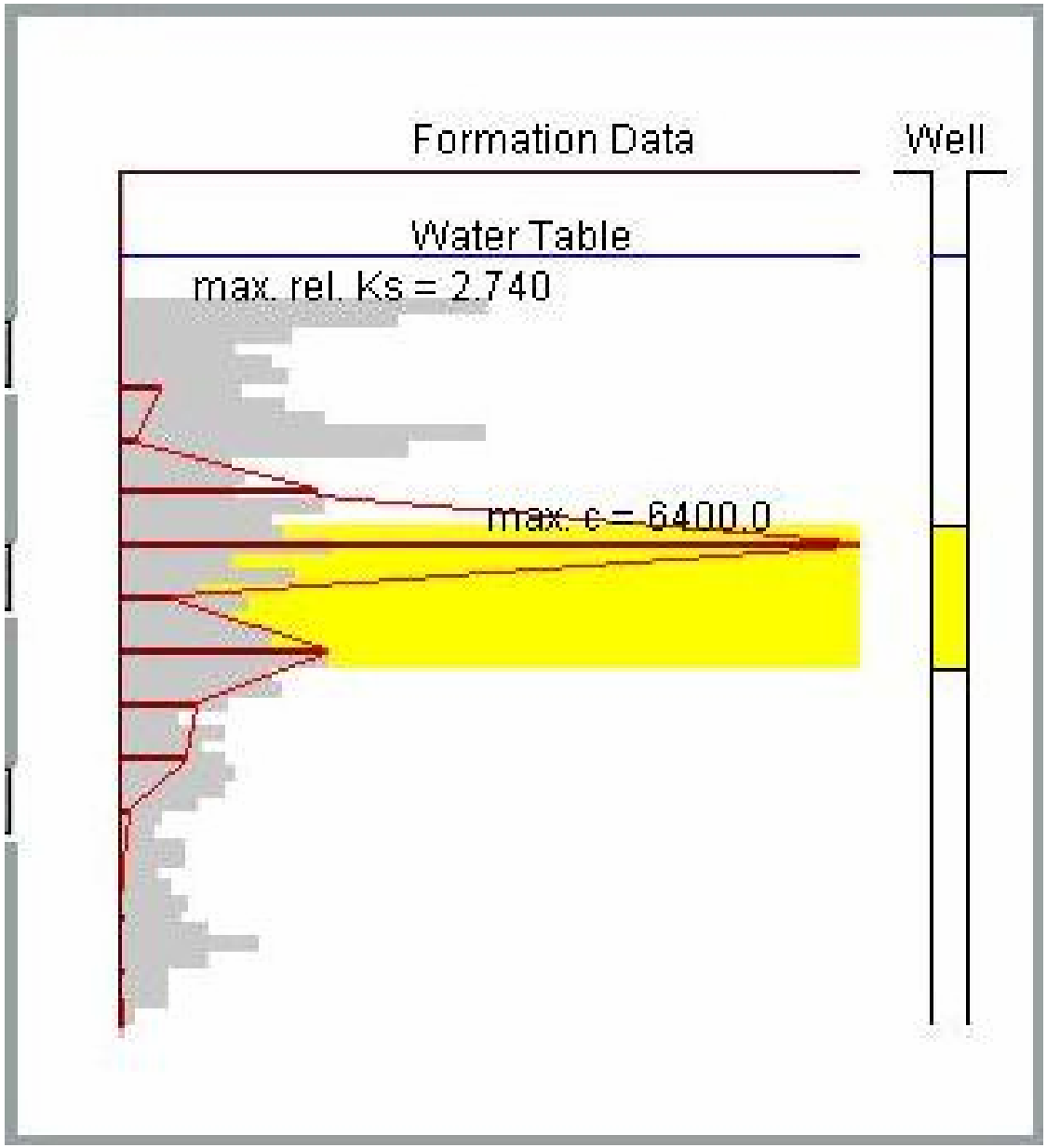
Gradually Diving Plume



Consequences of Missing Diving Plumes



- Inadequate evaluation of risk to receptors
- Under-designing corrective actions
- Inadequate assessment of remedial performance


Formation Data
Well
Water Table
max. rel. Ks = 2.740
max. c = 6400.0

“Diving” MTBE Plumes

- MTBE is often associated with the phenomena of “diving plumes” because it is
  - highly soluble
  - does not sorb significantly
  - is often slow to biodegrade
- Consequently, MTBE will often migrate greater distances from a source than other LNAPL constituents such as BTEX and thus be more suseptable to recharge impacts

API Technical Bulletin

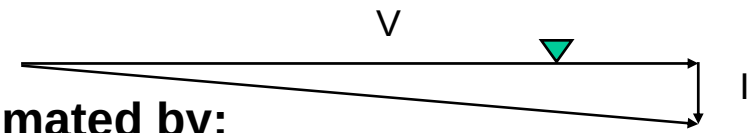
- **Roth, T. and E. Nichols 2006. Diving Plumes: Assessment, Significance, and Implications for Characterization and Monitoring. API Soil and Groundwater Technical Bulletin Number 24.**
- Describes the **phenomena** and its **significance**
- Provides **methods to assess** potential for and magnitude of diving plumes

Available at **www.api.org/bulletins**

Methods to Assess Potential for and Magnitude of Diving Plumes

- **Analytical and Numerical Models**
- Field Characterization Techniques
- Geochemical Assessment

Screening model: Ratio of Recharge Rate to Groundwater Discharge Rate



The slope of plume dive can be estimated by:

$$Slope = \frac{I}{V} = \frac{i}{q}$$

Where:

Slope = change in depth per change in horizontal distance, relative to the water table surface [m/m]

I = Accretion rate [m/yr]; recharge rate divided by porosity, where the recharge rate is the net annual recharge to groundwater in m/year

i = recharge rate [m/yr]

V = horizontal groundwater seepage velocity [m/yr]; the specific discharge divided by porosity

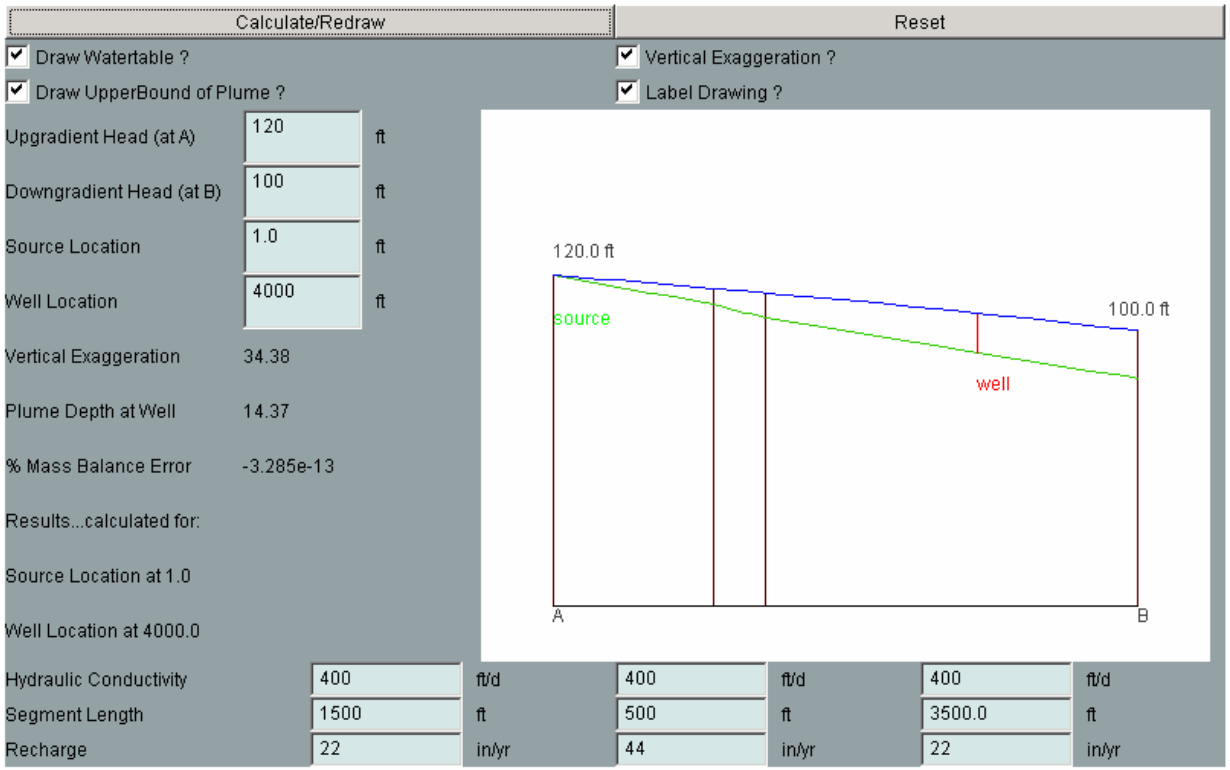
q = specific discharge, also known as Darcy velocity [m/yr]

Assumes:

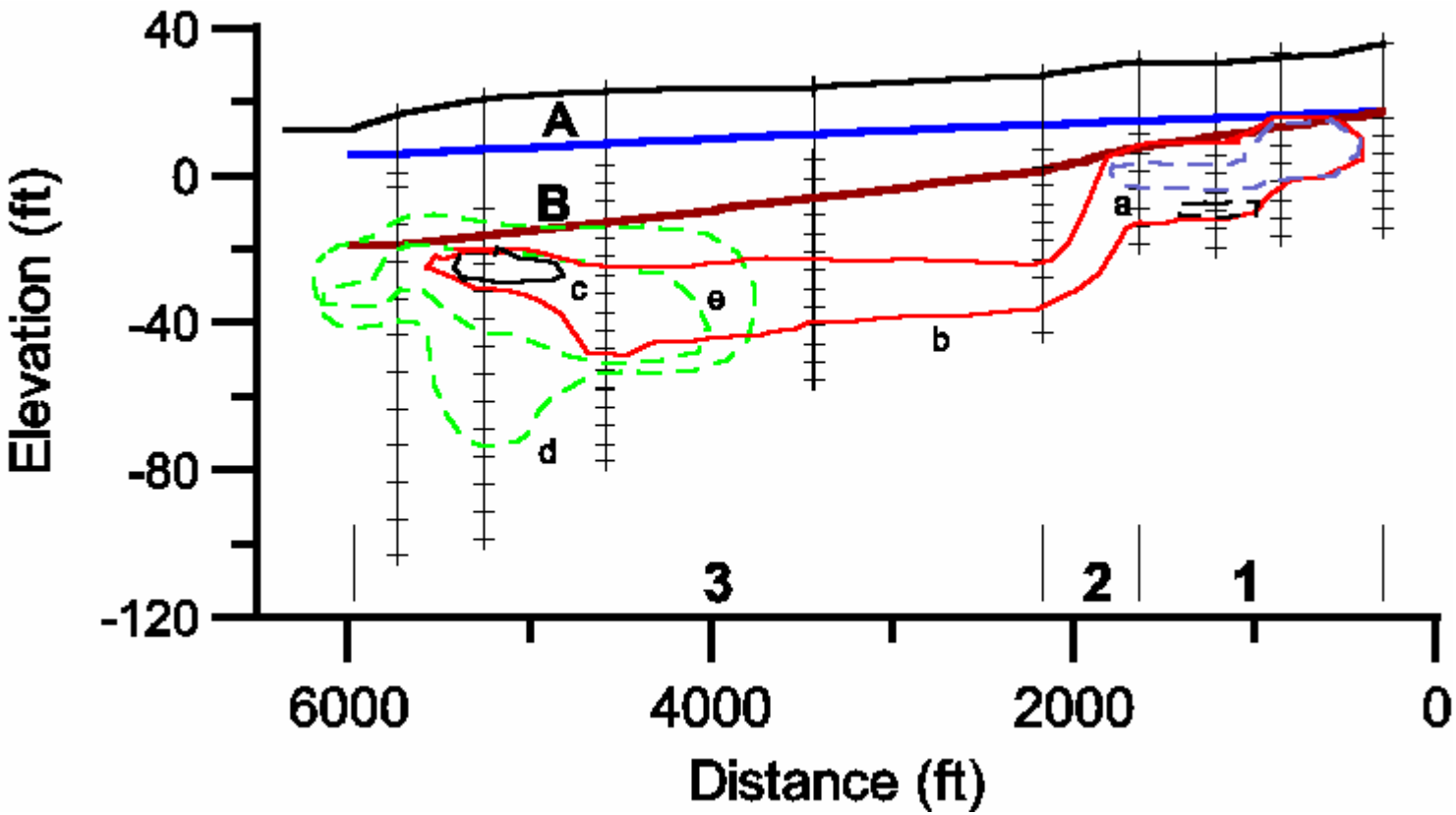
- evenly distributed recharge
- homogeneous subsurface,
- aquifer is thick relative to the accumulation of recharge
- rate of plume dive is uniform

USEPA Plume Dive Calculator

- Current version uses analytical solution of one-dimensional flow to simulate each portion of a segmented aquifer.
- http://www.epa.gov/athens/learn2model/part-two/onsite/diving.htm
- Split aquifer into segments – differing properties to each



Plume diving calculations for East Patchogue site



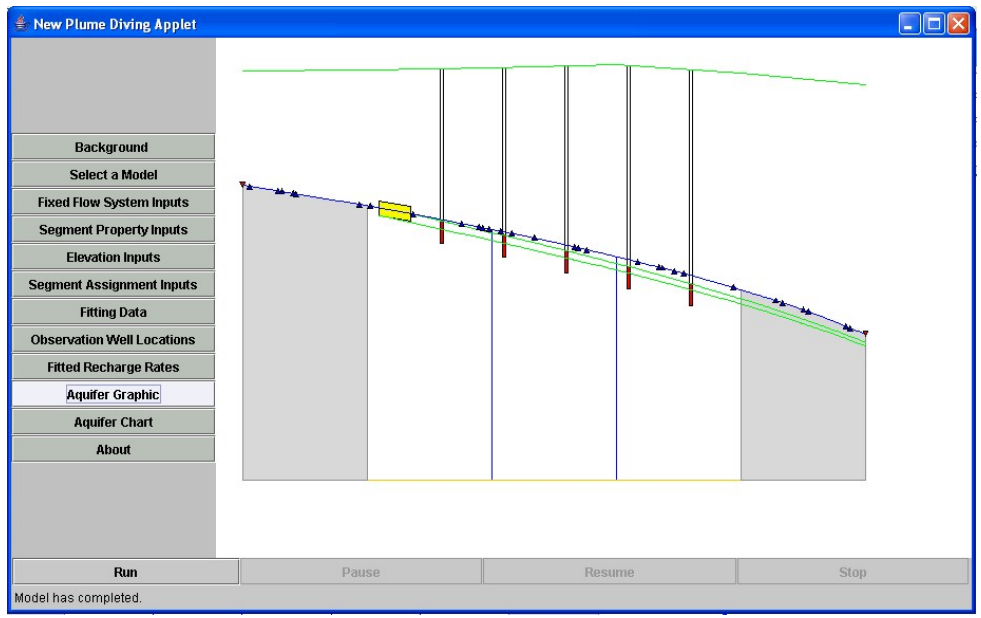
"A" = calibrated water table

"B" = uncalibrated bounding streamline

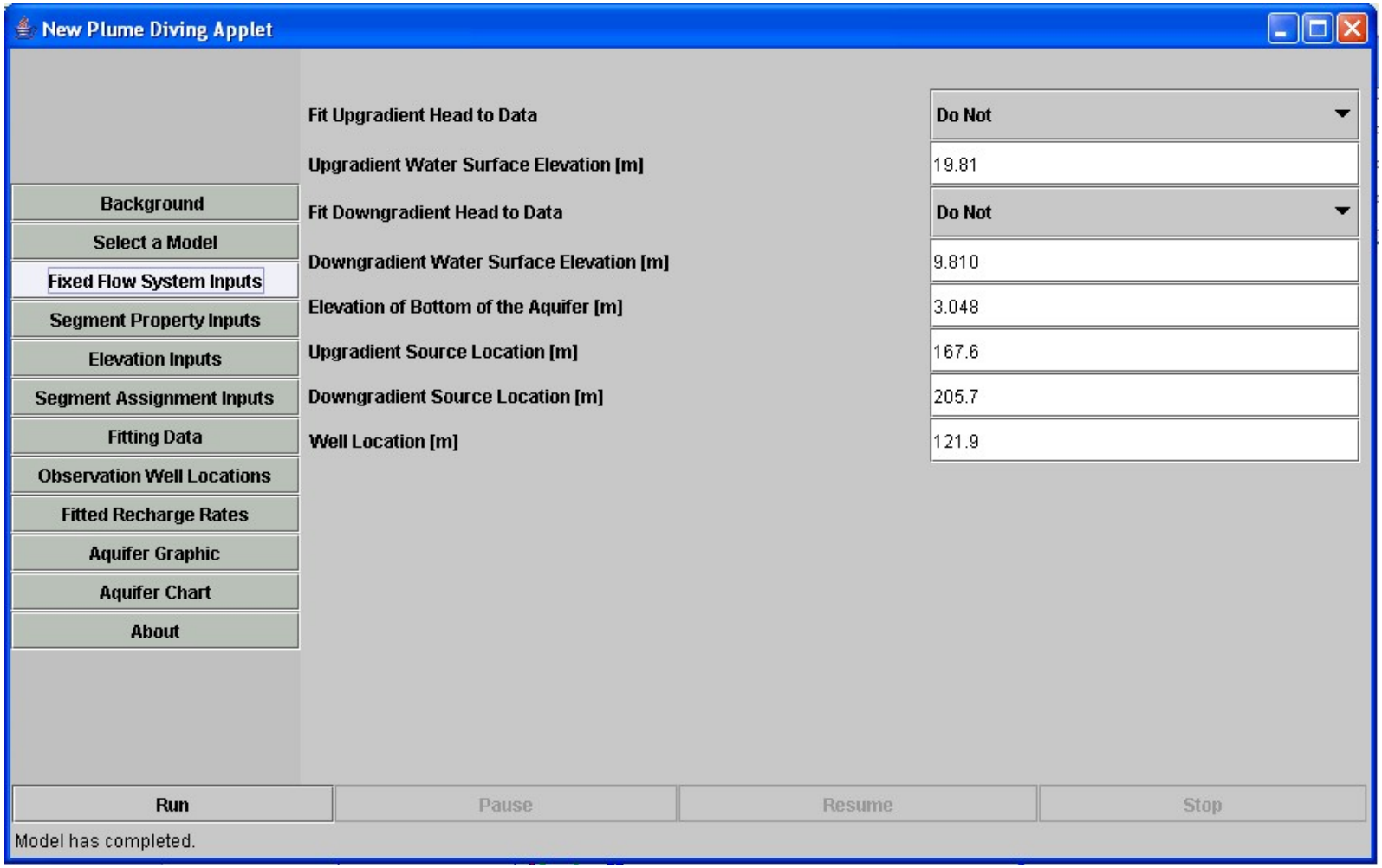
www.epa.gov/athens/learn2model/part-two/diving.htm

New Version will be an On-Line Numerical Model

- Previous methods are highly sensitive to recharge rate
- Recharge rate is often uncertain
- New calculator can rely on measured water levels, rather than estimated recharge rates
- Recharge rates are estimated via numerical inversion

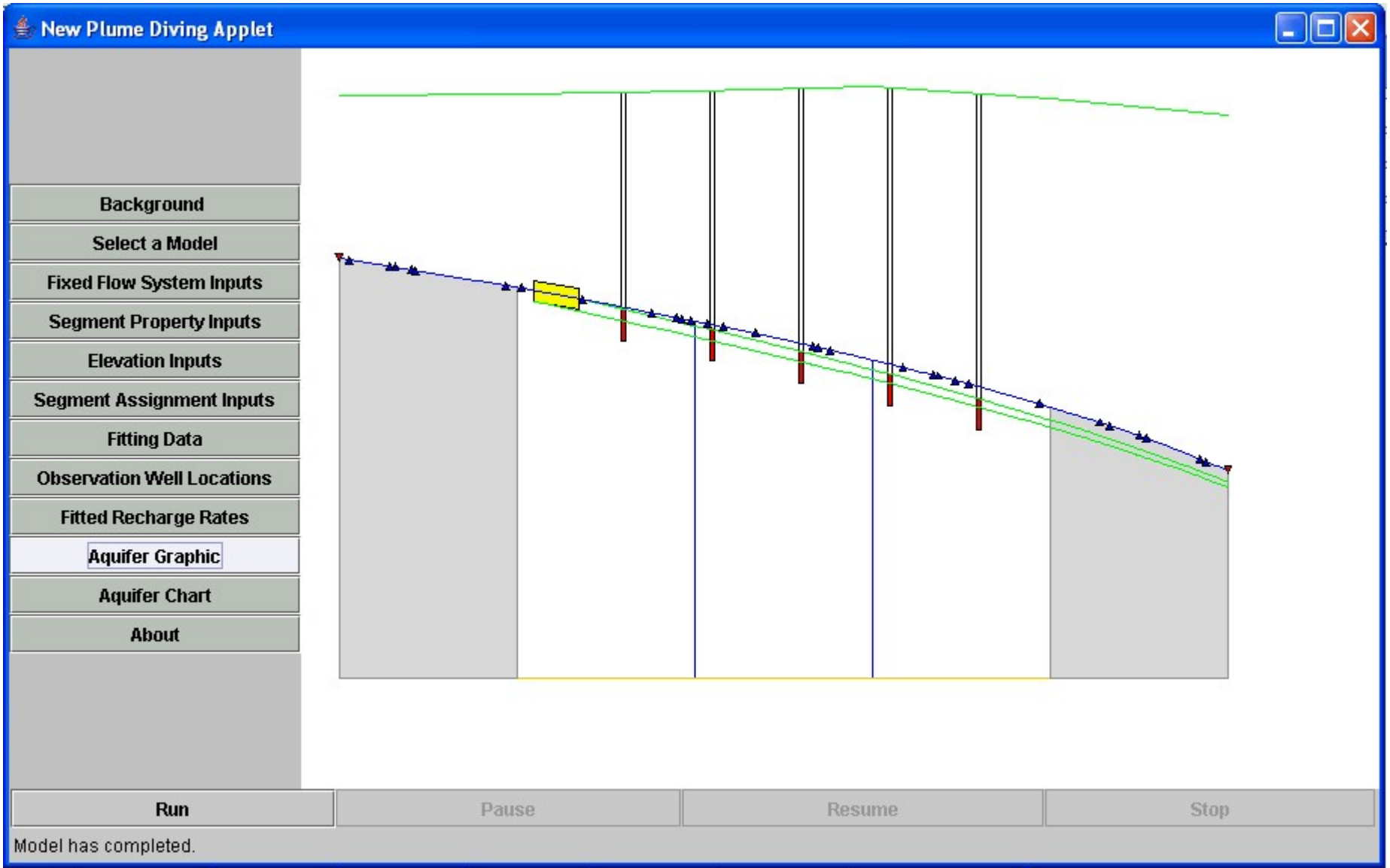


New, Improved Plume Dive Calculator

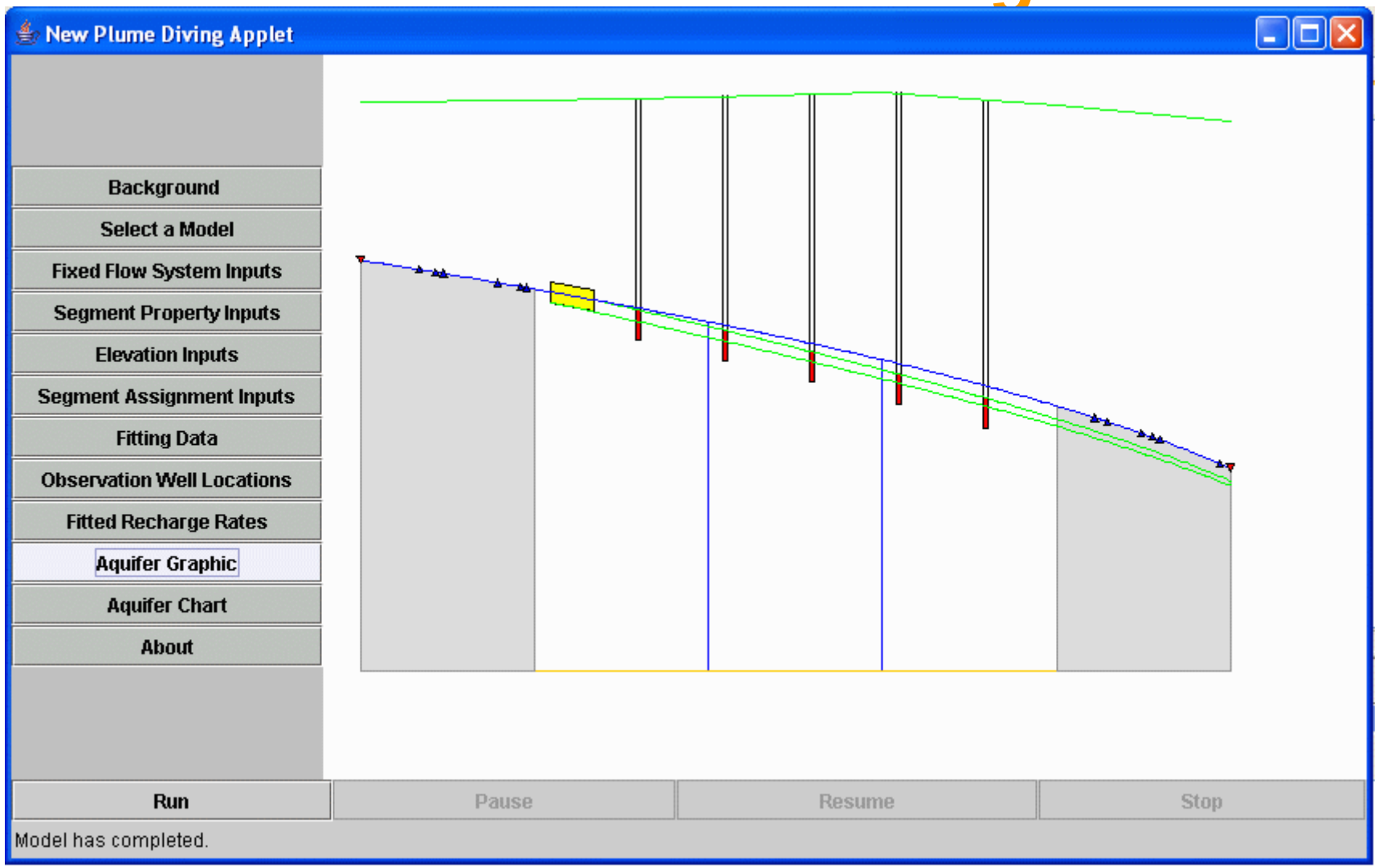


Courtesy of James W. Weaver and Vikenti M. Gorokhovski, U.S. EPA

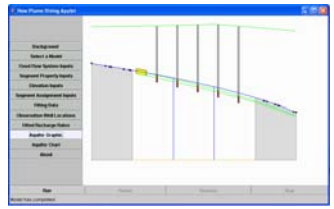
An On-Line Numerical Model



Estimating Dive in Uncharacterized Segments



Site Assessment



- Use initial site conceptual model/data to predict plume diving
  - Recharge rates
    - regional estimates (USGS studies)
    - water balance, e.g., baseflow separation from discharge to river
  - Water levels from initial monitoring points
- From installed sample points refine estimates
- Test results via sampling

Disclaimer

- Although this work was reviewed by EPA and approved for presentation, it may not necessarily reflect official Agency policy.

Plume Diving References

- **Calculator**: http://www.epa.gov/athens/onsite
- **On-line Tools for Assessing Petroleum Releases**, EPA 600/R-04/101, http://www.epa.gov/athens
- **Diving Plumes and Vertical Migration at Petroleum Hydrocarbon Release Sites** LUSTLine # 36
- **Using Direct-Push Tools to Map Hydrostratigraphy and Predict MTBE Plume Diving** Wilson et al., Ground Water Monitoring and Remediation, Summer 2005
- **Diving Plumes: Assessment, Significance, and Implications for Characterization and Monitoring**. Roth, T. and E. Nichols. API Soil and Groundwater Technical Bulletin Number 24. 2006