Oļģerts Aleksāns

TWO-PHASE LIQUID FLOW IN THE GROUNDWATER AQUIFER

The 70th Scientific Conference of the University of Latvia, Session of Geology
Section „Groundwater in Sedimentary Basins”

GeoExpert Ltd.

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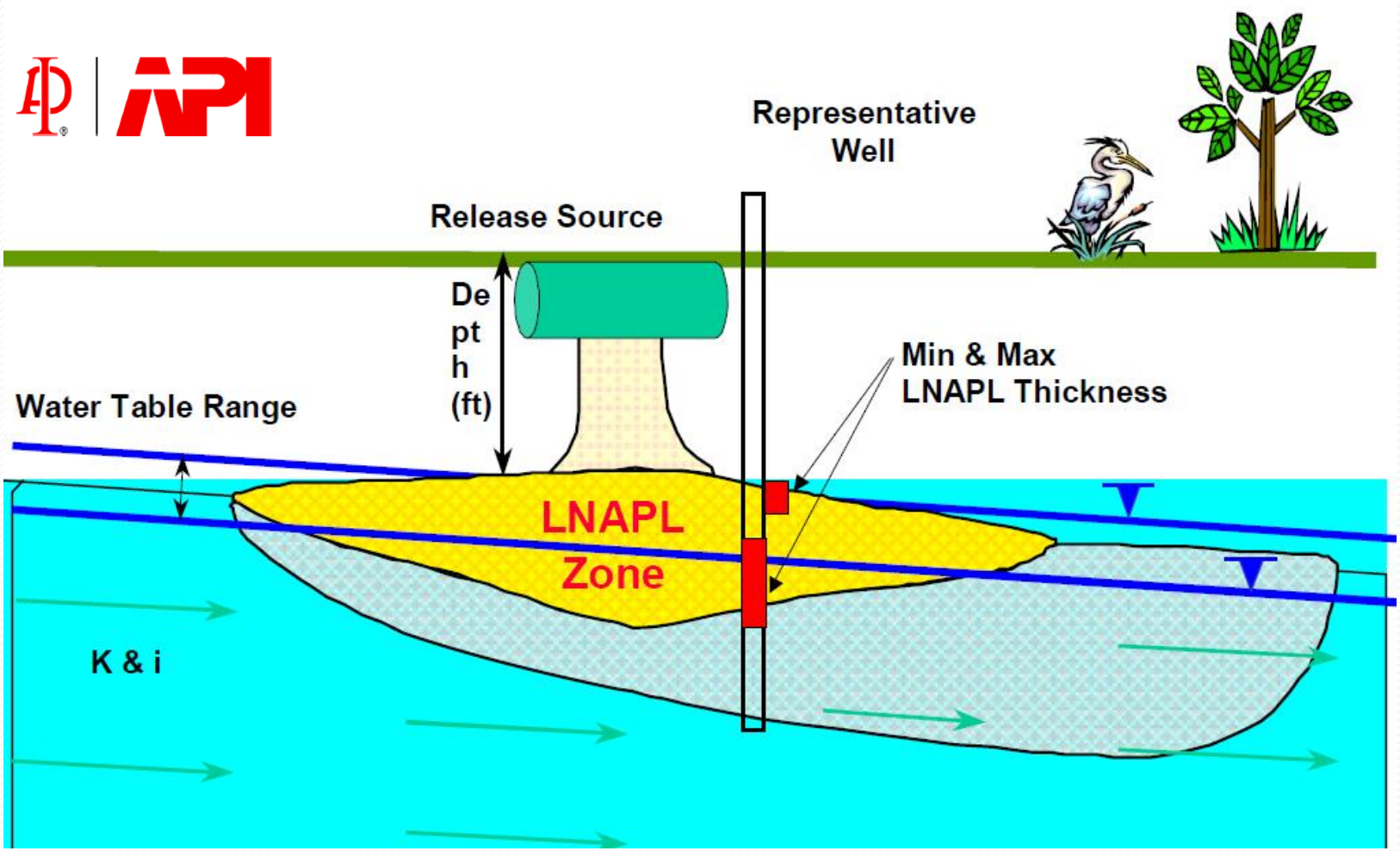
A little bit from history

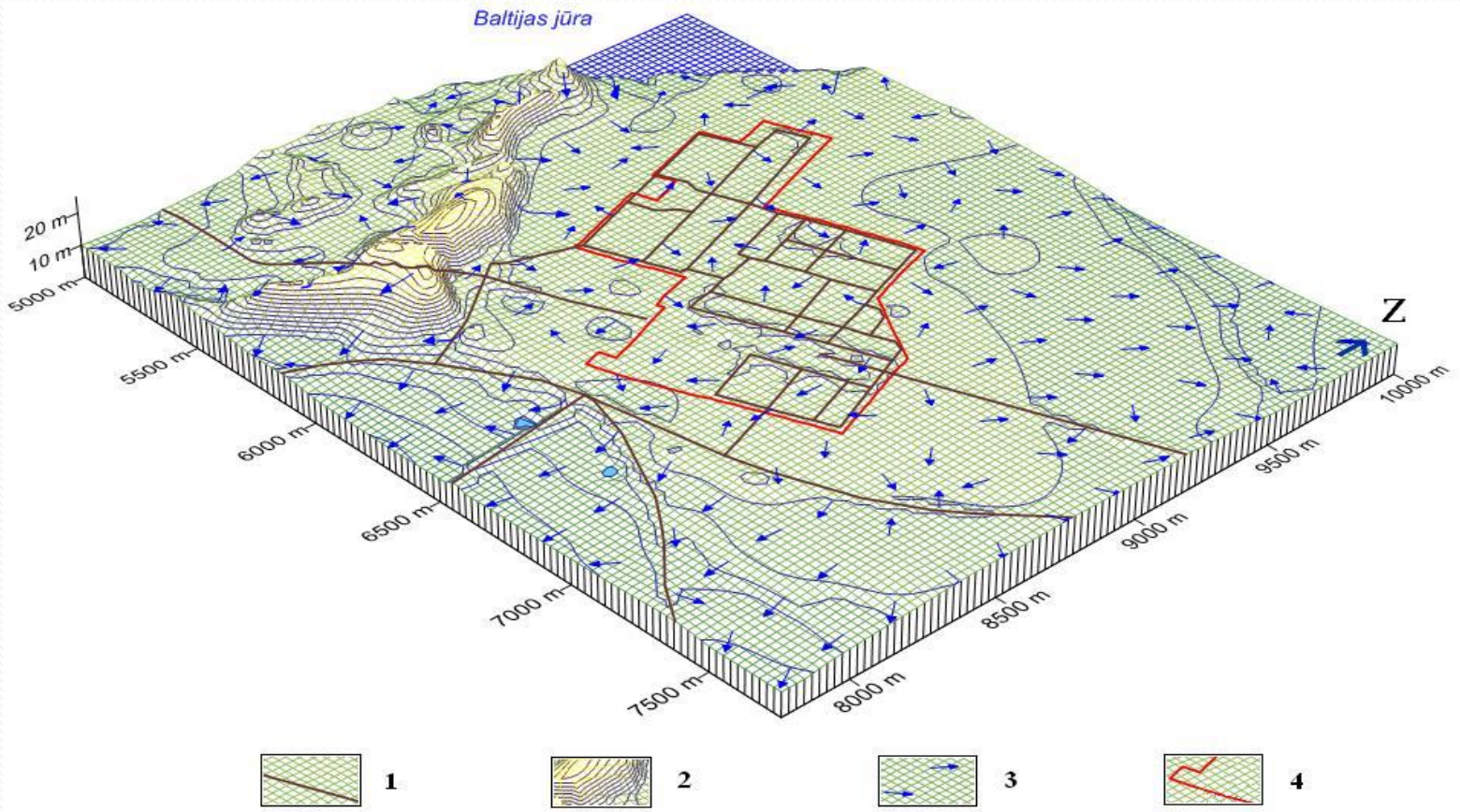
- In the last century's 50-60's years, it was erroneously considered, that free-phase liquid layer in the groundwater aquifer forms above water strictly separated floating lens in which 100% pore volume is filled with the free-phase liquid.
- Only in the 70s years of last century subsequent studies (**Brook**, **Corey**, 1964; **Genuchten**, 1980; **Lefebvre**, 2006) was established that capillary force influence on free-phase liquid layer in groundwater aquifer creates a complex multiphase system.

Simple Conceptual Site Model



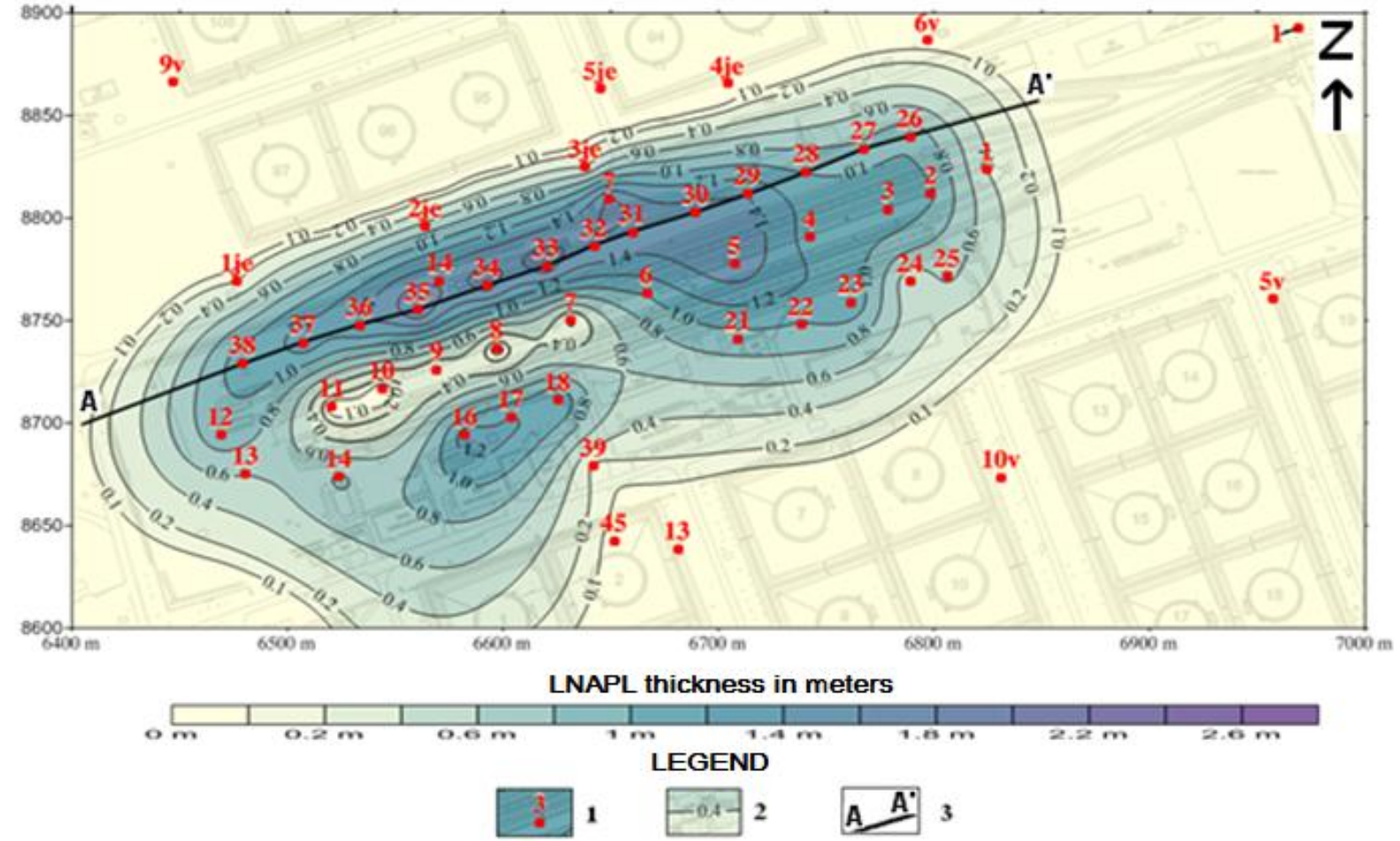
Study site location scheme

The 3D model of study area



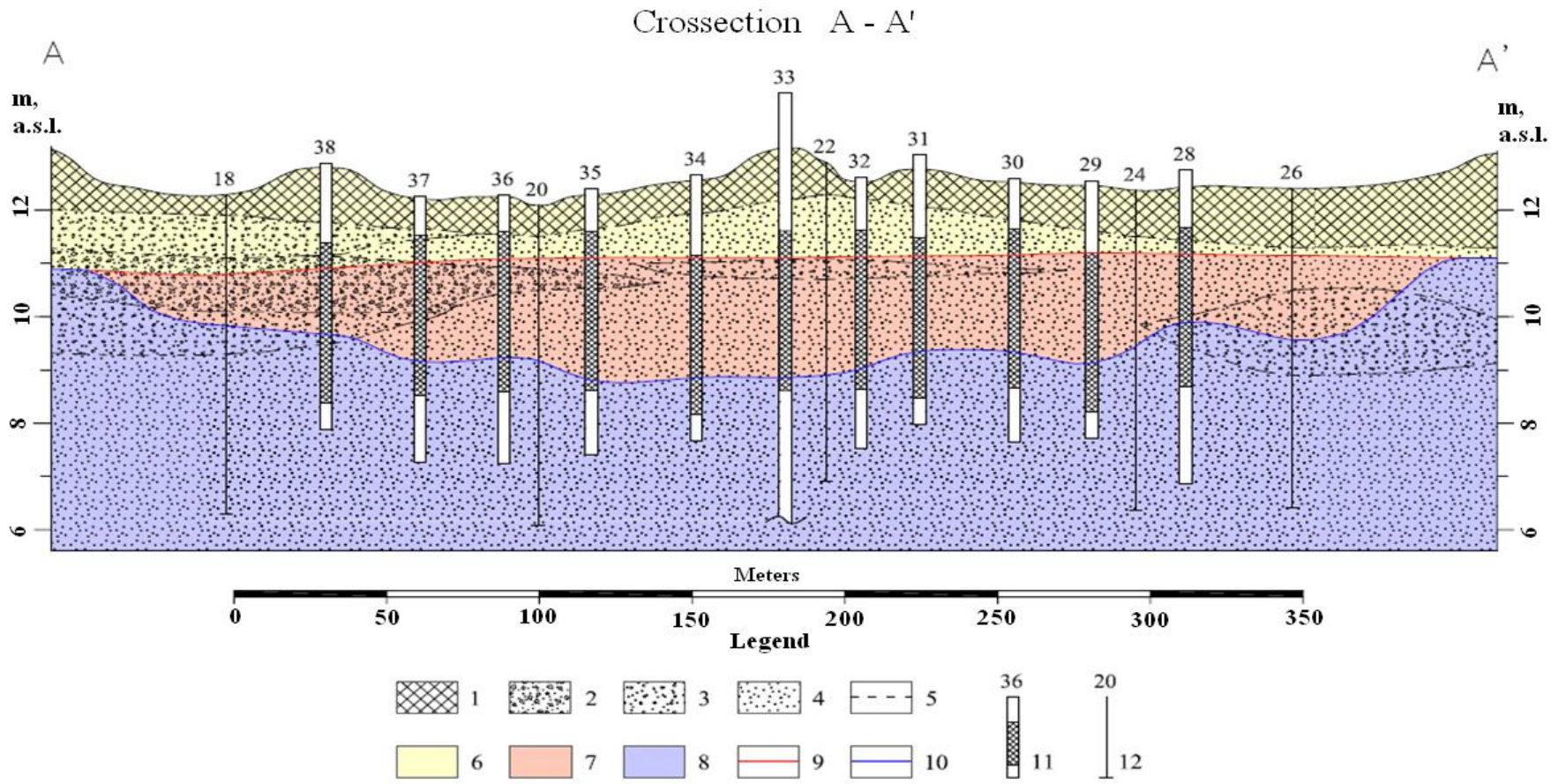
LEGEND.1 – infrastructures; 2 – geometric trace of surface elevation; 3 – groundwater flow direction; 4 – the study site area

Free-phase liquid layer distribution map and locations of observation wells



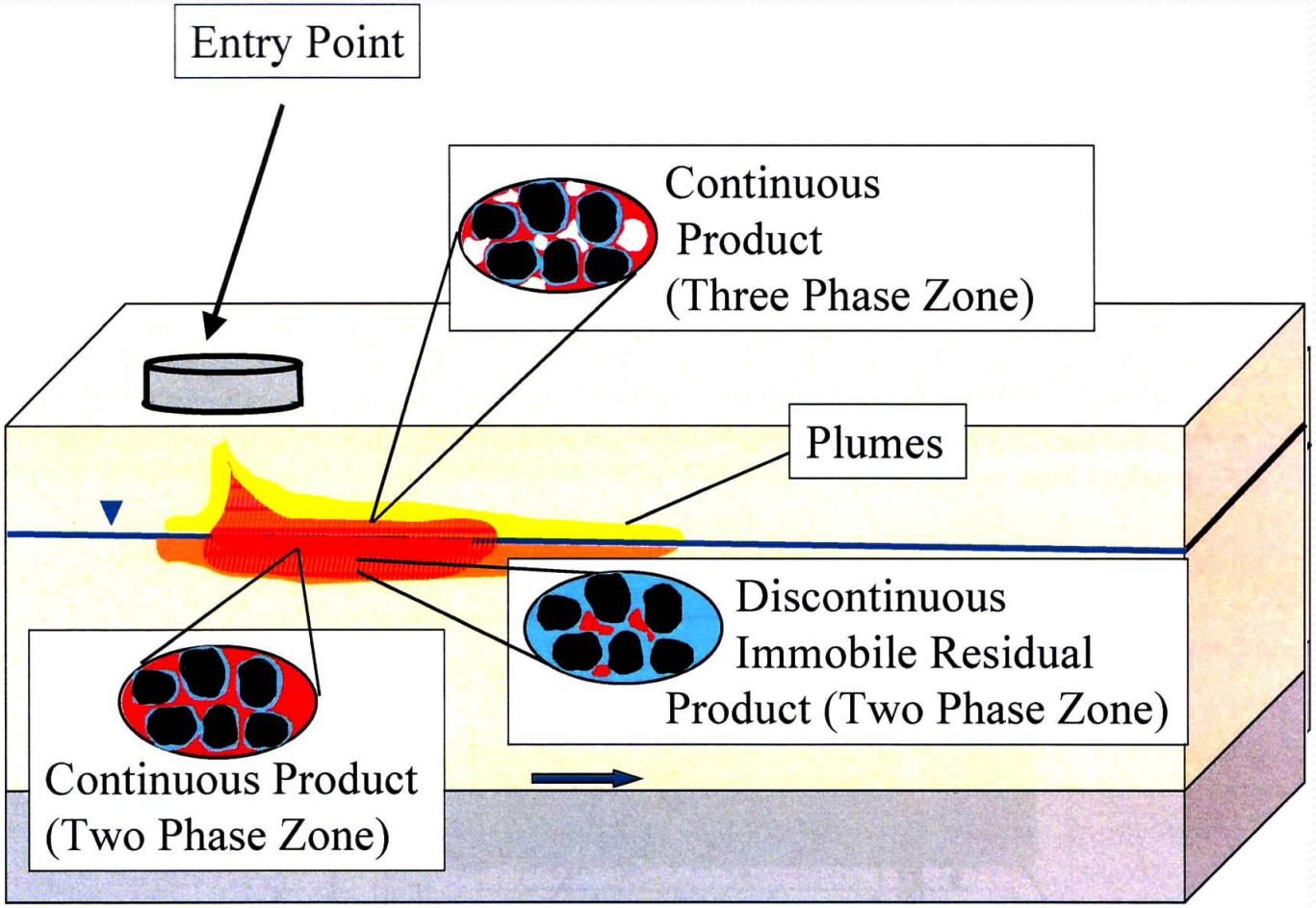
LEGEND. 1 - drilling well and its umber, 2 - geometric trace of free-phase liquid layer thickness, in meters, 3 –hydro geological cross section line

Hydro geological cross section

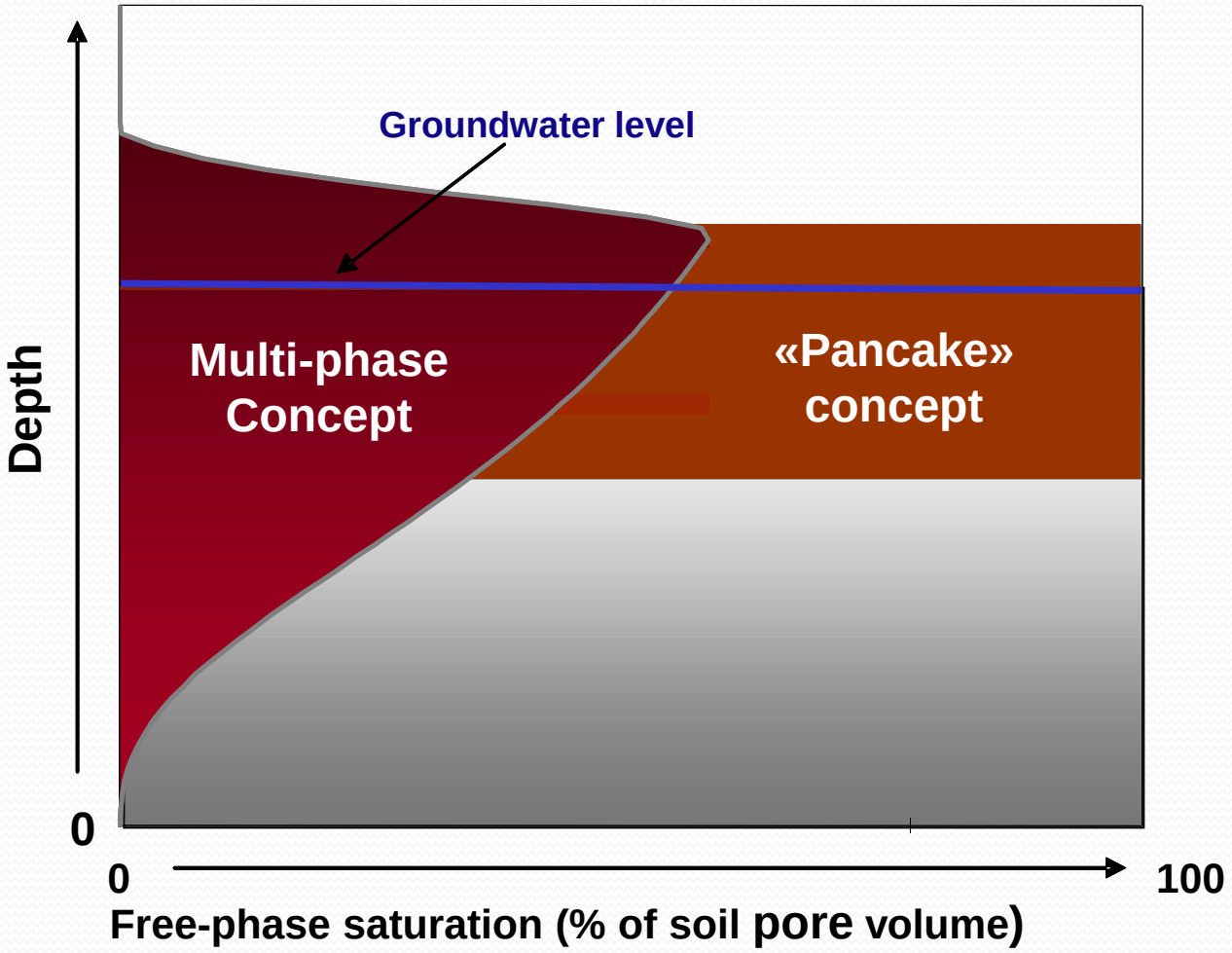


LEGEND. 1- embankment, 2 - gravel sand, 3 - medium coarse sand, 4 - fine sand, 5 - lithological boundary, 6 - vadose zone, 7 - free-phase liquid layer, 8. groundwater, 9 - non aqueous phase liquid table, 10 - groundwater and non aqueous phase liquid interface 11- pumping well and its number 12 - exploration well and its number.

The concept of multi-phase liquid presence in the soil



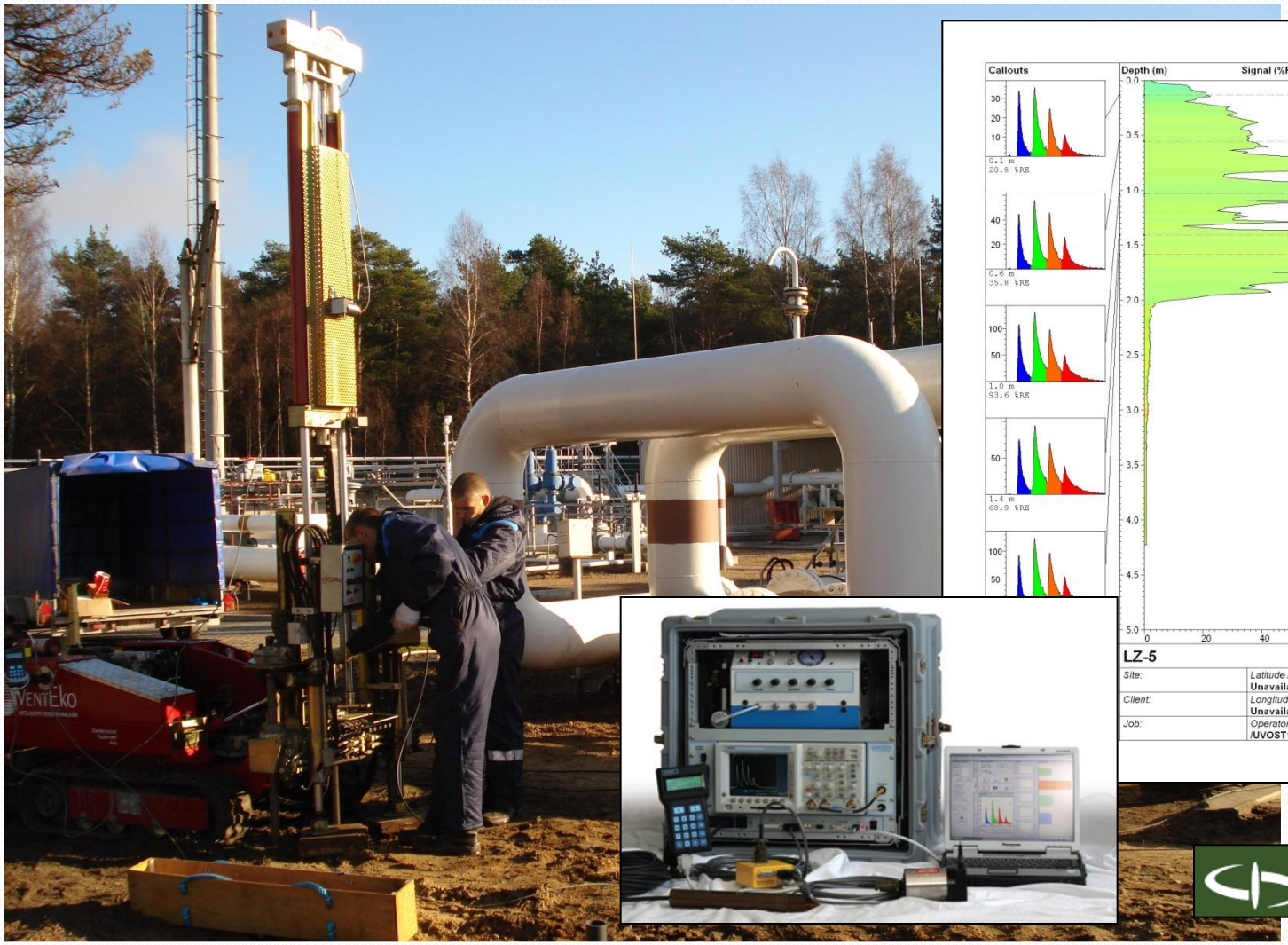
Two concepts of free-phase liquid layer distribution in the groundwater aquifer

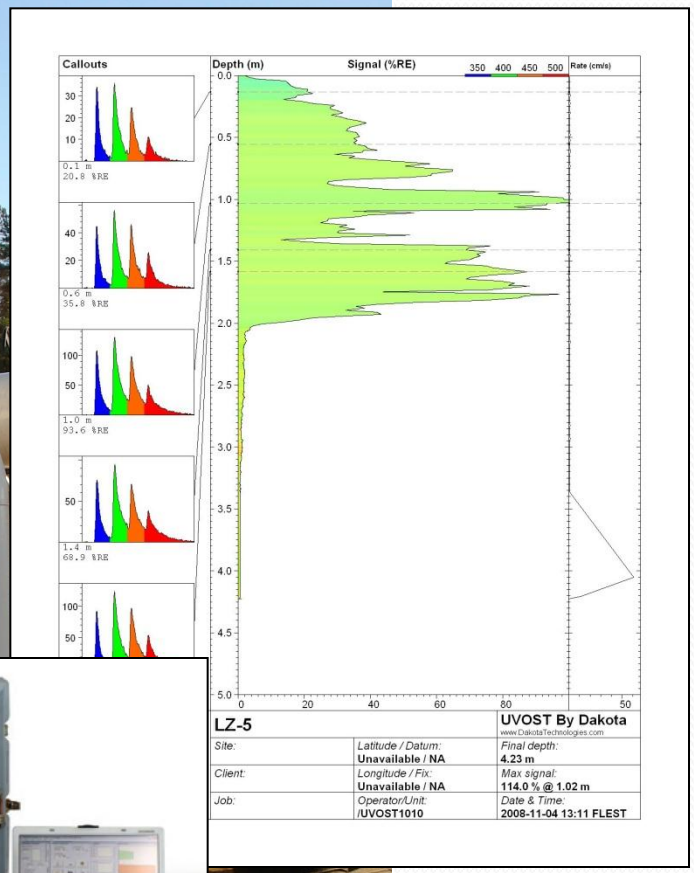


The techniques used for free-phase liquid layer thickness detection

- Laser Induced Fluorescence (LIF) site investigation (Geophysical or Direct measuring, method)
- Empirical determinations of free-phase liquid layer thickness (Pumping tests)
- Numerical calculations of free-phase liquid layer thickness (Modeling)

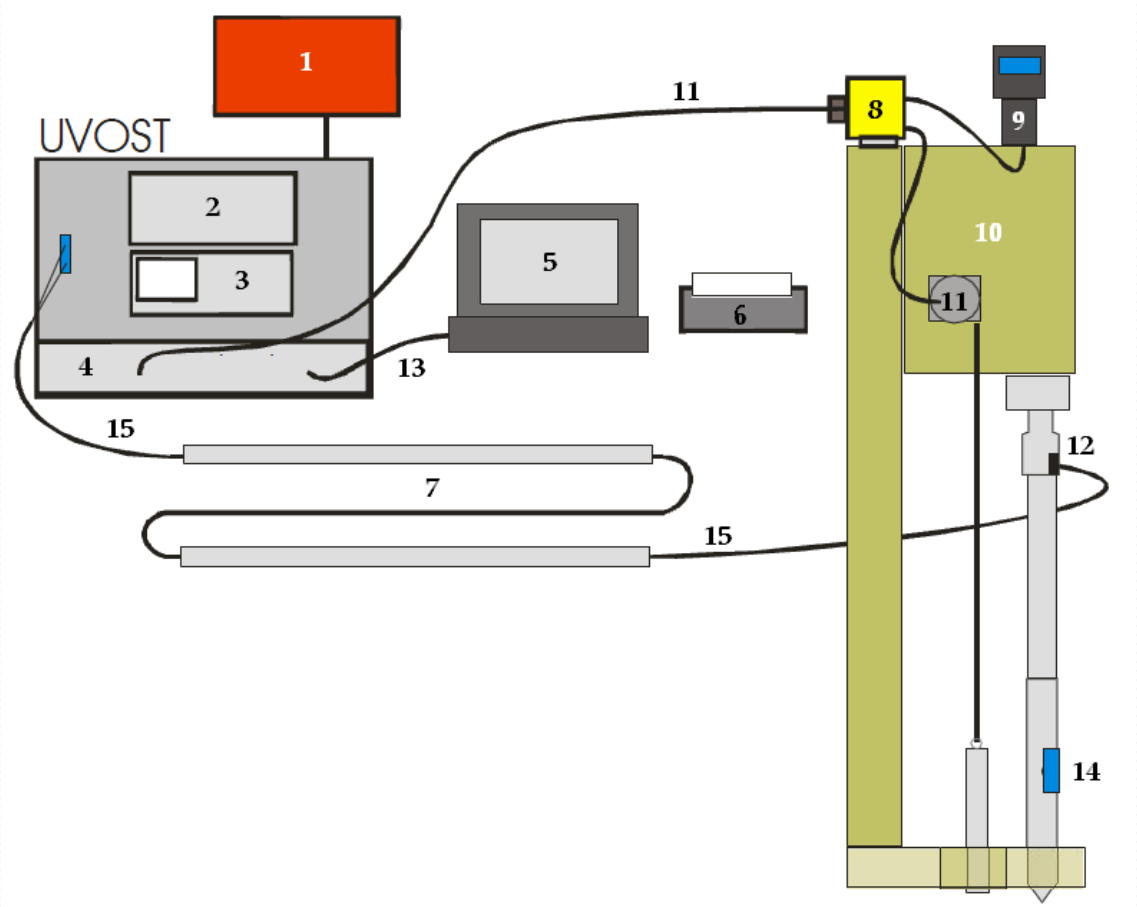
UVOST – Ultra Violet Optical Screening Tool





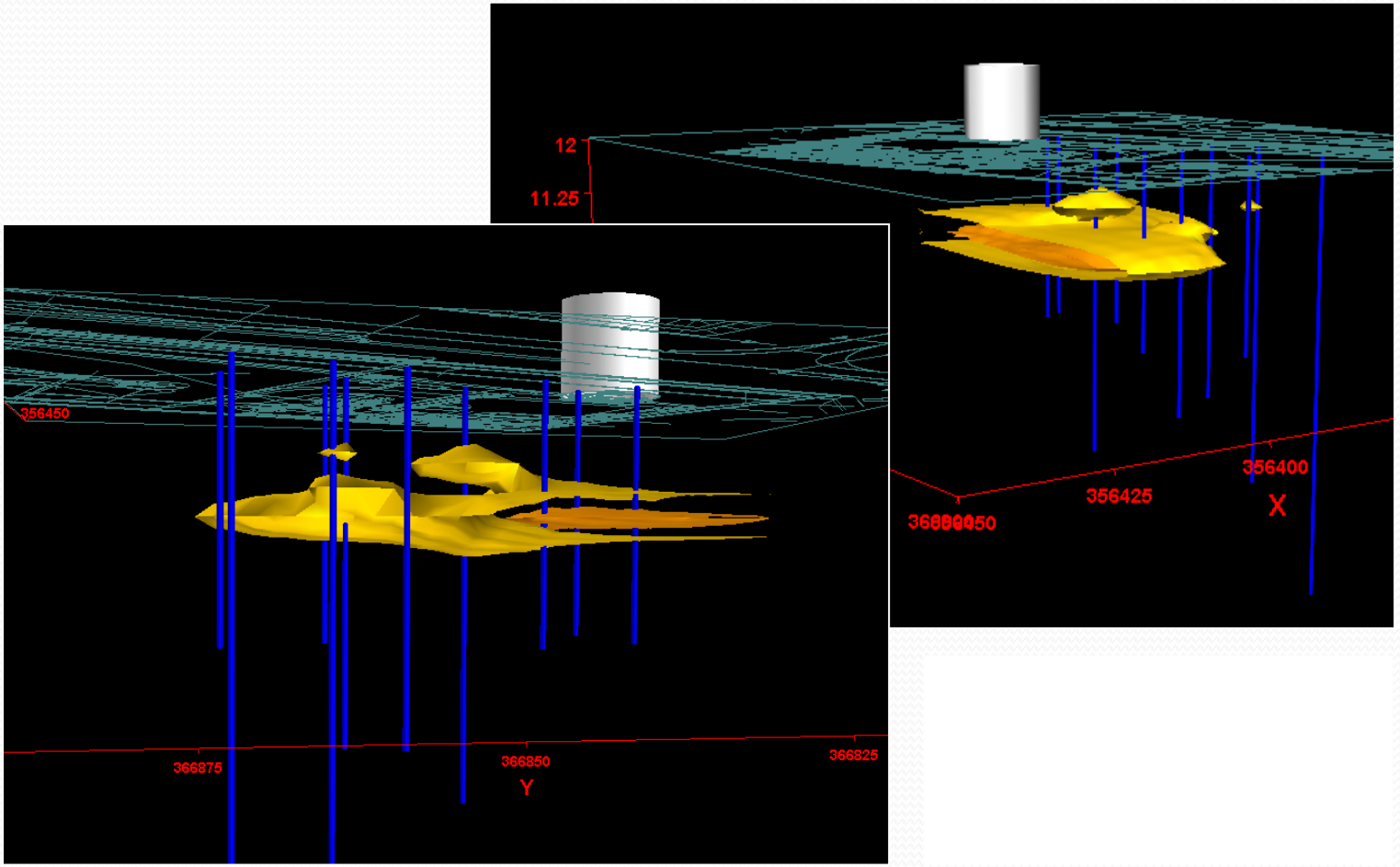
DAKOTA TECHNOLOGIES

The principal scheme of laser-induced fluorescence (LIF) probing device

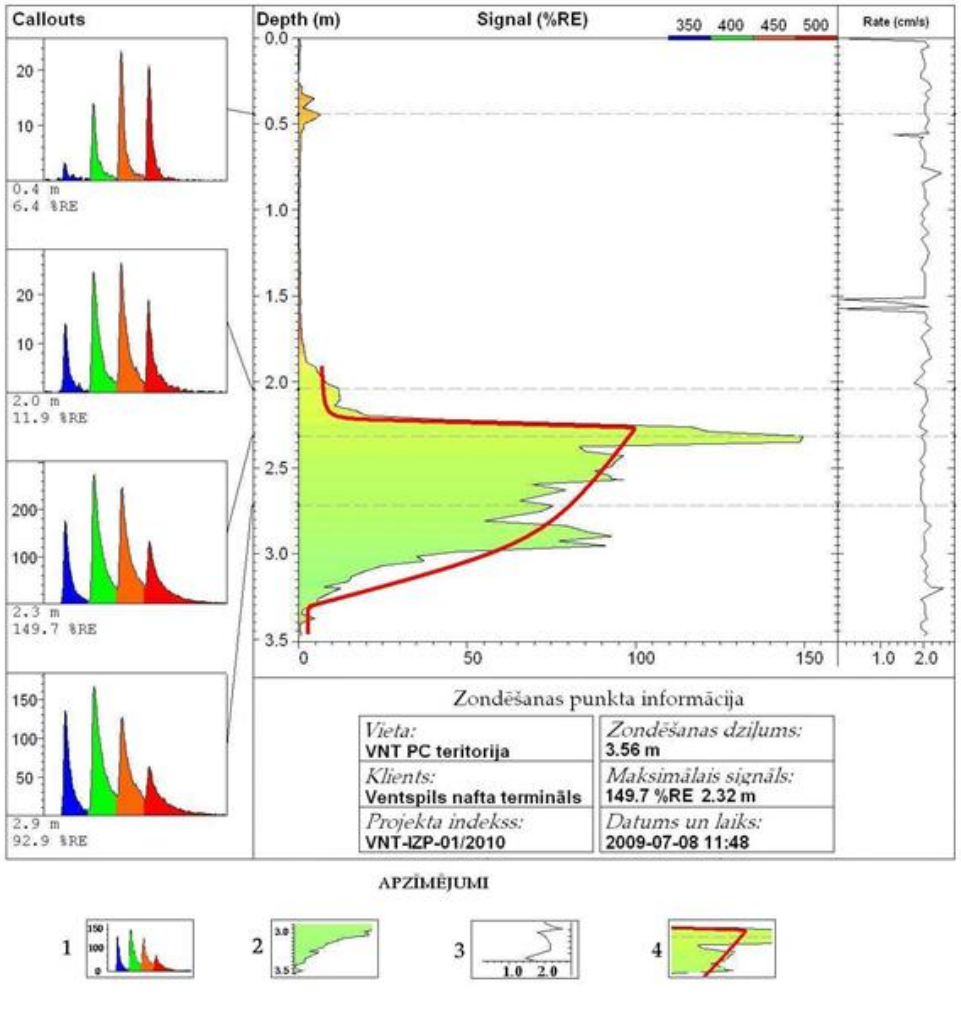


LEGEND. UVOST – Ultra Violet Optical Screening Tool. 1 – generator, 2 – laser, 3 – scope, 4 – e-deck, 5 – PC, 6 – printer, 7 – roads, 8 – breakout box, 9 – remote display, 10 – direct push equipment, 11 – umbilical, 12 – split cup, 13 – LAN, 14 – window in the road for laser excitation and receiving emitted light, 15 – fiber optic cable.

3D spatial models for free-phase distribution in the soil



Two-phase liquid fluorescence–depth vertical profile



LEGEND:

1.Laser Induced Fluorescence (LIF) wavelength-time matrix (WTM)

2.Free phase liquid saturation in the soil obtained by LIF method

3.Probing velocity from the top to bottom ($cm \times s^{-1}$)

4.Match between measured LIF (green area) and predicted by model (red line) free phase liquid saturation in the soil

Two-phase liquid fluorescence–depth vertical profile for heterogeneous deposits aquifer

LEGEND

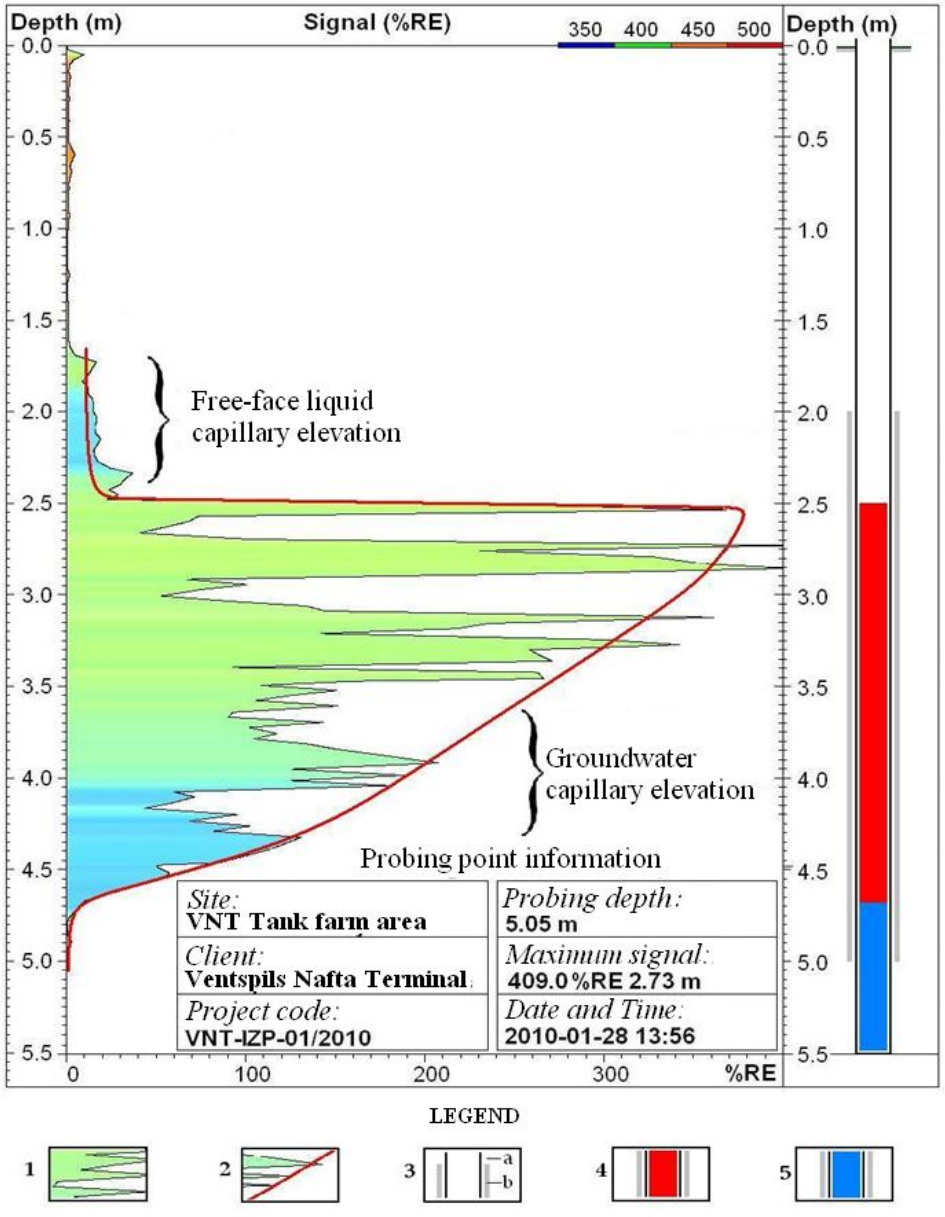
1 – the total fluorescence–depth profile;

2 – match between measured (green area) and predicted by model (red line) free phase liquid saturation in the soil;

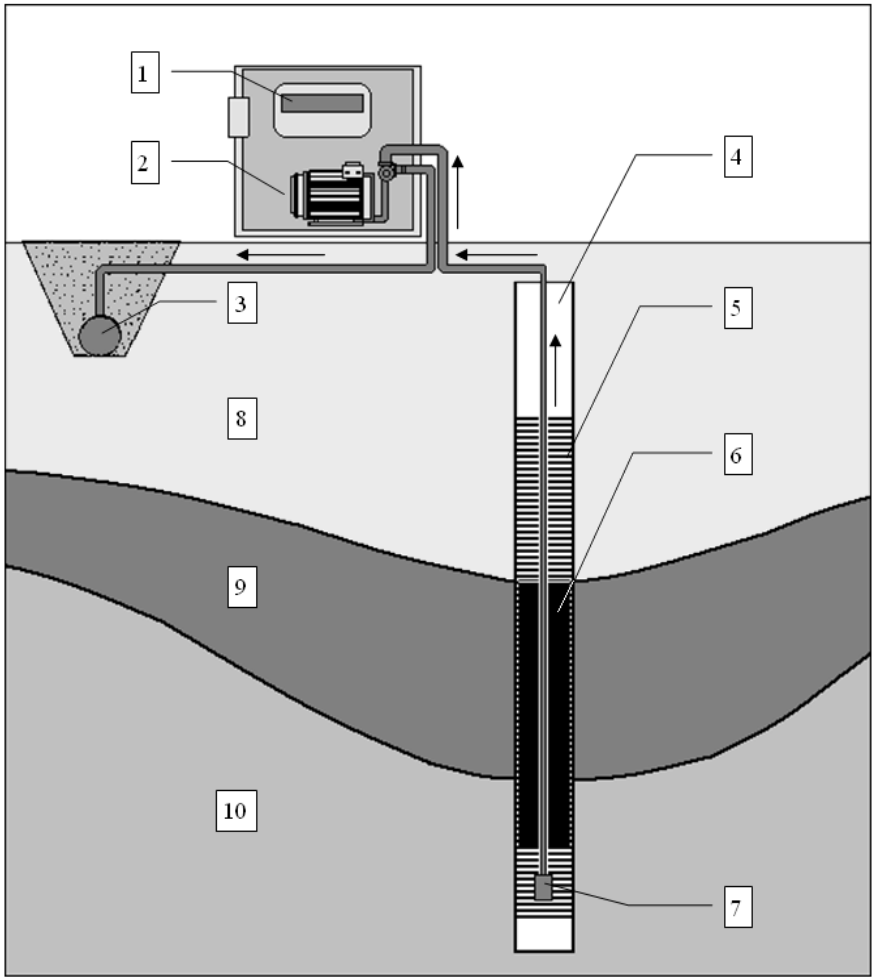
3 – well: a) casing, b) screen;

4 – free-phase liquid in the well;

5 – water in the well.



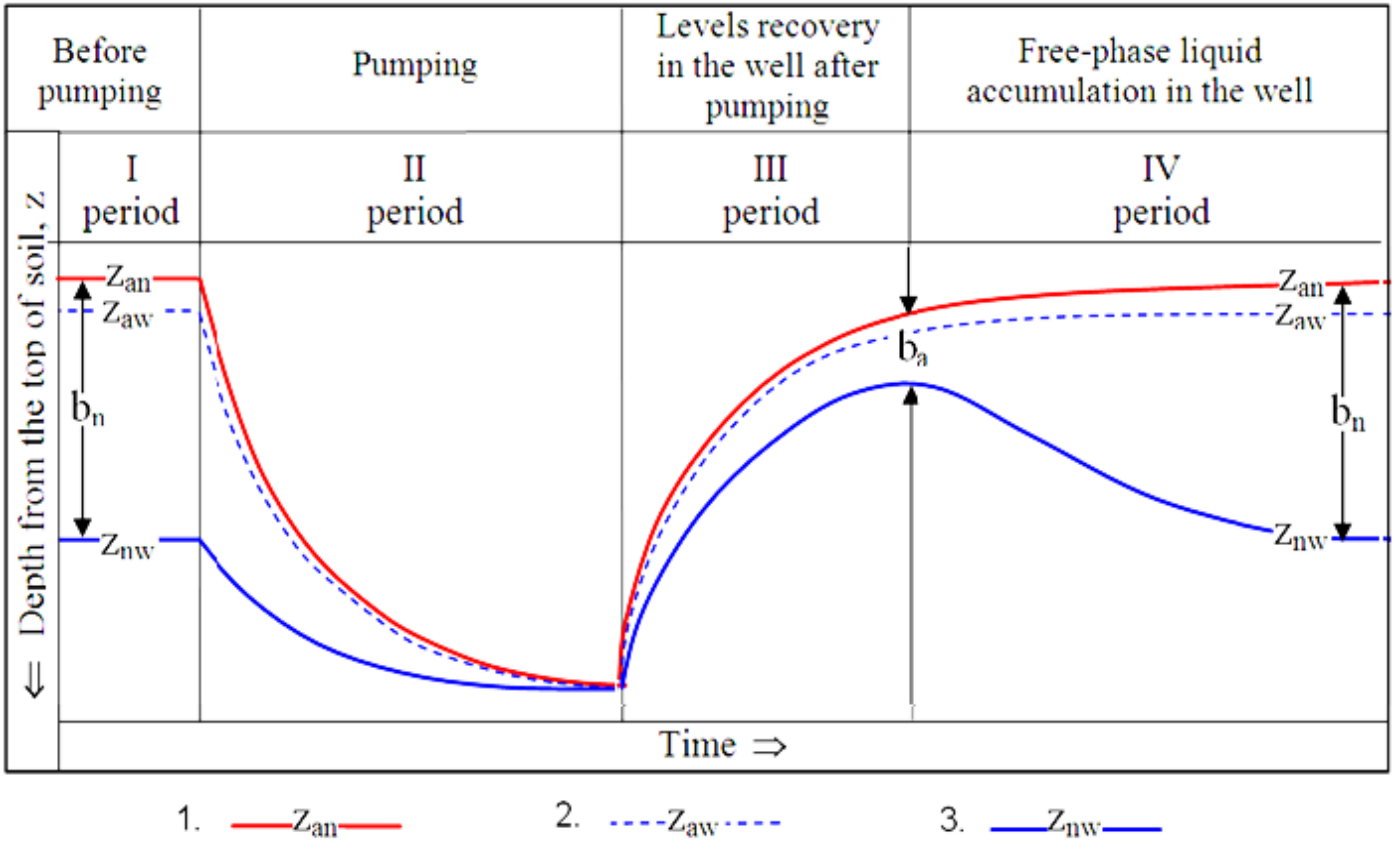
Principal scheme of pumping system



LEGEND:

1 - control panel,
2 - surface centrifugal pump,
3 - industrial sewage,
4 - pumping well,
5 - well screen,
6 - free-phase liquid layer in the well,
7 - check valve,
8 - vadose zone,
9 - free-phase layer in the groundwater aquifer,
10 – groundwater.

Free-phase liquid layer thickness changes in the well during the pumping test



LEGEND:

1 - air and free-phase liquid interface,

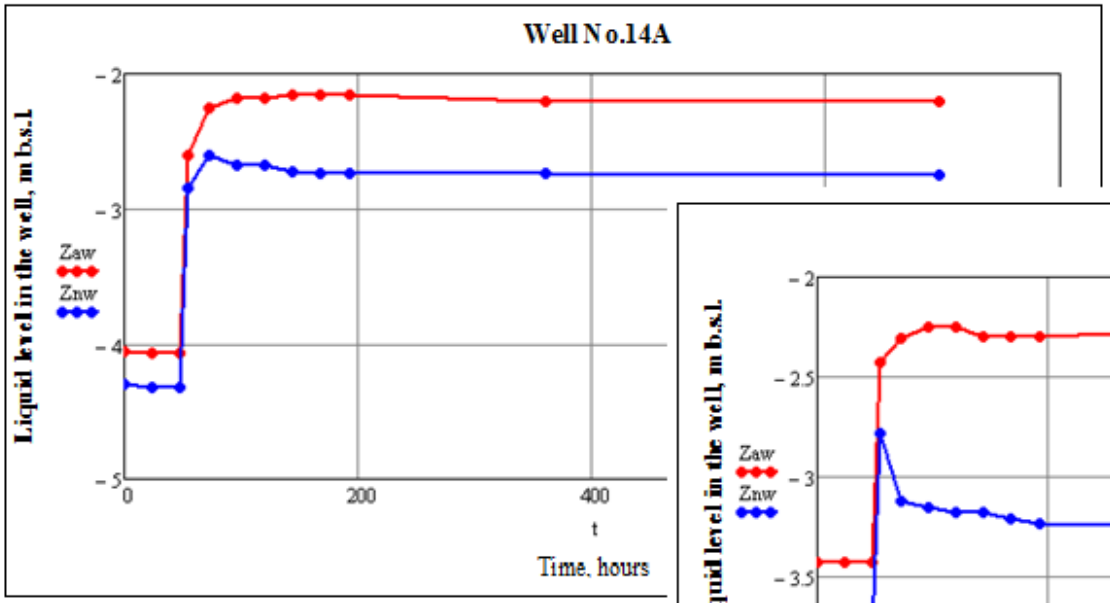
2 - hypothetical (piezometric) ground-water level,

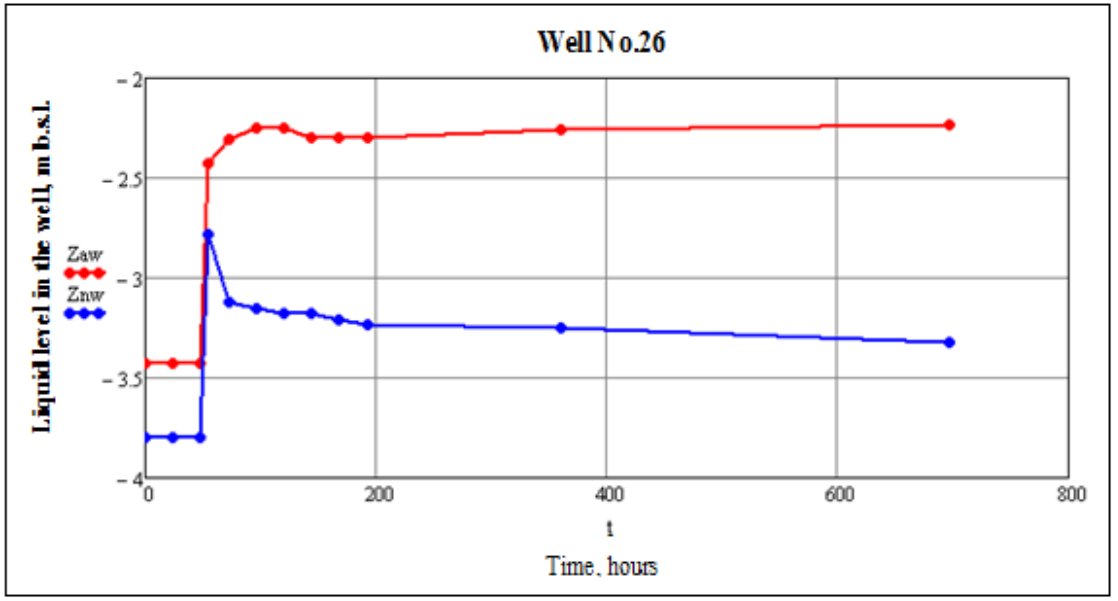
3 - free-phase liquid and water interface,

$\mathbf{b_a}$ - actual (real) free-phase liquid layer thickness in the aquifer,

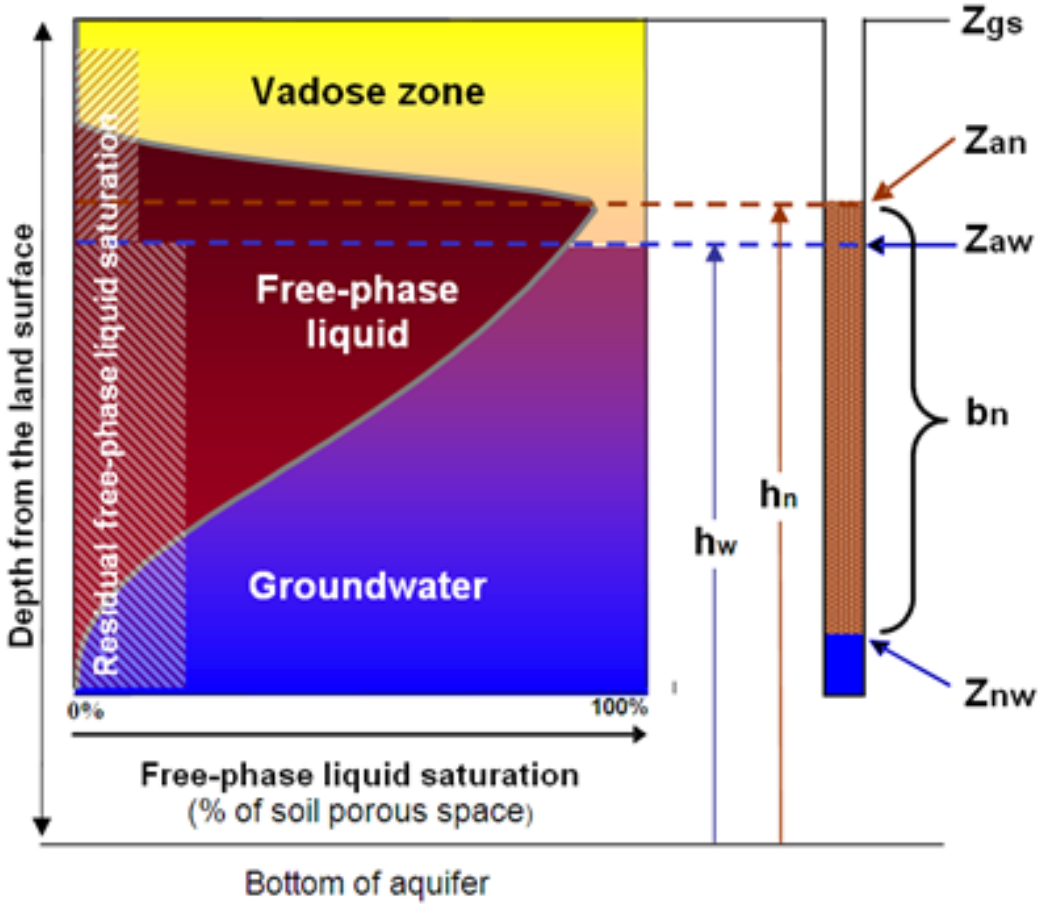
$\mathbf{b_n}$ - observed free-phase liquid layer thickness in the monitoring well.

Free-phase liquid layer thickness changes observed in the wells No.14A and No.26





Physical model of two-phase liquid vertical distribution in the groundwater aquifer



LEGEND:

z_{gs} - reference level (from the top of surface),

z_{an} - air and free-phase liquid interface,

z_{aw} - hypothetical (pizometric) groundwater level)

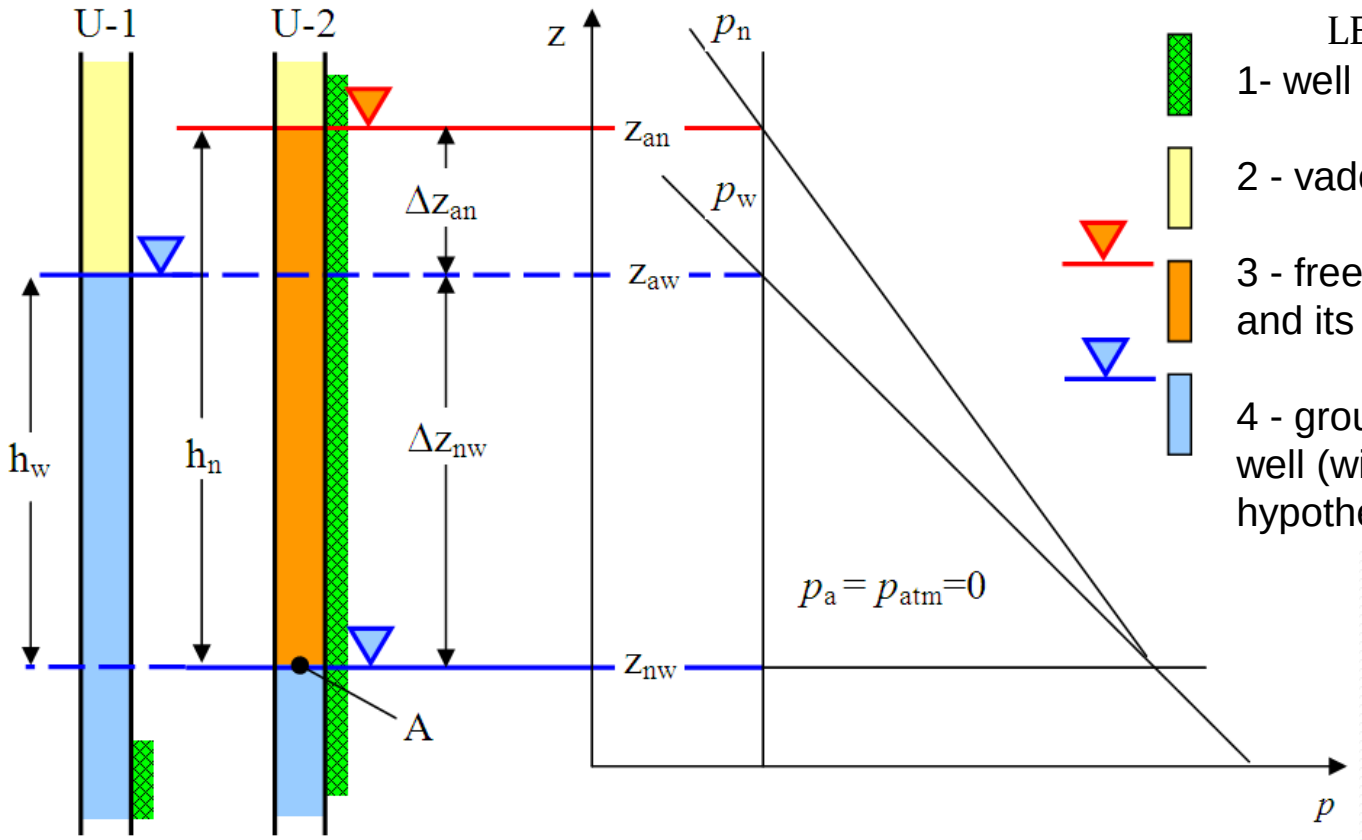
b_n - observed free-phase liquid layer thickness in the monitoring well,

z_{nw} - free-phase liquid and water interface,

h_w - water rising altitude (pressure) in the groundwater aquifer,

h_n - free-phase liquid rising altitude (pressure) above its and groundwater interface.

The scheme of two-phase liquid pressure forces distribution in the observation well (Lefebvre, 2006)



LEGEND:

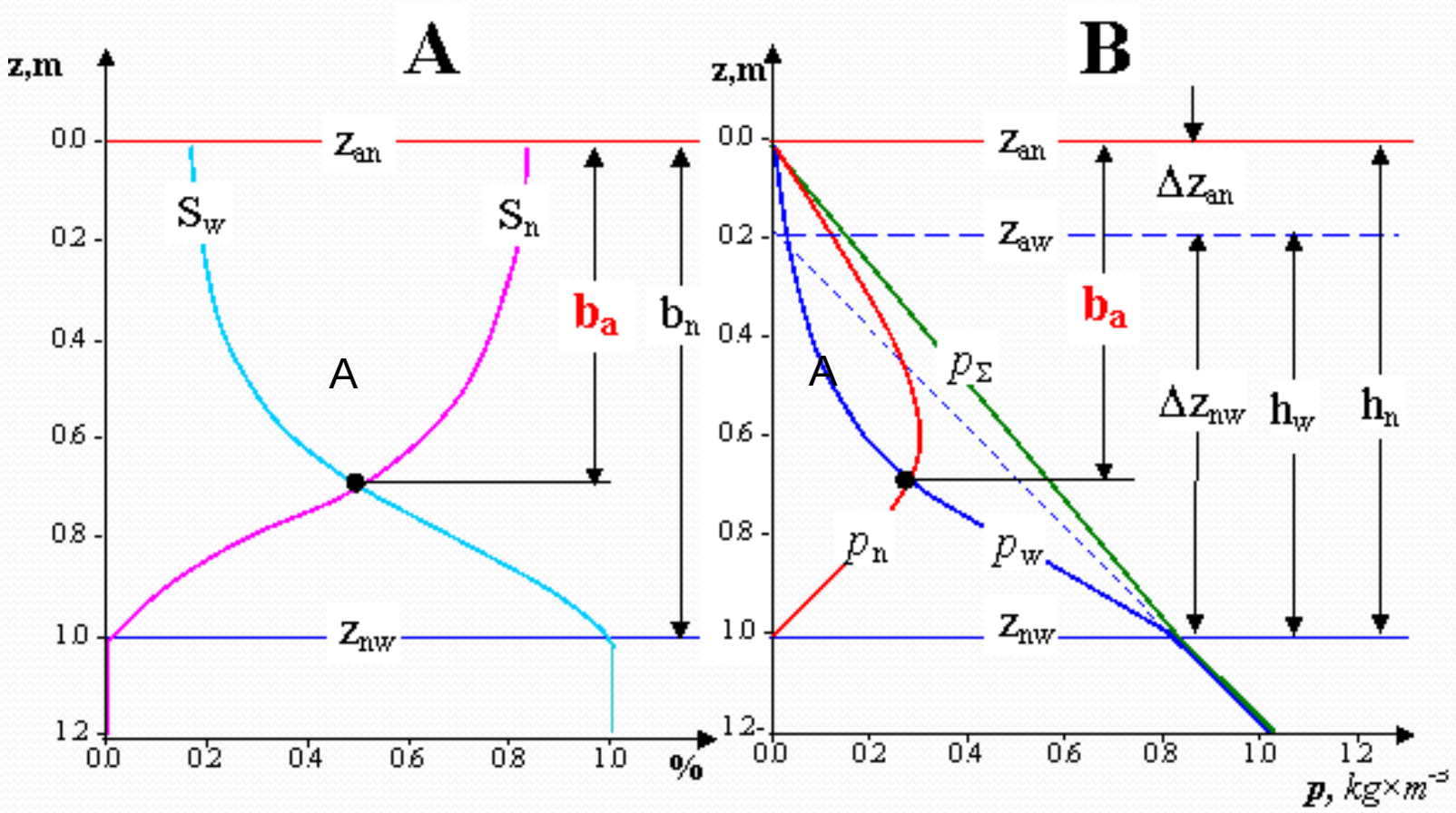
1- well screen interval,

2 - vadose zone,

3 - free-phase liquid layer and its level in the well,

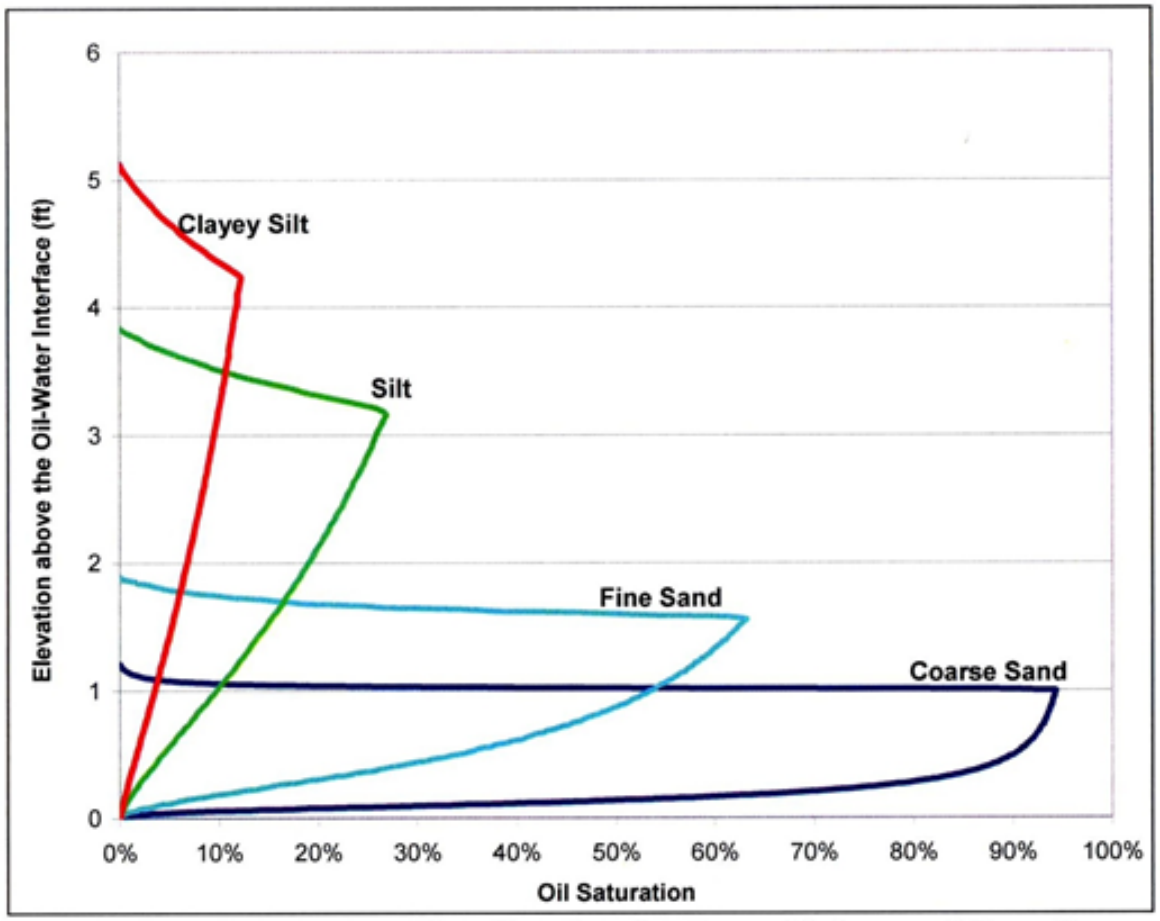
4 - ground water level in the well (with a dotted line - hypothetical)

Two-phase liquid vertical distribution key parameters

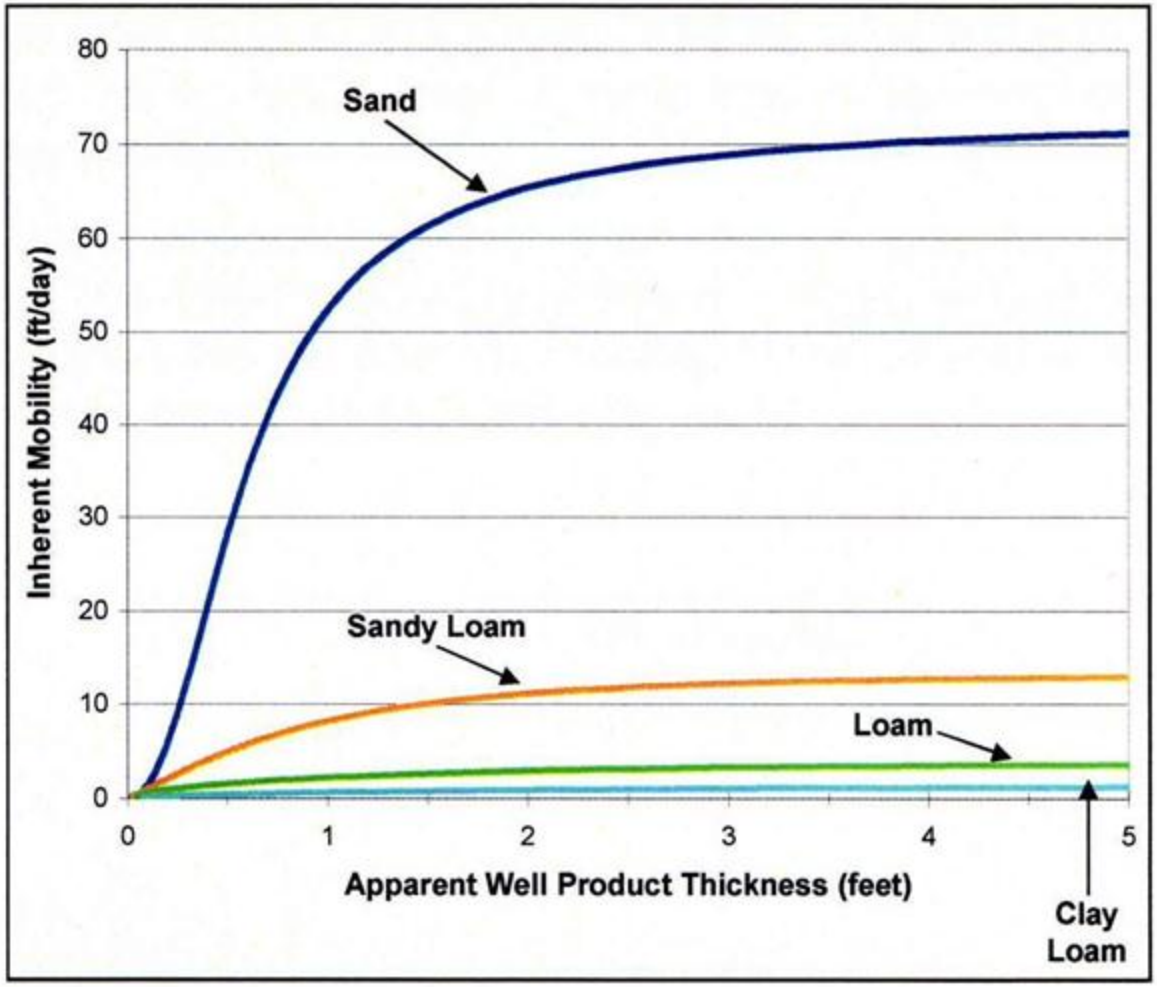


LEGEND. ***p*w** - water pressure, ***p*n** - free-phase liquid pressure, p_Σ - cumulative pressure, **Sw, Sn** – water and free-phase liquid vertical distribution for saturated zone at the level (z); **A** – free phase liquid and water interface point.

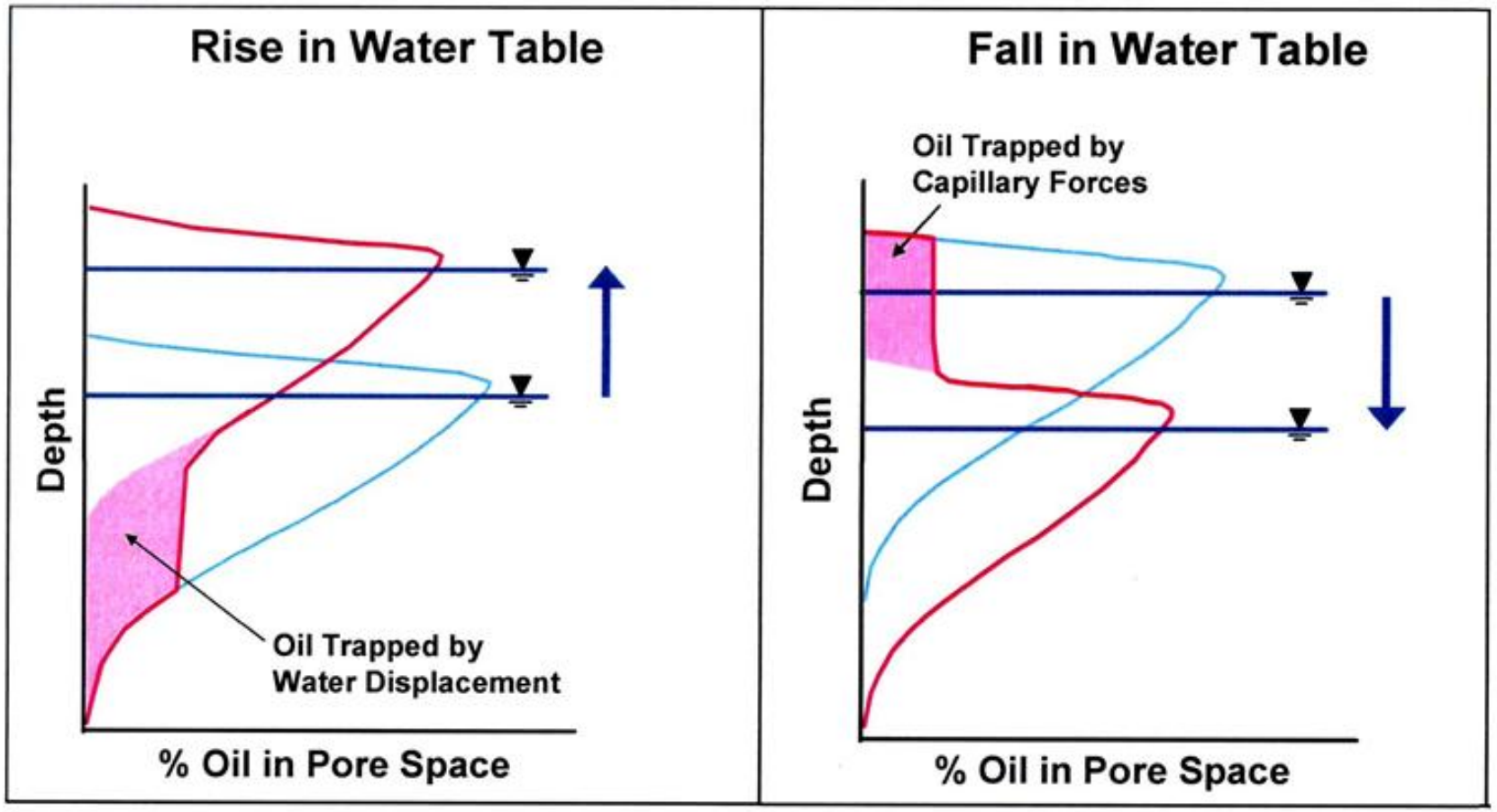
Oil saturation profile for the same volume of gasoline in various soil types



Inherent free-phase mobility of gasoline in various soil textures



Changes in free-phase saturation profile Due to water fluctuations



Residual and mobile free-phase liquid saturation distribution in the area of well No.44, determined by LIF method

LEGEND

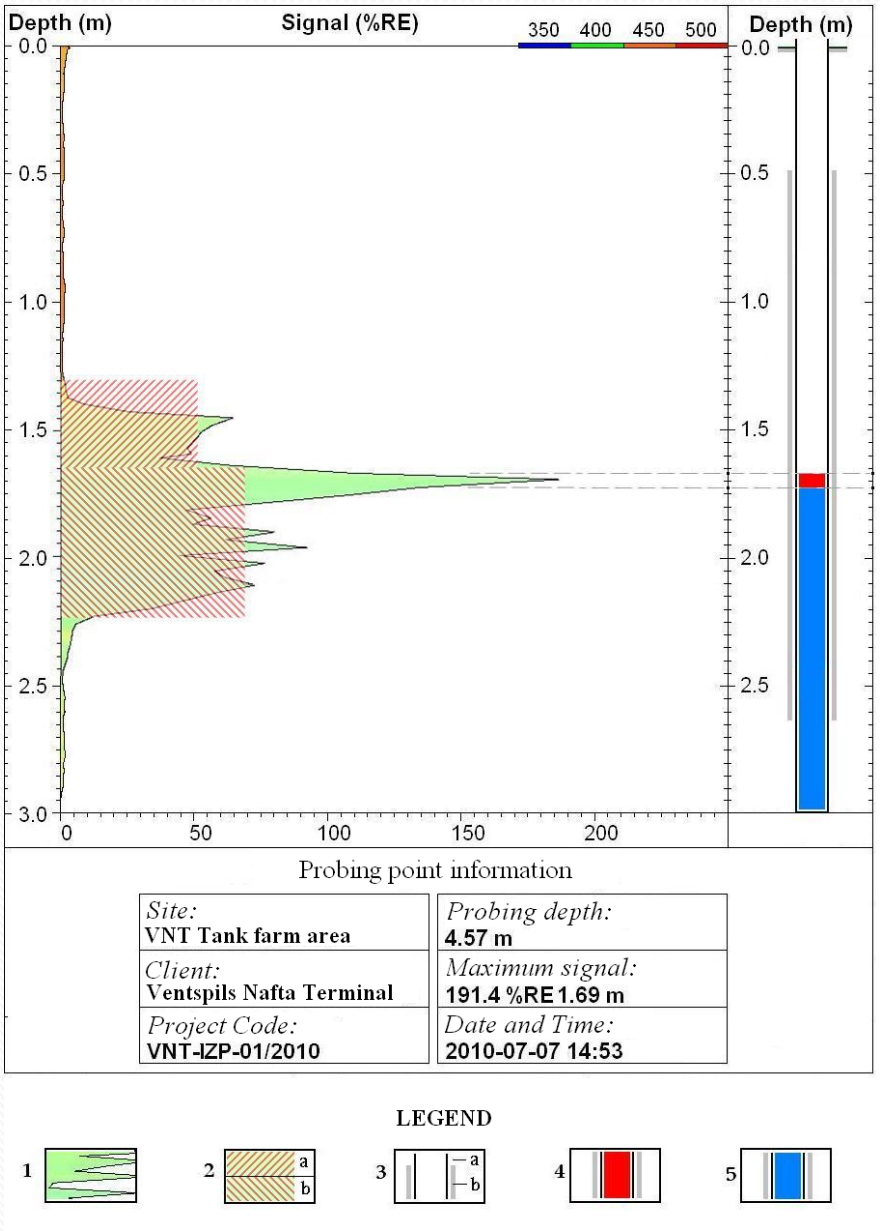
1 – The total fluorescence–depth profile;

2 – residual free-phase liquid saturation;
a) in vadose zone, b) in saturated zone;

3 – well: a) casing, b) screen;

4 – free-phase liquid in the well;

5 – water in the well.

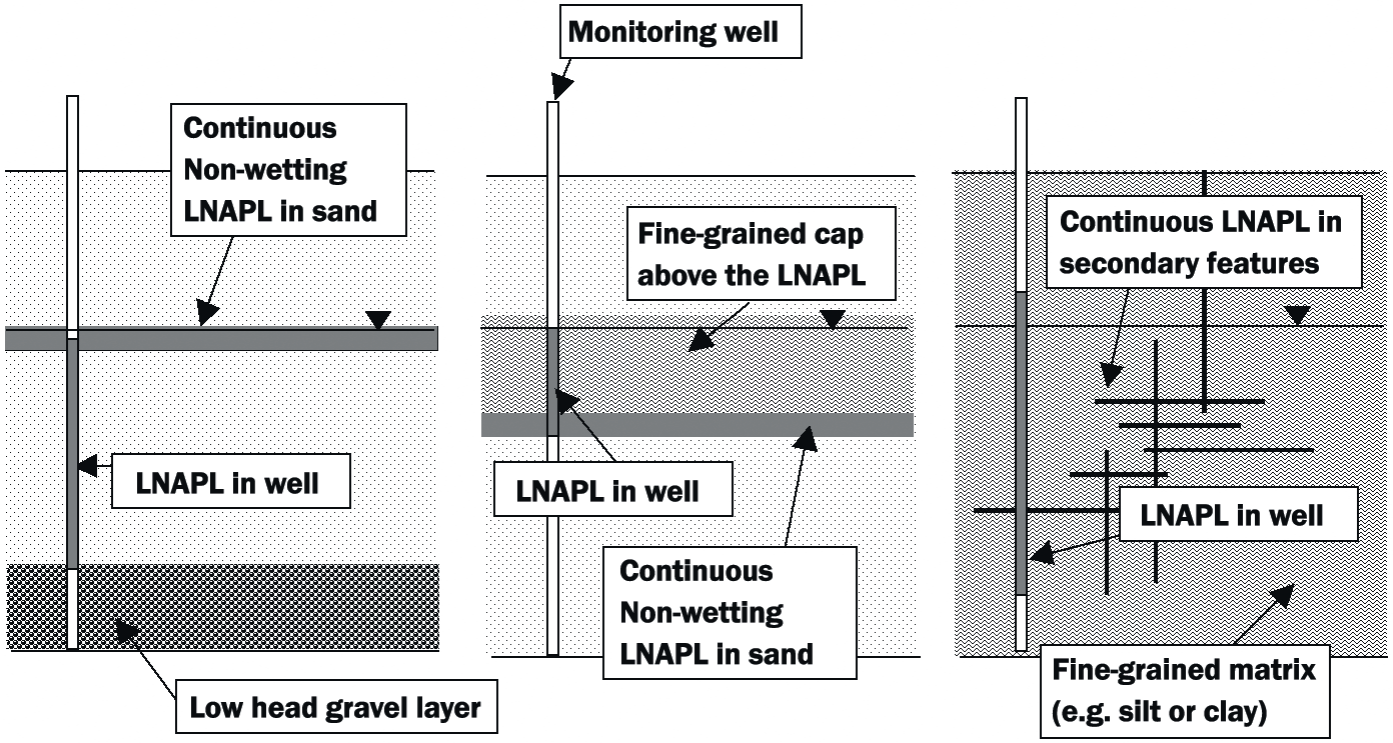


Other possible conditions effecting thickness of free-phase liquid layer thickness in wells

1) Underlying low head gravel draws LNAPL down the well

2) A fine grained layer above the LNAPL acts as a cap

3) LNAPL is limited to secondary joints and seams



Conclusions

- Oil pollution of groundwater aquifer is characterized by a two-phase liquid state, that is one of the most pressing environmental problems study of which requires special techniques and special measuring equipment.
- In contrast to normal flow in groundwater aquifer, two-phase saturation conditions are completely different and requires specific studies to be found out.
- Two-phase flow patterns are intensively scientifically researched all around the world and therefore this determines importance and topicality of the study.

Thank you for attention !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