Groundwater Mounding Analysis for Onsite Wastewater Discharge: From Simple to Innovative

J. Graham Bradley[1], Glenn M. Duffield[2], and Vitaly A. Zlotnik[3]
grahame.bradley@vermont.gov

[1] Vermont DEC
[2] HydroSOLVE, Inc.
[3] University of Nebraska-Lincoln

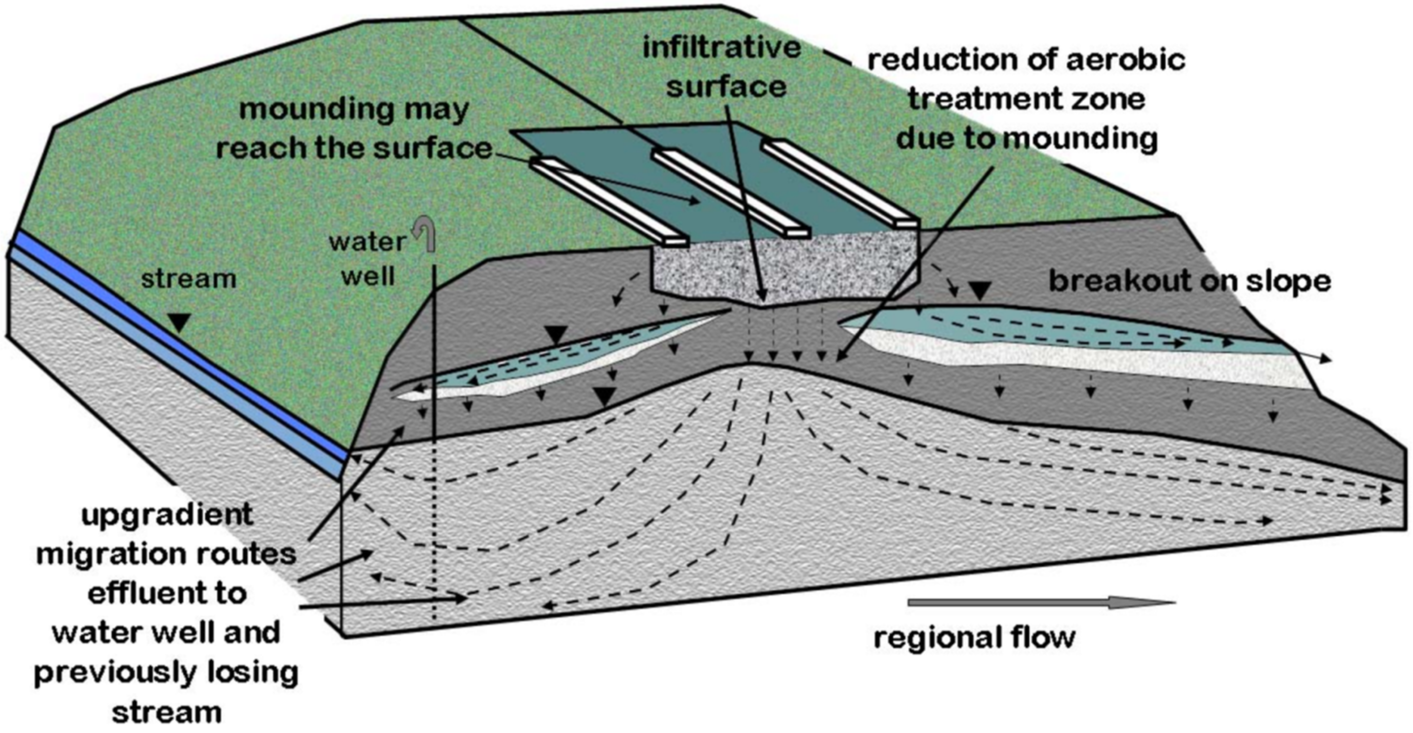
Today's Talk

1. **Why care about groundwater mounding?**
2. **Vermont:** Wastewater System & Potable Water Rules
3. **From Simple:**
   - a Darcy-based method for non-hydrogeologists
4. **… to Complex:**
   - numerical models
   - Khan et al. (1976)
   - Hantush (1967)
5. **… to Innovative:**
   - Zlotnik et al. (2017) and MOUNDSOLV software

What causes groundwater mounding?

Perched Mounding – where aquitard in unsaturated zone with low hydraulic conductivity cannot transmit water vertically faster than infiltration rate

Unconfined Aquifer Mounding – where hydraulic conductivity and thickness of unconfined aquifer cannot transmit water horizontally faster than infiltration rate

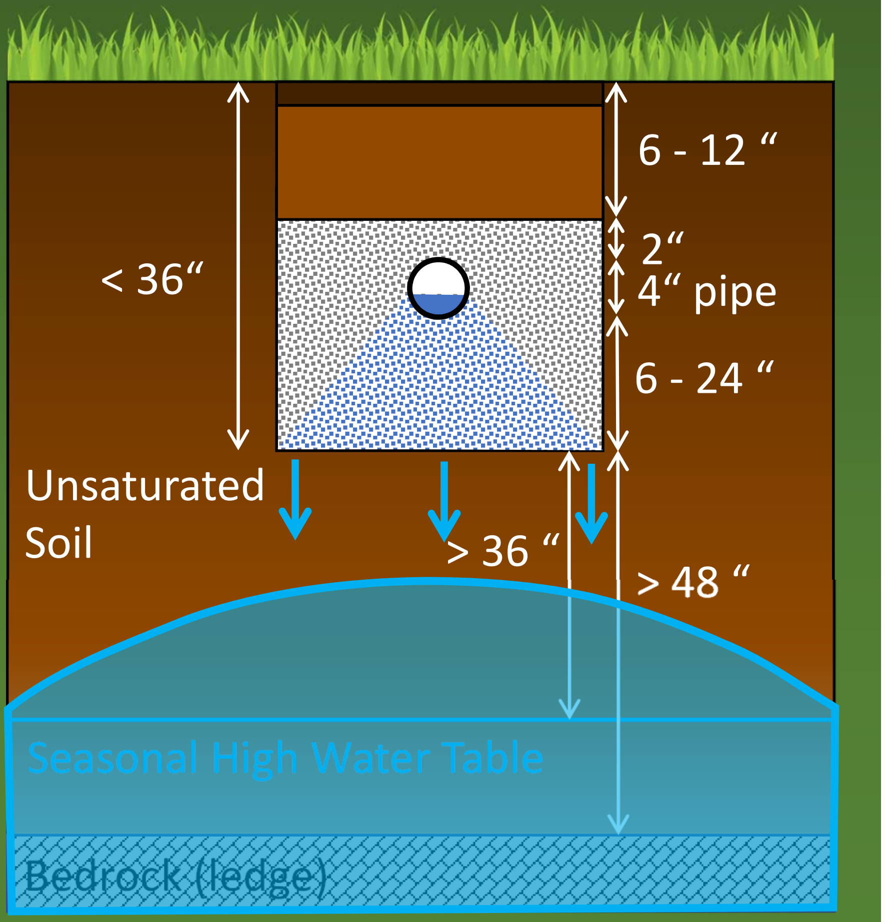


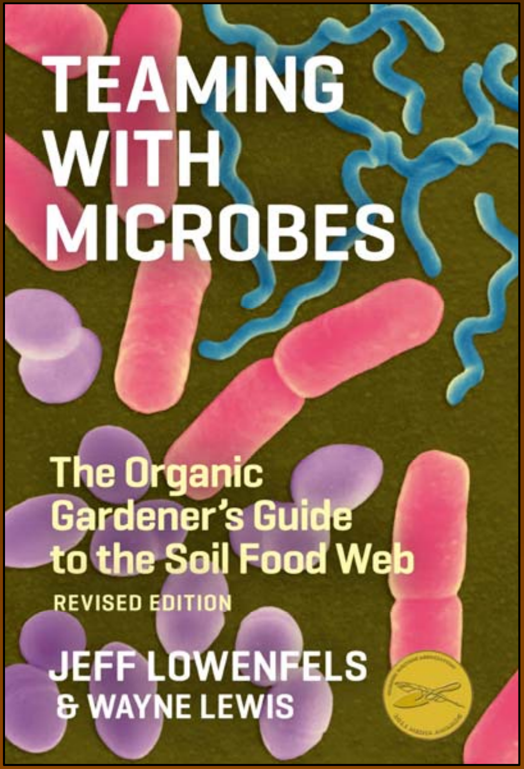
NDWRCDP (2005) Guidance for Evaluation of Potential Groundwater Mounding

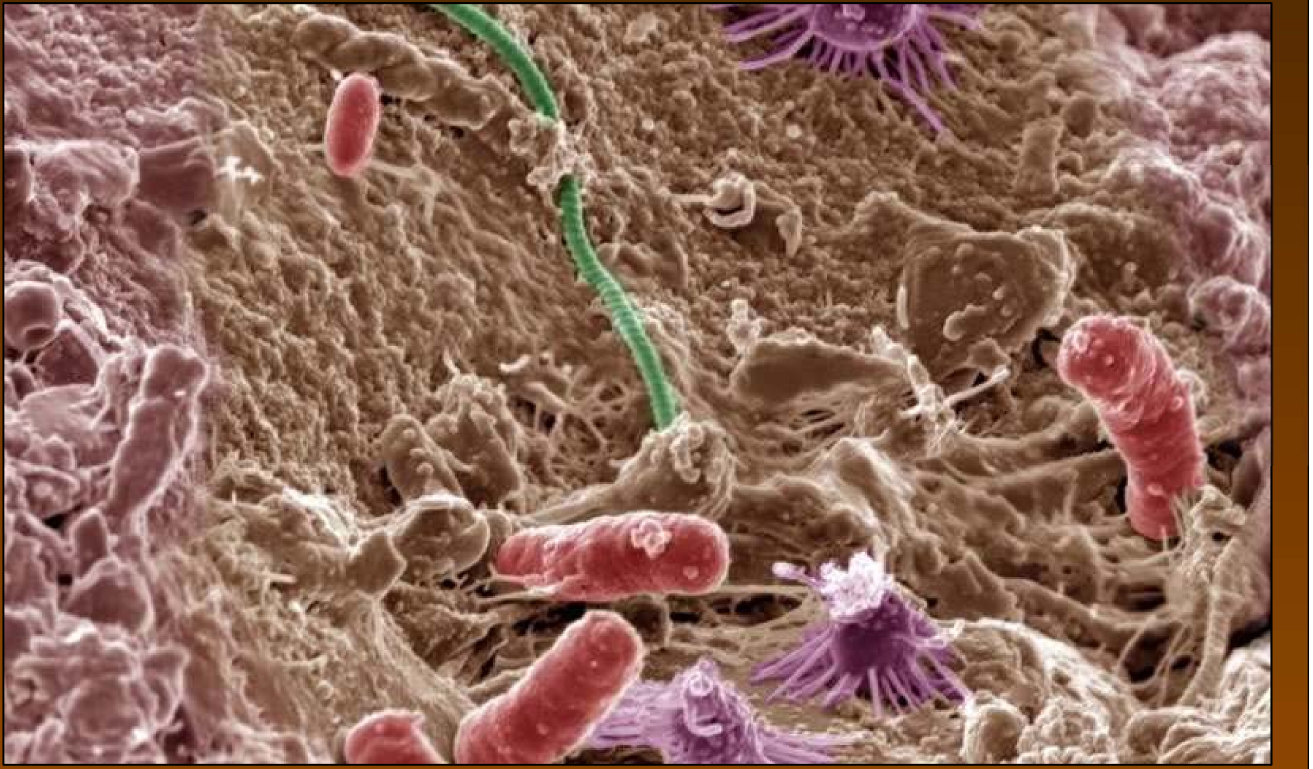
Why care about groundwater mounding?

1. **Potential effluent surfacing**
   (failed wastewater system)
2. **Reduction in thickness of aerobic treatment zone**
   (compromised WW system)
3. **Change in hydraulic gradient towards receptors**
   (failed water supply or compromised surface water)

Vermont In-Ground Trench







Designers, engineers
…and microbe farmers?

Vermont Wastewater System and Potable Water Supply Rules

A groundwater mounding analysis must be completed for:

- All bottomless sand filters
- Leachfields in-mound more than 1000 gpd
- Leachfield in-mound when Seasonal High Water Table less than 24” bgs
- Leachfields in-ground or at-grade more than 2000 gpd
- When groundwater mounding created by two leachfields will overlap

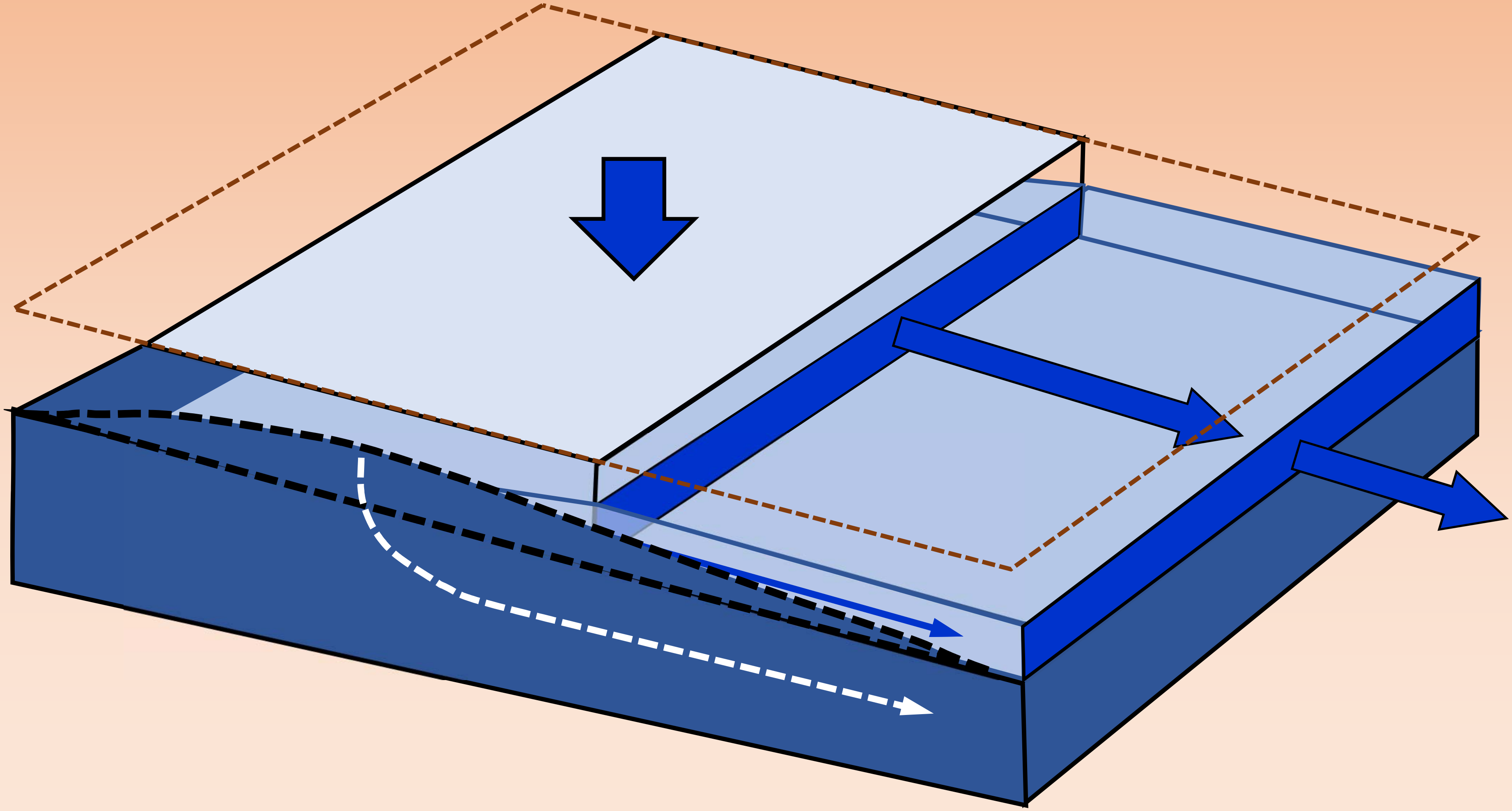
Minimum depth of natural soil to induced water-table shall be 6” beneath the mound*, or at least 6” beneath the limit of the fill**

All Licensed Designers can use the simplified method (Darcy-based) described in the Rules (given design and size restriction of license class)

Only ‘hydrogeologists’ can use other methods e.g. Khan et al. (1976), Hantush (1967), Zlotnik et al. (2017) etc.

*can be demonstrated using the Simplified Method
** cannot be demonstrated using the Simplified Method

From Simple: Darcy-based method for non-hydrogeologists



Monsieur Henry Philibert Gaspard Darcy

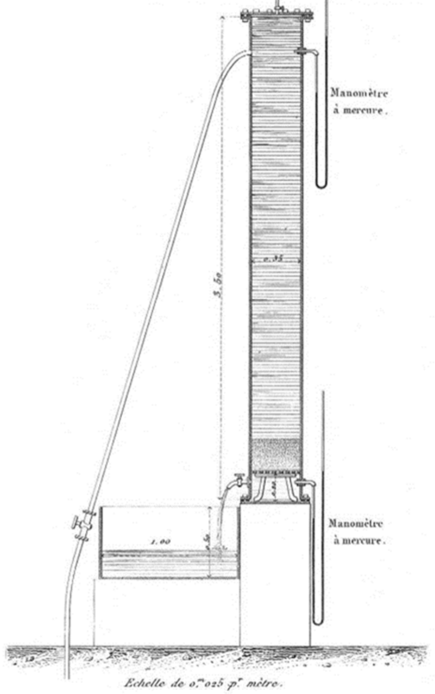


Fig. 3.
Appareil destiné à déterminer la loi
de l'écoulement de l'eau à travers le sable.

THE

PUBLIC FOUNTAINS

OF THE CITY OF DIJON

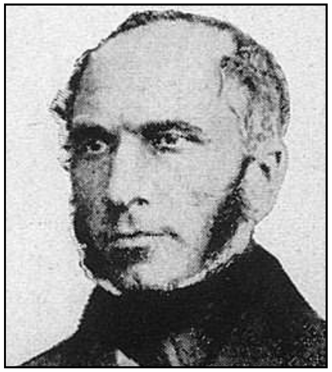
EXPERIENCE AND APPLICATION

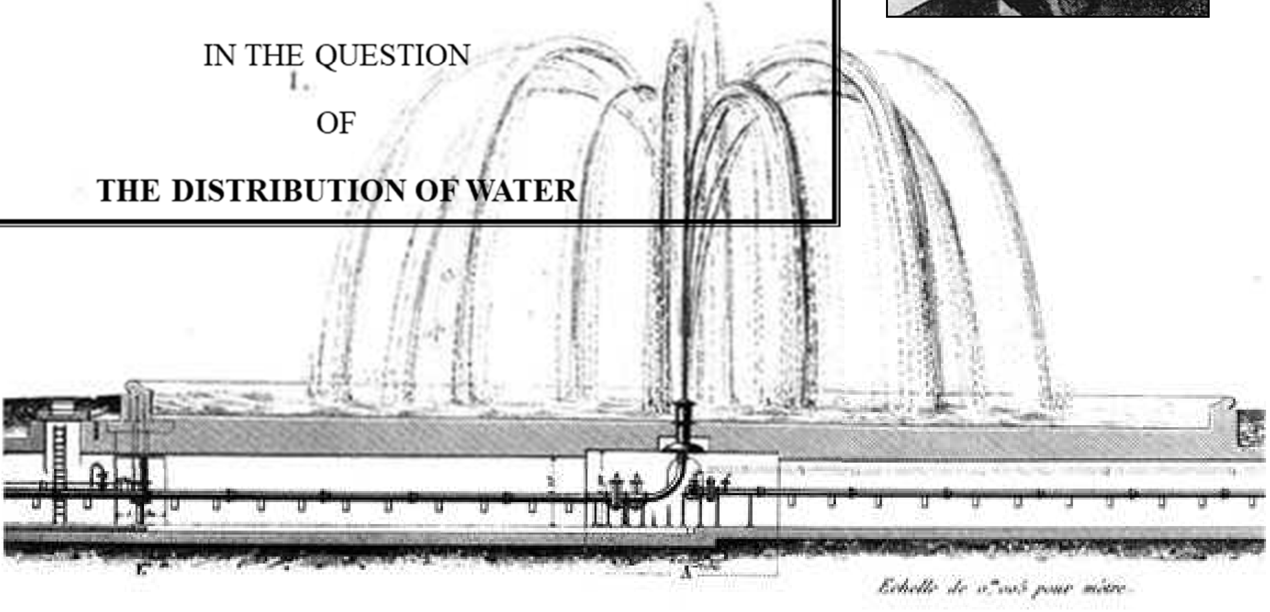
PRINCIPLES TO FOLLOW AND FORMULAS TO BE USED

IN THE QUESTION

OF

THE DISTRIBUTION OF WATER





1857

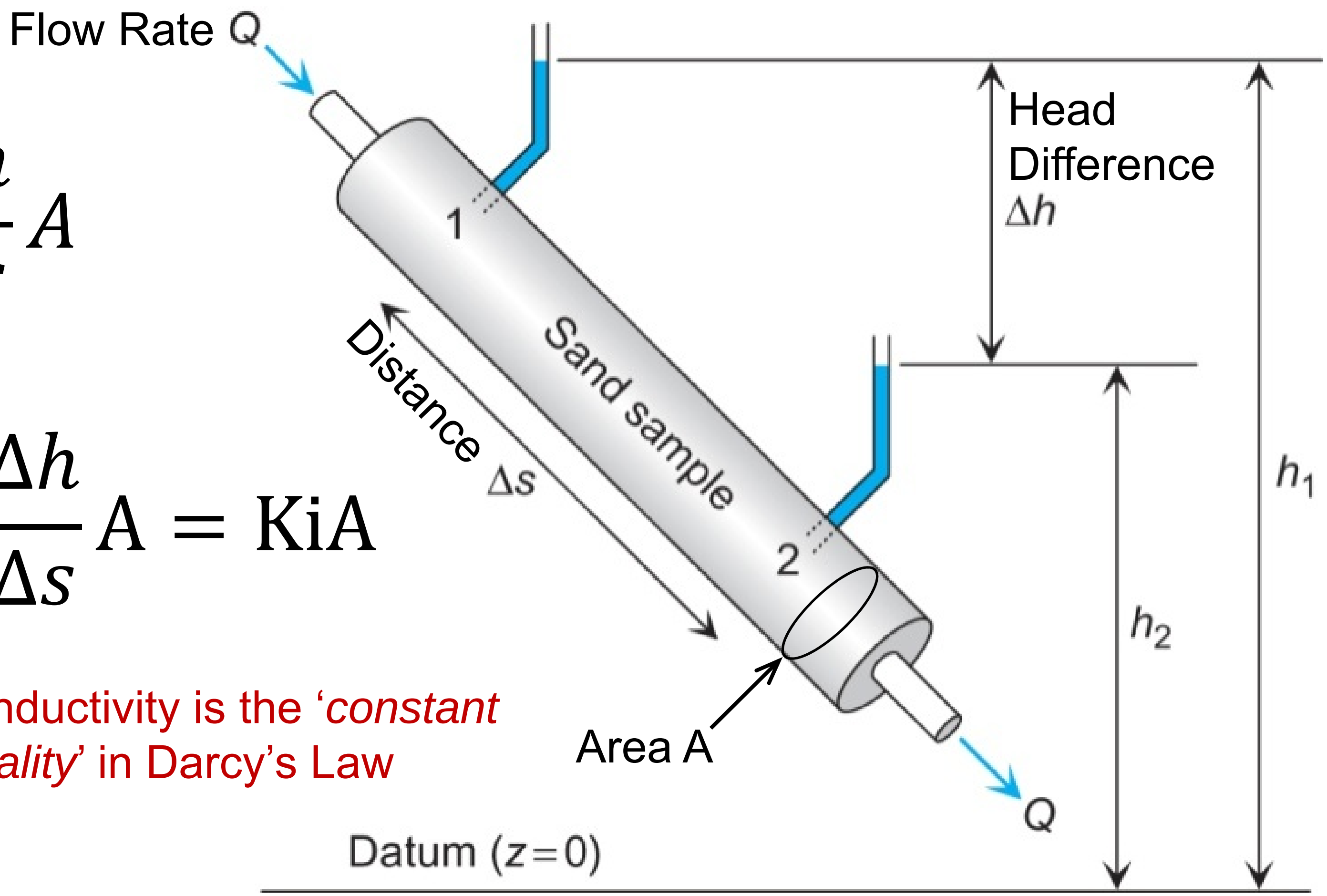
Darcy's Law and Hydraulic Conductivity

$$Q \propto \frac{\Delta h}{\Delta s} A$$

$$Q = \enclose{circle}{K} \frac{\Delta h}{\Delta s} \mathrm{A} = \mathrm{KiA}$$

↑

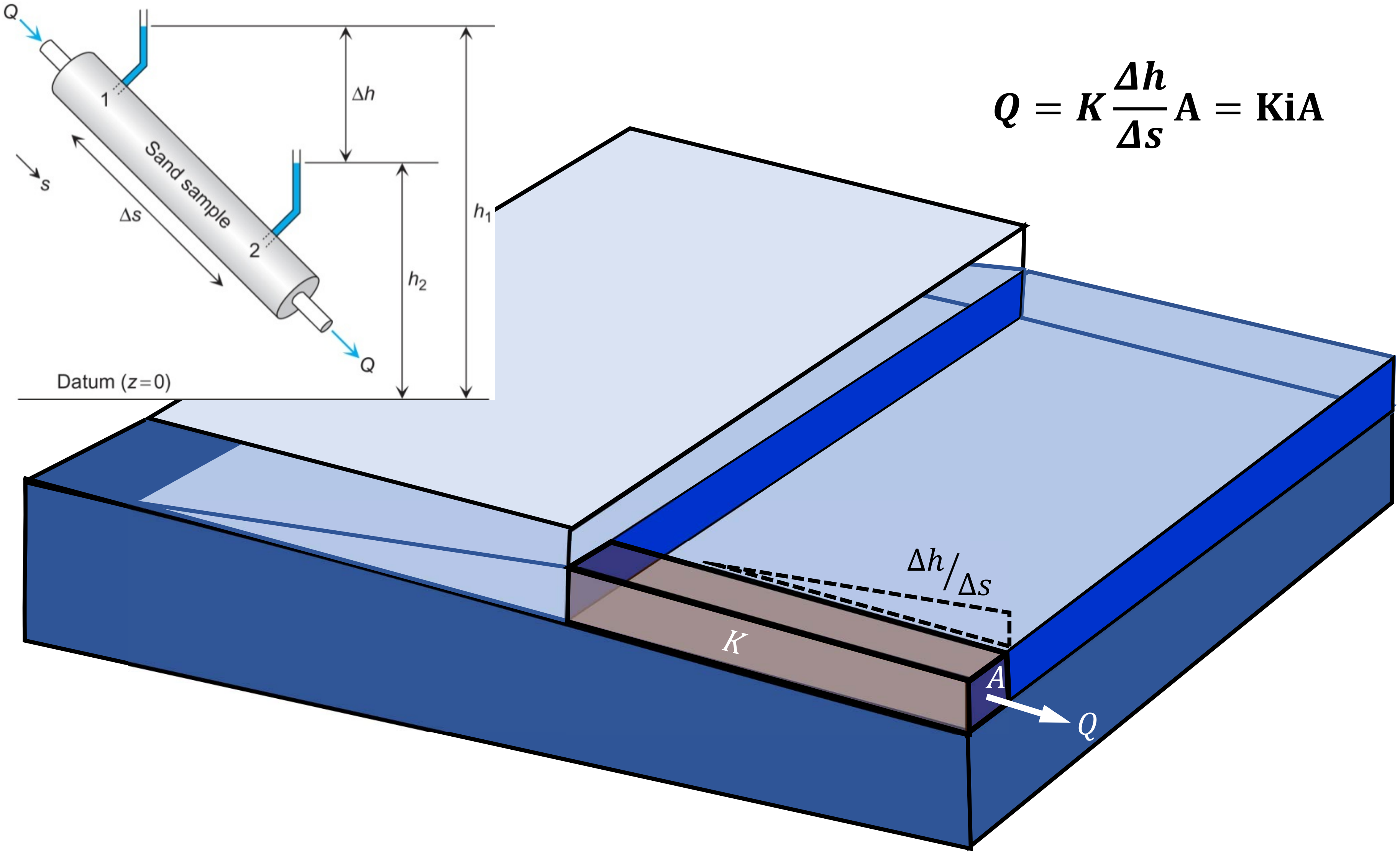
Hydraulic conductivity is the '*constant of proportionality*' in Darcy's Law



Darcy Applied

to Groundwater Mounding Analysis

$$Q = K\frac{\Delta h}{\Delta s}A = KiA$$



Vermont Simplified Method for Non-Hydrogeologists

Darcy's Law $Q = K.i.A$

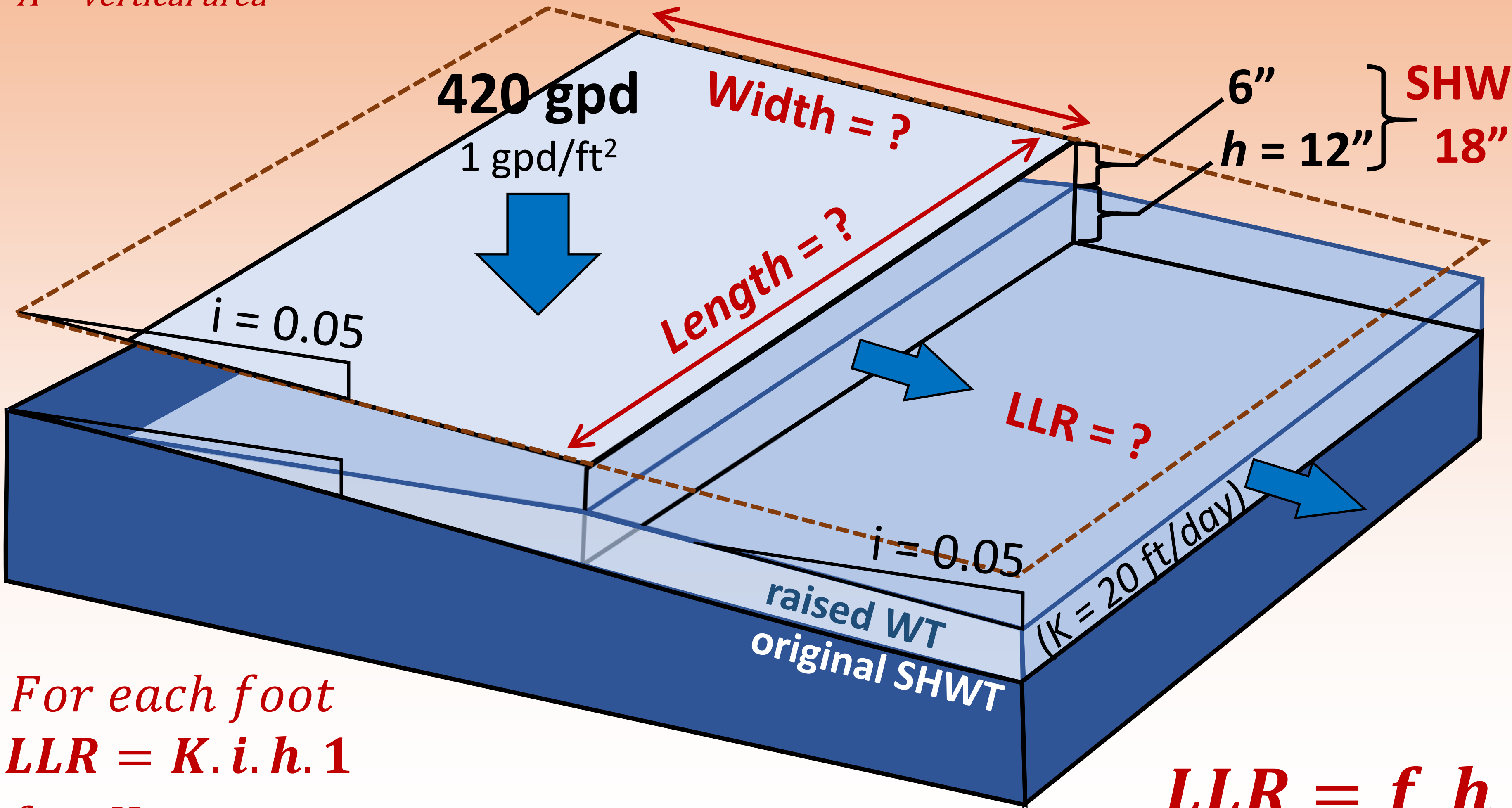
$Q = K.i.h.L$

$Q =$ *flow rate,*

$K =$ *hydraulic conductivity*

$i =$ *hydraulic gradient*

$A =$ *vertical area*

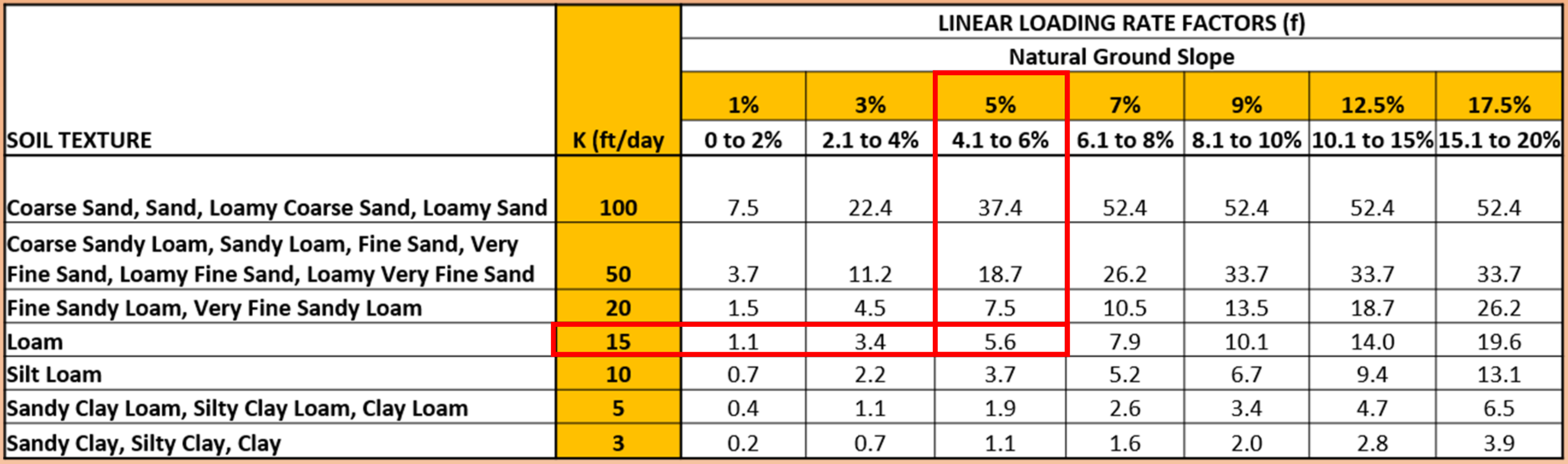


For each foot

$LLR = K.i.h.1$

$f = K.i.conversion$

$$LLR = f.h$$



SOIL TEXTURE	K (ft/day)	LINEAR LOADING RATE FACTORS (f)						
		Natural Ground Slope						
		1%	3%	5%	7%	9%	12.5%	17.5%
		0 to 2%	2.1 to 4%	4.1 to 6%	6.1 to 8%	8.1 to 10%	10.1 to 15%	15.1 to 20%
Coarse Sand, Sand, Loamy Coarse Sand, Loamy Sand	100	7.5	22.4	37.4	52.4	52.4	52.4	52.4
Coarse Sandy Loam, Sandy Loam, Fine Sand, Very Fine Sand, Loamy Fine Sand, Loamy Very Fine Sand	50	3.7	11.2	18.7	26.2	33.7	33.7	33.7
Fine Sandy Loam, Very Fine Sandy Loam	20	1.5	4.5	7.5	10.5	13.5	18.7	26.2
Loam	15	1.1	3.4	5.6	7.9	10.1	14.0	19.6
Silt Loam	10	0.7	2.2	3.7	5.2	6.7	9.4	13.1
Sandy Clay Loam, Silty Clay Loam, Clay Loam	5	0.4	1.1	1.9	2.6	3.4	4.7	6.5
Sandy Clay, Silty Clay, Clay	3	0.2	0.7	1.1	1.6	2.0	2.8	3.9

Example: Using the Simplified Method, calculate the length of a leachfield in a mound for: Design Flow of **420 gpd** (3 bedroom); ground slope **5%**; restrictive layer at **36”**; **loam** soil; with seasonal high water table at **18”.** Assume maximum mound Application Rate = **1 gpd/ft^2**

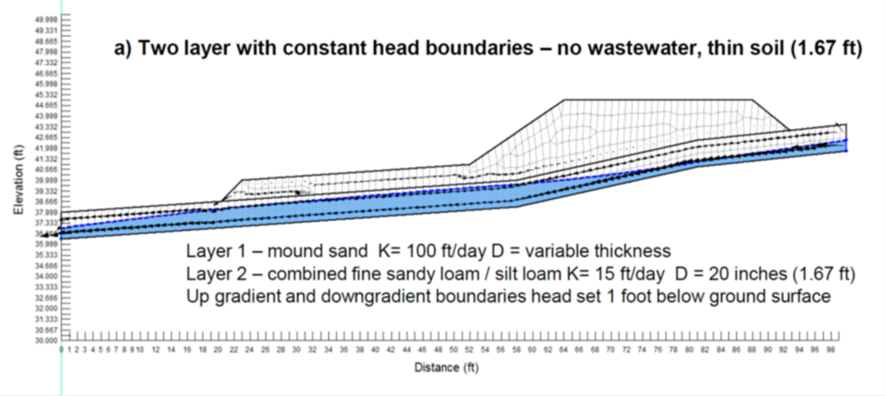
1.	Calculate thickness of available soil for water table rise	**h = 18 – 6 = 12” = 1.0 ft**
2.	Determine LLR factor (f) from table	**f = 5.6**
3.	Calculate **Linear Loading Rate** (from Darcy’s Law)	**LLR = h × f =1.0 × 5.6 = 5.6 gpd/ft**
4.	Calculate system length = Design Flow / LLR	**Length = 420 / 5.6 = 75 ft long**
5.	Calculate system width = Minimum Area / Length	**Width = 420 / 75 = 5.6 ft wide bed**
6.	For **septic effluent** vertical separation = 36”	**2.5 ft sand beneath leachfield**

…to Complex: Numerical Modeling

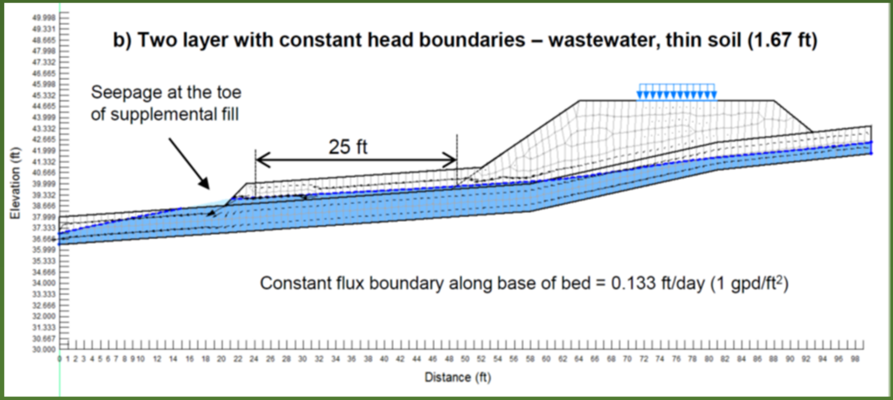
Numerical models divide the modeled region into small discrete elements interconnected at nodes.

Simultaneous differential equations are solved for each element by iteration until a potential and mass balance is achieved.

- **The geometry is very flexible**
- **Requires specialist software and skills**
- **Relatively time consuming**
- **Potentially expensive**
- **The model calibration is only as good as the quality of the input data**
- **Ideally, results should be corroborated against independent data set**

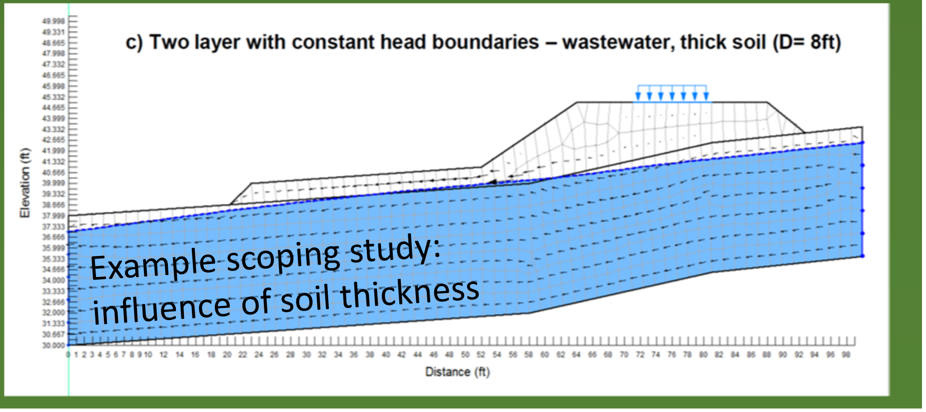

a) Two layer with constant head boundaries – no wastewater, thin soil (1.67 ft)

Layer 1 – mound sand K= 100 ft/day D = variable thickness
Layer 2 – combined fine sandy loam / silt loam K= 15 ft/day D = 20 inches (1.67 ft)
Up gradient and downgradient boundaries head set 1 foot below ground surface


b) Two layer with constant head boundaries – wastewater, thin soil (1.67 ft)

Seepage at the toe of supplemental fill

Constant flux boundary along base of bed = 0.133 ft/day (1 gpd/ft²)


c) Two layer with constant head boundaries – wastewater, thick soil (D= 8ft)

Example scoping study: influence of soil thickness

and… Analytical Modeling

e.g. Khan, Kirkham, & Handy (1976) Perched Mounding

recharge (R) × leachfield width (w) = vertical hydraulic conductivity (K_2) × mound width (L)

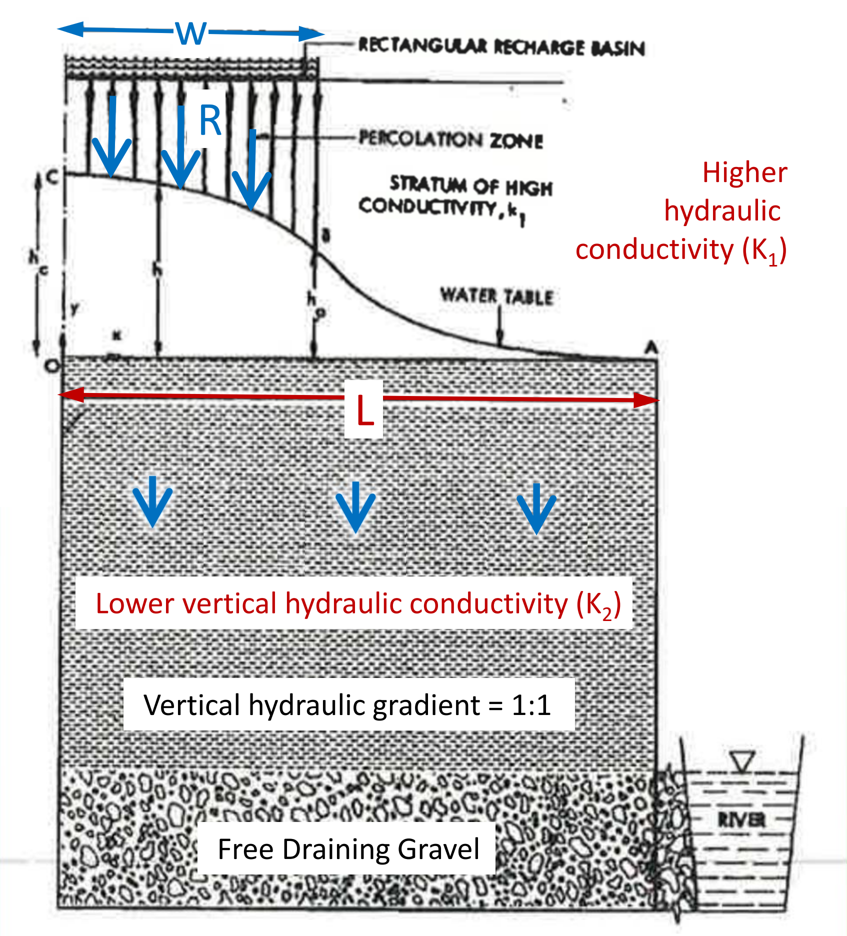
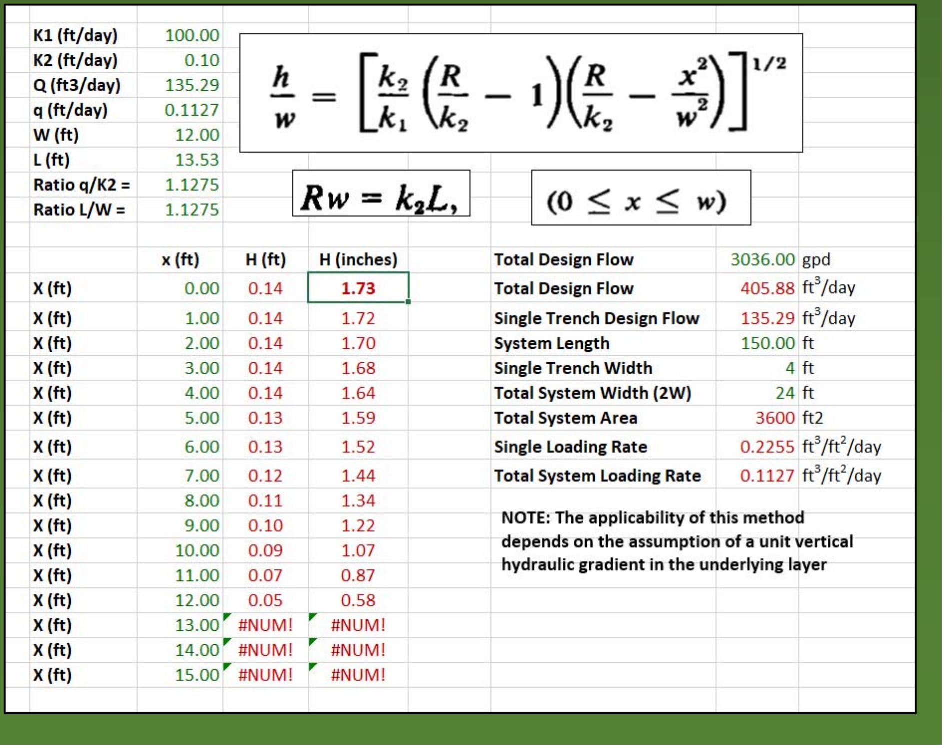


Fig. 1. Semisection of a two-dimensional groundwater mound formed by infiltration from a rectangular recharge basin.

Hydrogeological conceptual model is rarely applicable in Vermont

Requires underlying drainage layer,

and downward 1:1 hydraulic gradient



K1 (ft/day)	100.00
K2 (ft/day)	0.10
Q (ft3/day)	135.29
q (ft/day)	0.1127
W (ft)	12.00
L (ft)	13.53
Ratio q/K2 =	1.1275
Ratio L/W =	1.1275

$$\frac{h}{w} = \left[\frac{k_2}{k_1}\left(\frac{R}{k_2} - 1\right)\left(\frac{R}{k_2} - \frac{x^2}{w^2}\right)\right]^{1/2}$$

$$Rw = k_2 L,$$

$$(0 \leq x \leq w)$$

	x (ft)	H (ft)	H (inches)
X (ft)	0.00	0.14	1.73
X (ft)	1.00	0.14	1.72
X (ft)	2.00	0.14	1.70
X (ft)	3.00	0.14	1.68
X (ft)	4.00	0.14	1.64
X (ft)	5.00	0.13	1.59
X (ft)	6.00	0.13	1.52
X (ft)	7.00	0.12	1.44
X (ft)	8.00	0.11	1.34
X (ft)	9.00	0.10	1.22
X (ft)	10.00	0.09	1.07
X (ft)	11.00	0.07	0.87
X (ft)	12.00	0.05	0.58
X (ft)	13.00	#NUM!	#NUM!
X (ft)	14.00	#NUM!	#NUM!
X (ft)	15.00	#NUM!	#NUM!

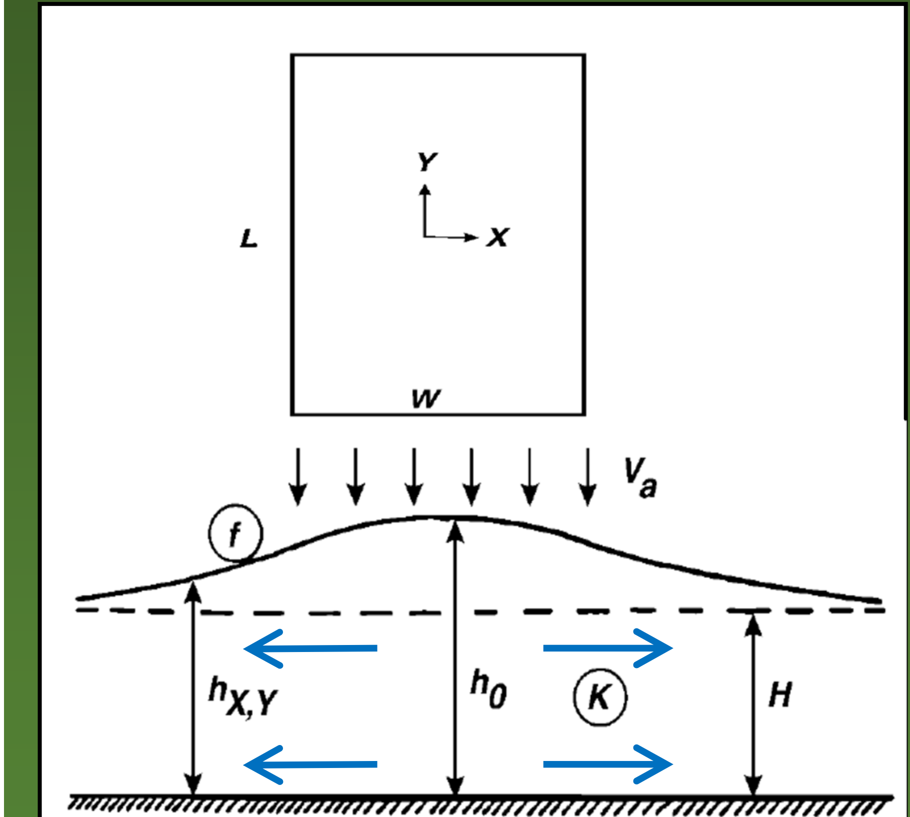
Total Design Flow	3036.00	gpd
Total Design Flow	405.88	ft^3/day
Single Trench Design Flow	135.29	ft^3/day
System Length	150.00	ft
Single Trench Width	4	ft
Total System Width (2W)	24	ft
Total System Area	3600	ft2
Single Loading Rate	0.2255	ft^3/ft^2/day
Total System Loading Rate	0.1127	ft^3/ft^2/day

NOTE: The applicability of this method depends on the assumption of a unit vertical hydraulic gradient in the underlying layer

e.g. Hantush (1967)

Unconfined Aquifer Mounding with a Horizontal Base

$$
\begin{aligned}
h_{x,y,t} - H = \frac{V_a t}{4f} \{ & F[W/2+x)n,(L/2+y)n] \\
& +F[W/2+x)n,(L/2-y)n] \\
& +F[W/2-x)n,(L/2+y)n] \\
& +F[W/2-x)n,(L/2-y)n]\}
\end{aligned}
$$



Hantush (1967) in Bouwer (2002)

$h_{x,y,t}$	*height of water-table above restrictive layer*
$\boxed{H}$	*original height of water-table (SHWT) above restrictive layer*
$\boxed{V_a}$	*recharge rate*
$\boxed{t}$	*time since start of recharge*
$\boxed{f}$	*fillable porosity (specific yield)*
$\boxed{L}$	*length of leachfield*
$\boxed{W}$	*width of leachfield*

$$n = (4.t.T/f)^{-1/2}$$

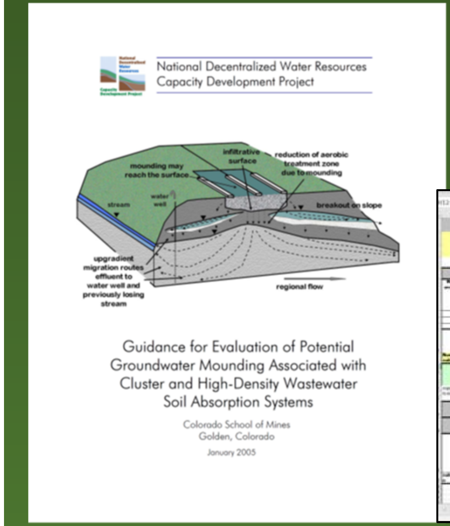
T	*transmissivity = K.H*
$\boxed{K}$	*horizontal hydraulic conductivity*

Scary mathematical function that describes curved water-table surface →

$$F(\alpha,\beta) = \int_0^1 erf\left(\alpha\tau^{-1/2}\right).erf\left(\beta\tau^{-1/2}\right) d\tau$$

Hantush (1967) Implementations

Free Spreadsheets

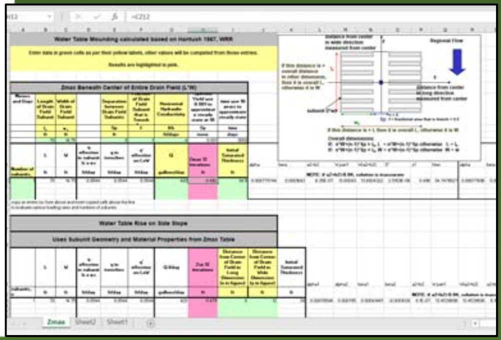

National Decentralized Water Resources Capacity Development Project

Guidance for Evaluation of Potential Groundwater Mounding Associated with Cluster and High-Density Wastewater Soil Absorption Systems

Colorado School of Mines
Golden, Colorado
January 2005

NDWRCDP (2005)

http://www.ndwrcdp.org/documents/wu-ht-02-45/wuht0245_electronic.pdf


Water Table Mounding calculated based on Hantush 1967, WRR

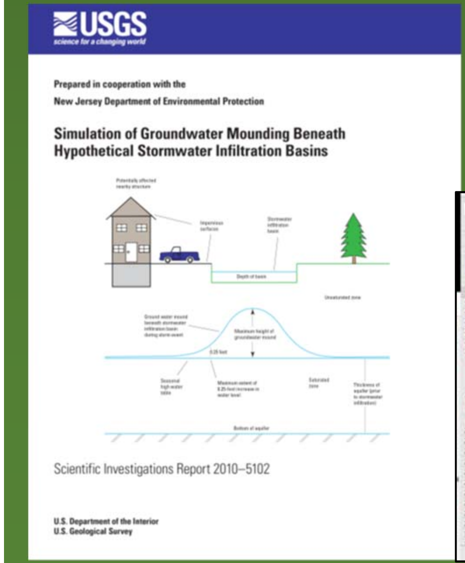
Enter data in green cells as per their yellow labels, other values will be computed from those entries.

Results are highlighted in pink.

Zmax Beneath Center of Entire Drain Field (L*W)

Water Table Rise on Side Slope

Uses Subunit Geometry and Material Properties from Zmax Table



Prepared in cooperation with the
New Jersey Department of Environmental Protection

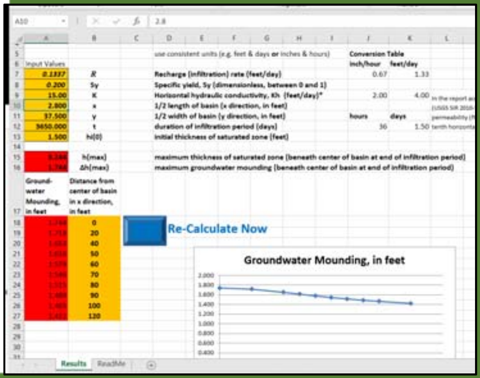
Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins

Scientific Investigations Report 2010–5102

U.S. Department of the Interior
U.S. Geological Survey

USGS (2010)

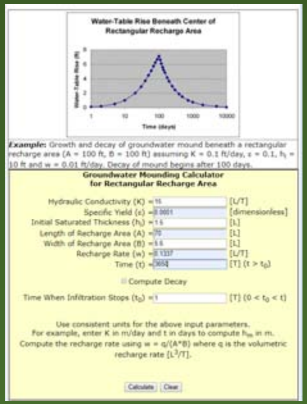
https://pubs.usgs.gov/sir/2010/5102/


use consistent units (e.g. feet & days or inches & hours)

Input Values			Conversion Table	
			inch/hour	feet/day
0.1337	R	Recharge (infiltration) rate (feet/day)	0.67	1.33
0.200	Sy	Specific yield, Sy (dimensionless, between 0 and 1)		
15.00	K	Horizontal hydraulic conductivity, Kh (feet/day)*	2.00	4.00
2.800	x	1/2 length of basin (x direction, in feet)		
37.500	y	1/2 width of basin (y direction, in feet)	hours	days
3650.000	t	duration of infiltration period (days)	36	1.50
1.500	hi(0)	initial thickness of saturated zone (feet)		
[illegible]	h(max)	maximum thickness of saturated zone (beneath center of basin at end of infiltration period)		
[illegible]	Δh(max)	maximum groundwater mounding (beneath center of basin at end of infiltration period)		

Ground-water Mounding, in feet	Distance from center of basin in x direction, in feet
[illegible]	0
[illegible]	20
[illegible]	40
[illegible]	50
[illegible]	60
[illegible]	70
[illegible]	80
[illegible]	90
[illegible]	100
[illegible]	120

Max. Mound Online Calculators



Example: Growth and decay of groundwater mound beneath a rectangular recharge area (A = 100 ft, B = 100 ft) assuming K = 0.1 ft/day, ε = 0.1, h_i = 10 ft and w = 0.01 ft/day. Decay of mound begins after 100 days.

Groundwater Mounding Calculator for Rectangular Recharge Area

Hydraulic Conductivity (K) = 15 [L/T]
Specific Yield (ε) = 0.0001 [dimensionless]
Initial Saturated Thickness (h_i) = 1.5 [L]
Length of Recharge Area (A) = 75 [L]
Width of Recharge Area (B) = 5.6 [L]
Recharge Rate (w) = 0.1337 [L/T]
Time (t) = 3650 [T] (t > t_0)

☐ Compute Decay

Time When Infiltration Stops (t_0) = 1 [T] (0 < t_0 < t)

Use consistent units for the above input parameters.
For example, enter K in m/day and t in days to compute h_m in m.
Compute the recharge rate using w = q/(A*B) where q is the volumetric recharge rate [L^3/T].

Calculator 9 - Groundwater Mounding Calculator

GROUNDWATER MOUND UNDER A RECTANGULAR RECHARGE AREA

Using the Hantush (1967) Derivation

Back to Calculators

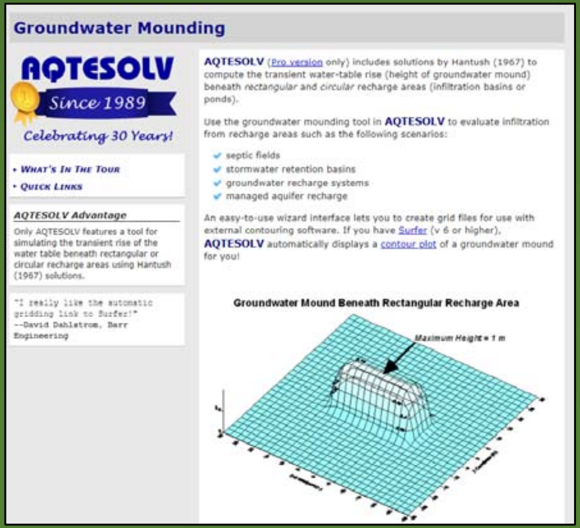
You can also perform mounding calculations with graphical display using:

GROUNDWATER MOUND UNDER A RECTANGULAR

http://www.aqtesolv.com/forum/rmound.asp

http://www.groundwatersoftware.com/calculator_9_hantush_mounding.htm

Commercial Software Example


Groundwater Mounding

AQTESOLV Advantage

Only AQTESOLV features a tool for simulating the transient rise of the water table beneath rectangular or circular recharge areas using Hantush (1967) solutions.

"I really like the automatic gridding link to Surfer!"
--David Dahlstrom, Barr Engineering

AQTESOLV (Pro version only) includes solutions by Hantush (1967) to compute the transient water-table rise (height of groundwater mound) beneath *rectangular* and *circular* recharge areas (infiltration basins or ponds).

Use the groundwater mounding tool in **AQTESOLV** to evaluate infiltration from recharge areas such as the following scenarios:

- ✓ septic fields
- ✓ stormwater retention basins
- ✓ groundwater recharge systems
- ✓ managed aquifer recharge

An easy-to-use wizard interface lets you to create grid files for use with external contouring software. If you have Surfer (v 6 or higher), **AQTESOLV** automatically displays a contour plot of a groundwater mound for you!

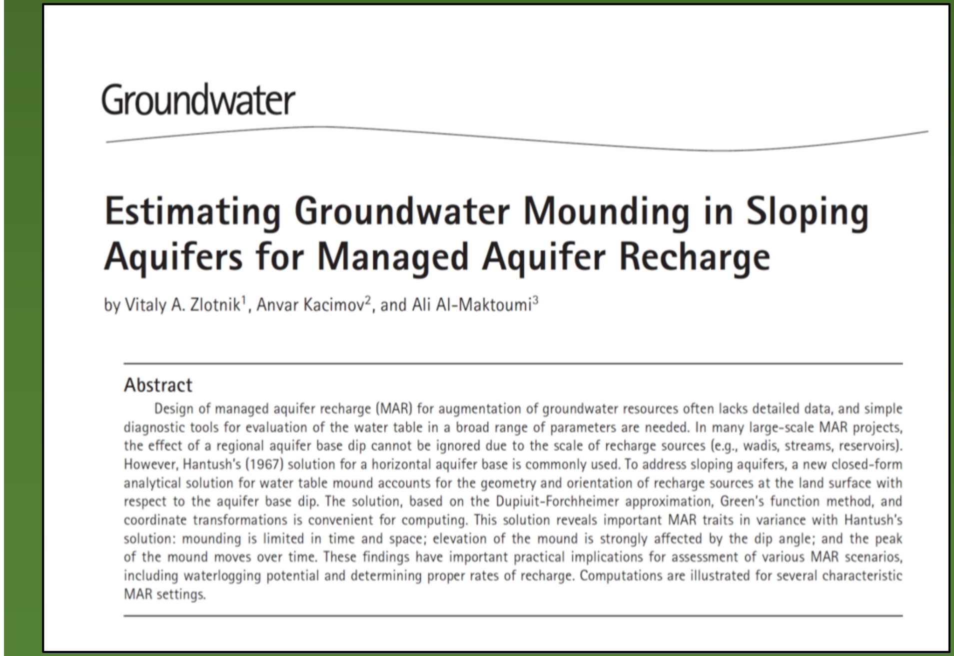
Groundwater Mound Beneath Rectangular Recharge Area

http://www.aqtesolv.com/mounding_analysis.htm

…to Innovative: New Method for Estimating Groundwater Mounding in a Sloping Aquifers

Theory

Vitaly Zlotnik et al. (2017)



Groundwater

Estimating Groundwater Mounding in Sloping Aquifers for Managed Aquifer Recharge

by Vitaly A. Zlotnik[1], Anvar Kacimov[2], and Ali Al-Maktoumi[3]

Abstract

Design of managed aquifer recharge (MAR) for augmentation of groundwater resources often lacks detailed data, and simple diagnostic tools for evaluation of the water table in a broad range of parameters are needed. In many large-scale MAR projects, the effect of a regional aquifer base dip cannot be ignored due to the scale of recharge sources (e.g., wadis, streams, reservoirs). However, Hantush's (1967) solution for a horizontal aquifer base is commonly used. To address sloping aquifers, a new closed-form analytical solution for water table mound accounts for the geometry and orientation of recharge sources at the land surface with respect to the aquifer base dip. The solution, based on the Dupuit-Forchheimer approximation, Green's function method, and coordinate transformations is convenient for computing. This solution reveals important MAR traits in variance with Hantush's solution: mounding is limited in time and space; elevation of the mound is strongly affected by the dip angle; and the peak of the mound moves over time. These findings have important practical implications for assessment of various MAR scenarios, including waterlogging potential and determining proper rates of recharge. Computations are illustrated for several characteristic MAR settings.

Implementation

Glenn Duffield (2019)

MOUNDSOLV Wizard by HydroSOLVE, Inc.

MOUNDSOLV Wizard v0.92

Groundwater Mounding Analysis
For A Sloping Water-Table Aquifer

Developed by Glenn M. Duffield
HydroSOLVE, Inc.
www.aqtesolv.com

Quick Start Tutorial

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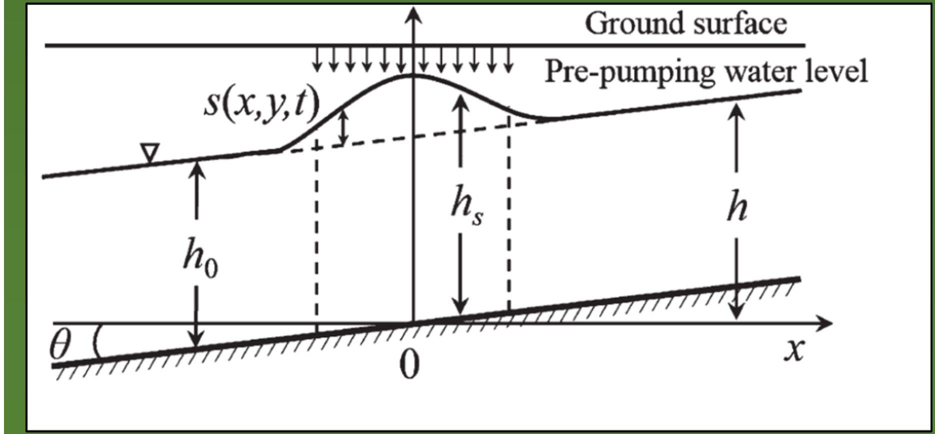
Estimating Groundwater Mounding in Sloping Aquifers

Vitaly Zlotnik, Anvar Kacimov, and Ali Al-Maktoumi (2017)

Steady-state solution

$$s_\infty(x^*, y^*) = \frac{Q}{8\pi lwT\alpha^2} \int_{\alpha(y^*-l)}^{\alpha(y^*+l)} \times e^{\alpha v \sin\phi} \left[\int_{\alpha(x^*-l)}^{\alpha(x^*+l)} e^{-\alpha u \cos\phi} \cdot K_0\left(\sqrt{u^2+v^2}\right) \mathrm{d}u \right] \mathrm{d}v,$$

$$\alpha = \frac{\tan\theta}{2h_0} \qquad (15)$$



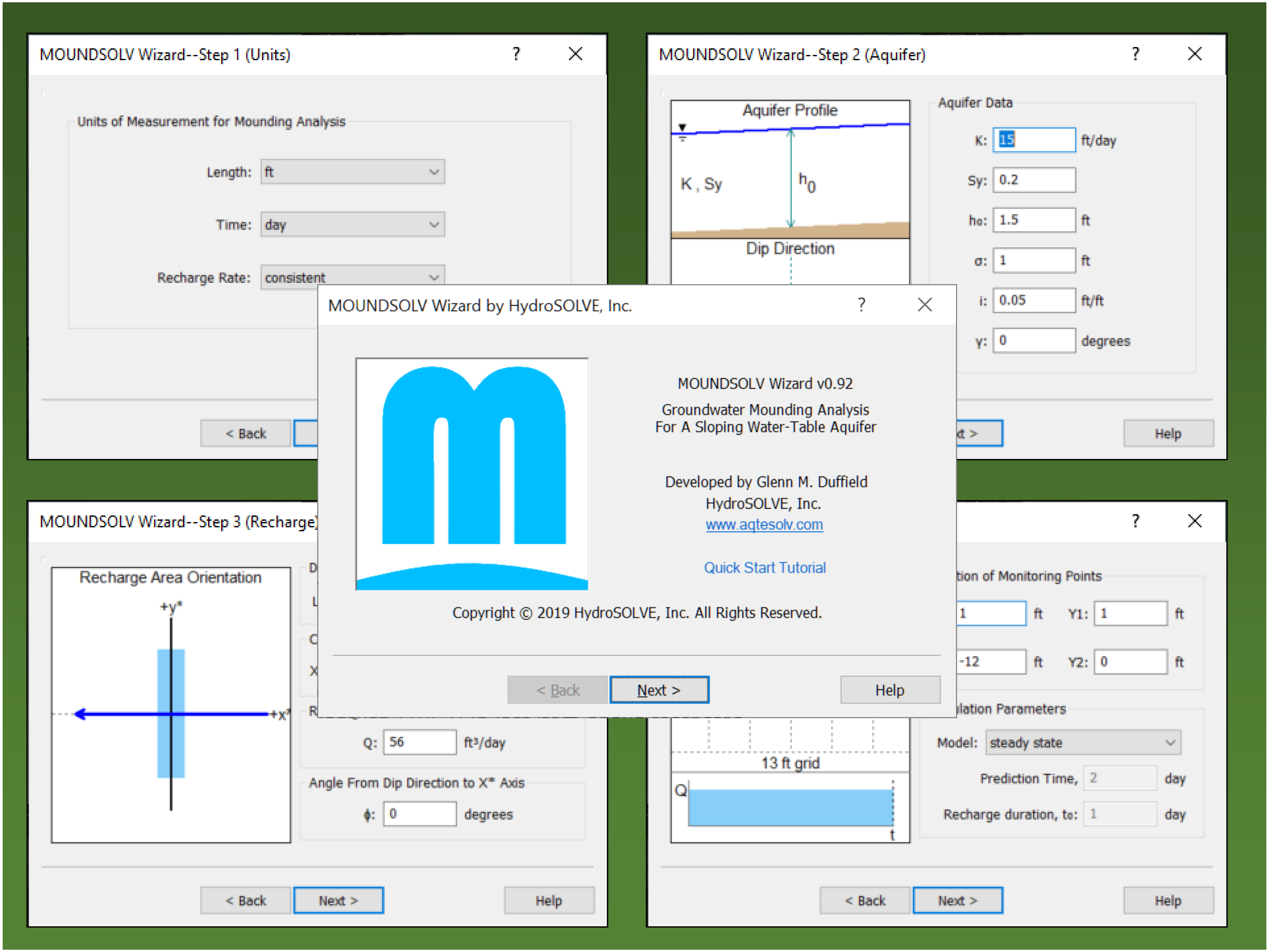
Output Parameter:

$s_{\infty x^*,y^*}$	*height of induced water-table above original water-table*

Input Parameters:

Q	*design flow into leachfield*
T	*transmissivity = $K.h_0$*
H_0	*original height of water-table (SHWT) above restrictive layer*
K	*horizontal hydraulic conductivity*
θ	*maximum slope angle*
l	*½-length of leachfield*
w	*½-width of leachfield*
ϕ	*angle with respect to x axis*

No time or specific yield required for steady-state



MOUNDSOLV Wizard--Step 1 (Units)

Units of Measurement for Mounding Analysis

Length: ft

Time: day

Recharge Rate: consistent

MOUNDSOLV Wizard--Step 2 (Aquifer)

Aquifer Data

K: 15 ft/day

Sy: 0.2

h_0: 1.5 ft

σ: 1 ft

i: 0.05 ft/ft

γ: 0 degrees

MOUNDSOLV Wizard by HydroSOLVE, Inc.

MOUNDSOLV Wizard v0.92

Groundwater Mounding Analysis
For A Sloping Water-Table Aquifer

Developed by Glenn M. Duffield
HydroSOLVE, Inc.
www.aqtesolv.com

Quick Start Tutorial

MOUNDSOLV Wizard--Step 3 (Recharge)

Q: 56 ft³/day

Angle From Dip Direction to X* Axis

ϕ: 0 degrees

tion of Monitoring Points

1 ft Y1: 1 ft

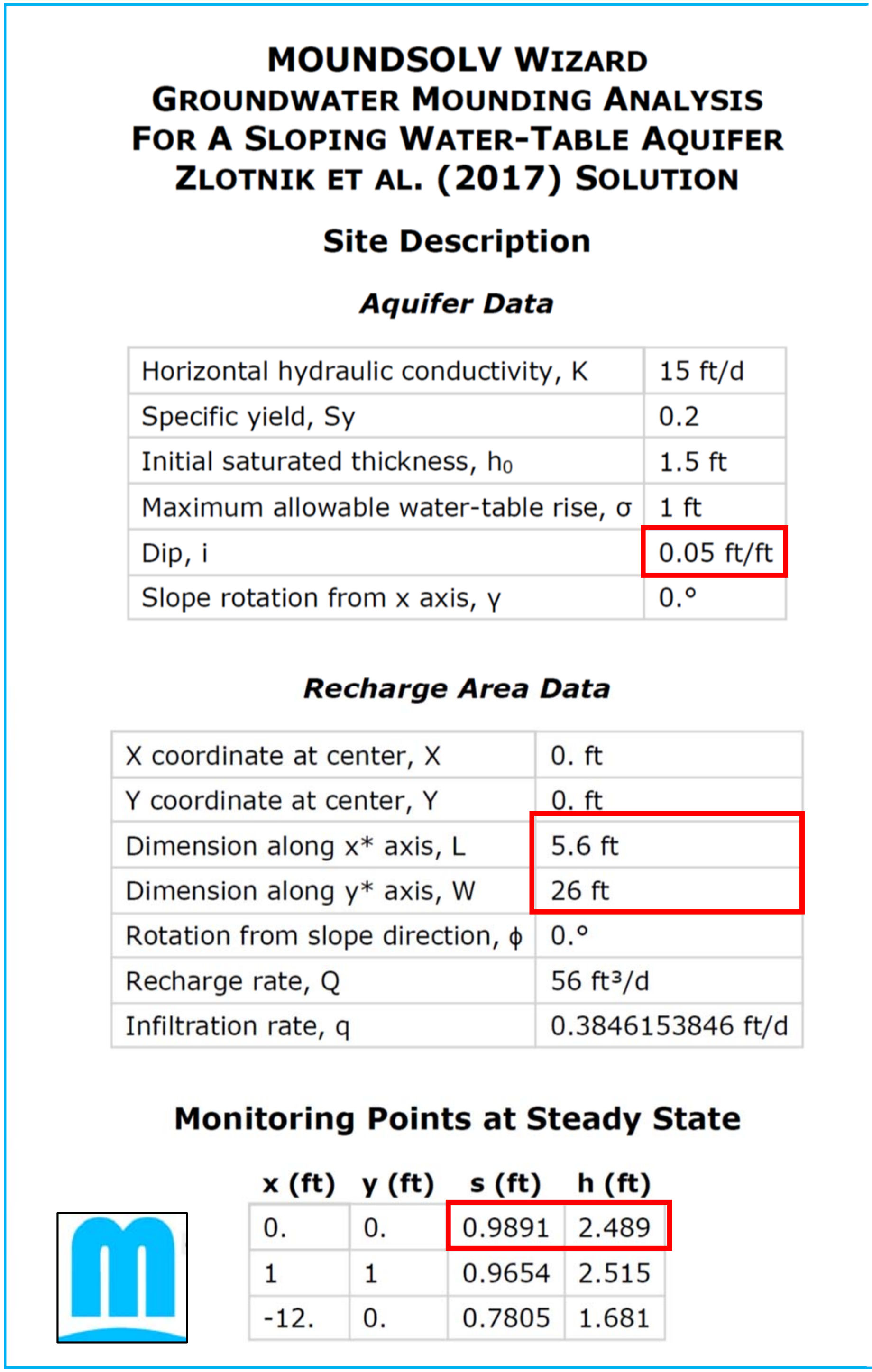
-12 ft Y2: 0 ft

lation Parameters

Model: steady state

Prediction Time, 2 day

Recharge duration, t_0: 1 day



MOUNDSOLV WIZARD GROUNDWATER MOUNDING ANALYSIS FOR A SLOPING WATER-TABLE AQUIFER ZLOTNIK ET AL. (2017) SOLUTION

Site Description

Aquifer Data

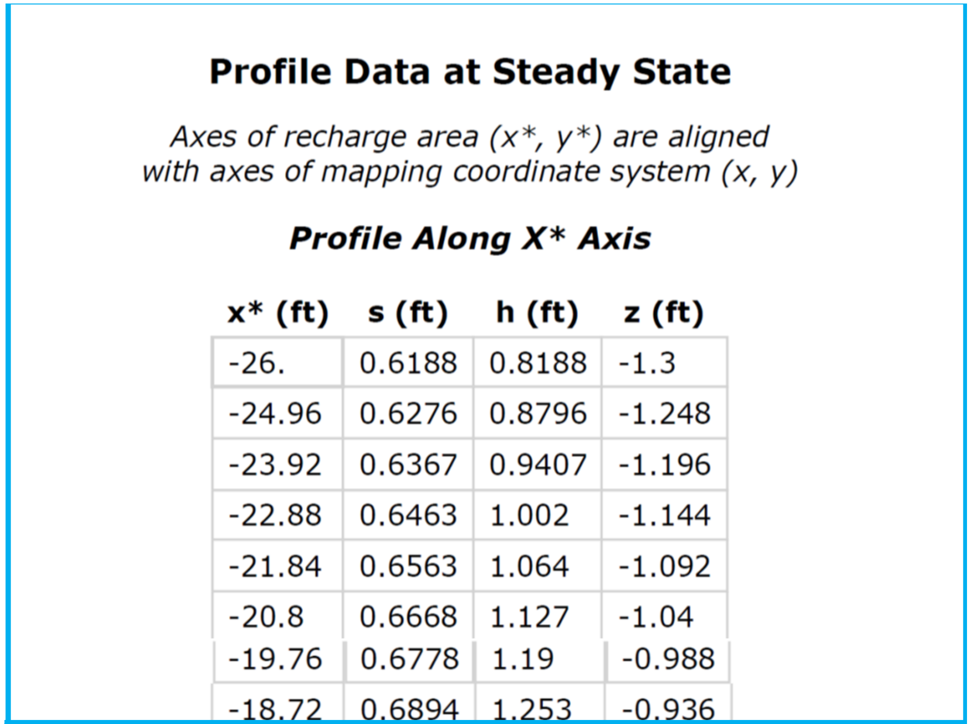
Horizontal hydraulic conductivity, K	15 ft/d
Specific yield, Sy	0.2
Initial saturated thickness, h_0	1.5 ft
Maximum allowable water-table rise, σ	1 ft
Dip, i	0.05 ft/ft
Slope rotation from x axis, γ	0.°

Recharge Area Data

X coordinate at center, X	0. ft
Y coordinate at center, Y	0. ft
Dimension along x* axis, L	5.6 ft
Dimension along y* axis, W	26 ft
Rotation from slope direction, ϕ	0.°
Recharge rate, Q	56 ft³/d
Infiltration rate, q	0.3846153846 ft/d

Monitoring Points at Steady State

x (ft)	y (ft)	s (ft)	h (ft)
0.	0.	0.9891	2.489
1	1	0.9654	2.515
-12.	0.	0.7805	1.681

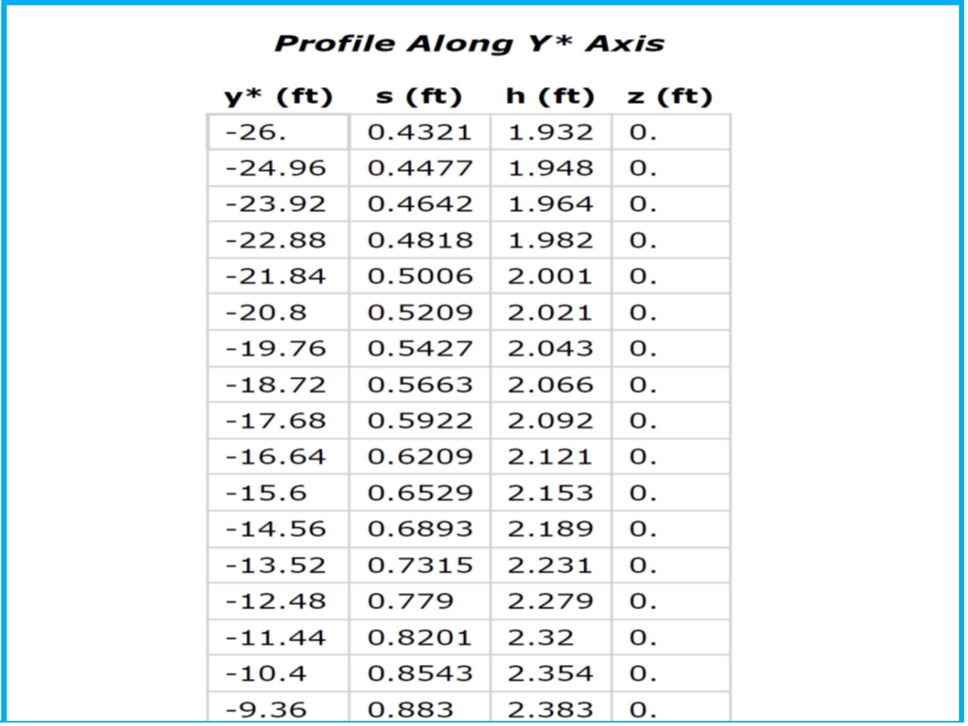


Profile Data at Steady State

Axes of recharge area (x, y*) are aligned with axes of mapping coordinate system (x, y)*

Profile Along X Axis*

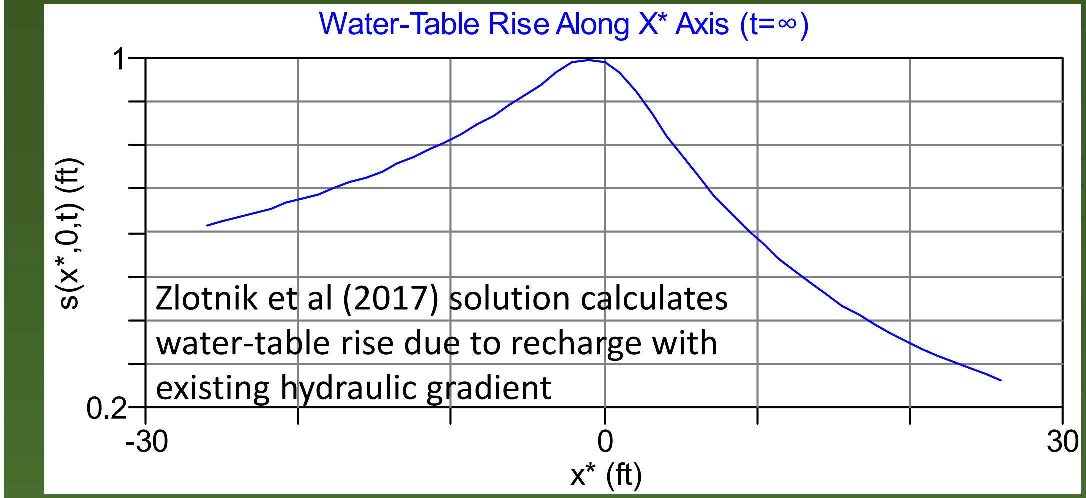
x* (ft)	s (ft)	h (ft)	z (ft)
-26.	0.6188	0.8188	-1.3
-24.96	0.6276	0.8796	-1.248
-23.92	0.6367	0.9407	-1.196
-22.88	0.6463	1.002	-1.144
-21.84	0.6563	1.064	-1.092
-20.8	0.6668	1.127	-1.04
-19.76	0.6778	1.19	-0.988
-18.72	0.6894	1.253	-0.936



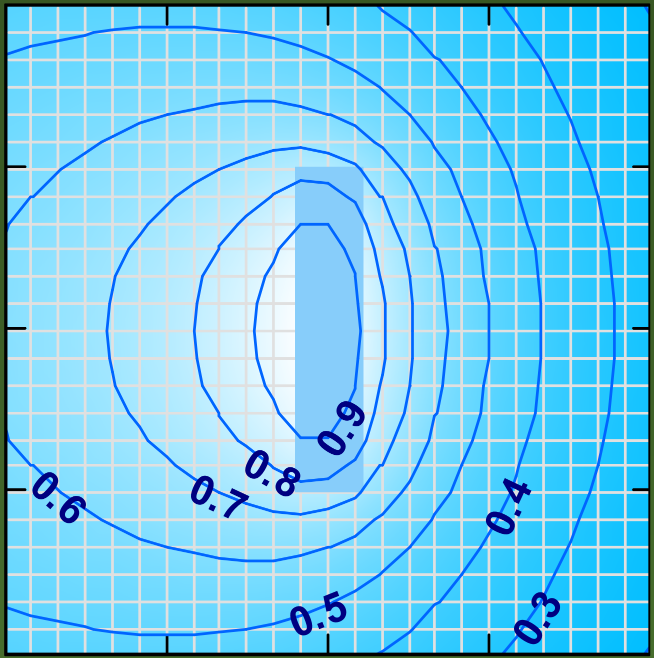
Profile Along Y Axis*

y* (ft)	s (ft)	h (ft)	z (ft)
-26.	0.4321	1.932	0.
-24.96	0.4477	1.948	0.
-23.92	0.4642	1.964	0.
-22.88	0.4818	1.982	0.
-21.84	0.5006	2.001	0.
-20.8	0.5209	2.021	0.
-19.76	0.5427	2.043	0.
-18.72	0.5663	2.066	0.
-17.68	0.5922	2.092	0.
-16.64	0.6209	2.121	0.
-15.6	0.6529	2.153	0.
-14.56	0.6893	2.189	0.
-13.52	0.7315	2.231	0.
-12.48	0.779	2.279	0.
-11.44	0.8201	2.32	0.
-10.4	0.8543	2.354	0.
-9.36	0.883	2.383	0.

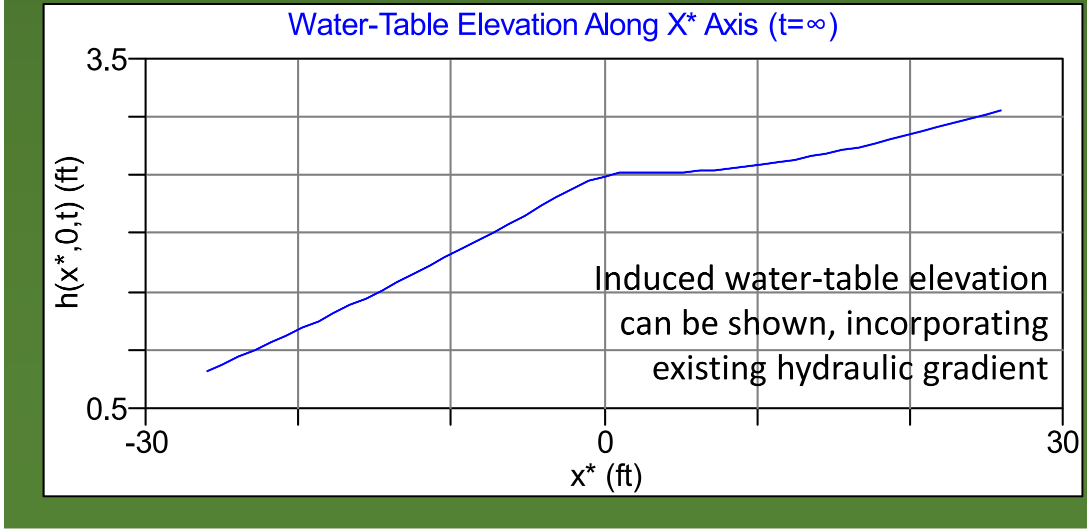
Induced rise above original water-table


Water-Table Rise Along X* Axis (t=∞)

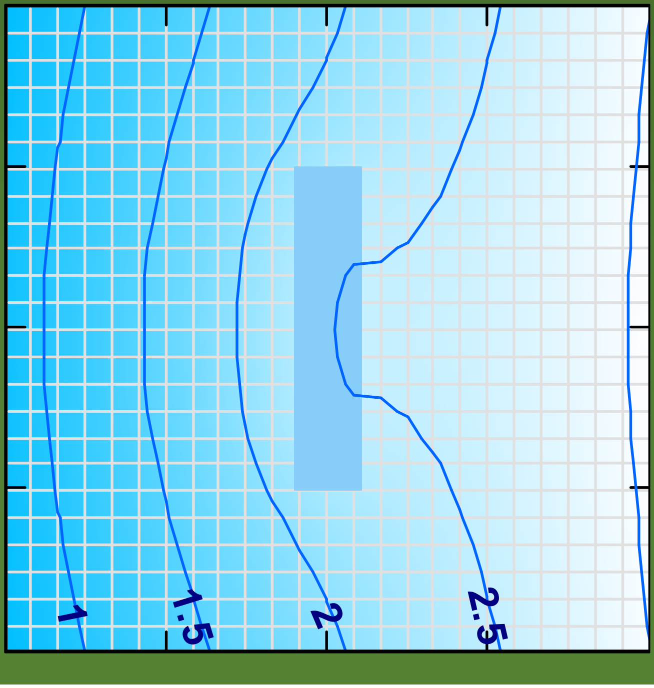
Zlotnik et al (2017) solution calculates water-table rise due to recharge with existing hydraulic gradient



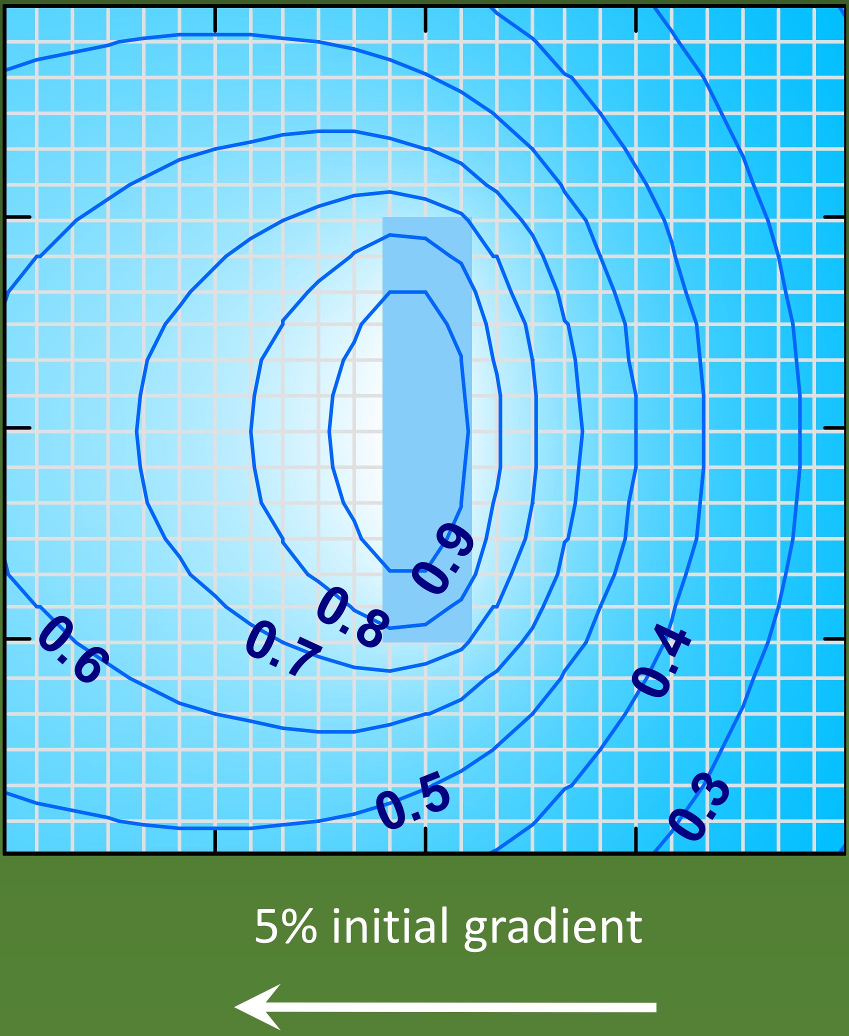
Induced water-table elevation relative to base of aquifer beneath mound


Water-Table Elevation Along X* Axis (t=∞)

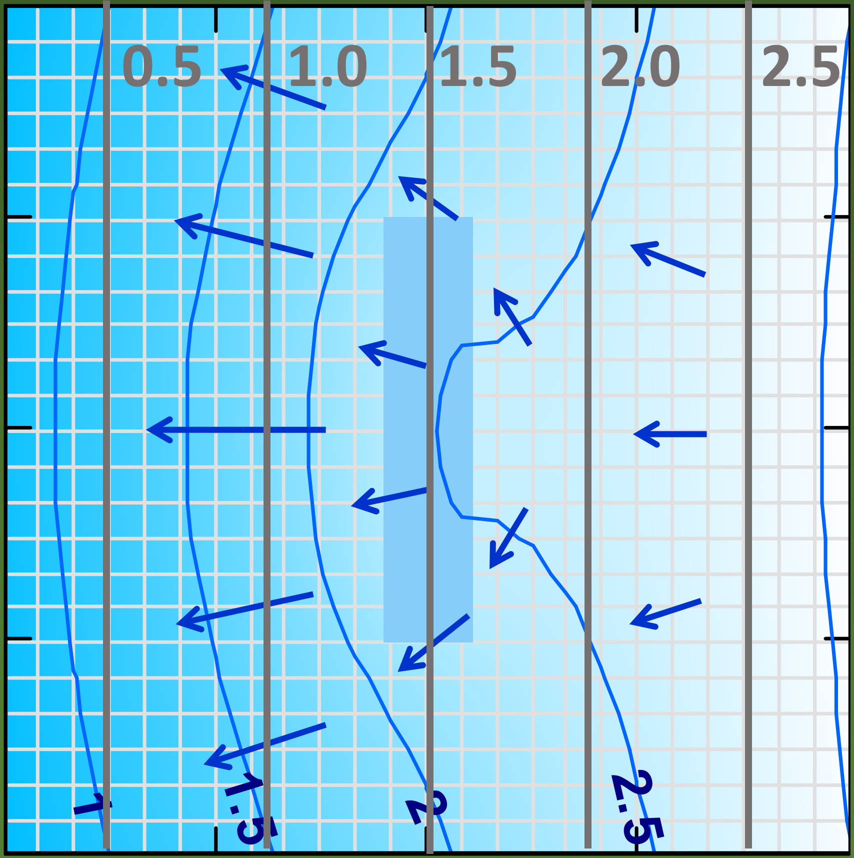
Induced water-table elevation can be shown, incorporating existing hydraulic gradient



Induced rise above original water-table



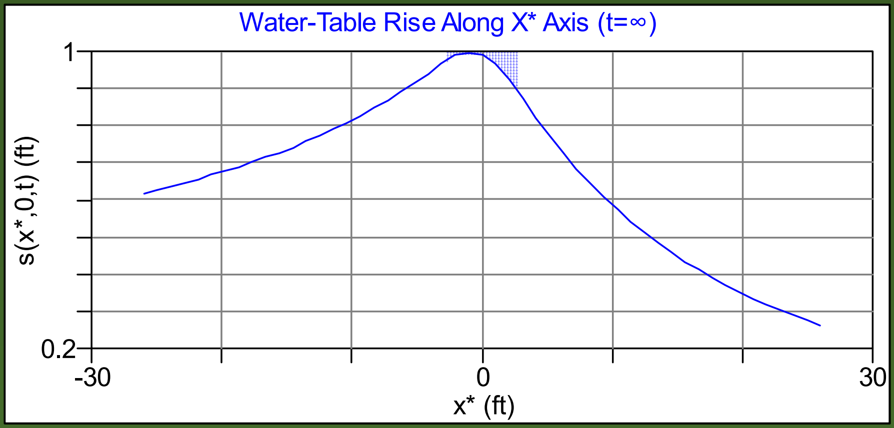
Induced water-table elevation relative to base of aquifer beneath mound

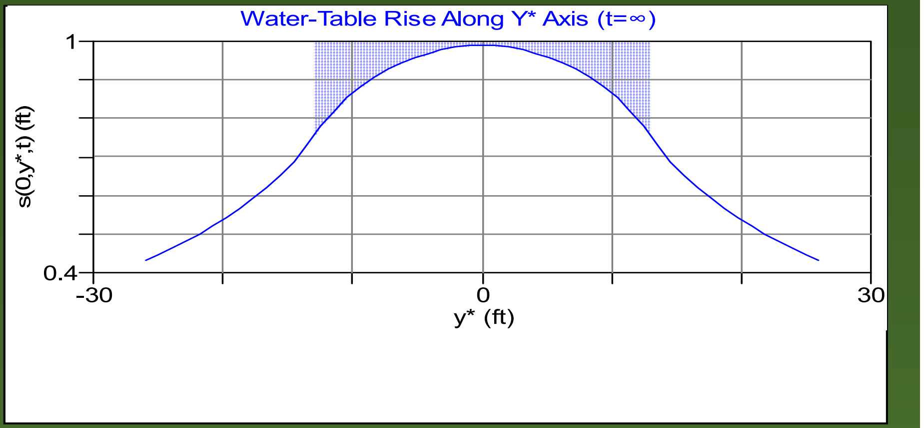


| 1.5 Initial water-table elevations before recharge (ft above base of aquifer beneath mound)

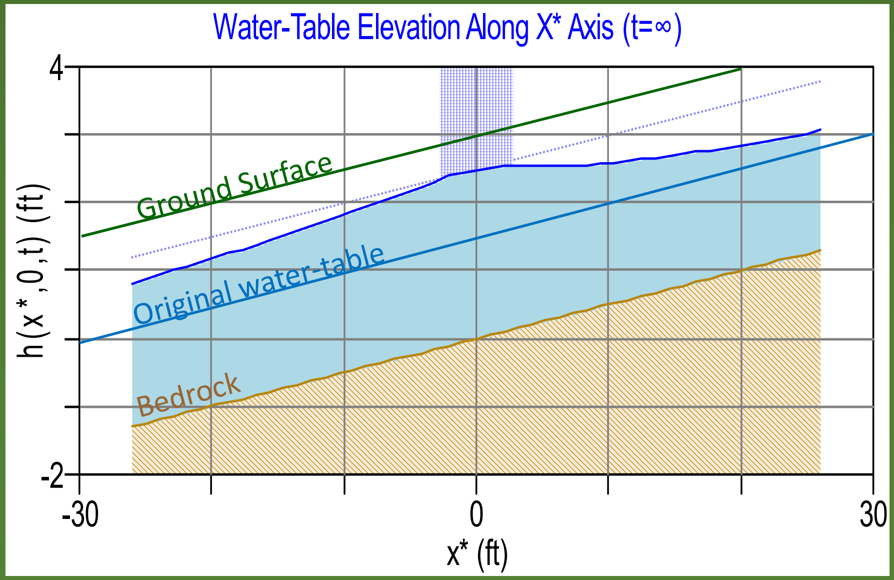
Parallel to Slope *Perpendicular to Slope*

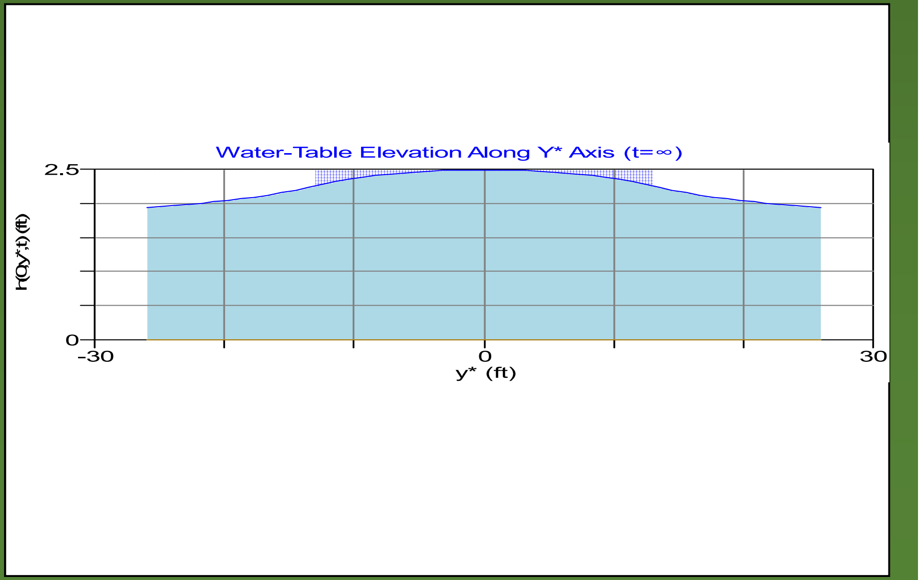
Induced rise above original water-table


Water-Table Rise Along X* Axis (t=∞)


Water-Table Rise Along Y* Axis (t=∞)

Induced water-table elevation relative to base of aquifer under mound


Water-Table Elevation Along X* Axis (t=∞)


Water-Table Elevation Along Y* Axis (t=∞)

Comparison of Groundwater Mounding Methods

	Darcy Method	Hantush (1967)	Zlotnik et al. (2017)	Zlotnik et al. (2017)
Design Flow (gpd)	420	420	420	420
Design Flow (ft^3/day)	56.1	56.1	56.1	56.1
Recharge, r (ft/day)	0.13	0.13	0.13	0.39
Specific Yield, Sy (-)	N/A	0.0001	N/A	N/A
Hydraulic Conductivity, K (ft/day)	15	15	15	15
Hydraulic Gradient, i (ft/ft)	5%	No Slope	5%	5%
Width of Leachfield, x (ft)	5.6	5.6	5.6	5.6
Length of Leachfield, y (ft)	75	75	75	26
Duration, t (days)	Steady State	3650	Steady State	Steady State
Initial saturated thickness $h_{i(0)}$, (ft)	*N/A*	1.5	1.5	1.5
Seasonal High Water Table (ft bgs)	1.5	1.5	1.5	1.5
Maximum Water-Table Rise (ft)	**1.00**	**1.97**	**0.63**	**1.00**
"Freeboard" (ft bgs)	**0.50**	**-0.47**	**0.87**	**0.50**

Discussion

1. When should mounding calculations be performed?
2. Who should conduct the mounding calculations?
3. Which methods are acceptable for input parameters?

In Vermont:

1. Water-table < 24” below ground surface, or all bottomless sand filters, in-mound > 1000 gpd, in-ground > 2000 gpd
2. ‘Hydrogeologists’ if not using ‘simplified method’
3. K values often based on soil texture, structure, grade

   Hydraulic gradient often based on ground slope

   Permeable soil (aquifer) thickness often based on deepest test pit and/or nearby drinking well logs

Conclusions

1. Prescriptive sand-mound design suitable when seasonal high water table is over 2 feet below ground surface
2. Simplified Darcy-based method of estimating groundwater mounding suitable for use by non-hydrogeologists
3. For large design flows or near-surface induced water-table appropriate methods should be used by hydrogeologists for: perched aquifers; or unconfined horizontal aquifers; or unconfined sloping aquifer
4. New tool based on Zlotnik et al. (2017) is in development to estimate groundwater mounding in sloping (and horizontal) unconfined aquifers
5. Remember: 1) parameter uncertainty and 2) error in estimation of groundwater mound over 50% original aquifer thickness