Review of pros and cons of building a repository of high-level nuclear fuel-waste in recharge versus discharge areas of regional groundwater flow

Judit Déri-Takács, Daniel Skoreyko

Student Competition on Regional Groundwater Flow
43rd IAH Congress
September 28, 2016

UNIVERSITY OF ALBERTA
HYDROGEOLOGY
EARTH and ATMOSPHERIC SCIENCES

Introduction

Deep geological storage
- Preferred option for long-term isolation and storage of HLW
- Sweden is in the most advanced stage of building a repository

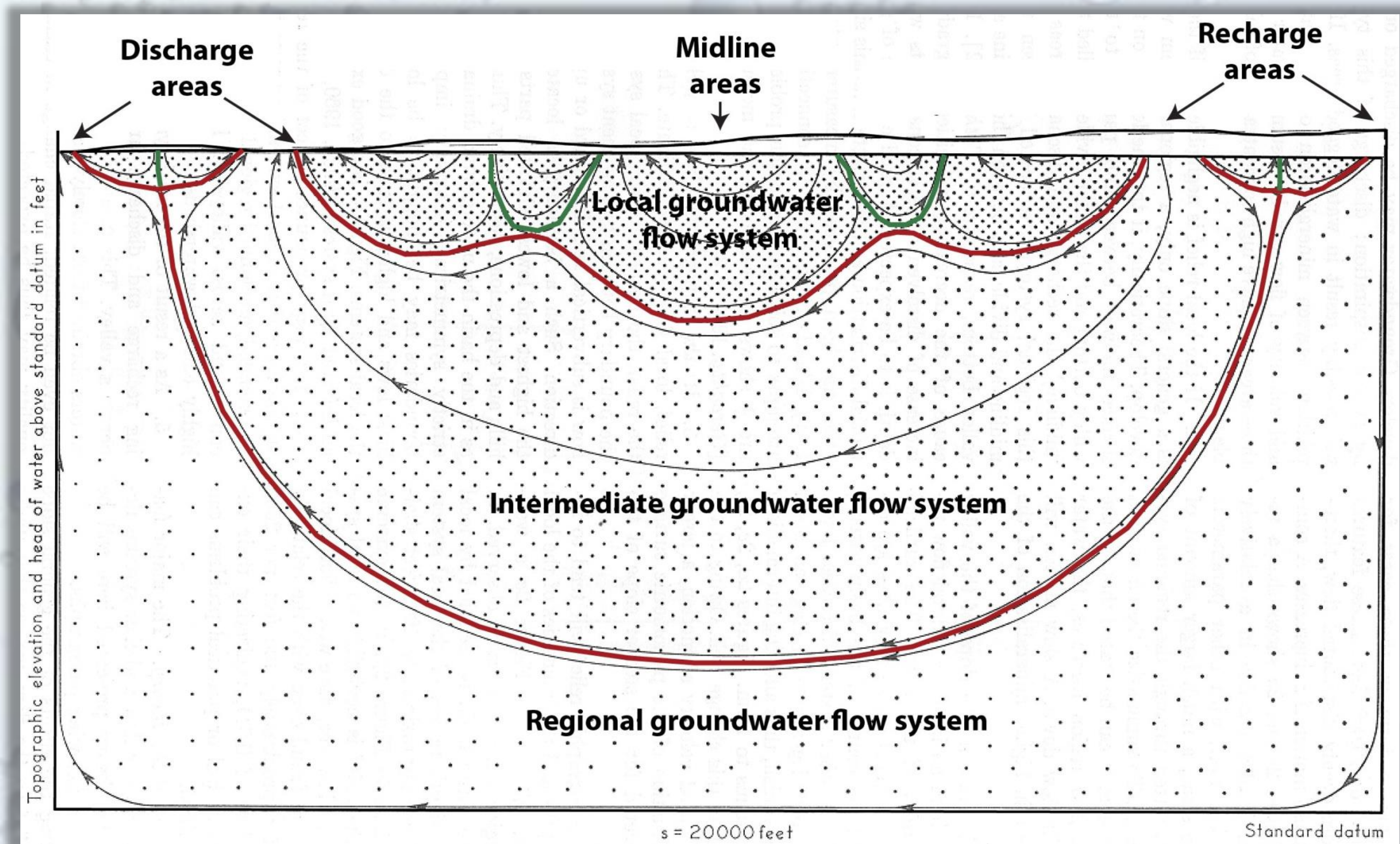
HLW Repository in Canada
- 1982: Underground Research Laboratory
- 2007: Adaptive Phased Management accepted
- 2010: site selection process initiated
- 2016: 9 possible sites

Key features of underground storage
1. the maximum travel time from the repository to the biosphere
2. the maximum degree of dilution from the repository site to the biosphere
3. the minimum prediction uncertainty in reservoir characteristics

"The **primary mechanism** for the likely introduction of the radioactive elements into the biosphere is that of **ground water transport.**" (Runchal and Maini, 1980)

Considering regional groundwater flow patterns in repository siting is imperative!

Gravity-driven groundwater flow



(modified after Tóth, 1963)

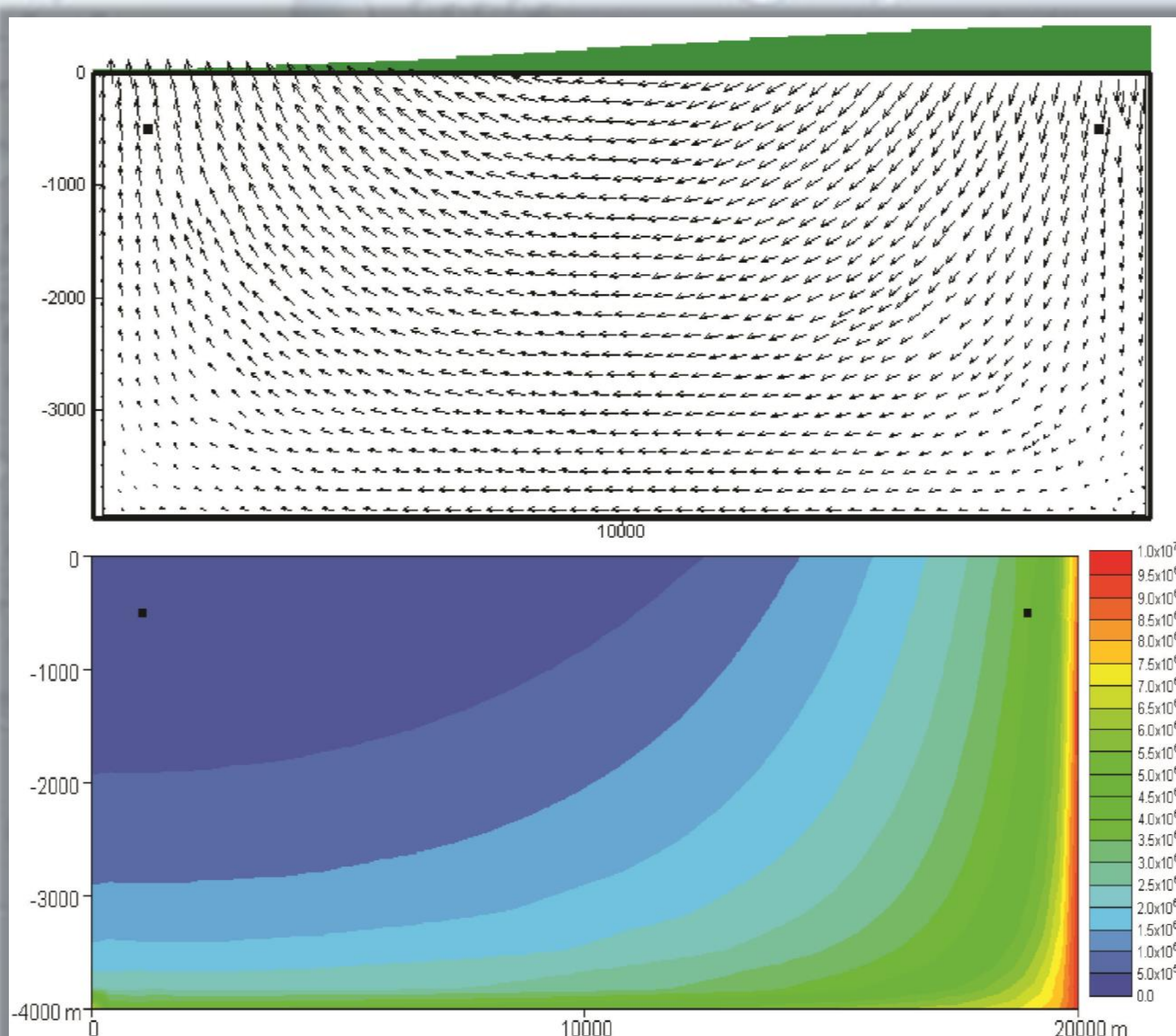
Recharge Area Concept

1) Recharge areas allow for maximum dilution, and maximum travel time back to land surface

2) In a recharge area, groundwater flow characteristics are the least sensitive to discrepancies in assumed from actual properties

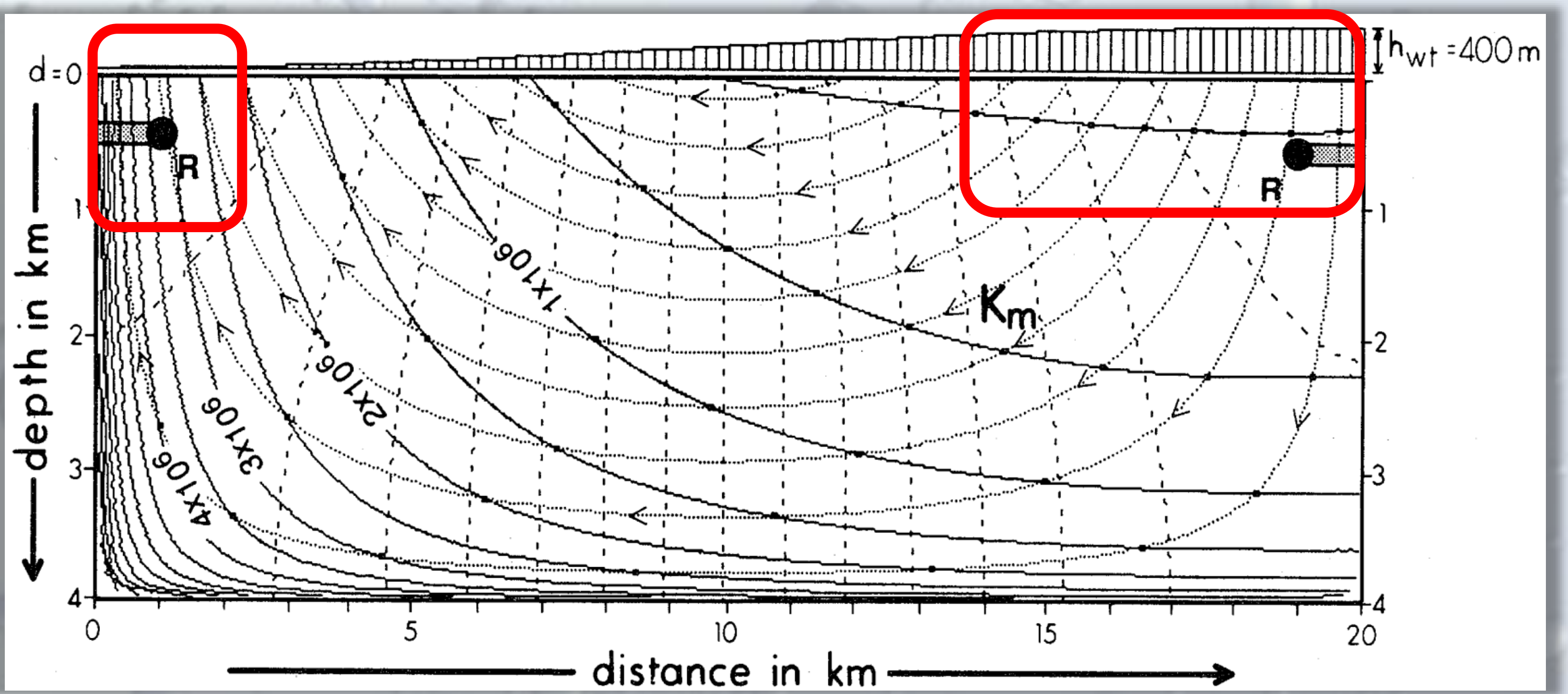
Repository Location	Travel Time	Faulted
Recharge Area	10^6 Years	No
Discharge Area	10^5 years	No
Recharge Area	10^5 years	Yes
Discharge Area	10^4 years	Yes

(modeled results after Tóth and Sheng, 1996)



(modified after Voss and Provost , 2001)

Recharge Area Concept



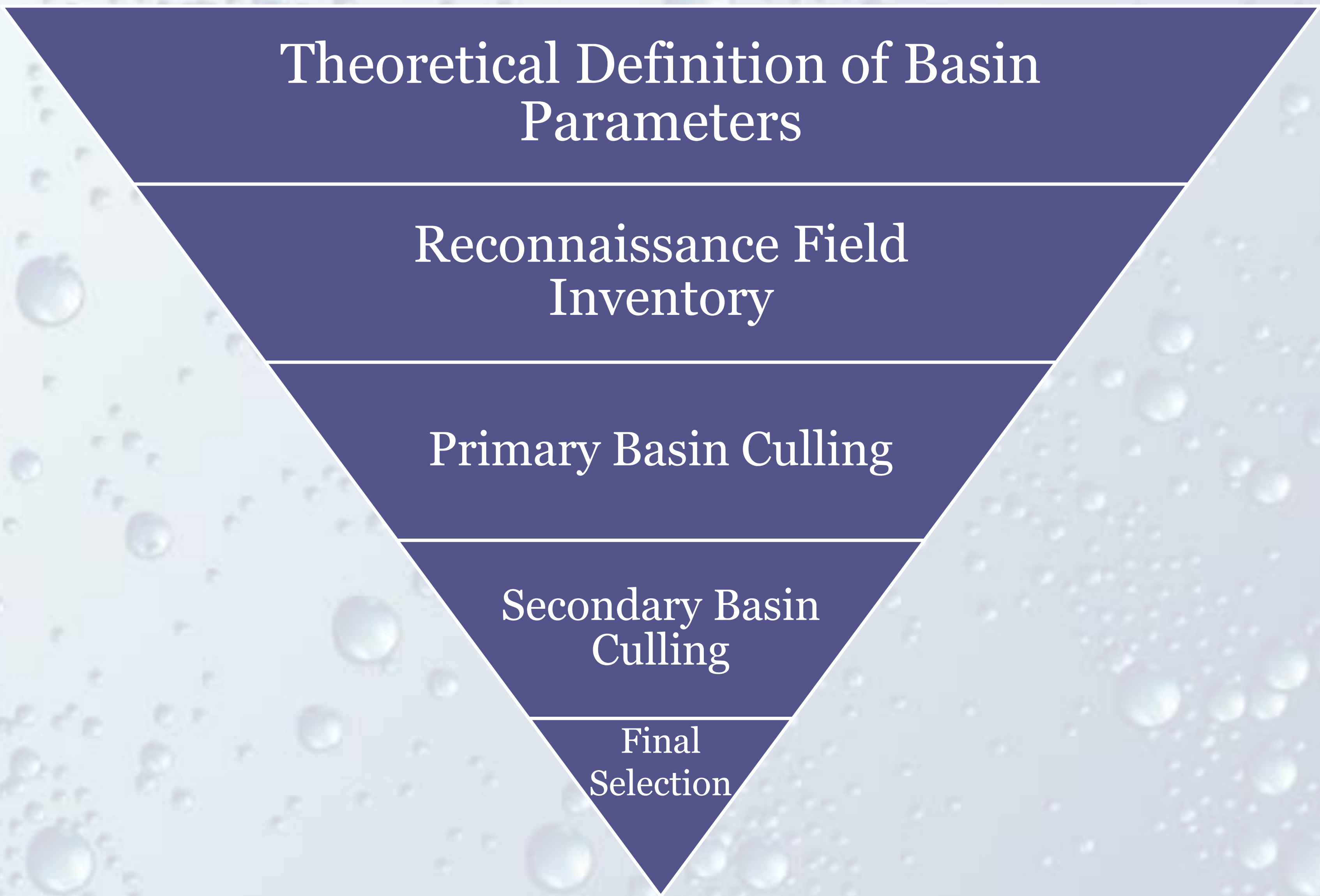
(modified after Tóth and Sheng, 1996)

Water age unrepresentative of return travel time!

Repository Location	Travel Time (years)	Water Age (Years)
Recharge Area	3.4×10^6	8.0×10^4
Discharge Area	9.5×10^4	3.4×10^6

(modeled results after Tóth and Sheng, (1996)

Recharge Area Concept - Application



Key elements of Recharge Area Concept

- Regional recharge area is **least sensitive to presence of faults** or **discrepancies** in the flow domain

- Recharge areas provide the **longest minimum travel times** and the **longest travel path** lengths

- **Water age ≠ stagnancy (!)**

- ***A priori*** implementation based on general principles

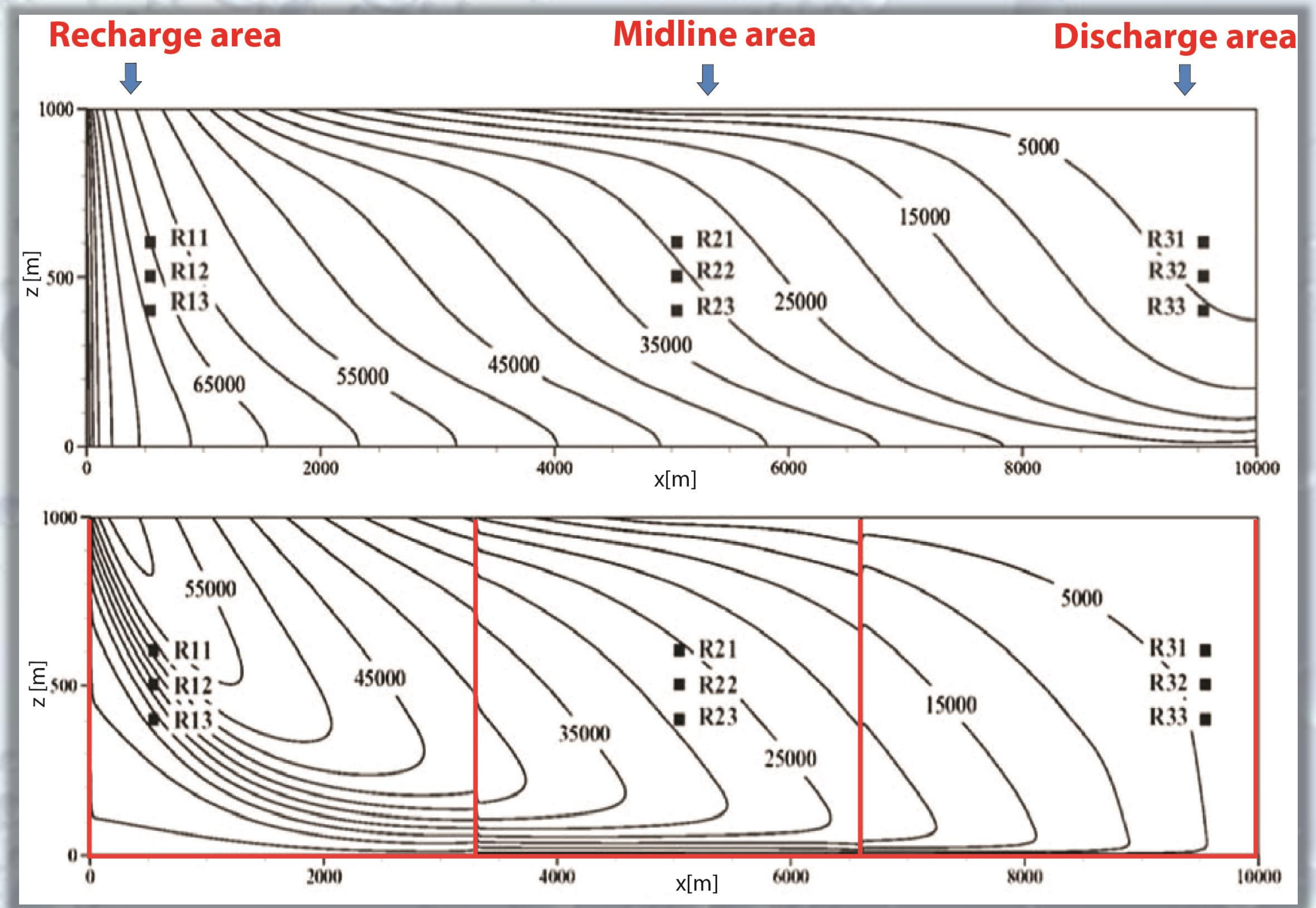
Reception of Recharge Area Concept

Recharge Area Concept

- Effects of variable-density fluids
- Effects of transient flow
- Effects of anisotropy
- Effects of fractures

Factor	Effect	Does it matter?
Anisotropy	If Kv>Kh, travel time decreases on regional recharge.	**NO.** Impact on travel time is not large enough to undermine superiority of regional recharge areas
Variable-density fluids	Travel time for recharge entering the deep brine system significantly increases	**NO.** Results improve reliability of regional recharge areas
Transient flow	Transient conditions will affect the ground-water-flow fields, however rate of changes are uncertain	Probably **NO.** Predictions are uncertain; BUT! turning a regional recharge into a local discharge would take significant amount of time
Fractures		

Effects of fractures



(modified after Cornaton et al, 2008)

Factor	Effect	Does it matter?
Anisotropy	If Kv>Kh, travel time decreases on regional recharge.	**NO.** Change in travel time is not large enough to undermine superiority of regional recharge areas
Variable-density fluids	Travel time for recharge entering the deep brine system significantly increases	**NO.** Results improve reliability of regional recharge areas
Transient flow	Transient conditions will affect the ground-water-flow fields, however rate of changes are uncertain	Probably **NO.** Predictions are uncertain; BUT! turning a regional recharge into a local discharge would take significant amount of time
Fractures	Fractures , especially horizontal ones do have significant impact on travel time.	Yes and **NO.** Results can contradict with the superiority of regional recharge areas. BUT! It does not disprove RAC.

Summary and take-home message

- **Recharge Area Concept proves the superiority of regional recharge areas over discharge areas**
  - **Regional recharge areas provide significantly longer travel times and travel paths than discharge areas**
  - **Regional recharge areas are less sensitive to presence of faults or discrepancies, than discharge areas**
- **It also shows that – since regional groundwater flow can be predicted and verified- regional groundwater flow can improve geosphere as a natural barrier**
- **The concept dispels the misconception that high water age means stagnancy**
- **Selection of suitable sites for a proposed repository should involve application of general principles in the first place rather than relying on detailed predictions**

"Everything should be made as simple as possible, but not simpler."

(Albert Einstein)

References

- Cornaton, F. J., Y.-J. Park, S. D. Normani, E. A. Sudicky, and J. F. Sykes (2008): Use of groundwater lifetime expectancy for the performance assessment of a deep geologic waste repository: 1. Theory, illustrations, and implications, Water Resources Research, 44, W04406, doi:10.1029/2007WR006208.
- Park, Y.-J., F. J. Cornaton, S. D. Normani, J. F. Sykes, and E. A. Sudicky (2008): Use of groundwater lifetime expectancy for the performance assessment of a deep geologic radioactive waste repository: 2. Application to a Canadian Shield environment, Water Resources Research, 44, W04407, doi:10.1029/2007WR006212.
- Runchal, A and Maini, T (1980): The impact of a high level Nuclear waste repository on the regional groundwater flow. Int. J. Rock Mech. Min Sci. & Geomech. Abstr., vol 17, pp 253-264.
- Sykes, J.F. (2003): Characterizing the geosphere in high-level radioactive waste management. Nuclear Waste Management Organization, Toronto, Background Papers 4-2., pp 53.
- Sykes, J.F., Normani, S.D, Jensen, M.R., Sudicky, E.A. (2009): Regional-scale groundwater flow in a Canadian Shield setting. Canadian Geotechnical Journal, 46:813-827.
- Tóth J (1963) A theoretical analysis of groundwater flow in small drainage basins. J Geoph Res 68(16):4795–4812
- Tóth, J. and Sheng, G. (1996): Enhancing safety of nuclear waste disposal by exploiting regional groundwater flow: The Recharge Area Concept. Hydrogeology Journal, 4(4): 4-25.
- Voss, C. I. and Provost, A. M. (2001): Recharge-Area Nuclear Waste Repository in Southeastern Sweden – Demonstration of Hydrogeologic Siting Concepts and Techniques. Swedish Nuclear Power Inspectorate (SKI) Report 01:44. US Geological Survey, Reston, VA., U.S.A.
- Leiss, W. (2009): What is happening in other countries? Paper 3. Nuclear Waste Management Organization, Canada.

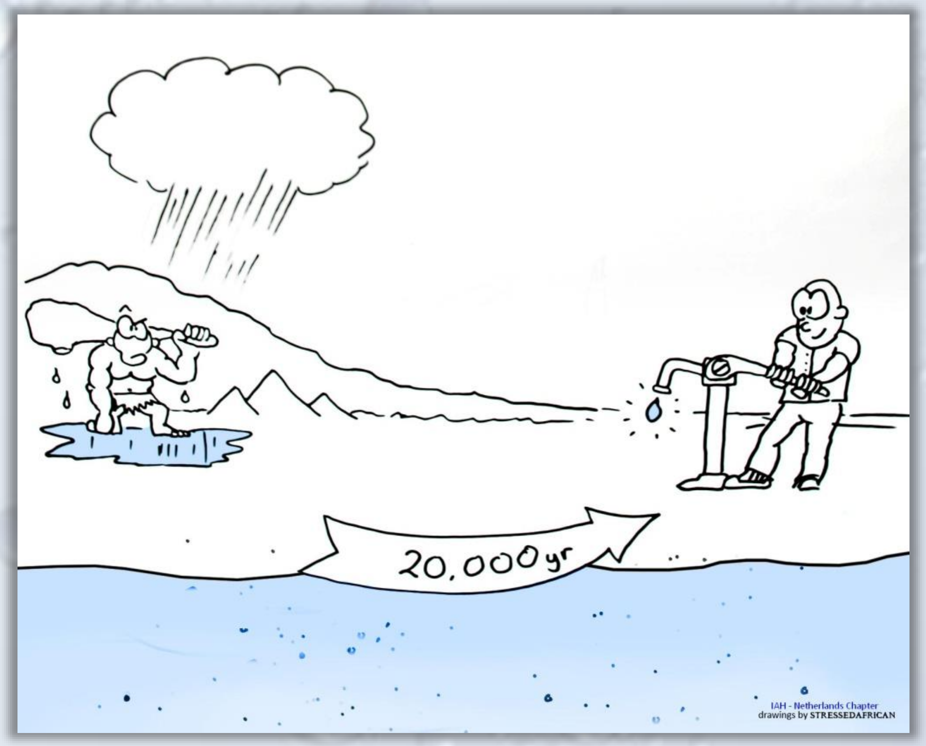
- www.nwmo.ca

Ackowledgement

- Dr Carl Mendoza, University of Alberta

Thank you for your attention!

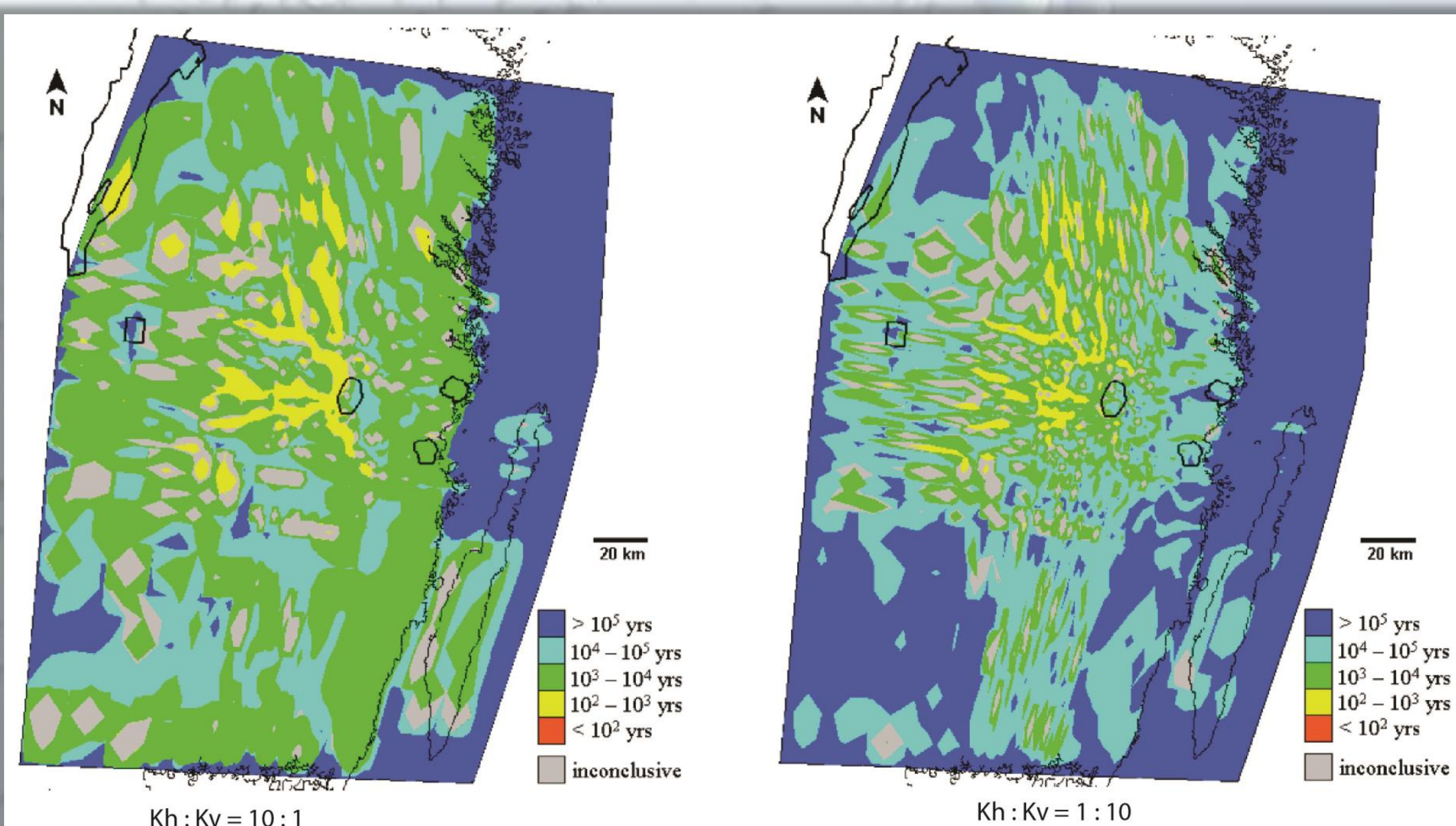
Questions?



Supplementary slides

Limitations of Recharge Area Concept

1. Effects of anisotropy

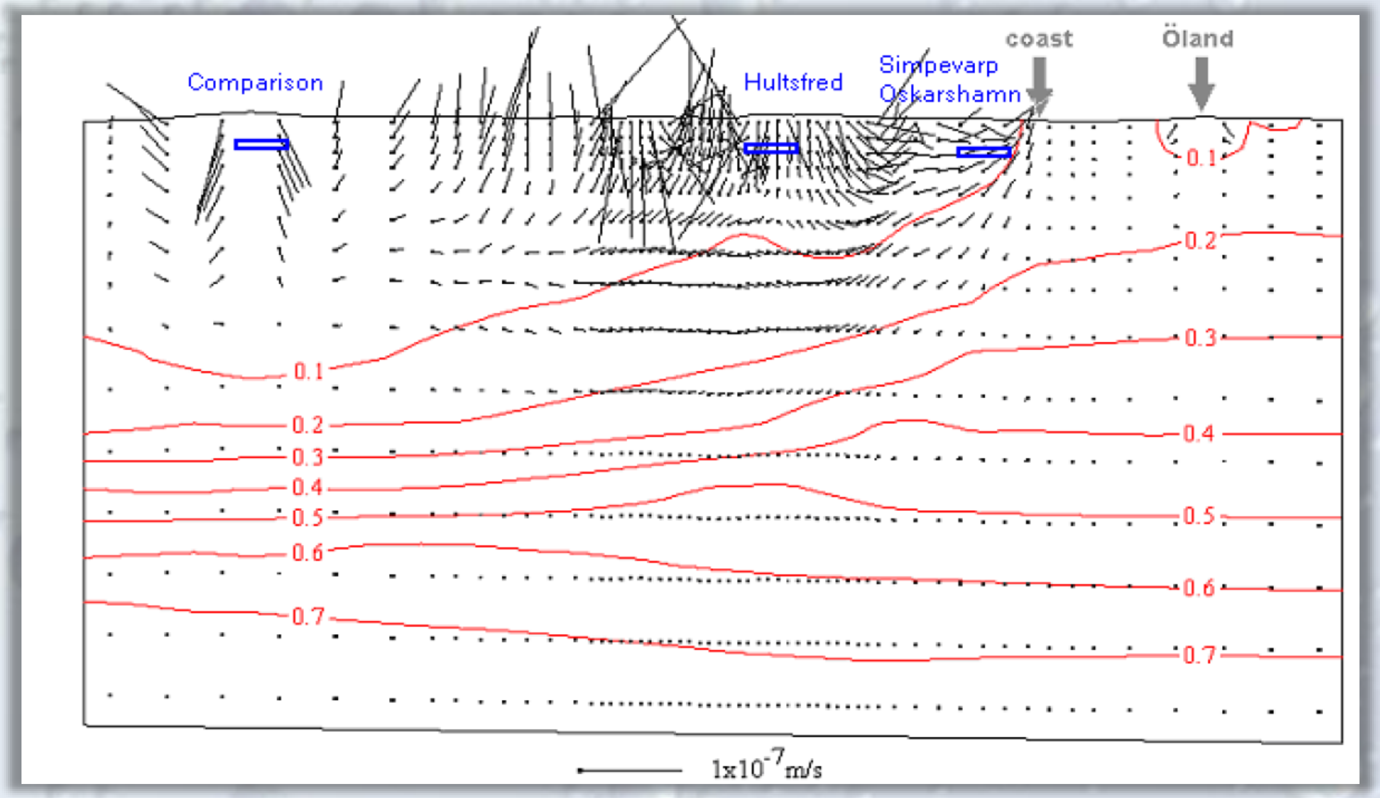


(modified after Voss and Provost, 2001)

Limitations of Recharge Area Concept

Effects of variable-density fluids

a) lower flow intensity

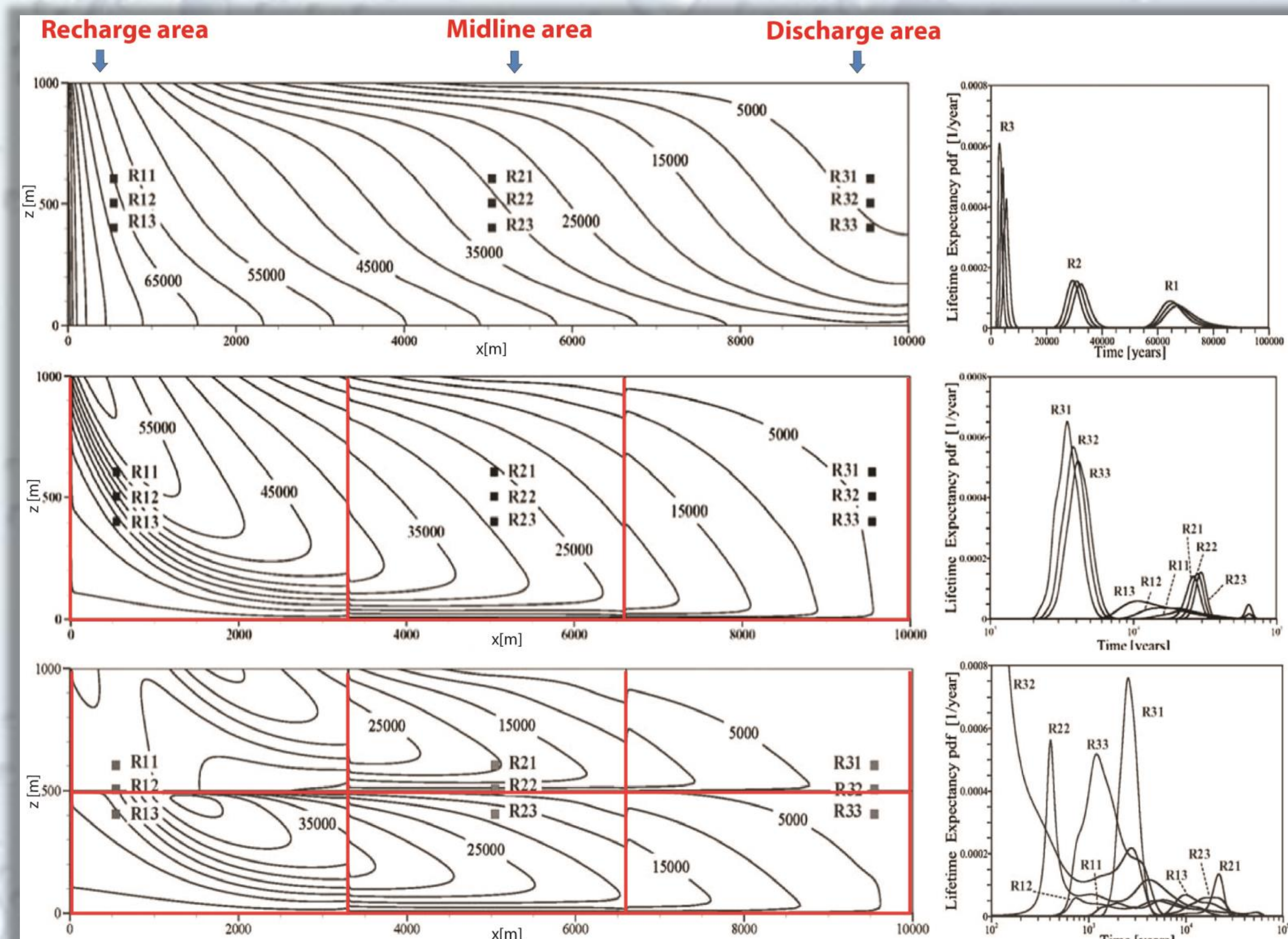


(Voss and Provost, 2001)

b) greater dispersion?

Limitations of Recharge Area Concept

4. Effects of fractures



(modified after Cornaton et al, 2008)

Recharge Area Concept - Application

Theoretical Definition of Basin Parameters

Reconnaissance Field Inventory

Primary Basin Culling

Secondary Basin Culling

Final Selection

Preliminary modeling conducted to find suitable topographic configuration

Using GIS find **±50 locations** with suitable topography; select **±10** what could qualify as repository locations

Preform initial site assessment of geologic and hydrogeologic parameters
±5 sites remain

Detailed geologic and hydrogeologic characterization performed
Detailed modeling conducted and compared to actual site

±3 sites remain
All technically sound choose based on social, economic, and political factors