

When a Tailings Facility Becomes a Groundwater Mound: Understanding Hydraulic Control of Seepage from Elevated Water Storages

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Research Article

Keywords: groundwater mound, seepage, tailings storage facility, hydraulic gradient, groundwater modelling, groundwater connectivity, particle tracking, seepage control, environmental risk, groundwater flow

Posted Date: October 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10940404/v1>

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Additional Declarations: No competing interests reported.

Abstract

Tailings storage facilities, water storages, evaporation ponds, infiltration systems, and other engineered water-retaining structures can significantly alter local groundwater regimes by creating artificial hydraulic mounds. These mounds modify groundwater gradients, redirect flow pathways, increase hydraulic connectivity, and influence seepage migration over large distances. Despite the widespread recognition of seepage risks, groundwater mound development remains poorly understood and is often simplified within environmental assessments.

This study presents a hydrogeological framework for understanding groundwater mounding beneath elevated water-storage systems. Using numerical groundwater simulations, groundwater budgets, particle tracking, and conceptual hydrogeological analysis, the study examines how elevated hydraulic heads influence seepage divergence, groundwater migration pathways, travel times, and receptor connectivity. Particular attention is given to the interaction between pond geometry, hydraulic gradients, seepage-control measures, and groundwater-system response.

Results demonstrate that artificial groundwater mounds can become the dominant control on local groundwater movement. Groundwater flow diverges outward from elevated hydraulic heads, modifying natural groundwater-flow patterns and potentially extending seepage impacts well beyond the storage footprint. Engineering controls such as liners, cutoff curtains, and pond-configuration changes alter the shape, extent, and magnitude of induced groundwater mounds. The study provides a transferable framework for evaluating seepage behaviour and groundwater risk associated with engineered water-storage systems.

1. Introduction

Groundwater systems are strongly influenced by hydraulic gradients. Where artificial storages create water levels substantially above ambient groundwater conditions, groundwater-flow systems may be significantly modified through the development of groundwater mounds (Bear, 1979; Freeze & Cherry, 1979).

Groundwater mounding occurs when infiltration exceeds the ability of surrounding materials to dissipate hydraulic pressures. The resulting increase in groundwater head may alter groundwater-flow directions, induce seepage pathways, accelerate groundwater migration, and establish hydraulic connectivity between engineered structures and environmental receptors (Anderson et al., 2015; Fetter, 2018).

Examples include:

- tailings storage facilities;
- water dams;
- evaporation ponds;
- wastewater infiltration systems;

- managed aquifer recharge schemes;
- stormwater basins; and
- artificial recharge operations.

In each case, elevated hydraulic heads create artificial groundwater-flow systems superimposed on the natural groundwater regime.

Although seepage assessments frequently quantify seepage rates and groundwater levels, comparatively less attention is given to groundwater mound development itself. Yet groundwater mounding often controls:

- groundwater migration pathways;
- travel times;
- seepage locations;
- receptor connectivity;
- environmental risk.

A clearer understanding of groundwater-mound behaviour is therefore essential for environmental assessment, groundwater management, and engineering design.

1.1 Study Objectives

The objectives of this study are to:

- examine groundwater mound formation beneath elevated water storages;
- evaluate the influence of groundwater mounds on seepage pathways;
- investigate the relationship between hydraulic gradients and groundwater migration;
- assess how engineering controls modify mound behaviour; and
- develop a transferable conceptual framework for evaluating groundwater mounding and seepage risk.

The novelty of this paper lies in focusing on groundwater mounds themselves rather than seepage rates alone, highlighting groundwater mounding as a primary driver of environmental risk and hydrogeological change.

2. Conceptual Basis of Groundwater Mounding

Groundwater mounds develop when recharge or seepage increases groundwater heads above surrounding equilibrium conditions. Groundwater-mound development has been widely documented beneath recharge basins, infiltration systems, irrigation schemes, wastewater reuse projects, and engineered water-storage facilities (Hantush, 1967; Philips & Kitching, 1995; Yihdego, 2017).

Under natural conditions, groundwater generally flows according to regional hydraulic gradients. However, when a water-storage structure imposes a sustained hydraulic head above surrounding groundwater levels, groundwater movement becomes strongly influenced by the resulting mound.

The conceptual process is illustrated in Fig. 1.

Groundwater mounds may persist for years or decades depending on:

- seepage rates;
- hydraulic conductivity;
- aquifer storage;
- recharge conditions;
- engineering controls.

3. Hydrogeological Controls on Groundwater Mounds

Several factors influence groundwater mound behaviour.

3.1 Hydraulic Head Difference

The magnitude of groundwater mounding is fundamentally controlled by the difference between pond water levels and surrounding groundwater heads.

Greater hydraulic-head differences produce:

- steeper groundwater gradients;
- larger seepage fluxes;
- longer migration pathways.

The relationship between hydraulic-head difference and groundwater-mound development is well established in both analytical and numerical groundwater studies (Bear, 1979; Domenico & Schwartz, 1998).

3.2 Aquifer Hydraulic Conductivity

Hydraulic conductivity controls the rate at which groundwater pressures dissipate.

Low-permeability systems tend to:

- retain elevated pressures;
- create larger groundwater mounds;
- increase groundwater residence times.

High-permeability systems:

- dissipate hydraulic pressures rapidly;
- produce broader but lower groundwater mounds.

3.3 Storage Characteristics

Specific yield and specific storage control the capacity of the groundwater system to absorb hydraulic loading.

Systems with low storage capacity typically exhibit:

- greater groundwater-level rise;
- more pronounced mounding;
- stronger transient behaviour.

4. Groundwater Mounds and Seepage Pathways

Groundwater mounds represent one of the most important hydrogeological consequences of elevated water storage systems. As hydraulic heads increase beneath a storage area, groundwater flow is redirected away from the mound and follows multiple pathways governed by hydraulic gradients, geological structure, and aquifer properties.

Unlike simplified seepage concepts that assume predominantly vertical flow beneath a storage footprint, groundwater mounds commonly generate **divergent groundwater movement**. Groundwater may migrate simultaneously toward several downgradient locations, creating multiple potential receptor pathways and increasing the complexity of groundwater-system behaviour.

The conceptual relationship between groundwater mounding, pathway divergence, and receptor connectivity is illustrated in Fig. 2.

The figure demonstrates that groundwater originating beneath a single storage area does not necessarily migrate toward a single receptor. Instead, groundwater flow may diverge into multiple pathways, each with different travel times, groundwater-flow velocities, attenuation potential, and environmental consequences.

4.1 Pathway Divergence

Pathway divergence occurs when groundwater movement is redistributed by hydraulic gradients generated beneath the groundwater mound.

Several factors influence this process:

- hydraulic conductivity contrasts;
- geological heterogeneity;
- structural controls such as faults and fractures;
- groundwater storage properties;
- boundary conditions.

Consequently, groundwater pathways may evolve through time and differ substantially from those expected from local seepage observations alone.

Similar groundwater-mound behaviour has been reported for recharge systems, managed aquifer recharge projects, and wastewater infiltration facilities where elevated hydraulic heads became the dominant control on groundwater movement (Philips & Kitching, 1995; Yihdego, 2017).

4.2 Multiple Receptors and Connectivity

One of the most significant implications of groundwater mound development is the creation of hydraulic connectivity with multiple receptors.

These receptors may include:

- groundwater-dependent ecosystems;
- surface-water bodies;
- groundwater users;
- engineered infrastructure;
- wetlands;
- environmental receptors located at considerable distances from the source.

As shown in Fig. 2, groundwater originating from a single storage system may ultimately influence several receptors simultaneously. This observation highlights the importance of evaluating the complete groundwater-flow system rather than focusing solely on seepage immediately beneath the storage facility.

4.3 Implications for Environmental Assessment

Traditional seepage assessments frequently focus on seepage magnitude while placing less emphasis on groundwater migration pathways. However, environmental consequences often depend more on where groundwater travels than on the seepage rate itself.

The groundwater-mound framework presented in Fig. 2 demonstrates that environmental assessments should evaluate:

- groundwater-flow directions;
- pathway divergence;

- travel times;
- groundwater connectivity;
- receptor sensitivity.

Failure to assess these factors may underestimate the extent of groundwater influence and environmental exposure.

5. Influence of Engineering Controls

The groundwater-flow divergence shown in Fig. 2 demonstrates why control measures must be assessed at the groundwater-system scale. Reducing seepage beneath one part of a storage facility may alter the distribution of pathways and redirect groundwater toward alternative receptors rather than eliminating groundwater movement altogether.

5.1 Liners

Liners are typically designed to reduce vertical seepage.

However, liners do not necessarily eliminate groundwater mounds.

In some situations, liners:

- reduce vertical seepage;
- increase hydraulic pressures;
- redistribute flow laterally.

Consequently, groundwater mounding may still occur despite reduced leakage.

5.2 Cutoff Curtains

Cutoff curtains provide hydraulic resistance to groundwater movement. Comparable hydraulic-gradient redistribution effects have been reported for engineered barriers, cutoff walls, and groundwater-control structures used in both environmental and geotechnical applications (Yihdego, 2016).

Their principal effects include:

- reduction of lateral seepage;
- redistribution of groundwater gradients;
- modification of mound geometry.

Different seepage-control measures influence groundwater systems in different ways. Some controls primarily reduce vertical seepage, while others modify lateral migration or groundwater mounding

behaviour. The principal hydrogeological effects of commonly used seepage-control measures are summarised in Table 1.

Table 1
Typical hydrogeological responses associated with common seepage-management measures.

Engineering Control	Primary Effect	Influence on Groundwater Mound
Liner	Reduces vertical seepage	May increase local head
Cutoff Curtain	Restricts lateral flow	Reduces mound extent
Drainage System	Removes groundwater	Reduces mound height
Pond Relocation	Changes hydraulic geometry	Alters flow divergence

As shown in Table 1, many seepage-control measures influence groundwater-mound behaviour as much as they influence seepage magnitude.

5.3 Pond Configuration

Storage geometry can be just as important as physical barriers.

Central pond placement generally:

- reduces edge gradients;
- shortens seepage pathways;
- improves hydraulic efficiency.

Changes to pond geometry may alter hydraulic gradients more effectively than some engineered barriers. By reducing local hydraulic loading and modifying the shape of groundwater mounds, pond relocation can significantly influence seepage pathways and groundwater connectivity. These interactions reinforce the importance of considering groundwater-mound behaviour alongside seepage fluxes and engineering controls.

6. Environmental Implications

Groundwater mounds may influence:

- groundwater quality;
- surface-water interaction;
- groundwater-dependent ecosystems;
- infrastructure performance;
- environmental receptors.

Groundwater mounds influence a range of environmental receptors beyond the storage footprint. The environmental consequences of groundwater mounding depend on how groundwater pathways, hydraulic gradients, and connectivity interact with local receptors. Typical groundwater-mound impacts are summarised in Table 2.

Table 2
Examples of environmental and hydrogeological impacts associated with groundwater-mound development.

Impact Category	Potential Effect
Groundwater	Elevated heads and modified flow paths
Surface Water	Increased baseflow or seepage expression
Ecosystems	Changed groundwater availability
Infrastructure	Increased seepage risk
Environmental Receptors	Enhanced hydraulic connectivity

Table 2 highlights that groundwater mounding should be considered an environmental process rather than simply a hydrological response because it may influence receptors, ecosystems, and infrastructure over large spatial scales.

An important implication is that seepage may remain environmentally relevant even where concentrations are low if groundwater connectivity increases substantially.

7. Discussion

The results demonstrate that groundwater mounds frequently become the dominant controls on groundwater migration. As shown conceptually in Fig. 2, seepage originating beneath a storage area may split into multiple groundwater pathways and connect with several receptors simultaneously. Consequently, seepage assessment should focus not only on seepage quantities but also on the distribution of groundwater pathways and receptor connectivity.

Traditional seepage assessments often focus on:

- seepage rate;
- groundwater-level impact;
- compliance monitoring.

However, groundwater mounds control many of the processes ultimately responsible for:

- receptor connectivity;
- travel times;

- seepage migration;
- environmental risk.

The study also demonstrates that engineering controls frequently redistribute seepage rather than eliminate it.

Consequently, groundwater-mound assessment provides a more complete framework for evaluating groundwater-system response than seepage-flux assessment alone.

Similar groundwater-mounding and hydraulic-redistribution mechanisms have been documented for irrigation systems, managed aquifer recharge projects, infiltration basins, hydraulic barriers, and engineered groundwater-containment systems (Hantush, 1967; Yihdego, 2016; Yihdego, 2017).

8. Conclusions

Groundwater mounds represent a critical but frequently underappreciated component of seepage assessment and groundwater management.

This study demonstrates that:

- elevated water-storage systems generate artificial groundwater mounds;
- groundwater mounds modify natural groundwater-flow systems;
- seepage pathways commonly diverge outward from the mound rather than moving vertically downward alone;
- multiple groundwater pathways may create hydraulic connectivity with several receptors simultaneously;
- engineering controls frequently redistribute groundwater movement rather than eliminate it.

The pathway-divergence framework illustrated in Fig. 2 highlights an important hydrogeological principle: groundwater mounds frequently control both groundwater connectivity and environmental consequence. Understanding seepage behaviour therefore requires consideration of pathway evolution, receptor interaction, and groundwater-system response in addition to seepage magnitude.

The principal contribution of this paper is the recognition that groundwater mound behaviour provides a more complete explanation of seepage risk than seepage flux alone. By integrating groundwater mounding, flow-path divergence, hydraulic connectivity, and receptor interaction, the proposed framework offers a transferable methodology for evaluating seepage processes across a broad range of environmental and hydrogeological applications.

Ultimately, effective groundwater assessment requires moving beyond the question of **“how much water leaks?”** and focusing instead on **“where does the water go, what does it connect to, and why does it matter?”**.

Declarations

Author Contribution

Y.Y. conceptualized the study, developed the methodology, conducted the analysis, interpreted the results, prepared figures and tables, wrote and revised the manuscript, and approved the final version.

References

1. Anderson MP, Woessner WW, Hunt RJ (2015) Applied Groundwater Modeling: Simulation of Flow and Advective Transport. Academic
2. Bear J (1979) Hydraulics of Groundwater. McGraw-Hill
3. Diersch HJG (2014) FEFLOW: Finite Element Modeling of Flow, Mass and Heat Transport in Porous and Fractured Media. Springer
4. Doherty J (2015) Calibration and Uncertainty Analysis for Complex Environmental Models. Watermark Numerical Computing
5. Domenico PA, Schwartz FW (1998) Physical and Chemical Hydrogeology, 2nd edn. Wiley
6. Fetter CW (2018) Applied Hydrogeology (5th Edition). Waveland Press
7. Freeze RA, Cherry JA (1979) Groundwater. Prentice Hall
8. Hantush MS (1967) Growth and decay of groundwater mounds in response to uniform percolation. Water Resour Res 3:227–234
9. Hill MC, Tiedeman CR (2007) Effective Groundwater Model Calibration. Wiley
10. Konikow LF, Bredehoeft JD (2020) Groundwater model reliability under uncertainty. J Hydrol 586:124138
11. Phillips PJ, Kitching R (1995) Groundwater mounding beneath recharge basins and infiltration systems. Hydrogeol J 3:52–61
12. Pollock DW (1988) Semianalytical computation of path lines for finite-difference models. Groundwater 26(6):743–750
13. Refsgaard JC, van der Sluijs JP, Højberg AL, Vanrolleghem PA (2007) Uncertainty in the environmental modelling process. Environ Model Softw 22:1543–1556
14. Rojas R, Feyen L, Dassargues A (2008) Conceptual model uncertainty in groundwater modelling. Hydrogeol J 16:1261–1274
15. Scanlon BR, Healy RW, Cook PG (2002) Choosing appropriate techniques for quantifying groundwater recharge. Hydrogeol J 10(1):18–39
16. Sophocleous M (2002) Interactions between groundwater and surface water. Hydrogeol J 10:52–67
17. Taylor RG, Scanlon BR, Döll P, Rodell M, van Beek R, Wada Y et al (2013) Groundwater and climate change. Nat Clim Change 3:322–329

18. Winter TC, Harvey JW, Franke OL, Alley WM (1998) Ground Water and Surface Water: A Single Resource, vol 1139. U.S. Geological Survey Circular
19. Yihdego Y (2016) Evaluation of flow reduction due to hydraulic barrier engineering structure: Case of urban area flood, contamination and pollution risk assessment. Geotech Geol Eng 34(5):1643–1654
20. Yihdego Y (2017) Simulation of groundwater mounding due to irrigation practice: Case of wastewater reuse engineering design. Hydrology 4(2):19
21. Younger PL, Banwart SA, Hedin RS (2002) Mine Water: Hydrology, Pollution, Remediation. Springer

Figures

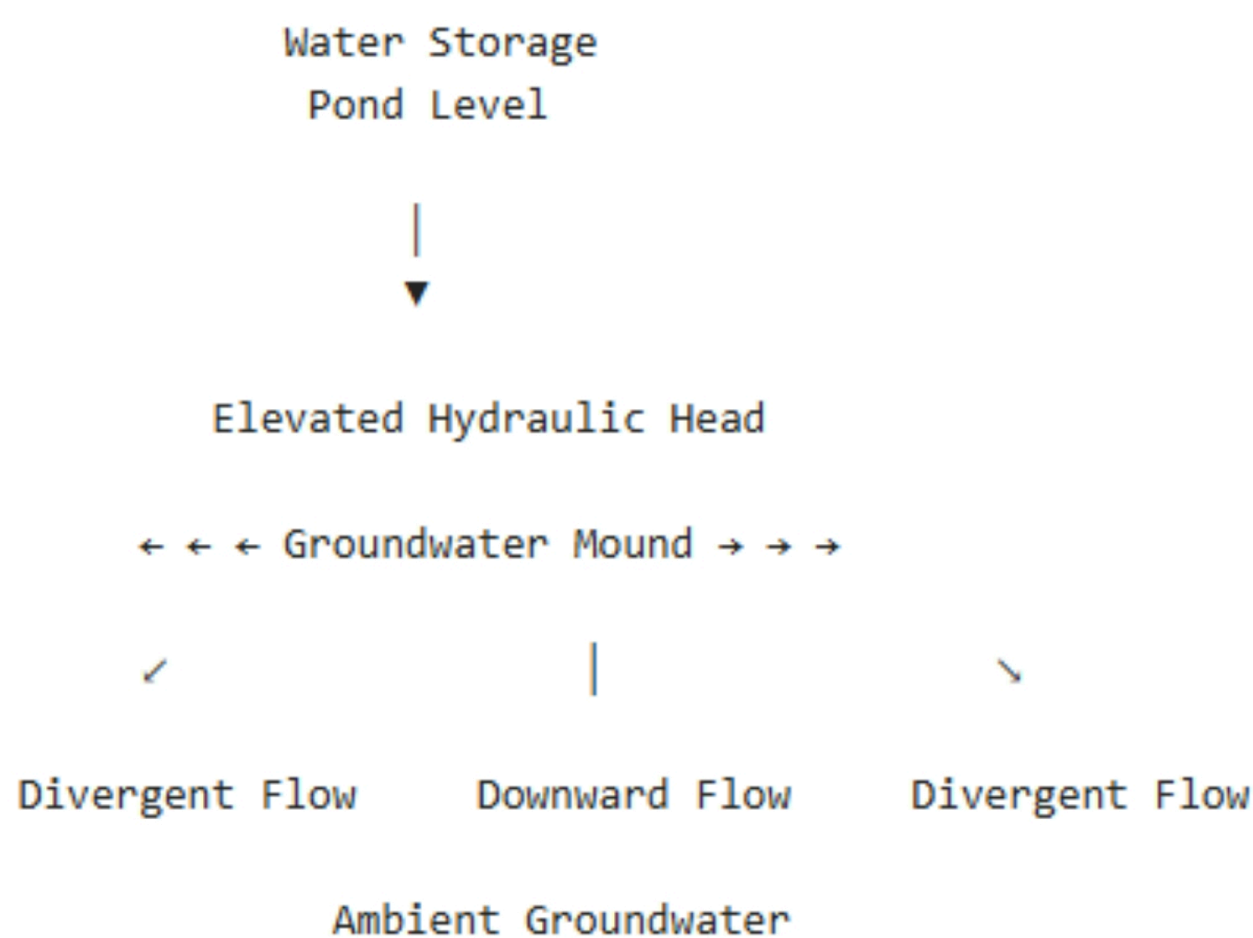


Figure 1

Conceptual evolution of groundwater mounding beneath an elevated water storage. Elevated hydraulic heads induce divergent groundwater flow, increased seepage, and extension of groundwater connectivity beyond the storage footprint.

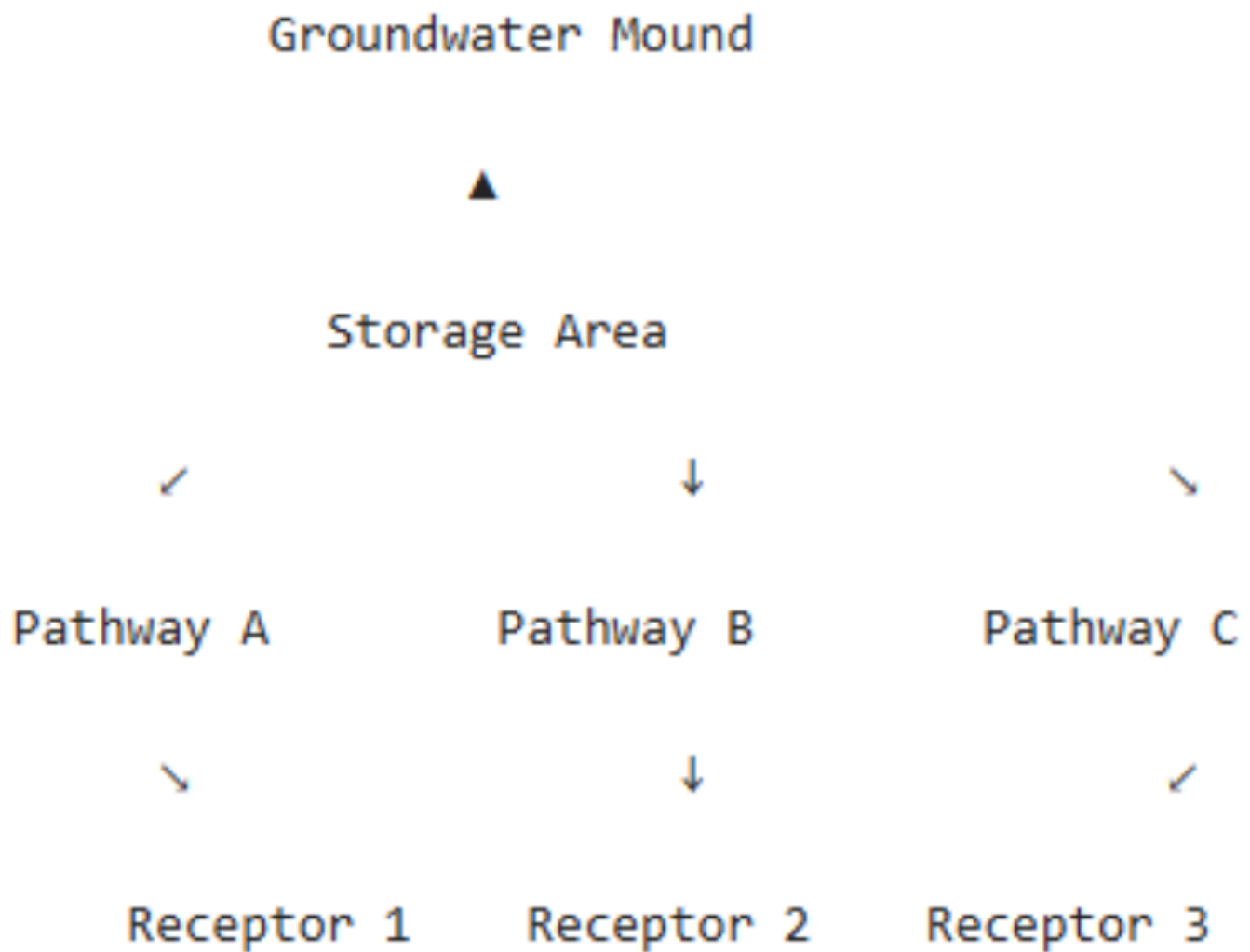


Figure 2

Conceptual groundwater-flow divergence from an engineered groundwater mound showing multiple seepage pathways extending outward from the storage footprint toward different receptors.