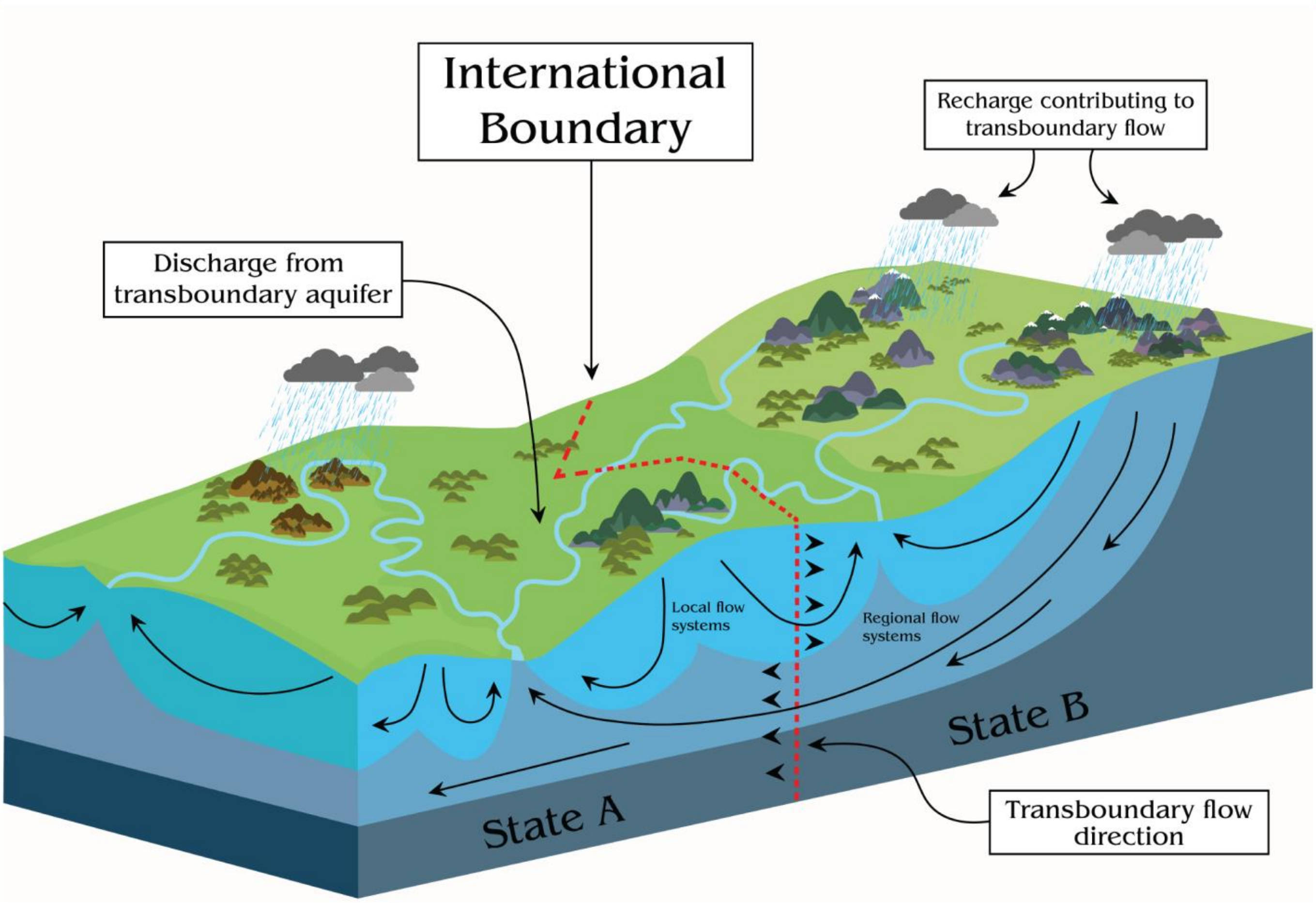

Cross-Border Impacts Related to Transboundary Aquifers:

Characterizing Legal Responsibility and Liability

Gabriel Eckstein and
Yoram Eckstein

THE GROUNDWATER PROJECT

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Characterizing Legal Responsibility and Liability

The Groundwater Project

Gabriel Eckstein

Professor of Law, JD, LLM, M.S., B.A.
Director of the Energy, Environmental, & Natural Resource Systems Law Program
Texas A&M University School of Law
Fort Worth, Texas, USA

Yoram Eckstein

Professor of Hydrogeology (Retired)
Kent State University
Kent, Ohio, USA

Cross-Border Impacts Related to Transboundary Aquifers:

Characterizing Legal Responsibility and Liability

The Groundwater Project
Guelph, Ontario, Canada
Version 3, July 2024

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Thank you.

Published by the Groundwater Project, Guelph, Ontario, Canada, 2024.

Cross-Border Impacts Related to Transboundary Aquifers: Characterizing Legal Responsibility and Liability / Gabriel Eckstein, Yoram Eckstein – Guelph, Ontario, Canada, 2024.
110 pages

ISBN: 978-1-77470-065-5
DOI : https://doi.org/10.21083/978-1-77470-065-5↗.
https://doi.org/10.21083/978-1-77470-065-5

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APA (7th ed.) Citation:
Eckstein, G., & Eckstein, Y. (2024). *Cross-border impacts related to transboundary aquifers: Characterizing legal responsibility and liability*. The Groundwater Project. https://doi.org/10.21083/978-1-77470-065-5.

THE GROUNDWATER PROJECT

Cover Image: Original to The Groundwater Project, 2022.

Dedication

This book is my last collaboration with my father, Yoram Eckstein (1938–2020). I dedicate it to the man who inspired me in so many ways, and who spent much of his life focused on research, education, and sharing of knowledge in hydrogeology.

Gabriel Eckstein

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The Groundwater Project Foreword

The UN-Water Summit on Groundwater, held on 7-8 December 2022, at the UNESCO Headquarters in Paris, France, concluded with a call for Government and other stakeholders to scale up efforts to better manage groundwater. The intent of the call to action was to inform relevant discussions at the UN 2023 Water Conference that was held on 22-24 March 2023 at UN Headquarters in New York City. One of the required actions is *strengthening human and institutional capacity*, to which groundwater education is fundamental.

The 2024 World Water Day theme is '*Water for Peace*', which focuses on the critical role water plays in the stability and prosperity of the world. The UN Water website states that *more than 3 billion people worldwide depend on water that crosses national borders*. There are 468 transboundary aquifers; yet most of these aquifers do not have an intergovernmental cooperation agreement in place for sharing and managing the aquifer. While groundwater plays a key role in global stability and prosperity, it also makes up 99% of all liquid freshwater, so it is at the heart of the freshwater crisis. *Groundwater is an invaluable resource*.

The Groundwater Project (GW-Project) is a registered Canadian charity founded in 2018, committed to the advancement of groundwater education as a means to accelerate action related to our essential groundwater resources. We are committed to *making groundwater understandable* and, with that, enable *building the human capacity for sustainable development and management of groundwater.* To that end, the GW-Project creates and publishes high-quality books about *all-things-groundwater*, for all who want to learn about groundwater. Our books are unique in that they synthesize knowledge, are rigorously peer reviewed, are translated in many languages, and are free of charge. An important tenet of GW-Project books is a strong emphasis on visualization with clear illustrations to stimulate spatial and critical thinking. The GW-Project started publishing books in August 2020, and, by the end of 2023 had published 44 original books and 58 translations. The books are available at gw-project.org↗.

The GW-Project embodies a new type of global educational endeavor made possible through the contributions of a dedicated international group of volunteer professionals from diverse disciplines. Academics, practitioners, and retirees contribute by writing and/or reviewing books aimed at diverse levels of readers including children, teenagers, undergraduate and graduate students, as well as professionals in groundwater fields and the general public. More than 1,000 dedicated volunteers from 70 countries and six continents are involved—and participation is growing. Revised editions of the books are published from time to time. Readers are invited to propose revisions.

We thank our sponsors for their ongoing financial support. Please consider donating to the GW-Project so we can continue the publication of books free of charge.

The GW-Project Board of Directors, January 2024

Foreword

It would be reasonable to expect that competition among water users will intensify, especially when groundwater flows cross political boundaries, but it emerges that cooperation rather than dispute is the norm. In fact, some transboundary agreements have remained in place for decades, even during wartime. However, water quality and supply continue to present challenges. As the focus turns more toward development, protection, use, and conservation, the United Nations has determined that stronger measures are needed to ensure groundwater resource agreements are enforceable and include conflict resolution provisions.

Cross Border Impacts Related to Transboundary Aquifers: Characterizing Legal Responsibility and Liability addresses aquifers and aquifer systems that underlie more than one country: currently, 468 aquifers and aquifer systems in the world have been identified as transboundary. This designation means groundwater in an aquifer beneath one country flows naturally to areas beneath one or more neighboring countries, just as a river can flow from one country to the next.

Transboundary water issues do not occur if the groundwater in a country is withdrawn without influencing the groundwater in the neighboring country. However, if—for example—the drawdown effect of groundwater withdrawal causes an increase in groundwater flow from the upgradient country into the receiving country, a transboundary water issue may ensue. Similarly, a transboundary water issue may develop if contaminated groundwater from one country migrates beneath another country.

Although the number of aquifers identified as transboundary involve more than a hundred countries, the legal aspects are little developed and, beyond the United States, legal precedents have not been established through formal dispute mechanisms. In this book, the authors focus on the concepts of responsibility and liability in diverse cross border circumstances and present numerous scenarios. In each hypothetical example, the hydrogeologic framework is presented as a three-dimensional sketch to visually model the circumstances of the country borders in relation to the groundwater flow or contaminant plumes. The models provide a framework to develop spatial thinking among the readers as a basis for understanding the notion of legal accountability concerning cause and effect. This is the first of a pair of Groundwater Project books concerning transboundary groundwater; the second one—soon to follow—is Identifying International Legal Trends for Managing Transboundary Groundwater Resources (Eckstein, in press).

The authors of this book are father and son with more than 75 years of collective practical, field, and academic experience. Dr. Gabriel Eckstein is a professor of law at Texas A&M University who has spent more than 25 years teaching, researching, and practicing water law and policy at national and international levels. Dr. Yoram Eckstein (1938–2020) was a professor of hydrogeology at Kent State University who spent more than 50 years teaching, researching, and conducting field work in numerous countries around the world. Together, in this book they present the foundation for a broader understanding and application of the factors that need to be considered in transboundary groundwater disputes and agreements and international law and policy.

John Cherry, The Groundwater Project Leader

Guelph, Ontario, Canada, December 2023

Preface

Groundwater resources that traverse political boundaries are now recognized as critical sources of freshwater worldwide. This has created situations in which the use, management, exploitation, pollution, or administration of a transboundary aquifer could result in negative consequences to one or more neighboring states.

Using various conceptual models of transboundary aquifers to assess cause and effect relationships, this book explores issues of responsibility and liability related to such consequences and describes varying scenarios and examples in which one state may be legally accountable to a neighboring state for activities related to a cross-border aquifer. The analysis is entirely grounded in the science of hydrogeology and utilizes notions of gaining and losing stream relationships, unconfined and confined aquifers, cones of depression and areas of influence, natural versus anthropogenic contamination, and other hydrogeological concepts to explain the various scenarios and circumstances that could result in cross-border responsibility and liability.

Upon completion of this book, the reader will:

1. be able to identify potential cross-border consequences resulting from use, management, and mismanagement of transboundary groundwater and aquifer resources;
2. understand the concepts of cross-border responsibility and liability in the context of transboundary groundwater and aquifer resources; and
3. apply the concepts of responsibility and liability in diverse cross-border circumstances and scenarios.

Acknowledgments

We deeply appreciate the thorough and useful reviews of and contributions to this book by the following individuals:

- Claire Tiedeman, Scientist Emeritus, US Geological Survey;
- Jean Fried, Project Scientist, University of California Irving, California, USA;
- Alfonso Rivera, Chair of IAH Transboundary Aquifers Commission; Former Chief Hydrogeologist at the Geological Survey of Canada, Ottawa, Ontario, Canada;
- Dave Owens, Professor of Law, UC Hastings Law, San Francisco, California, USA;
- Kevin Pietersen, Extraordinary Senior Lecturer, University of the Western Cape, Cape Town, Republic of South Africa; and
- Everton de Oliveira, President of Hidroplan, Brazil Director-President of the Instituto Água Sustentável (Sustainable Water Institute), São Paulo, Brazil.

We thank Arielle Kalin for working with us to make excellent figures for this book. I am grateful to Amanda Sills and the Formatting team for their oversight and copyediting of this book. We thank Eileen Poeter (Colorado School of Mines, Golden, Colorado, USA) for reviewing, editing, and producing this book.

Sources of figures and tables are cited when adapted from other published works. Where a source is not cited, the figures or tables are original to this book.

1 Introduction

Groundwater resources that traverse political boundaries (transboundary aquifers or TBAs; Figure 1) have become increasingly important sources of freshwater in international and national arenas worldwide. This growing focus is a direct extension of the rising needs of nations and communities for new sources of water, as well as the impact that excessive extraction, pollution, climate change, and other anthropogenic activities have had on surface waters (Mukherjee et al., 2021). The increasing focus on TBAs is also a function of the growing realization that groundwater respects no political boundaries, and that aquifers traverse jurisdictional lines at all levels of political geography and civil society.

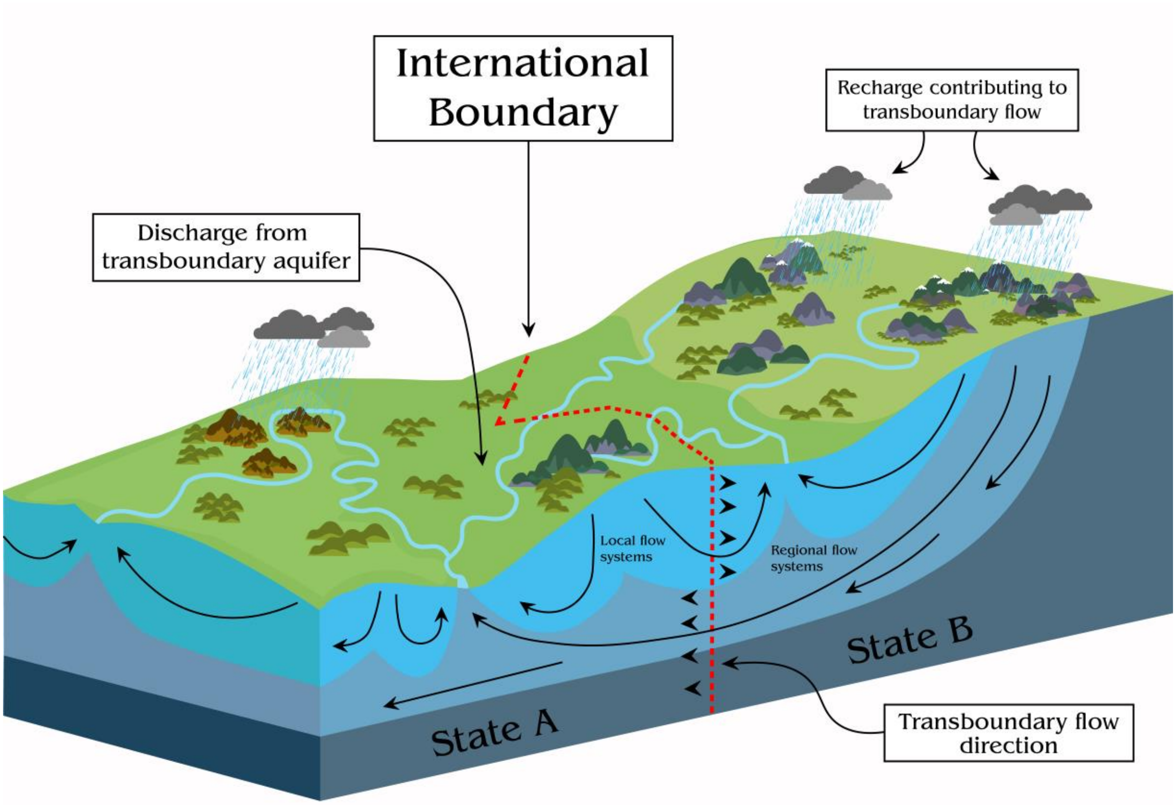


Figure 1 - Example of a transboundary aquifer traversing an international boundary.

A map produced by the International Groundwater Resources Assessment Centre (IGRAC) shows the 468 transboundary aquifers and aquifer systems—those that have been identified globally through 2021 are shown in Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, and Figure 7.

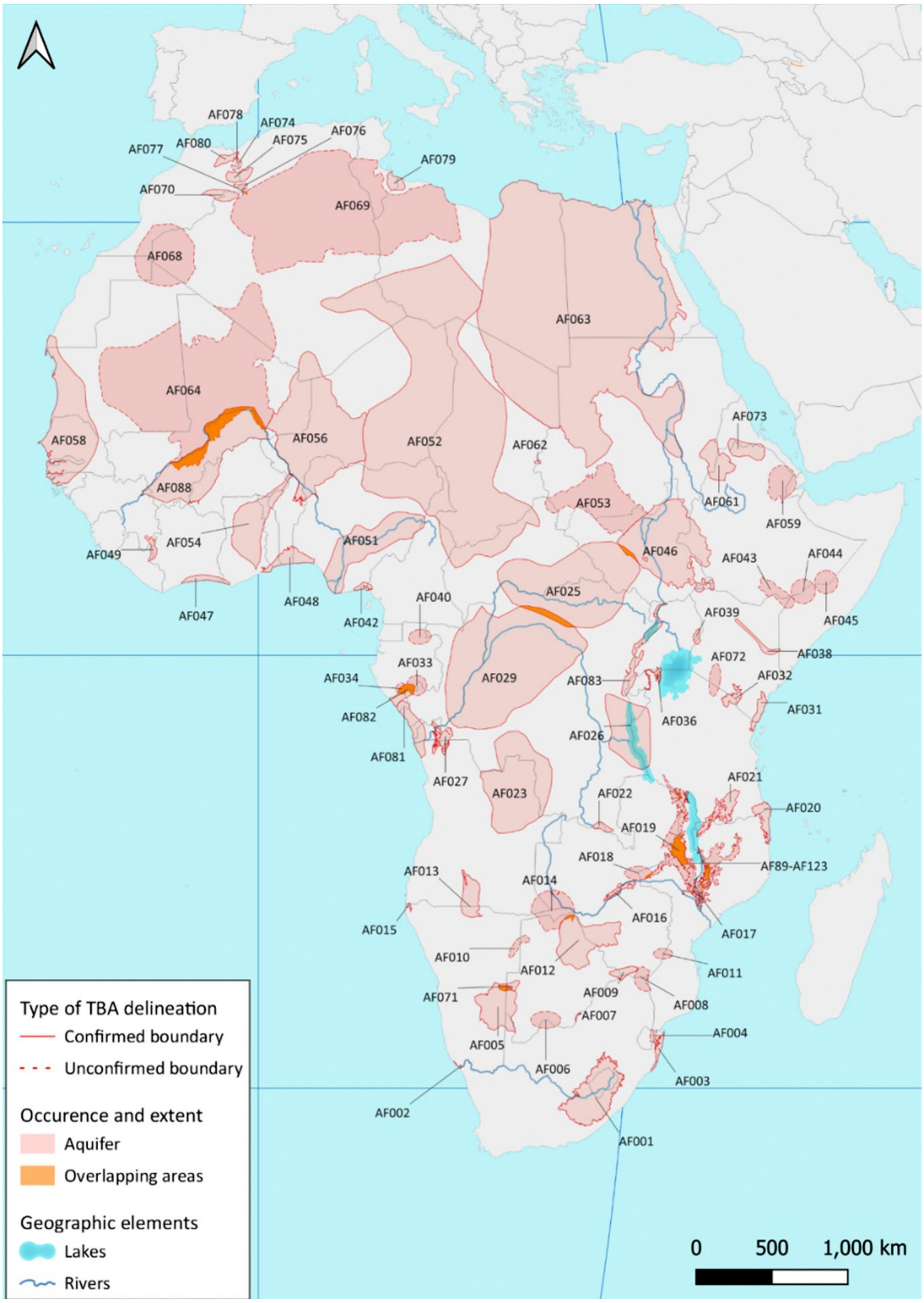


Figure 2 - Transboundary aquifers (TBAs) in Africa (reproduced from IGRAC, 2022). The aquifer labels are defined on the back of the IGRAC map↗.

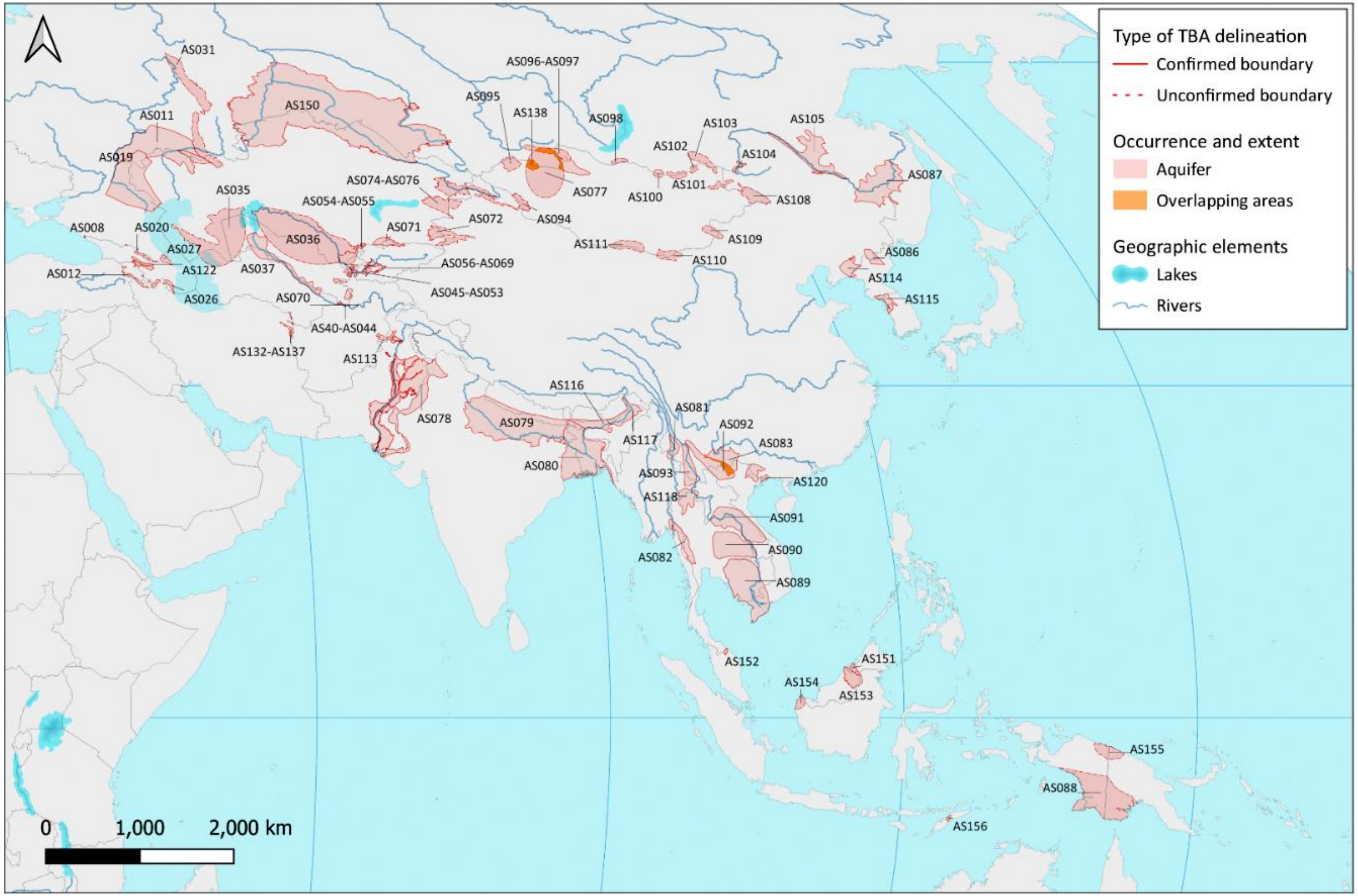


Figure 3 - Transboundary aquifers (TBAs) in Asia and Oceania (Reproduced from IGRAC, 2022). The aquifer labels are defined on the back of the IGRAC map↗.

Figure 4 - Transboundary aquifers (TBAs) of Central and South America (reproduced from IGRAC, 2022). The aquifer labels are defined on the back of the IGRAC map↗.

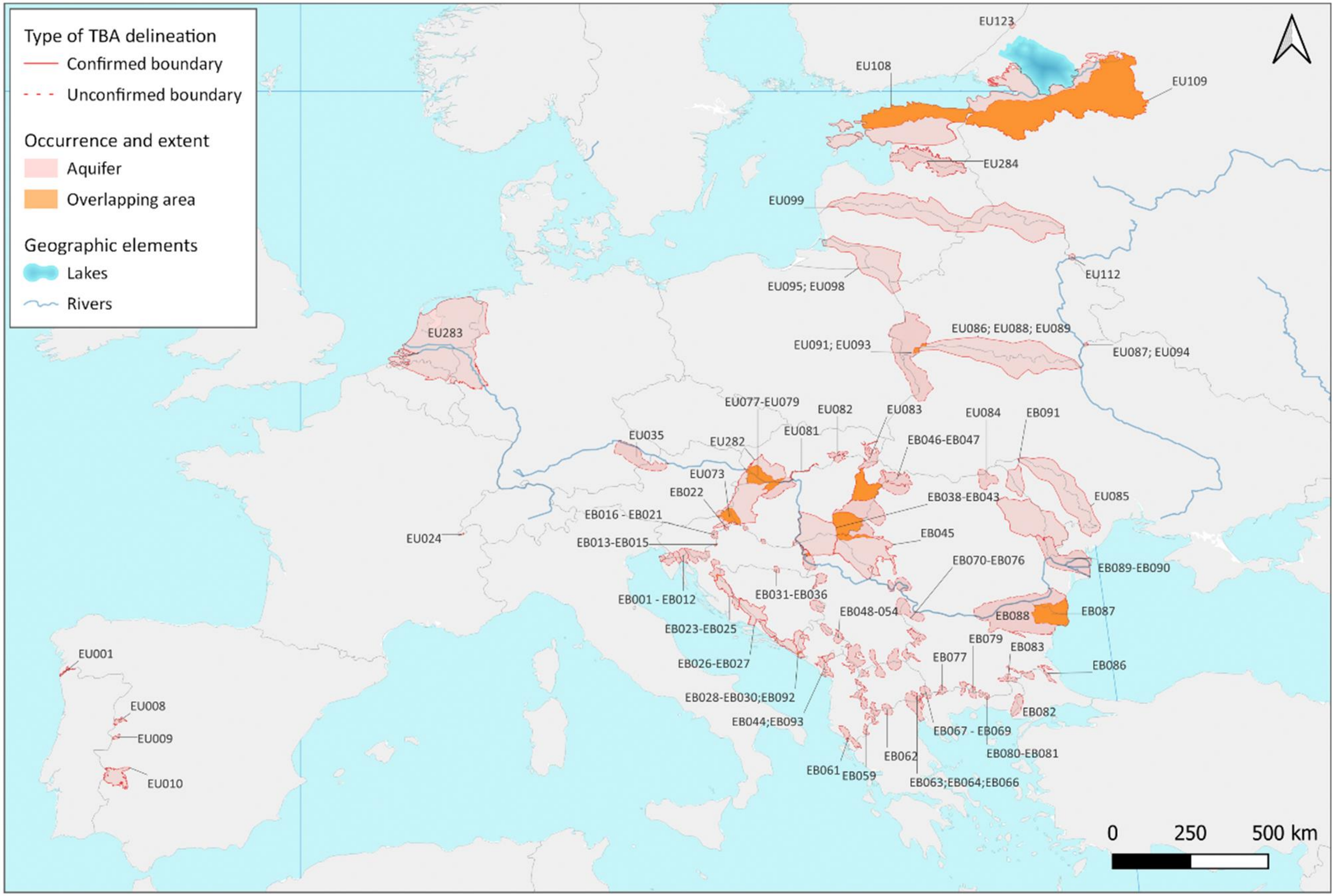


Figure 5 - Transboundary aquifers (TBAs) of Europe (reproduced from IGRAC, 2022). The aquifer labels are defined on the back of the IGRAC map↗.

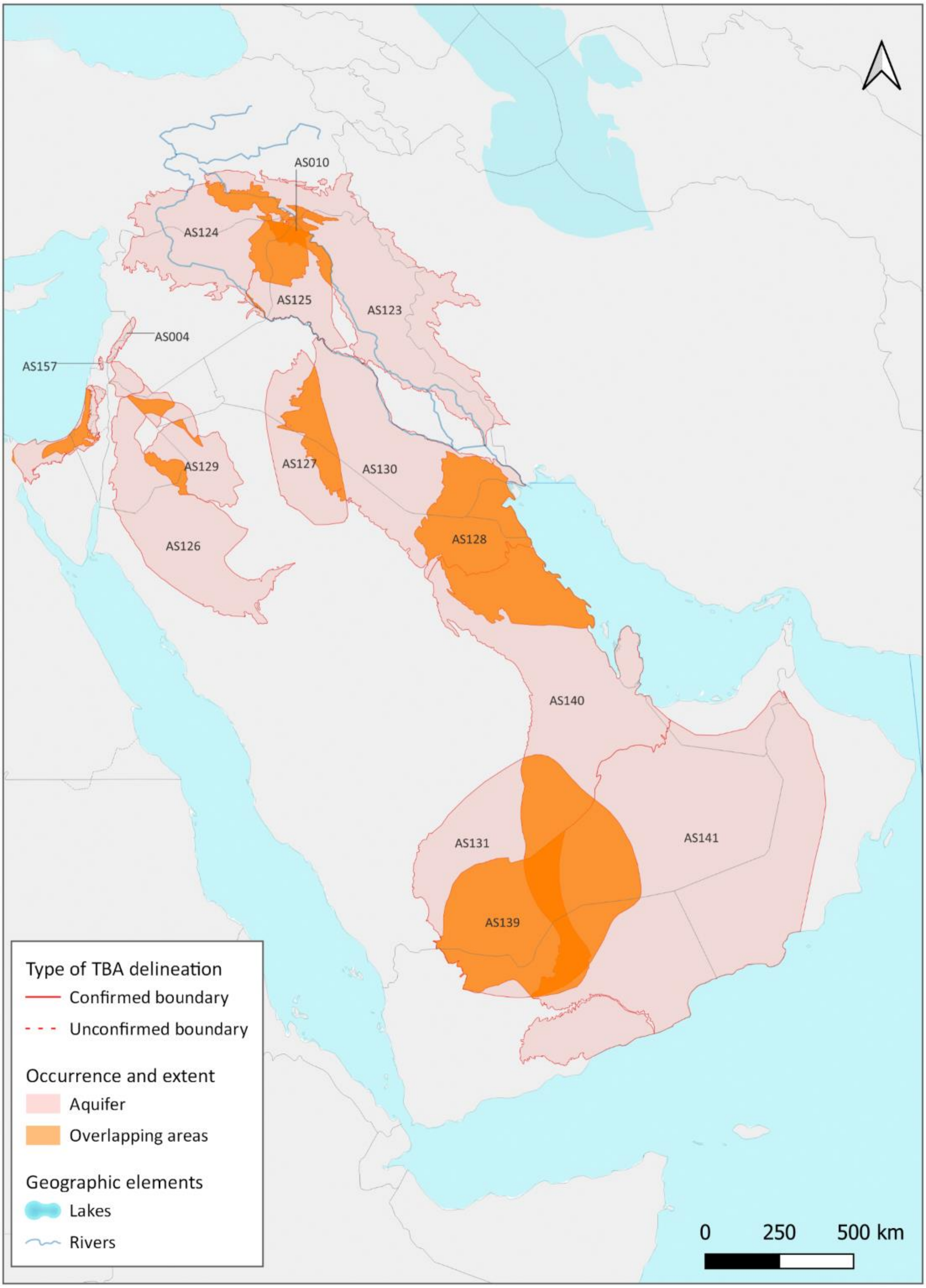


Figure 6 - Transboundary aquifers (TBAs) of Middle East (reproduced from IGRAC, 2022). The aquifer labels are defined on the back of the IGRAC map↗.

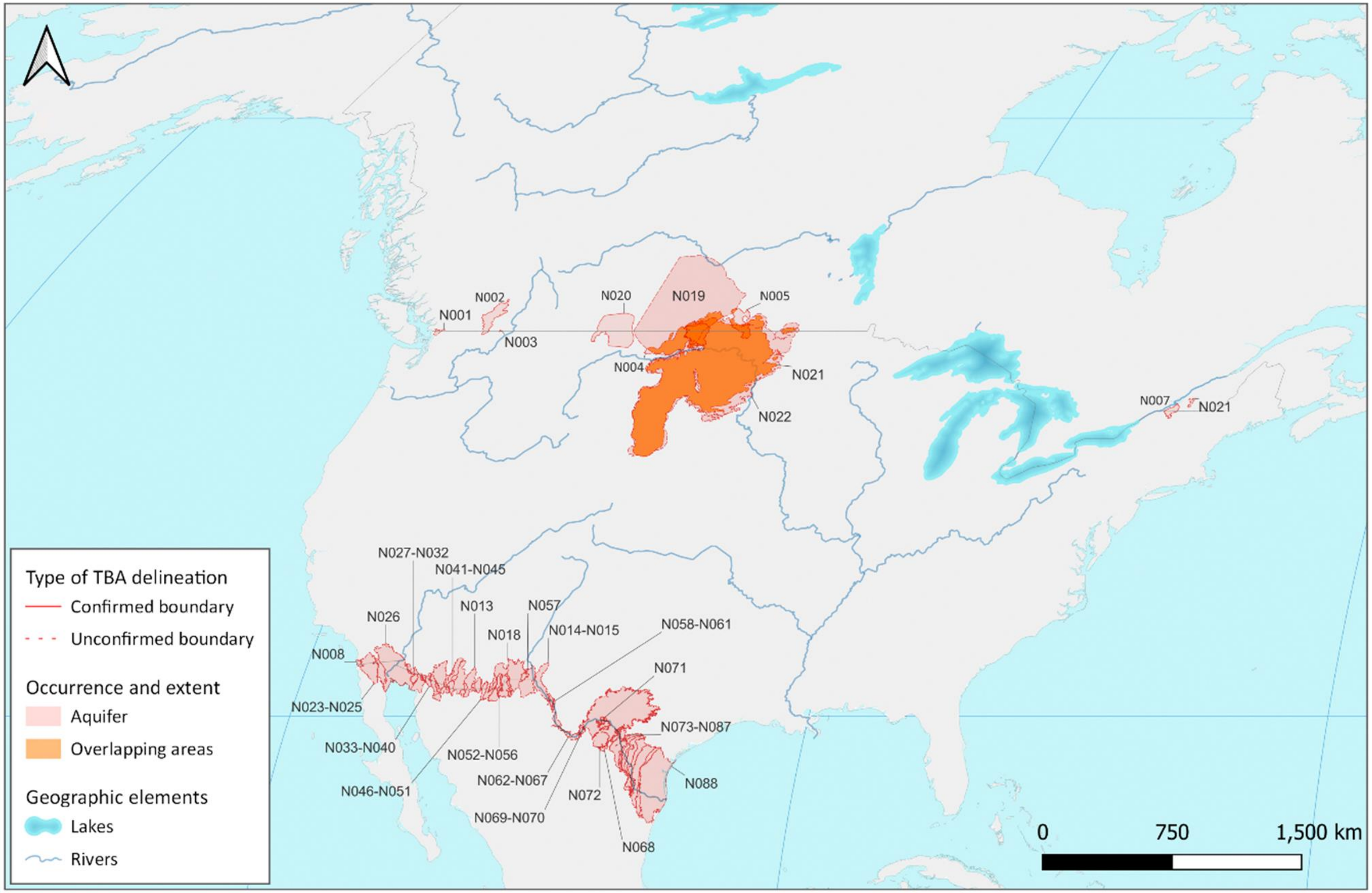


Figure 7 - Transboundary aquifers of North America (reproduced from IGRAC, 2022). The aquifer labels are defined on the back of the IGRAC map↗.

As a result of the growing understanding of TBAs, and transboundary groundwater resources more generally, questions pertaining to responsibility and liability have been raised in relation to the exploitation and administration of groundwater resources that traverse geopolitical frontiers (Hayton & Utton, 1989). This has occurred at both the international level where two or more sovereign nations overlay a common aquifer and at the domestic level where two or more subnational political units overlay a common aquifer.

At the international level, the topic has been addressed at least as early as the 1950s when the International Law Association, a non-governmental professional association, recognized that:

> *Until now international law has for the most part been concerned with surface waters although there are some precedents having to do with underground waters. It may be necessary to consider the interdependence of all hydrological and demographic features of a drainage basin.* (International Law Association, 1958, p. 924)

However, while various scholars explored the topic in academic circles, questions related to the legal rights in and regulation of TBAs remained a secondary or even tertiary priority on the international agenda until the early 2000s, as shown in Table 1 (Eckstein, 2017). That is when the United Nations (UN) International Law Commission (UNILC) began working on what became the Draft Articles on the Law of Transboundary Aquifers (UN General Assembly Resolution on the Law of Transboundary Aquifers, 2008).

Table 1 - Brief history of groundwater in international law (Based on Eckstein, 2017)

Year	**Brief history of groundwater in international law**
Mid-1800s	Earliest, albeit indirect, references to groundwater in international treaties by way of allusions to the rights of the parties to springs in the border region
Mid-1900s	Recognition of the interrelationship between surface water and groundwater begins to appear in international treaties
1978	First treaty exclusively focused on a transboundary aquifer between two nations (France and Switzerland) is ratified
2002	UN International Law Commission undertakes the task of codifying and progressively developing the international law applicable to transboundary aquifers
2008	UN General Assembly issues first resolution on the UNILC's[1] Draft Articles on the Law of Transboundary Aquifers, commending them to the attention of the UN member states for their consideration (repeated in 2011, 2013, 2016, 2019)
2012	UNECE[2] adopts Model Provisions on Transboundary Groundwaters as guidelines for members of the Convention on the Protection and Use of Transboundary Watercourses and International Lakes
2022	UN declares 2022 the year of groundwater under the theme *Making the Invisible Visible*
2022	International law for transboundary aquifers and groundwater resources remains indefinite and without explicit rules for cross-border responsibility or liability for the use, management, exploitation, or administration of a shared aquifer

[1] UNILC: United Nations International Law Commission

[2] UNECE: United Nations Economic Commission for Europe

At the domestic level, relatively few efforts have been made around the world to formulate general standards and models to address the transboundary implications of cross-border aquifers as between two subnational political units. Focusing on the USA, Eckstein and Hardberger (2008) explored the few transboundary aquifer arrangements that exist between states in the USA and identified some commonalities. Hall and Cavataro (2013) considered interstate groundwater law, focusing on the applicability of the US Supreme Court doctrine of equitable apportionment as a mechanism for allocating transboundary aquifers shared between states. Hall and Regalia (2016) then explored the relevance of the US common law doctrine of nuisance to the management of transboundary aquifers through focusing on the dispute between Mississippi and Tennessee over the transboundary Sparta-Memphis aquifer. More recently, Caccese and Fowler (2020) briefly discussed the few examples in the eastern USA of interstate groundwater disputes and river basin commissions that regulate groundwater withdrawals across multiple states and identified lessons learned. Similar analyses over subnational transboundary aquifers in other countries around the world have not been found.

As a result, the law applicable to transboundary groundwater resources at both the international and national levels is quite primitive, incomplete, and at a very early stage of development. There are no definitive rules addressing questions of responsibility and liability in relation to the use, management, exploitation, and administration of a common aquifer underlying two or more nations or subnational political units.

To provide a foundation for the development of such laws and regulations, this book explores the circumstances under which the use, management, or exploitation of a transboundary aquifer in one jurisdiction might cause physical or economic harm to a neighboring political unit and, thereby, might result in legal responsibility and/or liability. We examine the exploitation and management of transboundary groundwater resources from a legal perspective rather than a scientific one.

For hydrogeologists and other water scientists, this approach may seem imprudent to the sound management of groundwater resources. Political lines, laws, and water rights can often be unscientific, artificial creations that have no bearing on flow paths, hydrostatic pressure, or groundwater chemistry. Yet, the reality of modern society is that laws and policies are the tools—albeit blunt ones—most often used by people and communities to manage natural resources.

Notwithstanding the legal perspective, our analysis is grounded in the science of water. We explore cause and effect relationships in the exploitation, contamination, and management of groundwater resources using conceptual models of transboundary aquifers. We then translate that analysis into notions of responsibility and liability that are more common in the legal realm.

As a preliminary matter, it is worthwhile differentiating between responsibility and liability (Table 2). As used in this book, responsibility refers to a legal determination that an actor can be blamed for a particular situation or outcome. Responsibility, however, does not necessarily create an obligation to redress the problem. Thus, a country could be found to be responsible for a cross-border impact but may not be liable to pay for any resulting harm.

Table 2 - Responsibility versus liability defined.

Term	Definition
Responsibility	Legal determination assigning blame
Liability	Legal determination regarding the obligation to take corrective or compensatory measures

In contrast, liability refers to a legal finding that an actor is obligated to take some corrective or compensatory measure to address a particular situation or outcome. In the transboundary context, this can mean anything from halting the offensive conduct to repairing a damaged environment to paying compensation for the harm caused. In most cases, a party can only be deemed liable after it is shown that the same party is responsible for the conduct resulting in the harmful outcome.

2 The Quandary of Mixing Groundwater and Law

Boundaries demarcating the territorial lines of sovereign states and subnational political units typically serve as the basis for those jurisdictions to assert claims to solid natural resources found within their territory. For example, rights to coal, uranium, and other mineral deposits that traverse political frontiers are typically divided in relation to geographic boundaries with each state's or sub-state unit's entitlement directly related to those resources physically found within its territory (Figure 8). However, dividing up fluidic deposits like groundwater between two or more jurisdictions presents unique complications, especially where groundwater is renewable and actively flowing across the frontier.

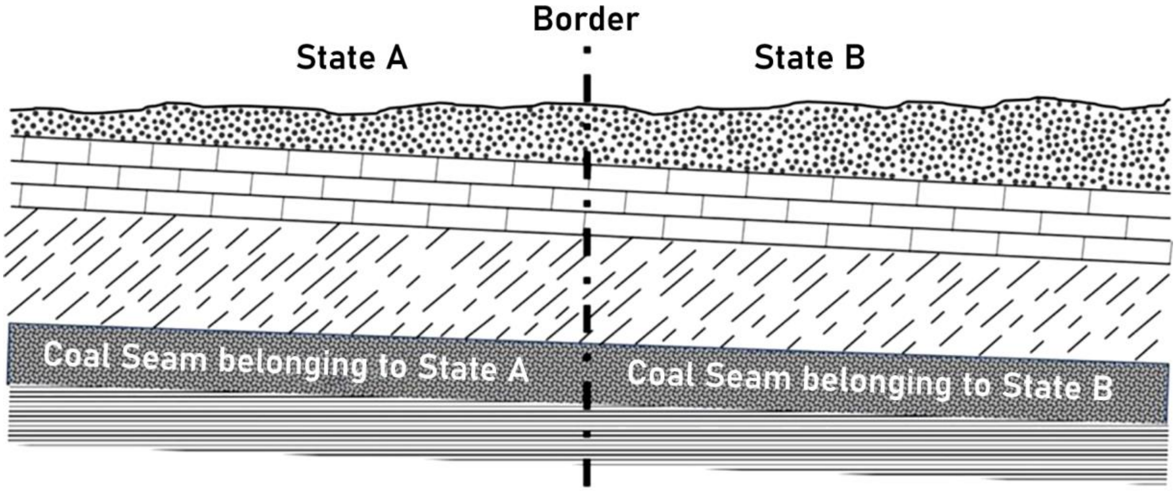


Figure 8 - Rights to mineral deposits that traverse administrative frontiers, such as this coal seam, are typically divided in relation to the political boundaries, with each state or sub-state entitled to those resources physically found underneath its territory.

Groundwater flow does not respect political boundaries, jurisdictional lines, or other artificially drawn demarcations. Rather, it courses toward and through the path of least resistance as a function of permeability, porosity, pressure, and other geological and natural factors (Figure 9). As a result, groundwater flows can traverse international and intranational administrative boundaries, thereby making national and subnational political units riparian to the same aquifer system. In law, a *riparian* is a person or political unit that owns land immediately adjacent to a natural watercourse or body of water, or immediately over an aquifer. In both science and law, an aquifer is a geologically defined formation while groundwater is the fluid moving through that formation. Thus, in a cross-border context with two adjacent political units, a transboundary aquifer is located in and underneath the two political units, the groundwater flows between the two political units, and the two political units are both riparian to the aquifer. A holistic understanding of groundwater science is critical for understanding and assessing rights related to transboundary groundwater resources.

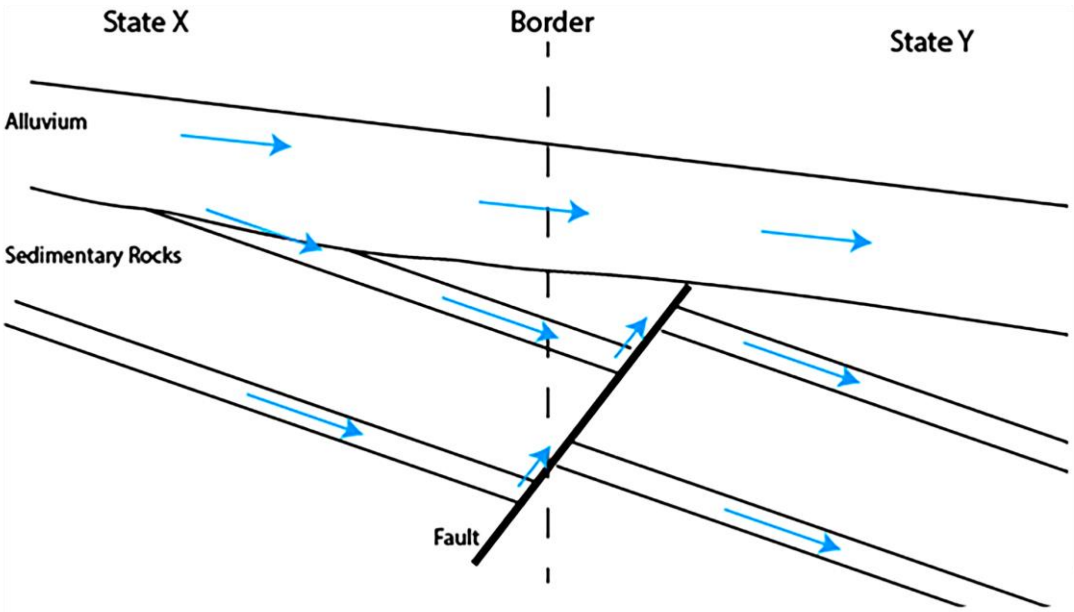


Figure 9 - Groundwater flow—blue arrows show flow directions—beneath States X and Y, with flow traversing the political boundary.

In terms of law, sovereignty, and notions of ownership in groundwater resources, the challenge lies in determining the precise quantities, or rights thereto, that should accrue to each riparian. The situation, however, is further complicated by the fact that groundwater flow occurs unseen, underground, does not typically move in a linear direction, and can be difficult to measure accurately. Thus, for purposes of allocating legal ownership or *usufructuary* rights—the legal right to use but not to own the water—to groundwater resources, it is impracticable even to attempt to attach a point of origin to any drop of water, or to predict the precise moment that a droplet in a transboundary aquifer crosses a political boundary.

In addition, with the possible exception of fossil groundwater (that dates back thousands or millions of years) and connate groundwater (trapped in the pores of a rock during formation of the aquifer), most aquifers are hydrologically linked to the water cycle, and regularly receive water from and transmit water to other components of the system. As a result, an aquifer may be subject to fluctuations in both water quantity and quality in relation to recharge, discharge, precipitation, evaporation, and other changes in the system. This further complicates designation of sovereign and other rights related to transboundary subsurface freshwater resources and requires a holistic understanding of the science of groundwater when assessing legal implications.

Under what circumstances might groundwater or an aquifer raise transboundary legal implications at either the international level or among subnational political units?

What conditions might trigger cross-border consequences, and under what scenarios might they be negated? These queries are the types of questions now being asked by sovereigns at the national and sub-national levels, which necessitate further scrutiny, and are explored in the pages to follow.

3 Law Governing Aquifers that Traverse Political Boundaries

Before discussing the transboundary legal implications of shared groundwater resources, it is necessary first to identify what rights aquifer riparians enjoy.

The international law for managing and allocating transboundary groundwater resources is still in its infancy and the rights of countries to such resources have yet to be fully defined; as yet there is no broadly accepted series of customary norms that encapsulate the rules governing state conduct in this realm (Eckstein, 2017). The most significant attempt to formulate legal norms for the use, management, exploitation, and administration of groundwater traversing international frontiers was undertaken from 2002 to 2008 by the UN International Law Commission: the Draft Articles on the Law of Transboundary Aquifers (UN International Law Commission, 2008; as indicated in Table 1 of this book). That work product was submitted to the UN General Assembly (UNGA) for its consideration and has been on the Assembly's agenda in 2008, 2011, 2013, 2016, 2019 and 2022. Each time, however, the subject matter was commended to the attention of UN member states with further considerations tabled for a future meeting. The Draft Articles were last slated for the UNGA's agenda in the fall of 2026 (UNGA, 2022).

As a matter of substantive international law, based on the Draft Articles and the handful of treaties and arrangements that currently exist for transboundary aquifers around the world, the most that can be said today is that:

1. an aquifer riparian has some yet-to-be fully defined rights to use and enjoy groundwater from an aquifer that underlies both its territory and that of a neighboring jurisdiction; and,
2. when that use and enjoyment interferes with the equivalent rights of the neighboring aquifer riparian to use and enjoy the groundwater underlying its own territory, such rights may be subject to restrictions and possible liability (Eckstein, 2017).

Whether the conflicting rights are grounded in the two cornerstone principles of international water law—equitable and reasonable use, and no significant harm—has yet to be determined. In terms of procedural rights and obligations for the use of transboundary aquifers, four principles appear to be trending toward customary legal acceptance. Eckstein (2017) describes these principles as including the obligations to:

1. regularly exchange data and information about the transboundary aquifer,
2. monitor and generate supplemental data and information about the transboundary aquifer,
3. provide prior notice of planned activities that may adversely affect either the territory of another aquifer riparian or the transboundary aquifer itself, and

4. create an institutional mechanism to facilitate or implement the above obligations.

At the national interstate level, the situation is not much better. The law applicable to such cross-jurisdictional resources necessarily depends on the domestic laws of the country in which the resource is found. In federal systems, where subnational units have some measure of sovereignty over resources and activities occurring within their borders—like those of the USA, India, Brazil, and Australia—the law hinges on the legal relationship between the federal and state governments, as well as the intrastate jurisprudence that may exist in the country. Thus, in the USA for example, disputes over interstate waters can be resolved by the US Supreme Court under the doctrine of equitable apportionment. In fact, that venerable Court recently adjudicated the first case ever decided by any nation's high court involving interstate groundwater resources. In the case of *Mississippi v. Tennessee*, the Court concluded that US states may not exercise exclusive ownership or control over the waters of an interstate aquifer and that such aquifers are subject to equitable apportionment among the overlying riparians (Mississippi v. Tennessee, 2021). As the first case of its kind, there is yet a dearth of experience and jurisprudence from which responsibility and liability for cross-border impacts at the national interstate level can be derived.

Given that the rights and obligations of aquifer riparians are still in their early development and remain inconclusive at all jurisdictional levels, the scrutiny that follows is somewhat crude in that it simply considers various scenarios of cross-border interference with the potential legal rights of neighboring political units. Despite its simplistic approach, the analysis offers some insight into when legal responsibility and/or liability might arise from the use, management, exploitation, or administration of a transboundary aquifer. The focus here is on violations of substantive principles—those that infringe on the rights or, at this stage, the possible rights—of states and can result in physical or economic harm.

These principles are of particular concern when states embark on affirmative activities directly related to an aquifer such as pumping groundwater, intentionally or unintentionally polluting an aquifer, mining an aquifer's matrix, diverting tributary flows that—under natural conditions—feed the aquifer, and managing activities in an aquifer's recharge zone in a manner that affects the volume or quality of natural recharge. Remedies for violations of substantive rights range from halting the offensive conduct to repairing any damage caused to paying compensation for the harm. In this book, we will not consider violations of procedural duties where the remedy typically entails compliance with those obligations.

4 Characterizing Responsibility and Liability for Cross-Border Impacts

Building on Eckstein and Eckstein (2005) and Eckstein (2017), sub-sections of this Section 4 present models of scenarios in which groundwater resources can have transboundary implications. These conceptual models represent the most likely circumstances under which use of an aquifer could have an impact—usually negative but potentially positive—across a political boundary. Through the explication of the models, we highlight and examine specific circumstances for transboundary impacts, and identify responsibility and instances of potential liability. Significantly, the models apply internationally (that is, between nations) as well as among domestic subnational political units. They also are all scientifically valid generic models in that they comport with the current state of knowledge of the science of groundwater.

While this book focuses primarily on aquifers that traverse international political boundaries, the discussion is equally applicable to aquifers that traverse subnational political borders, such as between subnational states. For simplicity, the analysis will use the term *State* when discussing distinct political jurisdictions, whether at the international or the subnational level. Thus, throughout our discussion, the term State can easily be substituted with *nation*, *canton*, *province*, *county*, or other jurisdictional designation to fit the particular cross-border scenario. In addition, the reader should note that many technical concepts are described in particular detail when discussing the scenario labeled Model A, but—to move the discussion along—less so in subsequent sections referencing other models. Hence, a thorough reading of Model A is strongly encouraged in order to better understand the other models.

4.1 Model A: Unconfined Transboundary Aquifer Hydrologically Linked to a Contiguous Transboundary River

Model A (Figure 10) depicts an unconfined aquifer that is linked hydrologically with a *contiguous river*, a river that flows along and forms the border between two riparian states. In this case, the river forms the border between State A and State B. The aquifer is considered transboundary because the geologic formation *and* the groundwater contained within the formation traverse underneath and across the political boundary.

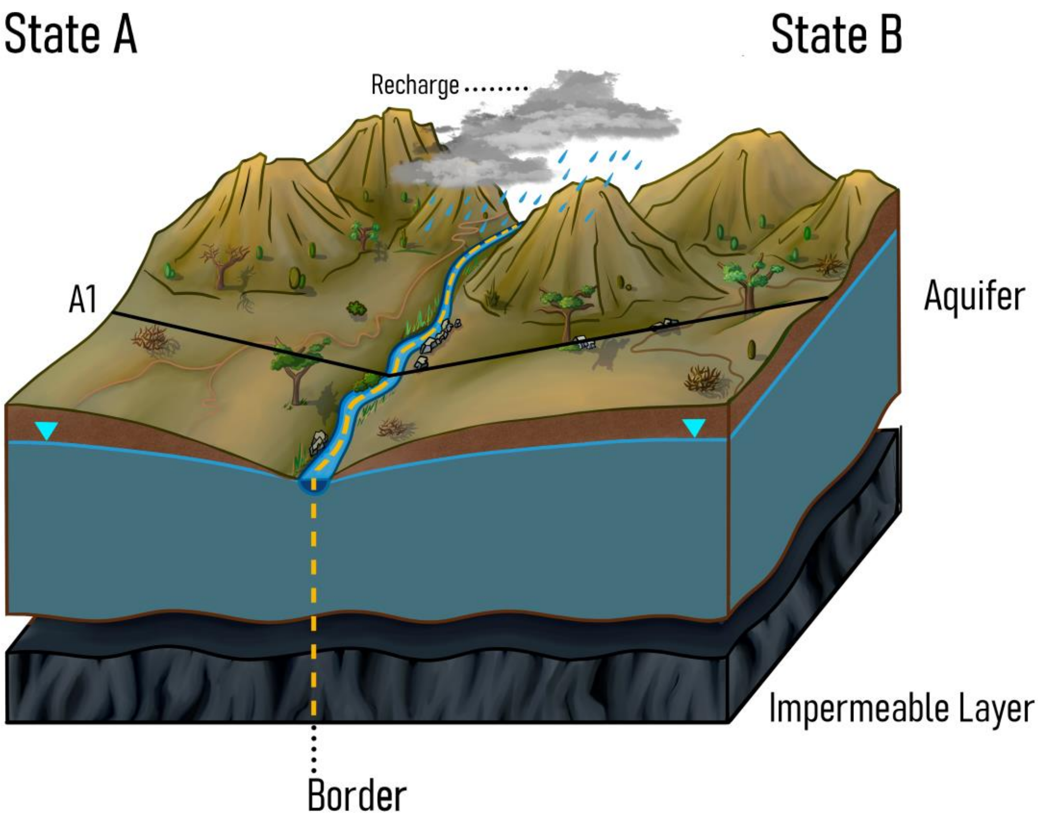


Figure 10 - Model A: An unconfined aquifer hydrologically linked to a contiguous river. The line labeled A1 indicates the location of the cross section referenced in subsequent diagrams.

Figure 11 illustrates the water table and groundwater flow directions along cross section A1 under natural conditions (no pumping), showing that groundwater discharges to the river from both sides of the boundary between States A and B. The river is also deemed to be transboundary where the official boundary between the two states is found within the channel itself—as is true in the vast majority of contiguous river-forming borders—rather than on the bank of one of the riparians, which would make the flow entirely domestic to the other neighboring riparian. In such a scenario, the water within the watercourse is considered to flow both alongside and within both states.

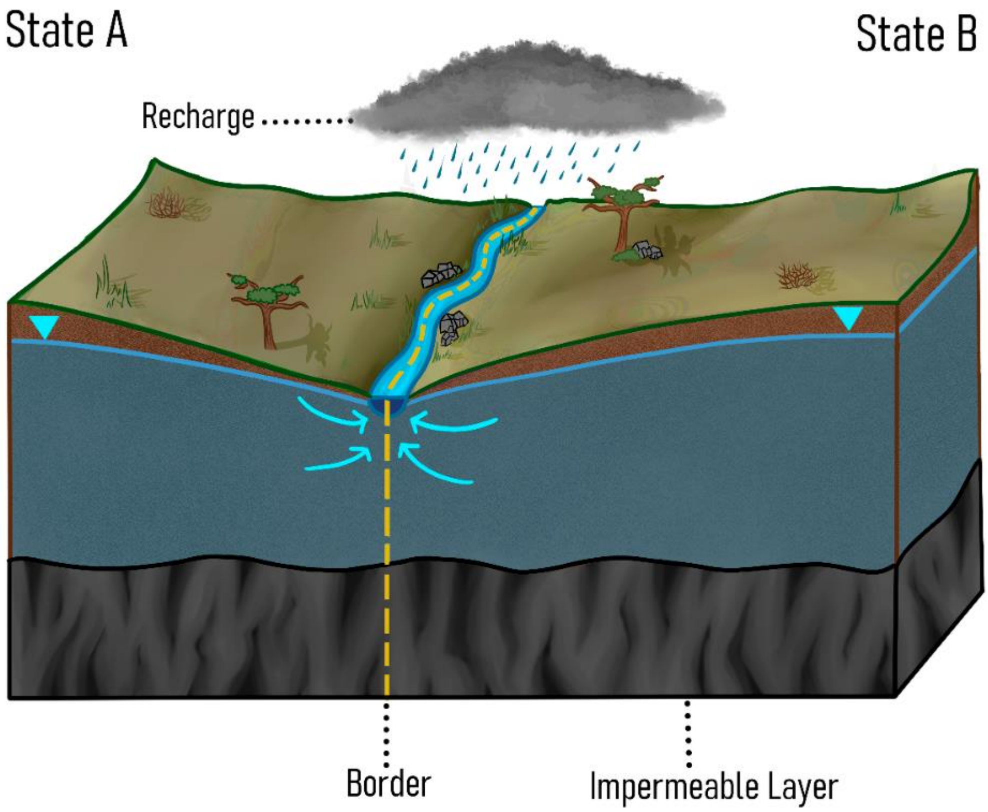


Figure 11 - Model A with a gaining river and natural (no pumping) hydrologic conditions showing the water table and groundwater flow directions along cross section A1. The groundwater system is recharged by precipitation falling on the land surface; all discharge is to the river.

One of the critical geologic characteristics of this model is that the unconfined aquifer is bisected by an interrelated contiguous river. Although the aquifer constitutes a single body of water—parts of which reside on either side of the political boundary—the river's bifurcation of the aquifer precisely along the frontier line, under natural conditions, can minimize the impacts that activities on one side of the border (e.g., State A) may have on the other side (e.g., State B). This is true where the river is either a *gaining stream* (receiving water from the aquifer) or a *losing stream* (leaking water into the aquifer).

For example, consider that State A in Model A has decided to artificially exploit its section of the transboundary aquifer by drilling one or more wells in the vicinity of the border. Also assume, as suggested in Model A, that the contiguous river bisecting the unconfined aquifer is a gaining stream. The outcome of this illustration depends largely on the extent of State A's extraction activities and results in three possible scenarios that are displayed in Figure 12, Figure 13, and Figure 14. Of the three, the second (Figure 13) and the third scenario (Figure 14) result in a negative transboundary impact that may be actionable under law.

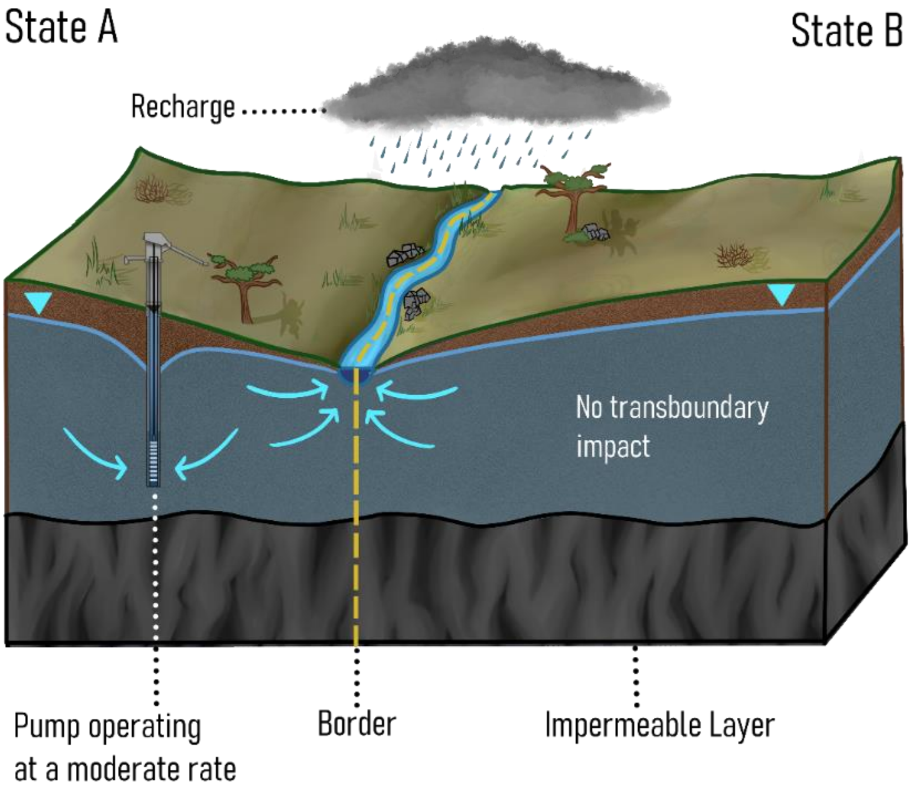


Figure 12 - State A pumps at a moderate rate in Model A with a gaining river, producing the water table configuration and groundwater flow directions shown along cross section A1. The area of influence—the area around the well that is affected by pumping of the well—does not reach the river; there is no impact on the river flow until groundwater stored in the zone of pumping is depleted and the system approaches steady-state conditions. Ultimately the river flow will decrease no more than the pumping rate which captures recharge that would have gone to the river. The decreased stream flow may be less than the pumping rate because depression of the water table may decrease the loss of groundwater to evapotranspiration. Therefore, there is no transboundary impact on State B.

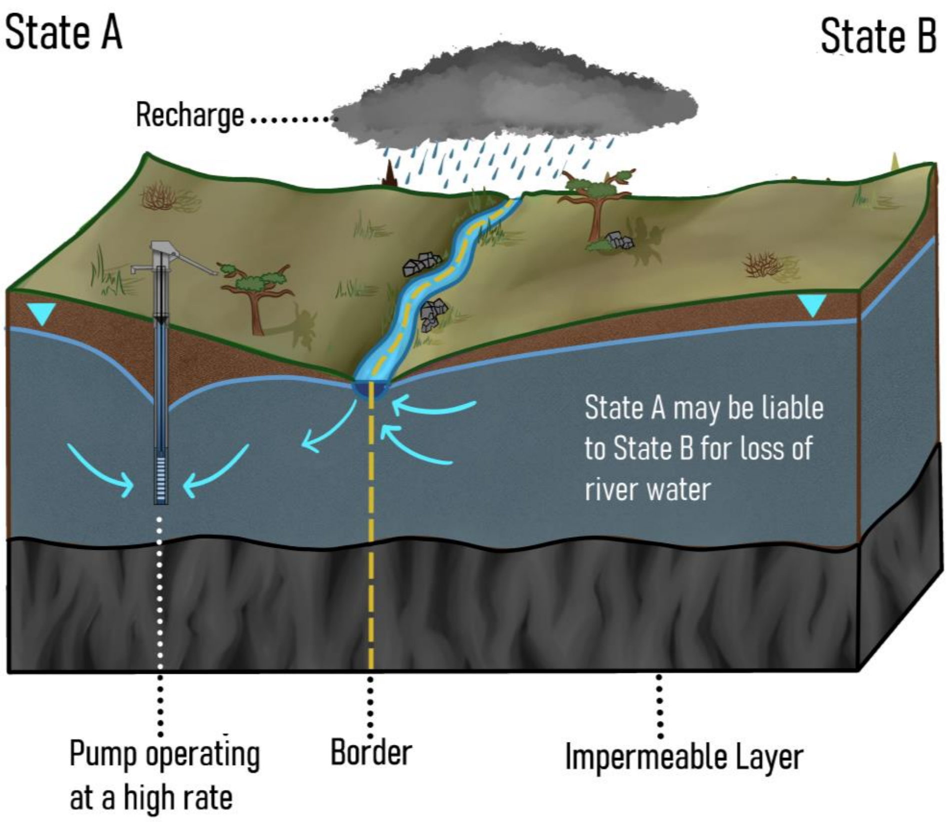


Figure 13 - State A pumps at a high rate in Model A with a gaining river, producing the water table configuration and groundwater flow directions shown along cross section A1. The area of influence of the pumping well extends to the river, causing some of the water flowing in the river to seep into the groundwater system thus decreasing the river stage compared to the previous scenario (Figure 12). Because of the decreased flow in the river, State B has a possible liability claim against State A for loss of use of river water.

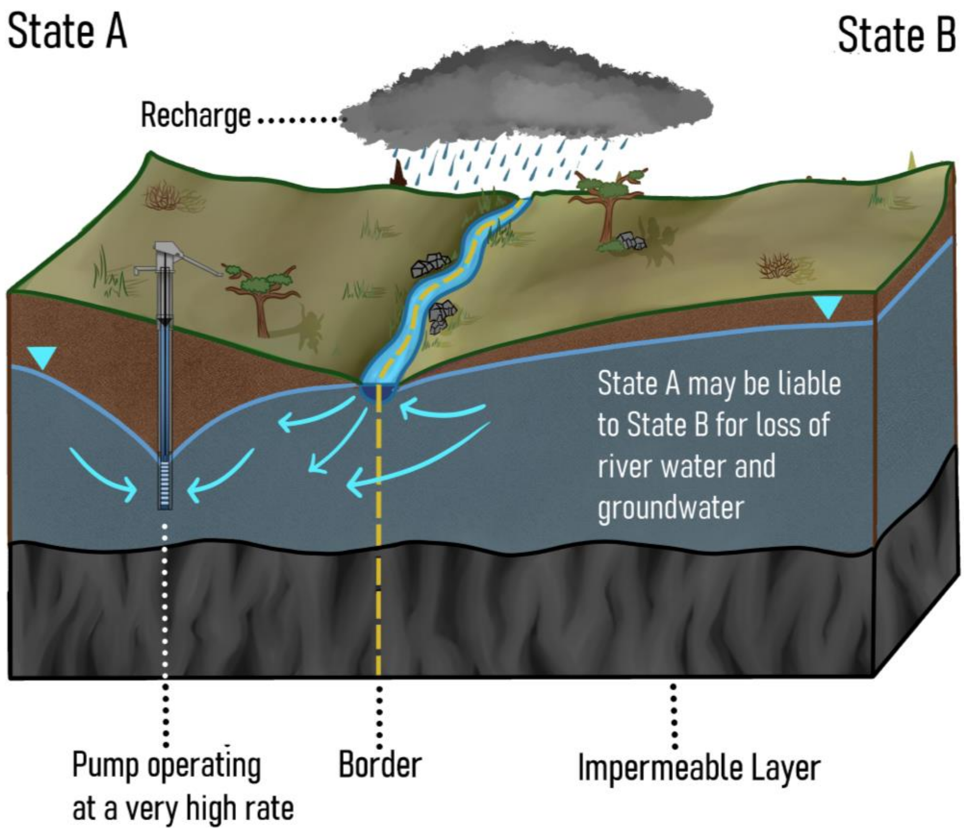


Figure 14 - State A pumps at a very high rate in Model A with a gaining river, producing the water table configuration and groundwater flow directions shown along cross section A1. The area of influence of the pumping well extends beyond the river and into State B, depleting groundwater storage underneath State B and causing groundwater to flow across the boundary from State B to State A. The flux from the river to the aquifer increases compared to the previous scenario (Figure 13), causing lower river levels. State B has a possible liability claim against State A for loss of use of both river water and groundwater.

In the first scenario, where the artificial extraction from the well in State A occurs at a moderate rate in relation to natural recharge, the hydraulic potential of the aquifer, combined with the downstream flow of the contiguous river, would buffer quantity and quality effects on both sides of the boundary (Figure 12). Since the flow direction in a gaining stream is from the aquifer to the river, extraction from the aquifer in State A at such a moderate rate would have little if any impact on the aquifer section in State B or on the binational river. As a result, transboundary impact in this scenario would be insignificant and, thus, no basis for a legal claim.

In the second scenario, the rate and volume of groundwater pumping in State A intensifies to the point that the area of influence around the well extends to the river, though not beyond it (Figure 13). Here, the impact of the artificial extraction activities could affect the river by causing its gaining relationship with the aquifer to change to a losing association within the cone of depression. As a result, some of the water that had flowed in the river under natural conditions would now be pulled into the aquifer and toward the well on State A's side of the border. In this sense, State A would be responsible for the localized, cross-border impact. To the extent that this has a significant impact on State B's ability to use or enjoy its equitable and reasonable share of the water from the transboundary river, State B also might have a liability claim against State A.

It is noteworthy that in this second scenario, the cone of depression is located only in State A (Figure 13). As a result, on the opposite side of the aquifer in State B, the side not being pumped, the river will continue its natural gaining relationship with the aquifer. Similarly, other sections of the river that lie outside of the area of influence—on both sides of the river, both upstream and downstream of State A's well—will also maintain their natural flow paths and gaining relationship with the aquifer and will encounter no impact from State A's pumping activities.

The second scenario sets the stage for the third scenario, where State A's artificial extraction activities are so considerable that the pumping well's area of influence extends across the border into State B. In this scenario, pumping in State A would have an impact on both the river and the aquifer within State B (Figure 14).

Because the area of influence extends across the border, the river could change from a gaining to a losing relationship with the aquifer within the cone of depression on both sides of the river and, thereby, in both states. As in the second scenario (Figure 13), to the extent that this has a significant impact on State B's ability to use or enjoy its equitable and reasonable share of the river's water, State B might have a claim for liability against State A. In addition, because the cone of depression extends into State B, the pumping in State A could change the natural flow path of the aquifer within the cone's area of influence and cause groundwater to flow from State B across the border into State A. Where that flow significantly impacts State B's ability to extract, use, or enjoy the aquifer's water, State A may be liable to State B.

Figure 12, Figure 13, and Figure 14 each show conditions at a single point in time; however, in aquifers subject to pumping, flow paths change over time as pumping proceeds. A series of videos is provided showing time-varying flow paths under pumping conditions in a transboundary aquifer that is similar to Model A:

- Video 1 (Figure 15) shows a cross-section view.
- Video 2 (Figure 16) shows a three-dimensional view.
- Video 3 (Figure 17) shows both views and includes explanations of changes that occur as pumping proceeds.

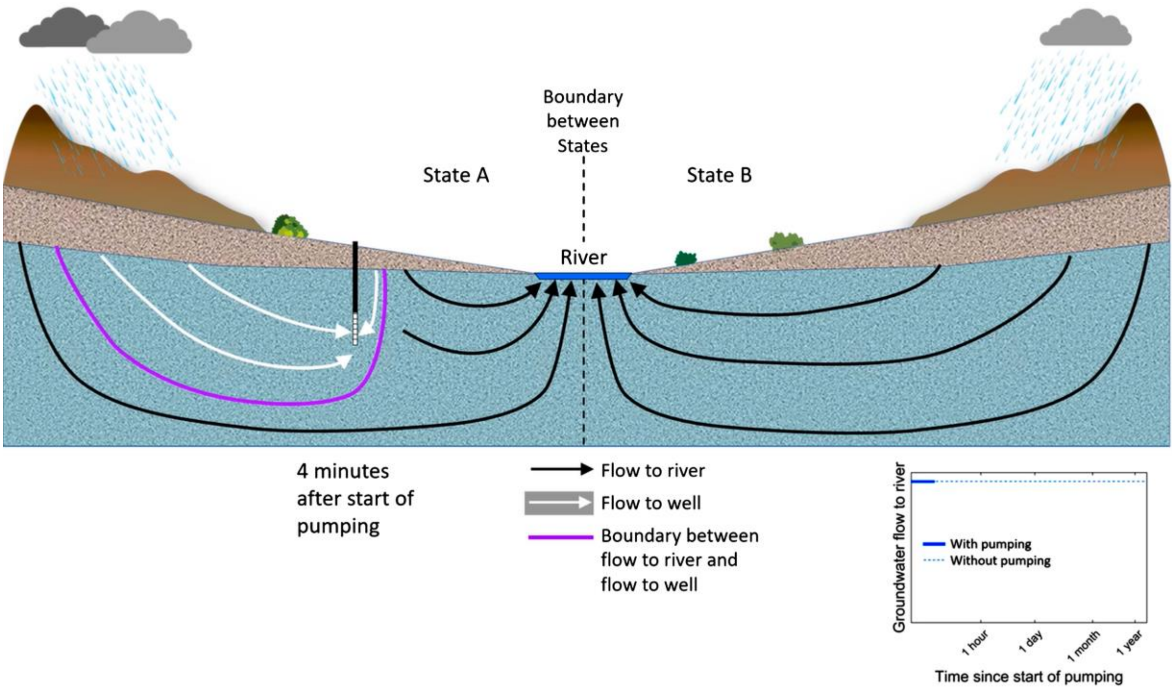


Figure 15 - This image is taken from a video showing an animation of time-varying groundwater flow paths under pumping conditions in a transboundary aquifer connected to a gaining river that are similar to Model A. The video is available by clicking on the link in this caption that is indicated by the white arrow in the red box.

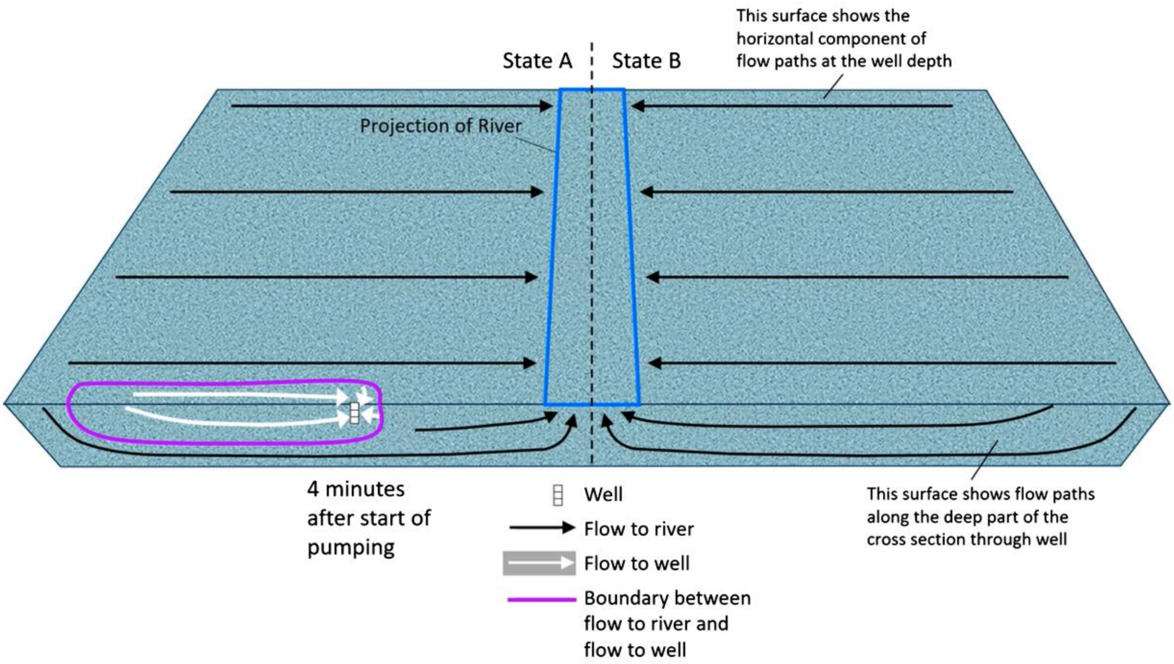


Figure 16 - This image is taken from a video showing an animation of time-varying groundwater flow paths deep within a transboundary aquifer connected to a gaining river under pumping conditions that are similar to Model A. This view depicts the horizontal component of flow on a plane at the depth of the well with the location of the river at land surface projected down to this depth, and it shows flow along a cross section through the well. The video is available by clicking on the link in this caption that is indicated by the white arrow in the red box.

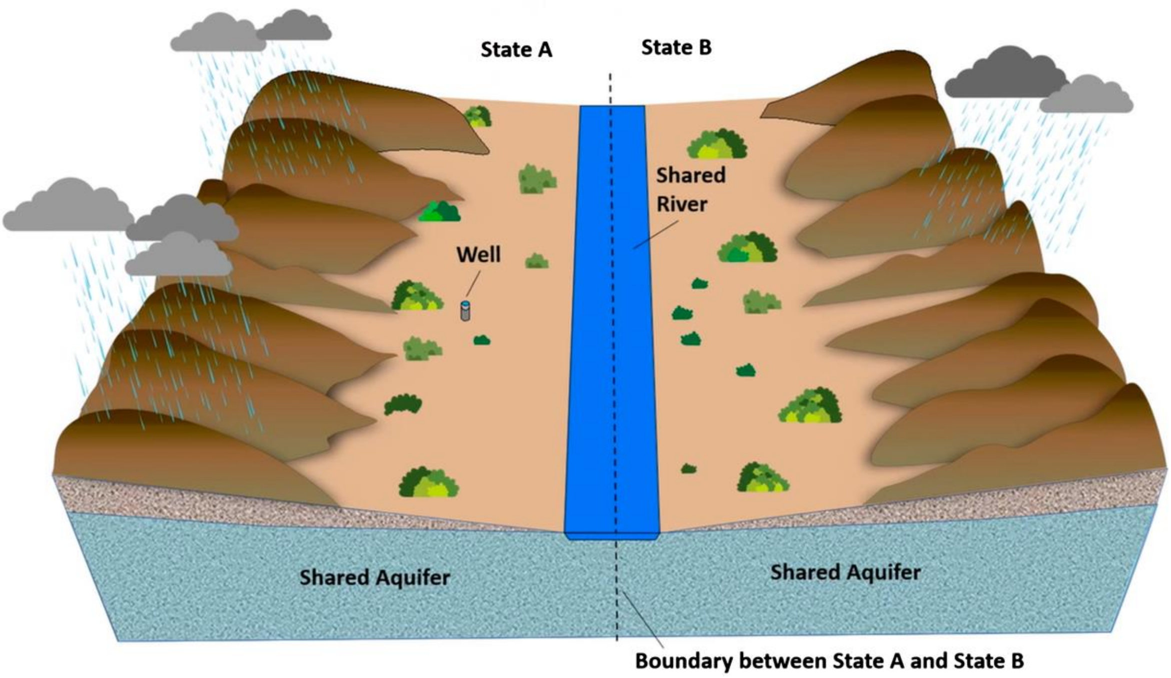


Figure 17 - This image is taken from a video showing an animation of a hypothetical transboundary aquifer connected to a gaining river. Both the aquifer and river are shared by States A and B. This video will illustrate how groundwater flow changes when State A pumps from a well near the boundary. The video is available by clicking on the link indicated by the white arrow in the red box in this caption.

While the discussion to this point addresses the potential transboundary consequences to water quantity, there also could be water quality issues. A transboundary aquifer hydrologically linked to a contiguous gaining river could cause negative, cross-border water quality concerns. A naturally flowing, gaining, contiguous river bisecting an unconfined aquifer will impede pollutants and other negative traits on one side of the aquifer from crossing over to the other side by drawing them into the river. Thus, if one of the riparian states introduces pollutants into the river (Figure 18), because of the gaining relationship of the river to the aquifer, the aquifer in the other state would not be contaminated. Of course, the state introducing the pollution would be responsible and potentially liable for any consequences in and to the river, as well as to riparians utilizing the river downstream from the point of contamination. Similarly, if State A artificially introduced pollutants into the aquifer within its own territory, those contaminants could be drawn into and contaminate the river since the river is gaining (Figure 18). That too could result in liability for State A.

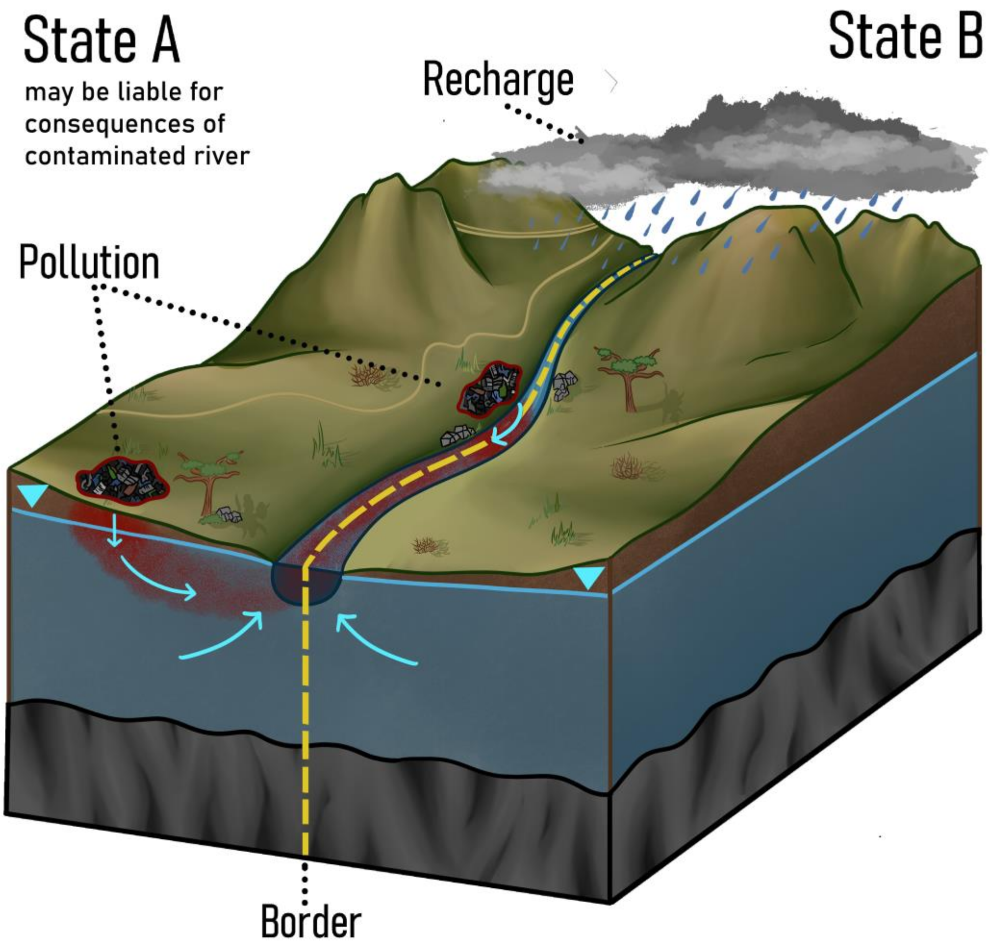


Figure 18 - Under natural (no pumping) conditions in Model A with a gaining river, pollution at the land surface enters the underlying groundwater and migrates to the river. The front face of the image shows groundwater flow and the pollution plume along cross section A1. State B and downstream river users have a possible liability claim against State A for the consequences of the polluted river.

Building on this example, we assume that after State A pollutes the aquifer on its side of the border, State B begins extracting groundwater from within its territory at a substantial rate such that its area of influence extends across the border into State A (Figure 19). As the area of influence of State B's well expands across the border, it begins to draw contaminated groundwater from underneath State A and causes it to migrate across the border toward the pumping well, thereby contaminating the aquifer in State B. In this scenario, State A could be deemed responsible for the contamination of the aquifer in State B. However, whether liability should be imposed on State A for contaminating State B's portion of the aquifer would depend on additional facts and circumstances. For example, if State B knew about the contamination in State A prior to pumping the aquifer, but nevertheless continued its intense pumping activities, it may be deemed responsible for the migration; therefore, it would have no claim of liability against State A. Alternatively, if State A knew about the artificial contamination in its territory and the likelihood of it flowing across the border in response to pumping in State B, and if State A is found to have failed to provide that knowledge to State B in a timely manner, State A might be deemed liable for some or all of the transboundary harm to State B. Likewise, if State A is deemed responsible for accelerating or amplifying the cross-border flow through some intervention, that also could result in a finding of liability for State A. In contrast, if State B is found to have accelerated or amplified the cross-border flow through its activities, State B may be deemed responsible for the transboundary migration of the contaminants, which may absolve State A of some or all responsibility and liability.

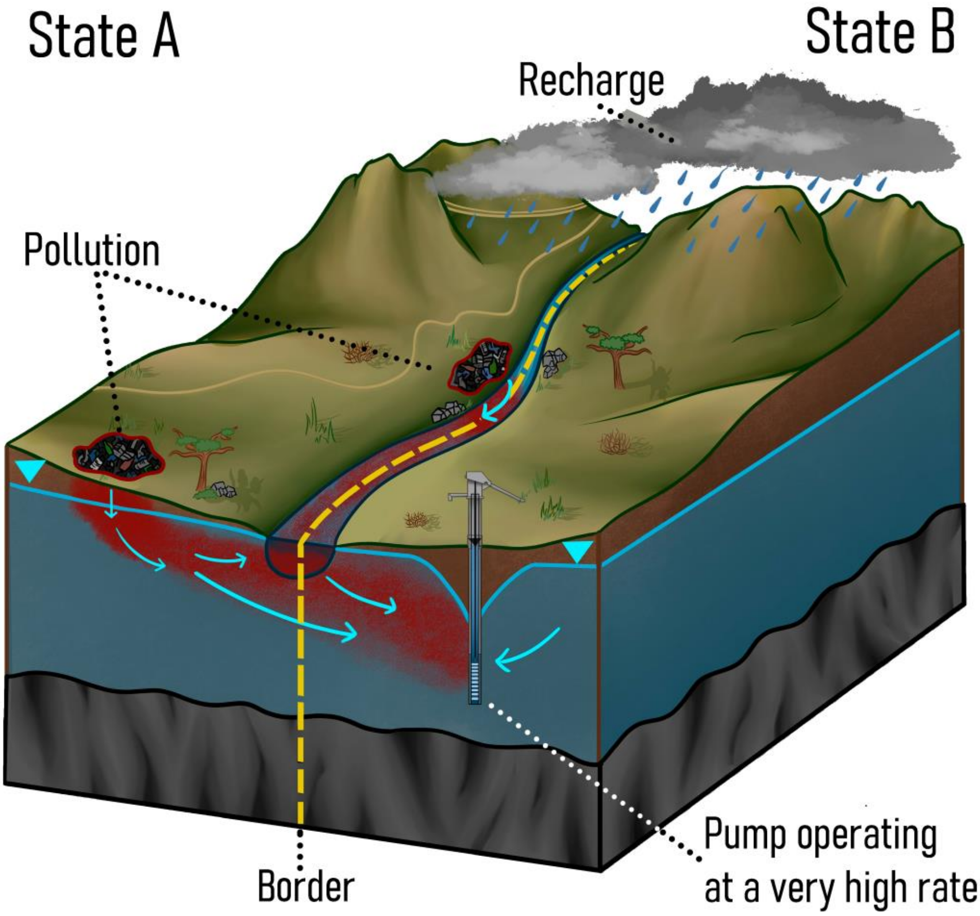


Figure 19 - State B pumps at a very high rate in Model A with a gaining river, pollution at the land surface enters the groundwater beneath State A, and contaminated groundwater in State A discharges to the river. The front face of the image shows groundwater flow and the pollution plume along cross section A1. The area of influence of State B's pumping well extends across the boundary to State A, and contaminated groundwater is drawn into State B's well; some contaminated groundwater also discharges to the river. Liability for this scenario depends not only on the hydrologic conditions but also on additional circumstances such as the knowledge provided by one State to another. For example, State A may be liable for the consequences of a contaminated river and aquifer; however, if State B knew about the contamination prior to pumping, that could weaken its claim. On the other hand, if State A failed to notify State B of the pollution, that could strengthen State B's claim.

In a somewhat similar but distinct scenario, consider a situation in which negative characteristics are naturally found in State A's section of the aquifer—such as native arsenic or fluoride. Using our example in Model A of a transboundary aquifer hydrologically linked in a gaining relationship to a contiguous river, those contaminants could be drawn into and contaminate the river. Like the immediately preceding example, responsibility and liability would depend on several factors.

In the simplest scenario in which both states take no or little action in relation to the aquifer, because of the natural origin of the contaminants, State A would not be liable to State B or any downstream state for any deleterious consequences suffered from the natural migration of that contaminant into the river or into State B's segment of the aquifer. However, responsibility and potential liability could arise if State A undertakes conduct that accelerates or amplifies that flow and thereby causes harm to State B or downstream riparians.

In contrast, if State B itself undertakes any action that accelerates or amplifies that migration, such as pumping from the aquifer inside its territory, State A would not be liable for harm resulting to State B. A possible exception to this last scenario might occur where State B has no knowledge of the natural contaminants in the aquifer in State A, and State A knows of their presence and knows that State B's pumping would cause the migration of the pollutants but fails to provide that information to State B in a timely manner.

While the scenarios provided in this discussion describe transboundary implications that begin from a baseline in which a contiguous river and a hydrologically linked aquifer have a gaining relationship, cross-border consequences can also arise for cases with a baseline in which the river loses water to the aquifer. In such an example, the flow paths of groundwater within the aquifer would typically move parallel to or away from the river boundary (Figure 20).

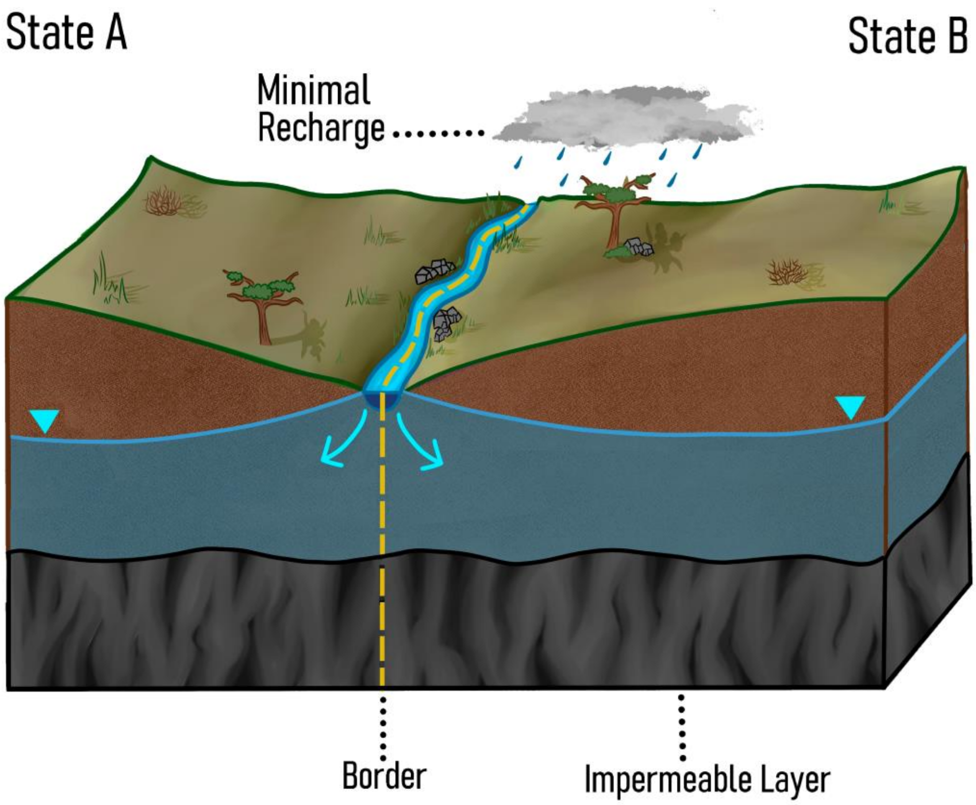


Figure 20 - Model A with a losing river and natural (no pumping) hydrologic conditions, showing the water table and groundwater flow directions along cross section A1.

In this case, artificial extraction activities within State A would not affect the aquifer section located in State B (Figure 21) so long as the pumping is less than the aquifer's natural capacity to replenish itself. If extraction in State A were excessive, the impact would first affect the boundary river by enhancing the losing relationship within the cone of depression's area of influence by drawing additional water from the river—beyond natural infiltration—in the direction of the well until the water table completely falls below the bed of the river (Figure 22). That action could result in a transboundary consequence since State A would reduce the flow and volume of water in the watercourse, which would be felt downstream on both sides of the border. While such action would evidence State A's responsibility for the outcome, if this diverted flow has a significant impact on State B's ability to equitably and reasonably use and benefit from the river's water, State B might have a liability claim against State A.

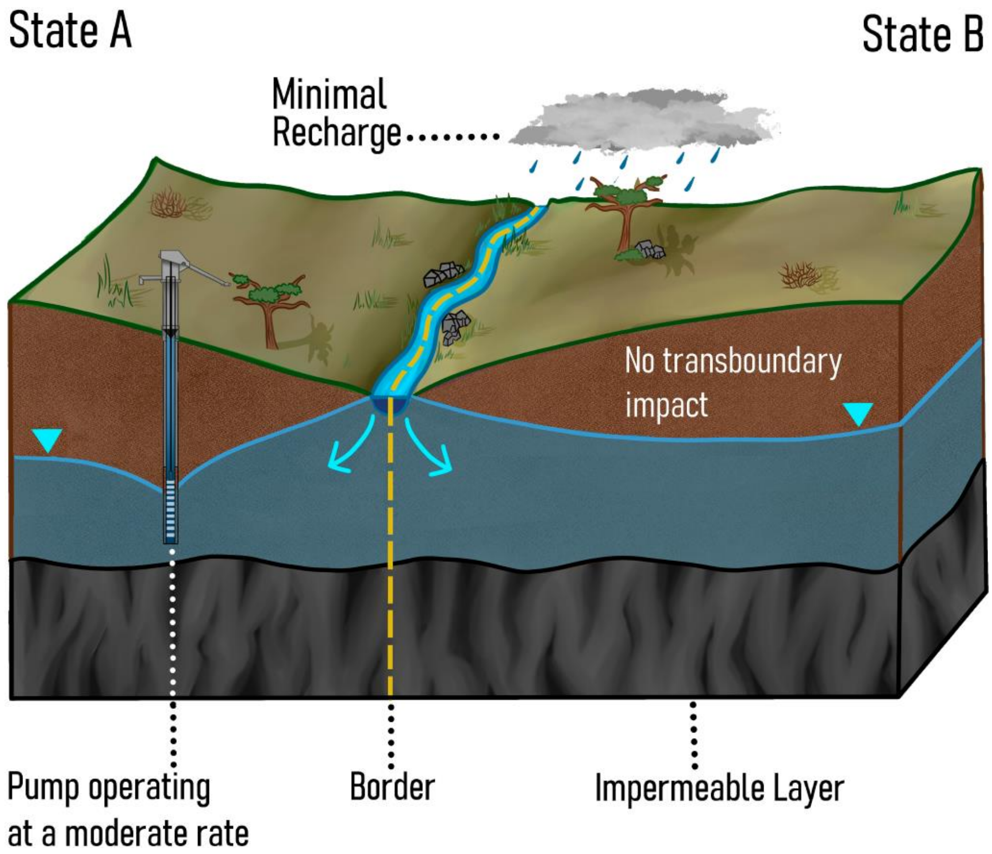


Figure 21 - State A pumps at a moderate rate in Model A with a losing river. Its pumping activities exceed the aquifer's natural capacity to replenish itself, producing the water table configuration and groundwater flow directions shown along cross section A1 on the front face of this image. The area of influence for the pumping well does not reach the river, and there is only minimal impact on the river flow. Therefore, there is no transboundary impact on State B.

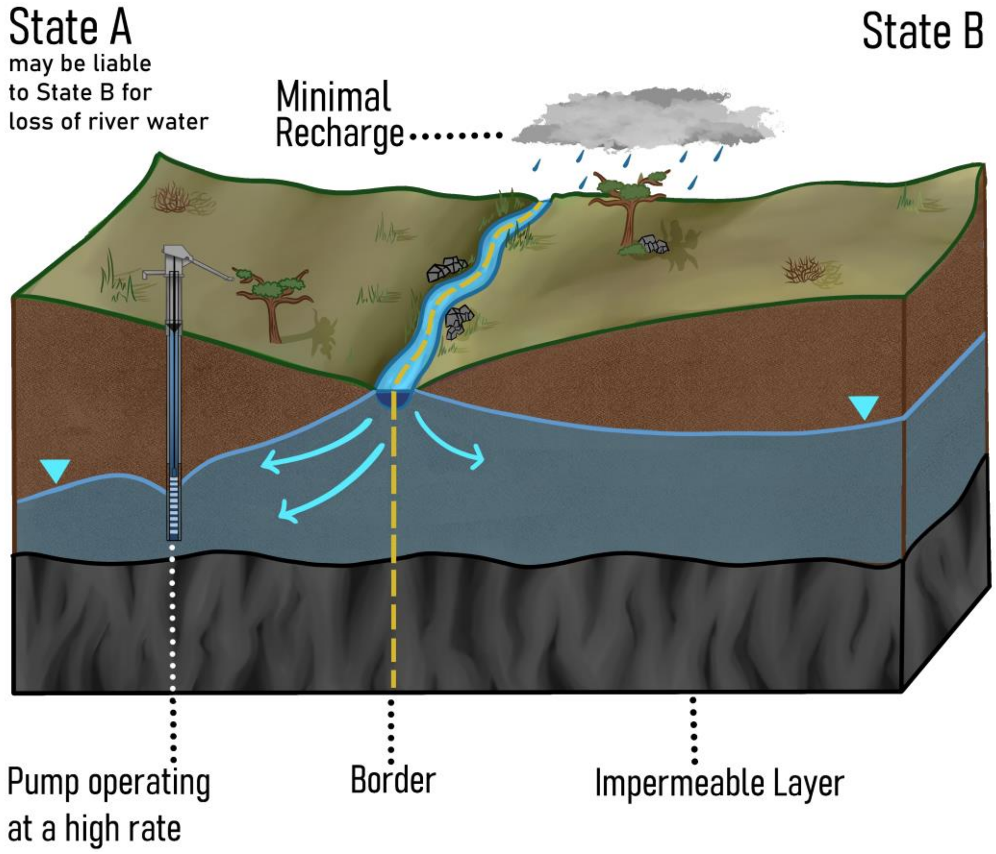


Figure 22 - State A pumps at a high rate in Model A with a losing river, producing the water table configuration and groundwater flow directions shown along cross section A1 on the front face of this image. The area of influence for the pumping well reaches the river, increasing the flux of water from the river into the aquifer in State A and reducing flow in the river. If this diverted flow has a significant impact on State B's use of river water, State B might have a liability claim against State A

In addition, if State A's pumping continued to increase, eventually the area of influence surrounding State A's extraction well would extend underneath the contiguous river into State B and first draw water from storage in the aquifer section located within State B followed by capture of recharge to the aquifer in State B (Figure 23). Thus, as in the immediately preceding example (Figure 22), to the extent that depletion of the river deprives State B of the equitable and reasonable use and benefit of the river's water, and to the extent that State B's ability to extract, use, or enjoy groundwater within its territory is negatively impacted, State B might have a liability claim against State A.

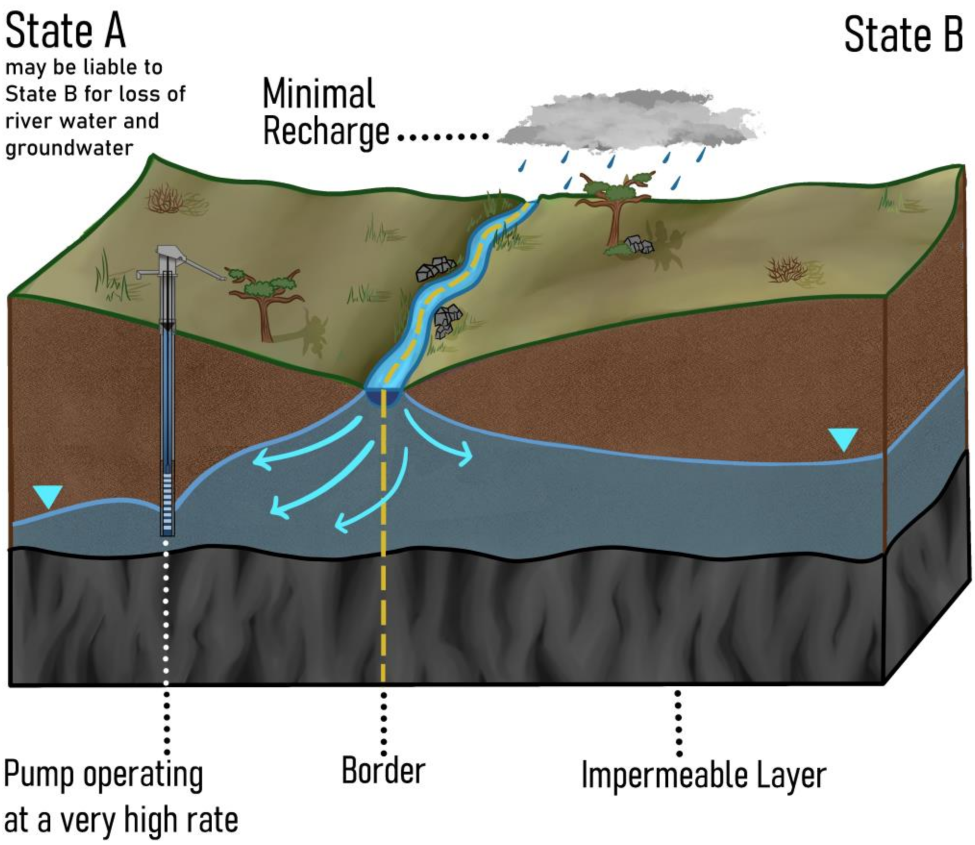


Figure 23 - State A pumps at a very high rate in Model A with a losing river, producing the water table configuration and groundwater flow directions shown along cross section A1 on the front face of this image. The area of influence for the pumping well extends beyond the river into State B, causing the well to draw water from the part of the aquifer in State B. If this depletion of groundwater in State B significantly affects State B's use of the groundwater, State B may have a liability claim against State A for the loss of use of both river water and groundwater.

Similarly, the hydraulic potential and flow paths of a losing, contiguous river bisecting an unconfined aquifer would serve as a barrier to pollutants and other negative traits and prevent them from flowing from one side of the aquifer across the political boundary to the opposite side. Since the groundwater flow paths in the two aquifer sections are away from the bisecting river, any subsurface contamination found in State A is unlikely to impact the aquifer in State B. However, pollutants introduced into or originating in a losing river could readily infiltrate into the aquifer on both sides of the river, thus exacerbating the transboundary implications through both the river and the aquifer (Figure 24). If State A was deemed responsible for polluting the river, that State would also be responsible, and possibly liable, for the resulting contamination of the hydrologically connected aquifer sections in State B.

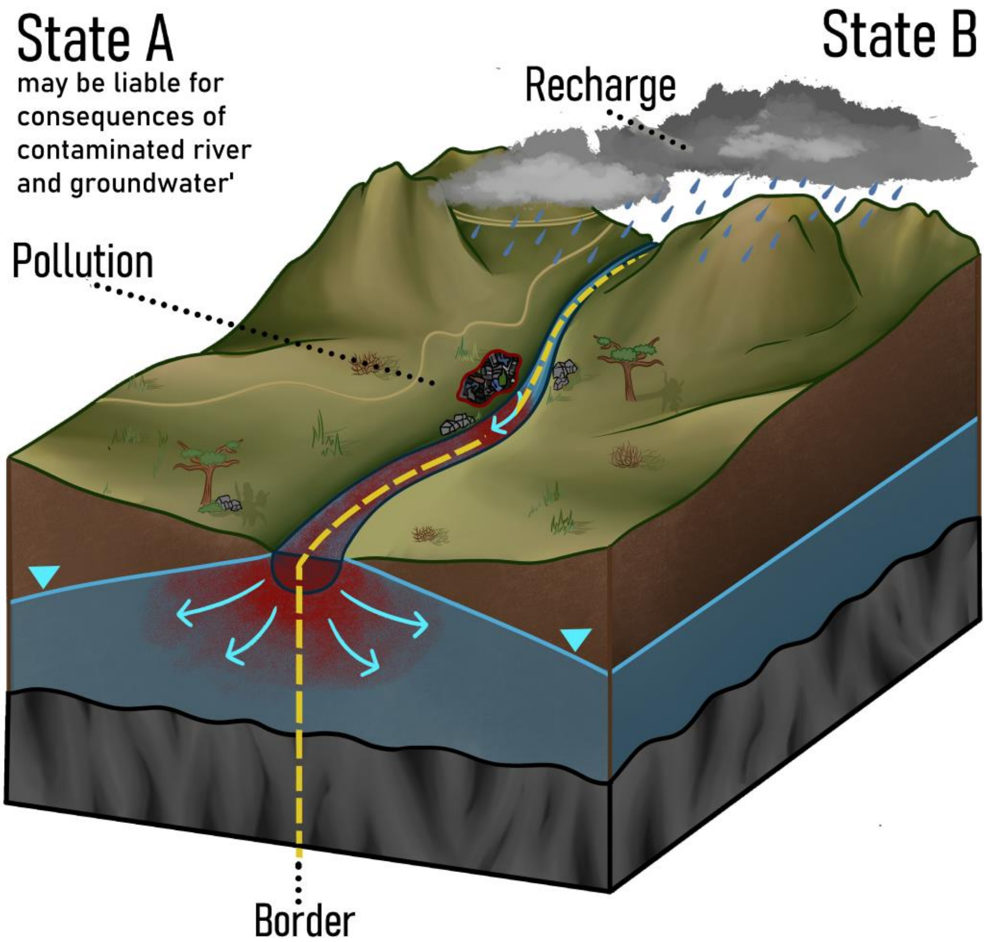


Figure 24 - Under natural (no pumping) conditions in Model A with a losing river, pollution directly introduced into the river in State A subsequently migrates through the riverbed into the aquifer. Groundwater flow and the pollution plume are shown along cross section A1 on the front face of this image. This creates a basis for liability for State A to State B and downstream river users for the consequences of the polluted river, as well as for State B based on the impact of the contamination on the aquifer on its side of the border.

Finally, if State A was responsible for contaminating the river, and groundwater extraction in State B exceeded the aquifer's natural recharge rate, the cone of depression could eventually extend to the losing river thereby enhancing the infiltration of contaminated river water into State B's section of the aquifer (Figure 25). However, if State A contaminated the aquifer within its territory, that contamination would not flow to State B unless State B began to pump the aquifer intensively, its area of influence extended into State A's jurisdiction, and the natural flow of the groundwater in State A within the area of influence changed direction and began flowing toward State B's well (Figure 26). In such a case, while State A would be responsible for the initial contamination, State B would be responsible for causing that contamination to migrate more readily into State B. Thus, State A is unlikely to be liable to State B unless other extenuating factors were established, including some of those noted previously—for example, State A's knowledge and notification efforts, and State B's conduct despite having knowledge.

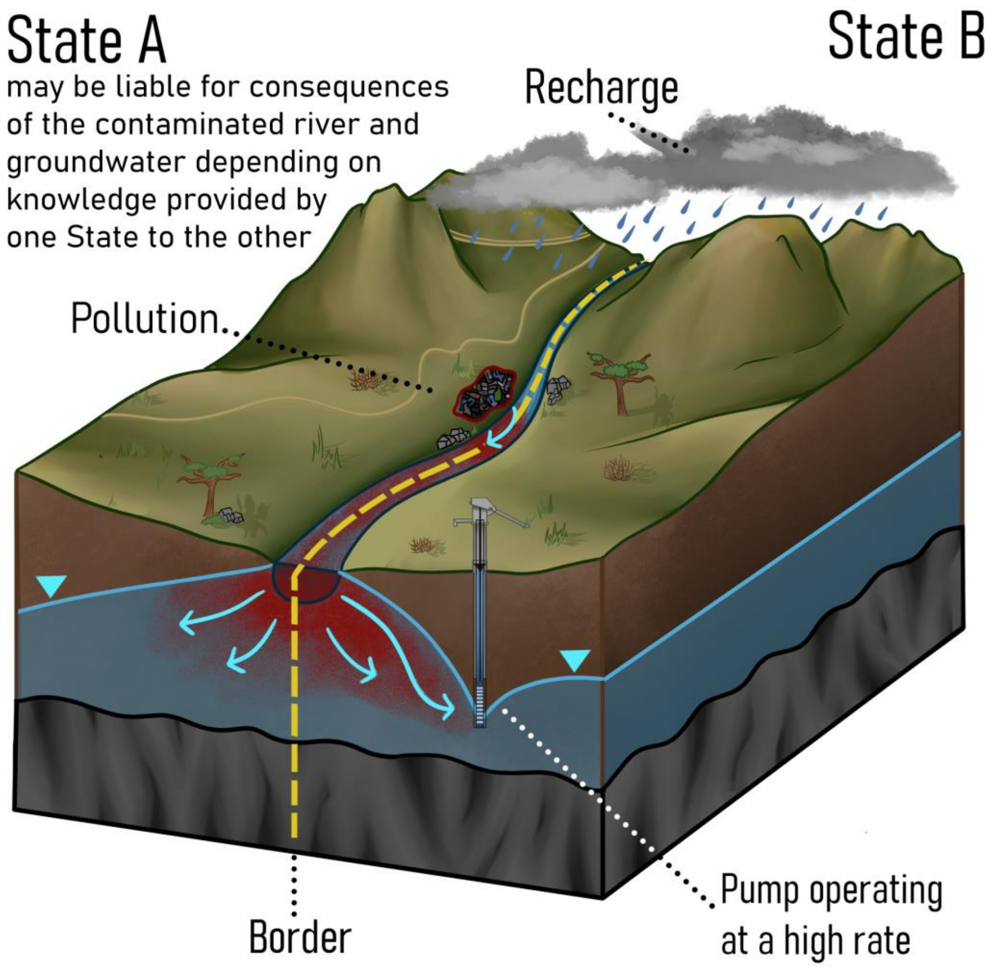


Figure 25 - State B pumps at a high rate in Model A with a losing river, and pollution is directly introduced into the river in State A. This pollution migrates through the riverbed into the aquifer. Groundwater flow and the pollution plume are shown along cross section A1 on the front face of this image. The area of influence for State B's pumping well reaches the river, increasing the flux of water from the river to the aquifer in State B, and reducing flow in the river. As a result, it enhances the flow of pollution from the river into State B's portion of the aquifer. This creates a basis for liability for State B and downstream river users against State A for the consequences of the polluted river. Liability for the impact on the aquifer on State B's side of the border depends not only on the hydrologic conditions but also on additional circumstances such as the knowledge provided by one State to another. For example, State A may be liable for the consequences of a contaminated river and aquifer; however, if State B knew about the contamination prior to pumping, that could weaken its claim. On the other hand, if State A failed to notify State B of the pollution, that could strengthen State B's claim.

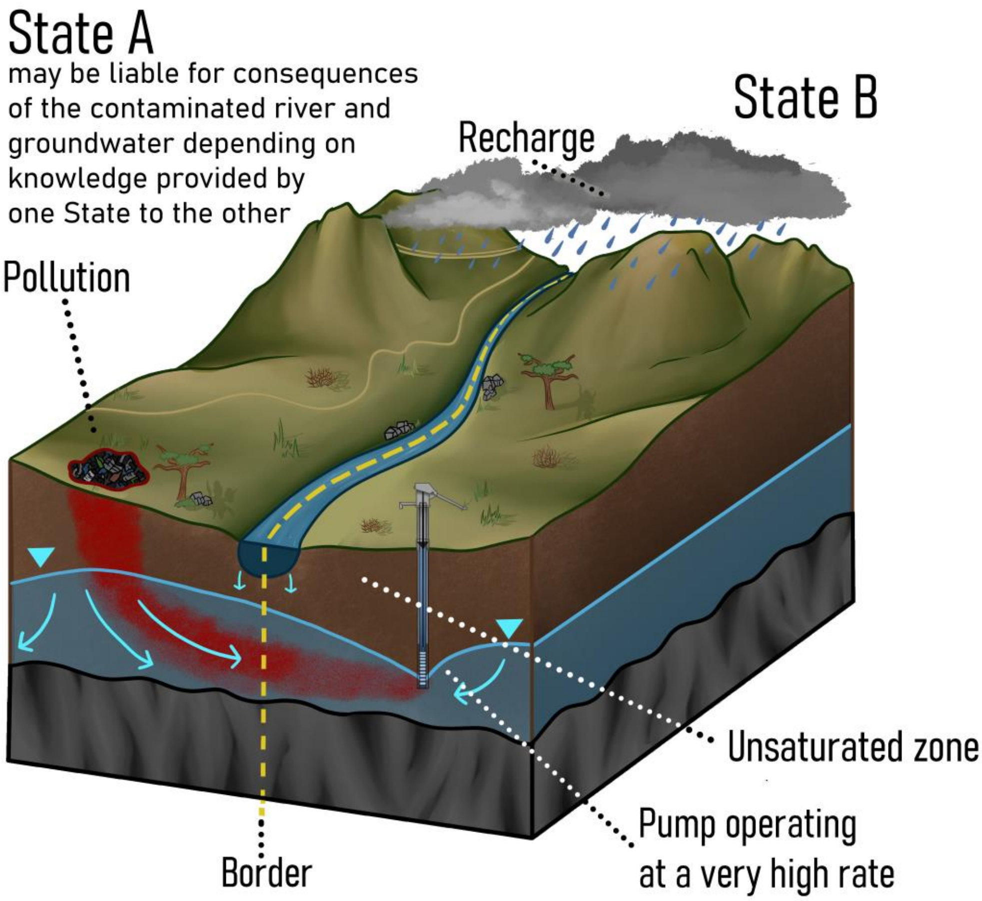


Figure 26 - State B pumps at a very high rate in Model A with a losing river, under conditions of contaminated groundwater in State A. Groundwater flow and the pollution plume are shown along cross section A1 on the front face of this image. Due to the pumping in State B, the water table has fallen below the riverbed and river water seeps through the unsaturated zone to recharge the aquifer, at a rate much lower than the pumping rate. Because the area of influence for State B's pumping well extends beyond the river into State A, the well draws contamination from State A's part of the aquifer toward State B's well. Liability for the impact on the aquifer beneath State B depends not only on the hydrologic conditions but also on additional circumstances such as the knowledge provided by one State to the other. For example, if State B knew about the groundwater contamination in State A before it began pumping from the aquifer at a high rate, its liability claim against State A for the contamination of State B's well will be weakened. It is unclear, however, whether State A was obligated to inform State B about the groundwater contamination since the natural flow of the aquifer, prior to State B's pumping activities, was away from State B. If State B can establish that State A had that notification obligation, State B's claim against State A will be strengthened.

Examples of unconfined aquifers that traverse an international political boundary and are hydrologically linked with a contiguous cross-border river that bisects the aquifer include the Red Light Draw, Hueco Bolson, and Rio Grande aquifers underlying the USA and Mexico border (Figure 27). All three aquifers are unconfined, directly connected to the Rio Grande River, and flow along the border between the state of Texas in the USA and the state of Chihuahua in Mexico (Hibbs et al., 1998; International Boundary and Water Commission (IBWC), 1998).

Figure 27 - Map of the geographic extent of the transboundary unconfined aquifers underlying the USA and Mexico border: the Valle de Juarez-Hueco Bolson (orange), Conejos Medanos-Mesilla Bolson (light blue), and Red Light Draw Bolson (purple), and Rio Grande aquifers. All these aquifers are unconfined and directly connected to the Rio Grande River (reproduced from Rodriguez, 2022a).

Another example is the Danube alluvial aquifer, which flows underneath and is connected to the Danube River—the watercourse that forms a border between Hungary and Slovakia, Croatia and Serbia, and Bulgaria and Romania—and traverses underneath multiple other European national boundaries (Mijatovic, 1998). A similar example—but in a subnational context—includes the unconfined Mississippi alluvial aquifer in the USA (Figure 28). Underlying the states of Arkansas, Louisiana, and Mississippi, this aquifer is hydrologically connected to the Mississippi River, which forms the border between the states of Arkansas and Mississippi and farther downstream between Louisiana and Mississippi (Renken, 1998).

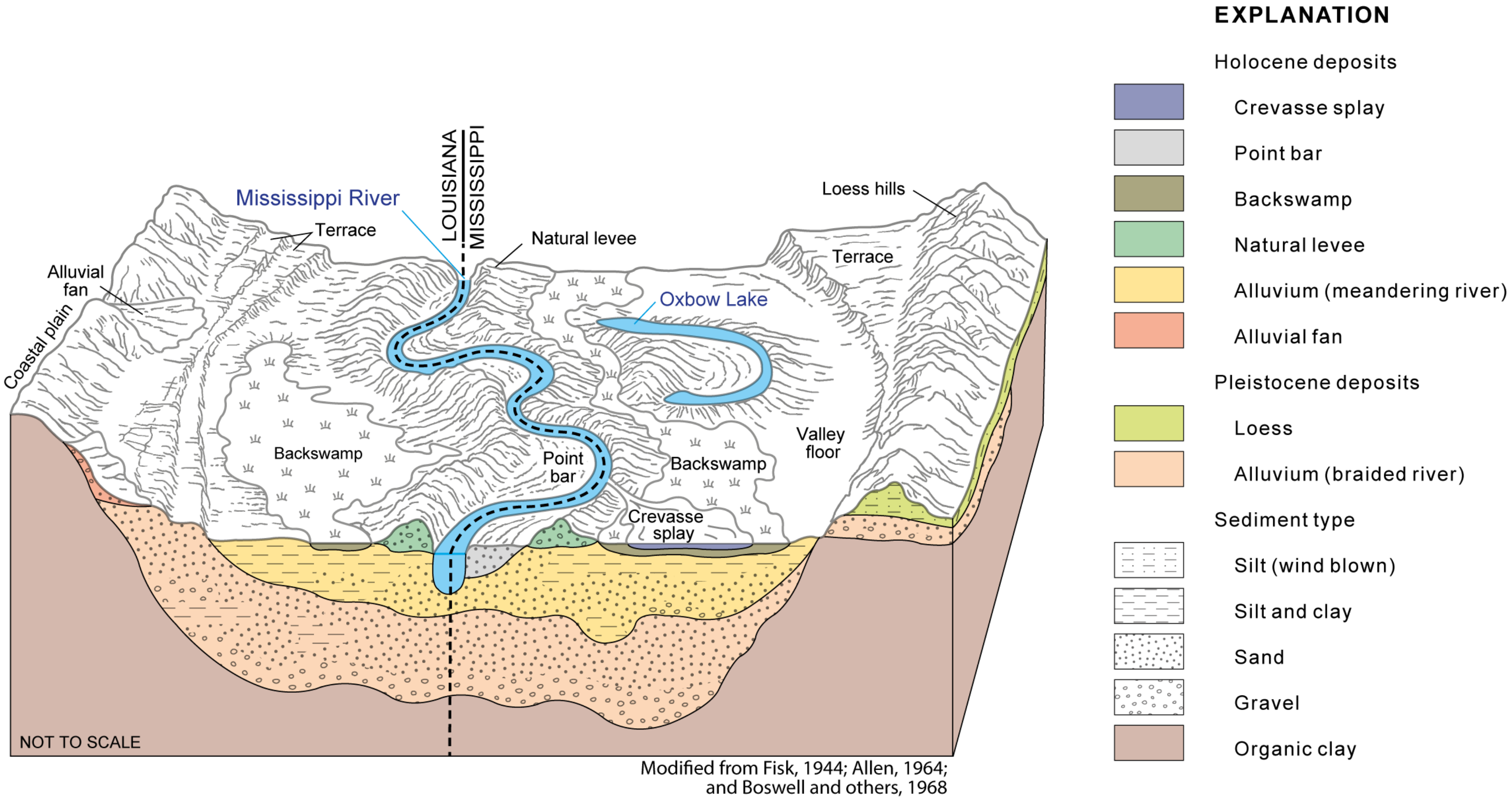


Figure 28 - Block diagram of the Mississippi Alluvial Aquifer, which underlies the USA states of Arkansas, Louisiana, and Mississippi. This aquifer is hydrologically connected to the Mississippi River, which forms the border between the states of Arkansas and Mississippi and farther downstream between Louisiana and Mississippi (reproduced from Renken, 1998).

4.2 Model B: Unconfined Transboundary Aquifer Hydrologically Linked to a Successive Transboundary River

The scenario illustrated in Model B (Figure 29) is like that found in Model A in that it depicts an unconfined aquifer intersected by a political boundary and bisected by a transboundary river. The key difference, however, is that the river in Model B is a *successive river*—a river that flows across a frontier from one political jurisdiction and into another—rather than a contiguous river. In other words, the political boundary divides both the aquifer *and* the hydrologically connected river. In this model, State A is positioned as the upper riparian for both the aquifer and the river.

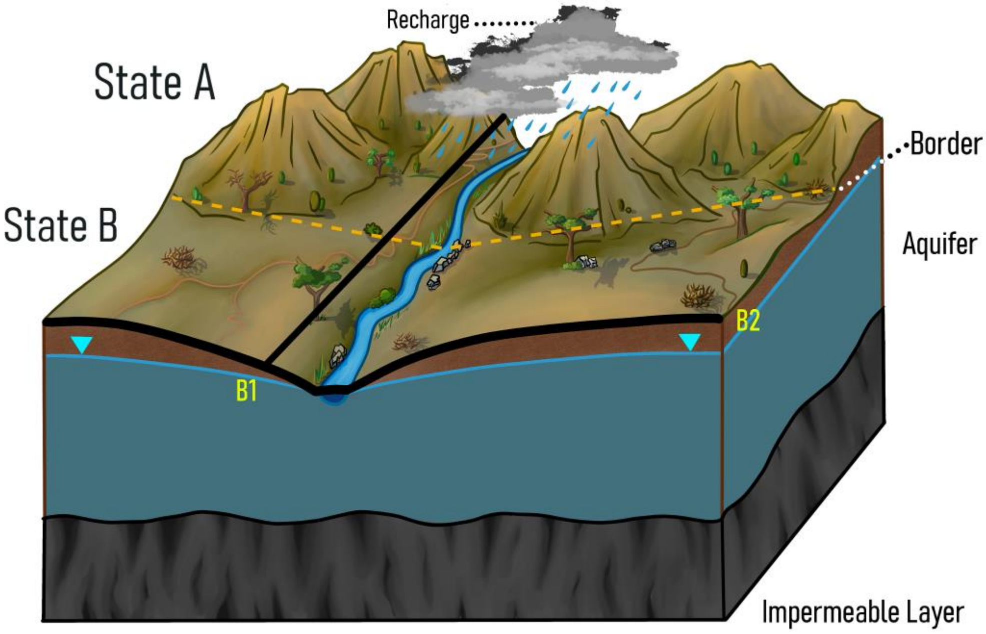


Figure 29 - Model B: An unconfined aquifer intersected by a political boundary and hydrologically connected with a successive, transboundary river. The black lines labeled as B1 and B2 indicate locations of cross sections than run parallel to and perpendicular to the river respectively. B1 and B2 are referenced in subsequent diagrams.

As depicted in Model B, water in both the unconfined aquifer and the hydrologically connected river flows largely in relation to slope and gravity that, under natural conditions, would be from State A to State B (Figure 30).

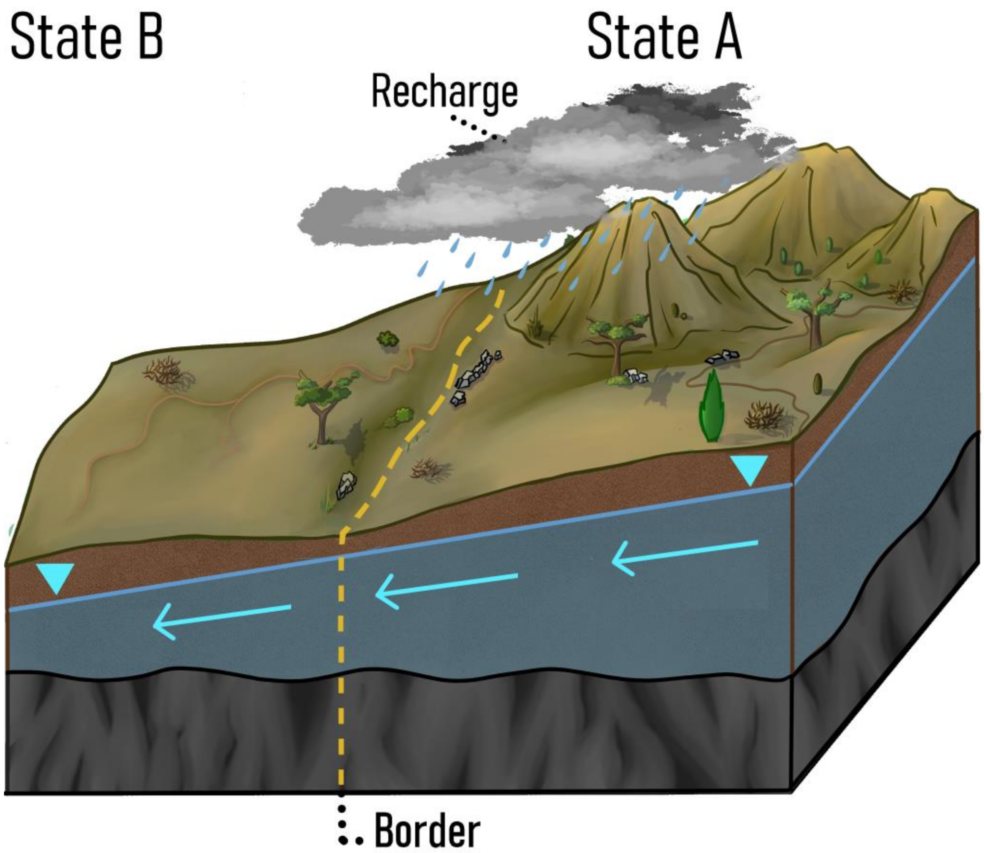


Figure 30 - Flow along cross section B1 of Model B under natural (no pumping) hydrologic conditions, showing the water table and groundwater flow directions. Groundwater flows from State A to State B.

In this case there are more occasions in which State A could cause negative impacts to befall State B. In contrast, any artificial extraction of water from the river or the aquifer—or contamination of those water bodies—in State B is unlikely to affect State A. One exception is if State B installs wells along its frontier with State A and excessively pumps the aquifer to the extent that it accelerates or amplifies the natural flow, thereby depriving State A from using it and lowering water levels in State A to the point at which the economic advantage of pumping is compromised (Figure 31). However, while State B might be responsible for depriving State A of some groundwater, the dispossession of groundwater would likely have to be substantial, such that it results in significant harm to State A, to be actionable under law given that in Figure 30**Figure 30**, the groundwater appears to originate largely in State A.

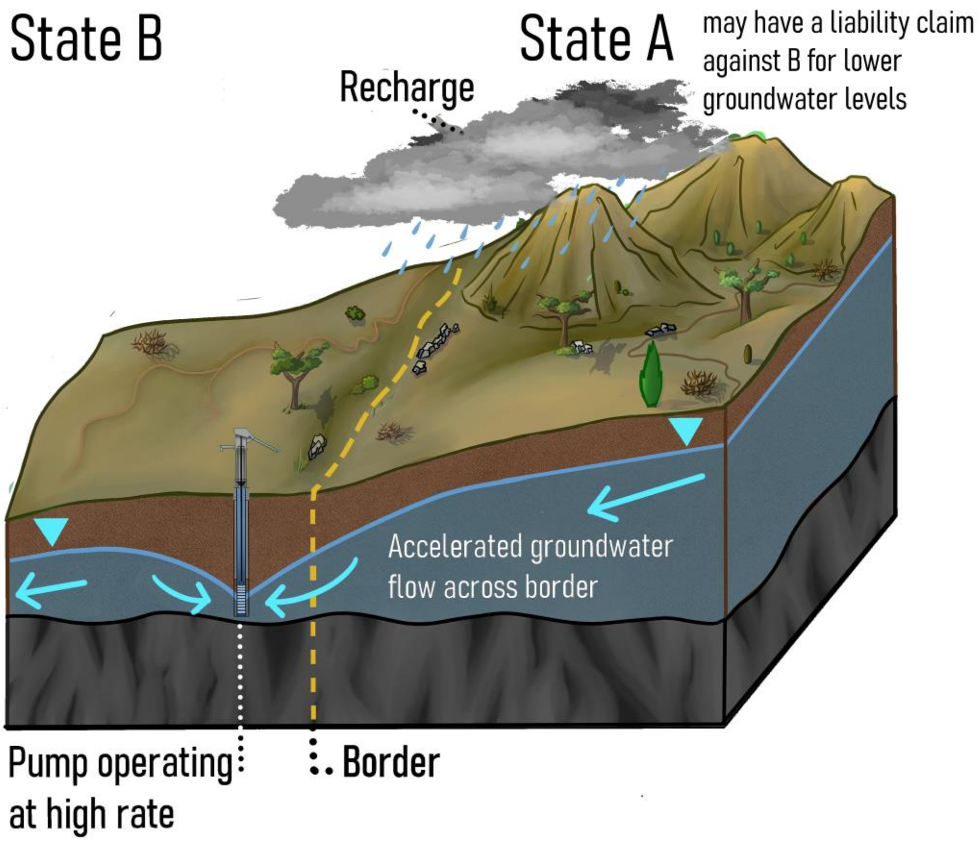


Figure 31 - Flow along cross section B1 of Model B with State B pumping at a high rate, lowering groundwater levels in State A. The pumping causes groundwater flow across the border from State A to State B to accelerate within the well's area of influence. State A may have a liability claim against State B for loss of use of the groundwater and the economic advantage of pumping, but only if the loss results in significant harm to State A.

In contrast, any artificial extraction of water from the river or the aquifer in State A could have a negative impact on State B. Whether, and the extent to which, State A's conduct is subject to liability would depend on such factors as whether the river's relationship with the aquifer is gaining or losing, the volume of water withdrawn, and the extent of the impact that those circumstances have on State B.

Regarding the gaining or losing character of the river, if the river maintains a gaining relationship with the aquifer throughout its entire course—as suggested in Model B—any diversion from the river in State A will impact the flow of river water downstream in State B. However, it will have little effect on the aquifer in State B, except where river flow is so reduced that it increases groundwater flow into the river in State B because of the greater head difference between the aquifer and the river (i.e., the difference between the elevation of the water table in the aquifer and the elevation of the surface of the water in the river).

In contrast, any extraction from the aquifer in State A could have an impact on cross-border water flow in both the river and the aquifer. If the pumping well is installed close to the river, it could reduce the volume of water flowing from the aquifer, into the river, and downstream into State B. The further from the river the groundwater withdrawal occurs, the lower the impact will be on river flow in this gaining relationship.

Another example of State A's greater likelihood of having a negative impact on State B arises where State A installs a well in the vicinity of its border with State B (Figure 32). While this could reduce the natural flow of groundwater into State B, if the pumping was strong enough, State A could actually reverse the natural flow of groundwater within the cone of depression causing it to flow back from State B into State A toward the well (Figure 33). However, the effects of such pumping would be localized and limited to the well's area of influence and would not affect groundwater flow elsewhere along the border.

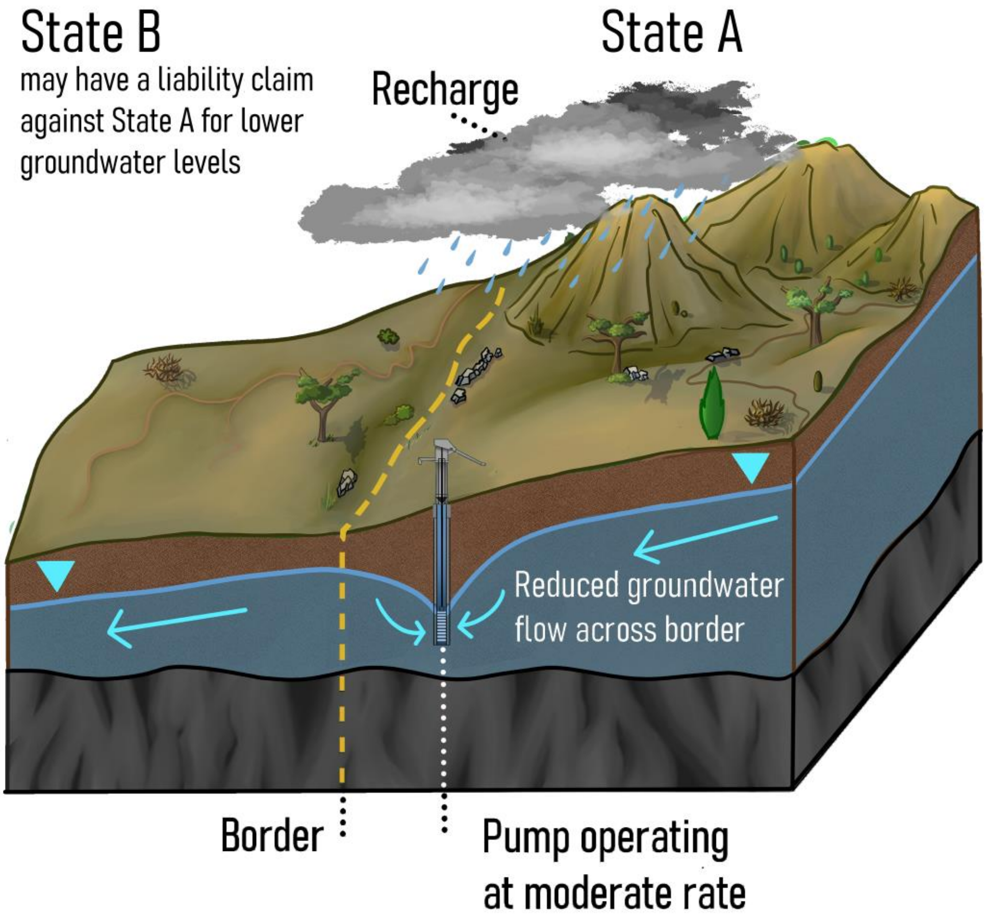


Figure 32 - Flow along cross section B1 of Model B with State A pumping at a moderate rate, lowering the water table . The pumping reduces groundwater flow across the border from State A to State B within the well's area of influence. State B has a possible liability claim for loss of use of groundwater if the loss results in significant harm to State B.

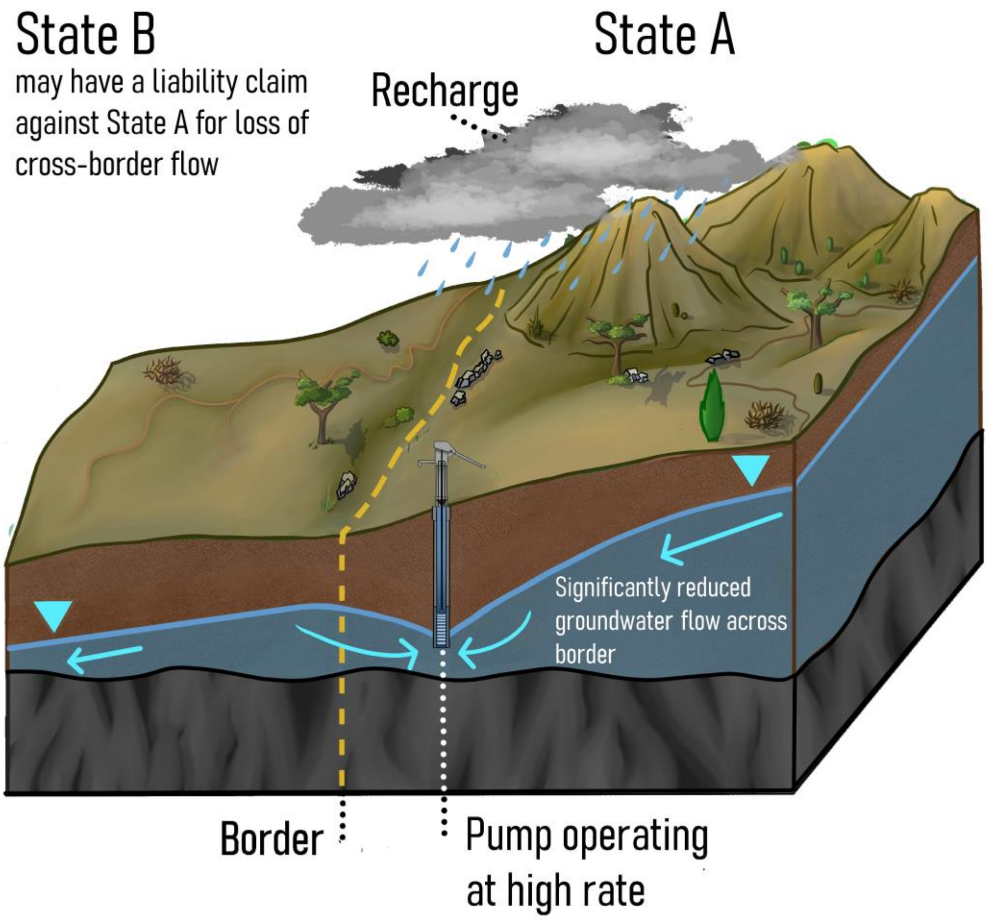


Figure 33 - Flow along cross section B1 of Model B with State A pumping at a high rate, lowering the water table and reversing groundwater flow direction within the cone of depression. State B has a possible liability claim for loss of use of groundwater and the economic advantage of pumping if the loss results in significant harm to State B.

The scenario depicted in Figure 33 occurred along the Mexico-US border in the states of Sonora, Mexico, and Arizona, USA. In the late 1960s, Mexico installed a well field just south of the border near San Luis in the northwestern corner of the Mexican state of Sonora. As a result of Mexico's pumping activities, groundwater that naturally flowed northward toward the USA reversed direction within the well field's area of influence and began flowing toward Mexico's wells (Figure 34).The situation raised tensions between the two aquifer riparians and required negotiations (Mumme, 1988).

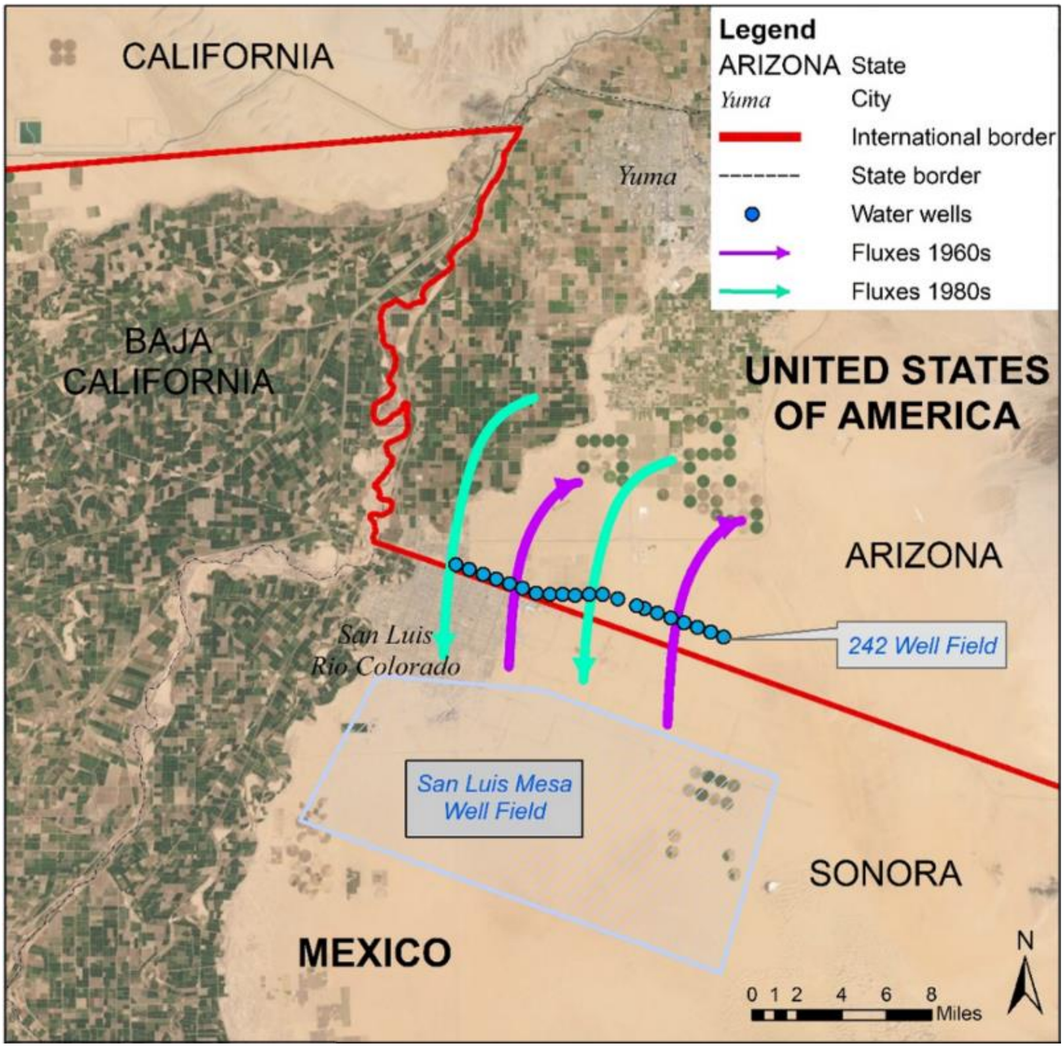


Figure 34 - Map showing Mexico-US border area where in the late 1960s, Mexico installed wells just south of the border near the town of San Luis that reversed the natural flow of groundwater so it flowed southward into Mexico (reproduced from Rodriguez, 2022b). Following the negotiations of Minute 242↗ between the Mexican and US sections of the International Boundary and Water Commission, the US installed its own well field along the border and the two countries restricted pumping within five miles of the border (Mumme, 1988).

With regard to water quality impacts, because the aquifer-river relationship in Model B is characterized as a gaining river, any contamination of the river in State A would affect downstream use of river water by State B but have no impact on the aquifer in State B (Figure 35).

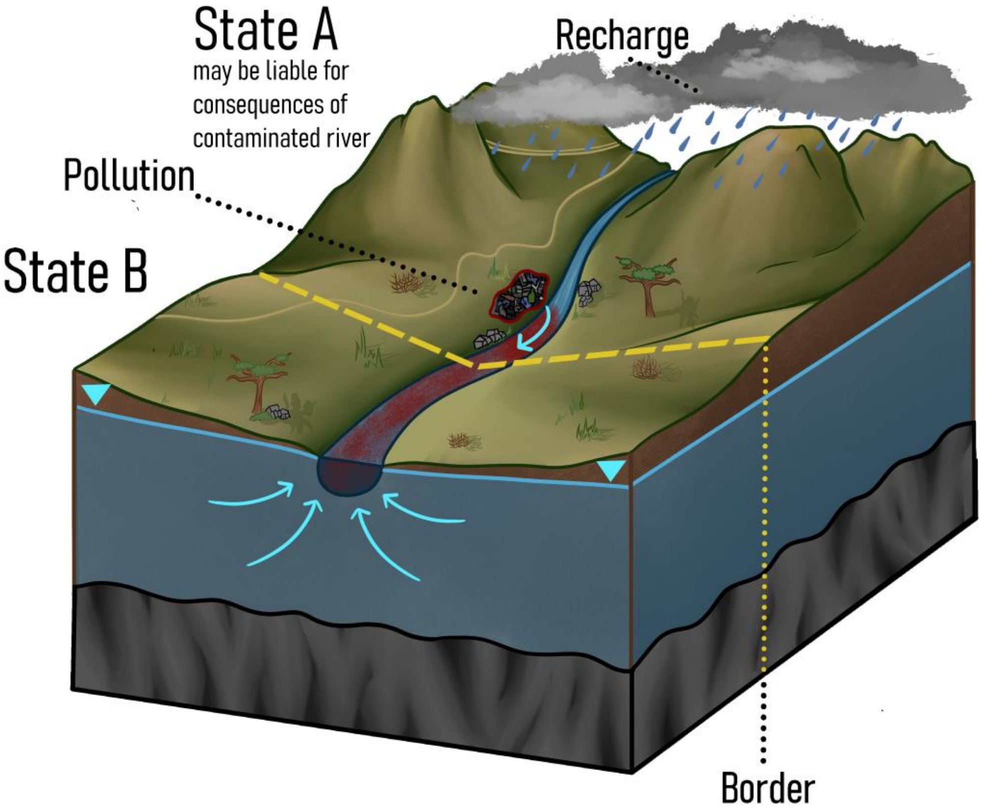


Figure 35 - Under natural (no pumping) conditions in Model B with a gaining river, State A has contaminated the river. Groundwater flow directions are shown along cross section B2 on the front face of this image. The groundwater in State B remains uncontaminated because of the gaining river condition, but the river in State B is contaminated. State B has a possible liability claim for the consequences of the contaminated river.

However, any contamination of the aquifer in State A could have a negative impact on both the river and the aquifer in State B as contaminants would reach State B both through the gaining river and groundwater flow across the border. In contrast, if the river is losing throughout its course, any pollution or other negative characteristics originating in the river in State A would be carried downstream and contaminate the river as well as the aquifer on both sides of the river in State A and B (Figure 36).

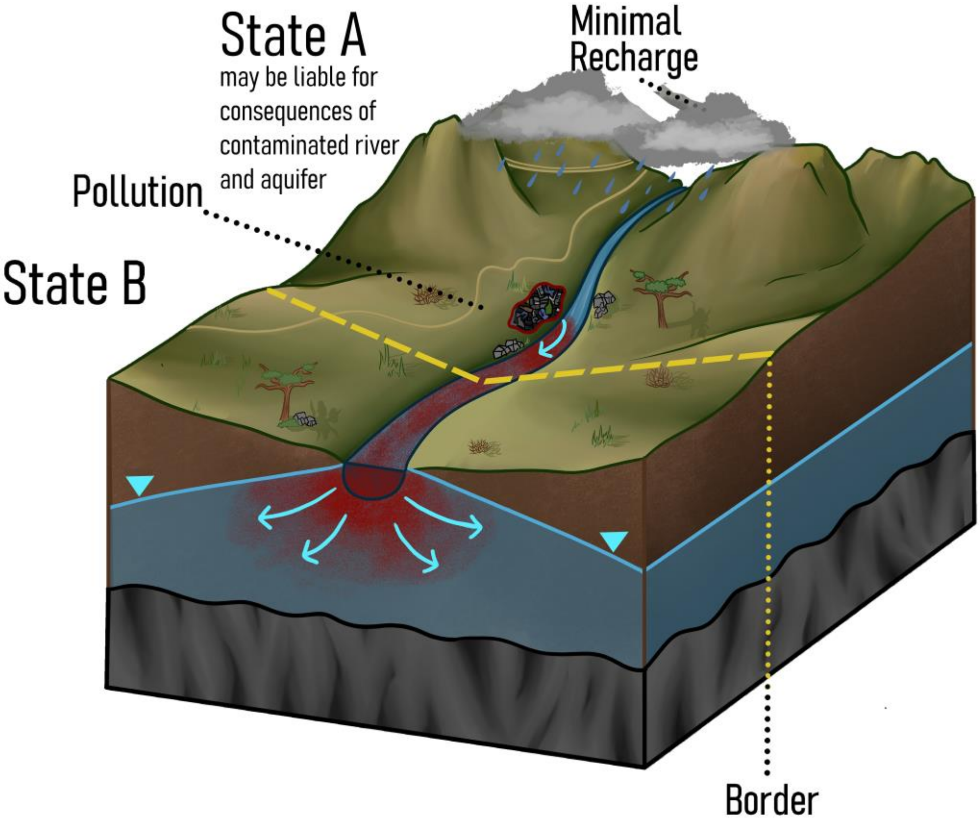


Figure 36 - Under natural (no pumping) conditions in Model B with a losing river, State A has contaminated the river. Groundwater flow directions along cross section B2 in Model B are shown on the front face of this image. Both the river and the groundwater in State B are likely to be contaminated because of the losing river condition. State B has a possible liability claim for the consequences of the contaminated river and aquifer.

At the international level, the Abbotsford-Sumas aquifer (Figure 37) is an example of an unconfined aquifer intersected by a political boundary and linked hydrologically with a successive, transboundary river. This aquifer traverses the border between the province of British Columbia in Canada and the state of Washington in the USA. It is directly connected to the Sumas River, Bertrand Creek, and Fishtrap Creek, which all flow from Canada into the USA (British Columbia Ministry of Environment, n.d.).

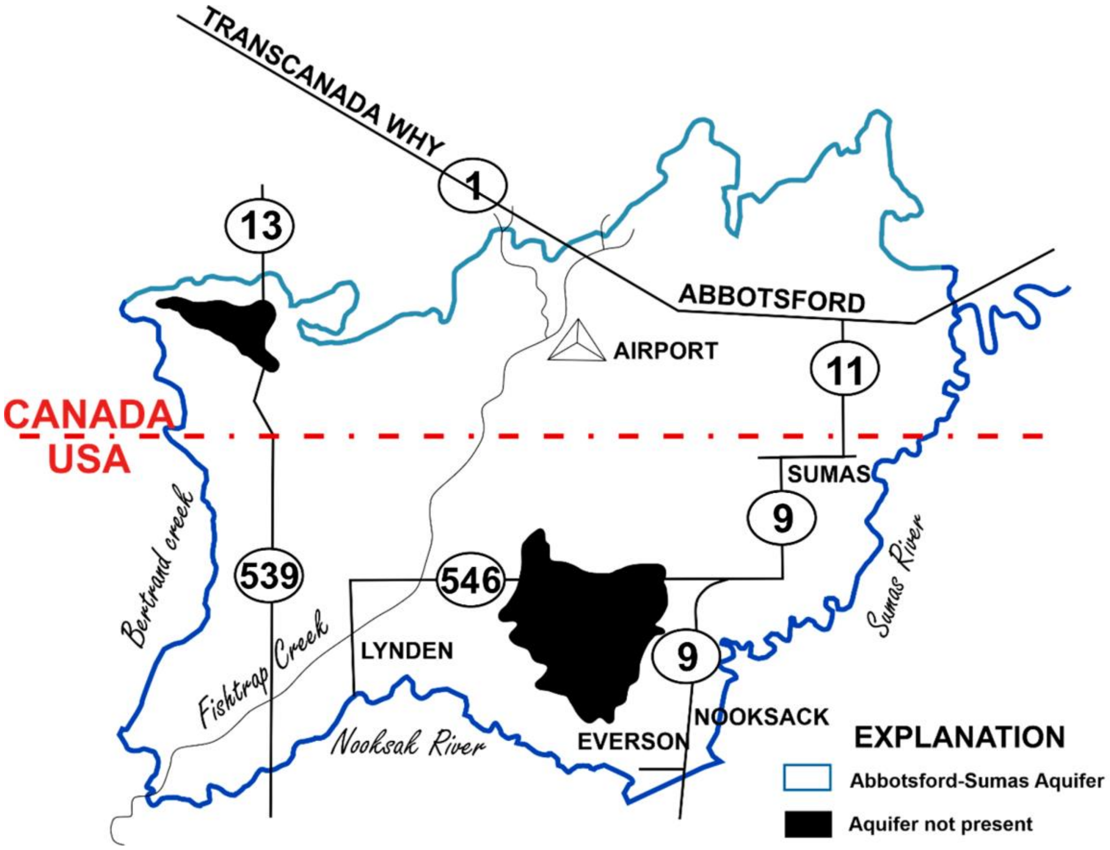


Figure 37 - Map of the geographic extent of the Abbotsford-Sumas aquifer, an unconfined aquifer intersected by an international political boundary and linked hydrologically with a successive, transboundary river. This aquifer traverses the border between the province of British Columbia in Canada and the state of Washington in the USA and is hydrologically connected to the Sumas River, Bertrand Creek, and Fishtrap Creek, which all flow from Canada into the USA The numbered ovals indicate route numbers for the roads that are shown as black lines. (modified from British Columbia Ministry of Environment, n.d.)

Two other examples include the Mures/Maros aquifer underlying Hungary and Romania, which is hydrologically connected to the overlying Mures/Maros River, a tributary to the Tisza River, which flows into the Danube River (European Commission, 2007), and the predominantly unconfined San Pedro Basin Aquifer (Figure 38) that traverses the border between northern Sonora in Mexico and southern Arizona in the USA and is linked hydrologically to the San Pedro River, which flows northward into the USA and merges with the Gila River, a major tributary of the Colorado River (Arias, 2000).

Figure 38 - Map of the geographic extent of the transboundary Pedro Basin Aquifer. This predominantly unconfined aquifer traverses the border between northern Sonora in Mexico and southern Arizona in the USA and is linked hydrologically to the San Pedro River, which flows northward into the USA and merges with the Gila River, a tributary of the Colorado River (reproduced from Rodriguez, 2022c).

At the subnational level, the Canadian River alluvial aquifer (Figure 39) is an example of an unconfined aquifer traversing multiple interstate boundaries within the USA and linked hydrologically with a successive, transboundary river. The river originates in the Sangre de Cristo Mountains in southern Colorado, flows southeasterly across the border into New Mexico, and then eastward into Texas, Oklahoma, and Arkansas before flowing into the Arkansas River (Ellis et al., 2017). While the alluvial aquifer connected to the Canadian River is not homogeneous along the entire length over which it is connected to the Canadian River, it traverses below the Texas-Oklahoma and Oklahoma-Arkansas borders (Ryder, 1996; Oklahoma Water Resources Board, 2012a; Oklahoma Water Resources Board, 2012b).

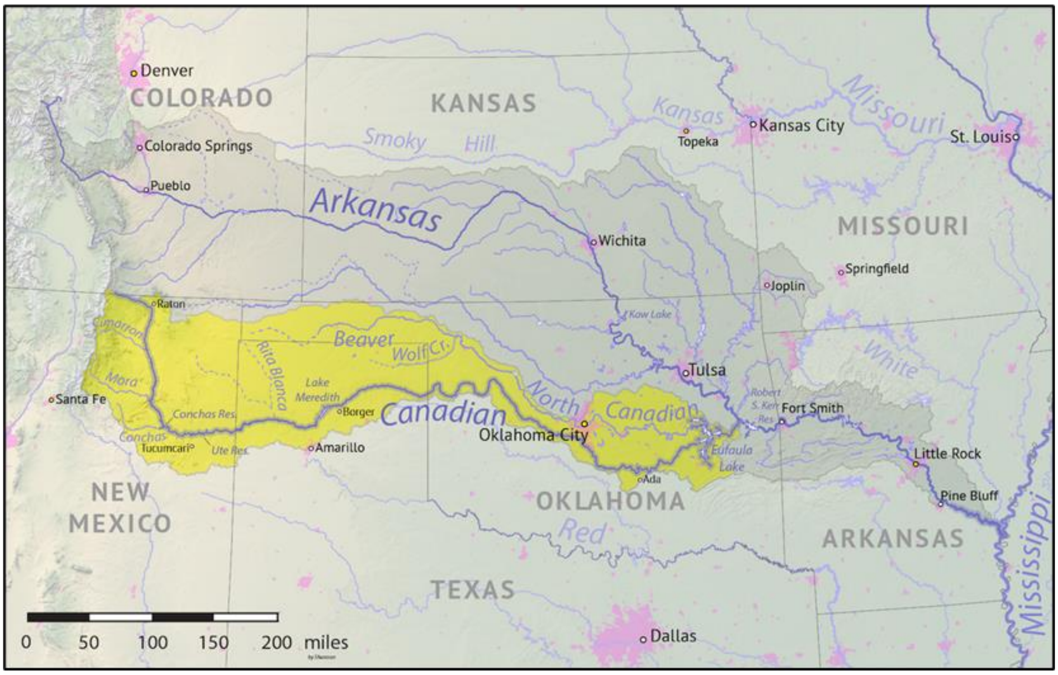


Figure 39 - Map of the Canadian River drainage basin, which has an alluvial aquifer connected to the river that traverses the Texas-Oklahoma and Oklahoma-Arkansas borders ("Canadian River Basin Map," 2022).

4.3 Model C: Unconfined Transboundary Aquifer Hydrologically Linked to a Domestic River

As with the first two models, Model C (Figure 40) depicts an unconfined aquifer that is intersected by a political boundary and is hydrologically linked to a river that bisects the aquifer. Unlike the first two models, the river in this example does not flow across or along any frontier; rather, the river is entirely domestic within the territory of one of the jurisdictions—here, State B.

As a result, a key feature of this model is that the transboundary character of this aquifer-river example is found entirely in the aquifer. This characteristic is important because the transboundary implications of this model rely solely on the groundwater flow within the aquifer. This is not to say that the river in this model is insignificant. Rather, the river is important to the extent that it influences water flow in the aquifer, which depends largely on whether it has a gaining or losing relationship with the aquifer.

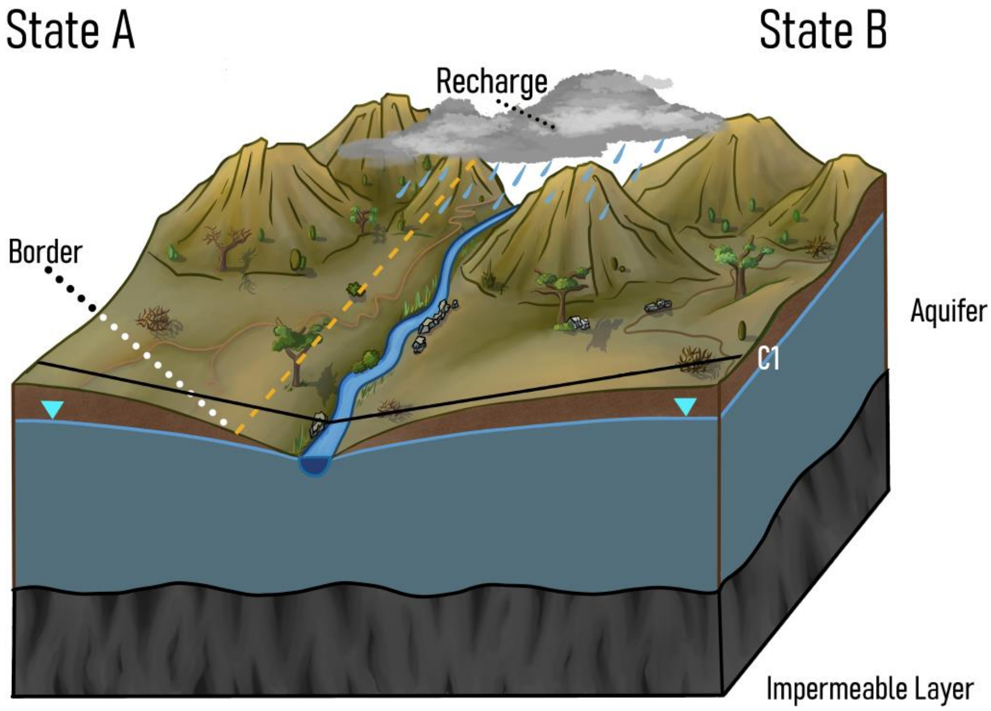


Figure 40 - Model C: An unconfined aquifer that flows across a political boundary and is hydrologically connected to a river that flows entirely within the territory of one of the jurisdictions. The black line labeled C1 indicates the location of the cross section referenced in subsequent diagrams.

With the water table in Figure 41 sloping toward the river, Model C suggests a gaining relationship between the aquifer and river. This indicates that in a transboundary context, groundwater moves naturally from State A into State B and eventually toward State B's domestic river (Figure 41).

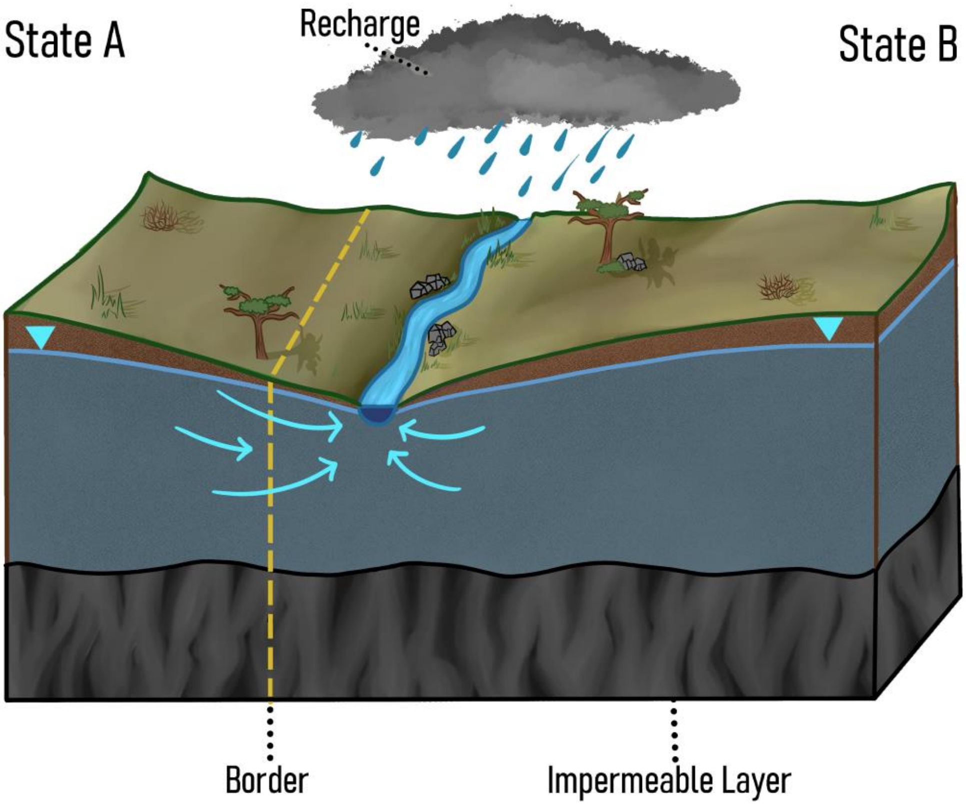


Figure 41 - Model C with a gaining river and natural (no pumping) hydrologic conditions. The water table and groundwater flow directions are shown along cross section C1 on the front face of this image. The groundwater system is recharged by precipitation falling on the land surface, and all discharge is to the river in State B. Groundwater flows from State A to State B.

If State A were to extract groundwater from the aquifer section located within its border, depending on its rate and extent of pumping, State A could reverse groundwater flow within the area of influence of the well such that groundwater would flow from State B to State A (Figure 42).

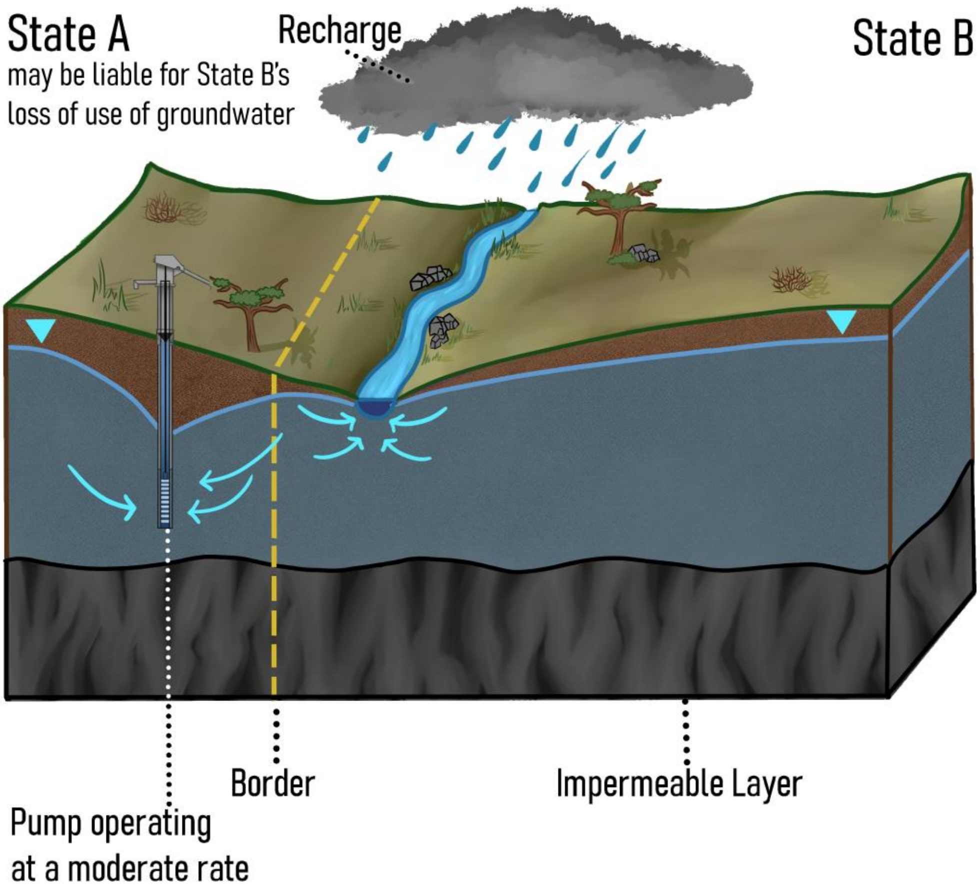


Figure 42 - State A pumps at a moderate rate from the aquifer section located on its side of the border in Model C with a gaining river, producing the water table configuration and groundwater flow directions shown along cross section C1 as shown on the front face of this image. The well's area of influence reaches across the border causing groundwater to flow from State B to State A within the well's area of influence. In this image, that area of influence does not reach the river, so there is only minimal impact on the river flow. State B may have a claim for liability against State A, depending on the degree of harm that State B suffers from the loss of use of groundwater whose flow was reversed to State A.

In an extreme situation, if its pumping is strong enough, State A's activities might even diminish water flow in State B's domestic river by causing river water to seep into the aquifer and toward State A (Figure 43). In such scenarios, less groundwater would flow into State B's segment of the aquifer, as well as into State B's river. Depending on the degree of harm that State B suffers from this reduction of groundwater flow, it may have a claim for liability against State A.

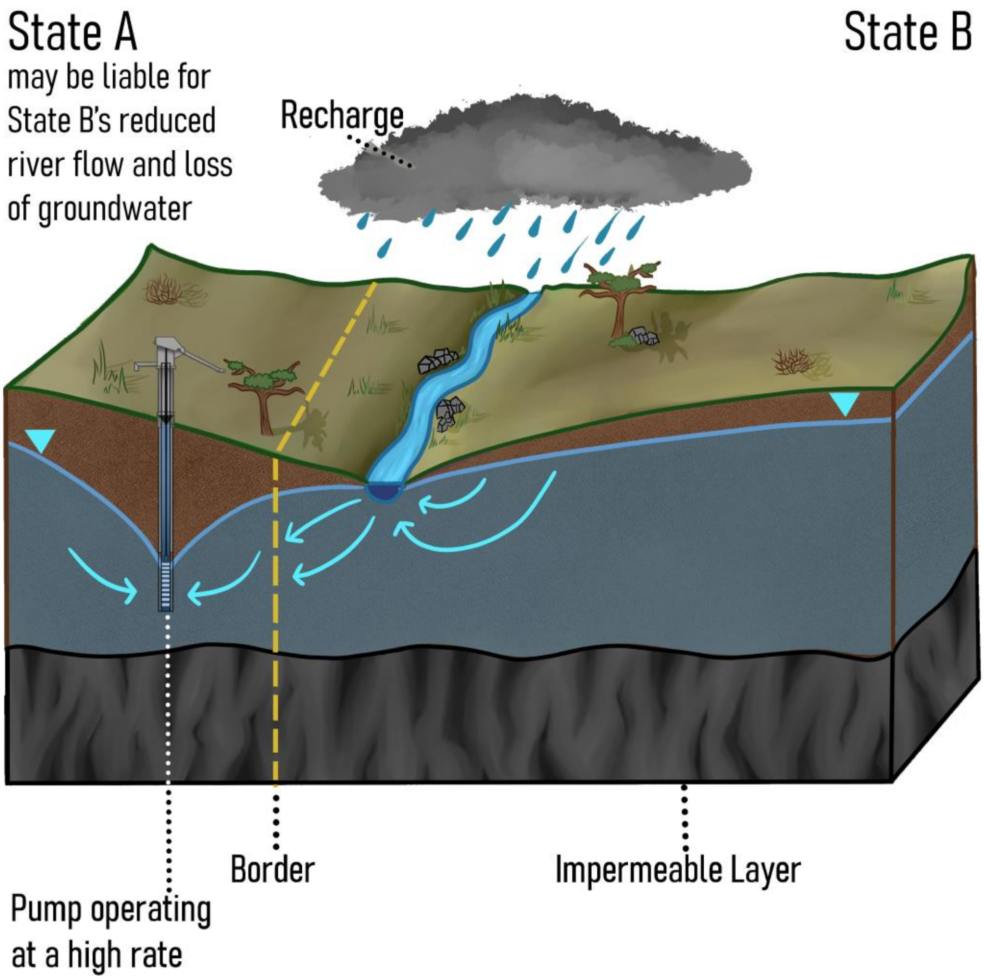


Figure 43 - State A pumps at a high rate from the aquifer section located on its side of the border in Model C with a gaining river, producing the water table configuration and groundwater flow directions shown along cross section C1 on the front face of this image. The well's area of influence reaches across the border and to State B's domestic river, causing groundwater and river water to flow from State B to State A. State B may have a claim for liability against State A, depending on the degree of harm that State B suffers from the loss of use of groundwater and river water on its side of the border.

In contrast, if State B were to pump groundwater from the aquifer section located within its border, depending on the rate and extent of pumping, it could accelerate that flow locally within the well's cone of depression, thereby reducing the amount of groundwater that State A is able to enjoy (Figure 44). In this last scenario, however, while State B might be responsible for depriving State A of some groundwater, the dispossession of groundwater would likely have to be substantial to be actionable under law given that under natural conditions the groundwater already flows from State A to State B.

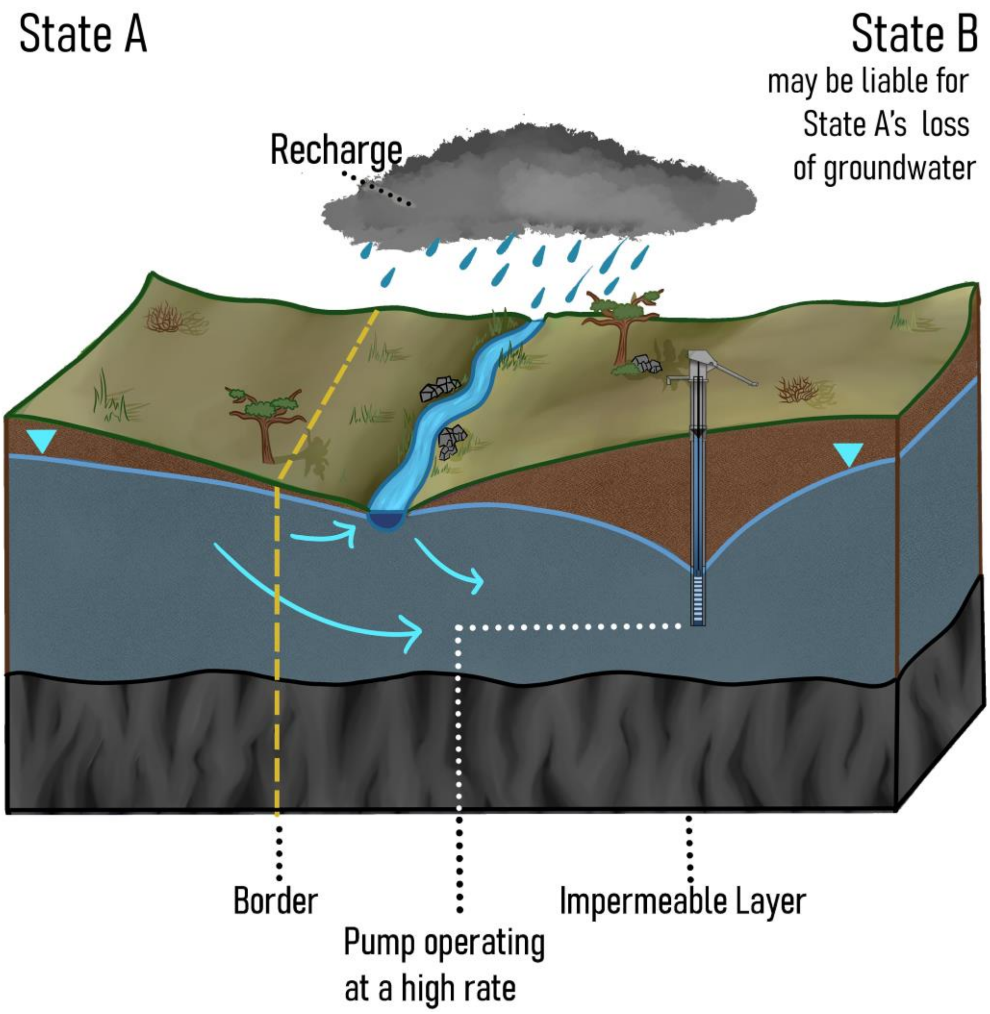


Figure 44 - State B pumps at a high rate from the aquifer section located on its side of the border in Model C with a gaining river, producing the water table configuration and groundwater flow directions shown along cross section C1 on the front face of this image. The pumping causes an increase in the groundwater flow rate across the border from State A to State B, thereby reducing the amount of groundwater available to State A. The loss of groundwater by State A would likely have to be substantial to be actionable under law given that under natural conditions the groundwater already flows from State A to State B.

Similar scenarios of responsibility and liability can be depicted for any anthropogenic or naturally occurring pollutant found in the aquifer within State A. Such contaminants would naturally flow toward State B, including into State B's river (Figure 45).

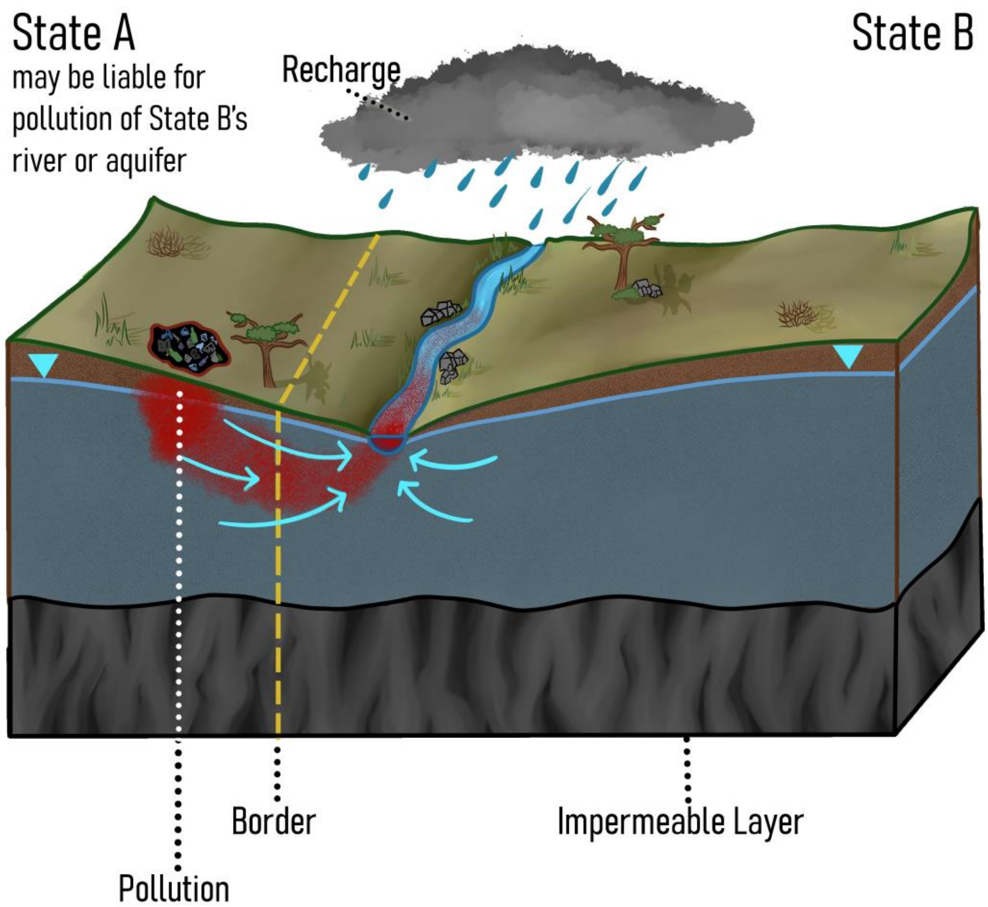


Figure 45 - Under natural (no pumping) conditions in Model C with a gaining river, State A has contaminated the aquifer. Groundwater flow directions are shown along cross section C1 on the front face of this image. Contaminants from the pollution source flow toward State B as a result of the natural flow of groundwater, including into State B's river. State A would be liable for significant harm that the pollution causes to the aquifer and the river in State B.

As suggested in a prior section, State A would have no liability to State B for naturally occurring contaminants migrating under natural conditions into State B. However, State A would be responsible for non-natural contaminants that it may introduce into the aquifer within its jurisdiction, and may be liable for significant harm that results to State B. Moreover, it may be liable for harm resulting from the acceleration or amplification of the contaminant flow into State B. In contrast, State B may not be able to claim liability for harm suffered if it is found responsible for accelerating or amplifying that cross-border pollution flow for example by installing a well on its side of the border that draws the pollution from State A toward State B.

Analogous explanations apply if the model depicted the river as losing, meaning that water naturally flowed from the river into the aquifer, albeit with a different set of responsibilities and liabilities. Under such circumstances, groundwater would flow naturally from State B across the border into State A (Figure 46). As a result, if State A installed a well near its border with State B, it could enhance and accelerate the flow and volume of groundwater crossing the border within the well's area of influence (Figure 47).

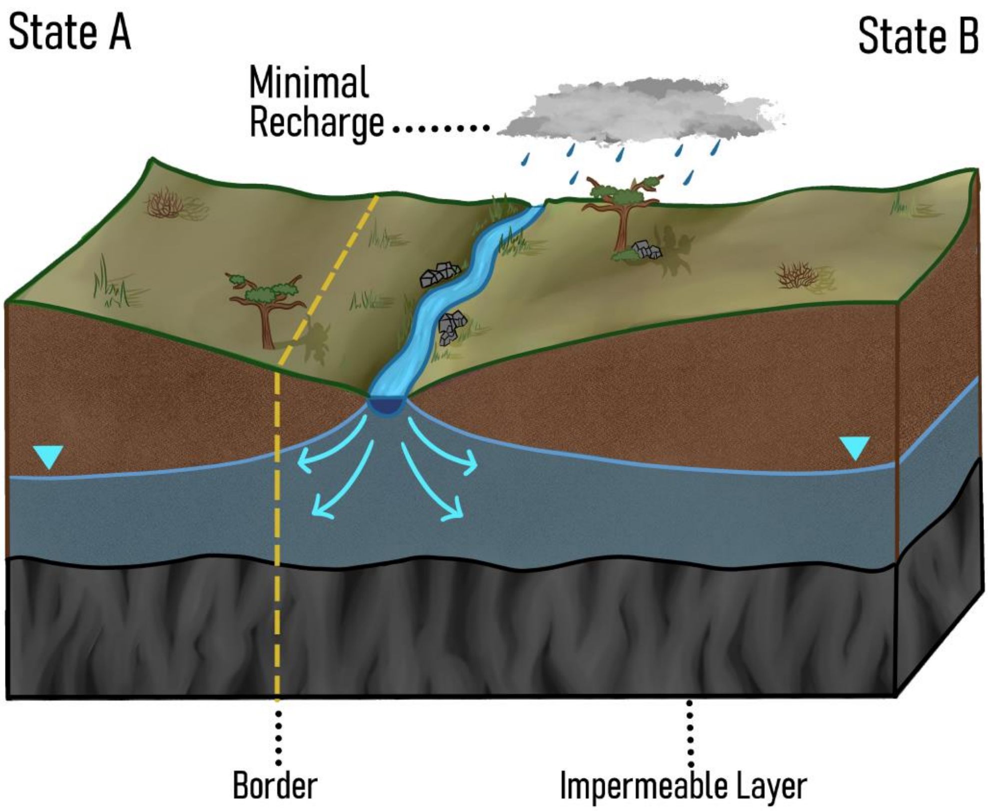


Figure 46 - Model C with a losing river and natural (no pumping) hydrologic conditions, showing the water table and groundwater flow directions along cross section C1 on the front face of this image. Groundwater flows naturally from State B to State A.

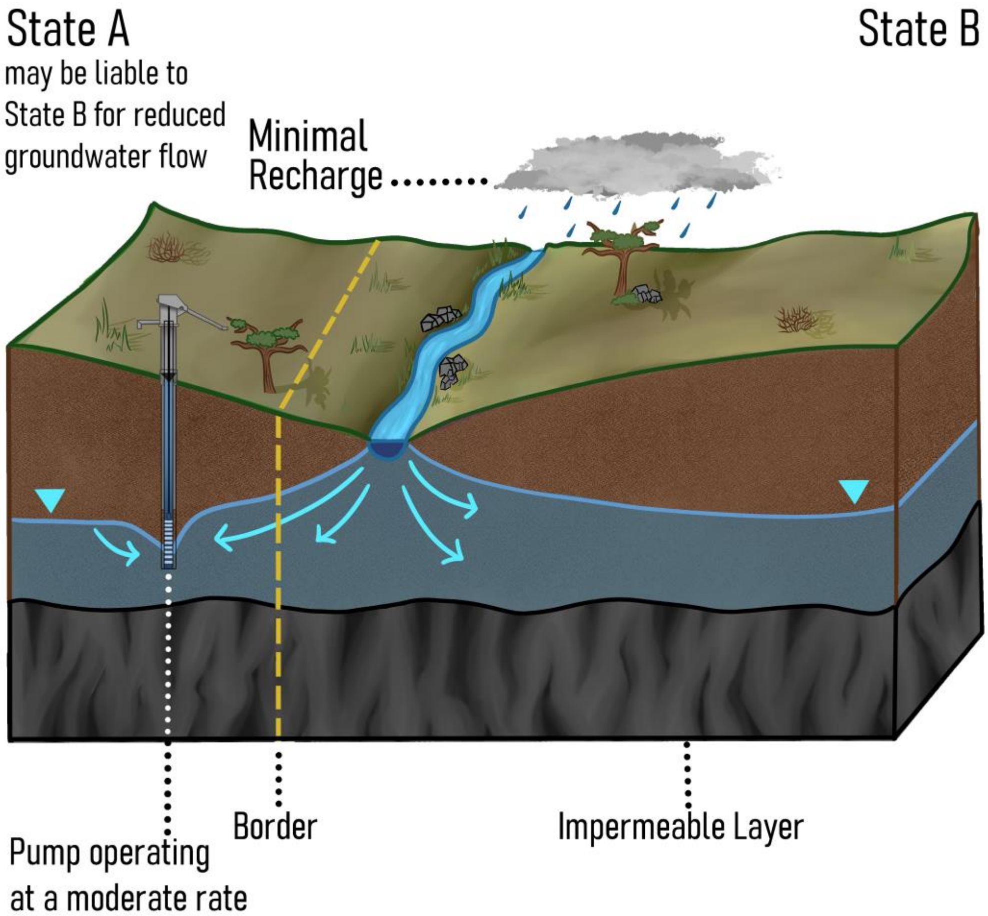


Figure 47 - State A pumps groundwater at a moderate rate from the aquifer section located on its side of the border in Model C with a losing river. Within the area of influence of the well, the pumping accelerates the flow of groundwater from State B to State A, as shown along cross section C1 on the front face of this image. Under such conditions, State B may have a claim for liability against State A depending on the degree of harm that State B suffers from the loss of use of groundwater in its territory.

The pumping could also enhance and accelerate the cross-border flow of any contamination found in State B's segment of the aquifer. Moreover, if State A's pumping was strong enough it could eventually impact water flow in State B's domestic river by enhancing the natural losing state of the river—causing more river water to seep into the aquifer and toward State A (Figure 48).

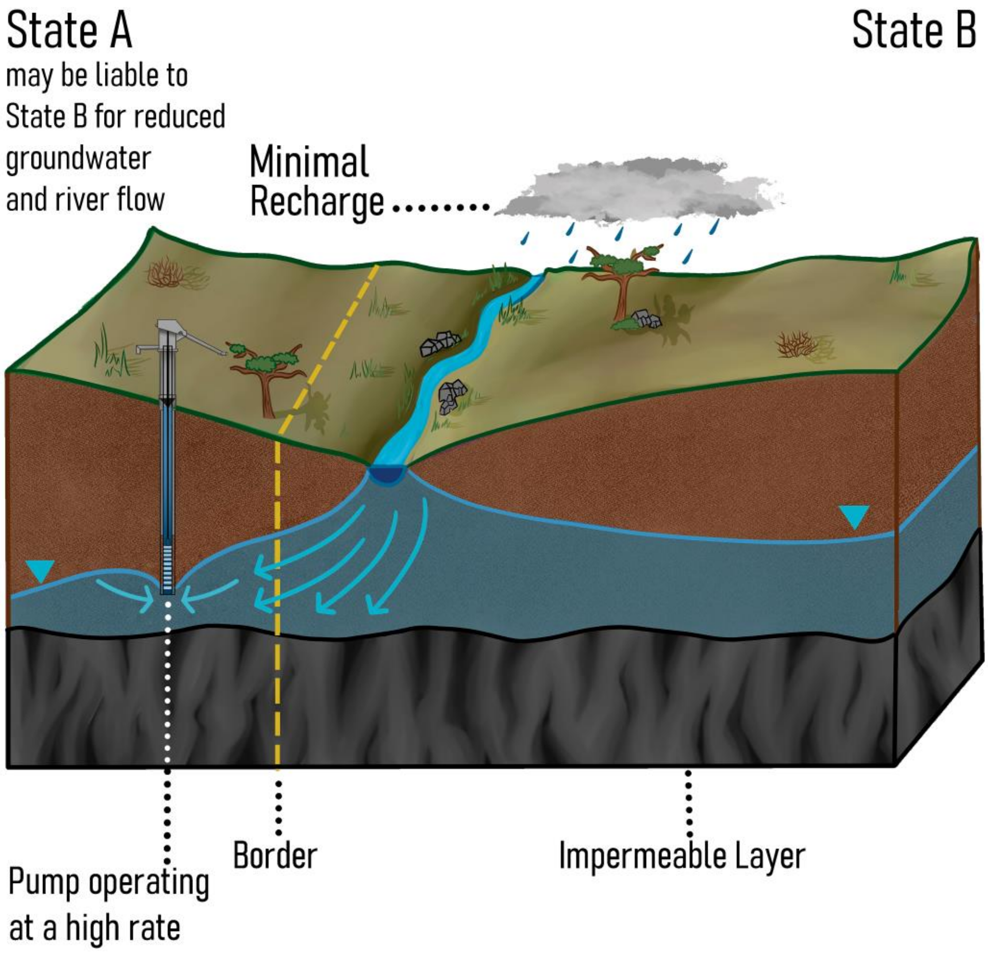


Figure 48 - State A pumps groundwater at a high rate from the aquifer section located on its side of the border in Model C with a losing river. Within the area of influence of the well, the pumping causes the groundwater divide under the river to shift slightly away from the pumping well, accelerates the flow of groundwater from State B to State A, and increases the proportion of river water that seeps into the aquifer and flows across the border to State A, as shown along cross section C1 on the front face of this image. Under such conditions, State B may have a claim for liability against State A depending on the degree of harm that State B suffers from the loss of use of groundwater and river flow in its territory.

On the other hand, if State B installed a well near its border with State A, it could reduce the natural flow of groundwater across the border and even reverse that natural flow within the well's area of influence (Figure 49). Likewise, it could cause any contaminants found in State A's segment of the aquifer to flow toward the well in State B.

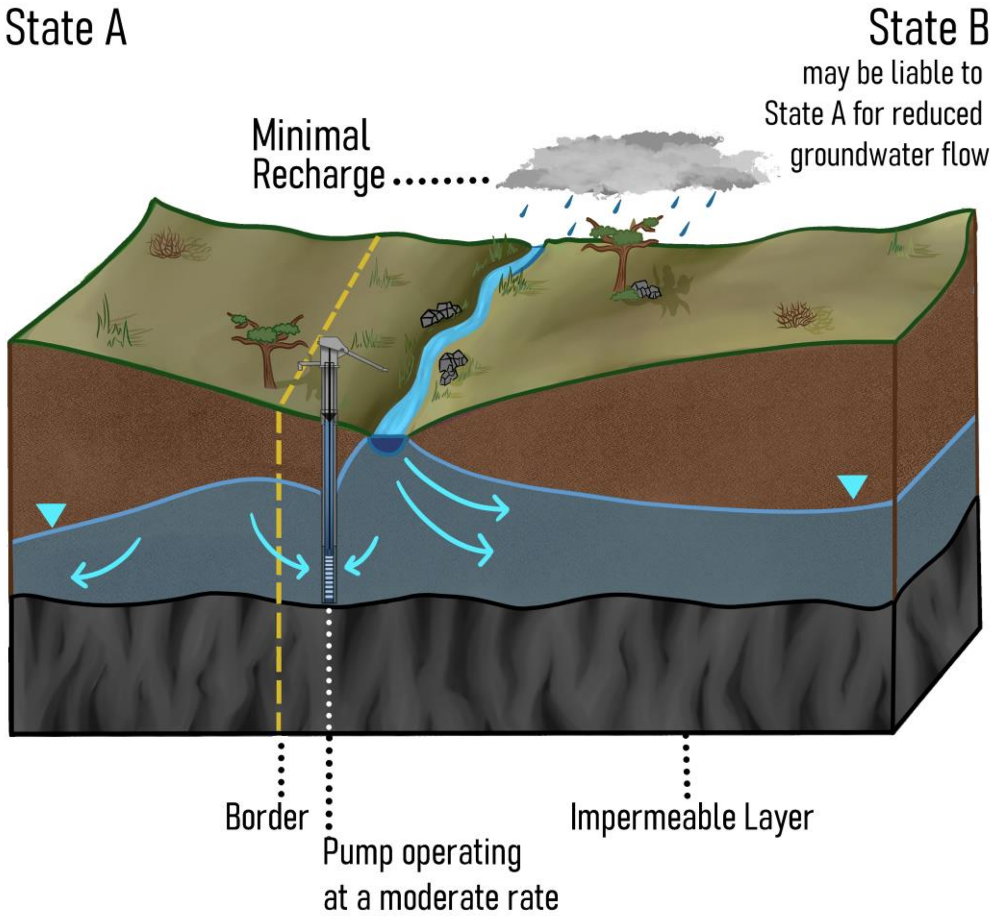


Figure 49 - State B pumps groundwater at a moderate rate from the aquifer section located on its side of the border in Model C with a losing river. The pumping causes groundwater to flow from State A to State B, which is a reversal of the flow under natural conditions (Figure 46), as shown along cross section C1 on the front face of this image. As a result, State B may be liable to State A depending on the degree of harm that State A suffers from the reduced groundwater flow into its territory.

An example of an unconfined aquifer traversing an international boundary and bisected by a domestic river can be found along the Mexico-USA border. The Mimbres Basin Aquifer is an unconfined aquifer that traverses northwestern Chihuahua in Mexico and southwestern New Mexico in the USA (Figure 50). The aquifer is hydrologically linked to the Mimbres River, which flows entirely within the USA and has a losing relationship with the aquifer (Hebard, 2000).

Figure 50 - Map of the geographic extent of the transboundary Mimbres aquifer. The unconfined aquifer is hydrologically connected to the Mimbres River, which flows entirely within the US and has a losing relationship with the aquifer (reproduced from Rodriguez, 2022d).

4.4 Model D: Unconfined Domestic Aquifer Hydrologically Linked to a Transboundary River

To some extent, Model D (Figure 51) is the converse of Model C. Here, the model depicts a river that traverses a political boundary and that is hydrologically connected to an intra-jurisdictional or domestic unconfined aquifer—for example, the aquifer is located entirely within the jurisdiction of one State. The river in State A in this example is flowing over bedrock or other impermeable material or flows at such a steep angle that the possibility of an aquifer forming is minimized. Hence, the key feature of this model is that the transboundary character of this aquifer-river example is found exclusively in the river. However, this does not mean that the aquifer in this model is insignificant. In fact, this model can be subdivided into two sub-models.

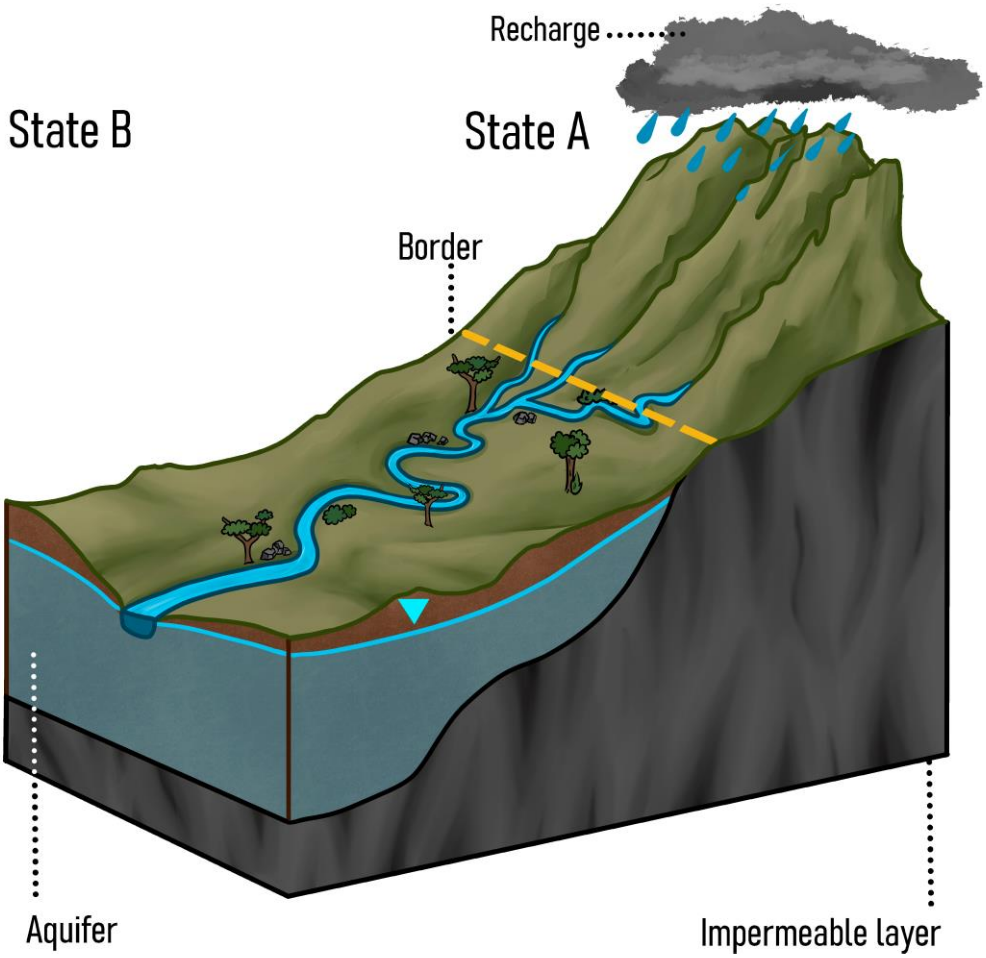


Figure 51 - Model D: A river flowing across an international border that is hydrologically linked to an unconfined aquifer that is completely within the territory of the downstream watercourse State.

Model D illustrates the scenario in which the aquifer is in the downstream jurisdiction (State B). In other words, in this example the aquifer is exclusively domestic to State B. Here, the transboundary implications would be solely dependent on river volume and quality flowing from State A to State B. As such, State A in this model would have the singular opportunity and responsibility for ensuring the water flowing down the river into State B, including any diminution in the quantity or quality of that downstream flow. Thus, if State A were to divert that flow within its territory (Figure 52), absent an agreement with State B, it could be subject to liability to State B if the diversion significantly reduced downstream flow into State B.

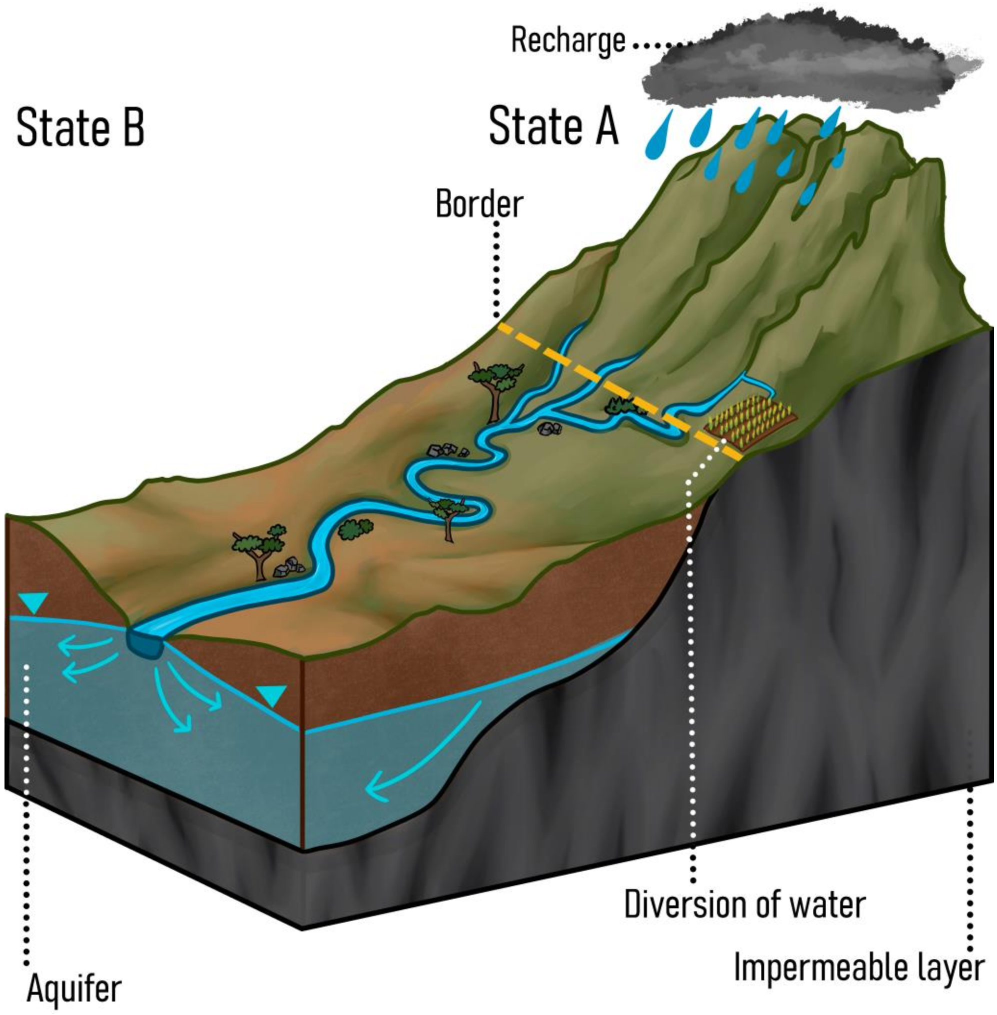


Figure 52 - Diagram showing a transboundary river hydrologically connected to an aquifer in a losing relationship with the river that is entirely domestic to State B, and where State A is diverting water from the river for use within its territory.

If the river in State B was a losing stream (Figure 52), State A would have the additional opportunity and responsibility (albeit it is unclear if State A would suffer legal liability if it failed) to safeguard the quantity and quality of water in the hydrologically connected aquifer underlying State B. This is because any activity in State A that adversely impacts the river's volume or chemical composition could impact State B's domestic aquifer. One exception to this scenario is if the diminished quantity or quality of the downstream flow is the sole result of natural causes such as climatic changes or impurities native to the riverbed, in which case State A would bear no liability for downstream consequences.

An example of this model can be found in the Mesopotamian Basin of the Tigris and Euphrates Rivers (Figure 53). The two rivers have their headwaters in the crystalline massif of southeastern Anatolia in Turkey and then flow across international boundaries. The Tigris flows southeast into Iraq, while the Euphrates flows first southward through Syria and then southeast into Iraq. In Iraq, the two rivers flow over the large sedimentary basin of Mesopotamia forming an unconfined aquifer, which in some places is as thick as 300 m (984 ft) (FAO, 2008).

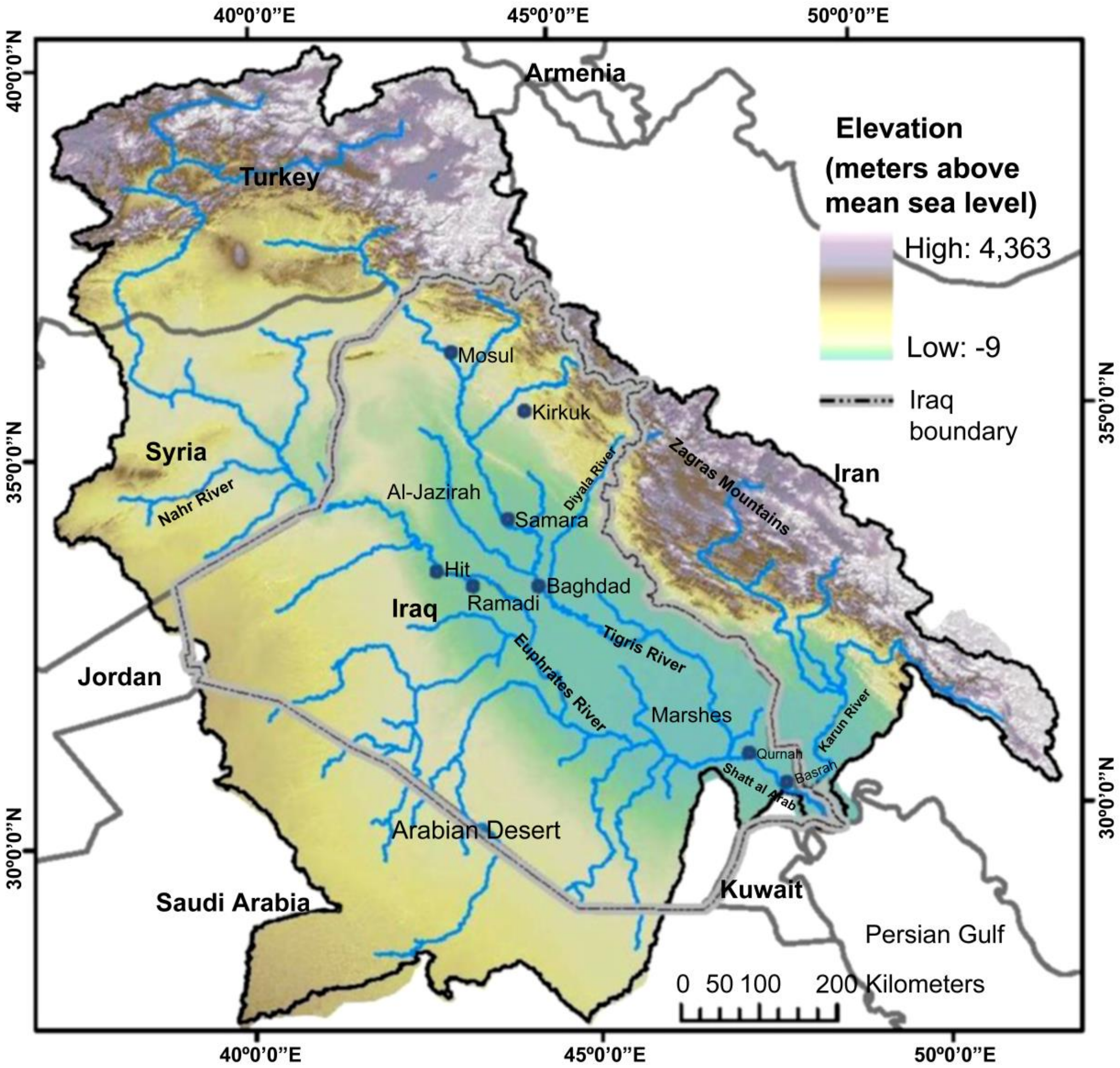


Figure 53 - Map of the Tigris and Euphrates Rivers catchment area (reproduced from Flint et al., 2011). The two rivers traverse the borders of Turkey and Syria and into Iraq where they flow over a large unconfined sedimentary basin.

A variation on this model comprises the reverse situation from that illustrated in Model D whereby the domestic aquifer is in the upstream jurisdiction, State A (Figure 54).

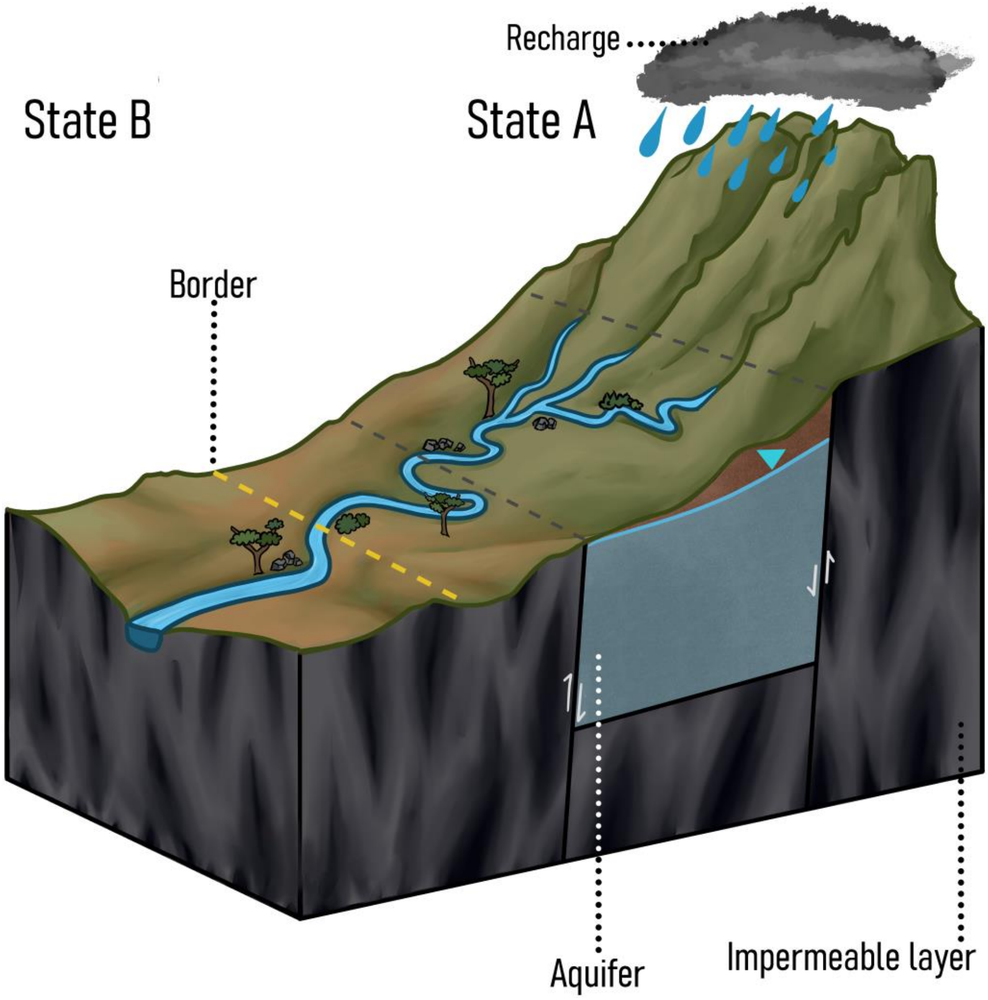


Figure 54 - Diagram showing a transboundary river hydrologically connected to an aquifer located entirely within the upper river riparian state. Dashed gray lines show the subsurface extent of the aquifer.

As in the prior example, cross-border implications for State B would be entirely in State A's hands and depend on the quantity and quality of water flowing in the river downstream into State B. However, the river also would be influenced by the river-aquifer relationship in State A, thus imposing the added responsibility on State A of managing its domestic aquifer in a manner that would not negatively impact the water flow in the river. If the river was gaining in State A, any pollutant found in State A's domestic aquifer could migrate into the river and flow into State B (Figure 55).

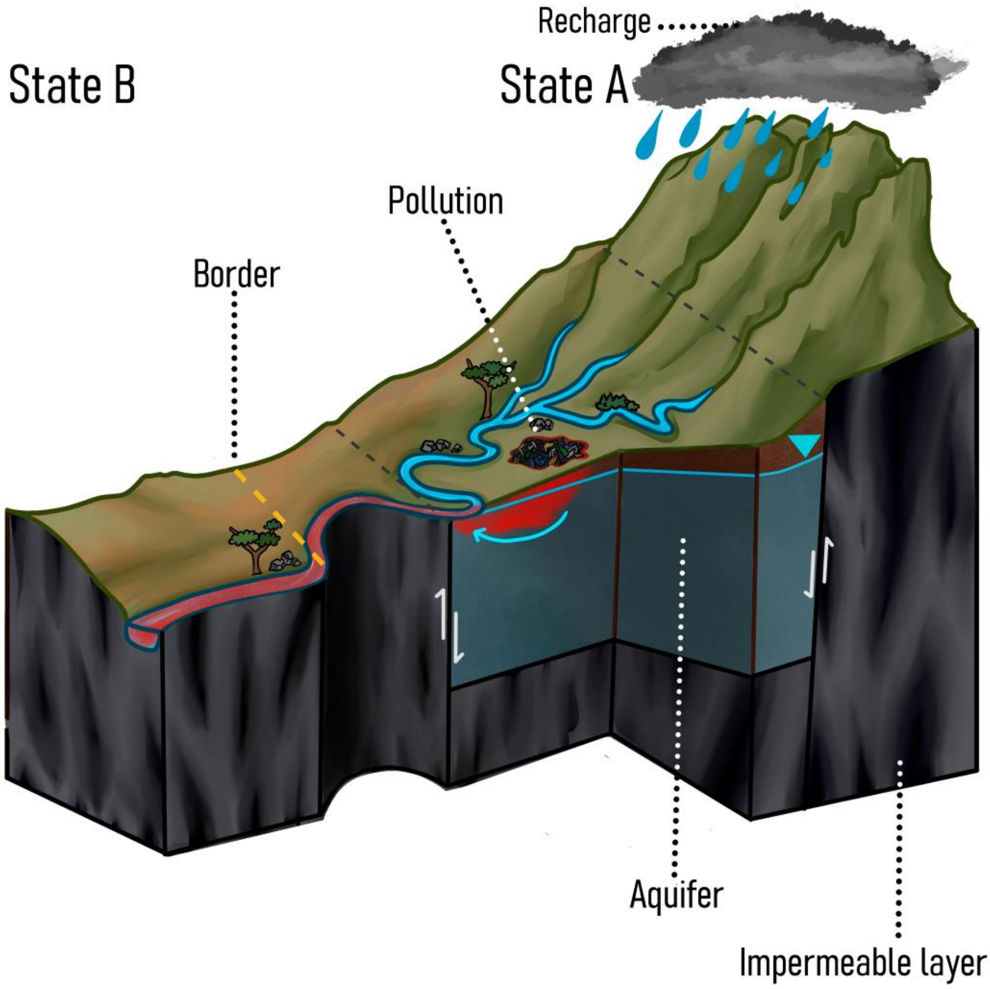


Figure 55 - Diagram showing a transboundary river in a gaining relationship with an aquifer located entirely within the upper river riparian state (State A). Any pollution occurring in State A's domestic aquifer could migrate into the river and flow into State B.

If the river was losing, the contamination found in State A's domestic aquifer would remain in State A (Figure 56). In a similar vein, if the river was losing in State A and pollution was introduced into the river at some significant distance from the political frontier, that pollution would be—at least partially—removed from the river before it reaches State B as a result of the infiltration from the river into State A's aquifer (Figure 57). Regardless of whether the river is gaining or losing, however, any pumping in the vicinity of the river where the cone of depression reaches the river could diminish the volume of water flowing downstream into State B. Notwithstanding, any activity in State A with respect to the aquifer or river that has a substantial cross-border impact on State B through the river could be deemed actionable and result in liability for State A.

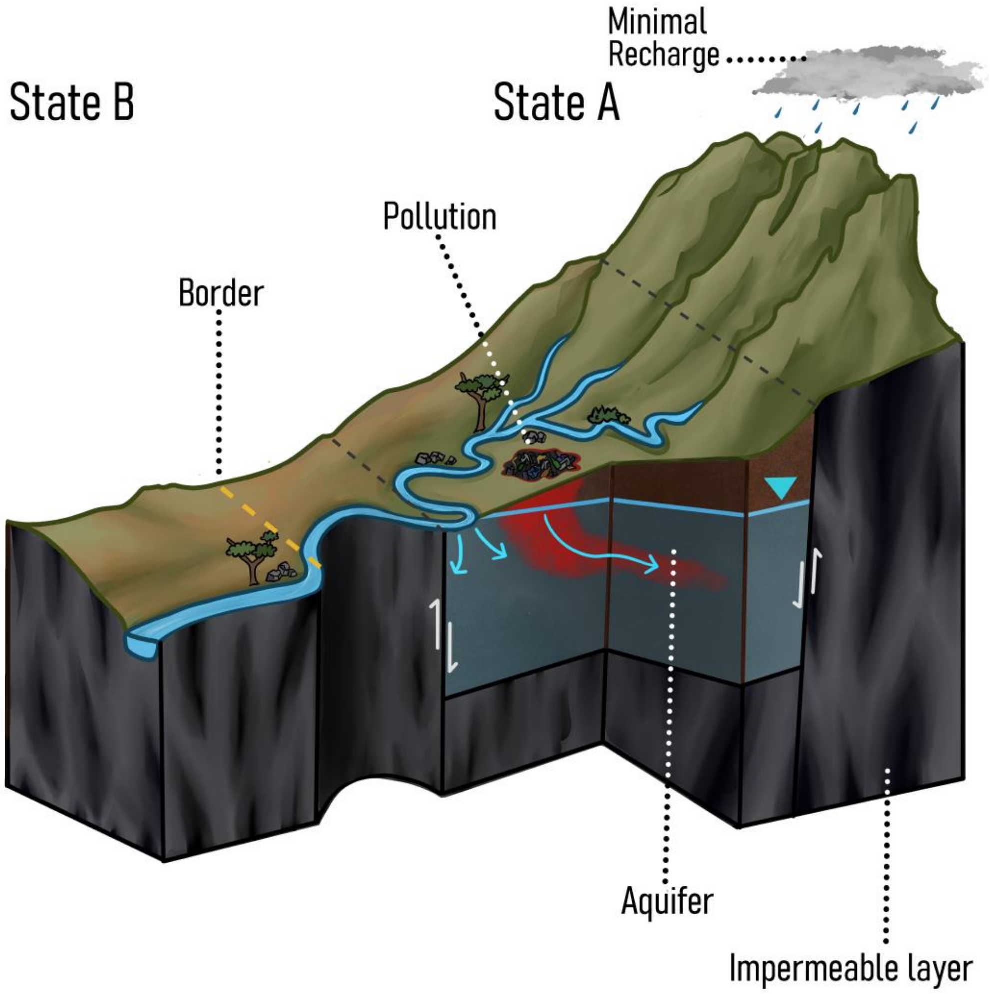


Figure 56 - Diagram showing a transboundary river in a losing relationship with an aquifer located entirely within the upper river riparian state (State A). Any pollution occurring in State A's domestic aquifer would remain in State A.

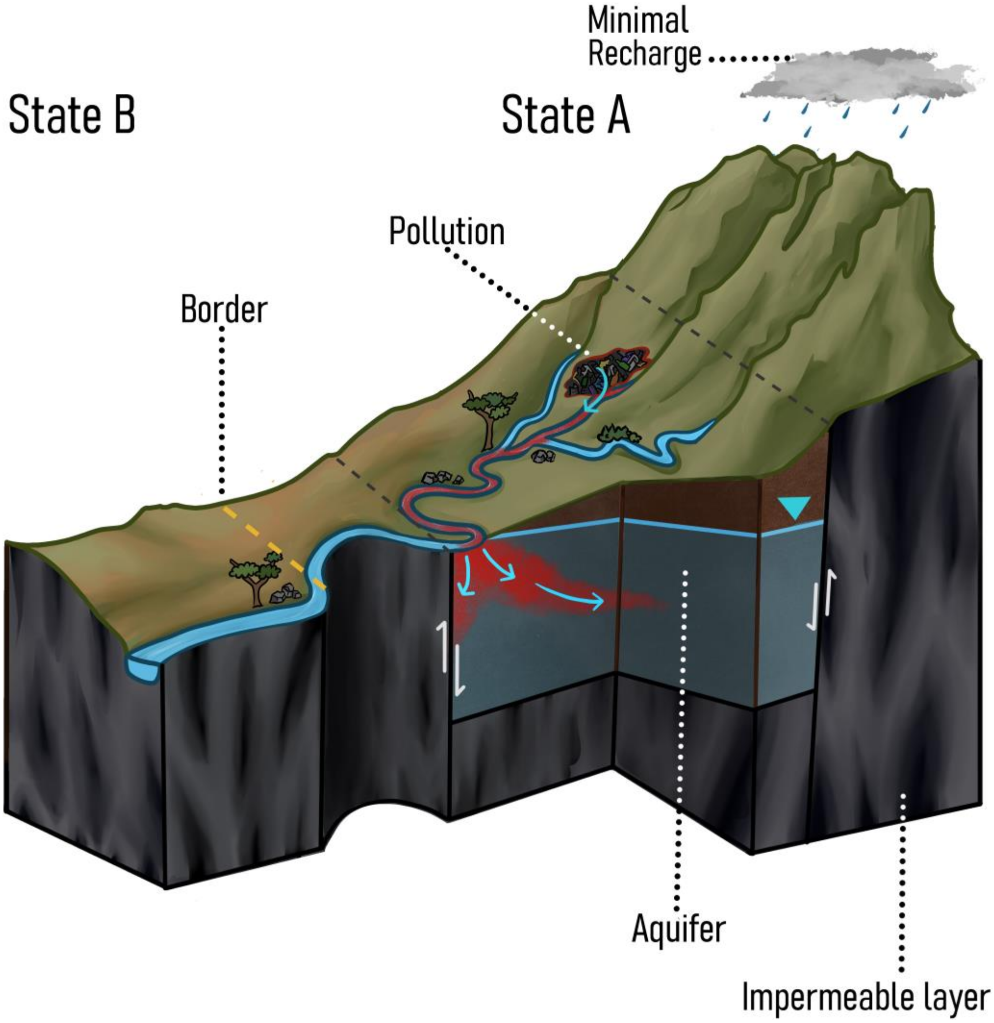


Figure 57 - Diagram showing a transboundary river in a losing relationship with an aquifer located entirely within the upper river riparian state (State A). Any pollution introduced into the river in State A would—at least partially—be removed from the river before it reaches State B because of the infiltration from the river into State A's aquifer.

It is worth noting that these two versions of Model D are intentionally simplistic to identify and explore the cross-border implications more easily. In the natural world, it is entirely possible that a transboundary river could be hydrologically connected to independent domestic aquifers located in both State A and State B, as well as an additional transboundary aquifer. It is also possible that the aquifer located in the upstream State would actually be hydraulically connected to a tributary of the river that traverses the political boundary. The key point here is that depending on the hydrologic relationship between the river and the domestic aquifer in State A, as well as on river and aquifer-related activities in State A, State A would be responsible and potentially liable for transboundary consequences to downstream State B.

An example of this model, in which the aquifer is entirely located in the upper riparian state and is connected to a transboundary river in a mostly losing relationship is the alluvial aquifer that is hydraulically connected to the Gila River in southern Arizona, USA. The Gila River is a tributary of the Colorado River just before the Colorado River flows across the border from the USA into Mexico. Domestic alluvial aquifers flow along various segments of the Gila River in Arizona in the general direction of the river and, for the most part, recharge from precipitation and the river (Anderson, 1995). Effectively, these aquifers are in an upper riparian state (USA) and are connected to a tributary of a transboundary surface water body (the Colorado River) in a mostly losing relationship that flows into a lower riparian state (Mexico). To evaluate your understanding of this topic, Exercise 1↴ provides an opportunity to work with these concepts.

4.5 Model E: Confined Transboundary Aquifer with a Recharge Zone in Only One Riparian Jurisdiction

This fifth model, Model E (Figure 58), presents a confined aquifer traversing a political boundary with a recharge zone in an unconfined portion of the aquifer, which is located entirely in one of the neighboring states. In this model, while there is no connection to a surface water body, the aquifer is connected to the hydrologic cycle through the recharge zone. Here, the model depicts groundwater flowing in the general direction from State A toward State B. This means that State A would have distinct responsibility for ensuring the quantity and quality of water flowing into and through the aquifer as it flows below State B. While all transboundary implications will be functions of the groundwater flow through the aquifer, a key feature for purposes of assessing responsibility and liability is the location of the jurisdictional frontier in relation to the aquifer, its confined and saturated segments, and the recharge zone. One possible scenario for the jurisdictional/aquifer relationship is the example specifically depicted in the model in which the confined portion of the aquifer traverses the political boundary, and the recharge zone is located exclusively in one of the aquifer riparian jurisdictions—State A (Figure 58).

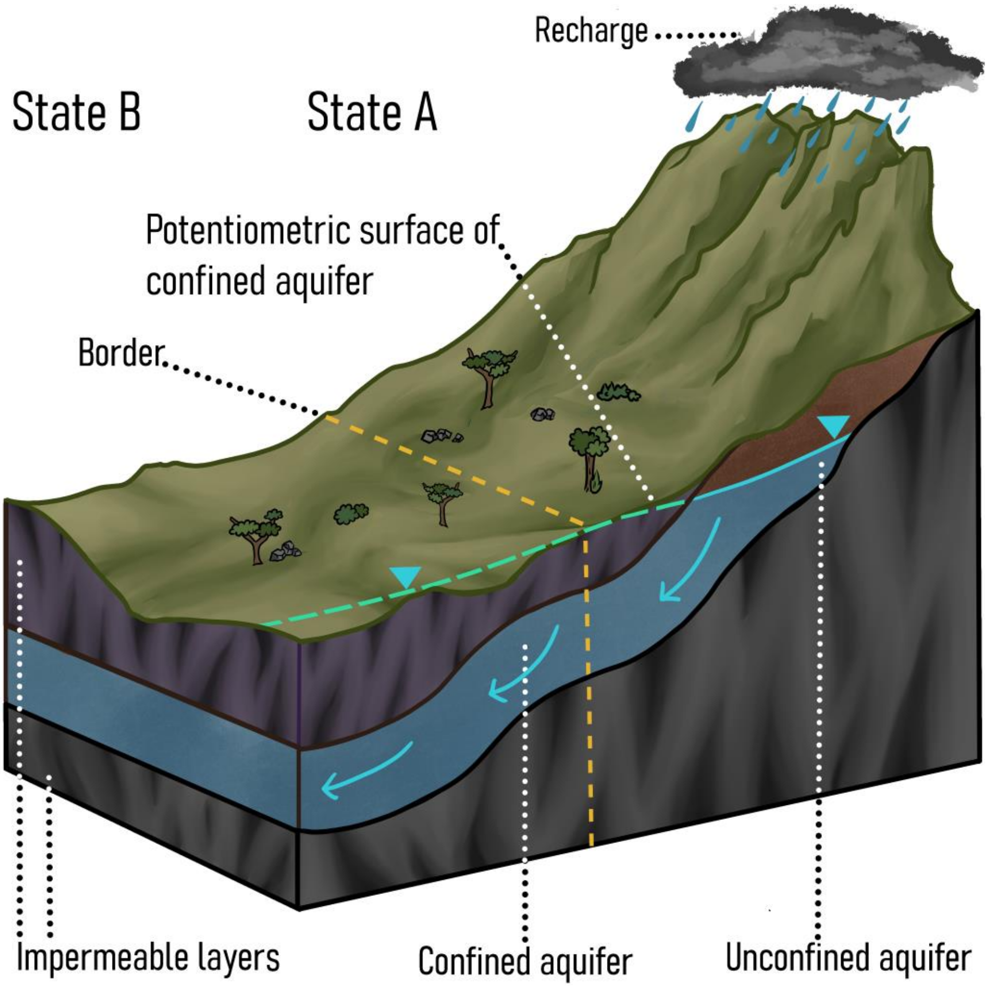


Figure 58 - Model E: A confined aquifer traversing a political boundary with a recharge zone in only one of the riparian jurisdictions. The model shows the water table in an unconfined portion of the aquifer, potentiometric surface in the confined section of the aquifer, and groundwater flow directions under natural conditions (no pumping).

In this scenario, any excessive pumping in one or both jurisdictions will have the potential to result in an impact across the border. For example, if State A began vigorously withdrawing groundwater along the border in excess of natural recharge, its cone of depression—or, more precisely, the reduction in the hydraulic head surrounding the pumped well—could extend into State B (Figure 59).

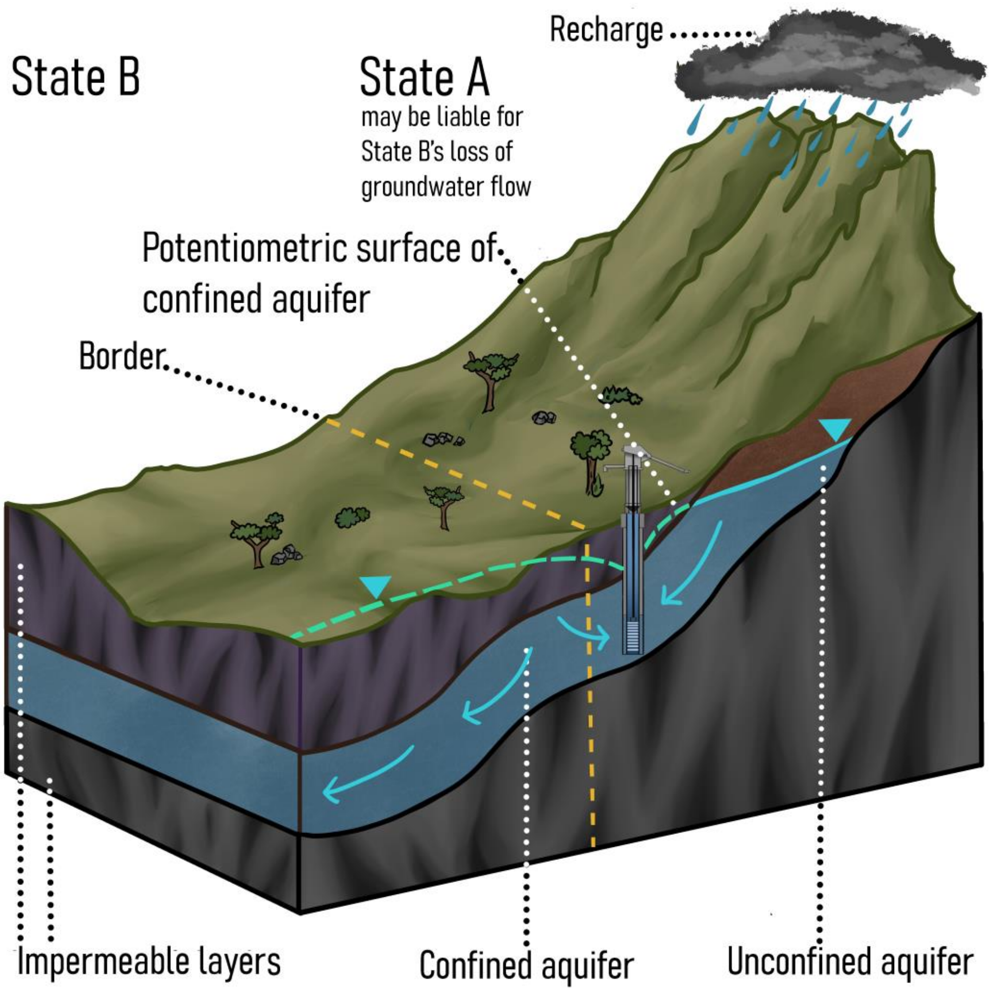


Figure 59 - State A pumps at a high rate from the aquifer on its side of the border in Model E, producing changes in the potentiometric surface of the confined zone and groundwater flow directions. In the vicinity of the well, this pumping can reverse the direction of natural groundwater flow across the border, causing groundwater to flow from State B to State A within the well's area of influence. Depending on the degree of harm that State B suffers from the reduced groundwater flow into its territory, State B may have a liability claim against State A.

Whether that reduced hydraulic head impacts State B in a substantial manner will depend on a variety of factors including head differential, poroelastic parameters of the confined formation, specific storage coefficient, associated time scales, among others. While such an analysis may be complex—and while the impact may take weeks, months, or years to be felt across the border—the potential for cross-border impact does exist and could include a reduction of hydraulic head and possibly groundwater flow from State A to State B within the area of influence surrounding State B's well (Figure 59).

In addition, natural or artificial contaminants found in the aquifer's recharge zone within State B could be transported to State A because of natural flow—that is, from State B to State A (Figure 60). Moreover, the transboundary advective transport of pollutants due to pumping by one of the aquifer states would occur where the hydraulic head within the area of influence in the pumping state is lower than that found in the non-pumping state.

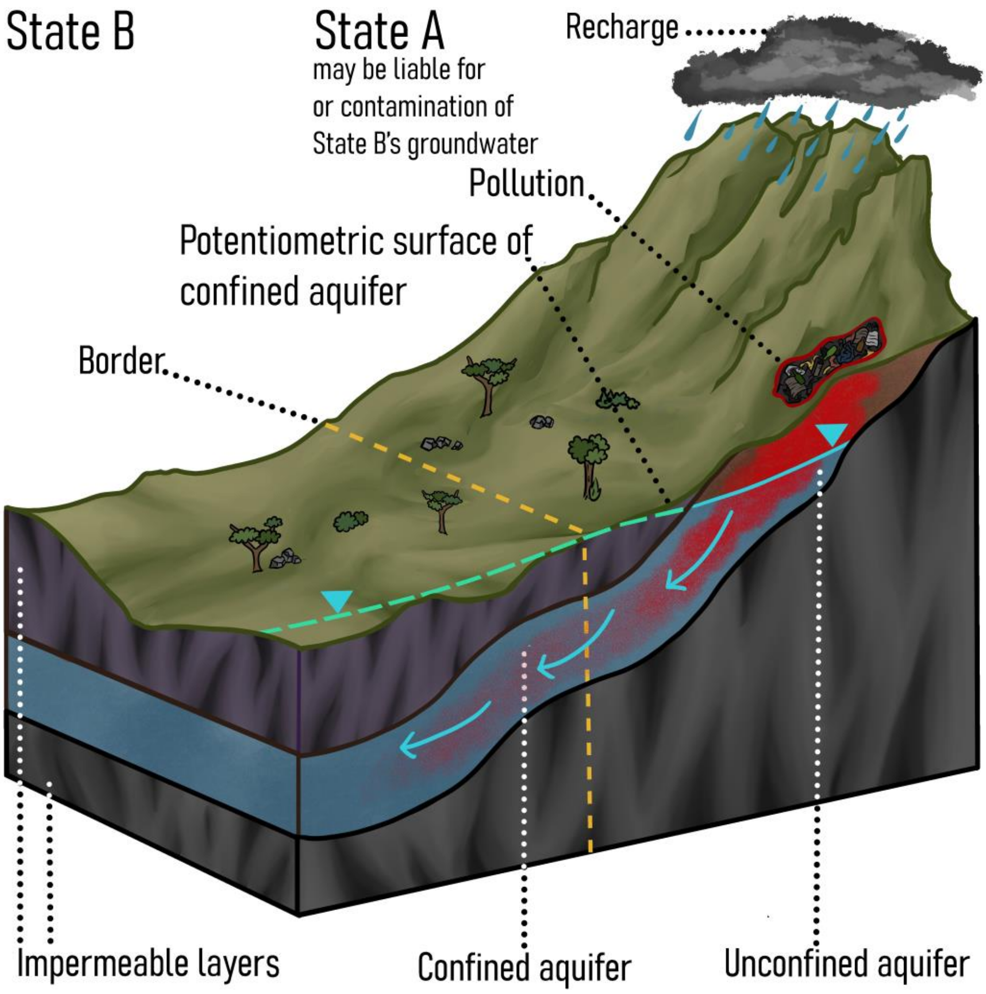


Figure 60 - Pollution in State B's recharge zone causes contamination of the unconfined portion of the aquifer. Under natural (no pumping) conditions, the contamination migrates into the confined section of the aquifer and across the border into State B. Under such conditions, State B may have a liability claim against State A for polluting its section of the aquifer.

In addition, the scenario described in Figure 60 presents another possibility for responsibility and liability. Since the recharge zone is located solely within State A's territory, State A could take action that lessens the natural recharge of the aquifer such as by capturing or diverting surface runoff in the vicinity of the recharge zone for use within State A (Figure 61). Such action could deprive State B of some of the natural flow of groundwater within the aquifer. Moreover, State A could pursue activities that pollute the surface and any water used in the recharge zone (e.g., agricultural runoff, and untreated municipal and industrial waste), which could then infiltrate the aquifer and cause the contaminants to migrate to State B (Figure 60). Such implications place an additional burden on State A to safeguard the aquifer in terms of ensuring the character and sustainability of the recharge area. Because the confined and saturated portion of the aquifer in Model E traverses the frontier between the two jurisdictions in this scenario, it is reasonable to assume that State A would, in fact, undertake such protective measures since it too can benefit from the aquifer and a properly functioning recharge zone.

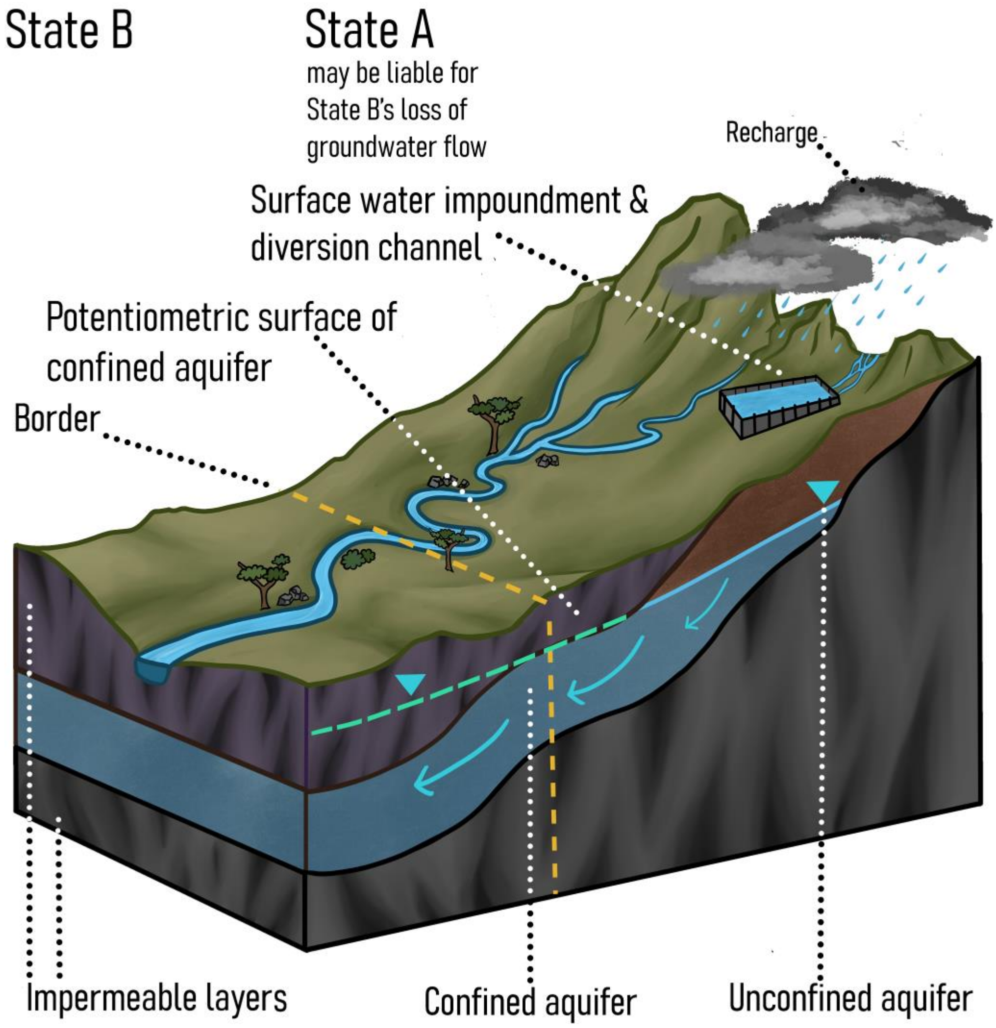


Figure 61 - State A diverts water from the recharge area to a surface water impoundment. This causes a reduction in the volume of water infiltrating the recharge zone and reaching the aquifer, a lowering of the water table in State A, and a consequent reduction in flow through the confined aquifer and lowering of its potentiometric surface. Depending on the degree of harm that State B suffers from the reduced groundwater flow into its territory and reduced pressure in its portion of the confined aquifer, State B may have a liability claim against State A.

This, however, suggests the possibility of a slightly altered scenario in which harm might occur, but where liability under international law might not be easily assigned. Consider the last scenario presented above, but where the aquifer is confined and most of its unconfined saturated portion is located entirely in one jurisdiction—for example, in State B—and where the recharge zone either traverses the political boundary or is found entirely in another jurisdiction—for example, in State A (Figure 62). In this instance, transboundary implications would exclusively depend on whether and the extent to which the jurisdiction where part or all the recharge zone is located undertakes measures to protect the aquifer.

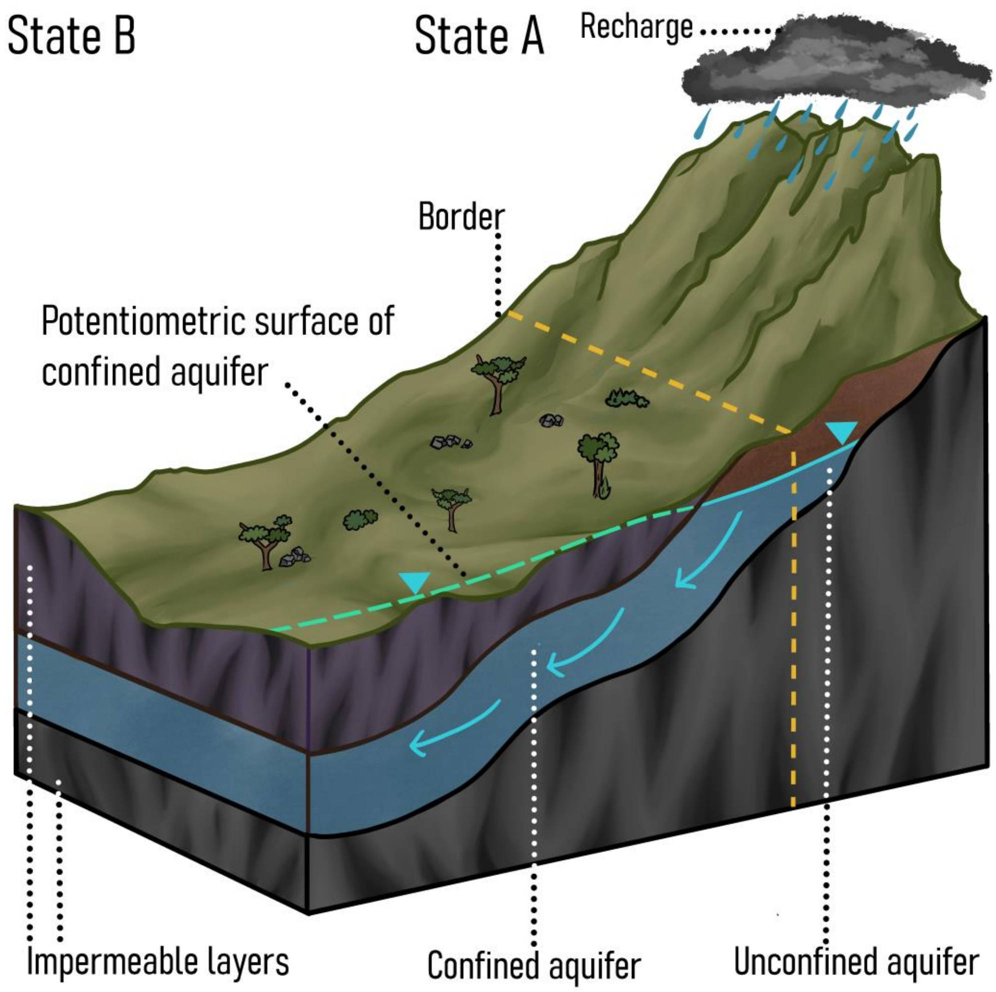


Figure 62 – Model: E with a modified border position so that the confined portion of the aquifer is located entirely in State B. State A has relatively little access to the saturated portion of the aquifer, and thus has little incentive to protect the aquifer in State B; State B is dependent on State A practicing good stewardship of the recharge zone, including maintaining the volume and quality of the recharge water. This creates a dilemma that has yet to be addressed by either international water law or nations' domestic water laws for subnational units overlying a common aquifer.

The challenge here is that State A—the state where much of the recharge zone is located has little incentive, other than good neighborliness, to implement protective measures. Since this jurisdiction only overlies a small section of the formation's saturated layer, its ability to derive substantial benefits from the water in the aquifer is limited, especially in comparison with State B. This creates a dilemma for which international water law as well as all nations' domestic water laws for subnational units have yet to address. For now, there is a gap in water law that leaves the state in which the storage resides completely dependent on the good graces of its less fortunate neighbor. While that state could decide to share its bounty, there is nothing in international or domestic law that mandates such conduct. And it is unclear whether liability would apply to the state with the recharge zone for failing to actively protect the interests of its aquifer state neighbor.

However, under general international law—as compared with international water law—good neighborliness and related principles would still apply to this scenario and would require the state with the recharge zone to ensure that activities within its territory do not harm the state with the aquifer storage. Notwithstanding, the state with the aquifer storage would be entitled to exploit resources within its own territory to meet its own societal and economic development needs. The result is not unlike other situations in which neighboring States and subnational units must evaluate their activities in relation to possible cross-border harm. Hence, requiring implementation of specific protective measures, as well as the determination of responsibility and liability, may be best resolved through negotiations rather than judicial or other mechanisms.

Examples of this model include:

- the series of deep, confined aquifers in the Syr Darya River Basin of Kazakhstan, which are not linked to the Syr Darya River but are recharged in the high mountains of Turkmenistan and Tajikistan (Sydykov & Veselov, 1993);
- the Mountain Aquifer (Figure 63) between Israel and the Palestinian Territory of the West Bank, where the calcareous formations of the Upper Cretaceous (Turonian-Cenomanian) are exposed and recharged in the highlands within the Judean and Samaria Mountains, and slope westward across the 1949 Armistice Demarcation Line—which separates Israel proper from the West Bank—toward the Mediterranean Sea and underneath a confining layer (Eckstein & Eckstein, 2003); and
- the Guarani Aquifer (Figure 64) underneath Argentina, Brazil, Paraguay, and Uruguay, which is confined in 90 percent of its extent (Kemper at al., 2003; Tujchneider et al., 2003).

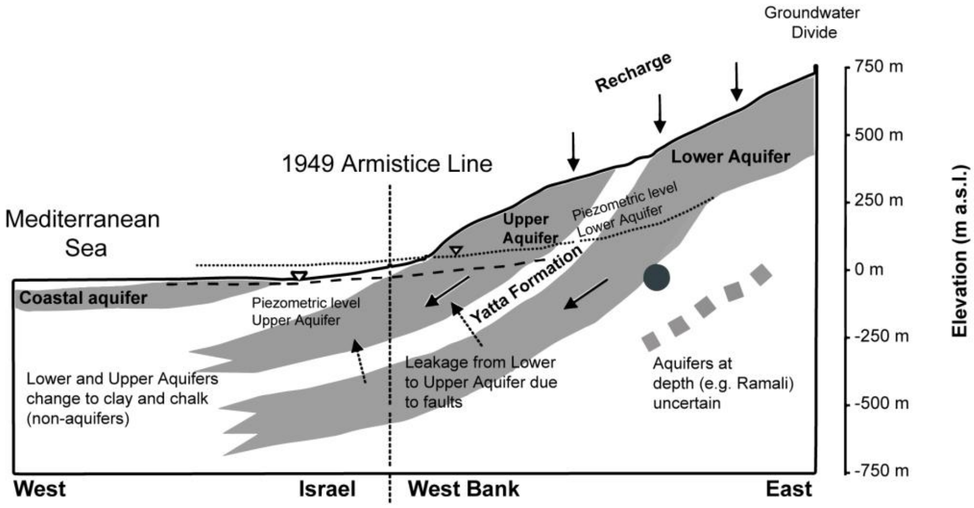


Figure 63 - Image showing a 70 km-long (44 mile) west–east cross section from the Mediterranean coast across Israel and the central part of the Western Aquifer Basin (reproduced from Mansour et al., 2012). The 1949 Armistice Line serves as the de facto border between Israel and the Palestinian Territory of the West Bank.

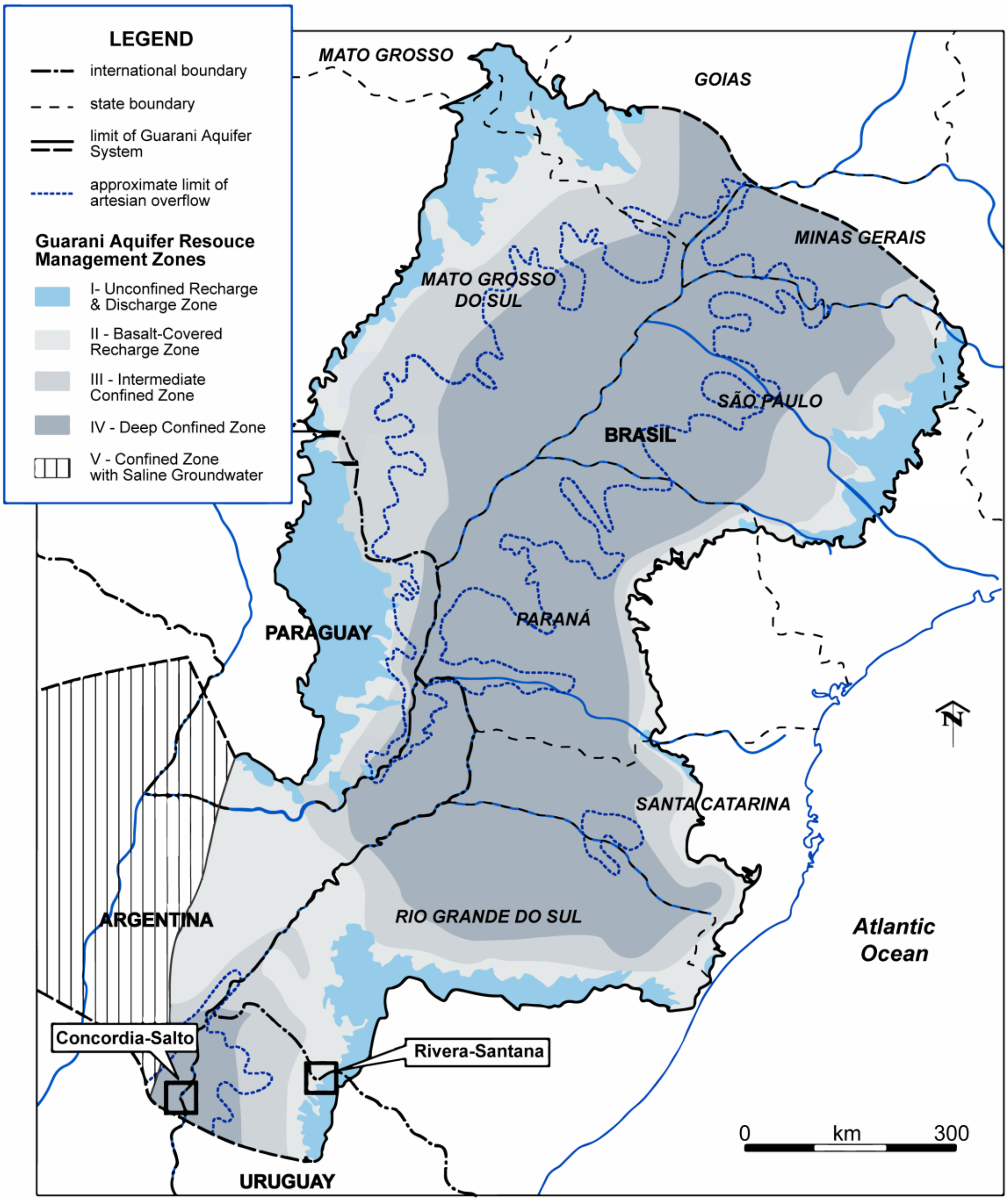


Figure 64 - Guarani Aquifer System showing resource management zones (reproduced from Foster et al., 2009).

4.6 Model F: Non-Recharging Transboundary Aquifer

The final model, Model F (Figure 65), in this series also presents a scenario that both international law and nations' domestic laws have yet to fully consider. This model depicts a cross-border aquifer that is unrelated to any surface water body and receives no or only insignificant recharge. Such aquifers, often containing ancient waters, may be confined or unconfined and fossil or connate (Bouwer, 1978). As such, these aquifer types are non-recharging and cannot be sustainably exploited.

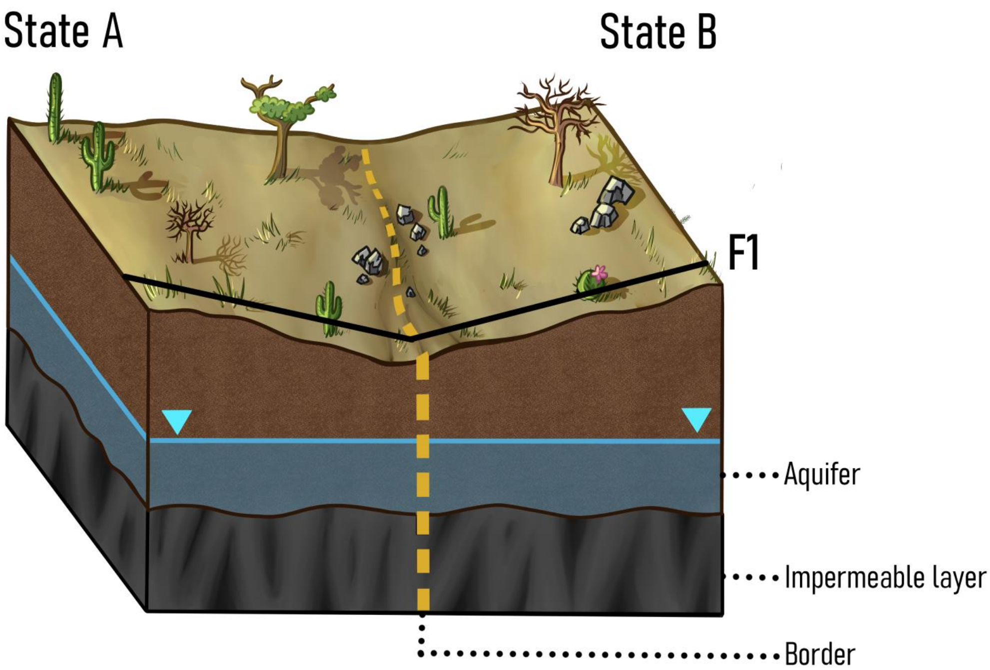


Figure 65 - Model F: A transboundary aquifer that is unrelated to any surface waterbody and is devoid of any meaningful recharge. The black line labeled as F1 indicate the location of a cross section that will be referenced in subsequent figures for this model.

Any extraction from a non-recharging aquifer will deplete the aquifer. As a result, the cross-border consequences associated with these distinct geologic formations are almost exclusively a function of pumping from the aquifer in one or more of the overlying jurisdictions. When a jurisdiction commences production of groundwater from a well penetrating such an aquifer, it will generate an ever-expanding cone of depression that eventually will encroach across the political frontier (Figure 66). Any restrictions on the rates of continuous pumping that domestic, international law, or agreement between the two (or more) overlying jurisdictions impose on extraction may reduce the rate of the expansion of the cone of depression but will never stop it from expanding.

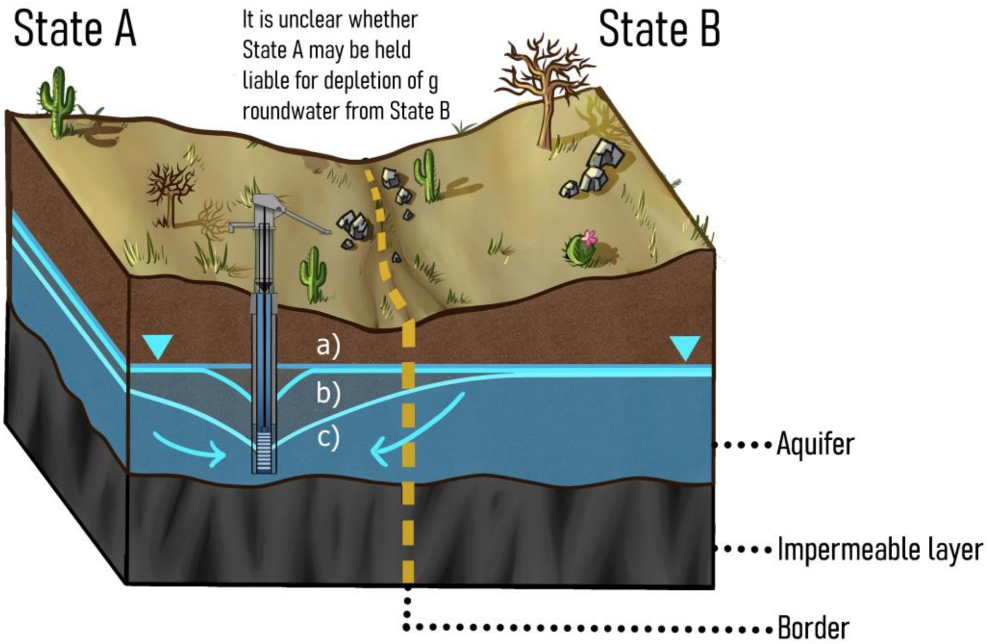


Figure 66 - State A pumps from the non-recharging aquifer on its side of the border in Model F, as shown by the expanding cone of depression along cross section F1 on the front face of this image. a) Water table before pumping starts. b) Water table a short time after the onset of pumping, with the cone of depression entirely within State A. c) Water table after sustained pumping, with the cone of depression extending a great distance into State B. Groundwater flow directions in the diagram are associated with condition c). While State A may be responsible for depleting the aquifer, including on State B's side of the aquifer, it is unclear whether State A may be held liable for that depletion because of the non-recharging nature of the aquifer.

Moreover, two competing wells on opposite sides of a border will create two cones of depression that eventually will overlap and coalesce. The rates of expansion of the cones of depression will depend on the particular rates of extraction and hydraulic properties of the aquifer (Figure 67). In either scenario, whether pumping occurs on one or both sides of the political boundary, if the overlying jurisdictions do not completely stop extracting groundwater, eventually the aquifer will be fully depleted. As a result, while responsibility for a particular outcome should not be difficult to assign because cross-border harm is inevitable, determining whether liability should apply is another matter. Possibly, where one state causes extreme depletion of the aquifer, liability may be appropriate. Yet, determining where the line is between acceptable and unacceptable depletion is a subjective assessment that may be best left to negotiations rather than adjudication.

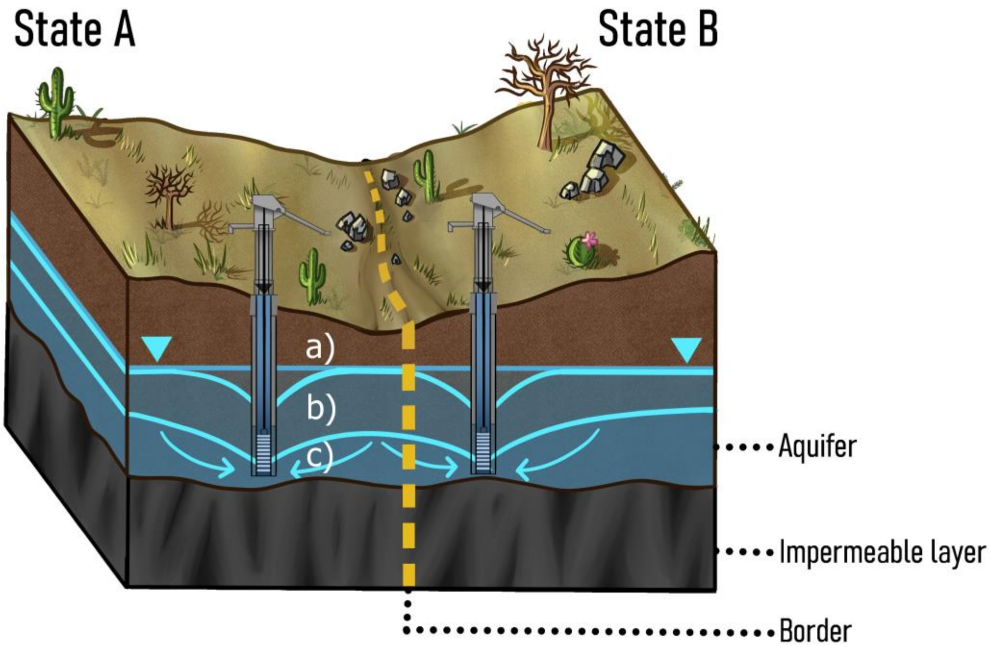


Figure 67 - State A and State B pump at an equal rate in Model F, shown by the expanding cones of depression along cross section F1 on the front face of this image. The well in State A is further from the border than the well in State B. a) Water table before pumping starts. b) Water table a short time after the onset of pumping, with the cone of depression for each well remaining entirely within the state containing the well. c) Water table after sustained pumping, with the cones of depression merging and groundwater flowing from State A to State B because State B's pumping well is closer to the border than State A's well. Groundwater flow directions in the diagram are associated with condition (c). While State B may be responsible for causing groundwater to flow from beneath State A toward State B's well and thereby depleting State A's section of the aquifer, it is unclear whether State B may be held liable for that conduct given that this is a non-recharging aquifer.

Another concern for the non-recharging aquifer depicted in Model F is that it can be susceptible to pollution under distinct situations. If pollutants are injected into the aquifer at a low or moderate rate, or naturally occurring contaminants are found in one section of the aquifer, those impurities will remain localized and concentrated because of the absence of any meaningful flow and the lack of incoming fresh water for dilution in non-recharging aquifers (Figure 68). However, once an extraction well is installed in the aquifer, the pumping action will create an artificial flow that can both disperse the pollutants through a portion of the aquifer and also pull them toward the well. Thus, the aquifer could become more widely tainted if it is pumped at any time after the contaminants arrived in the aquifer.

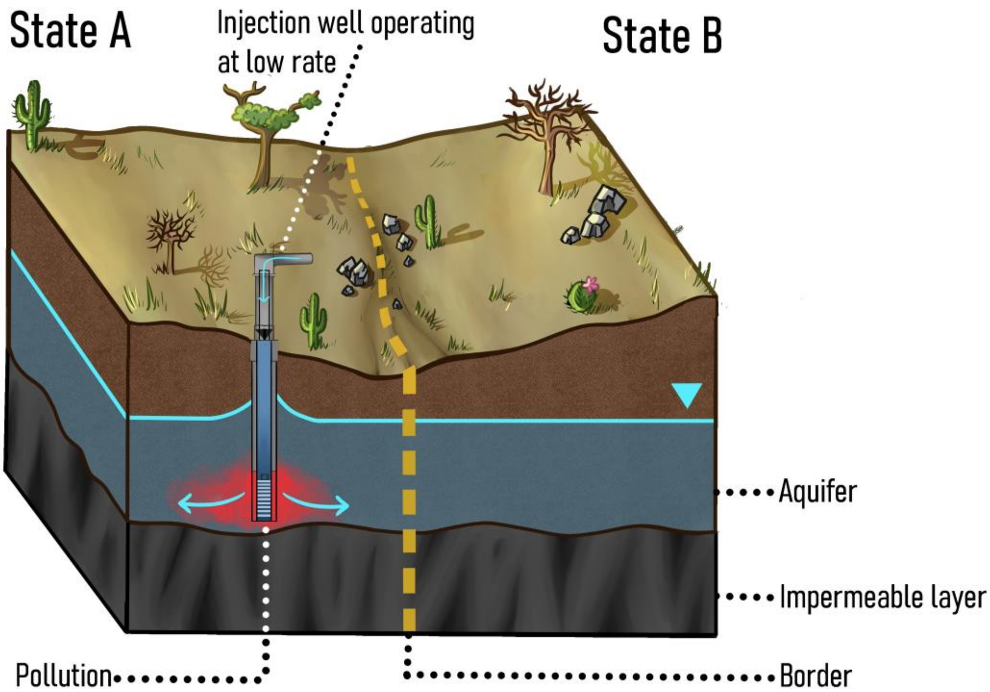


Figure 68 - State A introduces pollutants into the aquifer at a relatively low injection rate. The pollutants remain localized around the well and stay within State A, as shown along cross section F1 on the front face of this image.

If a withdrawal well is relatively close to the pollution, the extraction process can aid in removing contamination from the aquifer. However, if the extraction well is located in the neighboring (non-polluting) State, the well will draw the pollution across the border (Figure 69). Moreover, the further away the well is from that pollution source, the more it will disperse the contamination in the aquifer (Figure 70). Once such aquifers become polluted, they are extremely difficult—if not impossible—to remediate. Moreover, the absence of natural recharge and flow to and within the aquifer minimizes most of the natural attenuation processes common to flowing aquifers.

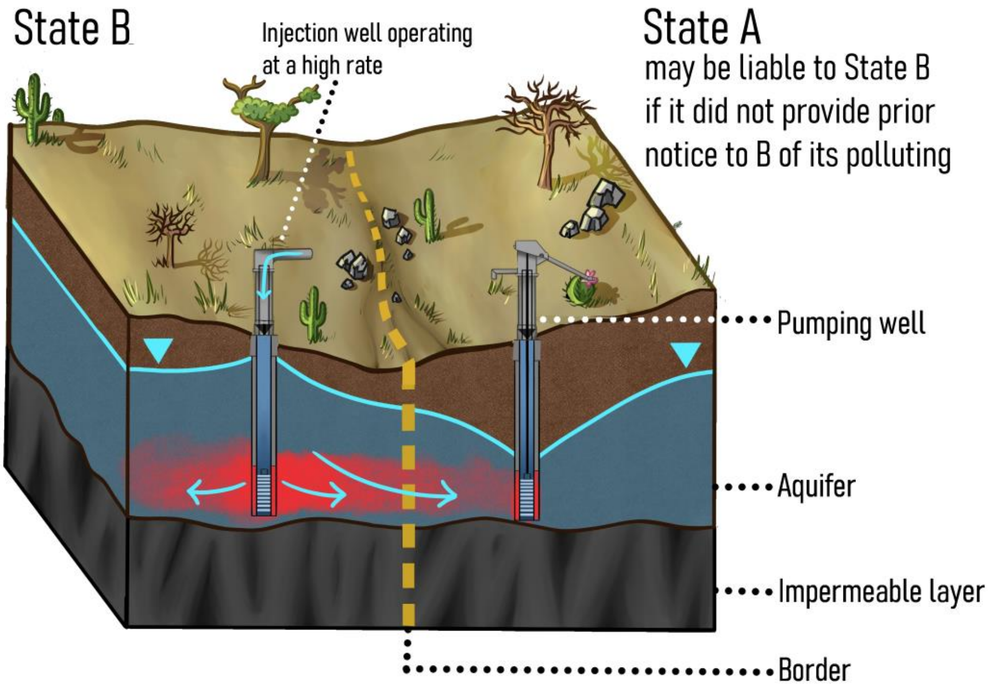


Figure 69 - State A introduces pollutants into the aquifer at a high rate and State B pumps from a well near the border. The pollutants migrate across the border to State B because of the pumping well, but the pollutants are not widely dispersed in State B because of the proximity of the well to the border, as shown along cross section F1 on the front face of this image. While State A may be responsible for introducing pollutants into the aquifer, it is State B that is responsible for causing the pollution to flow across the border into State B. If State A failed to provide State B with adequate prior notice of its pollution injection, it might be found liable to State B. However, if State B knew about State A's activities and the contamination before it commenced its withdrawals, its liability claim against State A will be significantly weakened.

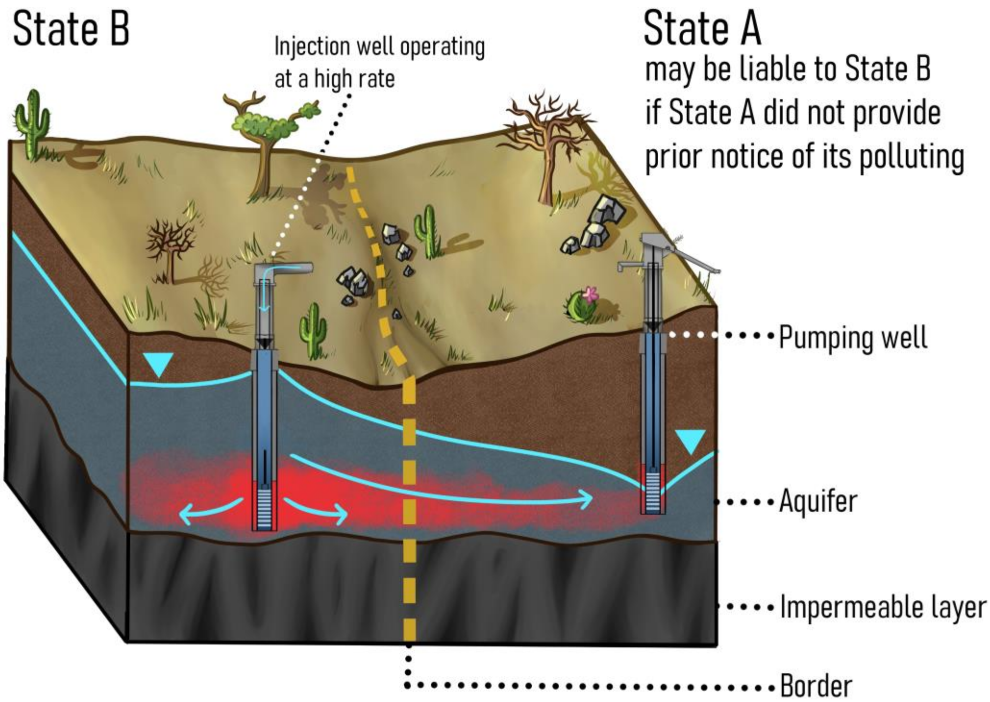


Figure 70 - State A introduces pollutants into the aquifer at a high rate and State B pumps from a well far from the border. The pollutants migrate across the border to State B and are widely dispersed in State B because of the distance of the well from the border, as shown along cross section F1 on the front face of this image. The same liability analysis applied to Figure 69 applies here.

With regard to liability for cross-border pollution in a non-recharging aquifer, where State A introduces pollutants into the aquifer, the absence of any meaningful flow would leave the contamination localized (Figure 68). Unless that injection of pollutants was done right at the border knowing that the localized contaminated area would traverse the boundary, no liability would ensue for State A. If State B began to withdraw groundwater on its side of the border causing the pollution to migrate into its territory (Figure 69 and Figure 70), given its responsibility for that cross-border flow, State A would probably not be held liable to State B unless other extenuating factors were established. For example, if State A failed to inform State B about its introduction of pollution into the aquifer, State B's claim against State A will be strengthened. However, if State B knew about the groundwater contamination in State A before it commenced its pumping activities, its liability claim against State A will be significantly weakened.

The scenario depicted in Model F shows an unconfined, non-recharging aquifer traversing a political boundary. Such aquifers are most often located in arid zones where recharge rates are negligible. Examples include:

- the Nubian Sandstone Aquifer (Figure 71) underneath Libya, Chad, Egypt, and Sudan (LaMoreaux et al., 1985; Sultan et al., 2004);
- the North-Western Sahara Aquifer System (Figure 72) underlying Algeria, Libya, and Tunisia (Gonçalvès et al., 2013); and

- the Disi Aquifer (Figure 73)—also known as the Saq-Ram Aquifer—underlying southern Jordan and northern Saudi Arabia (United Nations Economic and Social Commission for Western Asia (UN-ESCWA) & Bundesanstalt für Geowissenschaften und Rohstoffe [Federal Institute for Geosciences and Natural Resources] (BGR), 2013).

As there is neither a distinct recharge nor discharge zone—except for evaporation from the exposed groundwater table in oases—the groundwater table in these aquifers is quasi-horizontal and the water is stagnant with little perceptible flow, most often toward existing wells.

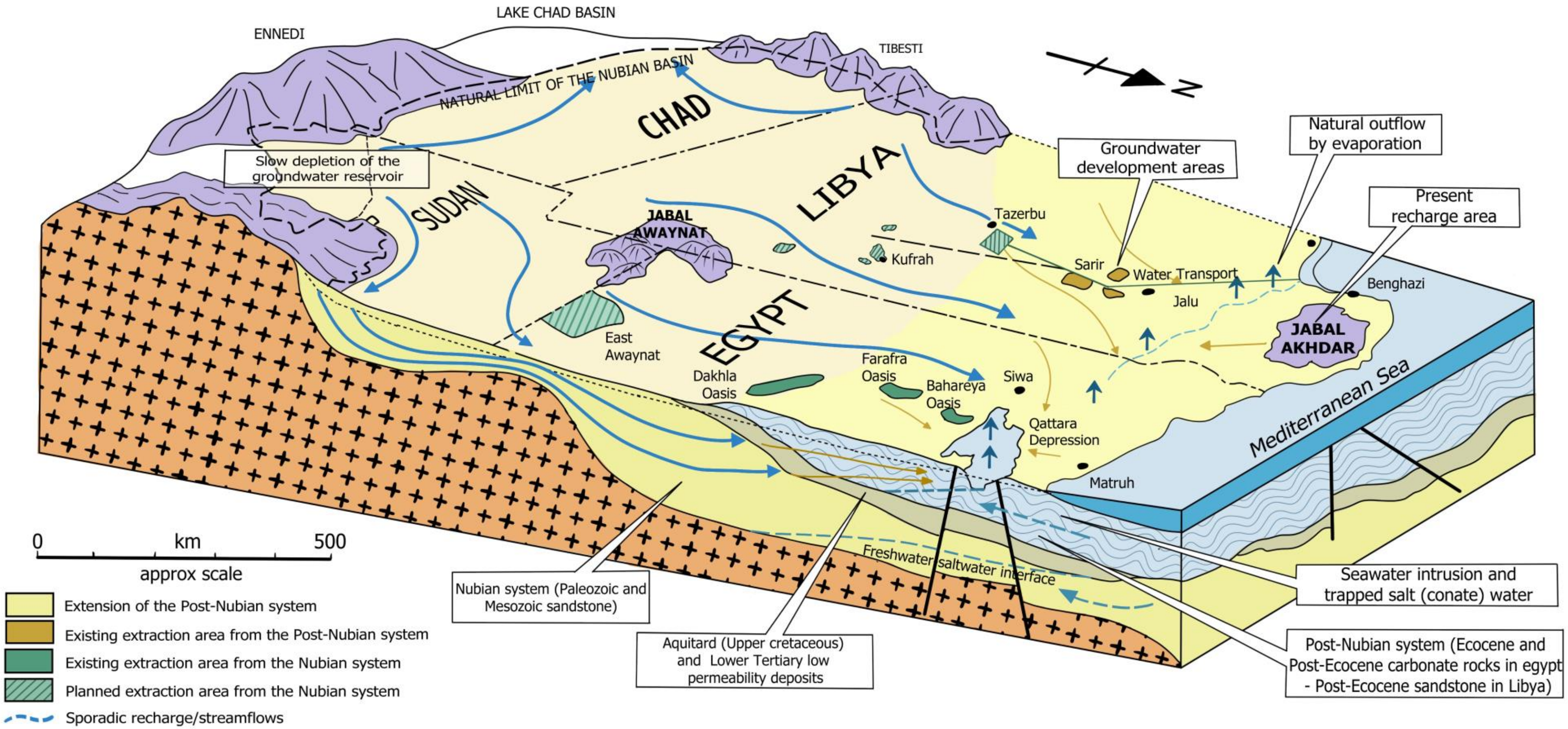


Figure 71 - The non-recharging Nubian Sandstone Aquifer underlying parts of Libya, Chad, Egypt, and Sudan (modified from Abdellatif & Sirag, 2015).

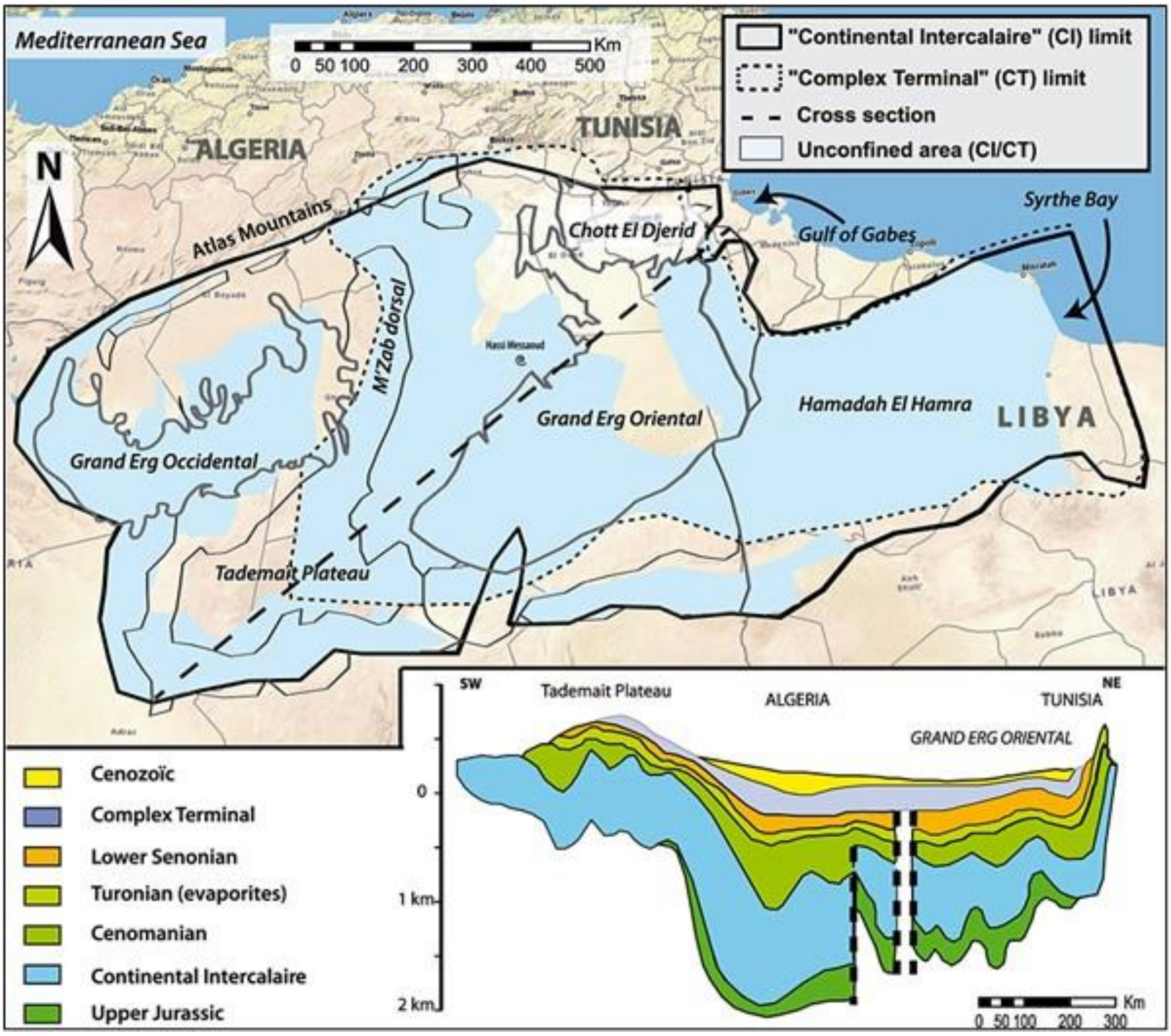


Figure 72 - The non-recharging North-Western Sahara Aquifer System traversing the borders of Algeria, Libya, and Tunisia (reproduced from Gonçalvès et al., 2013).

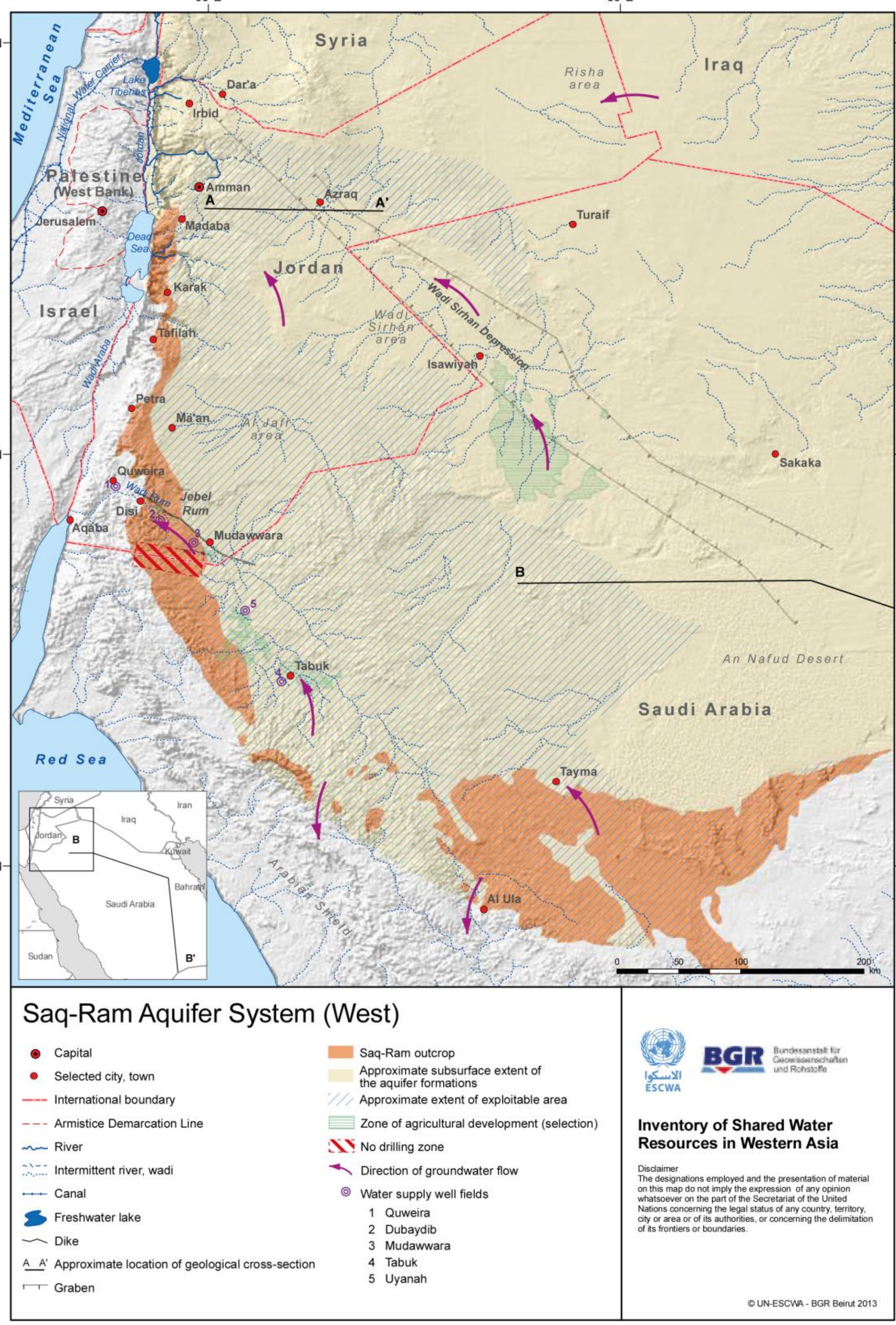


Figure 73 - The non-recharging Disi Aquifer—also known as the Saq Ram Aquifer—underlying southern Jordan and northern Saudi Arabia (reproduced from United Nations Economic and Social Commission for Western Asia, 2013).

Some scholars have drawn comparisons between fossil and connate aquifers to other non-renewable, depletable natural resources—such as oil and natural gas deposits—and explored applying similar legal regimes to renewable groundwater resources (Caponera & Nanni, 2019; Jarvis, 2014). Such rules, however, typically focus on maximizing the exploitation of the resource rather than on the uses to which groundwater can and should be put. Under these rules, ownership rights are divided vis-à-vis negotiated and agreed-upon volumes, or in relation to the pumper's capacity to extract the resource. Moreover, liability for cross-border harm or interference with rights to subsurface, transboundary oil and gas resources arises primarily in the context of contract violations, and occasionally for allegations of intentional theft of the resources.

While the exploitation focus of this approach may not negate its relevance and applicability to transboundary groundwater resources, it must be recognized that groundwater, whether recharging or non-recharging, has qualities that are unique in comparison with those of oil and gas deposits. For one, the hydrocarbon development regime is not designed to consider the human rights, cultural, and environmental benefit aspects of groundwater resources. It also cannot compensate for the reality that while energy resources like oil and gas have alternatives—for example, solar, wind, hydro, and so on—water does not. In addition, non-recharging aquifers can be recharged through artificial means by injection or infiltration pools or from excess surface runoff, return flows, and treated wastewaters. Thus, the life of such resources can be extended in ways that oil and gas deposits cannot and managed in ways that would be uneconomical in the hydrocarbon sector.

The lack of experience in managing such non-renewable resources in an interstate or intrastate manner has hampered the emergence of relevant principles and rules for their governance. Thus, the similarities to oil and gas deposits do present appealing possibilities to some. Nevertheless, given the disparities noted in this discussion, it may be reasonable to suggest that responsibility and liability for transboundary fossil and connate groundwater depletion or contamination should be broader in scope to account for the non-economic aspects of groundwater, such as human rights and cultural issues. In addition—and for the same reason—the regime should likely have a threshold for harm and interference that is lower than that applied to cross-border oil and gas deposits.

5 Additional Considerations for Determining Responsibility and Liability

With respect to ascribing responsibility and liability for the use and management of aquifers that traverse political boundaries, the models and discussion presented in this book offer various factors and circumstances that must be taken into consideration. None are exhaustive, especially because natural conditions can be variable.

For example, a river-aquifer relationship can vary along the extent of that relationship's interface. In other words, a river can be gaining with an underlying aquifer along one section of its course and losing along a different section. This can occur with the same or a different aquifer based on topography, underlying geology, precipitation, soil permeability, and hydraulic conductivity. Further, the gaining and losing relationship between a river and an underlying aquifer are subject to climatic conditions and can literally change with the weather, thereby creating the potential for intermittent transboundary consequences (Woessner, 2020).

In a similar vein, numerous factors must be ascertained when assessing conditions of cross-border contamination. For example, contamination from natural sources usually is not actionable. In other words, a claim by State B against State A for naturally occurring arsenic or radium that flows naturally across the border is unlikely to succeed. This is true where the flow is natural as well as if State B's well causes tainted water from State A's section of the aquifer to flow into State B. However, where contamination is artificial—for example, anthropogenic pollutants—the outcome of a claim could depend on natural flow direction, the extent of pumping activity, the length of time that the contamination has been present in State A, prior knowledge and notification of the contamination, mitigatory measures undertaken, and other factors. Thus, where anthropogenic pollution in State A migrates across the border as a function of the natural flow of the aquifer, State B could have a claim against State A depending on the severity of the contamination.

On the other hand, if pumping in State B is deemed responsible for causing the pollution to migrate from State A's section of the aquifer into State B, an argument could be made that State B's claim for liability should fail. This would depend, however, on various legal norms related to State A's prior knowledge of the contaminants in its territory, State B's knowledge of the contamination in State A, whether State A provided State B with adequate warning of the situation, and any efforts that both states may have taken to mitigate potential cross-border migration of the contaminants. This is the topic of Exercise 2⤵.

6 Wrap Up

Transboundary groundwater and aquifers at both the national and international levels are becoming increasingly critical sources of freshwater for communities worldwide. Simultaneously, excessive extraction, pollution, climate change, and other anthropogenic activities are jeopardizing many of these resources. As a result, policymakers and stakeholders at various levels of civil society are now seeking rules and norms for their governance to safeguard the resources into the future. Many seek to understand the responsibilities and possible liabilities that may arise from transboundary impacts resulting from the use and exploitation of these subsurface treasures. This is occurring both at the international level among two or more sovereign nations that overlay a common aquifer, as well as at the domestic level between two or more subnational political units.

The reality is that the law applicable to transboundary groundwater resources at both levels of governance is in a nascent stage. Moreover, establishing responsibility and liability in the context of transboundary groundwater resources can be a rather complex endeavor that requires policymakers to have specialized knowledge of the science of groundwater. Nevertheless, as nations and subnational political units continue to expand their reliance on transboundary aquifers, they will need to develop principles and norms that are both grounded in sound science and built on an understanding of the distinct value of groundwater for people and the environment.

7 Exercises

In the two exercises that follow, the task is to consider the following three items:

1. identify the circumstances that have the potential for cross-border impacts,
2. characterize those circumstances in terms of potential responsibility and/or liability, and
3. consider actions where individual parties might avoid liability.

Exercise 1 - The Unconfined Leo Aquifer

As depicted in the image that accompanies this exercise, the States of Byakko, Dawon, and Maahes overlie portions of the Leo Aquifer. There are no meaningful surface water bodies in the region except during an occasional flash flood.

- The Leo Aquifer is primarily an unconfined aquifer.
- Byakko and Dawon are arid jurisdictions and receive very little precipitation such that any rainfall evaporates quickly and rarely infiltrates into the ground to reach the underlying Leo Aquifer.
- The main source of recharge for the Leo Aquifer occurs in the higher elevations of the region, which is located primarily in the semi-arid nation of Maahes.
- Because of the characteristics of the aquifer formation, as well as the terrain within Maahes, Maahes has very little opportunity to use the aquifer within its territory in a manner that would be economical or meaningful.
- The general flow of groundwater within the aquifer is southward toward the Endless Sea where the aquifer discharges. The rate of flow is relatively slow and water infiltrating in Maahes can take 500 to 1,000 years to reach the Endless Sea.

Dawon has been pumping along its western border for the past ten years for use in its growing manufacturing sector. The rate of extraction has lowered the water table in the vicinity of the well field and caused groundwater to flow toward the well field in a radius of 50 km (≅31 miles) around the well field.

Byakko and Dawon have several unique oases near their border that are fed by springs where the aquifer formation outcrops on the surface. Dawon's groundwater pumping has affected water flow to and within the oases and reduced the geographic scope of the oases. As a result, the wildlife that inhabited the oases, including migratory birds, has been negatively affected. Environmental groups in all three nations have voiced their concerns to both governments to no avail, although Byakko appears to be far more concerned about the oases than Dawon.

Groundwater supplies around Byakko's capital, Byakko City, have been contaminated by infiltrating sea water. Accordingly, Byakko plans to develop a well field north of its oasis's region. The impact of this scheme is unknown, but Dawonian hydrogeologists are concerned that it will negatively impact the well field in Dawon and reduce Dawon's extraction rates. Environmental groups in both Byakko and Dawon are very concerned about the impact the new well field will have on the already stressed oases.

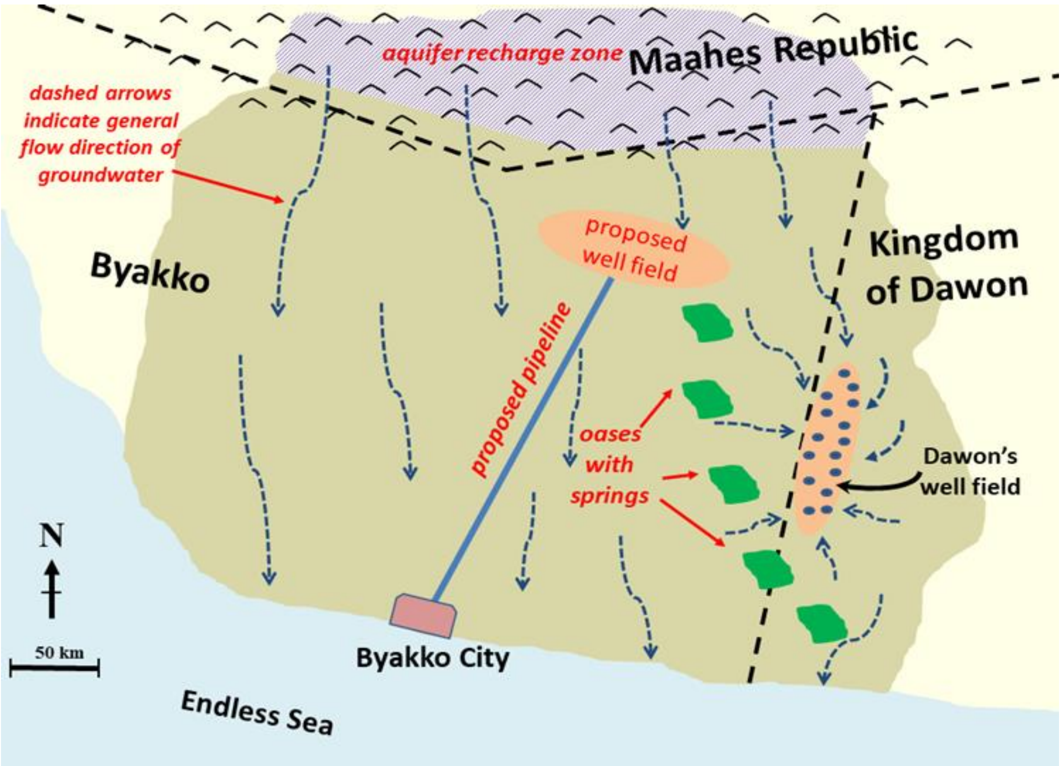
Byakko plans to begin construction of the well field and the transmission pipe in approximately four months.

To meet its growing population and food demand, Maahes has begun to expand the hillside terrace farming techniques that its inhabitants have been using for generations. As part of that expansion, Maahes has started to implement two modern techniques.

1. To enhance agricultural productivity, it has introduced fertilizers and pesticides.
2. To make more water available for agricultural purposes, it constructed numerous small dams and water retention ponds with lined bottoms to prevent leakage.

Although no studies have been conducted, many communities in northern Byakko, as well as a few in Dawon, have complained about the worsening quality and quantity of their groundwater and accuse Maahes of causing that deterioration.

Individually none of the States have adequate resources to conduct technical studies on the aquifer, its flow, and water quality. The following image shows a map for this exercise.



Map for Exercise 1. [50 km ≅ 31 miles]

The solution to Exercise 1 is presented in three parts:

1. Dawon's well field along its western border,
2. Byakko's plan to develop a well field north of its oases region, and
3. Maahe's agricultural practices.

For each of these scenarios, the reader is asked to undertake three tasks:

a) identify the circumstances that have the potential for cross border impacts,
b) characterize those circumstances in terms of potential responsibility and/or liability, and
c) consider actions where individual parties might avoid liability.

Solution to Exercise 1↴

Return to where text linked to Exercise 1↥

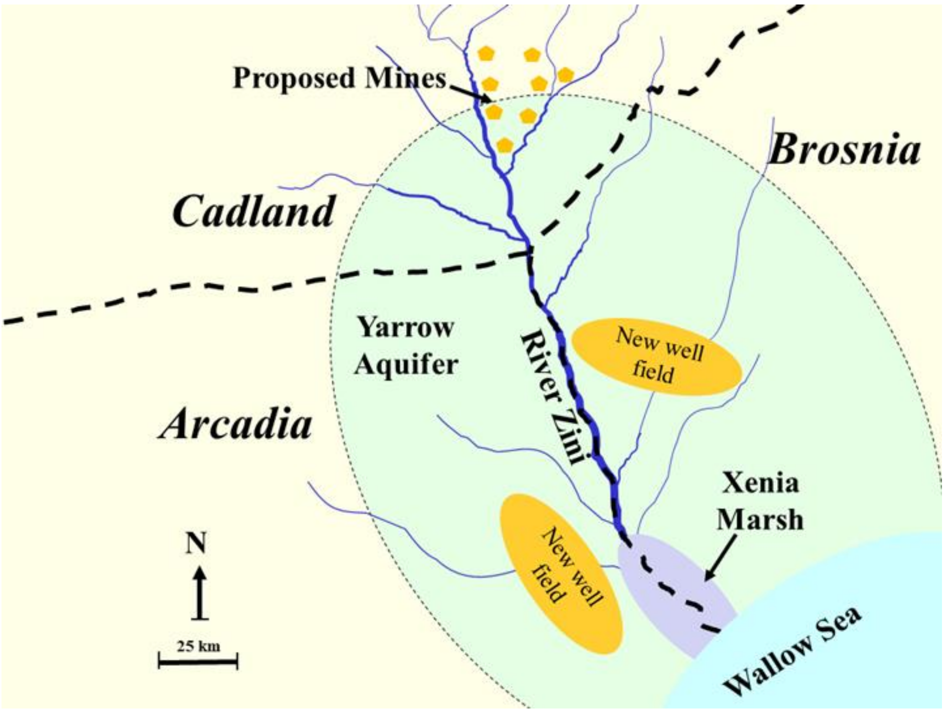
Exercise 2 - The River Zini and Yarrow Aquifer

As depicted in the image that accompanies this exercise, portions of the States of Arcadia, Brosnia, and Cadland all lie within the watershed of River Zini. All three also overlay portions of the Yarrow Aquifer.

- The Yarrow Aquifer, whose geographic extent and boundaries have yet to be fully identified, is primarily an unconfined aquifer.
- The center point of River Zini serves as the border between Arcadia and Brosnia from the tri-border region to the Wallow Sea.
- The river and the aquifer are hydrologically linked. In the upper reaches of the watershed, the Zini is a gaining river; somewhere near the tri-border region, the Zini changes to a losing river in the more arid climate; then, just above its last tributary, River Zini becomes a gaining river as it enters the Xenia Marsh just before emptying into the Wallow Sea.
- Xenia Marsh is a stopping point for millions of migrating birds including some that are considered threatened due to loss of habitat in other distant countries where they spend half the year.
- The region's climate is semi-arid, and rainfall occurs primarily in the late winter. The rest of the year is relatively hot and dry, although temperatures are more moderate in Cadland, which is located at a higher elevation. The amount of rain that falls on the region varies from year to year and is often unpredictable.
- Cadland is in the lower end of the World Bank's *lower-middle income* classification scale; both Arcadia and Brosnia are in the middle of the Bank's *upper-middle income* classification scale.

Because of its topography and relatively more plentiful surface waters, Cadland is more interested in developing River Zini and its tributaries in Cadland. One of Cadland's priorities is its budding mining industry, which it plans to expand. The mining activity requires considerable volumes of water to cleanse the ore, and Cadland intends to use the river for its return flow. However, environmental groups in Arcadia and Brosnia have raised water pollution concerns and are mobilizing their governments to engage with Cadland on the subject.

Arcadia and Brosnia have both just started to develop well fields pumping from the Yarrow Aquifer within their respective territories. Both States need the water to expand their agricultural sectors to feed their growing population. The following image provides a map for this exercise.



Map for Exercise 2 [25 km ≅ 16 miles]

The solution to Exercise 2 is presented in two parts:

1. Cadland's budding mining industry, and
2. Arcadia and Brosnia's well fields.

For each of these scenarios, the reader is asked to undertake three tasks:

a) identify the circumstances that have the potential for cross-border impacts,
b) characterize the circumstances in terms of potential responsibility and/or liability, and
c) consider actions where individual parties might avoid liability.

Solution to Exercise 2↴

Return to where text linked to Exercise 2↥

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9 Exercise Solutions

In answering these questions, readers should be aware that there are no absolutely correct or incorrect answers. Questions of responsibility and liability under law—both domestic laws of nations and international law—are subject to thresholds below which responsibility or liability may or may not attach. Thus, advocates arguing violation of law must establish that the cross-border impact is of such magnitude that it surmounts the threshold needed to establish liability. In addition, the decision as to whether a threshold has been surmounted—for example, establishing that harm is *significant* or that a use is not *equitable*—is often situational and depends on the specific facts of a case. Thus, while a certain level of pollution may be actionable in one scenario—such as a slow-flowing basin where dispersal and reduction of concentrations is limited—it might not be actionable in another situation—for example, a fast-flowing basin where dispersal and reduction of concentrations is significant.

In addition, questions related to threshold often depend on the ability of the advocates to convince a tribunal of their position, and the receptiveness of that tribunal to such arguments. Regarding advocates, while some may have similar training and experiences, their advocacy skills, knowledge of the science of groundwater, understanding of the facts and consequences, and other factors may differ significantly. And as for tribunals, while they are supposed to be unbiased, each judge brings their unique backgrounds and understanding of science, law, and life in ways that can have disparate perspectives on where the threshold line lies in a particular case.

Accordingly, the following answers are only examples and do not represent the full range of possible circumstances with the potential for cross-border impacts, claims of possible responsibility and liability that the parties could raise, or actions that the parties could take to avoid liability.

Solution Exercise 1

This solution to Exercise 1 is presented in three parts:

1. Dawon's well field along its western border,
2. Byakko's plan to develop a well field north of its oases region, and
3. Maahe's agricultural practices.

For each of these scenarios, the reader was asked to undertake three tasks:

a) identify the circumstances that have the potential for cross-border impacts,
b) characterize those circumstances in terms of potential responsibility and/or liability, and
c) consider actions where individual parties might avoid liability.

1. Dawon's well field along its western border

a) Identify the circumstances that have the potential for cross-border impacts.

- Dawon's well field along its western border appears to have a cross-border impact as the pumping is causing groundwater around the well field in a radius of 50 km (≅31 miles) to be diverted toward the well field. This includes in the direction of Byakko where groundwater flows are being diverted from their natural pathway because of the pumping. Moreover, the facts suggest that the oases in Byakko are being negatively affected—for example, reduced geographic scope and impacts on native wildlife.

b) Characterize those circumstances in terms of potential responsibility and/or liability.

- Dawon's pumping might be the basis of a claim by Byakko against Dawon, arguing that:
  - Dawon is taking more than its fair share of groundwater from the shared aquifer, especially from underneath Byakko; and/or
  - Dawon's pumping is causing harm to Byakko.
- Some of the legal questions that could arise in terms of defining responsibility and liability include how much groundwater each nation is entitled to use; what standard should be used to assess fairness in allocating groundwater from a shared aquifer; and what standard and threshold should be used to assess whether harm has resulted from Dawon's pumping.
- However, depending on how these issues are addressed, responsibility may not equate with liability. Dawon could be found responsible for having an impact in Byakko but may not be liable for that impact unless that impact surpasses the particular threshold for the norm being applied.
  - For example, Dawon may not be liable for violating the international legal norm of equitable and reasonable use—if a tribunal determines the

relevance of that norm to the case—unless the factors used to assess that norm establish that Dawon's pumping was inequitable and unreasonable.

- Similarly, Dawon may not be liable for causing significant harm—if a tribunal determines the relevance of that norm to the case—unless the tribunal finds that the harm caused to Byakko, to the aquifer segment underlying Byakko, to the groundwater in Byakko, and to the oases in Byakko and their wildlife exceeded the *significant* threshold or whatever threshold the tribunal determines is the relevant standard.

c) Consider actions where individual parties might avoid liability.

- Cooperation is typically the main avenue for parties to avoid liability. If parties agree on certain actions, any negative results of those actions—at least in theory—could be incorporated into and recognized by the cooperation agreement.
  - For example, the parties could agree that Dawon's current pumping, which causes cross-border groundwater flow, is acceptable and not in violation of international law.
  - Or, they could agree to have Dawon reduce its pumping by a certain amount to lessen the negative cross-border impacts in Byakko. Of course, that would have a negative impact on Dawon's pumping, but that would be considered in the cooperation agreement.
  - Similarly, the parties could cooperate on studies to better understand the cross-border impact of Dawon's pumping. They could even agree to have Dawon supply Byakko City with the needed water rather than developing the new well field in Byakko.
- The key is to have the parties cooperate to define actions and responsibilities in ways that set acceptable standards for cooperation, agree on actions that each state would take, and ultimately avoid liability.

2. Byakko's plan to develop a well field north of its oases region

a) Identify the circumstances that have the potential for cross-border impacts.

- Byakko's proposed well field appears to be of concern to Dawon as its hydrogeologists suggest that the pumping could negatively impact the yield of Dawon's well field. While the impact has yet to be studied, a simple review of the map suggests it is possible that Byakko's proposed well field may divert groundwater away from Dawon's well field. Also, the proposed well field could also affect the oases in both countries.

b) Characterize those circumstances in terms of potential responsibility and/or liability.
   - Regarding the potential impact on Dawon, an analysis like the one presented in part 1b) of this solution pertaining to the cross-border impact of Dawon's well field also applies here.
   - However, the questions of equity, reasonableness, threshold of harm, and other standards would be distinct to the scenario presented here to the extent that now both nations would be pumping from and utilizing the aquifer with cross-border effects.
   - Regarding the impact on the oases located entirely within Byakko, that would be subject to Byakko's national jurisdiction and domestic laws and not to any claims under international law. As for the possible impact on oases in Dawon, while Dawon could raise a valid complaint under international law, it would be tempered by the reality that its own pumping is also negatively affecting the oases.

c) Consider actions where individual parties might avoid liability.
   - As noted in the response to the cross-border impact of Dawon's well field, an agreement on activities and responsibilities could avoid liability for both nations.
   - Through such agreements, nations can decide what could be deemed an acceptable cross-border negative impact—for example, responsibility without liability. In addition, it may be productive to combine the cooperative efforts to include the issues and concerns from Dawon's existing well field and Byakko's proposed well field.

3. Maahes's agricultural practices

a) Identify the circumstances that have the potential for cross-border impacts.
   - Maahes's actions have the potential for two different types of cross-border impact:
     - First, Maahe's use of modern fertilizers and pesticides in the recharge zone of the aquifer could have negative effects on the quality of water flowing through the aquifer. This will certainly depend on the quantity and types of chemicals used in their agricultural practices, as well as the aquifer's capacity to dilute those chemicals. However, complaints have arisen in both Byakko and Dawon.
     - The second action with possible cross-border consequences is Maahes's construction of numerous small dams and water retention ponds with lined bottoms to prevent leakage. The implication here is that by retaining

the water in Maahes, that country is reducing recharge of the aquifer, which is reducing downgradient water availability.

b) Characterize those circumstances in terms of potential responsibility and/or liability.
   - Regarding Maahes's actions, both the impact on water quality and quantity would be subject to the same analysis as discussed in part 1(b). But just as that analysis explained that questions of equity, reasonableness, threshold of harm, and other standards would be tailored to the distinct scenarios, the same applies here.
   - Thus, in the case of the alleged cross-border water quality impacts, even if it was described by a Byakko or Dawon or a tribunal as cross-border pollution, it would not automatically be deemed inequitable, unreasonable, and/or as causing significant harm. Rather, the circumstances of Maahes's use of modern fertilizers and pesticides—such as the need to expand its agricultural activities, the impact of the activity, alternatives to modern fertilizers and pesticides, and so on—would be evaluated, as would the circumstances of Byakko's and Dawon's use of the aquifer, for example, the quality of the groundwater in relation to the desired uses, and so on. As for the possible impacts on water quantity in Byakko and Dawon, the same tailored analysis apply.
   - One complication that would arise in this case pertains to the fact that Maahes is not making use of the aquifer itself—and, according to the facts, cannot make economic or meaningful use of the aquifer's groundwater. Rather, it is Maahes's activities in the recharge zone that are at issue. Thus, this is not a case in which the parties can simply allocate a volume of water to each country. Moreover, it is a case where other fields of international law may be relevant, such as international environmental law and the law of state responsibility—both of which are beyond the scope of this book.

c) Consider actions where individual parties might avoid liability.
   - Again, cooperation is the key for addressing these scenarios and minimizing liability. Given that the cross-border consequences of Maahes's actions have not been investigated and given that none of the States individually have the resources to explore this situation, perhaps the parties can collaborate on such a study. Of course, Maahes may not be enthusiastic to learn the results of the study. Thus, it may be in Byakko's and Dawon's interests to explore other avenues to support Maahes's agricultural objectives.
   - International agreements need not focus exclusively on one issue. In fact, negotiations among nations often incorporate issues and topics that on their

face have little to do with each other (for example, enhanced instream flows on one stretch of a transboundary river in exchange for reduced restrictions on cross-border commerce in another border area).

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Solution Exercise 2

The solution to Exercise 2 is presented in two parts:

1. Cadland's budding mining industry, and
2. Arcadia and Brosnia's well fields.

For each of these scenarios, the reader was asked to undertake three tasks:

a) identify the circumstances that have the potential for cross-border impacts,
b) characterize the circumstances in terms of potential responsibility and/or liability, and
c) consider actions where individual parties might avoid liability.

1. Cadland's budding mining industry

a) Identify the circumstances that have the potential for cross-border impacts.

- Cadland's proposed expansion of its mining industry certainly could be a source of legal conflict with its downstream neighbors. However, one of the challenges with this scenario is that Cadland only has "plans to expand" its mining industry but hasn't done so yet. As a result, Cadland's actions have not yet resulted in any cross-border impact. Of course, Arcadia and Brosnia would not want to wait for the harm to manifest before raising their claims; however, they would have to establish the likelihood that they would suffer cross-border harm from Cadland's proposed actions of a magnitude that would result in liability for Cadland. That could be a high threshold to overcome: the likelihood that harm will occur.
- Regardless, on the assumption that Arcadia and Brosnia could present such claims, Cadland's proposed actions potentially could result in four distinct cross-border, downstream impacts on water quality, and four on water quantity. The first water quality-related impact is on Brosnia's recently developed well field.
  - In this stretch of River Zini, just below the tri-border region, the river is a losing river, meaning that the river feeds the adjacent aquifer. Thus, any pollutants found in the river are likely to be transferred to the aquifer and Brosnia's well field, and thereby contaminate the groundwater that Brosnia pumps.
  - The extent of the pollution in that groundwater, however, will depend on the type and amount of mine pollution that Cadland puts into River Zini in its territory, the ability of River Zini to dilute those pollutants before it reaches the tri-border region, and the aquifer's cleansing capacity to remove remaining pollutants in the water flowing from River Zini, into the aquifer, and then to Brosnia's well field.

- The first water quantity-related impact also is on Brosnia's new well field. Since River Zini is a losing river below the tri-border region, any reduction in river flow could reduce the volume of water infiltrating from the Zini into the aquifer. That, in turn, could lower the water table in this predominantly unconfined aquifer and reduce the volume of water available to Brosnia at its new well field.
    - Thus, even if the water quality was unaffected, there could still be a water quantity concern for Brosnia.
- The second possible cross-border, downstream impact on water quality pertains to Arcadia's new well field. In this stretch of River Zini, the river is a gaining stream. However, as Arcadia's well field is further developed, because of its proximity to River Zini, it is conceivable that the pumping could reverse that flow into a losing relationship with the aquifer within the well field's area of influence.
    - If that occurs, any pollutants found in the river could be transferred to the aquifer and Arcadia's pumps.
    - Given that this is further downstream as compared with Brosnia's well field, it is plausible that the impact would be less than the impact on Brosnia's well field. Extent of the impact will depend on similar factors as those identified for Brosnia's well field.
- A second, albeit more remote, water quantity impact could negatively affect Arcadia's well field. Conceivably, it is possible that Arcadia's pumping could transform River Zini from a gaining river to a losing river within the well field's area of influence, but then be impacted by the reduced flow in River Zini because of Cadland's mining activities.
    - This will depend on the rate of Arcadia's groundwater extraction from the well field, the extent to which Arcadia's pumping changes River Zini's flow regime, and the extent to which Cadland's activities reduce the flow of water in River Zini.
- The third possible water quality-related impact is on Xenia Marsh where the deterioration in water quality due to Cadland's mining activities could have a negative impact on the marsh's unique wildlife.
    - The extent of the impact will depend on the type and amount of mine pollution that Cadland puts into River Zini in its territory, the ability of River Zini to dilute those pollutants before it reaches Xenia Marsh, and the capacity of the marsh to absorb those pollutants without negatively impacting the wildlife. Marshes and other wetlands typically have some capacity to absorb and dilute certain pollutants.

    - In a similar vein, Cadland's mining activities could reduce water quantity to Zenia Marsh and, thus, negatively impact the marsh's wildlife. The extent of the impact will depend on the extent to which Cadland's activities reduce the flow of water that reaches the marsh.
- Additional water quality and water quantity impacts were not highlighted in the hypothetical example but could be deduced from the facts. The entire length of River Zini below the tri-border area could suffer from some degree of water quality defects and water quantity reductions because of Cadland's mining activities. Thus, all users of the river could be affected to varying extents.

b) Characterize those circumstances in terms of potential responsibility and/or liability.

- Both Arcadia and Brosnia may have water quality and water quantity-related claims against Cadland for the downstream effects of its mining activities. If their well fields, or any downstream segment of River Zini, are indeed affected by Cadland's activities, they both could assert that:
    1) Cadland is taking more than its fair share of the river's water; and
    2) Cadland's mining is causing cross-border harm to both downstream nations.
- Some of the legal questions that could arise in terms of defining responsibility and liability include: how much groundwater and river water each nation is entitled to use, what standard should be used to assess fairness in allocating groundwater from a shared aquifer and river water from a shared river, and what standard and threshold should be used to assess whether harm has resulted or is likely to result from Cadland's activities.
- Depending on how these issues are addressed, however, responsibility may not equate with liability. Cadland could be found responsible for having an impact in either or both downstream nations, but it may not be liable for that impact unless that impact surpasses the particular threshold for the norm being applied.
    - Thus, for example, Cadland may not be liable for violating the international legal norm of equitable and reasonable use—if a tribunal determines the relevance of that norm to the case—unless the factors used to assess that norm establish that Cadland's water extractions were inequitable and unreasonable in relation to the equivalent rights of Arcadia and Brosnia.
    - Likewise, Cadland may not be liable for causing significant harm—if a tribunal determines the relevance of that norm to the case—to either or both downstream nations unless the tribunal finds that the harm caused (for example, to Arcadia and/or Brosnia, to the aquifer segment underlying

either or both downstream nations, to the groundwater in Arcadia and/or Brosnia, to Xenia Marsh and its wildlife, and so on) exceeded the *significant* threshold, or whatever threshold the tribunal determines is the relevant standard.

c) Consider actions where individual parties might avoid liability.
- Given that Cadland's actions related to its mining industry are still in a *proposed* stage, it would behoove Arcadia and Brosnia to engage with Cadland in a dialogue toward an agreement that could minimize downstream impacts.
  - Thus, Arcadia and Brosnia could seek to negotiate with Cadland on its plans and objectives, whether there are alternatives to Cadland's plans, whether there are mechanisms that could minimize downstream impacts, and how Arcadia and/or Brosnia might engage with Cadland to achieve their respective goals and interests.
  - In addition, they could agree on a threshold of downstream impact that would be permissible to the parties and not actionable for claims of liability.
- All of this might seem obvious and possibly in the best interest of all parties. Yet, because each nation is entitled to its sovereignty within its respective territory and because international law is a function of international politics, such negotiations and diplomacy are both critical and challenging.

2. Arcadia's and Brosnia's well fields

a) Identify the circumstances that have the potential for cross-border impacts.
- As an entirely separate matter, both Arcadia's and Brosnia's new well fields could have negative impacts downstream on River Zini and Xenia Marsh.
  - While Brosnia's well field is in the river's losing segment, depending on its rate of withdrawals, Brosnia could accelerate the flow of water from the river into the aquifer and toward its well field. This would reduce the volume of water further downstream and water flowing into Xenia Marsh.
  - In a similar manner, depending on its rate of extraction, if Arcadia reverses the gaining stream relationship of River Zini within its well field's area of influence and converts it into a losing relationship, it too could affect the volume of water that reaches Xenia Marsh through River Zini.

b) Characterize those circumstances in terms of potential responsibility and/or liability.
- Both Brosnia and Arcadia could have claims against each other for potential impacts on Xenia Marsh. Moreover, since Brosnia's well field is further

upstream than that of Arcadia, it is possible that Arcadia could have a claim against Brosnia for reducing water flow in River Zini upstream of the marsh.

- Like the arguments against Cadland, the two nations could assert that each one is taking more than its fair share of the river's water by siphoning it off via their respective well fields, and that the result is cross-border harm.
  - On the issue of harm, in the case of Arcadia's claim, it may be able to argue harm by Brosnia both to the lower reaches of River Zini as well as to the marsh on its side of the border, while Brosnia would likely only be able to argue harm by Arcadia to the marsh to its side of the border, based on the simple map supplied with the hypothetical example.
  - Of course, if additional facts indicate that Arcadia's pumping is so significantly depleting River Zini above Xenia Marsh, then Brosnia may have a claim against Arcadia for the quantity impact on River Zini.
  - All of this will depend on the extent of each country's extractions and their impact on River Zini and the marsh.
- In addressing these issues, the same legal questions noted above—e.g., entitlement to water, standards to assess fairness in allocating water, standard and threshold for assessing harm—would apply equally here, albeit in relation to the specific facts and context of these complaints.

c) Consider actions where individual parties might avoid liability.

- As suggested for the relationship between Arcadia and Brosnia and their upstream neighbor, Cadland, Arcadia and Brosnia could engage with each other to cooperate over their respective objectives and interests related to expanding water production, managing the border-forming River Zini, and managing their shared Xenia Marsh. This could include data sharing, monitoring, joint projects, and other collaborative actions.
- The key, again, is to have the parties cooperate to define actions and responsibilities in ways that set acceptable standards for cooperation, agree on actions that each state would take, and ultimately avoid liability.

Return to Exercise 2↑

Return to where text linked to Exercise 2↑

10 About the Authors

Gabriel Eckstein is an internationally recognized expert in international and comparative water and environmental law and policy with over 30 years of experience consulting, teaching, and researching in these fields. At Texas A&M University, he serves as professor of law↗ and the director of the law school's Energy, Environmental & Natural Resources Systems Law Program↗. Dr. Eckstein regularly advises UN agencies, national and sub-national governments, NGOs, and other groups on international and US water and environmental issues. He has served as the president of the International Water Resources Association↗, and currently serves on the executive council of the International Association for Water Law↗, as the associate editor for *Brill Research Perspectives: International Water Law*↗, and on the editorial board of The *Journal of Water Law*↗. Dr. Eckstein holds a Juris Doctor and an LLM in International Environmental Law, an MS in International Affairs, and a BA in Geology.

Yoram Eckstein was an internationally recognized expert in hydrogeology, geothermics, and groundwater contamination with over 50 years of consulting, teaching, and research experience in these fields. Before his retirement in 2013, he was professor of geology at Kent State University, the president and chief scientist of the consulting firm Eckstein & Associates, and an associate editor with *Water International* and the *Journal of Hydrogeology*. Thereafter, he served for a year as a Fulbright Senior Professor of hydrogeology at Tomsk Polytechnic University, Tomsk, Russia. Previously, Dr. Eckstein served as senior geologist at the Geological Survey of Israel. He was fluent and published professionally in four languages (English, Polish, Russian, and Hebrew) and held a PhD from the Hebrew University in Jerusalem. He passed away in June 2020.

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Modifications to Original Release

Changes from the Original Version to Version 2

Original Version: January 31, 2024, Version 2: May 24, 2024

Page numbers refer to the original PDF.

page i, added Version 2

page 96, enhanced references for Rodriguez 2022 a, b, and d

page 111-112, figure caption was moved from top of page 112 to bottom of page 111

Changes from the Version 2 to Version 3

Original Version: January 31, 2024, Version 2: May 24, 2024, Version 3: July 18, 2024

Page numbers refer to the PDF of version 2.

page ii, added credentials for first author

page ii, changed to Version 3, July 2024

page vii, changed 592 to 468 in the Groundwater Project Foreword