Dynamics of Groundwater-Surface Water Interactions

Saju Kumar L.
Lecturer in Civil Engineering, Govt. Polytechnic College, Adoor, Kerala, India

ABSTRACT
Among many other things, interactions between surface and groundwater maintain ecosystems that depend on groundwater and control biogeochemical cycles and river temperature. Rivers, springs, lakes, and wetlands are examples of freshwater habitats where these interactions take place. In coastal environments, they happen through tidal pumping, undersea groundwater release, and seawater intrusion. Quantification of GW–SW interactions and related pollutant transport has grown in significance due to the necessity of integrated management of groundwater (GW) and surface water (SW). In hydrological systems, surface water-ground water interaction is essential because it affects water quality, availability, and ecosystem sustainability. A mechanistic knowledge of the underlying mechanisms governing the temporal dynamics and spatial patterns of groundwater–surface water interactions is essential for preserving drinking water supplies and ecosystem health. We will talk about it in this paper. Groundwater-Surface Water Interaction Dynamics.

***Keywords**: Groundwater, Surface Water, River Temperature, Biogeochemical Cycles, Water Availability, Hydrological, Water Table Depth, Lakes, Wetlands, Ecosystems, Streams, Transition-Losing Stream.*

INTRODUCTION
In the past, groundwater (GW) and surface water (SW), two crucial components of the water cycle, were viewed as distinct entities and were studied and measured independently for a considerable amount of time. Their deep interdependency has been investigated over time. All of the earth's landscapes experience the GW-SW interaction in different ways. When water enters the hyporheic zone from either of the two sources, the interaction phenomena begin. The Greek words hypo, which means under or underneath, and rheos, which denotes a stream ('rheo' means 'to flow'), are the origins of the word hyporheic. [1]

Surface water (SW) and groundwater (GW) are two interdependent parts of a same resource, and changes to one will unavoidably have an impact on the amount or quality of the other. GW and SW resources have always been seen and managed as two distinct entities, despite the fact that early hydrological research had already highlighted these connections between GW and SW. However, growing demands on water resources and climate change-related uncertainty in water supply have led to a steady increase in awareness of the need to manage GW and SW as a single resource. This awareness has also permeated new legal frameworks in many countries that regulate the sustainable use of water resources. Researchers and managers face new challenges as a result of this new understanding of GW–SW interactions and their operational significance, which extends beyond the management of water quantity and quality to include the management and preservation of riparian habitat and groundwater-dependent ecosystems.

Nearly every place on Earth has surface water (such as rivers, lakes, reservoirs, wetlands, estuaries, etc.) and groundwater interactions. Surface water loss to groundwater, groundwater seepage to surface water bodies, or a mix of the two are the ways in which this interaction occurs. Each is usually impacted by the development or contamination of groundwater or surface water supplies. Therefore, a basic understanding of the interplay between surface water and groundwater is vital for better management and sound decision making connected to water-resource challenges. [2]

Addressing the following water-resource concerns requires an understanding of groundwater-surface water interactions:

- Combining the utilization of surface and groundwater supplies.
- It can be challenging and contentious to account for groundwater flows to and from surface water bodies when discussing water rights.

- Evaluation and reduction of water discharge delays and losses from surface water reservoirs.
- Flood assessment and mitigation in river valleys.
- Evaluation and management of groundwater-induced surface water contamination and vice versa.
- Planning and management of watersheds should incorporate groundwater flows.
- Assessing how riparian zones affect the quality of river water.
- Aquatic life is governed by groundwater-surface water interactions, and any modifications may arise from shifts in the strength and direction of these interactions.
- Providing aquatic wildlife with food and sustaining dynamic habitats at the interface, which preserves a varied ecosystem and shows the condition of aquatic water quality.
- Preservation of existing wetlands and the creation of new ones for conservation.

Hyporheic exchange (shallow mixing of GW and SW), SW infiltration, GW discharge, bank storage, and overbank return flows to floodplains are all examples of interactions between GW and SW under a variety of circumstances. Numerous elements influence GW–SW exchanges, such as the chemical and physical characteristics of aquifer and interface sediments, spatiotemporally dynamic SW networks, GW flow, and hydrological drivers of water table depth, evaporation, and precipitation. The amount, location, and timing of exchanges have been drastically changed over the past few decades by a combination of human actions (such as land-use change, GW pumping, dam construction, and water diversion projects) and climate change. GW and SW operate as a single, tightly connected system. As a result, taking into account the hydrological, topographical, hydrogeological, and biological processes functioning over a range of geographical and temporal scales is necessary to comprehend and forecast dynamic GW–SW transitions. [3]

Scales of Groundwater-Surface Water Interaction

GW and SW interact on a variety of dimensions, including local-scale interactions within the hyporheic zone that are primarily governed by stream-bed characteristics and large-scale interactions where the entire catchment or watershed influences the interaction process. The area of sediment and porous space beneath and next to a stream bed is known as the hyporheic zone, and it is here that surface water and shallow groundwater combine. Groundwater flow systems (on a regional and intermediate scale) regulate the recharge-discharge dynamics of groundwater in the case of large-scale interaction. Groundwater flow systems are characterized by boundary conditions imposed by the physiographic framework and recharge distribution. A region's topography and geology make up its physiographic framework, whilst the climate regulates the distribution of recharge. Toth (1963) divided flow systems into three categories: local, intermediate, and regional. While local-flow systems are refilled at local water divides and release into local (lower order) streams, regional flow systems are refilled at regional water divides and release into regional (higher order) streams. Low hydraulic gradients in large flat areas restrict the development of flow systems. The regional-flow systems tend to be deep, steady, slow (low flux), and more mineralized, while local-flow systems are shallow, unsteady (high variability), rapid (higher flux), and less mineralized. Surface water body location in relation to groundwater flow systems, anisotropy and hydraulic conductivity contrasts of the groundwater system, regional flow, water table configuration, and surface water body depth all affect how surface water and groundwater interact at regional to local scales. [4]

Review of Literature:

The interdependence of surface water and groundwater as hydrologic systems is commonly acknowledged (Winter et al., 1998). Since the 1930s, multidisciplinary studies on groundwater-surface water (GW-SW) interactions have been published in a wide range of academic disciplines, including hydrogeology, hydrology, limnology, and many more. Given the wide spectrum of processes that both influence and are influenced by GW-SW interactions, this multidisciplinary perspective is essential. For instance, GW-SW exchange is a hydrological process that has significant biogeochemical and ecological functions, such as maintaining riparian zone vegetation, controlling processes like denitrification and oxygen redistribution in the hyporheic zone, and regulating surface water temperature regimes. [5]

The process through which water in surface water bodies, such as lakes, streams, wetlands, and coastal waters, interacts with groundwater flowing in aquifers is known as groundwater–surface water interaction. Because of its implications for the integrated water management of water resources (surface and groundwater) and valuable groundwater-dependent ecosystems under the Groundwater Daughter Directive and the Water Framework Directive (European Commission, 2000), this interaction has drawn more attention in recent decades. Studying the interaction between groundwater and surface water presents a number of difficulties, from the fact that it is a highly variable process in both place and time to the difficulty of incorporating flow exchange mechanisms in integrated hydrological modeling that takes into account two distinct forms of water flow. [6]

In general, compared to rivers or streams, research on the interactions between groundwater and surface water in groundwater-dependent ecosystems (GDEs) has not gotten as much attention. When all or a portion of an ecosystem's water needs are met by groundwater and its functions are disrupted in its absence, resulting in significant changes to the ecosystem's structure, the ecosystem is said to be groundwater-dependent. Different classification systems have been developed, and several varieties of GDEs have been found (Kløve et al., Citation 2011). [7]

Objectives:

- To Study the dynamics of Groundwater-Surface Water Interactions
- To Different stream-water and groundwater interaction scenarios
- To Explain Hydraulic connections between GW flows and spatiotemporally dynamic SW systems

Research Methodology:

In the vast topic of surface water-ground water interactions, it offers a summary of recent developments and creative methods. We can comprehend the intricate relationships forming the surface water-groundwater systems by taking a multidisciplinary approach, which will help us make wise decisions and manage resources efficiently in a changing environment. The secondary data used in this research work was collected from reliable sources, including newspapers, textbooks, journals, and the internet. The research design of the study is mostly descriptive.

Result and Discussion:

Groundwater - Surface Water Interactions:

Groundwater - surface water interactions occur when water moves between surface and groundwater systems. The nature and level of connectedness between surface water and groundwater systems vary greatly across all sorts of landscapes where streams and groundwater interact. Three fundamental techniques can be used to characterize interaction: [8]

- streams that receive water from groundwater entering through the streambed,

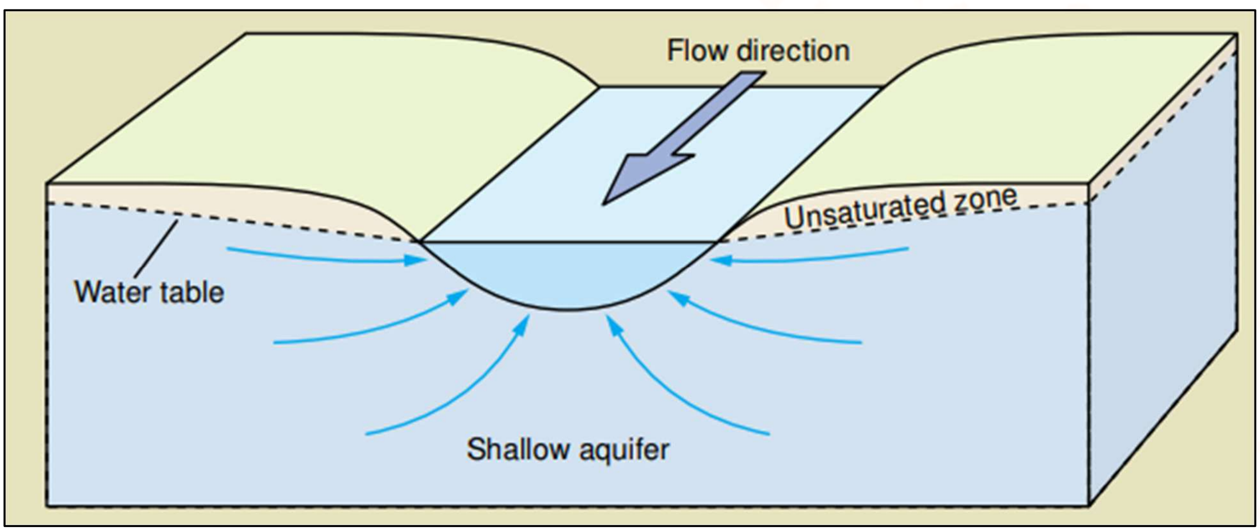

Figure 1: In Flow Direction

- streams that lose water to groundwater through discharge via the streambed,

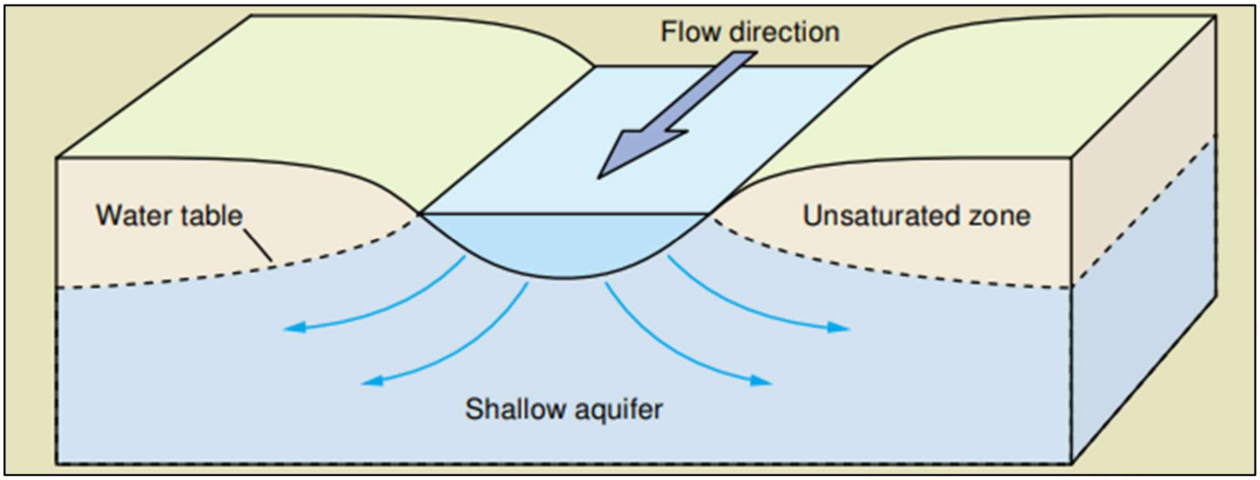

Figure 2: Outflow Direction

- streams that do both, either increasing in certain areas and decreasing in others, or maybe fluctuating between the two based on cyclical shifts in the relative levels of groundwater and streams.

The ecology of streams and the turnover of solutes carried by the stream network and nearby aquifers depend heavily on the area where groundwater and streams meet. Understanding and measuring the combined effects of hydrologic and climatic variability (stream flow, groundwater level, temperature) and structure (pool-riffle sequences, gravel bar) on water flows, redox zonations, and solute turnover along morphological units and stream reaches is our goal. We carry out numerical tests using coupled computational fluid dynamics (CFD) simulations and flow and (reactive) mass transfer in groundwater, and we create enhanced monitoring equipment that is tailored to the dynamic circumstances in streambeds. [9]

Figure 3: Water flow around and through a gravel bar (source https://www.ufz.de/)

Surface water-aquifer systems are divided into six categories according to the level of interaction between them. Groundwater seeping into the stream is known as a gaining stream (Figure 4a), whereas water seeping from the stream into the aquifer is known as a losing stream (Figure 4c, d). Conversely, both types of interactions occur in transition-losing streams (Figure 4b). Losing and parallel linked streams (Figure 4e) have the groundwater table at or below the stream bed, whereas hydraulically disconnected streams have a thick unsaturated zone between the stream and groundwater. The groundwater levels on either side of the stream bed vary as the flow passes through streams (Figure 4f). The hydrologic cycle and human life are impacted by the interplay between surface and groundwater. Since pollution and extraction can damage both systems, it is essential to comprehend how they are related in order to manage land and water effectively. The analysis of riparian zone phenomena has focused on both quantitative and qualitative assessment of surface water-groundwater interactions. In order to comprehend acid rain and eutrophication, the GW–SW interaction between lakes and groundwater was investigated in the 1960s. Similarly, because the ecosystems involved were in danger of going extinct, scientists concentrated more on the relationship between groundwater and wetlands and coastal areas between the 1960s and 1980s. [10]

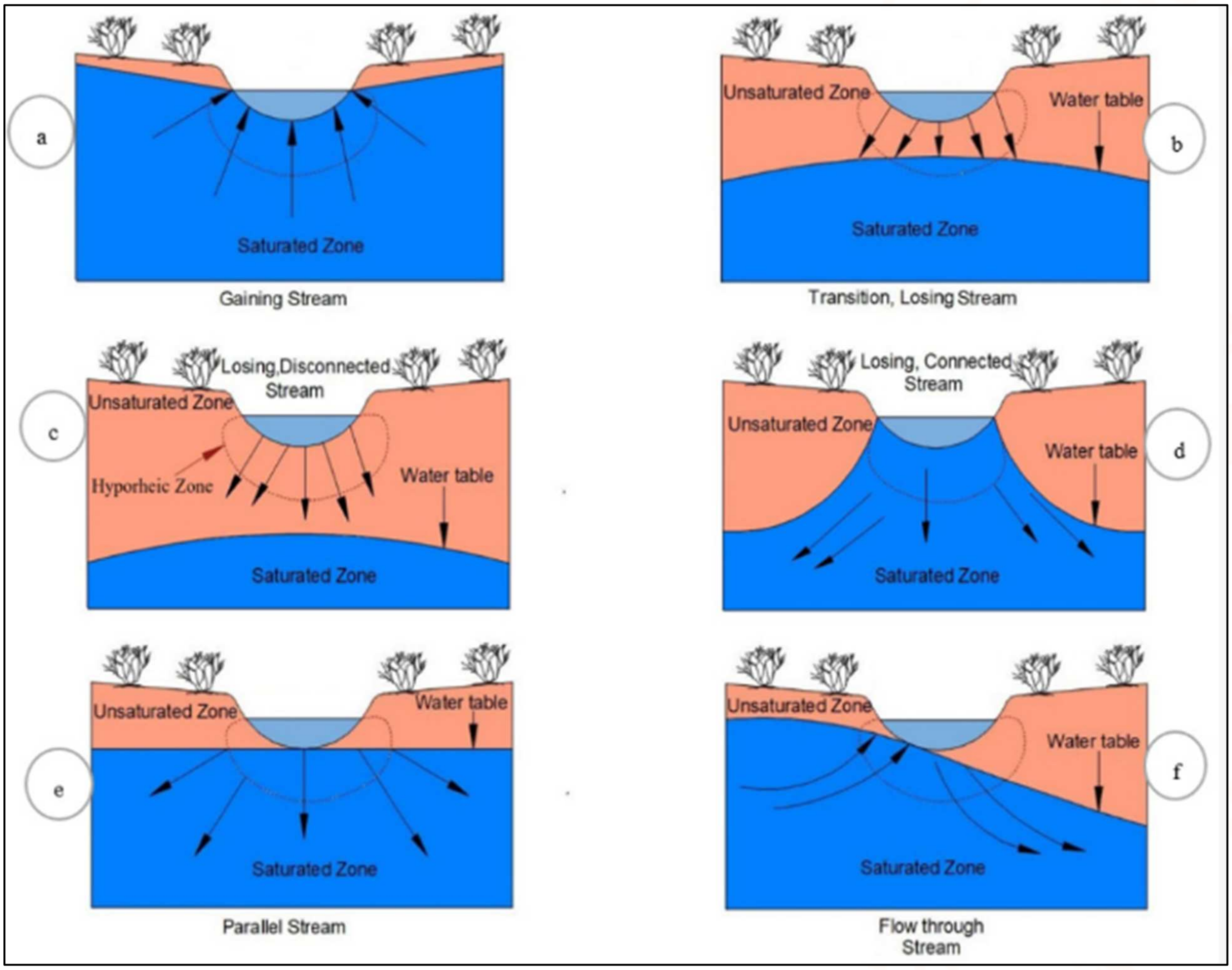

Figure 4. Different stream-water and groundwater interaction scenarios, (a) gaining stream, (b) transition-losing stream, (c) losing-disconnected stream, (d) losing-connected stream, [11] (e) parallel stream, (f) flow-through stream. The arrows denote the directions of fluid flow.

(Source: https://encyclopedia.pub/)

Patterns And Controlling Factors of Groundwater– Surface Water Interactions:

Interactions Across Scales:

In addition to fluxes and water exchange at the GW–SW interface, flow patterns and related biogeochemical and ecological activities in the transition zone close to the contact are also referred to as GW–SW interactions. There is no doubt that GW–SW interchange produces multiscale patterns. Hyporheic exchange occurs close to rivers when water from the river or stream moves through bedrock fissures and porous subterranean sediments before returning to the river. This flow process, which might involve tidal and wave pumping, is frequently referred to as "benthic exchange" in the vicinity of marine waters. In both fresh and marine aquatic environments, a wide range of interactions are formed by SW infiltration, regional GW discharge, and return flow from overbank or coastal flooding. GW discharge happens through processes that can be spatially diffuse or spatially targeted, and it can be incorporated in hyporheic and benthic interaction in a variety of SW systems (Figure 5). [12]

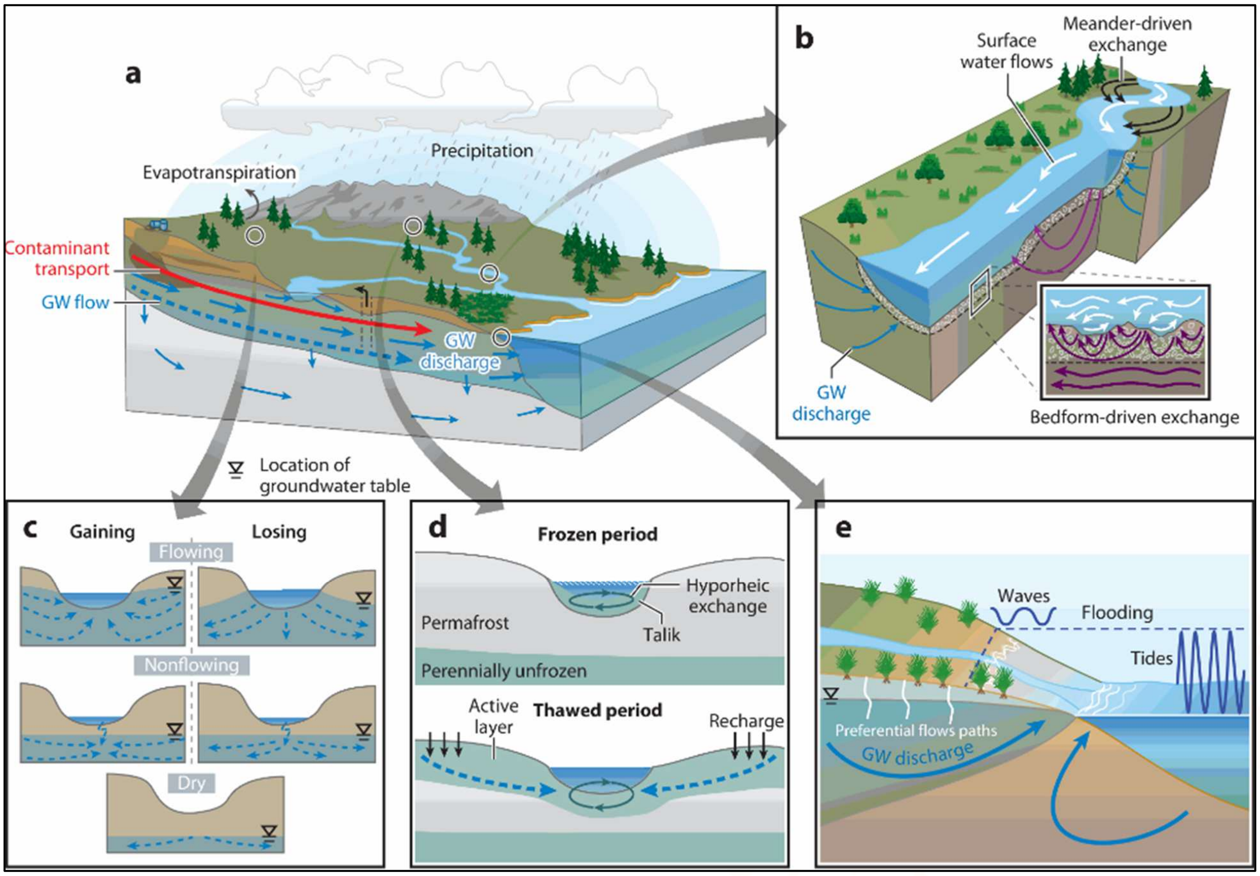

Figure 5: A conceptual model illustrating GW–surface water interactions across spatial scales, controlled by distinct factors, encompassing (a) the watershed scale, (b) perennial surface water, (d) surface water in permafrost areas, and (e) salt water in marine coastal settings. Abbreviation: GW, groundwater.
(Source: https://www.annualreviews.org/)

Interactions between GW and SW occur at various spatial scales. The majority of research has been on either the transect or reach scale (meters to hundreds of meters) or the point scale (centimeters to meters). River research communities have been interested in the hyporheic zone for decades because of its ecological relevance. They mostly study hyporheic exchange and related biogeochemical processes that take place on timescales of days to years. [13]

Factors Controlling Groundwater–Surface Water Interactions

In the exchange between GW and SW at various scales, complex spatiotemporal patterns rely primarily on (a) the hydraulic connections between GW flows and spatiotemporally dynamic SW systems; and (b) the distribution of aquifer and interface sediments with different hydraulic properties and GW flow patterns. (c) intricate geomorphological features of SW networks, such as islands, bars, bedforms, and branching or meandering channels (including those in deltas and other coastal systems); (d) dynamic surface flow factors, such as the severity, duration, and frequency of floods or storm surges; and (c) the outcomes of human activities, such as GW extraction, agricultural irrigation, urbanization, and the building of dams, levees, and seawalls. From millimeter-scale circulation beneath the sediment–water interface to kilometer-scale pathways through the landscape, the spatial scales impacted by GW–SW interactions range across orders of magnitude. [14]

Conclusion:

The interactions between surface and ground water under various natural circumstances are discussed in this article, along with the dynamics and regime of groundwater runoff to rivers, seas, and oceans. It talks about the permafrost zone as well as surface and ground water interaction systems in mountain and plain areas. It covers the function of surface and ground water in the water balance of large lakes and seas and illustrates how river sediments change the interplay between surface and ground water in river walleyes. The quality of both water sources may be impacted by interactions between groundwater and surface water. The quality of groundwater can be impacted by contaminants found in surface water seeping into it. On the other hand, contaminated groundwater can leak into bodies of surface water, affecting the quality of the water. Effective management of water resources requires an understanding of the interplay between surface water and groundwater.

References:

[1] Winter, T.C.; Harvey, J.W.; Franke, O.L.; Alley, W.M. Groundwater and Surface Water: A Single Resource, Circular 1139; US Geological Survey: Denver, CO, USA, 1998; p. 79.

[2] Sprenger, C.; Lorenzen, G.; Huelshoff, I.; Gruetzmacher, G.; Ronghang, M.; Pekdeger, A. Vulnerability of bank filtration systems to climate change. Sci. Total Environ. 2011, 409, 655–663.

[3] Alpers, C. N., & Whittemore, D. O. (1990). Hydrogeochemistry and stable isotopes of ground and surface waters from two adjacent closed basins, Atacama Desert, northern Chile. Applied Geochemistry, 5(5–6), 719–734.

[4] Andersen, M. S., Nyvang, V., Jakobsen, R., & Postma, D. (2005). Geochemical processes and solute transport at the seawater/freshwater interface of a sandy aquifer. Geochimica et Cosmochimica Acta, 69(16), 3979–3994.

[5] Winter, T.C., Harvey, J.W., Franke, O.L., Alley, W.M., 1998. Ground water and surface water: A single resource (No. 1139), Circular. U.S. Geological Survey.

[6] European Commission. (2000). European Commission Directive 2000/60/EC of the European Parliament and of the Council, of 23 October 2000, establishing a framework for community action in the field of water policy. Official Journal of the European Communities, 327, 1–73.

[7] Kløve, B., Ala-Aho, P., Bertrand, G., Boukalova, Z., Ertürk, A., Goldscheider, N., Ilmonen, J., Karakaya, N., Kupfersberger, H., Kvœrner, J., Lundberg, A., Mileusnić, M., Moszczynska, A., Muotka, T., Preda, E., Rossi, P., Siergieiev, D., Šimek, J., Wachniew, P. … Widerlund, A. (2011). Groundwater dependent ecosystems. Part I: Hydroecological status and trends. Environmental Science & Policy, 14(open in a new window) (7(open in a new window)), 770–781.

[8] Colvin, C., Le Maitre, D., Saayman, I., & Hughes, S. (2007). *An introduction to aquifer dependent ecosystems in South Africa*. Pretoria: Natural Resources and the Environment, CSIR.

[9] Head of the Department of Hydrogeology, Institute of Water Problems, Russian Academy Sciences, Moscow, 1968 - present.

[10] Sophocleous, M. Interactions between groundwater and surface water: The state of the science. Hydrogeol. J. 2002, 10, 52–67.

[11] Winter, T.C. Recent advances in understanding the interaction of groundwater and surface water. Rev. Geophys. 1995, 33, 985–994.

[12] Visiting Research Professor, Fulbright Scholar, University of California, Santa Barbara, Geography Department, 10 months 1997-1998.

[13] Zektser, I. S. and Loaiciga, H. A. 1993. Groundwater fluxes in the global hydrologic cycle: past, present and future. Journal of Hydrology. 144(1- 4): 405-427.

[14] Schneider, R. L., Negley, T. C., and Wafer, C. 2005. Factors influencing groundwater seepage in a large, mesotrophic lake in New York. Journal of hydrology. 310(1): 1-16