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Surface Water and Groundwater in a Changing Environment

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Abstract: Water resources are being impacted by anthropogenic climate change worldwide, the nature and severity of that impact is determined by geographic position, local topography, underlying geology, and human influences such as land use, water availability, and water regulation. As global temperatures continue to rise due to greenhouse gas emissions, it is imperative that we better understand how water availability fluctuates with changes in air temperature, rainfall, snowpack, and glacial ice. Traditionally, management of water resources has focused on surface water or ground water as if they were separate entities. As development of land and water resources increases, it is apparent that development of either of these resources affects the quantity and quality of the other. Nearly all surface-water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with groundwater. These interactions take many forms. In many situations, surface-water bodies gain water and solutes from ground-water systems and in others the surface-water body is a source of ground-water recharge and causes changes in ground-water quality. As a result, withdrawal of water from streams can deplete ground water or conversely, pumpage of ground water can deplete water in streams, lakes, or wetlands. Pollution of surface water can cause degradation of ground-water quality and conversely pollution of ground water can degrade surface water. Thus, effective land and water management requires a clear understanding of the linkages between ground water and surface water as it applies to any given hydrologic setting. This study presents an overview of current understanding of the interaction of ground water and surface water, in terms of both quantity and quality, as applied to a variety of landscapes across the Nation. It serves as a general educational document rather than a report of new scientific findings. Its intent is to help the Federal, State, and local agencies build a firm scientific foundation for policies governing the management and protection of aquifers and watersheds. Effective policies and management practices must be built on a foundation that recognizes that surface water and ground water are simply two manifestations of a single integrated resource. It is our hope that this study will contribute to the use of such effective policies and management practices.

Keywords: *Surface water, ground water, changing environment, agricultural development, water supply*

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I. INTRODUCTION

As the Nations concerns over water resources and the environment increase, the importance of considering ground water and surface water as a single resource has become increasingly evident. Issues related to water supply, water quality, and degradation of aquatic environments is reported on frequently. The interaction of ground water and surface water has been shown to be a significant concern in many of these issues. For example, contaminated aquifers that discharge to streams can result in long-term contamination of surface water; conversely, streams can be a major source of contamination to aquifers. Surface water commonly is hydraulically connected to ground water, but the interactions are difficult to observe and measure and commonly have been ignored in water-management considerations and policies. Many natural processes and human activities affect the interactions of groundwater and surface water. The purpose of this study is to present our current understanding of these processes and activities as well as limitations in our knowledge and ability to characterize them [1].

According to [2], the hydrologic cycle describes the continuous movement of water above, on, and below the surface of the Earth. The water on the Earths surfacesurface wateroccurs as streams, lakes, and wetlands, as well as bays and oceans. Surface water also includes the solid forms of water snow and ice. The water below the surface of the Earth primarily is ground water, but it also includes soil water. The hydrologic cycle commonly is portrayed by a very simplified diagram that shows only major transfers of water between continents and oceans, as in Figure 1. However, for understanding hydrologic processes and managing water resources, the hydrologic cycle needs to be viewed at a wide range of scales and as having a great deal of variability in time and space. Precipitation, which is the source of virtually all freshwater in the hydrologic cycle, falls nearly everywhere, but its distribution, is highly variable. Similarly, evaporation and transpiration return water to the atmosphere nearly everywhere, but evaporation and transpiration rates vary considerably according to climatic conditions. As a result, much of the precipitation never reaches the oceans as surface and subsurface runoff before the water is returned to the atmosphere. The relative magnitudes of the individual components of the hydrologic cycle, such as evapotranspiration, may differ significantly even at small scales, as between an agricultural field and a nearby woodland.

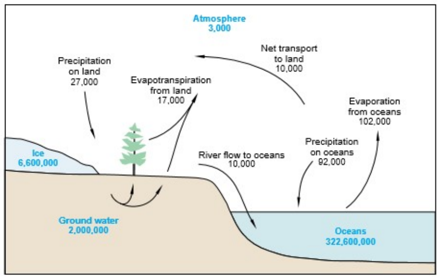

Fig. 1. Groundwater is the second smallest of the four main pools of water on Earth, and river flow to the oceans is one of the smallest fluxes, yet groundwater and surface water are the components of the hydrologic system that humans use most. (Modified from [2], BiogeochemistryAn analysis of global change: Academic Press, San Diego, California).

To present the concepts and many facets of the interaction of groundwater and surface water in a unified way, a conceptual landscape is used (Figure 2). The conceptual landscape shows in a very general and simplified way the interaction of groundwater with all types of surface water, such as streams, lakes, and wetlands, in many different terrains from the mountains to the oceans. The intent of Figure 2 is to emphasize that groundwater and surface water interact at many places throughout the landscape. Movement of water in the atmosphere and on the land surface is relatively easy to visualize, but the movement of groundwater is not. Concepts related to ground water and the movement of groundwater is introduced in Box A. As illustrated in Figure 3, groundwater moves along flow paths of varying lengths from areas of recharge to areas of discharge. The generalized flow paths in Figure 3 start at the water table, continue through the groundwater system, and terminate at the stream or at the pumped well. The source of water to the water table (groundwater recharge) is infiltration of precipitation through the unsaturated zone. In the uppermost, unconfined aquifer, flow paths near the stream can be tens to hundreds of feet in length and have corresponding travel times of days to a few years. The longest and deepest flow paths in Figure 3 may be thousands of feet to tens of miles in length, and travel times may range from decades to millennia. In general, shallow groundwater is more susceptible to contamination from human sources and activities because of its close proximity to the land surface. Therefore, shallow, local patterns of groundwater flow near surface water are emphasized in this study [2].

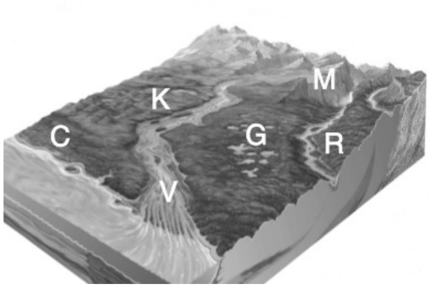

Fig. 2. Groundwater and surface water interact throughout all landscapes from the mountains to the oceans, as depicted in this diagram of a conceptual landscape. M, mountainous; K, karst; G, glacial; R,riverine (small); V, riverine (large); C, coastal (Schelesinger, 1999)...

Small-scale geologic features in beds of surface water bodies affect seepage patterns at scales too small to be shown in Figure 3. For example, the size, shape, and orientation of the sediment grains in surface-water beds affect seepage patterns. If a surface water bed consists of one sediment type, such as sand, inflow seepage is greatest at the shoreline, and it decreases in a nonlinear pattern away from the shoreline (Figure4). Geologic units having different permeabilities also affect seepage distribution in surface water beds [3]. For example, a highly permeable sand layer within a surface-water bed consisting largely of silt will transmit water preferentially into the surface water as a spring (Figure 5).

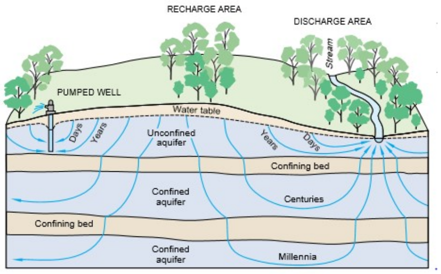

Fig. 3. Groundwater flow paths vary greatly in length, depth, and travel time from points of recharge to points of discharge in the groundwater system.

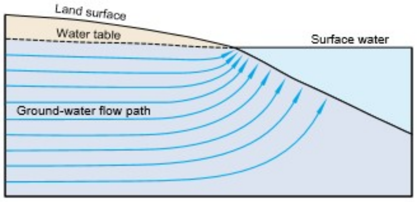

Fig. 4. Groundwater seepage into surface water usually is greatest near shore. In flow diagrams such as that shown here, the quantity ofdischarge are equal between any two flow lines; therefore, the closer flow lines indicate greater discharge per unit of bottom area.

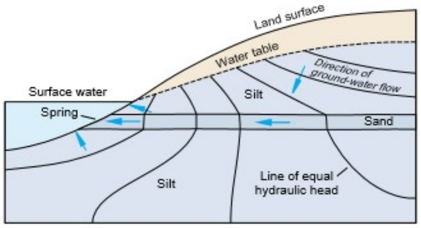

Fig. 5. Subaqueous springs can result from preferred paths of ground-water flow through highly permeable sediments (Mcclymont,et al., 2010).

II. SUBSURFACE WATER

According to [4], water beneath the land surface occurs in two principal zones, the unsaturated zone, and the saturated zone (Figure 6). In the unsaturated zone, the voidsthat is, the spaces between grains of gravel, sand, silt, clay, and cracks within rockscontain both air and water. Although a considerable amount of water can be present in the unsaturated zone, this water cannot be pumped by wells because it is held too tightly by capillary forces. The upper part of the unsaturated zone is the soil-water zone. The soil zone is crisscrossed by roots, voids left by decayed roots and animal and worm burrows, which enhance the infiltration of precipitation into the soil zone. Soil water is used by plants in life functions and transpiration, but it also can evaporate directly to the atmosphere [5].

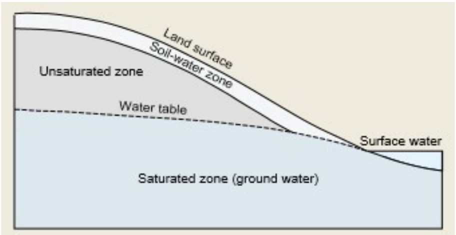

Fig. 6. The water table is the upper surface of the saturated zone. The water table meets surface water bodies at or near the shoreline of surface water if the surface-water body is connected to the groundwater system.

In contrast to the unsaturated zone, the voids in the saturated zone are completely filled with water. Water in the saturated zone is referred to as groundwater. The upper surface of the saturated zone is referred to as the water table. Below the water table, the water pressure is great enough to allow water to enter wells, thus permitting groundwater to be withdrawn for use. A well is constructed by inserting a pipe into a drilled hole; a screen is attached, generally at its base, to prevent earth materials from entering the pipe along with the water pumped through the screen [6]. The depth to the water table is highly variable and can range from zero, when it is at land surface, to hundreds or even thousands of feet in some types of landscapes. Usually, the depth to the water table is small near permanent bodies of surface water such as streams, lakes, and wetlands. An important characteristic of the water table is that its configuration varies seasonally and from year to year because groundwater recharge, which is the accretion of water to the upper surface of the saturated zone, is related to the wide variation in the quantity, distribution, and timing of precipitation [7].

III. GROUNDWATER MOVEMENT

The groundwater system as a whole is actually a three-dimensional flow field; therefore, it is important to understand how the vertical components of groundwater movement affect the interaction of groundwater and surface water. A vertical section of a flow field indicates how potential energy is distributed beneath the water table in the groundwater system and how the energy distribution can be used to determine vertical components of flow near a surface-water body [8]. The term hydraulic head, which is the sum of elevation and water pressure divided by the weight density of water, is used to describe potential energy in groundwater flow systems. For example, Figure 7 shows a generalized vertical section of subsurface water flow. Water that infiltrates at land surface moves vertically downward to the water table to become ground water. The groundwater then moves both vertically and laterally within the groundwater system. Movement is downward and lateral on the right side of the diagram, mostly lateral in the center, and lateral and upward on the left side of the diagram. Flow fields such as these can be mapped in a process similar to preparing water-table maps, except that vertically distributed piezometers need to be used instead of water-table wells [9]. A piezometer is a well that has a very short screen so the water level represents hydraulic head in only a very small part of the ground-water system. A group of piezometers completed at different depths at the same location is referred to as a piezometer nest. Three such piezometer nests are shown in Figure 7 (locations A, B, and C). By starting at a water-table contour, and using the water-level data from the piezometer nests, lines of equal hydraulic head can be drawn. Similar to drawing flow direction on water-table maps, flow lines can be drawn approximately perpendicular to these lines of equal hydraulic head, as shown in Figure 7 [10].

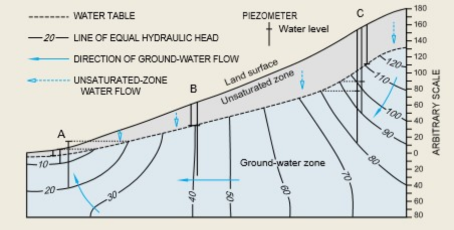

Fig. 7. If the distribution of hydraulic head in vertical section is known from nested piezometer data, zones of downward, lateral, and upward components of ground-water flow can be determined

Actual flow fields generally are much more complex than that shown in Figure 8. For example, flow systems of different sizes and depths can be present, and they can overlie one another, as indicated in Figure 8. In a local flow system, water that recharges at a water-table high discharges to an adjacent lowland [11]. Local flow systems are the most dynamic and the shallowest flow systems; therefore, they have the greatest interchange with surface water. Local flow systems can be underlain by intermediate and regional flow systems. Water in deeper flow systems has longer flow paths and longer contacts time with subsurface materials; therefore, the water generally contains more dissolved chemicals. Nevertheless, these deeper flow systems also eventually discharge to surface water, and they can have a great effect on the chemical characteristics of the receiving surface water [6].

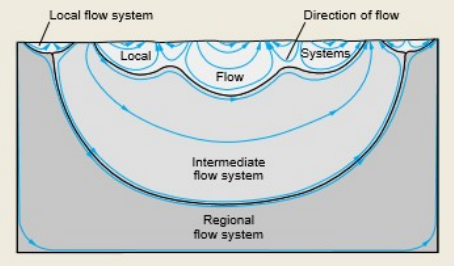

Fig. 8. Groundwater flow systems can be local, intermediate, and regional in scale. Much groundwater discharge into surface water bodies is from local flow systems. (Figure modified from [6], A theoretical analysis of groundwater flow in small drainage basins: p.7596 in Proceedings of Hydrology Symposium No. 3, Groundwater, Queens Printer, Ottawa, Canada.)

IV. GROUNDWATER DISCHARGE

The quantity of ground-water discharge (flux) to and from surface-water bodies can be determined for a known cross section of aquifer by multiplying the hydraulic gradient, which is determined from the hydraulic-head measurements in wells and piezometers, by the permeability of the aquifer materials. Permeability is a quantitative measure of the ease of water movement through aquifer materials. For example, sand is more permeable than clay because the pore spaces between sand grains are larger than pore spaces between clay particles. Changing meteorological conditions also strongly affect seepage patterns in surface water beds, especially near the shoreline [12]. The water table commonly intersects land surface at the shoreline, resulting in no unsaturated zone at this point. Infiltrating precipitation passes rapidly through a thin unsaturated zone adjacent to the shoreline, which causes water-table mounds to form quickly adjacent to the surface water (Figure 9). This process, termed focused recharge, can result in increased ground-water inflow to surface-water bodies, or it can cause inflow to surface-water bodies that normally have seepage to ground water. Each precipitation event has the potential to cause this highly transient flow condition near shorelines as well as at depressions in uplands (Figure 9) [13].

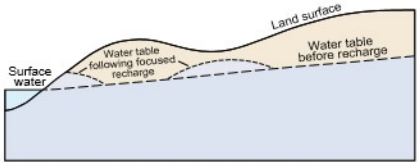

Fig. 9. Ground-water recharge commonly is focused initially where the unsaturated zone is relatively thin at the edges of surface-water bodies and beneath depressions in the land surface.

Transpiration by near shore plants has the opposite effect of focused recharge. Again, because the water table is near land surface at edges of surface-water bodies, plant roots can penetrate into the saturated zone, allowing the plants to transpire water directly from the groundwater system (Figure 10). Transpiration of groundwater commonly results in a drawdown of the water table much like the effect of a pumped well. This highly variable daily and seasonal transpiration of groundwater may significantly reduce groundwater discharge to a surface-water body or even cause movement of surface water into the subsurface [14]. In many places it is possible to measure diurnal changes in the direction of flow during seasons of active plant growth; that is, ground water moves into the surface water during the night, and surface water moves into shallow groundwater during the day. These periodic changes in the direction of flow also take place on longer time scales: focused recharge from precipitation predominates during wet periods and draw down by transpiration predominates during dry periods. As a result, the two processes, together with the geologic controls on seepage distribution, can cause flow conditions at the edges of surface-water bodies to be extremely variable. These edge effects probably affect small surface-water bodies more than large surface-water bodies because the ratio of edge length to total volume is greater for small water bodies than it is for large ones [15].

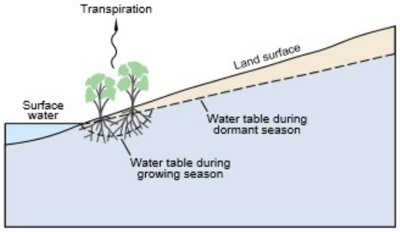

Fig. 10. Where the depth to the water table is small adjacent to surface-water bodies, transpiration directly from ground water can cause cones of depression similar to those caused by pumping wells. This sometimes draws water directly from the surface water into the subsurface.

V. THE EFFECT OF GROUNDWATER WITHDRAWALS ON SURFACE WATER

Withdrawing water from shallow aquifers that are directly connected to surface-water bodies can have a significant effect on the movement of water between these two water bodies. The effects of pumping a single well or a small group of wells on the hydrologic regime are local in scale. However, the effects of many wells withdrawing water from an aquifer over large areas may be regional in scale. Withdrawing water from shallow aquifers for public and domestic water supply, irrigation, and industrial uses is widespread [16]. Withdrawing water from shallow aquifers near surface-water bodies can diminish the available surface-water supply by capturing some of the ground-water flow that otherwise would have discharged to surface water or by inducing flow from surface water into the surrounding aquifer system. An analysis of the sources of water to a pumping well in a shallow aquifer that discharges to a stream is provided here to gain insight into how a pumping well can change the quantity and direction of flow between the shallow aquifer and the stream. Furthermore, changes in the direction of flow between the two water bodies can affect transport of contaminants associated with the moving water. Although a stream is used in the example, the results apply to all surface-water bodies, including lakes and wetlands [17]. A ground-water system under predevelopment conditions is in a state of dynamic equilibriumfor example, recharge at the water table is equal to groundwater discharge to a stream (Figure 11). Assume a well is installed and is pumped continually at a rate, Q1. After a new state of dynamic equilibrium is achieved, inflow to the groundwater system from recharge will equal outflow to the stream plus the withdrawal from the well. In this new equilibrium, some of the ground water that would have discharged to the stream is intercepted by the well, and a ground-water divide, which is a line separating directions of flow, is established locally between the well and the stream (Figure 11B). If the well is pumped at a higher rate, Q2, at a later time a new equilibrium is reached. Under this condition, the ground-water divide between the well and the stream is no longer present and withdrawals from the well induce movement of water from the stream into the aquifer (Figure 11C). Thus, pumpage reverses the hydrologic condition of the stream in this reach from a groundwater discharge feature to a groundwater recharge feature. In the hydrologic system depicted in Figures 11A and 11B, the quality of the stream water generally will have little effect on the quality of the shallow ground water. However, in the case of the well pumping at the higher rate, Q2 (Figure 11C), the quality of the stream water, which locally recharges the shallow aquifer, can affect the quality of ground water between the well and the stream as well as the quality of the ground water withdrawn from the well. This hypothetical withdrawal of water from a shallow aquifer that discharges to a nearby surface water body is a simplified but compelling illustration of the concept that ground water and surface water are one resource. In the long term, the quantity of ground water withdrawn is approximately equal to the reduction in stream flow that is potentially available to downstream users [18].

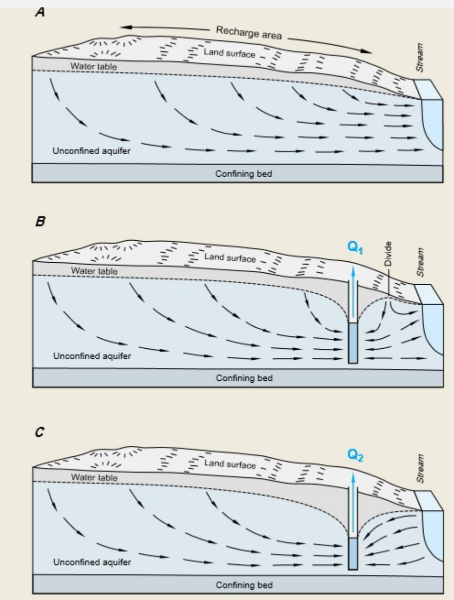

Fig. 11. In a schematic hydrologic setting where ground water discharges to a stream under natural conditions (A), placement of a well pumping at a rate (Q1) near the stream will intercept part of the ground water that would have discharged to the stream (B). If the well is pumped at an even greater rate (Q2), it can intercept additional water that would have discharged to the stream in the vicinity of the well and can draw water from the stream to the well (C).

Where stream flow is generated in headwaters areas, the changes in stream flow between gaining and losing conditions may be particularly variable (Figure 12). The headwaters segment of streams can be completely dry except during storm events or during certain seasons of the year when snowmelt or precipitation is sufficient to maintain continuous flow for days or weeks [19]. During these times, the stream will lose water to the unsaturated zone beneath its bed. However, as the water table rises through recharge in the headwaters area, the losing reach may become a gaining reach as the water table rises above the level of the stream. Under these conditions, the point where ground water first contributes to the stream gradually moves upstream. Some gaining streams have reaches that lose water to the aquifer under normal conditions of stream flow. The direction of seepage through the bed of these streams commonly is related to abrupt changes in the slope of the streambed (Figure 13A) or to meanders in the stream channels (Figure 13B). For example, a losing stream reach usually is located at the downstream end of pools in pool and riffle streams (Figure 13A), or upstream from channel bends in meandering streams (Figure 13B). The subsurface zone where stream water flows through short segments of its adjacent bed and banks is referred to as the hyporheic zone. The size and geometry of hyporheic zones surrounding streams vary greatly in time and space. Because of mixing between groundwater and surface water in the hyporheic zone, the chemical and biological character of the hyporheic zone may differ markedly from adjacent surface water and groundwater. Groundwater systems that discharge to streams can underlie extensive areas of the land surface (Figure 14). As a result, environmental conditions at the interface between groundwater and surface water reflect changes in the broader landscape. For example, the types and numbers of organisms in a given reach of streambed result, in part, from interactions between water in the hyporheic zone and groundwater from distant sources [20].

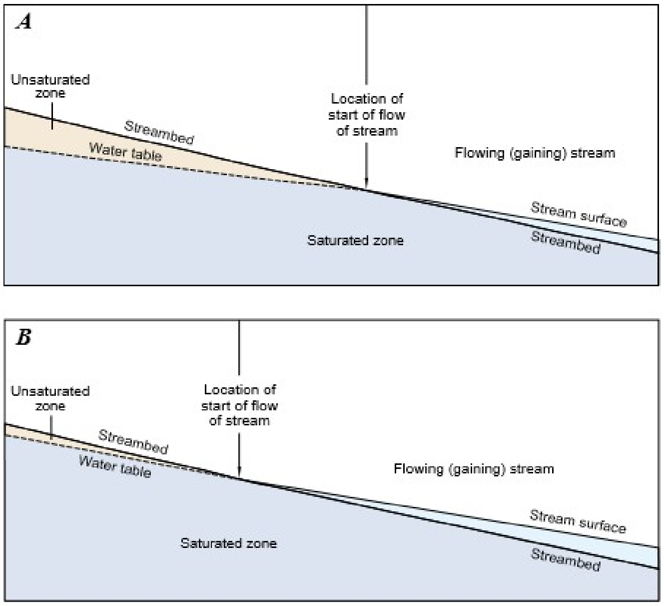

Fig. 12. The location where perennial stream flow begins in a channel can vary depending on the distribution of recharge in headwaters areas. Following dry periods (A), the start of stream flow will move up channel during wet periods as the ground-water system becomes more saturated (B).

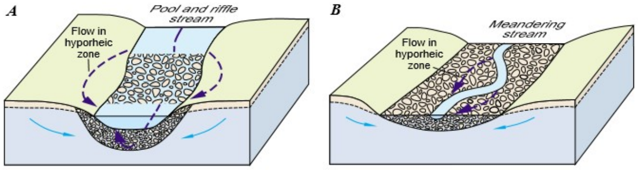

Fig. 13. Surface-water exchange with ground water in the hyporheic zone is associated with abrupt changes instreambed slope (A) and with stream meanders (B).

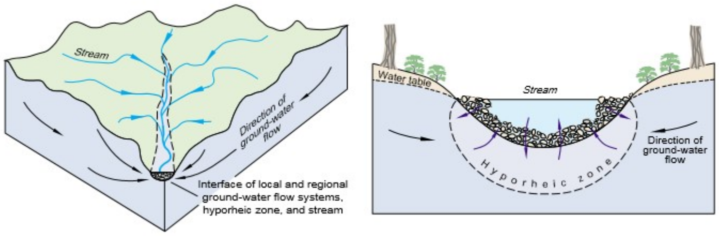

Fig. 14. Streambeds and banks are unique environments because they are where ground water that drains much ofthe subsurface of landscapes interacts with surface water that drains much of the surface of landscapes [19].

VI. CHEMICAL INTERACTIONS OF GROUNDWATER AND SURFACE WATER

A. *Evolution of Water Chemistry in Drainage Basins*

Two of the fundamental controls on water chemistry in drainage basins are the type of geologic materials that are present and the length of time that water is in contact with those materials. Chemical reactions that affect the biological and geochemical characteristics of a basin include (1) acid-base reactions, (2) precipitation and dissolution of minerals, (3) sorption and ion exchange, (4) oxidation-reduction reactions, (5) biodegradation, and (6) dissolution and exsolution of gases [21]. When water first infiltrates the land surface, microorganisms in the soil have a significant effect on the evolution of water chemistry. Organic matter in soils is degraded by microbes, producing high concentrations of dissolved carbon dioxide (CO2). This process lowers the pH by increasing the carbonic acid (H2CO3) concentration in the soil water. The production of carbonic acid starts a number of mineral-weathering reactions, which result in bicarbonate (HCO3) commonly, being the most abundant anion in the water. Where contact times between water and minerals in shallow groundwater flow paths are short, the dissolved-solids concentration in the water generally is low [22]. In such settings, limited chemical changes take place before ground water is discharged to surface water. In deeper ground-water flow systems, the contact time between water and minerals is much longer than it is in shallow flow systems. As a result, the initial importance of reactions relating to microbes in the soil zone may be superseded over time by chemical reactions between minerals and water (geochemical weathering). As weathering progresses, the concentration of dissolved solids increases [23]. Depending on the chemical composition of the minerals that are weathered, the relative abundance of the major inorganic chemicals dissolved in the water changes. Surface water in streams, lakes, and wetlands can repeatedly interchange with nearby ground water. Thus, the length of time water is in contact with mineral surfaces in its drainage basin can continue after the water first enters a stream, lake, or wetland. An important consequence of these continued interchanges between surface water and ground water is their potential to further increase the contact time between water and chemically reactive geologic materials [24].

VII. CHEMICAL INTERACTIONS OF GROUNDWATER AND SURFACE WATER IN STREAMS, LAKES, AND WETLANDS

Groundwater chemistry and surface water chemistry cannot be dealt with separately where surface and subsurface flow systems interact. The movement of water between groundwater and surface water provides a major pathway for chemical transfer between terrestrial and aquatic systems. This transfer of chemicals affects the supply of carbon, oxygen, nutrients such as nitrogen and phosphorus, and other chemical constituents that enhance biogeochemical processes on both sides of the interface. This transfer can ultimately affect the biological and chemical characteristics of aquatic systems downstream [25].

VIII. EFFECTS OF HUMAN ACTIVITIES ON THE INTERACTION OF GROUNDWATER AND SURFACE WATER

Human activities commonly affect the distribution, quantity, and chemical quality of water resources. The range in human activities that affect the interaction of groundwater and surface water is broad. The following discussion does not provide an exhaustive survey of all human effects but emphasizes those that are relatively widespread [20]. To provide an indication of the extent to which humans affect the water resources of virtually all landscapes, some of the most relevant structures and features related to human activities are superimposed on various parts of the conceptual landscape (Figure 15). The effects of human activities on the quantity and quality of water resources are felt over a wide range of space and time scales. In the following discussion, short term implies time scales from hours to a few weeks or months, and long term may range from years to decades. Local scale implies distances from a few feet to a few thousand feet and areas as large as a few square miles, and sub regional and regional scales range from tens to thousands of square miles [26].

A. *Agricultural Development*

According to [27], agriculture has been the cause of significant modification of landscapes throughout the world. Tillage of land changes the infiltration and runoff characteristics of the land surface, which affects recharge to groundwater, delivery of water, sediment to surface water bodies, and evapotranspiration. All of these processes either directly or indirectly affect the interaction of ground water and surface water. Agriculturalists are aware of the substantial negative effects of agriculture on water resources and have developed methods to alleviate some of these effects. For example, tillage practices have been modified to maximize retention of water in soils and to minimize erosion of soil from the land into surface water bodies. Two activities related to agriculture that are particularly relevant to the interaction of ground water and surface water are irrigation and application of chemicals to cropland.

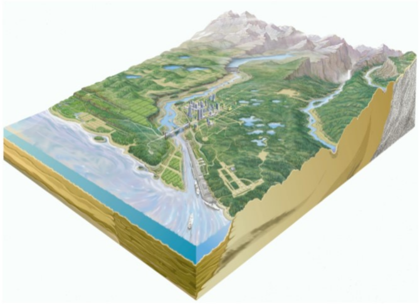

Fig. 15. Human activities and structures, as depicted by the distribution of various examples in the conceptual landscape, affect the interaction of groundwater and surface water in all types of landscapes.

B. *Challenges And Opportunities*

The interaction of groundwater and surface water involves many physical, chemical, and biological processes that take place in a variety of physiographic and climatic settings. For many decades, studies of the interaction of groundwater and surface water were directed primarily at large alluvial stream and aquifer systems [28]. Interest in the relation of groundwater to surface water has increased in recent years as a result of widespread concerns related to water supply; contamination of groundwater, lakes, and streams by toxic substances (commonly where not expected); acidification of surface waters caused by atmospheric deposition of sulfate and nitrate; eutrophication of lakes; loss of wetlands due to development; and other changes in aquatic environments. As a result, studies of the interaction of groundwater and surface water have expanded to include many other settings, including headwater streams, lakes, wetlands, and coastal areas. Issues related to water management and water policy were presented at the beginning of this report. The following sections address the need for greater understanding of the interaction of groundwater and surface water with respect to the three issues of water supply, water quality, and characteristics of aquatic environments [29].

C. *Water Supply*

Water commonly is not present at the locations and times where and when it is most needed. As a result, engineering works of all size shave been constructed to distribute water from places of abundance to places of need. Regardless of the scale of the water supply system, development of either ground water or surface water can eventually affect the other. For example, whether the source of irrigation water is groundwater or surface water, return flows from irrigated fields will eventually reach surface water either through ditches or through groundwater discharge [30]. Building dams to store surface water or diverting water from a stream changes the hydraulic connection and the hydraulic gradient between that body of surface water and the adjacent ground water, which in turn results in gains or losses of groundwater. In some landscapes, development of groundwater at even a great distance from surface water can reduce the amount of groundwater inflow to surface water or cause surface water to recharge groundwater. The hydrologic system is complex, from the climate system that drives it, to the earth materials that the water flows across and through, to the modifications of the system by human activities. Much research and engineering has been devoted to the development of water resources for water supply. However, most past work has concentrated on either surface water or groundwater without much concern about their interrelations. The need to understand better how development of one water resource affects the other is universal and will surely increase as development intensifies [26].

D. *Water Quality*

For nearly every type of water use, whether municipal, industrial, or agricultural, water has increased concentrations of dissolved constituents or increased temperature following its use. Therefore, the water qualities of the water bodies that receive the discharge or return flow are affected by that use. In addition, as the water moves downstream, additional water use can further degrade the water quality. If irrigation return flow, or discharge from a municipal or industrial plant, moves downstream and is drawn back into an aquifer because of ground-water withdrawals, the ground-water system also will be affected by the quality of that surface water [31]. Application of irrigation water to cropland can result in the return flow having poorer quality because evapotranspiration by plants removes some water but not the dissolved salts. As a result, the dissolved salts can precipitate as solids, increasing the salinity of the soils. Additional application of water dissolves these salts and moves them farther down gradient in the hydrologic system. In addition, application of fertilizers and pesticides to cropland can result in poor-quality return flows to both groundwater and surface water. The transport and fate of contaminants caused by agricultural practices and municipal and industrial discharges are a widespread concern that can be addressed most effectively if groundwater and surface water are managed as a single resource. Water scientists and water managers need to design data-collection programs that examine the effects of biogeochemical processes on water quality at the interface between surface water and near surface sediments. These processes can have a profound effect on the chemistry of ground water recharging surface water and on the chemistry of surface water recharging ground water [32]. Repeated exchange of water between surface water and near surface sediments can further enhance the importance of these processes. Research on the interface between ground water and surface water has increased in recent years, but only a few stream environments have been studied, and the transfer value of the research results is limited and uncertain. The tendency for chemical contaminants to move between groundwater and surface water is a key consideration in managing water resources. With an increasing emphasis on watersheds as a focus for managing water quality, coordination between watershed-management and groundwater protection programs will be essential to protect the quality of drinking water. Furthermore, ground-water and surface-water interactions have a major role in affecting chemical and biological processes in lakes, wetlands, and streams, which in turn affect water quality throughout the hydrologic system. Improved scientific understanding of the interconnections between hydrological and biogeochemical processes will be needed to remediate contaminated sites, to evaluate applications for waste-discharge permits, and to protect or restore biological resources [33].

IX. CONCLUSION

The interface between groundwater and surface water is an areally restricted, but particularly sensitive and critical niche in the total environment. At this interface, groundwater that has been affected by environmental conditions on the terrestrial landscape interacts with surface water that has been affected by environmental conditions upstream. Furthermore, the chemical reactions that take place where chemically distinct surface water meets chemically distinct ground water in the hyporheic zone may result in a biogeochemical environment that in some cases could be used as an indicator of changes in either terrestrial or aquatic ecosystems. The ability to understand this interface is challenging because it requires the focusing of many different scientific and technical disciplines at the same, areally restricted locality. The benefit of this approach to studying the interface of ground water and surface water could be the identification of useful biological or chemical indicators of adverse or positive changes in larger terrestrial and aquatic ecosystems. Wetlands are a type of aquatic environment present in most landscapes; yet, in many areas, their perceived value is controversial. The principal characteristics and functions of wetlands are determined by the water and chemical balances that maintain them. These factors in large part determine the value of a wetland for flood control, nutrient retention, and wildlife habitat. As a result, they are especially sensitive to changing hydrological conditions. When the hydrological and chemical balances of a wetland change, the wetland can take on a completely different function, or it may be destroyed. Generally, the most devastating impacts on wetlands result from changes in land use. Wetlands commonly are drained to make land available for agricultural use or filled to make land available for urban and industrial development. Without understanding how wetlands interact with ground water, many plans to use land formerly occupied by wetlands fail. For example, it is operationally straightforward to fill in or drain a wetland, but the groundwater flow system that maintains many wetlands may continue to discharge at that location. Many structures and roads built on former wetlands and many wetland restoration or construction programs fail for this reason. Saline soils in many parts of the central prairies also result from evaporation of groundwater that continues to discharge to the land surface after the wetlands were drained. Riparian zones also are particularly sensitive to changes in the availability and quality of groundwater and surface water because these ecosystems commonly are dependent on both sources of water. If either water source changes, riparian zones may be altered, changing their ability to provide aquatic habitat, mitigate floods and erosion, stabilize shorelines, and process chemicals, including contaminants. Hence, effective management of water resources requires an understanding of the role of riparian zones and their dependence on the interaction of groundwater and surface water.

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