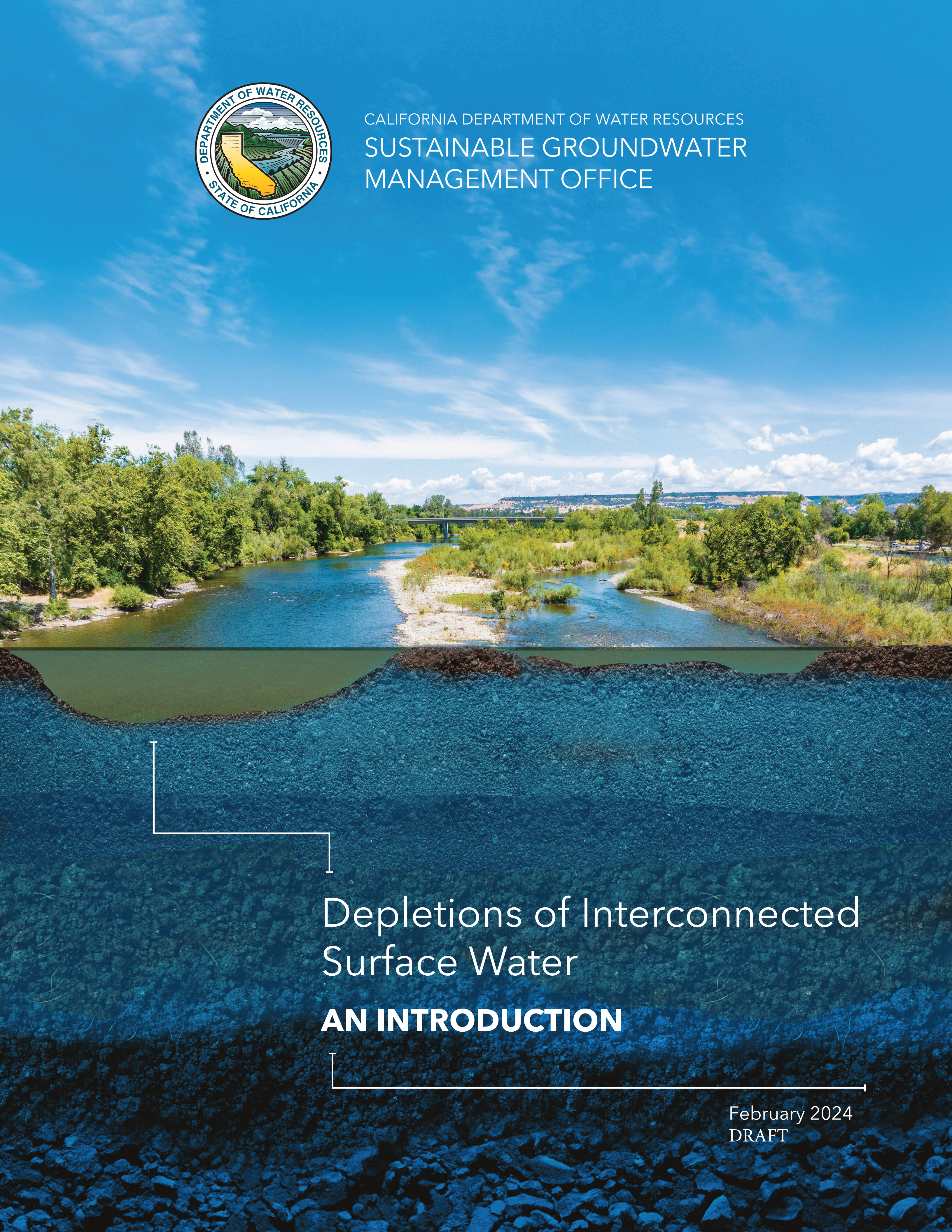

CALIFORNIA DEPARTMENT OF WATER RESOURCES

SUSTAINABLE GROUNDWATER MANAGEMENT OFFICE

Depletions of Interconnected Surface Water

AN INTRODUCTION

February 2024

DRAFT

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1 Introduction

1.1 Purpose

This paper is the first of a three-paper series on interconnected surface water (ISW) and depletions of ISW published by the California Department of Water Resources (DWR). The series aims to provide Groundwater Sustainability Agencies (GSA) and the California water resources community with informational resources to help identify, understand, and communicate the nature, occurrence, and estimation of depletions of ISW.

This document introduces foundational concepts of ISW and depletions and generally accepted definitions of key terms. The two subsequent papers, entitled *Techniques for Estimating Depletions of Interconnected Surface Water* and *Examples of Approaches for Estimating Depletions of Interconnected Surface Water,* provide additional details.

1.2 Background

Groundwater[1] and surface water[2] systems are two linked components of the water cycle, where water moves from one system to another, and additions to or subtractions from one system are reflected in the other. Surface water bodies such as streams, rivers, unlined canals, lakes, wetlands, and ponds interact with groundwater in all landscapes under natural conditions and in response to human activities.

The interaction between surface water and groundwater takes place primarily in three ways: (i) surface water gains water from groundwater, (ii) surface water loses water to groundwater, or (iii) both, gaining in some locations and losing in other locations or gaining at some times and losing at other times. The interaction results in the movement of a volume of water with a certain chemistry and temperature, which can affect the water quality of the receiving system. Precipitation, climate, season, geology, and water management affect surface water and groundwater interactions.

Additionally, groundwater elevations can impact the interaction when surface water is hydraulically connected to groundwater. Where surface water courses are disconnected, groundwater levels do not impact the interaction. When and where groundwater and surface water bodies are connected and interact, the surface water body would be considered an ISW.

[1] Groundwater in this document refers to "water that exists underground in saturated zones beneath the land surface" (USGS, 2023).
[2] Surface water in this document refers to rivers, streams, lakes and can also include surface water found in canals, reservoirs, ponds, and marshes.

Groundwater pumping plays an important role in the interaction between ISW and groundwater aquifers. Groundwater pumping causes (1) a reduction of inflow to an ISW from groundwater or (2) an increase in outflow from an ISW to groundwater. The resulting reductions in the volume of surface water caused by groundwater pumping in both situations are called depletion of ISW.

Identifying the locations of ISW, where depletions occur, and quantifying the amount of depletions poses a significant challenge for water managers. Interconnectivity can be highly variable and dynamic. ISW can show interconnectivity in all, or some locations of the surface water bodies and during all or some periods of time.

Furthermore, the location and amount of depletion of an ISW from groundwater pumping cannot be directly observed or measured. As a result, water professionals need to estimate the location, quantity, and timing of depletions. These estimations require consideration of surface water and groundwater conditions and the material properties of the subsurface environment, all of which have their own variability and uncertainty. In addition, the estimations need to overcome limited information on the location, depth, timing, and volume of groundwater pumping. These gaps in understanding and lack of data lead to uncertainty in all methods used to identify where ISWs are located and the timing, quantity, and location of depletions. However, to meet the requirements of SGMA, GSAs should endeavor to provide the most reasonable estimate of depletions of ISW possible using the best available science available, identify and fill data gaps, and revise ISW estimates in light of new information as appropriate.

1.2.1 SGMA and Depletions of Interconnected Surface Water (ISW)

SGMA identifies that an undesirable result occurs if, among other reasons, groundwater use occurring in a basin causes depletions of ISW that significantly and unreasonably impact beneficial uses of the surface water (CWC § 10721(x)(6)). Depletions of ISW under SGMA are only related to impacts caused by groundwater use, although a GSA will likely need to have some understanding of the various causes of reduced surface water flow to accurately determine the component due to groundwater. To comply with SGMA requirements, the GSAs should identify where ISW exists; determine the location, timing, and quantity of depletions; and then develop sustainable management criteria for managing depletions of ISW. Projects and management actions addressing depletions of ISW may also be proposed to support sustainable groundwater management.

2 What is Interconnected Surface Water?

"Interconnected surface water refers to surface water that is hydrologically connected[1] at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted."

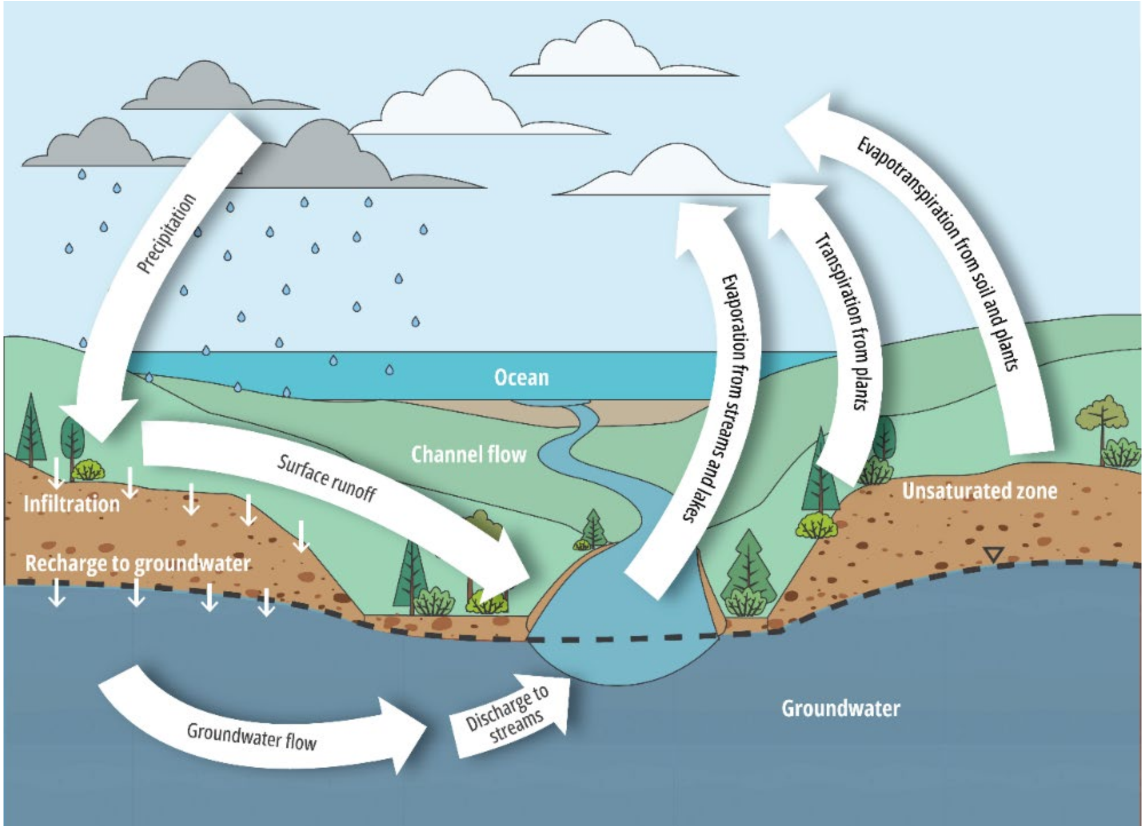
(Title 23 California Code of Regulations § 351[o]).

2.1 Fundamental Concepts of Groundwater and Interconnected Surface Water

Groundwater and surface water systems are two important components of the water cycle (**Figure 1**), which describes the constant movement of water on, above, and below the surface of the Earth (USGS, 2022). **Figure 1** depicts the interaction between surface water and groundwater systems to present only basic water cycle elements, including showing a river gaining water from groundwater. As can be inferred from the water cycle, surface water volume and flow can be affected by a number of factors, including precipitation, climate, surface water diversions and regulation, and groundwater conditions.

[1] A hydraulic connection is present when the saturated zone (groundwater) reaches the bottom of the surface water body; that is, there is no unsaturated zone between the saturated zone and the surface water body.

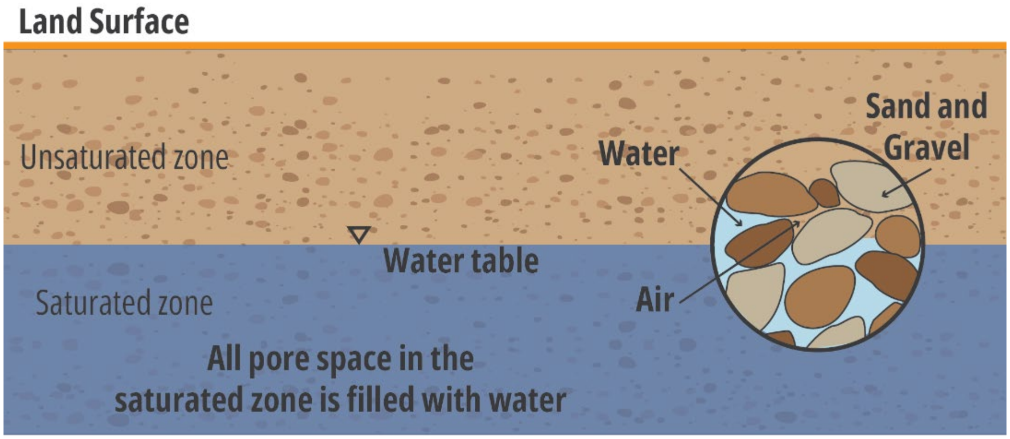
Figure 1: Simplified components of a continuous water cycle



(adapted from Kansas Geological Survey: n.d.)

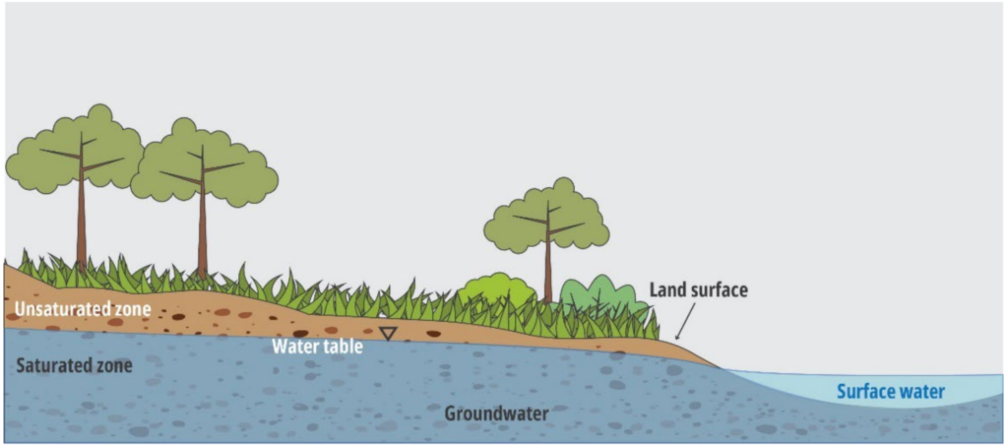
A basic understanding of groundwater is important to understand ISW. Alluvial groundwater basins are typically filled with aquifer-forming strata composed of gravel, sand, silt, and clay particles with open spaces, or pores, between them. These pores are filled with air, water, or both. The subsurface zone in which the pores are filled with both air and water is called the unsaturated zone. The subsurface zone in which pores are filled only with water is called the saturated zone, also known as groundwater. If there is sufficient saturated material to yield a significant amount of water to wells and springs, it is known as a groundwater aquifer. The top surface of the saturated zone, which is also the bottom of the unsaturated zone, is termed the water table, denoted in figures with a line labeled with the symbol ▽. (**Figures 2** and **3**).

Figure 2: Pore space is filled with air and water in the unsaturated zone and with water in the saturated zone.



(adapted from: USGS, 1999)

Figure 3: An interconnected surface water body connected with groundwater by a continuous saturated zone.



In some cases, the unsaturated zone may not be present, with groundwater reaching the ground surface, while in other cases the unsaturated zone can be hundreds of feet thick. Similarly, the saturated zone can be very thin or hundreds of feet thick, extending downward to bedrock or depths where groundwater becomes unsuitable for most uses due to poor water quality.

For a surface water body to be considered an ISW, it should be hydraulically connected at any point by a continuous saturated zone to the underlying aquifer (23 CCR § 351 (o)). Therefore, in an ISW condition, there is no unsaturated zone below the surface water body, with the saturated zone reaching at least the bottom of the surface water body.

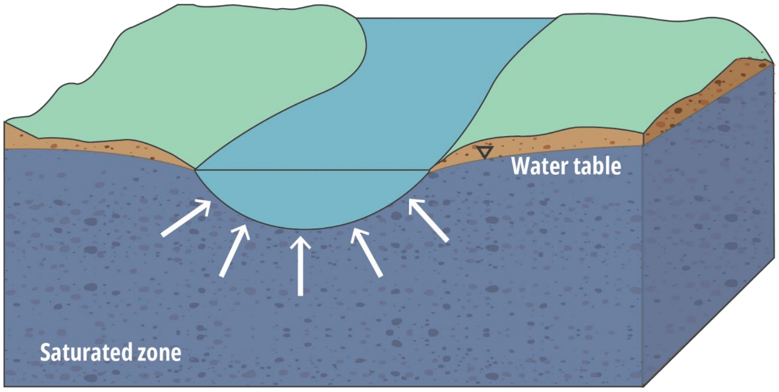
2.2 Factors Affecting Flow Between Groundwater and Interconnected Surface Water

The flowrate of water between groundwater and ISW is controlled by two factors: hydraulic gradient and hydraulic conductivity. The hydraulic gradient can be defined as the difference in water elevation or hydraulic pressure between two points. When all other factors are equal, water flows at a higher rate between groundwater and ISW when the hydraulic gradient is greater. This relationship can be demonstrated by how water flows rapidly down a steep street and more slowly across a nearly flat parking lot.

Hydraulic conductivity is a measure of the ease with which a material allows water to flow through it. The subsurface materials controlling water flow include streambed or lakebed materials and aquifer materials. Some materials transmit water better than others. For instance, coarser materials such as gravel and sand transmit water relatively quickly, while finer materials such as silts and clays transmit water relatively slowly.

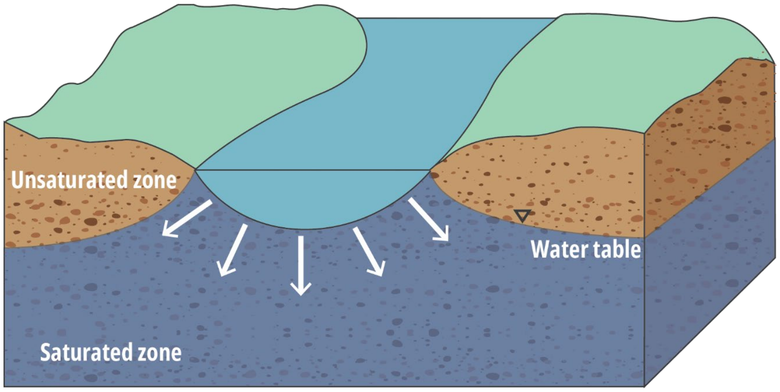
Figures 4a and 4b demonstrate how elevation differences between groundwater and ISW affect the flow direction when there is a continuous saturated zone between the two. **Figure 4c** introduces the concept of a disconnected surface water body where groundwater is separated from the surface water body with an unsaturated zone. Understanding and being able to determine the relationships will help in the identification of ISW, noting that these relationships can vary over time and over different portions of the surface water body.

Figure 4a: Groundwater elevation is higher than surface water elevation.



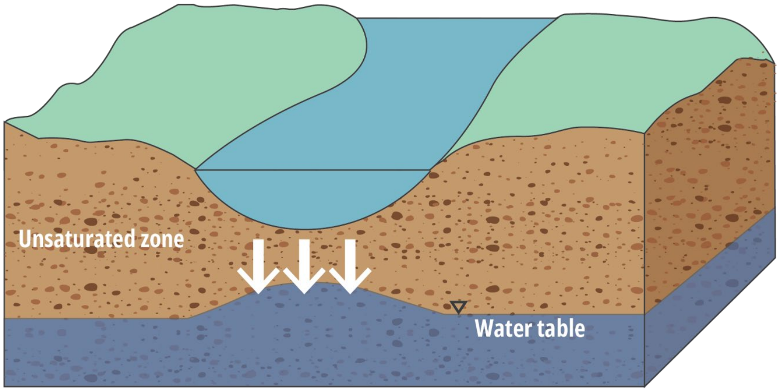
When groundwater elevation is higher than surface water elevation, groundwater flows into the surface water—the surface water is "gaining." If groundwater elevations are lowered, then the difference in elevation between groundwater and surface water is reduced. This results in a decrease in the flow of water from groundwater to surface water.

Figure 4b: Surface water elevation is higher than groundwater elevation.



When surface water elevation is higher than groundwater elevation, surface water flows into groundwater—the surface water is "losing." If groundwater elevations are lowered even more, then the difference in elevation between surface water and groundwater is increased. This results in an increase in the flow of water from surface water to groundwater.

Figure 4c: Groundwater is disconnected from surface water.



When groundwater elevations are low enough below the bottom of the surface water body, there is no longer a continuous saturated zone hydraulically connecting the surface water body with groundwater. Instead, an unsaturated zone beneath the surface water body separates the surface water from groundwater.

When groundwater is physically disconnected from surface water, surface water flows from the surface water system into the unsaturated zone. Water in the unsaturated zone flows into the saturated zone over time. However, further lowering of groundwater elevations in this case of a physically disconnected system does not change the flowrate from the surface water system to the groundwater system. Similarly, raising groundwater elevations will not change the flowrate between surface water and groundwater systems until the groundwater levels rise to the point at which the two systems are hydraulically connected again.

3 Where Does Interconnected Surface Water Occur and How is it Identified?

Any surface water body is an ISW if it has water in it and maintains hydraulic connectivity with the groundwater aquifer at some point in time at some location. A surface water body can have certain reaches that are ISW while other reaches may not be an ISW. A reach that is an ISW may lose its ISW property at times depending on the changes in groundwater table in relation to the surface water body elevation. Surface water body types, as defined by USGS,[1] are:

- **Perennial** surface water bodies typically always have water in their channels.
- **Intermittent** surface water bodies flow only when they receive water from rainfall runoff, springs, or some surface source such as melting snow.
- **Ephemeral** surface water bodies have water in their channels only in direct response to precipitation; they receive little or no water from springs, melting snow, or other sources; their channels are always above the water table.

Perennial and intermittent surface water bodies are most likely to be ISW, while ephemeral surface water bodies are generally not ISW due to their relationship to the groundwater aquifer.

Rivers and streams that are ISW can be regulated, with a reservoir controlling flows, or unregulated. However, the identification of ISW should not be restricted only to flowing rivers and streams; water managers should extend the consideration to

[1] US Geologic Survey, https://water.usgs.gov/water-basics_glossary.html

relevant types of surface water found in and around their basin, such as lakes and wetlands.

Determining if a surface water body is an ISW can be challenging. A common method is to compare groundwater elevation data at wells near the surface water body with the elevation of the bottom of the surface water body. The use of groundwater elevation data for determining the presence of ISW conditions is discussed below for two general conditions. Streams and streambeds are used as examples in the diagrams below, but the same could be said for lakes and lakebeds, wetlands, or other forms of surface water bodies. This listing is not exhaustive, and GSAs may use other appropriate methods based on the best available science and information for their area.

1. **Condition 1: Shallow groundwater elevations are similar to or higher than the streambed elevation.** Shallow groundwater elevations close to the elevation of the streambed may suggest connectivity through a saturated zone (**Figures 5a-c**). Shallow wells are most suited for analyzing connectivity as the surface water bodies directly interact with these shallow groundwater levels.

   Consideration should be given to the distance between the well and the surface water body and to the screen depth of the well. Although more distant wells may show groundwater elevations below streambed elevation, the surface water body may still be hydraulically connected and thus an ISW, as shown in **Figure 5d**.

   There will be situations where shallow monitoring wells may not be available, representing a data gap for the GSA to address. Relatively deeper wells may be used to aid in identifying ISW, but consideration should be given to the potential that shallow groundwater may interact with the surface water body even if groundwater elevations in the deeper wells are lower than the streambed elevation.

   While water levels in wells provide evidence or possible indications of interconnection (or disconnection), the certainty with which the data can be used to determine interconnection depends on the well's distance from the stream and the difference between stream levels and groundwater levels. Care should be taken with the information used in evaluating the hydraulic connection between the two systems and correctly interpreting the data. Available data may often be incomplete and uncertain, and professional judgment using the best available science should be used together with the identification of data gaps and data uncertainties.

   Examples of these relationships are presented in a set of diagrams in **Figure 5**, which shows a range from higher confidence in ISW presence (**Figure 5a)** to lower confidence in ISW presence (**Figure 5e)**.

Figure 5: Considerations and interpretation of ISW based on five example cases of nearby groundwater elevation data

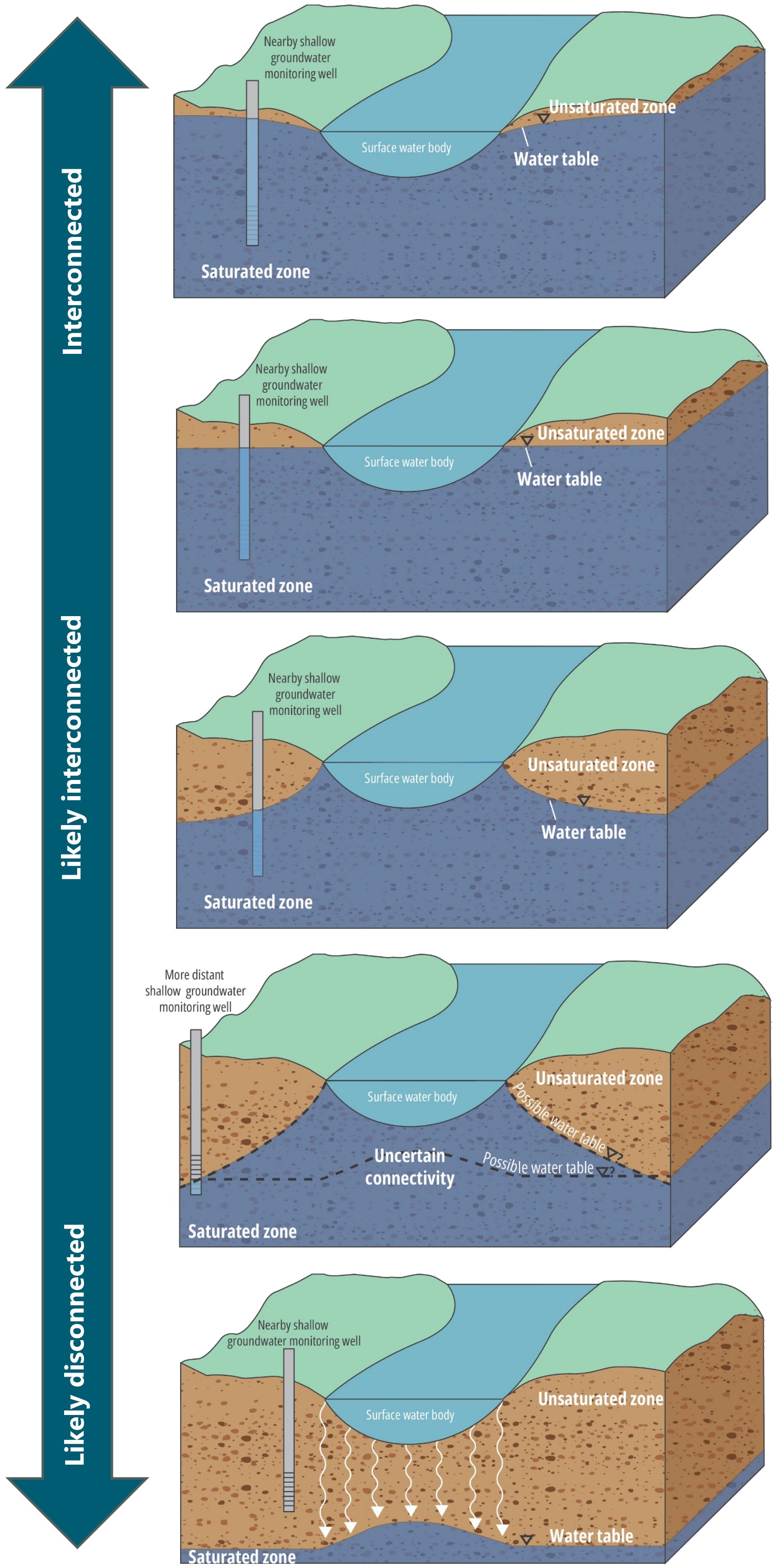


Figure 5a: a stream and a nearby shallow monitoring well with a groundwater elevation above the bottom of the streambed and above the elevation of the surface water, strongly suggesting an ISW.

Figure 5b: a stream and a nearby shallow monitoring well with a groundwater elevation above the bottom of the streambed and similar to the elevation of the surface water, suggesting an ISW.

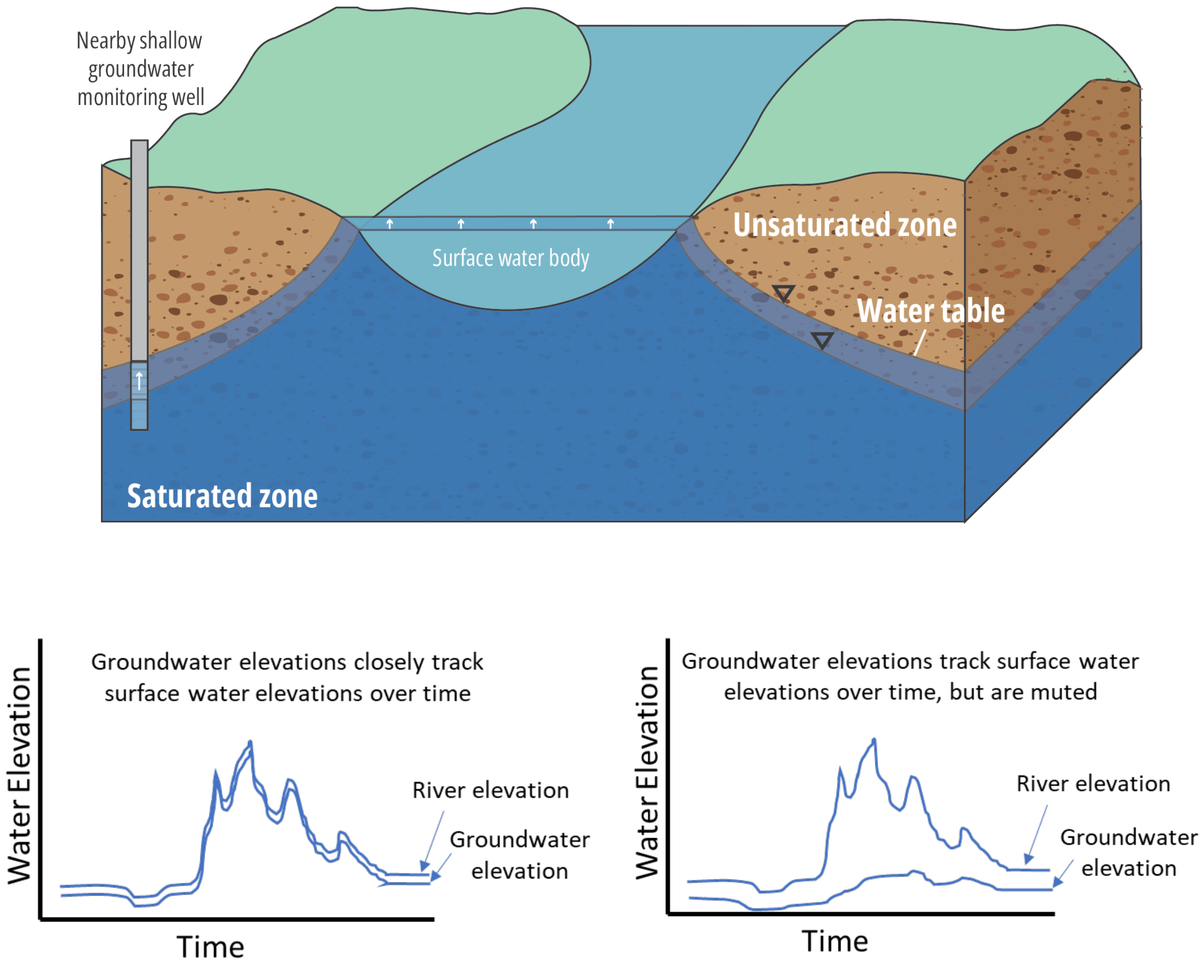
Figure 5c: a stream and a nearby shallow monitoring well with a groundwater elevation similar to the bottom of the streambed, suggesting a likely ISW.

Figure 5d: a stream and a more distant shallow monitoring well with a groundwater elevation below the bottom of the streambed. Without additional data it is difficult to determine if the stream is an ISW.

Figure 5e: a stream and a nearby shallow monitoring well with groundwater elevation substantially below the bottom of the streambed, suggesting a disconnected stream, not an ISW.

2. **Condition 2: Groundwater elevations appear to track stream stage elevations.** Nearby shallow wells that exhibit groundwater elevations that mirror water levels in the adjacent surface water body may indicate a connection at that location (**Figure 6**). It should be noted that the ability to detect the impacts of changes in the magnitude of the ISW on groundwater elevations diminishes with distance from the surface water body and depth below the surface.

Figure 6: Groundwater elevations tracking stream stage elevation are a potential condition of ISW.



River elevation compared to groundwater elevation at a nearby shallow monitoring well. Indicative of an ISW.

River elevation compared to groundwater elevation at a more distant shallow monitoring well. Indicative of an ISW.

In addition to the conditions presented above, other methods are available to help understand the relationship between groundwater and surface water, such as thermal imaging, isotopes, tracers, water quality testing, geophysical surveys, aquifer tests, flow measurements, and groundwater analytical and numerical modeling.

Numerical groundwater models can be a valuable tool to aggregate known information about the surface water and groundwater systems and develop a basin-wide or regional assessment of the location of ISW. The conditions and tools discussed above can be used to develop the model and to assess the accuracy of model-based identification of ISW. Further information on the use of numerical groundwater models to identify ISW is provided in Paper 2 and Paper 3.

Regardless of the approach used to identify ISW, conclusions should be based on the best available science, information, and professional judgment; convey the uncertainty associated with those conclusions; and recommend reasonable approaches to fill identified data gaps.

4 What are Depletions of Interconnected Surface Water?

For this paper, depletions are defined as conditions where groundwater pumping results in reductions in flow or water levels of ISW. This definition is consistent with existing scientific literature, SGMA, and the GSP Regulations.[1] Note that the definition above differs from how depletions may be defined in other hydrologic contexts, where they can refer to any surface water losses without considering the cause.

In natural systems without pumping, groundwater flows toward natural discharge areas such as surface water bodies like rivers or springs. This applies to both shallow and deep groundwater. Shallow groundwater typically follows relatively short flow paths from the source of recharge, through the aquifer, and to the point of discharge. Deep groundwater may follow long flow paths across many years or decades, from recharge areas to discharge areas that may be great distances from where water enters the aquifer system.

Water removed from an aquifer by groundwater pumping alters these natural flow paths. As described by the water cycle, no new water is created when groundwater is pumped. Instead, groundwater pumping alters components of groundwater and surface water flow. Pumping lowers groundwater levels, which results in a reduction in streamflow or volume of water in a surface water body in two ways: (1) a reduction of inflow to an ISW from groundwater or (2) an increase in outflow from an ISW to groundwater. Both cases result in less water in the surface water body caused by pumping. These reductions in surface water volume due to pumping are called depletions.

Depletions occur with any volume or rate of pumping; there is no level of pumping that would not affect ISW. Further, depletions occur regardless of hydrologic conditions or other factors influencing surface water and groundwater. Many basins have complex subsurface conditions, such as confining layers and faulting. Depletions will occur regardless of these features, although they may occur over a longer time horizon or at more distant locations as a result. Such a situation is shown in **Figure 7**, which introduces a confining layer. In this case, pumping from below the confining layer may impact the shallow aquifer slowly over time, with lower groundwater levels in the shallow aquifer eventually depleting the surface water body. Alternately, pumping from below the confining layer may impact more distant areas with lower levels of confinement, ultimately depleting surface water in those areas. While confining layers and other subsurface features may change the location and timing of depletions, the depletions still occur so long as ISWs are present in the basin.

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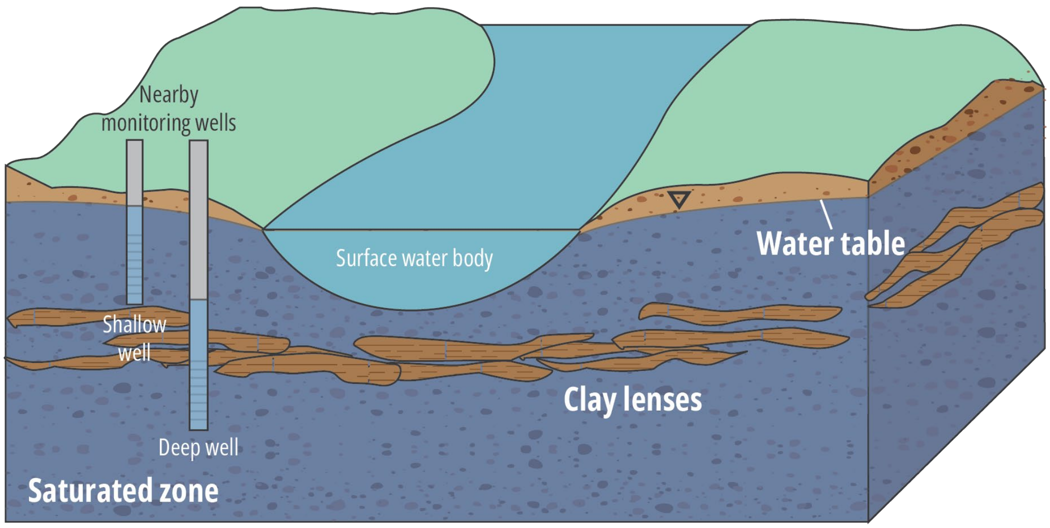
[1] See, e.g., Barlow and Leake (2012), Water Code §10735 (d) and 23 CCR §354.28(c)(6).

Figure 7: Depletions occur due to groundwater pumping from shallow or deep aquifers



This does not, however, mean that groundwater pumping is the only cause of changes in surface water volume. For example, extended drought may cause a decrease in runoff from upper portions of a watershed, thereby reducing streamflow. Increased surface water diversions also reduce streamflow. In such situations, an observer may interpret that surface water is "depleted" (or decreased) in a general sense. However, this reduction in streamflow due to decreased runoff or increased diversion, among others, is beyond the control of groundwater managers and is not caused by groundwater pumping; therefore, such reductions in streamflow are not considered depletions of ISW for the purpose of quantifying impacts of groundwater pumping under SGMA.

Groundwater managers need to understand the depletions caused by basinwide pumping (the subject of this paper and the remaining two papers in the series) and then set sustainable management criteria based on their interpretation of the effects the depletions would cause to the beneficial uses and users of ISW.

5 Understanding and Managing Depletions

Many characteristics of groundwater, such as pumped quantity, groundwater level, or groundwater quality, can be measured directly. Furthermore, some effects of groundwater use, such as land subsidence and seawater intrusion, can be measured directly. However, depletions cannot be measured directly because they represent the difference between surface water flows with groundwater pumping in place, which can be measured, and surface water flows without groundwater pumping in place, which cannot be measured.

Although depletions of ISW cannot be directly measured, groundwater professionals use tools and techniques like groundwater and surface water models to assess depletions. Section 7 below provides several references that offer details on depletions and how they can be quantified, and two subsequent papers in this series discuss these tools and techniques. All methods to assess depletions that are available today require simplifying assumptions. Professionals use the best available information to inform their analysis, but future data and more refined analysis can substantially improve the understanding and estimation of depletions of ISW.

5.1 Understanding Current and Historical Depletions

To describe current and historical groundwater conditions, GSAs should identify the locations of ISW within the basin and estimate the quantity and timing of depletions of those systems. Documenting depletions of ISW is an important part of the overall characterization of groundwater conditions and provides interested parties with information needed to understand and manage groundwater conditions, providing the foundation to develop projects and management actions for sustainable groundwater management.

Specifically, this information is important for basin-scale groundwater management to support:

- An understanding of the overall volume of depletions, allowing for an assessment of impacts on surface water users.
- An understanding of which surface water bodies are being depleted, allowing for comparison with the sensitivity of those locations to reduced flow or volume.
- An understanding of when surface water bodies are being depleted, allowing for a comparison with the sensitivity of those time periods to reduced flow or volume.

It is infeasible to provide details of data and analysis for estimation of depletions of ISW for every time scale and for every location of every surface water body. Thus, water managers need to select spatial and temporal scales appropriate for their basin and the beneficial uses and users that need to be considered. Subsequent papers provide additional information on this issue.

While characterization of current and historical depletions can be presented in several ways, it is recommended that documentation includes:

- Estimates of basinwide depletions from the current period backward in time as far as practical given the tools available for the basin. Papers 2 and 3 will address considerations for preparing this information, but it will generally include graphical (for example, time series plots of monthly depletions) and tabular (for example, annual quantities of depletions) representations. The selected period should be sufficient to show trends and variability of depletions over time.
- Comparisons between basinwide depletions and basinwide pumping.
- Maps or tables showing how depletions are distributed among different portions of surface water bodies (for example, by reach) throughout the basin or subbasin.
- Details on basin- or subbasin-specific concerns, such as additional detail on the timing or location of depletions in specific focus areas.

5.2 Understanding Depletions for Ongoing Management

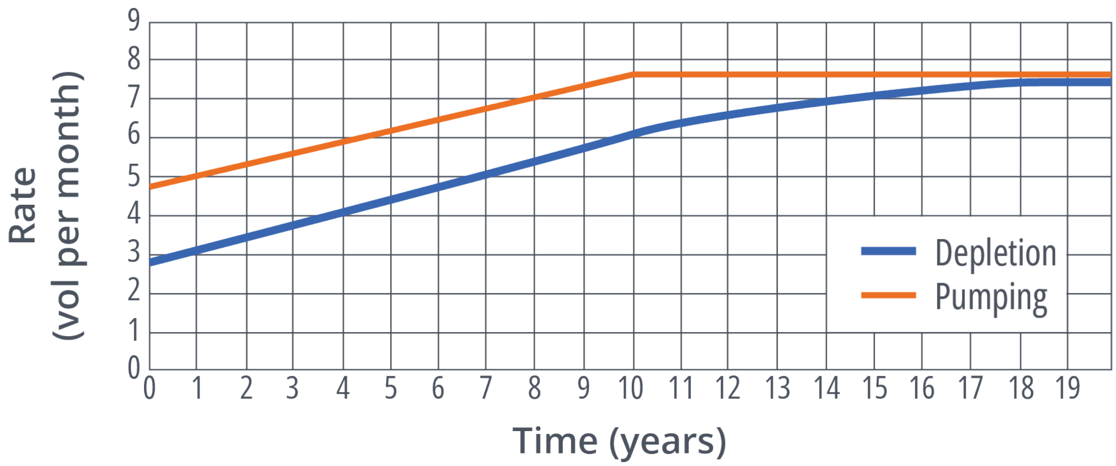
Once current and historical depletions are characterized, groundwater managers can use this information to develop management criteria for depletions and, subsequently, to develop projects and management actions to maintain or achieve sustainability.

Management of depletions is best accomplished through the management of groundwater pumping, as, absent other changes in water use, long-term depletions will be the same as long-term pumping. However, when developing sustainable management criteria and projects and management actions, groundwater managers should consider the delayed nature of depletions and how pumping in different areas of the basin or region results in depletions in different ISWs.

5.2.1 Managing the Delayed Nature of Depletions

Additional analysis beyond the characterization of current and historical depletions is necessary to support groundwater management. Additional analysis is necessary due to the complexity of depletions, notably the time lag between pumping and depletions. It may take years, decades, or centuries after pumping before the full impact of groundwater pumping on depletions is experienced. Thus, while a basin may plan, for example, to cap groundwater pumping to stabilize groundwater levels, depletions may continue until the total volume of depletions is experienced. This concept is shown in **Figure 8**, where basinwide pumping was capped in Year 10, and the rate of depletions was less than the pumping rate. Despite that cap, depletions continued to increase until reaching an equilibrium with the pumping rate some years later. In this case, if basin managers wished to maintain Year 10 levels of depletions into the future, groundwater pumping would need to be lower than what was pumped in Year 10. The nature of the timing of the response to pumping will vary by basin, but some time lag will always be present. Readers unfamiliar with the concept of lagged depletions are referred to two brief articles written by the Nebraska Department of Natural Resources in 2010 for additional introductory explanation (see Section 7 for references).

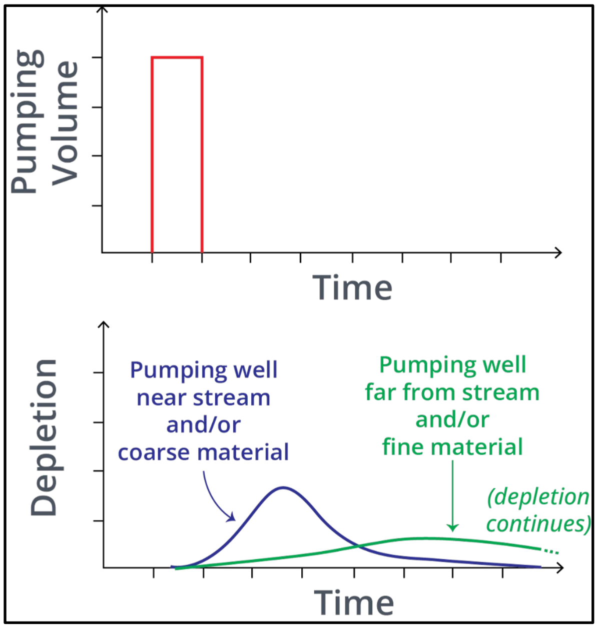
Figure 8: Basin-wide Depletions over Time, Continuing to Increase after Pumping Stabilizes



5.2.2 Considerations for Managing Pumping, Location, and Timing

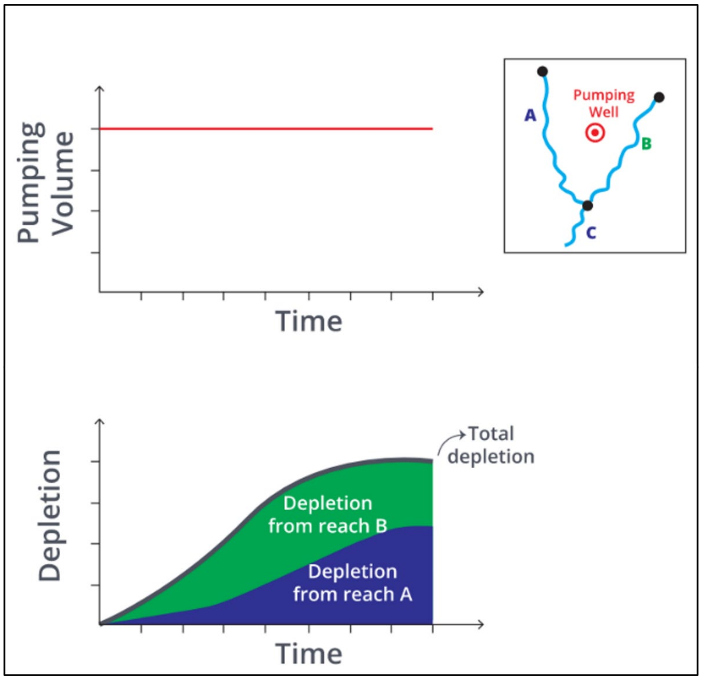
While long-term regional depletions are a function of long-term groundwater pumping, localized impacts can be more specific to the timing of pumping and location of wells, requiring more innovative approaches to develop projects and management actions to support groundwater sustainability in the basin.

Figure 9: Depletions over Time in Response to Pumping Under Different Conditions



GSAs may conduct groundwater modeling studies to understand better the timing of depletions from individual wells or wellfields in areas that may have more sensitivity for environmental conditions. For example, shallow pumping wells located very close to streams with environmental flow requirements and/or needs and connected by coarser subsurface materials typically result in depletions relatively soon after initiation of pumping, with a more focused peak in the rate of depletions estimate, when compared to deeper, more distant pumping wells that are connected to the surface water body by finer materials (**Figure 9**). If the wells pump more in the spring or summer, depletion could have greater impacts on the immediate summer or fall flows, which are typically important to other surface water users. Moving these wells deeper or farther from the environmentally sensitive streams could result in a delay in the depletions and spread the depletions over a longer period, potentially moving some impacts from the summer and fall periods to other times of the year.

Figure 10: Depletions over time in different ISW



Furthermore, wells could be moved to an alternative location to reduce the depletions on certain environmentally sensitive reaches of an ISW, instead impacting other less environmentally sensitive ISW locations. These less sensitive ISWs may not have the same habitat or flow requirements, may not have the same immediate downstream needs, or may be more easily managed through projects and management actions, among other characteristics. The connectivity relationship described previously remains relevant to depletions occurring at multiple streams. Depletions will be higher in relatively close streams connected with the aquifer by relatively more coarse material. Groundwater modeling studies can inform how wells located in different portions of the basin will impact different ISWs (**Figure 10**). GSAs can then develop projects and management actions based on this information to reduce the impacts of depletions, potentially through moving wells, changing well depths, or imposing site-specific restrictions on new or existing wells.

Depletions can also be managed through recharge or other supply augmentation. These efforts can be studied to implement projects that offset basin-wide depletions and offset depletions at key time periods and locations. The effect of pumping on depletions is like that of recharge on depletions, but the opposite. Recharge occurring at the surface near an ISW and connected through coarse material could offset impacts of depletions more quickly and over a shorter period of time than recharge occurring at depth, farther from an ISW, and connected through fine material. Groundwater modeling analysis can be performed to design and implement recharge operations to reduce effects of groundwater pumping on depletions of ISW.

6 Summary

California is crisscrossed by surface water bodies carrying runoff from precipitation, baseflow, agricultural diversions, and tailwater. Many of these surface water bodies are hydraulically connected to regional groundwater aquifers at various locations and over a window of time. These surface water bodies are identified as Interconnected Surface Waters (ISW). Depletion of ISW are defined as reductions in the volume of surface water that are caused by groundwater pumping.

All use of groundwater in basins with ISW has associated depletions that GSAs need to consider for sustainable groundwater management. Depletions of ISW can occur at a wide range of time scales (from days to decades to centuries) and can vary across different segments of a river or different portions of a lake or wetland. Depletions of ISW can occur in non-intuitive ways, such as reductions in streamflow in more distant rivers or from stream segments in neighboring subbasins.

Determining where ISW exists, characterizing the depletions of ISW, and managing depletions of ISW are complex tasks that require considering multiple types of data and robust analysis techniques and tools. This analysis is subject to data gaps and uncertainty, but available tools can provide meaningful results for estimation of depletions of ISW to guide sustainable groundwater management. The tools and overall analysis are based on several fundamental principles:

- Absent other changes in water use, pumping from groundwater basins with ISW will, over time, reduce volumes of surface water bodies by an amount approximately equal to the volume of pumped groundwater.
- Pumping closer to streams and in systems that transmit water relatively easily will cause a higher and more rapid peak in depletions relative to pumping farther from a stream or in an aquifer system that does not as readily transmit water.
- Depletions occurring today are a function of pumping that occurred both very recently and, potentially, decades ago; therefore, future depletions will be affected by both historical and future pumping.

This paper introduced ISW, where it occurs, and what depletions of ISW are. Various techniques can be used to identify ISW and to estimate the quantity, location, and timing of depletions of ISW. The techniques and examples are discussed in two subsequent papers, "*Approaches for Estimating Depletions of Interconnected Surface Water*" and "*Examples of Approaches for Estimating Depletions of Interconnected Surface Water*."

7 Additional Information and Available References

The following references provide additional information on ISW, depletions of ISW and their impacts. We recommend that readers new to, or unfamiliar with, the concepts of ISW and depletions of ISW should also consider reading Barlow and Leake (2012) and the information provided in the Nebraska Department of Natural Resources Water Matters Newsletters (2010).

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California Department of Water Resources
715 P Street
Sacramento, CA 95814

www.water.ca.gov