Guidebook

California Water Course

Science, Policy and Management

by Dr. Samuel Sandoval Solís
Main Collaborator: Dr. Laura E. Garza Diaz
Edited by Dr. Erik Porse, Dr. Sooyeon Yi and Dr. J. Pablo Ortiz Partida

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Course Description

Objective: Provide relevant and applied education of water science, management and water policy to residents, businesses, community water advocates, and entry level professionals in California.

Audience: People working in the water sector (entry level) or people interested in water in California

Minimum requirements: Course enrollees should have basic knowledge of arithmetic and algebra.

Student learning objectives: At the end of the course, the student will be able to

- **identify** the natural and human-made components of their water system and recognize how they are connected
- **evaluate** the current **water management** in their region of interest,
- **distinguish** the **water policies** that apply in their region of interest and
- **critique** and **propose** alternative **water management alternatives** for their region of interest be able to understand the scientific and policy context of Water in California

Length: 40 hours self-guided + 16 to 24 hours in person

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Module 1: Water Systems

What are water systems?

A water system is a **group of natural and human-made elements** in a **basin** that are linked naturally or because of human intervention where the **water cycle** occurs. All water systems have a spatial component, an area where water is collected, diverted, used, treated and disposed. Let's start with the natural boundaries of water systems: **a basin**.

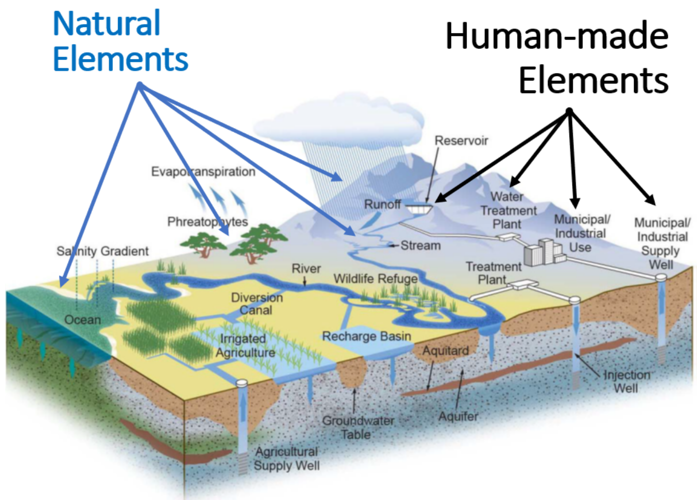
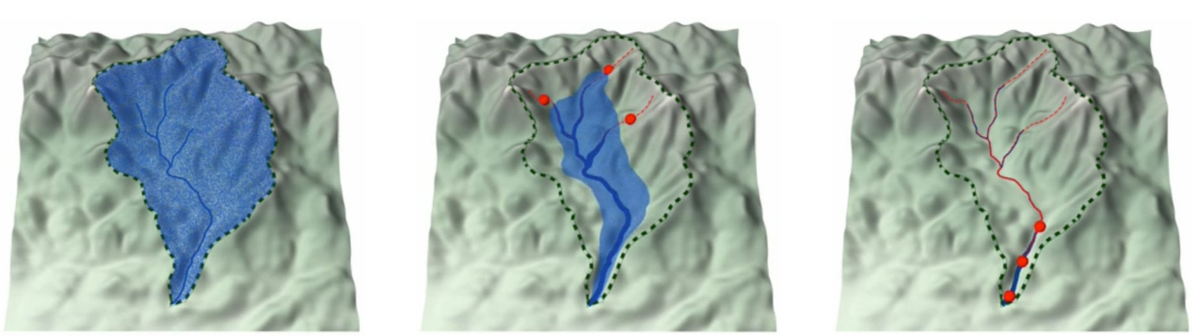


Figure 2-2, DWR (2020). Handbook for Water Budget Development

Figure 1 – Natural and human-made elements in a water system

What is a basin?

A basin is the area where all the rain is drained at a single point, it is the spatial delimitation of the water cycle in the landscape. Rivers in a basin drain into major river systems, a lake, or ocean. **Basin** and **watershed** sometimes are used interchangeably, when referring to the **drainage area of a point along the stream**. The correct term used in hydrology to refer to the drainage area is watershed; however, the term **basin** is more frequently used than watershed, and in this course, we will use those terms as synonyms. A basin includes all surface water (e.g. rivers, lakes, wetlands) and groundwater (aquifers) resources. Think of it as the area of influence of rainfall, meaning that when it rains all the water is collected and exited at a single point.



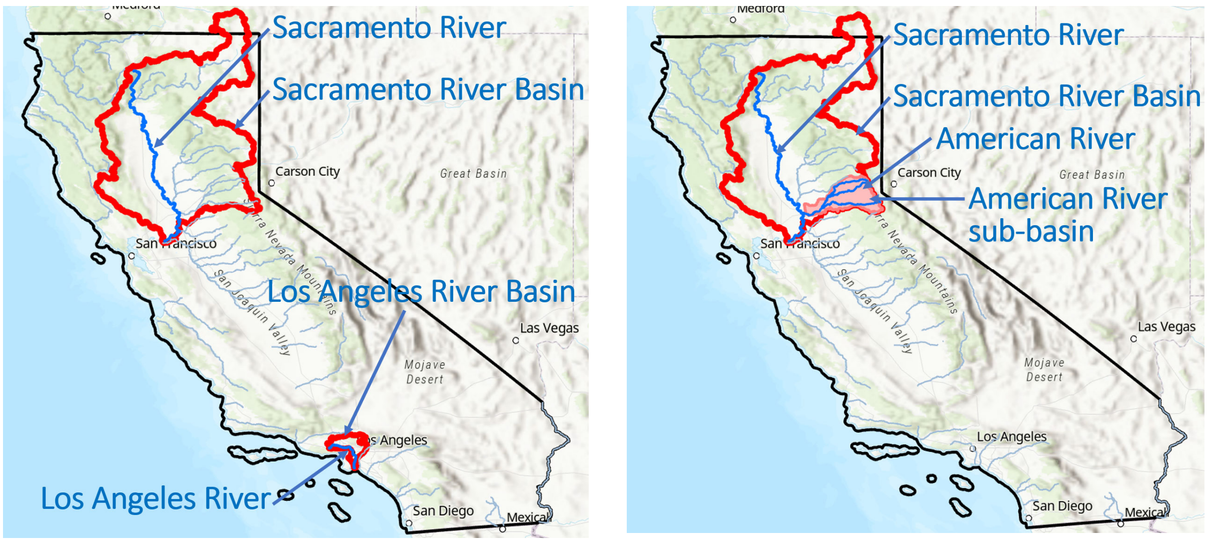
a) Basin under a precipitation event

b) Precipitation is been drained as surface runoff

c) Runoff has reached the outlet of the basin

Figure 2 – Description of runoff in a basin

Basin are named using the main river that drains them (e.g. Sacramento River basin or Los Angeles River Basin). Because the main river is fed by tributaries (i.e. smaller rivers), the drainage area of those tributaries is called sub-basin, for instance, the American River is a tributary of the Sacramento River, and thus the American River sub-basin is part of the Sacramento River basin.



a) Example of two basins: Sacramento River Basin and Los Angeles River Basin

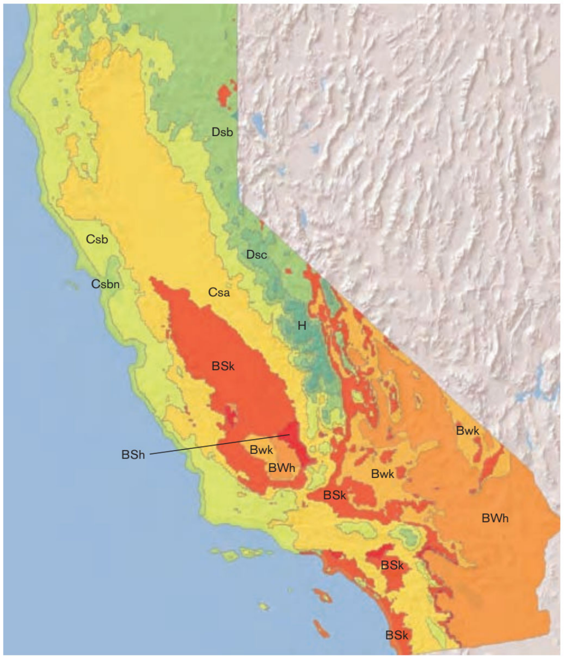
b) Example of sub-basin: the American river is a sub-basin of the Sacramento river basin

Figure 3 – Examples of Basin and Sub-basin

What are the natural elements of a water system?

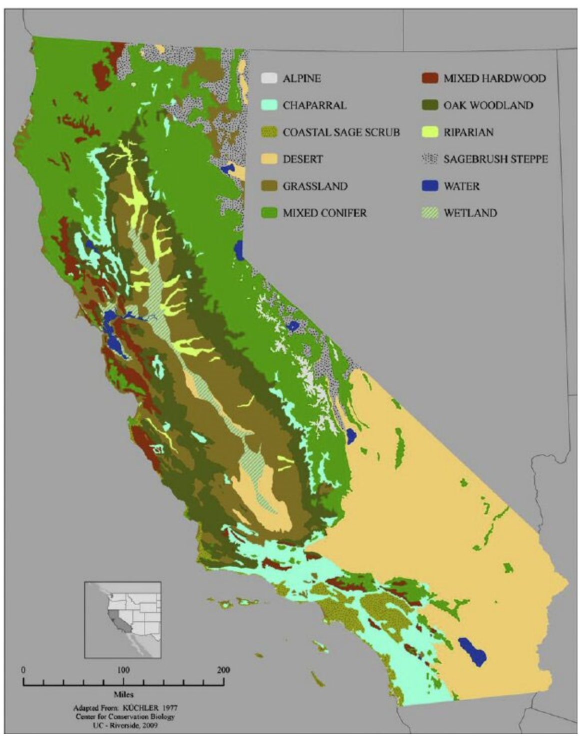
The *natural elements* of a water system are those related with the natural:

- **landscape** (e.g coast, desert, mountain),
- **orography** (e.g. foothills, valleys, range),
- **soils** (e.g. bedrock, alluvial, clay, silt)
- **land cover** (e.g. forest, brushland, native vegetation),
- **climate** (e.g. Mediterranean climate, desert climate, monsoon climate),
- **ecosystems** (e.g. terrestrial, riparian and freshwater ecosystems, some specific "the Mojave desert ecosystem")



Map of Climates in California

Map of more prominent landscapes in California



Map of land cover and vegetation in California

Map of bioregions in California

Figure 4– Natural Elements of a water system

What are the human-made elements of a water system?

<u>Human-made elements</u> are those **human interventions** done to the natural system due to (a) an **economic activity** (e.g. building dams to store water for agriculture or generation of energy; or land use change from forest to agriculture) or (b) **those interventions for human needs** (e.g. drilling a series of wells, treatment plant and drinking water network (a bunch of pipes) to supply water for domestic or municipal use).

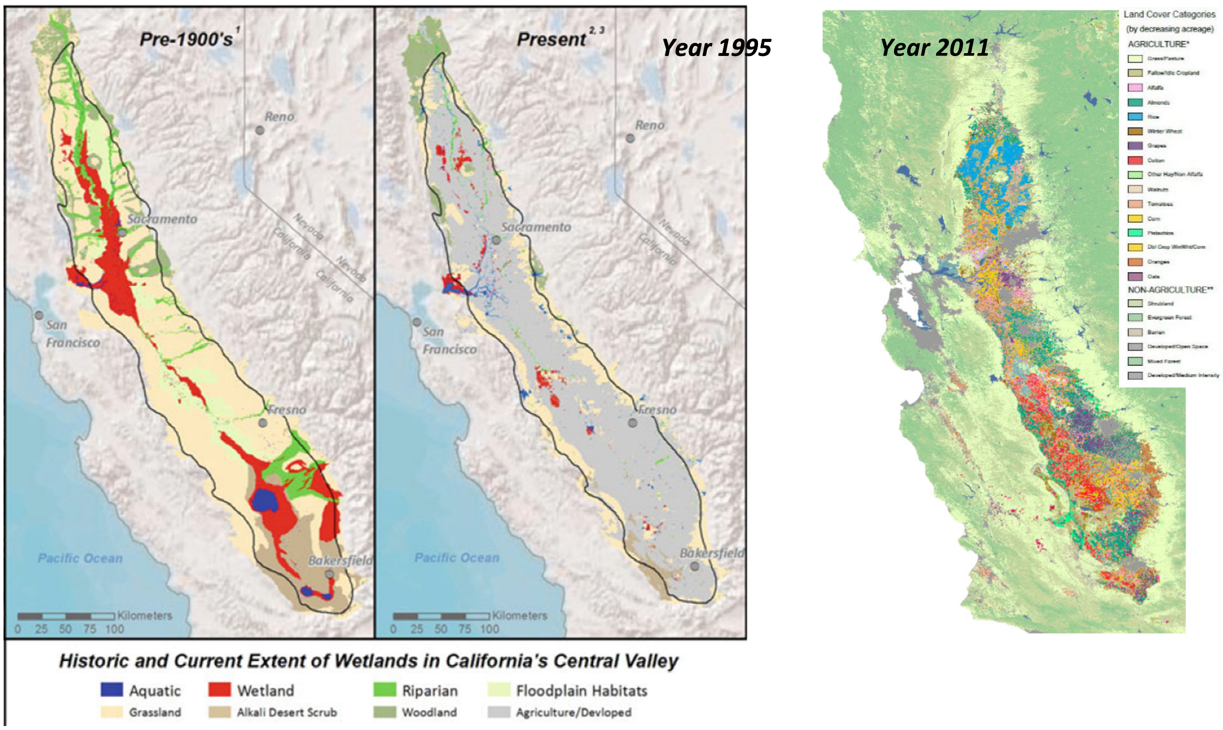


Figure 5 – Land use change in the Central valley over a century

Land use change of California's Central Valley for an economic activity: Agriculture. Figures adapted from Reid et al. 2018 from CSU Chico. Wetlands of California's Central Valley. (Springer Nature) and Land Use from DWR.

Those human-made elements are related with:

1) **water diversions**, e.g. wells that extract water from aquifers, weirs that divert water from rivers, pumps that divert water from rivers, water intakes in lakes or dams that divert water to cities far away.
2) **conveyance facilities**, e.g. aqueducts that move water through long distances, canals that move water from the diversion points to fields, pipes that move water from rivers to houses or drinking water treatment plants,
3) **water storage**, e.g. dams along rivers to store water for later use for cities, ponds to store water for agriculture or for cattle, tanks to store water, water barrels at home to store water, etc.
4) **point of use,** e.g. cities where water is used for homes, industry and commercial buildings; agricultural fields where water is used to grow food, feed for animals or crops for highly processed food. Many of the points of use require a land use change, for example from wetlands to agriculture, or from forest to residential development

5) **water treatment**, e.g. drinking water plants to treat water for safe human consumption, wastewater treatment plants to treat water for its disposal or reuse,
6) **climate infrastructures**, e.g. levees for flood management, floodwalls, coastal barriers and seawalls are built to protect communities from flooding and to withstand the impacts of climate change.
7) **power generation**, e.g. hydroelectric power plants often involve diverting water from rivers or reservoirs to pass through turbines, generating electricity


Water diversion: a well extracting groundwater from an aquifer


Conveyance facility: Delta Mendota Canal (left) and California Aqueduct (right)


Water Storage: Oroville Dam supply water to Southern California cities and farms in the Central Valley


Point of use: use of water in the City of Los Angeles, Exposition Park Rose Garden


Water Treatment: drinking water treatment plant for the cities of Davis and Woodland

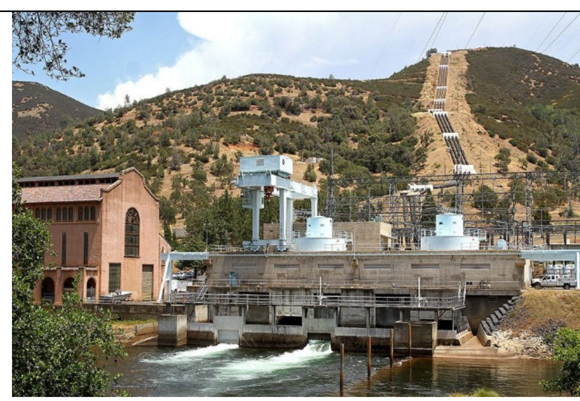

Power generation: Mocasin Hydropower Station, Hetch Hetchy Water System

Figure 6– Examples of human-made elements of a water system

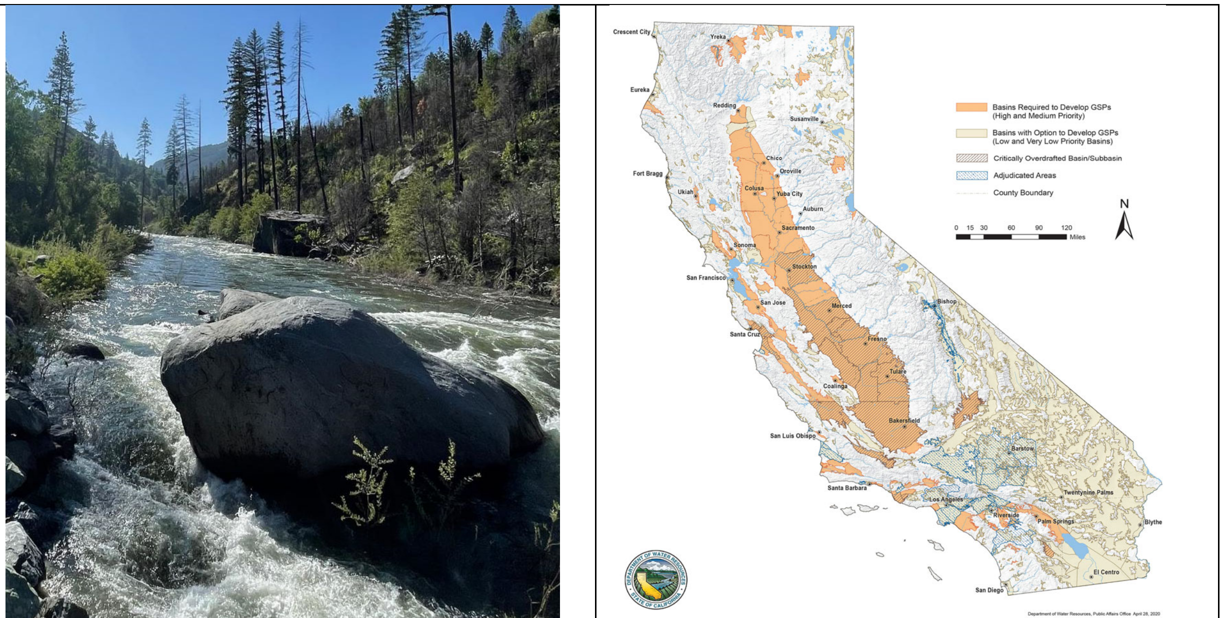
What are key events of the water cycle to remember?

The events of the water systems are rooted in the **water cycle** which is the continuous movement of water in space and time through the atmosphere, earth, and water bodies. Here is how these events that will occur naturally:

- **precipitation** (e.g. snowfall, rainfall, hail, fog, and dew)
- **interception** from vegetation canopy
- **evaporation** the sun heats up water from the soil and from lakes, ponds, etc,
- **Transpiration** from plants, crops, trees, grass.
- **Evapotranspiration** which is the coupled process of evaporation of water from the soil and the transpiration of water from plants. It's used to estimate how much water is used by crops, trees and natural vegetation.
- **runoff** is overland flow reaching rivers, AKA as streamflow
- **infiltration** of water from the surface into the soil
- **percolation** water moving through the soil into the water table, an aquifer, or even to a stream
- **aquifer** recharge and storage
- **storage of water** in the atmosphere (clouds, vapor), in the surface (rivers, lakes, ocean, glaciers, icebergs) and in the ground (soil and aquifers)

a) Precipitation in form of snow

b) Evapotranspiration from crops



c) Runoff

d) Aquifers

Figure 7 – Key events of the water cycle

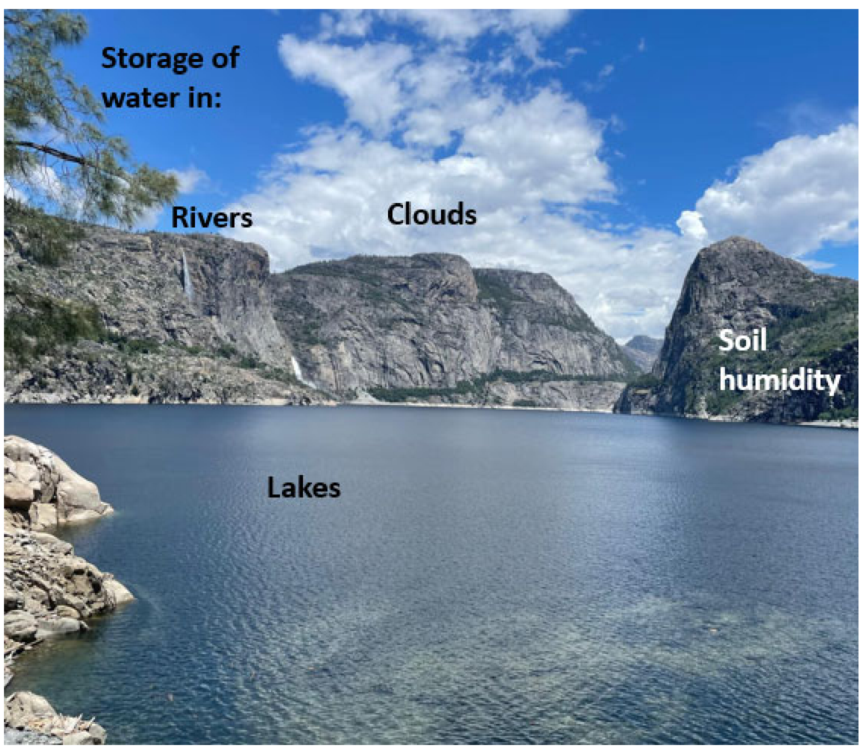


Figure 8 – Storage of water in the landscape. Hetch Hetchy Valley, California

How human activities and climate change are affecting the water cycle?

Regardless if the elements of the water system are natural or artificial, the water cycle will occur. However, recently the accumulation of human activities and climate change have modified these natural processes:

- **Altered precipitation patterns** - Climate change is altering when and how intensely rain and snowfall occur. In certain areas, the rainy season has become shorter, but when it does rain, it's often more intense. (This leads to longer dry spells between rainfall, impacting water availability and potentially leading to drought conditions.)
- **Modified interception** - Deforestation and land use change have decreased the interception of precipitation increasing runoff
- **Increased evaporation and transpiration** - As the temperature of the Earth increases, so does the evaporation from the soil and transpiration from plants.
- **Augmented runoff rates** - Land use changes and erosion lead to higher runoff rates causing risks of flooding.
- **Reduced infiltration and percolation** - Changes in ground such as soil compaction reduces infiltration of water into the ground which eventually disrupts the groundwater movement.
- **Changes in water storage** - the creation of artificial infrastructure in surface water storage such as dams, reservoirs, and canals have modified the flow and form of rivers. And the over extraction of groundwater can sink down the ground.

How many water systems are there?

In general, there are three types of water systems: natural, human-made and mixed. In reality, nearly all water systems are mixed, as us, humans, have exerted a great influence on the landscape, so there are very few places untouched by the human kind. We should definitely feel part of a water system, so we can protect and take charge of it. For the purpose of this course, it is easier to explain these two water systems separate (natural and human-made), so, later we can mix them up and see how they interact. It is like building a lego figure, where some pieces are natural and others are human-made.

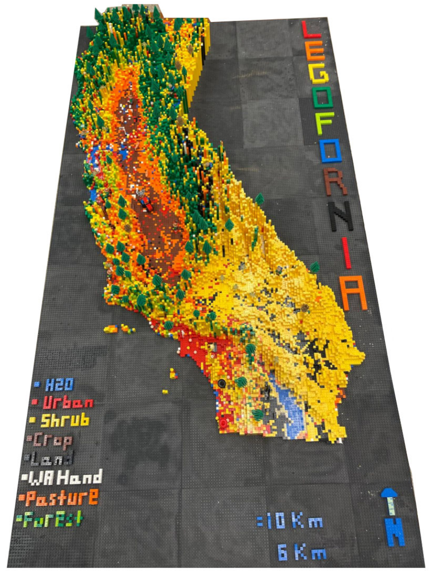


Figure 9 – Elevation model of California using Lego's blocks

How natural water systems work? How water moves naturally in California?

Water moves in different ways, depending on the state that water is (liquid, solid or gas) and the place on earth where is located, within the continent, in the ocean, in the ice caps, etc. For the purpose of this course **we will focus in the movement of surface water and groundwater in the continent**. We will not discuss how water moves in estuaries, the ocean or glaciers, we will focus on movement of freshwater in the continent.

For **surface water**, we have three main classes rivers: (1) snowmelt driven rivers, those occurring mostly in high elevations, (2) rainfall driven rivers, occurring at mid-elevations, and (3) rainfall and aquifer driven rivers in valleys and lowlands, occurring at low-elevations.

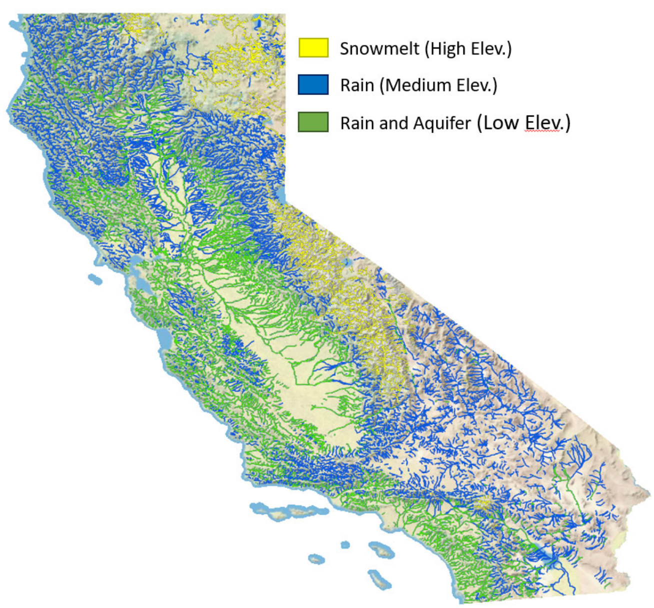


Figure 10 – Natural Streamflow Classification of California

Snowmelt driven rivers (High-elevation).

Typically, these rivers are located in the headwaters (where the rivers starts) and in elevations of 7,500 feet above sea level (2,200 m). They receive precipitation mostly as snowfall during winter, and that snow is stored, or if you will "frozen in time", until the snow is melting when temperatures rise later in spring and summer; or because of the melting of snow due to rainfall. These rivers are called snowmelt driven rivers, and have a specific signature (or flow regime) where the amount of water flowing increases when melting start, and it will keep increasing up to a point to the peak of snowmelt, and then starts decreasing once all the snow has melted, leaving only a small discharge from water that is slowly released from the soil. Typically, these rivers are located where the underlying soil is bedrock, covered by a layer of 2 to 10 feet of soil. Water in these river may end up stored in the soil, evaporated by the vegetation, or exited as runoff, that's why they are called "rainfall-runoff rivers". These rivers are at the mercy of climate, if there is a good winter with plenty of snowfall, then there will be a good amount of water coming from these rivers; but if not, then the ecosystems, people and industries that depend on them will be at risk. In addition, snowmelt-driven rivers are in danger of extinction because of climate change, as temperature rises, we are receiving more precipitation in terms of rain and less as snow, not only changing drastically their flow signature (flow regime) but also losing the storage of water in form of snow to be used later in the season.

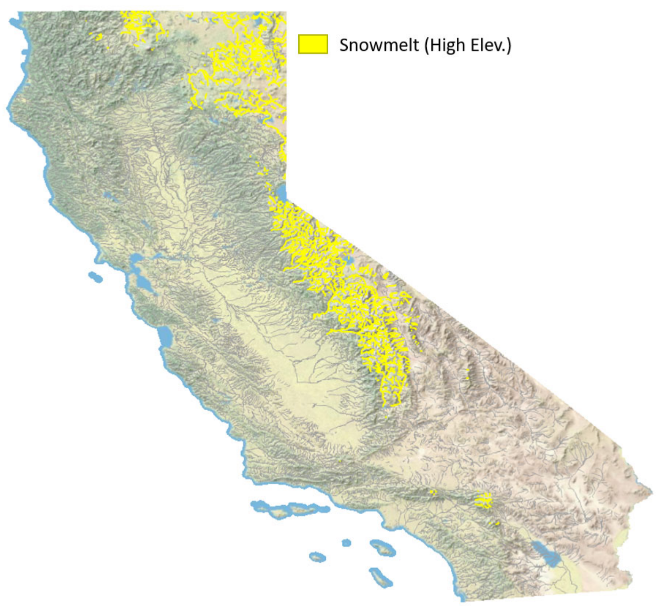


Figure 11 – Snowmelt-driven rivers in California

Rainfall driven rivers (Mid-elevation).

Typically, these rivers are fed by snowmelt rivers upstream of them, or their headwaters are located in elevations between 7,500 and 3,500 feet above sea level (2,200 to 1,000 m). They receive precipitation mostly as rain during winter, and that rain is stored in the soil, evaporated by the vegetation, or exited as runoff, they are also called "rainfall-runoff rivers". These are temperamental rivers that can increase their discharge when rain or an atmospheric river occurs and their flow can decrease rapidly as the rain is gone, leaving only a small discharge from water that is slowly released from the soil. Also, rainfall-driven rivers are located where the underlying soil is bedrock, covered by a layer of 2 to 10 feet of soil in the mountains and foothills. Rainfall-driven rivers are becoming more dangerous because of the increased in precipitation intensity due to climate change. If precipitation occurs with higher intensity, the flow in rivers can increase rapidly creating flash floods, increasing risk of flooding and erosion, affecting the habitat of freshwater ecosystem and people living close to river that can experience flooding. There are two types of rainfall driven rivers: (a) perennial, meaning hat they have an all year around flow "perennial flow", and (b) ephemeral, meaning they have flow during a certain period of time.

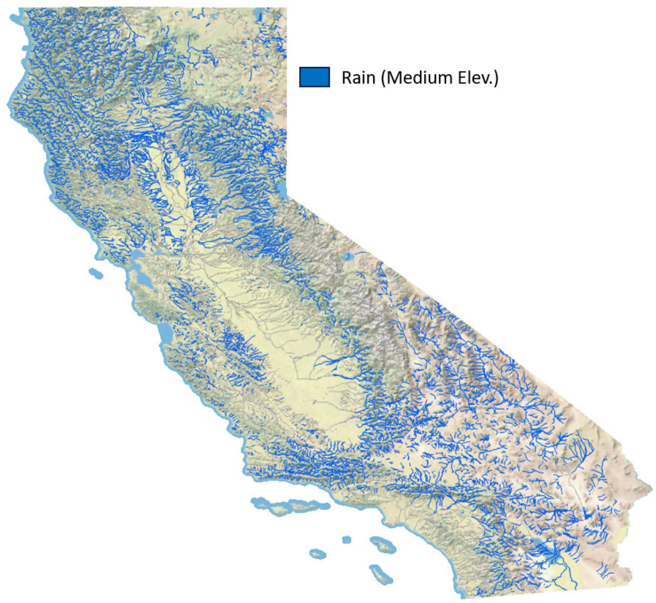


Figure 12 – Rainfall-driven rivers in California

Rainfall and aquifer driven rivers in valleys and lowlands (Low-elevation)

They are located in valleys throughout the state of California (Central Valley, Salinas Valley, Los Angeles Valley, San Fernando Valley, Owens Valley, Santa Maria Valley, Paso Robles, Imperial and Coachella Valley, Ukiah Valley, Alexander Valley, Napa Valley, Sonoma Valley, and so on). Typically, they are located in elevations below 3,500 feet above sea level (1,000 m). The main characteristic of these rivers is that the underlaying layer is not bedrock, but a series of deep sediment layers that can store water within their porous, called aquifers. They receive precipitation mostly as rain and fog during winter and that water is stored in the soil filling it, and then passes through the soil to recharge the aquifer underneath, filling it. They also receive water from snowmelt and rainfall-driven rivers upstream of them. Later in the year, during spring and summer, the aquifer discharges its water into these rivers maintaining them with a permanent (perennial) flow. Because of all of these interaction, they are also called "rainfall-aquifer-runoff rivers". These rivers are at the mercy of climate change and human mismanagement. If there is a drought or rivers upstream did not receive a good year of precipitation because of climate change, then there will be a small amount of water flowing through them. If humans over-exploit the amount of water taken from the underlaying aquifers, then we can lose the aquifer river connection and the river may run dry, affecting the freshwater ecosystem and people living that depend on them.

Figure 13 – Rivers located in Valleys throughout California

Groundwater movement underneath the valleys.

There are three main definitions to know first, groundwater which is water in the ground, second, aquifer which is the container that stores groundwater, and third, water-table which is the elevation of groundwater in the soil, we measure this elevation with using a “piezometer”. We will focus on groundwater stored in aquifers underneath the valleys, there are comprehensive maps of aquifer location throughout California. The first rule is that groundwater fallows gravity, it will try to move downwards. However, as it is moving downwards it is an obstacle race because water is moving around all the soil particles that are in their way, thought the “porous space”. Once groundwater reaches the aquifer, it will increase the water table of the aquifer, it will increase the level of the groundwater. However, precipitation does not fall even throughout the valleys, thus, in some places more precipitation will fall and increase the water table on those places, and in other places, there may not be any rain and thus not increasing the water table. Similarly, if a well is turned on and groundwater is extracted, it will leave a depression or lower elevation of the water table, and groundwater from the surrounding are will move towards that place to fill it up. Thus, groundwater can also move laterally trying to level itself, meaning to have the same water table elevation throughout the aquifer. When the water table in an aquifer is at higher elevation than the water level in a river then the aquifer will discharge into the river, and when the water table of an aquifer is at lower elevation than the water level of the river the opposite occurs, water from the river recharges the aquifer.

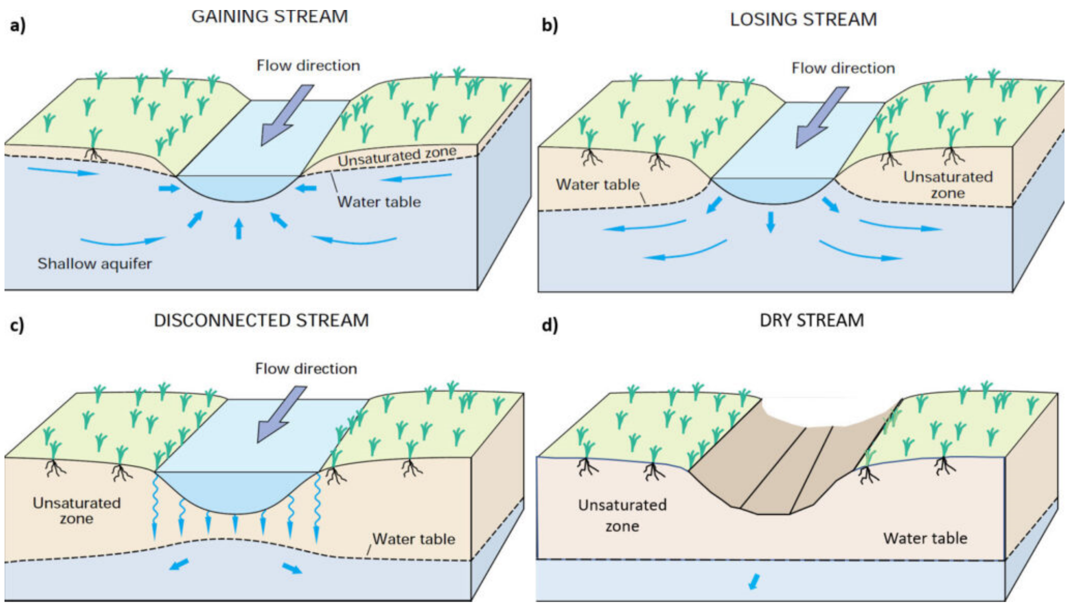


Figure 14 – River and Aquifer interactions

How human-made water systems work?

Urban (and industrial) systems

Drinking water supply systems consist of a water diversion or intake (for example, an intake in a dam, a pump extracting water from a river or an aquifer), then a conveyance facility to a drinking water treatment plant, after that another conveyance facility to move the water into the water supply network to bring the water to all houses. Then, water is used, roughly, half of it is used indoors and the other half outdoors, then there is a grey water sewer system to collect water, a waste water treatment plant and their discharge either into another water body (rivers, aquifers, or the ocean) or to another facility for its reuse (purple pipes that reuse the treated water). Now, not all the drinking water supply systems are the same.

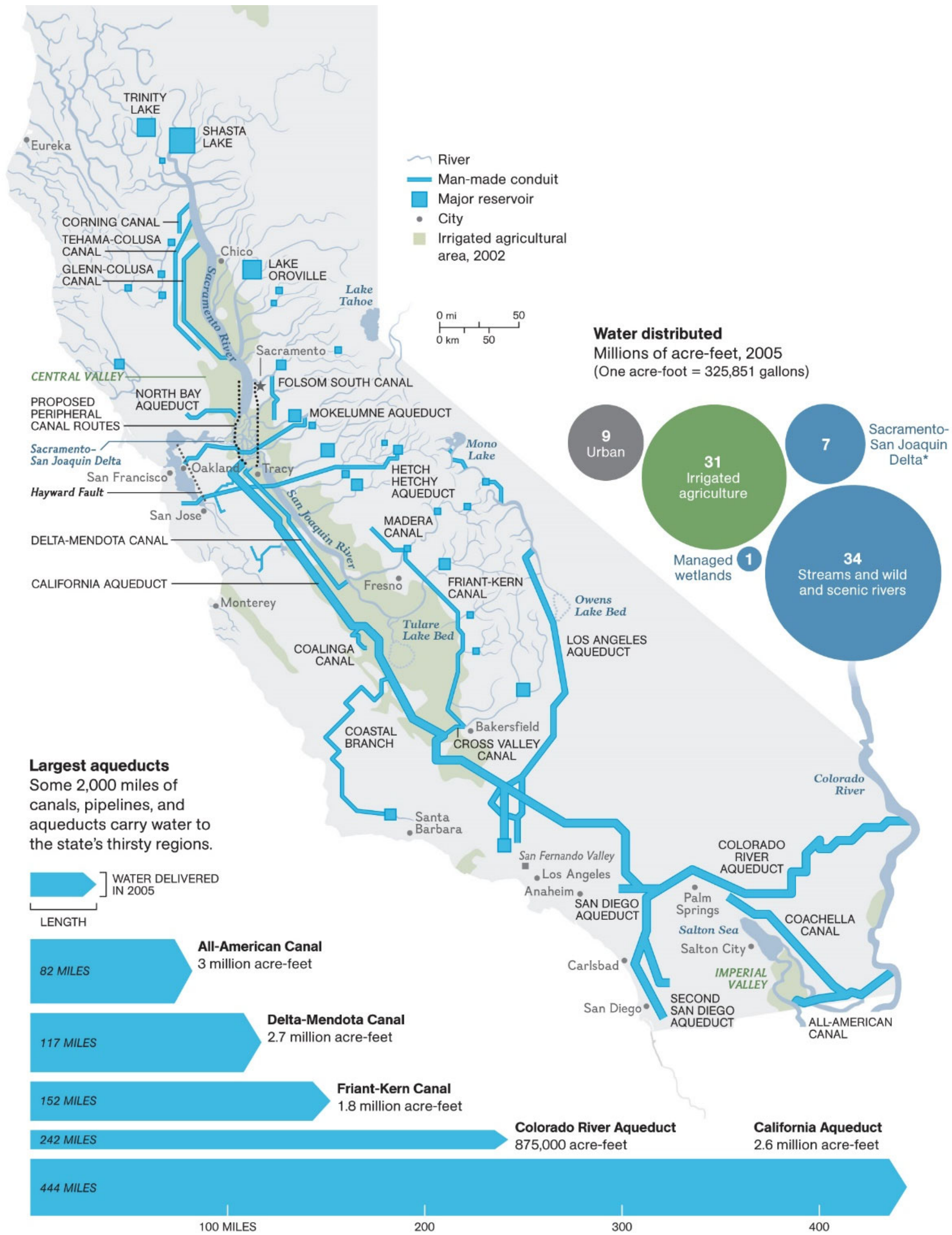


Figure 15 – California Large Water Infrastructure Schematic. Source: National Geographic.

- **For Large cities**, typically they exhaust all the local water resources in the early 1900 and looked for water resources far away, since then they have been importing water. This is the case of Los Angeles, San Francisco, the Bay Area, San Diego, Marin, Santa Barbara and San Luis Obispo counties, just to mention a few. Now, not because everyone did it, it means it was ok to do it, this strategy of importing water dispossessed water resources to the communities from which water is imported, including indigenous and rural communities. Think of this, "would you like that a city far away from where you lived come and take the water available in your surroundings?" If your answer is no, then this same answer and feeling of the people from where water is been exported. Also, agencies importing water have an important challenge to treat the large amount of waste water for its adequate discharge to other users downstream and the environment.

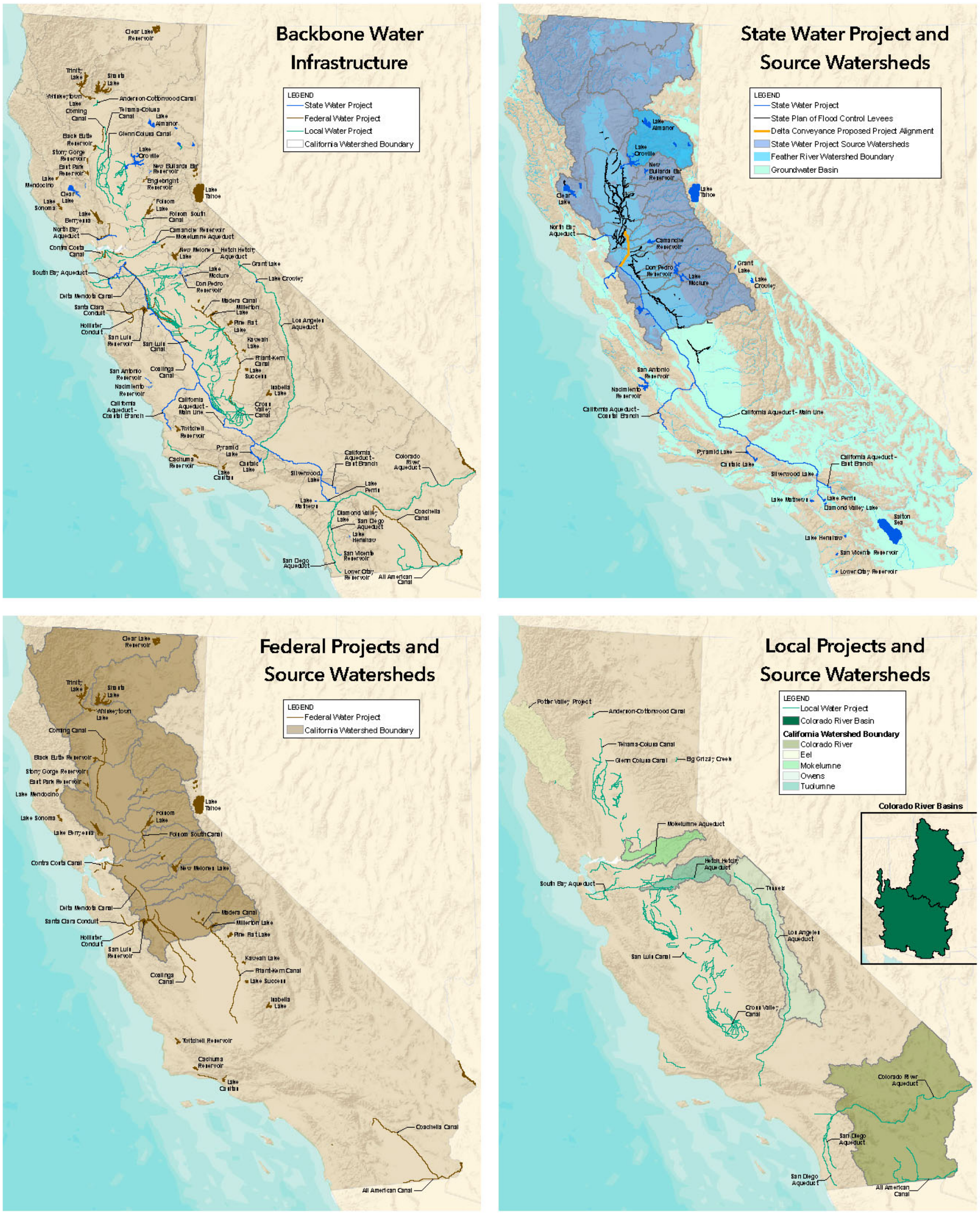


Figure 16 – Map of large water infrastructure systems in California (Source: [Water Plan Update 2023](#))

- **For rural cities**, typically rely in local water resources, such as rivers or aquifers. They have a problem of collecting enough funds to keep a drinking water supply and waste water treatment system up to date for the need of their community at an affordable price.
- **For individual houses and small communities**, typically they rely on domestic wells for their water supply. These systems have several issues. First, in terms of water quantity, they are competing with other nearby wells that may use a lot more water, let say wells for irrigating a walnut, almond or pistachio orchard. In fact, during droughts, thousands of domestic well have gone dry because of this competition with other water users. Second, in terms of water quality, they may be extracting water that is naturally contaminated (e.g. arsenic) or man-made contaminated (e.g. nitrogen coming for synthetic fertilizers or pesticides), and they may not have the resources to treat that water or to keep up with the maintenance for the treatment. Finally, the majority of the people or communities relying on domestic wells are disadvantaged communities (i.e. low income families) that struggle with economic resources.

Agricultural systems

Agricultural water supply systems consist of a water storage system (reservoirs, aquifers, the snow), a water diversion (for example, a weir that diverts water into canals or a series of wells), then a conveyance facility that typically are canals, a turnout (a large valve) that diverts water from the canals into the agricultural fields, then an irrigation systems, that can be from furrows, all the way to a drip system or moving sprinklers, then a drainage system for the excess water, and finally a discharge into another water body (rivers, aquifers, or the ocean). Similarly, not all the agricultural water supply systems are the same:

- **Conventional agricultural systems**, that considers water only as one part of the inputs for food production and economic profit, typically these systems bring water from far away (reservoirs, canals), do not rely or account for rain in their irrigation calculations, use synthetic fertilizers for soil nutrition, use chemical pesticides for getting rid of pests because they plant a monoculture, they do not use cover crops and use as practice bare soil for their practices. In summary, this type of agriculture creates a man-made ecosystem with the philosophy that it is possible to control nature, rather than working with nature in a respectful and responsible way.
- **Sustainable agricultural systems (organic, sustainable, and biodynamic food products)** , these are part of the regenerative agriculture movement that considers the agriculture as an activity positive to the environment with water, soils, sun and air as key elements for food production and environmental protection. Typically, these systems collect water locally (in the soil), use water from the rain and fog as part of their water inputs, use cover crops, manure and compost for soil nutrition, integrated pest management, mechanical, and biological controls for managing pests, they use cover crops for soil health and for water infiltration in soils and aquifers, just to mention a few. This type of agriculture integrates agricultural practices with the local ecosystem with the philosophy that we are part of nature, respecting and taking care of it.

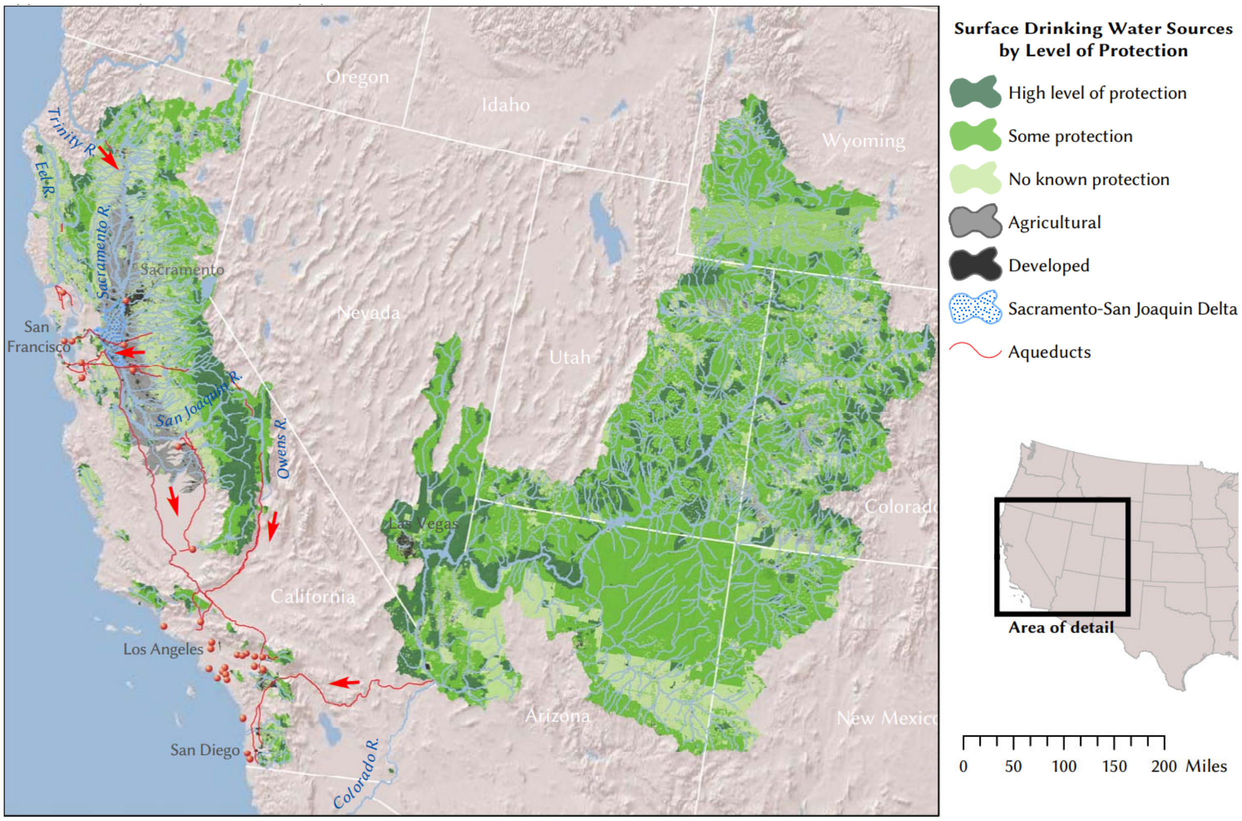


Figure 17 – Surface drinking water sources for California (Source: The Nature Conservancy 2012)

Hydropower

Hydropower systems were built with the purpose to generate electricity, they consist of an intake, a conveyance system to the turbines, the turbines to generate electricity, and a conveyance system for the discharge. There are two main types of hydropower systems: (1) those with a reservoir to store and regulate water and head for electricity production, these plants may produce electricity permanently throughout the year, and (2) those without storage that use a portion of the flow in the river to produce electricity, these plants, called runoff the river, they may produce intermittent electricity throughout the year. The main issue with hydropower plants are: (1) they are located at the entrance of the headwaters and thus blocking the access to high quality habitat for migratory fish, (2) they alter the flow regime, they produce electricity for the peak time of electric consumption in the morning and afternoon (called hydro-peaking) thus, altering the flow drastically within a day, a condition that species are not used to, and (3) they alter the sediment transport regime, they withhold sediment behind the dam and the rivers below does not have any sediment making then unsuitable for good habitat. In many cases, hydropower dams were built to raise funds for irrigation districts and agricultural projects that were not economically feasible (for the production of certain low value crops, such as alfalfa), thus, they were built to subsidize agricultural projects. Now that those projects have been re-paid, and that the society is paying for the environmental restoration of rivers, it comes into question "why should we keep those dams?” There are many of those dams that are been decommissioned and demolished, such as iron gate in the Klamath River.

Flood protection

Flood protection systems were built with the purpose to protect cities/towns and economic activities (industrial plants, agriculture, etc.) from the impact of rare but devastating flood events. They consist of storage and controlled flow release infrastructure (dams that have flood control storage and spillways, detention ponds, etc.), conveyance infrastructure (canals, rivers, bypasses, culverts, pipes, etc.), and containment infrastructure (such as levees, floodwalls, etc.).

The main issue with flood protection infrastructure is: (1) this infrastructure was designed for a quick drainage of flood event in canals and rivers, frequently increasing discharge and with this, greater sediment erosion, and more danger to communities that live along the river corridor, (2) this water can’t be utilized for other purposes; because flood water pass fast in the system, this water can’t be captured as it occurred naturally, reaching floodplains and infiltrating water into the aquifers, (3) a false sense of security, many communities (low income, communities of color) are built close/behind levees or downstream of reservoir with a fault sense of security. Flood plains are now used for agricultural production, these create a fault sense of security and while flood are rare events, once they happened they create enormous damage. All this infrastructure was designed with last century climate and hydrologic records that at this point are outdated considering a changing climate. Climate change is stressing these systems with more intense precipitation, in infrastructure that have lacked maintenance.

What are key Water quality parameters to be aware off?

For practical purpose, we will divide water quality parameters for drinking water and freshwater ecosystem health.

Drinking Water Quality

For drinking water we have drinking water standards that are monitored using the maximum contaminant levels (MCLs) to meet public health goals (PHGs) (comparison with EPA federal MCLs)

- Primary MCLs: Inorganic Chemicals (Arsenic, Chromium, Nitrate, Cyanide, Fluoride, Mercury, Nickel, etc.), Cooper and Lead, Radiological and Radionuclides (Radium, Uranium), Volatile Organic Chemicals “VOCS” (products derived from oil and gas such as Benzene, Ethylbenzene, Toluene, etc.), Non-Volatile Synthetic Organic Chemicals “SOCs” (Pesticides, such as Atrazine, Glyphosate, 1-2-3 TCP - Trichloropropane), Disinfection byproducts (Bromate, Chlorite), Micro-biological contaminants (Total Coliforms rule, E. Coli)
- Secondary MCLs: They are set are set on the basis of aesthetic concerns: Color, Odor, Turbidity, Total Dissolved Solids, Chloride, salts,
- Unregulated contaminants for which there are health-based advisory levels, that when exceeding those levels, it prompts certain requirements and recommendations. For instance: 1,4-dioxane (stabilizer for solvents that are carcinogenic), hexavalent chromium (heavy metal that has been used in industrial applications and found naturally occurring, MCL 2011: (0.02

μg/L)), nitrosamines (rocket fuels), microplastics, and "PFAS" or Forever chemicals (Perfluorooctanoic acid (PFOA) and Perfluorooctanesulfonic acid (PFOS))

Environmental Water Quality

- Temperature
- DO – Dissolved Oxygen, which is the oxygen available in the water column, the presence of a sufficient concentration of dissolved oxygen is critical to maintaining the aquatic life and aesthetic quality of streams and lakes
- BOD – Biochemical Oxygen Demand, which is represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic (oxygen is present) conditions at a specified temperature.
- Total Suspended Solid (TSS) are particles that are larger than 2 microns found in the water. Most suspended solids are made up of inorganic materials, though bacteria and algae can also contribute to the total solid concentration.
- Total Dissolved Solids (TDS) are all particles that are smaller than 2 microns found in the water (mg/liter,) combine the sum of all ion particles as well as other compounds such as dissolved organic matter. Depending on the ionic properties, excessive total dissolved solids can produce toxic effects on fish and fish eggs.
- Turbidity – nephelometric turbidity units (NTUs) – it measure of relative clarity of water.
- PH – measures the acidity of water
- Salinity –is the total concentration of all dissolved salts in water (chloride, sodium, magnesium, sulfate, calcium, potassium, bicarbonate and bromine) measured in Electrical Conductivity

Website: https://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/#Turbid4

What is a key principle that all water systems follow?

Any water systems follow a very basic principle: there is a water source (Inflows), water may (or may not) be stored in the water system (storage) and water leave the water system (outflows). Think of a small piggy bank (cash box), where you are putting money in, storing money there, and taking money away. At any moment on time we can estimate how much money is saved, in other words, calculate a bank statement. In our case we can do a water balance, where we estimate how much water come into the water system (inflows), how much water was used (outflows) and how much water was stored for a given period of time, this is a very useful principle to know.