Groundwater Basin Evaluation
A Primer
With an Eye Toward Sustainable Perennial Yield

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Executive Summary

The California Sustainable Groundwater Management Act (SGMA) was signed into law in September 2014. After years of drought and declining water levels statewide, and the corresponding negative effects that go along with it, SGMA was enacted to allow local and regional agencies to develop and implement sustainable groundwater plans (GSPs) with the State as the backstop, should it prove necessary, to adopt an interim groundwater management plan.

Groundwater Management Plans are not written overnight. A good, well thought out plan will incorporate a great deal of information which is both current and which has been collected over time. Before any type of planning can occur in a groundwater basin, the basin itself must be evaluated and well understood.

Groundwater basin evaluations will be the cornerstone of SGMA. As GSPs begin to develop around the State, it is inevitable that certain basins will lack sufficient data to actually develop a plan and studies may have to be undertaken to better evaluate and understand the basin.

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Part 1.0 Introduction

The Sustainable Groundwater Management Act of 2014 (SGMA) is a game changer. After years of severe to exceptional drought the California Legislature passed SGMA, prior to which groundwater use in California was largely unregulated except for adjudicated basins and certain special act districts. Left to individual pumpers and pumping organizations, the unregulated use of groundwater led to the drastic lowering of water tables, dried up domestic wells, and in some cases land subsidence (DWR, 1980).

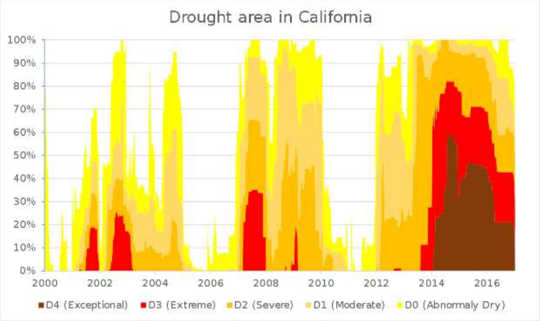


Diagram showing drought cycles in California over time.
Source: U.S. Drought Monitor

The purpose of SGMA is to address these and other impacts in order to provide long-term protection of groundwater resources. The road is not easy. SGMA applies to alluvial basins, outlined in *California's Groundwater* (California Department of Water Resources Bulletin 118, updated in 2003), which have been assigned a medium or high priority based on the California Statewide Groundwater Elevation Monitoring (CASGEM) program. This law establishes a new structure for managing groundwater resources at the local level by local agencies and stakeholders. In order to comply with SGMA, local agencies and stakeholders were required to form local Groundwater Sustainability Agencies (GSAs) by mid-2016. Now these GSAs must prepare Groundwater Sustainability Plans (GSPs by January of 2020 for high priority basins and January 2022 for medium priority basins.

Conducting a pumping test at an Industrial Park to determine the well's extraction rate.

Understanding a groundwater basin is the key to managing it. The basic components include:

- Geologic and hydrogeologic knowledge of the basin's dimensions (basin boundaries),
- Determination of groundwater flow within the basin and across the boundaries (basin inflow and outflow),
- Groundwater extraction,
- Groundwater recharge and recharge areas,
- The evaluation of groundwater/surface water interactions, and,
- Groundwater quality, both naturally occurring and anthropogenic, throughout the basin.

When a basin is well understood, it is then possible to estimate the safe, sustainable yield of the basin, also known as maximum perennial yield. This is generally defined as the maximum quantity of water that can be withdrawn annually from a basin without causing an undesirable result. Undesirable results can vary depending on the basin. SGMA describes six specific undesirable results the law is designed to mitigate:

- Chronic lowering of groundwater levels,

- Seawater intrusion,
- Degraded groundwater quality and plume migration,
- Depletions of interconnected surface water,
- Land subsidence, and
- Reduction of groundwater storage.

Part 2.0 Overview of the Basin Evaluation Process

At a minimum, the basin study area is described in terms of its physical location, topography, geology and hydrogeology, general climate, precipitation, and vegetation and seasonal temperature ranges. Additional information desired includes well locations and well construction details (if available), and current and historical water production. Existing local basin geologic and hydrogeologic studies should be reviewed and incorporated. The GSP will require accurate geologic maps and cross sections, well location maps, and groundwater contour maps be developed from available current and historical data. Much of this task involves information collection and review.

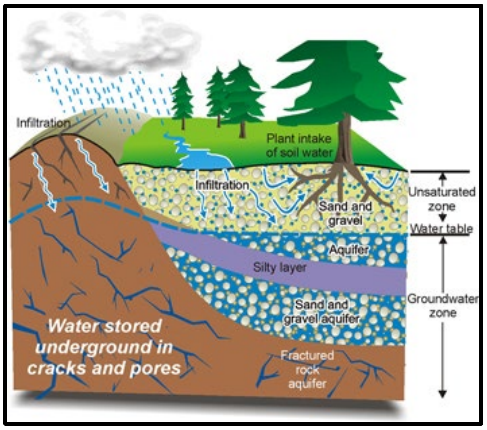
2.1 Basin Description

The basin of interest should be generally described in terms of its location and boundaries (if known). The Department of Water Resources (DWR), Bulletin 118, Chapter 7, October 2003 has identified and delineated 431 groundwater basins underlying about 40% of the State's surface area. Of those, 24 basins are subdivided into a total of 108 subbasins, giving a total of 515 distinct groundwater systems. However, with detailed studies, basin boundaries are subject to change and the SGMA process allows for basin boundary changes.

2.2 Geology

An understanding of the regional geologic setting should be obtained. This includes sediment types and formation names, the bedrock complex, structural features such as faults, and other features that are important to an understanding of the basin, its flow regime, and its ability to store groundwater. Published geologic maps and cross-sections are widely available and more detailed mapping studies may be found at local water district offices and university libraries.

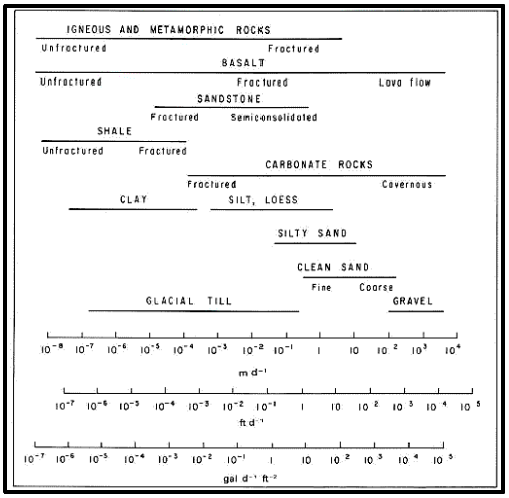
In many parts of the country, groundwater is produced from fractured bedrock and there are little to no alluvial sediments. In San Diego County, CA there are thirty-six water districts, many of whom overlie fractured, granitic bedrock. Flow regimes in these areas are restricted to openings in the rock (fractures) and an experienced hydrogeologist will want to perform a fracture trace analysis.



Generic Cross Section of Aquifer System
Source: Alberta Water Portal, 2013

2.3 Hydrogeology

Groundwater management is first about having an excellent understanding of the basin hydrologic regime. This analysis should incorporate both surface water as well as groundwater. Precipitation and runoff data should be obtained and reviewed, and the groundwater recharge and discharge zones should be delineated as well as the base of fresh water bearing formations. Groundwater recharge can occur from infiltration or subsurface inflow, or both. Protecting natural recharge locations is one of the most cost effective means of achieving long-term groundwater recharge to groundwater basins.



Estimates of hydraulic conductivity have been developed for several consolidated and unconsolidated materials (Heath, 1983).

Many basins have more than one aquifer system. For instance the Los Angeles Basin contains at least six aquifer systems contained within about 600 feet of the San Pedro and Lakewood Formations. These aquifers are both confined and semi-confined. In addition, the basin has aerially dispersed unconfined aquifer systems that are generally shallow in nature and of poor water quality (DWR Bulletin 104, 1961). On a general level groundwater flows from regional areas of recharge to regional areas of discharge. Pumping information from the basin is also required because pumping depressions can develop around well fields which alters the natural flow regime. The characterization of the occurrence and flow of the groundwater system(s) leads to a fundamental understanding of the basin overall.

Pumping test data and aquifer coefficient information (transmissivity (T) and hydraulic conductivity (K) is extremely useful to obtain in order to evaluate groundwater flow. Analysis of aquifer test data is used to develop estimated values of transmissivity and permeability (specific yield) in water bearing sedimentary deposits. In the absence of pumping test data, values for T can be estimated by evaluating driller's logs and assigning permeability values to potential aquifers, although pumping test data is preferable.

2.4 Historical Groundwater Level Trends

The groundwater level trends of a basin, as can be depicted on hydrographs, tell an important story. Extraction in a basin can have a direct effect on water levels. If you work with water supply in California, it is no secret that many basins have been rigorously pumped over many years causing drastic groundwater level decline along with other "undesirable effects" as outlined earlier in this paper. An understanding of aquifer level response in relation to pumping is an important relationship to evaluate and understand.

2.5 Groundwater Storage

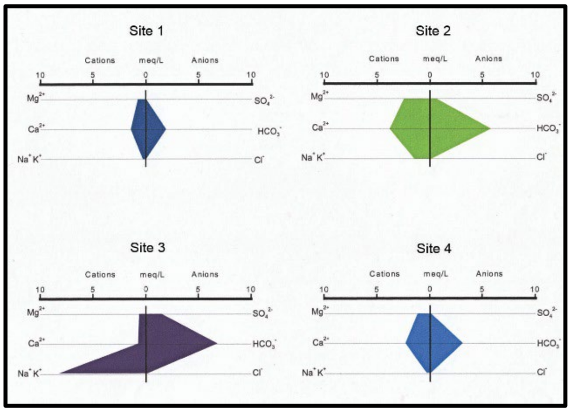
In alluvial groundwater basins, the amount of available groundwater in storage is estimated by the following equation:

$$\textit{Available Storage} = \textit{Volume of Sediments} \times \textit{Effective Porosity}$$

A simple computation of groundwater storage capacity is determined by multiplying the total volume of a basin by the average specific yield. The volume of sediments can be estimated by subtracting the surface elevation less a depth of the elevation of the base of fresh water bearing sediments for the surface area of the basin (if known). Effective porosity, also known as specific yield, can be estimated from charts that give typical values of effective porosity for the types of sediments found in the basin.

2.6 Water Quality

The water quality character of the groundwater is typically determined by analysis of the concentrations of the key cations (calcium, magnesium, and sodium) and the key anions (bicarbonate, sulfate and chloride). The analysis is usually performed using Stiff water quality pattern diagrams developed by H. Stiff in 1951. The diagrams are useful for identifying the character of groundwater from different wells in a basin and for allowing comparison of the groundwater character from different wells across an entire groundwater basin.



Example of Stiff Diagrams showing key cation and anion concentrations in groundwater.

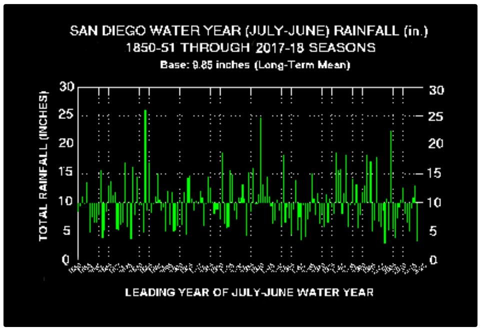
The locations of soil and groundwater contamination sources in groundwater basins within California are tracked and cataloged by the California State Water Resource Control Board (SWRCB). Information about these sites, including location and contaminant types may be found on their GeoTracker website. Database searches of local agency records may also provide useful information regarding water quality degradation zones and the locations of contaminant sites.

Part 3.0 Water Balance of a Groundwater Basin

A water budget is an analysis of a groundwater basin's inflows and outflows to determine the change in groundwater storage. The equation of hydrologic equilibrium is known also as the water balance, or hydrologic budget. In its most simple form it is written as follows:

Inflow – Outflow = Change in Storage

When inflow is greater than outflow more water will be held in storage, and the storage value will rise. Conversely, when outflow exceeds inflow, such as by over-pumping a basin, the storage value will decline as less water will be stored. The water budget takes into account the various components of the hydrologic cycle. These components include:



San Diego Rainfall totals
Period: 1850 through 2018

- Precipitation - Precipitation is the primary water input to the hydrologic cycle and is evaluated for all water budget calculations.
- Evaporation – Evaporation is the process by which water from an open water surface is converted directly to water vapor.
- Evapotranspiration - Evapotranspiration is similar to evaporation, except that it applies to the combined effect of evaporation from the land surface and transpiration from growing plants. While evaporation is controlled exclusively by climatic factors, evapotranspiration also depends on the type of soil and plants.

- Surface Runoff - Surface runoff is computed using the runoff curve number method (RCN), which was developed by the Soil Conservation Service in 1954. The combination of a hydrologic soil group and a land use and treatment class is a hydrologic soil-cover complex. Each combination is assigned a RCN, which is an index to its runoff potential.
- Groundwater flow - In order to determine the groundwater flow component, one needs to have estimates of transmissivity (T) of the aquifer materials in different areas of the aquifer(s) around the basin. Hydraulic conductivity (K) of the soil, or its ability to transmit water, can be can be estimated from T values derived from well records or pump test records of individual wells.

Achieving sustainable groundwater management under SGMA requires local agencies to develop and implement sustainable, balanced water budgets within their groundwater basin.

3.1 Inflows and Outflows

Inflows to the basin and outflows from the basin are some of the key parameters evaluated in a groundwater basin evaluation. Typical inflows include:

- Natural recharge from precipitation.
- Seepage from surface water channels.
- Intentional recharge via ponds, ditches, and injection wells.
- Recharge of applied water for irrigation uses.
- Unintentional recharge from leaky conveyance pipelines, and
- Subsurface inflows from outside basin boundaries (DWR Bulletin 118, 2003)

Typical outflows include:

- Groundwater extraction by wells.
- Groundwater discharge to surface water bodies and springs.
- Evaporation and Evapotranspiration.
- Subsurface outflow across the basin or subbasin boundaries.

Detailed knowledge of each budget component is necessary to obtain a good approximation of the change in storage. However, in many basins this information will not be available. The change in groundwater storage can also be estimated by determining the average change in groundwater elevation over the basin, multiplied by the area overlying the basin and the average specific yield (or storativity value if the aquifer is confined).

3.1 Groundwater Models

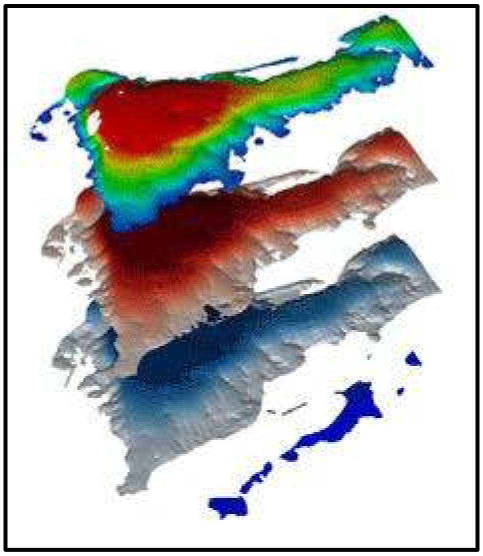
A groundwater model is a computer-based representation of the essential features of a natural hydrogeological system that uses the laws of science and mathematics. Its two key components are a conceptual model and a mathematical model. The conceptual model is an idealized representation of the hydrogeological understanding of the key flow processes of the system. A mathematical model is a set of equations, which, subject to certain assumptions, quantifies the physical processes active in the aquifer system(s) being modelled (Kumar, 2012).

Groundwater models that have been well calibrated play an important role in the development and management of groundwater resources by **1)** simulating the effects of steady-state flow in a groundwater basin, and **2)** simulating the effects of varying management scenarios, including pumping, recharge and conjunctive use.

Using models developed by the United States Geological Survey (USGS), known as MODFLOW (there are various versions), steady state and transient flow can be simulated in both unconfined and confined aquifers. A variety of features and processes such as rivers, streams, drains, springs, reservoirs, wells, evapotranspiration, and recharge from precipitation and irrigation also can be simulated (USGS, 1997).

In addition to MODFLOW, there are also several software packages that work in conjunction with MODFLOW that can be used to simulate contaminate migration in aquifers.

A model is only as good as the data (input) that goes into it. Much of the data discussed above will serve to be used as input to a groundwater model. The development of a model for a basin also helps to determine where more data may be needed.



Modeling allows the hydrogeologist to evaluate the basin from various perspectives.

Part 4.0 Estimating Safe Yield

Safe yield is defined as the amount of groundwater that can be continuously withdrawn from a basin without adverse impact (Bull 118, Todd 1959). A somewhat detailed groundwater budget as described above is needed to accurately estimate safe yield (Bull 118). Sustainable yield can be viewed as existing along a sliding scale that varies from no groundwater pumping on one end to “safe yield” on the other (Moran and Wendell, 2015).

The Water Balance Method is a good way to determine safe yield. It involves a rigorous analysis of inflow and outflow to the basin. However, there are other methods that can be used to estimate safe yield. One Hydrogeology firm used three methods and then averaged them to come up with an estimated safe yield in the Hollywood Basin in California. Some of the other methods include the the Zero Net Draft Method and the Hill Method.

4.1 Other Methods

The Hill Method - The Hill Method (Chow, 1964) plots average annual production in acre-ft/year vs. change in water levels over the same period. Hill measured the safe yield as the draft which corresponds to a zero groundwater elevation change.

The Zero Net Draft Method – The Zero Net Draft Method (Chow, 1964) is used to estimate safe yield for an entire basin. Similar to the Hill Method it involves plotting the average groundwater elevation over a select time period and comparing it to groundwater production for the same period. If the mean groundwater elevation remains unchanged over the period the production is assumed to be the safe yield.

Part 6.0 Conclusions

Evaluating and gaining a greater understanding of a groundwater basin is the key component to developing a solid groundwater management plan. That plan will then be the framework from which to develop a GSP under SGMA. A good hydrogeologist should be employed to help with these studies as he/she can evaluate the existing data and help “fill in the holes” where there are important data gaps. The information provided by the hydrogeologist will be crucial in the overall development of the GSP.

Part 7.0 References

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