GAINING THE NECESSARY GEOLOGIC, HYDROLOGIC, AND GEOCHEMICAL UNDERSTANDING FOR ADDITIONAL BRACKISH GROUNDWATER DEVELOPMENT, COASTAL SAN DIEGO, CALIFORNIA, USA

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Abstract. *Local water agencies and the United States Geological Survey are using a combination of techniques to better understand the scant freshwater resources and the much more abundant brackish resources in coastal San Diego, California, USA. Techniques include installation of multiple-depth monitoring well sites; geologic and paleontological analysis of drill cuttings; geophysical logging to identify formations and possible seawater intrusion; sampling of pore-water obtained from cores; analysis of chemical constituents including trace elements and isotopes; and use of scoping models including a three-dimensional geologic framework model, rainfall-runoff model, regional groundwater flow model, and coastal density-dependent groundwater flow model. Results show that most fresh groundwater was recharged during the last glacial period and that the coastal aquifer has had recurring intrusions of fresh and saline water. These intrusions disguise the source, flowpaths, and history of ground water near the coast. The flow system includes a freshwater lens resting on brackish water; a 100-meter-thick flowtube of freshwater discharging under brackish estuarine water and above highly saline water; and broad areas of fine-grained coastal sediment filled with fairly uniform brackish water. Stable isotopes of hydrogen and oxygen indicate the recharged water flows through many kilometers of fractured crystalline rock before entering the narrow coastal aquifer.*

Keywords: *Brackish groundwater, monitoring wells, geochemistry, models, management*

1. INTRODUCTION

Coastal hydrogeologic systems, particularly in areas of modest rainfall, runoff, and recharge, are complex and difficult to decipher. The primary forcing function of less precipitation results in less erosion, smaller aquifers, slower groundwater flowrates, and a predominance of brackish groundwater. The coastal area of San Diego, California, USA, is such a setting where water managers are challenged by the scant local water supplies, and by an increasing population (fig. 1).

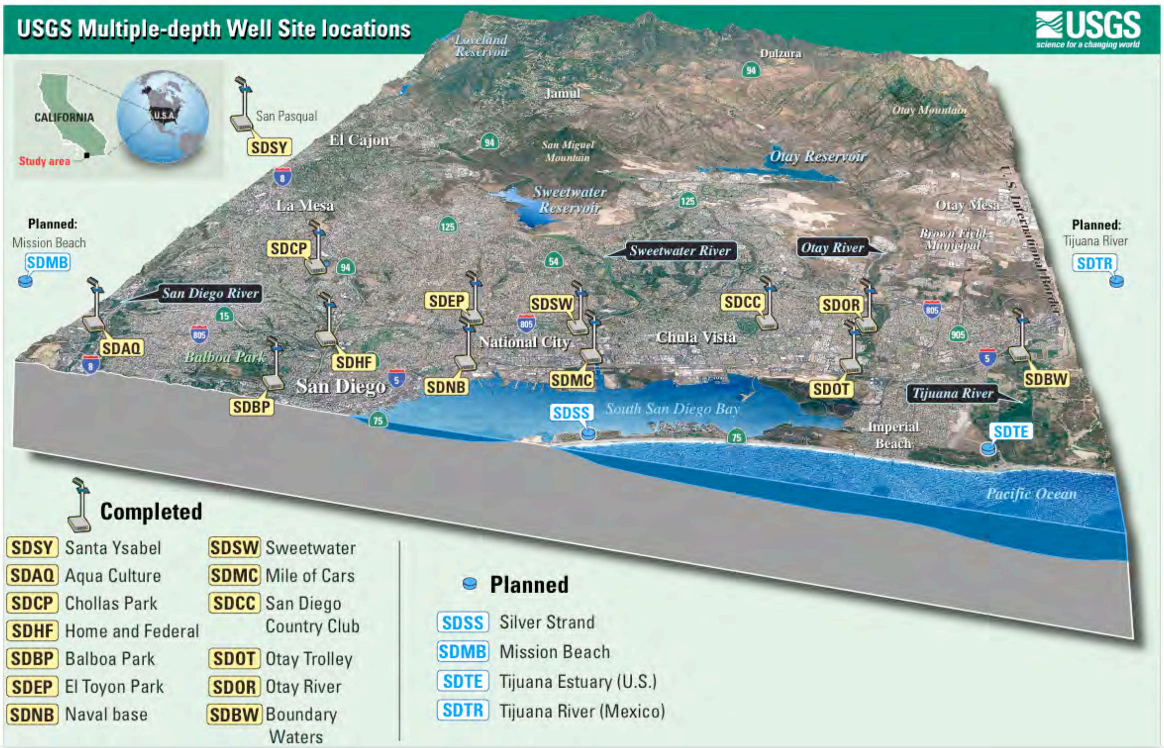

Figure 1. *Study area of coastal San Diego County, California, USA.*

Moderately permeable sedimentary formations, mostly of Pliocene and Eocene age, form a narrow coastal aquifer extending from coastal reservoirs to the Pacific Ocean (fig. 1). Further east, where most of the recharge occurs, weathered and fractured granitic and metavolcanic rocks form the more extensive, but less permeable hardrock aquifer. Most of the coastal plain is underlain with brackish (2,000 parts per million dissolved solids) groundwater.

2. METHODS

Local water agencies and the United States Geological Survey (USGS) are using a combination of techniques to provide the necessary understanding of the geology, hydrology, and geochemistry to develop the scant freshwater resources and the much more abundant brackish resources. The techniques include installation of twelve 500-meter-deep multiple-depth monitoring well sites, each with 4 to 6 piezometers equipped with pressure-recording transducers (fig. 1). These water-level data are uploaded to the USGS database and linked to the project webpage [http://ca.water.usgs.gov/sandiego] to aid in realtime water management. The well sites are located in east-west pairs (e.g. SDSW–SDMC, fig. 1), aligned with the general direction of groundwater flow and positioned along drainages to monitor stream-aquifer interaction. The eastern well monitors existing well fields (Danskin and Church, 2005); the western well is a sentry to detect seawater intrusion (Cronquist and others, 2011).

During installation of the well sites, drill cuttings are collected and analyzed for color, grain-size, provenance, and paleontological indicators of age and depositional environment. Geophysical logs are obtained to identify formations and depths of saline water. Cores are collected and analyzed for hydraulic characteristics, and for optical thermal luminance and paleomagnetic reversals to indicate age since deposition. These data are combined to create a three-dimensional geologic framework model (fig. 2).

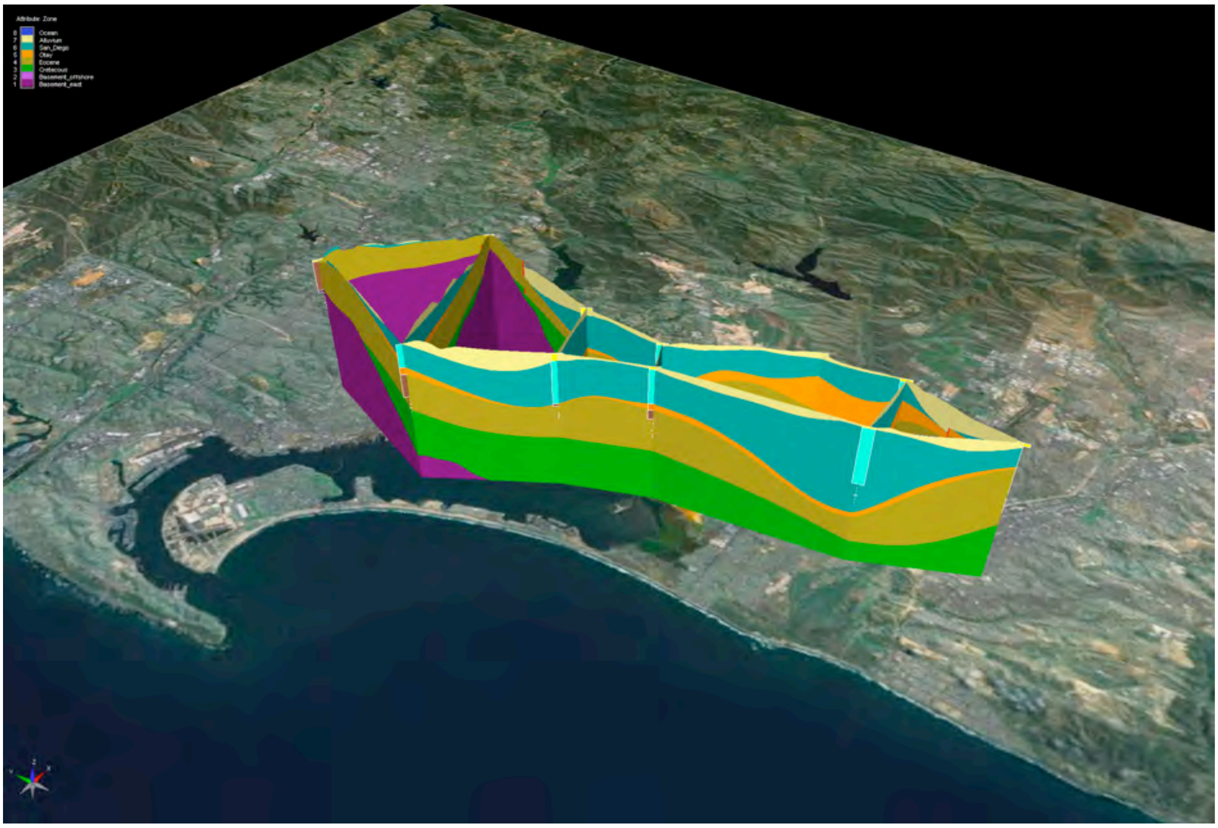

Figure 2. *Fence diagram created from the USGS geologic framework model. Six layers include crystalline rock (purple), Cretaceous rock (green), Eocene sediment (tan), Oligocene sediment (orange), Pliocene San Diego Formation (blue), and Quaternary sediment (yellow). Multiple-depth well sites form vertices of the fence diagram.*

Geochemical analysis includes samples of pore-water squeezed from cores, and subsequent sampling of the piezometers for a broad range of chemical constituents including trace elements and isotopes. Stable isotopes of hydrogen and oxygen are used to identify the likely area of recharge. Major ions and strontium isotopes are used to identify possible groundwater flowpaths (Anders and Futa, 2010).

A suite of numerical models is used to integrate data and to test ideas about geologic structure and arrangement of formations, location and quantity of recharge, quantity and flowpaths of groundwater, interaction of surface water and groundwater, configuration of fresh and saline water, and possible areas to extract additional brackish groundwater. These numerical models include a three-dimensional geologic framework model using RockWorks^{TM} and EarthVision^{R} software (Glockhoff, 2011; fig. 2), a rainfall-runoff model using the BCM method (Flint and Flint, 2007), a regional groundwater flow model using the USGS MODFLOW code, and a coastal density-dependent groundwater flow model using the USGS SUTRA code.

3. RESULTS

Results of the investigation show that most of the fresh water was recharged during the last glacial period, and that the coastal aquifer has had recurring intrusions of fresh and saline water (Cronquist and others, 2011; fig. 3).

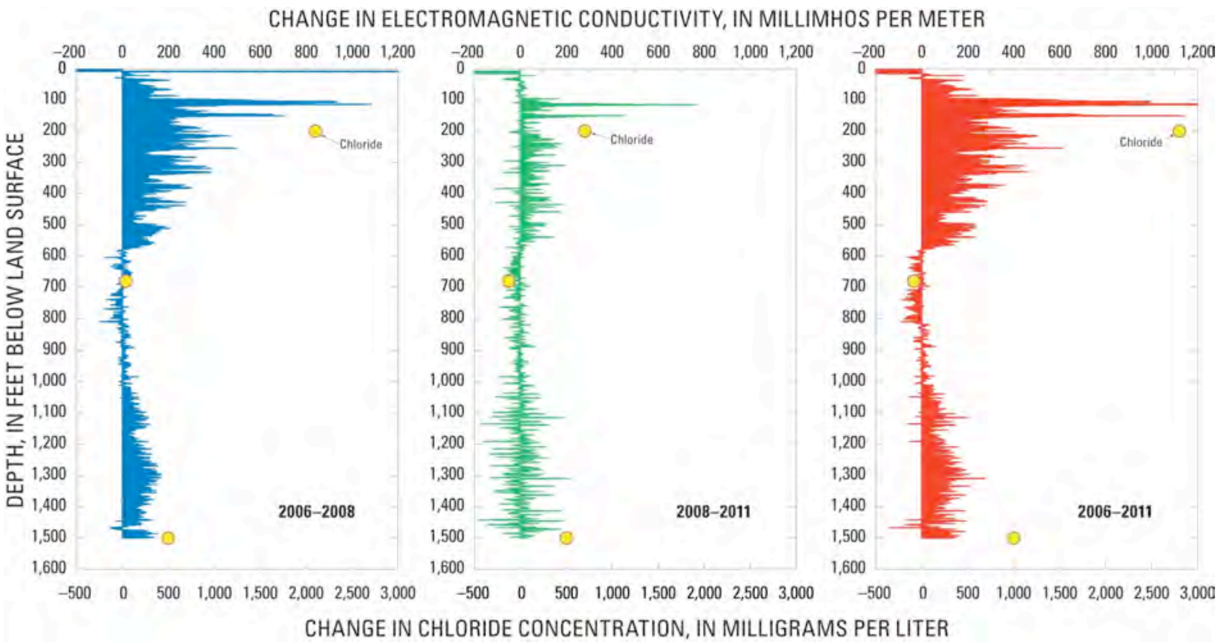

Figure 3. *Electromagnetic logging at the SDNB well site (fig. 1) measures changes in salinity with depth from 2006 to 2011. Data show an upper zone of saline intrusion (0-600), a middle zone of freshwater intrusion (600-1000), and a lower zone of highly saline water (1000-1500).*

These intrusions disguise the source, flowpaths, and history of groundwater near the coast. Complexity of the groundwater flow system includes a relatively small area with a freshwater lens resting on brackish water; a 100-meter-thick flowtube of freshwater discharging under brackish estuarine water and above highly saline water (fig. 3); and broad areas of fine-grained coastal sediment filled with fairly uniform brackish water.

Stable isotopes of hydrogen and oxygen identify the likely areas of the recharge, more than 20 km east and upgradient from the semiarid coastline (Anders and Futa, 2010; Wright and others, 2011). Chemical data indicate the recharged water flows through many kilometers of fractured crystalline rock before it enters the narrow sedimentary coastal aquifer.

The management challenge of increasing municipal supply is to capture more of the fresh groundwater on its way to the ocean and extract some of the brackish groundwater for treatment using reverse osmosis. The deep multiple-depth well sites are being used to characterize the geologic, hydrologic, and geochemical systems and to monitor seawater intrusion, land deformation, and effects on coastal riparian systems.

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