CHAPTER 16
GROUNDWATER HYDROLOGY

UPDATE CHRONOLOGY

NOVEMBER 30, 2005—VERSION 1

GROUNDWATER WELL, PUMP, AND DISTRIBUTION PIPES

PURPOSE

This chapter summarizes the basic groundwater hydrology of Napa County and documents the construction of a local integrated groundwater model. The groundwater hydrology analysis and model development were designed to establish a baseline of existing conditions to support countywide programs.

TABLE OF CONTENTS

FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

3-D	three dimensional
ac-ft	acre-feet
ac-ft/yr	acre feet per year
BDR	Napa County Baseline Data Report
CB	Carneros Groundwater Basin
CB	Carneros Basin
CEQA	CEQA
DHI	DHI Water & Environment
EPA	U.S. Environmental Protection Agency
ft	feet
gpm	gallons per minute
K	hydraulic conductivity
K	spatial distribution of hydraulic conductivity
MIKE SHE	3-Dimensional Groundwater Model
MIKE SHE/MIKE11	3-Dimensional Groundwater Model
MST	Milliken-Sarco-Tulocay
MSTB	Milliken-Sarco-Tulucay Groundwater Basin
NNVB	North Napa Valley Groundwater Basin
PCG	preconditioned conjugate gradient
RWQCBs	Regional Water Quality Control Boards
S	storage coefficient
SWRCB	State Water Resources Control Board
S_y	specific yield
USGS	U.S. Geological Survey

INTRODUCTION

This chapter of the Napa County Baseline Data Report (BDR) describes the baseline conditions for groundwater hydrology of Napa County (County). In addition to summarizing the hydrogeologic system, this chapter documents the construction of a local integrated surface water and groundwater model developed for the BDR for areas where groundwater is a significant resource.

Groundwater hydrologic analysis and modeling were conducted with the intention of applying the model and analysis for future planning.

This chapter describes the groundwater component of the hydrologic cycle in Napa County, documents the groundwater system, and describes the methods used to determine existing groundwater hydrology and the policies that apply to groundwater in Napa County. In addition, this chapter details the approach and data used in developing a local integrated surface water and groundwater model. As the focus of this chapter is groundwater and the saturated zone, this analysis is complementary and builds on the general surface water hydrology discussion presented in Chapter 15, *Surface Water Hydrology*, of the BDR. A supporting technical report (*Napa BDR Groundwater Hydrology Modeling Report*) includes a more complete documentation of the groundwater model construction, calibration, sensitivity analysis, and presentation of results. Consulting hydrologists from DHI Water & Environment led the surface hydrology, groundwater, and water quality tasks of the BDR (Chapters 15, 16, and 17, respectively), working collaboratively with other specialists from the Jones & Stokes/EDAW project team.

PURPOSE

The groundwater hydrologic analyses and modeling efforts conducted in support of the BDR were undertaken with the explicit intention of applying the models and analyses toward future planning considerations. More specifically, the surface water hydrology (see Chapter 15), groundwater (this chapter), and surface water quality (see Chapter 17) studies supporting the BDR were designed to establish baseline conditions by which Countywide planning programs could be assessed and evaluated for their benefits, constraints, and environmental impacts.

SPECIALIZED TERMS USED

- *Aquifer:* A permeable body of rock capable of yielding quantities of groundwater to wells and springs.
- *Alluvial aquifer:* Aquifer of water-bearing sand and gravel typically found near lakes, streams, and rivers, deposited by a stream and retainsinga hydraulic connection with the depositing stream.
- *Confined aquifer:* An aquifer that is bound above and below by impermeable layers of rock and that contains water under pressure.
- *Unconfined aquifer:* An aquifer without an upper confining layer of impermeable soil or rock material. The water table is exposed to the atmosphere through a series of interconnected openings in the overlying permeable soil and/or rock layers and is in equilibrium with atmospheric pressure.
- *Acre-foot (ac-ft):* The volume of water required to cover one acre of land to a depth of one foot (43,560 cubic feet or 325,851 gallons). An acre-foot can be visualized as water a foot deep, covering an area about the size of a football field.
- *Artesian well:* A well into water held under pressure in porous rock or soil, confined by impermeable geologic formations. Under this pressure, an artesian well is free-flowing to the surface.
- *Darcy's Law:* An equation that can be used to compute the quantity of water flowing through an aquifer, which describes the flow rate of water through porous materials as proportional to the hydraulic gradient. The constant of proportionality is the hydraulic conductivity.
- *Drawdown:* The drop in the water table or level of water in the ground when water is being pumped from a well.
- *Groundwater basins:* A groundwater reservoir defined by all the overlying land surface and the underlying aquifers that contain water stored in the reservoir. Boundaries of successively deeper aquifers may differ and make it difficult to define the limits of the basin.
- *Groundwater recharge:* Process where water enters the soil and eventually reaches the saturated zone. Groundwater recharge can occur through natural means (precipitation, streamflow) or human enhanced means (injection, etc.).
- *Groundwater:* Subsurface water occupying the pores and voids of the saturated zone and moving under the force of gravity. In many instances, groundwater is an important source of well water for domestic and agricultural use.
- *Hydraulic conductivity:* A measure of the capacity of a substance to allow water to flow through it.
- *Interflow:* That part of the precipitation which infiltrates the surface soil and moves laterally through the upper soil horizons above the water table toward surface waters. Also called subsurface runoff or shallow subsurface flow.
- *Losing streams:* Streams that lose water over their downstream course as they supply water to groundwater basins through infiltration from their beds.
- *Permeability:* The ability of a material to allow the passage of a liquid, such as water, through rocks. Permeable materials, such as gravel and sand, allow water to move quickly through them, whereas impermeable materials, such as clay, do not allow water to flow freely.

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- *Potentiometric surface:* The potential level to which water will rise above the aquifer's water level in a well that penetrates a confined aquifer; if the potential level is higher than the land surface, the well will overflow.
- *Safe yield volumes:* The annual amount of water that can be taken from a source or supply over a period of years without depleting that source beyond its ability to be replenished naturally in "wet years."
- *Specific yield:* Specific storage, storativity and specific yield (S_s, S and S_y) are aquifer properties; they are measures of the ability of an aquifer to release groundwater from storage, due to a unit change in hydraulic head. These properties are often determined in hydrogeology using an aquifer test.

POLICY CONSIDERATIONS

The following federal, state, and local policies and agencies are pertinent to and involved in management of groundwater in Napa County.

FEDERAL POLICIES

There are no applicable federal policies regulating groundwater in Napa County. In California, the State Regional Water Quality Control Boards set beneficial uses and water quality objectives for groundwater, usually consistent with Title 22 of the California (state) drinking water standards.

STATE POLICIES

GROUNDWATER RIGHTS

Groundwater rights in California are similar to surface water rights (see Chapter 15, *Surface Water Hydrology*, of the BDR); however, no permit system or comprehensive regulatory method exists. The exception is groundwater deemed to be part of a subterranean stream or underflow that is hydraulically connected to a surface water body. In such cases, the source is classified as surface water and remains subject to the permitting authority of the State Water Resources Control Board (SWRCB) (discussed in detail in Chapter 15). Groundwater law is primarily expressed through previous legal decisions, and disputes among groundwater users are usually settled through judicial actions or adjudications.

There are two main types of groundwater rights: overlying and appropriative.

OVERLYING RIGHTS

Overlying rights apply to parcels that overlie a groundwater basin. Overlying rights are analogous to riparian rights for surface water. Overlying users do not have priorities with respect to one another, and each holder has a right to a reasonable share of the total groundwater supply available. Overlying rights may be active or dormant, and are generally senior to appropriative rights (defined below). Note that water devoted to public uses (e.g., municipal water supply systems) is considered in most cases to be an appropriative use, rather than an overlying use, regardless of the location of the water use with respect to the aquifer.

> There are two main types of groundwater rights: overlying and appropriative. Overlying rights apply to parcels that overlie a groundwater basin. Appropriative rights apply to groundwater extractions used on lands that do not overlie the aquifer in question.

APPROPRIATIVE RIGHTS

Appropriative rights apply to groundwater extractions used on lands that do not overlie the aquifer in question. Appropriate rights are analogous to appropriative rights for surface water. Appropriative rights are protected by the construction and use of a well, and putting the pumped water to reasonable and beneficial use. These rights are subject to a seniority system, where the appropriative right holder with the longest standing right has first priority to groundwater in a condition of shortage.

> Groundwater quality is regulated through the federal Clean Water Act and State Porter-Cologne Act. Additional regulatory authority is exercised by the Regional Water Quality Control Board and California Department of Health Services.

GROUNDWATER QUALITY

Groundwater quality is regulated through the federal Clean Water Act and State Porter-Cologne Act, and administered by the U.S. Environmental Protection Agency (EPA), the SWRCB, and local Regional Water Quality Control Boards (RWQCBs). These laws and associated regulations are discussed in Chapter 17, *Surface Water Quality*, of the BDR. Additional regulatory authority is exercised by the RWQCB and California Department of Health Services regarding standards for installation, use, and abandonment of wells and septic systems, to ensure that drinking water standards and other water quality criteria are met and beneficial uses of the aquifer are maintained.

LOCAL POLICIES

NAPA COUNTY DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

The County's Department of Environmental Planning is responsible for multiple issues related to groundwater in the County, including toxic site cleanup, management of groundwater quality, and permitting of underground storage tanks. The department enforces the Safe Drinking Water Act, per agreement with the California Department of Health Services, Division of Drinking Water and Environmental Management. For more information on the Department of Environmental Management's

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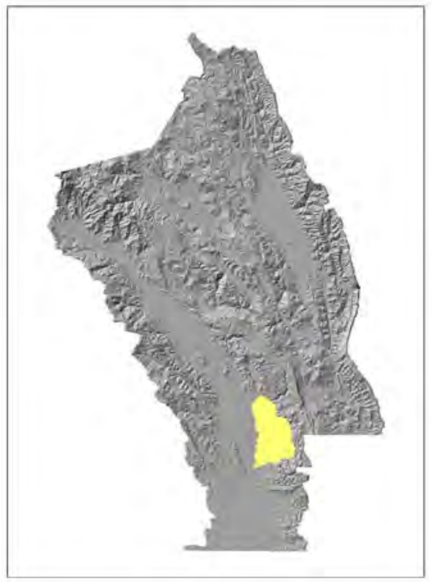

Milliken-Sarco-Tulocay Groundwater Basin

The Milliken-Sarco-Tulocay area is a groundwater deficient area. Due to the sensitive nature of the MST groundwater basin, the County requires special consultation to determine the need for a groundwater permit.

Analysis of the Napa County's groundwater system involved construction of a spatially referenced numerical model. Following initial data collection, a conceptual model was developed to describe groundwater functioning and identify significant hydrologic variables. This two-step process provided the basis for developing a valid mathematical model.

oversight of groundwater, see the County's website: http://www.co.napa.ca.us/GOV/Departments/DeptPage.asp?DID=40500&LID=984).

GROUNDWATER ORDINANCE

The Napa County Board of Supervisors adopted a groundwater ordinance in 1996, revised in 2003, to regulate the extraction, use, and preservation of the County's groundwater resources. Compliance with this ordinance applies to development of new water systems or improvements to an existing water system that may use groundwater. Specifically, the ordinance applies to agricultural land development or re-development activities located on parcels within groundwater deficient areas, including the Milliken-Sarco-Tulocay (MST), Pope Valley, Chiles Valley, Capell Valley, and Carneros groundwater basins. The ordinance identifies issuance of groundwater permits based on three types of applications—exempt, ministerial, and required—and the process by which compliance with the ordinance is determined. Applications for a groundwater permit require identification of existing and future uses of any existing water system which is supplied by groundwater, potential alternative water sources, the number of existing and future connections, intent of groundwater use, and an assessment of the potential impacts to the affected groundwater basin. Because groundwater resources are highly valued in the County, further guidance for activities conducted within the MST groundwater deficient area have been developed, as detailed below.

GUIDELINES FOR PROJECTS WITHIN THE MILLIKEN-SARCO-TULOCAY GROUNDWATER DEFICIENT AREA

The Milliken-Sarco-Tulocay area is a groundwater deficient area. Due to the sensitive nature of the MST groundwater basin, the County requires special consultation to determine the need for a groundwater permit. This particularly applies to construction projects, erosion control plans for new or expanded agricultural projects, and new or expanded wineries that intend to use groundwater from the MST basin. Depending on the governing authority (either the Environmental Management or Conservation Development and Planning Department), the appropriate department will determine which of the following three situations is applicable to the proposed project and its potential effect on the MST groundwater basin.

- No groundwater permit is required.
- A ministerial groundwater permit is required.
- A groundwater permit is required.

A groundwater permit would not be required if agricultural land development is less than or equal to a 0.25 acre, for additions or alterations to existing dwellings, or for swimming pools that are not filled with water from the MST.

Ministerial groundwater permits for new residential units and agricultural land re-development require compliance with water use conditions. For new residential units, the total amount of water used on the parcel must be less than 0.6 acre feet per year (ac-ft/yr). Re-development of agricultural land must limit the total water use on the parcel to an average of 0.3 acre feet per acre per year calculated as an average over a three-year period, with no yearly use exceeding the total average by more than 15%. All water use must be reported to the Department of Public Works under both types of development where a ministerial groundwater permit is issued.

Groundwater permits are issued upon compliance with the "no net increase" and "fair share" standards. The "no net increase" standard encourages applicants to reduce their impact on the MST by giving up an existing groundwater use, changing practices to reduce consumption, or by importing water from outside the MST (only applies for agricultural activities). If the additional water required by the proposed use would not meet the "no net increase" standard, the Planning Department or applicant must conduct a California Environmental Quality Act (CEQA) review to assess the potential environmental impacts of the proposed use. Additionally, the proposed use must comply with the "fair share" standard that no more than 0.3 acre-feet (ac-ft) of groundwater per acre of land owned is used.

METHODOLOGY

DEFINITION OF STUDY AREA

The study area for the analysis of groundwater hydrology is all of Napa County.

GENERAL APPROACH

Analysis of the Napa County's groundwater system (as a component of the hydrologic cycle) involved a literature review, data analysis, and construction of a spatially referenced numerical model. Extensive research was conducted to provide a scientific and valid basis for understanding the groundwater resources of Napa County. Sources for information included but were not limited to local, state, and federal agency reports and data; publicly available data; university research studies; professional engineering and geology reports; privately collected water-use data from throughout the County; and personal communication with various groundwater specialists. A more complete list of sources can be found in the References section below.

Following initial data collection, the main features and driving forces of the groundwater hydrologic system were identified and a conceptual model was developed to describe groundwater functioning and to identify any significant hydrologic variables that would be required in the numeric model. This two-step process of data collection and conceptual model development provided the basis for developing a valid mathematical model.

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Consistent with the description of model selection in Chapter 15, *Surface Water Hydrology*, the numerical model selected to simulate the hydrologic cycle in Napa County is based on the MIKE SHE/MIKE11 code developed by DHI Water & Environment (2005). The MIKE SHE/MIKE11 code has the capability to simulate the major flow components of the hydrologic cycle, including an integrated surface water and groundwater component, which makes the model very well suited for simulating current and future water distribution in Napa County. A more detailed description of the model's capabilities and data requirements is provided in Chapter 15, *Surface Water Hydrology*. A specific discussion of the groundwater module's computational algorithms and outputs is presented in the section *3-Dimen*sional Groundwater Model, below, or can be viewed at http://www.dhisoftware.com/mikeshe/ (DHI Water & Environment n.d.)

EXISTING STUDIES AND DATA SOURCES

DHI reviewed hydrogeologic reports and studies within Napa County. Of the reports reviewed, only one provided a comprehensive overview of the hydrogeology of the entire County. One study described the development of a numerical hydrogeologic model that simulates groundwater flow on a regional scale; however it only covered a limited portion of Napa County. The documents reviewed provide valuable guidance in understanding the hydrogeologic system in Napa County and were used in the development of the local integrated surface water and groundwater models for the areas where groundwater is a significant and valued resource.

GROUNDWATER RESOURCES STUDIES

Water Resource Study for the Napa County Region (Napa County Flood Control and Water Conservation District 1991) provides an overview of the groundwater hydrology in Napa County within the context of an examination of the current and future water use needs for the County. The report used data collected from the review of the County's general plan, master water supply plans, water management plans, agricultural land use practices, historic water production and metered sales records, historical and projected population data, and land use maps and data, as well as consultation with various agency personnel. The report provides a comprehensive overview of the agricultural, domestic, commercial, municipal, and industrial uses of water; and information regarding locations and volumes of groundwater pumping occurring throughout the County. The report also provides some basic descriptive information for each of the major groundwater basins identified in the County.

Ground-Water Hydrology of the Lower Milliken-Sarco-Tulucay Creeks Area, Napa County California by the U.S. Geological Survey (USGS) (Johnson 1977) discusses the water-bearing properties of the various hydrogeologically significant geologic formations in the Milliken-Sarco-Tulucay Groundwater Basin (MSTB). The report also discusses the occurrence, movement, recharge, discharge, water-level fluctuations, ground-water storage capacity, and changes in groundwater storage in the MSTB.

Ground-Water Resources in the Lower Milliken-Sarco-Tulucay Creeks Area, Southeastern Napa County California, 2000-2002 (Farrar and Metzger 2003) is a more recent update to the 1977 USGS study discussed above. The report discusses recharge to the aquifers in the MSTB in terms of an analysis of streamflow gains and losses, and discharge from the aquifers in terms of groundwater pumping and groundwater underflow. Groundwater levels and groundwater movement are evaluated in terms of annual, seasonal, and long-term changes in levels and flow directions. The report provides numerous datasets, including maps of the potentiometric surfaces in the aquifers, and stratigraphic information in the form of hydrogeologic cross sections.

Geology and Groundwater in Napa and Sonoma Valleys, Napa and Sonoma Counties California (Kunkel 1960) provides information on the water-bearing properties of the various geologic formations in the Napa Valley. The report discusses the groundwater hydrology of each of the significant groundwater reservoirs in the Napa Valley in terms of the groundwater abstractions, fluctuations in water levels, and storage capacities. Also included are estimates of total groundwater pumpage from wells in the Napa Valley, volume estimates of the alluvium at various depth intervals, average specific yield and groundwater storage capacities, water-level measurements and water-table maps, and driller's logs of wells developed in the Napa Valley.

Ground-Water Hydrology of Northern Napa Valley California (Faye 1973) provides information on the water-bearing properties of the various geologic formations in the northern Napa Valley. The report discusses the groundwater hydrology of each of the significant water-bearing deposits in terms of the spatial and hydrologic properties, recharge and discharge, fluctuations in water levels and streamflows; and the response of these factors to precipitation inputs. The report also documents the construction and calibration of a simple steady-state and transient mathematical groundwater flow model of the alluvial aquifer in the northern portion of the Napa Valley.

Historical Groundwater Levels in Napa Valley (California Department of Water Resources 1995) gives a summary of groundwater level data collected in the Napa Valley through 1994. It includes the locations of wells, information related to a monitoring program, hydrographs depicting changes in groundwater levels over time, and a tabulation of groundwater level measurements for 139 wells in the valley.

A series of USGS reports from 1973 are available, which contain data for selected wells within the Napa (Bader and Svitek 1973a), St. Helena (Bader and Svitek 1973b), Rutherford (Bader and Svitek 1973c), Yountville (Svitek 1973), and Calistoga (Svitek and Bader 1973) quadrangles. These reports provide a description of the wells located in each quadrangle as well as water-level records, driller's logs, pumping test results, and groundwater pumpage data for each well.

Water Resource Study for the Napa County Region (Napa County Flood Control and Water Conservation District 1991) provides an overview of the groundwater hydrology in Napa County within the context of an examination of the current and future water use needs for the County.

GEOLOGIC CONTEXT FOR GROUNDWATER

This section provides a general overview of the geology that is important to understanding groundwater resources in Napa County. A more complete discussion of the Napa County geology is presented in Chapter 1, *Geological Resources*, of the BDR.

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In the higher elevations, geologic structures that surround the structural troughs/basins of the County create source areas for surface water and groundwater.

GEOLOGIC STRUCTURE

The Napa Valley and the smaller basins in Napa County are typically structural troughs formed by folding and faulting associated with the transformation of a subduction zone into the strike-slip movements of the San Andreas and related faults (Howell and Swinchatt 2000). These basins are 1–2 million years old, and have a northwestward trend typical of the coastal basins throughout California (Planert and Williams 1995). Underlying the basins and forming the surrounding mountains are Mesozoic marine sediments and metamorphic and igneous rocks. The basins are partially filled with unconsolidated to semiconsolidated marine sedimentary rocks deposited episodically during times of high sea level. Additionally, the basin fill consists of weathered igneous and sedimentary rock clasts, deposited by mountain streams as well as permeable basalt and tuff in some locations. The rolling topography of the floor of the Napa Valley is the result of its formation primarily on alluvial fan deposits (Planert and Williams 1995).

Numerous faults present within the County generally trend to the northwest (Figure 16-1). Though the majority of these faults are not active, a few are active and others show evidence of displacement within the last 2 million years. Major faults in the County that are still active include the West Napa fault Zone, Green Valley fault Zone, Carneros fault, Cordelia fault Zone, Soda Creek fault, Wilson fault, and the Wragg fault.

Geologic structures create source areas for surface water and groundwater in the higher elevations that surround the structural troughs/basins of the County. Faults, joints, and fractures in the bedrock of Napa County act as preferential flowpaths enhancing groundwater recharge from precipitation and streamflow in some areas. In other areas, geologic structures act as barriers to groundwater flow, restricting the movement of water in the subsurface.

SURFICIAL GEOLOGY

Geologic formations exposed at the surface in the County include Surficial Deposits, the Clear Lake Volcanics, the Sonoma Volcanics, the Great Valley Complex, and the Franciscan Complex (Figure 16-1) (Graymer et al. 2004).

SURFICIAL DEPOSITS (HISTORIC TO LATE PLEISTOCENE)

This formation consists of stream channel deposits, alluvium, terrace deposits, alluvial fan deposits, landslide deposits, basin deposits, bay mud, and artificial fill. The largest contiguous area of these deposits is along the floor of Napa Valley proper. The deposits extend away from the mainstem of the Napa River along the lower reaches of most of the major tributary basins; and in the southern portion of the valley, the deposits extend further along the tributaries over most of their length. Isolated deposits occur away from the valley along Troutdale Creek, Van Ness Creek, Conn Creek, Dry Creek, Milliken Creek, and adjacent to Lake Hennessey on the southeast side. Additionally, the deposits are prevalent in the southern most areas of the County that experience tidal influence. Surficial deposits are also present within Pope Valley, Chiles Valley, Capell Creek Valley, Wooden Valley, Suisun Valley, the upper Putah Creek area, along major tributaries feeding Lake Berryessa from the north, and along the northeastern shores of Lake Berryessa (Graymer et al. 2004). In terms of groundwater resources, surficial deposits are typical pathways for groundwater recharge to the nearest surface aquifers and, depending on the properties and depths of the surficial deposits, may hold groundwater to varying capacity. Within the Napa Valley floor, the majority of the groundwater is hosted within these deposits.

CLEAR LAKE VOLCANICS (HOLOCENE TO PLIOCENE)

This formation consists of rhyolite, basalt, tuff, and siltstone, sandstone, conglomerate, and poorly consolidated gravel. Rocks of this formation outcrop in the northern portions of the Putah Creek subbasin, particularly in the vicinity of the upper reaches of Putah Creek, as well as in the southwestern portion of the study area in the vicinity of Huichica Creek and Carneros Creek subbasins. These rocks are outliers of the large volcanic complex around Clear Lake to the north of the study area. The complex is very young and thought to be related to the initiation of the San Andreas fault system (Fox et al. 1985). In terms of groundwater resources, permeable rocks within the Clear Lake Volcanics exposed in Napa County are the southern extension of an aquifer system that extends northward into Lake County.

SONOMA VOLCANICS (PLIOCENE TO LATE MIOCENE)

These rocks consist of rhyolite, dacite, andesite, basaltic tuff, glass, flow rock, pyroclastic breccia, intrusives, and interbedded volcanoclastic sedimentary rocks. These rocks are exposed over much of the Napa Valley and are the second most commonly exposed rocks in Napa County. They compose the majority of the hills and mountains to the north and east of the valley as well as large portions of the Mayacama Mountains to the west of the valley. These volcanics are thought to have formed along with the Clear Lake Volcanics as part of the northward trending series of volcanic centers related to initiation of the San Andreas fault system (Fox et al. 1985). In terms of groundwater resources, tuffaceous units within the Sonoma Volcanics host significant volumes of groundwater in many parts of Napa County. In the Napa Valley, these rocks underlie the surficial deposits and receive recharge from the overlying alluvial aquifer, and host significant volumes of groundwater under both confined and unconfined conditions. In the Milliken, Sarco, and Tulucay Creeks area, these deposits are the primary aquifer material and host significant volumes of groundwater primarily under confined conditions. The other units within the Sonoma Volcanics are relatively impermeable and act as confining units, restricting the horizontal and vertical movement of groundwater.

GREAT VALLEY COMPLEX (EARLY CRETACEOUS TO LATE JURASSIC)

This formation consists of the Great Valley sequence and the Coast Range ophiolite. The Great Valley sequence consists of sandstone, shale, conglomerate, wacke, and serpentinite. The Coast Range ophiolite consists of basaltic pillow lava and breccia, mafic intrusives, gabbro, serpentinite, silica carbonate rocks, and mélange. Outcrops of this formation are exposed extensively throughout the Putah Creek and Suisun Creek subbasins and are the most commonly exposed rocks in Napa County. Exposures are also found in the central and southern portions of the Mayacama Mountains, along Conn Creek, and in the extreme southwest portion of the study area (Graymer et al. 2004). In terms of groundwater resources, the rocks of the Great Valley Complex are relatively impermeable and act as confining units restricting the horizontal and vertical movement of groundwater.

FRANCISCAN COMPLEX (EARLY CRETACEOUS TO LATE JURASSIC)

This complex consists of mélange, serpentinite, graywacke, chert, greenstone, sandstone, metagraywacke, metachert, metagreenstone, and other undifferentiated high-grade metamorphic rocks. These rocks are exposed in the central portion of the Mayacama Mountains, in the vicinity of Moore Creek and Sage Creek in the central portion of the County, in the vicinity of James Creek and upper Putah Creek, and in the region just south of Lake Berryessa (Graymer et al. 2004). In terms of groundwater resources, the rocks of the Franciscan Complex are relatively impermeable and act as confining units restricting the horizontal and vertical movement of groundwater.

OVERVIEW OF GROUNDWATER IN NAPA COUNTY

An analysis of the groundwater system in a particular region requires an understanding of the dominant groundwater processes occurring in that region. These processes include groundwater recharge in terms of the mechanisms of recharge and the spatial and temporal distribution of recharge throughout the region's groundwater basins. Groundwater discharge is another important process. An understanding of the pathways of discharge and the volumes and timing of discharge is critical to the understanding of the regional groundwater system. One important source of discharge is the anthropogenic (human) abstraction of groundwater through production wells. An understanding of the hydrogeologic properties of the various significant geologic units is also critical, as these properties influence the storage and movement of groundwater throughout the system.

This section of the chapter provides a general overview of the groundwater resources of Napa County in terms of the available groundwater supply; the mechanisms and volume estimates of aquifer recharge; the locations of the groundwater in terms of depths below land surface; and groundwater usage in terms of the volumes used, the timing and locations of use, and the types of users and uses of groundwater.

GROUNDWATER SUPPLY AND PRINCIPAL BASINS

Napa County consists of a series of roughly parallel basins filled to varying depths with unconsolidated and semiconsolidated alluvial material (Figure 16-1). Underlying the basins and forming the intervening mountain ranges are Mesozoic marine sediments, and metamorphic and igneous rocks. The largest volumes of groundwater are hosted in the alluvium, and in general the Mesozoic rocks act as confining units that restrict the flow of groundwater. One major exception is the tuffaceous beds within the Mesozoic volcanic rocks, which are permeable and host significant volumes of water. The water-bearing deposits are often lenticular (spatially discontinuous) in nature and the deeper deposits are offset by faults resulting in a series of variously connected and isolated aquifers (Planert and Williams 1995). Groundwater in the alluvium occurs primarily under unconfined conditions and groundwater in the tuffaceous volcanic rocks occurs under both confined and unconfined conditions.

The major aquifers of the County are the North Napa Valley Groundwater Basin (NNVB) with an estimated storage volume of approximately 300,000 ac-ft, and the MSTB with an estimated storage volume of approximately 200,000 ac-ft (Figure 16-2) (Napa County Flood Control and Water Conservation District 1991) (an ac-ft can be visualized as water a foot deep covering an area about the size of a football field). Smaller aquifers include the Carneros Groundwater Basin (CB) and small basins within the Putah Creek subbasin. Storage estimates for many of these smaller basins do not exist; however, Napa County Flood Control and Water Conservation District (1991) estimates that these basin storage volumes range from less than 1,000 ac-ft to approximately 10,000 ac-ft, and the total storage volume for all of the smaller basins is likely 50,000 ac-ft or less. Map 16-1 shows the primary groundwater basins in Napa County.

GROUNDWATER RECHARGE

Recharge to the alluvial aquifers occurs primarily by direct infiltration of precipitation and to a lesser extent by the application of applied water from irrigation and infiltration through the stream and lake beds. In the NNVB, average annual recharge between 1962 and 1989 was on the order of 26,800 ac-ft/yr (Napa County Flood Control and Water Conservation District 1991). Due to the dominance of precipitation as the mechanism for recharge, variations in annual recharge rates are strongly correlated with variations in annual precipitation.

Groundwater recharge in the tuffaceous volcanic rocks occurs primarily from infiltration through the stream and lake beds and subsurface inflows from outside the groundwater basins. Also contributing to the recharge but less significantly is the recharge associated with direct infiltration of precipitation and applied water from irrigation. In the MSTB, annual recharge is on the order of 5,400 ac-ft/yr, with

Groundwater recharge in the alluvial aquifers occurs primarily by direct infiltration of precipitation. Recharge in the tuffaceous volcanic rocks occurs primarily from infiltration through the stream and lake beds and subsurface inflows from outside the groundwater basins. In both the alluvial aquifers and tuffaceous volcanic aquifers, applied water from irrigation is a relatively minor component of the total recharge.

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Approximately 92% of the land under irrigation in the County is used for vineyards. Water for irrigation and frost protection are the most significant uses of groundwater in the County.

The stratigraphy, or the layers (or strata) of the aquifers, is a significant factor in the hydrogeology of groundwater basins.

3,050 ac-ft/yr derived from streambed infiltration, 2,100 ac-ft/yr derived from subsurface inflow from the Howell Mountains, and 250 ac-ft/yr derived from direct infiltration of precipitation (Johnson 1977).

In both the alluvial aquifers and tuffaceous volcanic aquifers, applied water from irrigation is a relatively minor component of the total recharge due to the dominance of vineyard growth as the primary agriculture in the County and the efficiency of the irrigation techniques used in vineyard cultivation (Farrar and Metzger 2003; Napa County Flood Control and Water Conservation District 1991).

ESTIMATED DEPTHS TO WATER

Groundwater in the unconfined alluvial aquifers occurs at relatively shallow depths ranging from approximately 50 to 300 feet below land surface (Napa County Flood Control and Water Conservation District 1991). Within the tuffaceous volcanic aquifers, groundwater occurs over a wide range of depths primarily ranging between 10 and 500 feet below land surface (Farrar and Metzger 2003).

GROUNDWATER USE

The characterization of groundwater use presented in this section is based on the most current and reliable information available at the time this chapter was prepared. This section does not include information from the *2050 Napa Valley Water Resources Study* (Napa County Flood Control and Water Conservation District 2005). An updating of the groundwater use characterization, including Updated information on water demand and water use in Napa County from the long-range 2050 study will be provided in the supporting groundwater technical report (*Napa BDR Groundwater Hydrology Modeling Report*).

USERS AND PURPOSE OF USE

Groundwater is not a significant source of water for municipal use, and based on safe yield data from 1989, only 0.25% of the total volume is used for municipal use chiefly by the city of Calistoga (Napa County Flood Control and Water Conservation District 1991). No estimates of the proportions of water use for the other categories of use are known for the County as a whole. Estimates are, however, available for the MSTB. The estimates from this basin indicate that approximately 73% of the total use is for irrigation purposes, and 27% for rural domestic use (Farrar and Metzger 2003). This distribution is probably fairly representative of the County as a whole where the dominant use is for irrigation, followed in relative importance by rural domestic use, and then by municipal use.

VOLUMES USED

Estimating groundwater pumping rates and volumes is a challenging task due to limited data availability. Estimates of safe yield volumes from groundwater resources in the County are available from 1989, which in conjunction with projections of water needs can be used as a proxy for total pumping volumes. These estimates indicate that approximately 28,700 ac-ft of groundwater was pumped from the various aquifers in the County in 1989, representing 46.4% of the total yield from all sources (Napa County Flood Control and Water Conservation District 1991). Assuming this percentage is representative of the proportion of groundwater used to meet the projected water needs, estimates of abstracted groundwater volumes are 30,100 ac-ft and 31,500 ac-ft for 2000 and 2005, respectively (Napa County Flood Control and Water Conservation District 1991).

TIMING AND LOCATION OF USE

The majority of the groundwater is abstracted from the NNVB, and based on the safe yield data, approximately 79% of the total groundwater use comes from this basin (Napa County Flood Control and Water Conservation District 1991). The safe yield data does not differentiate between the MSTB and the CB; however, an independent estimate of pumping volumes from the MSTB for the period 2000–2002 indicates that approximately 5,350 ac-ft were abstracted (Farrar and Metzger 2003). Using this estimate indicates that approximately 18% of the total groundwater use comes from this basin, and 2% from the CB. The remaining 1% comes from basins within the Putah Creek Watershed and from other areas throughout the County (Napa County Flood Control and Water Conservation District 1991).

The majority of the land under irrigation in the County (approximately 92%) is used to grow vineyards, making irrigation and other agricultural use the primary use of water in the County, accounting for approximately 61% of the total water use (Napa County Flood Control and Water Conservation District 1991). The next largest category of use in the County is municipal use, which accounts for approximately 29% of the total water use (Napa County Flood Control and Water Conservation District 1991). It is important to note that these estimates represent total water use from all sources and do not necessarily reflect the proportions of groundwater use. For example, only 0.25% of the total groundwater use is municipal, even though municipal use accounts for 29% of the total water use from all sources. These observations indicate that water for irrigation and frost protection are the most significant uses of groundwater in the County. The timing of water application to vineyards for irrigation and frost protection is likely correlated to the timing of groundwater pumping in the County in general. Groundwater is applied to vineyards during two main periods: from June through October for irrigation purposes, and from February through March for frost protection; presumably, the majority of the groundwater pumping in the County occurs during these periods as well.

GROUNDWATER BASIN OVERVIEW

This section provides a more-detailed overview of the hydrogeology of individual groundwater basins in Napa County in terms of the stratigraphy of the aquifers, the aquifer properties, the recharge to and discharge from the aquifers, the water levels and general directions of groundwater flow in the aquifers, and the groundwater pumping activities taking place in the basins. The discussion of groundwater pumping activities is based on the best information available at the time this chapter was prepared and does not include information from the *2050 Napa Valley Water Resources Study* (Napa County Flood

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Control and Water Conservation District 2005). As described above, updated information regarding groundwater pumping will be provided in a supporting technical report (*Napa BDR Groundwater Hydrology Modeling Report*). Map 16-1 shows the primary groundwater basins in Napa County.

NORTH NAPA VALLEY BASIN

The largest groundwater basin in the County is the NNVB. The basin extends from just north of the city of Napa up the valley floor to the northwestern end of the valley just north of the city of Calistoga covering and an area of approximately 60 square miles (Figure 16-2). By far the most productive aquifer in the basin occurs within the alluvial material, which can locally provide water to wells at rates in excess of 3,000 gallons per minute (gpm) (Faye 1973). This aquifer is an unconfined aquifer in most locations except locally where clay lenses lead to confined conditions. A tuffaceous member of the Sonoma Volcanics, which underlies the alluvium, composes an additional aquifer in the basin, and wells tapping this aquifer yield water at an average rate of 32 gpm (Napa County Flood Control and Water Conservation District 1991). Groundwater in this aquifer occurs under both confined and unconfined conditions.

STRATIGRAPHY

The majority of the valley floor is alluvium consisting of poorly sorted lenticular stream deposits of sand and gravel interspersed with floodplain deposits of silts and clays. These deposits vary in thickness from over 300 feet at the southern end of the valley to less than 50 feet near Calistoga (Faye 1973). The alluvium also tends to be thickest near the center of the valley and the Napa River, and decreases in thickness toward the valley margins. Underlying the alluvium in most locations are the Sonoma Volcanics, which are believed to be up to 2000 feet thick. The tuffaceous member of the volcanics located within the upper half of the deposits yields moderate amounts of water, while the remaining rocks have relatively low permeabilities and serve as confining units. The Franciscan and Great Valley Complexes on the southern half of the west side of the valley are also low permeability and serve as confining units locally (Faye 1973).

AQUIFER PROPERTIES

Interpretation of driller's logs and specific capacity data indicates that the hydraulic conductivity (K) (hydraulic conductivity is a measure of the capacity of a substance to allow water to flow through it) of the alluvium ranges from 10 to greater than 100 ft/day (Faye 1973). Variations in K result from spatial variations in the relative proportions of sand and gravel in the aquifer. Although the distribution of these materials is irregular, K values follow a general pattern, increasing from north to south as well as from the valley margins toward the Napa River. K values in the tuffaceous member of the Sonoma Volcanics are on the order of 10^{-2} to 10^{-3} ft/day while the other volcanic rocks have K values on the order of 10^{-4} ft/day or less (Faye 1973).

AQUIFER RECHARGE AND DISCHARGE

Recharge in the basin occurs primarily by direct infiltration of precipitation, and to a lesser extent by the application of applied water from irrigation and by infiltration through the streambeds of losing streams (stream systems that supply water to groundwater basins). Average annual recharge between 1962 and 1989 was on the order of 26,800 ac-ft/yr (Napa County Flood Control and Water Conservation District 1991). Discharge from the aquifer occurs in the forms of evapotranspiration, discharge to the Napa River and its tributaries, groundwater pumping/extraction, and subsurface outflow. Evapotranspiration is the largest component of discharge from the basin, accounting for about half of the total outflow. Groundwater pumping and discharge to streams are the next largest components of discharge, and subsurface outflow along the southern boundary of the basin accounts for a relatively small portion of the total outflow (Napa County Flood Control and Water Conservation District 1991). A groundwater hydrologic budget for the basin was calculated for the period from 1962 to 1989, suggesting that the basin was in a state of dynamic equilibrium during this period (the total inflow to the basin from recharge approximately equaled the total discharge from the basin).

GROUNDWATER LEVELS AND FLOW DIRECTIONS

Groundwater in both the alluvial aquifer and the tuffaceous volcanic aquifer occurs at depths ranging from approximately 50 to 300 feet below land surface. Water-table elevation maps indicate groundwater flow in the basin occurs from the valley edges toward the valley axis, as well as southward toward San Pablo Bay. These general flow patterns are modified locally by faults along the valley floor; however, the only fault that has been documented to obstruct flow in the basin is the Soda Creek fault (Napa County Flood Control and Water Conservation District 1991). Water-level data collected between 1962 and 1989 indicates that significant drawdowns have not occurred within the NNVB and that as of at least 1989, the aquifer has been in a state of dynamic equilibrium (Napa County Flood Control and Water Conservation District 1991).

GROUNDWATER PUMPING

The volume of groundwater pumped from the basin can only be estimated because domestic wells are for the most part not metered and power consumption records for irrigation wells are generally not available. Direct estimates of the volumes of groundwater withdrawn from the basin in recent years are not available; however, projections of water needs for 2000 and 2005 in the basin based on estimates of water needs determined in 1989 are available (Napa County Flood Control and Water Conservation District 1991). Additionally, estimates of the relative percentages of water available from surface water and groundwater sources are available (Napa County Flood Control and Water Conservation District 1991). These two data sets allow estimates of the total volumes of groundwater pumped from the basin in both 2000 and 2005 as given by Equation 16-1.

St. Helena has the largest groundwater basin in Napa County. By far the most productive aquifer in the basin occurs within the alluvial material; it can locally provide water to wells at rates in excess of 3,000 gallons per minute.

Equation 16-1:

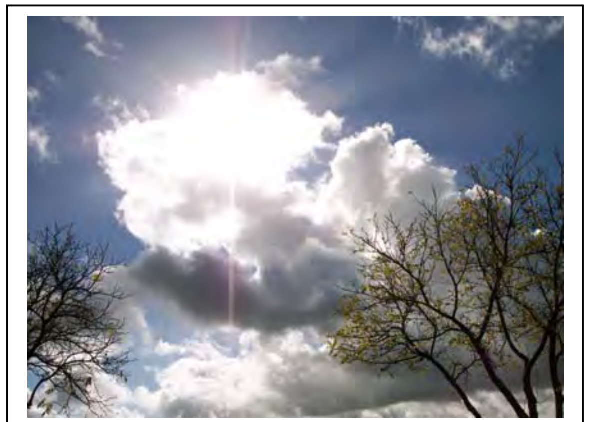
$$Q_p = P_{gw} \times V_{pn}$$

where

Q_p = the total annual groundwater pumping,
P_{gw} = the proportion of the annual water supply derived from groundwater, and
V_{pn} = the projected annual water need.

Using this method, a total of 19,000 and 19,900 ac-ft of water were abstracted from the basin in 2000 and 2005 respectively.

MILLIKEN-SARCO-TULUCAY BASIN



Aquifer recharge in the basin occurs primarily by direct infiltration of precipitation.

The MSTB is the second largest groundwater basin in the County. It is located adjacent to the city of Napa along the eastern edge of the valley floor and covers an area of approximately 15 square miles (Figure 16-2). The area is distinct from the NNVB because of the high-yielding nature of the Sonoma Volcanics to the east of the Soda Creek fault. To the west of the fault, alluvium is the primary water-bearing material and to the east of the fault, the volcanics are the primary water-bearing material. Groundwater in the basin occurs primarily under confined conditions within tuffaceous units of the Sonoma Volcanics (Farrar and Metzger 2003).

STRATIGRAPHY

West of the Soda Creek fault, the primary water-bearing units are the alluvial deposits, and east of the fault, groundwater is found almost exclusively in the Sonoma Volcanics. The andesitic member is the basal member of the Sonoma Volcanics which underlies the entire basin. These rocks have a low primary permeability and serve as a lower confining unit to the aquifers, except locally in interflow zones and where fracture zones created from folding and faulting are present. Overlying the andesitic member is the tuffaceous member which hosts the majority of the groundwater in the basin. The tuffaceous deposits constitute a leaky multilayered aquifer system with permeable tuffs interbedded with igneous flows and clay of low permeability (Johnson 1977). A high point in the impermeable andesitic bedrock underlying the tuffaceous rocks acts as a groundwater divide splitting the basin into a north basin containing Milliken and Sarco Creeks and a south basin containing Tulucay Creek.

AQUIFER PROPERTIES

Johnson (1977) estimated the specific yield (S_y) of the various deposits in the basin based on inspection of well logs. In the lower Tulucay Creek drainage basin, S_y values ranged from 0.037 to 0.052. In the central hilly portion of the basin, S_y values ranged from 0.019 to 0.037. In the lower portions of the drainage basins of Milliken and Sarco Creeks east of the Soda Creek fault, S_y values ranged from 0.04 to 0.054 and to the west of the Soda Creek fault, values ranged from 0.048 to 0.053. An aquifer test from one location in the basin indicated that the storage coefficient (S) of the tuffaceous member was on the order of 0.00026. Few estimates of K for the aquifer were found; however, Johnson (1977) estimated that the average value in the lower Tulucay Creek basin and west of the Soda Creek fault was on the order of 2 ft/day.

AQUIFER RECHARGE AND DISCHARGE

Recharge in the basin occurs primarily by infiltration through the streambeds of losing streams, groundwater inflow from the Howell Mountains to the east of the basin, and direct infiltration of precipitation. The application of applied water for irrigation is a relatively minor component of recharge except in localized situations. In 1975, total recharge to the basin was on the order of 5,400 ac-ft/yr, with 3,050 ac-ft/yr derived from streambed infiltration, 2,100 ac-ft/yr derived from subsurface inflow, and 250 ac-ft/yr derived from direct infiltration of precipitation (Johnson 1977). Discharge from the basin occurs primarily as groundwater abstractions and underflow across the western boundary of the basin and toward the Napa River. Estimates of annual groundwater pumping in 2000–2002 range from 3,600 to 7,100 ac-ft/yr, with an average of 5,350 ac-ft/yr (Farrar and Metzger 2003). The volume of water discharging as underflow across the western boundary of the basin was estimated to be about 600 ac-ft/yr in 2000 as determined based on the application of Darcy's Law and estimates of the K values of the deposits.

GROUNDWATER LEVELS AND FLOW DIRECTIONS

Water levels in the tuffaceous rocks of the Sonoma Volcanics range from 10 to 500 feet below ground surface (Farrar and Metzger 2003) (Figure 16-3). Cones of depression are formed around the largest groundwater pumping centers in the basin, and the predominant directions of groundwater flow are from areas of recharge around the margins of the basin toward the various cones of depression (Figure 16-3). Water levels have been gradually declining since at least the 1960s and probably since the early 1900s, when groundwater in many of the wells occurred under artesian conditions (Farrar and Metzger 2003). Over the period between 1975 and 2001, groundwater levels declined by as much as 125 ft in many portions of the basin, while in other areas levels were relatively unchanged or even increased by as much as 50 ft (Farrar and Metzger 2003). The observed declines in water levels are likely the result of groundwater pumping activities in the basin. In addition to these long-term trends in water levels, seasonal fluctuations in water levels by as much as 50 ft occur as a result of variable recharge rates, due to seasonal changes in streamflow and precipitation, variations in evapotranspiration rates, and differences in groundwater pumping rates (Farrar and Metzger 2003).

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GROUNDWATER PUMPING

The volume of groundwater pumped from the MST basin can only be estimated because domestic wells are for the most part not metered and power consumption records for irrigation wells are generally not available. Using the data from the Napa County Flood Control and Water Conservation District (1991) report as described above, estimates of the total volume of groundwater pumped from both the MSTB and CB are in the range of 6,860 and 7,110 ac-ft for 2000 and 2005, respectively. In the absence of pumping rates tied to individual well locations, it is difficult to detail the distribution of pumping throughout the basin; however, the distribution of completed wells can serve as a proxy for understanding pumping distributions. The greatest number of wells occurs near Hagen Road, in the east-central portion of the basin, and centered around Third Avenue between Coombsville Road and North Avenue in the southeastern portion of the basin (Farrar and Metzger 2003).

A report by the USGS from 2003 (Farrar and Metzger 2003) provides some detailed estimates of groundwater pumping volumes in the basin. Using both a well-based method and a population-based method, domestic pumping in the basin was estimated at between 800 and 2,100 ac-ft/yr for 2000–2002. Farrar and Metzger 2003). Using both a well-based method and a land-use based method, pumping for irrigation of agriculture was estimated at between 1,180 and 3,440 ac-ft/yr for the same period (Farrar and Metzger 2003). Finally, pumping for irrigation of improved open spaces (golf courses, cemeteries, and public institutions) was estimated, using a land-use based method, at approximately 1,560 ac-ft/yr for 2000–2002. In total, the estimated volume of groundwater abstracted from the basin ranges from 3,600 to 7,100 ac-ft, with an average value of 5,350 ac-ft (Farrar and Metzger 2003).

CARNEROS BASIN

The Carneros Basin (CB) is located in the southwestern portion of Napa County (Figure 16-2) and very little hydrologic or hydrogeologic information is available for the region. The valley floor consists of alluvium and is underlain by Pleistocene Huichica Formation, which in turn is underlain by the Sonoma Volcanics. The alluvium in this area is generally very thin with much of its volume located above the saturated zone (Napa County Flood Control and Water Conservation District 1991). As a result, the Huichica Formation is the primary water-bearing material in the basin. No estimates of storage were found for the basin; however, lower well yields indicate that storage is probably much less than in the two previously described basins (Napa County Flood Control and Water Conservation District 1991).

STRATIGRAPHY

The floor of the Carneros Valley consists of Pleistocene terrace deposits and recent alluvium, with some Pleistocene Huichica Formation flanking the sides of the southern end of the valley (Napa County Flood Control and Water Conservation District 1991). The Huichica Formation underlies much of the basin and consists of fluvial deposits of gravel, silt, sand, and clay with interbedded tuff. The lower 200 to 300 feet contains reworked pumice from the underlying Sonoma Volcanics. The Huichica Formation is the primary water-bearing unit in the basin and the underlying Sonoma Volcanics act as a lower confining unit. Limited information is available regarding the thickness of the Huichica Formation in the basin; however it is reported to achieve a maximum thickness of 900 feet (Napa County Flood Control and Water Conservation District 1991).

AQUIFER PROPERTIES

Limited data concerning the aquifer properties of the deposits found in the basin are available; however, the Huichica Formation is described as having a low permeability, and well yields are generally less than 5 gpm, indicating relatively low K values (Napa County Flood Control and Water Conservation District 1991).

AQUIFER RECHARGE AND DISCHARGE

Recharge to the basin is reported to occur primarily from direct infiltration of precipitation falling over areas of geologic outcrops, which are primarily located along the hillsides bordering the Carneros Valley. Infiltration from streambeds is also an important source of recharge to the basin (Napa County Flood Control and Water Conservation District 1991). Groundwater pumping from the basin is likely a significant source of discharge; however, limited availability of data make it difficult to estimate the relative importance of the various inflows and outflows within the basin.

GROUNDWATER LEVELS AND FLOW DIRECTIONS

Groundwater occurs primarily under unconfined conditions and at relatively shallow depths in the basin; however, no water-table maps were found for the basin, making it difficult to specify depths to water and predominant directions of groundwater flow.

GROUNDWATER PUMPING

No estimates of the volumes of groundwater pumped from the CB basin are available. However, estimates of pumping from both the MSTB and the CB are described in the section *Overview of Groundwater in Napa County*. Taking the estimate for both basins of 6,860 ac-ft and subtracting the estimate for the MSTB determined in the Farrar and Metzger (2003) report (see *Milliken-Sarco-Tulucay Basin* above) yields a rough estimate of groundwater pumping from the CB on the order of 1,510 ac-ft/yr for 2000–2002.

Three-dimensional Mike SHE groundwater models were constructed for the North Napa Valley Groundwater Basin, Milliken-Sarco-Tulucay Groundwater Basin, and Carneros Groundwater Basin. The models can be used to produce maps showing the distribution of water levels in the aquifers under existing conditions and detailed water budgets describing the inflows to and outflows from the basins; to assess and evaluate the relative influence of land use changes on groundwater conditions; and to quantify the volumes of existing groundwater supplies and estimate the safe yield from the various aquifers.

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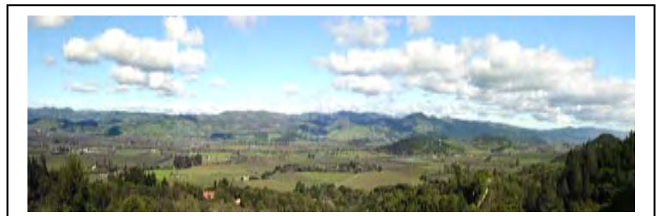
THREE-DIMENSIONAL GROUNDWATER MODEL (MIKE SHE)

OVERVIEW

Mike SHE groundwater models were constructed for the three groundwater basins described in the sections above (NNVB, MSTB, and CB). These three models utilize the same data and methodology described in Chapter 15, *Surface Water Hydrology*, for precipitation, evapotranspiration, overland flow, and unsaturated flow (see surface water modeling portion of the text). In the saturated zone, the models differ from the surface water models in that they utilize a fully distributed (physically/spatially based) approach, where the aquifer geometries and aquifer properties are represented explicitly in three dimensions (3-D), as opposed to the simplified conceptual approach used in the surface water models.

MODELING ALGORITHM

The 3-D groundwater model used in the saturated zone describes the spatial and temporal variations of the dependent variable (hydraulic head) mathematically using a 3-D Darcy equation solved numerically by an iterative implicit finite difference technique. The models use the preconditioned conjugate gradient (PCG) groundwater solver developed by the USGS based on a preconditioned conjugate gradient solution technique. The saturated zone component of flow interacts with the other components of MIKE SHE primarily by using the boundary flows from the other components implicitly or explicitly as sources and sinks.



The three largest groundwater basins in the County are the North Napa Valley, Milliken-Sarco-Tulucay, and Carneros Basins.

DATA REQUIREMENTS

A key requirement to characterize the saturated flow component is a 3-dimensional geometric description (or mapping) of the hydrogeologic units involved in the study area. Borehole logs and geologic maps are used to delineate the contact locations between geologic units and thereby describe the geometry and spatial relationships between these units. Aquifer property data are also needed. These data include the spatial distribution of hydraulic conductivity (K) values and either the specific yield (S_y) or the storage coefficient (S) depending on the type of aquifer being simulated (i.e. confined vs. unconfined). Additional data requirements include information on the boundary conditions of the models including water levels and discharges. These boundary conditions will be determined form the results of the regional surface water model simulations and estimates of groundwater pumping determined from the literature and available data. Finally, measured water levels at representative locations in the basins are needed in order to calibrate the models to existing conditions.

ASSUMPTIONS AND LIMITATIONS

The models assume a constant density of the water in the saturated zone. The models also assume that the hydraulic properties within each hydrogeologic unit being considered are isotropic and homogenous. Additional assumptions include the assumption that no flow across the lower boundary of the models is present, that recharge due water applied for irrigation is an insignificant portion of the total recharge, and that distributing total annual volumes of groundwater withdrawals based on the distribution of wells developed in the various aquifers accurately represents the effects of anthropogenic (human) use of groundwater in each basin.

Limitations of the models include the inherent limitations associated with numerical modeling codes. Restrictions regarding the detail of input and calibration data, as well as inaccuracies associated with available data, place additional limitations on the accuracy of the models. Specific data gaps include a lack of groundwater pumping rates tied to individual well locations, a lack of detailed stratigraphic information for portions of the NNVB and CB, and a lack of information delineating the spatial variation of aquifer properties. When representing the myriad of complex hydrologic processes occurring in these basin with numerical models, the simplifying assumptions necessary to construct and calibrate the models also leads to inherent limitations in the applicability of the modeling results. Further information regarding the assumptions and limitations of the models will be provided in a supporting technical report (*Napa BDR Groundwater Hydrology Modeling Report*).

USES OF THE MODEL AND INITIAL RESULTS

The models can be used to produce maps showing the distribution of water levels or potentiometric surfaces in the aquifers under existing conditions, as well as detailed water budgets describing the magnitudes of the various inflows to and outflows from each of the three basins. Applications of the models include estimating changes in water levels, potentiometric surfaces, and water balances associated with changes in land-use and/or groundwater abstractions. There are also several direct linkages between surface land cover and land use and resulting infiltration, runoff/streamflow, and groundwater conditions, as described above for general groundwater processes and sources and in Chapter 15 on the main components of the hydrologic cycle. The groundwater models developed for the BDR can be used to assess and evaluate the relative influence of land use changes at the surface on groundwater conditions. The models can also be used to quantify the volumes of existing groundwater supplies and estimate the safe yield from the various aquifers. A more complete description of the groundwater models and presentation of their results will be provided in a supporting technical report (*Napa BDR Groundwater Hydrology Modeling Report*).

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CONCLUSIONS AND REPORT UPDATE RECOMMENDATIONS

The primary water-bearing deposits in Napa County are recent and older alluvium which host groundwater primarily under unconfined conditions, and tuffaceous units within the Sonoma Volcanics which host groundwater primarily under confined conditions. The three largest groundwater basins in the County are the North Napa Valley, Milliken-Sarco-Tulucay, and Carneros Basins. Existing information and data concerning basin boundaries, storage capacities, recharge and discharge, groundwater levels, and groundwater pumping activities are available for each of these basins and allow for the characterization of the hydrogeology in each basin, as well as provide the framework for the construction of a numerical groundwater flow model. As described above, information regarding groundwater use was based on available information. Groundwater use information from the recent *2050 Napa Valley Water Resources Study* (Napa County Flood Control and Water Conservation District 2005 will be provided in the supporting groundwater technical report (*Napa BDR Groundwater Hydrology Modeling Report*).

A surface water model has been developed in MIKE SHE/MIKE 11 that simulates the major components of the hydrologic system active in Napa County on a regional scale. Data from the established MIKE SHE-MIKE 11 surface hydrology model will be modified to develop a more detailed coupled surface water and groundwater model for areas of Napa County where groundwater is a significant resource. This model will utilize a 3-D finite-difference approach to simulating flow in the saturated zone, and will focus on simulating flow in the three largest groundwater basins in the County; North Napa Valley, Milliken-Sarco-Tulucay, and Carneros.

Limitations of the combined MIKE SHE/MIKE 11 modeling arise from the inherent limitations of numerical models, the lack of detailed input and calibration data, and inaccuracies associated with available data. If the model is to be used for purposes other than regional hydrology, hydraulic, or local hydrology studies, then additional data of the study area may need to be collected for the model. The developed model will be sensitive to changes in land use and can be used for impact analyses comparing baseline conditions to future scenarios.

The Napa County MIKE SHE/MIKE 11 model is a dynamic model that can be refined and expanded as data becomes available and as new questions are identified. Because the model is set up for a regional analysis of the Napa County hydrologic system, it can be used to help evaluate alternatives developed as part of the current updating of the Napa County General Plan. More detailed recommendations for future model updates and improvements will be provided in a supporting technical report (*Napa BDR Groundwater Hydrology Modeling Report*).

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