

WHITE WOLF SUBBASIN TECHNICAL STUDY

TABLE OF CONTENTS

<u>Section</u>	<u>Page No.</u>
1.0 INTRODUCTION	1
1.1 Basin Boundary Emergency Regulation Requirements	1
1.2 Purpose	2
2.0 WHITE WOLF SUBBASIN SUBBASIN DESCRIPTION.....	7
2.1 Boundaries.....	7
2.1.1 Lateral Boundaries	7
2.1.2 Definable Bottom of the Subbasin	8
2.2 Topography.....	8
2.2.1 Mountain Ranges	9
2.2.2 General Physical Features	9
2.3 Surface Water Features.....	10
2.4 Climate.....	10
2.5 Land Use	12
2.5.1 Irrigated Agriculture	12
2.5.2 Commercial and Industrial Areas	13
2.5.3 Oil and Gas Exploration.....	13
2.5.4 Undeveloped Areas	13
2.6 Water Suppliers	13
2.6.1 Wheeler Ridge-Maricopa Water Storage District.....	14
2.6.2 Arvin-Edison Water Storage District	15
2.6.3 Tejon-Castac Water District.....	15

WHITE WOLF SUBBASIN TECHNICAL STUDY

TABLE OF CONTENTS

<u>Section</u>	<u>Page No.</u>
3.0 WHITE WOLF SUBBASIN GEOLOGY.....	17
3.1 Geologic History	17
3.1.1 Paleogene	17
3.1.2 Miocene.....	17
3.1.3 Pliocene to Present	18
3.2 Stratigraphy	18
3.2.1 Crystalline Basement Complex	18
3.2.2 Undifferentiated Tertiary Sedimentary	18
3.3 Structural Geology	19
3.3.1 Faulting.....	20
3.3.2 Folding.....	22
4.0 WHITE WOLF SUBBASIN HYDROGEOLOGY.....	23
4.1 Principal Aquifers.....	23
4.1.1 Younger and Older Alluvium.....	23
4.1.2 Kern River Formation	24
4.1.3 Chanac and Santa Margarita Formations.....	25
4.2 Groundwater Development.....	26
4.2.1 Groundwater Well Characteristics	27
4.2.2 Groundwater Use – Wheeler Ridge-Maricopa Water Storage District	28
4.2.3 Groundwater Use – Arvin-Edison Water Storage District	29
4.2.4 Groundwater Use – Tejon-Castac Water District.....	29

WHITE WOLF SUBBASIN TECHNICAL STUDY

TABLE OF CONTENTS

<u>Section</u>	<u>Page No.</u>
4.2.5 Groundwater use – Private Landowners	29
4.3 Groundwater Levels in the White Wolf Subbasin	30
4.3.1 Historical Trends.....	30
4.3.2 Spatial Variability	31
4.3.3 Seasonal Variability	32
4.4 Groundwater Flow Patterns in the White Wolf Subbasin	32
4.4.1 Groundwater Flow Direction	32
4.4.2 Impediments to Flow	33
4.4.3 Groundwater-Surface Water Interactions	35
4.4.4 Recharge and Discharge Areas	35
4.5 Aquifer Testing.....	36
4.5.1 Aquifer Property Testing.....	36
4.5.2 Boundary Response Testing – Prior Studies.....	37
4.5.3 Boundary Response Testing – Current Study	37
4.6 Groundwater Quality	40
4.7 Land Subsidence	42
5.0 WHITE WOLF SUBBASIN WATER BALANCE	43
5.1 Inflows.....	44
5.1.1 Percolation of a Portion of Applied Irrigation Water	44
5.1.2 Percolation from Surface Water Streams	46
5.1.3 Percolation of Precipitation on Non-Agricultural Lands.....	48

WHITE WOLF SUBBASIN TECHNICAL STUDY

TABLE OF CONTENTS

<u>Section</u>	<u>Page No.</u>
5.1.4 Percolation of Wastewater Discharges	48
5.1.5 Groundwater Inflow From Adjacent Basins	49
5.2 Outflows	49
5.2.1 Groundwater Pumping for Agricultural Use	49
5.2.2 Groundwater Flow Across the White Wolf Fault	49
5.2.3 Discharges to Springs	50
5.2.4 Pumping For Municipal and Industrial Use	50
5.3 Change in Storage	51
5.4 Discussion	52
6.0 GROUNDWATER MANAGEMENT	54
6.1 Management Agencies	54
6.2 History of Sustainable Groundwater Management	54
6.2.1 Groundwater Management – Wheeler Ridge-Maricopa Water Storage District	55
6.2.2 Groundwater Management – Arvin-Edison Water Storage District.....	56
6.2.3 Groundwater Management – Tejon-Castac Water District	57
6.3 Current and Future Sustainable Groundwater Management	57
6.3.1 SGMA Implementation	58
6.3.2 Planned Groundwater Management Projects	58
7.0 CONCLUSION	60
8.0 REFERENCES	62

WHITE WOLF SUBBASIN TECHNICAL STUDY

TABLES

Table 1 – DWR Requirements for a Scientific Basin Boundary Modification Request

Table 2 – Historical Climatic Conditions

Table 3 – Estimated Hydraulic Properties of the White Wolf Subbasin Alluvial Aquifer

Table 4 – Typical Groundwater Production Well Characteristics in the White Wolf Subbasin

Table 5 – Precipitation and Reference Evapotranspiration Data Used in Water Balance Calculations

Table 6 – Summary of White Wolf Subbasin Water Balance

FIGURES

Figure 1 – Proposed White Wolf Subbasin Boundary

Figure 2 – Water Suppliers overlying the White Wolf Subbasin

Figure 3 – Surficial Geology in and Surrounding the White Wolf Subbasin

Figure 4 – White Wolf Fault Traces by Various Investigators

Figure 5 – Locations of Oil Fields and Depth to Base of Fresh Water

Figure 6 – Prominent Surface Water Features in the White Wolf Subbasin

Figure 7 – Land Use in and Surrounding the White Wolf Subbasin

Figure 8 – Geologic Cross-Section through the White Wolf Subbasin

Figures 9a-b – Conceptual Model of the White Wolf Subbasin

Figure 10 – White Wolf Subbasin Index Well Hydrograph

Figure 11a – Groundwater Elevation Contours, Spring 2015

Figure 11b – Groundwater Elevation Contours, Spring 2011

Figure 11c – Groundwater Elevation Contours and Data, Spring 2013 and Spring 2011

WHITE WOLF SUBBASIN TECHNICAL STUDY

Figure 12 – Water Level Transects for Hydrographs

Figures 13a-e – Transect and Well Pair Hydrographs

Figure 14 – Water Balance Schematic

Figure 15 – Location of Pumping Test Well in Relation to White Wolf Fault

Figure 16a-d – Hydrographs From February 2016 Step-Drawdown Pumping Test

Figure 17 – Water Quality Subareas and Stiff Diagrams

Figure 18 – Groundwater Elevation Change, Spring 2005 – Spring 2010

APPENDICES

Appendix A – Selected DOGGR Oil Field Information

- A.1 Comanche Point
- A.2 North Tejon
- A.3 Pleito
- A.4 Tejon
- A.5 Tejon Flats
- A.6 Tejon Hills
- A.7 Valpredo
- A.8 Wheeler Ridge

Appendix B – Geology and Stratigraphy of the White Wolf Subbasin

- B.1 WRMWSD (2007)
- B.2 Sheirer (2003)
- B.3 Goodman and Malin (1992)

Appendix C – Water Level Data Showing the White Wolf Fault as a Significant Impediment to Groundwater Flow

- C.1 DWR
- C.2 USGS
- C.3 WRMWSD
- C.4 AEWSD
- C.5 Bookman-Edmonston (1995)
- C.6 Hagan (2001)

Appendix D – Selected References Regarding the White Wolf Fault as a Significant Impediment to Groundwater Flow

- D.1 Dibblee (1955)
- D.2 Davis et al. (1959)
- D.3 Wood and Dale (1964)
- D.4 Anderson et al. (1979)
- D.5 Hagan (2001)
- D.6 AEWSD (2003)
- D.7 WRMWSD (2007)

Appendix E – Selected Groundwater Models Including the White Wolf Fault as a Significant Impediment to Groundwater Flow

- E.1 Williamson et al. (1989)
- E.2 Bookman-Edmonston (2007)
- E.3 Faunt et al. (2009)
- E.4 Brush et al. (2013)

Appendix F – Water Quality Data and Maps

- F.1 Wood and Dale (1964)
- F.2 WRMWSD (2007)
- F.3 USGS
- F.4 Hagan (2001)

Appendix G – Land Subsidence

- G.1 Lofgren (1975)
- G.2 WRMWSD (2007)

Appendix H – Memorandum of Understanding Between AEWSD, WRMWSD, and TCWD Regarding the White Wolf Subbasin

1.0 INTRODUCTION

The first comprehensive groundwater legislation in California history, the Sustainable Groundwater Management Act of 2014 (SGMA), was enacted on 16 September 2014 as part of a three-bill package including Assembly Bill (AB) 1739 (Dickinson), Senate Bill (SB) 1169 (Pavley), and SB 1319 (Pavley). The legislation provides a framework for the sustainable management of groundwater by local agencies, with an emphasis on the preservation of local control. The state agencies primarily responsible for implementing SGMA are the California Department of Water Resources (DWR) and the State Water Resources Control Board (SWRCB).

Implementation of SGMA will be phased in over several years, and the first major milestone was achieved in November 2015 with the adoption of the Basin Boundary Emergency Regulations. As directed by California Water Code (CWC) §10722.2, DWR developed these regulations to provide local agencies the opportunity to petition DWR to consider a change to existing groundwater basin boundaries. The regulations allow basin boundary modification requests to be submitted on both jurisdictional and scientific grounds. Basin boundary modification requests will be accepted by DWR between 1 January and 31 March 2016, and at certain intervals thereafter coincident with the update of *Bulletin 118 – California’s Groundwater*.

1.1 Basin Boundary Emergency Regulation Requirements

The DWR Basin Boundary Emergency Regulations require that documentation of specific processes and information be submitted by an agency a part of a basin boundary modification request. The requirements of a requesting agency include, but are not limited to:

- Notifying DWR and providing public information about the request within 15 days of the initial decision to explore boundary modification;
- Consulting with all affected local agencies¹ or systems² regarding the proposed revision and providing copies of all associated communications;

¹ Affected agency is defined by DWR as “a local agency, as defined in Water Code §10721(m), whose jurisdictional area would, as a result of a boundary modification, include more, fewer, or different basins or subbasins than without the modification.”

² Affected system is defined by DWR as “a public water system, as defined in Water Code §10721(r), whose service area would, as a result of a boundary modification, include more, fewer, or different basins or subbasins than without the modification.”

WHITE WOLF SUBBASIN TECHNICAL STUDY

- Providing copies of the requesting agency's enabling statute and a resolution adopted by the agency formally initiating the boundary modification request;
- Providing a detailed description of the proposed basin boundaries, including a written description, graphical map, and supporting geographic information system (GIS) files;
- Developing a "Hydrogeologic Conceptual Model" that provides a detailed description of the proposed basin or subbasin demonstrating key geologic and hydrologic characteristics³;
- Conducting a comprehensive technical study including further geologic and hydrologic evidence of groundwater conditions within the proposed basin or subbasin⁴;
- Determining if the proposed revision will trigger action under the California Environmental Quality Act (CEQA) and, if so, providing necessary information to enable DWR to satisfy its requirements as a responsible agency; and
- Notifying all interested local agencies and systems within five days of receiving notice from DWR that the request is complete.

All information required of boundary modification requests must be submitted through DWR's web-based submission platform, the Basin Boundary Modification Request System.

1.2 Purpose

The purpose of the *White Wolf Subbasin Technical Study* (Study) is to support the basin boundary modification request (Request) being jointly submitted to DWR by Wheeler-Ridge Maricopa Water Storage District (WRMWS), Arvin-Edison Water Storage District (AEWS), and Tejon-Castac Water District (TCWD) (collectively referred to as the Districts), in accordance with the Basin Boundary Emergency Regulations.⁵ The

³ Information to be provided in the hydrogeologic conceptual model includes, but is not limited to: principal aquifer units; recharge and discharge areas; definable bottom of the basin or subbasin; geologic features impeding or impacting flow; aquifer characteristics impeding or impacting flow, key surface water bodies, groundwater divides; significant recharge sources; degree of confinement; facies changes; truncation of units; and faults and folds.

⁴ Information to be provided in the technical study includes, but is not limited to: a qualified map depicting lateral boundaries; subsurface data illustrating vertical thickness; a qualified map depicting geology structures or features impeding flow; historical potentiometric surface maps; current potentiometric surface map; groundwater level data; recharge and discharge areas; aquifer performance testing results; water quality information; geophysical investigations and supporting data; and other relevant technical information

⁵ While TCWD is the requesting agency for the Request, WRMWS and AEWS have adopted resolutions supporting the filing of the request and have participated actively in the process of developing the Request and this Study.

WHITE WOLF SUBBASIN TECHNICAL STUDY

Request is a scientific request that involves the subdivision of the Kern County Subbasin of the San Joaquin Valley Groundwater Basin (DWR Basin 5-22.14) into two separate subbasins: the Kern County Subbasin and the White Wolf Subbasin (Subbasin). As shown on Figure 1, the proposed revision divides the subbasins along the White Wolf Fault (WWF), relying upon scientific evidence that demonstrates that the WWF provides a significant impediment to groundwater flow.

This Study presents technical information compiled from publically-available data, peer-reviewed scientific studies, government publications, and reports and data provided by local water agencies. Several reports were relied on heavily in the development of this report, including the following: seminal hydrogeological research conducted in the region by Wood and Dale (1964); groundwater management plans developed by WRMWSD (WRMWSD, 2007) and AEWSD (AEWSD, 2003); a dissertation investigating the WWF's impact on groundwater flow (Hagan, 2001); and a comprehensive geologic study conducted in the region (Goodman and Malin, 1992). Additionally, original data and data analysis are included in the Study based on work done on behalf of TCWD.

The information provided herein fulfills the technical requirements specified in the Basin Boundary Emergency Regulations, including a comprehensive description of the Subbasin hydrogeology. The Study also describes the on-going sustainable groundwater management within the Subbasin by TCWD and the other overlying water districts, WRMWSD and AEWSD. Specifically, the following information is included in the Study:

- Section 1 – Introduction
- Section 2 – White Wolf Subbasin Subbasin Description
- Section 3 – White Wolf Subbasin Geology
- Section 4 – White Wolf Subbasin Hydrogeology
- Section 5 – White Wolf Subbasin Water Balance
- Section 6 – White Wolf Subbasin Groundwater Management

Additional supporting data, figures, and reports are included as Appendices A through H. A summary of DWR's requirements, as specified in the Basin Boundary Emergency Regulations, and where they are addressed in this Study, is presented in Table 1.

WHITE WOLF SUBBASIN TECHNICAL STUDY

Table 1 – DWR Requirements for a Scientific Basin Boundary Modification Request

Requirement	Study Section	Basin Boundary Revision Regulation
Procedural		
<i>Notifications</i>		
Notify DWR within 15 days of initial decision to explore request	--	§343.9 (a)
Post public information within 15 days of initial decision	--	§343.9 (a)
Notify local agencies within five days of complete request	--	§343.10 (d)
Respond to public input	--	§343.12 (d)
Satisfy requirements of CEQA	--	§344.18
Supporting Information		
<i>Requesting Agency Information</i>		
Name and mailing address	--	§344.2 (a)
Statutory or legal authority	--	§344.2 (b)
Resolution to initiate boundary modification request	--	§344.2 (c)
Name and contact information for request manager	--	§344.2 (d)
<i>Notice and Consultation</i>		
List of all local agencies or public water systems in the affected basins or subbasins	--	§344.4 (a)
Explanation of methods used to identify affected agencies or systems	--	§344.4 (b)
Description of nature of consultation with affected agencies or systems	--	§344.4 (c)
Summary of public meetings	--	§344.4 (d)
Summary of public comments	--	§344.4 (e)
<i>Description of Proposed Boundary Modification</i>		
Category of boundary modification	1.1	§344.6 (a) (1)
Identify all affected basins or subbasins	1.1	§344.6 (a) (2)
Proposed name of new basin or subbasin	1.1	§344.6 (a) (3)
<i>Local Agency Input</i>		
Proof that information was provided to affected agencies or systems	--	§344.8 (a) (1)
Comments and documents of support or opposition	--	§344.8 (a) (2)
Evidence rebutting statements of opposition	--	§344.8 (a) (3)

WHITE WOLF SUBBASIN TECHNICAL STUDY

Table 1 – DWR Requirements for a Scientific Basin Boundary Modification Request

Requirement	Study Section	Basin Boundary Revision Regulation
General Information		
<i>Define Basin Boundaries</i>		
Lateral boundaries	2.1.1	§344.10 (a)
Definable bottom of the basin or subbasin	2.1.2	§344.10 (a)
<i>Graphical Map</i>		
Proposed basin or subbasin boundary	Fig. 1	§344.10 (b)
Existing DWR basin or subbasin boundary	Fig. 1	§344.10 (b)
Local agencies within or bordering proposed basin	Fig. 2	§344.10 (b)
Hydrogeologic Conceptual Model		
Principal aquifer units	4.1	§344.12 (a) (1)
Recharge and discharge areas	4.4.4	§344.12 (a) (3)
Definable bottom of the basin	2.1.2	§344.12 (a) (4)
<i>Lateral Boundaries of Proposed Basin</i>		
Geologic features impeding or impacting groundwater flow	4.4.2	§344.12 (a) (2) (A)
Aquifer characteristics impeding or impacting flow	4.4.2	§344.12 (a) (2) (B)
Key surface water bodies	2.3	§344.12 (a) (2) (D)
Groundwater divides	4.4.1	§344.12 (a) (2) (D)
Significant recharge sources	4.4.4, 5.1	§344.12 (a) (2) (D)
Other geologic and hydrologic features:		
Confined or unconfined nature of the aquifer	4.1	§344.12 (a) (2) (C)
Facies changes	3.2, 4.1	§344.12 (a) (2) (C)
Truncation of units	3.2, 4.1	§344.12 (a) (2) (C)
Faults and folds	3.3	§344.12 (a) (2) (C)

WHITE WOLF SUBBASIN TECHNICAL STUDY

Table 1 – DWR Requirements for a Scientific Basin Boundary Modification Request

Requirement	Study Section	Basin Boundary Revision Regulation
Technical Study		
<i>Extent of Aquifers</i>		
Qualified map depicting lateral boundaries	Fig. 3	§344.14 (a) (1)
Technical study with subsurface data	App. B	§344.14 (a) (2)
<i>Presence of Impediments to Subsurface Groundwater Flow</i>		
Qualified map depicting geologic structures or features impeding flow	Fig. 8	§344.14 (b) (1)
Technical study providing geologic or hydrologic evidence of groundwater conditions, as appropriate:		
Historical potentiometric surface maps	Fig. 11b, Fig. 11c, App. C	§344.14 (b) (2) (A)
Current potentiometric surface map	Fig. 11a	§344.14 (b) (2) (A)
Groundwater levels	4.3	§344.14 (b) (2) (A)
Recharge and discharge areas	4.4.4	§344.14 (b) (2) (A)
Aquifer performance testing results	4.5	§344.14 (b) (2) (B)
Water quality information	4.6	§344.14 (b) (2) (C)
Geophysical investigations and supporting data	3.2 3.3	§344.14 (b) (2) (D)
Other relevant technical information	--	§344.14 (b) (2) (E)
Other technical information required by DWR	--	§344.14 (b) (3)

2.0 WHITE WOLF SUBBASIN SUBBASIN DESCRIPTION

As shown on Figure 1, the proposed Subbasin is located at the southern end of the San Joaquin Valley, approximately 16 miles southwest of Bakersfield along State Highway 99. The Subbasin consists of 107,526 acres that are bounded on the north by the WWF and by mountain ranges on the other three sides. The majority of the Subbasin is included in the service areas of WRMWSD, AEWSD, and TCWD (see Figure 2). Irrigated agriculture is the primary land use and is facilitated by a semi-arid climate and the delivery of imported surface water by the Districts. The Subbasin has also been a productive region for oil and gas exploration. The Subbasin is described in detail in the following subsections.

2.1 Boundaries

Consistent with DWR's definition of groundwater basins in *California's Groundwater – Bulletin 118, Update 2003*⁶ (DWR, 2003), the western, southern, and eastern boundaries of the Subbasin are defined by extent of alluvium, and the northern boundary is defined by a fault (the WWF) that significantly impedes groundwater flow. The bottom of the Subbasin is defined by the depth to base of freshwater. The lateral and vertical boundaries of the Subbasin are described in the following subsections.

2.1.1 Lateral Boundaries

As shown on Figure 3, the Subbasin is bounded on the east, south, and west by the extent of alluvium, as drawn in geologic maps produced by the California Division of Mines and Geology (CA DMG, 1964; CA DMG, 1969). The extent of alluvium in these maps was utilized by DWR when it established the current Kern County Subbasin boundaries in *California's Groundwater – Bulletin 118, Update 2003* (DWR, 2003). Thus, there is no proposed revision to the existing western, southern, and eastern boundaries of the Subbasin.

The northern boundary of the Subbasin is formed by the WWF. The history and structure of the WWF are summarized in Section 3.3.1. As discussed in detail in Section 4.4.2, the preponderance of evidence indicates that the WWF acts as a significant impediment to subsurface groundwater flow. After compiling more than a dozen published traces of the fault, presented on Figure 4, and reviewing historical water level and water quality data, the Wood and Dale (1964) trace was selected as the northern

⁶ Groundwater basin boundaries are presented in Figure 3, Figure 20, and the accompanying digital map. Groundwater basins are defined in Chapter 6, and the methodology utilized in the development of the current groundwater basin boundaries is summarized in Appendix G.

Subbasin boundary based on its conformance to the hydrologic data. This trace of the WWF extends southwest from Comanche Point in the northeast to the center of Wheeler Ridge in the northwest. The Subbasin boundary then follows the extent of alluvium around the south side of Wheeler Ridge until it meets the San Emigdio Mountains.

2.1.2 Definable Bottom of the Subbasin

The bottom of the Subbasin is defined by the depth to alluvium or the base of fresh water. Geological and statistical data, including depth to base of fresh water, has been collected at oil and gas fields throughout the region. These data have been aggregated by the California Department of Oil, Gas, and Geothermal Resources (DOGGR) and are presented in Appendix A. Figure 5 presents contours of the depth to base of fresh water, as defined by DOGGR to be the depth where groundwater exceeds 3,000 milligrams per liter (mg/L) of total dissolved solids (TDS)⁷. The vertical extent of fresh water in the Subbasin is deepest in the center of the valley trough and in the northern portion of the Subbasin; depth to freshwater in these areas exceeds 2,000 feet below ground surface (ft bgs). Investigations of the Subbasin in the 1970s determined that fresh water occurs in water-bearing strata to depths of nearly 2,500 ft bgs (Bookman-Edmonston, 1975; Anderson et al., 1979). The depth to base of fresh water declines towards the margins of the Subbasin, where alluvial layers thin and eventually meet bedrock at the Subbasin boundary. North of the WWF, in the Kern County Subbasin, the depth to base of fresh water is generally greater than in the Subbasin, with values ranging from 2,500 to 5,500 ft bgs.

2.2 Topography

Ground surface elevations in the Subbasin range from approximately 700 feet above mean sea level (MSL) at in the vicinity of the WWF to greater than 1,600 feet MSL in the southern portion of the Subbasin. The Subbasin is bordered on the east, south, and west by mountain ranges.

⁷ The United States Environmental Protection Agency (US EPA) defines water with a TDS concentration of less than 3,000 mg/L to be suitable for livestock consumption or crop irrigation. Water between 3,000 mg/L and 10,000 mg/L is defined as “usable quality water” and water exceeding 10,000 mg/L is defined as “brine.” The United States Geological Survey (USGS) commonly refers to water with a TDS concentration of less than 1,000 mg/L as freshwater. A recent USGS report (Osborn et al., 2013) completed as part of the Brackish Groundwater Assessment defined saline groundwater as follows: “slightly saline” groundwater containing a TDS concentration between 1,000 and 3,000 mg/L; “moderately saline” groundwater containing a TDS concentration between 3,000 and 10,000 mg/L; “very saline” groundwater containing a TDS concentration between 10,000 and 35,000 mg/L; and “brine” containing a TDS concentration exceeding 35,000 mg/L. For the purposes of this Study, the DOGGR definition of 3,000 mg/L was utilized to describe the base to fresh water.

2.2.1 Mountain Ranges

To the east and north of the Subbasin lies the Sierra Nevada, a north-south trending, westward-tilting, fault block. Summit elevations in this portion of the mountain range are typically between 5,000 and 7,000 feet MSL, with some local peaks exceeding 8,000 feet MSL. The southern terminus of the 370-mile Sierra Nevada occurs just to the east of the Subbasin, at the junction with the Tehachapi Mountains.

The Tehachapi Mountains are located to the south and east of the Subbasin and form the southern border of the San Joaquin Valley. Although topographically continuous with the Sierra Nevada, the two ranges bear little structural or genetic resemblance. Rather, the Tehachapi Mountains, which consist of a complex horst lifted principally by faulting, possess more similarities to the Transverse Ranges to the south and Central Coast Ranges to the west (Buwalda, 1954). The Tehachapi Mountains extend approximately 50 miles southwest from the junction with the Sierra Nevada to Grapevine Creek. Elevations in the Tehachapi Mountains are generally 4,000 to 5,000 feet MSL.

To the west of the Subbasin, the San Emigdio Mountains extend from the intersection with the Tehachapi Mountains at Grapevine Creek to Cienaga Canyon, where they meet the Temblor Ranges. Elevations in the San Emigdio Mountains are typically between 5,000 and 6,500 feet MSL.

2.2.2 General Physical Features

Davis et al. (1959) identified four common landforms observed throughout the San Joaquin Valley: dissected uplands; low plains and fans; flood plains and channels; and overflow lands and lake bottoms. Dissected uplands consist of a discontinuous belt of hills of moderate relief that constitute the transition from the steep upper slopes of the mountain ranges to the more rounded slopes of the foothills. In the Subbasin, the most prominent dissected uplands are the Tejon Hills and a group of hills south of Tejon Creek. Throughout the Subbasin, dissected uplands also occur where old alluvial deposits are eroded by creeks, such as the alluvial plain south of Comanche Point, old terrace remnants near the mouth of Tejon Canyon, and dissected alluvial fans east of Pastoria Creek (Wood and Dale, 1964). Low plains and coalescing alluvial fans connect these dissected uplands to the flat valley floor. Flood plains and channels are observed in the Subbasin perpendicular to mountain ranges before they disappear in the alluvial plains. Overflow lands and lake bottoms are not present in the Subbasin, but are observed nearby in the now-dry Buena Vista Lake and Kern Lake in the Kern County Subbasin to the north.

2.3 Surface Water Features

The southern portion of the San Joaquin Valley consists of a series of drainage systems that convey runoff from the surrounding mountain ranges to terminal lakebeds, such as Buena Vista Lake, Kern Lake, and Tule Lake. Although these lakes historically held water, most flows from contributing streams are diverted for irrigation or percolate before reaching the valley trough (Wood and Dale, 1964). The largest surface water feature in the region, Kern River, is almost entirely diverted before it reaches Kern Lake and Buena Vista Lake.

Surface water features in the Subbasin are shown on Figure 6 and include ephemeral streams draining the Tehachapi Mountains, the California Aqueduct, and a network of irrigation canals and ditches. The primary streams in the Subbasin are Tejon Creek, El Paso Creek, Tunis Creek, Pastoria Creek, Grapevine Creek, and Salt Creek. Due to the intermittent nature of flows in these creeks, flow measurement data in, and contributing to, the Subbasin are sparse. Under normal conditions, water in these creeks percolates into the alluvial sediments and minimal surface water reaches the valley floor (AEWSD, 2003; WRMWSD, 2007). The California Aqueduct, operated by DWR as the backbone of the State Water Project (SWP), runs southeast from the northwest corner of the Subbasin to the southern boundary, where the A.D. Edmonston Pumping Plant lifts water up and over the Tehachapi Mountains. Irrigation in the Subbasin is supported mostly by a network of distribution pipelines. The only major irrigation canal in the Subbasin is the 850 Canal, a seven-mile, concrete-lined canal operated by WRMWSD. Private landowners utilize irrigation ditches and holding ponds to convey and store water on their properties.

2.4 Climate

The Subbasin is characterized as a semi-arid climate with favorable conditions for agriculture. A summary of average monthly climatic conditions is presented in Table 2. Mean daily maximum temperatures in the summer exceed 96 degrees Fahrenheit (°F) and mean daily minimum temperatures in the winter are less than 37°F. The Subbasin is located in Reference Evapotranspiration (ET_o) Zone 15, as defined by California Irrigation Management System (CIMIS), which is distinguished from other areas of the San Joaquin Valley by the prevalence of fog in the winter. The average annual Zone 15 ET_o is 57.9 inches, and from 1995 to 2015 the actual annual average ET_o in the Subbasin region was 60.24 inches.⁸

⁸ Based on daily climatic data from the CIMIS Arvin-Edison Station.

WHITE WOLF SUBBASIN TECHNICAL STUDY

Total precipitation throughout the Subbasin averaged 9.00 inches per year over the period 1986 through 2014⁹. The Subbasin receives over 87% of its rainfall in the wet months of November through April. The historic drought of 2012 to 2015 significantly impacted rainfall in the Subbasin; two of the driest three years since 1986 occurred in 2014 and 2013, with total annual precipitation of 2.64 inches and 4.56 inches, respectively. The maximum recorded rainfall during the same period occurred in 1998 (18.78 inches).

Table 2 – Historical Climatic Conditions

Month	Mean Total Precipitation (inches) (a)	Mean Reference Evapotranspiration (inches) (b)	Mean Daily Maximum Temperature (degrees F) (b)	Mean Daily Minimum Temperature (degrees F) (b)
January	1.58	1.54	58.7	38.7
February	1.54	2.33	63.6	41.7
March	1.76	4.12	69.5	45.7
April	0.78	5.61	73.7	48.5
May	0.33	7.65	82.0	55.4
June	0.06	8.65	89.9	61.2
July	0.04	9.08	96.3	66.8
August	0.06	8.45	95.3	64.7
September	0.15	6.12	90.3	59.7
October	0.45	4.07	79.3	50.4
November	1.01	2.06	66.8	42.1
December	1.25	1.42	59.2	36.8
Total	9.00	61.10	--	--

(a) Precipitation based on spatially weighted average over Subbasin of gridded monthly normal (1981-2010) precipitation data from the National Weather Service Advanced Hydrologic Prediction Service.

(b) Reference evapotranspiration in Subbasin based on data from Arvin-Edison CIMIS station.

Precipitation in the Subbasin varies spatially, with higher rainfall occurring in the foothills to the south and east. For example, average annual rainfall over the period 1986 through 2014 was more than half an inch higher at a weather station in the southern portion of the Subbasin¹⁰ (8.25 inches) than average rainfall in the central portion of the

⁹ Precipitation based on spatially weighted average over Subbasin of gridded monthly normal (1981-2010) precipitation data from the National Weather Service Advanced Hydrologic Prediction Service.

¹⁰ Measured at the WRMWSD Spillway Basin Climate Station, located at the end of the 850 Canal near Pastoria Creek.

Subbasin¹¹ (7.69 inches). Precipitation is highest in the southeastern portion of the Subbasin; rainfall at a weather station¹² in this area over the same period averaged 10.89 inches.

2.5 Land Use

The Subbasin has experienced relatively limited urban and industrial development to date and the primary land uses in the Subbasin are irrigated agriculture and grazing. As shown on Figure 1, Interstate 5 runs north-south through the western portion of the Subbasin, and State Highway 99 overlies a small portion of the northwestern portion of the Subbasin before it merges with Interstate 5. As shown on Figure 6, the California Aqueduct enters the Subbasin in the northwest, passes through the Ira J. Chrisman Wind Gap Pumping Plant, traverses the southwest portion of the Subbasin, and exits at the A.D. Edmonston Pumping Plant, where water is pumped up and over the Tehachapi Mountains.

The Subbasin consists of irrigated agriculture, limited development along Interstate 5, oil and gas exploration, and undeveloped land along the margins of the Subbasin. Current land uses within and adjacent to the Subbasin are presented on Figure 7 and described below.

2.5.1 Irrigated Agriculture

The primary land use in the Subbasin is irrigated agriculture, comprising 41% of the total land area in the Subbasin (44,090 acres) in 2013. As described further in Section 2.6, WRMWSD and AEWSD deliver imported surface water and pumped groundwater for agricultural purposes in the Subbasin.

Permanent crops within the WRMWSD service area include the following: almonds, apples, pears, cherries, plums, prunes, citrus, grapes, subtropical trees, miscellaneous deciduous crops, peaches, nectarines, apricots, and pistachios. In 2013, almonds, citrus, and grapes represented nearly 70% of irrigated acreage in the district's service area (WRMWSD, 2015). Over 90% of WRMWSD is irrigated with micro-drip systems, with the remainder irrigated with other high-efficiency systems such as micro-sprinklers and sprinklers.

¹¹ Measured at the WRMWSD PA-2 Pumping Plant Climate Station, located near the intersection of Interstate 5 and Highway 99.

¹² Measured at the National Oceanic and Atmospheric Association Tejon Rancho Station.

The dominant crops in AEWSD's service area from 2007 through 2011 were grapes, citrus, potatoes, carrots, and small grains (AEWSD, 2015). Based on a spring 2011 land used survey (AEWSD, 2015), the predominant land uses within AEWSD's portion of the Subbasin were vineyard, truck and field crops, and deciduous orchard. Since the late 1960s, the proportion of permanent crops in the AEWSD service area has risen from approximately 20% to 50%.

2.5.2 Commercial and Industrial Areas

The Tejon Ranch Commerce Center (TRCC), owned and operated by the Tejon Ranch Company and served by TCWD, is the only large non-agricultural development in the Subbasin. Covering 1,450 acres along Interstate 5, TRCC leases land for commercial purposes such as warehousing and distribution and retail outlets. In addition to TRC, the Subbasin contains a power plant and an active gravel mine. The Pastoria Energy Facility, owned and operated by Calpine Corporation, is located on the southern border of the Subbasin, adjacent to the A.D. Edmonston Pumping Plant. Griffith Company operates a sand and gravel mine in the Subbasin.

2.5.3 Oil and Gas Exploration

The Subbasin has historically been a productive region for oil and gas exploration. Active oil fields in the Subbasin are shown on Figure 5 and include the following¹³: Comanche Point, North Tejon, Pleito, Tejon, Tejon Hills, Valpredo, and Wheeler Ridge. The Tejon Flats oil field has been abandoned. In 2014, oil fields in the Subbasin produced nearly 160,000 barrels of oil and a net of approximately 860,000 million cubic feet of gas (DOGGR, 2015).

2.5.4 Undeveloped Areas

The western, southern, and eastern margins of the Subbasin have not experienced the agricultural, commercial and industrial, or oil and gas development that has occurred elsewhere in the Subbasin. These portions of the Subbasin are outside of the water service areas of the Districts.

2.6 Water Suppliers

Three water suppliers serve customers in the Subbasin: WRMWSD, AEWSD, and TCWD. The locations of these water suppliers in relation to the Subbasin is shown on Figure 2. These water suppliers have a long history of active groundwater management

¹³ Oil field locations were obtained from the DOGGR GIS Database.

in the Subbasin, and their efforts have played a significant role in the Subbasin recovering from a period of groundwater overdraft that was observed prior to the 1970s.

2.6.1 Wheeler Ridge-Maricopa Water Storage District

The WRMWSD overlies nearly 150,000 acres in the southern San Joaquin Valley, including a substantial portion of the Subbasin and contiguous lands to the north and west. Lands located within the Subbasin (57,900 acres) comprise about 38% of WRMWSD's total service area.¹⁴ The WRMWSD was formed in 1959 for the purpose of securing and executing a surface water supply contract from the Feather River Project, the predecessor to the SWP. In 1971, WRMWSD began serving SWP water to its service area, and deliveries to the Subbasin began in 1975. The WRMWSD has been actively engaged in groundwater management within the Subbasin for decades, as described in more detail in Section 6.2. The WRMWSD is governed by nine elected members forming a Board of Directors and is operated by a staff of 43 employees.

The WRMWSD delivers an average of 169,000 acre-feet per year (AFY) of imported surface water and groundwater, including approximately 39,000 to 49,000 AFY in the Subbasin (Bookman-Edmonston, 2007). Over the period 2011 through 2015, WRMWSD delivered the following quantities of water to the Subbasin: 51,639, 38,210, 35,435, 22,738, and 20,832 acre-feet. The WRMWSD distribution system in the Subbasin is comprised of the following: the seven-mile long, concrete-lined 850 Canal, which conveys water from a turnout on Reach 15 of the California Aqueduct to the eastern portion of the Subbasin; four turnouts located on Reach 16 of the California Aqueduct distributed by a network of pipelines; and a series of pumping plants.

Imported SWP water is provided through a contractual agreement with the Kern County Water Agency (KCWA), which coordinates delivery of SWP water to 13 water districts in Kern County. The KCWA SWP Table A Contract Amount is 982,730 AFY, of which WRMWSD is entitled to 197,088 AFY. As discussed in more detail in Section 4.2, WRMWSD produces and distributes groundwater when SWP allocations are inadequate to meet irrigation demands. Additionally, private land owners within the district pump groundwater for irrigation. Over the years, WRMWSD has secured additional water supplies from groundwater banking projects and other imported supplies, such as Kern Water Bank, Pioneer Project, and Berrenda Mesa Project. The maximum combined recovery capacity for these banking programs was 93,800 AFY in

¹⁴ The portion of the WRMWSD service area that is served surface water through distribution lines and turnouts is sometimes referred to as the Surface Water Service Area (SWSA). For the purposes of this Study, the WRMWSD 'service area' refers to the entirety of the WRMWSD boundaries, including both the SWSA and non-SWSA lands.

2007 (WRMWSD, 2007). Groundwater management activities conducted by WRMWSD are summarized in Section 6.2.

2.6.2 Arvin-Edison Water Storage District

The AEWSD operates 170 miles of pipeline and 45 miles of canals to serve approximately 132,000 acres of land extending from the Subbasin in the south towards the cities of Arvin and Bakersfield to the north and east. The portion of AEWSD's service area overlying the Subbasin totals 23,363 acres, or over 17% of the total acreage. Within or near the Subbasin, AEWSD operates two pressurized pipeline systems known as the Tejon System and the White Wolf System. As described further in Section 6.2, like WRMWSD and TCWD, AEWSD is actively involved in groundwater management in the Subbasin, and its efforts have played a significant role in the Subbasin recovering from a historical period of groundwater overdraft (AEWSD, 2003). The AEWSD and WRMWSD manage approximately 20,000 acres of overlapping service areas in the northern portion of the Subbasin (i.e., the "checkerboard" area shown on Figure 2); groundwater management is coordinated between the two agencies in this area.

The AEWSD was formed in 1942 for the purpose of contracting with the federal government for water service from the Central Valley Project (CVP). In 1962, AEWSD began delivering CVP water to its service area in accordance with a long-term contract with the United States Bureau of Reclamation (USBR). Water deliveries to the Subbasin began in 1967. Arvin-Edison's USBR contract, which is valid through 2026 with provisions for renewal, provides for 40,000 AFY of firm Class 1 water and up to 311,675 AFY of non-firm Class 2 water from the Friant-Kern System of the CVP. The AEWSD also participates in exchange agreements with other public agencies that provide for the substitution of Friant-Kern water for Shasta CVP water, delivered through the California Aqueduct and Cross Valley Canal. The AEWSD has also engaged in banking agreements with Metropolitan Water District of Southern California and Rosedale-Rio Bravo Water Storage District to increase the reliability and flexibility of its surface water supplies. In addition to imported surface water, the AEWSD relies on groundwater to fulfill irrigation needs. Groundwater production by AEWSD and its private landowners is discussed in more detail in Section 4.2. The AEWSD is also investigating reuse of oilfield wastewater (AEWSD, email correspondence, 26 February 2016).

2.6.3 Tejon-Castac Water District

The TCWD manages approximately 12,400 acres in the Subbasin, of which approximately 9,500 acres overlap WRMWD's service area. Within the Subbasin,

TCWD provides water and wastewater service to the TRCC, the only commercial development in the Subbasin. In addition to the commercial and industrial demand at TRCC, TCWD contributes approximately 100 AFY of water for various regional and system-wide purposes. In the past, TCWD has occasionally conducted temporary transfers of surplus water supplies to other water users for uses such as agricultural irrigation.

The TCWD has rights to receive 5,278 AFY of SWP surface water supplies under contracts with KCWA. As discussed in Section 4.2.4, TCWD operates three groundwater wells in the vicinity of the TRCC. Additional water supplies include exchanges with a CVP contractor, water rights to high flows in the Lower Kern River, and water banking with the Kern Water Bank and Pioneer Project. The TCWD operates a 100,000 gallons per day (gpd) wastewater treatment facility, and tertiary-treated water from this facility produces recycled water for irrigation use at the TRCC.

3.0 WHITE WOLF SUBBASIN GEOLOGY

The Subbasin is located in the Southern San Joaquin Basin (SSJB) at the southern end of the Great Valley. The SSJB is bounded on the north by the Bakersfield Arch and on the south by the intersection of the San Andreas and Garlock Faults. The Subbasin is a sedimentary trough that is separated from the rest of the SSJB by the WWF system. Underlying the Subbasin is the U-shaped Tejon embayment, which is bounded on the east and south by a crystalline basement complex of the Tehachapi Mountains and on the west by Tertiary-age sedimentary rocks of the San Emigdio Mountains. The history, stratigraphy, and structural features of the Subbasin are described below.

3.1 Geologic History

Although the crystalline basement complex underlying the Subbasin was formed during the early Cretaceous period, the formation of the Subbasin itself occurred in the Tertiary and Quaternary periods. The geologic history of the Subbasin since the early Tertiary period is presented below.

3.1.1 Paleogene

In much of the Great Valley, bedrock is overlain by deposits related to late Cretaceous-early Tertiary subduction and the associated Sierra Nevada magmatic arc. In the SSJB, however, Late Cretaceous-Paleocene and early Eocene uplift events unroofed and removed up to 30 vertical kilometers (km) of Sierran arc material (Sharry, 1981). Consequently, the oldest Tertiary rocks found in the Subbasin are mid-Eocene marine sediments of the Tejon and San Emigdio Formations, described in detail in Section 3.2.2. In the Tejon embayment, Nilsen (1987) documented a marine transgression towards the east. Over the course of the Paleogene period, the SSJB experienced the following periods of uplift and subsidence: early Eocene and Late Cretaceous-Paleocene uplift, middle Eocene subsidence, late Eocene-early Oligocene uplift, and late Oligocene subsidence (Goodman and Malin, 1992).

3.1.2 Miocene

High- and low-angle normal faulting in the central Tejon embayment began in the late Oligocene and continued into early Miocene time, resulting in a graben system of many small blocks discussed in Section 3.3.1 (Goodman et al., 1989). During this time, the SSJB also experienced submarine and subaerial volcanism (Goodman and Malin, 1992). Changes in thickness and facies across these normal faults indicate that the Tejon embayment deepened in mid-Miocene time (Goodman et al., 1989). Alternating

periods of uplift and fault-related subsidence occurred throughout mid-Miocene time, until relative stability prevailed in the late Miocene.

3.1.3 Pliocene to Present

In early Pliocene time, the SSJB region shifted from a general pattern of extension to contraction. Over the past 5 million years (Ma), thrusting and folding along the western, southern, and southeastern boundaries of the Subbasin have exhumed the basement and Tertiary section as the center of the Subbasin subsided (Goodman and Malin, 1992). Sediment deposits since Plio-Pleistocene time have created alluvial layers, such as the Kern River Formation and unconsolidated Quaternary alluvium, which are discussed in detail in Section 3.2.2.

3.2 Stratigraphy

A subsurface geologic cross-section and stratigraphic columns of the Subbasin are presented on Figure 8 and in Appendix B, respectively. The stratigraphy of the Subbasin consists generally of the following components: pre-Tertiary, crystalline basement complex; Eocene to early Pliocene sandstone, siltstone, shale, conglomerates, and minor volcanics; and late Tertiary/Quaternary-age alluvial deposits, including the Kern River Formation. The stratigraphy and lithology of the Subbasin are discussed below.

3.2.1 Crystalline Basement Complex

The Tehachapi gneiss complex forms the crystalline basement in the Subbasin and is believed to be the exposed floor of the southern Sierra Nevada batholith. This basement complex is composed of heterogeneous mafic to felsic igneous and meta-igneous rock, and is believed to be aged 120 to 110 Ma (Sharry, 1981). Along the northern boundary of the Subbasin, the depth to bedrock is nearly 8,000 ft bgs near Comanche Point to the northeast and rises to 3,000 ft bgs near Wheeler Ridge to the southwest (Buwalda and St. Arnaud, 1955).

3.2.2 Undifferentiated Tertiary Sedimentary

Overlying the basement complex is a series of Eocene to early Pliocene layers consisting of sandstone, siltstone, shale, volcanic rocks, and conglomerates. The deepest layer is the Eocene Tejon Formation, which is made up of shale, siltstone, and fine- to medium-grained sandstone. Above the Tejon Formation is another layer of Eocene marine sandstone known as the San Emigdio Formation. Moving up the stratigraphic column, the continental Oligocene Tecuya Formation in the east interfingers with the marine deposits of the Oligocene Vedder Sand to the west.

Overlying these interbedded layers is the early Miocene Tunis Volcanic Member, which is more than 2,000 feet thick under the Tejon embayment (Goodman and Malin, 1992). Above the Tunis Volcanics lie a series of marine sands, siltstones, and shale layers, including the following: Freeman Silt, Jewett Sand, Olcese Sand, Round Mountain Silt, Fruitvale Shale, and Reserve Sand. These layers, along with the Vedder Sand below and the Santa Margarita and Chanac formations above, are high-producing oil formations. In some areas of the Subbasin, the vertical extent of this formation exceeds 1,000 feet, thickening from east to west (WZI, 2013). The Kern River Formation is stratigraphically equivalent to the Tulare Formation to the west and north of the Subbasin.

Unconsolidated Quaternary alluvium forms the uppermost portion of the stratigraphic column and is lithologically similar to the Kern River Formation. Croft (1972) characterized this alluvium as arkosic and coarser than the underlying Kern River Formation, and divided it into two groups based on source: Tehachapi and San Emigdio Mountain Alluvium and Sierra Nevada Alluvium. These alluvial deposits generally consist of discontinuous beds and lenses comprised of a heterogeneous combination of sand, sandy clay, silt, gravel, and clay (Wood and Dale, 1964).

In Recent times, streams on the eastern margins of the Subbasin – including Tejon Creek, El Paso Creek, Tunis Creek, and Pastoria Creek – have deposited coarse-grained material from the Sierra Nevada and Tehachapi Mountains. As a result, alluvium in the eastern portion of the Subbasin tends to be coarse grained and moderately to highly permeable (Wood and Dale, 1964). Streams on the southern and western margins of the Subbasin, such as Grapevine Creek, Tecuya Creek, and Salt Creek, carry similar coarse-grained granitic and metaigneous material. However, these streams also traverse foothill belts underlain by sedimentary rocks, picking up fine-grained material along the way. Consequently, Recent alluvium in this portion of the Subbasin is typically poorly sorted, and the higher fraction of fine-grained sediment results in lower permeabilities relative to the eastern portion of the Subbasin.

3.3 Structural Geology

The geologic structure of the Subbasin and the underlying Tejon embayment includes the WWF defining the northern boundary; high-angle faults and a central graben in the center of the Subbasin; surrounding thrust faults; and the prominent Wheeler Ridge and Comanche Point anticlines. The structural geology of the Subbasin is summarized below.

3.3.1 Faulting

The Subbasin is located in a tectonically active region located at the southern ends of both the Great Valley and Sierra Nevada. Tectonics in the region are driven by the convergence of the Pacific Plate and the North American Plate. The San Andreas Fault, which forms the tectonic boundary between these two plates, experiences a significant deviation in trend less than 20 miles to the west of the Subbasin. This feature, known as the “Big Bend”, has created numerous additional faults over a broad compressional zone. Faults in and surrounding the Subbasin are described in the following subsections.

3.3.1.1 White Wolf Fault

The WWF is a southeast-dipping, high-angle reverse fault that forms the northern boundary of the Subbasin. Along with the Stockton Fault to the north, the fault is one of two cross-valley faults that transect the San Joaquin Valley (Hackel, 1966). The fault was first noted by Lawson (1906) and first drawn on a geologic map by Hoots (1930). In 1952, the magnitude 7.7 Arvin-Tehachapi earthquake originated on the fault and caused surface ruptures along much of the fault zone, with the most pronounced fractures occurring to the northeast of the Subbasin between Bear Mountain and Caliente Creek. Following this earthquake, many investigators conducted geologic, seismologic, and geodetic studies of the fault¹⁵. Rupturing within the Subbasin was likely absorbed by deep alluvium, and thus surface effects were not observed in this region (Oakeshott, 1955). Due to the absence of fractures in this area, variations exist in the location of fault traces that have appeared in peer-reviewed journals, engineering reports, and government publications. A collection of available traces of the WWF is presented on Figure 4.

The WWF parallels the Garlock Fault to the south and extends southwest from Caliente Creek to Wheeler Ridge, where it appears to pass under the Pleito thrust (Hill, 1955). Dip varies along the length of the WWF, with the highest angle occurring in the Subbasin (Stein and Thatcher, 1981). Along the northern boundary of the Subbasin, the WWF extends approximately 13.5 miles southwest from Comanche Point in the northeast to Wheeler Ridge in the southwest. In this region, the angle of dip near the surface has been documented between 30° and 60° to the southeast (Buwalda, 1954; Wood and Dale, 1964). Based on seismological calculations, Oakeshott (1955) estimated that the WWF dips at an angle of 60° to 66° near Wheeler Ridge.

¹⁵ Including CA DPW (1953), Dibblee and Oakeshott (1953), Buwalda (1954), Dibblee (1955), Buwalda and St. Arnaud (1955), Oakeshott (1955), Kupfer et al. (1955), Webb (1955), Hill (1955), Stein and Thatcher (1981), and more.

The age of the WWF has not been firmly established. Dibblee (1955) concludes that the WWF has been most active since the Pliocene epoch and suggests that it may have been initiated as early as Miocene time. Ross (1986) proposes that the inception of faulting occurred much earlier, during deformational events in either late Cretaceous (90 to 80 Ma) or early Eocene (55 to 50 Ma) time.

Movement by the WWF has resulted in significant vertical displacement and minor horizontal displacement. Depth to bedrock shallows to the southwest along the length of the WWF, from about 8,000 ft bgs near Comanche Point to approximately 3,000 ft bgs near Wheeler Ridge (Buwalda and St. Arnaud, 1955). Total vertical displacement of the top basement surface across the WWF has been reported in excess of 10,000 feet both at Comanche Point and along the valley floor (Dibblee, 1955; Bartow, 1984). The depth to base of Plio-Pleistocene sediments also appears to differ by close to 10,000 feet on either side of the WWF. The left-lateral displacement of the WWF has been estimated to be less than 200 feet, as indicated by horizontal continuity in the Santa Margarita Formation across the WWF and lack of evidence of offset streams along the course of the WWF (Dibblee, 1955). During the 1952 earthquake, the WWF moved two to three feet horizontally, and the Subbasin was lifted about two feet (Buwalda, 1954).

Several investigators have suggested that the WWF is not entirely isolated, but rather that it is connected with another fault or is part of a larger fault system. Dibblee (1955) posited that the WWF continues southwest from Wheeler Ridge, under the San Emigdio Mountains, and joins the San Andreas Fault. This theory would suggest that the WWF is part of the “Big Bend” rift zone. Ross (1986) proposed that the WWF is connected with the Breckenridge and Kern Canyon faults to the northeast, forming one continuous 200 km-long fault system.

3.3.1.2 Other Faults

In addition to the WWF, there are numerous other faults in and near the Subbasin. These faults, presented in the inset of Figure 8, generally consist of high-angle normal faults in the center of the Subbasin and thrust faults surrounding the Subbasin.

In the center of the Subbasin lies a graben created by a system of buried high-angle faults formed in the Miocene epoch, as described in 3.1.2. The primary faults within the Subbasin are the northeast-trending Badger and Springs faults. The Badger Fault is located in the center of the Subbasin and dips 60° to 70° northwest (Goodman and Malin, 1992). The Springs Fault lies subparallel to the WWF in the southeastern portion of the Subbasin. In addition to these two faults, there are many unnamed normal faults in the Subbasin that generally trend northwest and northeast. The northwest-striking

faults dip at approximately 45° and are locally truncated by the steeper-angle, northeast-striking faults, which dip at about 70° at shallow depths (Goodman, 1989).

There are several thrust faults surrounding the rim of the Subbasin, including the Wheeler Ridge fault to the west, the Pleito thrust system to the southwest, and the Comanche thrusts to the northeast. These thrust systems lie between zones of normal faults, which they have locally exhumed and truncated (Goodman and Malin, 1992). The WWF likely intersects and passes under the south-dipping Wheeler Ridge and Pleito thrust faults (Hill, 1955).

Other major faults in the region include the San Andreas Fault to the west and south, the Garlock Fault to the south, and the Breckenridge and Kern Canyon faults to the north and east.

3.3.2 Folding

There are two prominent, thrust-fault-cored anticlines surrounding the Subbasin: Wheeler Ridge and Comanche Point (Medwedeff, 1988; Goodman et al., 1989). Wheeler Ridge is located at the northwest corner of the Subbasin and trends generally east-west. The structural feature forming this anticline is the Wheeler Ridge thrust fault. Comanche Point is located in the northeastern portion of the Subbasin and is formed by the Comanche thrusts. In addition to the anticlines, the southwest portion of the Subbasin is bounded by folded and imbricated Tertiary sedimentary rocks of the San Emigdio Mountains (Davis and Lagoe, 1988).

4.0 WHITE WOLF SUBBASIN HYDROGEOLOGY

A hydrogeologic conceptual model of the Subbasin, including the primary inflows and outflows to groundwater storage, is schematically presented on Figures 9a and 9b. Aquifers underlying the Subbasin are productive and have historically provided water generally suitable for irrigation uses. As a result, groundwater has been developed extensively, and the Subbasin has experienced a period of overdraft followed by a steady recovery. Groundwater flows generally northward from the southern foothills until it reaches the WWF, which appears to provide a significant impediment to flow. The hydrogeology of the Subbasin is described in detail below.

4.1 Principal Aquifers

The Subbasin contains productive, water-bearing strata with a total estimated storage capacity of 4.0 million acre-feet (Anderson et al., 1979). The degree to which aquifers in the Subbasin are confined or unconfined is not agreed upon, but groundwater is generally expected to be unconfined to semiconfined to depths of 1,000 feet or more (WRMWSD, 2007). Confinement in the Subbasin increases with depth and is likely related to sections of poorly sorted, fine-grained deposits, rather than a single blanket of lacustrine clay. The lenticularity and heterogeneity of deposits makes it difficult to distinguish separate aquifer units in some areas of the Subbasin. However, the principal aquifers are younger and older alluvium, the Kern River Formation, and the more confined Chanac and Santa Margarita formations (Wood and Dale, 1964; AEWSD, 2003; WRMWSD, 2007).

4.1.1 Younger and Older Alluvium

The shallow aquifer in the Subbasin is comprised of younger and older alluvium, including discontinuous beds of sand, silt, clay, and gravel alluvial deposits. Specific yields were reported by Davis et al (1959) for alluvium in the San Joaquin Valley. For those township-range subunits overlying the Subbasin, specific yields for the top 200 feet of alluvium were reported to range between 16% and 18%. Although this portion of alluvium is currently unsaturated in most of the Subbasin, these specific yields are likely to be generally consistent with deeper alluvium given the similar depositional nature and composition of the sediments. Since confinement and consolidation increases with depth, however, specific yields are likely lower for the deeper alluvium.

Thickness of alluvium varies throughout the Subbasin. As described in Section 2.1 and illustrated on Figure 3, the western, southern, and eastern Subbasin boundaries are defined by extent of alluvial sediments, and therefore alluvial layers are not believed to

exist outside these boundaries. Alluvium generally thickens with distance from the western, southern, and eastern margins of the Subbasin. Anderson et al. (1979) reported alluvial thickness increasing from the eastern margins to the northwest portion of the Subbasin. Near the TRCC in the west central portion of the Subbasin, the thickness of the alluvial aquifer has been documented as 900 feet (Bookman-Edmonston, 2007).

4.1.2 Kern River Formation

Stratigraphically equivalent to the Tulare Formation to the west and north, the Kern River Formation aquifer consists of coarse- to fine-grained sand and sandy clays interbedded with poorly-sorted sands, gravels, and boulders. This aquifer is considered to be moderately to highly permeable and yield moderate to large volumes of water (Bookman-Edmonston, 1995). The depth and thickness of the Kern River Formation varies throughout the Subbasin. Overall, the formation thickens and deepens with distance from the southern and eastern margins of the Subbasin. The formation pinches out approximately two miles from the southern boundary, in between Interstate 5 and the A.D. Edmonston Pumping Plant (WZI, 2013). To the north and west, the Kern River Formation thickens to over 1,000 feet, and the depth to the top of the formation increases from 400 ft bgs to nearly 900 ft bgs.

Bookman-Edmonston (2007) evaluated the potential for groundwater storage and recovery in the southern portion of the Subbasin near Pastoria Creek. As part of this investigation, hydraulic properties were estimated in this area of the Subbasin through production well testing and long-term aquifer testing. Production well testing consisted of 12-hour step-drawdown and 24-hour constant rate pumping tests, and the resulting data were analyzed using the Neuman method of analysis for anisotropic, unconfined aquifers. Long-term aquifer testing included three constant rate pumping tests conducted over a period of six weeks. Lastly, the information gathered as part of performance testing was reviewed and incorporated into a groundwater model for the entire Subbasin. Since Bookman-Edmonston (2007) experienced difficulty in distinguishing younger and older alluvium from the Kern River Formation, the two aquifers were reported in aggregate as “alluvium” (WRMWSD, email correspondence, 18 February 2016). Parameters for the alluvial aquifer developed by Bookman-Edmonston (2007) are summarized in Table 3. As discussed in Section 4.2.1, aquifers within the Subbasin are considered to be productive relative to elsewhere in the region, as evidenced by the high transmissivity (T) values reported below (WRMWSD, 2007).

WHITE WOLF SUBBASIN TECHNICAL STUDY

Table 3 – Estimated Hydraulic Properties of the White Wolf Subbasin Alluvial Aquifer

Parameter Source	Hydraulic Conductivity			Specific Yield			Transmissivity (T)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
	(ft/day)	(ft/day)	(ft/day)	(%)	(%)	(%)	(gpd/ft)	(gpd/ft)	(gpd/ft)
Production Well Testing	52	217	135	10	21	16	251,000	1,050,000	650,500
Long-term Aquifer Testing	48	213	92	2.2	11	6.5	232,000	1,030,000	685,000
Groundwater Model	18	145	--	--	--	12	--	--	--

Combined T values for the younger and older alluvium and Kern River Formation aquifers were reported by Bookman-Edmonston (1995) in the range of 60,000 to 187,500 gallons per day per foot (gpd/ft). A combined T value was also estimated through the step-drawdown pumping test conducted as part of the Study and discussed in Section 4.5. Using a commonly-applied empirical formula to estimate T from specific capacity (Dricoll, 1986), a T of 65,000 gpd/ft was estimated for the combined alluvial aquifer.

The DWR California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) treats the top 1,000 to 2,000 feet of the Subbasin as a single model layer. For this layer, which comprises both the Kern River Formation and the younger and older alluvium discussed in Section 4.1.1, the model assigned hydraulic conductivities ranging from about 40 feet per day (ft/day) in the western portion of the Subbasin to about 50 ft/day in the eastern portion (Brush et al., 2013), which is generally consistent with what Bookman-Edmonston (2007) found. The C2VSim model also assigned a specific yield of 12% to this layer for the entire Subbasin. Anderson et al. (1979) estimated that the weighted average of specific yields for all depth zones throughout the entire Subbasin was between 13.3% and 14.3%.

4.1.3 Chanac and Santa Margarita Formations

The Chanac Formation aquifer underlies the Kern River Formation in most of the Subbasin and contains several semi-confined and confined water-bearing units. This formation consists of poorly-bedded, coarse-grained, continental conglomerate (Dibblee, 1973). In the central portion of the Subbasin, the top of the formation occurs at average depths of approximately 2,700 ft bgs (below the depths of water wells in the

Subbasin) and has a porosity of about 30% (DOGGR, 1998). Hydraulic conductivities for the formation have been reported up to 8.5 ft/day (DOGGR, 1998). Bookman-Edmonston (2007) conducted a series of pumping tests in this aquifer and calculated T in the range of 109 to 329 gpd/ft. A clay-rich transition zone spans about 50 to 100 feet between the Chanac Formation and the underlying Santa Margarita Formation and may act as a confining layer to the Santa Margarita Formation aquifer.

The Santa Margarita Formation consists of well-sorted gray sandstone, gravel, and shale (Croft, 1972). The thickness of this formation in the Subbasin is 100 to 1,000 feet in the Tejon Hills and 700 to 900 feet near Pastoria Creek in the southern portion of the Subbasin (Hoots, 1930; Bookman-Edmonston, 2007). The porosity of the Santa Margarita Formation in the Subbasin ranges from 29% to 36%, with higher porosities occurring on the eastern portion of the Subbasin (DOGGR, 1998). Hydraulic conductivities range from 1.7 ft/day in the center of the Subbasin to 8.5 ft/day in the eastern portion of the Subbasin (WZI, 2013). Reliable T values for the Santa Margarita Formation aquifer are unavailable,¹⁶ but the Santa Margarita Formation aquifer, where tapped, is considered to be more productive than the Chanac Formation aquifer (AEWSD, email correspondence, 26 January 2016).

4.2 Groundwater Development

Groundwater has historically been and continues to be developed extensively in the Subbasin. Prior to the 1960s, the sole source of water for irrigation was groundwater, and in the 1954-55 agricultural year approximately 110,000 acre-feet was pumped in the Subbasin (Wood and Dale, 1964). From 1962 to 1964, average groundwater production in the Subbasin was approximately 103,000 AFY (Lofgren, 1975). Groundwater overdraft occurred in the 1950s and 1960s, and by 1979 1.5 million acre-feet of groundwater had been removed from the Subbasin's estimated 4.0 million acre-feet of storage (Anderson et al., 1979). As discussed in Section 5.2.1, current groundwater production is estimated to be approximately 27,000 AFY. Groundwater development in the Subbasin is described further below.

¹⁶ Based on data from a pumping test, a T of 79 gpd/ft was calculated for the aquifer (Bookman-Edmonston, 2007). However, this estimated T does not appear to be representative of the Santa Margarita Formation aquifer (AEWSD, email correspondence, 26 January 2016). The low T value reported by Bookman-Edmonston (2007) may be explained by partial penetration that occurred as a result of short screened intervals in the pumping well (WRMWSD, email correspondence, 18 February 2016).

WHITE WOLF SUBBASIN TECHNICAL STUDY

4.2.1 Groundwater Well Characteristics

Various investigators have compiled information on irrigation wells in the region, and typical well characteristics are summarized in Table 4. Wells in the Subbasin are, for the most part, deep agricultural wells with long perforated intervals. The WRMWSD (2007) reported an average perforated interval length of 800 feet. Hagan (2001) examined Well Completion Reports for water wells in the Subbasin dating back to 1913 and found that typical well completion depths range from 800 to 1,100 ft bgs, with a maximum depth of 2,800 ft bgs. The DWR Water Data Library contains well completion data for 13 wells in the AEWSD service area, just north of the Subbasin. These wells are generally screened from depths of 400 to 800 ft bgs.

Table 4 – Typical Groundwater Production Well Characteristics in the White Wolf Subbasin

Well Construction						
Source	Average Depth (feet)	Typical Perforated Interval				
		Top (feet)	Bottom (feet)			
Wood and Dale (1964)	1,000	300 – 400	900 – 1,100			
WRMWSD (2007)	1,200	400	1,200			
Hagan (2001)	800 - 1,100	300 – 400	800 – 1,100			
Well Production						
Source	Yield			Specific Capacity		
	Min (gpm)	Max (gpm)	Average (gpm)	Min (gpm / ft dd)	Max (gpm / ft dd)	Average (gpm / ft dd)
Wood and Dale (1964)	260	2,600	1,700	50	215	125
WRMWSD (2007)	1,000	2,000	--	15	100	58
Davis et al. (1964)	--	--	1,550	--	--	81
AEWSD (2003)	--	--	1,800	--	--	--

The specific capacities of wells in the Subbasin are considered to be high relative to other wells in the region (WRMWSD, 2007). Well yields in the Subbasin are generally reported in the range of 1,000 to 2,000 gallons per minute (gpm). The AEWSD (2003) noted that well yields varied significantly with depth to water. During the drought of the late 1980s and early 1990s, average production from AEWSD production wells fell from

1,800 gpm to 1,400 gpm. As water levels rebounded following the drought, higher well yields returned. Average specific capacities have been documented from about 60 gallons per minute per foot of drawdown (gpm/ft dd) to 125 gpm/ft dd. Wood and Dale (1964) estimated 'yield factors' for the Subbasin of between 11 and 50 gpm/ft dd per 100 feet of saturated materials screened by a well.

4.2.2 Groundwater Use – Wheeler Ridge-Maricopa Water Storage District

The WRMWSD supplements its imported surface water supplies with groundwater pumped directly into its conveyance system. This groundwater comes from two sources: WRMWSD-owned wells and private wells participating in the User Input Program, which is described below.

The WRMWSD owns and operates 16 wells, 13 of which are located in the Subbasin. The Subbasin is the most productive portion of the WRMWSD land area, with higher permeabilities and specific capacities than areas to the north and west (WRMWSD, 2007). The WRMWSD wells are not used every year and are relied on more heavily in dry years. For example, in 2011 WRMWSD received 81% of its maximum SWP Table A allocation and pumped approximately 1,000 acre-feet of groundwater throughout its service area (WRMWSD, 2015). In 2012 and 2013, WRMWSD received just 63% and 33%, respectively, of its SWP allocation. As a result, WRMWSD groundwater production increased to approximately 14,600 acre-feet in 2012 and 16,500 acre-feet in 2013, the majority of which was pumped from the Subbasin.

As part of WRMWSD's User Input Program, private well owners have the option of augmenting WRMWSD's water supply by pumping groundwater directly into the surface water conveyance system. Most groundwater production from private wells does not enter the WRMWSD distribution system, but is instead used locally for irrigation; this production is discussed in Section 4.2.5. Similar to production from WRMWSD-owned wells, participation in the User Input Program increases in dry years. As the drought of 2012-2015 intensified and imported surface water supplies decreased, groundwater delivered to the WRMWSD from private wells increased from approximately 1,200 acre-feet in 2011 to 5,900 acre-feet and 14,100 acre-feet in 2012 and 2013, respectively.

Groundwater production by WRMWSD wells and private wells participating in the User Input Program constitute a relatively small percentage of total water supplies for WRMWSD. In 2013, when surface water supply deliveries were at historic lows and groundwater production was expanded to meet irrigation demand, groundwater represented just 16% of total water deliveries.

4.2.3 Groundwater Use – Arvin-Edison Water Storage District

The AEWSD owns and operates 79 production wells throughout its service area, but none within the Subbasin. The AEWSD has compiled comprehensive groundwater extraction data from its production wells over the period 1966 to 2011 (AEWSD, 2015). During this time, groundwater was relied upon heavily in years of reduced surface water allocations, including in 1972, 1976, 1977, 1987-1992, 1994, 2001, 2002, 2004, and 2007-2009 (AEWSD, 2003; AEWSD, 2015). Maximum production occurred in 2007 (152,184 acre-feet) and average district groundwater production has been 31,000 AFY (AEWSD, 2015). Similar to WRMWSD, AEWSD has a “pump-in” program whereby private groundwater well owners can pump groundwater into the surface water conveyance system during drought/low allocation years, but these activities currently occur only outside of the Subbasin (AEWSD, email correspondence, February 2016).

The AEWSD conducts groundwater recharge with imported surface water, as described in detail in Section 6.2, and thus the role that groundwater extraction plays in overall deliveries varies greatly from year to year. Over the period of record, total groundwater extraction represented approximately 24% of total water deliveries.

4.2.4 Groundwater Use – Tejon-Castac Water District

The TCWD currently owns three wells within the Subbasin, located generally in the vicinity of the TRCC. These wells, which are screened between depths of 1,000 and 1,800 ft bgs, were historically used by TCWD to help meet peak demands and now primarily serve as an emergency water supply. An agreement between TCWD and WRMWSD allows for groundwater pumped from TCWD’s wells to be discharged into WRMWSD’s 850 Canal.

4.2.5 Groundwater Use – Private Landowners

There are believed to be approximately 265 private wells within the WRMWSD service area, of which approximately 84 are active (WRMWSD, email correspondence, 18 February 2016). Many landowners in this area supplement surface water deliveries with groundwater pumped from private wells. Additionally, some landowners within the WRMWSD boundaries that do not receive surface water rely solely on groundwater to meet irrigation demands. The WRMWSD does not monitor extraction from private wells, but rather calculates this groundwater production indirectly by estimating water demand for each crop type on a per-acre basis. The deficit between estimated applied water use and water delivered by WRMWSD is assumed to be supplied by private groundwater production. Using this methodology, WRMWSD (2007) estimated average groundwater extraction from private wells within its service area to be approximately 61,500 AFY

over the period 1971 to 2001. Similar to the pumping patterns of WRMWSD wells discussed in Section 4.2.2, private groundwater production is highest in dry years, though fallowing and crop substitution reduces the magnitude of these spikes. Maximum groundwater extraction by private wells occurred during the drought conditions in 1977 and 1991, when approximately 136,000 AFY and 120,000 AFY of groundwater was pumped. Although the location of this groundwater pumping within the WRMWSD service area is unknown, it is believed that a substantial portion occurs within the Subbasin (WRMWSD, 2007).

The AEWSD has also documented groundwater pumpage by private landowners. There are an estimated 350 private wells within AEWSD's service area. Over the period 1966 to 2002, average groundwater production from private wells throughout the AEWSD service area was estimated to be 209,500 AFY (AEWSD, 2003). This groundwater production estimate includes wells located outside of the Subbasin and, due to the overlapping boundaries in the northern portion of the Subbasin, may account for pumpage that is included in WRMWSD's production estimate.

4.3 Groundwater Levels in the White Wolf Subbasin

Water levels in the Subbasin vary spatially and over time. The historical trends, spatial variability, and seasonal variability of groundwater levels in the Subbasin are described below based on available data.

4.3.1 Historical Trends

Over the past 60 years, groundwater levels in the Subbasin experienced a decline followed by a steady recovery. Figure 10 illustrates this general trend for State Well 11N19W-24H001S. Prior to 1975, groundwater was the only source of water for irrigation in the Subbasin. As a result, significant groundwater overdraft occurred in the 1950s through the 1970s. Over a period of about 20 years, water levels in the region declined more than 150 feet. In 1967 overdraft in the Subbasin was estimated at 45,000 AFY (WRMWSD, 2007). With the importation of surface water to the region by the CVP in 1967 and the SWP in 1975, water levels began to recover. Over the past 40 years, water levels have risen steadily throughout the WRMWSD service area, including within the Subbasin, at rates of about one foot per year (WRMWSD, 2007). By 2007, water levels appeared to have recovered to within 50 feet of pre-1960 levels. As can be seen on Figure 10, the period between 2007 and 2015 was drier than normal, illustrated by the decline in cumulative departure from normal precipitation over this time frame. As a result, and as has been observed across the state, groundwater levels in the Subbasin have decreased over the past eight years.

Spring 2015 water levels within and adjacent to the Subbasin reported by DWR are presented on Figure 11a and generally vary between 100 and 200 feet MSL within the Subbasin. By comparison, pre-drought, Spring 2011 water levels reported by DWR are presented on Figure 11b and generally vary between 175 and 250 feet MSL. A comprehensive compilation of historical water level and potentiometric surface maps are included in Appendix C.

4.3.2 Spatial Variability

Groundwater levels in the Subbasin are highest in the foothills to the south and generally decrease to the north. Water level maps and water level contours developed by DWR, USGS, WRMWSD, AEWSD, and Hagan (2001) are included in Appendix C. These figures consistently show a localized pumping depression near the intersection of Interstate 5 and State Highway 99, as well as a groundwater mound near El Paso Creek in the east central portion of the Subbasin.

The most distinctive feature of water levels in the Subbasin is the steep groundwater gradient in the vicinity of the WWF. Spring 2015 water level contours reported by DWR, shown on Figure 11a, indicate gradients around the fault that vary from about 75 feet per mile to 85 feet per mile. Groundwater elevation contours for Spring 2011, reported by DWR, are presented on Figure 11b and are representative of pre-drought groundwater conditions. These contours also depict a strong water level discrepancy across the WWF, resulting in gradients ranging from about 45 feet per mile to 70 feet per mile. As shown on Figure 11c, water level data in the Subbasin is generally consistent between DWR, WRMWSD, and AEWSD sources for Spring 2013 and Spring 2011 (i.e., years for which data were available from all sources). The steepening of gradients along the WWF indicate the presence of a lower T zone (i.e., that the WWF serves as a significant impediment to flow). The presence of steep lateral hydraulic head gradients associated with a fault zone have been documented in other sedimentary aquifer systems (Walbraun, 1992; Bense et al., 2003; Bense and Person, 2006).

To examine the discrepancy of water levels across the WWF over time, a series of hydrographs was constructed for five transects along the length of the WWF. Data were collected from the DWR Water Data Library for all wells within two miles of the Wood and Dale (1964) fault trace¹⁷. Variability along the WWF was examined by categorizing wells into five, 2.4 mile-wide transects perpendicular to the WWF. Sufficient data were available to observe trends and patterns in water levels for all transects except

¹⁷ Data were discarded for all measurements with a 'Questionable Measurement Code' except those marked as 'Acoustical Sounder Measurement.'

Transect 5, where well data in the Subbasin were sparse. Figures for each transect include hydrographs for all wells within the transect over the period 1980 to 2012. Each figure also includes emphasized hydrographs for a well pair that was selected based on proximity to the WWF and continuity of water level data. The location of transects, well pairs, and wells used for hydrographs are presented on Figure 12. Transect hydrographs are presented on Figures 13a through 13e.

Results of the transect hydrograph analysis provide interesting insight into water level behavior in the Subbasin region. As expected, water levels in the Subbasin have consistently been significantly higher than water levels on the north side of the WWF in the Kern County Subbasin. This trend is particularly evident in the southwest portion of the fault, where Figures 13a and 13b illustrate the continuous presence of a 50 to 100 foot discrepancy in water levels between the two subbasins over a period of more than 30 years. These data provide further evidence of the role of the WWF as a significant impediment to flow because they demonstrate that groundwater backs up as it approaches the low permeability zone associated with the fault.

4.3.3 Seasonal Variability

Water levels in the Subbasin exhibit seasonal variability as a result of groundwater pumping for irrigation and variability in precipitation. With the exception of those irrigating trees, wells are typically pumped from January to September. In the vicinity of major production wells, water levels can decline 50 to 100 feet during the pumping season and recover over the winter when the pumping stress is alleviated (Wood and Dale, 1964; WRMWSD, 2007). Water levels in the Kern County Subbasin appear to exhibit stronger seasonal fluctuations than those in the Subbasin, as displayed in the well pair hydrographs for Transects 3 and 4 on Figures 13c and 13d. This stronger seasonal fluctuation may indicate a higher degree of confinement in the Kern County Subbasin than the Subbasin.

4.4 Groundwater Flow Patterns in the White Wolf Subbasin

The following subsections describe groundwater flow in the Subbasin, including flow direction, impediments to flow, interactions between groundwater and surface water, and areas of recharge and discharge. Substantial supporting information is included in Appendices C and D.

4.4.1 Groundwater Flow Direction

Historically, groundwater in the Subbasin flowed from recharge areas along the foothills in the south towards lower elevations in the north. The earliest available water level

contours, compiled by Wood and Dale (1964) for the year 1958 and included in Appendix C, indicate northeastward flow from Salt Creek and Tecuya Creek in the western portion of the Subbasin towards Comanche Point. Notably, contours in the Kern County Subbasin are perpendicular to the WWF, indicating no flow across the fault. Flow direction on the north side of the WWF appears to be reversed, with groundwater flowing parallel to the fault, southwest from Comanche Point to Wheeler Ridge. Water level contours by DWR, WRMWSD, AEWSD, Bookman-Edmonston (1995), and Hagan (2001), also included in Appendix C, indicate that groundwater typically flows towards the center of the Subbasin from the foothills in the south and east, with some flow into localized pumping depressions and away from a groundwater mound in the center of the Subbasin.

4.4.2 Impediments to Flow

The WWF appears to impede the flow of groundwater from the Subbasin to the Kern County Subbasin to the north. Faults have been shown to act as barriers to horizontal fluid flow in sedimentary aquifer systems similar to the Subbasin as a result of clay-smearing, drag of sand, grain re-orientation, and vertical segmentation of the fault plane (Bense and Van Balen, 2004; Bense and Person, 2006). The degree to which upper-crustal, brittle fault zones, such as the complex deformation associated with the WWF, influence fluid flow is variable and depends heavily upon fault zone architecture and permeability structure (Caine et al., 2011). In general, fault zones contain three main structural elements: a region of cracking in the surrounding rock; a cataclasite zone of crushed rock in the core of the zone; and thin lenses of clay within the cataclasite zone (Lopez and Smith, 1996). The characteristics of these structural elements, combined with the degree and location of mineralization, dictate whether a fault zone acts as a barrier, conduit, or conduit-barrier.

Over the past 60 years, numerous investigators have documented the presence of a significant impediment to groundwater flow along the WWF¹⁸. The USBR first suggested that the WWF may provide a hydrologic barrier in the spring of 1952, based on a discrepancy in water levels across the fault measured in the months prior to the 1952 earthquake (CA DPW, 1952). Over the next three years, this break in groundwater elevations was reaffirmed and was attributed to the offset of permeable layers across the fault (Dibblee and Oakeshott, 1953; Dibblee, 1955). In 1959, the USGS reported impedance of groundwater flow along the WWF, particularly in the northeastern portion near Comanche Point, and attributed this effect to offsetting of permeable aquifer units and cementation along the fault zone (Davis et al., 1959). The seminal USGS paper for

¹⁸ Excerpts from these studies and reports are provided in Appendix D.

the region, Wood and Dale (1964), reported a northeastward-trending barrier extending across the valley from Wheeler Ridge to Comanche Point without interruption. In the late 1970s, DWR conducted two hydrogeologic evaluations of the Subbasin, in which the department acknowledged the existence of a hydrologic barrier along the fault, while indicating that the existence of this barrier at shallow depths was unknown (Swanson, 1977; Anderson et al., 1979). Hagan (2001) found that the fault acts as a partial barrier to flow, with flow across the fault occurring in some areas during conditions of high water levels.

The WWF's role as a barrier to groundwater flow has further been recognized by several groundwater models in the region (Appendix E). The USGS groundwater models for the San Joaquin Valley previously treated the WWF as a no-flow boundary (Williamson et al., 1989) and currently recognize the fault as a potential barrier to horizontal groundwater flow (Faunt et al., 2009). The DWR C2VSim model also acknowledges the fault as a groundwater flow barrier, and a unique horizontal hydraulic conductivity was assigned to the fault based on calibration using the Parameter ESTimation (PEST) tool (Brush et al., 2013). A groundwater model utilized by WRMWSD treats the fault as a constant-head boundary with a low hydraulic conductivity and with very low groundwater outflows across the fault (Bookman-Edmonston, 2007). The hydraulic conductivity assigned to the fault zone in the alluvial aquifer (1 ft/day) is less than 1% of the hydraulic conductivity assigned to the central portion of the Subbasin (145 ft/day).

Water suppliers in the Subbasin have historically treated the WWF as a barrier to groundwater flow and have managed their service areas accordingly. Since 1995, WRMWSD has managed the Subbasin as a separate subarea (Bookman-Edmonston, 1995). Engineering reports produced by or for WRMWSD, AEWSD, and Tejon-Castac WD have consistently recognized the presence of a hydrologic barrier along the fault¹⁹.

The results of this Study support the existing conceptualization of the WWF as a significant impediment to groundwater flow. As discussed in Section 4.3.2, historical and current water level data provide compelling evidence for the existence of a barrier to flow extending from Comanche Point to Wheeler Ridge. Groundwater elevation contour maps, presented on Figures 11b and 11c and included in Appendix C, show contours stacking up parallel to the WWF, with a steep groundwater gradient across the fault. The transect hydrograph analysis, presented on Figures 13a through 13e, provides

¹⁹ Including, but not limited to: Jaspar, 1974; Jaspar et al., 1977; Tejon Ranch Company, 1984; Bookman-Edmonston, 1995; and WRMWSD, 2007.

evidence of a strong break in groundwater levels across the WWF over the past 32 years, including a continuous discrepancy of 50 to 100 feet in the southwest portion of the fault. Section 4.5 describes evidence of a boundary condition response provided by aquifer pumping tests conducted along the trace of the WWF.

The bulk of available evidence demonstrates that the WWF acts as a significant impediment to groundwater flow. While it is likely that some flow occurs across the fault, particularly when water levels are high and the gradient across the fault is steep, water level contours clearly show that the WWF provides a substantial impedance to groundwater flowing from the Subbasin to the Kern County Subbasin. This fact has been recognized by scientific studies, DWR and USGS reports, and groundwater models, and has led to local water agencies treating the Subbasin as a hydrologically separate unit.

4.4.3 Groundwater-Surface Water Interactions

There is minimal interaction between groundwater and surface water in the Subbasin. In most of the Subbasin, the water table lies hundreds of feet below land surface, and thus there is no groundwater contribution to stream flow. Evidence of groundwater discharge to springs is discussed in Section 5.2.3. The primary groundwater contribution to springs occurs in the vicinity of the Springs Fault, where groundwater backed up behind the fault results in a discharge to springs. Analysis conducted as part of the water balance discussed in Section 5 suggests that this discharge is approximately 200 to 500 AFY.

As discussed in Section 2.3, the primary surface water features in the Subbasin are losing streams that infiltrate into permeable alluvial deposits prior to reaching any significant distance beyond the foothills onto the valley floor. These streams provide the primary interaction between groundwater and surface water in the area by supplying recharge to groundwater, as described in detail in Sections 5.1.1 and 5.2.2. An investigation of groundwater storage in the Subbasin by DWR found that rapid infiltration of surface water occurs in the areas surrounding Grapevine Creek, Pastoria Creek, and El Paso Creek (Anderson et al., 1979). Neither WRMWSD, TCWD, nor AEWSD operate unlined canals in the Subbasin, but irrigation ditches operated by private landowners may contribute to groundwater recharge through seepage.

4.4.4 Recharge and Discharge Areas

The potential sources of recharge to and discharge from groundwater are illustrated on Figures 9a, 9b, and 14 and are discussed in detail in Sections 5.1. Potential sources of recharge to the Subbasin include the following: surface water runoff from adjacent

uplands, including both baseflow and stormflow; direct precipitation; surface water in irrigation ditches; and applied water for irrigation. Percolation of surface water runoff occurs in the drainages of streams in the Subbasin, including Tejon Creek, El Paso Creek, Tunis Creek, Pastoria Creek, Grapevine Creek, and Salt Creek (see Figure 6). This recharge occurs largely along the margins of the Subbasin, because streamflows percolate prior to reaching far into the valley floor. Infiltration of direct precipitation occurs throughout the Subbasin, although precipitation is higher in the foothills to the south and east. Seepage from unlined irrigation ditches and percolation of applied water occurs in areas of irrigated agriculture, which are primarily located in the central and northern portions of the Subbasin (see Figure 7).

Potential discharges from aquifers in the Subbasin include groundwater pumping, flow across the WWF, and evapotranspiration. Groundwater pumping occurs in areas of irrigated agriculture, as well as in commercial and industrial land areas, such as the TRCC. Flow across the WWF likely occurs along the length of the fault; the water balance discussed in Section 5.2.2 estimates that approximately 1,000 AFY of groundwater flow occurs across the WWF. Transect hydrographs, presented on Figures 13a and 13b and discussed in Section 4.3.2, suggest that flow across the WWF may be more likely to occur in the northeastern portion of the fault. Evapotranspiration from phreatophytes that draw water directly from groundwater is likely negligible due to the depth of the water table.

4.5 Aquifer Testing

Aquifer pumping tests have been conducted in the Subbasin by Bookman-Edmonston (2007) and Hagan (2001). Additionally, boundary response tests were conducted as part of the Study. The methodology and results of these aquifer tests are described in the following subsections.

4.5.1 Aquifer Property Testing

As described in Section 4.1, Bookman-Edmonston (2007) conducted a series of pumping tests and long-term and short-term aquifer tests in the Subbasin to quantify the hydraulic characteristics of the Subbasin's aquifers. Based on 12-hour step-drawdown and 24-hour constant rate tests, aquifer properties were estimated using Theis and Neuman methods for confined aquifers and anisotropic unconfined aquifers, respectively. Low T values were calculated for the confined Santa Margarita formation aquifer (79 gpd/ft)²⁰ and the confined portion of the Chanac formation aquifer (109 gpd/ft

²⁰ This estimated T does not appear to be representative of the Santa Margarita Formation aquifer (AEWSD, email correspondence, 26 January 2016). The low T value reported by Bookman-Edmonston

to 329 gpd/ft). In the alluvial aquifer, T was calculated at 1,050,000 gpd/ft and the horizontal hydraulic conductivity was estimated to be 217 ft/day. Specific yields for this aquifer were estimated to range from 10% to 21%. Bookman-Edmonston (2007) also reported results from several short-term constant rate aquifer tests for the alluvial aquifer in the central portion of the Subbasin. Bookman-Edmonston (2007) estimated T values ranging from 232,000 gpd/ft to 1,030,000 gpd/ft, with an average of 685,000 gpd/ft. Specific capacities were estimated to range from 2% to 11% and averaged 6.5%.

As described in Section 4.5.2, Hagan (2001) conducted a pumping test in the vicinity of the WWF in the northern portion of the Subbasin. This test utilized a pumping well that was perforated from a depth of 300 ft bgs to 1,014 ft bgs. Using Theis and Cooper-Jacob analyses, Hagan (2001) calculated much lower T values, ranging from 4,200 gpd/ft to 8,200 gpd/ft.

4.5.2 Boundary Response Testing – Prior Studies

Hagan (2001) attempted to perform a pumping test to determine a boundary condition response induced by the WWF. The test utilized a pumping well and an observation well, located a half-mile apart on opposite sides of the Bookman-Edmonston (1995) fault trace. The pumping well was operated at an estimated 1,100 gpm for four hours. In the middle of the test, however, the electric wire-line sounder in the observation well was lost. As a result, data from the pumping well was used to create drawdown curves, creating significant potential sources of error and complexity in analysis. A steepening of slope was observed after ten minutes of pumping, but the driver for this change could not be determined with confidence. Two potential options were considered: the change was due to emptying of the well casing and gravel pack, or the change was indicative of the well's cone of depression encountering a barrier to flow. If this pump test did identify a boundary response, the barrier was determined to be within 18 feet of the well.

4.5.3 Boundary Response Testing – Current Study

This section describes the performance and analysis of a step-drawdown pumping test that was conducted within the Subbasin in 2016 to evaluate evidence for a low-permeability hydraulic boundary associated with the WWF. Impermeable or “no-flow” hydraulic boundaries can be inferred through analysis of aquifer pumping test data. The presence of a very low permeability aquifer boundary can cause the slope of pumping test drawdown versus time data to increase by a factor of two, when elapsed time is plotted on a logarithmic scale (Lohman, 1972). This doubling of the slope of the

(2007) may be explained by partial penetration that occurred as a result of short screened intervals in the pumping well (WRMWSD, email correspondence, 18 February 2016).

drawdown curve follows from the principle of superposition and image well theory. The elapsed time of the inflection point where deviation from an idealized unbounded response occurs depends, among other things, the horizontal distance from the observation well to the no-flow boundary.

To test whether such an inflection point in the drawdown curve would occur during pumping of a well near the presumed WWF trace, an aquifer pumping test was performed in February 2016 on a new agricultural water supply well located near the northeastern portion of the WWF (see Figure 15). The tested well is 18 inches in diameter with a 0.09-inch aperture louvered screen from 440 to 700 ft bgs and 760 to 1,820 ft bgs. The test was a step-drawdown test consisting of three, three-hour steps followed by a 14 hour recovery. Groundwater levels in the pumping well were monitored continuously at six-second intervals using a data-logging pressure transducer, as well as manually using a water level sounder. No other wells were available to use as observation wells during the pumping test.

Flow rates during pumping were measured with a totalizing digital flow meter and were recorded manually approximately every one to 15 minutes, with greater frequency during the early part of each pumping rate step. Steps 1, 2, and 3 had average pumping rates of approximately 1,510 gpm, 1,760 gpm, and 2,200 gpm, respectively. The pumping rate during Step 1 was not uniform; the discharge decreased by approximately 3% over the period of pumping. Pumping rates during Steps 2 and 3 were more constant, with a discharge rate that varied less than 1%. Discharge of groundwater was conducted via a temporary ditch to the adjacent fallow field to the north.

An accelerated field schedule required that hydraulic testing occur on the day following completion of well development. As such, water levels in the pumped well were not completely stable prior to initiation of the step drawdown test. To correct drawdown data for this initial rising water level trend, water levels were graphed for the eight hours preceding the pumping test and a linear regression ($R^2 = 0.9948$) was performed, providing a recovery trend estimate of 4.6 feet per log cycle of time (in seconds), with time zero occurring at approximately 66,000 seconds (i.e., about 18 hours) prior to the start of the pumping test. This recovery trend then was extrapolated through the pumping and recovery periods of the step-drawdown test, providing a basis to remove the trend from water level data collected during pumping and post-test recovery.

Corrected drawdowns in the pumping well at the conclusion of Steps 1, 2, and 3 were 42.2 ft, 50.9 feet, and 65.8 feet, respectively (see Figure 16a). After removing the effect of drawdown from earlier step(s), the incremental drawdowns for Steps 2 and 3 were 7.2 feet and 13.6 feet, respectively. Therefore, the total 3-hr drawdowns for each step were 42.2 feet, 49.4 feet, and 63.0 feet, respectively and the calculated 3-hour specific

capacities are 35.8 gpm/ft, 35.6 gpm/ft, and 34.9 gpm/ft. The consistency of these values and the small decrease in specific capacity with increases in pumping rate indicates that development of the production well was complete, and that the well is hydraulically efficient.

Driscoll (1986) presented an empirical formula to estimate T from specific capacity in a confined aquifer in gpd/ft, where T is approximately 2,000 times the value of specific capacity, in gpm, at 24 hours. Using this approach, an estimate for T of 65,000 gpd/ft or 8,700 feet squared per day (ft^2/d) can be calculated from the step-drawdown test data. This value is based on the 24-hour extrapolated specific capacity from the first step, i.e., 32.5 gpm/ft, and is consistent with the published range of T values for the Subbasin as a whole (see Table 3).

A storage coefficient for an aquifer cannot be determined from a single-well test, and observation wells were not available for water level measurements during testing, thus no attempt was made to estimate aquifer storativity from the current data.

To test whether the drawdown data indicated the presence of a no-flow boundary, the water level drawdown time series data from each step were plotted on a semi-logarithmic scale and analyzed to determine (a) if a break in slope occurred, (b) at what time such an inflection point occurred, and (c) the ratio of slopes between the late-time and early-time data. A low-permeability boundary in the pumped aquifer would be expected to cause an approximately two-fold slope increase in the logarithmic time vs. drawdown data (Lohman, 1972).

First, the time data from each data point were rescaled to the start of the step in which it occurred. Then, as shown on Figures 16b through 16d, regression was used to fit two logarithmic equations to the data from each step - one equation for the early-time data and one for the late-time data. Using linear correlation coefficient (R^2) values to evaluate the fit of each regression equation to its corresponding segment of the time-drawdown data, various values of elapsed time for the inflection point were evaluated to determine when the optimal (best overall fit) inflection point occurred. Results indicated that the inflection point time giving the best average correlation coefficient (R^2) occurred at 20 minutes. The late time/early time slope ratio at this inflection point was 1.26 for Step 1, 2.99 for Step 2, and 2.31 for Step 3. Drawdown during Step 1 was affected by a slow decrease in pumping rates, from approximately 1,550 gpm to 1,500 gpm, and therefore the late-time drawdown slope and the late-time/early-time slope ratio during Step 1 are less than values to be expected during constant pumping.

The R^2 values for Steps 1, 2 and 3 with the inflection point at 20 minutes were 0.972, 0.963 and 0.971, respectively. For comparison purposes, a single regression equation

also was used to match each step (i.e., as opposed to dividing the data into early and late times). The resulting correlation coefficients for each pumping step were significantly lower: 0.918 for Step 2, and 0.946 for Step 3. This indicates that the drawdown response during the test is matched (to idealized conditions) better when an inflection point is assumed, especially for Steps 2 and 3 which had steady pumping rates. The slope ratio of approximately two also suggests a correlation between the observed break in log-time drawdown slope and a single impermeable barrier boundary effect (Lohman, 1972).

Further analysis using the “law of times” approach (Ingersoll et al., 1948) to estimate the horizontal distance from the pumped well to the hydraulic boundary is hampered by the lack of observation well data. The primary drawdown response measured in the pumping well is much greater than the incremental drawdown response that would be generated by a distant image well. However, it was observed through application of the principle of superposition, implemented numerically in a spreadsheet, that the time of the inflection point corresponds to the time when the well function argument for the image well, u , is equal to 1. Thus, assuming the well function for the distant image well is equal to 1 at the time of the inflection point, the distance to the no-flow boundary, x_b (ft), can be approximated by the equation:

$$x_b = (T t_{\text{infl}} / S)^{1/2}$$

where T (ft²/d) is the aquifer transmissivity, t_{infl} (days) is the time that the inflection point occurs after a change in pumping rate, and S (dimensionless) is the aquifer storativity. Assuming that an inflection point occurred at approximately 20 minutes of pumping (t_{infl}), that T is 8,700 ft²/d, and that the aquifer storage coefficient is within the range of 0.001 to 0.01, which is reasonable for a semi-confined aquifer system (Freeze and Cherry, 1979), the distance from the pumped well to the impermeable boundary is estimated to be between approximately 110 and 350 ft. Because of the square root in the equation, the calculated distance is not very sensitive to the values of T , S , and t_{infl} , reducing the impact of uncertainty in these parameters. This distance is consistent with the presumed distance of the WWF from the well used for hydraulic testing (see Figure 15). It should be noted that because the pumping well is screened from approximately 440 to 1,820 ft bgs and the WWF dips to the southeast, the fault zone is actually further south at the depth of the well screen than it is at the surface.

4.6 Groundwater Quality

Groundwater quality in the Subbasin is generally suitable for agriculture, with TDS generally less than 500 mg/L (WRMWSD, 2007). Water quality data in the Subbasin is collected by several entities, including WRMWSD, AEWSD, DWR, and the USGS. Data

collection and analysis mainly focuses on inorganic water quality, as organic constituents do not appear to be a concern for water quality in the Subbasin (WRMWSD, 2007). Groundwater quality data and maps from WRMWSD (2007), Hagan (2001), and the USGS (Wood and Dale, 1964; Burton et al., 2011) are included in Appendix F.

Wood and Dale (1964) identified three unique groundwater characteristics in and around the Subbasin. Groundwater in the central and northern portions of the Subbasin was termed 'transition' groundwater. This water originated as runoff from the Tehachapi Mountains and is primarily bicarbonate water of intermediate cation composition (containing comparable amounts of calcium, magnesium, and sodium). Groundwater in the western and southwestern portion of the Subbasin was termed 'west-side' groundwater and described as runoff from the San Emigdio Mountains. 'West-side' groundwater is of intermediate cation composition, with sulfate as the predominant anion. Along the eastern margin of the Subbasin, Wood and Dale (1964) described groundwater as consisting of chiefly sodium or calcium bicarbonate character. The temperature of water from wells tapping older formations was reported as 10°F warmer than that of wells elsewhere in the Subbasin.

The WRMWSD (2007) confirmed the general characterizations of Wood and Dale (1964), and noted a distinct geochemical signature in the Subbasin. Groundwater in the Subbasin was described as calcium-bicarbonate water, falling broadly into the 'transition' category, whereas groundwater to the north and west of the Subbasin contained higher levels of sulfates, like that of the 'west-side' groundwater. There may be a vertical distribution in water quality within the Subbasin, however. The WRMWSD (2007) found that deeper water in the Subbasin may fall into the 'west-side' category. If this analysis is correct, it is possible that the older, deeper water originated from the San Emigdio Mountains, whereas the shallower, younger water was sourced primarily from the Tehachapi Mountains.

Recent groundwater quality data was evaluated to investigate the continued presence of the spatial variability observed by Wood and Dale (1964) and reported by WRMWSD (2007). Water quality data for the period 2001 to 2015 was obtained from the SWRCB's Groundwater Ambient Monitoring and Assessment (GAMA) database. Based on initial findings, wells were characterized into three subareas: White Wolf; North of Fault, West; and North of Fault, East. Data were available for a total of 49 wells: four in the White Wolf Subarea; 15 in the North of Fault, West Subarea; and 30 in the North of Fault, East Subarea. Stiff diagrams, common graphical representations of a water sample's chemical character first developed in Stiff (1951), were constructed for each subarea to illustrate differences in water quality between the subareas in terms of the following

inorganic constituents: calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and nitrate. The results of this analysis are presented on Figure 17 and confirm that unique geochemical signatures exist in the region. The Stiff diagrams for the White Wolf Subarea and the North of Fault, West Subarea suggest that groundwater in these areas exhibit similar characteristics. Due to the pronounced sulfate concentrations, these wells likely tap the 'west-side' groundwater described by Wood and Dale (1964).

The Stiff diagrams on Figure 17 likely illustrate a difference in source water, where the North of Fault, West and White Wolf subareas contain groundwater sourced from the San Emigdio Mountains and the North of Fault, East Subarea contains groundwater originating in the Tehachapi Mountains. While there may be a difference in groundwater quality across the fault, the resolution of available data does not allow for such a conclusion.

4.7 Land Subsidence

Widespread land subsidence was first recognized in the region directly north of the WWF (i.e., outside of the Subbasin) in 1953, following the 1952 Arvin-Tehachapi earthquake. The Subbasin was upwarped as a result of the earthquake, but land subsidence in the valley alluvium north of the WWF was attributed principally by the extensive decline in groundwater levels, rather than tectonic activity (Lofgren, 1963). As shown in subsidence contours included in Appendix G, substantial land subsidence occurred over an area of nearly 500,000 acres, with maximum subsidence of nine feet (Lofgren, 1975). Subsidence was generally moderate until water levels declined more than 100 feet. Although some land subsidence occurred in the northern portion of the Subbasin, it was modest relative to subsidence experienced north of the WWF. Over the period 1959 to 1962, Lofgren (1975) reported that water-level decline contributed to up to 1.5 feet of subsidence north of the fault, whereas subsidence south of the fault was less than 0.15 feet.

The stabilization and steady recovery in water levels over the past forty years has reduced the immediate threat of subsidence in the Subbasin. Since 1980, AEWS D has not observed subsidence-related problems in its service area (AEWS D, 2003), and WRMS D does not consider subsidence to be a concern as long as water levels remain higher than levels observed in the 1970s (WRMS D, 2007). The DWR's recent assessment of subsidence in California similarly recognized that little subsidence has occurred in the Subbasin (DWR, 2014).

5.0 WHITE WOLF SUBBASIN WATER BALANCE

A water balance is an accounting of all of the inflows and outflows for a particular area or system. In order to achieve a balance, the difference between the sum of the inflows and the sum of the outflows is accommodated by a change in storage within the system. The water balance described below is defined for the Subbasin groundwater system and includes flow components within and between the groundwater, surface water, and agricultural lands, and a change in groundwater storage based on water levels within the aquifer. Figures 9a, 9b, and 14 illustrate the major inflows and outflows to the Subbasin.

While a water balance (or water budget) is not specifically required under the DWR Basin Boundary Emergency Regulations as part of the Hydrogeologic Conceptual Model or the Technical Study, the water balance described below is provided to give a more complete picture of the ways in which groundwater is added and removed from the groundwater system within the Subbasin, with approximate quantities for each component. The water balance presented in this section is in general accordance with the current groundwater model for the Subbasin (Bookman-Edmonston, 2007).

None of the components of the Subbasin water balance are directly measured; all must be estimated based on certain measured data (e.g., precipitation and potential evapotranspiration, land use, and groundwater levels) and certain assumptions (e.g., crop coefficients, irrigation efficiency, aquifer hydraulic properties, and the fraction of irrigation water supplied by imported surface water or non-local groundwater). The input parameters each have their own inherent levels of uncertainty and vary in terms of the time period over which they are defined, with some data (e.g., climate) based on long-term averages and other data (e.g., land use) based on recent years. Therefore, an inherent assumption of this water balance is that input parameters are representative of prevailing conditions, no matter what period they were originally based on.

Due to limitations in the available data and uncertainty in the input parameters and underlying assumptions, the water balance presented herein is considered approximate. The various water balance components are presented in the text below and associated tables and figures with a precision of 1,000 AFY, and the actual level of certainty for any given component in the estimates is likely no greater than +/-10%, which can be several thousand AFY in the case of the larger components. Specific sources of uncertainty are discussed within each section describing the estimation of the individual water balance components.

As described in the following sections, presented on Figure 14, and summarized in Table 5 in Section 5.4, the overall water balance for the Subbasin includes approximately 32,000 AFY of inflows and 28,500 AFY of outflows, and a net change in storage of approximately 3,500 AFY.

5.1 Inflows

Inflows to the Subbasin groundwater system include, in order from largest to smallest, percolation of a portion of applied irrigation water on agricultural lands, percolation from surface water streams, percolation of rainfall on non-agricultural lands, percolation of wastewater discharges, and groundwater inflow from adjacent basins. Each of these components is discussed below.

5.1.1 Percolation of a Portion of Applied Irrigation Water

The most significant inflow component of the Subbasin water balance is percolation of a fraction of applied irrigation water. Estimation of this component involves estimation of the total amount of crop water demand based on crop types, acreages, and crop water demand factors. Then an assumed irrigation efficiency value is used to calculate the amount of applied irrigation water that percolates to recharge the groundwater.

Cropping data from the Kern County Department of Agriculture and Measurement Standards (KCDAMS) was used to estimate irrigated agricultural acreage. Based on data from 2010 through 2015, a total of between approximately 45,000 and 52,000 acres of crops were permitted within the Subbasin. This total includes between approximately 26,000 and 27,000 acres of permanent crops such as vineyards and orchards and between 18,000 and 24,000 acres of non-permanent crops. It should be noted that in some cases the non-permanent crop acreage includes double-cropped land, and that some crops that were permitted may not have actually been grown. The actual total land area used for agriculture within the Subbasin, based on cropping maps and aerial photos is only approximately 35,000 acres, suggesting that non-permanent crops were grown on approximately 8,500 acres.

As described in Section 2.6, most agricultural land is within the service area of either WRMWSD or AEWS. Lands within these service areas receive a portion of their agricultural water from those districts and any remaining water needs are typically satisfied with groundwater pumped from district or privately owned wells. Agricultural areas outside of the service areas of TCWD, AEWS, and WRMWSD rely exclusively on pumped groundwater to meet their irrigation demands. The WRMWSD (2007) reported that approximately 26% of the total applied irrigation water within that district over a thirty year period from 1971 through 2001 was from local groundwater.

The average crop water demand within the Subbasin is estimated herein based on the average acreage for each crop type from the KCDAMS data from 2010 through 2015 multiplied by crop water demand factors from Table 21 of the WRMWSD Agricultural Water Management Plan (AWMP) (WRMWSD, 2015). The resulting estimated average irrigation demand for permanent crops is 66,438 AFY. For non-permanent crops, the average water demand factor of 2.00 AFY per acre was applied to the approximately 8,500 acres of non-permanent crops, plus another 1,266 acres of non-permanent crops to account for double cropping. This results in an estimated water demand for non-permanent crops of 19,500 AFY. The total crop water demand is therefore estimated to be 86,000 AFY.

Additional water is applied regularly to agricultural lands for the purposes of leaching out excess salt that accumulates due to crop evapotranspiration. The WRMWSD (2015) AWMP assumes that leaching demand is equal to 5% of the total crop water demand. AEWS (2008) presented leaching requirements of approximately 1%. Assuming a middle value of 3% is representative for crops in the Subbasin, an estimated 2,500 AFY of extra water is applied within the subbasin for leaching purposes.

Total applied irrigation water is also greater than crop water demand due to irrigation efficiency being less than 100%. The WRMWSD (2007) estimated that for the period from 1971 to 2001 applied water exceeded crop water demand by 21%, implying an irrigation efficiency of approximately 83%²¹. AEWS (2008) assumed that “cultural practices”, a term that accounts for application of water to crops in excess of crop water demand for various reasons, were 0.4 AF per acre, a value corresponding to between 10% and 40% of the crop water demand depending on the crop, with an average value of approximately 16% in 2005. The excess water that does not go towards satisfying the crop water demand is assumed to percolate and become recharge to the groundwater aquifer. Assuming that water is applied to crops at a rate 20% in excess of the estimated total crop water demand, which includes water applied for leaching purposes, gives a percolation of excess applied irrigation water estimate of approximately 17,000 AFY.

²¹ Irrigation efficiency is typically defined as the fraction of applied water that goes to crop water use. Since applied water exceeds crop water demand by 21%, that means that every 100 acre-feet of crop demand requires 121 acre-feet of applied water. Therefore, the fraction of applied water (121 acre-feet) that goes to crop water use (100 acre-feet) is approximately 83%. Improvements in irrigation practices since the 1971 to 2001 period (i.e., greater use of sprinkler and drip methods rather than furrow and flood methods) have improved irrigation efficiency in recent years.

5.1.2 Percolation from Surface Water Streams

Recharge from percolation of surface water entering the Subbasin from the upstream watersheds is the second largest inflow component of the water balance. Because streamflow records are unavailable for the various streams entering the Subbasin, this component is estimated herein by comparing the amount of precipitation falling on the watersheds and the amount of water use by the natural vegetation to determine the “excess” precipitation which is assumed to become runoff in the streams that flow into the Subbasin. Runoff from the watersheds is assumed to all percolate to the groundwater basin before having a chance to flow out as surface flow, an assumption which is supported by the coarse-grained texture of the streambed material and the fact that most mapped stream channels end shortly after entering the valley floor. It is further assumed that precipitation runoff in the watersheds is not directly used in any significant manner to supply the small populations of Lebec and Frazier Park.

As shown on Figure 6, a total of 10 named streams flow from the surrounding highlands into the Subbasin. From the northeast and progressing clockwise around the perimeter of the Subbasin, these streams are Chanac Creek, Tejon Creek, El Paso Creek, Tunis Creek, Pastoria Creek, Grapevine Creek (which includes the upstream Cuddy Creek watershed), Tecuya Creek, Deadman Creek, Colorful Creek, and Salt Creek. The total watershed area for these streams is approximately 203,100 acres.

As discussed in Section 2.4, the Subbasin is located in a relatively dry area of California. A pronounced orographic effect causes greater precipitation at higher elevations within the subbasin and in the contributing watersheds. Based on gridded precipitation data from the National Weather Service Advanced Hydrologic Prediction Service²², the weighted average annual normal precipitation (from 1981 to 2010) over the Subbasin is 9.00 inches per year, whereas precipitation over the contributing watersheds is 13.52 inches per year. This amounts to approximately 81,000 AFY of precipitation over the subbasin and approximately 229,000 AFY of precipitation over the contributing watersheds. Table 5 gives the average monthly normal precipitation depth, in inches, over the Subbasin and the contributing watersheds. Precipitation occurs in a strongly seasonal pattern; in both the Subbasin and the watersheds approximately 68% of the annual total occurs during the four months from December through March, and approximately 88% of the annual total occurs during the six months from November through April.

²² Available at: <http://water.weather.gov/precip/download.php>

WHITE WOLF SUBBASIN TECHNICAL STUDY

Table 5 – Precipitation and Reference Evapotranspiration Data Used in Water Balance Calculations

Month	Mean Total Precipitation In Subbasin (inches) (a)	Mean Reference Evapotranspiration In Subbasin (inches) (b)	Mean Total Precipitation In Watersheds (inches) (a)	Mean Reference Evapotranspiration In Watersheds (inches) (c)
January	1.58	1.54	2.38	1.55
February	1.54	2.33	2.56	2.24
March	1.76	4.12	2.43	3.72
April	0.78	5.61	1.07	5.10
May	0.33	7.65	0.45	6.82
June	0.06	8.65	0.11	7.80
July	0.04	9.08	0.08	8.68
August	0.06	8.45	0.12	7.75
September	0.15	6.12	0.21	5.70
October	0.45	4.07	0.63	4.03
November	1.01	2.06	1.47	2.10
December	1.25	1.42	2.00	1.55
Total	9.00	61.10	13.52	57.04

(a) Precipitation based on spatially weighted average, over Subbasin and contributing watersheds, of gridded monthly normal (1981-2010) precipitation data from the National Weather Service Advanced Hydrologic Prediction Service.

(b) Reference evapotranspiration in Subbasin based on data from Arvin-Edison CIMIS station.

(c) Reference evapotranspiration in watersheds based on CIMIS Zone 14 (Mid-Central Valley, Southern Sierra Nevada, Tehachapi & High Desert Mountains).

A portion of the precipitation that falls on these watersheds runs off and enters the Subbasin, the rest returning to the atmosphere via evapotranspiration (ET). It is assumed that the runoff from the contributing watersheds is equal to precipitation in wet winter months in excess of actual ET, which is estimated based on reference ET multiplied by a crop coefficient. Monthly reference ET values are based on the CIMIS values for Zone 14 (Mid-Central Valley, Southern Sierra Nevada, Tehachapi & High Desert Mountains), which total approximately 57 inches per year. With the exception of portions of the Chanac Creek watershed and the Grapevine/Cuddy Creek watershed, which include several developed areas including Lebec, Frazier Park, and the future Tejon Mountain Village, the contributing watersheds of the Subbasin are largely undeveloped with natural vegetation consisting of scrub at lower altitudes and forest at higher altitudes. Therefore, a crop coefficient of 1.15 is assumed for estimation of evapotranspiration in the contributing watersheds based on a representative year-round value for natural evergreen shrubbery (UCDANR, 1989). Based on the above assumptions, excess precipitation within the contributing watersheds that becomes

runoff and eventually percolates into the Subbasin groundwater system occurs in December and January, and is estimated to be 14,000 AFY. It should be noted that because the amount of precipitation in the contributing watersheds is large, the resulting runoff value is very sensitive to the assumed crop coefficient. Furthermore, while long-term average precipitation values were used in the calculation, precipitation and the resulting runoff and recharge are highly variable from year to year.

5.1.3 Percolation of Precipitation on Non-Agricultural Lands

A third, and relatively minor, inflow component of the Subbasin water balance is percolation of precipitation on non-agricultural (i.e., non-irrigated) lands, which comprise approximately 72,000 acres or 67% of the Subbasin area. The soils in the Subbasin are generally coarse and the non-agricultural areas are sparsely vegetated except for some grazing lands, both of which would tend to promote percolation of precipitation. On the other hand, where soils contain a hardpan layer the infiltrating precipitation can be retained in the upper zones of the soil and subsequently lost to evapotranspiration. Due to the dry climate, precipitation in excess of evaporation and ET occurs infrequently, and only during the wettest months of the year.

Percolation of precipitation is estimated herein as the difference between precipitation and actual ET, similar to how runoff was estimated for the contributing watersheds. In this case, precipitation is lower, approximately 9.00 inches per year, and reference ET is higher, approximately 61.10 inches per year based on the Arvin-Edison CIMIS climate station. A year-round crop coefficient of 0.9 is assumed to apply to the non-agricultural lands, based on the value suggested by UCDANR for grazed pasture (UCDANR, 1994). The resulting estimated percolation rate is approximately 1,000 AFY and occurs only in the month of January (based on monthly long-term average precipitation and ET).

5.1.4 Percolation of Wastewater Discharges

Municipal and industrial (M&I) demands within the Subbasin are largely concentrated in the TRCC located in the corridor surrounding Interstate 5. As discussed in Section 2.5.2, the TRCC is served by the TCWD, whose primary water source is imported surface water. TCWD also operates three groundwater supply wells in the area which provide a small amount of their total supply. The total water demand of the TRCC is approximately 154 AFY (California Water Service Company/MWH, 2013). Wastewater generated from this area is treated locally, after which the vast majority is re-used for non-potable uses such as landscape irrigation. Discharge of wastewater to percolation ponds is an alternative disposal method, but given the small volume of

wastewater effluent generated²³ and the fact that most is recycled, the volume of water that becomes groundwater recharge within the Subbasin is assumed to be negligible.

5.1.5 Groundwater Inflow From Adjacent Basins

As discussed in Section 4.4.1, maps of groundwater elevation indicate that groundwater in the Subbasin flows in a convergent fashion from the eastern, southern, and western margins northwards towards center of the Subbasin and then generally northwards across the WWF into the Kern County Subbasin. No other groundwater basins have a direct subsurface connection to the Subbasin. Groundwater inflow from the surrounding crystalline basement bedrock is insignificant. Therefore, groundwater inflows as a whole are assumed to be negligible.

5.2 Outflows

Outflows from the Subbasin include, from largest to smaller, groundwater pumping for agricultural use, groundwater flow across the WWF, discharges to springs, and pumping for M&I use. Each of these components is discussed below.

5.2.1 Groundwater Pumping for Agricultural Use

As discussed above, groundwater is used to supplement imported surface water provided by TCWD, WRMWSD and AEWSD for irrigation water supply in those areas within the service areas of the Districts. Outside of the Districts' service areas, agricultural demands are met exclusively with groundwater. Direct measurement of pumping for agricultural use has not been undertaken, and therefore the rate of pumping must be estimated indirectly. Total irrigation water demands, including water to satisfy crop water demands, leaching demands, and irrigation efficiency, are estimated to be 103,000 AFY in the Subbasin, based on the calculations described in Section 5.1.1 above. The WRMWSD (2007) estimates that for the period from 1971 to 2001 approximately 26% of all water applied to irrigated lands within its boundaries came from local groundwater. Assuming that this same fraction applies currently and to other irrigated lands within the Subbasin, the total volume of groundwater pumped for agricultural use is estimated to be approximately 27,000 AFY.

5.2.2 Groundwater Flow Across the White Wolf Fault

Groundwater levels and gradient directions indicate that some groundwater flows northwards across the WWF into the Kern County Subbasin. As it passes through the

²³ The total discharge of wastewater to percolation ponds at the TRCC is 75,000 gpd, or 84 AFY.

WWF zone the groundwater gradients steepen significantly, indicating that the fault zone has a reduced permeability compared to the aquifer further upgradient. In theory, a calculation of flow across the WWF could be done using Darcy's Law by multiplying the cross-sectional area of flow by the hydraulic gradient magnitude and the hydraulic conductivity. However, none of these components can be estimated with any certainty, and hydraulic conductivity of the WWF zone is especially uncertain. Because of the significant uncertainty associated with estimating Subbasin outflow by Darcy's Law, it is appropriate to treat this component of the water balance as a closure term (i.e., calculated as the residual after all other components, which are somewhat more certain, have been estimated). As shown in Table 6, when all other inputs and outputs of the water balance are accounted for, the results of the closure term – groundwater outflow across the WWF – is estimated to be approximately 1,000 AFY.²⁴

5.2.3 Discharges to Springs

In the vicinity of the Springs Fault, which is located within the southeastern corner of the Subbasin, evidence of spring flow includes a strip of natural well-watered vegetation in an otherwise dry land cover. The strip aligns well with the trace of the Springs Fault, and indeed, the fault was named for the springs that it causes. The shape of the vegetation strip is irregular, and appears to be driven by surface topography. Spring flow appears to be caused by groundwater backing up and rising to the ground surface on the south side of the Springs Fault due to the fault acting as a barrier to groundwater flow. The total area of spring-fed vegetation is approximately 50 to 100 acres. Assuming a crop coefficient of 1.0, based on the values for grazed pasture (0.9), wet light soil (1.05), and wet dark soil (1.10) from UCDANR (1994), the spring discharge rate is estimated to be approximately 200 to 500 AFY.

5.2.4 Pumping For Municipal and Industrial Use

As discussed above, the three wells located at the TRCC were historically used by TCWD to help meet peak demands and now primarily serve as an emergency water supply. Given that the total TRCC demand has been small and that groundwater only constituted a small fraction of that demand, the total groundwater pumping for M&I use is assumed to be negligible.

²⁴ The low groundwater flow values calculated in this water balance is in general accordance with the groundwater model for the Subbasin (Bookman-Edmonston, 2007) and the treatment of the fault in regional groundwater models developed by USGS and DWR (Williamson et al., 1989; Faunt et al., 2009; Brush et al., 2009).

5.3 Change in Storage

The water balance concept states that the difference between total inflows and total outflows from a system is accommodated by a change in storage. Changes in storage are indicated by changes in groundwater levels measured in wells. Based on the available historical data, groundwater levels in the Subbasin have generally been stable to increasing over the past several decades. As shown on Figure 10 and Figures 13a through 13e, groundwater levels in wells near the WWF but within the Subbasin rose approximately 50 to 80 feet from the early 1980s to the early 2010s, an average rate of approximately 0.4 to 2.5 feet per year. Water levels in the far northeastern portion of the basin along the WWF (shown on Figure 13e) have not shown the same type of rise, but this is in part due to a lack of continuous hydrograph data for that area. Figure 18 shows the change in water levels from Spring 2005 to Spring 2015 both within the Subbasin and in the Kern County Subbasin to the north. As shown on Figure 18, over the past decade water levels have risen or fallen in approximately the same number of wells in the Subbasin, and the declines have been limited for the most part to 10 feet or less. Figure 18 also shows hydrographs for three wells within the Subbasin that all show long-term increasing trends.

Despite some declines in recent years which may be attributable in part to the historic drought which caused agricultural water users to rely more on groundwater, or possibly to a shift to more permanent crops which have higher crop water demands, their remains an overall long-term trend of increasing groundwater levels within the Subbasin.

Translating changes in groundwater levels into an estimate of change in groundwater storage involves multiplying the groundwater level change by the area over which that change applies and then by the specific yield. For the purposes of this analysis, it is assumed that a representative rate of water level change is 1.0 feet per year, that the area over which this change applies coincides roughly with the agricultural land area of approximately 35,000 acres, and that a specific yield value 10% is representative of the aquifer in this area. Using the above assumptions, the estimated change in storage is approximately 3,500 AFY.

Estimating the change in storage component as described above relies on the simplified assumption that a single representative specific yield value and representative rate of water level change applies throughout the agricultural land area of the Subbasin. Since both of these parameters are spatially variable and uncertain, and because they are multiplied by a large number, i.e., the agricultural land area, the resulting change in storage estimate has a large uncertainty as well.

5.4 Discussion

Overall, these preliminary water balance results show that the Subbasin is in a state of relative stability, with long-term increasing trends in groundwater levels and groundwater storage. These trends date back to the beginning of importation of surface water supplies by TCWD, WRMWSD and AEWS to support irrigated agriculture. While inherent uncertainty in the various parameter values results in considerable uncertainty in some the water balance components, the following general statements can be made about the water balance:

- Percolation of applied irrigation water (i.e., return flows) and natural surface water runoff constitute the majority of inflows to the Subbasin.
- Groundwater pumping for agricultural use constitutes the majority of outflows from the Subbasin.
- The long-term trend of increasing water levels indicates that inflows have exceeded outflows over the last several decades.
- Groundwater flow across the WWF is likely only a small percentage of the total outflow.

WHITE WOLF SUBBASIN TECHNICAL STUDY

Table 6 – Summary of White Wolf Subbasin Water Balance

Water Balance Component	Amount, Rounded (AFY)	Method of Estimation	Notes and Assumptions
Inflows			
Percolation of a Portion of Applied Irrigation Water	17,000	Equals difference between total applied water (including leaching and irrigation efficiency demands) and crop water demand	- Unit crop water demand factors from WRMWSD (2015) - Crop areas from KCDAMS 2010 to 2015 data, with double cropping - Irrigation efficiency and leaching demand = 20% of crop water demand (WRMWSD, 2007 and 2015; AEWSD, 2008)
Percolation from Surface Water Streams	14,000	Equals difference between precipitation and evapotranspiration in contributing watersheds	- Precipitation from gridded NWS normals for watershed; - Reference ET from CIMIS Zone 14; - Crop coefficient = 1.15
Percolation of Precipitation on Non-Agricultural Lands	1,000	Equals difference between precipitation and evapotranspiration for non-agricultural lands	- Precipitation from gridded NWS normals for subbasin; - Reference ET from CIMIS Arvin-Edison station; - Crop coefficient = 0.9
Percolation of Wastewater Discharges	Negligible	Small fraction of small wastewater discharge	Most wastewater generated is recycled, lost to landscape evapotranspiration
Groundwater Inflow From Adjacent Basins	Negligible		No upgradient basins directly connected to subbasin
Total Inflows	32,000	Sum of inflow components	
Outflows			
Groundwater Pumping for Agricultural Use	27,000	Equals product of total applied water and groundwater fraction	Groundwater fraction = 26% of total applied water, based on WRMWSD (2007) value for WRMWSD lands during the 1971-2001 period
Groundwater Flow Across the White Wolf Fault	1,000	Closure term in water balance	
Discharges to Springs	500	Equals product of spring-fed vegetation area, reference ET, and crop coefficient	- Area = 100 acres - Reference ET from CIMIS Arvin-Edison station - Crop coefficient = 1.0
Pumping for Municipal and Industrial Use	Negligible		Most M&I water supplied by imported surface water
Total Outflows	28,500	Sum of outflow components	
Change in Storage	3,500	Equals product of groundwater level change, representative area, and specific yield	- Groundwater level change = 1 ft/yr; - Area = 35,516 acres (approx. irrigated agricultural area) - Specific yield = 0.10

6.0 GROUNDWATER MANAGEMENT

Groundwater in the Subbasin has historically been and continues to be sustainably managed by the Districts. Groundwater management in the Subbasin is described in detail in the following subsections.

6.1 Management Agencies

As described in Section 2.6, three water districts manage groundwater in the Subbasin: WRMWSD, AEWS, and TCWD. The WRMWSD has the largest jurisdiction in the Subbasin, comprising close to 58,000 acres. The AEWS manages approximately 23,400 acres in the northern portion of the Subbasin that overlaps much of WRMWSD's service area. The TCWD manages approximately 12,400 acres, of which approximately 9,500 acres overlap WRMWSD's service area. The Districts are actively engaged in groundwater management and have contributed significantly to the rebound in water levels that has occurred in the region over the past fifty years. The WRMWSD and AEWS have prepared groundwater management plans in accordance with AB 3030 (WRMWSD, 2007; AEWS, 2003).

Additionally, the region is within the geographical area covered by the Tulare Lake Basin Portion of the Kern County Integrated Regional Water Management Plan (IRWMP). Within this plan, the Subbasin is included as part of the South County subregion. The purpose of the Kern County IRWMP is to help coordinate and prioritize water resources-related projects for funding by DWR and the SWRCB within the Tulare Lake Basin. The IRWMP effort, which is funded entirely by local participating agencies, provides for implementation of a broad range of projects designed to enhance water resources management in the region.

6.2 History of Sustainable Groundwater Management

Active groundwater management in the Subbasin has helped the Subbasin recover from overdraft conditions that existed prior to the importation of surface water. Delivery of SWP and CVP water by the Districts has decreased the need to rely on groundwater to meet irrigation water demands. As shown on Figure 18, the increases in groundwater levels observed in the Subbasin stand in stark contrast to the widespread declines observed elsewhere in the Kern County Subbasin, which has been designated by DWR as a basin in "critical overdraft". Specific groundwater management activities conducted by WRMWSD, AEWS, and TCWD are described below.

6.2.1 Groundwater Management – Wheeler Ridge-Maricopa Water Storage District

The WRMWSD has been actively engaged in groundwater management since the 1970s. In 2007, WRMWSD adopted a GWMP for its service area in accordance with AB 3030. The WRMWSD also promotes efficient irrigation practices, and adopted an AWMP in 2015 pursuant to CWC §10826. The WRMWSD participates in groundwater management on a regional level through its participation in the 19-member Kern Groundwater Authority (KGA).

Since 1975, WRMWSD has contributed to the rebound and recovery of groundwater levels in the Subbasin by importing surface water that reduces the need for groundwater production. Over the period 1971 to 2013, WRMWSD delivered 7.2 million acre-feet of surface water to its service area (WRMWSD, 2015). This imported water supply represents an indirect recharge to groundwater because it is utilized in lieu of pumped groundwater.

The WRMWSD also manages its groundwater by participating actively in water banking programs in the region. These programs provide a source of water for WRMWSD in dry years, when it would have otherwise relied on groundwater pumping. The WRMWSD participates in three water banking programs: Kern Water Bank (maximum recovery capacity of 57,600 AFY), Pioneer Project (29,800 AFY), and Berrenda Mesa (6,400 AFY).

The User Input Program managed by WRMWSD allows a small volume of local surface water runoff to be fed into the surface water conveyance system, when available. The program also gives private well owners the opportunity to augment WRMWSD's water supply by pumping groundwater directly into the surface water conveyance system. Wells used for the User Input Program commonly provide Class I irrigation water, which has electrical conductivity values less than 1,000 microsiemens per centimeter (500 mg/L TDS) (WRMWSD, 2007). User Input Program wells that pump into the California Aqueduct are tested for California Code of Regulations (CCR) Title 22 constituents on an approved monitoring schedule.

As part of the development of the 2007 GWMP, WRMWSD established a series of Basin Management Objectives (BMOs) to guide future management actions. These BMOs are presented in Appendix H and include the following objectives:

- Prevent a return to historical overdraft conditions, which is defined as a groundwater basin experiencing chronic water level declines that result in water levels below historical lows, possibly inducing land subsidence;

- Maintain groundwater quality throughout the service area;
- Monitor water levels, water quality, and groundwater storage; and
- Estimate current groundwater production and future groundwater demands.

In support of the established BMOs, WRMWSD conducts extensive water level and water quality monitoring. Water level monitoring has been conducted by WRMWSD within its service area since the 1960s. The WRMWSD monitors water levels in approximately 100 wells within the district's service area. These monitoring events occur in February and October, corresponding to the typical maximum and minimum water levels. Water levels are measured with different instruments – including electric sounders, plunkers, airlines, or acoustic sounders – depending on well construction and access. Data exist for 517 individual wells, including 32 wells within the Subbasin, with the earliest measurements dating back to 1950 (WRMWSD, 2007). Most wells contain about 25 measurements over a 20 year period. In addition to WRMWSD water level monitoring, DWR and KCWA monitor wells within the WRMWSD service area.

The WRMWSD conducts water quality monitoring for eight active agricultural wells in the Subbasin. Water samples are collected in June or July of each year and analyzed for general minerals, boron, sodium adsorption ratio, and Langelier indices. Water quality data from WRMWSD sampling events, as well as historical data from other sources, exist for 406 wells in the WRMWSD service area dating back generally to the 1960s, with data for five wells in the 1950s and one well in 1910 (WRMWSD, 2007). Although the number of constituents analyzed varies for each well, almost all of the wells have at least one value for TDs, total hardness, and pH. The WRMWSD coordinates with AEWS and KCWA in the collection and analysis of water quality data within its service area.

6.2.2 Groundwater Management – Arvin-Edison Water Storage District

The AEWS adopted a GWMP in accordance with AB 3030 in 2003 and an AWMP in 2005 pursuant to CWC Section 10826. Through implementation of its Water Resources Management Program, AEWS has been responsible for a substantial net recharge to groundwater reserves in the region. Across its service area over the period 1966 to 2011, AEWS extracted approximately 1.4 million acre-feet and percolated over 2.1 million acre-feet into recharge, resulting in 700,000 acre-feet of net positive change in storage (AEWS, 2015). When imported surface water exceeds irrigation demands, excess water is banked in underground storage at three district-operated spreading basins: Sycamore Spreading Works, Tejon Spreading Works, and North Canal Spreading Basin. The Sycamore Spreading Works and Tejon Spreading Works have

been operated since 1966 and 1972, respectively. The North Canal Spreading Basin was constructed in 1999.

Although the spreading basins are not located in the Subbasin, AEWS D has contributed to the recovery of groundwater in the Subbasin by providing imported surface water to alleviate stress on the aquifer. The AEWS D provided approximately 5.9 million acre-feet of surface water to its service area from 1966 to 2011, which has offset demands that would have otherwise been met by groundwater.

The BMOs established in the 2003 AEWS D GWMP, are included in Appendix H and address specific actions associated with the following topics: water supply reliability; water supply affordability; groundwater overdraft; groundwater quality; and compliance with contracts, agreements, laws, and cooperation with other agencies; inelastic land surface subsidence; and groundwater monitoring.

The AEWS D groundwater monitoring plan was created with the beginning of district operations in the late 1960s. Water levels are measured in AEWS D production wells and private landowner wells twice annually, in the spring and the fall, using an electrical well sounder, an acoustic well sounder, or with airlines and compressed air. Pumping or static water levels in all AEWS D production wells are measured monthly before, during, and after each pumping season. Water quality samples are collected from selected AEWS D production wells and private landowner wells once a year and analyzed for agricultural suitability.

The AEWS D also participates in regional groundwater management through its active participation in the KGA.

6.2.3 Groundwater Management – Tejon-Castac Water District

The TCWD plays an active role in groundwater management on the regional level, as evidenced by the district's participation in the KGA and the Kern County IRWMP. The TCWD also coordinates extensively on the local level and has strong relationships with both WRMS D and AEWS D. For example, TCWD has an existing relationship with WRMS D whereby groundwater pumped from TCWD wells is discharged into WRMS D's 850 Canal.

6.3 Current and Future Sustainable Groundwater Management

The Subbasin has benefitted from sustainable groundwater management in the past, and the proposed boundary modification will allow the Subbasin to benefit from similarly effective groundwater management in the future. The redesignation of the Subbasin as a separate subbasin will enhance sustainable groundwater management by facilitating

more efficient coordination in the implementation of SGMA. Furthermore, there is compelling reason to believe that the Subbasin can be managed sustainably because the Districts have demonstrated strong stewardship of the Subbasin and are planning to implement additional groundwater management projects in the Subbasin, as described below.

6.3.1 SGMA Implementation

As SGMA is implemented, the Districts in the Subbasin will be able to effectively provide sustainable groundwater management. With only four managers of groundwater in the Subbasin – the Districts and Kern County²⁵ – development of a single Groundwater Sustainability Agency (GSA) and an accompanying Groundwater Sustainability Plan (GSP) will not face many of the coordination and agreement hurdles present in the Kern County Subbasin. These entities have cooperated in the Subbasin in the past, through coordination of data collection and management of overlapping service areas. The Districts have signed a Memorandum of Understanding, included as Appendix G, through which each party has agreed to cooperate in the timely formation of a single GSA for the Subbasin, and to thereafter develop a single GSP for the Subbasin. There is strong reason to believe that the Subbasin will continue to be managed efficiently and effectively by these entities in the future.

While successful intra-basin coordination is crucial to meeting SGMA sustainability objectives, inter-basin coordination is also a critical component of SGMA implementation. The entities in the Subbasin have a proven record of success in cooperating in regional water resources management planning. For example, the Districts and the County have been active participants in the 19-member KGA, which coordinates groundwater management programs in Kern County. The Districts have also been engaged in the regional Kern County IRWMP planning process. Furthermore, WRMWSD, AEWSD, and Kern County all manage land in the Kern County Subbasin, and there will therefore be a significant nexus between SGMA implementation in the two subbasins.

6.3.2 Planned Groundwater Management Projects

The WRMWSD has investigated the potential for groundwater storage and recovery in the Subbasin (Bookman-Edmonston, 2007). The proposed project would be located in the vicinity of WRMWSD's 850 Canal near Grapevine Creek and involves annual

²⁵ Under SGMA, each county is responsible for management of the areas of medium- and high-priority basins within their borders which are not within the jurisdiction of other local agencies. These areas are known as "white areas".

recharge volumes of up to 50,000 acre-feet. Construction costs for this conceptual layout, which includes 434 acres for spreading and 25 extraction wells, are estimated to be approximation \$46 million. In 2011, this project was the seventh highest ranked project out of 136 potential projects evaluated for implementation as part of the Kern County IRWMP (Kennedy/Jenks, 2011). While support for the project remains strong, the remaining hurdle is obtaining a supplemental water supply to ensure consistent operation of the spreading basins.

In June 2015, AEWSO received \$500,000 from the USBR as part of the Agricultural Water Conservation and Efficiency Program. As a participant in this grant program, AEWSO will implement a pilot groundwater metering project over the next 20 years. The AEWSO will use the funds to purchase and install water measurement devices to quantify actual groundwater extractions throughout the district. This extraction data will fill a key data gap and help inform AEWSO and the other districts as they jointly implement SGMA in the Subbasin.

7.0 CONCLUSION

The Districts' Request to subdivide the Kern County Subbasin into two separate subbasins, the Kern County Subbasin and the Subbasin, is founded on a body of scientific evidence that demonstrates the WWF provides a significant impediment to groundwater flow and that sustainable groundwater management can continue in the Subbasin without impacting sustainable management of adjacent groundwater basins. Over the past 60 years, many investigators have documented the presence of a barrier to groundwater flow along the WWF, including government agencies such as the USBR, California Department of Public Works, USGS, and DWR. The seminal USGS paper for the region, Wood and Dale (1964), reported a northeastward-trending barrier extending across the valley from Wheeler Ridge to Comanche Point without interruption. In the late 1970s, DWR acknowledged the existence of a hydrologic barrier along the WWF (Swanson, 1977; Anderson et al., 1979). The WWF's role as a significant impediment to groundwater flow has also been recognized by several groundwater models in the region developed by or for USGS, DWR, and the Districts (Williamson et al., 1989; Faunt et al., 2009; Brush et al., 2013; Bookman-Edmonston, 2007). Furthermore, water suppliers in the Subbasin have historically treated the WWF as a barrier to groundwater flow and have managed Subbasin as a hydrologically separated subarea.

The results of the Study support the existing conceptualization of the WWF as an impediment to groundwater flow. As discussed in Section 4.3.2, historical and current water level data provide compelling evidence for the existence of a barrier to flow extending from Comanche Point to Wheeler Ridge. Groundwater elevation contour maps, presented on Figures 11a through 11c and included in Appendix C, show contours stacking up parallel to the WWF, with a steep groundwater gradient across the WWF. The transect hydrograph analysis, presented on Figures 13a through 13e, provides evidence of a strong break in groundwater levels across the WWF over the past 32 years, including a continuous discrepancy of 50 to 100 feet in the southwest portion of the WWF. In support of this Study, a step-drawdown pumping test was conducted in the vicinity of the WWF. As described in Section 4.5, the results of this test provide compelling evidence in support of the WWF as a significant barrier to groundwater flow.

The proposed basin boundary modification would not impact the ability of the adjacent Kern County Subbasin to achieve sustainable groundwater management in accordance with SGMA. Although some flow occurs across the WWF, predominantly during periods of high water levels (Hagan, 2001), the water balance described in Section 5 suggests that this flow is relatively minor (approximately 1,000 AFY). Furthermore, the requested basin boundary modification would not be expected to decrease this flow in the future.

In fact, it is possible that more effective groundwater management resulting from the boundary modification will result in higher water levels within the Subbasin, thereby creating a steeper hydraulic gradient across the fault and increasing groundwater flow into the Kern County Subbasin. Therefore, the creation of the Subbasin will not hinder the ability of the Kern County Subbasin to manage groundwater sustainably.

The three water districts that manage groundwater in the Subbasin – WRMWSD, AEWSD, and TCWD – have a proven track record of sustainable groundwater management in the Subbasin. Through the conjunctive use of imported surface water and local groundwater, the Districts have contributed directly to the steady recovery of groundwater levels in the Subbasin. As shown on Figure 18, this pattern of recovery is unusual elsewhere in the Kern County Subbasin, where water levels have declined substantially. The Districts have successfully coordinated groundwater management on a regional scale, illustrated by their participation in the KGA and Kern County IRWMP. This ability to compromise and cooperate, combined with the pre-existing relationships between districts in the Kern County Subbasin and the Subbasin, will facilitate inter-basin coordination as SGMA is implemented, particularly with regards to GSP development and implementation. Moreover, the Districts have worked together to manage the Subbasin for five decades and are committed to the sustainable management of groundwater in the Subbasin in the future, as evidence by the Memorandum of Understanding between the Districts (included in Appendix H) expressing the intent to form a joint GSA to manage the Subbasin, and thereafter develop a single GSP for the Subbasin.

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