UNDERSTANDING MORE ABOUT SURFACE AND GROUNDWATER IN THE UPPER VENTURA RIVER BASIN BETWEEN MEINERS OAKS AND OAK VIEW

BY BRUCE KUEBLER
RETIRED CIVIL ENGINEER

JUNE, 2016

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INTRODUCTION

Background

A variety of hydrologic studies have been done on the Ventura River. John Turner's 1971 report was among the first to focus in detail on groundwater. In 2001, Entrix found that Turner's "… report is the only source identified during this review that had the geographic scope, range of groundwater characteristics, and surface hydrology information appropriate for further analysis." (p.3-2). Other studies looked at surface/groundwater interactions and conjunctive use. Surface flows are the subject of ongoing studies relative to steelhead trout.

Entrix cited lack of groundwater pumping data as a limitation on their ability to separate natural and groundwater extraction effects on groundwater levels and patterns.

> "However, the usefulness of interpreting additional, specific hydrographs was limited by the lack of concurrent groundwater extraction pumping rates, volume, and/or level data (sic) without pumping rates and or volumes associated with specific wells or groups of wells for the years of observations, it is not possible to sort out the relative or absolute effect of natural hydrologic variability, surface water operations, and groundwater extraction on groundwater levels and patterns." p. 3-2

Entrix also had the following to say about surface groundwater relationships:

> "The initial field and groundwater well locations, well ground surface elevations, and well distances from the active Ventura River channel indicated a potential for localized pumping impacts on surface flow. However, the potential impacts from a specific well or group of wells appeared secondary to the overall seasonal fluctuations in groundwater

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[11] Although he is a member of the Board of Directors of the Ventura River Water District, he prepared this as an individual. This study was neither requested by, approved by, nor intended to represent the views of, the District.

elevations throughout the Upper Ventura River Basin. Therefore, the study focused on determining the system-wide relationship between groundwater and surface water." p. 3-4

The goal of this report is to build on those studies using groundwater pumping from water districts and all available observation well data to increase understanding of the basin's hydrology between Meiners Oaks and Oak View. This stretch downstream of the Robles Diversion structure is commonly referred to as the dry reach. The southerly portion the basin was excluded because it would involve the San Antonio Creek watershed, including drainage from the Ojai Groundwater Basin. There are insufficient observation wells and no specific yields along San Antonio Creek for calculating groundwater flow with an accuracy consistent with the study area. The study period is the 9 water years from 2005-06 through 2013-14.

Of particular interest are the amount and year-to-year variation of groundwater flow; the amount and annual variation of pumping by the Ventura River Water District (VRWD) and the Meiners Oaks Water District (MOWD), collectively the water districts; the patterns in annual and year-to-year fluctuations of the water table; the rate of groundwater basin recharge from the Ventura River; and the effect of the Arroyo Parida Santa Ana and Villanova Faults on groundwater flow.

Three big differences between this study and previous studies are: use of water districts' monthly well pumping data; use of the Ventura River flow measurement near Meiners Oaks (VRNMO) instead of the more commonly used measurement at Foster Park; and use of the shortest possible interval for looking at hydrologic changes. Turner looked at water table changes between fall and spring for two sets of years and storage change over one year. Entrix (2001) did a simplified groundwater flow evaluation to estimate nodal storage changes over a 3-month period and also used selected seasons and years for their analyses. This study uses the shortest intervals for which observation well data are available from the Ventura County Watershed Protection District's (VCWPD) records. This means bi-monthly from 2005-06 through 2009-10 and quarterly thereafter, resulting in 46 time periods.

Report Organization

This report has two sections. Section 1 is a presentation of data. Its purpose is to show all data on river flow, groundwater table elevations, and water districts' pumping together so it can be viewed for patterns. There are no analytical calculations.
It has two sets of hydrographs: one showing the above components; the other showing well hydrographs near the Arroyo Parida Santa Ana and Villanova Faults. Included are observations about patterns and inconsistencies.

Section 2 has hydrologic analyses. Its purpose is to estimate groundwater basin parameters with the goal of identifying riverbed infiltration rates, aquifer permeability, and storage coefficients so groundwater flow can be calculated for different water table elevations. There is a set of hydrographs showing results from calculations to determine groundwater recharge and groundwater flows in a quasi-natural state, i.e., with effects of water districts' pumping taken out. There are also hydrographs and figures dealing with riverbed infiltrations rates, and water districts' pumping and groundwater table storage declines. Observations about patterns, inconsistencies, and conclusions about additional data and study needs are also included.

SECTION 1

Approach

Overview

Plate 1 shows the Upper Ventura River Groundwater Sub-basin boundaries as delineated by DWR Bulletin 118 and Ventura County Watershed Protection District (VCWPD), Turner's study boundary for that basin, locations of observation and water districts' wells, and Turner's flow node network. The study area, in terms of Turner's nodes, focuses on nodes nearest the river, i.e., nodes 18, 19, 20, 23, 24, 25, 26, and 27.

Plate 2 is the 'Geologic Map of the Matilija 7.5'Quadrangle, Ventura County, California: a Digital Database, Version 1.0' by Siang S. Tan and Terry A. Jones, 2006. It shows geologic faults, observation wells used in this study, and water districts' pumping wells. Plate 2a is its legend. Solid fault lines represent accurate locations; long dashed lines approximate locations; short dashed lines inferred locations; and dotted lines concealed locations. There is no indication of size or significance of the faults.

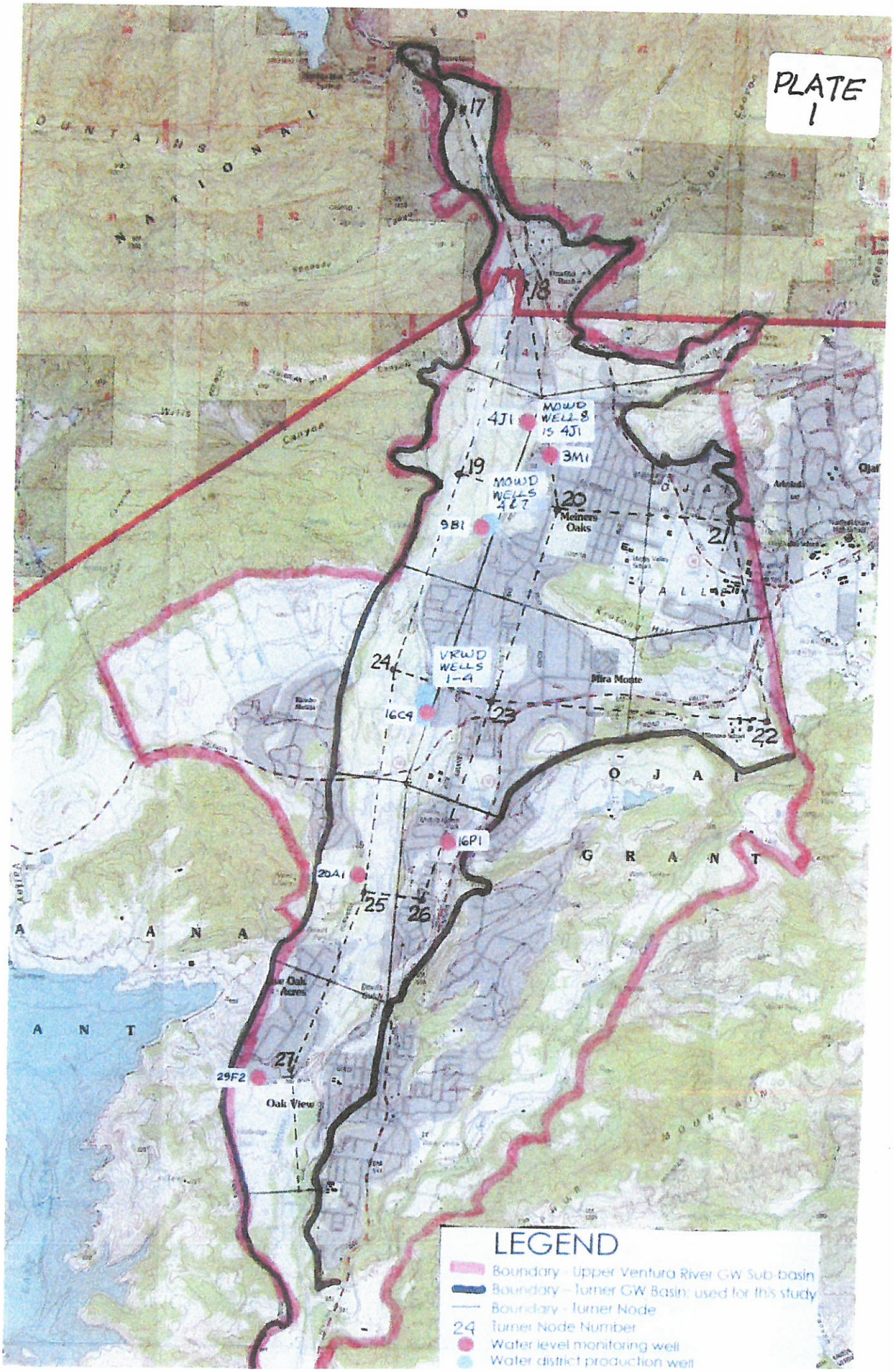
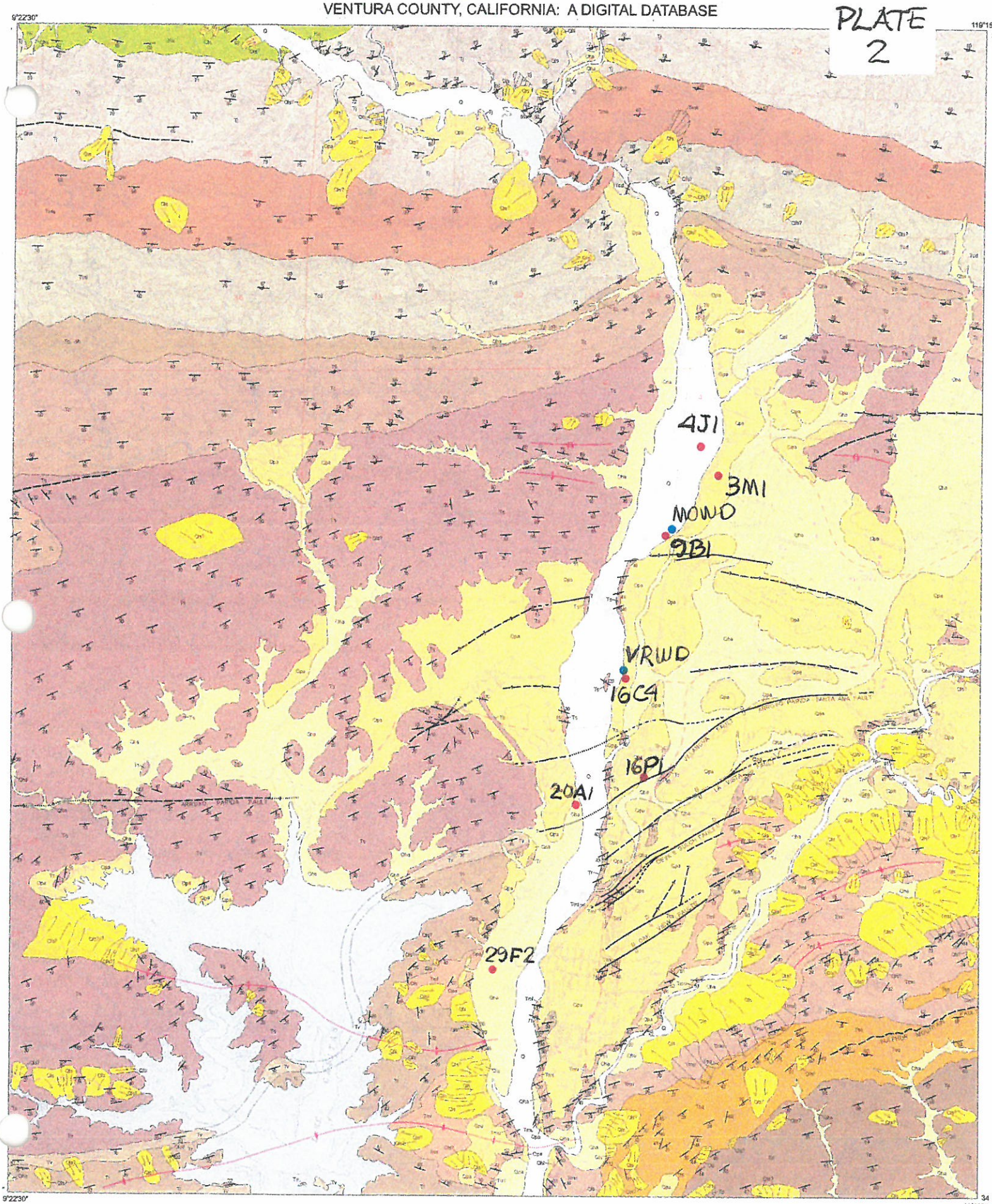


PLATE 1
17
18
19
20
21
22
23
24
25
26
27
4J1
MOWD WELL 8 IS 4J1
3M1
MOWD WELLS 4 & 7
9B1
Meiners Oaks
VRWD WELLS 1-4
16C4
Mira Monte
16P1
20A1
29F2
Oak View
O J A I
G R A N T
A N A
A N T
LEGEND
Boundary - Upper Ventura River GW Sub-basin
Boundary - Turner GW Basin: used for this study
Boundary - Turner Node
24 Turner Node Number
Water level monitoring well
Water district production well

GEOLOGIC MAP OF THE
MATILIJA 7.5' QUADRANGLE
VENTURA COUNTY, CALIFORNIA: A DIGITAL DATABASE

PLATE 2



Topographic base from U.S. Geological Survey
Matilija 7.5-minute Quadrangle, 1988

• Observation well
• Water District wells

This geologic map was funded in part by the
U.S. Geological Survey National Cooperative

PLATE 2a

http://www.conservation.ca.gov/cgs/rghm/rgh/preliminary_geologic_map/

'00"
34°30'00"

GEOLOGIC MAP OF THE MATILIJA 7.5' QUADRANGLE VENTURA COUNTY, CALIFORNIA: A DIGITAL DATABASE

VERSION 1.0

By

Siang S. Tan[1] and Terry A. Jones[1]

Digital Database by Carlos I. Gutierrez[2]

2006

USGS science for a changing world

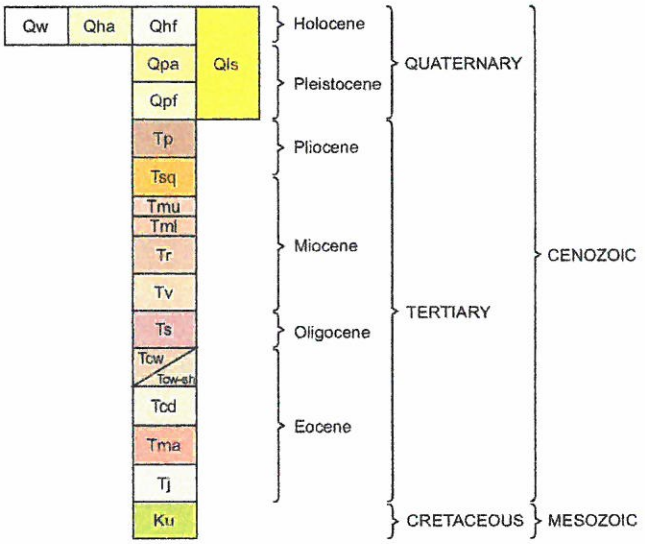
CGS CALIFORNIA GEOLOGICAL SURVEY

1. California Geological Survey, 888 South Figueroa Street, Suite 475, Los Angeles, CA 90017
2. California Geological Survey, 801 K Street, MS 12-32, Sacramento, CA 95814

Unit Explanation

- **Qw** — **Active wash deposits within major river channels (Holocene)** - Composed of unconsolidated silt, sand and gravel.
- **Qha** — **Alluvial and colluvial deposits, undivided (Holocene)** - Located on the floors of valleys; includes active stream deposits in hill slope areas; composed of unconsolidated sandy clay with some gravel.
- **Qhf** — **Alluvial fan deposits (Holocene)** - Deposited by streams emanating from mountain canyons onto alluvial valley floors; deposits originate as debris flows, hyper-concentrated mudflows, or braided stream flows; composed of moderately to poorly sorted, and moderately to poorly bedded, sandy clay with some gravel.
- **Qls** — **Landslide deposits (Holocene to late Pleistocene)** - Includes numerous active landslides, composed of weathered, broken up rocks; extremely susceptible to renewed landsliding, including their head scarp areas.
- **Qpa** — **Alluvial deposits, undivided (late Pleistocene)** - Consists of semi-consolidated silt, sand, clay, and gravel.
- **Qpf** — **Alluvial fan deposits (late to middle Pleistocene)** - Semi-consolidated poorly sorted gravel, boulder, sand, silt and clay; often form elevated, slightly tilted, terraces on hill slope areas.
- **Tp** — **Pico Formation, undivided (Pliocene)** - Composed of claystone, siltstone, and sandstone; locally pebbly; generally susceptible to landsliding.
- **Tsq** — **Sisquoc Shale (Pliocene-Miocene)** - Silty shale and claystone; generally susceptible to landsliding. Locally contains siliceous shale similar to the Monterey Formation.
- **Tmu / Tml** — **Monterey Formation (middle and late Miocene)** - Consists of siliceous and diatomaceous shale and some sandstone and limestone; generally susceptible to landsliding. Tml = lower section, containing punky thin-bedded shale; Tmu = upper section, composed of platy brittle siliceous thin-bedded shale.
- **Tr** — **Rincon Shale (early Miocene)** - Composed of shale and siltstone; generally susceptible to landsliding.
- **Tv** — **Vaqueros Sandstone (early Miocene)** - Consists of sandstone, locally calcareous.
- **Ts** — **Sespe Formation (Oligocene)** - Composed of sandstone; locally pebbly, siltstone and claystone; rocks are generally reddish in color.
- **Tcw / Tcw-sh** — **Coldwater Sandstone (late Eocene)** - Composed of hard arkosic sandstone with siltstone and shale interbeds; locally reddish in color, similar to appearance of Sespe Formation. Tcw-sh consists predominantly of shale.
- **Tcd** — **Cozy Dell Shale (late Eocene)** - Consists of micaceous shale with arkosic sandstone interbeds; generally susceptible to landsliding.
- **Tma** — **Matilija Sandstone (middle to late Eocene)** - Composed of hard arkosic sandstone with micaceous shale interbeds.
- **Tj** — **Juncal Formation (early to middle Eocene)** - Consists of micaceous shale with arkosic sandstone interbeds; generally susceptible to landsliding.
- **Ku** — **Unnamed conglomerate (late Cretaceous)** - Conglomerate with arkosic sandstone and micaceous shale interbeds.

Unit Correlation



References

The bedrock geology is largely modified from Dibblee (1987).

Barnard, M., 1979, Geologic map of the Lake Casitas area *in* Geology of the Lake Casitas area, Ventura County, California: Field trip guidebook, Coast Geological Society and Pacific Section, American Association of Petroleum Geologists, 1979 Spring field trip, 57 p.

California Division of Mines and Geology, 1986, Earthquake Fault Zones, Matilija Quadrangle, Official Map of July 1, 1986. scale 1:24,000.

Clark, M.N., 1982, Tectonic geomorphology and neotectonics of the Ojai Valley and upper Ventura River: University of California, Santa Barbara, M.S. thesis, 77 p., 5 plates, scale 1:24,000.

Dibblee, T.W., Jr., 1987 Geologic map of the Matilija Quadrangle, Ventura County, California: Dibblee Geological Foundation Map DF-12, scale 1:24,000.

Earth Technology Corporation (ERTEC), 1981, Seismotectonic study for Casitas Dam and vicinity, Ventura County, California: Report prepared by Ertec Western for U.S. Bureau of Reclamation, Contract No. 1-07-DV-0112, Ertec Project No. 81-159, 96 p., 7 plates, scale 1:12,000.

Edwards, R.D., Rabey, D.F., and Kover, R.W., 1970, Soil survey of the Ventura area, California: U.S. Department of Agriculture, Soil Conservation Services, 151 p., scale 1:24,000.

Hydrographs were prepared for the study period and each water year. Each annual hydrograph has weekly river flow; water table elevations for each monitoring well with corresponding riverbed elevation references; and monthly water districts' pumping plotted adjacent to the nearest monitoring well's hydrograph.

The effect of geologic faults was analyzed by looking at water table changes immediately upstream, within, and downstream of the zone between the Santa Ana Arroyo Parida and Villanova faults over the range of water table fluctuations during the study period.

Key data are: daily flows in the Ventura River measured at Casitas Municipal Water District's weir in the Ventura River (VRNMO); monthly pumping by the VRWD and MOWD, and water level elevations from the following five key monitoring wells read by VCWPD:

4N23W4J1
4N23W9B1
4N23W16C4
4N23W20A1
4N23W29F2

The following descriptions characterize each of those wells. Some of these wells are close to pumping wells or occasionally may be a pumping well. If a pumping well, the well operator was asked to turn the pump off a day or two before the measurement is taken. The reading thus approximates a static water level. If the well was pumping, a notation thereof was made on the water table measurement log.

Observations Wells Characterizations

J1 (4N23W4J1)

Location. This is MOWD well 8. It is on the flood plain about 625' south of a westerly extension of Fairview Road, and about 785' west of Rice Road measured along an east-west line. A line extending westerly intersects the river about 300' north of the northerly of the two large swimming holes along western cliff of flood plain.

River Proximity. The main river channel is about 1,700' west to lowest active river channel elevation of 702'.

Pumping Proximity. From Oct 2005 through Sept 2014, well 8 pumped only during periods from July 2011 through July 2012; Feb through Aug 2013; and May, 2014.

Water Table Fluctuation. 60′, from 625′ to 685′.
Active Wells. There is one well within a 1,000′ radius of J1; and a total of 7 wells within a 2,000′ radius according to VCWPD map of active wells as of July, 2014.

B1 (4N23W9B1)
Location. This is Gramckow south well. It is on the flood plain near the intersections of Lomita Street and Rice road, about 245′ west south west of MOWD wells 4 & 7.
River Proximity. The closest low channel is 610′ west with elevation 651′. The closest active low channel is 930′ west with elevation 645′. Closest water flow in April 2011 was 930′.
Pumping Proximity. MOWD wells 4 & 7 are 245′ to the east north east.
Water Table Fluctuation. 73′, from 578′ to 651′.
Active Wells. There are 2 wells within a 1,000′ radius of B1; and a total of 5 well within a 2,000′ radius according to VCWPD map of active wells as of July 2014.

C4 (4N23W16C4)
Location. Among wells of VRWD, just north of Old Baldwin Road, approximately 90 ft. south of well 4 and about 45 ft. east of centerline between wells 4 and 2.
River Proximity. About 425′ to lowest channel elevation of 552′; and about 950′ to lowest active channel elevation of 552′.
Pumping Proximity. Within 100′ of wells 2 & 4; 660′ from well 1; and 330′ from well 3.
Water Table Fluctuation. 72′, from 480′ to 552′.
Active Wells. There are 6 wells within a 1,000′ radius of VRWD wells 1-4; and a total of 16 wells within a 2,000′ radius according to VCWPD map of active wells as of July 2014.

A1 (4N23W20A1)
Location. At 1000 Burnham Road, about 2,900′ south of Hwy 150 and about 150′ east of Burnham Road across from Los Encanos Apartments. It is about 1,900′south of the Arroyo Parida Santa Ana fault and 400′ north of the Villanova fault.
River Proximity. About 555′ to lowest channel at elevation of 483′; about 780′ to lowest active channel elevation of 476′.

Pumping Proximity. This may be a private pumping well, as it has a power supply. Unknown when or how much was pumped, although it was primarily used for watering horses, according to Marvin Hanson, retired hydrographer from VCWPD and long time member of VRWD Board of Directors.
Water Table Fluctuation. 29′, from 455′ to 484′.
Active Wells. There is one well within radius of 1,000′ and a total of 4 wells within a radius of 2,000′ according to VCWPD map of active wells as of July 2014.

F2 (4N23W29F2)
Location. At 873 Santa Ana Blvd. in Oak View.
River Proximity. About 1,315′ to lowest active channel elevation of 390′.
Pumping Proximity. This may be a private well that hasn't been used for an unknown period, according to the owner.
Water Table Fluctuation. 54′, from 334′ to 388′.
Active Wells. There are 4 wells within a 1,000′ radius and a total of 10 wells within a 2,000′ radius according to VCWPD map of active wells as of July 2014.

Two more observation wells were used, but only to make adjustments to storage coefficients for a few of Turner's flow nodes. 4N23W3M1, located along Devereaux Dr., midway between La Luna and Rice Roads in Meiners Oaks, was used to adjust Node 20. 4N23W16P1, located at the south end of Rice Road near the southwest corner of the Ojai Oaks Village trailer park in Mira Monte, was used to adjust Node 26. P1 is on the Villanova fault.

Set One Hydrographs

Overview

These hydrographs show water table elevations at each observation well, river flow volume, and monthly quantities of water districts' pumping. Depth to water (DTW) can be seen by comparing the water table elevation with an observation well's ground surface reference, which is the lowest elevation of the nearest active river channel. It is the horizontal line of the same color as the observation well's hydrograph. Figure 1 is an overview showing those data for the study period and contains quarterly river flow volumes. Note: observation well data were bi-monthly

through 2009-10; to fit the quarterly river volume data, some elevations are interpolations and won't match exactly the bi-monthly values in Figures 1a through 1e. Figures 1a through 1i are for water years 2005-06 through 2013-14, respectively, and contain weekly river flow volumes.

Observations

This set is a presentation of basic data; there is no interpretation. Hydrographs 1c, 1d, 1e, 1f, 1h, and 1i (years 2008, 2009, 2010, 2011, 2013, and 2014 respectively) have more frequent well readings. These show how quickly water tables rise in response to river flow.

Figure 1 2005-06 to 2013-14

- Similarity of hydrograph shapes for the 5 key wells.
- Similarity of hydrographs for B1 and C4 in pumping nodes with F2 in a non-pumping node.
- Big difference in range of water table changes between J1 and M1, which are only about 1,200′ apart.
- Nearly constant water table at P1, which is on the Villanova fault, 3,800′ from C4, and 3,000′ from A1.
- A1 has the shallowest water table and smallest fluctuation range of the 5 key wells.
- Substantial rise in water table from river flow when water table is low and small rise when water table is high. The latter indicates rejected recharge.

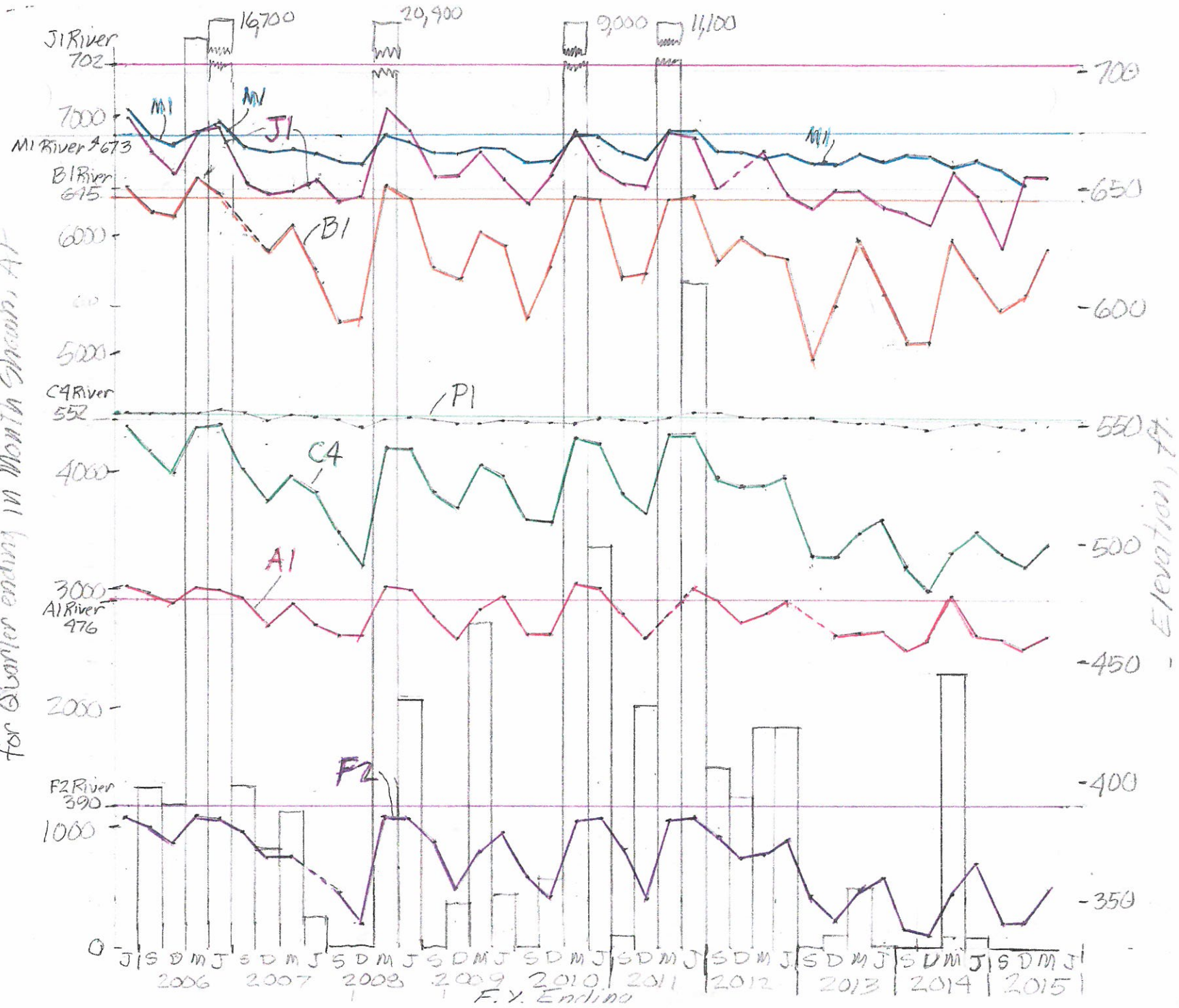

Quarterly River Volume at VRNMO Gage for Quarter ending in Month Shown, AF
J1 River 702
M1 River 673
B1 River 615
C4 River 552
A1 River 476
F2 River 390
16,700
20,900
9,000
11,100
M1
M1
J1
B1
P1
C4
A1
F2
7000
6000
5000
4000
3000
2000
1000
0
700
650
600
550
500
450
400
350
Elevation, ft.
J S D M J S D M J S D M J S D M J S D M J S D M J S D M J S D M J S D M J S D M J
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
F.Y. Ending

FIG. 1

Figure 1a 2005-6

- Major storms in late March and early April had relatively little effect on water tables, indicating rejected recharge because the groundwater basin was full.
- Declines in water table during relatively large river flows indicates groundwater flow exceeded recharge, low infiltration rates, effect of water districts' pumping, or a combination of those.
- During Jun-Jul, similar declines at J1 non-pumping node and B1 pumping node; steeper decline at C4 with larger pumping; and A1 level.
- During Aug-Sep, similar declines at B1 and C4, despite C4's larger pumping.
- During Aug-Sep, F2 (non-pumping node) gradually declines with significant river flow, indicating rejected recharge or infiltration rates less than groundwater flow.

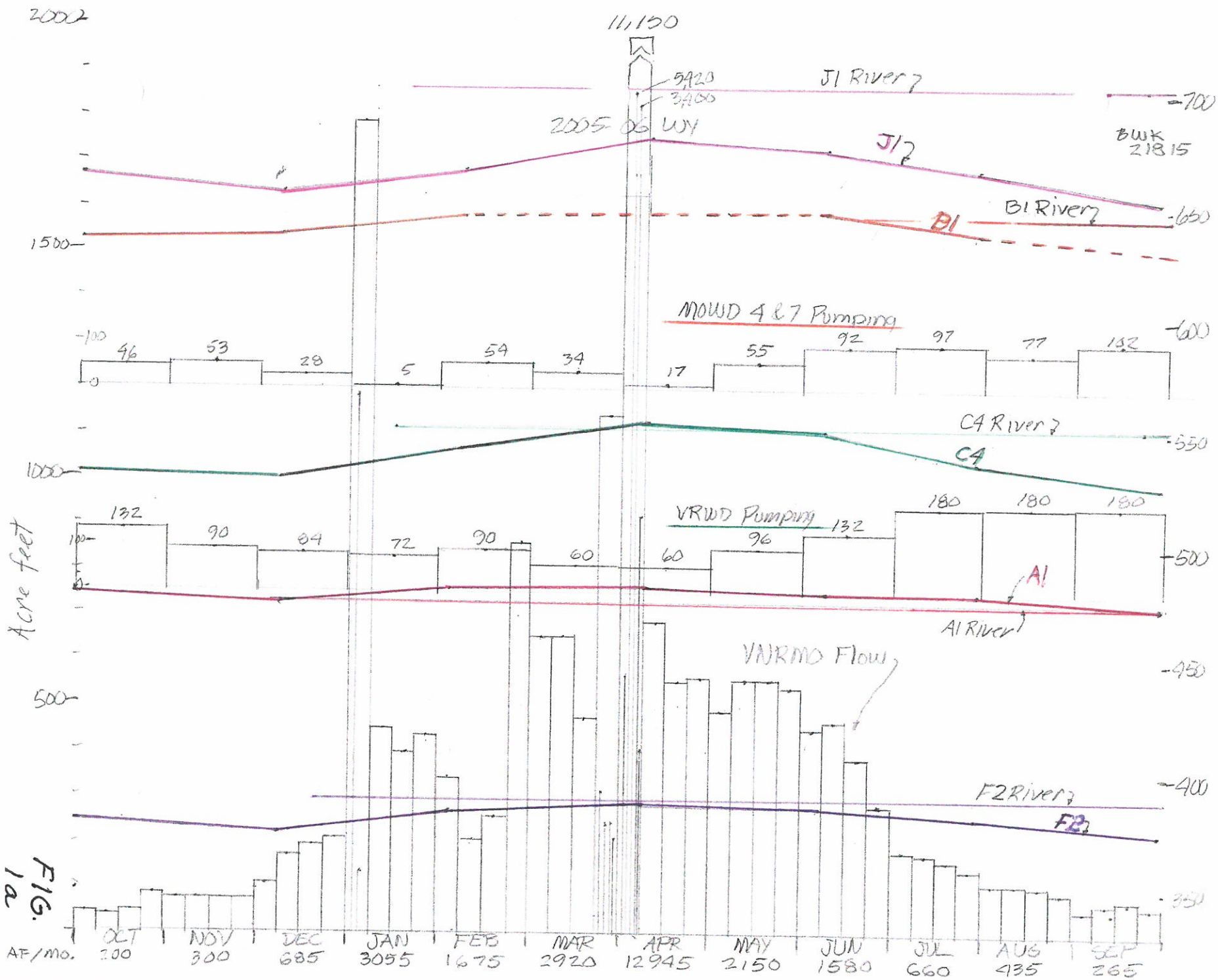

2000
1500
1000
500
Acre feet
11,150
5420
3400
2005-06 WY
J1 River
J1
B1 River
B1
BWK 21815
700
650
600
550
500
450
400
350
MOWD 4 & 7 Pumping
46
53
28
5
54
34
17
55
92
97
77
142
C4 River
C4
VRWD Pumping
132
90
84
72
90
60
60
96
132
180
180
180
A1
A1 River
VNRMO Flow
F2 River
F2
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
AF/mo.
200
300
685
3055
1675
2920
12945
2150
1580
660
435
265

FIG. 1a

Figure 1b 2006-7

- Narrow range of water table changes in J1, which is closest to largest flow.
- During Feb-Mar, drop in B1 with relatively low pumping while all other wells went up.
- During Apr-May, all water levels went down except J1, which rose; and similar declines in C4 with pumping and A1 without pumping.
- During Jun-Jul, steeper decline in B1 with less pumping compared to C4 with more pumping.

During Aug-Sep, F2 without pumping declines more steeply than B1 and C4 with pumping.

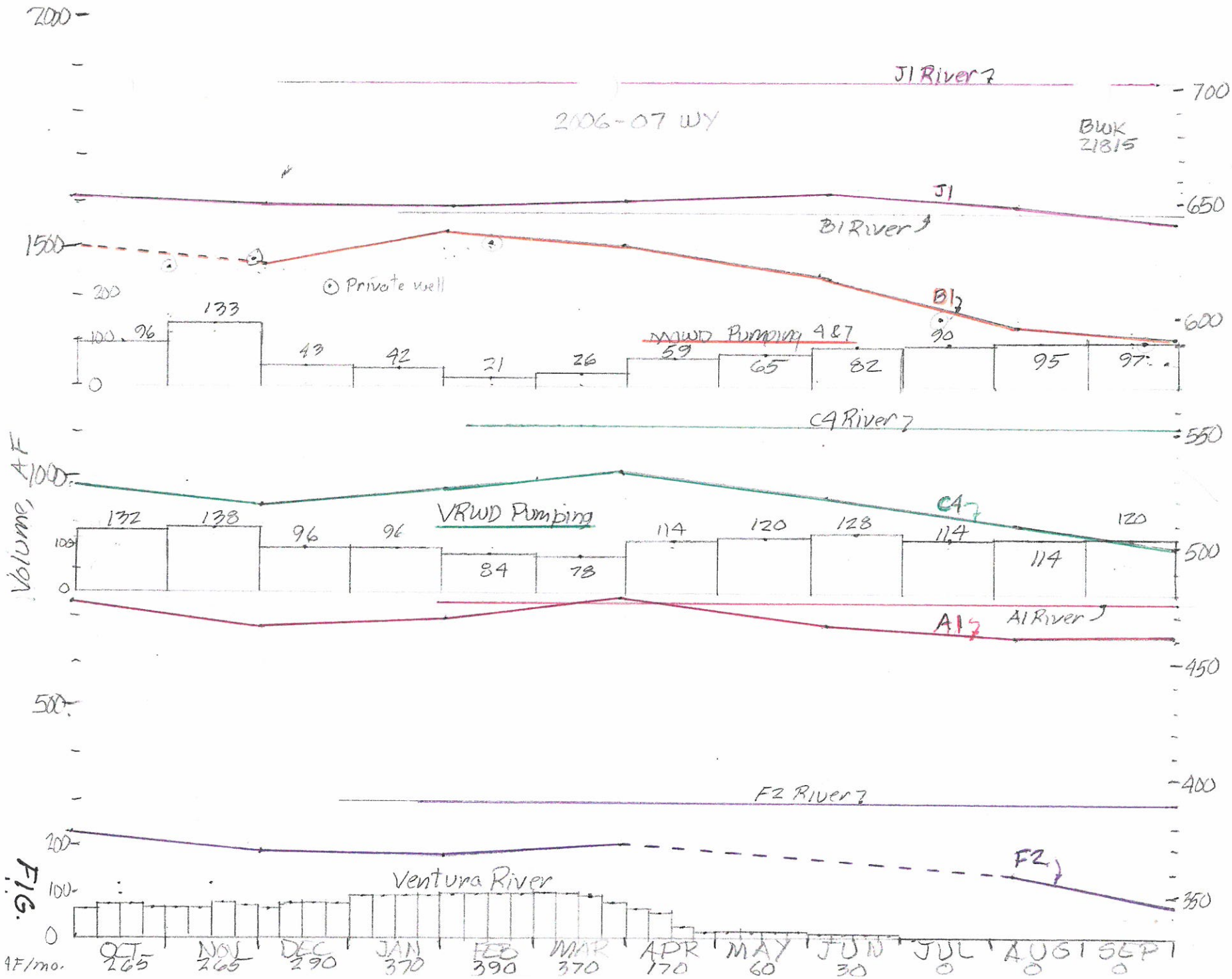

2006-07 WY
BWK 21815
J1 River
J1
B1 River
B1
Private well
WWWD Pumping 4&7
96
133
43
42
21
26
59
65
82
90
95
97
C4 River
C4
VRWD Pumping
132
138
96
96
84
78
114
120
128
114
114
120
A1
A1 River
F2 River
F2
Ventura River
Volume, AF
OCT 265
NOV 265
DEC 290
JAN 370
FEB 390
MAR 370
APR 170
MAY 60
JUN 30
JUL 0
AUG 0
SEP 0
AF/mo.

FIG.

Figure 1c 2007-8

- During Oct-Nov, J1 and B1 rose while C4 and F2 dropped.
- During Dec-Jan, B1 has extra data points from private well nearby giving a more accurate picture of water table response to large river flow. All wells show substantial increases due to large river flow and initially low water table.
- During Feb-Mar, C4 was only water table to rise, indicating continuing recharge; others were stable or slightly declined.
- During Apr-May, water table north of fault zone (J1, B1, AND C4) declined while to the south it didn't change. J1 decline indicates rejected recharge or infiltration volume less than groundwater flow.
- During Aug-Sep, water tables declines were similar except for J1, which had the smallest.

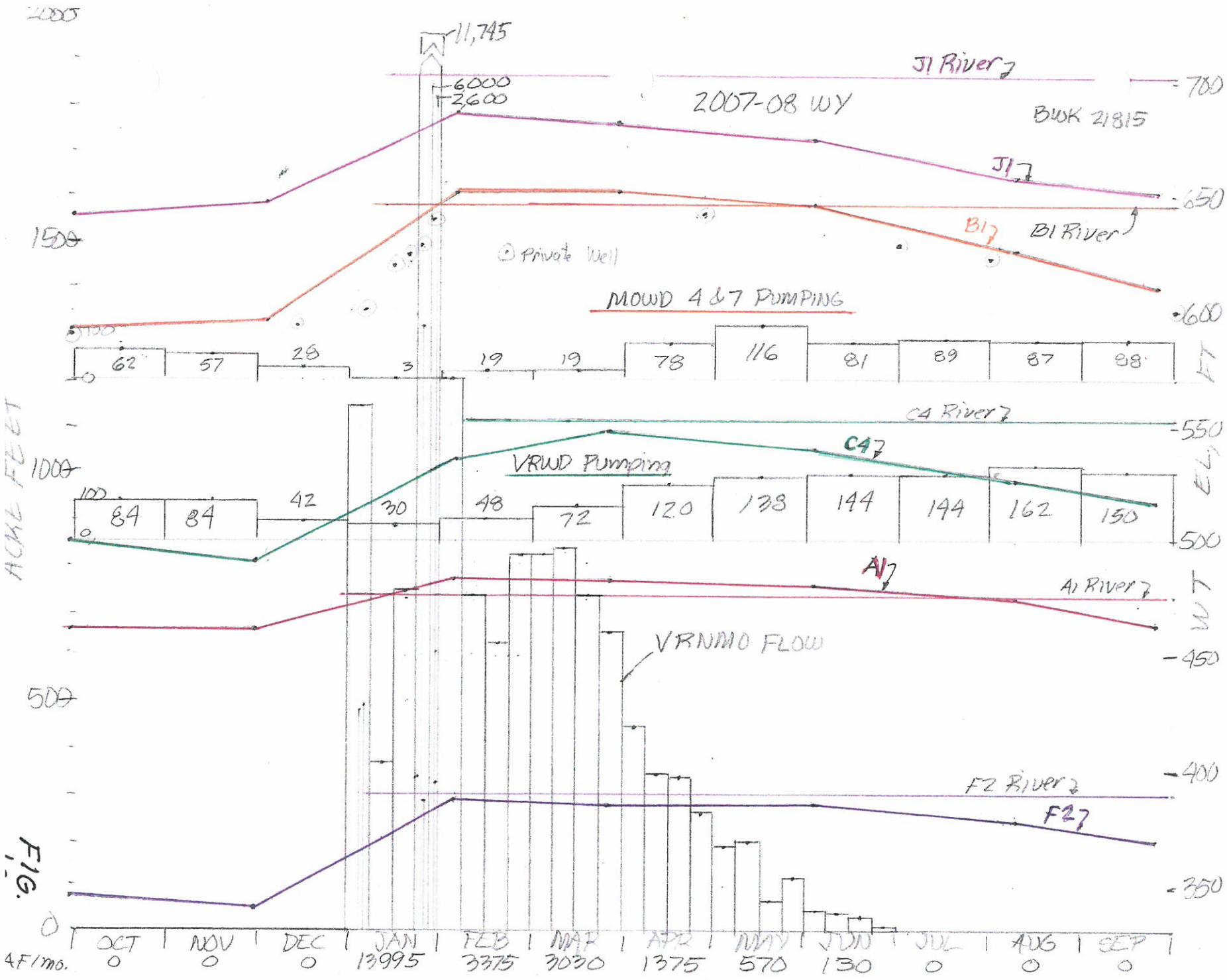

2000
1500
1000
500
0
ACRE FEET
11,745
6000
2600
2007-08 WY
BWK 21815
J1 River
J1
B1
B1 River
Private Well
MOWD 4 & 7 PUMPING
62
57
28
3
19
19
78
116
81
89
87
88
C4 River
C4
VRWD Pumping
100
84
84
42
30
48
72
120
138
144
144
162
150
A1
A1 River
VRNMO FLOW
F2 River
F2
700
650
600
550
500
450
400
350
ELEV. FT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
AF/mo.
0
0
0
13995
3375
3030
1375
570
130
0
0
0

FIG.

Figure 1d 2008-9

- During Dec-Mar, MOWD #7 extra data points near B1 show more accurate water table response.
- During Apr-May, J1 with no pumping declines similarly to B1 and C4 with pumping.
- During Apr-Sep, B1 and C4 with water districts' pumping show steadier declines than non-pumping areas.
- During Jun-Jul, similar declines in A1 with no pumping and B1 and C4 with pumping.
- During Aug-Sep, F2 declines much faster than A1, despite overall similarity of hydrographs.
- During Aug-Sep, A1 is level while F2 with no pumping declines more steeply than B1 and C4 with pumping.

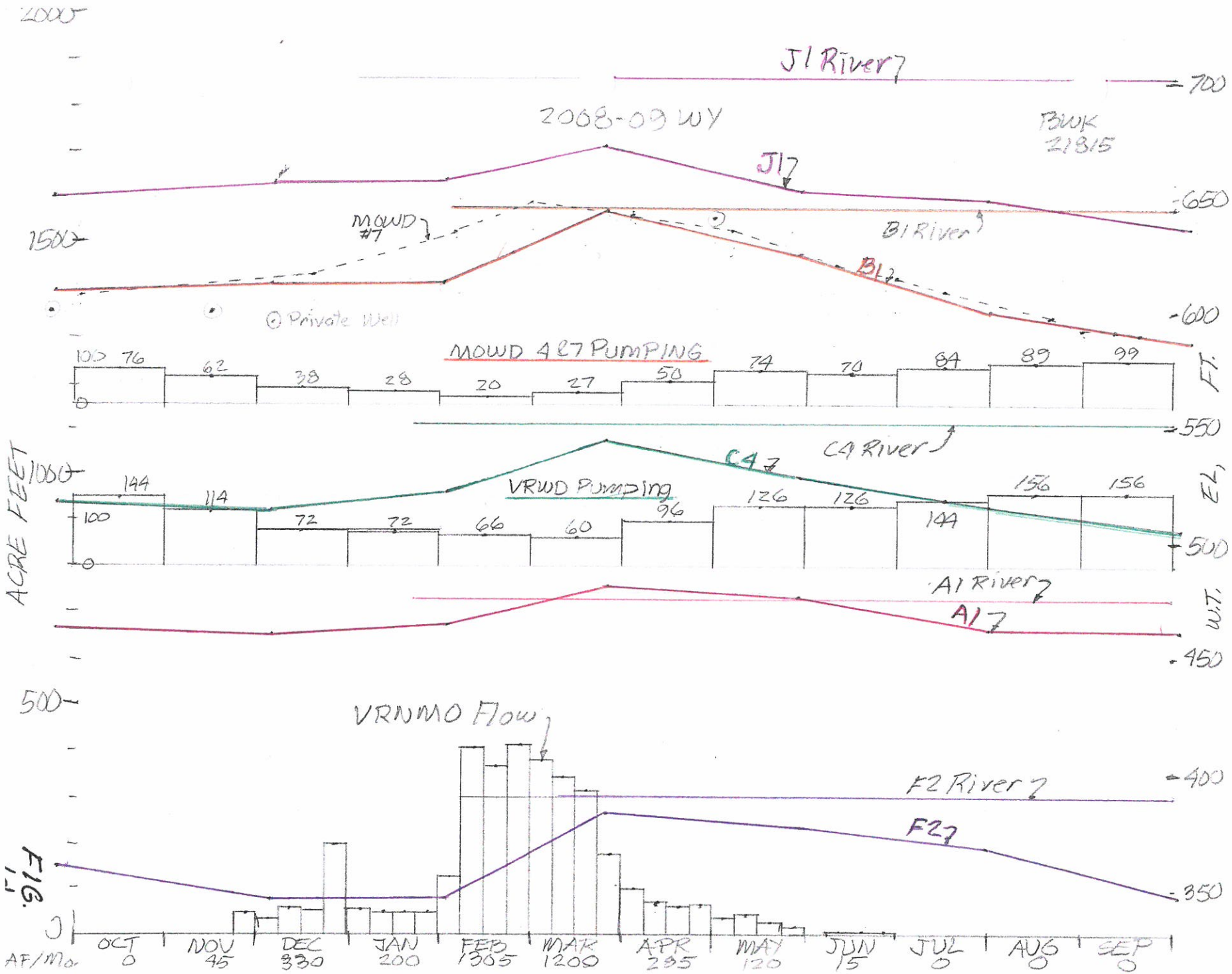

2000
J1 River
700
2008-09 WY
BWK
21815
J1
650
1500
MOWD #7
B1 River
B1
600
Private Well
MOWD A&7 PUMPING
105 76 62 38 28 20 27 50 74 70 84 89 99
FT.
550
C4 River
C4
1000
144 114 72 72 66 60 96 126 126 144 156 156
VRWD Pumping
100
ACRE FEET
EL.
500
A1 River
A1
W.T.
450
500
VRNMO Flow
F2 River
400
F2
FIG. 1
0
350
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
AF/Mo 0 45 330 200 1305 1200 285 120 15 0 0 0

Figure 1e 2009-10

- During Oct-Nov, relatively large rise in J1 and B1 with low river flow may indicate limit of recharge area along river from a small storm.
- During Feb-Jun, water table represents a full basin with rejected recharge. Decline in J1 implies infiltration volume is less than groundwater flow volume.
- During Jun-Jul, J1 decline with small river flow indicates groundwater flow exceeds recharge flow.
- During Aug-Sep, J1 declines more slowly than others, possibly indicating increased groundwater flow from Matilija Canyon.
- Overall, water level changes track with runoff pattern. Delay in occurrence of peak water table may indicate a groundwater wave moving through the basin.

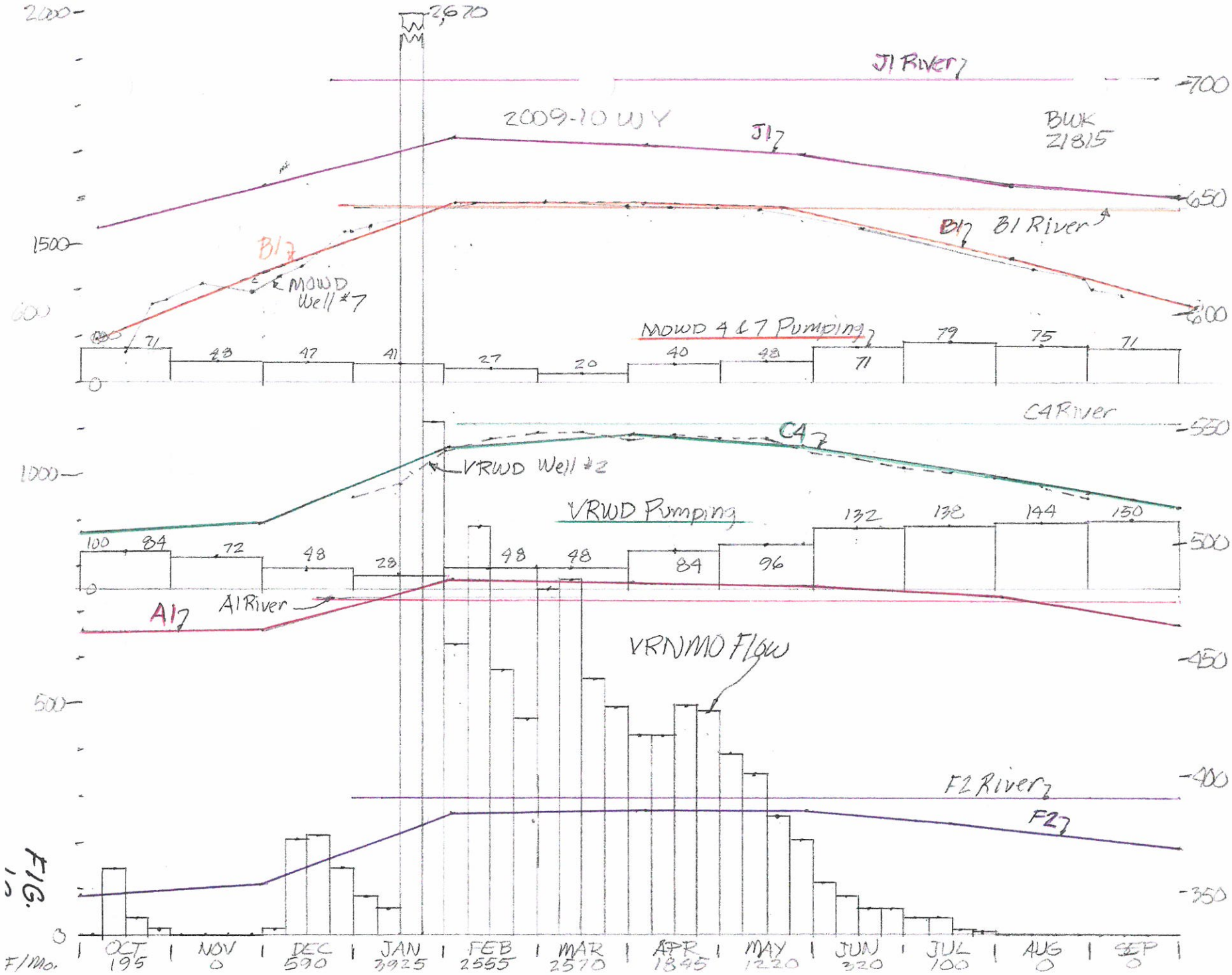

2,670
J1 River
2009-10 WY
J1
BWK
21815
B1
B1 River
MOWD
Well #7
MOWD 4 & 7 Pumping
71
48
47
41
27
20
40
48
71
79
75
71
C4 River
C4
VRWD Well #2
VRWD Pumping
100
84
72
48
28
48
48
84
96
132
138
144
150
A1
A1 River
VRNMO Flow
F2 River
F2
2000
1500
1000
500
0
700
650
600
550
500
450
400
350
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
F/Mo.
195
0
590
3925
2555
2570
1845
1220
320
100
0
0

FIG. 12

Figure 1f 2010-11

- During Oct-Nov, F2 goes down significantly; J1, C4, and A1 are stable; and B1 rises with no river flow.
- The Dec storm produced large rapid increases in B1 and C4, which are apparent only because of observation well data covering a shorter interval than County data. Most of rise occurred within 3 weeks of storm.
- During Apr-Jun, A1 and F2, away from water districts' pumping, continue to rise indicating continuing recharge. B1 and C4, near pumping, remain level, as does J1, which is away from pumping. J1 indicates groundwater flow volume and recharge volume are equal or rejected recharge.
- During Apr-Jun, J1 remains level with large river flow, probably indicating a full basin in that node.
- During Jun-Sep, J1 steady decline with significant river flow indicates groundwater flow exceeding recharge flow and possible effect of MOWD #8 pumping, although decline starts before pumping begins.

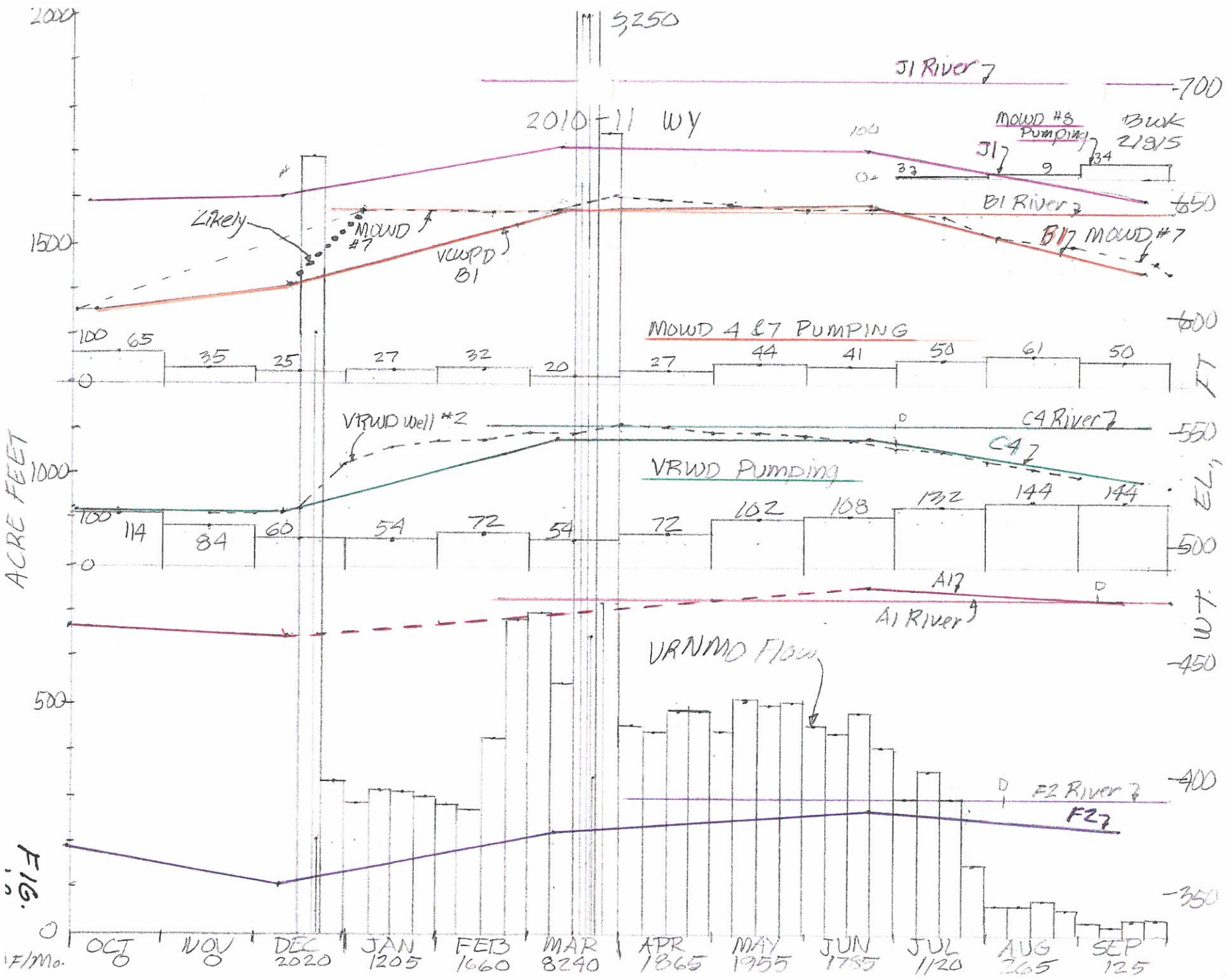

2000
1500
1000
500
0
ACRE FEET
5,250
2010-11 WY
J1 River
700
MOWD #8 Pumping
Buck 2/8/15
J1
100
33
9
34
B1 River
650
Likely
MOWD #7
VCWPD B1
B1
MOWD #7
MOWD 4 & 7 PUMPING
600
100
65
35
25
27
32
20
27
44
41
50
61
50
FT
VRWD Well #2
C4 River
550
C4
VRWD Pumping
EL.
100
114
84
60
54
72
54
72
102
108
132
144
144
500
A1
A1 River
WT.
VRNMD Flow
450
400
F2 River
F2
350
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
AF/Mo.
0
0
2020
1205
1660
8240
1865
1955
1785
1120
265
125

FIG.

Figure 1g 2011-12

- During Oct-Dec, B1 rises while C4 is level, and A1 and F2 decline. This may indicate the limited extent of recharge from low river flow.
- River flow is low but relatively constant from Nov-May resulting in stable water tables at all observation wells during that period, whether near water districts pumping or not.
- During Apr-Jun, J1 drops significantly compared to others and the change is out of proportion to the amount of pumping. This may indicate groundwater flow volume exceeding recharge volume.
- During Jun-Sep, A1 remained nearly level while B1 and C4 with pumping declined about the same as F2 without pumping. J1 had a small decline with a little pumping and no river flow.

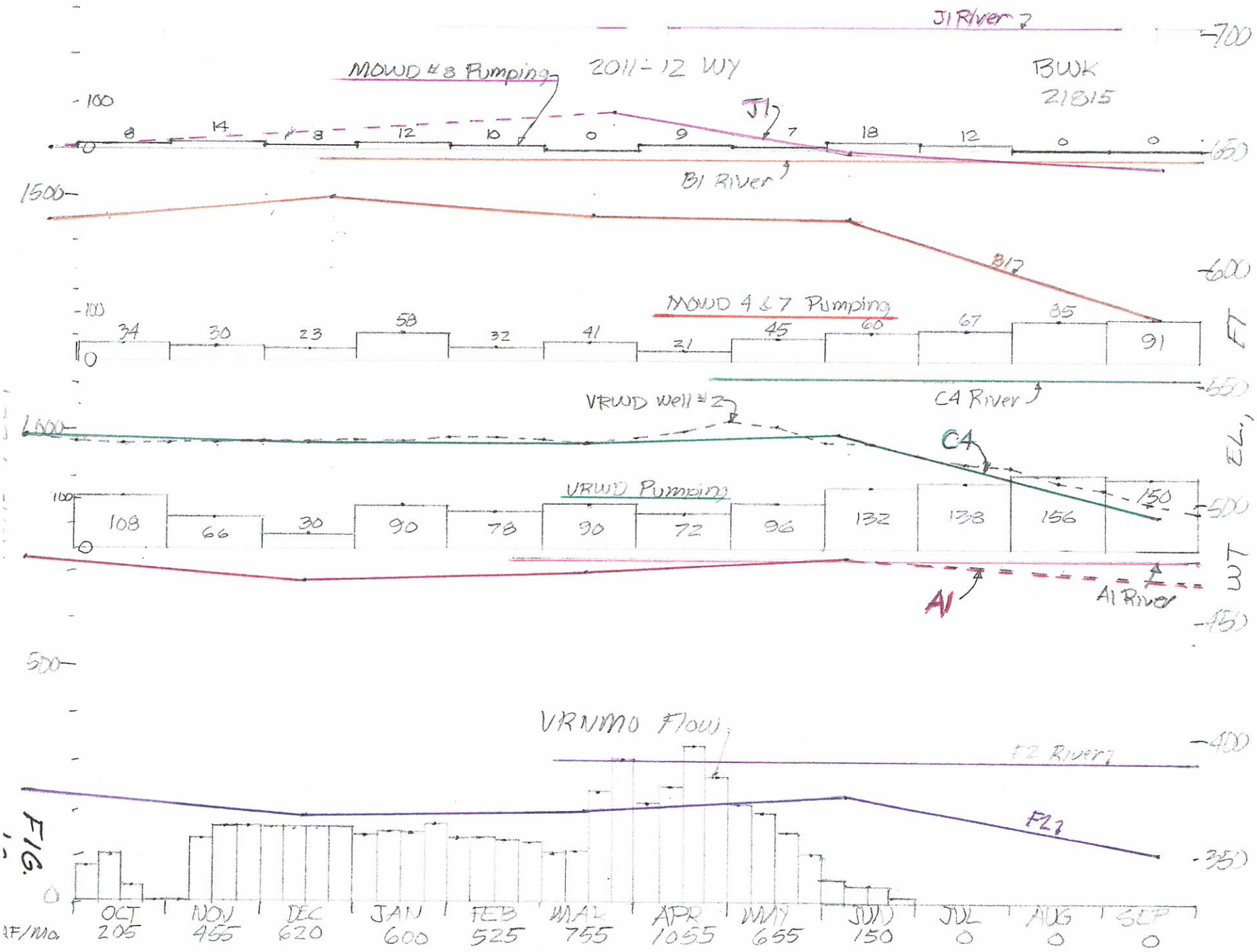

J1 River
MOWD #8 Pumping
2011-12 WY
BWK
21815
J1
8
14
8
12
10
0
9
7
18
12
0
0
B1 River
B1
MOWD 4 & 7 Pumping
34
30
23
58
32
41
31
45
60
67
85
91
C4 River
VRWD well #2
C4
VRWD Pumping
108
66
30
90
78
90
72
96
132
138
156
150
A1
A1 River
VRNMO Flow
F2 River
F2
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
AF/Mo.
205
455
620
600
525
755
1055
655
150
0
0
0
FT
EL.
WT
700
650
600
550
500
450
400
350
100
0
1500
1000
500

FIG.

Figure 1h 2012-13

- Overall, this is the most puzzling hydrograph.
- Dramatic difference between J1 and B1. J1 would be expected to rise more than B1 because, being farthest upstream, it has most flow.
- J1 and A1 decline very little despite very low river flow and pumping at J1.
- During Oct-Dec, F2 declines while others are stable or rise.
- During Oct-May, B1 rises substantially, peaking in Mar, while C4 with pumping and F2 without pumping show moderate rises continuing for several months after flow stopped, despite the year's very low river flow.
- Two-month delay in timing of peak water table at B1 and C4 suggests a groundwater flow wave from recharge.

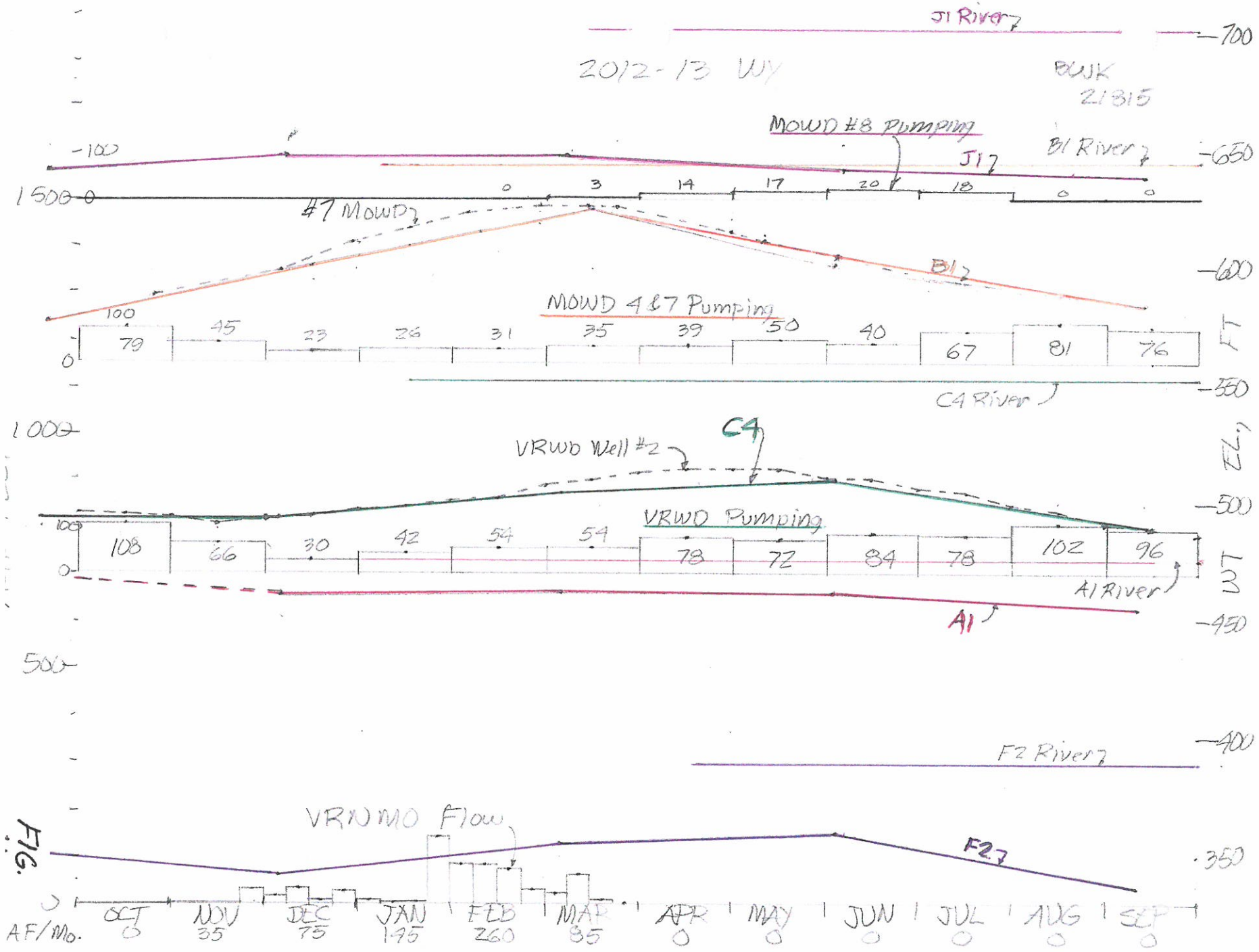

2012-13 WY
BWK
21815
J1 River
J1
MOWD #8 Pumping
B1 River
B1
#7 MOWD
MOWD 4 & 7 Pumping
C4 River
C4
VRWD Well #2
VRWD Pumping
A1 River
A1
F2 River
F2
VRNMO Flow
FIG.
AF/Mo.
OCT 0
NOV 35
DEC 75
JAN 145
FEB 260
MAR 85
APR 0
MAY 0
JUN 0
JUL 0
AUG 0
SEP 0
FT
EL.
FT

Figure 1i 2013-14

- River flow only from late Feb to late Apr. This was an intense short duration storm.
- During Dec-Jun, the rises in water tables didn't occur until after the early Mar storm, as shown by water table data from MOWD well 7 and VRWD well 2.
- C4 and F2 peaked in June while the others peaked in Mar.
- During Mar-Jun, the quick large rise in B1 compared to a smaller, slower rise in C4 indicates substantially more recharge at B1. River flow occurred at B1 for about 20 days while it was less than 10 days at C4.
- Differences between J1, B1, C4, and F2 may represent a groundwater flow wave similar to Fig. 1h, although this phenomenon isn't as apparent in most of the other hydrographs.
- During Mar-Jun, C4 and F2 both rise while A1, which is between those two wells, declines. This is unusual.
- During Jun-Sep, A1 would be expected to decline, as happens with the other wells with no river flow, but it stays level.

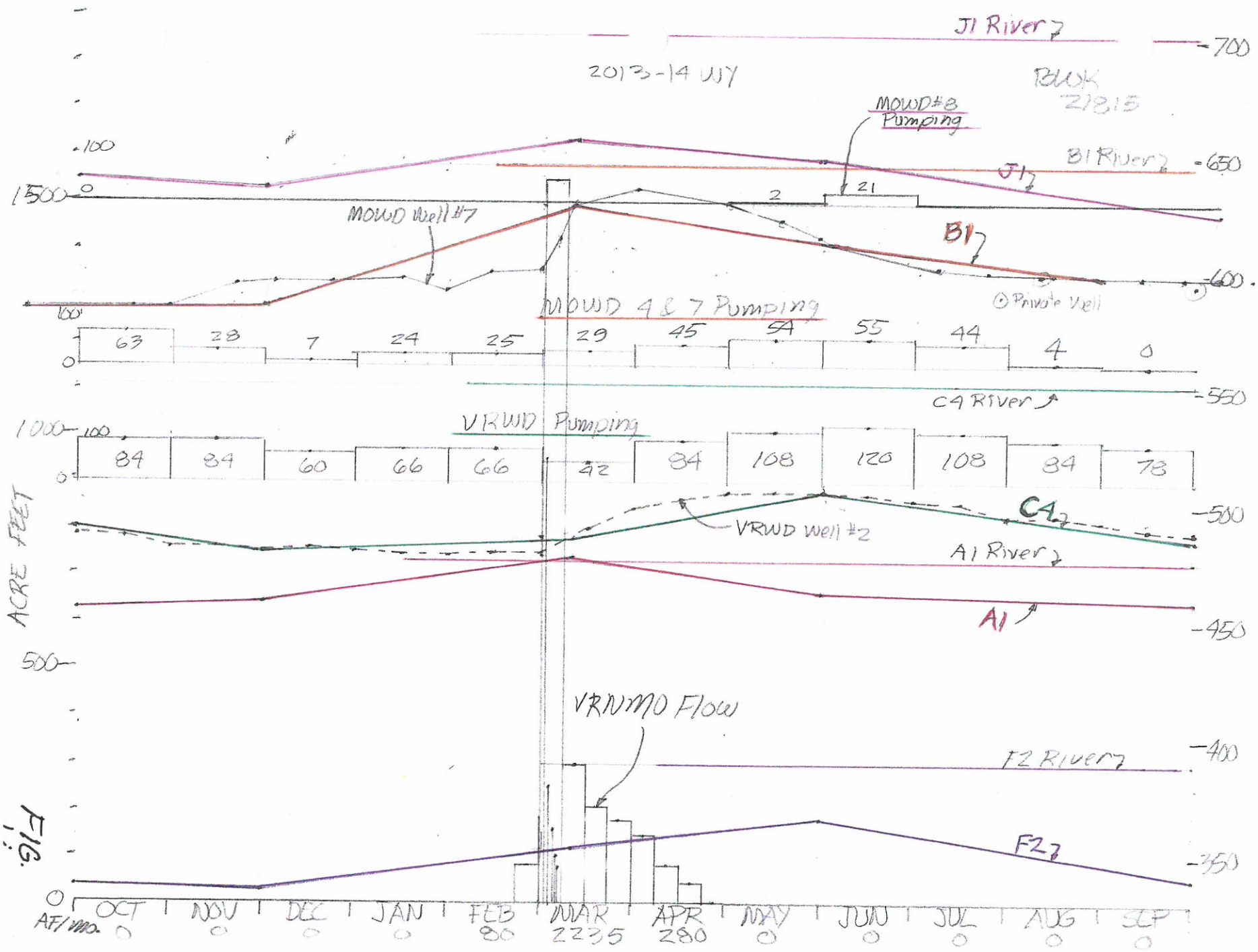

2013-14 WY
BLOCK 21&15
J1 River
B1 River
J1
B1
MOWD#8 Pumping
MOWD Well #7
MOWD 4 & 7 Pumping
Private Well
C4 River
C4
VRWD Pumping
VRWD Well #2
A1 River
A1
VRNMO Flow
F2 River
F2
ACRE FEET
700
650
600
550
500
450
400
350
1500
1000
500
0
100
63
28
7
24
25
29
45
54
55
44
4
0
84
84
60
66
66
42
84
108
120
108
84
78
2
21
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
AF/mo.
0
0
0
0
80
2235
280
0
0
0
0
0

FIG. 1

Conclusions

- Annual hydrographs generally show similar changes at each observation well, whether in pumping nodes or not.
- Changes in water tables give insights into relationships between surface and groundwater flow. For example, a decline in water table with river flow indicates groundwater flow exceeds recharge, a full basin meaning recharge is rejected, effects of water districts' pumping, or some combination of both.
- Hydrographs 1c, 1d, 1e, 1f, 1h, and 1i (years 2008, 2009, 2010, 2011, 2013, and 2014 respectively) have supplemental, more frequent well readings. These show how quickly water tables rise in response to river flow.
- Water districts' pumping doesn't seem to have a consistent effect when comparing water level changes between years. For example, comparing 1f (2011) and 1i (2014) during Jul-Oct, C4 went down about 20' each time, yet there was 1,500 AF of river flow and 420 AF of pumping in 2011 and no river flow with 270 AF pumping in 2014.
- There are also inconsistencies lacking explanations, such as in Fig. 1i for Mar-May when C4 and F2 gain storage while A1 losses storage.

Set Two Hydrographs

Overview

These hydrographs deal with effects of faults, which generally impede groundwater flow. Entrix concluded, "The Santa Ana/Arroyo Parida fault is likely a major influence on downvalley movement of groundwater." p. 5-1. This was based on a finding by EDAW (1981) that there was a threshold effect such that when the water table dropped below 495' at C4, groundwater flow south of the fault would substantially decrease. This would lead to drying of the river's 'wet reach' just south of its confluence with San Antonio Creek. Thus, there are two issues needing evaluation; fault effects on groundwater flow, and the threshold effect. The following is an analysis of those issues.

Set two hydrographs were developed to evaluate the Entrix' threshold hypothesis and, more generally, to see if there were discernable effects of other faults on groundwater flow. These hydrographs show water table elevations upstream, within, and downstream of the Arroyo Parida Santa Ana and Villanova fault zone. Refer back Plate 2 for locations of faults, observation wells, and water districts' pumping wells.

Turner and Entrix mention only the Santa Ana Fault in the study area. Plate 2 shows there could be at least three other faults that could be significant because those are mapped on both sides of the river: the Villanova Fault; an unnamed fault near VRWD wells; and another unnamed fault southerly of MOWD wells. There are many faults in the Mira Monte and Oak View areas that are not mapped west of the river. There is a question of whether faults are just in bedrock or extend into alluvium.

Figure 2a has profiles of the Ventura River and the effective base of the groundwater basin (as determined by Turner) between observation wells J1 and F2. The river elevations are for the lowest active channel closest to the adjacent observation wells. Included are locations of the wells, Arroyo Prida/Santa Ana faults, and the lowest water table elevation for each of the wells. Notice the deeper basin upstream of the Arroyo Parida Santa Ana Fault, which has a bottom elevation of 400' compared with 480' downstream. The threshold effect hypothesis raises a question about the accuracy of Turner's effective base of groundwater at that fault. His elevation downstream of the fault is 480'. However, it would have to be less than that by roughly 15', i.e. 465',which was calculated using the 495' elevation at C4, the typical groundwater slope in this area of 1.2%, and the distance between C4 and the fault, i.e., 30' lower than C4. Note that the lowest water table between C4 and A1 at that fault is about 467', which is consistent with a lower threshold elevation. The calculated base in this area is shown by a dashed line in Figure 2a.

Figures 2b-2e are geologic cross-sections of the groundwater basin prepared by Jordan Kear, Geohydrologist, for the Upper Ventura River Basin Boundary Modification Request. Figure 2b is a cross-section along the River from Camino Cielo to Foster Park; Figures 2c thru 2e are various cross-sections through the basin.

Discussion

One apparent effect of faults on groundwater levels can be seen by comparing ranges of water table changes at

UPPER VENTURA RIVER GW BASIN PROFILE

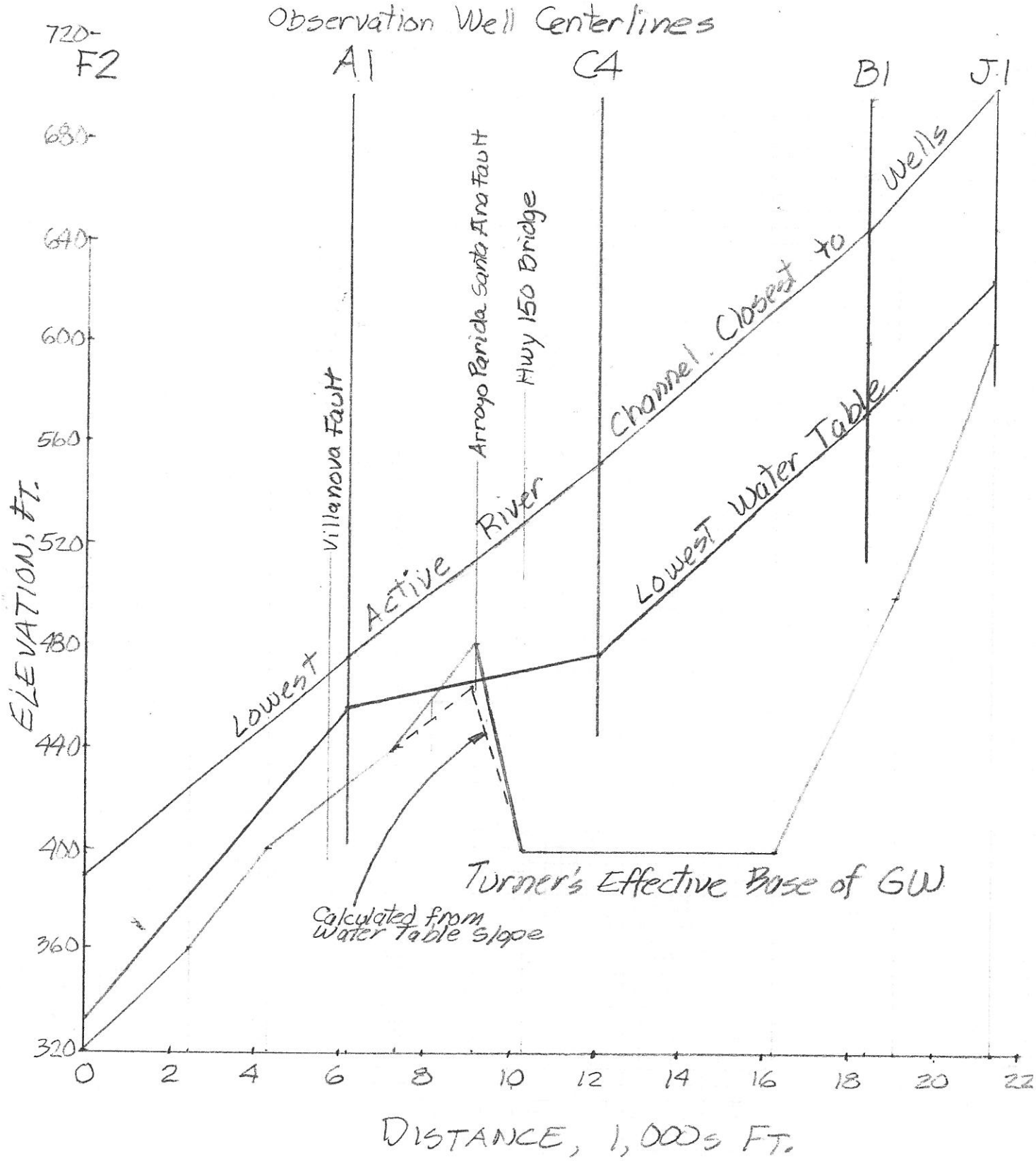


FIG. 2a

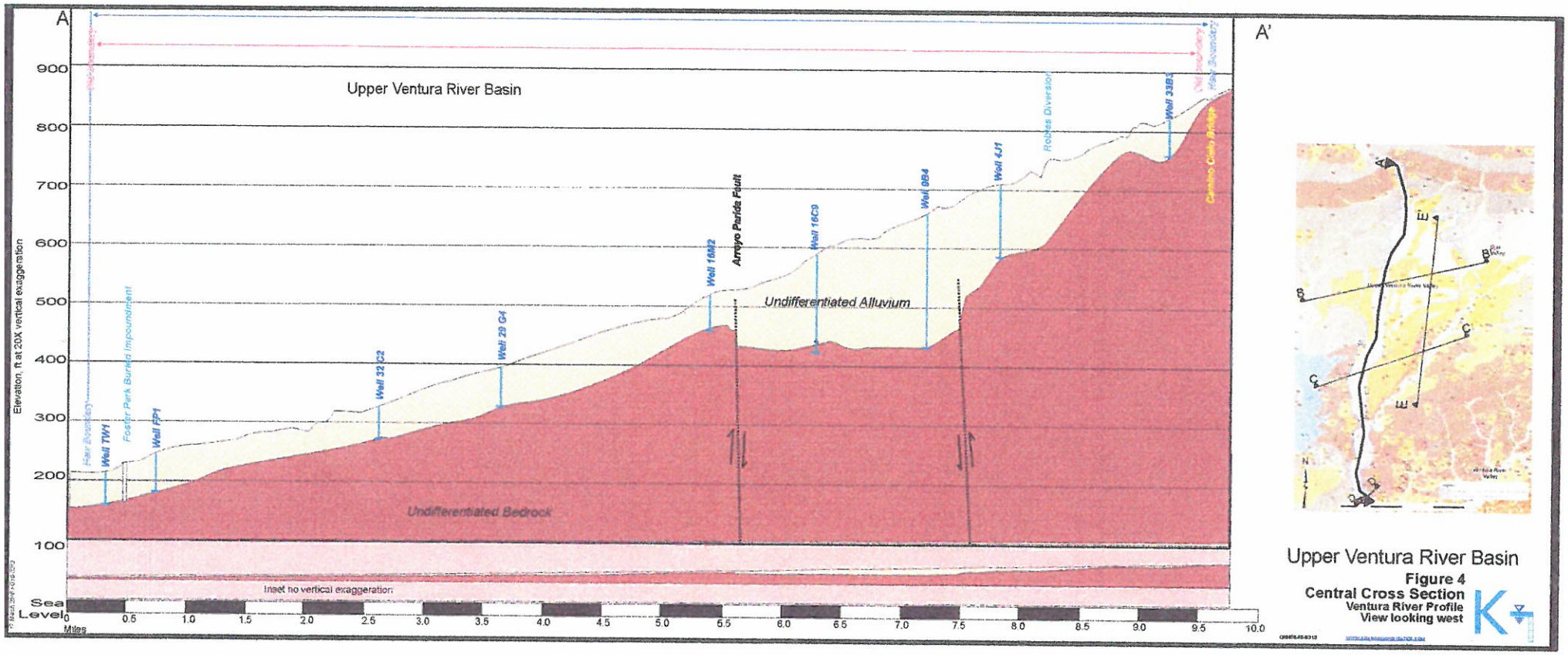

A
A'
Upper Ventura River Basin
Elevation, ft at 20X vertical exaggeration
900
800
700
600
500
400
300
200
100
Sea Level
Well TW1
Foster Park Buried Impoundment
Well FP1
Well 32 C2
Well 29 G4
Well 16M2
Arroyo Parida Fault
Well 16C9
Well 9B4
Well 4J1
Robles Diversion
Well 33B3
Undifferentiated Alluvium
Undifferentiated Bedrock
Inset no vertical exaggeration
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Miles
Upper Ventura River Basin
Figure 4
Central Cross Section
Ventura River Profile
View looking west

FIG. 2b

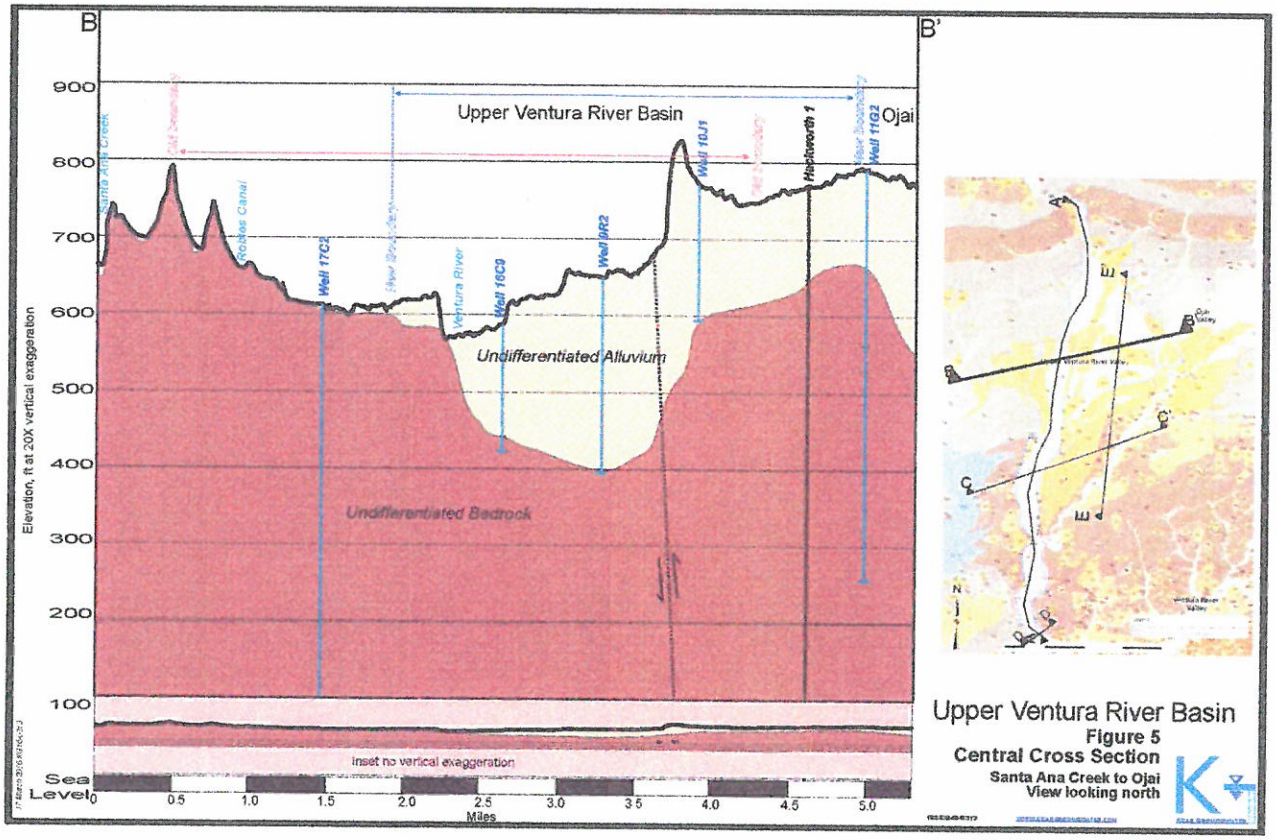

B
B'
Upper Ventura River Basin
Ojai
Santa Ana Creek
Rosales Canal
Ventura River
Well 17C2
Well 16C9
Well 9R2
Well 16J1
Hopkins 1
Well 11G2
Undifferentiated Alluvium
Undifferentiated Bedrock
Inset no vertical exaggeration
Elevation, ft at 20X vertical exaggeration
900
800
700
600
500
400
300
200
100
Sea Level
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Miles
Upper Ventura River Basin
Figure 5
Central Cross Section
Santa Ana Creek to Ojai
View looking north

FIG. 3c

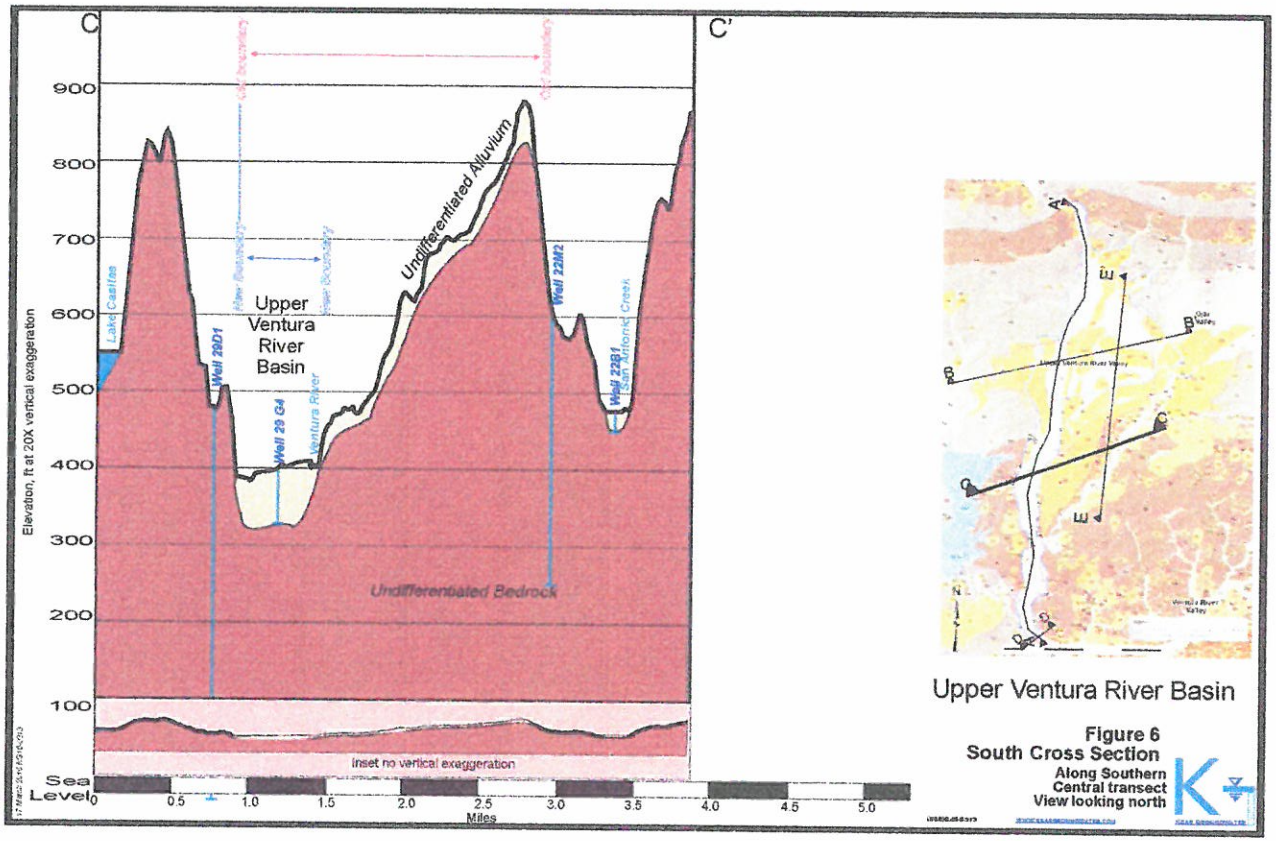


Figure 6
South Cross Section
Along Southern
Central transect
View looking north

FIG. 2A

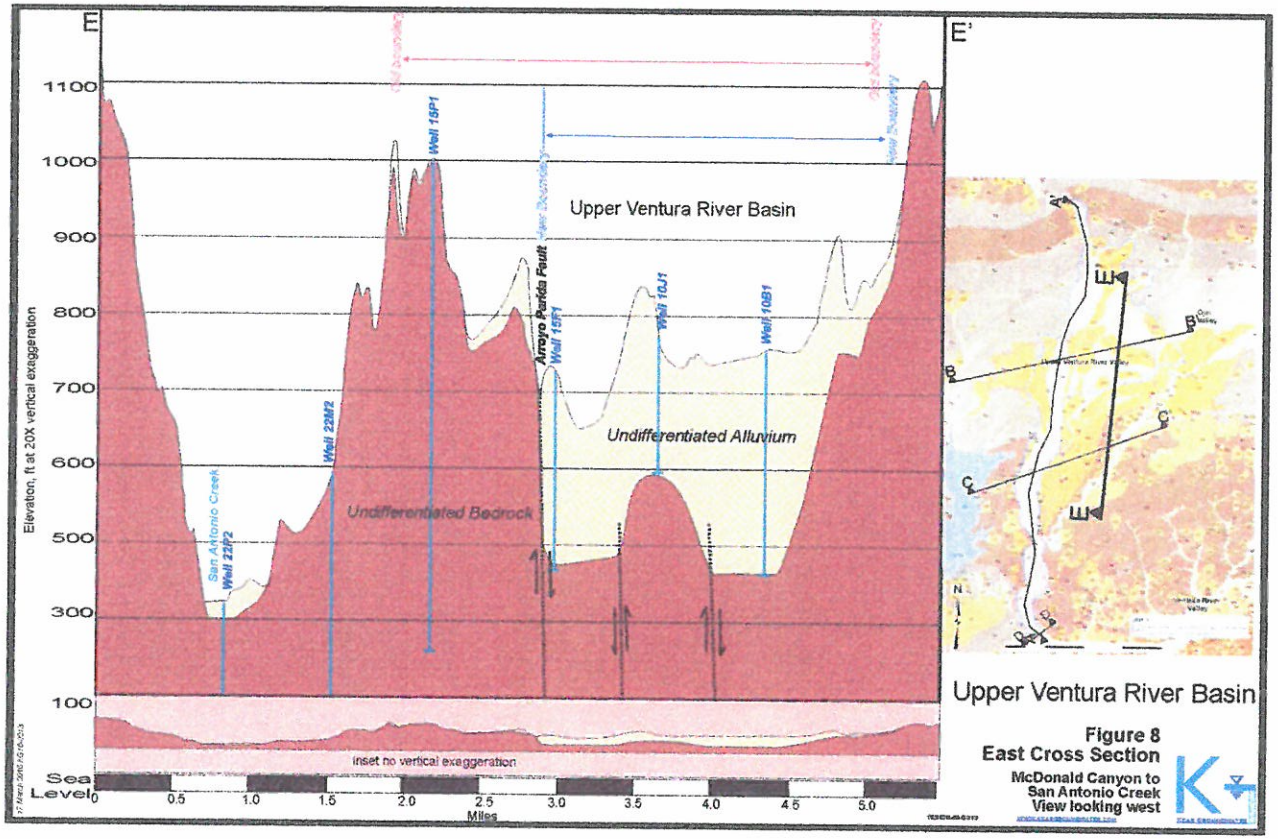


Figure 8
East Cross Section
McDonald Canyon to San Antonio Creek
View looking west

FIG. 7

wells near and away from faults. Well P1 is on the Villanova Fault and its 5 foot water table elevation variation was the smallest of any well. Well A1 is in a fault zone, about 400′ north of the Villanova Fault and its 29′ table elevation variation was the smallest of any of the 5 key wells. Wells C4 and F2 are 2,000′ and more than 6,000′, respectively, from those major faults and their variations were 72′ and 54′ respectively.

Figure 2f shows December water table elevations for C4 north, A1 within, and F2 south of the fault zone from 2005 to 2015. December levels are typically the annual low. The only extended period when C4 is below 495′ begins in 2012 and continues through 2015. Comparing C4 and A1, the shapes of the hydrographs are similar, except for 2007, with A1 having smaller relative changes. F2, about 7,000′ south of A1, shows a pattern that very closely follows C4 north of the fault zone. The range of changes in water table immediately downstream of fault zone (29′ for A1) is less than upstream (72′ for C4). Farther downstream, the range of changes increases (54′ for F2).

Figure 2g shows water table hydrograph segments for two observation wells closest to the fault zone, C4 to the north and A1 in the zone, for June through December, each year's driest period when fault effects would likely be most observable. Note: The fall 2012 elevation at A1 of 441′ must be an error, although no error code is shown on the County's spreadsheet. The last time the elevation was that low was 12-1-54 and it was preceded by elevations of 462′ on 10-29-54 and 1-20-55. Rises of 20+′ have only occurred during winter so the rise from 441′ to 461′ from October to December 2012 is another reason to doubt its validity. As a result, the 441′ value was ignored and a straight-line interpolation was used between the June and December values for calculations. Overall, movements of the water table upstream and in the fault zone are similar in timing and relative magnitude, even during periods of the lowest water table, i.e., 2012-2015. There are a few exceptions when the opposite effect is seen, i.e., A1 stabilized while C4 dropped. This occurred between September and December 2007; and in 2013 when A1 rose between September and December while C4 dropped. From December 2014 to March 2015, both C4 And A1 rose without any flow at VRNMO for more than 6 months.

Figure 2h takes a closer look at 2012-2015 (when C4 was usually below 495′) using complete hydrographs for wells C4, A1, and F2. There are three periods where threshold effects would be expected: from Aug 2013 to Apr 2014; Aug 2014 to Feb 2015; and from Aug 2015 through Dec 2015. Figure 2h also has hypothetical hydrographs for A1 and F2 assuming the threshold effect is valid. Conceptually it shows A1 and F2 declining faster after C4 is below 495′

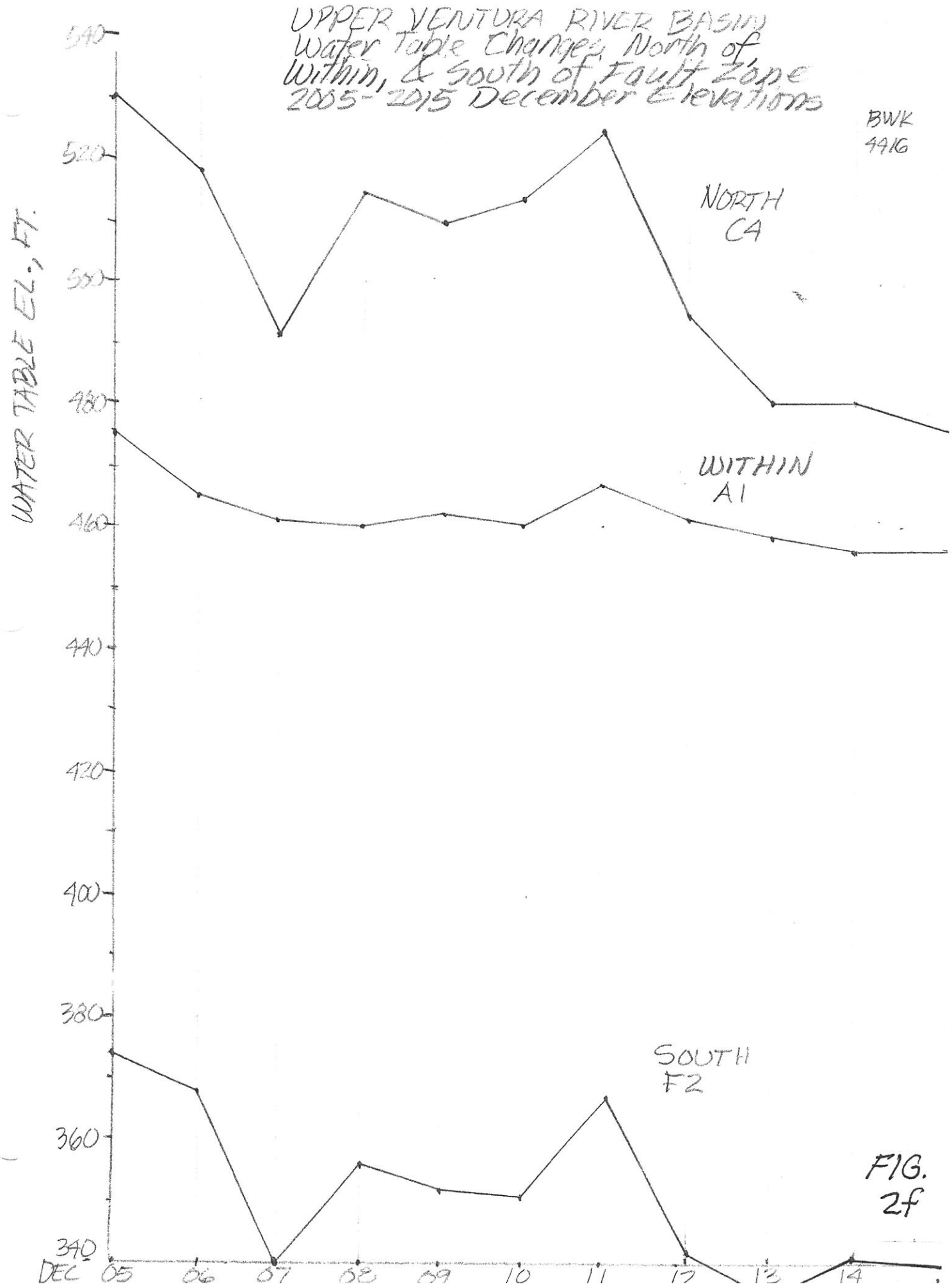

UPPER VENTURA RIVER BASIN
Water Table Changes North of,
Within, & South of Fault Zone
2005-2015 December Elevations
BWK
4416
NORTH
CA
WITHIN
A1
SOUTH
F2
WATER TABLE EL., FT.
540
520
500
480
460
440
420
400
380
360
340
DEC 05
06
07
08
09
10
11
12
13
14

FIG. 2f

UPPER VENTURA RIVER BASIN
Summer & Fall Hydrograph Segments,
North of & within Fault Zone

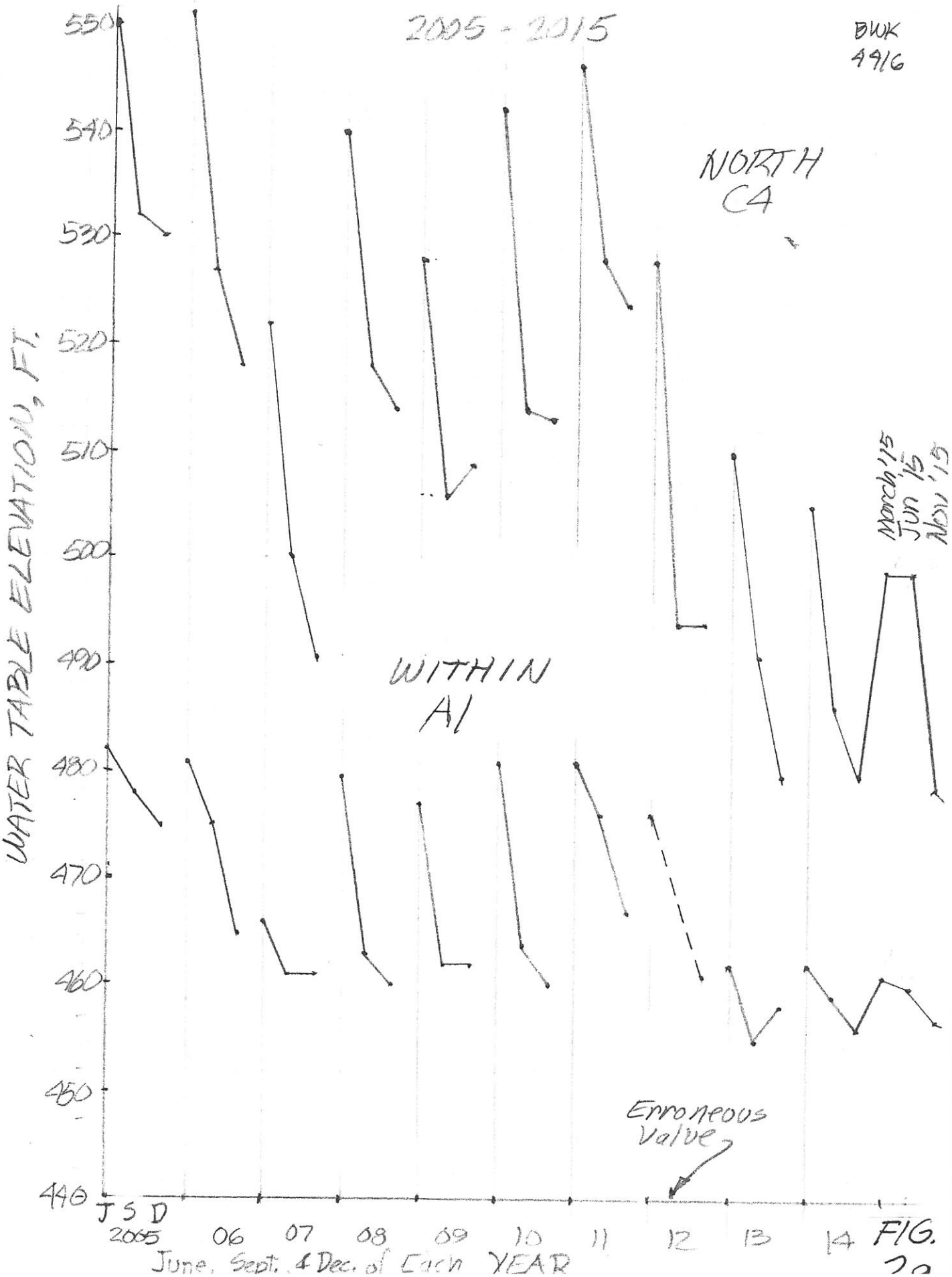


FIG. 2a

UPPER VENTURA RIVER BASIN

Threshold Effect Evaluation Hydrographs

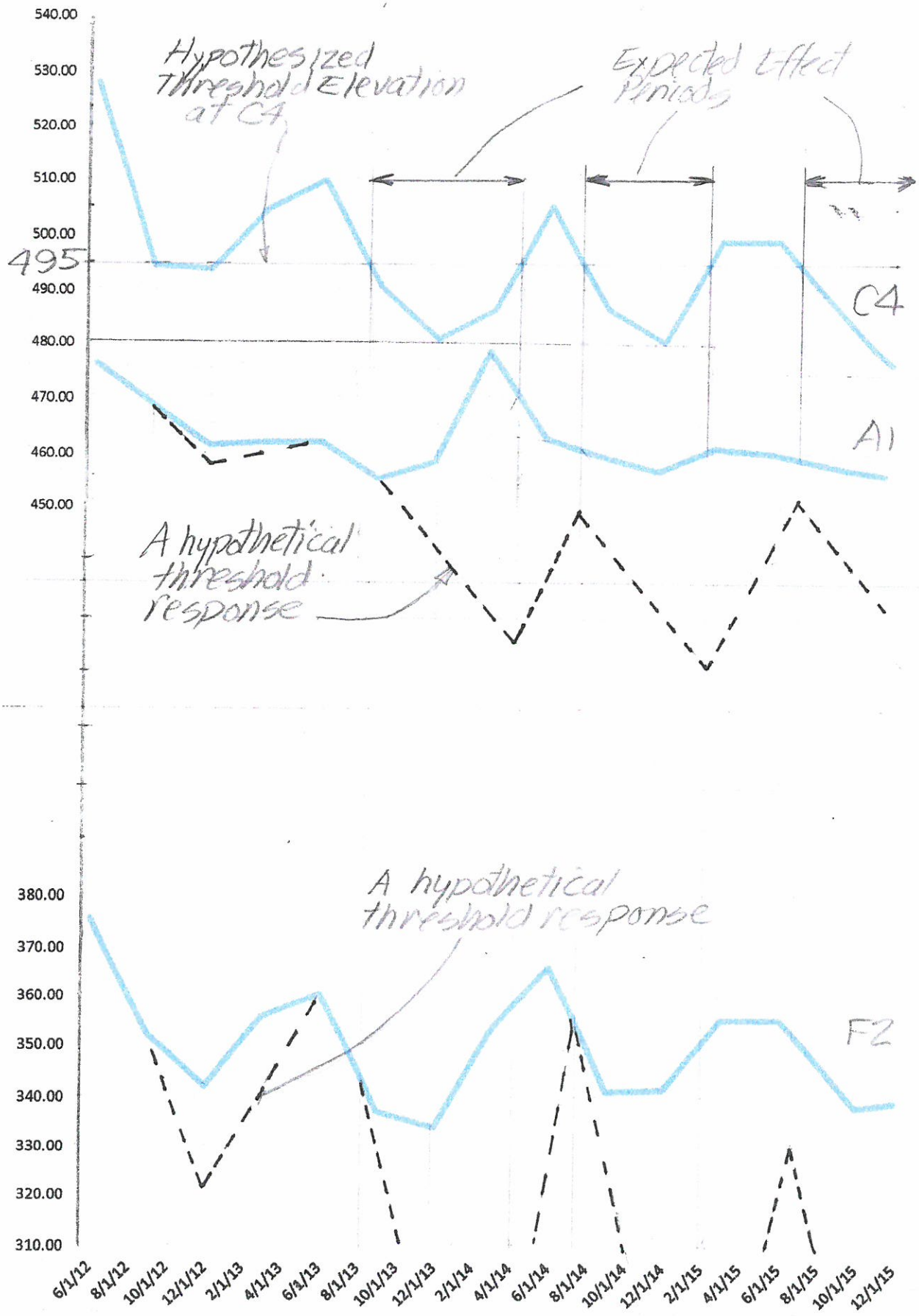


FIG. 21

because groundwater inflow would be cutoff and down valley groundwater flow would drain the aquifer. The hypothetical hydrographs don't increase again until C4 is above 495'. To exaggerate the possible effect, river recharge was assumed to be 0, although there was a sharp rise in A1 from the 3-1-14 storm.

Comparing the actual and hypothetical hydrographs shows no threshold effect. Between Aug and Dec 2013, A1 rises while C4 goes down below 495'. From Dec to Apr 2014, it rises faster than C4 while C4 is below 495'. Between Jun and Dec 2014, A1 declines at a constant rate as C4 drops below 495'. A similar effect occurs during Jun to Dec 2015. A similar analysis applies to F2. In 2013, it declines less rapidly as C4 drops below 495'. In the later part of 2014, its decline is unchanged as C4 goes below 495'. It then remains level while C4 declines and starts going up before C4 reaches 495', with no river flow.

Plate 2 shows a fault mapped on both sides of the river between B1 and C4. To determine if any fault effects were evident, hydrographs for B1 and C4 were compared in Figure 2i. Overall, the hydrographs are very similar. C4's hydrograph shape diverges somewhat from B1 beginning in 2013. However, that is unlikely to be a fault effect because any such effect should be evident over the entire period and B1 remains within its fluctuating range while C4 goes below its range.

Conclusions

The hypothesized threshold effect is not supported by data from observation wells upstream, within, and downstream of the major fault zone. This is different than Entrix's conclusion and its finding of a "… disconnection in groundwater flow across the fault.". This is despite its qualification that, "The magnitude of impact of the disconnection on groundwater support to the downstream reaches (including the 'live stretch') cannot be assessed without considering the duration, rate, and total volume of downvalley groundwater discharge." p. 4-2.
Absence of a threshold effect is, however, consistent with Entrix's observations about flow in the 'live reach', based on observation well 3N23W5B1 in Casitas Springs,

> "During some years, both wells experience low levels (e.g., 1961, 1977, 1990, 1991), which may reflect natural climatic conditions, the threshold-response relationship for groundwater flow across the Santa

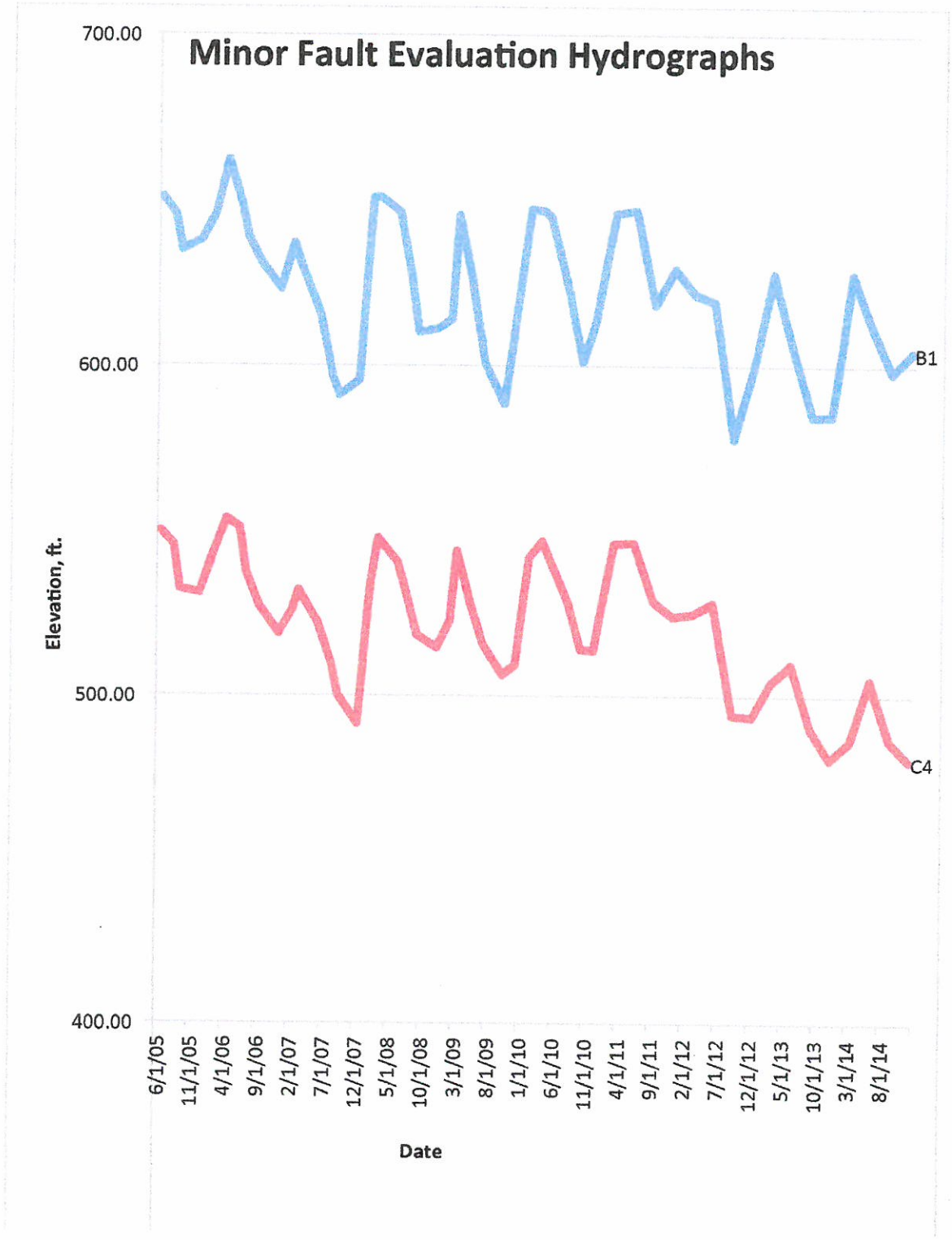

Minor Fault Evaluation Hydrographs
700.00
600.00
500.00
400.00
Elevation, ft.
B1
C4
6/1/05
11/1/05
4/1/06
9/1/06
2/1/07
7/1/07
12/1/07
5/1/08
10/1/08
3/1/09
8/1/09
1/1/10
6/1/10
11/1/10
4/1/11
9/1/11
2/1/12
7/1/12
12/1/12
5/1/13
10/1/13
3/1/14
8/1/14
Date

FIG. 7:

Ana/Arroyo Parida Fault, and similar groundwater use patterns. Each of the four years with low levels in both wells were the second of two relatively dry years in a row. Some years have low levels only in the downstream well, and these are not years following a low level in the upstream wells (e.g., 1949, 1951-51, 1957, 1972, 1986, 1993, and 1994). This suggests that local influences in the vicinity of the downstream well might be the controlling factor in these years, not downvalley groundwater contributions." p. 4-6.

The two major faults (Arroyo Parida Santa Ana and Villanova) appear to reduce water table fluctuations in proportion to the distance between well and fault. However, shapes of the hydrographs appear not to be affected. In other words, hydrographs remain parallel but for wells closer to major faults, fluctuations are damped.

No discernable effects were seen from the smaller faults that cross the river or from those mapped east of the river in Mira Monte and Oak View.

SECTION TWO

This section analyses data to estimate groundwater flow and looks for patterns suggesting relationships between river flow, groundwater levels, and water districts' pumping.

Limitations And Assumptions

River Flow

There is only one gauge, Ventura River Near Meiners Oaks (VRNMO), and it has good ratings up to 70 cfs and use of equations up to 1,000 cfs. Ratings are poor above 1,000 cfs. These data were obtained from CMWD Annual Robles Fish Passage Progress Reports.

Groundwater Pumping

Private Wells - There are no data on private pumping with which to assess possible effects on observation wells J1, A1, and F2. Observation well J1 is MOWD well #8, which was pumped only from July 2011 thru July 2012; February 2013 thru August 2013; and in May 2014.

The following estimates of domestic and agricultural pumping were not used in any of this study's calculations but are included for comparison with water districts' pumping. There are 172 private wells in the Upper Ventura Groundwater Basin based on records of the Ventura County Watershed Protection District as of April, 2016. An estimate of how many of those are between Meiners Oaks and Oak View, based on the County's July 2014 well map, is roughly 60%, or about 100. The numbers of domestic and agricultural wells are about equal.

Pumping records for these private wells don't exist so it is necessary to make some assumptions. Assume 1 acre-foot per year for each domestic well, equivalent to a water use for a family of 4 of 223 gallons per person day. Private domestic use would then be 50 acre-feet per year. Also assume each agricultural well supplies a 5 acre parcel with 3 acre-feet per year per acre, about what citrus trees need, for a annual use of 15 acre-feet. Agricultural use would then be 750 acre-feet per year. Total annual use for private wells would then be 800 acre-feet per year.

Water Districts' Wells - Water districts' pumping reduces groundwater flow and could reduce river flow if the water table is in hydrologic continuity with the riverbed and if the riverbed is within the cones of depression of water districts' pumping. An aquifer test at MOWD wells 4 and 7 in 2012 determined the cone of depression; pumping's effect on lowering the water table 1,000' away was measured in inches. That distance is about how far the water districts' wells are from the current active river channel. To simplify assessing the effect of pumping on river flow, it was assumed each acre-foot of pumping would reduce river flow by the same amount. If pumping exceeded river flow, pumping reduced groundwater flow by an equal amount.

Nodes

Geo-hydrologic data are from Turner's 1971 report, which has estimates of groundwater basin depth and specific yields. A flow network was also used from his report to calculate storage coefficients for each of the nodes along the river. One observation well was used to represent each of Turner's nodes along the river. There is no observation well in Node

18 representative of conditions in the widest part of that node. Therefore, J1 was used, although it is in Node 19 about 800′ south of the nodes 18/19 boundary. The other option would have been well 5N23W33G1, but it is several thousand feet upstream of VRNMO in Matilija Canyon, close to node 17. Note on Plate 1 that VRNMO is very close to the center of Node 18. Node lengths are shown below.

18	2,000 ft
19	6,200
24	6,400
25	6,300
27	6,600

Regarding terminology, a primary focus of this study is water level changes. Most of the descriptions and discussions refer to the observation well numbers instead of the nodes, upon which storage coefficients were based. Here are the correlations:

4J1 or just J1	Node 18
9B1 or just B1	Nodes 19 & 20
16C4 or just C4	Nodes 23 & 24
20A1 or just A1	Nodes 25 & 26
29F2 or just F2	Node 27

Adjustments were made to Turner's node network to account for the time it takes for groundwater to flow through the basin when time periods of two and three months are used. The need for this was made clear when comparing observation wells 4N23W16P1 and A1. P1 is on the Villanova Fault and A1 is 400′ upstream. P1 water table elevations vary by less than 5′ over the study period, while A1 varies by 29′. Specific yield at P1 is 6% compared to about 12% at A1. In this case, only the westerly 400′ of Node 26 containing P1 was added to Node 25 (A1) to calculate storage changes. The 400′ was calculated based on a straight-line interpolation between water table ranges of A1 and P1.

A similar adjustment was made based on comparing observation wells 4N23W3M1 and B1. M1 elevations have a range of 25% of B1, while the specific yields are similar. Only the westerly 300′ of Node 20 containing M1 was added to node 19 (B1) for storage change calculations.

Another adjustment was made for Node 23, even though there was no easterly observation well upon

which to base a calculation. Instead, it was assumed that the westerly 300′ would be used to be consistent with the upstream and downstream nodes.

These node adjustment assumptions reduced calculated amounts of groundwater flow.

Groundwater Flow

Groundwater flow is calculated using the formula Q=KIA, where Q is the flow, K is the coefficient of permeability, I is the hydraulic gradient, and A is the cross-sectional area of the basin's saturated portion. The initial approach for this study was to determine values for K (related to Turner's estimates of specific yield) for each flow node so the formula could be used to calculate groundwater flow between nodes. Entrix used this approach, listing in the table of contents "Appendix C. Simplified Groundwater Flow Evaluation of the Upper Ventura River Basin" p. ii; "… a literature-derived hydraulic conductivity value (K) based on the average specific yield for each node." p. 3-4; and "The simple spreadsheet flow model (Appendix C) that represents seasonal down gradient flow volumes and rates, the physical aquifer properties (VCFCD 1971), …" p. 4-5. Apparently Appendix C does not exist, as neither Cardno-Entrix nor the City of Ventura, for whom the study was done, has been able to find that appendix. Therefore, groundwater flow was assumed to be equal to the product of water table change and storage coefficient (i.e., the product of specific yield and nodal area).

Any decrease in storage, i.e., drop in water table, was assumed to equal groundwater flow. If water districts' pumping exceeded river flow, the difference was added to the groundwater flow indicated by the drop in water table. Under that condition, the amount of groundwater flow represents what would have happened had there been no water districts' pumping.

Any increase in water table increased groundwater storage. If water districts' pumping exceeded river flow, the difference was added to the increase in storage indicated by the rise in water table. Under that condition, the storage increase represents what would have happened had there been no water districts' pumping.

It was assumed that groundwater flow during a storage increase would follow a straight-line

interpolation between the closest before and after water table drops within the observation well's node. This probably underestimates groundwater flow.

It is important to note that groundwater flows calculated through this process are in addition to groundwater flow coming out of the mouth of Matilija Canyon. In other words, the flows are riding on top of a variable 'base' groundwater flow, the amount of which can only be determined through additional data collection and study.

Storage Coefficients

Storage coefficient is the product of specific yield and nodal area. Table 1 shows the coefficients used by Turner, Entrix, and for this study.

Initially it was assumed that storage coefficients would not change with changing water levels, although those should decrease as the water table drops, primarily because the groundwater basin narrows. Specific yields could also change with depth related changes in the aquifer. That assumption resulted in large groundwater flows with low water table conditions during drought. Groundwater flow becomes surface flow in the 'live' reach near Casitas Springs, so those large drought flows defy the reality of very low or no flow in the 'live reach' at very low water tables. Thus, some adjustments were made to groundwater flow calculations. Observation well water table readings are a reality with no room for interpretation. The only other factor in the calculation is the storage coefficient. Whether the specific yield changes or the area changes doesn't matter as long as the calculated flows were consistent with previous hydrologic studies.

The first attempt to tailor the groundwater flows to fit dry year conditions observed in the 'live' reach was to apply my analytical approach to data used by Entrix for 1970 and 1977. 1970 was considered a 'full' basin, having followed the very wet 1969 winter and groundwater flow from the Ventura river at Foster was estimated at 9,900 AF. 1977 was considered a very dry year and groundwater flow was estimated at 3,400 AF. My approach was to calculate a 'tailoring' factor that would account for a storage coefficient that varies with water table depth. Ideally, the factor would reduce my groundwater flows to the range of 3,400 to 9,900 AF per year. I assumed the 9,900 AF

TABLE 1 STORAGE COEFFICIENTS

NODE	TURNER STORAGE COEFFICIENT	ENTRIX STORAGE COEFFICIENT	KUEBLER STORAGE COEFFFICIENT
18	51	20.3	17
19	39	30	39
20	32		3
23	40		4
24	33	32.5	33
25	36	37.1	36
26	15		4
27	57	56.2	57

NOTES

1. Turner, table 2, p. 24. Calculated as product of nodal area and average specific yield.
2. Entrix, Table 1, p. 4-8. Only nodes along the river centerline were used.
3. Kuebler node 18. Observation well J1 was used. Only portion of node south of VRNMO was used.
4. Kuebler nodes 19 & 20. Observation well B1. Westerly portion of 20 added to 19 for storage coefficient of 42.
5. Kuebler nodes 23 & 24. Observation well C4. Westerly portion of 23 added to 24 for storage coefficient of 37.
6. Kuebler nodes 25 & 26. Observation well A1. Westerly portion of 26 added to 25 for storage coefficient of 40.

would occur when the basin was at its fullest during my study period and the 3,400 AF at its emptiest. Those correspond to 2005-6, when the basin was at 69% full and 2013-14, when the basin was at 7%, respectively. Using those values and assuming a linear relationship between basin storage and groundwater flow, I developed the following formula for calculating the variable storage coefficient tailoring factor:

T.F. = 1.57 – 0.013 x Depth To Water (DTW)

The factors varied from a high of 1.20 @69% to a low of 0.36 at 7%. This reduced groundwater flows significantly but the range was still too large, varying from 4,300 AF to 12,100 AF.

Another way to develop a variable storage coefficient would require a complete water balance for the groundwater basin involving all basin inflows and outflows. Data with an accuracy consistent with river flow, water table changes, and water districts' pumping are not available for all those inflows and outflows, such as percolation from rainfall, septic tank percolation, sewer leaks, evapotranspiration, and recharge from irrigated agriculture and landscaping. Therefore, my second attempt was to tailor my average groundwater flows for my study period to the average estimated by Daniel B. Stevens and Associates in the "Groundwater Balance …" report in 2010. Assuming all agricultural and private pumping takes place between Oak View and Meiners Oaks, I used 5,000 AF per year as the average flow at Santa Ana Blvd in Oak View. My study period average groundwater flow was 7,500 AF per year so I reduced the T. F. above by a water balance tailoring factor of 0.67. The new groundwater flows vary from a low of 3,000 to a high of 9,400 AF per year with an average of 5,600 AF per year.

The overall tailoring factor reduces groundwater flow and also the portion of VRNMO river flow that recharges the groundwater basin. DBS&A estimated recharge from the riverbed of roughly 1,300 AF per year average ("Groundwater Budget and Approach to a Groundwater Management Plan, Upper and Lower Ventura River Basin", December, 2010, p 11 and Table 5). My calculated average from the second attempt was 2,400 AFY ranging from 1,100 to 4,400 AFY.

A further check on variation of storage coefficient with depth was made with pumping and water table levels at VRWD. Bert Rapp, General Manager, calculated aquifer storage volumes for 10' intervals

between elevation 520′ and 490′. Those levels correspond to DTW as percent of range of 44 to 72, respectively. The ratio of stored water volume between 520 and 510 to that between 490 and 480 feet was 1.46. The ratio between my overall Tailoring Factor for those elevations was 1.59. The difference is 9%, well within the accuracy of other aspects of this study. (Personal communication with Mr. Rapp, April 2015)

Summary

In view of the foregoing limitations and assumptions, patterns and relationships between key elements are more important than numbers.

Method

The information presented in Set Three Hydrographs was developed with a two-step process using the following basic formula to calculate flows through nodes for each period:

OUTFLOW = INFLOW – CHANGE IN STORAGE

Step one used VRNMO river flow so the formula was:

RIVER OUTFLOW = RIVER INFLOW – DISTRICTS′ PUMPING

Most of the time, VRNMO flow becomes groundwater as it percolates through the porous riverbed, so subtracting water districts′ pumping accounts for the reduction of groundwater flow caused by that pumping. The exception is during relatively short periods of high flow when most water goes to the ocean. There were periods when pumping exceeded river flow. In those cases, the difference in volumes was treated as a storage change in step two.

Step two used groundwater flow so the formula was:

GW OUTFLOW = GW INFLOW – CHANGE IN STORAGE

Change in storage in each node was calculated as the product of the water table change and the storage coefficient. Basically, groundwater flow resulted from a water table drop. If the water table rose, it was assumed that groundwater flow would follow a straight-line interpolation between the closest before and after water table drops within the observation well's node.

During those periods identified in step one when water district's pumping exceeded river flow, the difference between those amounts increased the

calculated amount of storage occurring with a water table rise or increased the calculated groundwater flow occurring with a water table drop. In other words, storage increases and groundwater flows in Set Three Hydrographs represent a quasi-natural condition, the effects of pumping having been separated so the relative amounts can be easily compared.

The first node (J1) had inflow based only on a water table drop because 'base' flow from Matilija Canyon was unknown. Outflow became an inflow for the next node (B1) and any storage change was accounted for to obtain the outflow, which became an inflow for the next node (C4). This was followed for nodes C4, A1, and F2. Total groundwater flow used in the hydrographs, in effect, was the sum of outflows from each node.

Set Three Hydrographs

Overview

This set presents analytical results from calculations to determine groundwater storage changes and groundwater flows in a quasi-natural state, i.e., with effects of water districts pumping taken out. Hydrographs show river flow, groundwater flow (storage decrease), recharge (storage increase), water districts' pumping, and average water table depth on Dec. 1, the start of the wet period and usually the lowest water table of the year. Average water table changes were normalized by using depth to water as a percentage of the observation well's water table range, rather than the depth in feet, so that a well with a 29' range could be compared to one with a 73' range.

A water year summary of river flow, groundwater flow, recharge, water districts' pumping, and average water table change for the 5 observation wells are in Table 2. Figure 3 shows those items for the study period and depicts that portion of river flow recharging the groundwater basin, i.e., aquifer storage increase. Figures 3a through 3i are for water years 2005-06 through 2013-14, respectively.

TABLE 2
STUDY PERIOD SUMMARY OF KEY ELEMENTS

Water Year	River Flow, AF	Recharge, AF	GW Flow, AF	Water Dist. Pump, AF	Ave. WT Change %
2005-06	26,625	2,600	5,100	2,015	Down 10
2006-07	2,210	1,400	6,000	2,185	Down 43
2007-08	22,475	3,300	3,000	1,945	Up 24
2008-09	3,500	2,900	6,800	2,050	Down 23
2009-10	13,320	4,400	6,100	1,710	Up 18
2010-11	20,235	3,200	4,800	1,620	Up 21
2011-12	4,775	1,100	9,400	1,795	Down 38
2012-13	490	1,800	5,700	1,455	Down 15
2013-14	2,595	1,200	3,200	1,360	Up 2
Average	10,690	2,400	5,600	1,790	

Ave. WT change is ave. percent of ranges, October to October.

Observations

Figure 3

- Groundwater flow varies between 3,000 and 9,400 AF/Yr. These amounts are similar to Entrix's estimation of between 3,400 to 10,000 AF/Yr. (p. 5-1, 2001)
- Groundwater flow generally goes up with rising water tables. One exception is '07, probably resulting from previous year's full basin; another is '11, when significant river flow in '10 didn't result in water table and groundwater flow increases.
- Generally, there appears to be a one-year delay between runoff events and water table response. This results because annual data are used. Water tables can rise quickly in response to large river flows, as can be seen in Figures 2f and 2i.
- Water table and groundwater flow changes are roughly parallel from 2008 to 2012.

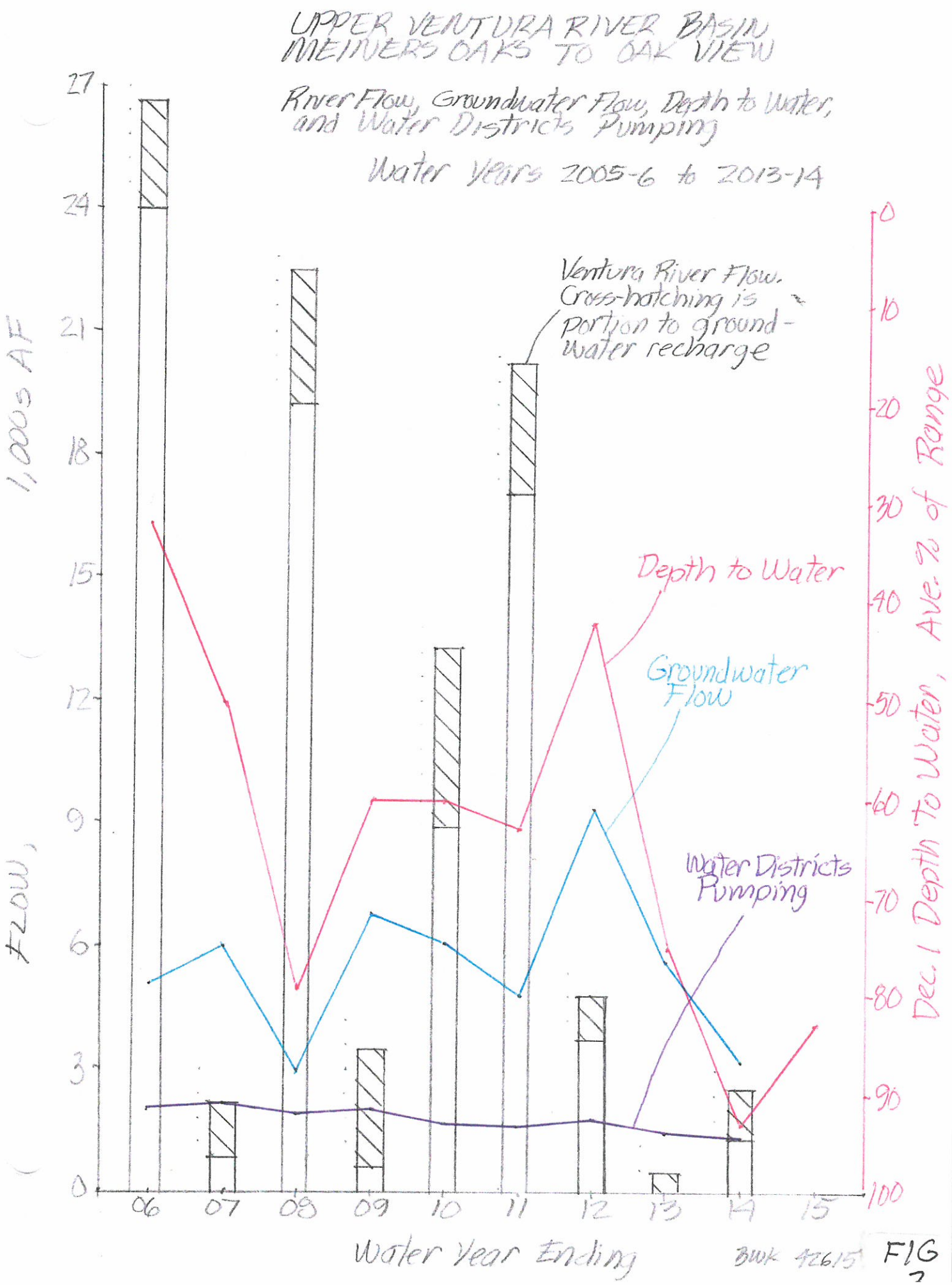

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW
River Flow, Groundwater Flow, Depth to Water, and Water Districts Pumping
Water Years 2005-6 to 2013-14
Ventura River Flow. Cross-hatching is portion to ground-water recharge
Depth to Water
Groundwater Flow
Water Districts Pumping
FLOW, 1,000s AF
Dec. 1 Depth To Water, Ave. % of Range
Water Year Ending
06
07
08
09
10
11
12
13
14
15
0
3
6
9
12
15
18
21
24
27
0
10
20
30
40
50
60
70
80
90
100
BWK 42615
FIG 3

Figure 3a 2005-06

- Groundwater flow increase lags water table rise by several months.
- Water table is high at start of year.
- During Dec-May, decline in recharge with greater river flow suggests a full basin. Groundwater flow becomes larger in following months.
- During Jun-Sep, groundwater flow increases faster than water districts' pumping.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW

2005-6 Water Year

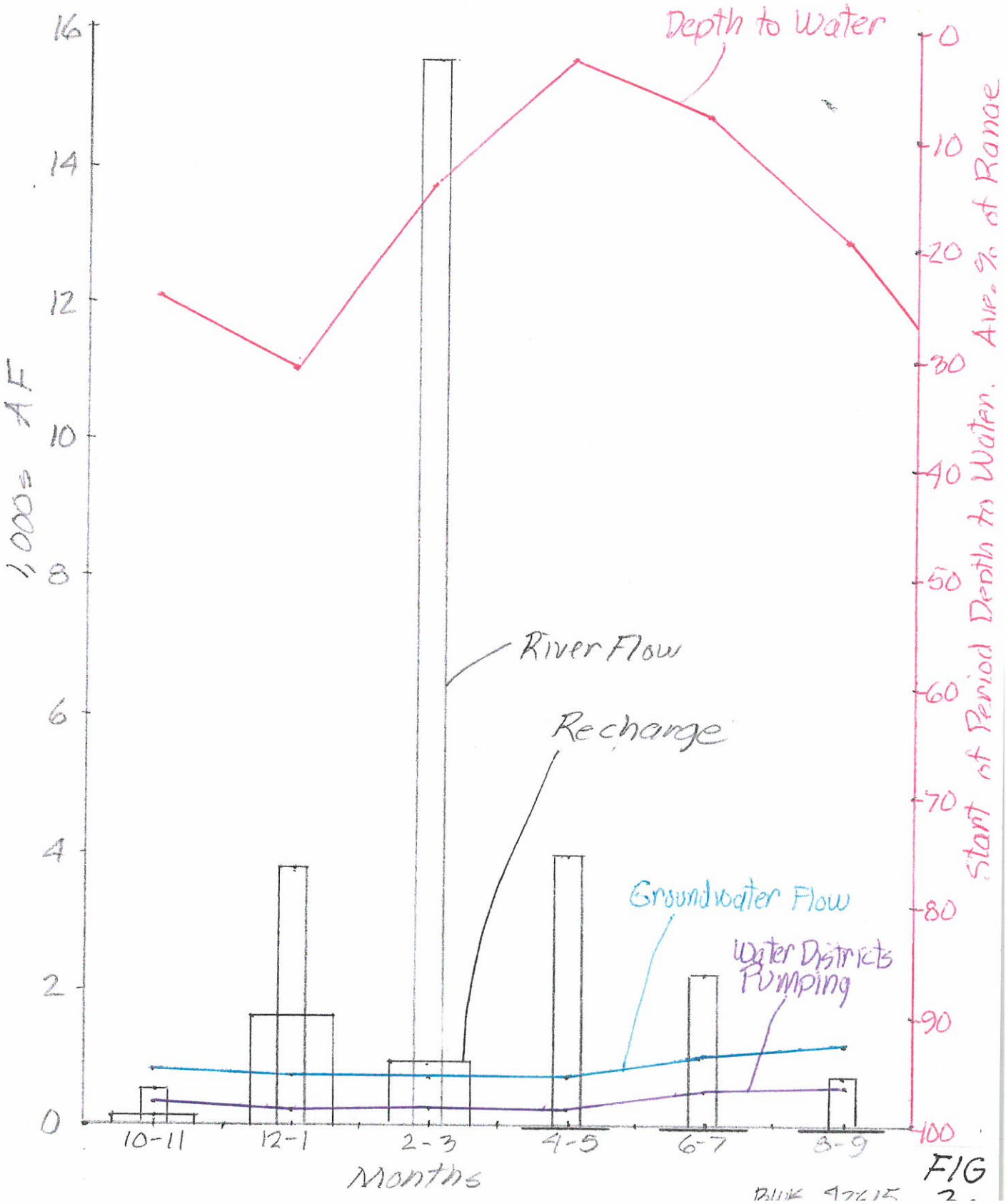


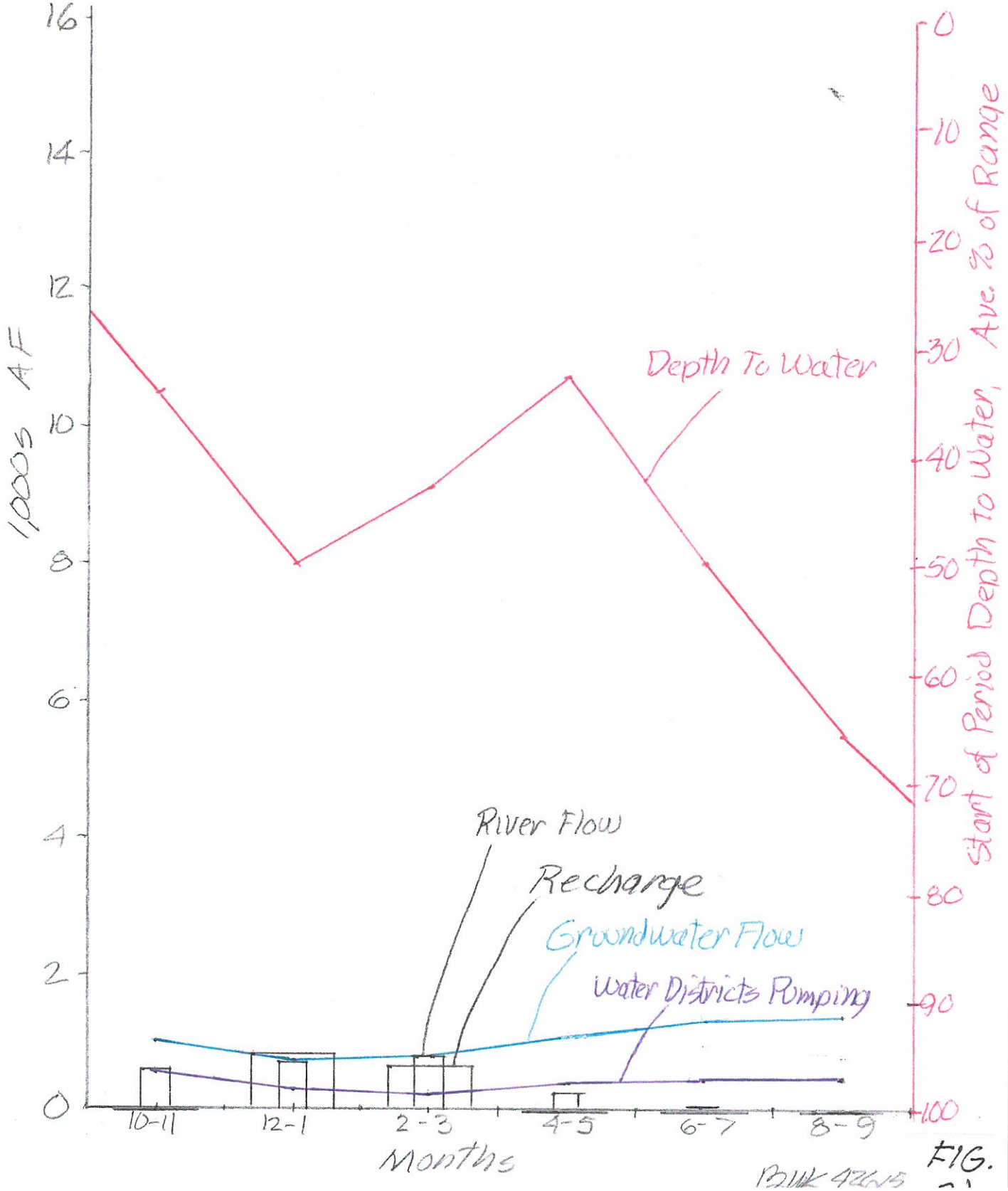
FIG 3

Figure 3b 2006-07

- During Dec-May, with low river flow, there is a significant water table rise and significant recharge.
- During Jun-Sep, declining water tables and increased groundwater flow suggest basin draining.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW

2006-7 Water Year



BUK 4265

FIG.

Figure 3c 2007-08

- During Oct-Nov, some recharge with no river flow.
- During Oct-May, groundwater flow is very low and constant, despite large increase in water table. This is the lowest sustained groundwater flow during study period.
- During Mar-May, basin is practically full, with significant runoff in Mar not causing water table rise.
- During Jun-Sep, water table declines more quickly compared to '05-'06, despite starting from about the same elevation.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW

2007-8 Water Year

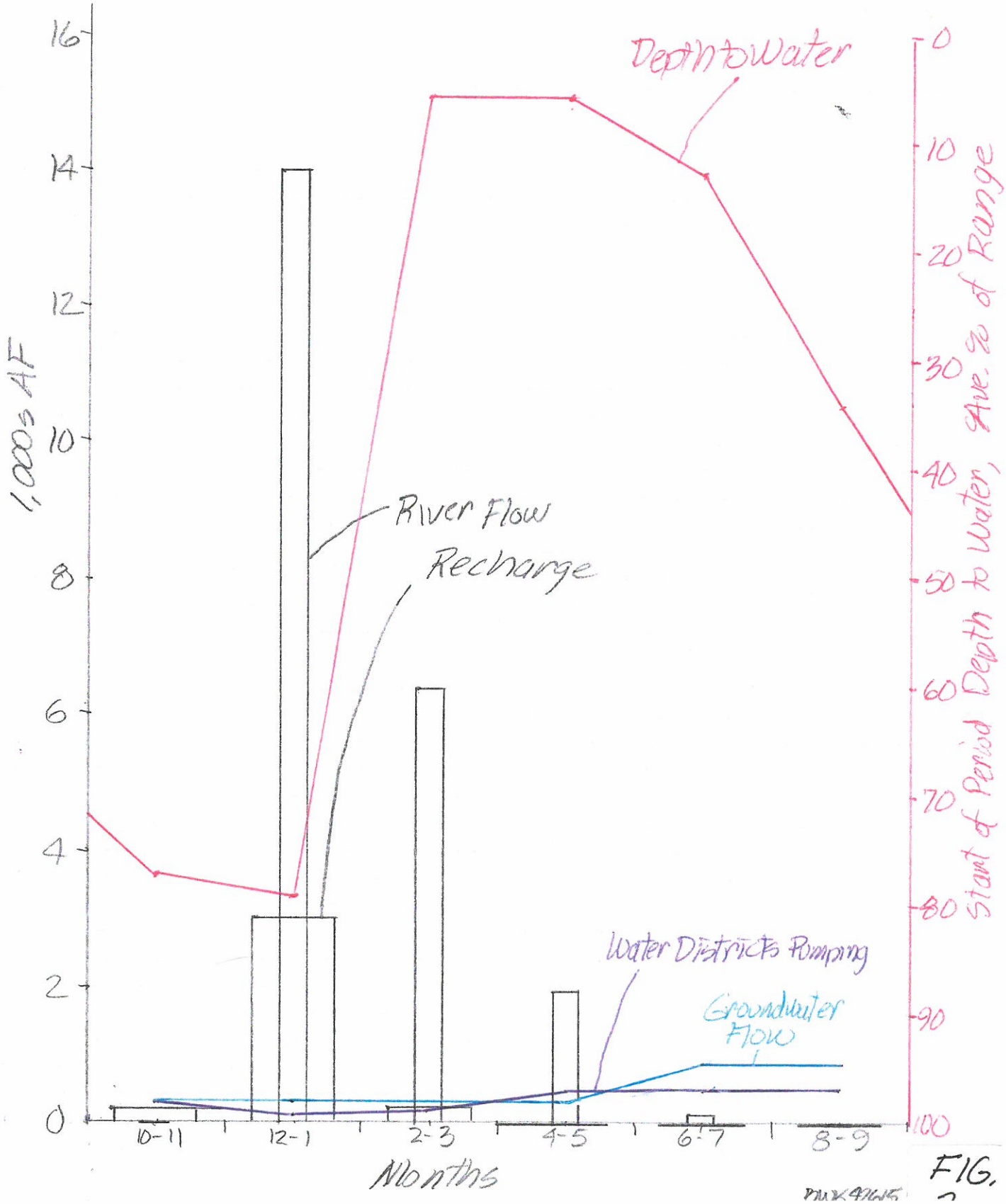


FIG. 2

Figure 3d 2008-09

- During Feb-May, a relatively modest river flow raises basin from roughly 50% full to nearly 90% full.
- During Jun-Sep, basin drains nearly as quickly as it filled.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW

Water Year 2008-9

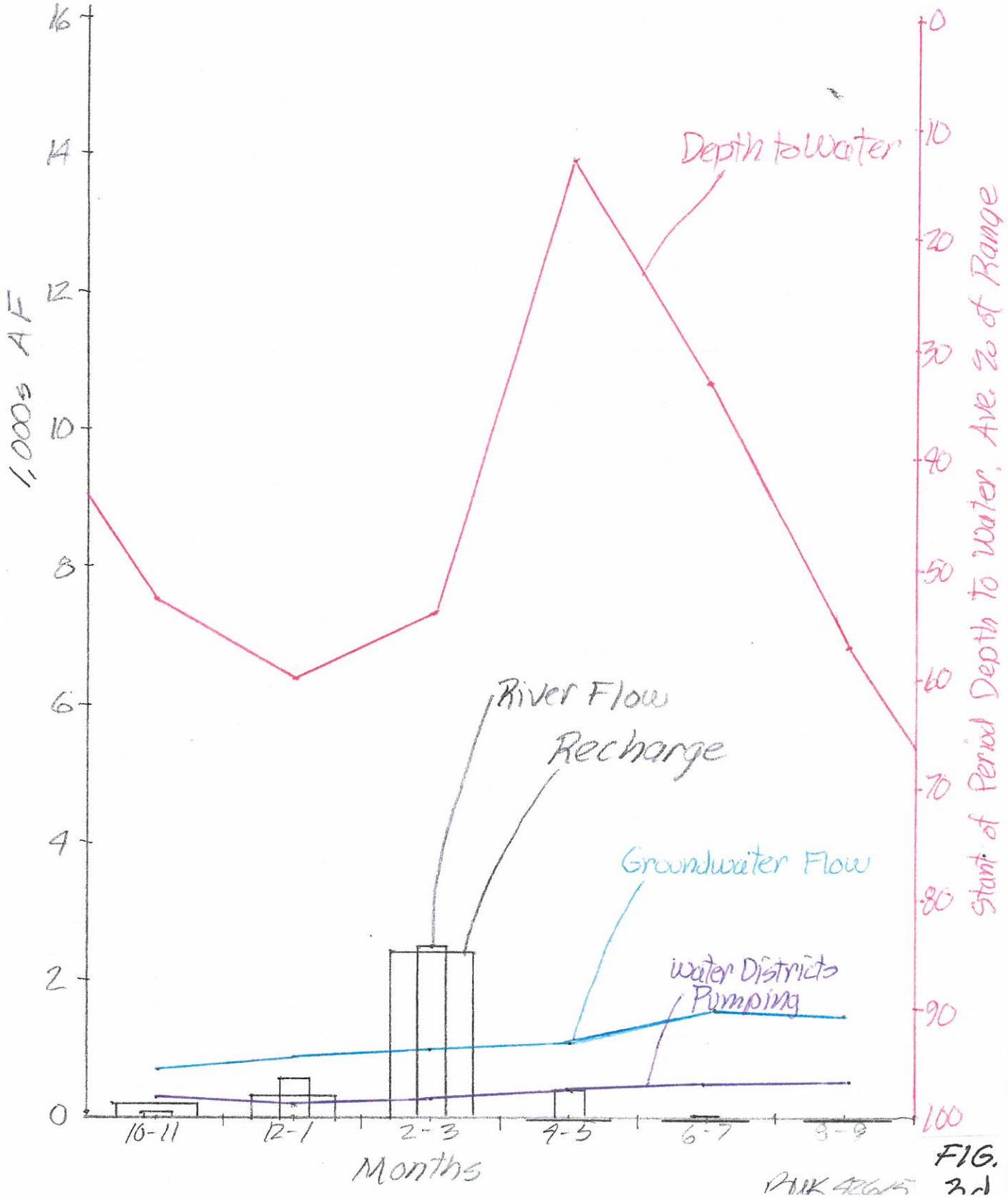


FIG. 3d

Figure 3e 2009-10

- During Feb-Jul, basin remains nearly full. This it its highest sustained level, despite relatively moderate river flow.
- Basin is practically full in Feb-Mar because river flow larger than Dec-Jan didn't increase water table.
- During Oct-May, declining groundwater flow seems to contradict moderate river flow and rise in water table.
- During Oct-Jan, significant storage increase with very low river flow.
- During Dec-Jan, a relatively moderate river flow of 4,500 AF produced one of the largest amounts of recharge, about 3,000 AF, with the basin about 40% full. In contrast, during Dec-Jan 2007-08, a large river flow of 14,000 AF produced about the same 3,000 AF of recharge with the basin about 20% full.
- During Jun-Sep, increase in groundwater flow with constant water districts' pumping.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW

2009-10 Water Year

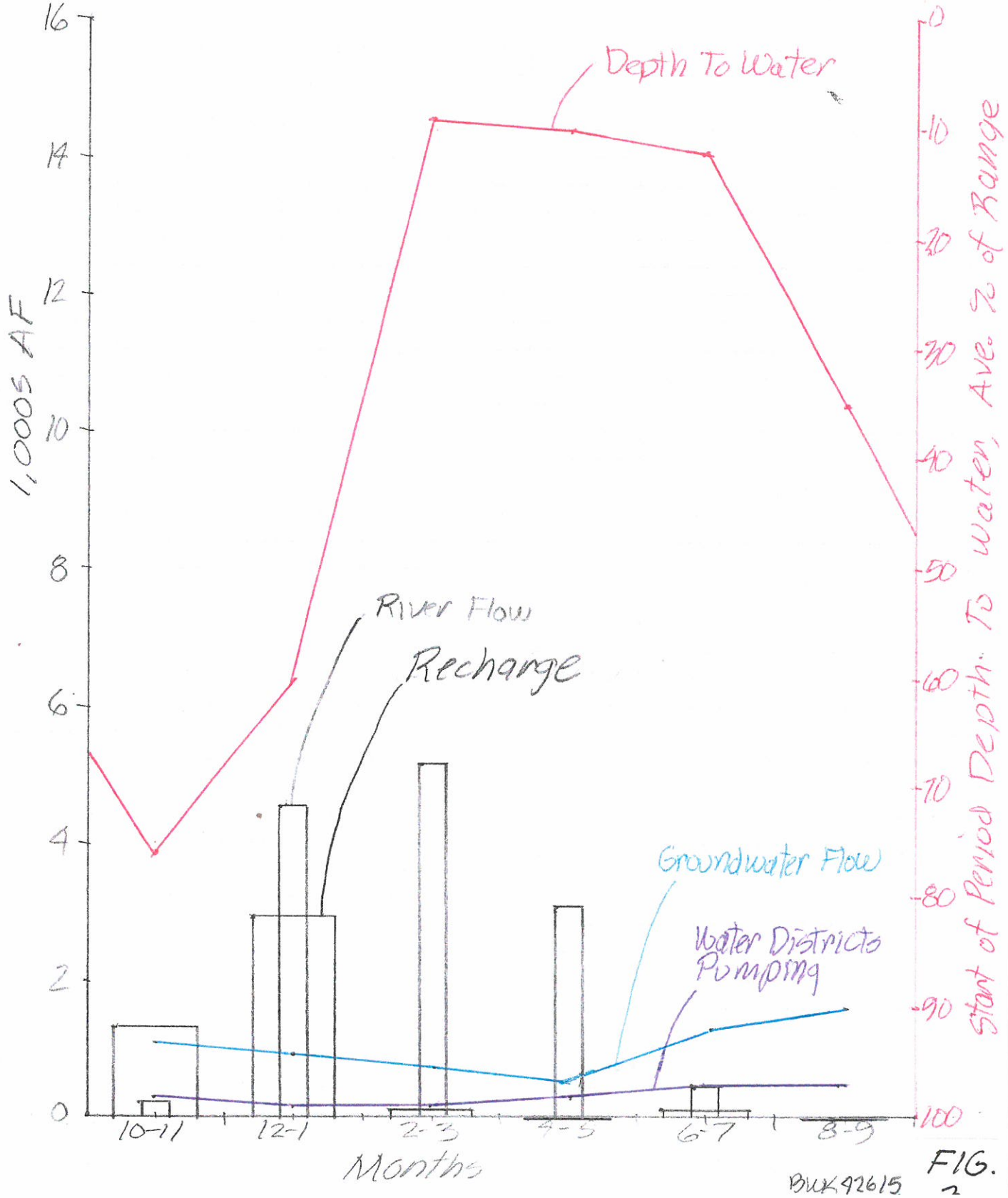


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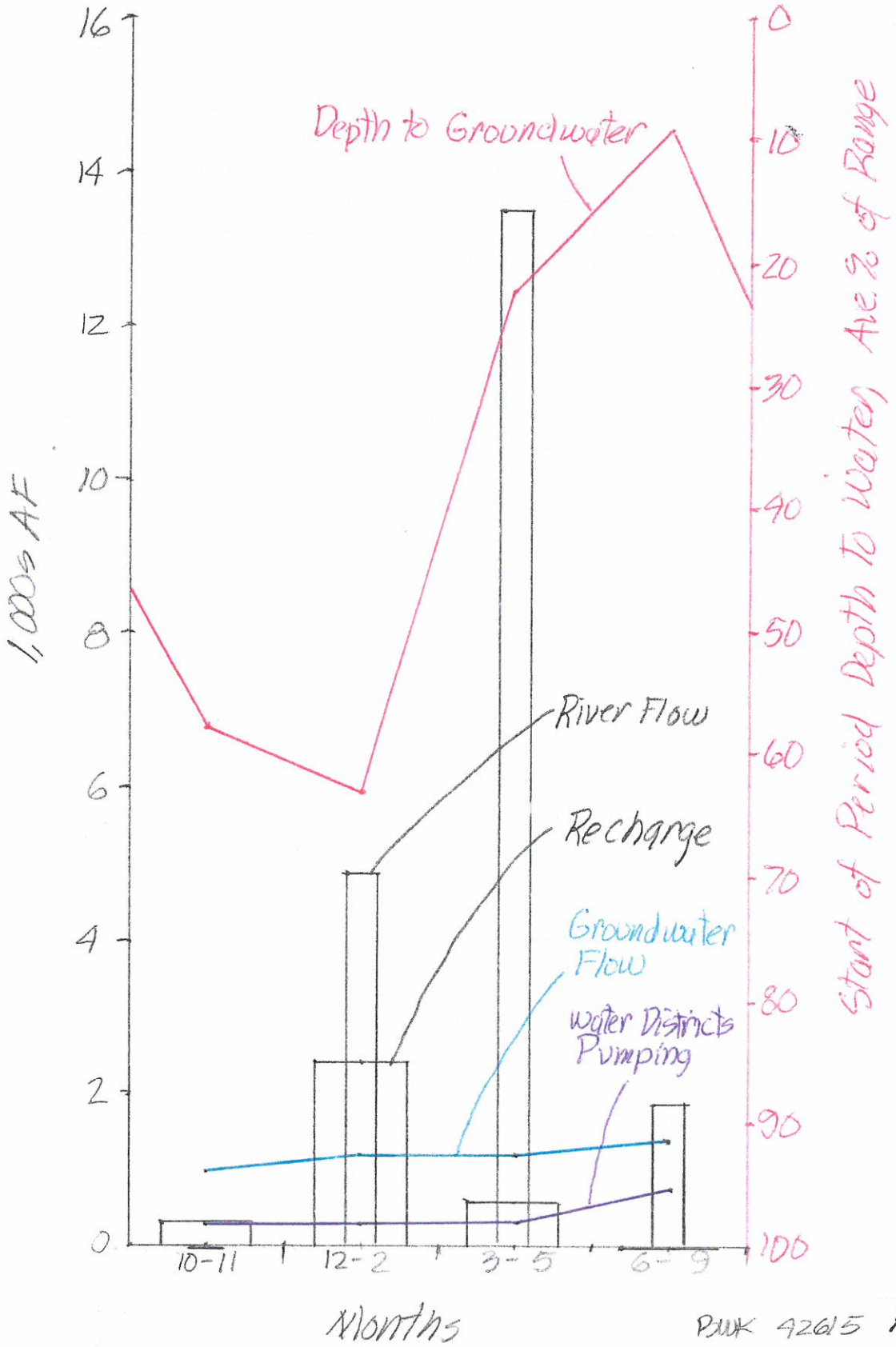
FIG. 3

Figure 3f 2010-11

- During Oct-Nov, recharge with no river flow.
- During Dec-Sep, smaller storage increases with large river flow indicates basin is nearing capacity.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW
Water Year 2010-11



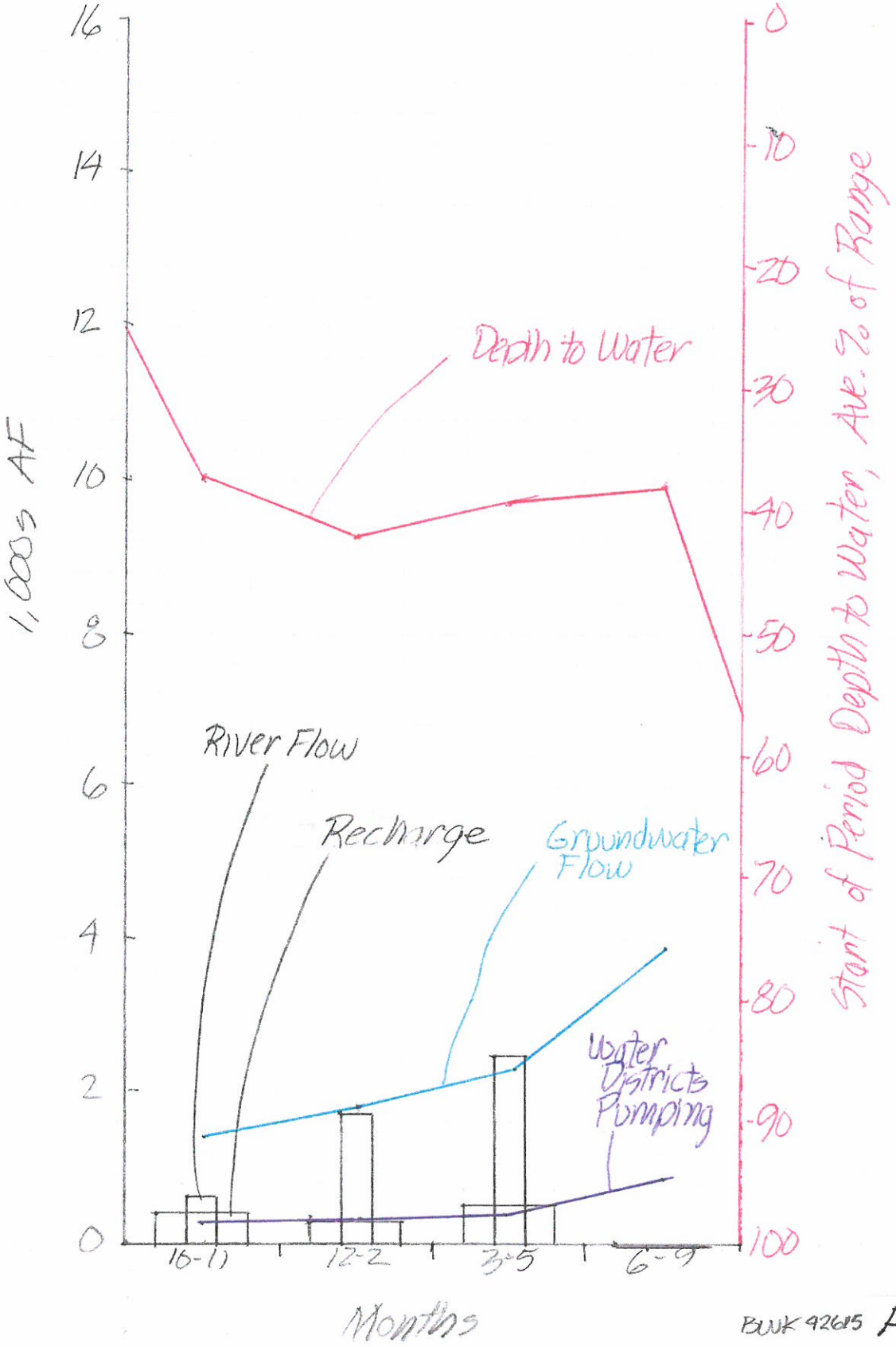
PWK 42615 FIG. 3C

Figure 3g 2011-12

- During year, the water table is the most stable for any year of study period. No summer basin drain down.
- Groundwater flow is the largest of any year.
- During Mar-Sep, groundwater flow has a large increase, despite a stable water table. Its effect on the water table is shown in following year.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW

2011-12 Water Year



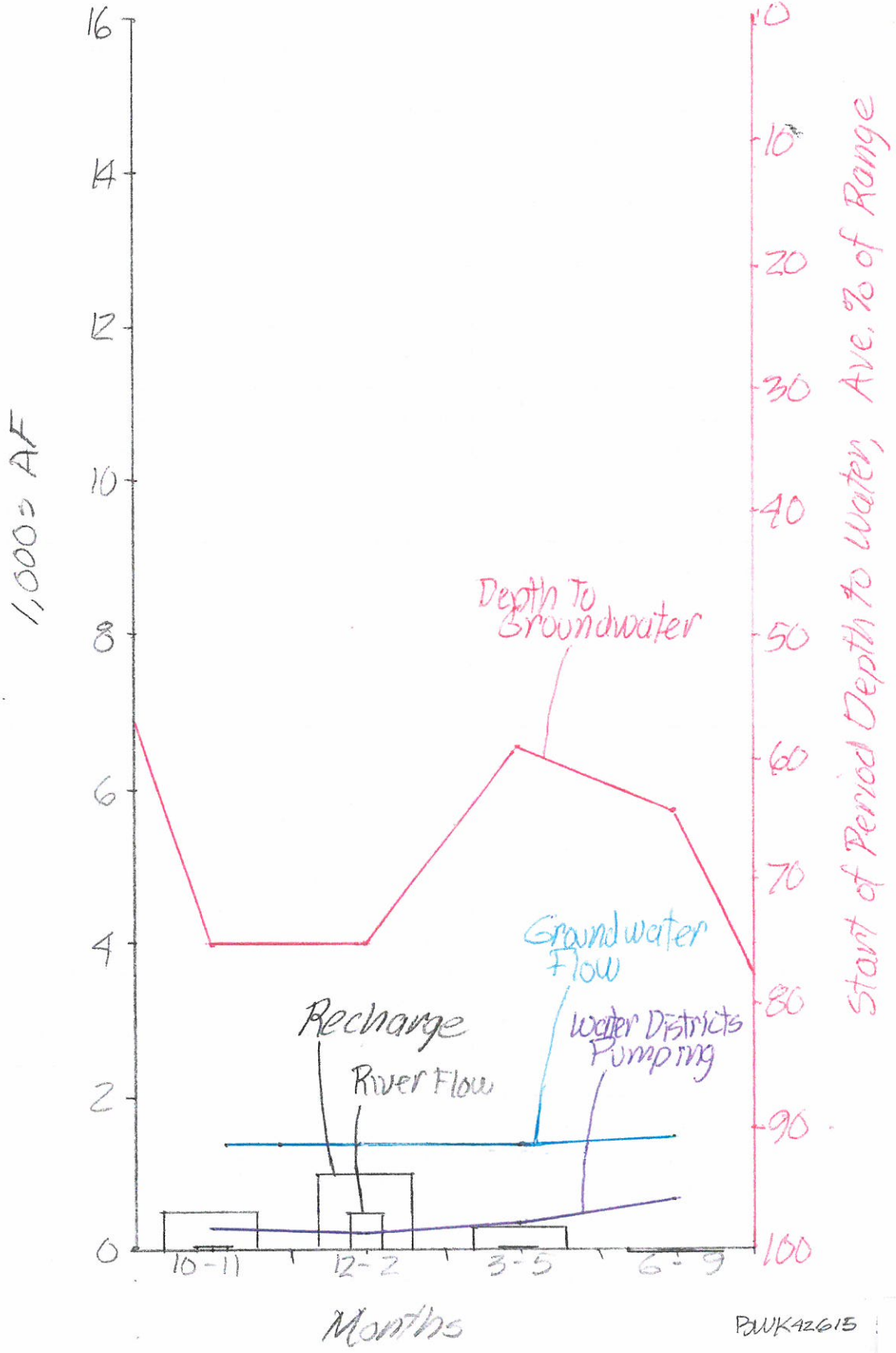
BUNK 92615 FIG 3

Figure 3h 2012-13

- During Oct-May, small recharge with low to no river flow.
- Nearly constant groundwater flow, despite increase in water table.
- Basin started year roughly 25% full, down from about 60% full at end of 2011-12.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW

2012-13 Water Year



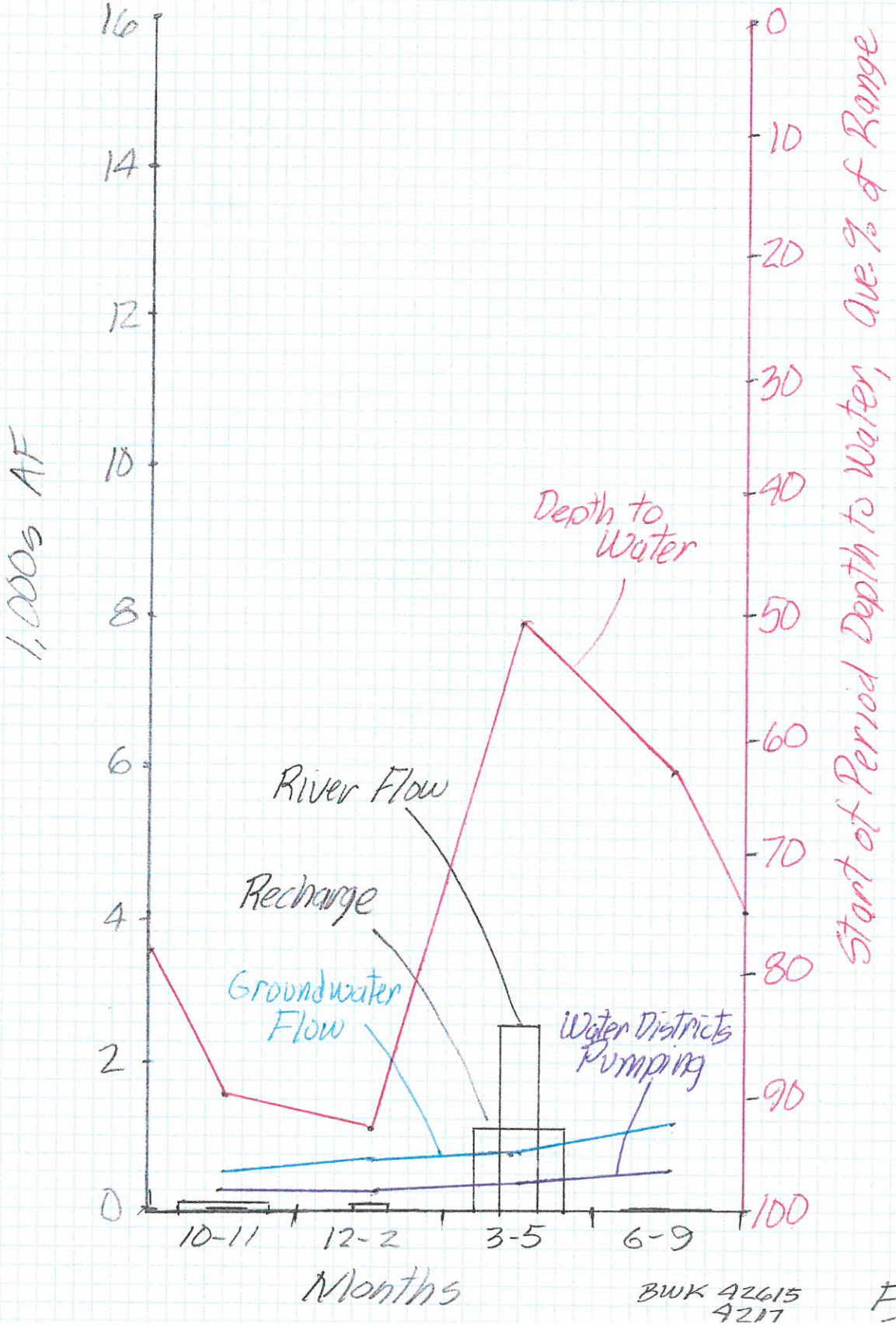
PWK42615

FIG.

Figure 3i 2013-14

- Basin starts year at lowest level of study period.
- During Mar-May, a short duration storm brings basin from about 10% full to 50% full.

UPPER VENTURA RIVER BASIN
MEINERS OAKS TO OAK VIEW
2013-14 Water Year



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4217

FIG.

Conclusions

Groundwater flow is usually lower with higher water tables. The basin is full when it is at 90-95% of capacity. Higher water tables result in smaller amounts of recharge. This can also be seen in Figure 6, 'Depth to Water and Infiltration Rates'. Water districts' pumping is usually between 1/3 and 1/2 of groundwater flow.

As noted in Limitations and Assumptions, calculated groundwater flows are assumed to ride on top of variable 'base' flow from Matilija Canyon. Unusual conditions in March 2016 made it conducive to estimate this base flow. The water table was rising with essentially zero flow at VRNMO so the storage increase came not from infiltration but base flow. Water table data were available from MOWD well 4 and VRWD well 2, which are very close to B1 and C4, respectively. The level came up 9' at well 4 during March, which works out to a flow of 380 AF/month or 6.2 cfs using the storage coefficient for B1. Similarly, the level came up 5.6' at well 2 during the same period, for a flow of 207 Af/month or 3.4 cfs.

Water Level Changes in Pumping and Non-pumping Nodes

An evaluation was made of water level changes in pumping and non-pumping nodes to see if the rates of water table decline were greater in the nodes with water districts' pumping than in those without. The periods studied were over the summer when there was usually no river flow at VRNMO. Pumping nodes were represented by wells B1 (nodes 19 & 20) and C4 (nodes 23 & 24); the non-pumping nodes were represented by F2 (nodes 26 & 27) and J1 (node 18). Each water year in the study period was used. Changes in water levels were normalized by calculations as a percentage of the well's range. To account for different storage coefficients, the percentage change in water table was divided by the storage coefficient, since water table change would be inversely proportional to storage coefficient. That quotient is referred to as the Change Coefficient.

Results are shown in Table 3. Node A1 was evaluated but not included in Table 3 as a non-pumping node because it is in the fault zone between the Arroyo Parida Santa Ana and Villanova faults, and it had the smallest water level

TABLE 3 WATER LEVEL CHANGES IN PUMPING AND NON-PUMPING NODES

Water Year Ending	River Flow ended	Obs. Well	Water Level Change	% of Range	Change Quotient
2006	Sep.	B1	8	11	0.26
		C4	10	14	0.38
		J1	15	25	1.47
		F2	6	11	0.19
2007	Apr	B1	5	7	0.17
		C4	10	14	0.38
		J1	6	10	0.59
		F2	14	26	0.46
2008	Jun	B1	15	20	0.48
		C4	8	11	0.3
		J1	6	10	0.59
		F2	8	15	0.26
2009	May	B1	13	18	0.43
		C4	10	14	0.38
		J1	12	20	1.18
		F2	21	39	0.68
2010	Jul	B1	21	29	0.69
		C4	14	19	0.51
		J1	5	8	0.49
		F2	9	17	0.3
2011	Sep	B1	28	38	0.9
		C4	18	24	0.65
		J1	21	35	2.06
		F2	8	15	0.26
2012	May	B1	42	58	1.38
		C4	34	46	1.24
		J1	6	10	0.59
		F2	23	42	0.74
2013	Mar	B1	21	29	0.69
		C4	20	27	0.73
		J1	3	5	0.29
		F2	23	43	0.75
2014	Apr	B1	14	19	0.45
		C4	19	26	0.7
		J1	22	37	2.18
		F2	25	46	0.81

Water level change is from July to Oct thru 2010 and Jun thru Oct after.
Change quotient is % of range divided by storage coefficient for node.
Storage coefficients are: B1 - 42; C4 - 37; F2 - 57; and J1 - 17
B1 and C4 are pumping nodes; F2 and J1 are non-pumping, except J1 in 2011 and 2013.

fluctuation range of the 5 key observation wells. Larger Change Quotients indicate larger relative water table drawdowns. One would expect pumping nodes to have consistently larger Change Coefficients. However, there doesn't seem to be any such trend. Below is a summary:

- In 3 years (2010, 2011, and 2012), pumping nodes had larger Change Coefficients. J1 was a pumping node in 2011 with a very high value. A1 was higher in 2 of the 3 years. 2010 and 2011 were wet; 2012 was dry.
- In 3 years (2007, 2009, and 2014), non-pumping nodes had larger Change Coefficients. J1 was very high in 2014. A1 was lower in 2 of the 3 years. These years were 3 of the 4 driest of the study period.
- In 2 years (2006 and 2008), pumping nodes were sandwiched between non-pumping nodes, being lower than 2 of the latter in both years. In 2006, J1 was very high compared to the other nodes. These two years were the wettest of the period.
- In 1 year (2013), 4 of the Change Coefficients were about equal. J1 was a pumping node and was very low. 2013 was the driest.
- The two years with the largest average water table changes were 2012 and 2014.
- The two years with the smallest average water table changes were 2006 and 2008.

Conclusion

Overall, data are inconsistent. The only indication of a pattern is non-pumping nodes having larger Change Coefficients during drier years. One interpretation suggested by the second quote from Entrix, on page 1 above, is that natural hydrologic variations are large enough such that effects of pumping are masked.

Storage Declines in Pumping and Non-pumping Nodes

Another comparison was made between pumping and non-pumping nodes to determine the extent to which pumping reduced groundwater flow and to determine the percentage reduction caused by pumping. Calculations were made for the Aug-Sep periods from 2006 through 2010 and for the June-Sep periods from 2011-2014. Variable storage coefficients were used with start of period average depth to water as % of range, as in Set Three Hydrographs.

Results are in Table 4 and graphically in Figure 4, Water Districts' Pumping as a Percentage of Storage Declines. The tailoring factor is the product of the

TABLE 4
STORAGE DECLINES IN PUMPING AND NON-PUMPING NODES
VARIABLE STORAGE COEFFICIENTS, LATE SUMMERS, 2006-2014

Pump Storage AF 1	Nodes WD pump AF 2	Non-pump Nodes AF 3	Decline Sub-Total AF 4=1 + 3	Start of period DTW Ave. of Range % 5	Tailoring Factor 6	Decline Total AF 7=4x6	Decline Caused by GW Flow AF/cfs 8=7-2	Decline Caused by GW Pump % 9=2x100/7
706	539	797	1,503	19	0.88	1,323	784/7	41
580	426	900	1,480	66	0.48	710	284/2	60
926	487	1,038	1,964	34	0.76	1,493	1,006/8	33
916	500	1,441	2,357	57	0.56	1,320	820/7	38
1,400	440	1,078	2,478	35	0.74	1,834	1,394/12	24
1,842	776	1,013	2,855	9	0.97	2,769	1,993/8	28
3,022	909	1,733	4,755	38	0.72	3,424	2,515/10	27
1,622	662	1,642	3,264	64	0.50	1,632	970/4	41
1,291	514	1,919	3,210	63	0.50	1,605	1,091/5	32

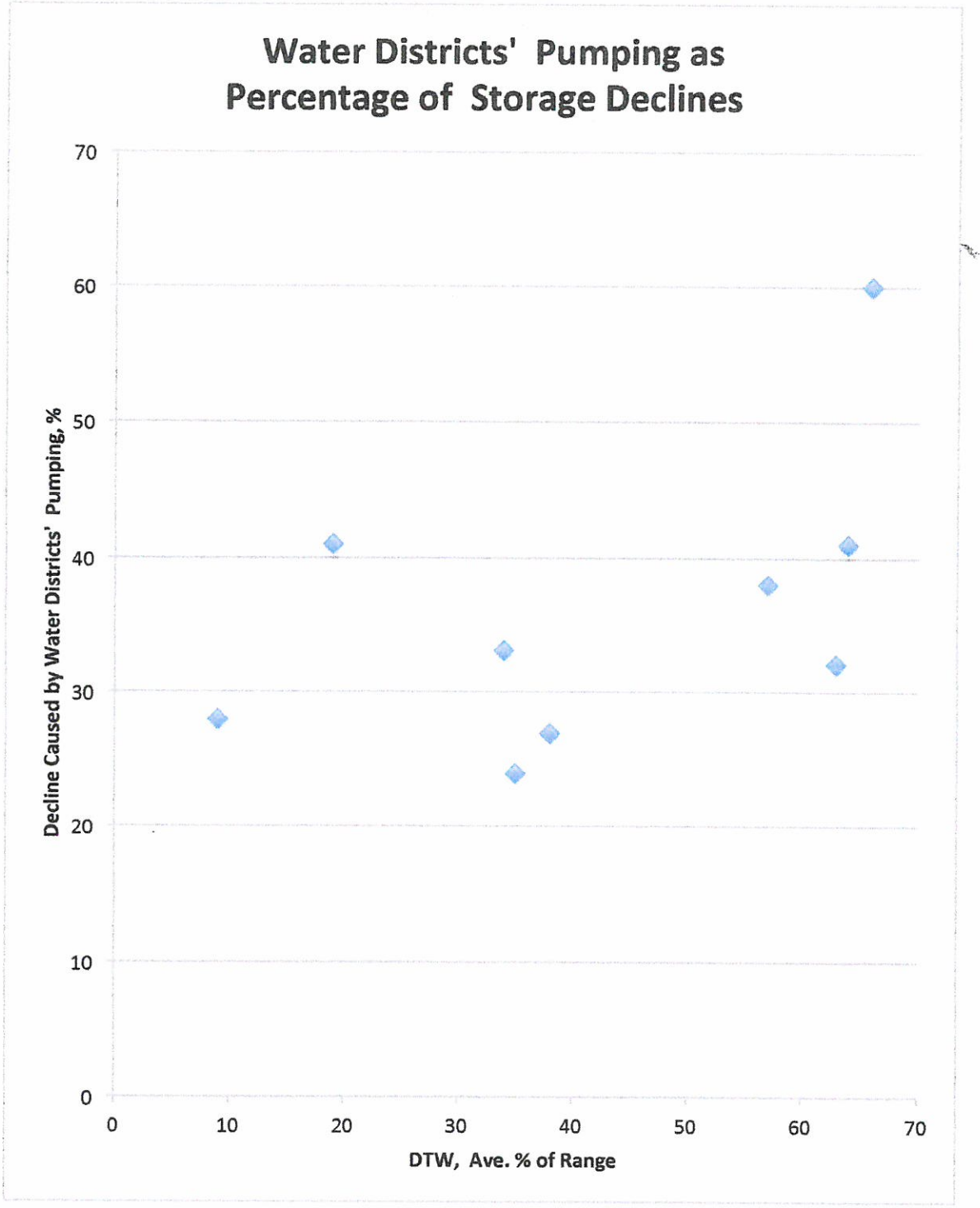

Water Districts' Pumping as Percentage of Storage Declines
Decline Caused by Water Districts' Pumping, %
DTW, Ave. % of Range
0
10
20
30
40
50
60
70

FIG.

variable storage coefficient factor and the water balance factor, as discussed above under **Storage Coefficients.**

Conclusion

The effect of water districts' pumping on aquifer storage declines varied between 24% and 41% with no apparent trend related to water table depth. The only exception was 2007 when it was 60%.

Riverbed Infiltration Rates

Overview

Riverbed infiltration rate is an important hydrologic element because groundwater recharge occurs primarily from this source. It is a basis for estimating how much of river flow becomes groundwater and how much becomes ocean discharge. Two methods were followed: the first used nodal storage increases; the second used decreases in river flow.

Storage Increase Method

Water table increases at observation wells were assumed to result only from riverbed infiltration, ignoring groundwater underflow from Matilija canyon and percolation from rain, among other water balance items. Infiltration volume was simply the product of water table increase, in feet, and the storage coefficient. Rates were calculated by factoring in riverbed length and time period. The tailoring factors discussed above were used to adjust coefficients for variation with depth.

Results are shown below in Table 5. Infiltration rates are acre-feet per 1,000 feet of riverbed per day (AF/k'day). To put this in common terms, a rate of 1 AF/k'day would be about 0.5 cubic feet per second or 225 gallons per minute going underground per 1,000 feet of river per day. Generally, higher rates would be expected at J1 and B1, wells closest to highest flows. F2, with lowest flows, is an exception. Its had 9 of the highest rates of the 28 events.

Decrease in River Flow Method

In 2015, two data sets became available for use in this method. One is from MOWD, which began monitoring the leading edge of the Ventura River in January 2014. These data are usually weekly and are expressed in longitude and latitude. The other is CMWD surface flow data (personal communication with Scott Lewis, fisheries biologist studying steelhead trout under contract with CMWD). These

TABLE 5
STORAGE INCREASE METHOD
INFILTRATION RATES, AF/k'day

Period	J1	B1	C4	A1	F2	Average
10-11, 2005		0.3				0.3
12-1, 2006	1.3	1.2	1.2	0.7	1.4	1.2
Feb- Mar	2	0.1	1.1	0.1	1.1	0.9
12-1, 2007		1.6	0.7	0.4		0.9
Feb-Mar	0.4		0.7	1	0.7	0.7
Apr-May	0.4					0.4
Oct-Nov	0.9	0.5				0.7
12-1, 2008	5.5	6.3	4.2	2.3	6.8	5
Feb-Mar			1.2			1.2
Oct-Nov	0.6	0.2				0.4
12-1, 2009	0.3	0.2	0.8	0.3	0.1	0.3
Feb-Mar	2.2	3.5	2.1	1.9	3.7	2.7
Oct-Nov	2.8	3.3	0.3		0.6	1.8
12-1, 2010	2.9	3.4	3.2	2.3	4.5	3.3
Feb-Mar			0.5		0.1	0.3
Jun-Jul	2					2
Oct-Nov	0.3	1.4				0.8
12-2, 2011	2.1	2.5	2.1	0.7	2.2	1.9
Mar-May		0.1		0.8	1.1	0.7
Oct-Nov	1.2	1.1				1.2
12-2, 2012	0.8			0.2	0.2	0.4
Mar-May			0.3	0.4	0.6	0.4
Oct-Nov	1	2.5				1.8
12-2, 2013		2.1	0.6	0.1	1.2	1
Mar-May			0.4		0.5	0.4
Oct-Nov		0.1		0.3		0.2
12-2, 2014	2.1	3.2	0.4	1.4		1.8
Mar-May			1.2		1.2	1.2

data are expressed as lengths of river reaches categorized as wet, intermittent, or dry; began in February 2008, and continued through August 2015 at intervals varying from weekly to monthly, depending on river flow. Although focusing on river flow as it affects fish migration, these data are a useful tool in estimating riverbed infiltration.

In 2014, there was one intense runoff event with flow occurring from February 27 to April 27. Weekly flow volumes are shown in Figure 1i. Both of the above new data sets were used to calculate infiltration rates. The short duration made calculations relatively easy. Results are shown below.

Ventura River Infiltration Rates, 2014

Period	River Volume AF	# of days	Wet length 1,000's ft.	Infiltration Rate AF per 1,000 ft. per day
		MOWD		
3-1 thru 3-23	2,050	23	4.75	18.8
3-24 thru 3-30	160	7	3.64	6.3
3-31 thru 4-15	260	16	1.87	8.7
4-16 thru 4-24	40	9	0.99	4.5
		CMWD		
3-1 thru 3-3	1,250	3	33.1	12.6
3-4 thru 3-10	420	7	8.2	7.4
3-11 thru 4-7	700	28	3.3	7.6
4-8 thru 5-5	130	19	1.65	4.2

Note that on Mar 1, storm-water flowed to the ocean and the wet length at the first period's end was 4,750. The highest infiltration rate of 18.8 results from assuming the entire period flow percolated in that short distance. It is obviously not accurate. The same reasoning applies to the highest rate from CMWD surface flow data. Excluding those data, the average of the remaining values for each data set is 6.4 AF/k'day. For this event, infiltration rates appear reasonably accurate.

In contrast to this rather straightforward approach, years 2007-08 thru 2011-12 (no significant runoff in 2012-

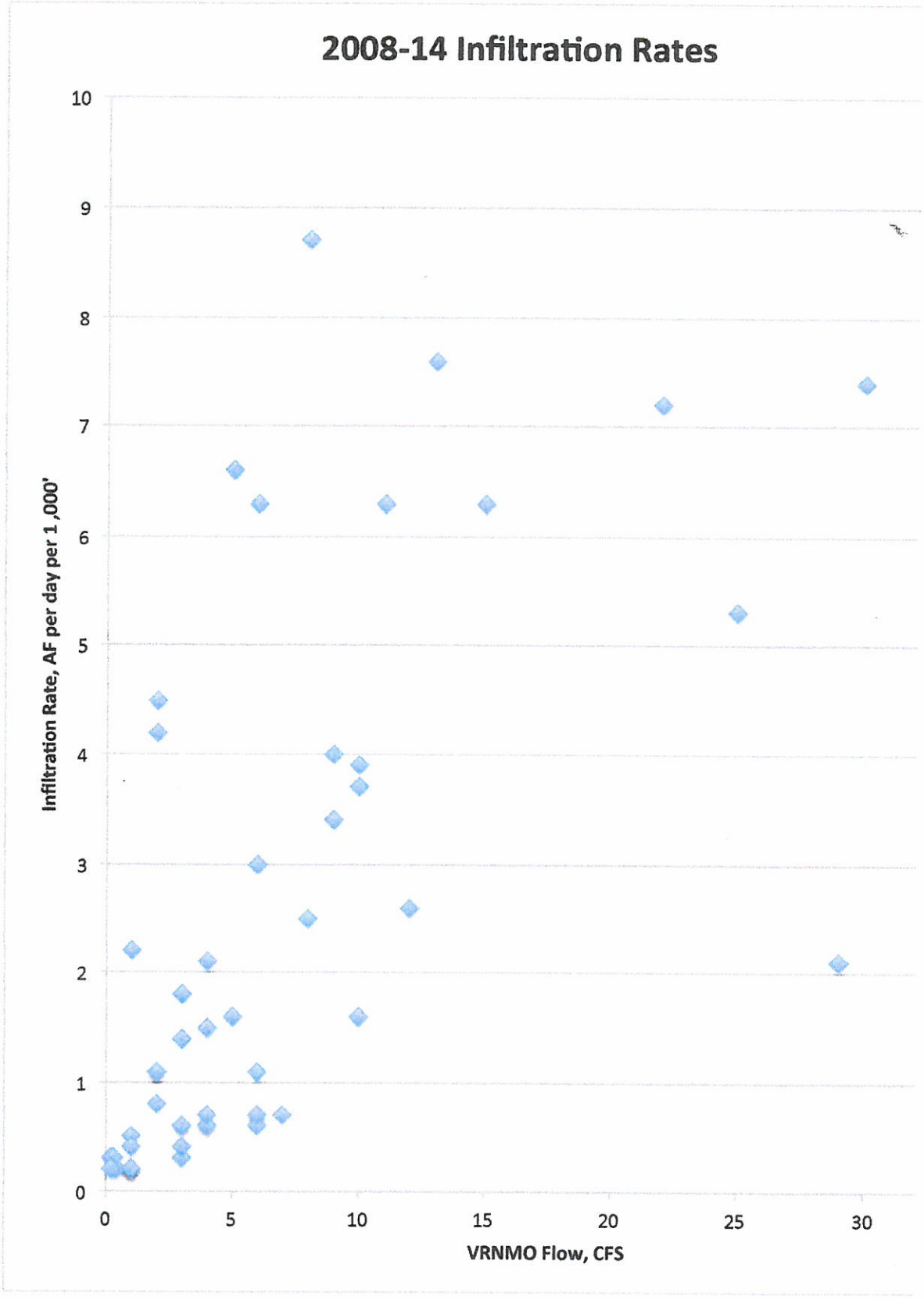
13) had larger and longer duration flows; and intermittent stretches were longer and interspersed with wet and dry, making determination of wet lengths more subjective. The following two assumptions were made for those years: intermittent was considered wet if Lewis categorized it as upwelling; and dry if it was downwelling.

Calculations of wet length depended indirectly on river flow. First, when the riverbed was wet nearly continuously to the ocean, VRNMO flow was assumed to infiltrate between VRNMO and San Antonio Creek confluence (river kilometer [rkm] 13.1) and any dry lengths therein subtracted from the 10.1 km between VRNMO (23.2 rkm) and San Antonio Creek. This would show maximum possible infiltration rates, although unrealistic, and for that reason, results are not included in this report. Second, when a dry reach of at least 0.2 km occurred downstream of Santa Ana Blvd bridge (rkm 15.5), wet length was calculated by adding wet lengths between there and VRNMO.

Figure 5 shows results for the study period 2006 – 2014. Figures 5a through 5g are for each water year starting with 2008. Infiltration rates are shown in AF per 1,000 feet of riverbed per day (AF/k'day). Normally rates are in feet per day for a given area. This was not possible because data are insufficient on riverbed width for each wet segment.

Figure 5 shows an average flow of 30 cfs at VRNMO can infiltrate within the dry reach, although it may go beyond. Using that flow and total nodal length of 27,500 feet works out to 2.2 AF/k'day as a maximum average infiltration rate. Theoretically, it would be higher near VRNMO and lower near Santa Ana Blvd bridge, although rates in Table 5 don't fit that hypothesis. Interestingly, an average flow of 29 cfs with wet length of 26,900 feet on 2-23-09 had an infiltration rate of 2.1 AF/k'day. In contrast, an average flow of 30 cfs and wet length of 8,500' on 3-10-14 had an infiltration rate of 7.4 AF/k'day. Comparing hydrographs for those two years (Figures 1d and 1i, respectively) shows river flow in 2009 to be low and sustained while in 2014, it was intense and short term. Apparently it made a wider than normal channel and as a result, percolated rapidly.

CMWD surface flow data can be used to define the dry reach's southern boundary by noting where the riverbed usually becomes wet. Most often, that occurs at about rkm 14.7, which is 0.8 km (½ mile) south of Santa Ana Blvd bridge. If driving on Santa Ana Road, that place would about even with the Foreman's house for Rancho Rio Vista, address 9998 Santa Ana Road.


2008-14 Infiltration Rates
Infiltration Rate, AF per day per 1,000'
VRNMO Flow, CFS
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30

FIG

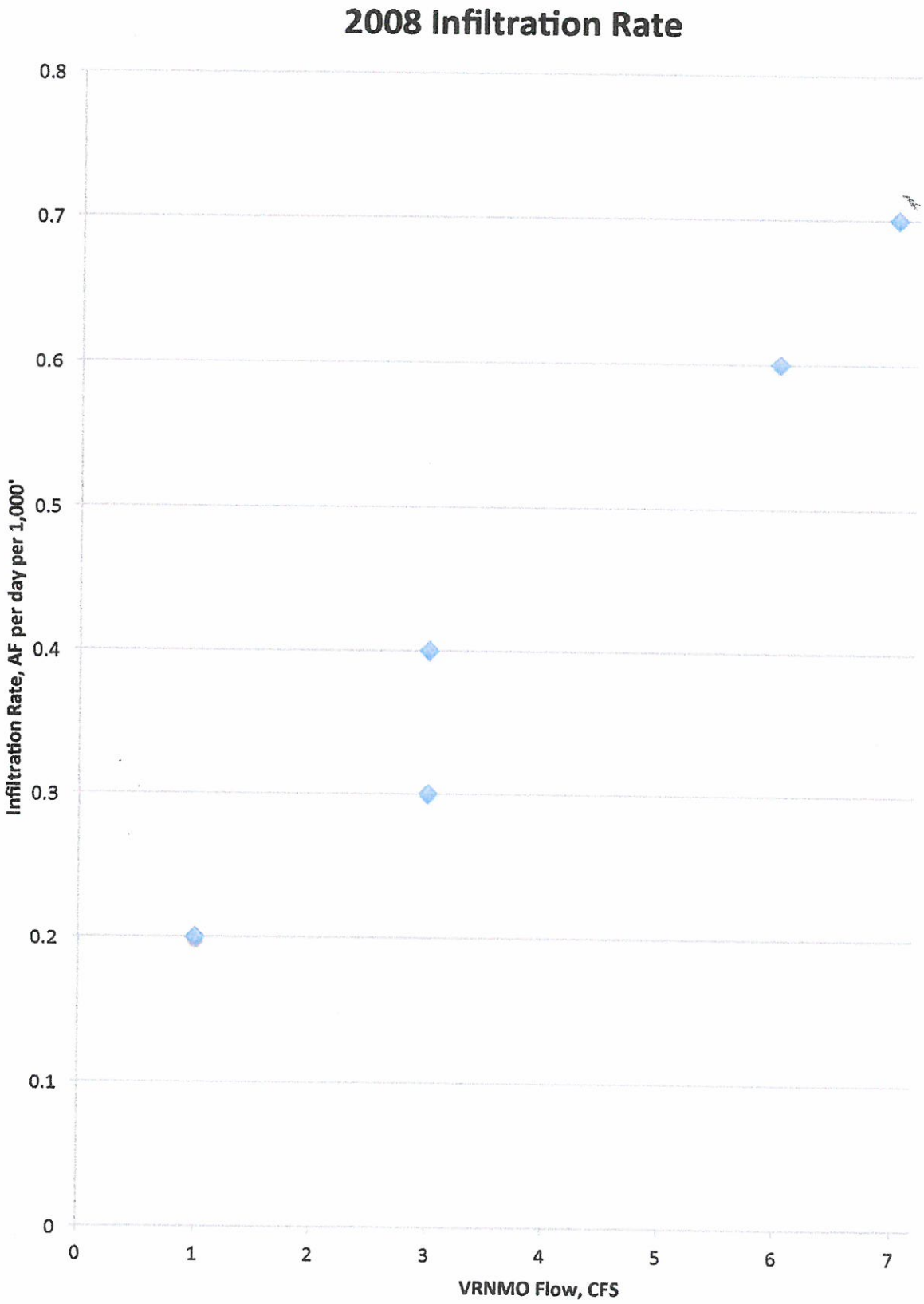

2008 Infiltration Rate
Infiltration Rate, AF per day per 1,000'
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
VRNMO Flow, CFS

FIG.

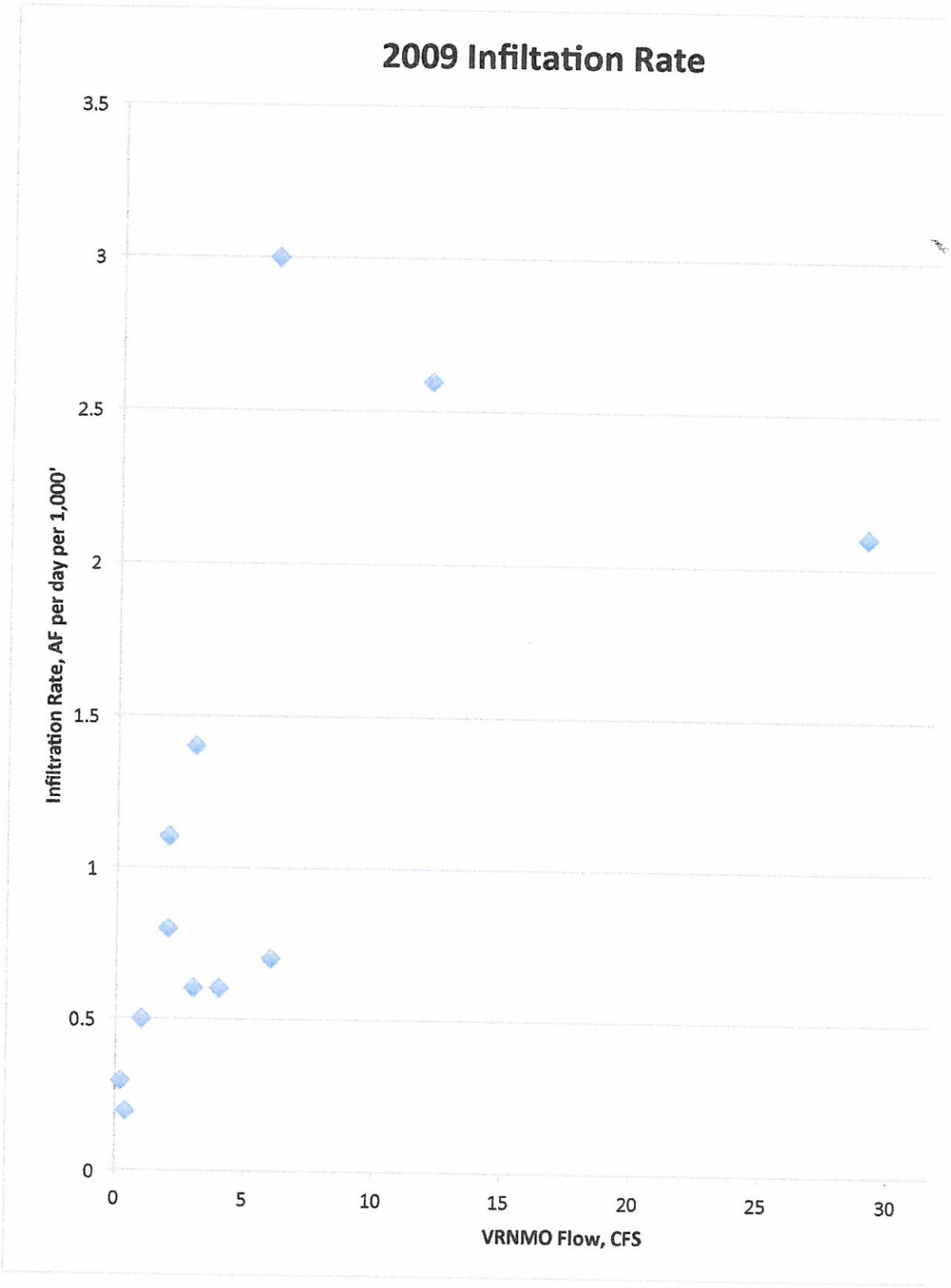

2009 Infiltation Rate
Infiltration Rate, AF per day per 1,000'
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
VRNMO Flow, CFS

FIG.

2010 Infiltration Rate

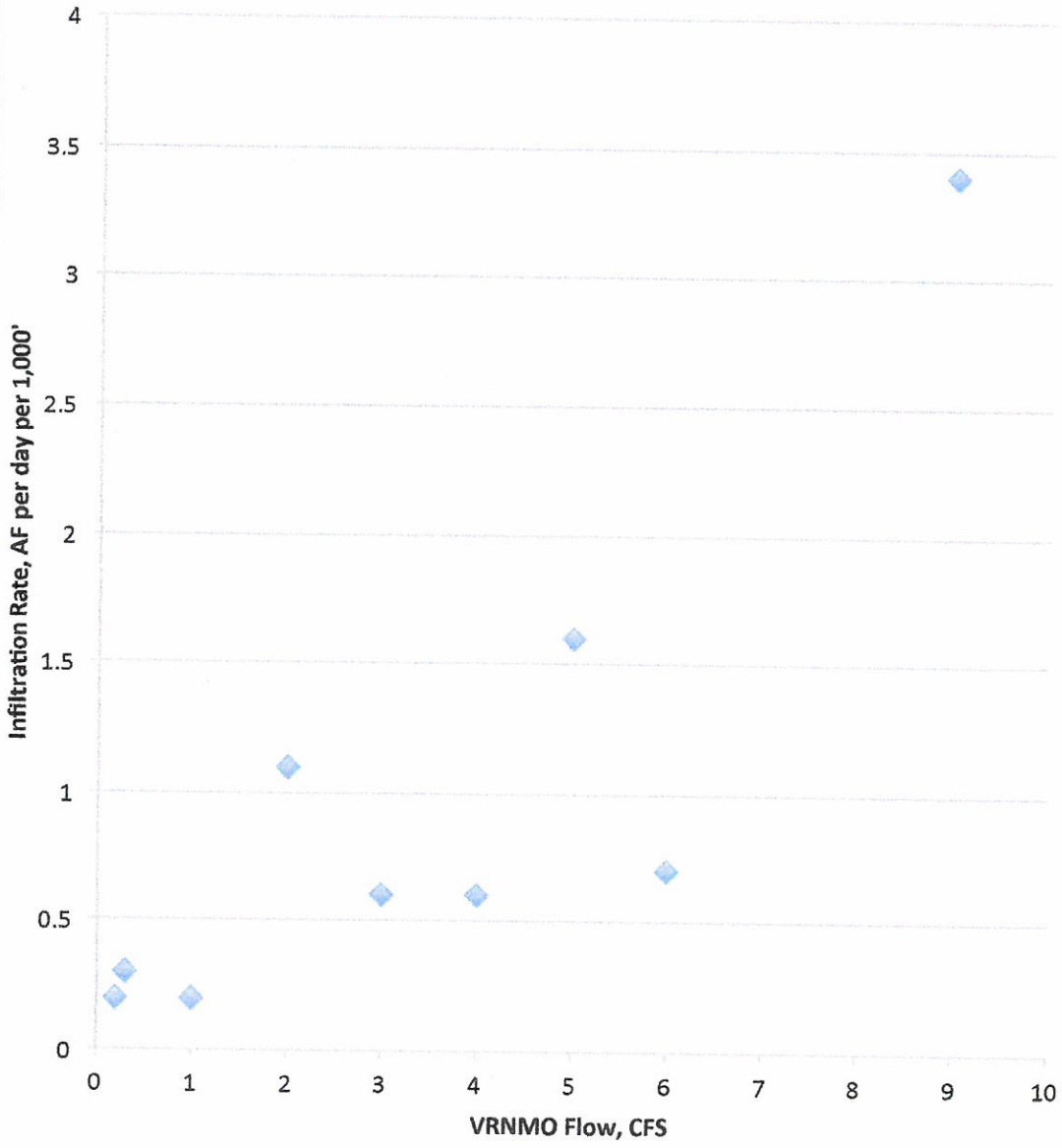


FIG.

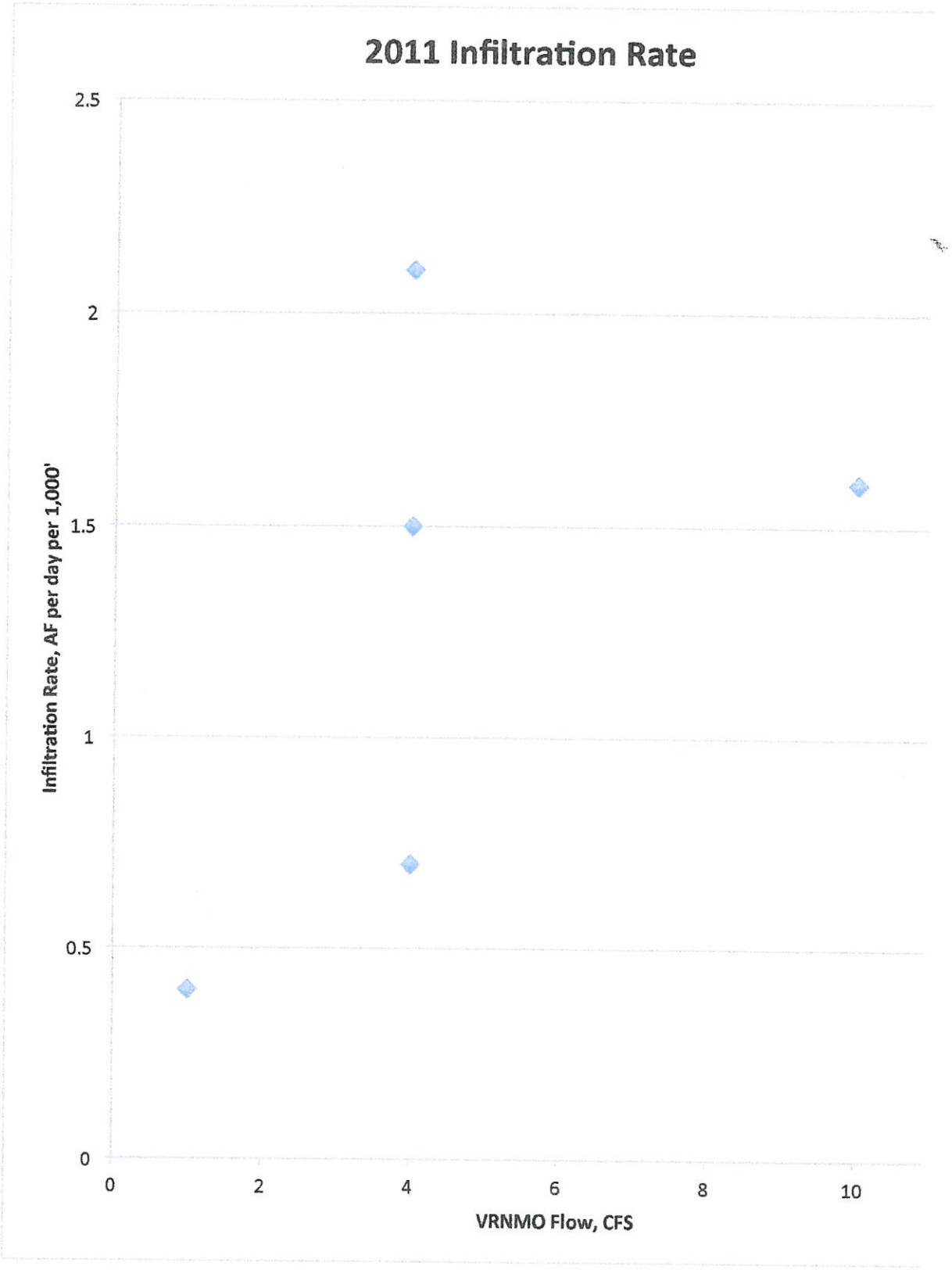

2011 Infiltration Rate
Infiltration Rate, AF per day per 1,000'
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
VRNMO Flow, CFS

FIG.

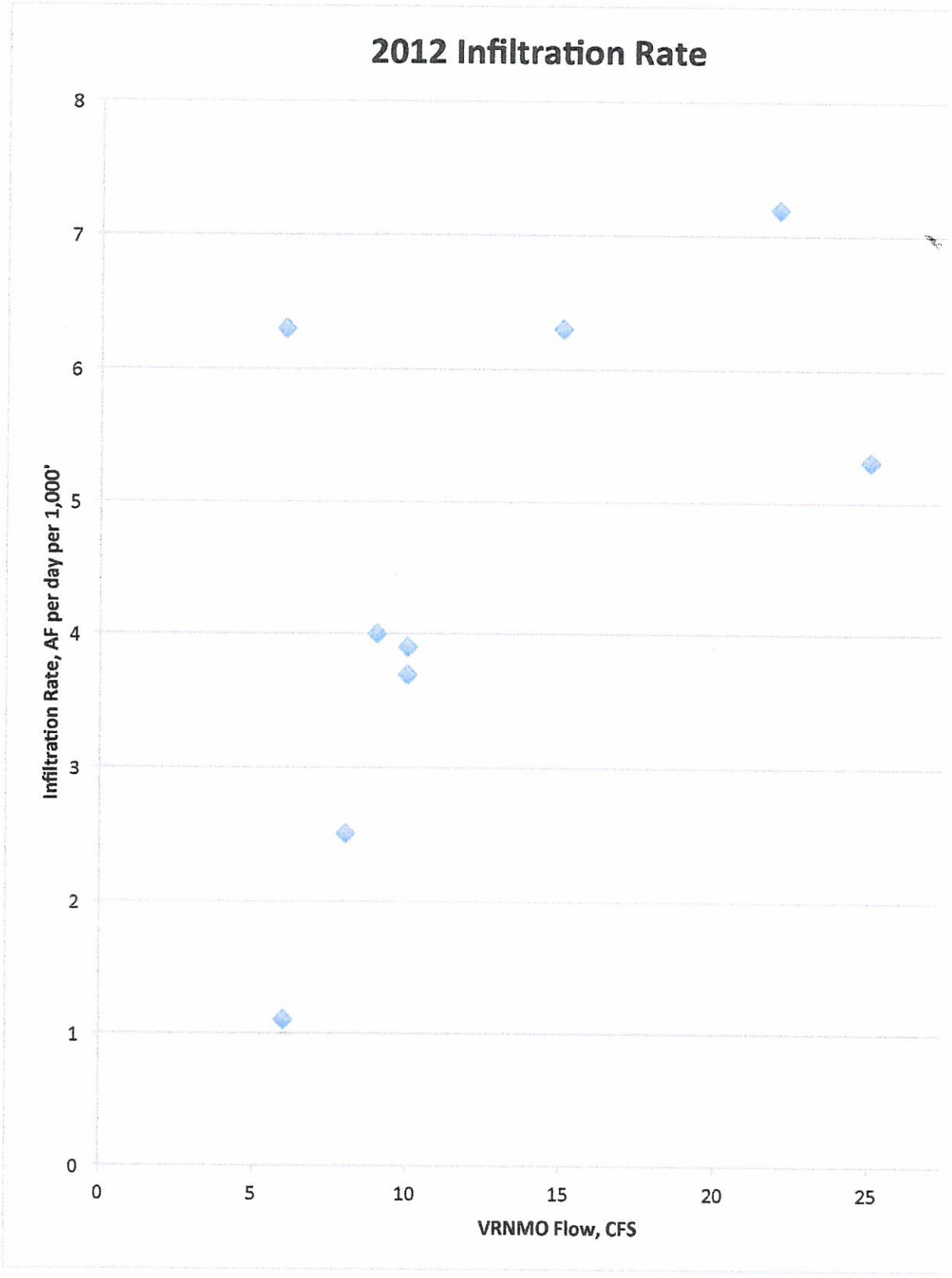

2012 Infiltration Rate
Infiltration Rate, AF per day per 1,000'
VRNMO Flow, CFS
0
1
2
3
4
5
6
7
8
0
5
10
15
20
25

FIG.

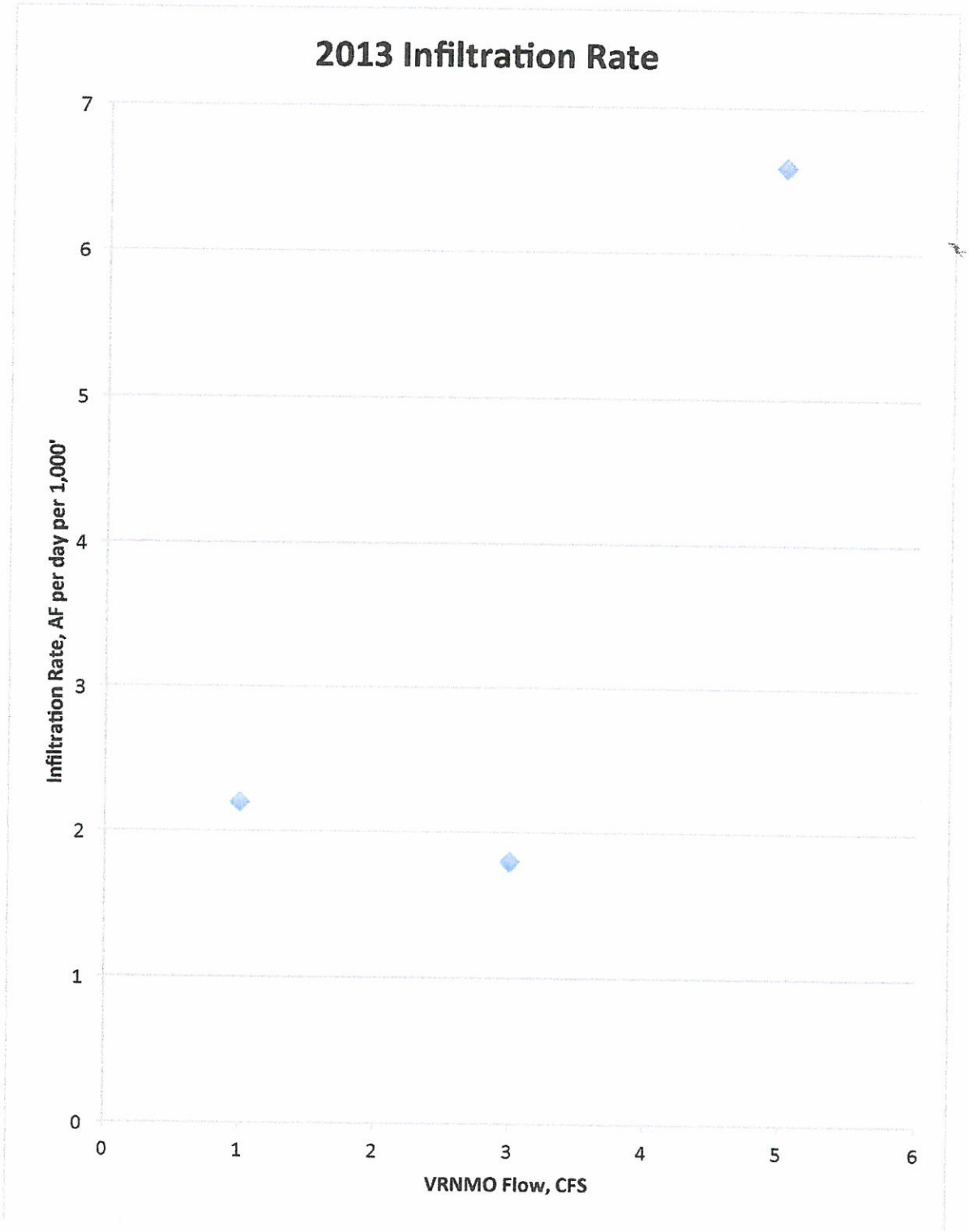

2013 Infiltration Rate
Infiltration Rate, AF per day per 1,000'
VRNMO Flow, CFS
0
1
2
3
4
5
6
7

FIG.

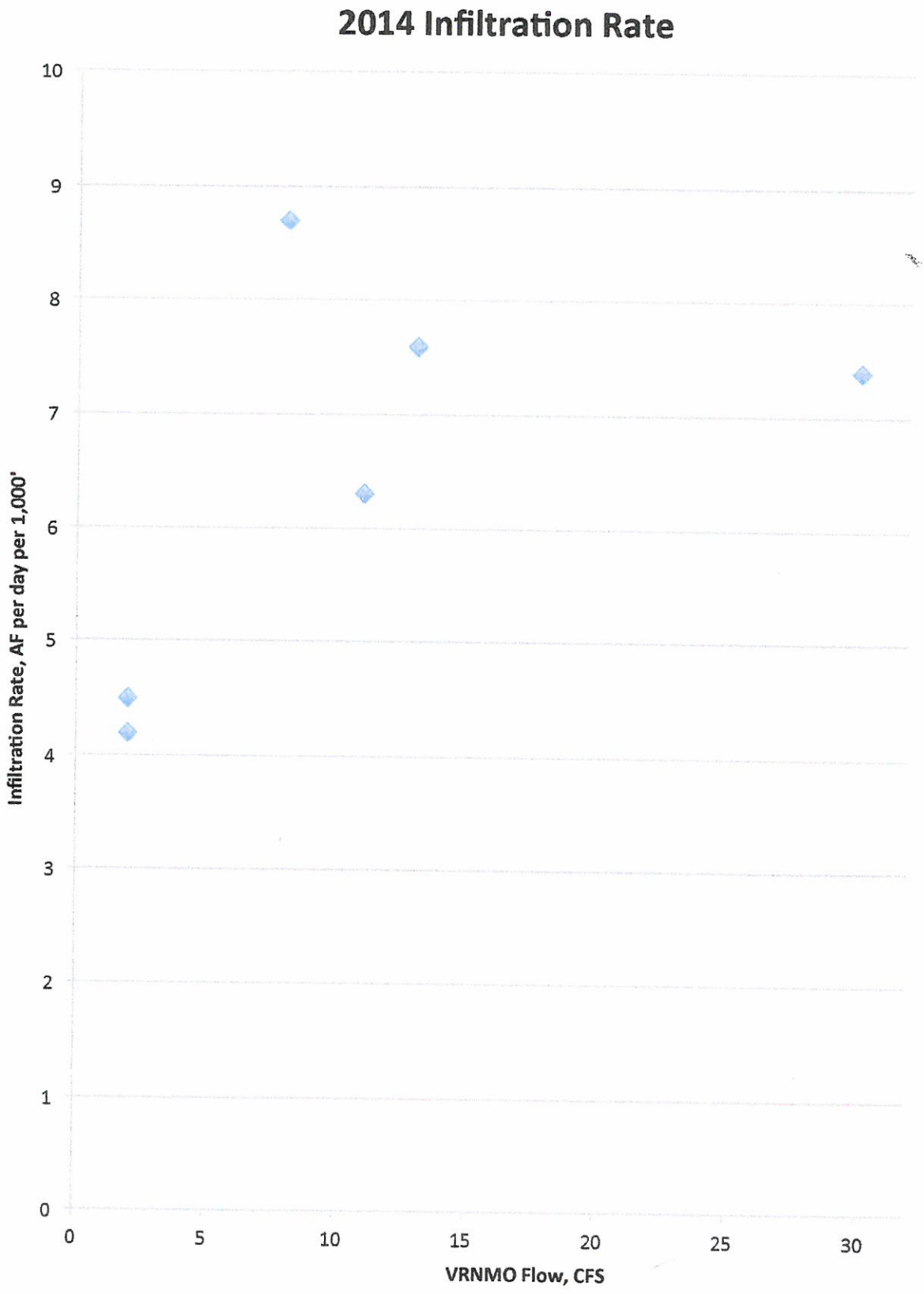

2014 Infiltration Rate
Infiltration Rate, AF per day per 1,000'
VRNMO Flow, CFS
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30

FIG. 5g

The highest three infiltration rates during the study period were in 2014.

Comparison of Infiltration Rate Methods

Looking at rates in Table 5 and on Figures 5a through 5g shows that for both the storage increase and decrease in river flow methods, most values range between 0.3 and 3 AF/k'day. Maximum rates are similar. However, rates are not close for similar time periods. This raises the question of which is more accurate. Difficulties with the storage increase method include longer time periods (two month minimum) versus a week or less by river flow method, treating entire river length as uniform through each node, and uncertainty of storage coefficients. The main difficulty with the decrease in river flow method is storage increases occurred primarily between December and March when river flow was large and those periods had to be excluded because river flow didn't infiltrate within a known distance.

For the storage increase method, the period with highest rates was Dec 2007-Jan 2008, averaging 5 AF/k'day with a range of 2.3 to 6.8 (Table 5). For the river flow method, the period was Mar-May 2014, averaging 6.4 with a range of 4.2 to 8.7 (Figure 5g). Hydrographs for those periods (Fig. 1c and 1i, respectively) are similar with relatively high peak flows and relatively rapid decreases. This is summarized in the listing below. The first river flow method value was in May 2008.

		2008	2014
River flow method,	ave	NA	6.4 AF/k'day
	range	NA	4.2-7.4
Storage inc. method	ave	5AF/k'day	1.2
	range	2.3-6.8	only one rate

A period of moderately high rates occurred in Feb-Mar 2009 with values from both methods:

River flow method,	ave 2.4 AF/k'day
Storage Inc. method	ave 2.7
River flow method	range 2.1-2.6 (two rates)
Storage Inc. method	range 1.9-2.7

Conclusion

The foregoing comparison suggests both methods give reasonable estimates for relatively short-lived high-flow

conditions and for moderately high infiltration rates. However, the river flow method can only be used when river flow infiltrates within a known length of river. In that situation, it is the more accurate method because it doesn't have the difficulties mentioned above and results based on CMWD surface flow data were confirmed by MOWD's data.

Riverbed – Water Table Connection

One factor affecting infiltration rate is whether the water table in hydraulically connected to the riverbed. A connected water table lowers infiltration. The depth at which connection ends varies depending on riverbed and groundwater basin permeability. To see if it might be possible to estimate where separation may occur, infiltration rates were plotted with depths to water. Depths to water were calculated using actual water depths (not normalized as in other sections of this report) from observations wells nearest the wet reaches and averaged with weighting based on wetted lengths. If the river was either wet or dry at all observation wells, an un-weighted average was used.

The result is shown in Figure 6, Depth to Water and Infiltration Rates. One would expect to see data trending from lower infiltration rates with shallow water tables to higher rates with deep water tables. However, data are so scattered there is no clear trend, with the possible exception of the largest rates occurring with average depths to water greater than 30 feet. Higher rates occur with higher flows so it is difficult to separate the effects of high flow from hydraulic connectivity. It wasn't possible to calculate rates for each observation well using the Decrease in River Flow Method because the length and volume of percolating flow wasn't known for each. Another complication is that J1 usually has the largest depth to water and, as the most upstream well, has the biggest flow, thereby consistently overshadowing other reaches. A1 has little effect on average depths because its fluctuation range is small. F2, the other most often used well in these calculations, also has a large range similar to J1. Finally, shallow water tables usually occur from large river flows. Those events were excluded from the data set for lack of accurate infiltration rates, i.e., river flow didn't percolate with a known distance.

Another approach was to use the Storage Increase Method to calculate infiltration rates for each observation well and plot those with depth to water. Results are shown in Figures 7a, 7b, 7c, and 7d for wells B1, C4, A1, and F2

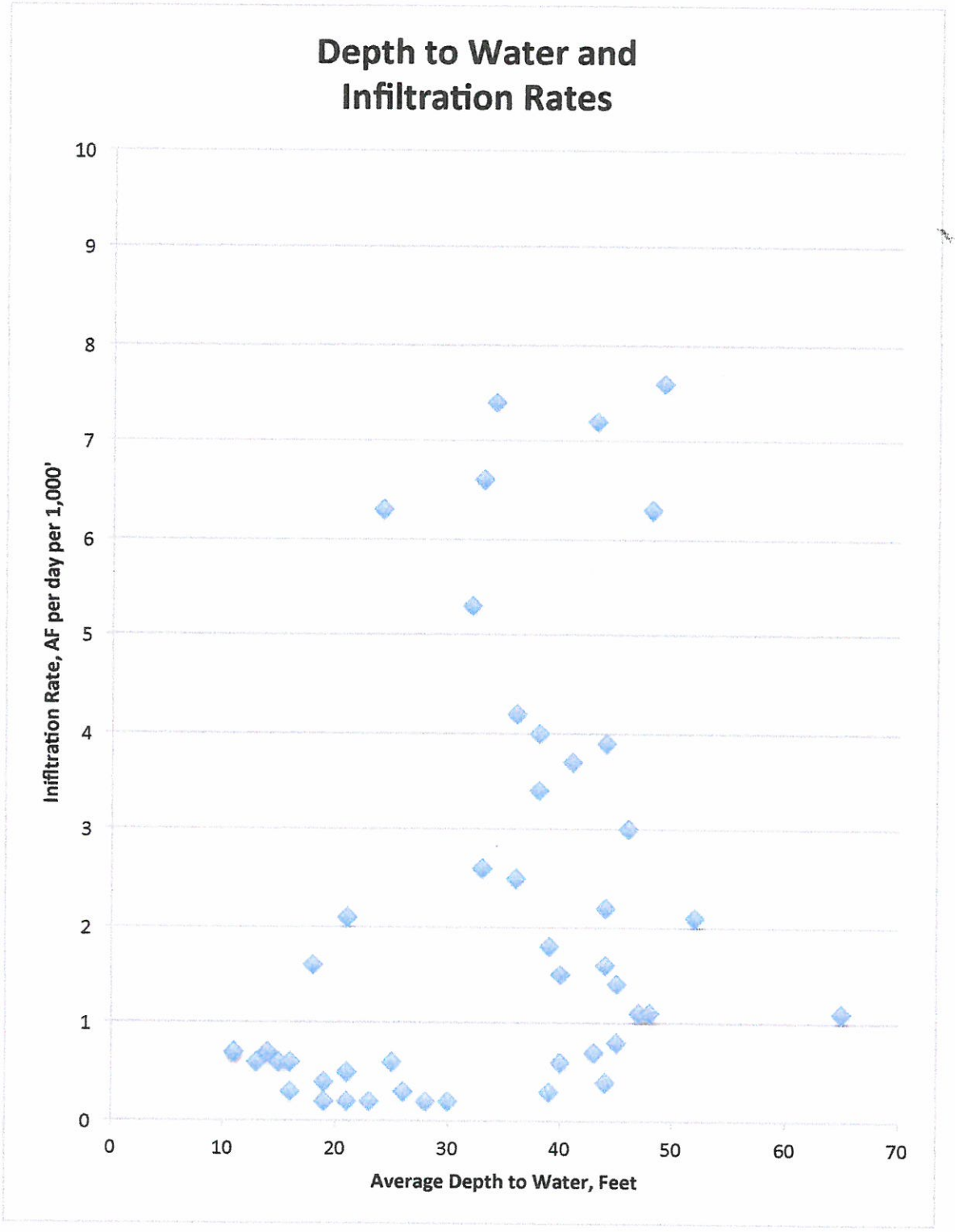

Depth to Water and Infiltration Rates
Inifiltration Rate, AF per day per 1,000'
Average Depth to Water, Feet
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70

FIG.

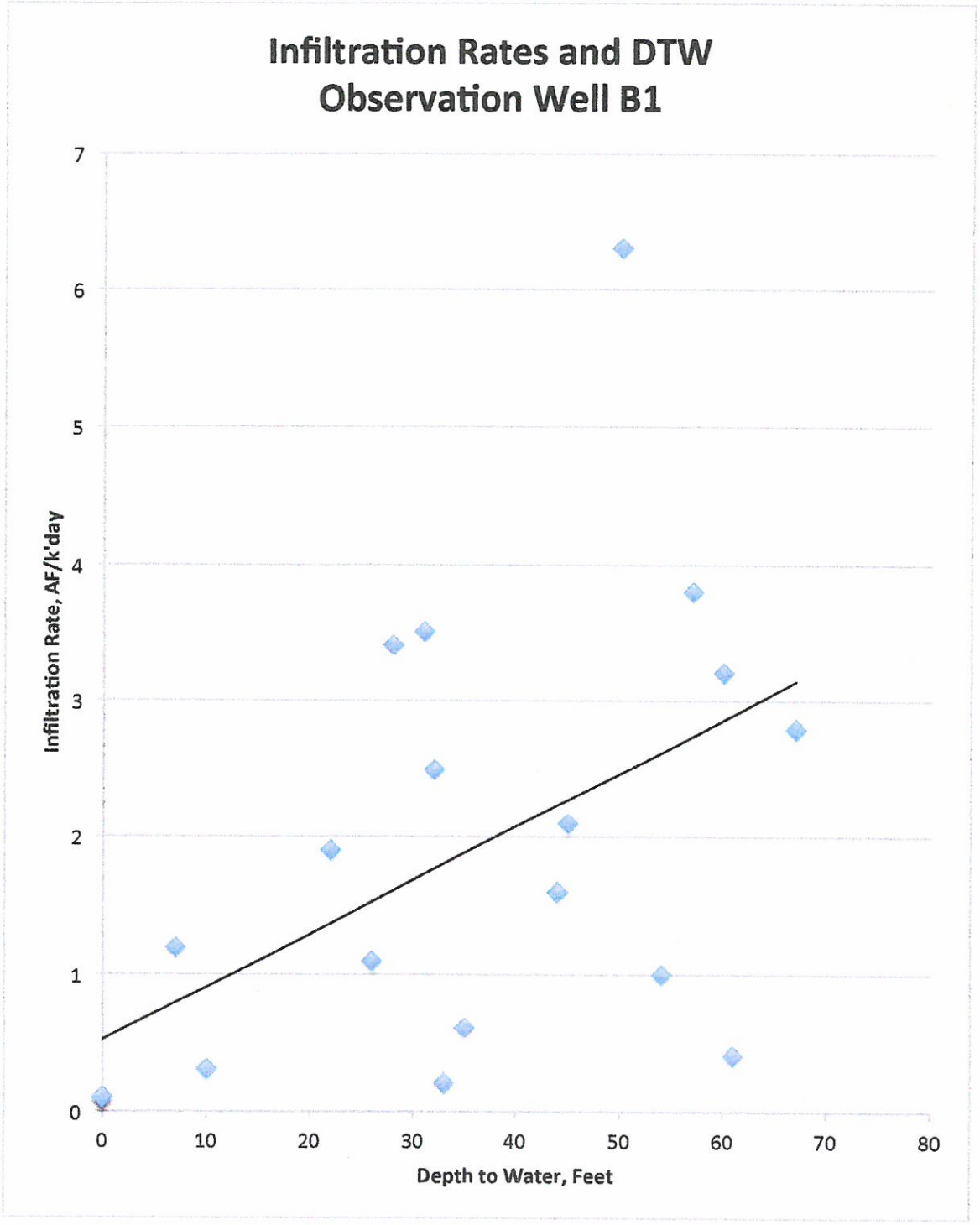

Infiltration Rates and DTW
Observation Well B1
Infiltration Rate, AF/k'day
Depth to Water, Feet
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80

FIG.

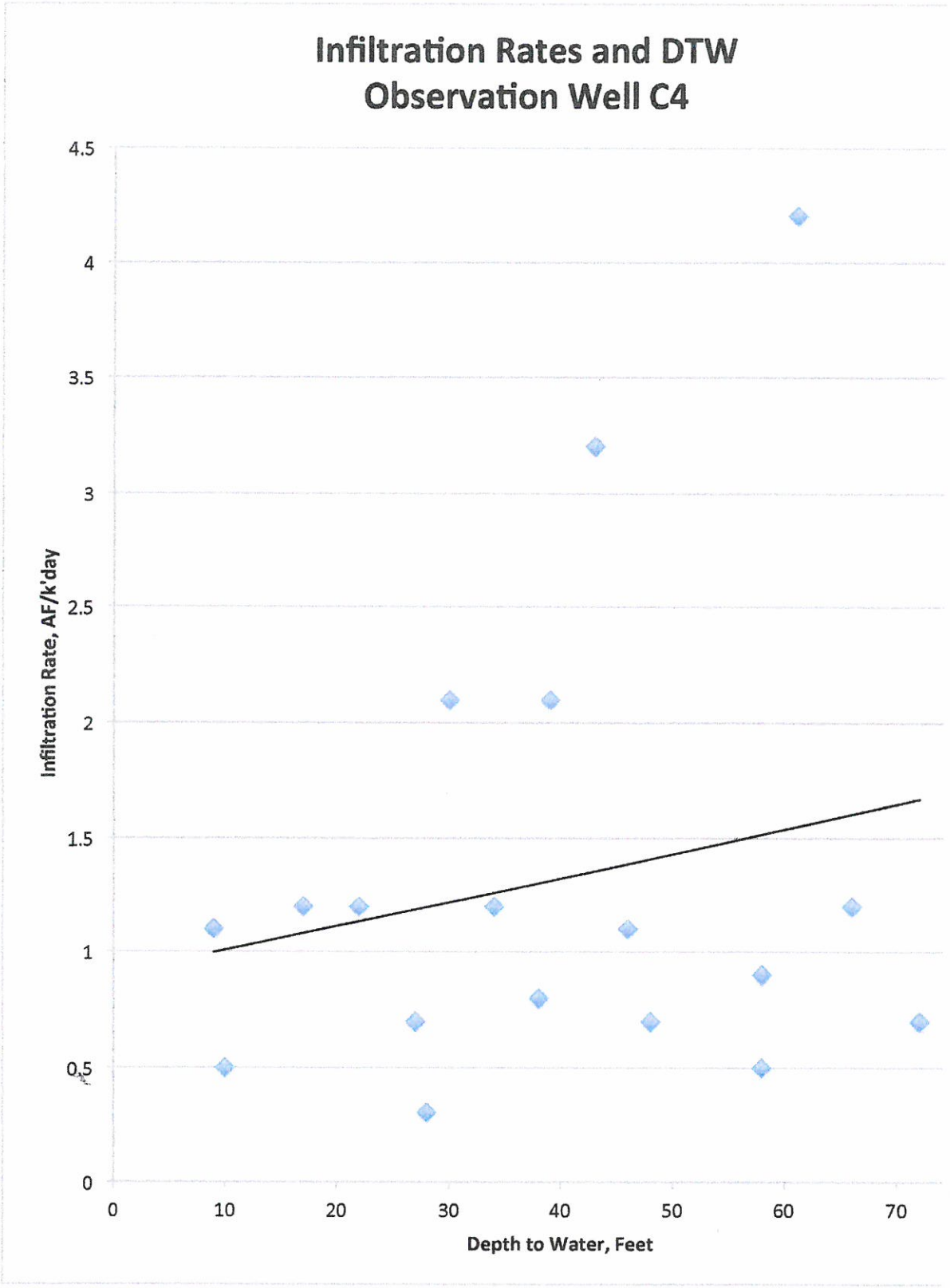

Infiltration Rates and DTW
Observation Well C4
Infiltration Rate, AF/k'day
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
Depth to Water, Feet

FIG.

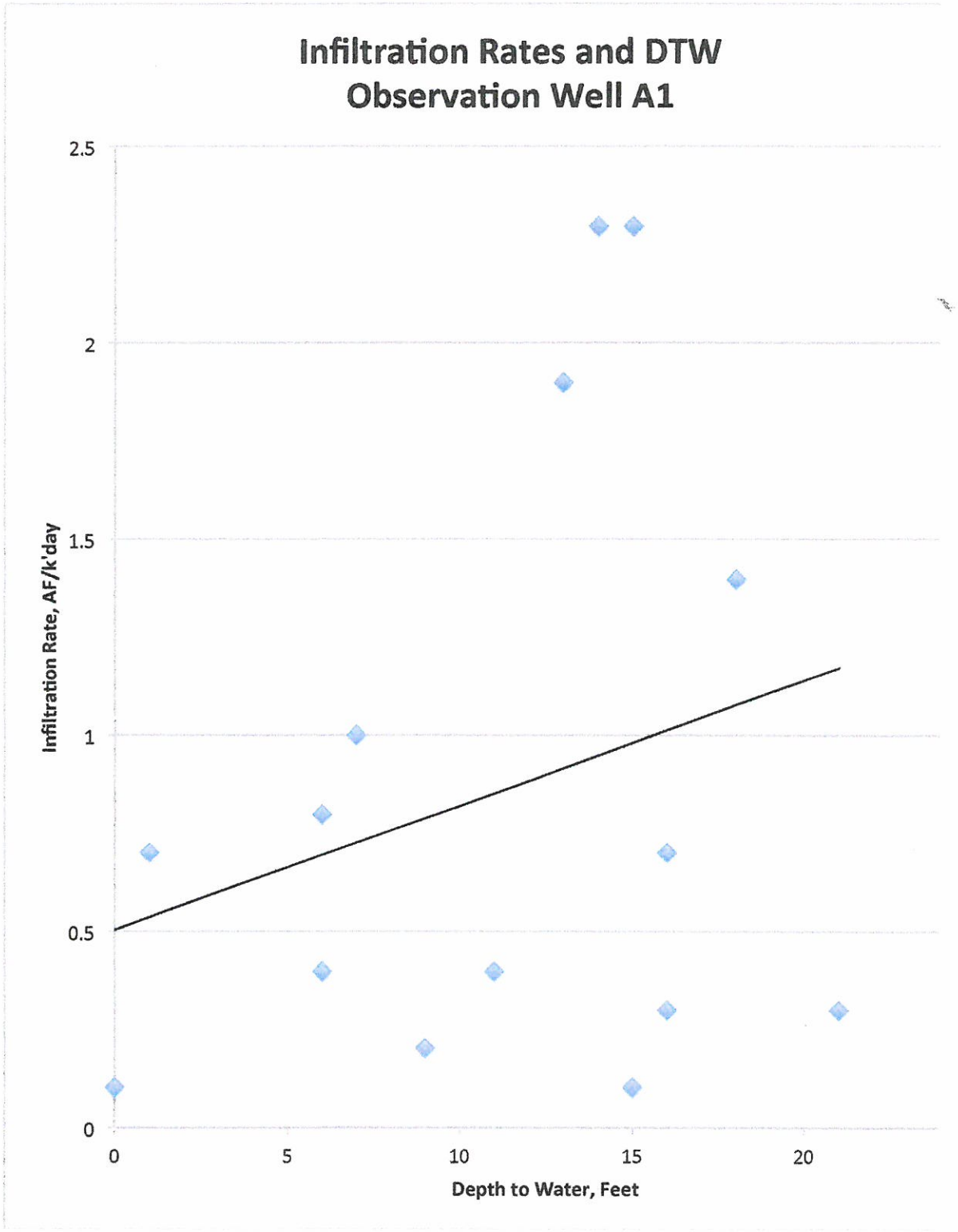

Infiltration Rates and DTW
Observation Well A1
2.5
2
1.5
1
0.5
0
Infiltration Rate, AF/k'day
0
5
10
15
20
Depth to Water, Feet

FIG. 7c

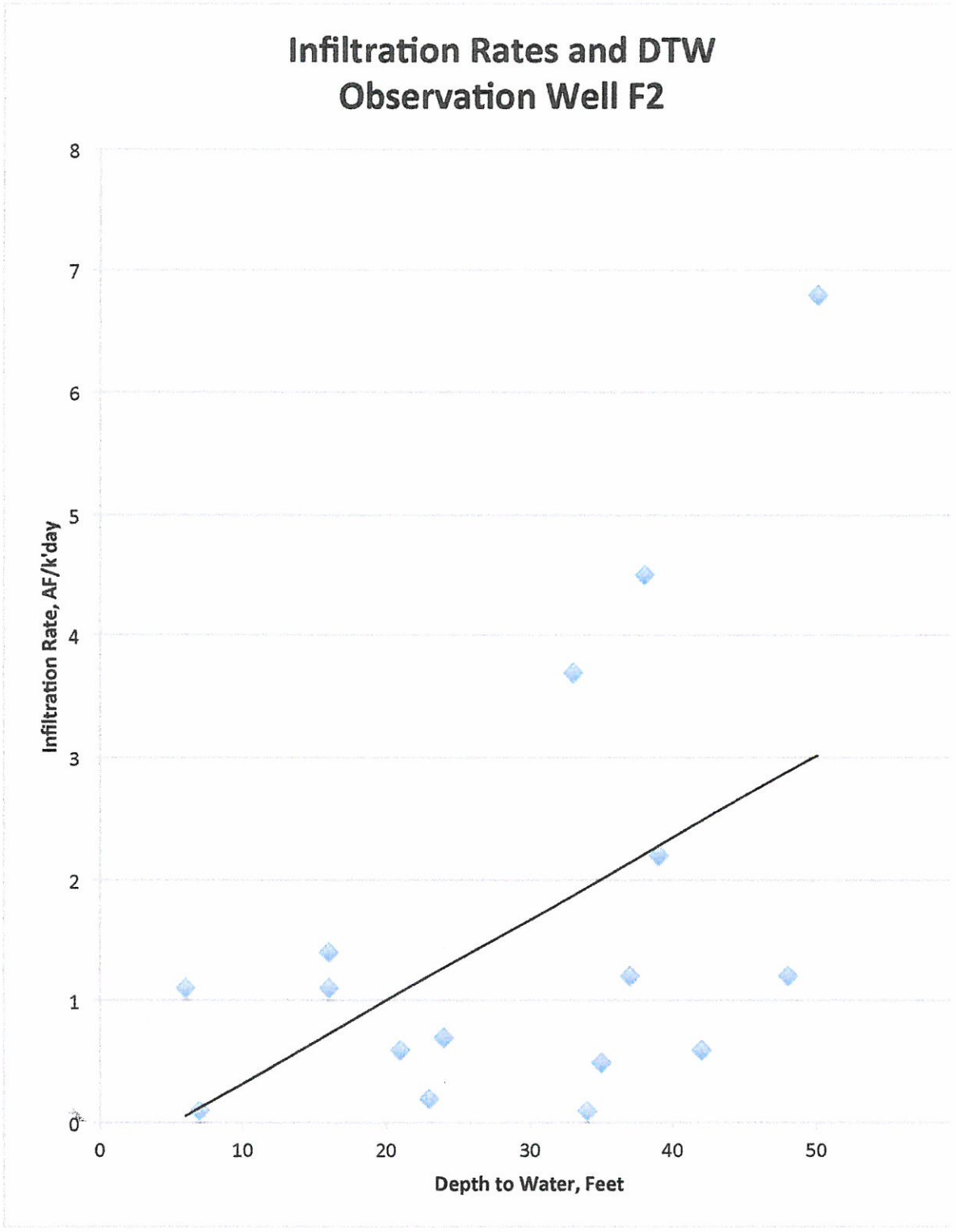

Infiltration Rates and DTW
Observation Well F2
Infiltration Rate, AF/k'day
Depth to Water, Feet
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50

FIG.

respectively. J1 was excluded because depth to water was typically between 30 and 60 feet, probably too great for hydraulic continuity. Trend lines are from the Excel tool bar. Rates tend to fit the theory that infiltration rates increase with increases in depth to water. However, these figures don't show where connectivity begins or ends because of too many complicating factors. For example, storage increases occur from groundwater flow and riverbed percolation; those couldn't be separated. Large flows can occur when water tables are any almost any depth; a high infiltration rate with large depth to water might just be a timing issue. Similarly, a low rate with large depth to water might just result from lack of river flow.

Conclusion

Data and analysis were inadequate to make reasonable estimates of where or when hydraulic connection occurs between surface and groundwater as it affects riverbed percolation rates.

RECAP OF CONCLUSIONS

Set One Hydrographs

- Annual hydrographs generally show similar changes at each observation well, whether in pumping nodes or not.
- Changes in water tables give insights into relationships between surface and groundwater flow. For example, a decline in water table with river flow indicates groundwater flow exceeds recharge, a full basin meaning recharge is rejected, effects of water districts' pumping, or some combination of both.
- Hydrographs 1c, 1d, 1e, 1f, 1h, and 1i (years 2008, 2009, 2010, 2011, 2013, and 2014 respectively) have supplemental, more frequent well readings. These show how quickly water tables rise in response to river flow.
- Water districts' pumping doesn't seem to have a consistent effect when comparing water level changes between years. For example, comparing 1f (2011) and 1i (2014) during Jul-Oct, C4 went down about 20' each time, yet there was 1,500 AF of river flow and 420 AF of pumping in 2011 and no river flow with 270 AF pumping in 2014.
- There are also inconsistencies lacking explanations, such as in Fig. 1i for Mar-May

when C4 and F2 gain storage while A1 losses storage.

Set Two Hydrographs

- The hypothesized threshold effect is not supported by data from observation wells upstream, within, and downstream of the major fault zone. This is different than Entrix's conclusion and its finding of a "… disconnection in groundwater flow across the fault.". This is despite its qualification that, "The magnitude of impact of the disconnection on groundwater support to the downstream reaches (including the 'live stretch') cannot be assessed without considering the duration, rate, and total volume of downvalley groundwater discharge." p. 4-2.
- Absence of a threshold effect is, however, consistent with Entrix's observations about flow in the 'live reach', based on observation well 3N23W5B1 in Casitas Springs,
- "During some years, both wells experience low levels (e.g., 1961, 1977, 1990, 1991), which may reflect natural climatic conditions, the threshold-response relationship for groundwater flow across the Santa Ana/Arroyo Parida Fault, and similar groundwater use patterns. Each of the four years with low levels in both wells were the second of two relatively dry years in a row. Some years have low levels only in the downstream well, and these are not years following a low level in the upstream wells (e.g., 1949, 1951-51, 1957, 1972, 1986, 1993, and 1994). This suggests that local influences in the vicinity of the downstream well might be the controlling factor in these years, not downvalley groundwater contributions." p. 4-6.
- The two major faults (Arroyo Parida Santa Ana and Villanova) appear to reduce water table fluctuations in proportion to the distance between well and fault. However, shapes of the hydrographs appear not to be affected. In other words, hydrographs remain parallel but for wells closer to major faults, fluctuations are damped.

- No discernable effects were seen from the smaller faults that cross the river or from those mapped east of the river in Mira Monte and Oak View.

Limitations and Assumptions

- In view of the foregoing limitations and assumptions, patterns and relationships between key elements are more important than numbers.

Set Three Hydrogrpaphs

- Groundwater flow is usually lower with higher water tables. The basin is full when it is at 90-95% of capacity. Higher water tables result in smaller amounts of recharge. This can also be seen in Figure 6, 'Depth to Water and Infiltration Rates'. Water districts' pumping is usually between 1/3 and 1/2 of groundwater flow.
- As noted in Limitations and Assumptions, calculated groundwater flows are assumed to ride on top of variable 'base' flow from Matilija Canyon. Unusual conditions in March 2016 made it conducive to estimate this base flow. The water table was rising with essentially zero flow at VRNMO so the storage increase came not from infiltration but base flow. Water table data were available from MOWD well 4 and VRWD well 2, which are very close to B1 and C4, respectively. The level came up 9' at well 4 during March, which works out to a flow of 380 AF/month or 6.2 cfs using the storage coefficient for B1. Similarly, the level came up 5.6' at well 2 during the same period, for a flow of 207 Af/month or 3.4 cfs.

Water Level Changes in Pumping and Non-pumping Nodes

- Overall, data are inconsistent. The only indication of a pattern is non-pumping nodes having larger Change Coefficients during drier years. One interpretation suggested by the second quote from Entrix, on page 1 above, is that natural hydrologic variations are large enough such that effects of pumping are masked.

Storage Declines in Pumping and Non-pumping Nodes

- The effect of water districts' pumping on aquifer storage declines varied between 24% and 41% with no apparent trend related to water table depth. The only exception was 2007 when it was 60%.

Riverbed Infiltration Rates

- The foregoing comparison suggests both methods give reasonable estimates for relatively short-lived high-flow conditions and for moderately high infiltration rates. However, the river flow method can only be used when river flow infiltrates within a known length of river. In that situation, it is the more accurate method because it doesn't have the difficulties mentioned above and results based on CMWD surface flow data were confirmed by MOWD's data.

Riverbed – Water Table Connection

- The foregoing comparison suggests both methods give reasonable estimates for relatively short-lived high-flow conditions and for moderately high infiltration rates. However, the river flow method can only be used when river flow infiltrates within a known length of river. In that situation, it is the more accurate method because it doesn't have the difficulties mentioned above and results based on CMWD surface flow data were confirmed by MOWD's data.

DATA NEEDS

A significant refinement in understanding interactions between surface and groundwater would be possible with following data:

- Groundwater flow at the mouth of Matilija canyon.
- Accurate riverbed infiltration rates between VRNMO and ½ mile south of the Santa Ana Blvd bridge.
- Accurate river flow immediately upstream of its confluence with San Antonio Creek or at Santa Ana Blvd. bridge
- Groundwater flow upstream of the San Antonio Creek - Ventura River confluence.
- Continuous recordings of depths to water data at the five key monitoring wells.

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