Robert H. Brumfield, Esq. (SBN 114467)
bob@brumfieldlawgroup.com
LAW OFFICES OF ROBERT H. BRUMFIELD
A Professional Corporation
1810 Westwind Drive, Suite 100
Bakersfield, CA 93301
Telephone: (661) 316-3010
Facsimile: (661) 885-6090

Attorneys for Johnny Zamrzla, Pamella Zamrzla, Johnny Lee Zamrzla and Jeanette Zamrzla (collectively "Zamrzla's")

SUPERIOR COURT OF CALIFORNIA

COUNTY OF LOS ANGELES – CENTRAL DISTRICT

Coordinated Proceeding, Special Title (Rule 1550(b)) ANTELOPE VALLEY GROUNDWATER CASES.	Judicial Council Coordination Proceeding No. 4408 LASC Case No. BC 32501 Santa Clara Court Case No. 1-05-CV-049053 Assigned to the Hon. Jack Komar, Judge of the Santa Clara County Superior Court **LIST OF EXHIBITS RE OPPOSITION BY THE ZAMRZLA'S TO THE WATERMASTER'S MOTION FOR MONETARY, DECLARATORY AND INJUNCTIVE RELIEF AGAINST ZAMRZLA'S** Date: November 12, 2021 Time: 9:00 a.m. Dept.: By Court call

COMES NOW the Zamrzla's, individually and jointly, and and submits their exhibit list as follows:

A. Letter from attorney Craig A. Parton regarding pumping of groundwater from the Antelope Valley Adjudicated Basin, dated June 9, 2018.

B. Emails to and from Craig A. Parton regarding Mr. Parton's June 9, 2018, letter, sent July 24, 2018.

C. Follow up email to and from Craig A. Parton regarding Mr. Parton's June 9, 2018, letter, sent August 6, 2018.

D. Email from Robert H. Brumfield to Craig Parton in Response to Request List of Information, sent October 26, 2018.

E. Letter from Patricia Rose regarding the Zamrzla's not being in compliance with the Antelope Valley Adjudication Meter Compliance program and Annual Reporting, dated November 21, 2018.

F. Copy of Johnny Zamrzla's invoice form Antelope Valley Watermaster, dated January 22, 2019.

G. Email from Robert H. Brumfield to Craig A. Parton regarding Johnny Zamrzla's Antelope Valley Watermaster invoice dated January 22, 2019, sent on February 4, 2019.

H. Responding email from Craig Parton to Robert H. Brumfield regarding the Antelope Valley Watermaster invoice, sent on February 13, 2019.

I. Antelope Valley Watermaster A/R Aging Summary dated August 31, 2021.

J. Email from Robert H. Brumfield to Craig A. Parton regarding further information provided by Zamrzla's about water usage, sent May 16, 2019.

K. Letter from Craig A. Parton sent via Certified Mail regarding Final Notice – Compliance with Metering Requirements, dated July 12, 2019.

L. Email from Craig A. Parton to Robert H. Brumfield regarding assessments payments by Zamrzla's, sent August 20, 2019.

M. Email from Robert H. Brumfield to Craig A. Parton regarding the 2018 Edison billing, sent October 24, 2019.

N. Email from Robert H. Brumfield to Craig A. Parton regarding the impact of the zero water production by Zamrzla "farm well" in 2018, sent November 6, 2019.

O. Email from Robert H. Brumfield to Craig A. Parton requesting Zamrzla's invoice be withdrawn in writing and removed from the books of the Watermaster as a receivable, sent July 22, 2020.

P. Zamrzla Assessment dated September 23, 2020.

Dated: November 3, 2021

LAW OFFICES OF ROBERT H. BRUMFIELD,
A Professional Corporation

By: ______________________________
Robert H. Brumfield, III
Attorney for Johnny Zamrzla, Pamella Zamrzla, Johnny Lee Zamrzla and Jeanette Zamrzla

EXHIBIT "A"

ANTELOPE VALLEY WATERMASTER
EST. 2016

June 09, 2018

RECEIVED
JUL 16 2018

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

Johnny Zamrzla
48910 80th St. West
Lancaster, CA 93536

Ref: APN: 3220-006-026

Re: **PUMPING OF GROUNDWATER FROM THE ANTELOPE VALLEY ADJUDICATIED BASIN**

Dear Mr. Zamrzla,

This office serves as staff to the Antelope Valley Watermaster. The Watermaster was created by the Los Angeles Superior Court and charged with assisting the Court in administering the terms of a Judgment and Physical Solution dated December 23, 2015 (hereinafter the "Judgment") relating to the Antelope Valley Adjudicated Basin. A copy of the Judgment can be found at www.avwatermaster.net under the "Resources" tab. The Judgment spells out in detail all the rights to groundwater production in the Antelope Valley Adjudicated Basin. Any groundwater pumping outside of an identified right to do so pursuant to the terms specified in the Judgment is strictly prohibited.

It is our understanding that you may be pumping groundwater from the Antelope Valley Adjudicated Basin. If you do not have a right to do so under the terms of the Judgment the Watermaster is required by the Court to stop all unauthorized pumping. This is our notice that you immediately comply with Section 20.9 of the Judgment. That Section of the Judgment provides a process for non-parties to intervene in the Judgment to become a party and to then seek the right to produce groundwater from the Adjudicated Basin.

Intervening to become a party to the Judgment actually has a number of potential advantages including having access to replacement water and the right to benefit from groundwater transfers and other privileges under the Judgment. In addition, by intervening in the Judgment you have the potential to obtain a legally recognized right to produce groundwater from the Adjudicated Basin thus directly affecting the value of your real property from which you may be currently extracting groundwater without the legal right to do so. We have been advised that the fact that you have no current legal right to extract groundwater from your property pursuant to the Judgment is a fact which you are likely obligated to disclose to potential purchasers or lenders interested in your property.

If you intervene in the Judgment and obtain a right to produce groundwater from the Adjudicated Basin, you may be able to acquire transfer water or will be required to pay replacement water costs for your groundwater production. If you continue to produce groundwater without intervening in the Judgment, we will ask the Court that you be found to be responsible to pay those replacement water costs for all past production, that you be prevented from further producing groundwater from your property and will also seek to recover all attorney's fees and other direct and indirect costs incurred in being required to engage in this legal process.

In short, if I am required to bring a motion before the court to determine your right to produce groundwater from the Adjudicated Basin, we may seek to halt your production of groundwater entirely and/or may seek imposition of Watermaster assessment costs on you for all past production in violation of the Judgment, as well as all legal and other costs incurred to obtain that order from the Court.

Please contact Watermaster Administrative offices at (661)234-8233, or PO Box 3025, Quartz Hill, CA. 93586 within 10 days, so that we can explain your options and address your groundwater production in the Adjudicated Basin.

If we do not receive a written response from you within 30 days from the date of this letter, the Watermaster will have no other choice but to proceed as discussed above and will seek to halt your groundwater production by bringing a motion before the Los Angeles Superior Court and seek recovery of our fees and associated costs for being forced to do so.

Thank you in advance for your cooperation and we look forward to working with you to obtain compliance with the judgement so that no Court action will be necessary.

Very truly yours,

Craig A. Parton

Craig Parton, Watermaster General Counsel
Price, Postal & Parma

cc: Watermaster Board of Directors
Watermaster Engineer

EXHIBIT "B"

From: Craig A. Parton <Cparton@ppplaw.com>
Sent: Tuesday, July 24, 2018 2:49 PM
To: Bob Brumfield <bob@brumfield-haganlaw.com>
Cc: Betsy Wright <bwright@ppplaw.com>; Serena Rivera <serena@brumfield-haganlaw.com>
Subject: RE: June 9, 2018 Letter to Various Landowners re "Pumping of Groundwater from the Antelope Valley Adjudicated Basis"

Mr. Brumfield: Thanks for so informing us of your clients' interest in intervening.....Let me discuss it with the Watermaster Engineer and be in touch.....Craig Parton

PRICE, POSTEL & PARMA LLP

Craig A. Parton
Price Postel & Parma LLP
200 E Carrillo Street, Suite 400
Santa Barbara, CA 93101
T: 805.962.0011 (Main);
T: 805.882-9822 (Direct)
F: 805.965.3978
E: cap@ppplaw.com
Website: http://ppplaw.com

From: Bob Brumfield [mailto:bob@brumfield-haganlaw.com]
Sent: Tuesday, July 24, 2018 2:41 PM
To: Craig A. Parton
Cc: Betsy Wright; Serena Rivera
Subject: June 9, 2018 Letter to Various Landowners re "Pumping of Groundwater from the Antelope Valley Adjudicated Basis"

Dear Mr. Parton:

Please be advised that my office represents 5 recipients of your June 9, 2018 letter sent to landowners in the Adjudicated Basin, which letter was received on either July 16, 18 or 19, 2018, as the case may be.

The 5 recipients that we represent are as follows:

1. Charles Tapia.

2. Mark Ritter.
3. Olin Derrick.
4. Johnny Zamrzla.
5. Johnny Lee Zamrzla.

As noted in your letter, I reviewed Section 20.9 of the Judgment and generally refreshed my memory of the Judgment and its terms.

Each of my clients would like to pursue intervening in the Judgment by way of stipulation with your client, the Watermaster.

Would your client be willing to so agree? And, if so, is there a draft stipulation you could send me to review?

Thank you, and we look forward to hearing from you. If you would prefer a call, just let me know.

Very Truly Yours,

BH
Brumfield & Hagan LLP

Robert H. Brumfield, III
2031 F Street
Bakersfield, CA 93301
-and-
325 Old Mammoth Road, B4
P.O. Box 146
Mammoth Lakes, CA 93546

Tele (661) 215-4980 | Fax (661) 215-4989
www.Brumfield-HaganLaw.com

EXHIBIT "C"

From: Craig A. Parton <Cparton@ppplaw.com>
Sent: Monday, August 6, 2018 5:30 PM
To: Bob Brumfield <bob@brumfield-haganlaw.com>
Cc: Betsy Wright <bwright@ppplaw.com>; Serena Rivera <serena@brumfield-haganlaw.com>
Subject: RE: June 9, 2018 Letter to Various Landowners re "Pumping of Groundwater from the Antelope Valley Adjudicated Basis"

Intend to respond fairly shortly.....Have not forgotten about you! Craig Parton

PRICE, POSTEL & PARMA LLP

Craig A. Parton
Price Postel & Parma LLP
200 E Carrillo Street, Suite 400
Santa Barbara, CA 93101
T: 805.962.0011 (Main);
T: 805.882-9822 (Direct)
F: 805.965.3978
E: cap@ppplaw.com
Website: http://ppplaw.com

From: Bob Brumfield [mailto:bob@brumfield-haganlaw.com]
Sent: Monday, August 06, 2018 12:22 PM
To: Craig A. Parton
Cc: Betsy Wright; Serena Rivera
Subject: RE: June 9, 2018 Letter to Various Landowners re "Pumping of Groundwater from the Antelope Valley Adjudicated Basis"

Dear Mr. Parton:

I was just checking in to see where we are on this matter. Thank you.

Very Truly Yours,

BH
Brumfield & Hagan LLP

Robert H. Brumfield, III

2031 F Street
Bakersfield, CA 93301
-and-
325 Old Mammoth Road, B4
P.O. Box 146
Mammoth Lakes, CA 93546

Tele (661) 215-4980 | Fax (661) 215-4989
www.Brumfield-HaganLaw.com

EXHIBIT "D"

Robert H Brumfield

From: Bob Brumfield
Sent: Friday, October 26, 2018 1:55 PM
To: 'Craig A. Parton'
Cc: 'Phyllis Stanin (PStanin@toddgroundwater.com)'; 'Kate White (KWhite@toddgroundwater.com)'; Serena Rivera
Subject: Zamarzla - Response to Request List of Information from Brumfield clients
Attachments: Zamrzla - 80th St. Ranch #3220-006-026.pdf; Zamrzla - Two 75th St Parcels-3220-006-002 & 003.pdf; Johnny Lee Zamarzla Response to Request for Information.pdf; Johnny Lee Zamarzla Water Well Report.pdf

Craig,

Attached please find the information for Johnny and Pamella Zamarzla's properties and the information for Johnny Lee and Jeanette Zamarzla's property.

Johnny Lee also had recent information regarding his well, and I attach that also.

Thank you.

Very Truly Yours,

BH
Brumfield&Hagan LLP

Robert H. Brumfield, III
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Bakersfield, CA 93301
-and-
325 Old Mammoth Road, B4
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www.Brumfield-HaganLaw.com

Johnny and Pamella Zamrzla, Property Owners
48910 80th Street West
Lancaster, CA 93536

Contact: Johnny Zamrzla
Office # 661/273-1336
johnnyz@westpacroof.com

APN # 3220-006-026

Year purchased: **1970**

Total acreage of parcel: **40 acres**

Sellers not parties to judgment (N/A)
Sellers name: (N/A)
Acres leased to others: None
Dates leased to others: N/A
Production Rights in the Judgment? No

Number of residences/houses on parcel: **One (1)**
Number of occupants living in residences: **Two (2)**

Number of wells on parcel: **One (1)**

Well information:

Date Drilled: **Prior to 1960**
Retrofit/Overhaul 1985
Retrofit/Overhaul 2015

Depth: **600 ft**

Diameter: **8" Casing**

Screened interval **340 Solid/260 Perf**

Current Depth to water: **207 ft**

Documented water levels: **1965 @ 308' / 1986 @ 228' / 2007 @ 214' / 2013 @ 207.1'**

Pumping capacity: **323 GPM**

Meter information N/A

Contact: Johnny Zamrzla
Office # 661/273-1336
johnnyz@westpacroof.com

APN # 3220-006-026

HISTORY OF IRRIGATION

FARMING:

Approx Dates	Acres	Method	Crop
1940's – 1970's	39 acres	Flood Irrigation	Alfalfa
1970's - 1990's	35 acres	Flood Irrigation	Alfalfa
1990's – 2000	20 acres	Sprinkler	Grain Hay

PASTURE IRRIGATION:

2000 – 2010 (approx)	10 acres	Wheel Line Sprinklers	Pasture/Rye Grass
2010 – Present	5 acres	Wheel Line Sprinklers	Permanent Pasture

RE: Crops grown, associated acreage, annual production, etc.

2016 – 2017 – 2018 No crop production.

HISTORY OF WATER USES OF WELL

1960's well was designed to produce 2000(+) GPM and 300 AF per year to farm 40 acres.*
1970 to 1990's - Domestic, Livestock and Irrigation (as noted above)

1990 to Present / 2016– 2017 -2018

Domestic, Livestock, Pasture, 150 Trees, Arena Watering**

The static water levels of our well have risen over 100 ft. since the 1960's.

Water Usage History reflects significant conservation of water and reductions in usage over the 48 years we have owned and lived on our property, i.e., eliminating flood irrigation, reducing acreage farmed, investing in wheel line sprinklers; and for nearly 20 years we have irrigated only our pasture, reducing that to currently 5 acres. *Current estimated water usage of 100 AF represents a 2/3's reduction.

**** We maintain and provide a performance arena that has been donated for use to local community groups and youth organizations including, California High School and Junior Rodeo Associations and AV Junior Rodeo.**

Future use of parcel: Same
Estimated annual water use in the future: 100 AF
Annual amounts of use of other water sources: N/A

Johnny and Pamella Zamrzla, Property Owners
48910 80th Street West
Lancaster, CA 93536

Contact: Johnny Zamrzla
Office # 661/273-1336
johnnyz@westpacroof.com

NOTE: These two parcels, #3220-006-002 & 003, adjoin the Zamrzla's 40 acre Home & Ranch on 8oth St. West (#3220-006-026)

	APN # 3220-006-002 75th St West & Ave D	APN # 3220-006-003 75th St. West & Ave D8
Year purchased:	**1986**	**1986**
Total acreage of parcel:	**39.2 acres**	**40 acres**

Sellers not parties to judgment (N/A)
Sellers name: (N/A)
Acres leased to others: None
Dates leased to others: N/A
Production Rights in the Judgment? No

Number of residences/houses on parcel:	**None**	**None**
Number of occupants living in residences:	**N/A**	**N/A**
Number of wells on parcel:	**None**	**One (1)**

Well information:

Date Drilled:	**Prior to 1965** **Retrofit/Overhaul 2006** **Retrofit/Overhaul 2016**

Depth:	**600 ft.**
Diameter:	**14"**
Current Depth to water:	**199 ft.**
Water level history:	**1966 @ 296 ft. / 1973 @ 295 ft. / 2013 @ 211 ft. / 2014 @ 200 ft.**
Pumping capacity:	**823 GPM**
Meter information	**N/A**

Contact: Johnny Zamrzla
Office # 661/273-1336
johnnyz@westpacroof.com

APN # 3220-006-002 APN # 3220-006-003

HISTORY OF IRRIGATION

Approx Dates	Acres	Crop
1950's – 1980's	75 acres	Various
1990 – 2010	75 acres	Various
2010 – 2015	75 acres	Alfalfa/Grain Hay/Sudan Grass
2016 & 2017	**75 acres**	**Alfalfa /Grain Hay/Sudan Grass**

Annual Water Production: Estimated 500 – 600 AF per year

Approx Crop Production: 6 to 7 cuttings per year

Method: Kwh/GPM

2018 No crop production.

NOTES:
- **> Investment in Wheel Line Irrigation System to conserve water.**
- **> Static water levels have continued to rise; from 295 ft. in 1973 to 199' currently.**

Future use of parcel: Same as 2016 -2017
Estimated annual water use in the future: 450 AF

Annual amounts of use of other water sources: N/A

September 18, 2018

John Lee Zamrzla and Jeanette Zamrzla

8165 West Avenue D8, Lancaster, CA 93536

661-492-5116 / jlee@westpacroof.com

Contact: Johnny Lee / Owner

APN numbers associated with Party's Property:

	3220-001-028	3220-001-027
Year purchased:	1999	2014
Sellers not parties to judgment		
Sellers name:	Lingaiah & Vijaya Janumpally	Nircisco Duldulao & Mr. Mrs. Bulacan
Total acreage of parcel:	10 acres	10 acres
Acres leased to others:	no	no
Dates leased to others:	N/A	N/A
No Lessees or Production rights on both property.		
No. of residences/houses on parcel:	1 house	Vacant land with NO Water
No. of occupants living in residences:	2 2016-2018	N/A
No. of Wells on parcel:	1	None

Well information

Date Drilled: 1965

Depth: 600'

Diameter: 14"

Screened interval: 322' Solid -280' perforated

Meter information: N/A

Depth to water: 212'

Pumping capacity: 150gpm

	3220-001-028	3220-001-027
Irrigated acreage in 2016, 2017, and 2018:	5 acres	10 acres
Crops grown in 2016, 2017, and 2018 and associated acreages of each:	5 acres pasture grass	10 acres Hay

Annual production in 2016, 2017, and 2018:

Method used to estimate production: Well efficiency testing by Southern California Edison & Power usage.

Water uses of well: domestic, livestock, irrigation and wheel lines on 10 acres of next door parcel.

Dates and annual amounts of use of other water sources: None None

Future use of parcel: Same

Estimated annual water use in the future: 200 AF

Sep 21 06 03:04p

p.1

QUADRUPLICATE
RETAIN THIS COPY R13W T8N Sec 24

WATER WELL DRILLERS REPORT

(Sections 7076, 7077, 7078, Water Code)

THE RESOURCES AGENCY OF CALIFORNIA

Do Not Fill In

№ 124610

State Well No.

Other Well No.

(1) OWNER:

Name Ben Sugimoto

Address 2842 West Ave. D

Lancaster, California

(2) LOCATION OF WELL:

County L.A. Owner's number, if any—

R.F.D. or Street No. 80th Street West

& Avenue "D-8"

Lancaster-Calif.

(3) TYPE OF WORK (check):

New well ☑ Deepening ☐ Reconditioning ☐ Abandon ☐

If abandonment, describe material and procedure in Item 11.

(4) PROPOSED USE (check):

Domestic ☐ Industrial ☐ Municipal ☐

Irrigation ☑ Test Well ☐ Other ☐

(5) EQUIPMENT:

Rotary ☑

Cable ☐

Dug Well ☐

(6) CASING INSTALLED:

SINGLE ☐ DOUBLE ☐

From ft. to ft. 11.34" Diam. 1/4" Gage of Well

If gravel packed: Diameter of bore 24" from ft. to ft.

Type and size of shoe or well ring

Size of gravel: P/G

Describe joint: Welded

(7) PERFORATIONS:

Type of perforator used: Machine Cut

Size of perforations in., length, by in.

From	ft. to	ft.	Perf. per row	Rows per ft.
	622	Solid		
	380	Perforations		

(8) CONSTRUCTION:

Was a surface sanitary seal provided? ☐ Yes ☐ No To what depth ft.

Were any strata sealed against pollution? ☐ Yes ☐ No If yes, note depth of strata

From ft. to ft.

Method of Sealing

(9) WATER LEVELS:

Depth at which water was first found ft.

Standing level before perforating ft.

Standing level after perforating 308' ft.

(10) WELL TESTS:

Was a pump test made? ☑ Yes ☐ No If yes, by whom? Drilling

Yield: gal./min. with ft. draw down after hrs.

Temperature of water Was a chemical analysis made? ☐ Yes ☐ No

Was electric log made of well? ☐ Yes ☐ No

(11) WELL LOG:

Total depth ft. Depth of completed well 602 ft.

Formation: Describe by color, character, size of material, and structure

From (ft.)	To (ft.)	Formation
0	23	Surface Soil
23	45	Sandy Clay
45	65	Sand Clay Streaks
65	105	Coarse Sand & Gravel
105	142	Sand Clay Streaks
142	156	Sand Gravel Clay Streaks
156	190	Rocks, Shale
190	220	Sand Gravel
220	260	Sand & Gravel
260	286	Sand & Gravel
286	310	Sand, Boulders
310	340	" "
340	370	Sand
370	390	Boulders & Sand
390	420	Sand & Gravel
420	545	Sand, Gravel, Clay Streaks
545	557	Rocks, Sand, Gravel
557	622	Sand, Clay, Streaks, Rocks

380' — 2 Sec. [illegible]

Work started 2-12-65 19 . Completed 3-26-65 19

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME Rotary Drilling Co
(Person, firm, or corporation) (Typed or printed)

Address 1211 West Ave "I"

Lancaster - Calif

[SIGNED]
Well Driller

License No. [illegible] Dated 19

ROTTMAN DRILLING CO.
46471 N. DIVISION STREET
LANCASTER, CA 93535
661-942-8125

JOB: Johnny Lee **DATE:** 3/29/2006
SWL: 221-feet 68 psi **AIRLINE:** 378-feet

		WATER LEVEL			GALLONS/MINUTE		
TIME	**OPERATION**	**LBS**	**P/L (feet)**	**INCHES**	**GALS**	**YIELD**	**REMARKS**
11:00	Development	60	239	8	725		Dirty
11:20	Development	60	239	15	1025	56.94	Dirty - Raised by itself
11:36	Development	60	239	15	1025	56.94	Dirty
11:50	Development	60	239	15	1025	56.94	Muddy
12:05	Development	60	239	15	1025	56.94	Muddy
12:15	Development	60	239	15	1025	56.94	Muddy
12:30	Development	60	239	15	1025	56.94	Clean
12:35	Increase	58	244	20	1200	62.17	Dirty
12:45	Development	58	244	20	1200	62.17	Muddy
13:00	Development	58	244	20	1200	62.17	Clean
1:15	Increase	54	253	30	1450		Muddy
1:35	Development	54	253	30	1450		Muddy
1:55	Development	54	253	30	1450		Clean
2:00	Increase	50	262	46	1850		Muddy
2:25	Development	50	262	46	1850		Clean
2:30	Increase	48	267	60	2100		Muddy
2:45	Development	48	267	60	2100		Clean
3:00	Development	48	267	60	2100		Clean
	SURGE 1						
3:10	Development	59	242	17	1125		Muddy
3:25	Development	59	242	17	1125		Clean
3:30	Increase	54	253	30	1450		Clean
3:45	Development	54	253	30	1450		Clean
3:47	Increase	52	258	46	1800		Clean
4:01	Development	52	258	46	1800		Clean
	SURGE 2						
4:06	Development	54	253	30	1450		Muddy
4:15	Increase	48	267		2100		Clean
4:30	Development	48	267		2100		
	SURGE 3						
4:36	Development	54	253	30	1450		A little dirty (1-minute)
4:50	Development	54	253	30	1450		Clean
5:00	Development	54	253	30	1450		Shut-down

ROTTMAN DRILLING CO.

46471 N. DIVISION STREET
LANCASTER, CA 93535
661-942-6125

JOB: Johnny Lee

SWL: 216-feet 70 psi

DATE: 3/30/2006

AIRLINE: 378-feet

		WATER LEVEL			GALLONS/MINUTE		
TIME	OPERATION	LBS	P/L (feet)	INCHES	GALS	YIELD	REMARKS
8:15	Start-up	70	216	34	1500		Dirty at Start-up
8:30	Constant Rate	56	249	34	1500		Clean
8:45	Constant Rate	53	256	34	1500		Clean
9:00	Constant Rate	53	256	34	1500		Clean
9:15	Constant Rate	53	256	34	1500		Clean
9:30	Constant Rate	53	256	34	1500		Clean
9:45	Constant Rate	53	256	34	1500		Clean
10:00	Constant Rate	53	256	34	1500		Clean
10:15	Constant Rate	53	256	34	1500		Clean
10:30	Constant Rate	53	256	34	1500		Clean
10:45	Constant Rate	53	256	34	1500		Clean
11:15	Constant Rate	53	256	34	1500		Clean
11:45	Constant Rate	53	256	34	1500		Clean
12:15	Constant Rate	53	256	34	1500		Clean
12:45	Constant Rate	53	256	34	1500		Clean
1:15	Constant Rate	53	256	34	1500		Clean
1:45	Constant Rate	53	256	34	1500		Clean

Vid-Pac — V llbore Video Report — welenco

Company	Rottman Drilling Company	Job Ticket	5849 Run No. 1
Address	46471 North Division	Well No	Johnny Lee
City	Lancaster State CA Zip 93535	Survey Date	March 13, 2006
Requested by	Danny P.O.	Well Owner	Johnny Lee
Copy To		Camera	CCV Color Flip Camera
Reason For Survey	General Inspection	Zero Datum	Top of Casing
Operator	Michael Miyahara Well Depth 600'	Video Vat	TO-3

Location Corner of DH and 80th W.

Casing I.D. at Surface 13.5" I.D. Reference Estimate from Video Build-Up Heavy, Increasing W/ Depth

SELECTED WELLBORE SNAPSHOTS

000'

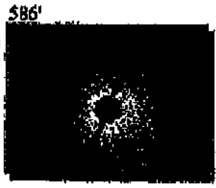
212' (See Other Side)

319' (See Other Side)

320' (See Other Side)

502' (See Other Side)

586'



TRUE DEPTHS	WELLBORE/CASING INFORMATION
	Downview Depths are 1 ' deeper than displayed
000'	Recording Starts - Zeroed on Sideview Lens at Top of Casing
212'	Downview of Static Water Level at 213'
	Poor Visibility from Static Water Level too 318'
319'	Downview of Clearer Water at 320'
320'	Sideview-Vertical Slots Open
502'	Sideview-Vertical Slots Open
586'	Downview of Fill at 587' End of Survey

welenco, Inc.
5201 Woodmere Dr.
Bakersfield, CA 93313

www.welenco.com
e-mail: welenco@welenco.com
Phone: 1-(800) 445-9914
Fax: 1-(661) 834-2550

Notes:

EXHIBIT "E"

ANTELOPE VALLEY
WATERMASTER
EST. 2016

November 21, 2018

Johnny Zamrzla
48910 80th St West
Lancaster, CA 93536

You are receiving this letter because you are not currently in compliance with the Antelope Valley Adjudication Meter Compliance program and Annual Reporting as required by the Judgment.

> Section 5.1.3.2 of the Judgment specifies that "should the Watermaster develop a reasonable belief that a Small Pumper Class Member household is using in excess of 3 acre-feet per Year, the Watermaster may cause to be installed a meter on such Small Pumper Class Member's well at the Small Pumper Class Member's expense."

The Watermaster has identified pre-qualified meter installers; you are required to work with one of these installers for meter documentation. They will assist you with selecting the proper meter and complying with these requirements. We have attached the meter requirements and list of Watermaster approved installers and tester for your convenience and use. Please confirm with us the name of that pre-qualified individual or firm you have selected by December 14th and inform us in writing by December 14th of the date certain (in no event later than February 28, 2019) for that individual or firm to perform and complete its services at your property. We will then be following up with both you and the individual or firm selected to confirm performance. Failure to confirm this information with us will be construed as failure to comply with the terms of the Judgment.

Also included in this packet are the 2016 and 2017 Production Reports. These annual reports need to be filled out and returned by December 14, 2018.

If you have any questions, please contact the Watermaster Administrative staff at (661) 234-8233 or by e-mail at prose@avwatermaster.net.

Sincerely,

Patricia Rose

AV Watermaster
Interim Secretary

cc: Watermaster Board
Watermaster Engineer

ANTELOPE VALLEY WATERMASTER

ANNUAL WATER PRODUCTION REPORT

2016 Calendar Year

Producer: ________________________________

Groundwater Production

State Well No.	*Well Designation*	*Production (Ac-Ft)*	*Method of Measurement*

Groundwater Production (cont.)

State Well No.	*Well Designation*	*Production (Ac-Ft)*	*Method of Measurement*

Imported Water Supply

Supplier	*Point of Delivery*	*Supply (Ac-Ft)*	*Method of Measurement*

Is this amount being reported to the state under Water Code § 5001 (required in Los Angeles County if total groundwater production exceeds 25 acre-feet)?
Yes ___ No ___

Total Groundwater Production (Ac-Ft) 0.0

Total Imported Water Supply (Ac-Ft) 0.0

Section 18.5.12 (Production Reports) of the Judgment states. "The Watermaster Engineer shall require each Producer, other than unmetered Small Pumper Class Members, to file an annual Production report with the Watermaster. Producers shall prepare the Production reports in a form prescribed by the rules and regulations. The Production reports shall state the total Production for the reporting Party, including Production per well, rounded off to the nearest tenth of an acre foot for each reporting period. The Production reports shall include such additional information and supporting documentation as the rules and regulations may reasonably require."

I certify to the best of my knowledge and belief that the foregoing information is true and correct

Individual ______________________ Company ______________________

Date ______________________ Company Agent ______________________

Date ______________________

ANNUAL WATER PRODUCTION REPORT
2017 CALENDAR YEAR
ANTELOPE VALLEY WATERMASTER

Submit by March 1, 2018

Please mail to: Antelope Valley Watermaster, P.O. Box 3025, Quartz Hill, California 93586 OR email to: info@avwatermaster.net

PRODUCER: ____________________
Contact Name: ____________________
Address: ____________________
Phone: ____________________ **email:** ____________________

TOTAL GROUNDWATER PRODUCED: ____________________ acre-feet in 2017

Please see tables on AVWM's website (www.avwatermaster.net) for Production Rights, 2017 Rampdown Production, 2017 Unused Federal Reserved Water Rights, 2017 Imported Water Return Flows, and available Carry Over Water.

1. Amount from **Production Right** from Native Safe Yield: ____________________ acre-feet
2. Amount from **Unused Federal Reserved Water Rights:** ____________________ acre-feet
3. Amount from **Rampdown Production for Exhibit 4 Parties:** (maximum can be 2017 Rampdown Production – Production Right): ____________________ acre-feet
4. Amount from **Imported Water Return Flows for Exhibit H Parties:** ____________________ acre-feet
5. Amount from **Carry Over Water:** ____________________ acre-feet
6. Amount from **Stored Water:** ____________________ acre-feet
   Supplier(s) and source(s) of each Stored Water source ____________________
   ____
7. Amount from **New Production:** ____________________ acre-feet
   Date New Production was approved: ____________________
8. Amount from **Other Rights to Produce:** ____________________ acre-feet
   Description of Other Rights to Produce: ____________________
9. Amount from **Transfers:** ____________________ acre-feet
   Suppliers and sources of each type of Transfer water used: ____________________
   ____
   ____
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   ____

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I certify to the best of my knowledge and belief that the information provided on this Production Form is true and correct.

Signature of Producer ____________________ Date ____________

Well Production Information for 2017

State Well Number	APN # Associated with the Production	Well Designation	Production (acre-feet)	Method of Measurement

Imported Water Use in 2017

Supplier	APN Numbers Associated with the Imported Water Use	Point of Delivery	Supply Used (acre-feet)	Method of Measurement

Antelope Valley Watermaster

Pre-Approved Meter Installers

S.A. Camp Pump & Drilling Co.
PO Box 82575
Bakersfield, CA 93380
(661) 399-2979
jreiland@sacamp.net

DRC Pump System, Inc
Jan Herrin/Red Houghton
44434 90th St. East
Lancaster, CA 93535
(661) 946-9444
drcpups@verizon.net

William Curry Consulting
William "West" Curry
33515 132nd Street East
Pearblossom, CA 93553
(661) 526-7873
w.curry.wc1@gmail.com

Layne Christensen Co
Robert Porter
1717 Park Avenue
Redlands, CA 92373
(760) 250-1375
Robert.porter@layne.com

Grewe Bryant Pump Service
Mike Grewe
PO Box 1378
Rosamond, CA 93560
(661) 256-2117
megpump@sbcglobal.net

Roadrunner Pump Service
Archie Floyd
PO Box 1052
Pearblossom, CA 93553
(661) 944-5073
roadrunnerpump@roadrunner.com

Bakersfield Well and Pump
Ruben Baltierra
7212 Fruitvale Avenue
Fruitvale, CA 93308
(661) 393-9661
rbaltierra@bwpumps.com

Cascade Drilling
Dale Emerson
1339 West 9th Street
Upland, CA 91786
(562)929-8176
demerson@cascade-env.com

Morrison Well
Anthony Morrison
42107 Quail Creek Dr
Lancaster, CA 93536
(661) 466-6031
morrisonwell @gmail.com

Pre-Approved Meter Installers

McCall's Meter Inc. Rick Bremer 1498 Mesa View St Hemet, CA 92543	(951) 654-3799 rick@mccallsmeters.com
Southern California Edison Rick Koch 10180 Telegraph Road Ventura, CA 93004	(805) 338-1398 rick.koch@sce.com
Layne Christensen Co Robert Porter 1717 Park Avenue Redlands, CA 92373	(760) 250-1375 Robert.porter@layne.com
S.A. Camp Pump & Drilling Co. PO Box 82575 Bakersfield, CA 93380	(661) 399-2979 jreiland@sacamp.net
Grewe Bryant Pump Service Mike Grewe PO Box 1378 Rosamond, CA 93560	(661) 256-2117 mgpump@sbcglobal.net

ANTELOPE VALLEY
WATERMASTER
EST. 2016

November 21, 2018

Johnny Zamrzla
8165 West Avenue D-8
Lancaster, CA 93536

You are receiving this letter because you are not currently in compliance with the Antelope Valley Adjudication Meter Compliance program and Annual Reporting as required by the Judgment.

> Section 5.1.3.2 of the Judgment specifies that "should the Watermaster develop a reasonable belief that a Small Pumper Class Member household is using in excess of 3 acre-feet per Year, the Watermaster may cause to be installed a meter on such Small Pumper Class Member's well at the Small Pumper Class Member's expense."

The Watermaster has identified pre-qualified meter installers; you are required to work with one of these installers for meter documentation. They will assist you with selecting the proper meter and complying with these requirements. We have attached the meter requirements and list of Watermaster approved installers and tester for your convenience and use. Please confirm with us the name of that pre-qualified individual or firm you have selected by December 14th and inform us in writing by December 14th of the date certain (in no event later than February 28, 2019) for that individual or firm to perform and complete its services at your property. We will then be following up with both you and the individual or firm selected to confirm performance. Failure to confirm this information with us will be construed as failure to comply with the terms of the Judgment.

Also included in this packet are the 2016 and 2017 Production Reports. These annual reports need to be filled out and returned by December 14, 2018.

If you have any questions, please contact the Watermaster Administrative staff at (661) 234-8233 or by e-mail at prose@avwatermaster.net.

Sincerely,

Patricia Rose

AV Watermaster
Interim Secretary

cc: Watermaster Board
Watermaster Engineer

ANTELOPE VALLEY WATERMASTER

ANNUAL WATER PRODUCTION REPORT

2016 Calendar Year

Producer:

Groundwater Production

State Well No.	*Well Designation*	*Production (Ac-Ft)*	*Method of Measurement*

Groundwater Production (cont.)

State Well No.	*Well Designation*	*Production (Ac-Ft)*	*Method of Measurement*

Imported Water Supply

Supplier	*Point of Delivery*	*Supply (Ac-Ft)*	*Method of Measurement*

Is this amount being reported to the state under Water Code § 5001 (required in Los Angeles County if total groundwater production exceeds 25 acre-feet)?
Yes___ No___

Total Groundwater Production (Ac-Ft) 0.0

Total Imported Water Supply (Ac-Ft) 0.0

Section 18.5.12 (Production Reports) of the Judgment states. "The Watermaster Engineer shall require each Producer, other than unmetered Small Pumper Class Members, to file an annual Production report with the Watermaster. Producers shall prepare the Production reports in a form prescribed by the rules and regulations. The Production reports shall state the total Production for the reporting Party, including Production per well, rounded off to the nearest tenth of an acre foot for each reporting period. The Production reports shall include such additional information and supporting documentation as the rules and regulations may reasonably require."

I certify to the best of my knowledge and belief that the foregoing information is true and correct

____________________ ____________________
Individual Company

____________________ ____________________
Date Company Agent

____
Date

8

ANNUAL WATER PRODUCTION REPORT
2017 CALENDAR YEAR
ANTELOPE VALLEY WATERMASTER

Submit by March 1, 2018

Please mail to: Antelope Valley Watermaster, P.O. Box 3025, Quartz Hill, California 93586 OR email to: info@avwatermaster.net.

PRODUCER: ______________________________
Contact Name: ______________________________
Address: ______________________________
Phone: ____________________ **email:** ____________________

TOTAL GROUNDWATER PRODUCED: ____________________ acre-feet in 2017

Please see tables on AVWM's website (www.avwatermaster.net) for Production Rights, 2017 Rampdown Production, 2017 Unused Federal Reserved Water Rights, 2017 Imported Water Return Flows, and available Carry Over Water.

1. Amount from **Production Right** from Native Safe Yield: ____________________ acre-feet
2. Amount from **Unused Federal Reserved Water Rights:** ____________________ acre-feet
3. Amount from **Rampdown Production for Exhibit 4 Parties:** (maximum can be 2017 Rampdown Production – Production Right): ____________________ acre-feet
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5. Amount from **Carry Over Water:** ____________________ acre-feet
6. Amount from **Stored Water:** ____________________ acre-feet
   Supplier(s) and source(s) of each Stored Water source ____________________
   ____
7. Amount from **New Production:** ____________________ acre-feet
   Date New Production was approved: ____________________
8. Amount from **Other Rights to Produce:** ____________________ acre-feet
   Description of Other Rights to Produce: ____________________
9. Amount from **Transfers:** ____________________ acre-feet
   Suppliers and sources of each type of Transfer water used: ____________________
   ____
   ____
   ____
   ____
   ____
   ____

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I certify to the best of my knowledge and belief that the information provided on this Production Form is true and correct.

Signature of Producer ______________________________ Date ____________

Well Production Information for 2017

State Well Number	APN # Associated with the Production	Well Designation	Production (acre-feet)	Method of Measurement

Imported Water Use in 2017

Supplier	APN Numbers Associated with the Imported Water Use	Point of Delivery	Supply Used (acre-feet)	Method of Measurement

Antelope Valley Watermaster

Pre-Approved Meter Installers

S.A. Camp Pump & Drilling Co.
PO Box 82575
Bakersfield, CA 93380
(661) 399-2979
jreiland@sacamp.net

DRC Pump System, Inc
Jan Herrin/Red Houghton
44434 90th St. East
Lancaster, CA 93535
(661) 946-9444
drcpups@verizon.net

William Curry Consulting
William "West" Curry
33515 132nd Street East
Pearblossom, CA 93553
(661) 526-7873
w.curry.wc1@gmail.com

Layne Christensen Co
Robert Porter
1717 Park Avenue
Redlands, CA 92373
(760) 250-1375
Robert.porter@layne.com

Grewe Bryant Pump Service
Mike Grewe
PO Box 1378
Rosamond, CA 93560
(661) 256-2117
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Roadrunner Pump Service
Archie Floyd
PO Box 1052
Pearblossom, CA 93553
(661) 944-5073
roadrunnerpump@roadrunner.com

Bakersfield Well and Pump
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Fruitvale, CA 93308
(661) 393-9661
rbaltierra@bwpumps.com

Cascade Drilling
Dale Emerson
1339 West 9th Street
Upland, CA 91786
(562)929-8176
demerson@cascade-env.com

Morrison Well
Anthony Morrison
42107 Quail Creek Dr
Lancaster, CA 93536
(661) 466-6031
morrisonwell @gmail.com

Pre-Approved Meter Installers

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Southern California Edison Rick Koch 10180 Telegraph Road Ventura, CA 93004	(805) 338-1398 rick.koch@sce.com
Layne Christensen Co Robert Porter 1717 Park Avenue Redlands, CA 92373	(760) 250-1375 Robert.porter@layne.com
S.A. Camp Pump & Drilling Co. PO Box 82575 Bakersfield, CA 93380	(661) 399-2979 jreiland@sacamp.net
Grewe Bryant Pump Service Mike Grewe PO Box 1378 Rosamond, CA 93560	(661) 256-2117 mgpump@sbcglobal.net

EXHIBIT "F"

Antelope Valley Watermaster
P.O. Box 3025
Quartz Hill, CA 93586
(661) 234-8233
www.avwatermaster.net

BILL TO
Johnny Zamrzla
c/o Robert Brumfield, III
2031 F Street
Bakersfield, CA 93301

INVOICE 1300CY18-4

DATE 01/22/2019

DUE DATE 02/21/2019

TYPE	DESCRIPTION	ACRE FT.	RATE	AMOUNT
FIXED	Administrative Assessments CY 2016 per Reported Production	650	1.00	650.00
FIXED	Administrative Assessments CY 2017 per Reported Production	650	5.00	3,250.00
FIXED	Administrative Assessments CY 2018 per Production Rights	650	5.00	3,250.00
2018 RWA	2018 Replacement Water Assessment (including credit of 9 acre feet for 3 wells)	641	415.00	266,015.00

Please include invoice number on check payment.

PLEASE NOTE:
Delinquent balances are assessed a 10% late fee.

TOTAL DUE **$273,165.00**

Per Resolution No. R-18-02 as passed by the Board of Directors of the Antelope Valley Watermaster at its meeting held January 24, 2018, in Palmdale, California

and

Judicial Council Coordination Proceeding No. 4408 Santa Clara Case No.: 1-05-CV-049053

PLEASE REMIT PAYMENT TO:
Antelope Valley Watermaster
P.O. Box 3025
Quartz Hill, CA 93586

EXHIBIT "G"

Robert H Brumfield

From:	Robert H Brumfield
Sent:	Monday, February 4, 2019 10:07 AM
To:	'Craig A. Parton'
Cc:	Angel Fitzpatrick; Patti Rose; Phyllis Stanin (PStanin@toddgroundwater.com); Kate White (KWhite@toddgroundwater.com); Serena Rivera
Subject:	Johnny Zamrzla and Johnny Lee Zamrzla Invoice
Attachments:	Johnny Zamrzla Invoice.pdf

Craig,

We received the attached invoice re the Zamrzla's. The amounts shown on this invoice are not correct as to the Zamrzla's actual usage which was less than 50 acre-feet for all of 2018 for each Johnny and Johnny Lee. The amounts shown on the data that we sent you were what my clients were hoping to be able to use on a going forward basis (as in 2019 and beyond) by agreement between them and the Watermaster.

My clients were looking at this as a going forward issue and have not used more than 50 acre-feet for any year for quite some time. The Zamrzla's also have ramped down their usage over the past few years.

Anyway, let me know when would be a good time to schedule a call.

PLEASE NOTE OUR NEW BAKERSFIELD ADDRESS AND TELEPHONE NUMBER EFFECTIVE JANUARY 1, 2019

Very Truly Yours,

Robert H. Brumfield, III
Law Offices of Robert H. Brumfield, PC
1810 Westwind Drive, Suite 100
Bakersfield, CA 93301
-and-
325 Old Mammoth Road, B4
P.O. Box 146
Mammoth Lakes, CA 93546

Tele (661) 316-3010 | Fax (661) 885-6090

www.brumfieldlawgroup.com

Antelope Valley Watermaster
P.O. Box 3025
Quartz Hill, CA 93586
(661) 234-8233
www.avwatermaster.net

BILL TO
Johnny Zamrzla
c/o Robert Brumfield, III
2031 F Street
Bakersfield, CA 93301

INVOICE 1300CY18-4

DATE 01/22/2019

DUE DATE 02/21/2019

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2018 RWA	2018 Replacement Water Assessment (including credit of 9 acre feet for 3 wells)	641	415.00	266,015.00

Please include invoice number on check payment.

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and

Judicial Council Coordination Proceeding No. 4408 Santa Clara Case No.: 1-05-CV-049053

PLEASE REMIT PAYMENT TO:
Antelope Valley Watermaster
P.O. Box 3025
Quartz Hill, CA 93586

EXHIBIT "H"

Robert H Brumfield

From:	Craig A. Parton <Cparton@ppplaw.com>
Sent:	Wednesday, February 13, 2019 11:38 AM
To:	Robert H Brumfield
Cc:	Angel Fitzpatrick; Patti Rose; Phyllis Stanin (PStanin@toddgroundwater.com); Kate White (KWhite@toddgroundwater.com); Serena Rivera
Subject:	RE: Johnny Zamrzla and Johnny Lee Zamrzla Invoice
Attachments:	Zamrzla - 80th St. Ranch #3220-006-026.pdf; Zamrzla - Two 75th St Parcels-3220-006-002 & 003.pdf; Johnny Lee Zamarzla Water Well Report.pdf; Johnny Lee Zamarzla Response to Request for Information.pdf; 2018 Water Production Report.pdf

Bob: Attached are the reports you originally supplied to us.....

If your clients believe the production numbers we are using for 2018 are incorrect, I think the best way to deal with that is to have them do two things: (1) pay now the uncontested portion of the invoice relating to Administrative Assessments for 2016 and 2017; and (2) have them complete the required Annual Water Production Report for Calendar Year 2018 and submit that information to the Watermaster for review right away (it is due March 1, 2019). I have attached a copy of that 2018 Production Report for your clients (available for download, by the way, from the Watermaster's website) so that the Zamrzlas can attest to the accuracy of the numbers they are supplying as to 2018.

I'd also very much appreciate an update as to the status of their compliance with the metering requirements. As I am sure you are aware, estimates of groundwater production derived from electrical records or other sources can have a significant error bar......Thank you in advance for your anticipated cooperation.....Craig

PRICE, POSTEL & PARMA LLP

Craig A. Parton
Price Postel & Parma LLP
200 E Carrillo Street, Suite 400
Santa Barbara, CA 93101
T: 805.962.0011 (Main);
T: 805.882-9822 (Direct)
F: 805.965.3978
E: cap@ppplaw.com
Website: http://ppplaw.com

From: Robert H Brumfield [mailto:bob@brumfieldlawgroup.com]
Sent: Monday, February 04, 2019 10:07 AM
To: Craig A. Parton
Cc: Angel Fitzpatrick; Patti Rose; Phyllis Stanin (PStanin@toddgroundwater.com); Kate White (KWhite@toddgroundwater.com); Serena Rivera
Subject: Johnny Zamrzla and Johnny Lee Zamrzla Invoice

Craig,

We received the attached invoice re the Zamrzla's. The amounts shown on this invoice are not correct as to the Zamrzla's actual usage which was less than 50 acre-feet for all of 2018 for each Johnny and Johnny Lee. The amounts shown on the data that we sent you were what my clients were hoping to be able to use on a going forward basis (as in 2019 and beyond) by agreement between them and the Watermaster.

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Very Truly Yours,

Robert H. Brumfield, III
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Bakersfield, CA 93301
-and-
325 Old Mammoth Road, B4
P.O. Box 146
Mammoth Lakes, CA 93546

Tele (661) 316-3010 | Fax (661) 885-6090

www.brumfieldlawgroup.com

EXHIBIT "I"

Antelope Valley Watermaster

A/R Aging Summary

As of August 31, 2021

	CURRENT	1 - 30	31 - 60	61 - 90	91 AND OVER	TOTAL
1100 Overlying Production Rights						$0.00
60th Street Association Water System				1,670.66	1,485.60	$3,156.26
Antelope Valley Joint Union High School District				29,009.18		$29,009.18
C. Louise R. Close Living Trust					28.76	$28.76
c/o George Brittner	34,755.46					$34,755.46
Calandri Water Company, LLC.		2,533.75				$2,533.75
eSolar Inc.; Sierra Sun Tower, LLC					94.32	$94.32
Gary Van Dam		2,298.20				$2,298.20
Gloria Terrazas					-5.00	$ -5.00
Granite Construction Company (Big Rock Facility)				0.40		$0.40
Granite Construction Company (Little Rock Sand and Gravel)					-104.05	$ -104.05
H & N Development Co. West Inc.				2,783.00	4,040.00	$6,823.00
High Desert Dairy LLC		9,356.15				$9,356.15
Irma Ann Carle Trust, Irma-Anne Carle, Trustee					-0.50	$ -0.50
James and Elizabeth Bridwell					11.00	$11.00
Leah Frankenberg					10.50	$10.50
Llano Del Rio Water Company					1,395.00	$1,395.00
Luis Hernandez					25.00	$25.00
Noel Pool					5.00	$5.00
Rudy Turk					-3.60	$ -3.60
Ruth C. Findley					12.40	$12.40
SGS Antelope Valley Development, LLC					1,636.19	$1,636.19
Sonrise Ranch, LLC c/o Gary Van Dam				1,655.00		$1,655.00
U.S. Borax Inc.					-2,284.25	$ -2,284.25
Total 1100 Overlying Production Rights	34,755.46	14,188.10		35,118.24	6,346.37	$90,408.17
1300 Small Pumpers						$0.00
Carlos and Paola Diaz Hernandez		4,925.00				$4,925.00
Charlie Tapia					180,917.06	$180,917.06
Johnny Zamrzla					273,165.00	$273,165.00
Total 1300 Small Pumpers		4,925.00			454,082.06	$459,007.06
1500 State of California						$0.00
California Department of Corrections and Rehabilitation					15.00	$15.00
California Department of Military					33.00	$33.00
California Department of Transportation					1,377.57	$1,377.57
California Department of Water Resources					520.00	$520.00
California State Lands Commission					20.64	$20.64
Total 1500 State of California					1,966.21	$1,966.21
1650 Phelan Pinon Hills						$0.00
Phelan Pinon Hills CSD				832.86		$832.86
Total 1650 Phelan Pinon Hills				832.86		$832.86
1675 Supporting Landowners (Formerly 2000)						$0.00

Antelope Valley Watermaster

A/R Aging Summary

As of August 31, 2021

	CURRENT	1 - 30	31 - 60	61 - 90	91 AND OVER	TOTAL
Reesdale Mutual Water Company		3,530.29				$3,530.29
SCI California Funeral Services, Inc. dba Joshua Memorial Park					11,354.00	$11,354.00
Total 1675 Supporting Landowners (Formerly 2000)		3,530.29			11,354.00	$14,884.29
1700 Federal						$0.00
412 CE/CENP -- FIS2AA				6,738.65	18,680.30	$25,418.95
Total 1700 Federal				6,738.65	18,680.30	$25,418.95
1950 New Production						$0.00
40th Street Mutual Water Company					-6,382.86	$ -6,382.86
Espiridion and Yvonne Perez	379.48					$379.48
Joshua Acres Mutual Water Company	8,710.80				18,368.00	$27,078.80
Larry Davison	491.00					$491.00
Mettler Valley Mutual Water Company	45,948.25				118,188.41	$164,136.66
Piute Mutual Water Company					19,008.32	$19,008.32
Total 1950 New Production	55,529.53				149,181.87	$204,711.40
TOTAL	$90,284.99	$22,643.39	$0.00	$42,689.75	$641,610.81	$797,228.94

EXHIBIT "J"

From: Robert H Brumfield
Sent: Thursday, May 16, 2019 3:10 PM
To: 'Craig A. Parton' <Cparton@ppplaw.com>
Cc: 'Angel Fitzpatrick' <afitzpatrick@avek.org>; 'Patti Rose' <prose@avek.org>; 'Phyllis Stanin (PStanin@toddgroundwater.com)' <PStanin@toddgroundwater.com>; 'Kate White (KWhite@toddgroundwater.com)' <KWhite@toddgroundwater.com>; Serena Rivera <serena@brumfieldlawgroup.com>
Subject: RE: Johnny Zamrzla and Johnny Lee Zamrzla

Good afternoon, Craig. After the below email, I did receive further information from both Johnny Lee Zamrzla and Johnny Zamrzla. I received this information in late March but it appears as though I did not forward it to you for consideration by the board. I apologize for my inadvertent delay in this regard.

In any event, the attached information breaks down as follows:

1. The attached information for 75th St. solely concerns Johnny and Pamella Zamrzla.
2. The attached information as to 80th St. solely concerns Johnny and Pamella Zamrzla.
3. The attached information as to D8 Well 80th St. solely concerns Johnny Lee and Jeanette Zamrzla.

Items 1 and 2 as to Johnny and Pamella is separate from item 3 which relates solely to Johnny Lee and Jeanette. In other words, items 1 and 2 should have its own invoice if any and item 3 should have its own invoice if any.

As I explained before, the information initially submitted by the Zamrzla's concerned the amount of water they wished to use, not actual usage. As shown on the attachments, they have now gone back and calculated the amount actually produced for the previous two or three years, as the case may be. They have also included a line item for their desired use in 2019.

My clients are requesting that the board reviewed this information at their next meeting and revise the amount that was billed to the Zamrzla's if any is owed.

Please let me know what further information you require in this matter. Thank you.

Very Truly Yours,

Robert H. Brumfield, III
Law Offices of Robert H. Brumfield, PC
1810 Westwind Drive, Suite 100
Bakersfield, CA 93301
-and-
325 Old Mammoth Road, B4
P.O. Box 146

Mammoth Lakes, CA 93546
Tele (661) 316-3010 | Fax (661) 885-6090

www.brumfieldlawgroup.com

March 18, 2019

Johnny and Pamella Zamrzla, Property Owners
48910 80th Street West
Lancaster, CA 93536

Contact: Johnny Zamrzla
Office # 661/273-1336
johnnyz@westpacroof.com

NOTE: These two parcels, #3220-006-002 & 003, adjoin the Zamrzla's 40 acre Home & Ranch on 8oth St. West (#3220-006-026)

		APN # 3220-006-002	APN # 3220-006-003
		75th St West & Ave D	75th St. West & Ave D8
Total combined acreage:	**79 acres**	**39.2 acres**	**40 acres**

Well information:

1966 Standing water level: 296'

2014 Standing Water level: 211'

Currently listed as small pumper

Well design in 1966: Flood irrigate 80 acres

Current design: Wheel line/ sprinkle 80 acres

Calculations per Edison Efficiency Test Completed February 2014

2016 Production 478 Acre Feet

2017 Production 349.20 Acre Feet

2018 Production 00 Acre Feet

Estimated annual water use in the future: 256 Acre Feet

March 18, 2019

Johnny and Pamella Zamrzla, Property Owners
48910 80th Street West
Lancaster, CA 93536

Contact: Johnny Zamrzla
Office # 661/273-1336
johnnyz@westpacroof.com

APN number associated with party's Property: # 3220-006-026

Total acreage of parcel: 40 acres

<u>Well information:</u>

1965 Standing water level: 308'

2018 Standing water level: 207'

Currently listed as small pumper

Well design in 1965: Flood irrigate 40 acres

Current design: Wheel line/sprinkle 5 acres and domestic use.

Calculations per Edison Efficiency Test completed September 2018

2017 Production 47.7 Acre Feet

2018 Production 75.29 Acre Feet

Estimated annual water use in the future: 100 AF

March 18, 2019

John Lee Zamrzla and Jeanette Zamrzla

8165 West Avenue D8, Lancaster, CA 93536

661-492-5116 / jlee@westpacroof.com

Contact: Johnny Lee / Owner

APN numbers associated with Party's Property: #3220-001-028 & #3220-001-027

Total combined acreage 20 acres

Well information:

1965 standing water level: 308'

2018 standing water level 212'

Currently listed as small pumper

Well design in 1965: Flood irrigate 80 acres

Current design: Wheel lines/ sprinkle 15 acres and domestic use.

Calculations per Edison Efficiency Test completed September 2018

Total Acreage		**20 ac**
2017	**Production:**	**53.29 Acre Feet**
2018	**Production:**	**18.46 Acre Feet**

Estimated annual water use in the future: 200 AF

EXHIBIT “K”

Todd A. Amspoker
Susan M. Basham
Kristen M. R. Blabey
Shannon D. Boyd
Timothy M. Cary
Melissa J. Fassett
Ian M. Fisher
Arthur R. Gaudi
Cameron Goodman
Christopher E. Haskell
James H. Hurley, Jr.
Eric P. Hvolbøll
Drew Maley
Mark S. Manion
Steven K. McGuire

PRICE, POSTEL & PARMA LLP
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Timothy E. Metzinger
Shereef Moharram
Craig A. Parton
Kenneth J. Pontifex
Douglas D. Rossi
Peter D. Slaughter
David W. Van Horne
C.E. Chip Wullbrandt
Ryan D. Zick

CAMERON PARK OFFICE
3330 Cameron Park Drive, Suite 100
Cameron Park, CA 95682-7652
Ph (805) 962-0011
Fax (805) 965-3978

Our File Number:
23641-1

June 12, 2019

CERTIFIED MAIL,
RETURN RECEIPT REQUESTED
Johnny Zamrzla
48910 80th Street West
Lancaster, CA 93536

Re: FINAL NOTICE – Compliance With Metering Requirements

Dear Landowner:

Your failure to comply with the meter installation and/or documentation requirements is a violation of the Judgment and subject to a Watermaster action for injunctive relief, including recovery of costs and attorney's fees. Please take notice that if you have not complied with your obligations under the Judgment as of the date of this letter, the Watermaster will pursue all available legal remedies to compel your compliance with the Judgment, including recovery of costs and attorney's fees. If you have any questions, please contact the Watermaster Administrator at (661) 234-8233.

Sincerely,

Craig A. Parton
Craig A. Parton
for PRICE, POSTEL & PARMA LLP

Cc: Phyllis Stanin, Watermaster Engineer
Watermaster Staff

EXHIBIT "L"

Robert H Brumfield

From: Craig A. Parton <Cparton@ppplaw.com>
Sent: Tuesday, August 20, 2019 4:37 PM
To: Robert H Brumfield
Cc: Serena Rivera; Patti Rose; Phyllis Stanin (PStanin@toddgroundwater.com); Kate White (KWhite@toddgroundwater.com)
Subject: Zamrzla Matter

Bob: It is time for us to address assessment payments by your clients Johnny Zamrzla Sr. (3 parcels and 2 wells) and for Johnny Lee Zamrzla Jr. (2 parcels and 1 well). To my knowledge, none of the 3 Zamrzla wells are metered. My understanding is that they have not paid any replacement water assessments for 2018.

First I think it would be helpful if you and I could agree as to the numbers at issue.

Watermaster staff and the Watermaster Engineer provided some very helpful information to me and here is the current "accounting" status of the Zamrzla matter:

1. The Watermaster originally invoiced Johnny Zamrzla Sr. for 2018 RWA in the amount of $269,750.00, based on production for that year of 650 AF at a cost of $415 AF.
2. After we sent the invoice to Mr. Zamrzla Sr. for 2018 RWA of $269,750.00, you informed me that actually Mr. Zamrzla Sr. recorded 650 AF of production in 2018 on the erroneous assumption that he was expressing his intent to produce that amount **in the future** and that his production in 2018 was actually less.
3. On May 16, 2019 you sent me some data which you claimed established that the amount for 2018 RWA owed by the Zamrzlas was far less and as follows:
    a. For Mr. Zamrzla Sr. he had 0 (zero) production in 2018 for 2 of his parcels totaling 79 acres (he estimates future water use on these 2 parcels to be 256 AFY). For the remaining parcel of 40 acres, Zamrzla Sr. says he produced 75.29 AF of water in 2018 (he states future water use on this remaining parcel to be 100 AFY).
    b. For Zamrzla Jr. he says he had 18.46 AF of production in 2018 on his 2 parcels totaling 20 acres (he estimates future water use on the two parcels to be 200 AFY).
    c. So combined Zamrzla Sr. and Jr. say they used 93.75 AF of groundwater in 2018 (75.29 + 18.46). Multiplied by $415 an AF (the cost of Replacement Water for 2018) would mean the Zamrzlas together owed a total of $38,906.25 for RWA in 2018 and not $269,750.00.
    d. That $38,906.25 breaks down as follows: Zamrzla Sr. would owe $31,245.35 in RWA for 2018 and Zamrzla Jr. would owe $7,660.90.

4. The Watermaster Engineer has now analyzed data, including aerial photographs (using infrared technology) of the 5 parcels taken in 2018 and calculated that all 5 Zamrzla parcels roughly totaled 114 acres of irrigated land in 2018 (as opposed to the Zamrzla's current position that only 60 acres of their combined lands were irrigated in 2018 (roughly 40 by Sr. and 20 by Jr.). The Watermaster Engineer further calculated that crop water requirements in 2018 were about 5.5 AF/acre for alfalfa in 2018. Scaling that crop coefficient down to 5 AF/acre leads to the conclusion that Zamrzla Sr. and Jr. combined to pump about 570 AF of groundwater in 2018 (5 x 114). That results in a total RWA for 2018 for both Zamrzla Sr. and Zamrzla Jr. of $236,550.00. That $236,550.00 breaks down roughly as follows: Zamrzla Sr. owes $195,050.00 (94 acres x 5 AF/acre x $415 AF) in RWA for 2018 and Zamrzla Jr. owes about $41,500 (20 acres x 5 AF/acre x $415 AF).
5. This really comes down to a question of how many acres were irrigated in 2018 (our calculation of 114 irrigated acres v. your clients' calculation of 60 irrigated) and the alfalfa irrigation coefficient used of 5 AF/acre.

The first thing we need to do is discuss the numbers and whether we can narrow the significant disparity relating to irrigated acres in 2018 and the issue of the irrigation coefficient for alfalfa for that year.....Your anticipated professional cooperation in that regard is much appreciated as we need to get this resolved as soon as possible.....Thanks and best, Craig

PFP PRICE, POSTEL & PARMA LLP

Craig A. Parton
Price Postel & Parma LLP
200 E Carrillo Street, Suite 400
Santa Barbara, CA 93101
T: 805.962.0011 (Main);
T: 805.882-9822 (Direct)
F: 805.965.3978
E: cap@ppplaw.com
Website: http://ppplaw.com

EXHIBIT "M"

Robert H Brumfield

From:	Robert H Brumfield
Sent:	Thursday, October 24, 2019 8:00 AM
To:	Craig A. Parton
Cc:	Serena Rivera; Patti Rose; Phyllis Stanin (PStanin@toddgroundwater.com); Kate White (KWhite@toddgroundwater.com); mknudson@avek.org
Subject:	Re: Zamrzla Matter
Attachments:	Edison Billing - Zamŕzla Farm Well - kWh Useage 2018 (Zero).pdf

Craig,

The Zamrzla's are working to get the 2018 Edison billings which may take a few more days since they can't get them online any longer.

But, as to Johnny Zamrzla's "farm well", I wanted to pass along what I was sent yesterday showing zero pumping in 2018 or, as stated in this case, no water production from that well. The Edison billings are going to support the information we already provided I am pretty sure.

Anyway, we will get them to you as soon as I have them.

If I did not mention it previously, they are moving forward on the metering.

Very Truly Yours,

Robert H. Brumfield, III
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and
325 Old Mammoth Road, Suite B4
P.O. Box 146
Mammoth Lakes, CA 93546-0146
Tele (661) 316-3010 | Fax (661) 885-6090

From: Robert H Brumfield <bob@brumfieldlawgroup.com>
Sent: Monday, October 21, 2019 11:56 AM
To: Craig A. Parton <Cparton@ppplaw.com>

SOUTHERN CALIFORNIA
EDISON

Your electricity b...

Customer account
2-22-863-5702

Service account
3-018-8788-08
75TH ST W
LANCASTER, CA 93536

Rotating outage
Group N001

Date bill prepared
01/04/19

Farm Well

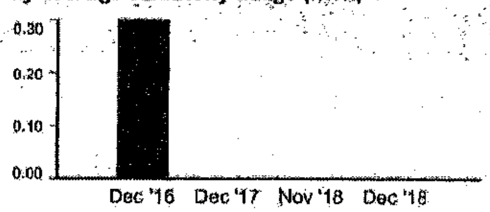
Amount due $45.09
Due by 01/23/19

Your account summary

Previous Balance	$45.09
Payment Received 12/19/18	-$45.09
Balance forward	$0.00
Your new charges	$45.09
Total amount you owe by 01/23/19	**$45.09**

SOUTHERN CALIFORNIA
EDISON

Your daily average electricity usage (kWh)



—0— usage in 2018

Usage comparison

	Dec '16	Dec '17	Jan '18	Feb '18	Mar '18	Apr '18	May '18	Jun '18	Jul '18	Aug '18	Sep '18	Oct '18	Nov '18	Dec '18
Total kWh used	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of days	30	30	29	32	30	29	32	29	30	29	32	29	33	31
Appx. average kWh used/day	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Details of your new charges

Paid "stand-by" charges only in 2018

Your rate: TOU-PA-2-B
Billing period: 12/03/18 to 01/03/19 (31 days)

Delivery charges - *Cost to deliver your electricity*

Customer charge		$43.15
Subtotal of your new charges		$43.15
Los Angeles Co UUT	$43.15 x 4.50000%	$1.94
Your new charges		**$45.09**

Your Delivery charges include:
- *$43.15 distribution charges*

Your overall energy charges include:
- *$0.39 franchise fees*

Additional Information:
- *Service voltage: 480 volts*

Bill & Payment History

2019

Date	Description	Amount	Balance
Mar 05, 2019	View Bill	$45.09	$45.09
Feb 19, 2019	SCE's online payment we received on	-$45.09	$0.00
Feb 01, 2019	View Bill	$45.09	$45.09
Jan 21, 2019	SCE's online payment we received on	-$45.09	$0.00
Jan 03, 2019	View Bill	$45.09	$45.09

2018

Farm Well – Standby Charge Only

Date	Description	Amount	Balance
Dec 19, 2018	SCE's online payment we received on	-$45.09	$0.00
Dec 03, 2018	View Bill	$45.09	$45.09
Nov 15, 2018	SCE's online payment we received on	-$45.09	$0.00
Oct 31, 2018	View Bill	$45.09	$45.09
Oct 17, 2018	SCE's online payment we received on	-$45.09	$0.00
Oct 15, 2018	Late payment charge adjustment	-$0.35	$45.09
Oct 02, 2018	View Bill	$45.09	$45.44
Sep 05, 2018	SCE's online payment we received on	-$45.09	$0.35
Aug 31, 2018	View Bill	$45.09	$45.44
Aug 20, 2018	SCE's online payment we received on	-$45.09	$0.35
Aug 02, 2018	View Bill	$45.09	$45.44
Jul 26, 2018	SCE's online payment we received on	-$45.09	$0.35
Jul 26, 2018	Late payment charge	$0.35	$45.44
Jul 03, 2018	View Bill	$45.09	$45.09
Jun 06, 2018	SCE's online payment we received on	-$45.09	$0.00
Jun 04, 2018	View Bill	$45.09	$45.09
May 09, 2018	SCE's online payment we received on	-$45.09	$0.00
May 03, 2018	View Bill	$45.09	$45.09
Apr 24, 2018	SCE's online payment we received on	-$45.09	$0.00
Apr 04, 2018	View Bill	$45.09	$45.09
Mar 26, 2018	SCE's online payment we received on	-$45.09	$0.00
Mar 06, 2018	View Bill	$45.09	$45.09
Feb 06, 2018	SCE's online payment we received on	-$45.09	$0.00
Feb 01, 2018	View Bill	$45.09	$45.09
Jan 08, 2018	SCE's online payment we received on	-$43.61	$0.00
Jan 03, 2018	View Bill	$43.61	$43.61

EXHIBIT "N"

Robert H Brumfield

From:	Robert H Brumfield
Sent:	Wednesday, November 6, 2019 8:24 AM
To:	Craig A. Parton
Cc:	Serena Rivera; Patti Rose; Phyllis Stanin (PStanin@toddgroundwater.com); Kate White (KWhite@toddgroundwater.com); mknudson@avek.org
Subject:	Re: Zamrzla Matter

Good morning Craig. On these records I sent on October 24, I neglected to mention the impact of the zero water production by the Zamrzla "farm well" in 2018 on the charges for water production being asserted by your client.

The impact is that the color picture you provided and the infrared picture are incorrect as to 2018 water production. You previously said the images showed water being produced whereas the SCE data for the "farm well", which is the well that would produce water for the land shown in the images, shows zero production in 2018. So, the picture and infrared are wrong as to 2018 water production meaning no water production from the "farm well" and therefore no farming activity on the property shown in the images occurred in 2018. In other words, the assumption the Watermaster is operating under for 2018 water production is wrong.

The other wells both Zamrzla's have are only residential use wells and we already provided responsive information on the other wells quite a while back.

Based upon the actual data that the "farm well" did not produce any water in 2018, is your client willing to reconsider its position as to 2018 water production by the Zamrzla's?

If you want SCE data on the residential wells, we can get it but that production is de minimis via-a-vis the "farm well".

Please advise.

Very Truly Yours,

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-and-
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www.brumfieldlawgroup.com

EXHIBIT "O"

Robert H Brumfield

From:	Robert H Brumfield
Sent:	Wednesday, July 22, 2020 4:47 PM
To:	Craig A. Parton
Cc:	Serena Rivera
Subject:	Re: AV Watermaster re Zamrzla

Craig,

We seem to be going in circles here. My clients have been very clear (and I have been as well) that they want the $273,000 invoice withdrawn in writing as it was a mistaken invoice. It needs to be removed from the books of the Watermaster as a receivable. My clients aren't doing anything else until this occurs.

My clients have never been invoiced for any water actually used which has been solely residential.

What are we agreeing to with these facts? Seems like nothing right now.

Please have the $273,000 invoice withdrawn and correspondence sent to my clients that it has been withdrawn as it was an erroneous invoice. Then, perhaps we can have a conference call with clients on the line and perhaps you and a board member and get this on the road to completion.

I don't see what is so hard about this.

Very Truly Yours,

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EXHIBIT "P"

Zamrzla Assessment – September 23, 2020

The Watermaster attorney is asking for more than $273,000 from the Zamrzlas for a replacement Water Assessment on several parcels for ground water pumping that never occurred.

After examining Dr. Hendrickx's memorandum, I see that the Watermaster Engineer's analysis of aerial photography of the five parcels of the Zamrzla property in question has included four serious errors which include misusing the Crop Coefficient Method, confusion of Russian Thistle (tumbleweed) and other weeds with alfalfa, using only one image, and not performing any ground truthing to verify or support their conclusions.

In addition, I know that Mr. Zamrzla provided a Southern California Edison bill to the Watermaster attorney, showing that during the time period, and for two of the parcels in question, no electricity was used to pump water. The Watermaster attorney should know that the only way to obtain water for these two parcels is to use a deep-well turbine groundwater pump that only uses electrical energy. If electricity is not used, no water can be pumped. Also, if an inoperable irrigation system is present, such as unconnected wheel lines, water cannot be applied to the fields.

These especially important realizations bring the number of significant errors up to six. In addition, many people are appalled that Mr. Zamrzla is having this sort of conversation with the Watermaster attorney. They know that no pumping occurred during the time period in question. They include Mr. Tim Hays, Agricultural Consultant and Pest Control Advisor and also co-author of "Crop Water Requirements" assembled by myself; an irrigation specialist at University of California at Davis, and all of the University of California Extension Farm Advisors assigned to Antelope Valley; and a local farm contractor that does the harvesting (cutting, baling and hauling) for local landowners including Mr. Zamrzla and many neighbors that are quite familiar with the appearance of the Zamrzla property and the lack of irrigation during the time period in question.

From the information I have, I believe that the Watermaster attorney and the entire Watermaster Board should rescind the Assessment which used the Watermaster attorney's numbers amounting to $273,165. Dr. Hendrickx's accompanying analysis shows, by using Landsat images, that no water was used on the -002, -003 and -027 parcels, not 570 AF/year as billed. There no doubt was some water used on other parcels, of which no estimate has yet been discussed. I know the Zamrzlas and believe that once the Watermaster attorney and Board has recalled their incorrect Assessment, the Zamrzlas will negotiate a settlement for any water they have used. This Landsat analysis presented by Dr. Hendrickx in his attached memorandum is discussed in the attached technical paper authored by Dr. Hendrickx and co-authored by well-known and respected experts. Some of these experts have testified as expert witnesses for State and Federal courts and also the United States Supreme Court. These numbers should be confirmed by the Watermaster attorney and the legal representative of the Zamrzlas.

From a broader point of view, I am dismayed at the analysis of the Watermaster Engineer and the Watermaster attorney. To help the Engineer, I have furnished them and others many technical papers that would help them. I also proposed that we establish a "Science Advisory Board." This situation would not have happened with the advice of such a Board. Regulations indicate that only "best-available science" should be used. The Watermaster attorney should have required some form of Due Diligence before allowing the bill to be sent to the Zamrzlas. However, what is going on in this case is not "best," it is an absolute mess with all sorts of errors. Where is the outcry from the members of the Watermaster Board? This situation requires an investigation of the operation of the Watermaster Board in an open and public hearing.

The great amount of money the Watermaster attorney wants to extract from the Zamrzlas with no evidence of wrongdoing has been incredibly stressful and caused public embarrassment to prominent and well-liked public figures such as the Zamrzlas. A public apology from the Watermaster attorney is now appropriate.

Thank you for your consideration of this matter.

Eugene B. Nebeker, Ph.D., P.E.

Date: September 23, 2020

From: Jan M.H. Hendrickx, Ph.D., Ir.

To whom it may concern

This memorandum is written at the request of Mr. Gene Nebeker who asked for my professional opinion on the Replacement Water Assessment prepared by the Antelope Valley Watermaster Engineer concerning the groundwater production on the Zamrzla parcels in 2018.

I understand that the 2018 Replacement Obligation of the Zamrzla's will pay for the volume of water that they pumped to irrigate five parcels of land in excess of their Production Rights (see Section 3.5.39 of the Judgment). I will comment on the calculations by the Watermaster Engineer that resulted in a Replacement Obligation of 570 AF. These calculations were documented in a memorandum from the Watermaster Engineer to the Antelope Valley Watermaster Legal Counsel on September 5, 2019.

Since the Zamrzla wells are not metered, the Watermaster Engineer made the correct decision to use remote sensing for their analysis because the volume of water pumped for irrigation will be approximately equal to actual crop water use that can be estimated from remote sensing imagery. Specifically, they used one USDA color infrared image of September 2018 in combination with the crop coefficient method to estimate the volume of 2018 actual crop water use on the five parcels. Because the Zamrzla's do not have any Production Rights on this land, the estimate of actual crop water use equals their total Replacement Obligation.

Unfortunately, the Watermaster's analysis for the calculation of the Replacement Obligation for which the Zamrzla's are responsible in 2018 is seriously flawed because (1) they use the crop coefficient method which is the wrong method to estimate actual crop water use; (2) they confuse Russian Thistle and other weeds with alfalfa; and (3) they use only one image of September and, thus, have no information about actual water use on the parcels during the periods of March-August and October-November.

The crop coefficient method is a common approach in California to estimate **potential** crop water use for a wide range of crops grown under optimal conditions of watering and fertilization. In other words, this method estimates maximum crop water use but not **actual** water use that can be considerably less. In addition, this method has the implicit requirements to know (1) what crop is grown; (2) date of planting and harvesting; and (3) dates of irrigation and significant precipitation. If one does not know what crop is grown at what time during the calendar year nor how many irrigations have been applied, it is impossible to calculate actual crop water use with the crop coefficient method. Since the Replacement Obligation is based on the actual volume pumped in excess of Production Rights, it equals actual crop water use rather than potential crop water use.

The Watermaster uses the red or faint red areas observed on the USDA color infrared image of September 2018 through parcels -002, -003 and -027 (Fig. 1) as an indication that alfalfa was grown on these parcels throughout the 2018 growing season from April through October. However, the spotty red-dots pattern seen on this aerial image does not look like alfalfa or any other irrigated crop. Did the Watermaster do any ground truthing as is the standard practice when using remote sensing in areas of uncertainty?

Using Landsat imagery, it is possible to go back in time and check the Watermaster's assertions. Figure 2 shows the Zamrzla parcels as seen on a Landsat 8 image of 16 September 2018. Just as on the USDA image, the spotty red-dots pattern is clearly visible. This pattern is quite different from the homogenous red colors observed on agricultural fields about 5 miles NW from the Zamrzla parcels (Fig. 3). In addition, comparison of these fields with parcels -026 and -028 reveals how weak the parcels' red color is compared to well water agricultural fields.

Figure 4 shows the Zamrzla parcels one year later on a Landsat 8 image of 19 September 2019. Just as in September 2018 live vegetation is observed throughout parcels -002 and -003. On October 22 and 25, 2019 I was able to inspect the fields myself for ground truthing. I found no alfalfa but much Russian Thistle (Fig. 4, lower picture) and other non-agricultural vegetation that resulted in the spotty red-dots pattern. Nor did I find any signs of irrigation other than the unconnected existing wheel line system.

In addition to the misclassification of the vegetation growing on parcels -002, -003 and -027, the Watermaster made another basic mistake. They used only one image in September 2018 to estimate crop water use over the entire growing period from March through November 2018 and made the unwarranted assumption that potential crop water use occurred during the entire growing season. This assumption easily could have been checked using Landsat images for 2018 that are freely available. For example, Fig. 5 shows the relative crop water use on the parcels in the middle of the growing season on July 14, 2018 as shown by Google Earth Engine (https://eeflux-level1.appspot.com/). The calculations are performed by EEFLUX which is an automatic implementation of the METRIC algorithms. Although EEFLUX can differ by 5 to 25% from a more accurate METRIC application, the image clearly shows the absence of any irrigation on parcels -002, -003 and -027. In addition, parcels -026 and -028 show a relative crop water use of, respectively, 30-45 and 25% percent which is much lower than potential or maximum water use. These low relative crop water uses are also echoed on the USDA image by the light red to pink colors on parcels -026 and -028 (Figs. 1-2). The Landsat images clearly indicate that water use on parcels -026 and -028 was about 25% and 38% of the potential crop water use calculated by the Watermaster. There are sufficient cloud free Landsat images available in 2018 to make a more accurate estimate of actual annual crop water use on these parcels if need be.

In my professional opinion, the true water use on the Zamrzla parcels is zero on parcels -002, -003 and -027; and a yet to be determined amount used on parcels -026 and -028. Thus, while any water used was a magnitude less than the Watermaster's assessment, an accurate Replacement Obligation can be determined using the methods described in my 2016 award winning paper that is attached.

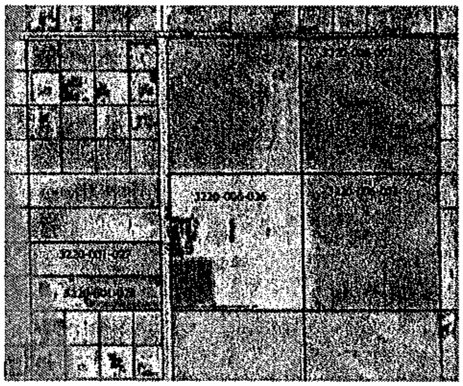

Figure 1. USDA color infrared image of September 2018 that is the only source used by the Watermaster for assessment of water use on the numbered parcels.

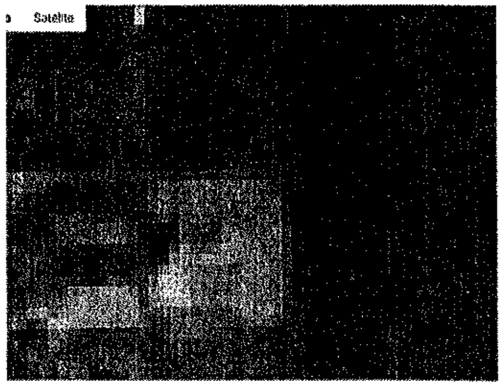

Figure 2. Landsat 8 color infrared image of 16 September 2018 covering the same area as shown in Fig. 1.

Figure 3. Landsat 8 color infrared image of 16 September 2018 showing irrigated agricultural fields about 5 miles to the NW of the Zamrzla parcels.

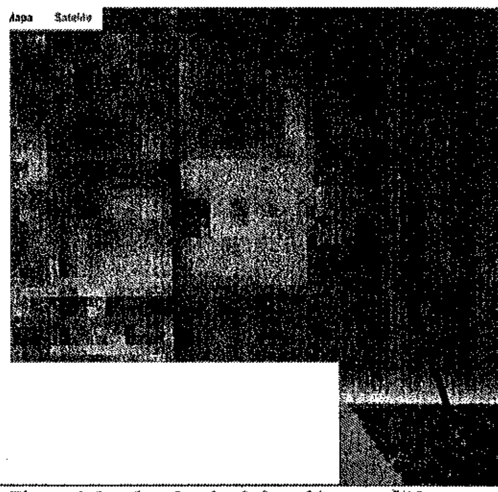

Figure 4. Landsat 8 color infrared image of 19 September 2019 covering the same area as shown in Fig. 1. An inspection visit on 25 October 2019 revealed that the red color coincided with the live vegetation of Russian Thistle; no alfalfa was observed on these parcels nor any sign of irrigation.

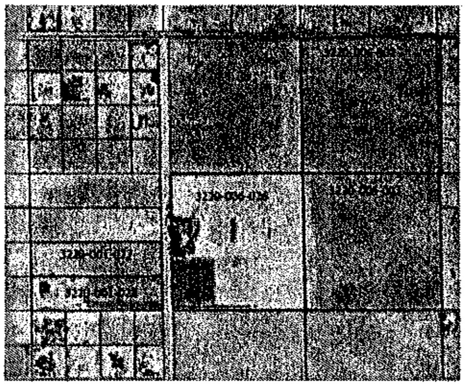

Figure 1. USDA color infrared image of September 2018 that is the only source used by the Watermaster for assessment of water use on the numbered parcels.

Figure 5. Google Earth Engine EEFLUX image overlaying a true color Landsat image of July 14, 2018 covering the same area as shown in Fig. 1. The dark brown color of the EEFLUX image in parcel -002 has a relative ET of about 2%. The light brown color in parcel -028 has a relative ET of about 25% and the light colors in the irrigated part of -026 vary between 30 and 45%. The non-colored areas that only show the true color image have a relative ET of zero.

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 52, No. 1 AMERICAN WATER RESOURCES ASSOCIATION February 2016

BENCHMARKING OPTICAL/THERMAL SATELLITE IMAGERY FOR ESTIMATING EVAPOTRANSPIRATION AND SOIL MOISTURE IN DECISION SUPPORT TOOLS[1]

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ABSTRACT: Generally, one expects evapotranspiration (ET) maps derived from optical/thermal Landsat and MODIS satellite imagery to improve decision support tools and lead to superior decisions regarding water resources management. However, there is lack of supportive evidence to accept or reject this expectation. We "benchmark" three existing hydrologic decision support tools with the following benchmarks: annual ET for the ET Toolbox developed by the United States Bureau of Reclamation, predicted rainfall-runoff hydrographs for the Gridded Surface/Subsurface Hydrologic Analysis model developed by the U.S. Army Corps of Engineers, and the average annual groundwater recharge for the Distributed Parameter Watershed Model used by Daniel B. Stephens & Associates. The conclusion of this benchmark study is that the use of NASA/USGS optical/thermal satellite imagery can considerably improve hydrologic decision support tools compared to their traditional implementations. The benefits of improved decision making, resulting from more accurate results of hydrologic support systems using optical/thermal satellite imagery, should substantially exceed the costs for acquiring such imagery and implementing the remote sensing algorithms. In fact, the value of reduced error in estimating average annual groundwater recharge in the San Gabriel Mountains, California alone, in terms of value of water, may be as large as $1 billion, more than sufficient to pay for one new Landsat satellite.

(KEY TERMS: soil moisture; evapotranspiration; GSSHA; SEBAL; METRIC; DPWM; distributed hydrologic modeling; optical/thermal satellite imagery; Landsat; MODIS; groundwater recharge; water management; hydrograph.)

Hendrickx, Jan M.H., Richard G. Allen, Al Brower, Aaron R. Byrd, Sung-ho Hong, Fred L. Ogden, Nawa Raj Pradhan, Clarence W. Robison, David Toll, Ricardo Trezza, Todd G. Umstot, and John L. Wilson, 2016. Benchmarking Optical/Thermal Satellite Imagery for Estimating Evapotranspiration and Soil Moisture in Decision Support Tools. *Journal of the American Water Resources Association* (JAWRA) 52(1): 89-119. DOI: 10.1111/1752-1688.12371

[1]Paper No. JAWRA-14-0179-P of the *Journal of the American Water Resources Association* (JAWRA). Received August 27, 2014; accepted September 28, 2015. **Discussions are open until six months from issue publication.**

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INTRODUCTION

Monitoring of regional evapotranspiration (ET) allows decision makers to (1) follow where, when, and how much water has moved into the atmosphere by ET; (2) monitor crop performance and the effects of drought for famine prediction; (3) better evaluate the performance of irrigation systems; (4) improve estimates by distributed hydrologic and weather models; and (5) estimate root zone soil moisture conditions. It is expected that the integration of regional ET maps derived from National Aeronautics and Space Administration (NASA) and United States Geological Survey (USGS) earth imaging products will improve decision support tools and, therefore, lead to superior decisions regarding water resources utilization. However, there is a need to quantify benefits realized through the use of satellite derived results in user decision support tools. When our study started in 2006, only a few research examples had been reported in the literature where NASA earth science results related to ET had been integrated into hydrologic models (Ahmad and Bastiaanssen, 2003; Schuurmans *et al.*, 2003) but no operational hydrologic decision support tools were known to our research team that used satellite-estimated ET products on a regular basis.

Therefore, the overall goal of this study was to see if the use of satellite optical/thermal imagery improves the performance of three operational hydrologic decision support tools: the ET Toolbox developed by the United States Bureau of Reclamation (USBR), the Gridded Surface/Subsurface Hydrologic Analysis (GSSHA) model developed by the U.S. Army Corps of Engineers, and the Distributed Parameter Watershed Model (DPWM) based on the Mass Accounting System for Soil Infiltration and Flow (MASSIF) model, developed in 2007 by Sandia National Laboratory, and since then continuously improved by Daniel B. Stephens & Associates (DBS&A) for the prediction of groundwater recharge in semiarid regions.

The ET Toolbox is a grid-based approach that uses the "crop coefficient reference ET approach" (Allen *et al.*, 1998; Jensen, 1998) to provide daily forecasts of water depletions, i.e., ET of agricultural and riparian vegetation as well as evaporation from open water, for the day in question and the following six days (Brower, 2008). The GSSHA (Downer and Ogden, 2004, 2006) is a physically based, distributed hydrologic model that simulates the hydrologic response of a watershed subject to given hydrometeorological inputs. It is used by the U.S. Army Corps of Engineers not only within the United States (U.S.) but also worldwide. The DPWM (Daniel B. Stephens & Associates, Inc., 2010a) is a distributed hydrologic model used for the evaluation of groundwater recharge in arid and semiarid basins (e.g., Daniel B. Stephens & Associates, Inc., 2008, 2010b, 2011; Hendrickx *et al.*, 2011a).

In the context of this study, benchmarking is the process of running a hydrologic decision support tool to assess the relative performance of using optical/thermal satellite imagery for the improvement of forcing functions (e.g., precipitation, ET, etc.), the appraisal of initial conditions (e.g., soil moisture, snow cover, etc.), and the estimation of model parameters (e.g., land use, soil texture, total available water for transpiration) (Toll, 2008). Our study objective was to benchmark traditional applications of ET Toolbox, GSSHA, and DPWM versus the use of optical/thermal satellite imagery on the forcing function of ET in ET Toolbox, the appraisal of initial soil moisture conditions in GSSHA, and the estimation of the model parameter "total available water for transpiration (TAW)" in DPWM.

BENCHMARKING METHOD

Our benchmarking method compared typical traditional applications of each decision support tool with ones that used information from optical/thermal satellite imagery. The comparisons were based on a "performance indicator," i.e., a measurement for assessing the quantitative performance of a system. The performance indicators selected were: annual ET forecasts for ET Toolbox, storm hydrographs for GSSHA, and average annual groundwater recharge volumes for DPWM. The goal of our research sponsor NASA was to benchmark the improvement, if any, to the "performance indicators" from the use of satellite imagery for the purpose of improving decision making in water resources management.

First, the optical/thermal satellite images were converted into maps of ET and root zone soil moisture with established algorithms: *Surface Energy Balance Algorithms for Land (SEBAL)*, *Mapping EvapoTranspiration (ET) at high Resolution with Internalized Calibration (METRIC)*, and the *Evaporative Fraction Method for Root Zone Soil Moisture Retrieval*. The inputs for these algorithms are the bands of Landsat and the Moderate Resolution Imaging Spectroradiometer (MODIS) presented in Table 1. The ET maps were then incorporated into the hydrologic decision support tools, either after conversion of the ET into the reference ET fraction (ETrF) using high-quality hourly weather data, or — where this was

TABLE 1. Band Spatial Resolutions (m) and Wavelengths (μm) of Landsat 5 and 7 and MODIS Sensors.

Sensors		Band number								
		1	2	3	4	5[1]	6	7	31	32
Landsat7 Landsat5	Pixel size (m)	30	30	30	30	30	60 (L7) 120 (L5)	30	NA[2]	NA[2]
	Band width (μm)	0.45-0.51	0.52-0.60	0.63-0.69	0.75-0.9	1.55-1.75	10.4-12.5	2.09-2.35	NA[2]	NA
MODIS	Pixel size (m)	250	250	500	500	500	500	500	1,000	1,000
	Band width (μm)	0.62-0.67	0.84-0.87	0.46-0.48	0.54-0.56	1.23-1.25	1.63-1.65	2.11-2.15	10.8-11.3	11.8-12.3

[1]MODIS band 6 is not used in this study because of streaking noise.
[2]Not available.

not possible — after conversion of the heat fluxes retrieved with SEBAL or METRIC into root zone soil moisture. The details of these three operations are presented below.

The SEBAL/METRIC Approach

SEBAL (Bastiaanssen *et al.*, 1998a, 2005) and METRIC (Allen *et al.*, 2007a, b) are "snapshot" energy balance models that use the strong thermal signals sensed by satellites that are associated with evaporation processes to provide high-resolution ET images. Spatial resolutions of retrievals range from 30 to 120 m with Landsat satellite data (Allen *et al.*, 2007a, 2011) and 250 to 1,000 m with MODIS (Allen *et al.*, 2008b; Trezza *et al.*, 2013). These energy balance algorithms are thermally driven, with ET computed as a residual of the surface energy balance, so that air humidity, air temperature, and vegetation canopy conductivities are not needed at each pixel of the image. METRIC employs an innovative Calibration using Inverse Modeling at Extreme Conditions method (Allen *et al.*, 2011; Irmak *et al.*, 2011; Irmak *et al.*, 2012) pioneered in the SEBAL model (Bastiaanssen *et al.*, 1998a) to overcome biases in land surface temperature retrievals and unknown spatial variation in near-surface air temperature during the estimation of sensible heat flux. As this calibration is based on a "cold" and "hot" pixel selected from within the image, it is often called an "internal" calibration. The METRIC/SEBAL approach has demonstrated ET accuracies of 15, 10, and 5% for daily, monthly, and seasonal time scales, respectively (Allen, 1997; Hendrickx and Hong, 2005; Allen *et al.*, 2007b; Hong, 2008). In this study, METRIC was used to benchmark the ET Toolbox and DPWM, while SEBAL was used for GSSHA. The main practical difference between METRIC and SEBAL is that the latter can be implemented without using meteorological observations—with some unknown decrease in accuracy—while METRIC needs hourly meteorological measurements including air humidity and temperature, wind speed, and solar radiation for calculation of the reference ET at one or more sites that are representative of the entire image or part of the image (Allen *et al.*, 2007a). The METRIC algorithm takes into account the effects of slope, aspect, and elevation on the energy balance which is critical for its application in mountains and over rolling terrain. It also captures the changes in soil evaporation and riparian vegetation transpiration due to capillary fluxes originating from the interaction between groundwater depth, soil texture, and even groundwater salinity. METRIC/SEBAL has been successfully used with Landsat and MODIS images in numerous practical applications (Bastiaanssen, 2000; Bastiaanssen *et al.*, 2000, 2002; Hafeez *et al.*, 2006; Allen *et al.*, 2008b; Hong *et al.*, 2009, 2011b). The ET estimates have, in turn, been used to derive evaporative fraction and soil moisture retrievals.

Like SEBAL, METRIC computes the latent heat flux as the residual of the surface energy balance

$$\lambda E = R_n - G - H \quad (1)$$

where R_n is net radiation, G the soil heat flux, H the sensible heat flux, and λE is the latent heat flux. METRIC deviates from SEBAL in its use of an internal calibration of the energy balance that incorporates effects of regional advection of energy and dry air, via the employment of the Penman-Monteith equation, that can substantially increase ET from irrigated agriculture and riparian vegetation (Allen *et al.*, 2007a) in semiarid and arid climates. METRIC retrievals of ET, when derived from Landsat or MODIS imagery, represent snapshots of ET during late morning. These time-snapshots are extended to daily totals using the fraction of reference ET, ETrF, a concept applied in METRIC, as the ETrF has been shown to be nearly constant over the course of a day for normal agricultural conditions (Allen *et al.*, 2007a, b). However, evaporative fraction has been suggested in place of ETrF for substantially stressed conditions such as exist for natural conditions (Allen *et al.*, 2011) following Brutsaert and Sugita (1992) and Bastiaanssen *et al.* (1998a). They also suggest using evaporative fraction for regional, rainfed conditions where, by definition, advection is small or nonexistent.

The Evaporative Fraction Method for Soil Moisture Retrieval in the Root Zone

This method is based on the long-known soil physical relationship between root zone soil moisture and the partitioning of sensible and latent heat fluxes at the land surface (Davies and Allen, 1973; De Bruin, 1983; Owe and van de Griend, 1990; Kustas and Norman, 1999). This method is a straightforward extension of the METRIC and SEBAL algorithms that derives reliable estimates of the energy balance fluxes from remotely sensed optical/thermal imagery (Bastiaanssen *et al.*, 1997, 1998a, b, 2005; Ahmad and Bastiaanssen, 2003; Scott *et al.*, 2003; Fleming *et al.*, 2005; Hendrickx and Hong, 2005; Hong *et al.*, 2005).

In many agro-hydrologic studies, root zone soil moisture is used to reduce potential ET to actual ET (Feddes *et al.*, 1978, 1988; Belmans *et al.*, 1983; Wagenet and Hutson, 1996; Allen, 2000; Anderson *et al.*, 2007; Hain *et al.*, 2009, 2011). When soil moisture in the root zone decreases and soil resistance to water movement increases, the net effect is a reduction in actual ET (λE). When the soil is wet, most of the available energy (net radiation, R_n, minus soil heat flux, G) is used for ET (latent heat flux) and almost no energy is left for sensible heat flux (H). When the soil is dry, most of the available energy is used to heat soil and air and latent heat flux (ET) is small. One way to express this partitioning of radiant energy is the evaporative fraction (Λ) that is defined as (Brutsaert and Sugita, 1992; Crago, 1996):

$$\Lambda = \frac{\lambda E}{\lambda E + H} = \frac{\lambda E}{R_n - G} \tag{2}$$

The energy partitioning calculated with the evaporative fraction is primarily related to the amount of vegetation and soil moisture content (Boni *et al.*, 2001). The following equation was derived by Ahmad and Bastiaanssen (2003) using *in situ* root zone soil moisture measurements and validated evaporative fraction data from the SEBAL

$$S = \frac{\theta}{\theta_{sat}} = e^{\frac{\Lambda - 1}{0.42}} \tag{3}$$

where S is degree of saturation (0.0-1.0), θ is volumetric water content, and θ_{sat} is volumetric water content at saturation. Equation (3) was derived from soil moisture measurements obtained on grassland in Kansas on alluvial soils and loess (Smith *et al.*, 1992), as well as from rainfed (vineyard, barley, wheat) and irrigated crops (maize, alfalfa) in Central Spain on sandy loams (Bolle *et al.*, 1993; Bastiaanssen *et al.*, 1997). A number of studies have successfully supported the use of Equation (3) for retrieval of root zone soil moisture using remote sensing algorithms (Scott *et al.*, 2003; Mohamed *et al.*, 2004; Fleming *et al.*, 2005).

Insertion of ET Fluxes in Hydrologic Models

The SEBAL/METRIC algorithms for ET mapping cannot provide a continuous series of daily ET estimates due to the fact that Landsat and MODIS images are only periodically available. Landsat imagery is potentially available every 16 days per satellite, while the daily MODIS images can only be used every 4 to 5 days when the satellite has a viewing angle of less than about 15° to the area of interest (Trezza *et al.*, 2013). The nadir-angled images are needed for reliable ET estimates from SEBAL and METRIC (Allen *et al.*, 2008b). In addition, the presence of clouds often causes longer time periods between images.

Another issue with constructing continuous series of ET with satellite imagery is the large temporal variability of ET fluxes. The daily ET can vary by a factor 2 or 3 from one day to another depending on weather conditions, especially cloudiness. As the ET observed from space on image days is often not representative of ET values on nonimage days, direct insertion of ET fluxes into hydrologic models can cause substantial error. Instead, more robust variables with less temporal variability such as the ETrF or *root zone soil moisture* (S or θ) are preferred for insertion into hydrologic decision support tools and for time-integration of ET between satellite overpass dates. As a consequence, the generation of a continuous series of daily ET maps is only possible by combining the available ET maps with a daily hydrologic model or other time-integration system that is based on relative ET, and for the same area or region.

The ETrF is calculated for each pixel of an image as

$$ET_rF = \frac{ET}{ET_r} \tag{4}$$

where ET is the actual ET estimated by SEBAL or METRIC for each pixel, and ET_r is the standardized reference ET for a tall crop (Allen *et al.*, 2005d). The ETrF is similar to the *crop coefficient* (K_c) that is defined as

$$K_c = \frac{ET_c}{ET_{ref}} \quad (5)$$

where ET_c is the crop ET under standard conditions and ET_{ref} is the (generic) reference ET. Crop ET under standard conditions refers to the actual ET from crops "that are grown in large fields under optimum soil water, excellent management condition and environmental conditions, and achieve full production under the given climatic conditions" (Allen *et al.*, 1998). The reference ET can be calculated for two types of reference surfaces representing clipped grass (a short, smooth crop) and alfalfa (a taller, rougher agricultural crop) resulting in, respectively, the reference ET for a short crop ET_o and for a tall crop ET_r (Allen *et al.*, 1998, 2005d). Due to the higher surface roughness of the tall crop, ET_r generally will be higher than ET_o for the same meteorological conditions (Irmak *et al.*, 2008). Therefore, one should use grass-based crop coefficients with ET_o and alfalfa-based crop coefficients with ET_r (Allen *et al.*, 2005d). If a reference ET other than ET_o or ET_r was used to develop the crop coefficients, it must be established that the equation yields values that are equivalent to ET_o or ET_r. For example, the daily "reference" ET that has been computed in the past by the New Mexico State University Penman equation ($ET_{o\text{-NMSU}}$) needs its own set of crop coefficients ($K_{c\text{-NMSU}}$) as explained in Case Study I.

Despite the similarity of Equations (4) and (5), a distinct difference can exist between reference ET fractions (ETrF) and traditional crop coefficients (K_c). The latter represent optimum agricultural management under well-watered conditions and are typically determined from point-based measurements; the former represent actual ETrF populations that may have inherent variation because of variation in water availability, crop variety, irrigation method, weather, soil type, salinity and fertility, and/or field management that can be different from the average K_c value for optimal crops.

The temporal robustness of the ETrF and K_c approach has been illustrated by lysimeter measurements for sugar beets that show ETrF and K_c values for sugar beets to be nearly identical on alternating clear and cloudy days with different ET values (Allen *et al.*, 2007b). Other agricultural crops, which are bred to maintain nearly constant and maximum stomatal conductivity so as to maximize biomass production, are expected to respond similarly. Thus, the daily ET for each pixel on nonimage days can be calculated using the ETrF derived by METRIC on the image day multiplied by the ET_r calculated from weather data on nonimage days. If two or more images are available, it is standard procedure to interpolate the ETrF between the image dates so that the dynamics of vegetation development are captured (Allen *et al.*, 2007a, 2011).

Root zone soil moisture is another robust hydrologic variable that is correlated with daily ET but without its large temporal variability (Hillel, 1998). For example, the dynamics of root zone soil moisture and actual ET at the Paynes Prairie State site in Florida show root zone soil moisture to vary gradually during the season, while the actual ET shows large variability from day to day caused by different weather conditions leading to different atmospheric demands (Jacobs *et al.*, 2002; Liu *et al.*, 2005).

Root zone soil moisture is an important tool for the incorporation of variable ET fluxes into hydrologic models when no high-quality hourly weather data are available to calculate ET_r during satellite overpass or in mountainous terrain where it is nearly impossible to estimate ET_r for each pixel due to the effects of slope, aspect, and elevation on incoming solar radiation, wind speed, air temperature, and relative humidity. Equations (2) and (3) show that the instantaneous heat fluxes from the METRIC/SEBAL approach yield sufficient information to obtain the root zone soil moisture condition of each pixel and to map soil moisture maps on image days for initialization of hydrologic models. For example, in GSSHA the actual ET, the potential evapotranspiration (PET), and volumetric soil water content are related as follows (Downer and Ogden, 2006):

$$ET = PET\left(\frac{\theta - \theta_{wp}}{0.75(\theta_{sat} - \theta_{wp})}\right) \quad (6)$$

where θ is the volumetric soil water content, θ_{wp} is the wilting point, and θ_{sat} is the saturated volumetric soil water content. If $\theta > 0.75\theta_{sat}$, the ET is considered equal to the PET. PET is considered equal to the reference ET for a tall crop (ET_r) that is calculated from the meteorological data measured at a ground-based station (Allen, 2001). The wilting point and the saturated volumetric water content are derived from the Natural Resource Conservation Service STATSGO database (*accessed* May 28, 2012, http://soildatamart.nrcs.usda.gov/) using established pedotransfer functions that yield θ_{wp} and θ_{sat} as a function of soil texture (Rawls *et al.*, 1982). Once GSSHA is initialized with a realistic soil moisture map, its daily ET predictions based on Equation (6) are expected to be more realistic as well. For long-term simulations, the soil moisture distribution of the model can be updated when new clear sky optical/thermal imagery becomes available.

CASE STUDY I: ET TOOLBOX IN THE MIDDLE RIO GRANDE CONSERVANCY DISTRICT

The ET Toolbox case study in the Middle Rio Grande Conservancy District (MRGCD) in New Mexico provides an example of how optical/thermal imagery can be used to derive the forcing function of ET in hydrologic models. The primary purpose of the ET Toolbox is to estimate daily water depletions, i.e., ET of agricultural and riparian vegetation as well as evaporation from open water, at a resolution of 1 × 1 km (previously 4 × 4 km), and to improve the efficiency of water management and irrigation scheduling by providing guidance — through ET charts — on when and where to deliver water and how much to apply (Brower, 2008). Daily ET forecasts for the day of interest and the following six days are accessible for water managers and other users through the internet (*accessed* August 30, 2011, www.usbr.gov/pmts/rivers/awards/Nm2/riogrande.html). For example, the Albuquerque office of the United States Bureau of Reclamation decides on a daily basis how much water to release from Cochiti reservoir to meet all agricultural, riparian, domestic, industrial, and minimum flow demands in the Rio Grande Valley between Cochiti and Elephant Butte reservoirs. As the travel time of river water from Cochiti reservoir to Elephant Butte reservoir is about five days (Langman, 2009), it is essential that the Bureau bases its releases on reliable ET forecasts. This information is critical because an error in the forecast "ends up in the river." If the ET forecast is larger than the actual ET, additional excess water may not be put to a beneficial use to those who could take the stored water later. On the other hand, if the forecast is smaller than the real ET, the legally binding minimum flow requirement of the river may be violated. This is especially important during periods of low flow and hot weather when a relatively small error in ET forecast can represent a considerable percentage of the minimum flow requirement.

The performance indicator used in evaluating the worth of ET estimates derived from NASA imagery on the ET Toolbox is the sum of all daily ET forecasts in 2007, i.e., the annual ET forecast. The inclusion of the ET forecasts for the following six days was also explored, but as they are usually similar to the first day's forecast under the climatic conditions of the MRGCD, only the first day's forecast was used. For this METRIC application we used MODIS imagery as its daily acquisition schedule all but assures that under the climatic conditions of MRGCD sufficient images will be available to force operational hydrologic decision support tools.

Benchmark Approach for ET Toolbox

We compared the annual sum of daily ET forecasts in 2007 using the traditional ET Toolbox approach ($ET_{Kc\text{-}NMSU}$) versus the annual sum derived from METRIC using 26 MODIS images distributed over the entire year (Table 2). The METRIC application resulted in twenty-six 500 × 500 m ETrF images that were aggregated to 1,000 × 1,000 m to coincide with the 1,000 × 1,000 m cell size of ET Toolbox. The 500×500 m pixels were developed by resampling 1,000 m MODIS thermal pixels to the 500 m resolution of most MODIS optical pixels (Trezza *et al.*, 2013). This was done to promote improved spatial fidelity of the ET retrievals. Following the production of ET, the product was resampled to the 1,000 m spatial resolution of the original thermal pixels. Figure 1 presents 12 monthly METRIC ETrF maps aggregated to 4 × 4 km to show the annual temporal and spatial dynamics of ETrF in the MRGCD. These METRIC ETrF values were used in two ways to estimate the annual sum of daily ET values: (1) the ETrF values were converted to ET Toolbox crop coefficients ($K_{c\text{-}METRIC}$) and then processed using the traditional ET Toolbox approach ($ET_{Kc\text{-}METRIC}$); (2) the ETrF values were processed using standard METRIC procedures without making use of ET Toolbox (ET_{METRIC}).

Traditionally, ET Toolbox has used the New Mexico State University Penman reference ET ($ET_{o\text{-}NMSU}$) instead of the ASCE Standardized Penman-Monteith reference ET (Brower, 2008) to calculate the crop ET under standard conditions as

$$ET_c = K_{c\text{-}NMSU} \times ET_{o\text{-}NMSU} \quad (7)$$

However the $ET_{o\text{-}NMSU}$, even though it is purported to be a grass reference method, produces higher

TABLE 2. Image Dates Used for the MODIS-METRIC Application in the Middle Rio Grande Valley of New Mexico for the Year 2007 (Allen *et al.*, 2008a).

Image No.	Date	Image No.	Date
1	January 28, 2007	14	June 30, 2007
2	February 6, 2007	15	July 7, 2007
3	January 1, 2007	16	July 16, 2007
4	March 17, 2007	17	August 8, 2007
5	March 26, 2007	18	August 24, 2007
6	April 2, 2007	19	September 18, 2007
7	April 18, 2007	20	September 25, 2007
8	April 27, 2007	21	October 11, 2007
9	May 13, 2007	22	October 20, 2007
10	May 29, 2007	23	October 27, 2007
11	June 5, 2007	24	November 21, 2007
12	June 14, 2007	25	December 23, 2007
13	June 21, 2007	26	December 30, 2007

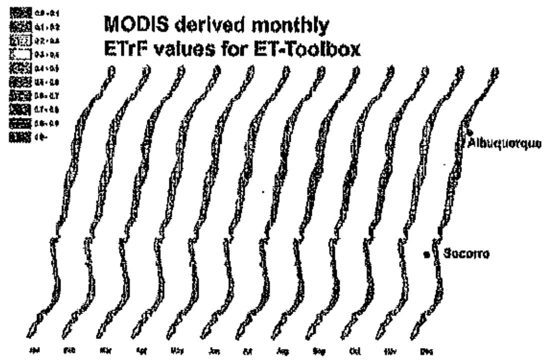

FIGURE 1. Monthly ETrF Aggregated to 4 km Sized Grid Cells of the ET Toolbox Grid along the Middle Rio Grande during 2007 (Allen *et al.*, 2008b).

estimates than the standard grass-reference ET_o of ASCE and FAO (Allen *et al.*, 2008a), and even exceeds the standardized ASCE alfalfa reference ET_r by 7.7% (Figure 2). Therefore, that reference method requires its own set of crop coefficients ($K_{c\text{-NMSU}}$) that were provided by Dr. Salim Bawazir of New Mexico State University on March 16, 2000 (Brower, 2008). In 2012, the ET Toolbox abandoned the New Mexico State University reference ET and switched to the ASCE Standardized Penman-Monteith reference ET method of Allen *et al.* (2005d).

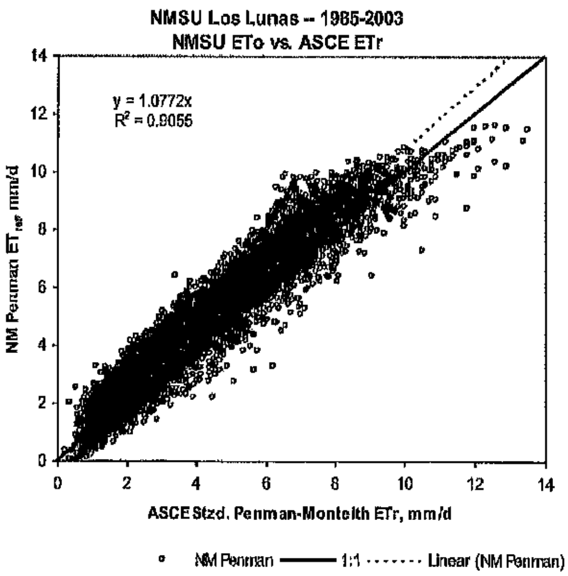

FIGURE 2. Daily "Reference" ET Computed by the New Mexico State University Penman Equation (of ET Toolbox) *vs.* Daily Alfalfa Reference ET Computed by the ASCE-EWRI (2005) Standardized Penman-Monteith Equation for 18 Years of Weather Data Collected at the NMSU Los Lunas Experiment Station (Allen *et al.*, 2008a).

Equation (7) was used to calculate the ET Toolbox ET-based forecasts for "today" and the following six days. The $ET_{o\text{-NMSU}}$ was calculated using weather data from a network of seven weather stations in MRGCD (Brower, 2008) as well as weather forecast parameters provided by the National Digital Forecast Database (*accessed* August 30, 2011, http://www.nws.noaa.gov/ndfd/). The daily assignment of a crop coefficient ($K_{c\text{-NMSU}}$) for each grid cell in the MRGCD was based on its land cover. Prior to June 8, 2004, the Middle Rio Grande Land Use Trend Analysis of 1992/93 (U.S. Bureau of Reclamation, 1997) was used as the land cover database. After that date, a high-resolution land cover map was produced using a combination of July 2000 IKONOS satellite imagery at 4 m resolution and 2001 Utah State University aerial photography at 0.5 m. That high-resolution land cover map was transposed to the grid cell map of ET Toolbox to determine acreage of each agricultural crop (Alfalfa, Corn, Pasture, Orchard, etc.), each type of riparian vegetation (Cottonwood, Salt Cedar, Russian Olive, etc.), and open water in each 1 × 1 km grid cell. As a consequence, the ET Toolbox land cover map generally was at least several years out of date. In this study for the year 2007, the land cover map was approximately six years old.

Important features in the ET Toolbox are the dates when a land cover is assumed to become active and ET begins, and when the area becomes inactive and ET stops. For example, corn was assumed to begin its growth phase starting on April 29, and remain active until November 20. Thus, a field classified on the imagery of 2001 as Corn would, in 2007, be estimated to consume water during six months and 22 days out of the year, with zero ET in the remaining period. Of course, in 2007, a field may actually be planted with alfalfa, which has a growing season from January 1 through October 20, or it may be bare, i.e., considered in ET Toolbox as inactive with zero ET, but underlain by a shallow groundwater table that almost certainly maintains a small soil evaporation rate (Hendrickx *et al.*, 2003). To mitigate the issue of out-of-date land cover maps, MRGCD switched, in 2012, to the use of crop reports developed from field surveys performed by ditch riders throughout the irrigation season so that the ET Toolbox now uses one-year-old land cover data. In this context, it is relevant to observe that no land cover data are needed for ET predictions using the SEBAL/METRIC approach (Allen *et al.*, 2011), although land cover information may somewhat increase the accuracy of ET predictions by improving estimates of the surface roughness of each cell.

The width of the Middle Rio Grande Valley varies from less than 1 km to about 8 km. As a result, there are many edge cells located on the boundary between low-lying valley lands and higher dry upland terrain. These boundary cells cover the area that remains between the last full-sized cell and the boundary between the floodplain and desert up-lands. As a consequence, many of these cells are considerably smaller than 1 km^2 which may lead to inaccuracies when re-projecting different data layers to a common projection and, therefore, they have been eliminated. As a result, all of our analyses are based on 831 approximately 1 × 1 km cells that are entirely located in the valley and mostly underlain by a shallow (0-5 m) groundwater table (Bexfield and Anderholm, 1997; S.S. Papadopulos & Associates, Inc., 2006).

The performance indicator, total annual ET for 2007, using the traditional ET Toolbox approach without MODIS imagery ($ET_{Kc\text{-}NMSU}$) was calculated in this study using:

$$ET_{K_c}\text{-NMSU} = \sum_{day=1}^{day=365} \sum_{cell=1}^{cell=831} (K_{c\text{-NMSU}} \times ET_{o\text{-NMSU}})/831 \quad (8)$$

In contrast, the performance indicators based on the ETrF maps generated by METRIC from MODIS imagery were not based on the New Mexico State University Penman reference ET, $ET_{o\text{-NMSU}}$, but on the ASCE standardized Penman-Monteith equation for the alfalfa reference, ET*r* (Allen *et al.*, 2007a). Because the data presented in Figure 2 suggest that

$$ET_{o\text{-NMSU}} = 1.077 \times ET_r \quad (9)$$

we developed a METRIC-derived crop coefficient ($K_{c\text{-METRIC}}$) to be used with $ET_{o\text{-NMSU}}$ as

$$K_{c\text{-METRIC}} = \frac{ETrF}{1.077} \quad (10)$$

and the performance indicator using METRIC ETrF inside the ET Toolbox ($ET_{Kc\text{-METRIC}}$) as

$$ET_{K_{c\text{-METRIC}}} = \sum_{day=1}^{day=365} \sum_{cell=1}^{cell=831} (K_{c\text{-METRIC}} \times ET_{o\text{-NMSU}})/831 \quad (11)$$

The primary difference between Equations (8) and (11) are that Equation (8) uses "static" K_c values developed by NMSU, and Equation (11) uses spatially varying K_c values developed from the METRIC application. The daily ETrF values were determined by linear interpolation between the ETrF images derived from the 26 MODIS images to simulate common interpolation practice.

The performance indicator based on METRIC only without using ET Toolbox (ET_{METRIC}) was calculated as

$$ET_{METRIC} = \sum_{day=1}^{day=365} \sum_{cell=1}^{cell=831} (ETrF \times ET_r)/831 \quad (12)$$

where ET_r was computed using the ASCE standardized Penman-Monteith equation and ETrF was produced from the METRIC process. The daily ETrF values of this performance indicator were not determined by linear interpolation but by fitting a spline between the ETrF images derived from the 26 MODIS images, which follows common METRIC practice (Allen *et al.*, 2007a). In general, the spline function tends to more smoothly follow the evolution of ETrF caused by evolution in vegetation development, than does a linear interpolation. In addition, the convex nature of ETrF *vs.* time of growing season tends to cause the linear interpolation to understate total ET due to undercutting of the convex curvilinear ETrF time-based curve (Allen *et al.*, 2007a). In METRIC, the quality controlled measurements at the two representative automated weather stations of Angostura and Boys Ranch were used for the calculation of an average daily ET_r for all 831 cells (Allen *et al.*, 2008a). The annual sum of these daily ET_r values was 1,950 mm and ideally this number should be similar to the annual ET_r that contributed to performance parameter $ET_{Kc\text{-METRIC}}$. One can insert Equations (9) and (10) into Equation (11) to confirm this. However, due to uncertainty of regression Equation (9) as well as the use of seven instead of two weather stations and spatial weighting schemes for assigning a reference $ET_{o\text{-NMSU}}$ to each grid cell in ET Toolbox, the annual ET_r for performance indicator $ET_{Kc\text{-METRIC}}$ was 1,767 mm, or about 10% less than the 1,950 mm for performance indicator ET_{METRIC}.

To benchmark the three different performance indicators ($ET_{Kc\text{-NMSU}}$, $ET_{Kc\text{-METRIC}}$, ET_{METRIC}) against each other, we not only used their averages over 831 cells but also their averages over different land covers. We calculated the values for the performance indicators for each land cover class defined in 2008 by the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (http://nassgeodata.gmu.edu/CropScape/, *accessed* September 10, 2012). The land covers consisted of agricultural crops (corn, sorghum, winter wheat, alfalfa, pecans), fallow land, and nonagricultural classes similar to the ones used in the 2006 National Land Cover Database (Fry *et al.*, 2011). All data were downloaded at a spatial resolution of 57 × 57 m. We used the 2008 NASS dataset as it was the first year available and sufficiently close to 2007 to identify the irrigated areas and other major land covers in the MRGCD. We then reclassified all agricultural crops into one new class of "irrigated lands." Before using these data, we aggregated the 57 × 57 m cells into 1,000 × 1,000 m cells assigning the land cover occurring with the highest frequency to the aggregated cells. For example, if 51% of the 57 × 57 m cells in one 1,000 × 1,000 m cell were "shrubland" and 49% were "irrigated land," then the aggregated cell would be classified as "shrubland." This aggregation process introduced considerable bias for many pixels, as the subpixel-scale variability of heat fluxes in the MRGCD was quite high (Kleissl *et al.*, 2009). Overall, the total ET aggregated over all 831 pixels of 1,000 × 1,000 m was assumed to have much lower bias than for individual pixels, due to randomized assignment of majority land use type on a pixel-by-pixel basis. The result would be cancellation of error in proportion to the square root of the number of cells, or a reduction of $831^{0.5}$ or about 29 times. The eight land cover classes were: Open Water (WAT), Woody Wetlands (WWE), Irrigated Land (IRR), Pasture/Hay (PAS), Grassland Herbaceous (GRA), Shrubland (SHR), Developed/Open Space (DEO), and Developed/Low intensity (DEL) (Table 3).

Benchmark Results for ET Toolbox

Table 3 presents the total annual ETs in 2007 estimated using ET Toolbox in its traditional way and with METRIC ETrFs. The average annual 2007 ET performance indicators — $ET_{Kc\text{-}NMSU}$, $ET_{Kc\text{-}METRIC}$, and ET_{METRIC} — were 543, 771, and 832 mm, respectively, over the 831 cells. The absolute and relative differences of (832-771=) 61 mm and 8% between the average $ET_{Kc\text{-}METRIC}$ and ET_{METRIC} was not expected as according to Equations (9)-(12) these performance indicators should have approximately the same value. This difference appears primarily caused by the interpolation method of the ETrF images for calculation of the ET performance indicator, linear interpolation for $ET_{Kc\text{-}METRIC}$, and the more accurate spline interpolation for ET_{METRIC} (Allen *et al.*, 2007a). A secondary possible cause is that the reference ETs used for the calculations of $ET_{Kc\text{-}METRIC}$ and ET_{METRIC} were based on data from different weather stations as explained in the previous section. The 8% difference is considered to be within the commonly accepted uncertainty of remotely sensed ET (Karimi and Bastiaanssen, 2015).

Because ET_{Kc_NMSU} and $ET_{Kc\text{-}METRIC}$ are both results of ET Toolbox, we focused our benchmark analysis on these two performance indicators. The absolute and relative differences between $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$ for all 831 cells were (771-543=) 228 mm and 30%. This is a large difference; however, one should keep in mind that the purpose of the traditional ET Toolbox is to estimate crop and riparian vegetation ET from "active" areas and open water evaporation within specified river reaches (Brower, 2008). The ET Toolbox was not developed to estimate ET from all areas, including what are classified by USBR as "inactive" areas that contain desert shrubs or bare soils, fallow fields, or agricultural fields during winter time. METRIC, on the other hand,

TABLE 3. The Average Annual Actual ET in Case Study I, Its Standard Deviation, and Its Coefficient of Variation for 831 Pixels of About 1 × 1 km for the Three Performance Indicators ($ET_{Kc\text{-}NMSU}$, $ET_{Kc\text{-}METRIC}$, ET_{METRIC}) for All Pixels and for Each Land Cover Class.

Land Cover[1]			Annual ET (mm/yr)			Standard Deviation of Annual ET (mm/yr)			Coefficient of Variation of Annual ET (-)		
	N[2]	AA[3]	$ET_{Kc\text{-}NMSU}$	$ET_{Kc\text{-}METRIC}$	ET_{METRIC}	$ET_{Kc\text{-}NMSU}$	$ET_{Kc\text{-}METRIC}$	ET_{METRIC}	$ET_{Kc\text{-}NMSU}$	$ET_{Kc\text{-}METRIC}$	ET_{METRIC}
ALL	831	40	543	771	832	246	205	230	45	27	28
WWE	123	40	621 B[4]	898 A	978 AB	199	188	170	32	21	17
WAT	38	41	605 B	878 AB	1,029 A	216	179	161	36	20	16
IRR	60	52	707 A	863 ABC	927 BC	155	168	172	22	18	19
PAS	178	41	632 AB	830 BCD	892 CD	185	166	178	29	20	20
GRA	35	44	640 AB	804 CD	790 EF	252	145	155	39	18	20
DEO	57	43	566 B	768 D	838 DE	223	193	207	39	25	25
SHR	260	36	439 C	700 E	744 F	258	176	244	59	25	33
DEL	80	31	355 D	545 F	616 G	230	201	179	65	37	29

[1]WWE, Woody Wetlands; WAT, Open Water; IRR, Irrigated Lands; PAS, Pasture/Hay; GRA, Grassland Herbaceous; DEO, Developed/Open Space; SHR, Shrubland; DEL, Developed/Low Intensity.
[2]N is number of 1,000 × 1,000 m cells present in each land cover class.
[3]The Active Area is the percentage of a pixel area where ET takes place; the Inactive Area is the percentage of a pixel area with bare and sparsely vegetated spots where ET Toolbox assumes zero ET. AA is annual mean active area used for the calculation of $ET_{Kc\text{-}NMSU}$ in the traditional ET Toolbox. The AA of IRR is significantly higher than all other classes; the AAs of WWE, WAT, and SHR are not significantly different.
[4]Values with a different letter are significantly different at the 5% significance level. For example, ET_{METRIC} values of Open Water (WAT) and Irrigated Lands (IRR) are significantly different because they do have different letters, respectively, an A and a B.

estimates a spatially continuous ET field over an entire region or watershed including shrubs and bare soils having low ET rates. For that reason it is to be expected that the cumulative ET derived from METRIC is higher than that estimated from the traditional ET Toolbox approach. Neither approach is necessarily "right" or "wrong," as they are designed to detect or estimate the ET from different areas of interest.

Table 3 also presents the $ET_{Kc\text{-}NMSU}$, $ET_{Kc\text{-}METRIC}$, and ET_{METRIC} for the eight land cover classes. An analysis of variance was conducted to test whether differences among $ET_{Kc\text{-}NMSU}$, $ET_{Kc\text{-}METRIC}$, and ET_{METRIC} depend on land cover. All three performance indicators did significantly ($p < 0.001$) depend on land cover but only a small part of their variability was explained by land cover as expressed in the R^2-values of 20, 26, and 26% for, respectively, $ET_{Kc\text{-}NMSU}$, $ET_{Kc\text{-}METRIC}$, and ET_{METRIC}. These low R^2-values were expected as (1) previous research demonstrated a large variability of heat fluxes within cells having dimensions of 1,000 × 1,000 m (Kleissl *et al.*, 2009); and (2) the NASS land cover classes do not capture well the true differences in land cover of an arid floodplain in New Mexico at a scale of 1,000 m. For example, visual false color image-based inspection of the land types occurring in land cover classes Pasture/Hay (PAS), Grassland Herbaceous (GRA), Developed/Open Space (DEO), and Developed/Low Intensity (DEL) revealed that they do contain irrigated parcels. For that reason we did not further consider these four land cover classes, but instead, focused our discussion on Open Water (WAT), Woody Wetlands (WWE), Irrigated Lands (IRR), and Shrubland (SHR) that represent truly different environments in MRGCD. Indeed, land cover Shrubland was significantly different from all other land covers for $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$, but cannot be distinguished significantly from Pasture/Hay for ET_{METRIC}. The land cover classes Woody Wetlands and Open Water were not significantly different for any of the three performance indicators, but together they represented the moist nonagricultural areas covering the river and adjacent wetlands.

The $ET_{Kc\text{-}METRIC}$ values were ranked from highest to lowest as they explain most of the variability caused by land cover; $ET_{Kc\text{-}NMSU}$ and ET_{METRIC} values followed this ranking in Table 3. The highest annual $ET_{Kc\text{-}METRIC}$ occurred in cells classified as Woody Wetlands with 898 mm, Open Water with 878 mm, and Irrigated Lands with 863 mm, but these values were not significantly different. The 700 mm value of Shrubland was significantly lower. A completely different ranking was found for $ET_{Kc\text{-}NMSU}$ with the highest value of 707 mm in Irrigated Lands and significantly lower values of 621 and 605 mm in Woody Wetlands and Open Water, respectively. Again, Shrubland was significantly lower with 439 mm. The ranking of ET_{METRIC} basically followed the one of $ET_{Kc\text{-}METRIC}$ with values of 978, 1029, and 927 mm for, respectively, Woody Wetlands, Open Water, and Irrigated Lands. Shrubland was the lowest with 744 mm.

The absolute and relative differences between $ET_{Kc\text{-}METRIC}$ and ET_{METRIC} for Woody Wetlands and Open Water cells were, respectively, 80/151 mm and 8/15%; for Irrigated Lands, the values are 64 mm and 7% and for Shrubland 44 mm and 6%. These values confirmed that the differences between $ET_{Kc\text{-}METRIC}$ and ET_{METRIC} are minor and mainly caused by their different approaches for calculation of the reference ET_r as discussed before. The absolute and relative differences between $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$ for Woody Wetlands and Open Water cells were, respectively, 277/273 mm and 31/31% while for Irrigated Lands these values were 156 mm and 18% and for Shrubland 261 mm and 37%. The standard deviations of $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$ for Woody Wetlands, Open Water, Irrigated Lands, and Shrubland were, respectively, 199/188 mm, 216/179 mm, 155/158 mm, and 258/176 mm, and the respective coefficients of variation were 32/21%, 36/20%, 22/18%, and 59/25%. The overall picture that arises from the magnitude of these differences is that the performance parameters $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$ for land cover class Irrigated Lands were more similar than for other classes. Not only were their absolute and relative ET differences of 156 mm and 18% smaller than those of Woody Wetlands, Open Water, and Shrubland, but also their standard deviations and coefficients of variation were nearly the same and the lowest among the land cover classes. The difference of 156 mm between performance parameters $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$ for land cover class Irrigated Lands is most likely largely due to capillary rise and bare soil evaporation during the winter season when ET Toolbox assumes evaporation to be zero on inactive lands, whereas the thermally based energy balance of METRIC was able to detect evaporation from wet soil. METRIC-based ET was aggregated over the calendar year to demonstrate the positive impact of considering evaporation and ET during all parts of the year. On average, during 2007, the active area of Irrigated Lands cells was 52% (Table 3), leaving 48% as inactive. As groundwater table depths in the floodplain of the Rio Grande are shallow (0-5 m below surface) (S.S. Papadopulos & Associates, Inc., 2006) and the soils generally have a medium to fine texture (Nelson *et al.*, 1914), capillary fluxes can vary from more than 1 mm/day to close to zero (Hendrickx *et al.*, 2003). Such fluxes could explain part of the ET difference of 156 mm between the traditional and

METRIC approaches. Yet, another reason for the discrepancy may be that the land use map used by ET Toolbox was more than six years old so that erroneous land use classes may have affected the total annual ET estimation.

The dynamics of performance parameters $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$ for land cover classes Woody Wetlands, Open Water, and Shrubland were quite different. The absolute and relative differences between $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$ were much larger than the 156 mm and 18% found in land cover Irrigated Lands; they were, respectively, 273, 277, and 261 mm, and 31, 31, and 31%. As for the irrigated lands, the differences in ET were most likely due to capillary rise and bare soil evaporation, not only during the winter season when ET Toolbox assumes evaporation to be zero, but also during the growing season on the bare soil patches that are typical of the riparian and shrub areas. The mean average active areas of Woody Wetlands, Open Water, and Shrubland were 39% so that their total inactive area, i.e., bare and sparsely vegetated spots where ET was set equal to zero, and is 61% or about 25% more than the 48% of Irrigated Lands. As explained earlier, capillary fluxes on inactive areas can make up part of the ET difference of 261-277 mm between the traditional and METRIC approaches for Woody Wetlands, Open Water, and Shrubland. Yet, another reason for the discrepancy may be the six-year-old land use map as discussed in the previous paragraph and the lack of a majority of any particular land use type in a 4 km grid cell, thereby impacting accuracy of the $ET_{Kc\text{-}NMSU}$ estimates.

The sharp decrease in the standard deviations and coefficients of variation is another characteristic of the statistics in Woody Wetlands, Open Water, and Shrubland (Table 3) when the traditional ET Toolbox approach was replaced by a METRIC-based one. While the standard deviation and coefficient of variation of Irrigated Lands for $ET_{Kc\text{-}NMSU}$ and $ET_{Kc\text{-}METRIC}$ basically remained the same, the standard deviation of Woody Wetlands, Open Water, and Shrubland decreased by, respectively, 11, 37, and 82 mm; coefficients of variation decreased from 32 to 21%, 36 to 20%, and 59 to 25%. Therefore, the standard deviations and coefficients of variations for Woody Wetlands, Open Water, and Shrubland approached those of Irrigated Lands or — in other words — the accuracy of annual ET estimates for these classes improved when METRIC was used. On the other hand, METRIC does not need annually varying land cover information as it directly determines the components of the energy balance. Another important factor explaining the higher accuracy of METRIC is that it captures, not only in active areas, but also in inactive areas, the change in soil evaporation and riparian vegetation transpiration due to capillary fluxes as a result of groundwater depth change between years and during a water year. Many studies have confirmed that groundwater depth is an important factor affecting ET, particularly in riparian and groundwater discharge areas with phreatic vegetation (White, 1932; Van Hylckama, 1974; Moayyad *et al.*, 2003; Shafike *et al.*, 2007). For example, Van Hylckama (1974) studied water use by salt cedar, a phreatophyte known to utilize groundwater, during a seven year period using lysimeters and found that the plant's ET rate was highly dependent on the depth to groundwater, with 2,150 mm/yr with depth of 1.5 m decreasing to less than 1,000 mm/yr for depth of 2.7 m.

A final aspect considered is whether METRIC applied with MODIS imagery yields accurate ET values. Previous studies have found generally good agreement between METRIC ET derived from MODIS compared with up-scaled Landsat ET maps (Allen *et al.*, 2008b; Hong *et al.*, 2009, 2011a). In addition, eddy-covariance ET measurements and HYDRUS1D simulations from 1999 at a flooded Salt Cedar site in the MRGCD yielded an annual ET of 1,120 and 1,140 mm/yr, respectively (Moayyad *et al.*, 2003), which suggests that the ET_{METRIC} value of 1,140 mm from 2007 at that location is accurate.

Benchmark Conclusions for ET Toolbox

Observing the large differences in estimation of annual ET in 2007 for the 831 cells in MRGCD by the three performance indicators $ET_{Kc\text{-}NMSU}$, $ET_{Kc\text{-}METRIC}$, and ET_{METRIC}, and considering the positive METRIC validations with MODIS imagery in the Rio Grande Valley, optical/thermal imagery has the potential to considerably improve the forecasts of ET in the MRGCD. It is very likely that a nearly real-time implementation of METRIC would generate benefits that outweigh the costs of such an operation, especially in light of recent efforts to reduce costs of human oversight and intervention on METRIC and similar model applications (Allen *et al.*, 2013) and implementation of the METRIC algorithms on the very fast Google Earth Engine cloud via an application named EEFlux (Earth Engine Evapotranspiration Flux) (Kilic *et al.*, 2014). All patterns of water use (when, where, and how much) need to be known during the entire year before water can be optimally managed in times of scarcity and drought. This information can only be obtained from the METRIC Landsat-based ET because the ET derived from the ET Toolbox only provides the expected average ET during the growing season under optimal conditions.

CASE STUDY II: GSSHA IN THE KISHWAUKEE WATERSHED

The GSSHA model case study is an example of how optical/thermal imagery can improve model hydrologic predictions through initialization of soil moisture state in the models. GSSHA (Ogden *et al.*, 2000; Downer and Ogden, 2004, 2006) is a two-dimensional, physically based, distributed parameter hydrologic model that simulates a variety of hydrologic processes, including: parameterizations for rainfall interception and infiltration, overland flow retention, ET, surface runoff and subsurface routing. GSSHA is applicable in most watersheds because its formulation includes Richards equation infiltration, two-dimensional implicit groundwater routing, and an optional conceptual base flow model based on the Sacramento Soil Moisture Accounting (SAC-SMA) model. GSSHA is used by the U.S. Army Corps of Engineers not only within the U.S. but also worldwide. GSSHA is public domain software maintained by the U.S. Army Corps of Engineers, Engineering Research and Development Center, and can be downloaded from the GSSHA Wiki (*accessed* August 23, 2014, www.gsshawiki.com/gssha/Gridded_Surface_Subsurface_Hydrologic_Analysis).

An accurate initialization of spatially distributed GSSHA soil moisture is critical when predicting peak discharges and maximum flood levels in rivers of interest on short notice in support of civilian and military operations. In applications without remotely sensed root zone soil moisture, there is little to no time to gather spatially distributed field estimates of the soil moisture conditions needed to initialize GSSHA. In the absence of field data, the model is initialized using an initially uniform soil moisture state such as dry, average, or wet, and running the model from before a previous rainfall recorded event. Errors in initial soil moisture estimates were found to be diminished after a significant rainstorm is simulated (Senarath *et al.*, 2000). However, this process first increases simulation time when time is of the essence and it also results in errors in the peak hydrograph and, thus, the prediction of maximum flood levels. We performed this study to see if improved initial soil moisture estimates significantly improve model performance, as well as increase parameter set uniqueness when calibrating. Therefore, we selected the predicted storm hydrograph as the performance indicator for GSSHA.

Benchmark Approach for GSSHA

For this study, we used GSSHA simulations in the Kishwaukee Watershed. The Kishwaukee River originates near Woodstock, Illinois, and flows to Rockford, Illinois, where it discharges into the Rock River. The watershed covers approximately 3,000 km^2 and contains a dense network of streams with a total length of about 1,600 km. Agricultural lands occupy about 70% of the watershed; the remainder is covered by forests, sloughs, wetlands, and urban areas. GSSHA simulations in the Kishwaukee watershed for the prediction of flood changes caused by land use conversion, removal of tile drains, and installation of a wetland were used as the basis for this study (Byrd, 2013). Average annual precipitation is 950 mm and average annual evaporation is 750 mm (Kay and Trugestaad, 1998).

Discharge measurements were made from April 1, 2002, through October 11, 2002 (Figure 3). Unfortunately, no matching hourly NEXRAD distributed precipitation data were available for this entire period. Therefore, Event 1 and Event 2 (Figure 3) have been split and simulated individually with GSSHA in this proof of concept study; Event 1 started on June 3 and Event 2 on August 21. Hourly NEXRAD distributed precipitation images have been used as input to the GSSHA model.

For our study period, only the Landsat image of June 18, 2002 was of sufficient cloud-free quality to map ET and soil moisture. This image is located in the tail of the hydrograph of Event 1 and is assumed to represent soil moisture conditions typical for periods in the growing season without precipitation as occurred just before Event 1 in early June and Event 2 in late August. A horizontal grid increment of 250 m was used in the simulations, resulting in approximately 48,000 grid cells within the watershed.

We benchmarked the prediction of two hydrographs after the two large storms occurring in June and August 2002 (Events 1 and 2 in Figure 3) using individual GSSHA simulations. Our approach for benchmarking and evaluating the value of using the Landsat-derived soil moisture product for initializing the GSSHA model is a straightforward application of Equation (6). First, GSSHA was run in its traditional manner with uniform initial soil water contents assigned to all cells in the model before running the model from before a previous significant rainfall event. GSSHA was then run for Event 1 in early June and Event 2 in late August using as the initial soil moisture distribution the one that was derived from a SEBAL analysis for the June 18, 2002, Landsat image (Hendrickx *et al.*, 2009). For the Landsat approach, the SEBAL-generated ET map (Figure 4a) was converted into a soil moisture map using Equation (6) while PET was calculated using daily meteorological data (Allen

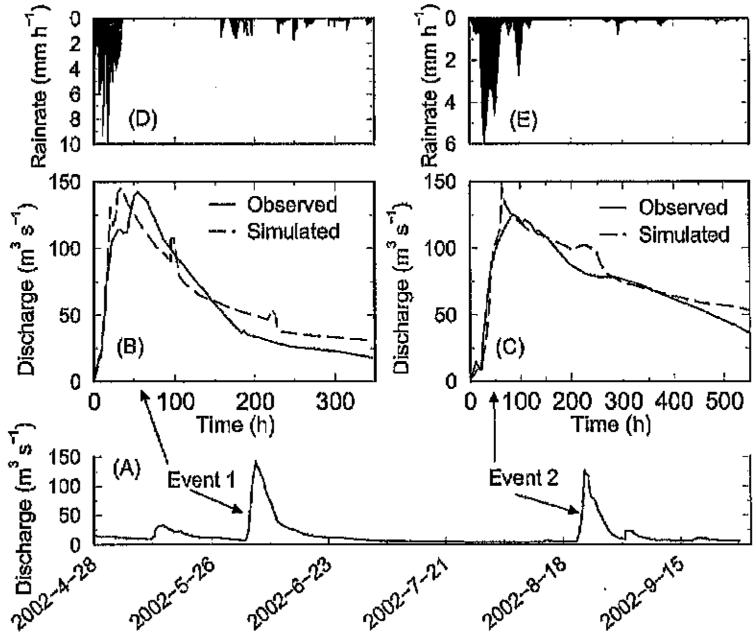

FIGURE 3. Time Series of the Average Radar Precipitation over the Kishwaukee Watershed as well as the Observed and Simulated Discharges at the Outlet of the Kishwaukee Watershed for Event 1 and Event 2 Using the Surface Energy Balance Algorithms for Land-Derived Soil Moisture Map to Initialize GSSHA. The precipitation values shown in this figure are the average values of the distributed radar rainfall over the watershed; in the simulations, the spatially distributed radar rainfall is used so that the cell with the maximum precipitation value receives far more precipitation than the average value (Pradhan *et al.*, 2012).

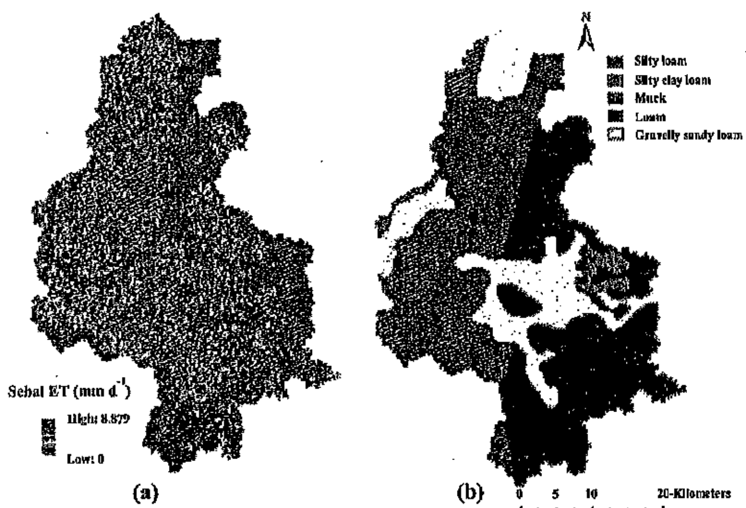

FIGURE 4. Kishwaukee Maps Used for This Study: (a) Surface Energy Balance Algorithms for Land actual ET (mm/day) on June 13, 2002; (b) soils by surface texture (Hendrickx *et al.*, 2009; Pradhan *et al.*, 2012).

et al., 2005d) from a weather station located at 42.11 N, 88.96139 W. For both the traditional and Landsat approaches, the soil map (Figure 4b) was used to determine θ_{wp} and θ_{sat} for each cell in the model using standard USDA soil parameters (Rawls *et al.*, 1982).

No Landsat images were available immediately before the storms of June 3 and August 21, 2002; the only available image was acquired on June 18, 2002, during a period that the discharge in the watershed was at a level somewhat higher than just before Event 1 and Event 2 (Figure 3). In humid regions like the Kishauwkee watershed, only a few clear sky Landsat images are typically available during periods with high rainfall (Sano *et al.*, 2007) and the probability of having a clear sky image just before a major storm event is rather low.

The use of daily MODIS images increases the availability of clear sky images due to the higher frequency of overpass. However, because the thermal band of MODIS has a resolution of 1,000 m, the MODIS ET and soil moisture maps have lower resolution than those of Landsat 5, which has a thermal band resolution of 120 m. This begged the question: What is the value of a soil moisture map obtained from moderate resolution Landsat imagery weeks before or after the storm event to be simulated, compared to a more frequent, but lower-resolution soil map? We hypothesized that the value of a higher resolution but less-frequent soil moisture map would be of considerable value because generally there exists a "temporal persistence of spatial patterns of soil water storage" (Kachanoski and de Jong, 1988) or, more accurately, a "time stability of the rank of individual observations in the probability distribution function of the whole population" (Vachaud *et al.*, 1985) of soil moisture values. The "rank order stability" of soil moisture patterns can be described then as the temporal persistence of spatial soil moisture patterns, i.e., even when the average soil moisture conditions change due to precipitation and ET; the rank order of soil moisture for each cell often will remain relatively unchanged. One important reason for time stability of soil moisture patterns is the strong relationship between soil texture, landscape position, and soil moisture (e.g., Vachaud *et al.*, 1985; Hendrickx *et al.*, 1990; Hillel, 1998; Jury and Horton, 2004). This relationship is so strong that soil boundaries between soil series can be determined using field soil water content measurements (Hendrickx *et al.*, 1986) or series of SEBAL-generated soil moisture maps (Engle *et al.*, 2010, 2014) similar to the map used in this case study. Therefore, we expected that the June 18 SEBAL soil moisture map would reveal soil moisture patterns similar to the ones existing in the watershed just before Event 1 starting on June 3 and Event 2 starting on August 21. If true, then the June 18 soil moisture map would be a better option for initialization of GSSHA than an artificial, spatially uniform soil moisture distribution, or lower resolution MODIS soil moisture map.

Benchmark Results for GSSHA

Figure 5 shows for Event 1 how the simulated runoff hydrograph varied with the various uniform initial soil-moisture conditions, which were evaluated with observed discharges using the Nash-Sutcliffe (N-S) efficiency. Table 4 presents for Event 1 the variation of the N-S efficiency, which represents a goodness-of-fit between the observed and simulated hydrographs. The N-S efficiency varies from −0.02 for uniform initial soil moisture of 70% to 0.81 for a uniform initial soil moisture of 40% during the sensitivity analysis and calibration of Kishwaukee watershed. Because discharge measurements are available, we recognize that the uniform 40% initial soil moisture produced the most efficient hydrograph using the traditional GSSHA initialization method. However, the use of the June 18 SEBAL soil moisture map resulted in N-S efficiencies of 0.88 and 0.85 for Events 1 and 2, respectively. This is a strong indication that soil moisture distributions during the period of discharge measurements have a robust rank order stability and that this knowledge substantially improves estimation of individual flood events. Senarath *et al.* (2000) showed that distributed-parameter physically-based hydrologic models are quite sensitive to assumed initial soil moisture values, and this sensitivity destroys the validity of single-event calibrations when assumed values are used. They also showed significant improvements in calibration verification when more realistic soil moistures were simulated. The results shown in Figure 5 and Table 4 clearly show that if SEBAL soil moisture estimates are available, model performance is considerably improved when used to initialize soil moisture.

GSSHA is a fully distributed hydrologic model that accounts for soil moisture conditions in each time step. Therefore, GSSHA can be used not only to predict hydrographs but also to predict real-time soil moisture dynamics in a watershed. Figure 6a presents the June 18, 2002 soil moisture distribution derived from the SEBAL ET map (Figure 4a) using Equation (6). This map was used to initialize the simulations of Events 1 and 2; this map contains substantial spatial details and is much more robust than the soil moisture distributions used for traditional GSSHA simulations. The model-predicted soil moisture distributions 16 days after Event 1 are shown in Figures 6b-6e. Figures 6b-6d show soil moisture distributions initiated with, respectively, 10, 40, and 70% uniform initial water content while Figure 6e shows the soil moisture distribution initiated using the SEBAL June 18-based soil moisture map (Figure 6a). Even after 16 days, the soil moisture maps initialized with uniform initial soil moisture distributions (Figures 6b-6d) still retain unrealistic features as compared with that produced using the SEBAL-initialized soil moisture map. Figure 6e shows a high spatial variability and much wider variability of soil moistures across the watershed. This latter feature is best seen by comparing the soil moisture density distributions of the simulations (Figure 7). Whereas the simulations initialized with uniform initial soil moisture have their densities concentrated in a rather narrow band, the density distribution resulting from the SEBAL soil moisture map spans a wide range of soil moisture conditions. For initialization with 10, 40, and 70% uniform initial soil moisture, the respective soil moisture values ranged from 0.10-0.17, 0.18-0.34, and 0.20-0.35 while the SEBAL initialization yielded a range of 0.12-0.39.

Benchmark Conclusion for GSSHA

Comparison of the measured hydrographs in this study with the hydrographs simulated with and without using spatially-distributed initial soil moisture state estimate derived from optical/thermal Landsat satellite imagery has established that such imagery has the potential to considerably improve the prediction of hydrographs and river levels using distributed hydrologic models. In addition, we observed that simulated soil moisture distributions exhibit greater variability that seems more natural when satellite imagery was used to initialize the GSSHA model.

This study also demonstrated that in cloudy regions where clear sky Landsat imagery is limited (Asner, 2001; Wohl *et al.*, 2012), the rank order stability of soil moisture patterns enables the use of SEBAL/METRIC-derived soil moisture maps for model initialization on dates that are days, weeks, or possibly even years (albeit in the right season) apart in the future or past from the image day.

TABLE 4. Goodness-of-Fit between Simulated and Observed Hydrographs as a Function of Initial Root Zone Soil Moisture Distribution. The uniform cases refer to Event 1.

Initialization of Soil Moisture	Nash-Sutcliffe Efficiency
Uniform soil moisture content of 10%	0.14
Uniform soil moisture content of 30%	0.63
Uniform soil moisture content of 35%	0.75
Uniform soil moisture content of 40%	0.81
Uniform soil moisture content of 70%	−0.02
SEBAL-distributed soil moisture map: Event 1	0.88
SEBAL-distributed soil moisture map: Event 2	0.85

These conclusions are based on data and measurements covering only two storm events in the Kishwaukee watershed and, therefore, need to be confirmed by more field studies. This study supports another research effort in Africa advocating that in un-gauged watersheds ET and soil moisture maps from the METRIC/SEBAL approach can be used as a means for the calibration of distributed hydrologic models (Winsemius *et al.*, 2008).

CASE STUDY III: DPWM IN THE SAN GABRIEL MOUNTAINS OF CALIFORNIA

The DPWM case study serves as an example of how optical/thermal imagery can improve the estimation of critical parameters in hydrologic models. One such parameter is the "total available water" (TAW) for ET that is critical to the parameterization of operational distributed water balance models that determine actual ET and aquifer recharge (Alley, 1984), quantify feedbacks between soil moisture and climate

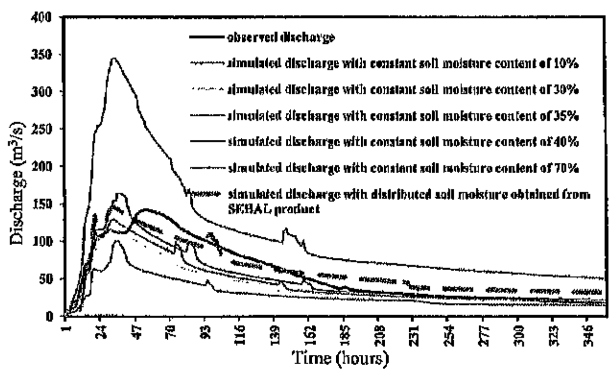

FIGURE 5. Sensitivity Analysis of the Effect of Initial Soil Moisture Distribution on the Difference between Simulated and Observed Hydrographs for Event 1 (Hendrickx *et al.*, 2009; Pradhan *et al.*, 2012).

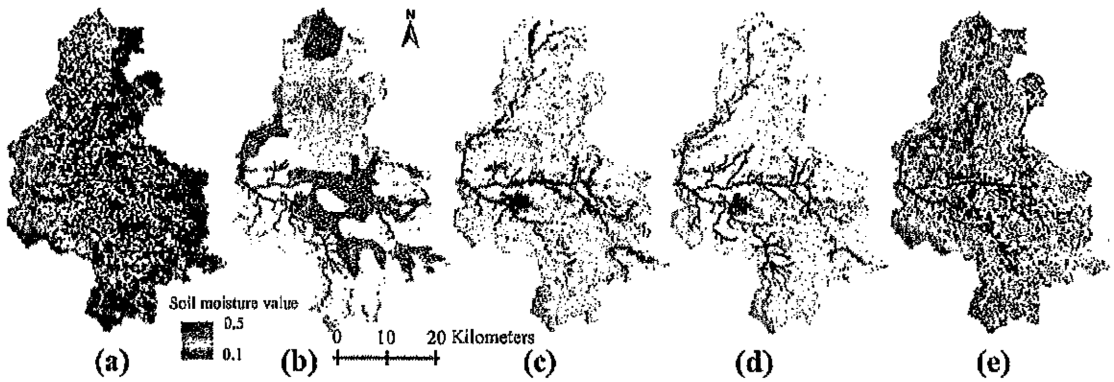

FIGURE 6. Relevant Soil Moisture Maps: (a) Surface Energy Balance Algorithms for Land (SEBAL)-derived soil moisture distribution on June 18, 2002, that is used to initialize the simulations of Event 1 starting on June 3 and Event 2 starting on August 21; GSSHA soil moisture predictions on day 16 of Event, i.e., June 18, starting with uniform initial soil moisture of, respectively, 10% (b), 40% (c), and 70% (d); (e) GSSHA soil moisture prediction on day 16 of Event 1, i.e., June 18, starting with distributed initial soil moisture derived from SEBAL soil moisture map on June 18.

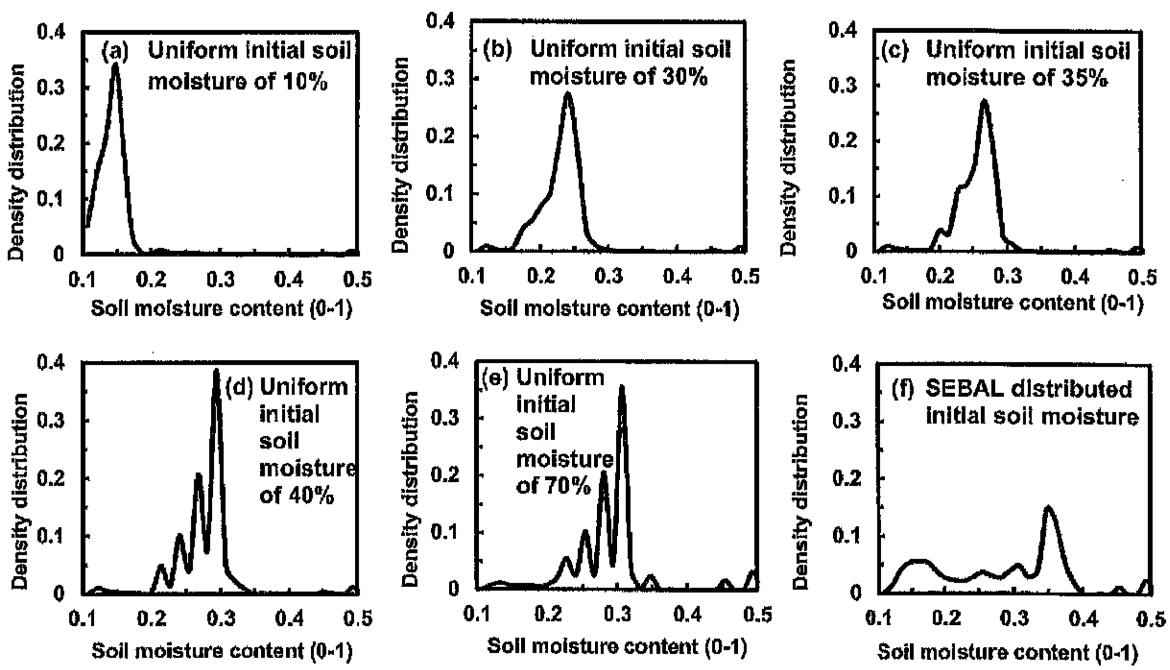

FIGURE 7. Comparison of Soil Moisture Density Distributions on Day 16, i.e., June 18, of the Simulation of Event 1. Each density distribution represents a different initial soil moisture condition. The horizontal axis represents "degree of saturation."

(Seneviratne *et al.*, 2010), estimate runoff (Schaake *et al.*, 1996), assess ET and soil moisture dynamics in ecohydrology (Guswa *et al.*, 2002), and optimize rainfed crop production (Ritchie, 1981b). In DPWM, the parameter TAW is critical to the assessment of groundwater recharge as — on a daily basis — all water added to a soil (precipitation, snowmelt and run-on) in excess of TAW becomes recharge.

DPWM estimates the daily water balance components of precipitation, ET, changes in soil water storage, runoff, recharge, sublimation, and snowmelt at fine-scale resolution within a watershed. The DPWM is a derivative of the MASSIF model developed by Sandia National Laboratory for the Yucca Mountain Project (Sandia National Laboratory, 2007). All components of MASSIF were developed from publically available, peer-reviewed literature and are primarily based on the United Nations FAO-56 methodology for computing ET (Allen *et al.*, 1998, 2005a, b, c, d). The DPWM improved on MASSIF and generalized the model application to areas outside of Yucca Mountain. Improvements include the following: (1) allowing for variable-sized grid cells for simulating concentrated surface water flow in ephemeral streams; (2) allowing for precipitation model data as input (e.g., PRISM, PERSIANN, or HRLDAS); (3) additional options for snowmelt and sublimation based on the HELP and INFIL model (Schroeder *et al.*, 1994; U.S. Geological Survey, 2008); and (4) incorporation of METRIC satellite data (Allen *et al.*, 2007a, b). DBS&A has applied DPWM to numerous basins in California, Nevada, and New Mexico for the determination of water rights and to estimate recharge and ET in groundwater models (Daniel B. Stephens & Associates, Inc., 2008, 2010a, b, 2011). METRIC has been incorporated in DPWM in the Salt Basin of New Mexico, the Clover Basin of Nevada, and the San Gabriel Mountains in California.

DPWM is a "second-generation" biophysical land surface model (Seneviratne *et al.*, 2010) that takes into account a storage reservoir for evaporation near the surface and one for transpiration from the root zone. Validation of the FAO-56 methodology against weighing lysimeter data and the water balance of the Imperial Irrigation District in California as well as against simulations with the HYDRUS model based on the Richards' equation (Šimunek *et al.*, 2008) demonstrated its strength to produce good estimates of evaporation from bare soils and transpiration from partial or full vegetation covers in agricultural lands (Allen *et al.*, 1998, 2005a, b, c; Allen, 2011). A DPWM validation for semiarid rangeland in southern New Mexico using 27 years of monthly soil water content measurements with the neutron probe to a depth of 130 cm showed that DPWM can adequately simulate observed root zone soil moisture dynamics at a point (Figure 8). These results as well as many other successful applications of relatively simple water balance models in the literature (Vereecken *et al.*, 2008; Seneviratne *et al.*, 2010) indicate that the physical basis of DPWM is rigorous and that it produces realistic representations of soil moisture dynamics and deep percolation if the model can be parameterized correctly.

This case study is conducted in the San Gabriel Mountains that are a fault-bounded mountain block north of the Los Angeles basin and south of the Antelope Valley. The mountains are primarily composed of granitic rocks with some marine sedimentary deposits in the northwest section of the block. Elevations range up to 3,069 m and snow is common at the highest elevations in winter months. Vegetation ranges from desert scrub where the mountain front meets the adjoining valleys to chaparral in the middle elevations up to large conifers at the highest elevations. Recharge from the San Gabriel Mountains provides groundwater to Antelope Valley to the north and to the Los Angeles basin to the south. Precipitation ranges from a mean annual rate of 1,400 mm at the mountain peaks down to 250 mm at the mountain front.

DPWM in its traditional application is parameterized using publically available data from the internet including the USDA SSURGO soils database, USGS GAP database on vegetation, USGS Digital Elevation Model (DEM), MODIS satellite data on vegetation cover, and USGS bedrock geology. Climate data were obtained from local weather stations and then spatially distributed over the model domain based on the PRISM algorithm. As the main purpose of DPWM is the prediction of long-term recharge rates, we selected the average annual groundwater recharge rate as the performance indicator for DPWM.

Benchmark Approach for DPWM

Benchmarking of DPWM was conducted by comparing the average annual groundwater recharge during 1980-2009 in the San Gabriel Mountains after calibration with Landsat-based METRIC and streamflow data to the recharge after calibration with streamflow data only, i.e., the traditional DPWM implementation. DPWM was calibrated to the METRIC data by adjusting in each cell the TAW for ET. The TAW is a permanent soil property for each cell; it is typically defined as

$$\mathrm{TAW} = \left(\theta_{\mathrm{fc}} - \theta_{\mathrm{wp}}\right) \times Z_{\mathrm{R}} \tag{13}$$

where θ_{fc} and θ_{wp} are the volumetric water contents at field capacity and wilting point in the root zone or evaporation zone, respectively, and Z_R is the rooting depth or the depth of the bare soil evaporation layer (e.g., Manabe, 1969; Allen *et al.*, 1998; Hillel, 1998; Romano and Santini, 2002; Kirkham, 2005). Equation (13) or variations thereof are often the method of choice for the assessment of TAW in distributed hydrologic models (Flint and Flint, 2007; Hyndman *et al.*, 2007; Sandia National Laboratory, 2007; U.S. Geological Survey, 2008; Daniel B. Stephens & Associates, Inc., 2010a) or in land data assimilation systems (Manabe, 1969; Sellers *et al.*, 1997; Seneviratne *et al.*, 2010). The equation is attractive as digitized

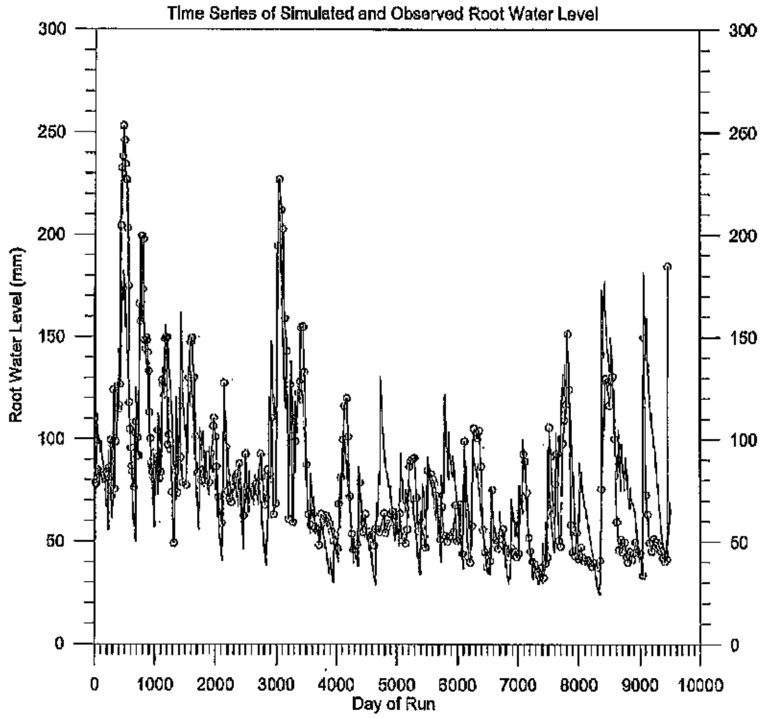

FIGURE 8. Comparison of Neutron Probe Measured (solid line) Versus Distributed Parameter Watershed Model (DPWM) Simulated (open circles) Root Zone Water Storage at a Desert Scrub Access Tube (C18) of the Jornada LTER Transect in New Mexico. The analysis shows that DPWM can simulate the long-term downward trend seen in the observed data as well as short-term changes in soil water increases following large precipitation events. Some discrepancies exist due to model error and/or measurement errors. The monthly measurements may miss peak increases in soil water in the top layer due to smaller rain storms; the neutron probe cannot measure soil water content well near the soil surface. Personal communication by Todd Umstot, November 2011.

geo-referenced soil and vegetation databases can be downloaded for determination of *field capacity* and *wilting point* as well as the *rooting depth* for each cell of distributed models. Soil data are provided by the Soil Survey Staff at the Natural Resources Conservation Service of the United States Department of Agriculture. The Soil Survey Geographic (SSURGO) Database for each state and the U.S. General Soil Map (STATSGO2) are available online at http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm (*accessed* June 15, 2015). USGS Land Cover Data are available at http://landcover.usgs.gov/usgslandcover.php and http://gapanalysis.usgs.gov (*accessed* June 15, 2015).

However, the simplicity of Equation (13) is deceptive because it is based on assumptions that have validity in deep homogeneous agricultural soils, but not in complex mountainous terrains. Field observations in the San Gabriel Mountains immediately revealed that roots search for water not only in well-defined soils but also in fractured bedrock; more advanced techniques even found enhanced vegetation water uptake by ectomycorrhizal fungi extending from bedrock roots (Allen, 2006). Bornyasz *et al.* (2005) estimated that in shallow soils on southern California hillsides plants extract as much as 86% of their water from the granite bedrock below the soil (Bornyasz *et al.*, 2005). Therefore, in shallow mountain soils barely covering fractured bedrock, the parameterization of Equation (13) using only soil and vegetation databases will result in a large bias in TAW and consequently significantly impact the simulation of ET, runoff, and deep percolation (Laio *et al.*, 2002; Rodriguez-Iturbe and Porporato, 2004).

Another assumption is that volumetric soil water content at *field capacity* and *wilting point* can be accurately derived from laboratory measurements or from information available in soil databases. However, these two terms are not well defined: *field capacity* is the "content of water remaining in a soil two or three days after having been wetted with water and after free drainage is negligible" and *wilt-*

ing point is "water content of a soil when indicator plants growing in that soil wilt and fail to recover when placed in a humid chamber" (Soil Science Glossary Terms Committee, 2008). Field capacity is influenced by many factors: soil texture, type of clay minerals, organic matter content, soil structure, depth of wetting, previous water content, presence of impeding layers in the profile, ET, water table depth, and temperature (Ritchie, 1981a, b; Ratliff *et al.*, 1983; Hillel, 1998; Kirkham, 2005). In the literature, soil water pressures of −330 cm and −100 cm have been typically used to identify field capacity but field capacities are reported to vary from −600 cm in a deep dryland soil to −5 cm in a highly stratified soil (Kirkham, 2005). Field capacities should be measured in the field as the effects of soil layering and hysteresis are difficult to mimic in the laboratory (Ratliff *et al.*, 1983; Cassel and Nielsen, 1986; Romano and Santini, 2002). In addition, there exists no definitive correlation between field capacity and soil texture (Bouma and Droogers, 1999; Ritchie *et al.*, 1999), nor is there justification to associate field capacity with a specific soil water pressure (Stein *et al.*, 2004). The wilting point is also a dynamic variable as it depends on the soil profile (soil texture, compaction, stratification), soil water contents, and root distributions at different depth, transpiration rate of the plant, temperature (Kirkham, 2005), and vegetation type (Hupet *et al.*, 2005; Seneviratne *et al.*, 2010).

The third assumption that the effective depth for root water uptake can be determined from field observations in soil pits may apply to agricultural fields with relatively shallow rooting depths but will fail in complex terrain due to the challenges of soil and root sampling at depth, and the difficulty of estimating *in situ* root activity over the entire root zone (Jackson *et al.*, 2000; Feddes *et al.*, 2001). In Australia, active soil depths, i.e., rooting depths, for agricultural crops, grass, and fallow based on field measurements of extractable water generally varied between 1 and 2 m, while those of trees are more variable ranging from 1 to 12 m, but active soil depths of 5 m were measured for crops and grass on deep sandy soils (Ladson *et al.*, 2006). In eastern Amazonia, water stored at 2-8 m soil depth contributed more than 75% of water uptake not only in forest but also in degraded pasture with deep-rooted woody plants during the severe dry season of 1992 (Nepstad *et al.*, 1994). Clearly, in mountainous areas where shallow soils force the roots to search for water in bedrock cracks, direct field observations for estimation of effective rooting depths are nearly impossible.

As the three assumptions needed for the use of Equation (13) are rarely met in complex terrain or even in agricultural areas, general consensus exists that instead of using some form of Equation (13) the TAW is best measured directly in the field (Israelsen and West, 1922; Ritchie, 1981a, b; Ratliff *et al.*, 1983; Hillel, 1998; Romano and Santini, 2002; Kirkham, 2005; Ladson *et al.*, 2006). However, field measurements in each soil-vegetation-geology unit of a watershed would take too much effort and expense even under the best of conditions with stone-free soils and shallow rooting depths. In addition, field measurements in areas where rooting depths exceed 2-3 m or where shallow soils are underlain by fractured bedrock are nearly impossible and certainly cannot be completed on a regional scale. The challenge of cost-effective regional TAW mapping can only be met by using remote sensing. Based on our experience with regional mapping of ET and root zone soil moisture in the southwestern U.S. (Fleming *et al.*, 2005; Hendrickx and Hong, 2005; Hong, 2008; Hong *et al.*, 2009, 2011b), Illinois (Hendrickx *et al.*, 2009), Panama (Hendrickx *et al.*, 2005), West Africa (Compaoré *et al.*, 2008), Afghanistan (Hendrickx *et al.*, 2011b), and — more recently — in the Sacramento Mountains of New Mexico and the San Gabriel Mountains of California (Hendrickx *et al.*, 2011a), we recognize that reliable TAW estimates can be derived from a series of Landsat images captured during seasons of water-limited conditions using the following procedure.

Step 1: Select Landsat Images. The availability and quality of Landsat images for any area of interest in the U.S. can be quickly determined at the USGS web page glovis.usgs.gov. After making an inventory of all cloud-free images for the San Gabriel Mountains, we applied two more selection criteria: (1) the image must reflect land surface conditions during the growing season when vegetation is active; and (2) the image must reflect land surface conditions with dry canopies and soil surfaces, i.e., no precipitation in the days before image acquisition. The first criterion assures that the effects of root water uptake are taken into account for determination of TAW in a pixel. The second criterion is needed as we need only information that reflects water uptake from the root zone or evaporation where soils are bare. Therefore, we want to eliminate images that will result in METRIC ET images that include the effects of evaporation from canopy and/or soil surface due to recent precipitation. For this study, we used 15 Landsat images acquired during the growing season in a wet (2005), normal (2003), and dry (2007) precipitation year.

Step 2: Use METRIC and the Evaporative Fraction Method for Retrieval of Soil Moisture Maps. Each Landsat image was processed with METRIC for derivation of the components of the energy balance for each pixel. Equations (2) and (3) were then used to generate the root zone soil moisture map; soil moisture on this map is expressed as the "degree of soil moisture" from 0 for dry conditions to 1 for conditions where soil moisture is not limiting ET.

Step 3: Determine the Wetness Score for Each Pixel. The wetness score of a pixel is the sum of its "degree of soil moisture" values for all soil moisture maps prepared for a project. If 15 Landsat images are used for the determination of TAW, the wetness score of a pixel may vary from 0 to 15 × 1.0 = 15.0. Thus, the wetness score is a relative measure of the overall wetness of a pixel compared to other pixels. As the METRIC algorithm and the evaporative fraction method for soil moisture have a sound scientific basis and have been validated by field measurements and observations, the wetness score map provides a reliable presentation of the overall wetness distribution in the San Gabriel Mountains. As the DPWM cell size is 270 × 270 m, the 30 × 30 m Landsat wetness scores have been up-scaled by averaging 81 Landsat scores for each DPWM cell.

Step 4: Determine the Qualitative Relationship between Wetness Score and Total Available Water (TAW). There is ample practical and theoretical evidence that the response of root zone soil moisture to precipitation and ET is, to a large extent, determined by TAW. Following an example by Ritchie (1981b), consider a crop canopy fully covering the ground growing in three soils I, II, and III having a TAW of 10, 120, and 300 mm, respectively. Before the onset of a 30-day period without any precipitation a net precipitation surplus of 300 mm was received that filled the three soils to their maximum TAW. In soils I and II only 10 and 120 mm, respectively, can be stored with the remainder of the surplus precipitation becoming runoff or deep percolation. Assume an ET rate of 5 mm/day and an onset of water stress when more than 50% of the extractable soil water is consumed. Then, these three soils will not show any stress for, respectively, 1, 12, and 30 days. In other words, the amount of available water in these three soils during the dry period is determined only by TAW: the larger the TAW, the higher the degree of soil moisture in the root zone and ET during the dry period. This empirical finding by Ritchie (1981b) has been confirmed by more complete studies using advanced stochastic bucket-type water balance models (Milly, 1994, 2001; Milly and Dunne, 1994; Rodriguez-Iturbe *et al.*, 1999; Laio *et al.*, 2001, 2002; Rodriguez-Iturbe and Porporato, 2004; Seneviratne *et al.*, 2006, 2010). Therefore, we conclude that for most practical applications under water-limited conditions a negative correlation exists between the TAW and the number of days with water-stressed vegetation between two precipitation events. In the context of this study, this means "the lower the wetness score, the lower the TAW."

Step 5: Quantify the Relationship between Wetness Score and Total Available Water (TAW). For the TAW parameterization of distributed bucket-type water balance models, we need a quantitative relationship between the wetness score determined from the soil moisture images retrieved by METRIC on days with cloud-free Landsat images and TAW. We quantify and optimize this relationship by minimizing the differences or mean error between METRIC-observed and DPWM-simulated "degree of soil moisture" distributions for seven different TAW distribution scenarios. Each TAW scenario is characterized by its minimum and maximum value. The lowest TAW value is taken as 15 mm thought to occur in a pixel where most of the water is stored in a few bedrock fractures; the highest TAW value is 1,000 mm thought to occur in a deep soil profile covered by trees. TAW scenario I has a constant low value of 15 mm in all pixels while TAW scenarios II through VII have a minimum value of 15 mm and maximum values of, respectively, 100, 200, 300, 400, 600, and 1,000 mm. These TAW values seem reasonable as compared to the values in the *Australia Data Base* published by Ladson *et al.* (2004, 2006) that contains field measured TAW values for 180 locations in Australia with annual precipitation from about 50 to 1,200 mm. The lowest and highest measured TAW values in Australian soils are, respectively, 20 and 690 mm with most values between 40 and 300 mm.

The optimization procedure that we used is based on a linear relationship between the wetness score and the TAW value. For example, in TAW scenario III, the maximum possible TAW value is set equal to 200 mm. Therefore, the maximum wetness score equals 200 mm and the minimum 15 mm. All other wetness scores for scenario III are found by linear interpolation between these two extreme values. Repeating this procedure for the other maximum possible TAW values yielded seven different regional TAW distributions. For each one of these TAW distributions, DPWM simulated deep percolation — the variable of most interest for groundwater recharge studies — for a period of 30 years generating a large number of daily soil moisture distributions. The optimal TAW distribution is the one with the smallest difference between observed soil moisture values (from METRIC) and simulated soil moisture values (by DPWM). Figure 9 shows that the TAW distribution based on a maximum TAW of 200 mm yields the smallest error and, therefore, we used this TAW distribution for the final simulation to determine the 30-year average groundwater recharge rate in the San Gabriel Mountains. The METRIC TAW distribution captures the variability of TAW at the 30 m pixel scale which is much finer than the traditional TAW

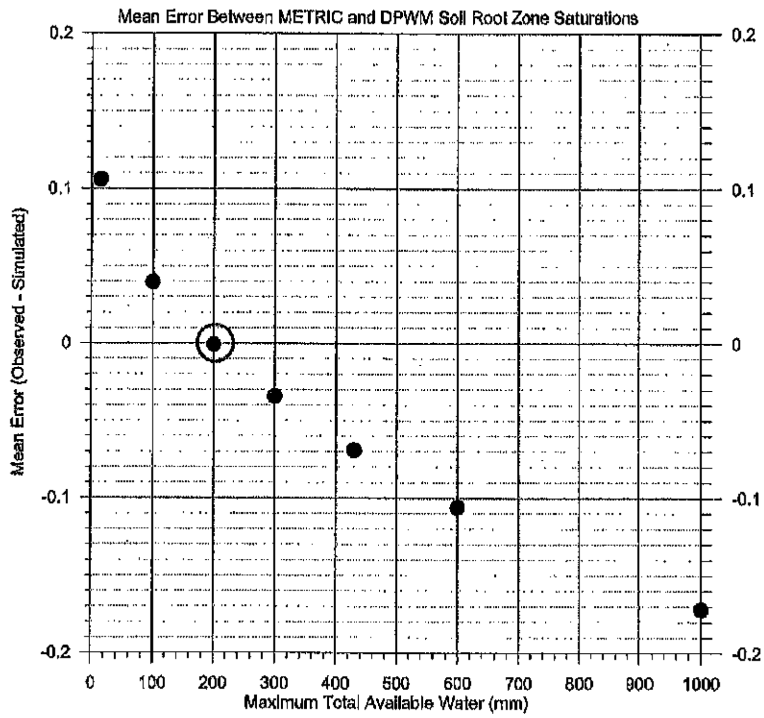

FIGURE 9. Mean Error between METRIC Observed and Distributed Parameter Watershed Model Simulated Root Zone Soil Moisture for Seven Different Total Available Water (TAW) Distributions Based on Their Maximum TAW Value. The TAW distribution with a maximum TAW value of 200 mm yields the smallest error.

distribution that mirrors the soil and vegetation unit scale on the order of 100 m or more.

Benchmark Results for DPWM

Figure 10 shows annual deep percolation, aggregated over the entire San Gabriel Mountain range, simulated with the traditional DPWM approach and with METRIC soil moisture information obtained from Landsat imagery. The average annual recharge for the traditional and METRIC DPWM implementations over the San Gabriel Mountains are, respectively, 0.532 and 0.380 cubic kilometer or 21.3 and 15.2 mm equivalent water depth. So, the use of Landsat imagery for parameterization of the TAW distribution resulted in a lower average annual recharge rate than the one estimated by the traditional DPWM approach. The reason is that Landsat imagery provides the tools to take into account the part of TAW that is stored in bedrock fractures while the traditional DPWM application based on Equation (13) does not. As the recharge rate is negatively correlated with TAW, it decreases when bedrock moisture storage and ET is included in the analysis.

Figure 11 shows the spatial distribution of average annual recharge for the San Gabriel Mountains after parameterizing DPWM with the METRIC-derived optimal TAW distribution (Hendrickx *et al.*, 2011a). The distribution of recharge partly reflects the distribution of the precipitation with higher recharge rates occurring at higher elevations where annual precipitation values increase to 1,400 mm and lower rates at lower elevations where annual precipitation is as low as 250 mm. Such pattern is typical of mountain regions (Guan *et al.*, 2009).

The validation of model-predicted groundwater recharge rates in semiarid regions and mountain blocks is challenging due to the wide range of topographic, geological, geomorphological, and climatic conditions. For that reason, it is recommended to use as many different techniques as possible to constrain estimates of recharge rates including the use of groundwater models (Hendrickx and Walker, 1997; Scanlon, 2004). A simple two-dimensional, cross-sectional groundwater model was developed along cross-section AA′ in the middle of the San Gabriel Mountains as shown in Figure 11. The cross-section runs from Crescenta Valley on the south, follows the Angeles Forest Highway across

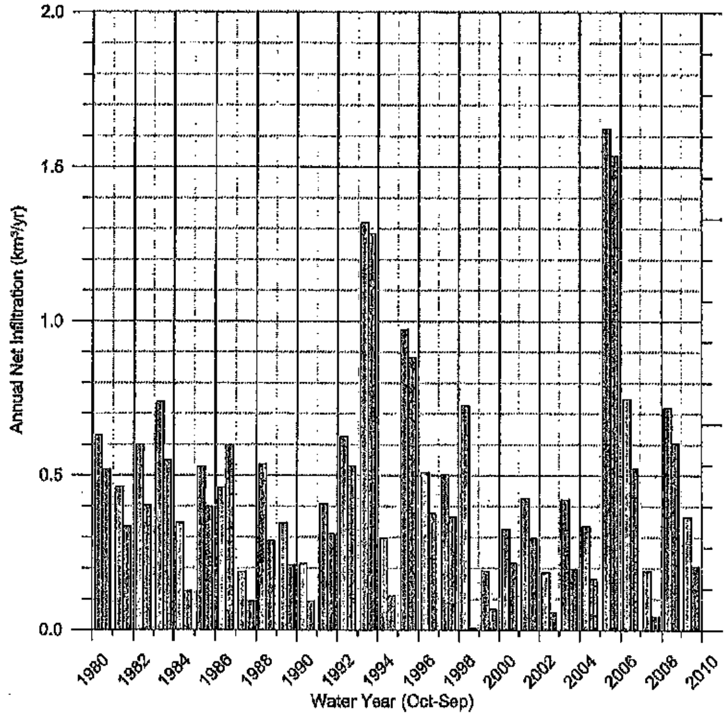

FIGURE 10. Comparison of Average Annual Deep Percolation before (brown) and after (yellow) Using Landsat Imagery for the Parameterization of the Total Available Water (TAW) Distribution in the San Gabriel Mountains.

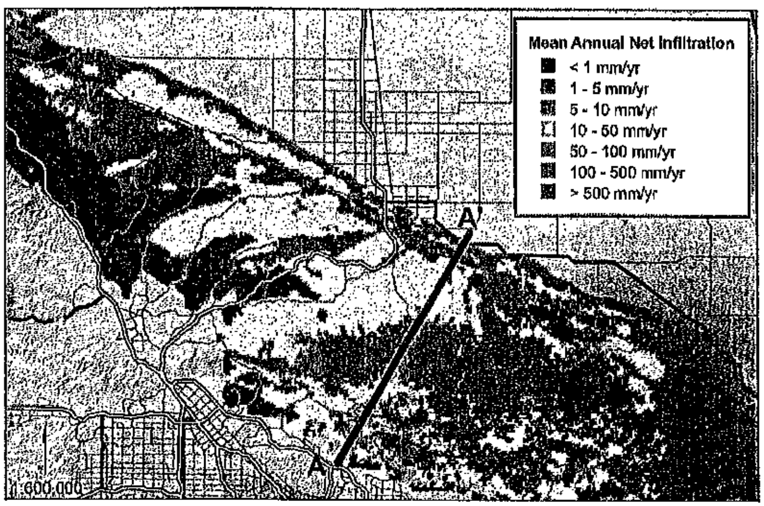

FIGURE 11. Average Annual Groundwater Recharge Rate of Each Pixel Using Landsat Imagery with 30 Years of Daily Simulations of Soil Water Balance with Distributed Parameter Watershed Model (DPWM). The cross-section AA' was used for the simulation of groundwater table depths before and after using METRIC soil moisture data for calibration of DPWM (see Figure 12).

the crest of the mountain, and terminates at Pearblossom, California on the north. To evaluate the water table elevation within the mountain block, steady-state groundwater simulations were conducted with MODFLOW-SURFACT using spatially distributed annual recharge estimated by DPWM for the 30-year simulation period. Constant heads were specified on the north and south ends of the cross-section based on the mean groundwater elevations observed in wells in the adjacent valleys. Drain boundary conditions were specified along the cross-section where the cross-section crossed a mapped stream. Hydraulic properties varied in the horizontal direction but were homogeneous in the vertical direction as it was assumed that the geologic unit mapped at the surface represented the underlying units. The vertical hydraulic conductivity used in the groundwater model was the same as assigned to DPWM while the horizontal hydraulic conductivity was assumed to be 10 times the vertical hydraulic conductivity. There are no known wells to provide observations of groundwater elevations along the cross-sections but it is known that streams at the lower elevations, such as Little Rock Creek, have perennial flow from groundwater discharge (Duell, 1987; California Department of Water Resources, 2004), while streams at the higher elevations only have ephemeral flow (Izbicki *et al.*, 2007). Therefore, simulated heads should be high enough to generate discharge at the drain boundary cells at lower elevations, while simulated heads at the higher elevations should be lower than the specified drain elevations. Before DPWM was calibrated with the METRIC soil moisture data, the estimated recharge and corresponding water table appeared too high because permanent discharges were simulated in a high-elevation stream that should be ephemeral. After calibration of DPWM to the METRIC data, the simulated water table corresponded with the observations of perennial and ephemeral stream discharges (Figure 12). This is strong evidence that the use of Landsat imagery can improve the parameterization of TAW distributions and the quality of the groundwater recharge simulations.

Another validation is obtained using detailed soil (Soil Survey Staff, 2013), vegetation (Lennartz *et al.*, 2008), and geology (Ludington *et al.*, 2007) databases. For the San Gabriel Mountains, these data-

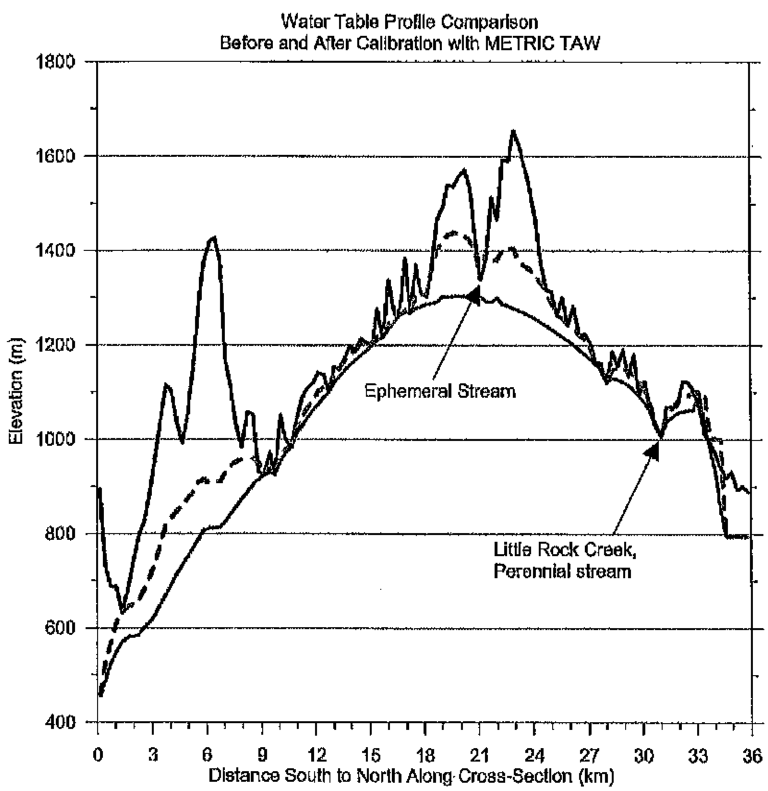

FIGURE 12. Land Surface Elevation and Simulated Groundwater Table Depths without (dashed line) and with (lower solid line) Using Landsat Imagery for the Parameterization of the Total Available Water in Distributed Parameter Watershed Model (DPWM). The ephemeral stream is discharging or perennial when no Landsat imagery is used but becomes clearly ephemeral or nondischarging when Landsat imagery is used for the parameterization of DPWM.

bases contain 229 different soil series, 20 vegetation classes, and 13 bedrock types; together they present 229 × 20 × 13 = 59,540 unique environmental units that affect the groundwater recharge processes. For the traditional DPWM approach, the 4,580 soil-vegetation units have been used in Equation (13) for the parameterization of the TAW_{trad} distribution. For the parameterization of the Landsat-based TAW_{METRIC} distribution, no information from these databases was used except the vegetation classes for the assessment of the vegetation height in each cell for estimation of the roughness length needed for calculation of the sensible heat flux. Therefore, TAW_{trad} is a product directly derived from the databases while TAW_{METRIC} has been determined independently from them. Yet, the cited literature above leaves no doubt that TAW principally depends on the soil and vegetation unit. This leads to the hypothesis that the TAW_{METRIC} distribution derived from Landsat imagery should show some relationship with the information in the databases. In other words, if the TAW_{METRIC} distribution is a true representation of total water availability distribution in the San Gabriel Mountains, it should be possible to predict with some degree of accuracy TAW_{METRIC} for each cell in the model from its soil, vegetation, and bedrock geology class. We test this hypothesis by performing a general linear models (GLM) procedure with SAS software; the results of the GLM analysis are presented in Table 5.

Sixty-eight percent of the variability of TAW_{METRIC} in the San Gabriel Mountains is explained by the independent variables Soil, Vegetation, and Bedrock and their interactions S*V, S*B, and V*B with a mean square error of 24 mm. In addition, the values in the table show several other interesting features. First of all, there are two R-squares with a value of 100%; these occur when the independent variables Soil and Vegetation plus their interaction term S*V are part of the linear model for explanation of the variability in the dependent variable TAW_{trad}. The value of 100% is expected as the use of Equation (13) for the calculation of TAW_{trad} only involves Soil and Vegetation characteristics. Of interest is the rather large interaction effect S*V that explains 100 − 62 = 38% of the variability in TAW_{trad}. It means that the effect of Soil on TAW_{trad} depends not only on the soil type but also on the type of Vegetation; the physics for this phenomenon are demonstrated in Equation (13) where in the same soil

TABLE 5. The General Linear Model Procedure of SAS Software Used to Assess How Total Available Water (TAW) Calculated Following the Traditional DPWM Approach (TAW_{trad}) and Using Landsat Imagery (TAW_{METRIC}) Depending on Soil, Vegetation and Bedrock Geology Classes. The dependent variables are TAW_{trad} and TAW_{METRIC}; the independent variables are soil class (S), vegetation class (V) and bedrock geology (B). This analysis was based on the values in 57,423 cells, i.e., the complete population of the area under consideration.

Dependent Variable	Independent Variable[1]	R^2 (%)	Coefficient of Variation (%)	Mean Square Error (mm)	F-value[2] (–)
TAW_{trad}	S, V, B, S*V, S*B, V*B	100	0	0	Infinity
TAW_{METRIC}	S, V, B, S*V, S*B, V*B	68	20	24	56
TAW_{trad}	S, V, B	62	92	78	364
TAW_{METRIC}	S, V, B	60	22	26	336
TAW_{trad}	S, V, S*V	100	0	0	Infinity
TAW_{METRIC}	S, V, S*V	64	21	25	73
TAW_{trad}	S, V	62	92	78	389
TAW_{METRIC}	S, V	60	22	26	346
TAW_{trad}	V, B, V*B	20	133	113	95
TAW_{METRIC}	V, B, V*B	36	28	33	216
TAW_{trad}	V, B	13	139	117	278
TAW_{METRIC}	V, B	34	28	33	952
TAW_{trad}	S, B, S*B	59	96	81	94
TAW_{METRIC}	S, B, S*B	63	21	25	109
TAW_{trad}	S, B	56	99	84	303
TAW_{METRIC}	S, B	58	23	27	327
TAW_{trad}	S	56	100	84	317
TAW_{METRIC}	S	57	23	27	338
TAW_{trad}	V	8	147	124	87
TAW_{METRIC}	V	25	30	36	992
TAW_{trad}	B	11	140	119	562
TAW_{METRIC}	B	16	32	38	941

[1]S = soil unit, V = vegetation unit, and B = bedrock unit. S*V = interaction effect between soil and vegetation, S*B = interaction effect between soil and bedrock, and V*B = interaction effect between vegetation and bedrock. S, V, and B are the main effects while S*V, S*B, and V*B are the interaction effects considered in the general linear models (SAS software).
[2]All F-values have a probability of occurrence <0.0001 indicating that all models are very significant.

different rooting depths will result in different values for TAW_{trad}. The linear model that uses only the independent variable Vegetation to explain the variability in TAW_{trad} yields the smallest R^2 value of 3% but this does not mean that Vegetation is nonsignificant. On the contrary, the S*V interaction effect is a major factor determining TAW_{trad}.

As a check on the GLM analysis, a third TAW distribution was generated consisting of randomly assigned TAW values to each cell of DPWM. The range of these TAW values was identical to the one of TAW_{METRIC}. The R^2 values of the random linear models were all close to zero and never larger than 0.025% indicating that no relationships exist between the independent and dependent variables. In large contrast, the R^2 values of the TAW_{METRIC} linear models ranged from a high of 68 to a low of 16%, although none of the subsurface soil, vegetation, and bedrock information in the databases was used for the generation of TAW_{METRIC}.

We conjecture that the 32% unexplained variability is due to soil, vegetation, and bedrock variability within map units that characterize the heterogeneous San Gabriel mountain block. For example, Bregt and Beemster (1989) found that spatial variability within soil map units caused an error of 50% in the estimation of moisture deficits for soil map scales between 1:25,000 and 1:50,000. Against this background, the explanation of 68% of the variability of TAW_{METRIC} by Soil, Vegetation, Bedrock, and their interactions is a remarkable feat that gives much confidence in the accuracy of the TAW_{METRIC} distribution obtained from Landsat imagery.

Benchmark Conclusion for DPWM

The difference between the average annual groundwater recharges determined without and with optical/thermal satellite imagery is 0.152 cubic kilometer or 6.1 mm. The relative difference between the traditional approach and the METRIC methodology is 28.5%. Therefore, optical/thermal satellite imagery has a large relative impact on the recharge estimates by DPWM. Two validations using the modeled groundwater table elevations along cross-section AA′ and the large percentage of the TAW_{METRIC} distribution explained by soil, vegetation, and bedrock variability provide a strong indication that thermal-equipped Landsat imagery has a great potential to considerably improve groundwater recharge estimates for semiarid mountain blocks.

A recharge difference of only 6.1 mm seems of minor societal importance but it is not. The present price for the water rights of one acre-foot of water in southern California is approximately $10,000. Thus, the monetary value of the recharge difference between the two approaches is well over one billion U.S. dollars and an accurate determination of groundwater recharge is of the utmost importance for fair and equitable settlements of water rights cases.

OVERALL CONCLUSION OF THE THREE CASE STUDIES

In this study, we have benchmarked applications of three operational hydrologic decision support models without and with using optical/thermal satellite imagery for forcing functions, estimation of initial conditions, and model parameterization. The three operational hydrologic decision support tools are the ET Toolbox, the GSSHA model, and the DPWM. Our benchmarking method is straightforward by comparing a typical traditional application of each decision support tool with one that uses information from optical/thermal satellite imagery. Each comparison is based on a performance indicator: annual ET forecasts for ET Toolbox, storm hydrographs for GSSHA, and average annual groundwater recharge volumes for DPWM. Using the SEBAL/METRIC approach for processing MODIS or Landsat imagery, we obtained spatial distributions of the forcing function of ET in ET Toolbox, initial soil moisture conditions in GSSHA, and the model parameter "total available water for transpiration (TAW)" in DPWM.

In the ET Toolbox benchmark test, the annual ET difference between ET computed from a traditional, assigned K_c ET_{ref} ($ET_{Kc\text{-}NMSU}$) and ET computed from K_c derived spatially from METRIC Landsat ($ET_{Kc\text{-}METRIC}$) over the MRGCD command area (i.e., between the traditional and satellite imagery approaches) was 228 mm or 30%; $ET_{Kc\text{-}METRIC}$ was the largest with 771 mm/yr. Considering the validated METRIC applications with MODIS imagery in the Rio Grande Valley, optical/thermal imagery has the potential to considerably improve not only the accuracy of the area-wide ET forecasts in the MRGCD but to also provide detailed information on when, where, and how much water evaporates and transpires. Such information is needed for the development of climate-proofing strategies (Kabat *et al.*, 2005) for the Middle Rio Grande Valley.

In the GSSHA benchmark test, the comparison of two measured hydrographs with the hydrographs simulated with and without using an initial soil moisture distribution generated from Landsat imagery established that the use of Landsat-generated initial soil moisture distributions resulted in superior simulations. In addition, we found that the rank order stability of soil moisture patterns can make it possible to use SEBAL/METRIC-derived soil moisture maps for model initialization on dates that are days or weeks apart in the future or past from the image day.

In the DPWM benchmark test, the difference between the average annual groundwater recharge determined without and with using a TAW parameterization generated from Landsat imagery equaled 0.152 cubic kilometer or 6.1 mm of water. The relative difference between the traditional approach and the METRIC methodology is a decrease of 28.5% using the latter. Two independent validations based on the groundwater table elevations along a cross-section through the San Gabriel Mountains and the large percentage of the TAW_{METRIC} distribution explained by soil, vegetation, and bedrock variability provide a strong indication that Landsat imagery has a great potential to considerably improve groundwater recharge estimates for semiarid mountain blocks.

The overall conclusion of this benchmark study is that the use of NASA optical/thermal satellite imagery can considerably improve hydrologic decision support tools compared to their traditional implementations. As the water resources of the U.S. are a $200 billion per year economic engine that supports hundreds of thousands of jobs, the costs for Landsat (estimated at about $250 million per year) (Western States Water Council, 2012) and MODIS are only a fraction of the potential benefits. Therefore, this benchmark study demonstrates that the benefits of improved decisions by hydrologic support systems using optical/thermal satellite imagery vastly exceed the costs for acquisition and use of such images.

ACKNOWLEDGMENTS

We acknowledge financial support by NASA under Cooperative Agreement #NNA06CN01A, support by the Idaho Agricultural Experiment Station, and support by the USGS Landsat Science Team (Allen).

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PROOF OF SERVICE (C.C.P. §1013a, 2015.5)

I am employed in the County of Kern, State of California. I am over the age of 18 and not a party to the within action; my business address is 1810 Westwind Drive, Bakersfield, CA 93301.

On November 12, 2021, I served the foregoing document(s) entitled:

LIST OF EXHIBITS RE OPPOSITON BY THE ZAMRZLA'S TO THE WATERMASTER'S MOTION FOR MONETARY, DECLARATORY AND INJUCNTIVE RELIEF AGAINST ZAMRZLA'S

X by placing _ the original, X a true copy thereof on all interested parties.

X **BY ELECTRONIC SERVICE:**
I posted the document(s) listed above to the Santa Clara Superior Court Website @ www.scefiling.org and Glotrans website in the action of the Antelope Valley Groundwater Cases.

X (State) I declare under penalty of perjury under the laws of the State of California that the above is true and correct.

Executed on November 12, 2021, at Bakersfield, California.

Serena Bravo
SERENA BRAVO