Case No. 84739

IN THE SUPREME COURT OF THE STATE OF NEVADA

Electronically Filed
Nov 08 2022 04:38 p.m.
Elizabeth A. Brown
Clerk of Supreme Court

ADAM SULLIVAN, P.E., NEVADA STATE ENGINEER, et al.

Appellants,

vs.

LINCOLN COUNTY WATER DISTRICT, et al.

<u>JOINT APPENDIX</u>

VOLUME 46 OF 49

Kane Springs Valley Well Construction and Testing

Prepared for

Lincoln County Water District and Vidler Water Company

Presentation to the

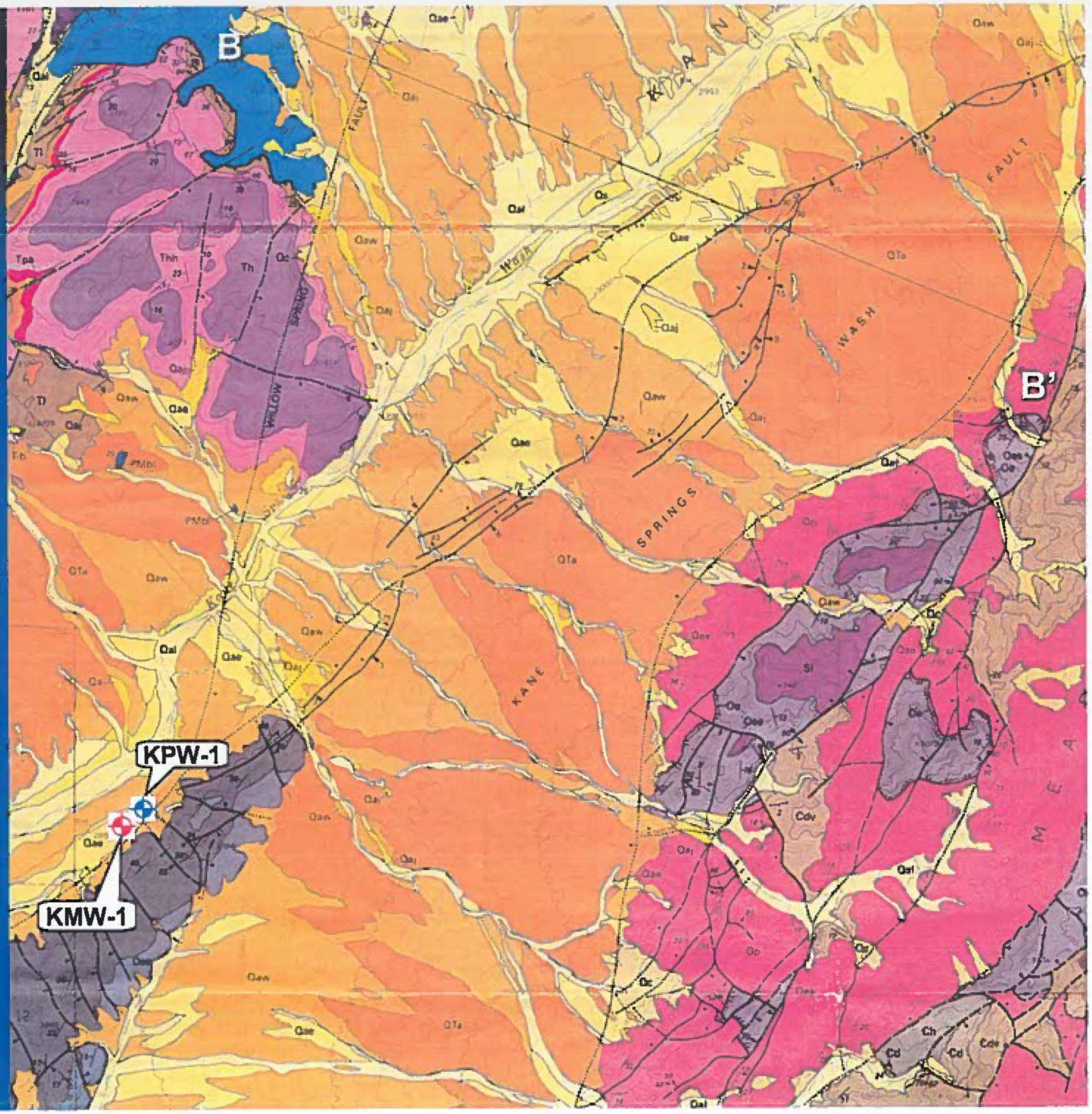
Office of the Nevada State Engineer

URS

April 2006

COPY EX22

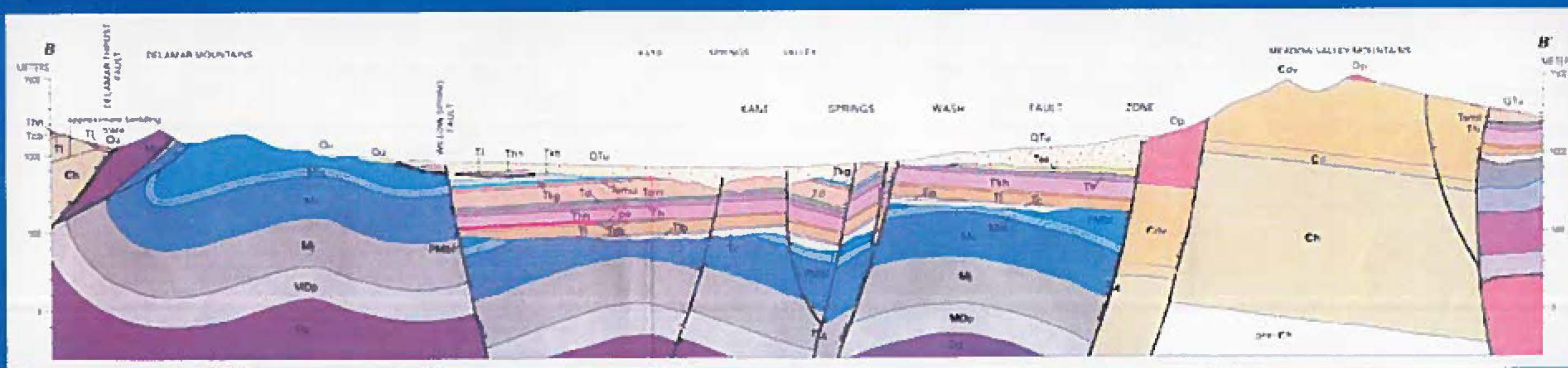
Geologic Map



Source:
Swadley et al. 1994

USGS Map GQ-1754

Geologic Cross-section
B-B' Kane Springs Valley



Source:
Swadley et al. 1994

USGS Map GQ-1754

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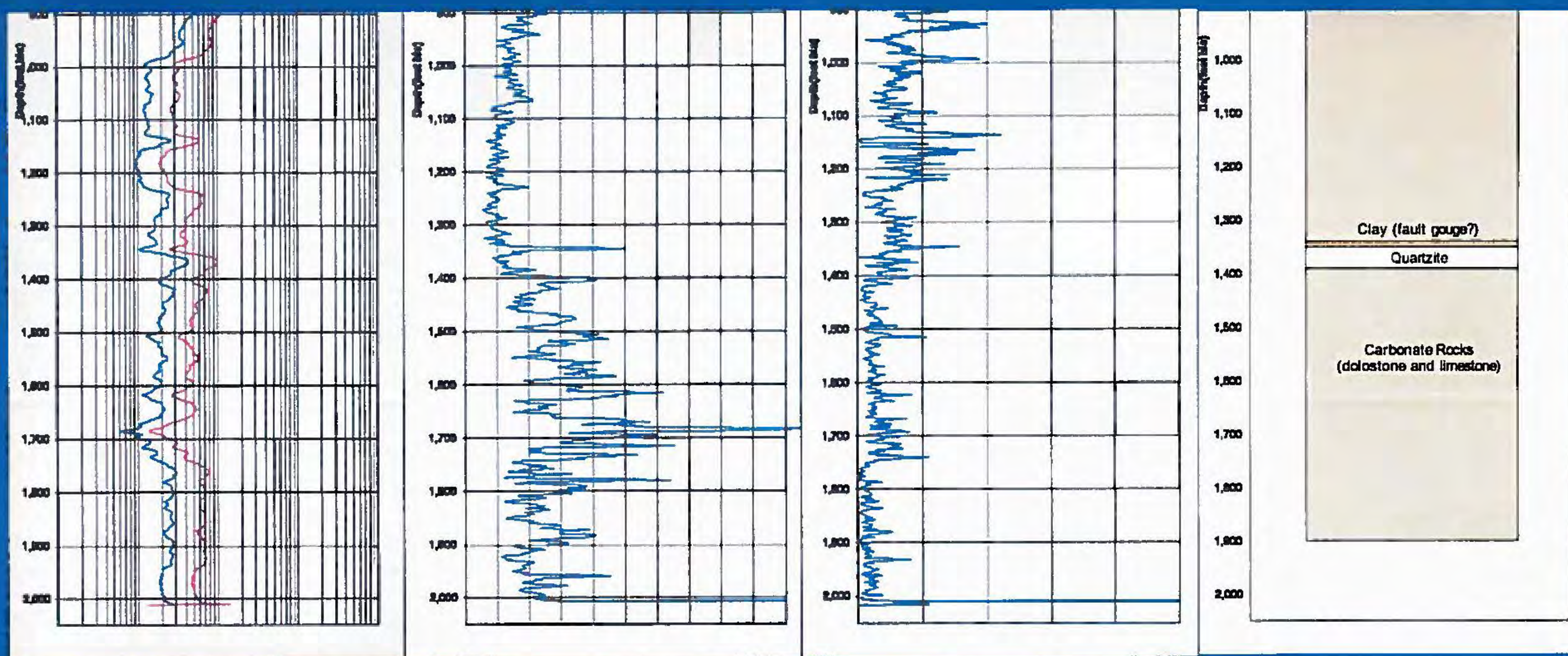
Geophysical and Geologic Columns for Well KMW-1



Resistivity Short- & Long-Normal (10-100,000 ohm-m)

Gamma (0-100 API units)

Porosity (0-50%)

Lithology

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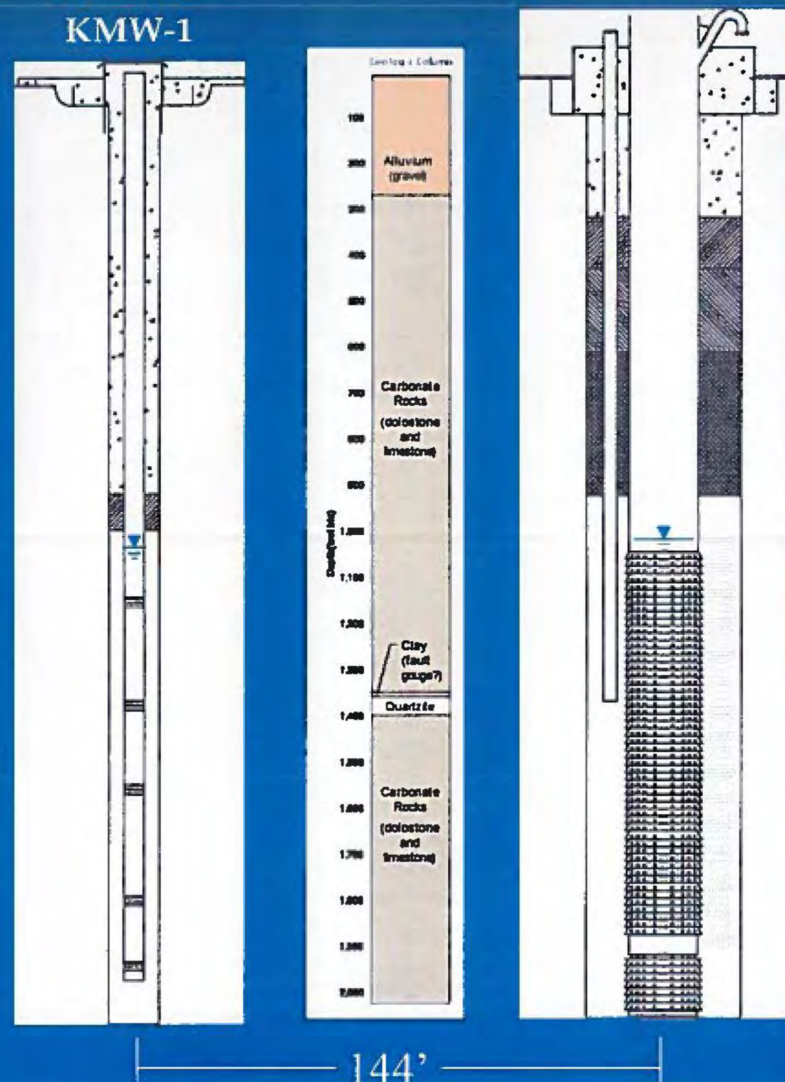
Kane Springs Valley Monitor and Production Well Designs

KMW-1

KPW-1



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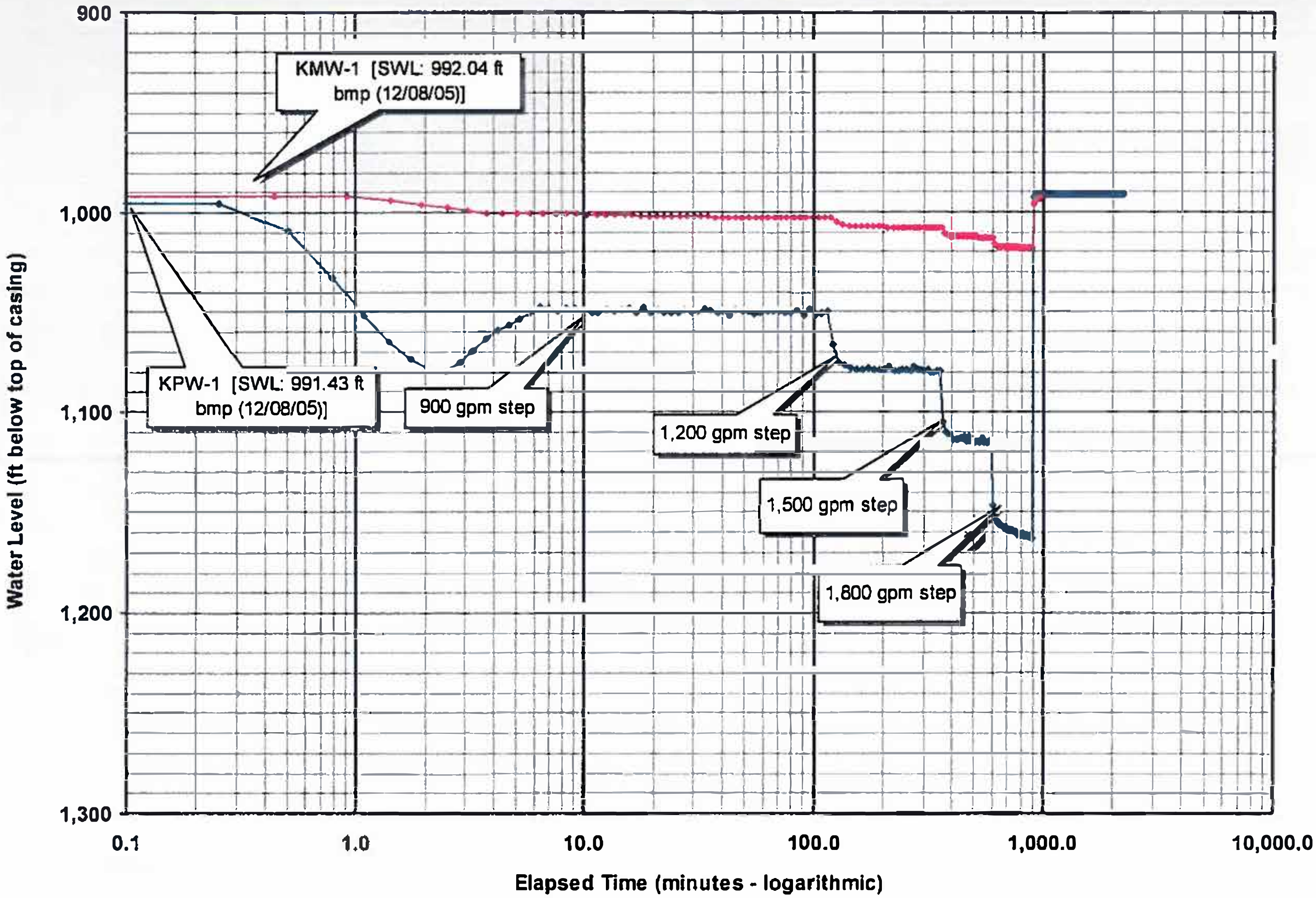
Kane Springs Valley Wells KMW-1 and KPW-1 Step-Discharge Test Results



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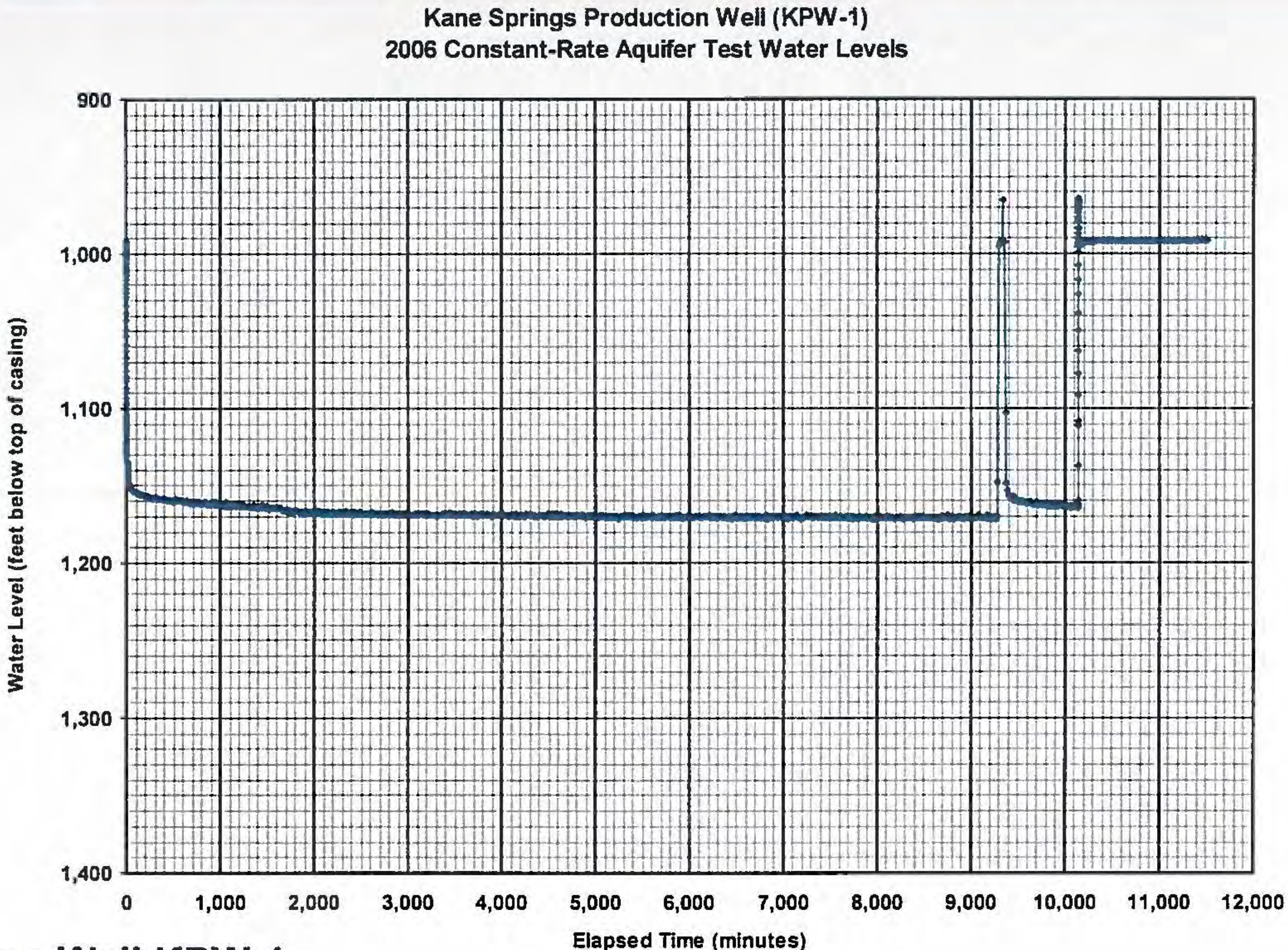
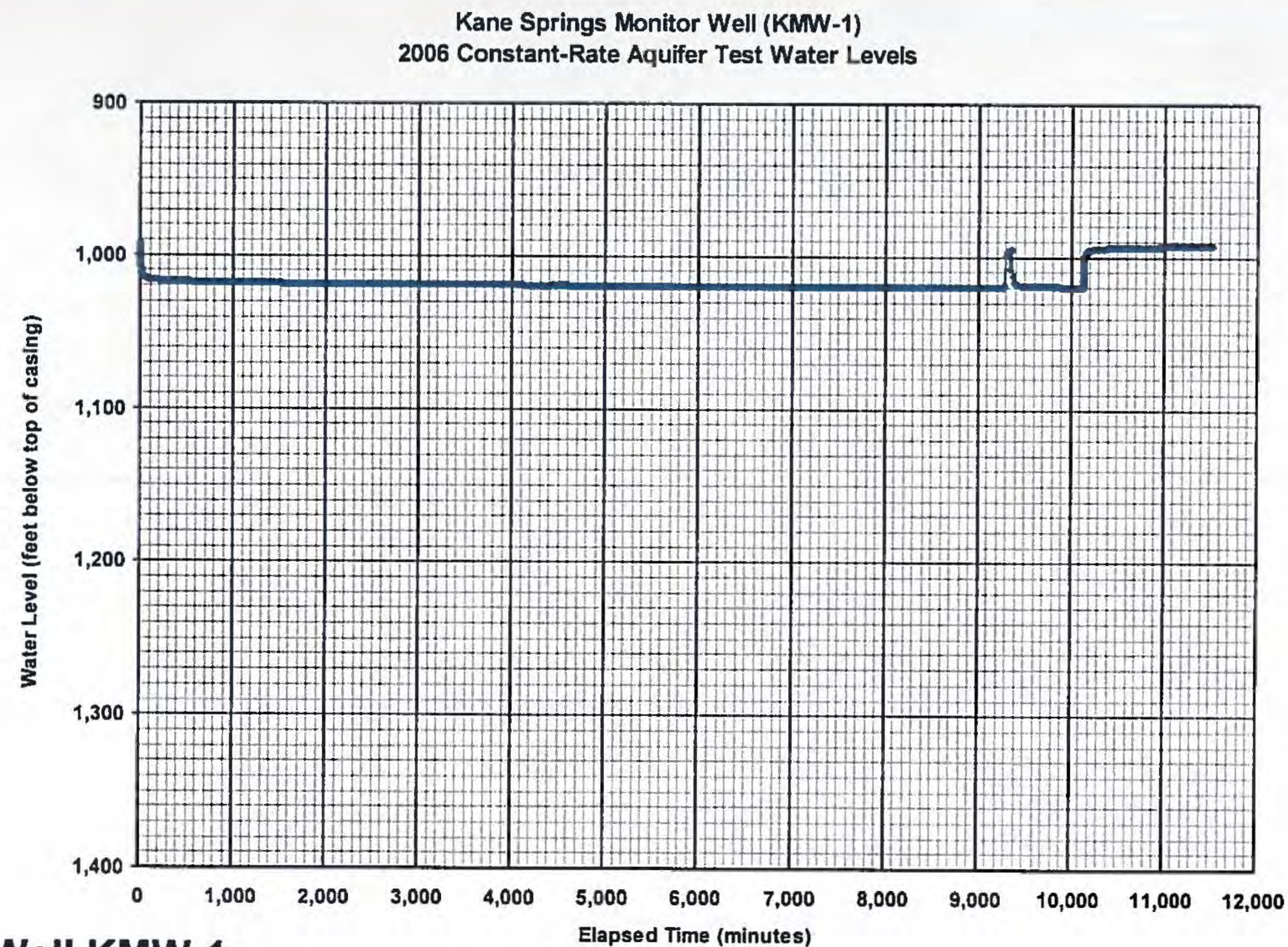
Constant-Rate Discharge Test Results



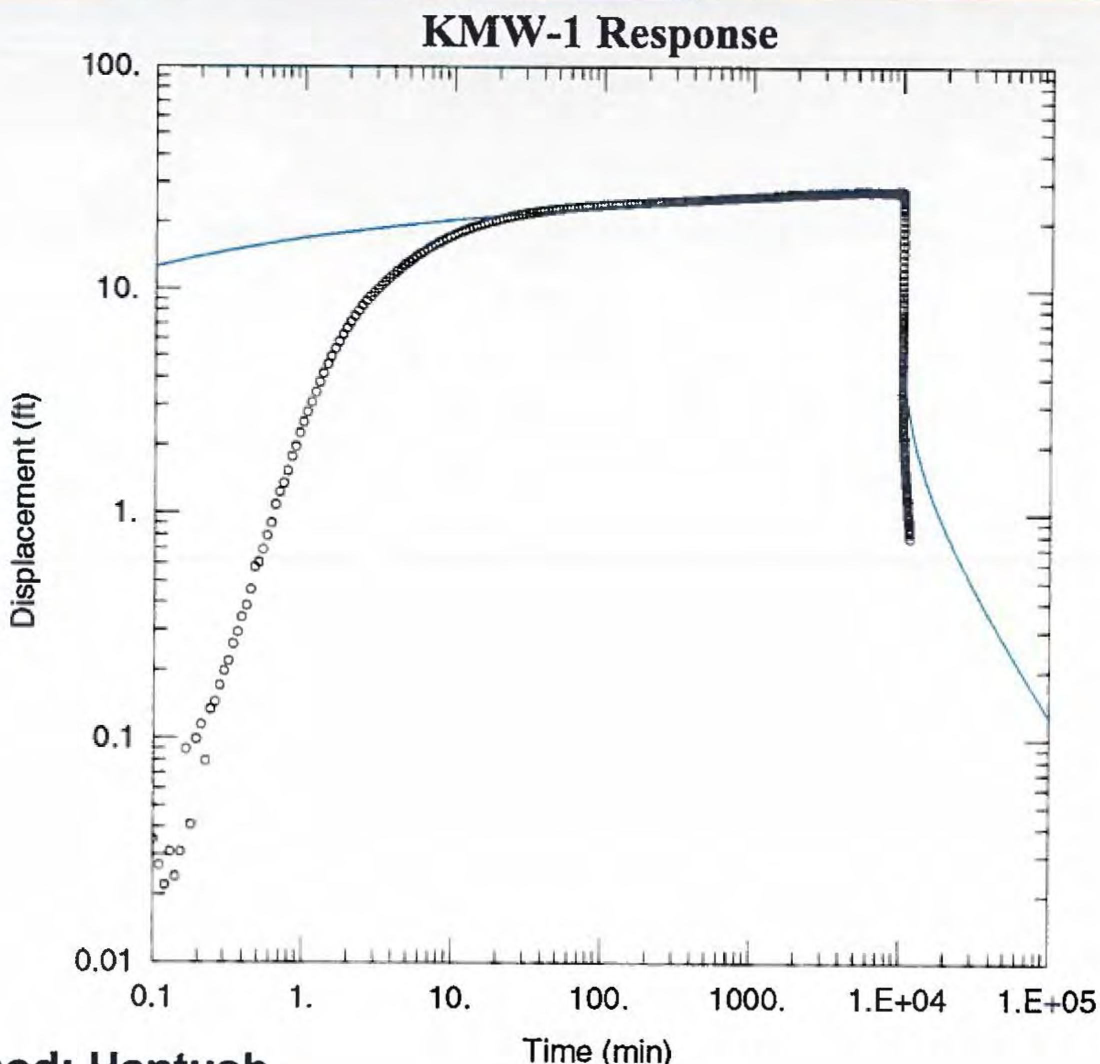
Production Well KPW-1

Constant-Rate Discharge Test Results



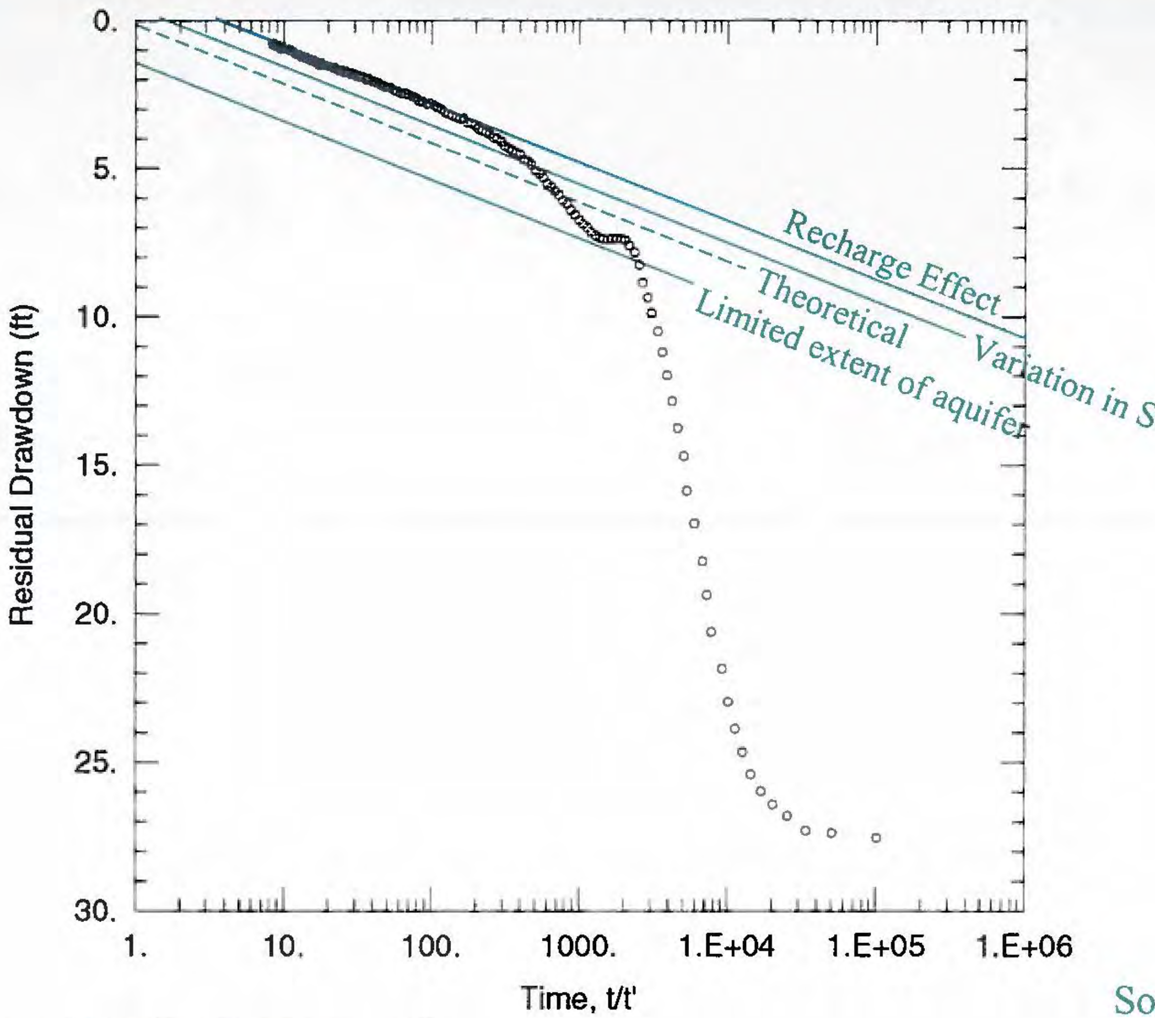
Monitor Well KMW-1

Aquifer Test Drawdown Data Analysis



Solution Method: Hantush

Aquifer Test Residual Drawdown (Recovery) Data Analysis



Source: Driscoll 1986 (page 259)

Solution Method: Theis (Recovery)

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Aquifer Test Data Summary

Well	Method	Transmissivity (gpd/ft)	Storage Coefficient
KMW-1 (Drawdown)	Hantush-Jacob (Leaky-Confined) Hantush (Leaky-Confined)	30,000 90,000	10^{-4} -
KMW-1 (Recovery)	Theis (mid t/t') Theis (late t/t')	95,000 240,000	- -
KPW-1 (Recovery)	Theis (late t/t')	380,000	-

1 Porous medium equivalency

2 No hydraulic barrier to flow

3 Recharge effect (fault zone)

4 High yielding well(s)

Source: Hantush 1960
Hantush 1955
Theis 1935

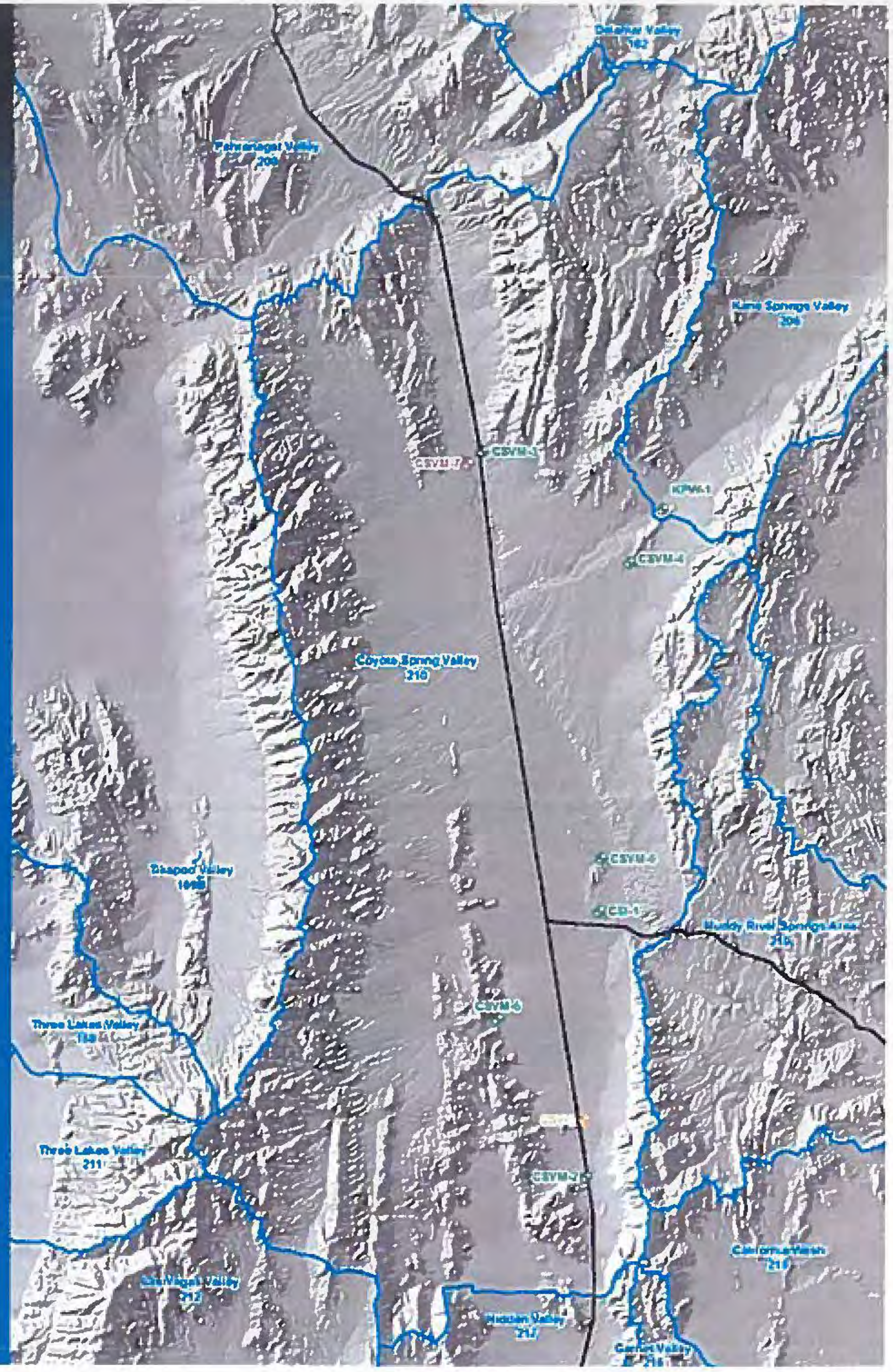
Kane Springs Valley and Coyote Spring Valley Water Quality Sampling

Kane Wells:

- KPW-1 — Carbonate-rock aquifer wells

Coyote Wells:

- CSVM -2
- CSVM-3
- CSVM-4 — Carbonate-rock aquifer wells
- CSVM-5
- CSVM-6
- CSI-1
- CSVM-7 — Volcanic aquifer well
- CSV-3 — Alluvial aquifer well



Kane Springs Valley and Coyote Spring Valley Water Quality Parameters Summary

General Chemistry:	
Bicarbonate Alkalinity	mg/L
Calcium	mg/L
Chloride	mg/L
Fluoride	mg/L
Magnesium	mg/L
Potassium	mg/L
Silica	mg/L
Sodium	mg/L
Sulfate	mg/L
Total Dissolved Solids	mg/L
Trace Metals	
Aluminum	mg/L
Arsenic	mg/L
Iron	mg/L
Nickel	mg/L
Dissolved Metals	
Iron, Dissolved	mg/L
Manganese, Dissolved	mg/L
Stable Isotopes	
$\delta^{13}C$	‰
$\delta^{18}O$	‰
δD ‰	‰

Summary

- Intersected fault zone
  - Carbonate-rock aquifer, 260 feet
  - Faulted/Fractured
  - Highly Productive
- Completed 7-day (167 hour) constant rate aquifer test 1,800 gpm
- T-Values
  - Fault induced high T- ~300,000 gpd/ft
  - Regional T value - ~50,000 gpd/ft
- S-Values ~10^{-4}

URS

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GREAT BASIN
WATER NETWORK

info4gbwn@gmail.com
GreatBasinWaterNetwork.org

June 27, 2019

The Honorable Tim Wilson, P.E.
Acting Nevada State Engineer
901 S. Stewart St., Suite 2002
Carson City, NV 89701

RE: GBWN Report on Order 1303

As a stakeholder that would be affected by potential water right developments in the Lower White River Flow System, the Great Basin Water Network (GBWN) respectfully submits the following report pursuant to Part VI, Section 2 of State Engineer Order 1303 (Jan. 11, 2019).

GBWN was formed to protect the water resources of the Great Basin for current and future residents – human, animal and plant. The Network is comprised of organizations, businesses and individuals dedicated to ensuring that decisions on all water development proposals in the Great Basin are made in the open with caution, coherence, and based on the best scientific information. GBWN also works to ensure that decisions are made without undue political and developer special interest pressure. The Network is supportive of efforts to tackle the challenging problems of water management in Nevada's over-appropriated basins in order to correct long-term and sometimes severe overdraft.

As it relates to Part VI, Section 2, Subsections (a) through (e) of Order 1303, we see the need to ensure that the State Engineer upholds his statutory obligations to protect the public interest and be the final arbiter deciding the merits of any management plan developed in the stakeholder process. To do so, we believe that it is paramount for the State Engineer to recognize and incorporate the interconnected nature of all basins comprising the White River Flow System ("WRFS") in his future decisions. Also critical is the need for the State Engineer to explain how stakeholder data will be evaluated in order to create a new means of regulating the hydrologic basins of the WRFS. Additionally, we want to make certain that public participation is not limited to only those who engage via the criteria outlined in Part VI, Section 2 of Order 1303. We also want to ensure the public has a robust role in the processes listed in Part VI, Sections 3 and 4 of the Order. Listed below is section by section input on Part VI of Order 1303.

Section 2(a) **<u>The geographic boundary of the hydrologically connected groundwater and surface water systems comprising the Lower White River Flow System</u>**

Pursuant to NRS 533.370 (2), we believe that in order to prevent long-term harm to the public interest and protect existing water rights the State Engineer must include in the scope of Order 1303 all interconnected basins in the WRFS such that pumping in those interconnected basins may be properly managed to ensure sustainability over the long term. We believe any calculation of water available for appropriation may not be fully informed if the State Engineer fails to take into account the interconnected nature of all the hydrologically connected basins in the WRFS.

Section 2(b) The information obtained from the Order 1169 aquifer test and subsequent to the aquifer test and Muddy River headwater spring flow as it relates to aquifer recovery since the completion of the aquifer test

Considering that the State Engineer has not determined the precise extent of the development of existing appropriations within the Lower White River Flow System ("LWRFS") that may occur without harming the fully decreed Muddy River, we believe the State Engineer should publicly disclose how he will decide what stakeholder data are accurate, fair, and in line with Nevada water law as it relates to determining spring flows and aquifer recovery in the stakeholder process outlined in Order 1303. The State Engineer also should convey how stakeholder-submitted data points will be used to create standards, such as sustainable yield, and for determining how the State will develop and implement a framework for conjunctively managing waters in the LWRFS. The Legislature has encouraged the State Engineer to use the best science available under NRS 533.024(1) (c). It is certainly in the public interest for the public to have a reasonable opportunity to review and offer comment on how the Division of Water Resources concludes what is "the best science."

Section 2(c) The long-term annual quantity of groundwater that may be pumped from the Lower White River Flow System, including the relationships between the location of pumping on discharge to the Muddy River Springs, and the capture of Muddy River flow

In order to maintain the integrity and long-term functionality of the essential groundwater resource that WRFS is for eastern Nevada, to protect the long-term public interest in the environment and species such as the Moapa Dace, and to prevent conflicts that would destroy the property and of senior water rights holders within the WRFS, the State Engineer must resolve the over-appropriation of the LWRFS in a way that accounts for all of the interconnected basins in the White River Flow System and the fact that any future appropriations in those hydrologic basins will affect one another.

Section 2(d) The effects of movement of water rights between alluvial wells and carbonate wells on deliveries of senior decreed rights to the Muddy River.

Because it is understood that pumping within the LWRFS has a direct interrelationship with the flow of the Muddy River, we believe that it is in the public interest to ensure that the scope of Order 1303 includes every WRFS basin with a hydrologic connection with the Muddy River. All decisions must take that connection into consideration or the State will risk continuing the unsustainable practice of over-appropriating basins.

Section 2(e) Any other matter believed to be relevant to the State Engineer's analysis.

Great Basin Water Network requests that the order provide for the following in order to ensure full public participation and transparency in this matter.

The State Engineer will continue to post on the Division of Water Resources website:

- State Engineer notices regarding deadlines or meetings.
- Rulings and Orders related to these proceedings.
- Minutes of the stakeholder meetings.
- All documents submitted by stakeholders or prepared by the State Engineer, including reports and rebuttals.
- All stakeholder proposals on how to address the future management and corrections of the over-appropriated basins.

The State Engineer will provide opportunities for concerned members of the public to provide comments to the State Engineer and stakeholders on the process, the submitted stakeholder documents, and any proposals to rectify the over-appropriation of the basins in the Administrative Unit. Areas of comment may include but not be limited to:

- Hydrologic, environmental, social, and economic impacts on the White River Flow System.
- Impacts on the Moapa Dace.
- Impacts on Moapa Warm Spring flows, on which the dace depends.

A reasonable amount of time for public comment shall be provided at all stakeholder meetings and be made part of the record.

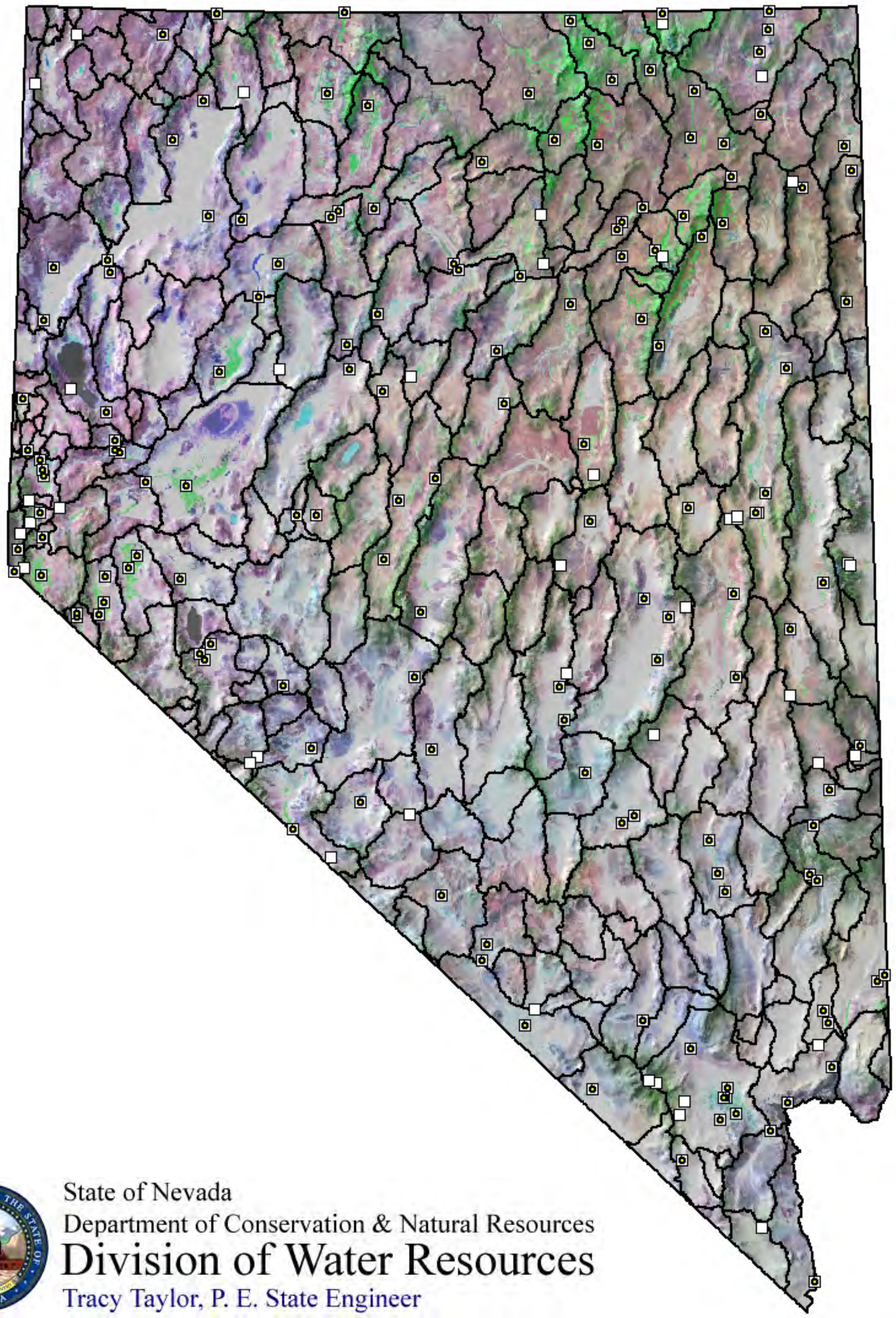
Thank you for considering the GBWN Order 1301 report and making it part of the record.

Sincerely,

s/s

Kyle Roerink
Executive Director

Evapotranspiration and Net Irrigation Water Requirements for Nevada



State of Nevada
Department of Conservation & Natural Resources
Division of Water Resources
Tracy Taylor, P. E. State Engineer

All compiled evapotranspiration data files are available via internet download from the following NDWR website:

http://water.nv.gov/NVET

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SE ROA 54252

Evapotranspiration and Net Irrigation Water Requirements for Nevada

By

J. L. Huntington[1] and R. G. Allen[2]

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[2] Professor of Water Resources Engineering, University of Idaho, Research and Extension Center, 3793 N. 3600 E., Kimberly, Idaho, 83301; PH (208) 423-6601; FAX (208) 423-6699; email: rallen@kimberly.uidaho.edu

January 2010

EXECUTIVE SUMMARY

Accurate estimates of evapotranspiration (ET) are becoming more important as increasing demands are placed on finite water supplies in Nevada and across the western U.S. Local, state, and federal water resource agencies require accurate crop ET (ET_{act}) and net irrigation water requirement (NIWR) estimates for evaluating irrigation development, transfers of irrigation water for municipal use, and litigation of water right applications and protests. The ET_{act} was calculated via a crop coefficient approach, where ET_{act} is equal to the reference ET multiplied by a crop coefficient. The NIWR is equal to the annual ET_{act} less the effective precipitation entering the root zone that is available for evaporation or transpiration. The major objective of this study was to update estimates of the ET_{act} and NIWR for Nevada. The methods for estimating the reference ET follow the new ASCE-EWRI Standardized Penman-Monteith (ASCE-PM) approach, while the ET_{act} and NIWR were estimated using a dual crop coefficient and daily soil water balance. Estimates of the ET_{act} and NIWR for major crops grown in Nevada were made for daily, monthly, and annual time steps at 190 locations using National Weather Service weather stations located throughout the state for available periods of record.

Assessing the error in estimated ASCE-PM reference ET using estimates of the ‘secondary’ weather parameters solar radiation, dewpoint, and wind speed, versus using measured data is of significant concern because estimation of these weather variables provides the ability to use NWS stations, which allows for sufficient spatial coverage and statewide application. To address this issue, a comparison was made between estimated reference ET at NWS stations, and calculated reference ET at nearby stations located in irrigated areas that measure the full suite of weather variables. Results of the comparison indicate that the ratios of annual reference ET based on estimated secondary weather parameters, to reference ET based on measured secondary weather parameters, range from 1.01 to 1.06 with an average of 1.03. These results are acceptable considering the overall error or uncertainty inherent to reference ET and crop coefficient calculations, which have been suggested to be about 10%.

To explore the accuracy of estimated alfalfa ET_{act}, a comparison was made to measured ET_{act} of alfalfa using results from previous studies for respective Hydrographic Areas (HAs) and time periods. The average ratio of estimated ET_{act} to the average of the reported ET_{act} is 1.04. Results generally agree well, however there are significant differences in some instances where published measurements of ET_{act} were likely being impacted by water limiting conditions or instrumentation biases.

For purposes of estimating the mean annual ET_{act} and NIWR for each HA, the analysis was limited to weather stations on valley floor areas representative of potential agricultural areas. Mean annual values of the ET_{act} and NIWR were assigned to the HA if a single station was available, or if multiple stations were available, a period of record

weighted average of the ET_{act} and NIWR was assigned to HAs. Of the 256 HAs in the state, 160 are absent of weather stations from which to estimate the ET_{act} and NIWR; therefore, spatial interpolation of weather station estimates of the mean annual ET_{act} and NIWR was performed for alfalfa, grass hay, pasture grass, turf grass, and small shallow open water bodies. Results of the NIWR per HA (Appendix 15 and Plate 1) indicate that in central and northern parts of Nevada, the NIWR for alfalfa is less than the typical permitted irrigation water right of 4 ac-ft/ac. However, in southern Nevada the NIWR may exceed the typical irrigation water right of 5 ac-ft/ac. These results represent the NIWR for pristine crop conditions under full water supply and should be considered the maximum.

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CONTENTS cont.

FIGURES

TABLES

APPENDIXES

ANNEX

PLATES

ACRONYMS

α	= albedo
AGRIMET	= U.S. Bureau of Reclamation Agricultural Weather Network
ASC	= Antecedent Soil Condition
ASCE-EWRI	= American Society of Civil Engineers – Environmental Water Resources Institute
ASCE-PM	= American Society of Civil Engineers Standardized Penman Monteith equation
AWC	= Available Water Holding Capacity
AZMET	= Arizona Meteorological Network
β	= angle of the sun above the horizon
B	= empirical solar radiation fitting coefficient
C_d	= ASCE-PM equation constant dependent on reference type
CEMP	= Community Environmental Monitoring Program
CGDD	= Cumulative Growing Degree Day
CIMIS	= California Irrigation Management Information System
CN	= Runoff Curve Number
C_n	= ASCE-PM equation constant dependent on reference type
CN_I	= Runoff Curve Number associated with dry antecedent soil conditions
CN_{III}	= Runoff Curve Number associated with wet antecedent soil conditions
Δ	= slope of the saturation vapor pressure-temperature curve
δ	= solar declination
d	= zero plane displacement height for the weather site vegetation
D_e	= Depletion of evaporative layer
d_r	= squared inverse relative distance factor for the earth-sun
DRI	= Desert Research Institute
e_a	= mean actual vapor pressure
$e^o(T)$	= saturation vapor pressure at a specified temperature T
$e^o(T_{dew})$	= actual vapor pressure at daily dewpoint temperature
e_s	= saturation vapor pressure
ET	= Evapotranspiration

ET_{act} = Actual Evapotranspiration
ET_o = Reference Evapotranspiration
ET_{os} = Standardized Grass Reference Evapotranspiration
ET_{sz} = Standardized Reference Evapotranspiration
f_{cd} = cloudiness function
$F_{timeroot}$ = fraction of time from the start of root growth until the time of maximum root depth
γ = psychrometric constant
G = soil heat flux
GDD = Growing Degree Day
h = vegetation height
HA = Hydrographic Area
φ = latitude
J = Julian day (1-365 or 366 for leap years)
K_b = index of atmospheric clearness
K_c = crop coefficient
K_{cb} = basal crop coefficient
K_{cmean} = mean crop coefficient curve (i.e. lumps evaporation, transpiration, and cutting effects)
K_d = diffuse radiation index
K_e = soil evaporation coefficient
K_o = dew point depression (i.e. $T_{min} - T_{dew}$)
K_s = stress coefficient
K_T = atmospheric transmissivity
K_{tb} = atmospheric turbidity coefficient
λ = latent heat of vaporization
LCRAS = Lower Colorado River Accounting System
MAD = Maximum allowable Depletion
NCGDD = Normalized Cumulative Growing Degree Day
NIWR = Net Irrigation Water Requirement
NRCS = Natural Resource Conservation Service
NWS = National Weather Service
P = mean atmospheric pressure
P_{inf} = depth of infiltrated precipitation
PPT = precipitation
R_a = exoatmospheric radiation
RAW = Readily Available water in the root zone
RAWS = Remote Automated Weather Station
REW = Readily Evaporable Water
RH = Relative Humidity
RMSE = Root Mean Squared Error
R_n = net radiation
R_{nl} = net long wave radiation
R_{ns} = net short wave radiation
RO = surface runoff
R_s = incoming short wave solar radiation

R_s/R_{so} = relative solar radiation
R_{so} = calculated clear sky radiation
S = maximum depth of water that can be retained as infiltration and canopy interception during a single precipitation event
σ = Stefan-Boltzmann constant
STATSGO = State Soil Geographic database
T = mean daily air temperature
TAW = Total Available Water in the root zone
T_{base} = base temperature used in the growing degree method
T_{dew} = dewpoint temperature
TEW = Total Evaporable Water
T_{Kmax} = maximum daily Kelvin temperature
T_{Kmin} = minimum daily Kelvin temperature
T_{max} = maximum daily air temperature
T_{min} = minimum daily air temperature
U_2 = mean daily wind speed at 2m height
USBR = U.S. Bureau of Reclamation
USDA = U.S. Department of Agriculture
USGS = U.S. Geological Survey
u_z = measured wind speed at z_w m above ground surface
VPD = Vapor Pressure Deficit (i.e. es – ea)
W = precipitable water in the atmosphere
ω_s = sunset hour angle
z = weather station site elevation above mean sea level
Z_{max} = maximum effective root depth
Z_{min} = initial root depth at planting or greenup
z_{om} = aerodynamic roughness length for the weather site vegetation
Z_r = effective root depth
z_w = height of measurement above ground surface

INTRODUCTION

Irrigation water requirements are primarily controlled by the evapotranspiration (ET) of agricultural crops. Quantifying the amount of ET for a particular type of vegetation and region is necessary for proper design of irrigation systems, basin water balance estimates, irrigation water management, and review and litigation of water right applications and disputes; all of which continue to receive high priority attention. In the past, the State of Nevada has based ET and net irrigation water requirement estimates on a combination of reports, mainly from the USDA Nevada Irrigation Guide (USDA-SCS, 1992), State of Nevada Report No. 3 (Pennington, 1980), and studies used in hearings associated with the Alpine Decree (Mahannah, 1979; Hill, 1979; Guitjens and Mahannah, 1977). These publications primarily utilized temperature based Blaney-Criddle, modified Blaney-Criddle, Jensen-Haise, and Penman equations for computing reference ET, as well as empirical relationships between estimated crop ET and crop yields, and soil moisture balance (depletion) estimates of ET, resulting in a wide range of estimates. Other publications specific to Nevada have outlined methods for computing potential ET (Behnke and Maxey, 1969), and have estimated statewide (Shevenell, 1996) and eastern Nevada (McCurdy and Albright, 2004) potential ET, and crop water use for eastern Nevada (Welch et al., 2007) and the Death Valley flow system (Moreo and Justet, 2008). Net irrigation water requirements (crop ET – (precipitation – runoff – deep percolation)) were not estimated in many previous publications, and if so, were estimated as the annual crop ET minus an assumed effective precipitation amount. While these reports have been extremely useful, their somewhat dated methods, or simplified approach for estimating evaporation from surface wetting and effective precipitation, and limited spatial coverage have created a need to update statewide ET and net irrigation water requirement estimates using a standardized and more detailed approach.

The major objective of this report was to update crop ET and net irrigation water requirement estimates for Nevada using newly available standardized methods and detailed soil water balance accounting. Estimates of crop ET and net irrigation water requirements were made for 34 different crop and land cover types using 190 National Weather Service stations located throughout the state (Figure 1).

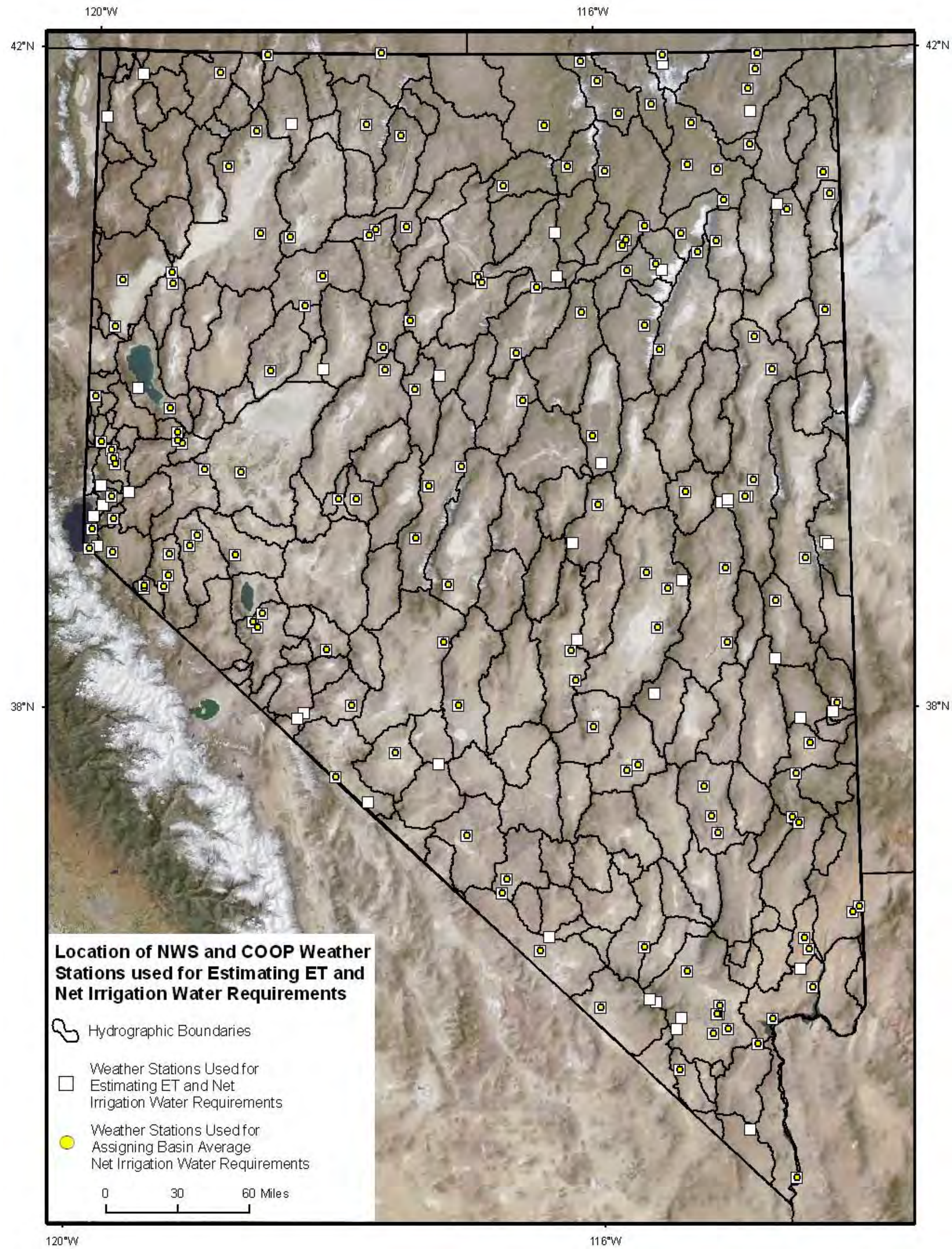

Figure 1. Weather stations used for calculating crop ET and net irrigation water requirements.

EVAPOTRANSPIRATION CALCULATION APPROACH

The approach used in this study for computing crop ET is the common crop coefficient – reference ET approach, where the reference ET is multiplied by a crop coefficient for estimating the actual ET (ET_{act}) of a vegetative surface. There are many methods available for estimating the reference ET (ET_o), while many are simple temperature-based techniques, others are data intensive as required for more physically based models. Estimates of ET_o vary widely among the methods, and there is considerable debate as to which is the more correct method. Generally, the lack of weather variables such as incoming solar radiation, dewpoint temperature, and wind speed needed for more physically based models of ET_o has led to the use of simple temperature based methods, even though investigators are often aware that more physically based methods result in more accurate and representative estimates of ET_o. Given that the number of weather stations that collect incoming solar radiation, relative humidity, and wind speed is limited, there is a great need to utilize basic National Weather Service (NWS) weather data of maximum and minimum temperature and precipitation, and apply these data to an ET_o equation that is robust and currently accepted in the literature and scientific community to estimate the ET_{act} and net irrigation water requirement (NIWR) throughout the state.

The Penman-Monteith method is a physically based method for calculating ET_o and is currently accepted as a standard method (ASCE-EWRI, 2005) for calculating a standardized and consistent value for ET_o, referred to here as ET_{sz}. The Penman-Monteith method requires weather variables that are not routinely measured at NWS stations. Recent advancements in estimating weather variables such as incoming solar radiation (Allen, 1997; Thornton and Running, 1999; ASCE-EWRI, 2005), generalization of dewpoint temperatures representative of irrigated areas (ASCE-EWRI, 2005; Allen et al., 1998; Allen and Robison, 2007) and regionalizing of wind speed (Allen and Robison, 2007) have proven useful for estimating ET_{sz} using the Penman-Monteith equation, while maintaining sufficient accuracy and spatial coverage for state-wide application. The grass reference Penman-Monteith equation is widely applied by Arizona and California State agencies for computing ET_{act} (i.e. AZMET and CIMIS), as well as the U.S. Bureau of Reclamation for their Lower Colorado River Accounting System (LCRAS) model. Consequently, the State of Nevada has adopted the daily time step grass reference Penman-Monteith equation (ET_{os}) as the basis for computing the ET_{act} and NIWR. As a result, this equation was applied in this study.

ET_{sz} refers to ET from a reference crop that is actively growing, not limited by soil moisture, and is at full cover and peak height. The ratio of ET_{act} to the ET_{sz}, otherwise known as a crop coefficient (K_c) representing specific crop types, must be applied to adjust the ET_{sz} to simulate the ET_{act} of a particular crop or surface. The majority of crop coefficients in the literature are derived from research weighing lysimeter measurements of actual ET from stress-free crops and calculated ET_{sz} at the lysimeter sites, mainly from Davis, CA, and Kimberly, ID (Doorenbos and Pruitt, 1977; Wright, 1981, 1982). This study utilizes a dual crop coefficient and daily soil water approach to compute the ET_{act}, where the K_c value is separated into a 'basal' crop coefficient, K_{cb}, and a soil evaporation coefficient, K_e (Allen et al., 1998; Allen et al., 2005). The heritage of many of the K_{cb} values used in this study can be traced to Wright (1982), but have been converted from Wright's alfalfa reference basis to the grass reference basis used here. The advantage of using a dual crop coefficient over a 'mean' or single crop coefficient approach is that it allows for separate accounting of transpiration and evaporation to better quantify evaporation from precipitation and irrigation events, and allows for accounting of winter time soil moisture storage.

METHODS

Weather Station Data Assembly

Weather station data from the NWS used in the computation of ET_{os} and NIWRs include daily maximum and minimum air temperature and precipitation, and observations of snowfall and snow cover depth for some stations. These data are officially collected and housed by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). Data are generally available from the NCDC from about 1930 onwards, however lengths of records vary widely from station to station in Nevada, ranging from less than 1 month to 120 years. Limiting weather station datasets to those stations having at least 4 years of complete annual records result in over 190 usable weather stations in Nevada. Missing data, which were usually at monthly periods due to the reporting of monthly data sheets to the NWS, were flagged using values of -999 for temperature and -99 for other variables. Missing temperature data for up to two consecutive days were estimated using the previous day's temperature, otherwise long term averages were used for purposes of computing growing degree days and 30 day mean temperatures to simulate the onset or end of growing seasons during the ET_{act} calculations. However, these periods of missing data were set back to -999 values for temperature and computed ET_{act} in later processing, and those years that contain any missing days were not used in statistical summaries.

Computing the NIWR for each hydrographic area (HA) was accomplished by using weather stations located on valley floor or near irrigated areas, and either assigning or computing the average of multiple station estimates of the NIWR. Limiting stations to valley floor and irrigated areas for computing the NIWR for each HA where weather stations exist reduces the number of weather stations to 148 (Figure 1), however the ET_{act} and NIWR was computed for all 190 stations for other potential uses such as assessing the ET_{act} for high elevation pasture grass, etc. Weather data and results are available through July of 2007, unless weather station data collection ended before this date. Appendix 1a and 1b list the full 190 weather station dataset, along with the respective NCDC station number, station location and altitude, period of record, number of complete years in the period of record, and HA name. Appendix 1a is sorted by weather station name, while Appendix 1b is sorted by HA name. Two weather stations operated and maintained by Washoe County Department of Water Resources were included in this analysis and are located in Washoe Valley and Redrock Valley. Details on data compilation for these stations and modifications made to temperature data for 2 NWS stations due to poor station siting are outlined in Appendix 2. In this report, statistics of ET results were computed over the most recent 30 years of valid data or over shorter periods if less than 30 years of valid data were available (minimum of 4 years). For further discussion on treatment of missing data in computed monthly, annual, and statistical summaries refer to Appendix 9.

Standardized Penman-Monteith Equation

As a part of a standardization effort, the ASCE Penman-Monteith (ASCE-PM) equation and associated equations for calculating aerodynamic and bulk surface resistance are combined and condensed into a single equation that is applicable to both grass and alfalfa surfaces by changing standardized constants (ASCE-EWRI, 2005). The ASCE-PM equation is intended to simplify and clarify the presentation and application of the method. As used in this analysis, the term ET_{os} refers to the standardized grass reference ET. Calculation of parameters required in the ASCE-PM equation was accomplished using guidelines from ASCE-EWRI (2005).

The standardized reference evapotranspiration equation is

$$ET_{sz} = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{C_n}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \qquad \text{Eq. 1}$$

where

ET_{sz} = standardized reference crop evapotranspiration for short (ET_{os}) or tall (ET_{rs}) surfaces [mm d^{-1}],

R_n = calculated net radiation for the standardized surface [MJ m^{-2} d^{-1}],

G = soil heat flux density at the soil surface [MJ m^{-2} d^{-1}], and is assumed to be 0 over a day,

T = mean daily air temperature at the 1.5 to 2.5m height [°C],

u_2 = mean daily wind speed at 2m height [m s^{-1}],

e_s = saturation vapor pressure at 1.5 to 2.5m height [kPa], calculated for daily time steps as the average of saturation vapor pressure at maximum and minimum air temperatures,

e_a = mean actual vapor pressure at 1.5 to 2.5m height [kPa],

Δ = slope of the saturation vapor pressure-temperature curve [kPa °C^{-1}],

γ = psychrometric constant [kPa °C^{-1}],

C_n = numerator constant that changes with reference type and calculation time step, and

C_d = denominator constant that changes with reference type and calculation time step.

Calculation of the Standardized Penman-Monteith Reference ET

Because NWS stations only measure and report daily maximum and minimum air temperature and precipitation, variables of daily incoming solar radiation, humidity, and wind speed required in Eq. 1 were estimated following recommendations similar to those in ASCE-EWRI (2005) and are discussed below.

Psychrometric and Atmospheric Variables

The standardized application of latent heat of vaporization, λ, equal to 2.45 MJ kg^{-1}, results in a psychrometric constant, γ, that is proportional to the weather station mean atmospheric pressure, P,

$$\gamma = 6.65 * 10^{-4} P \qquad \text{Eq. 2}$$

where P has units of kPa, and γ has units of kPa $^oC^{-1}$. Mean atmospheric pressure at weather stations was estimated from the site elevation using a simplified formulation of the Universal gas Law (Burman et al., 1987)

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26} \qquad \text{Eq. 3}$$

where

z = weather site elevation above mean sea level [m].

The slope of the saturation vapor pressure-temperature curve, Δ, was computed following Murray (1967) as

$$\Delta = \frac{2503\exp\left(\frac{17.27T}{T+237.3}\right)}{\left(T+237.3\right)^2} \qquad \text{Eq. 4}$$

where

Δ = slope of the saturation vapor pressure-temperature curve [$kPa^{o}C^{-1}$], and
T = daily mean air temperature [^{o}C].

Dewpoint temperature (T_{dew}) is defined as the temperature at which a parcel of air must be cooled to become saturated with water vapor. The dewpoint temperature can be used to represent the humidity content of the lower air mass, for example the relative humidity (RH) is at 100% when the air temperature is at the dewpoint. Because NWS stations do not record relative humidity, the T_{min} was used indirectly to estimate the humidity of the lower air mass. In an irrigated setting T_{min} will usually approach T_{dew}, especially in the early morning when winds are calm and soil moisture is high. Weather measurements taken from non-irrigated settings typically result in higher daily temperatures and lower humidity than those collected in irrigated areas due to the lack of available water, causing the net radiation to be partitioned into sensible heat instead of latent heat or ET. The use of humidity data collected from non-irrigated settings can cause overestimation of reference ET by as much as 20% - 26% (Brown, 2001; ASCE-EWRI, 2005), therefore corrections are required to bring the calculated T_{dew} closer to that which would be measured under irrigated conditions (Allen, 1996; Allen et al., 1998; ASCE-EWRI, 2005).

T_{dew} is typically calculated from actual vapor pressure of the air (e_a), which can be derived from measured maximum relative humidity (RH_{max}) and minimum relative humidity (RH_{min}) following recommendations by Allen et al., (1998) and ASCE-EWRI (2005). T_{dew} was calculated from e_a based on the Murray (1967) equation as

$$T_{dew} = \frac{116.91 + 237.3\ln(e_a)}{16.78 - \ln(e_a)} \qquad \text{Eq. 5}$$

where T_{dew} = the dewpoint temperature (^{o}C), and
e_a = actual vapor pressure (kPa).

Equation 5 can be rearranged to estimate actual vapor pressure, e_a, from T_{dew} as

$$e_a = e^o(T_{dew}) = 0.6108 \exp\left[\frac{17.27 T_{dew}}{T_{dew} + 237.3}\right] \qquad \text{Eq. 6}$$

where $e^o(T_{dew})$ = saturated vapor pressure at daily dewpoint temperature (kPa), and the saturation vapor pressure function for a specified temperature, $e^o(T)$, is

$$e^o(T) = 0.6108 \exp\left(\frac{17.27 T}{T + 237.3}\right) \qquad \text{Eq. 7}$$

where vapor pressure is in units of kPa and temperature is in ^oC. In this study daily T_{dew} at each NWS weather station was estimated from T_{min}, because of the lack of RH or T_{dew} measurements, as

$$T_{dew} = T_{\min} - K_o \qquad \text{Eq. 8}$$

where T_{min} is the daily minimum air temperature (^oC) and K_o is an offset coefficient (^oC) and is synonymous with the dewpoint depression. Typically, it is common in arid and semi-arid regions to have a T_{dew} of 2 to 5 ^oC below T_{min} under well watered conditions (Allen, 1996). K_o can be substantially higher in non-irrigated environments (i.e. non-reference conditions), sometimes reaching 10 ^oC in arid climates. However, the 2 to 5 ^oC range is generally observed in arid and semi-arid climates when the local and subregional environment is irrigated.

Most NWS weather stations are located in non-irrigated or only partially irrigated environments. Because non-reference conditions can cause an increase in air temperature due to the lack of the cooling effect of ET, it is recognized that the higher T_{min} may cause the T_{dew} to be overstated, even for reference conditions. Because the computation of vapor pressure deficit, VPD, in the ET_{ref} equation includes both T_{min} and T_{dew}, as

$$VPD = 0.5\left[e^o(T_{\max}) + e^o(T_{\min})\right] - e^o(T_{dew}) \qquad \text{Eq. 9}$$

where $e^o(T_{dew})$ = saturation vapor pressure at the dewpoint temperature (kPa), both the air temperature and dewpoint temperatures may be overstated for non-reference conditions (since the T_{dew} estimate is based on T_{min}). However, the upward biases in the $e^o(T)$ functions by all temperature parameters will tend to cancel, thereby producing a VPD that is generally representative of a reference condition (Allen et al., 1998; ASCE-EWRI 2005).

Rather than assign NWS stations temporally constant K_o values, spatially distributed K_o values that varied by month were derived and assigned to NWS stations. There are very few weather stations in Nevada that measure RH in irrigated areas to compute K_o, therefore mean monthly K_o values were computed from weather stations located in irrigated areas both in Nevada and in nearby areas outside Nevada (Figure 2), including the AZMET (Arizona Meteorological Network), CIMIS (California Irrigation Management Information System), AGRIMET, and Utah Agriculture Weather Network, as well as U.S. Geological Survey (USGS) micrometeorological stations located in irrigated areas in Nevada from studies by Maurer et al., (2006) and Allander et al., (2009). Calculated mean monthly K_o values for weather stations analyzed are listed in Appendix 3 and illustrated in Figures 3a-c, where it is apparent that mean monthly K_o values vary depending on the climate of the location. For instance, southern regions have higher monthly K_o values than northern regions. Mean monthly K_o values were assigned to NWS stations by spatial interpolation using inverse distance weighting. Spatially interpolated mean monthly K_o surfaces were averaged to individual HAs, and these mean monthly K_o values per HA were assigned to respective NWS stations. Measured mean monthly K_o values were assigned to NWS stations in HAs where measurements occurred. For illustration purposes the spatial distribution of the mean annual K_o is shown in Figure 4.

As expected, southern locations have a larger mean annual dewpoint depression (i.e. larger K_o value) than northern areas. This spatial trend is partially due to regional scale advection of dry air, and more specifically the climatology that governs regional scale advection such as precipitation and available water, the resultant surface energy balance from valley floor areas, and typical air mass origins or jet stream patterns. Figure 5 illustrates the spatial distribution of HA average PRISM precipitation (Daly et al., 1994), which exhibits a similar spatial distribution as the mean annual dewpoint depression and supports the fact that regional scale advection is largely controlled by available moisture and the resultant energy balance of the surrounding environment.

The degree of local advection and its effect on the ET rate of an irrigated area is dependent on the scale of the irrigated area. Local advection occurs when wind blows across a surface, which is discontinuous in temperature, humidity or roughness (Brakke, 1978), such as wind blowing from a dry area across an irrigated field. Many studies have concluded that ET on the leading edge of an irrigated field is highest due to local advection, and as the distance from the leading edge increases, the influence of local advection on ET decreases until the cooler and moist boundary layer is formed and horizontal uniformity is established (Rider et al., 1963; Dyer and Crawford, 1965; Goltz and Pruitt, 1970). Brakke et al., (1978) attempted to partition local and regional advection effects on ET from an irrigated field of alfalfa surrounded by non irrigated areas, and found that advection effects were greatly reduced within 100m downwind of

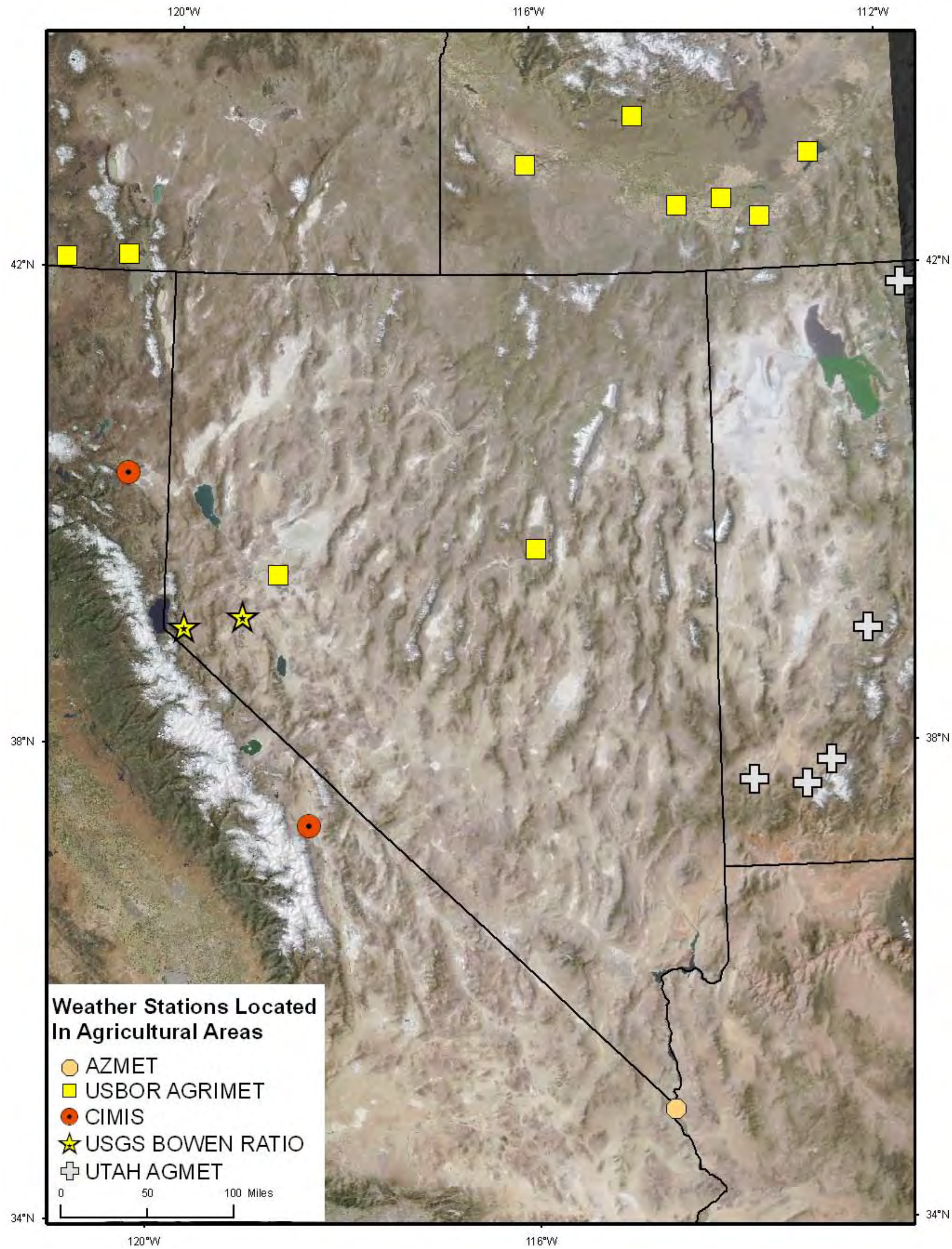

Figure 2. Weather stations located in irrigated areas measuring relative humidity representative of reference conditions. These stations were used for estimating the dewpoint at stations not measuring relative humidity.

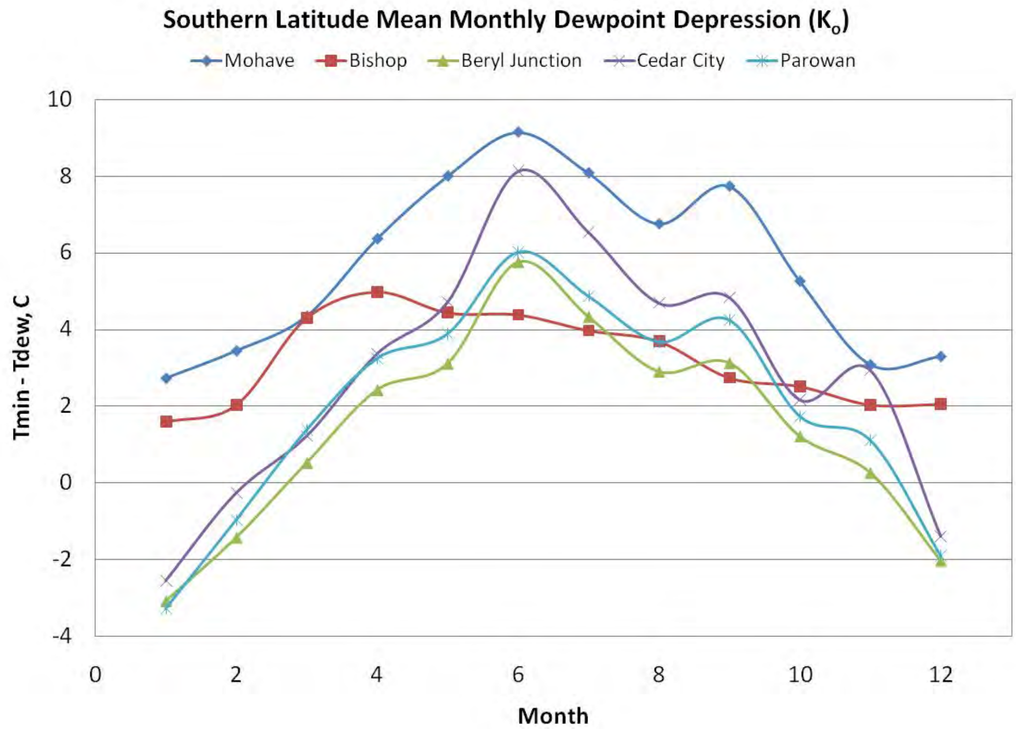

Figure 3a. Measured mean monthly dewpoint depression for southern latitude weather stations in reference (irrigated agriculture) environments.

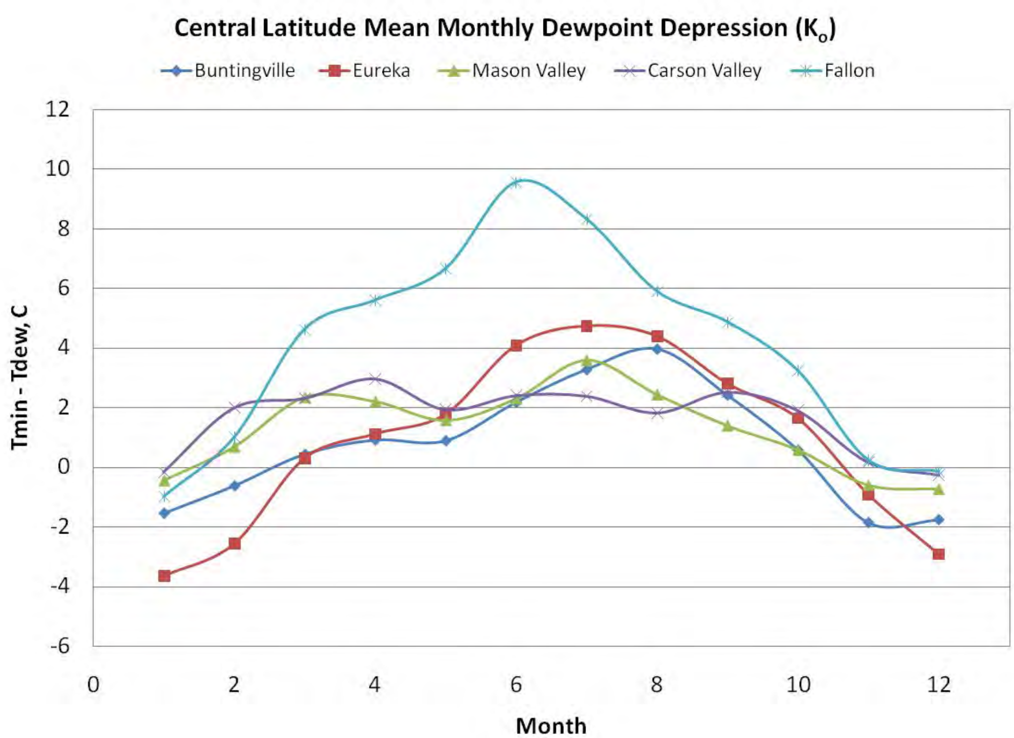

Figure 3b. Measured mean monthly dewpoint depression for central latitude weather stations in reference (irrigated agriculture) environments.

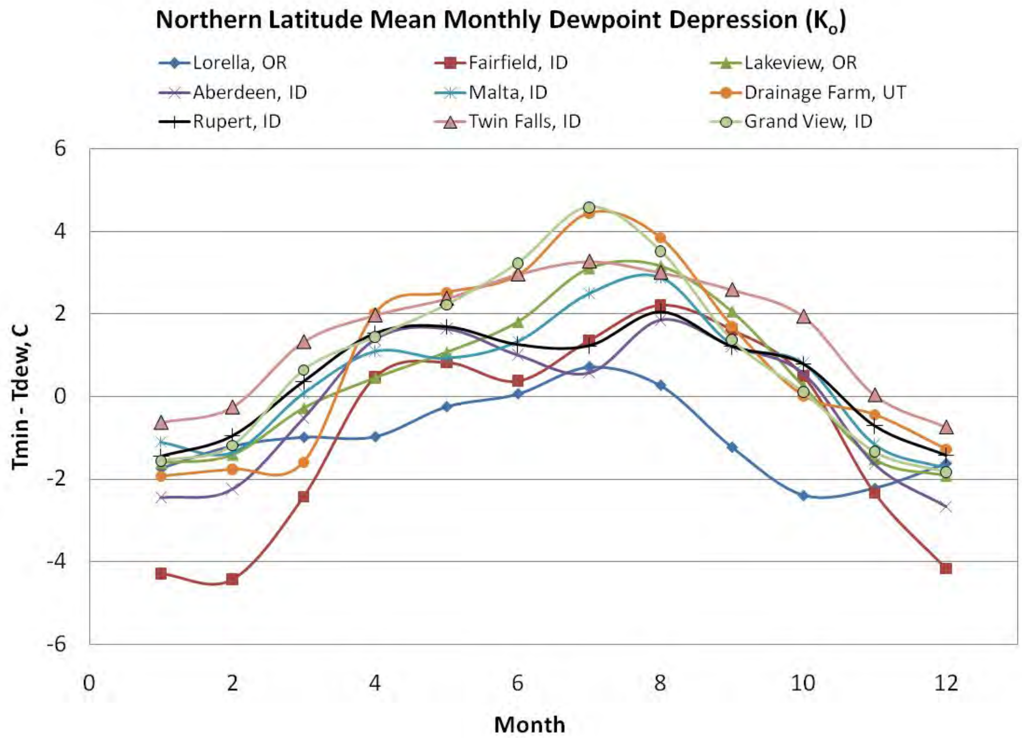

Figure 3c. Measured mean monthly dewpoint depression for northern latitude weather stations in reference (irrigated agriculture) environments.

the field. In this study, the use of weather stations located in predominately irrigated areas for computing regional monthly K_o values tend to minimize local advection effects while preserving regional advection effects that most irrigated areas in Nevada experience due to the arid climate and small scales of irrigation projects. For example, the mean monthly dewpoint depression, $K_{o,}$ for the Fallon AGRIMET site is significantly greater than surrounding stations located in irrigated environments as shown in Figure 3b. To verify this relative 'dryness' of the Fallon AGRIMET station, K_o from a weather station located nearby in a completely dry environment was compared against monthly K_o of the Fallon AGRIMET station. The mean monthly K_o computed at the Fairview Valley DRI weather station, located approximately 30 miles to the east of Fallon and at the same elevation but in a desert environment, indicates that the subregional air mass is much dryer than that found over agricultural areas near Fallon, where the desert K_o peaked at 18°C in the summer compared to 10°C for the Fallon AGRIMET station (Figure 6). This finding suggests that the Fallon AGRIMET site experiences some amount of conditioning of the boundary layer due to the cooling effect of evaporation in the area.

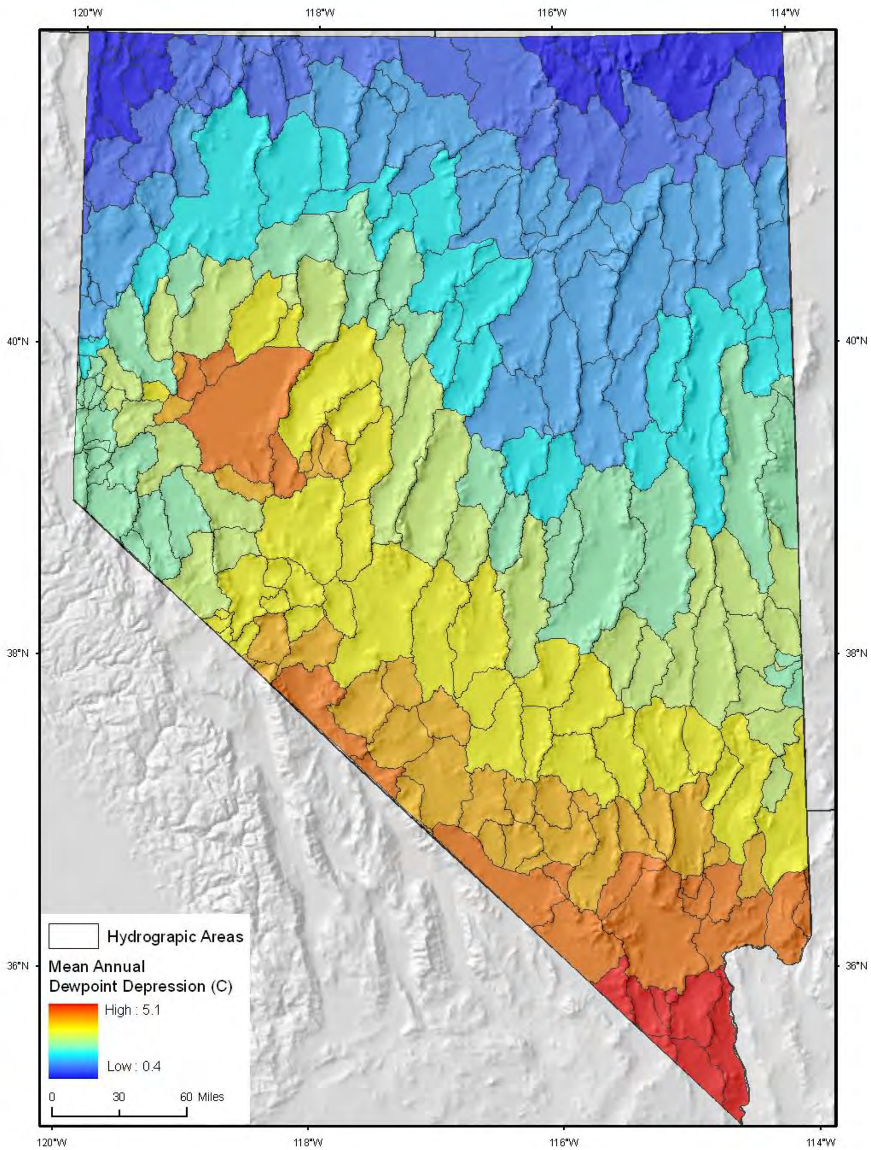

Figure 4. Spatially interpolated mean annual reference condition dewpoint depression.

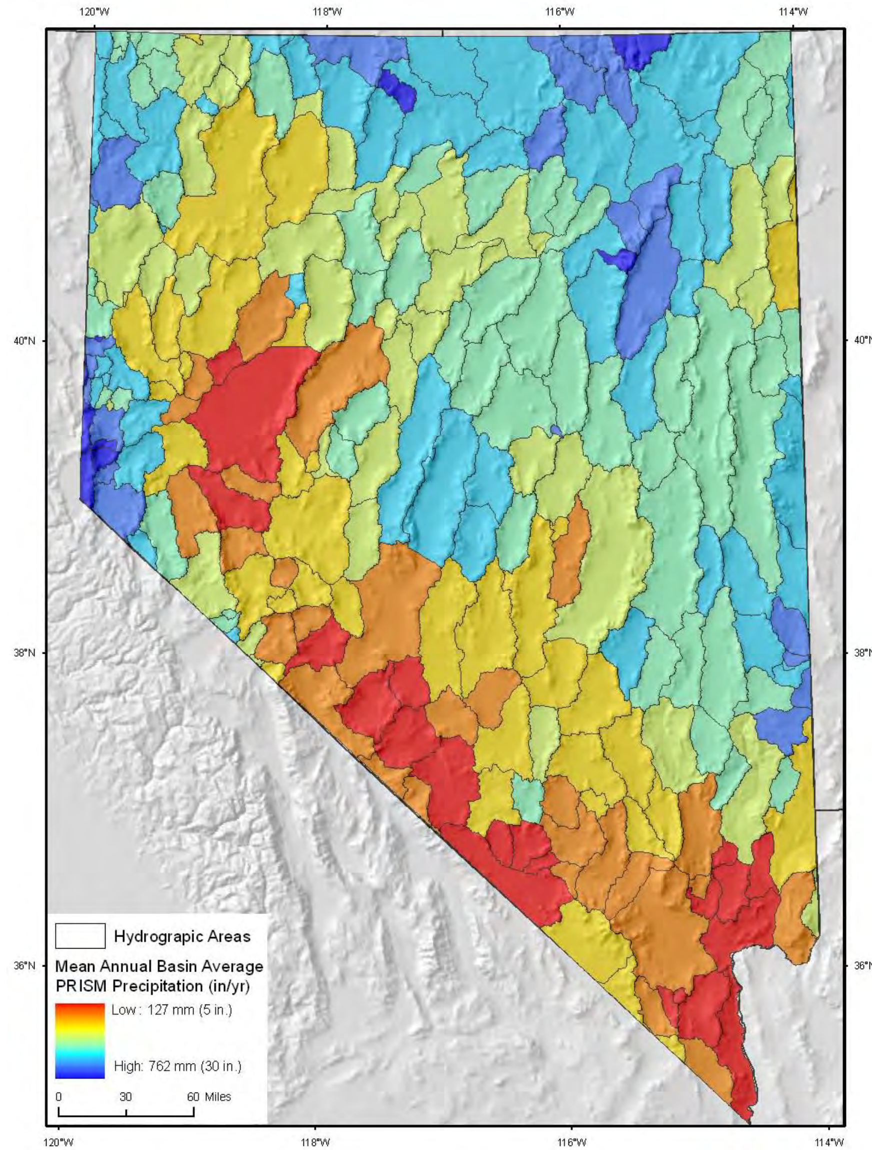

Figure 5. Basin average PRISM precipitation (800m v.2), which illustrates a similar spatial pattern as Figure 4, and supports the fact that regional scale advection is largely controlled by available moisture and the resultant energy balance of the surrounding environment.

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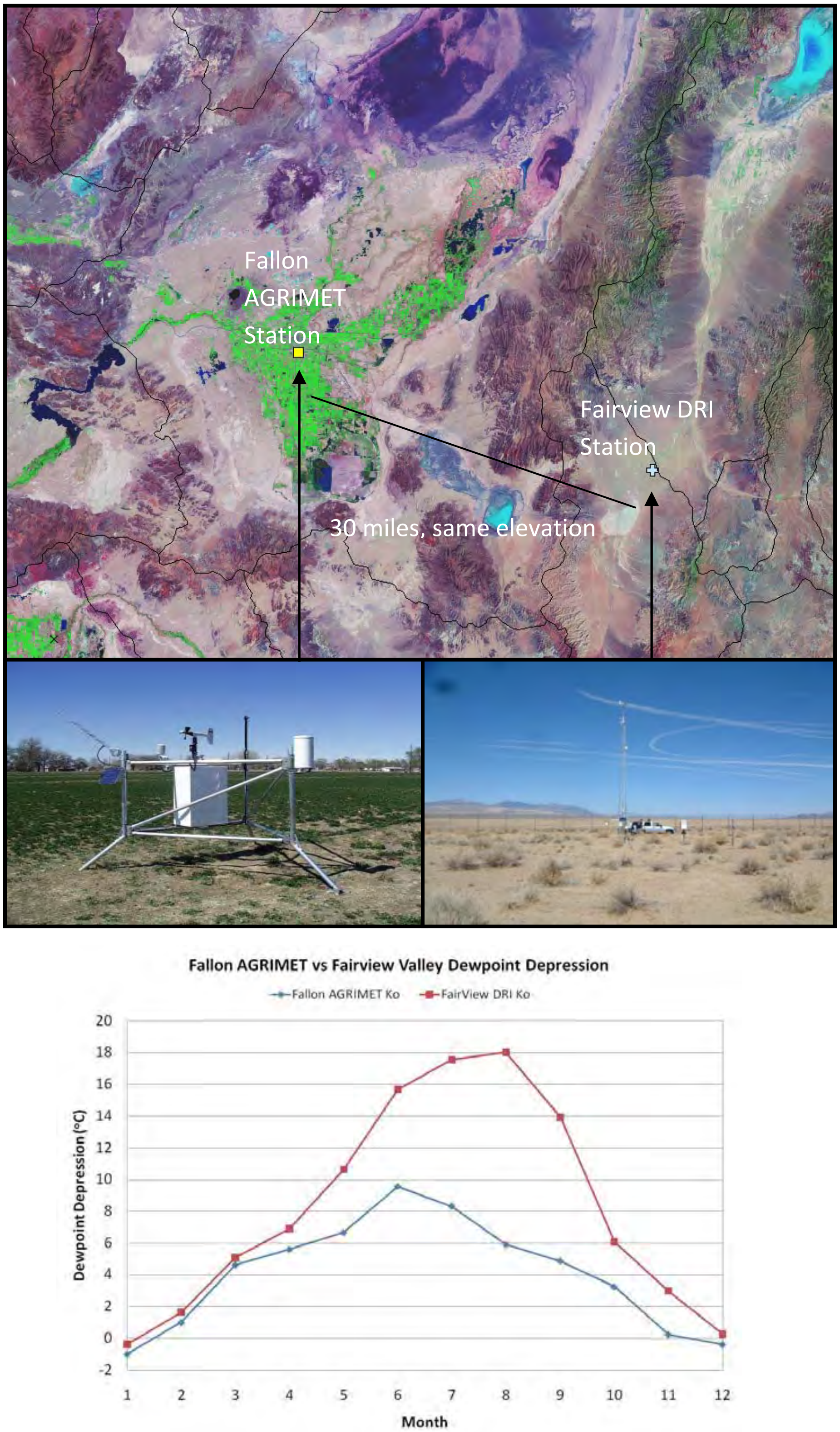

Figure 6. Comparison of dewpoint depression between the Fallon AGRIMET and Fairview Valley DRI stations illustrating how the presence of evaporation of irrigation water impacts the dewpoint depression, K_o.

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Net Radiation (R_n)

Net radiation, R_n, is the amount of radiant energy available at a surface that can be used for evaporation of water (latent heat flux), heating of the air (sensible heat flux), or heating of the surface (ground heat flux). R_n includes both long wave and short wave radiation components and defined following Brutsaert (1982) as

$$R_n = R_{ns} - R_{nl} \qquad \text{Eq. 10}$$

where

R_{ns} = net short wave radiation being positive downwards and negative upwards, [MJ m^{-2} d^{-1}], and
R_{nl} = net long wave radiation being positive upwards and negative downwards, [MJ m^{-2} d^{-1}].

Net short wave radiation is the result of the incoming and the reflected solar radiation and was estimated using a fixed albedo or canopy reflection coefficient for the standardized reference evapotranspiration equation as

$$R_{ns} = (1 - \alpha) R_s \qquad \text{Eq. 11}$$

where

α = albedo, and is fixed at 0.23, which represents the albedo of a grass surface [dimensionless],

and

R_s = incoming solar radiation [MJ m^{-2} d^{-1}].

Net Long Wave Radiation (R_{nl})

The methods of Brunt (1932, 1952) are used for the estimation of daily net long wave radiation for the standardized surface, which takes advantage of the actual vapor pressure to predict the net emissivity as

$$R_{nl} = \sigma f_{cd}\left(0.34 - 0.14\sqrt{e_a}\right)\left[\frac{T_{K\max}^4 + T_{K\min}^4}{2}\right] \qquad \text{Eq. 12}$$

where

σ = Stefan-Boltzmann constant [4.901 x 10^{-9} MJ K^{-4} m^{-2} d^{-1}],
f_{cd} = cloudiness function [dimensionless],
e_a = actual vapor pressure [kPa],
T_{Kmax} = daily maximum Kelvin temperature [K], and
T_{Kmin} = daily minimum Kelvin temperature [K].

The superscripts "4" in Eq. 12. indicate the need to raise the air temperature, expressed in Kelvin units, to the power of 4. For daily and monthly timesteps, f_{cd} was calculated following Jensen et al., (1990) and Allen et al., (1998) as

$$f_{cd} = 1.35\frac{R_s}{R_{so}} - 0.35 \qquad \text{Eq. 13}$$

where

R_s/R_{so} = relative solar radiation (limited to 0.3 – 1)
R_s = measured or calculated solar radiation [MJ m^{-2} d^{-1}], and
R_{so} = calculated clear sky radiation [MJ m^{-2} d^{-1}].

The ratio R_s/R_{so} in Eq. 13 represents relative cloudiness and is limited so that f_{cd} has limits of 0.05 – 1.0.

Incoming Solar Radiation (R_s)

Incoming solar radiation (R_s) is the primary variable for net radiation and therefore a primary variable for many ET estimation methods. Because NWS stations do not measure R_s, it was estimated at each NWS station following a method described by Thornton and Running (1999), which is based on the difference between daily maximum and minimum air temperature. The general premise of the method is based from the fact that during cloud cover maximum air temperatures generally decrease and the minimum temperature is increased due to increased downward emission of long wave radiation by clouds at night (Allen, 1997). The Thornton and Running (1999) method estimates R_s as

$$R_s = R_{so}\left[1 - 0.9\exp\left(-B\left(T_{max} - T_{min}\right)\right)^{1.5}\right], \quad \text{Eq. 14}$$

and

$$B = 0.023 + 0.1\exp\left(-0.2\Delta Tmonth\right), \quad \text{Eq. 15}$$

where R_{so} is the theoretical solar radiation on a clear day (MJ m^{-2} d^{-1}), T_{max} is the daily maximum air temperature (^oC), T_{min} is the daily minimum air temperature (^oC), and B is an empirical fitting coefficient which has a slightly modified form compared to Thornton and Running's original B function, where Allen and Robison (2007) derived coefficients in Eq. 15 using only western stations of Portland and Salt Lake City from the Thornton and Running paper. The generalized equation of Thornton and Running for B was based on weather stations throughout the US. R_{so} is computed using the exoatmospheric radiation, R_a, which is a function of latitude, day of year, and atmospheric transmissivity K_T. R_{so} is computed as

$$R_{so} = K_T R_a. \quad \text{Eq. 16}$$

For daily time steps R_a was calculated following Duffie and Beckman (1980) as

$$R_a = \frac{24}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \quad \text{Eq. 17}$$

where:

G_{sc} = solar constant [4.92 MJ m^{-2} h^{-1}],
d_r = squared inverse relative distance factor for the earth-sun [unitless]
ω_s = sunset hour angle [radians]
φ = latitude [radians], and
δ = solar declination [radians].

The squared inverse relative distance factor was calculated as

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365} J\right) \quad \text{Eq. 18}$$

where

J is the day in the year from 1 to 365 (366 for leap years), and the sunset hour angle was calculated as

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)]. \qquad \text{Eq. 19}$$

ASCE-EWRI (2005) provides an accurate method for estimating atmospheric transmissivity, K_T, needed for Eq. 16 that considers sun angle and the effects of water vapor as it relates to the absorption of short wave radiation as well as scattering of beam and diffuse radiation. ASCE-EWRI (2005) separates K_T into scattering and absorption components such that:

$$K_T = K_B + K_D \qquad \text{Eq. 20}$$

where K_B is a index of atmospheric clearness for direct beam radiation [unitless] and K_D is a index of transmissivity for diffuse radiation [unitless]. The ASCE-EWRI (2005) equation for K_B is:

$$K_B = 0.98\exp\left[\frac{-0.00146P}{K_{tb}\sin\beta} - 0.075\left(\frac{W}{\sin\beta}\right)^{0.4}\right] \qquad \text{Eq. 21}$$

where K_{tb} is a atmospheric clearness coefficient and ranges between 0 and 1, and $K_{tb} = 1$ for clean air and $K_{tb} <0.5$ for turbid, dusty, or polluted air. P is the atmospheric pressure at the station elevation [kPa], β is the angle of the sun above the horizon [radians], and W is the precipitable water in the atmosphere [mm]. A value of $K_{tb} = 1$ was used in Eq. 21 for this study, which represents clean, low aerosol air and is generally appropriate for Nevada due to the lack of consistent turbid conditions and significant development causing haze. Precipitable water in the atmosphere, W, was estimated as:

$$W = 0.14e_a P + 2.1 \qquad \text{Eq. 22}$$

where e_a is the actual vapor pressure of the air [kPa] and P is the atmospheric pressure at the station elevation [kPa].

The diffuse radiation index needed for Eq. 20 was estimated following Allen (1996) and ASCE-EWRI (2005) as:

$$K_D = 0.35 - 0.36K_B \quad \text{for} \quad K_B \geq 0.15 \qquad \text{Eq. 23}$$

$K_D = 0.18 + 0.82 K_B \quad \text{for} \quad K_B < 0.15$.

For daily time steps the average value of the angle of the sun above the horizon, β, was weighted according to R_a and was approximated by regression following Allen (1996) as:

$$\sin \beta_{24} = \sin\left[0.85 + 0.3\varphi \sin\left(\frac{2\pi}{365} J - 1.39\right) - 0.42\varphi^2\right] \qquad \text{Eq. 24}$$

where β_{24} is the average β during the daylight period, weighted according to R_a [radians].

The Thornton-Running equation has been found to produce more accurate estimates of R_s on a daily and monthly basis than the commonly used Hargreaves-Samani equation (Hargreaves and Samani, 1982) when compared to measurements of R_s, where the Hargreaves-Samani was found to consistently over estimate measured R_s by about 7% (Allen and Robison, 2007). One other advantage of the Thornton-Running equation is that it is self-limiting to the maximum value of R_s, being the clear sky solar radiation, R_{so}. For more information on the computation of R_{so} and its accuracy, see Allen (1996) and ASCE-EWRI (2005).

Estimated vs. Measured Incoming Solar Radiation

To evaluate the accuracy of R_s estimates using the Thornton-Running equation, a comparison was made between measured R_s at 14 weather stations and estimated R_s at nearby NWS weather stations. Weather stations that measure R_s in Nevada are part of several weather station networks including the US Bureau of Reclamation (USBR) AGRIMET, joint agency Community Environmental Monitoring Program (CEMP), Remote Automated Weather Stations (RAWS), and Desert Research Institute (DRI) networks. All weather stations within these networks measure R_s, air temperature, RH, wind speed and direction, and precipitation. Figure 7 illustrates the location of R_s measurement stations and respective NWS stations used for the comparison of measured and estimated R_s discussed below. While there are considerably more stations in Nevada that measure R_s that are part of the CEMP, RAWS, and DRI networks, a QAQC assessment of measured R_s from these stations following recommendations of Allen (1996) and ASCE-EWRI (2005) revealed that the majority of stations were inadequate for comparison to estimated R_s due to pyranometer malfunction or miscalibration.

Because R_{so} is the theoretical limit of measured R_s, it can easily be used as a check to ensure quality R_s measurements. An example comparing R_{so} to measured R_s is illustrated in Figure 8 for the Baker Flat RAWS station where it is obvious that the measured R_s exceeded the theoretical limit for the majority of the time series due to pyranometer drift or miscalibration, but compared very well with the R_{so} curve during some years. Figures 9 illustrates the comparison of R_{so} vs. measured R_s at the Fallon

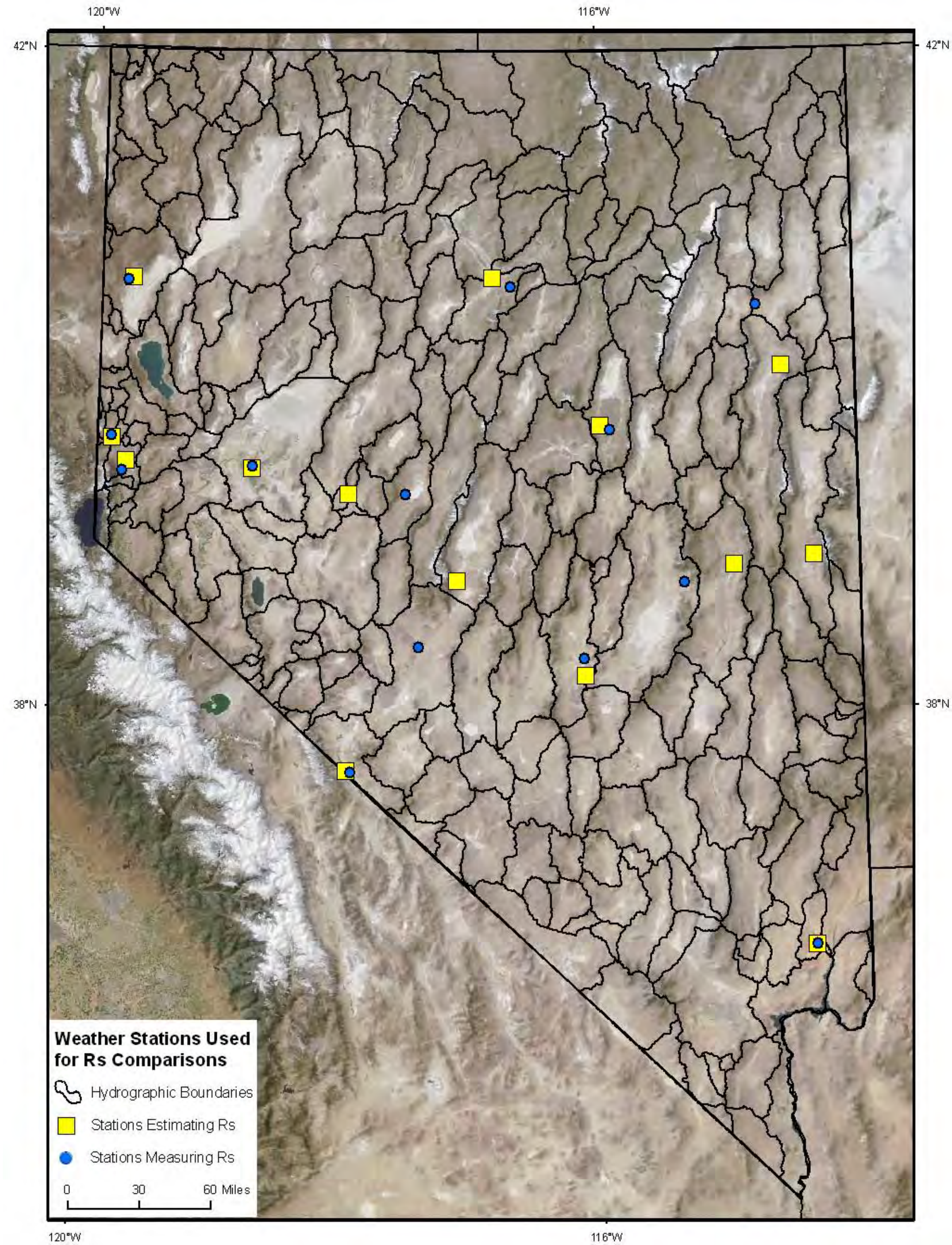

Figure 7. Location of weather stations used for comparing measured to estimated daily solar radiation, R_s.

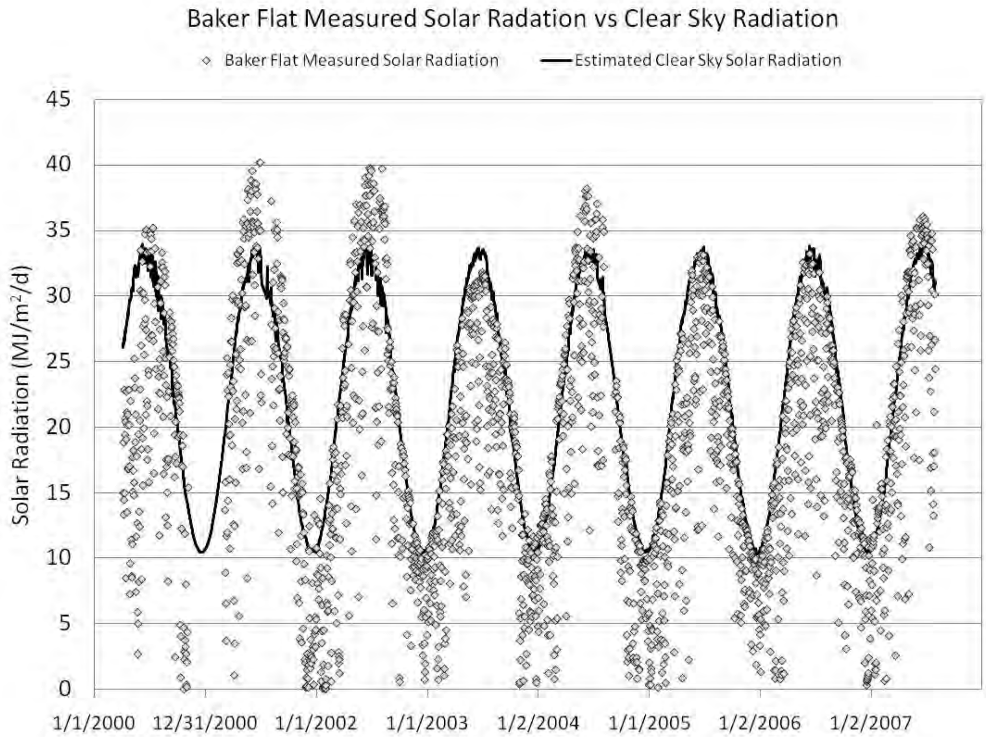

Figure 8. Baker Flat RAWS measured R_s and theoretical clear sky radiation, R_{so}, showing miscalibration of the pyranometer during years 2000, 2001, 2002, 2003, 2004, and 2007.

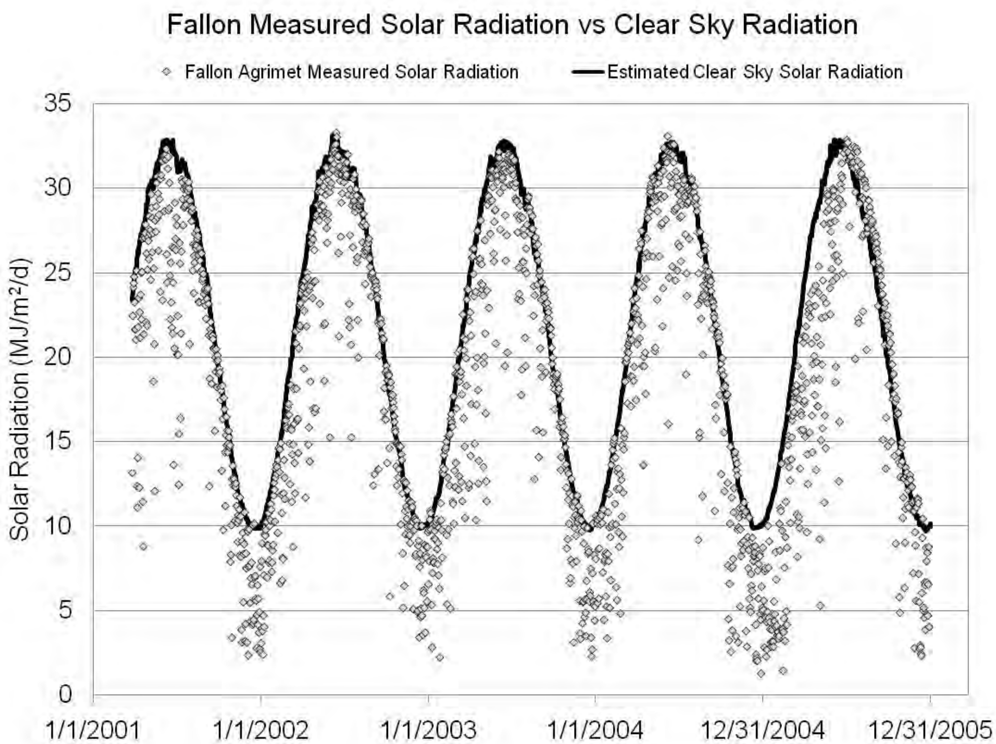

Figure 9. Fallon AGRIMET measured R_s and theoretical clear sky radiation, R_{so}, showing results from a well calibrated pyranometer, with the exception of 2005.

AGRIMET station. AGRIMET sites generally collect high quality R_s data and employ annual sensor calibration, which Figure 7 illustrates; however, it appears that the pyranometer drifted out of calibration or contains a time stamp error in 2005, therefore R_s measurements for 2005 were omitted from the larger comparison. Periods of record for the comparison were determined from the length of quality of R_s measurement and the respective period of record of the NWS station data.

When comparing daily time series of measured vs. estimated R_s, using Fallon as an example, it is evident that there are some discrepancies (Figure 10); however, this is expected since the estimates of R_s are based on only daily T_{max} and T_{min}. On a mean monthly basis, the estimated R_s compares well with the measured mean monthly R_s at most sites. Figure 11 illustrates the mean monthly comparison between measured R_s and estimated R_s for the Fallon AGRIMET station. Table 1 lists the R_s measurement stations and respective NWS stations used for the comparison, as well as the HAs where the stations are located, measurement station network, period of record used for the comparison, ratio of estimated to measured R_s, and root mean squared error (RMSE) of the daily estimated $R_{s.}$ The RMSE is computed as

$$RMSE = \sqrt{\frac{\sum \left(X_{est} - X_{meas}\right)^2}{n}} \qquad \text{Eq. 25}$$

where X_{est} is the estimated R_s and X_{meas} is the measured R_s, and n is the number of observations. The average ratio of estimated to measured R_s for all 14 stations was 1.02 with a standard deviation of 0.05, while the average RMSE for daily estimated R_s was 3.75 MJ/m^2/d. In general the Thornton-Running equation provides good estimates of R_s over the ranges measured and during all months of the year. The Thornton-Running equation was applied in similar applications for Idaho by Allen and Robison (2007).

Wind Speed

Wind speed (U) is not measured at NWS stations except at airport stations; therefore, mean monthly wind speed (Appendix 4) was derived from available data from NWS airport stations and weather stations operated by the Nevada Department of Transportation (NDOT), AGRIMET, CEMP, RAWS, and DRI networks located on valley floor areas with sufficient period of record, totaling 58 stations. These wind speed means were used to assign the mean monthly wind speed at each NWS station as

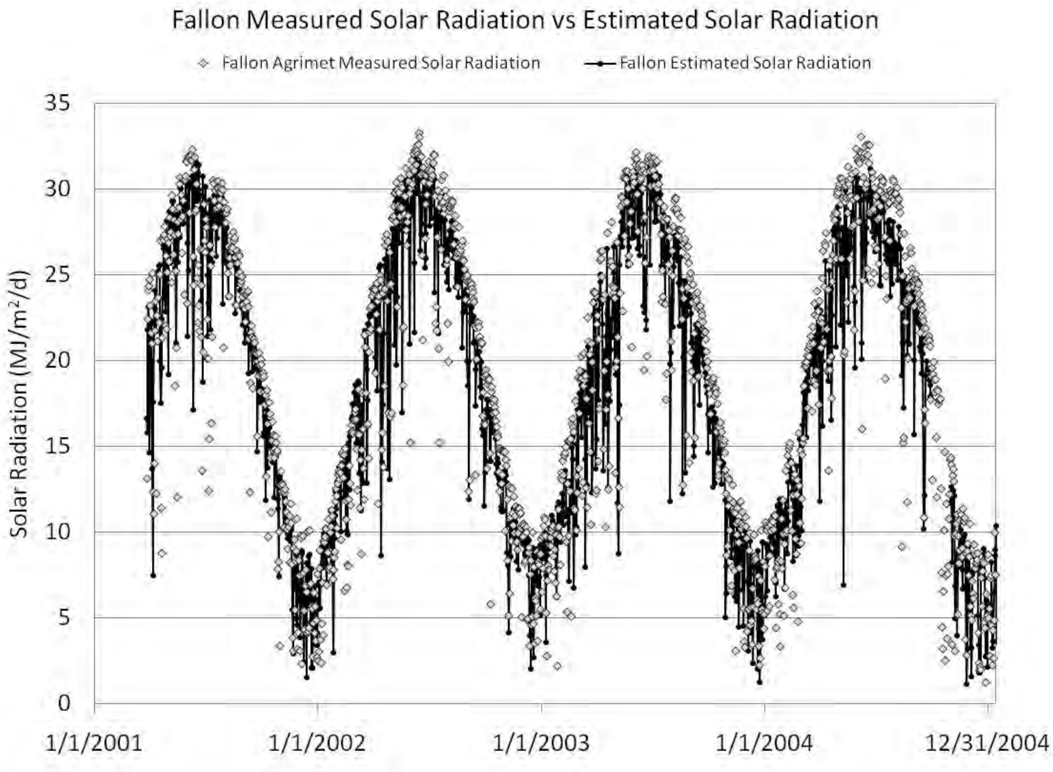

Figure 10. Fallon AGRIMET daily measured and estimated R_s.

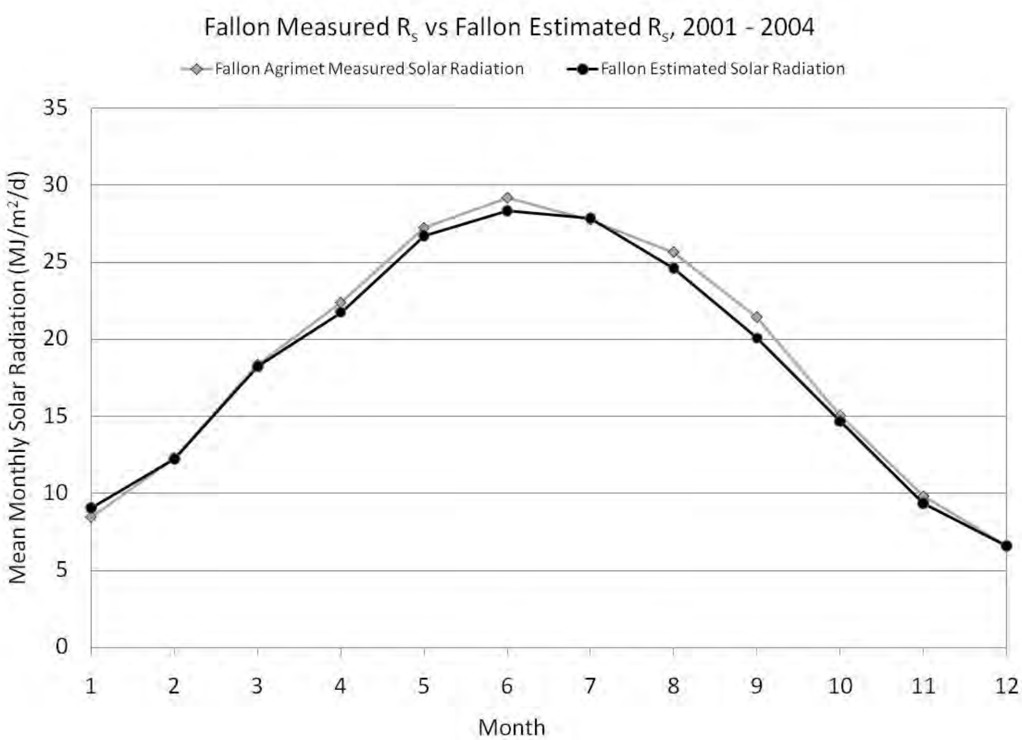

Figure 11. Fallon AGRIMET mean monthly measured and estimated R_s.

Table 1. Estimated solar radiation at NWS stations vs. measured solar radiation at weather stations nearby NWS stations.

Name of NWS Station for Rs Estimation	NWS Station Latitude	NWS Station Longitude	Basin of NWS Station Location	Name of R_s Measurement Station	R_s Station Latitude	R_s Station Longitude	Basin of R_s Station Location	Type of R_s Measurement Station	Period of Record for Comparison	Ratio of Estimated R_s to Measured R_s	RMSE for Daily Estimated R_s, $MJ\ m^{-2}d^{-1}$
Battle MTN AP	40.62	-116.90	Lower Reese River Valley	Beacon Light	40.56	-116.76	Lower Reese River Valley	RAWS	1/98 - 5/04	1.08	3.62
Smokey Valley	38.78	-117.17	Big Smokey Valley	Lower Big Smokey Valley	38.37	-117.47	Big Smokey Valley	DRI	12/03 - 6/07	1.01	3.77
Diamond Valley USDA	39.72	-116.05	Diamond Valley	Eureka AGRIMET	39.69	-115.98	Diamond Valley	AGRIMET	8/01 - 6/06	1.09	3.51
Dyer	37.62	-118.02	Fish Lake Valley	Dyer Wallace Farms	37.61	-117.99	Fish Lake Valley	DRI	4/03 - 7/06	1.01	3.65
Fallon EXP STN	39.45	-118.78	Carson Desert	Fallon AGRIMET	39.46	-118.78	Carson Desert	AGRIMET	3/01 - 12/04	1.01	3.00
Lages	40.07	-114.62	Steptoe Valley	Spruce Mountain	40.44	-114.81	Goshute Valley	RAWS	8/98 - 5/04	1.05	3.91
Lund	38.87	-115.02	White River Valley	Currant Creek	38.76	-115.41	Railroad Valley - Northern Part	RAWS	1/99 - 12/04	1.00	3.53
Middlegate - Lowery	39.30	-118.02	Cowkick Valley	Desatoya Mountain	39.30	-117.58	Smith Creek Valley	RAWS	1/99 - 5/05	1.09	3.77
Overton	36.55	-114.45	Lower Moapa Valley	Overton	36.55	-114.45	Lower Moapa Valley	CEMP	1/04 - 5/07	1.03	3.21
Reno INT AP	39.48	-119.77	Truckee Meadows	Reno Wolf Run Golf Course	39.42	-119.80	Truckee Meadows	DRI	4/00 - 3/06	0.99	3.67
Shoshone 5N	38.92	-114.40	Spring Valley	Currant Creek	38.76	-115.41	Railroad Valley - Northern Part	RAWS	1/99 - 12/04	1.00	4.04
Smoke Creek Espil	40.60	-119.75	Smoke Creek Valley	Buffalo Creek	40.58	-119.79	Smoke Creek Valley	RAWS	9/98 - 12/04	0.90	3.33
Stead	39.62	-119.88	Lemmon Valley	Stead Golf Course	39.63	-119.89	Lemmon Valley	DRI	7/01 - 9/04	0.99	5.55
Twin Springs Fallini	38.20	-116.18	Hot Creek	Pancake	38.30	-116.19	Hot Creek	RAWS	1/98 - 4/04	1.02	3.88
									Average of Ratios and RMSE	**1.02**	**3.75**
									Std. Dev. of Ratios and RMSE	**0.05**	**0.59**

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$$U_2 = U_{2\,meanmonthly_i} \qquad \text{Eq. 26}$$

where U_2 is the estimated daily 2 meter height wind speed for each NWS station, and $U_{2meanmonthlyi}$ is the measured mean monthly 2 meter height equivalent wind speed or HA spatially averaged 2 meter wind speed assigned from a measurement site. Adjustment to the measured wind speed was required to estimate the wind speed at the standardized 2 meter height using a typical logarithmic wind profile relationship

$$U_2 = \frac{\ln\left(\frac{2-d}{z_{om}}\right)}{\ln\left(\frac{z_w - d}{z_{om}}\right)} \qquad \text{Eq. 27}$$

where

U_2 = wind speed at 2m above ground surface [m s^{-1}],
u_z = measured wind speed at z_w m above ground surface [m s^{-1}],
z_w = height of measurement above ground surface [m],
d = zero plane displacement height for the weather site vegetation [m], and
z_{om} = aerodynamic roughness length for the weather site vegetation [m].

The wind speed measurement heights for weather stations used vary from 2-10 meters, and have vegetation surface heights that range from bare ground to small brush found in xerophyte communities. Given the range of vegetation height associated with wind speed measurements it was assumed that the standardized zero plane displacement height of d=0.67m, and standardized aerodynamic roughness length of z_{om} = 0.123h, representing a tall grass of 0.12m be employed. Station locations and measured wind speed time series from all selected stations were visually inspected during QAQC, in which many stations were rejected due to excessive anemometer height, fetch obstructions by buildings and or trees as determined from photos, or bad quality data due to anemometer calibration or lack of maintenance causing systematic error. For example, Figure 12 illustrates a decreasing trend in measured wind speed at the Caliente CEMP station. From observation of the Caliente station photo, the long-term decrease is likely caused by a growing tree next to the station. Analyses of measured wind speed time series generally reveal strong seasonal variations, with increased wind speeds in early spring and summer and decreased wind speeds in early fall and winter. Figure 13 illustrates 2m height equivalent mean monthly wind speed for selected stations located across the state. Of the 58 stations analyzed, the Lower Big Smokey Valley DRI station had the highest 2m equivalent mean annual wind speed of 3.6 m/s.

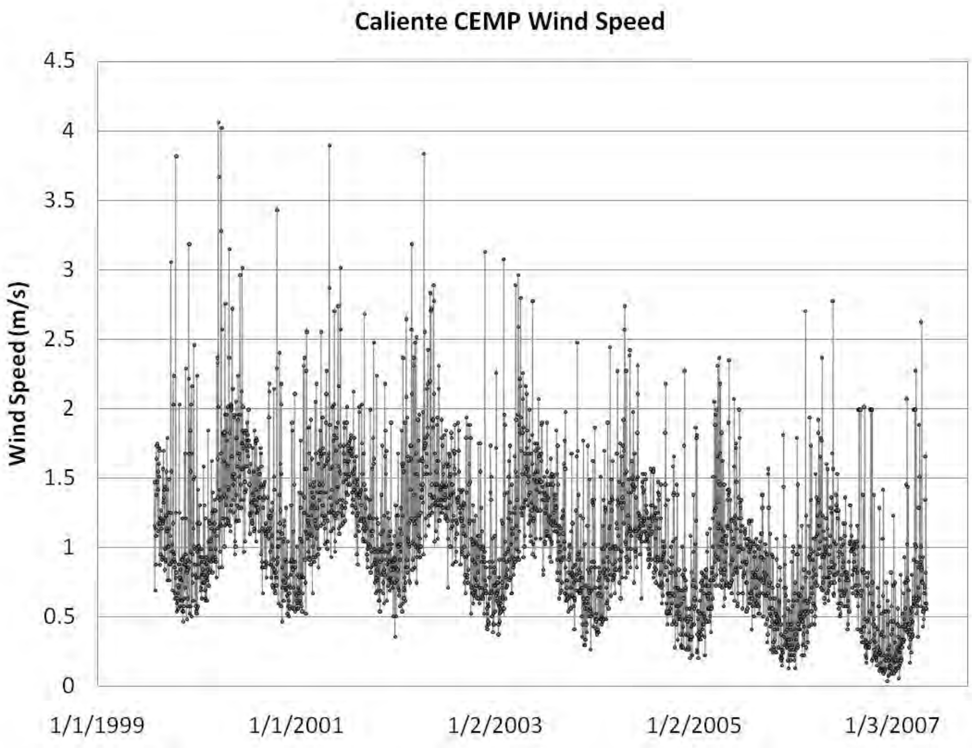

Figure 12. Daily measured wind speed at the Caliente CEMP weather station. The downward trend over time illustrates that the anemometer is likely being influenced by a nearby growing tree and/or failing bearing.

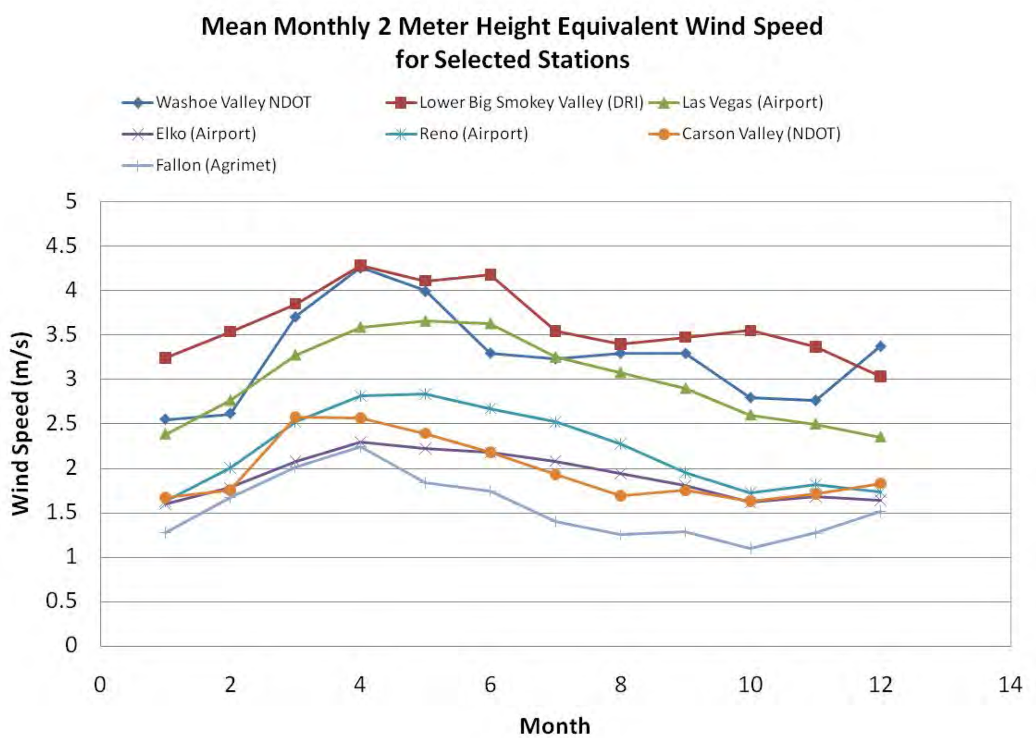

Figure 13. Mean monthly 2 meter height equivalent wind speed for selected stations across the state illustrating seasonal trends and magnitudes of wind speed.

Similar to the assigning of K_o values to NWS stations with no measurements within a HA, spatially interpolated mean monthly wind speed surfaces were generated using inverse distance weighting and were spatially averaged to HAs, where NWS stations were assigned respective spatially averaged mean monthly wind speed values for computation of ET_{os}. Figure 14 illustrates the weather stations used for spatially interpolating mean monthly wind speed as well as the spatial distribution of mean annual wind speed spatially averaged to HAs. In general, the spatial distribution of mean annual wind speed is spatially consistent with wind power maps produced by the Nevada State Office of Energy (NSOE) and U.S. Department of Energy, National Renewable Energy Laboratory (NREL) (data available at http://www.nrel.gov/).

Crop Evapotranspiration

Crop Coefficient Approach

The application of K_c values to ET_{os} simulates cutting periods, initial and late crop stages where the crop is not at full cover or peak height, roughness of the crop surface to account for turbulent effects, and crop geometry. Simply put, the effects of weather variables are incorporated into ET_{os}, whereas the effects that distinguish vegetated, bare, or open water surface from the reference surface are integrated into the crop coefficient. As such, the K_c is defined as the ratio of ET_{act} to the calculated ET_{os}, such that the crop evapotranspiration, ET_{act}, which includes evaporation from the soil surface following wetting by precipitation or irrigation is defined as

$$ET_{act} = K_c ET_{os} \quad \text{Eq. 28}$$

where

ET_{os} = the standardized reference ET
K_c = crop coefficient respective of the ET_{os}.

Several crop ET studies conducted in Nevada have applied the 'mean' K_c approach (Rashedi, 1983; Guitjens and Goodrich, 1994; Pennington, 1980; Moreo et al., 2003; Welch et al., 2007; Moreo and Justet, 2008), where all time-averaged effects of evaporation from the soil surface from precipitation and irrigations are averaged into the K_c value. The mean K_c therefore represents the average evaporation fluxes expected from the soil and plant surface under some average wetting interval, either by precipitation or irrigation. A more detailed K_c approach is the 'dual' K_c method, where the K_c value is separated into a 'basal' crop coefficient, K_{cb}, and a soil evaporation coefficient, K_e. The basal crop coefficient is defined as the ratio of ET_{act} to ET_{os} when the soil surface is dry and transpiration is solely derived from the root zone soil moisture present to support the full potential transpiration. The soil evaporation component is calculated

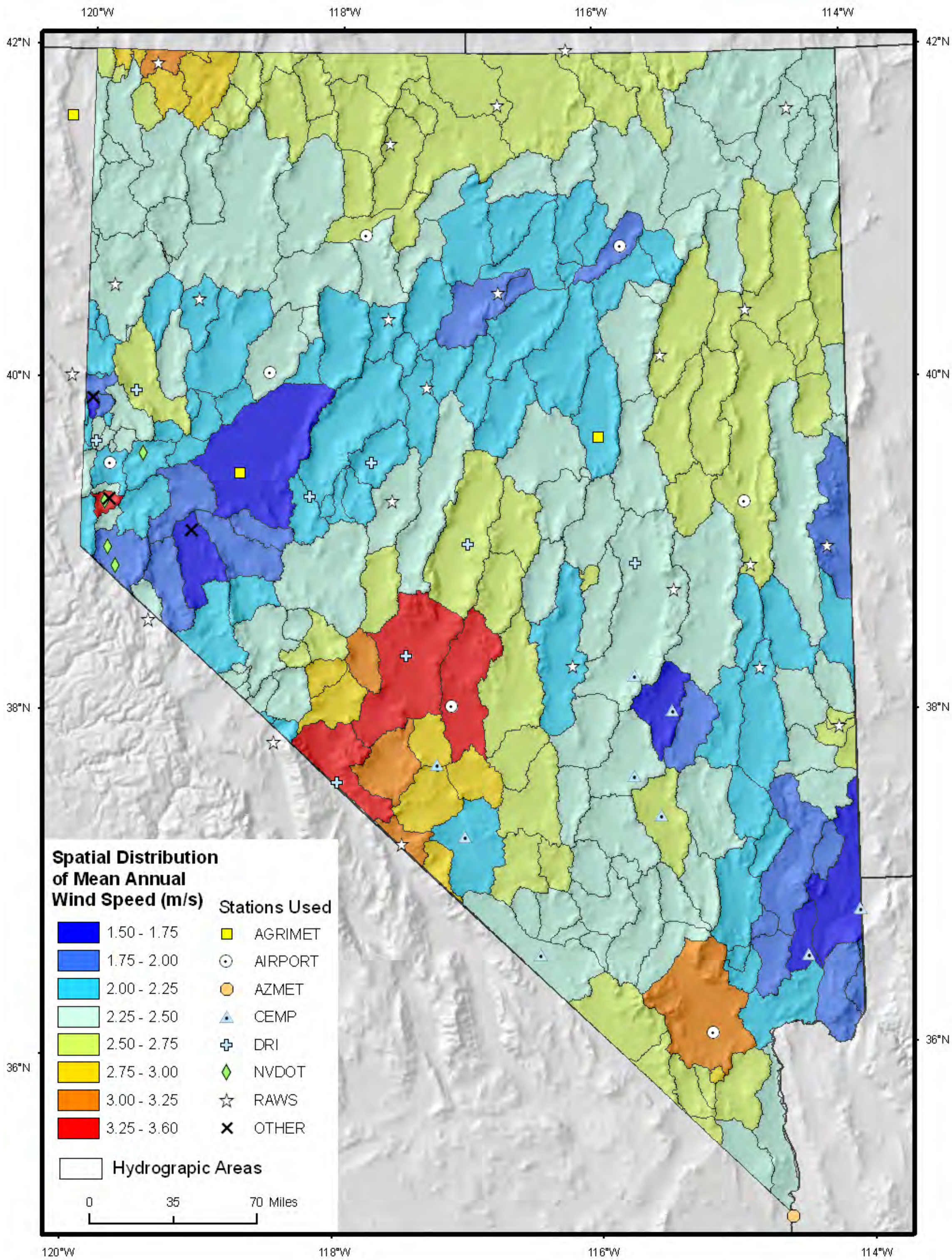

Figure 14. Spatially distributed mean monthly wind speed derived from multiple weather station networks located on valley floor areas. For basins where wind speed measurements exist, basins were assigned 2m height equivalent estimated wind speed, or the average 2m height equivalent estimated wind speed where multiple measurements exist. Basins with no wind speed measurements were estimated using inverse distance weighting.

separately according to precipitation and simulated irrigation events and is then added to the K_{cb} to produce the total K_c. The equation for the potential ET, ET_{pot}, in the dual K_c approach is

$$ET_{pot} = (K_{cb} + K_e)ET_{os} \qquad \text{Eq. 29}$$

where K_{cb} is the basal crop coefficient and K_e is the soil water evaporation coefficient. K_{cb} and K_e range from 0 to 1.4 when used with ET_{os} and are dimensionless. ET_{act} may be less than the ET_{pot} when the soil water content is less than that needed to sustain full rates of transpiration. In this situation the ET_{act} is calculated by incorporating a stress coefficient

$$ET_{act} = (K_s K_{cb} + K_e)ET_{os} \qquad \text{Eq. 30}$$

where K_s is a dimensionless coefficient ranging from 0 to 1 for when there is stress caused by low soil moisture not adequate to sustain full potential plant transpiration. K_s is equal to 1 when there is no water stress, as is the case for irrigated crops during the irrigation season opposed to rain fed crops or native vegetation.

A daily root zone water balance is required to calculate K_s, which incorporates the available soil moisture for the simulated effective root zone. An additional soil water balance is maintained for the estimation of K_e, and is limited to the upper 0.1m of the soil since this zone is assumed to be the only layer that supplies water for direct evaporation from the soil surface.

The daily water balance procedures and the calculation of K_s and K_e follow methods established in FAO-56 (Allen et al., 1998) and further refined in Allen et al., (2005). Included as an annex to this report (Annex 1) is the Allen et al., (2005) ASCE publication describing in detail the dual crop coefficient approach and daily soil water balance procedures used in this study. Departures from the FAO-56 and Allen et al., 2005) procedures implemented in this study are not in the soil water balance, but in the K_{cb} curves, which are curvilinear, similar to those published by Wright (1982), rather than the linear curves used in FAO-56 and Allen et al., (2005). This same modification was used by Allen and Robison (2007) for applications in Idaho and provides more flexibility in representing the changes in K_{cb} over the course of the growing season using a growing degree approach rather than using specified dates that define linear segments of the K_{cb} curves.

Soil Characteristics and Water Holding Properties

Infiltration characteristics and water holding properties needed for calculations of the soil and root zone water balance were estimated using spatial soils information. Spatial soil information was obtained from STATSGO (State Soil Geographic Database), a digital soils map developed by the USDA Natural Resource Conservation Service (NRCS). The STATSGO database depicts soil units at a regional scale (Figure 15) and contains attributes pertaining to the physical character of soils such as the available water holding capacity (AWC), layer thickness, soil texture, and permeability for use with the USDA-NRCS curve number method for estimating runoff. The primary variable used in the soil and root zone water balance is the AWC, which affects the estimation of irrigation scheduling, evaporation losses from soil, and deep percolation from root zones. Soil attributes of AWC and permeability for each polygon were depth weighted according to the reported layer thickness. Hydrologic soil groupings for use in the curve number method were assigned to soil polygons according to Allen and Robison (2007), where permeability ranges of greater than 4, 1-4, and less than 1 inch per hour were assigned hydrologic groupings of A, B, and C, respectively. Soil attributes were then assigned to weather stations based on weather station location. Rather than taking a spatial average of soil attributes associated with some boundary, such as a valley floor boundary, and assigning spatially averaged soil attributes to respective weather stations that are located within the boundary, a simple identity operation was performed. The identity operation simply assigns soil attributes to weather stations that fall within respective soil polygons. As illustrated in Figure 16, most irrigated areas are generally within contiguous soil units, making the assignment of soil attributes to respective weather stations generally representative of irrigated areas.

The daily soil water balance model includes the simulation of evaporation from the upper 0.10m of the surface layer of the soil, and is parameterized by the readily evaporable water (REW) and total evaporable water (TEW). The REW represents the cumulative depth of soil evaporation during the period when evaporation is energy limited (known as stage 1), and TEW is the maximum cumulative depth of soil evaporation that occurs from an initially wet soil at the AWC (total evaporation during stage 1 and stage 2). For further details on REW and TEW, see FAO-56 (Allen et al., 1996) or Annex 1. REW and TEW were estimated from regression equations of Allen and Robison (2007) as

$$REW = 0.8 + 54.4\frac{AWC}{1000} \qquad \text{Eq. 31}$$

and

$$TEW = -3.7 + 166\frac{AWC}{1000} \qquad \text{Eq. 32}$$

where AWC is in mm/m, the independent variables REW and TEW are in mm, and the dependent variable of depth weighted AWC was estimated from the STATSGO soils database. These regression equations were developed based on values of REW and TEW vs. AWC presented in Table 1 of Allen et al., (2005) shown in Annex 1, and have R^2 values of 0.88 and 0.85 respectively. The estimate for REW is limited to less than or equal to 0.8 TEW during the growing season and 0.7 TEW during winter periods having low ET. The primary parameters associated with the root zone soil water balance include the total available water in the root zone (TAW) and the readily available water in the root zone (RAW).

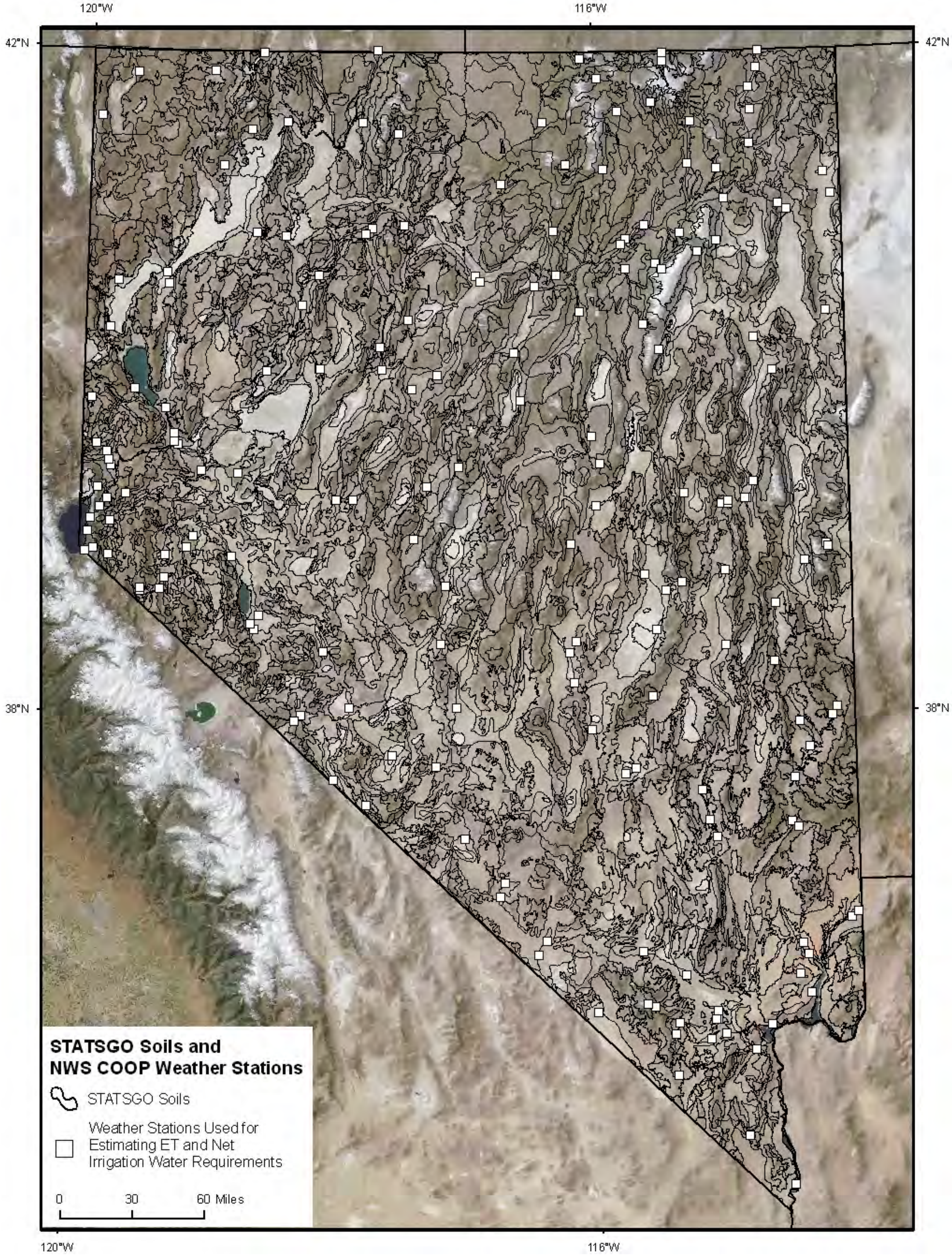

Figure 15. State Soil Geographic Database (STATSGO) used for estimating soil properties at weather stations for soil water balance simulations.

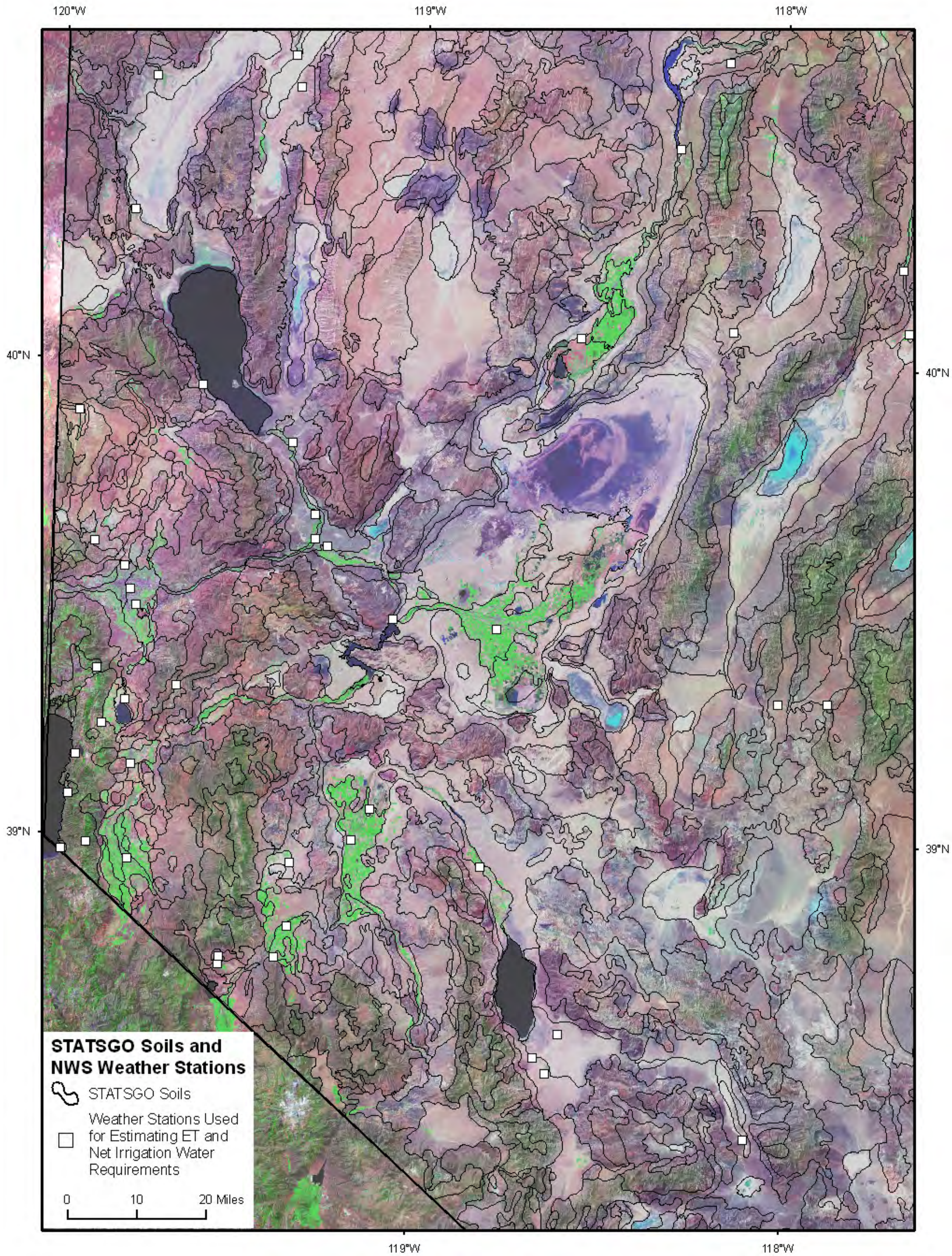

Figure 16. A close up view of the STATSGO soils database illustrating contiguous soil units that surround irrigated areas, which commonly include weather stations.

The TAW (mm) was estimated as

$$TAW = AWC * Z_r \quad \text{Eq. 33}$$

where Z_r is the root depth (m) and AWC is the available water holding capacity (mm/m), and was estimated from the STATSGO soils database. The RAW (mm) represents the fraction of TAW that a crop can extract from the root zone without suffering water stress, and was estimated as

$$RAW = TAW * \frac{MAD}{100} \quad \text{Eq. 34}$$

where MAD is the maximum allowable depletion of soil moisture for each crop (%) before stress occurs (see Appendix 5 for crop dependent MAD values). A conceptual model of the root zone soil water balance is shown in Figure 17. For more detailed information on the soil and root zone water balance and calculation of K_e and K_s coefficients, refer to FAO-56 (Allen et al., 1996) and Annex 1.

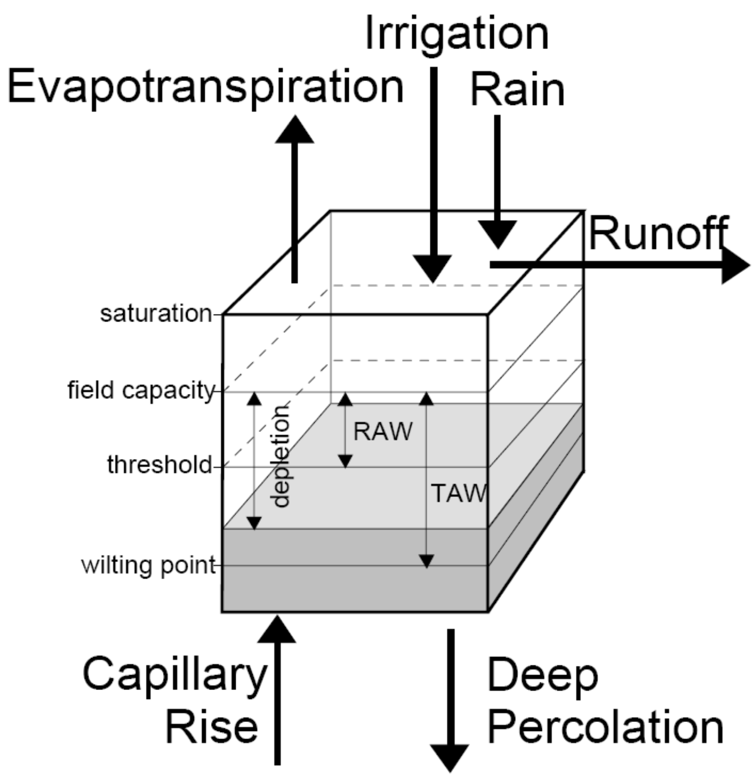

Figure 17. Conceptual model of the FAO-56 root zone water balance used in this study. Capillary rise in this study was assumed to be negligible. Modified from Allen et al., 1998.

Root Growth

Root depth is an important variable when considering the daily root zone soil water balance, specifically the amount of soil water available to plants over time. Root growth was estimated as a function of time between the initial rooting, assumed to occur at the time of planting or greenup, until the time of maximum effective rooting depth. Both initial and maximum effective root depths were specified for each crop (Appendix 5, crop parameter table). Initial and maximum root depths were adopted from FAO-56 and Allen and Robison (2007). The root depth between the initial and maximum root depth values were estimated using the Borg and Grimes (1986) sigmoidal function as

$$z_r = z_{\min} + [0.5 + 0.5\sin(3.03F_{timeroot} - 1.47)][z_{\max} - z_{\min}] \qquad \text{Eq. 35}$$

where z_r is the effective root depth at some time during the growing season, z_{min} is the initial root depth at planting or greenup, z_{max} is the maximum effective root depth, and $F_{timeroot}$ is the fraction of time from the start of root growth until the time of maximum root depth. The root depth variables can have units of meters or feet. The Borg and Grimes root growth function is illustrated in Figure 18.

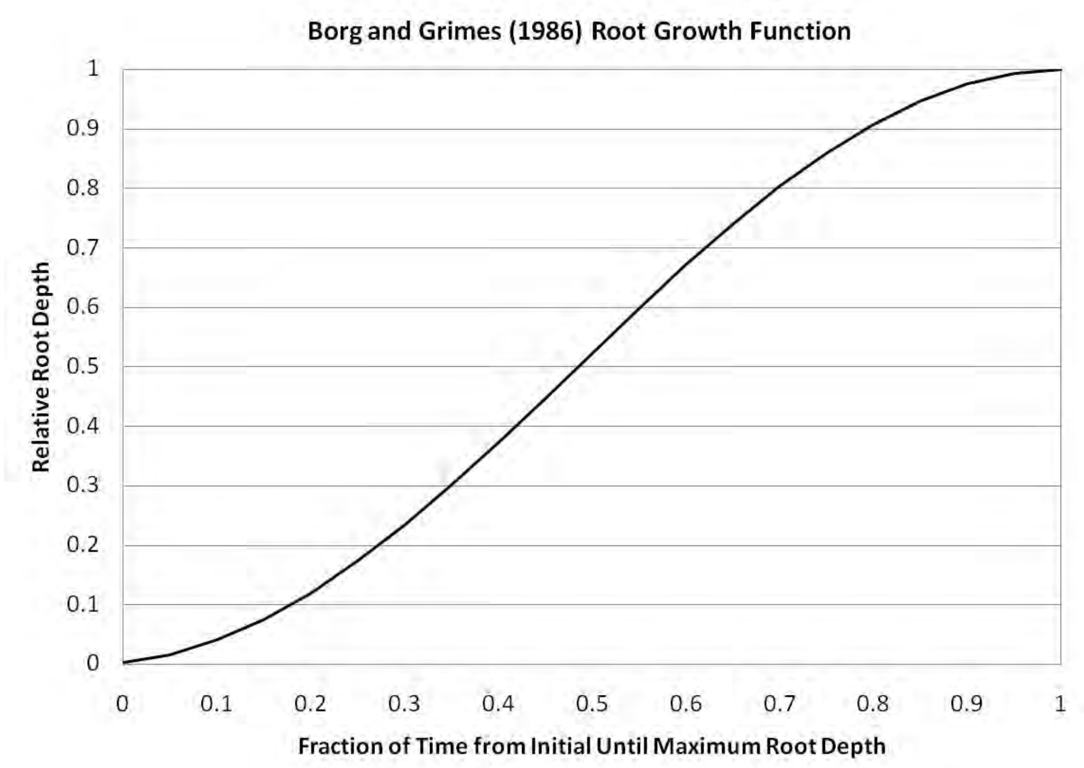

Figure 18. Root growth function following Borg and Grimes (1986) used for simulating root growth and plant available soil water in soil water balance calculations.

Runoff from Precipitation

Runoff during precipitation events is strongly influenced by soil texture, soil structure, sealing and crusting of the soil surface, slope, local land forming such as tillage and furrowing, antecedent moisture, and precipitation intensity and duration. Because of the complexities of estimating runoff, the simple, widely accepted USDA-NRCS curve number approach was applied in this study. Required data are daily precipitation depth and computation of a daily soil water balance to determine antecedent soil water conditions.

The curve number (CN) represents the relative imperviousness of a soil-vegetation surface and ranges from 0 for an infinite pervious surface to 100 for a completely impervious surface. Generally, the CN is selected from standard tables based on general crop and soil types and is adjusted for the antecedent soil conditions prior to the precipitation event. The soil water content prior to the rainfall event affects the CN value, as the soil infiltration rate is a function of the soil water content. Therefore, the CN was adjusted according to the estimated soil water content prior to the rainfall event. This soil water content is termed the antecedent soil condition (ASC). Adjustment of the CN based on the ASC is defined by the USDA-SCS (1972) for dry (ASC I) and wet (ASC III) conditions. USDA-SCS defined the ASC I occurring when "soils are dry enough for satisfactory plowing or cultivation to take place" and ASC III as when the "soil is practically saturated from antecedent rains."(National Engineering Handbook, Section 4 Hydrology, 1972, p. 4.10). The ASC II is defined as the average condition. CN values for the ASC II condition for various crop types and hydrologic groupings used in this study are listed in Table 2, which were adopted from SCS (1972) and Allen (1988).

Hawkins, et al., (1985) expressed tabular relationships in SCS (1972) in the form of equations relating CN values for ASC I and ASC III, to CN values for ASC II as:

$$CN_I = \frac{CN_{II}}{2.281 - 0.01281 CN_{II}} \qquad \text{Eq. 36}$$

and

$$CN_{III} = \frac{CN_{II}}{0.427 + 0.00573 CN_{II}} \qquad \text{Eq. 37}$$

where CN_I is the curve number associated with ASC I (dry), CN_{II} is the curve number associated with ASC II (average condition), and CN_{III} is the curve number associated with ASC III (wet).

The soil surface layer water balance associated with the dual K_c procedure was used to estimate the daily ASC condition. An approximation for the depletion of the soil surface layer at ASC III (wet) is when De=0.5 REW, that is when the evaporation process is halfway through stage 1 drying (Annex 1, Figure 2). This point will normally be when approximately 5 mm or less has evaporated from the top 150 mm of soil since the time it was last completely wetted. Thus, the relationship for De-ASC III is developed as

$$D_{e-ASCIII} = 0.5REW \qquad \text{Eq. 38}$$

where $D_{e\text{-}ASCIII}$ is the depletion of the evaporative layer at ASC III. AWC I (dry) can be estimated to occur when 10 to 20 mm of water have evaporated from the top 100 to 150 mm of soil from the time it was last completely wetted. This is generally equivalent to when the evaporation layer has dried to the point at which D_e exceeds 30% of the total evaporable water in the surface layer beyond REW. This depletion amount was expressed as

Table 2. Typical antecedent soil water conditions (AWC) II curve numbers (CN's) for general crops and hydrologic group classes. Hydrologic groups classes of A, B, and C, represent coarse, medium, and fine textured soils, respectively. Table modified from from SCS (1972) and Allen (1988).

	Soil Texture - Hydrologic Grouping		
Crop	Coarse-A	Medium-B	Fine-C
Spring Wheat	63	75	85
Winter Wheat	65	75	85
Field Corn	67	75	85
Potatoes	70	76	88
Sugar Beets	67	74	86
Peas	63	70	82
Dry Edible Beans	67	75	85
Sorghum	67	73	82
Garden Vegetables	72	80	88
Fruit Trees-Bare	65	72	82
Fruit Trees-Grnd.	60	68	70
Onions/Garlic	72	80	88
Tomatoes	65	72	82
Alfalfa Hay	60	68	77
Pasture	40	70	82
Lentils, canola, safflower, sunflower	58	72	83
Bare Soil	77	86	92
Suggested defaults	65	72	82

$$D_e = REW + 0.3(TEW - REW) \quad \text{Eq. 39}$$

where TEW is the total evaporable water in the surface layer. Therefore

$$D_{e-ASC\,I} = 0.7REW + 0.3TEW \quad \text{Eq. 40}$$

where TEW is the cumulative evaporation from the surface soil layer at the end of stage 2 drying. When D_e is in between these two extremes, that is when 0.5REW < De < 0.7REW+0.3TEW, then the ASC is near the ASC II condition and the CN value is linearly interpolated between CN I and CN III. In equation form, the CN for the intermediate ASC condition becomes

$$CN = CN_{III} \text{ for } De \leq 0.5REW \text{ ,} \quad \text{Eq. 41}$$

$$CN = CN_I \text{ for } De \geq 0.7REW + 0.3TEW \text{ ,} \quad \text{Eq. 42}$$

and

$$CN = \frac{(D_e - 0.5REW)CN_I + (0.7REW + 0.3TEW - D_e)CN_{III}}{0.2REW + 0.3TEW} \quad \text{Eq. 43}$$

for the condition where

$$0.5REW < D_e < REW + 0.3(TEW - REW) . \quad \text{Eq. 44}$$

Equation 43 produces CN_{II} when D_e is half way between the endpoints of CN_I and CN_{III} due to the symmetry of CN_I and CN_{III} relative to CN_{II}.

Parameter S [mm] in the CN procedure is the maximum depth of water that can be retained as infiltration and canopy interception during a single precipitation event, and is calculated as

$$S = 250\left(\frac{100}{CN} - 1\right) \quad \text{Eq. 45}$$

and surface runoff is then calculated from the standard curve number method for P > 0.2S as

$$RO = \frac{(PPT - 0.2S)^2}{PPT + 0.8S} \qquad \text{Eq. 46}$$

where RO is the depth of surface runoff during the precipitation event [mm], and PPT is the depth of precipitation during the event [mm]. The 0.2S term represents the abstracted precipitation that is intercepted by canopy and soil surface before any runoff occurs. Once the surface runoff depth was estimated using the CN procedure, the depth of precipitation infiltrated was calculated as

$$P_{\inf} = PPT - RO \qquad \text{Eq. 47}$$

where P_{inf} is the depth of infiltrated precipitation [mm] and RO is the depth of surface runoff [mm]. If P_{inf} exceeds the depth of the soils AWC, the remainder is considered deep percolation.

Simulated Irrigations

The simulation of irrigations was accomplished using the daily root zone soil water balance. Irrigations are simulated when the root zone dries to the maximum allowable depletion threshold point where stress will begin to occur (point where RAW is exceeded). The simulated irrigation amount is the difference between the cumulative depletion at or slightly beyond the RAW (due to that day's depletion), and the TAW ($AWC*Z_r$). In other words, at the threshold where stress is to occur, irrigations are scheduled to fill the root zone from the cumulative depletion amount to the field capacity (see Figure 17). Irrigations are scheduled on the day that the cumulative depletion first exceeds the RAW. The initiation of the irrigation season begins when K_{cb} exceeds 0.22 during the initial K_{cb} curve development period to prevent a series of frequent, light irrigations early in the season when the root zone is shallow. The irrigation frequency and depth per irrigation represent surface and fixed grid types of sprinkler systems such as wheel line and hand lines. The frequency would be greater for center pivot and solid set types of sprinkler systems where smaller depths are applied.

Deep Percolation

Deep percolation is defined as the flux of water past the root zone. Deep percolation is simulated when the soil water content is at the AWC and additional water is applied via precipitation. Deep percolation is also simulated to occur during irrigation events where 10% of the irrigation depth was assumed to contribute to deep percolation. This 10% of the irrigation depth was included in the soil water balance computations to provide recharge to depths in the soil profile within the maximum rooting depth but below the current rooting depth of the crop. This was necessary to simulate buildup of soil water during irrigation events that is used later in the season as roots deepen. This phenomenon is typical in practice. The deep percolation from irrigation is summed separately from deep percolation from PPT in output data files.

Crop Coefficient Curves

Vegetation phenology is impacted by seasonal changes in solar radiation, temperature, precipitation, and agricultural practices. The crop coefficient curve represents changes in vegetation phenology of a particular crop or vegetation type. The shape of the crop coefficient curve is dependent on the growing season and changes in vegetation cover and maturation. During the beginning of the growing season, which is often shortly after planting of annuals or the emergence of new leaves for perennials, the value of K_{cb} is small, typically ranging from 0.1 to 0.2. When soil evaporation of non-growing season accumulation of soil moisture is accounted for by adding the K_e coefficient to the K_{cb} coefficient, the total K_c value typically ranges from 0.3 to 0.4 during the beginning of the growing season. As the vegetation develops over the course of the growing season and leaf area increases, covering more of the soil surface, the K_{cb} curve increases until the vegetation reaches full cover. Depending on the vegetation or crop type during the middle of the growing season the K_{cb} curve is generally constant, or is reduced based on simulated cuttings and harvest. Later in the growing season the K_{cb} curve is reduced due to aging and drying of the leaves (Figure 19).

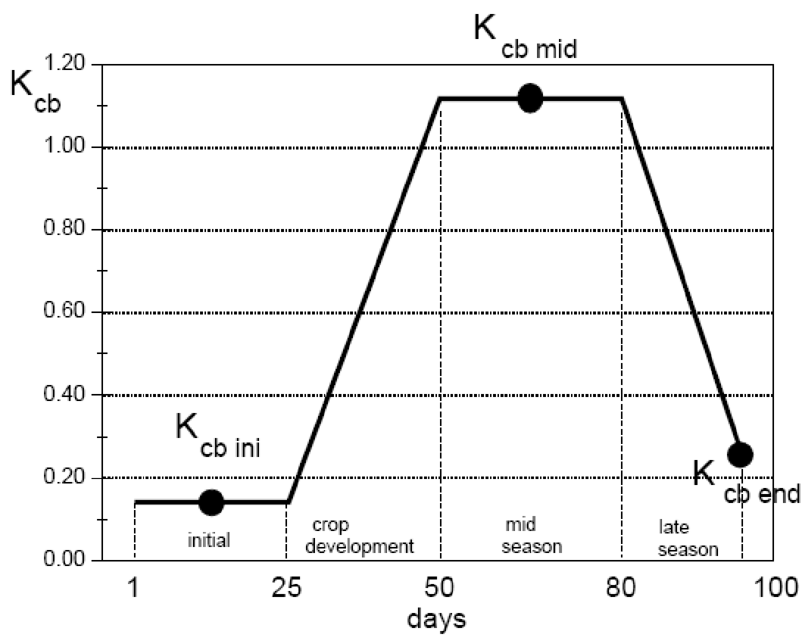

Figure 19. Schematic showing the typical shape of the FAO-56 K_{cb} curve with four different crop stages dependent on development of vegetation. Modified from Allen et al., (1998).

As described above, K_{cb} curves represent changes in vegetation phenology, which can vary from year to year depending on the start, duration, and termination of the growing season, all of which are dependent on air temperature conditions during spring, summer, and fall periods. Three different methods were used to define the shape and duration of the K_{cb} curves to allow the curves to be scaled differently each year according to weather conditions based on relative time scales or thermal units. These methods are:

1) Normalized cumulative growing degree-days from planting to effective full cover, with this ratio extended until termination,
2) Percent time from planting to effective full cover, with this ratio extended until termination, and
3) Percent time from planting to effective full cover and then number of days after full cover to termination.

Basal crop coefficient curves from Allen and Robison (2007) for 34 crop types were adopted for this study and are listed in Table 3, along with the type of normalizing basis used for scaling the curve and primary source of the curve. The K_{cb} curves listed in Table 3 were originally based on percent time from planting or greenup until effective full cover and days after effective full cover following procedures described by Wright (1981, 1982), and were later normalized to a cumulative growing degree base by Wright (2001) and Allen and Robison (2007), and converted for use with the ASCE standardized Penman-Monteith tall reference equation (ET_{rs}) by Allen and Wright (2006). In this study the more widely accepted ASCE standardized Penman-Monteith short reference (ET_{os}) method was used, therefore the family of K_{cb} curves derived from Wright (2001) and Allen and Robison (2007) for use with ET_{rs} were converted to an ET_{os} basis for the Nevada applications by multiplying the K_{cb} curve values by 1.20, which is the standardized ratio for alfalfa to grass reference for the standard climate condition proposed by FAO (Allen et al., 1998), where mean wind speed at 2m is 2m/s and mean daily minimum relative humidity is 45%. Departures from the standard climate condition were accounted for during daily calculations by adjusting the daily K_{cb} value upward based on the estimated daily RH, wind speed, and simulated crop height following procedures outlined in FAO-56 (Allen et al., 1998). Tables of K_{cb} values and for each crop and land cover type simulated in this study are listed in Appendix 6.

Application of cumulative growing degree-days (CGDD) has been widely used as a basis for crop coefficient development representing crop phenology, allowing for the scaling of lengths of development and growth periods and transferability among regions (Sammis et al., 1985; Slack et al., 1996; Howell et al., 1997; Snyder et al., 1999; Wright, 2001; deTar, 2004; Marek et al., 2006; Allen and Robison, 2007). Because air temperature regulates nearly all plant functions, the phenology of vegetation is closely related to the amount of heat the crop and soil is exposed to, as opposed to calendar dates. For this reason, the CGDD has gained wide spread use and was adopted in this study. The equation for the general growing degree-day (GDD) method following Mitchell (1997) and Wright (2001) is

$$GDD = \max\left(\frac{T_{\max} + T_{\min}}{2} - T_{base}, 0\right) \quad \text{Eq. 48}$$

where T_{max} and T_{min} are the daily maximum and minimum air temperatures, respectively, and T_{base} is the base temperature. If T_{min} is far enough below T_{base} to cause the average daily temperature to be below T_{base}, then GDD is zero. This formulation is suggested by Wright (2001) to be realistic for many crops in semi-arid climates, where cold nighttime temperatures can limit growth. Values for T_{base} for this study range from 0^oC to 5^oC depending on the crop type and are listed in Appendix 5 (crop parameter table). For corn crops a variation of the GDD equation is used that assumes no growth at air temperatures above 30^oC and no negative adjustment to the GDD value if the minimum temperature goes below 10^oC, and is defined as

Table 3. Basal crop coefficient type, normalizing basis, and source.

Crop Curve Name	Type of Basis[1]	Primary Source
Spring Grain (wheat, barley)	1	modified from Wright(1982)
Winter Grain (wheat, barley)	1	modified from Wright(1982)
Peas, seed	1	modified from Wright(1982)
Peas, fresh	1	modified from Peas, seed
Sugar Beets	1	modified from Wright(1982)
Potatoes (baking)	1	modified from Wright(1982)
Potatoes (processing)	1	modified from Potato, baking
Field Corn	1	modified from Wright(1982)
Sileage Corn	1	modified from Wright(1982)
Sweet Corn	1	modified from Wright(1982)
Snap Beans (dry)	1	modified from Wright(1982)
Snap Beans (fresh)	1	modified from snap beans, dry
Alfalfa 1st cycle	1	modified from Wright(1982)
Alfalfa Intermediate cycles	1	modified from Wright(1982)
Alfalfa Last cycle	1	modified from Wright(1982)
Garden Vegetables	1	modified from Onion curve
Grass Hay	1	modified from AGRIMET
Onions	2	modified from AGRIMET
Winegrapes	2	modified from AGRIMET
Melons	2	modified from AGRIMET
Hops	2	modified from AGRIMET
Orchards	2	modified from AGRIMET
Canola	2	modified from AGRIMET
Sunflower/Safflower	2	modified from Canola
Turf/Lawn	2	modified from AGRIMET
Pasture Highly Managed	3	modified from Allen and Robison (2007)
Pasture Low Managed	3	modified from Allen and Robison (2007)
Alfalfa Seed	3	modified from Allen and Brockway (1983)

[1] Curve Basis
1 = Normalized cumulative growing degree days (NCGDD)
2 = Percent of time from planting or greenup to effective full cover, applied all season
3 = Percent of time from planting or greenup to effective full cover, then days after effective full cover

$$GDD_{corn} = \left(\frac{\max(\min(T_{max}, 30), 10) + \max(\min(T_{min}, 30), 10)}{2} \right) - 10 . \qquad \text{Eq. 49}$$

This formulation of the GDD equation is commonly referred to as the standard corn GDD equation or heat unit equation.

In this study the starting date for accumulation of GDD was specified as January 1 for all crops except for winter wheat, which was specified as October 1. The CGDD was normalized following Wright (2001) by the quantity of CGDD required to advance the K_{cb} curve from planting or greenup to effective full cover. The normalized CGDD, NCGDD, ranges from 0 to 1 for the period from planting or greenup until effective full cover, and typically ranges from 1 to 2 for the period of effective full cover to harvest or the killing frost. The NCGDD is defined as

$$NCGDD = \frac{CGDD_i}{CGDD_{EFForTERM}} \qquad \text{Eq. 50}$$

where $CGDD_i$ is the cumulative growing degree-day for the i^{th} day, and $CGDD_{EFF\ or\ TERM}$ is the cumulative growing degree-day from planting or greenup to effective full cover, or the cumulative growing degree-day from planting or greenup to termination depending on the crop type. Formulation of the x axis for percent time based K_{cb} curves is similar to equation 50, but time based. The K_{cb} curves are advanced by interpolating between K_{cb} values according to the NCGDD or percent of time. NCGDD or percent of time and their respective K_{cb} values are listed in Appendix 6. Harvests or termination of crops were calculated by evaluating when the CGDD value, percent of time since planting or greenup, or days after effective full cover, exceed threshold values that are specified for each crop (Appendix 5), or a killing frost occurs.

Defining the length of the growing season, time to effective full cover, and harvest dates are all important aspects of estimating the ET_{act} and NIWR. The greenup and time to effective full cover of perennial vegetation during spring months is strongly impacted by short-term weather conditions, primarily by air temperature, soil temperature, and water availability. Likewise, planting dates for annual crops are affected by temperature conditions, in particular the soil temperature at seed depth. Sakamoto and Gifford (1970) published spring and fall low temperatures and growing season probabilities for 71 locations in Nevada by statistically analyzing NWS weather station minimum air temperature data. The Nevada Irrigation Guide (USDA-SCS, 1992) outlines earliest planting dates and termination dates based on daily minimum air temperatures. The Bureau of Reclamation’s Lower Colorado River Accounting System (LCRAS) ET_{act} estimates are based on fixed dates defining the time limit and shape of K_c curves for different crops (Jensen, 1998). Estimating growing season length and crop phenology from fixed minimum air temperatures and/or dates is useful for general applications, however an approach that takes into account year to year variations of air temperature and provides the ability to estimate year to year variations in time to greenup or planting, time to effective full cover, harvest, and termination, is desired for a more detailed analysis of the ET_{act} and NIWR as proposed in this study.

Two methods were used for estimating the greenup or planting dates for various crops in this study, a 30-day moving average of mean daily air temperature, T_{30}, and CGDD depending on the crop type following Allen and Robison (2007). Values of T_{30} and CGDD used in this study are listed for each crop or land cover type in Appendix 5. The T_{30} approach for defining greenup and planting dates has been previously applied in Washington (James et. al., 1982) and Idaho (Allen and Brockway, 1983; Allen and Robison, 2007), and the CGDD approach has been recently applied in Idaho (Wright, 2001; Allen and Robison, 2007), Texas (Marek et al., 2006), Oregon (Mitchell, 1997), and Nebraska (NHPCC, 2006). Both the T_{30} and CGDD approaches provide the ability to account for annual variations in temperature and automate the selection of the greenup or planting dates. While the T_{30} and CGDD approaches take into account temperature variations, actual farm and field practices can significantly alter the greenup, planting, time to effective full cover, harvest, and termination dates, therefore calculated dates defining crop stages from this study should be considered general.

Values of T_{30} and CGDD that define greenup dates were initially adopted from Allen and Robison (2007), which were originally developed from noted planting and greenup dates during lysimeter studies in Kimberly, ID (Wright, 1982) and modified to reflect more recent observations and current cultivars. After analyzing computed greenup and planting dates using initial CGDD and T_{30} values from Allen and Robison (2007), CGDD and T_{30} values were adjusted to reflect known greenup and planting dates for specific crops grown in Nevada. Calibration of greenup and planting T_{30} and CGDD values was based on computing T_{30} and CGDD using temperature data collected at NWS stations located in valleys where early spring photos were available, documented greenup or planting dates were available from previous studies, or verbal and written communication was obtained from phone interviews. If 'typical' greenup or planting information was obtained, the simulated mean annual greenup or planting date was calibrated. Likewise if detailed yearly greenup or planting date information was available, respective year-to-year calibration was performed.

Calibration of the CGDD for simulating harvests is similar to calibration of greenup and planting dates. Calibration of CGDD and T_{30} for simulating greenup and planting dates is simpler than calibration of CGDD for predicting harvest and termination dates due to the wide variation in farming practices, impacting harvest. For example, some farming operations have dozens of fields of alfalfa, in which they need to stagger cutting dates to have a continuous flow of cut, dry, and bail cycles. Recognizing the reality of large variations in cutting, harvest, and termination dates, both generalized and specific cutting and harvest dates that were assumed to be 'typical' were used for calibrating CGDD, percent time since effective full cover to harvest, and days after effective full cover to harvest values.

Calibration of CGDD, T_{30}, percent time from effective full cover to harvest, and days after effective full cover to harvest, for simulating greenup and harvest dates was ultimately accomplished by minimizing the error in simulated vs. documented/typical greenup, planting, and harvest dates outlined in Table 4, which lists the results and specific information used in the calibration. Figures 20 and 21 illustrate the calibration results for alfalfa where the best fit CGDD value from January 1 until greenup for alfalfa was 300 ^{o}C-days, and the best fit CGDD value for time from greenup until the first cutting for alfalfa was 880 ^{o}C-days, and 740 ^{o}C-days for later cuttings. Calibrated CGDD values give promising results across the state considering the extreme spatial variation of air temperature. General descriptions of greenup, planting, and harvest information obtained from farmers and ranchers, including locations of observations and dates, are summarized in Appendix 7.

Crop Specific K_{cb} Curves

As discussed earlier, three different methods were used, depending on crop type, to define the time to effective full cover, and harvest and/or termination for the construction of K_{cb} curves (see Appendix 5). The first method, the normalized cumulative growing degree-days from planting to effective full cover, with this ratio extended until termination, is used for advancing the K_{cb} curve for many primary crops grown in Nevada, including alfalfa. In the following sections, each crop simulated will be discussed in terms of the K_{cb} curve used, source of the K_{cb} curve, parameters used defining the shape of the K_{cb} curve, and some details about the implementation. Crops chosen for simulation of ET_{act} were primarily based from common knowledge of occurrence and crops chosen in the Nevada Irrigation Guide (USDA-SCS, 1992). Some crops were simulated that are not grown in Nevada to assess potential water use.

Normalized cumulative growing degree-days from planting to effective full cover, with this ratio extended until termination:

Alfalfa

Alfalfa farming practices in Nevada can vary significantly depending on the climate, water availability, and market prices. For example, in central western Nevada harvesting beef hay typically results in three large cuttings, while harvesting dairy hay typically results in four cuttings, often before any bloom occurs. However, some beef hay farmers get four cuttings depending on climate, water availability, and length of growing season. Dairy hay is cut more frequently to increase the protein content of the hay and to reduce steminess, and tends to be a less dormant genotype with quicker re-growth, but with less longevity. For simplicity only one type of alfalfa crop was simulated, which could be considered more representative of beef hay than dairy hay; however, calibration of cutting dates used information from both beef and dairy hay farmers. Calibration of CGDD values to predict known cutting cycles of both beef and dairy hay farmers was accomplished by optimization of CGDD values to known cutting dates for both

Table 4. Documented/typical greenup and harvest dates vs. simulated greenup and harvest dates.

Crop	Hydrographic Area	Weather Station Used for Analysis	Documented/Typical Green Up or Planting Dates	Simulated Mean Green Up or Planting Dates	Documented/Typical Cutting and Harvest Dates	Simulated Mean Cutting/Harvest Dates	Source	Notes
Alfalfa	Carson Desert	Fallon EXP	3/20	3/23	6/15, 7/19, 9/1, 10/21	6/12, 7/22, 9/1, 10/21	Rashedi (1983)	Simulated and Measured Greenup and Cutting Dates are an average from 1974, 75, 77, 78, 81, 82, 83
Alfalfa	Carson Desert	Fallon EXP	3/20-4/1	3/21	6/1-6/10, every 30-40 days after, 3-4 cuttings	6/8, every 40 days after, 3-4 cuttings	Latin Farms (2008), Verbal Communication	Simulated Greenup and Cutting Dates are the 1971-2005 average
Alfalfa	Carson Valley	Minden	3/20-4/5	4/2	6/15, 8/1, 9/15	6/19, 7/29, 9/10, sometimes a 4th cutting at 10/29	Aldax (2008), Verbal Communication	Simulated Greenup and Cutting Dates are average annual estimates from 1971-2006
Alfalfa	Carson Valley	Minden	3/20-4/5	3/27	6/8, 7/28, 9/20, no 4th cutting	6/15, 7/26, 9/4, no 4th cutting	Aldax (2006), Written Communication via USGS	Documented and Simulated Cutting Dates are an average for the 2003-2004 growing season. The reported last cutting date average of 9/20 is abnormally late for a 3rd cutting.
Alfalfa	Carson Valley	Minden	3/20-4/5	3/27	6/8, 7/21, 9/5, no 4th cutting	6/14, 7/24, 9/3, no 4th cutting	Godecke (2006), Written Communication via USGS	Documented and Simulated Cutting Dates are for the 2004 growing season
Alfalfa	Smith Valley	Yerington	NA	4/1	6/2, 7/12, 8/17 no 4th cutting	6/5, 7/13, 8/17, no 4th cutting	Rush (1976)	Simulated Greenup and Cutting Dates are from 1973 to match study period of Rush (1976)
Alfalfa	Mason Valley	Yerington	3/15-4/1	3/20	5/25-6/5, every 35-45 days after, mostly 4 cuttings	6/3, every 39 days after, 9 out of 10 years have 4 cuttings (6/3, 7/12, 8/17, 9/28)	Snyder Livestock (2008), Verbal Communication	Simulated Greenup and Cutting Dates are the 1971-2006 average

Table 4 cont. Documented/typical greenup and harvest dates vs. simulated greenup and harvest dates.

Crop	Hydrographic Area	Weather Station Used for Analysis	Documented/Typical Green Up or Planting Dates	Simulated Mean Green Up or Planting Dates	Documented/Typical Cutting and Harvest Dates	Simulated Mean Cutting/Harvest Dates	Source	Notes
Alfalfa	Moapa Valley	Overton	2/1-2/20	2/9	4/5-4/20, every 30 days after	4/18, every 32 days after	Hardy (2008), Verbal Communication	Simulated Greenup and Cutting Dates are a 1949-2006, 15 year average
Alfalfa	Antelope Valley	Antelope Valley Farr	4/1-4/15	4/6	6/15, 8/5, 10/15, no 4th cutting	6/24, 8/3, 10/17, no 4th cutting	Farr Farms (2008), Verbal Communication	Simulated Greenup and Cutting Dates are a 1985-1997 average
Alfalfa	Lake Valley	Gyser Ranch	4/10-4/20	4/20	6/15-6/30, every 35-45 days after, 3-4 cuttings	7/3, every 48 days after, 3-4 cuttings	Atlanta Farms (2009), Verbal Communication	Simulated Greenup and Cutting Dates are a 1944-1987, 14 year average
Alfalfa	Boulder Flat	Beowawe	4/1-4/15	4/9	5/25-6/15, 7/21-8/4, 9/29-10/13, no 4th cutting	6/19,7/27, 10/10, no 4th cutting	TS Ranch (2008), Written Communication	Documented and Simulated Greenup and Cutting Dates are for the 2004 growing season
Onions (fresh)	Mason Valley	Yerington	4/1-4/15	4/7	8/20-9/20	9/7	Snyder Livestock and Peri and Sons (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Garlic	Mason Valley	Yerington	4/1-4/15	4/7	8/15-9/10	8/29	Snyder Livestock and Peri and Sons (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Garlic	Black Rock Desert	Gerlach	4/5-4/20	4/16	8/15-9/15	9/3	Empire Farms and Orient Farms (2009), Verbal Communication	Simulated Greenup and Harvest Dates are the 1994-2003 average
Potatoes (fresh)	Lake Valley	Gyser Ranch	4/10-5/10	5/4	9/15-10/10	9/30	Atlanta Farms (2009), Verbal Communication	Simulated Greenup and Harvest Dates are the 1972-1977 average
Potatoes (processing-early)	Paradise Valley	Paradise Valley	4/1-5/15	4/5	9/1-10/15	9/1	Winnemucca Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970-2007 average
Potatoes (fresh-late)	Paradise Valley	Paradise Valley	4/1-5/15	4/5	9/20-10/20	9/19	Winnemucca Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970-2007 average
Spring Wheat	Antelope Valley	Antelope Valley Farr	4/1-4/20	4/5	7/10-7/31	7/31	Farr Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1985-1997 average

Table 4 cont. Documented/typical greenup and harvest dates vs. simulated greenup and harvest dates.

Crop	Hydrographic Area	Weather Station Used for Analysis	Documented/Typical Green Up or Planting Dates	Simulated Mean Green Up or Planting Dates	Documented/Typical Cutting and Harvest Dates	Simulated Mean Cutting/Harvest Dates	Source	Notes
Spring Wheat	Paradise Valley	Paradise Valley	3/20-4/20	4/10	7/15 - 9/15	8/5	Winnemucca Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Spring Wheat	Carson Desert	Fallon EXP	3/10-4/1	3/13	7/10-7/31	7/15	Latin Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Winter Wheat	Paradise Valley	Paradise Valley	9/15-10/30	10/15	7/15-8/15	7/29	Winnemucca Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Winter Wheat	Carson Desert	Fallon EXP	9/20-10/20	10/15	6/1-6/30	6/30	Latin Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Melons	Carson Desert	Fallon EXP	5/1-5/15	5/9	8/10-8/20	8/19	Latin Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Fresh Beans	Carson Desert	Fallon EXP	5/10-5/20	5/14	8/10-8/20	8/10	Latin Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Sweet Corn - Early	Carson Desert	Fallon EXP	4/20-5/10	4/27	8/10-9/1	8/23	Latin Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average
Silage Corn	Carson Desert	Fallon EXP	4/20-5/10	4/27	9/20-10/10	9/29	Latin Farms (2008), Verbal Communication	Simulated Greenup and Harvest Dates are the 1970 -2007 average

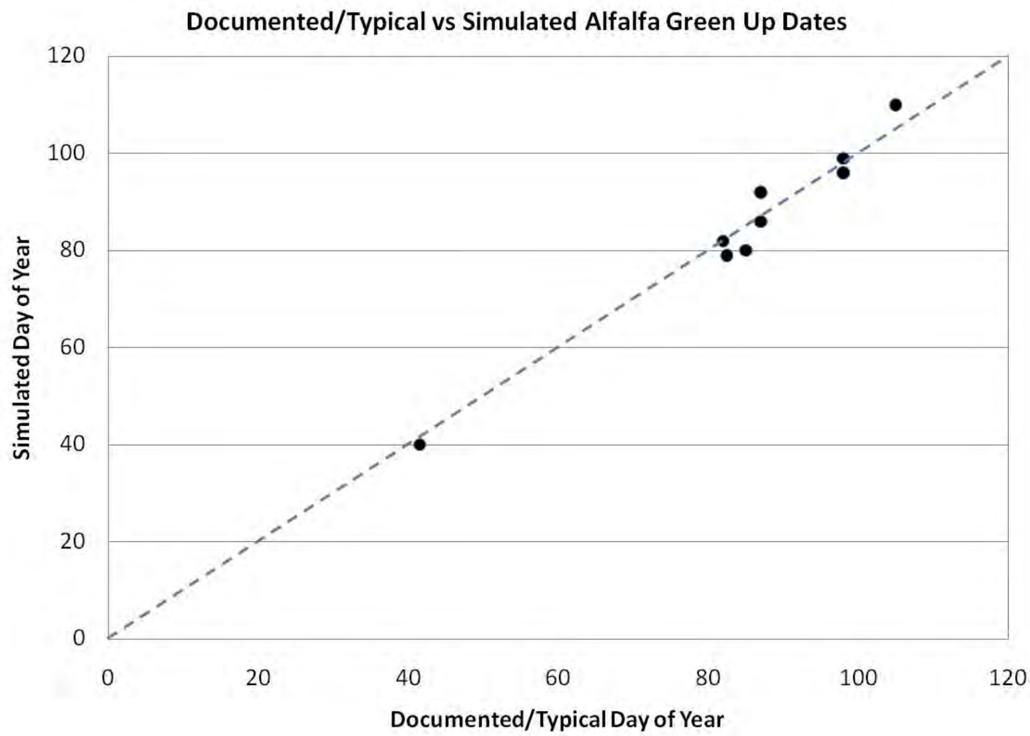

Figure 20. Documented and typical greenup dates compared to simulated greenup dates for alfalfa for 9 locations using a CGDD value of 300 °C-days from January 1.

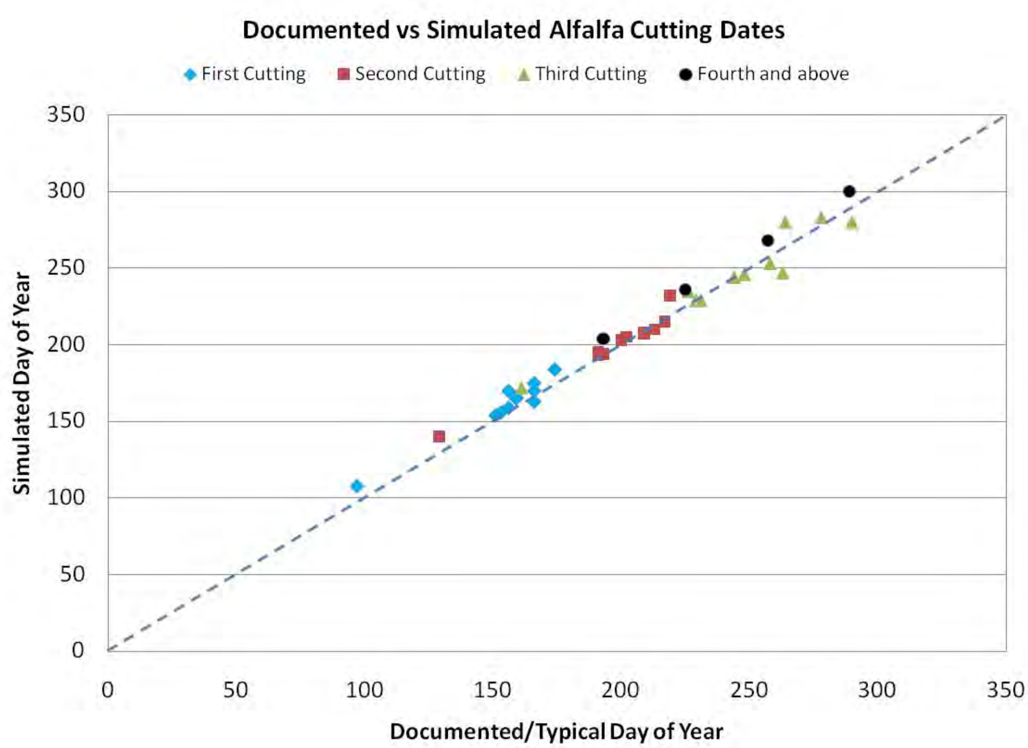

Figure 21. Documented and typical cutting dates compared to simulated cutting dates for alfalfa using a CGDD value of 880 °C-days from greenup to the first cutting, and 740 °C-days for later cuttings.

dairy and beef hay as discussed in the previous section. Results from initial simulations of ET_{act} using separate dairy and beef hay parameterizations of CGDD revealed that the ET_{act} for the two different classes are nearly identical, due to the fact that while the dairy hay reaches a max K_{cb} value faster than beef hay, dairy hay is cut more frequently, reducing the simulated ET_{act}, and making ET_{act} of both classes nearly equal.

Three different alfalfa K_{cb} curves were used according to the cycle of growth, that being an initial cycle, an intermediate or mid cycle, and a late cycle curve according to Wright (1981, 1982) and lysimeter records in Kimberly, ID (Figure 22). Implementation of three different K_{cb} curves for alfalfa is consistent with the fact that the first cycle or cutting of alfalfa has the largest yield and hence water consumption, with subsequent cuttings having less yield, and the final cutting generally having the least amount of yield. The second and later cycles require more CGDD since these cycles contain a period of no growth after cutting prior to launch of rapid growth that is not present in the first growth cycle. The CGDD values for the first growth cycle are accumulated beginning at greenup of the crop in spring, and from the time of cutting for all subsequent growth cycles. The killing frost temperature of -7°C defines termination of the growing season for alfalfa. This temperature was also used by Allen and Robison (2007) in Idaho.

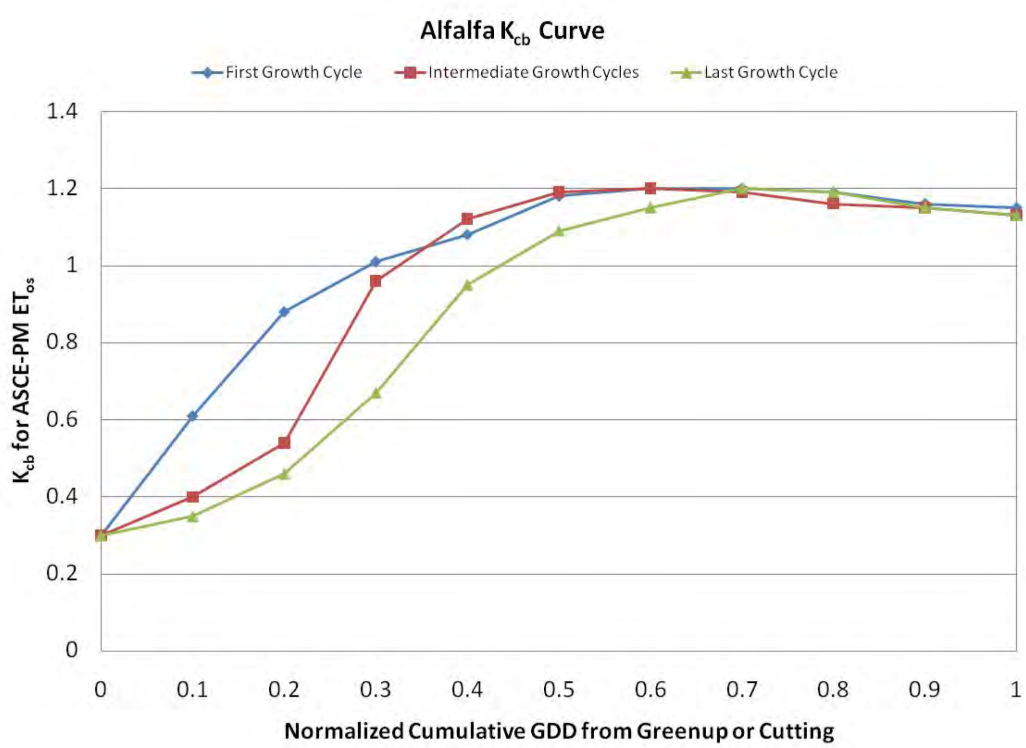

Figure 22. Alfalfa K_{cb} curve for the first, intermediate, and last growth cycles.

The number of cuttings of alfalfa varies significantly from southern to northern Nevada due to the large variation in growing season length, therefore an automated approach was applied to determine when to shift to the late cycle K_{cb} curve. To accomplish this, the average number of cuttings for the period of record for each weather station was recorded during an initial simulation, and then specified in a subsequent simulation using the recorded average number of cuttings. The average number of cuttings was rounded to the nearest whole number, and the late cycle K_{cb} curve for each year was implemented by evaluating if the cutting count exceeded the rounded average number of cuttings minus one.

Adjustments were made to the computed K_{cb} curves during fall periods following Allen and Robison (2007) to account for effects of cold nighttime temperatures and occasional light but non-killing frosts. The adjustments reduced the value for K_{cb} following the first occurrence of a –3°C in the fall by 0.005 each day following the -3°C temperature. For example, this reduction of 0.005/day would equate to a total reduction in K_{cb} of 0.10 by the 20th day following the first occurrence of T_{min} < -3°C. Justification for the reduction is based on field observation of stunted and retarded growth, and verbal communication with farmers and ranchers in Nevada.

Grass Hay

The grass hay K_{cb} curve was constructed to follow the shape of the K_{cb} curve for the first cycle of alfalfa, but with a peak K_{cb} of 1.14 rather than 1.2, and about a 25% longer CGDD required until a single large cutting (1200 °C-days at a base of 0°C), usually occurring around mid July in central and northern Nevada (Davidson et al., 1988). Following the single large cutting (at NCGDD = 1.0), the K_{cb} was assumed to stay near 0.90 and then decline towards fall, when subsequent grazing or smaller cuttings may occur (Figure 23). The curve was terminated at the killing frost as listed in Appendix 5. The shape is similar to the AGRIMET grass hay curve.

Winter and Spring Grain

Winter wheat and spring grain K_{cb} curves (Figures 24 and 25) were derived from Wright (1982). The K_{cb} vs. NCGDD curve for winter wheat is begun on October 1 and run through the winter. The planting date of October 1 was selected based on typical planting dates of winter wheat for most areas of Nevada where winter wheat is grown. Adjustments to winter wheat CGDD following Allen and Robison (2007) are implemented to account for extremely cold weather retarding growth. Adjustments to winter wheat CGDD are made using the following criteria. Whenever T_{min} was below –25°C and there is no documented snow cover present, 10% of the canopy was assumed to be frost burnt, with the reduction in green material implemented by reducing any CGDD accumulated since Oct. 1 by 10% on the day following the low temperature. Also, whenever T_{min} was below -10°C, the GDD for the following day, if greater than 0, was reduced by 5 GDD units to reflect retarded growth on the day after the cold freeze

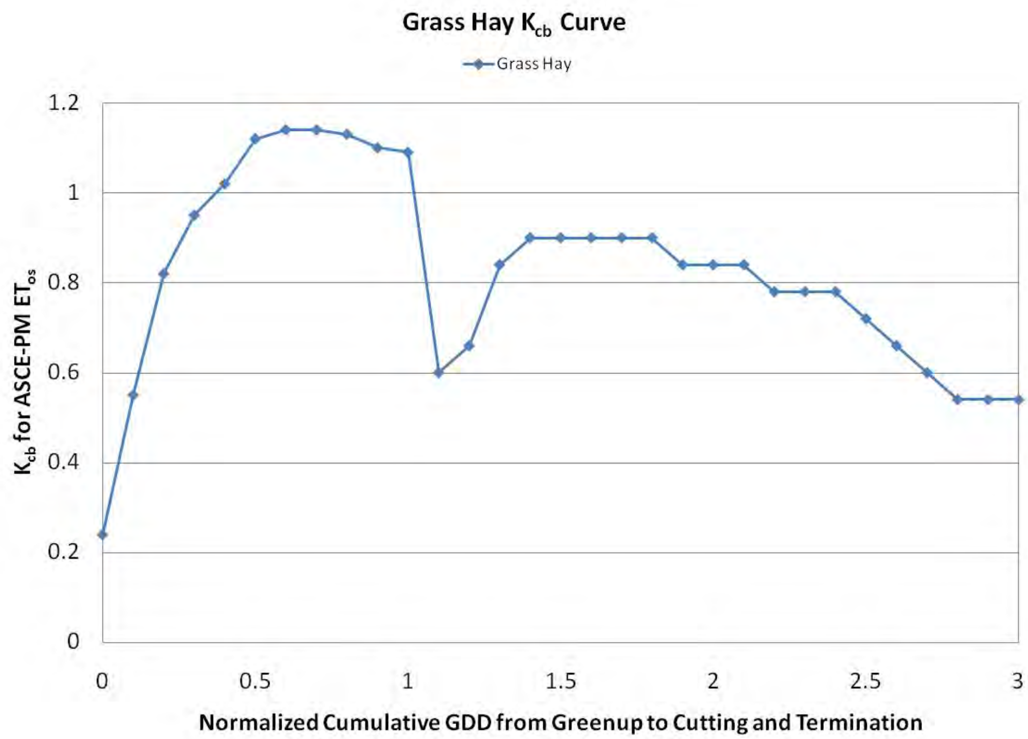

Figure 23. Grass hay K_{cb} curve which assumes one large cutting, and later smaller cuttings or grazing.

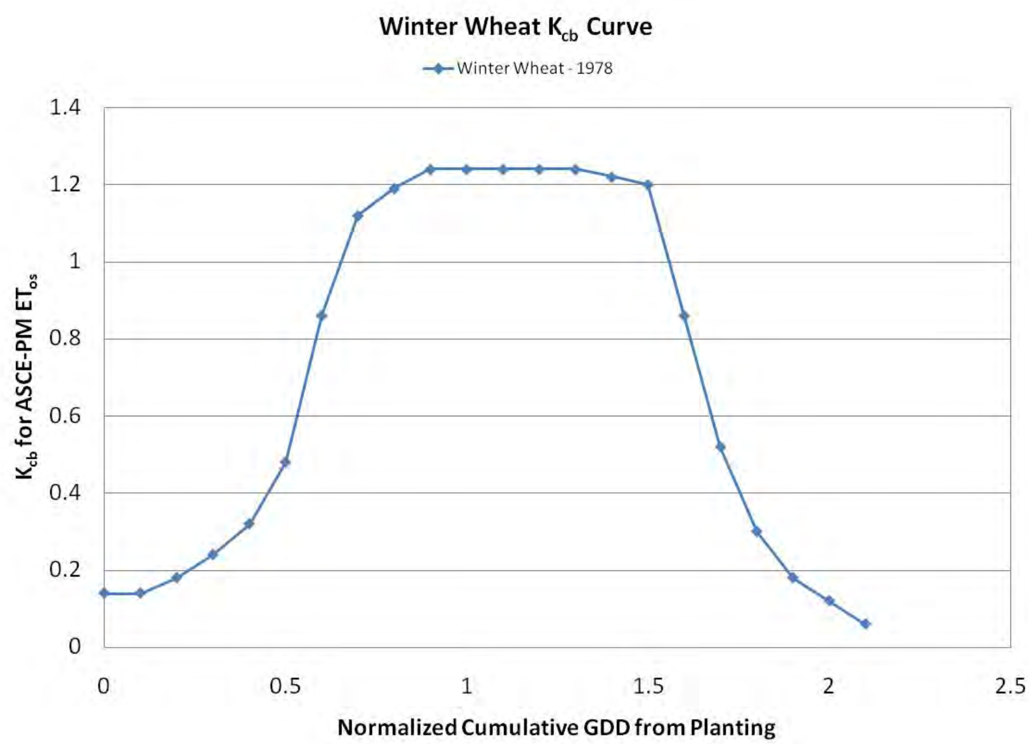

Figure 24. Winter wheat K_{cb} curve.

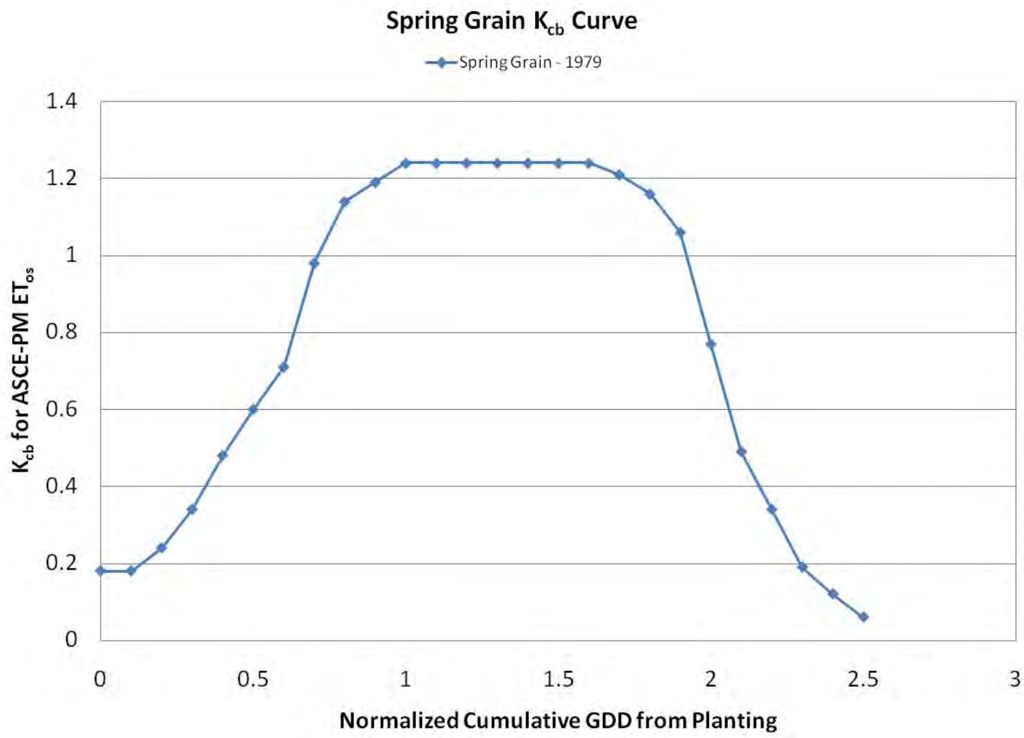

Figure 25. Spring grain K_{cb} curve.

due to cold shock. Finally, if T_{min} was below –4°C, then the GDD for that day was assumed to be zero regardless of the T_{max} or T_{mean} to reflect no growth during the day due to cold shock. These adjustments are from Allen and Robison (2007) and were based on personal communication between Wright and Allen (2002) and observations of winter behavior of winter wheat in southern Idaho by Allen and Robison. No adjustments were made to spring grain.

Potatoes

Potato crops were separated into two classes, a) long season varieties representing baking potatoes and varieties that are harvested in September and October, and b) short season varieties representing processing potatoes that begin to be harvested as early as August. Planting and development dates for both varieties are generally similar and therefore a single curve was used for the period between planting and effective full cover. Separate curves were used from effective full cover to harvest and both are based on a normalized cumulative growing degree-day scale. The K_{cb} vs. NCGDD relationship for the long season class was developed from Wright (1982). The K_{cb} vs. NCGDD relationship for the short season class was developed from the long season variety and modified by shortening the relative time required for maturity and reducing values of K_{cb} beginning at about 1.75 times NCGDD as shown in Figure 26. The recommended CGDD at harvest for the long season variety is about 1800 GDD and the short season variety is about 1600 GDD.

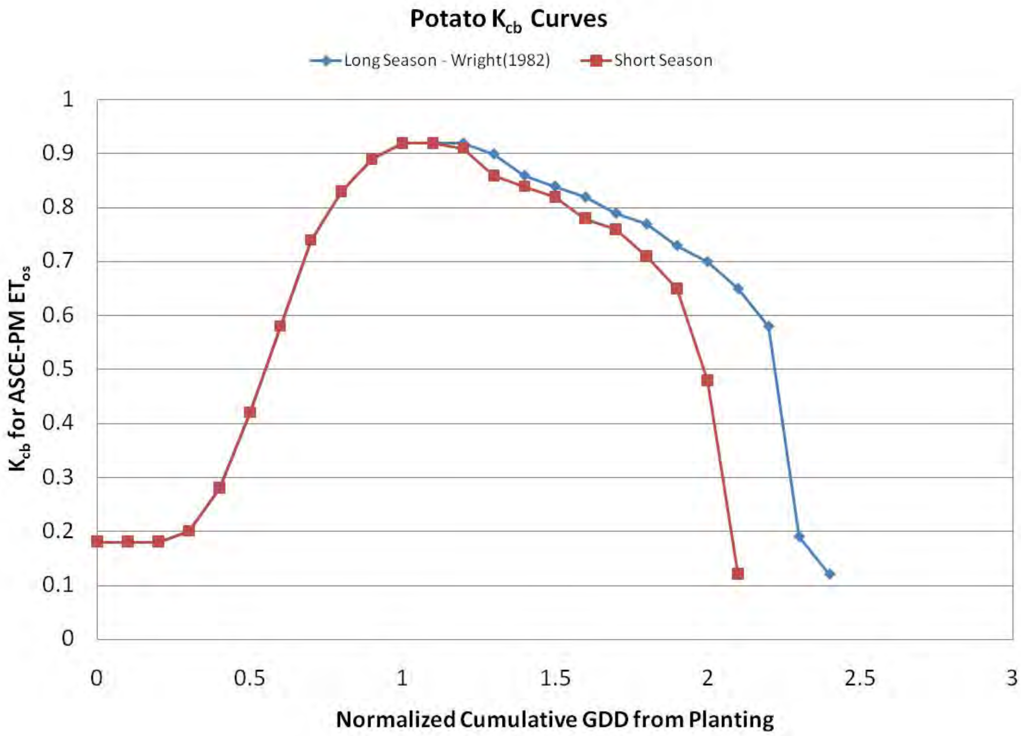

Figure 26. Potato K_{cb} curves for two different classes representing baking (long season) and processing (short season) potatoes.

Corn

Three different corn crops of field corn, sweet corn, and silage corn were simulated using K_{cb} vs. NCGDD curves from Wright (1982) for field corn and sweet corn (Figure 27). The silage corn K_{cb} vs. NCGDD curve was derived from the field corn curve by reducing the field corn K_{cb} beginning at NCGDD = 2.2 and terminating at 0.1 at NCGDD = 2.3. The silage K_{cb} curve ends sooner than field corn due to the abrupt end of the season when it is harvested. Sweet corn also has a shorter life cycle than field corn, since it is harvested during the 'milk' stage of the ear as opposed to silage corn that is harvested at a later stage.

Beans

The K_{cb} vs. NCGDD curve for snap beans (also known as dry, edible beans) was derived from Kimberly, ID lysimeter data for a snap bean crop grown in 1973 (Figure 28). The fresh snap beans K_{cb} vs. NCGDD curve was derived from the dry snap beans curve by terminating the curve at NCGDD = 1.6, which represents harvest.

Sugar Beets

The K_{cb} vs. NCGDD curve for sugar beets from Wright (1982) was adopted for this study and was derived from 1975 lysimeter data for a crop of sugar beets (Figure 29).

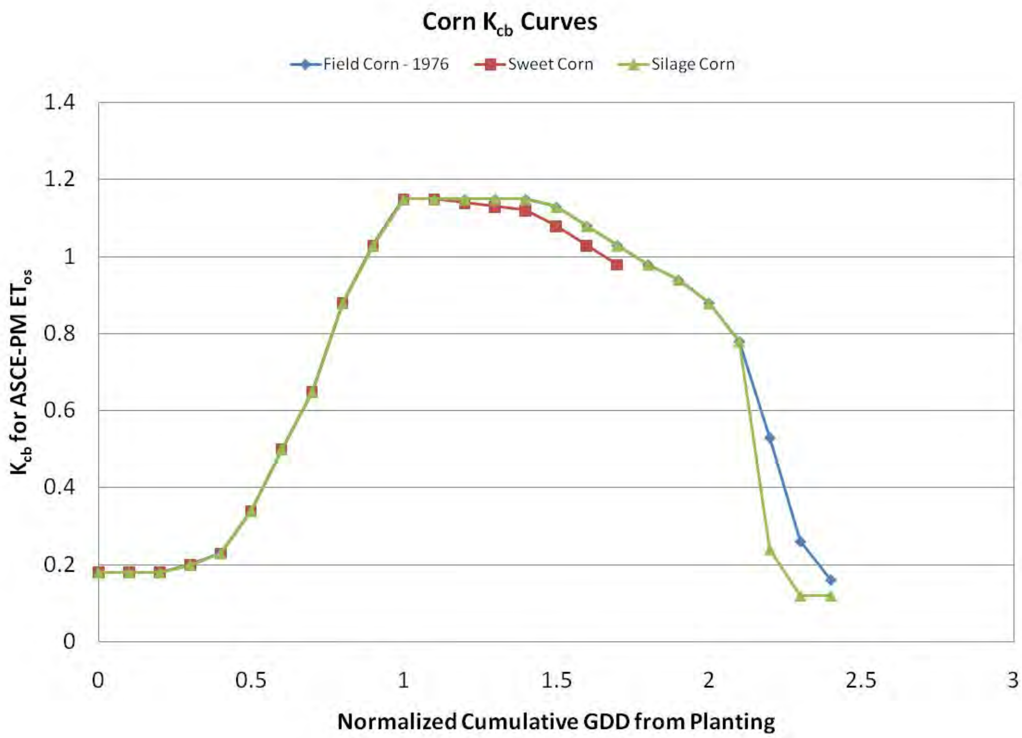

Figure 27. Corn K_{cb} curves for three different classes representing field, sweet, and silage corn.

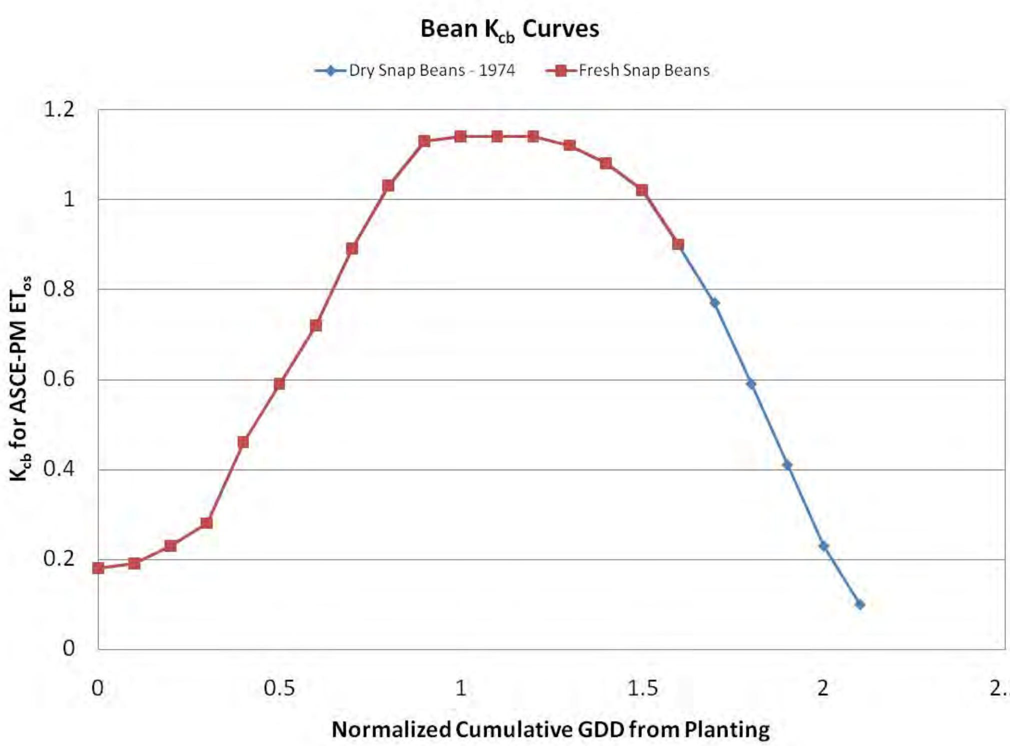

Figure 28. Bean K_{cb} curves representing dry and fresh snap beans, which are harvested earlier than dry beans.

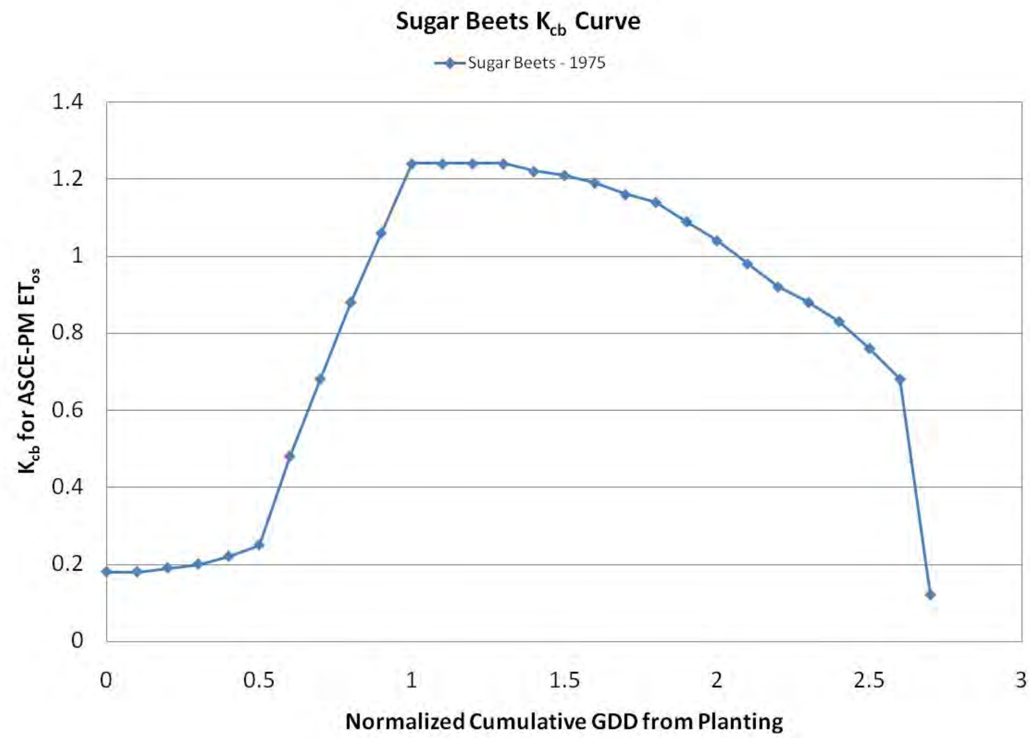

Figure 29. Sugar beet K_{cb} curve.

Peas

Dry peas (for seed) and fresh peas were simulated using the K_{cb} vs. NCGDD curve for dry peas from Wright (1982), derived from lysimeter data from a crop of dry peas in 1977. The K_{cb} vs NCGDD curve for fresh peas was derived from the dry peas curve by terminating the curve at NCGDD = 1.6, which represents harvest (Figure 30).

K_{cb} based on percent time from planting or greenup to effective full cover, with this ratio extended until termination:

Onions and Garlic

The onion and garlic K_{cb} curve (Figure 31) was developed from the K_{cmean} curve of AGRIMET by multiplying by 0.75 to adjust to a basal condition and adding values of 0.15 during the planting to emergence period, as AGRIMET K_{cmean} curves characteristically begin only at emergence. The 25% difference between the AGRIMET mean K_c curve and the K_{cb}

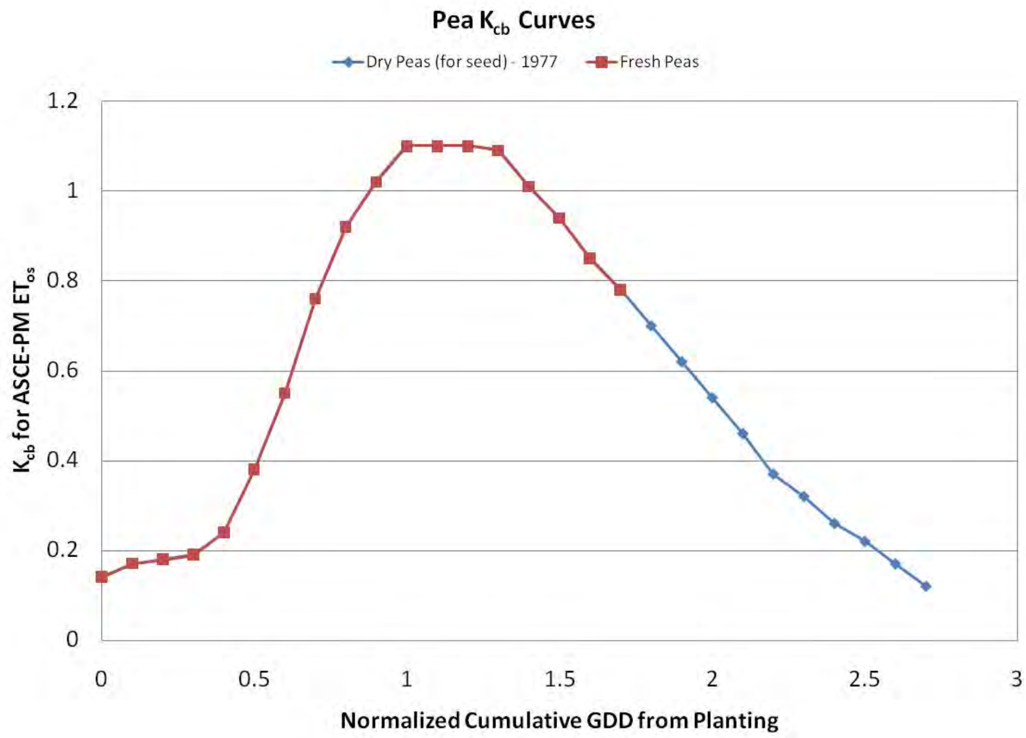

Figure 30. Pea K_{cb} curves for dry peas (for seed) and fresh peas, which are harvested earlier.

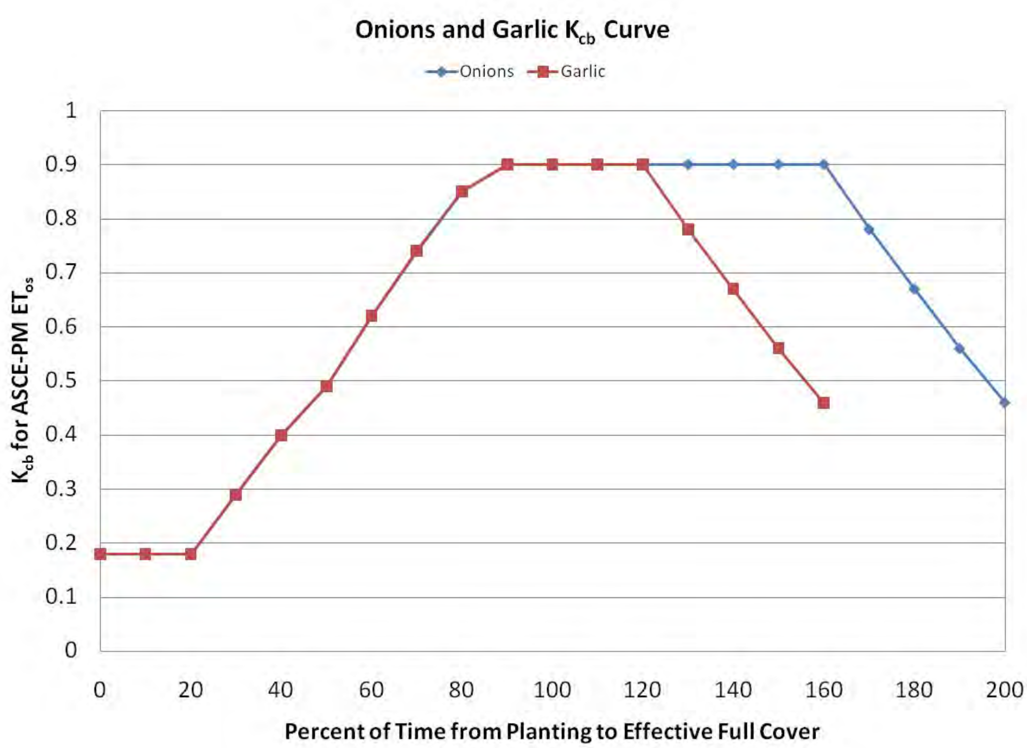

Figure 31. Onion and garlic K_{cb} curves modified from AGRIMET. Garlic was terminated earlier due to earlier harvest.

curve is to account for the evaporation component that is embedded in the AGRIMET mean K_c curve. Evaporation is considered separately in the dual crop coefficient approach employed in this study. The full cover date was approximated by AGRIMET, when half of the onion stand has about 12 leaves. For applications in this report, 80 days from planting to effective full cover was assumed, with generally an early April planting and mid September harvest. The garlic K_{cb} curve was created by shortening the onion curve by 20% to account for the cease in irrigation that takes place to dry the garlic before harvest, which is about 3-4 weeks before onions, usually in mid July to early August in central western Nevada.

Wine Grapes

The K_{cb} curve for wine grapes (Figure 32) is similar to the K_{cmean} curve used by AGRIMET and modified by Allen and Robison (2007), where the AGRIMET curve was extended past 200% of time from greenup to effective full cover to 270% by the addition of K_{cb} = 0.72. This extension is to allow the grape K_{cb} curve to extend until frost, which is when grape leaves in Nevada typically brown.

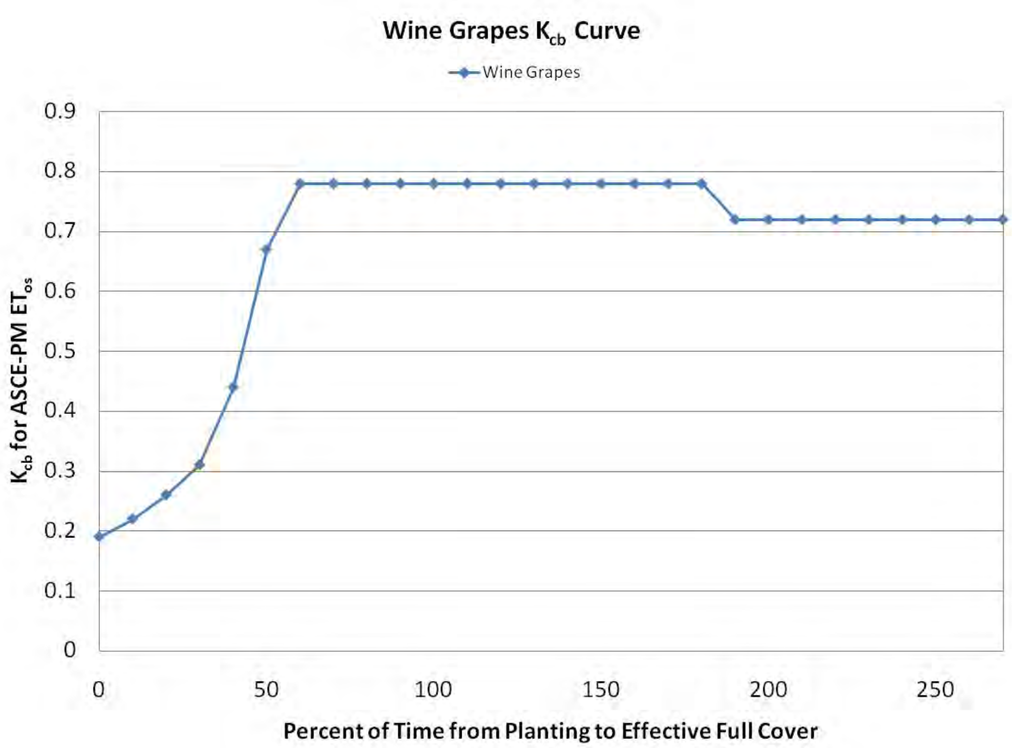

Figure 32. Wine grape K_{cb} curve modified from AGRIMET.

Melons

The melon K_{cb} curve (Figure 33) was derived from AGRIMET by shifting the curve in time by the equivalent of 10 days to account for the period between planting and emergence, as AGRIMET K_{cmean} curves characteristically begin only at emergence.

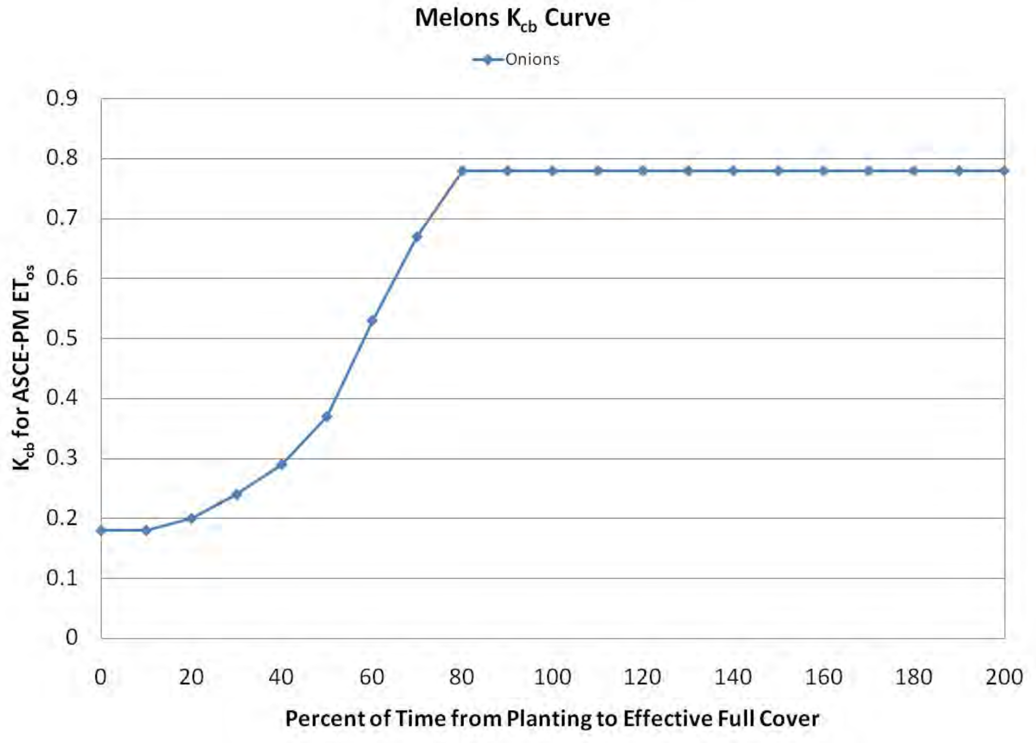

Figure 33. Melon K_{cb} curve modified from AGRIMET.

Hops

The K_{cb} curve for hops (Figure 34) was derived from a K_{cmean} curve developed by Wright (Pers. Comm., 2003) for use with AGRIMET. The K_{cb} curve was derived by subtracting 0.05 from the AGRIMET K_{cmean} curve to convert to a basal curve.

Orchards

The K_{cb} curve for orchards (Figure 35) was developed for apple/cherry orchards having ground cover of grass or other vegetation, and no ground cover, and based on FAO-56 K_{cb} data. The general curve shape was made similar to the AGRIMET apple K_{cmean} curve by approximating the effective full cover to occur approximately 55 days after bloom or greenup. Both K_{cb} curves were progressed through percent of time from greenup to effective full cover until the killing frost. K_{cb} was reduced after 175% of time from greenup to effective full cover to account for leaf aging.

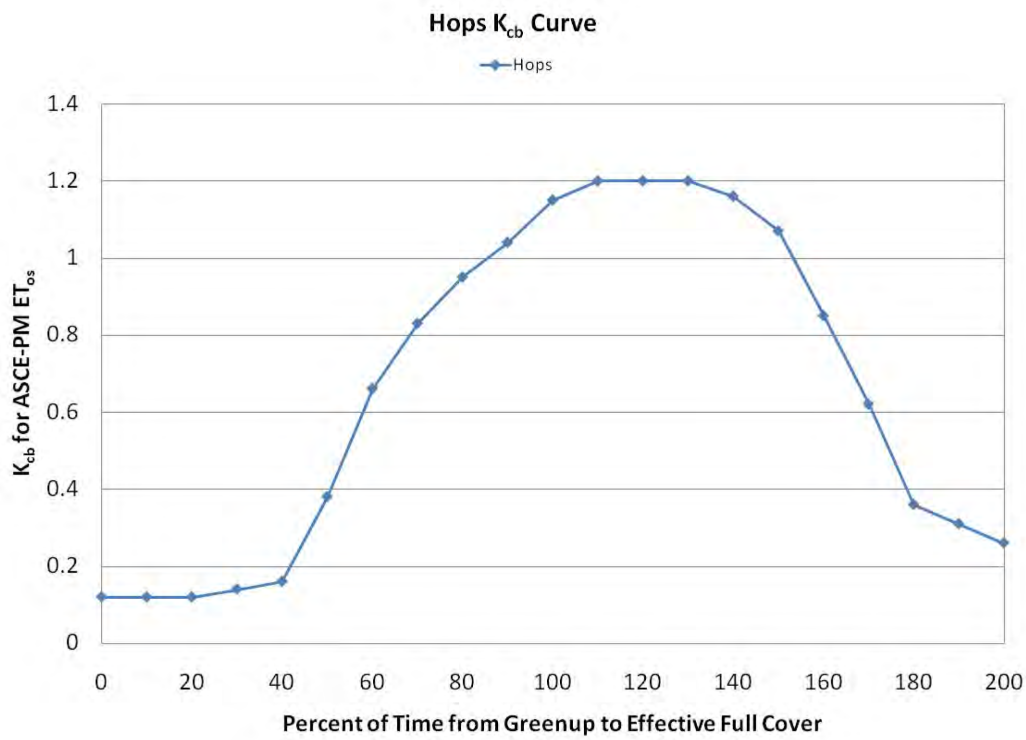

Figure 34. Hops K_{cb} curve modified from AGRIMET.

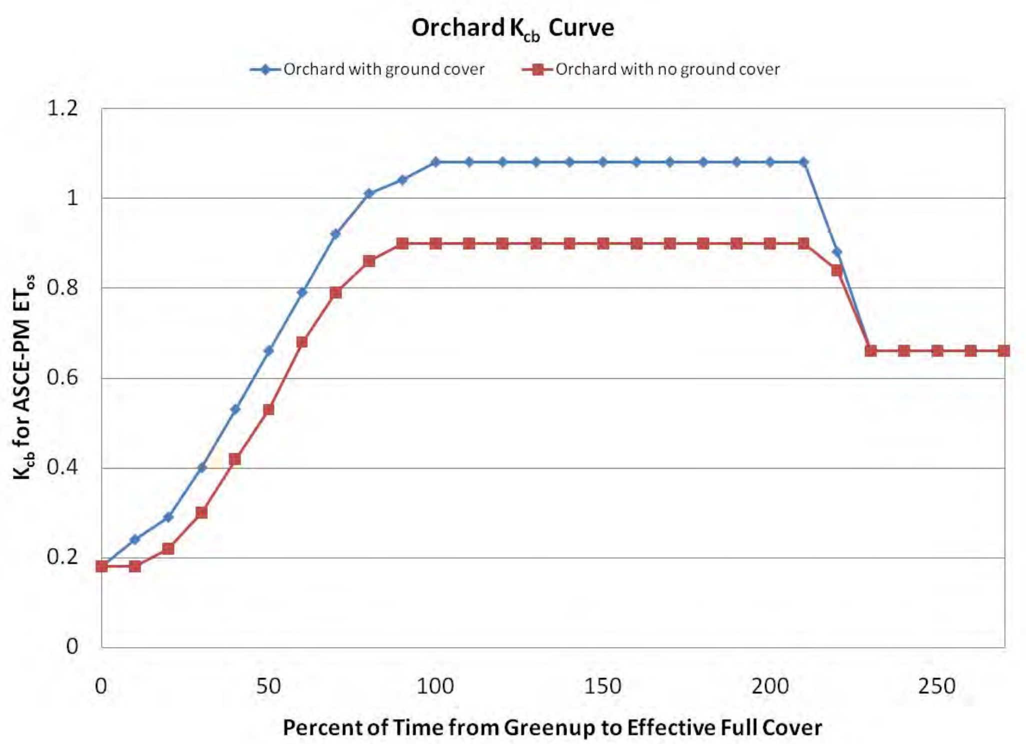

Figure 35. Orchard K_{cb} curves modified from FAO-56 and AGRIMET.

Canola and Sunflower/Safflower

The K_{cb} curve for canola (Figure 36) was patterned after the AGRIMET rapeseed curve, but with 7 days added to the beginning of the curve to account for the planting to emergence period and 0.03 subtracted during the midseason to convert the K_{cmean} AGRIMET curve to a K_{cb} curve. The sunflower/safflower curve was developed by Allen and Robison (2007) from the canola K_{cb} curve by subtracting 0.10 during the peak period to account for less dense planting and ground cover for sunflower and safflower as compared to canola and for the tendency of these plants to exhibit some stomatal control under high vapor pressure deficit conditions (Tardiew et al., 1996).

Turf Grass

The K_{cb} curve for lawn or turf grass (Figure 37) was developed from the AGRIMET turf K_{cmean} curve by subtracting 0.10 during the peak period to convert the curve to a K_{cb} type curve. The curve was progressed at a constant K_{cb} value until killing frost. The resultant K_{cb} values are similar to FAO-56 turf grass K_{cb} values.

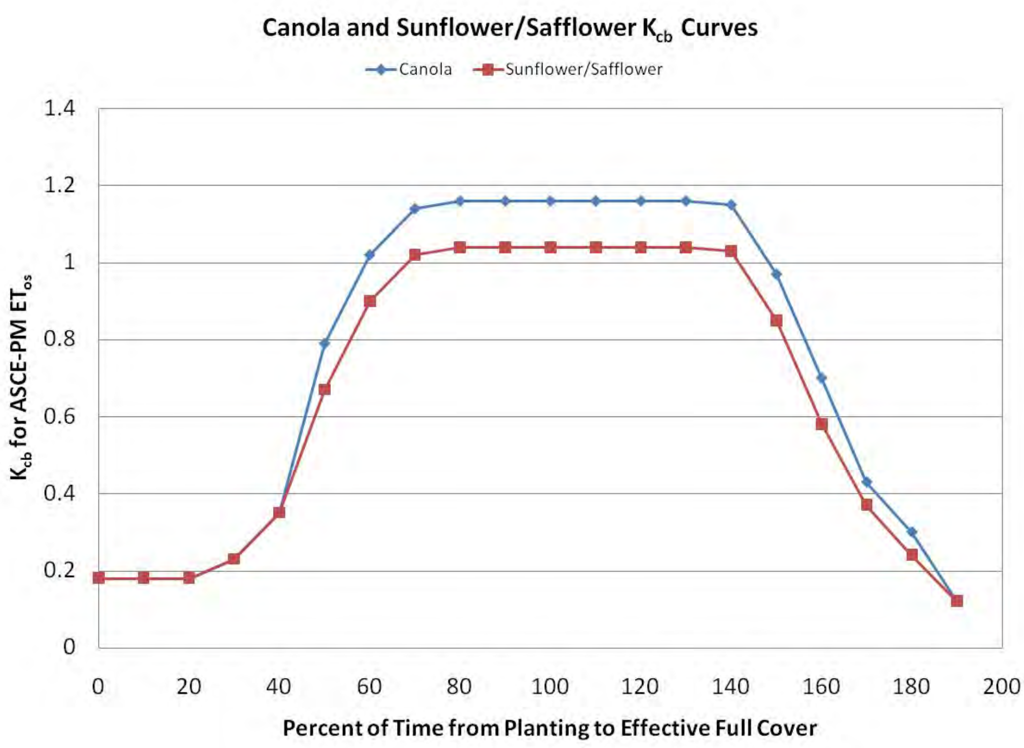

Figure 36. Canola and Sunflower/Safflower K_{cb} curves modified from AGRIMET.

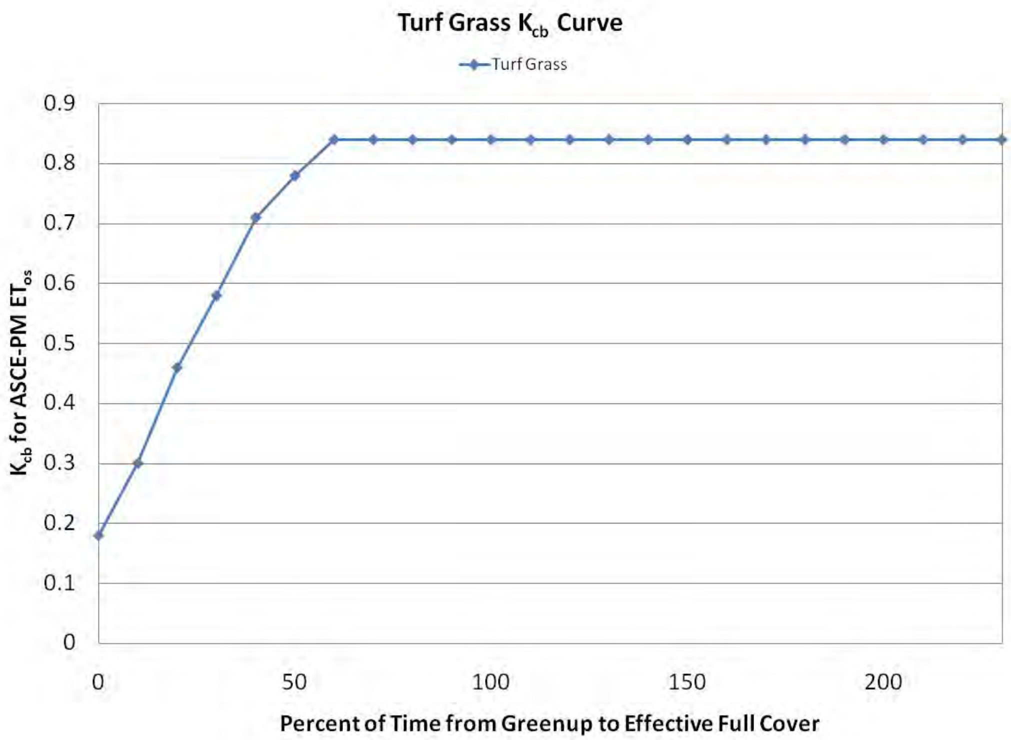

Figure 37. Turf grass K_{cb} curve modified from AGRIMET.

K_{cb} vs. Percent Time from Planting or Greenup until Effective Full Cover and Days After Effective Full Cover:

Pasture Grass

Pasture grass was simulated using two different K_{cb} curves (Figure 38). The first K_{cb} curve represents a pasture having high management and rotated grazing, while the second K_{cb} curve represents having relatively low management and with less vigorous growth and with sustained lower grazing height. The two curves were developed by Allen and Robison (2007) from the AGRIMET K_{cmean} curve for pasture by multiplying by 1.17 for the high management K_{cb} curve so that the peak K_{cb} equals 0.96, and by multiplying by 0.88 for the low management K_{cb} curve so that the peak K_{cb} equals 0.72 (these values are equivalent to 0.8 and 0.6 for an alfalfa reference basis). In addition, the AGRIMET curve was converted to a percent time from greenup to effective full cover and days after effective full cover so that the K_{cb} curves would equal 0.48 and 0.36, for highly managed and low managed pasture grass, respectively, during the fall until terminated by a killing frost.

Alfalfa Seed

The alfalfa seed K_{cb} curve (Figure 39) was adopted from Allen and Brockway (1983), but with 0.05 subtracted to convert to a K_{cb} curve.

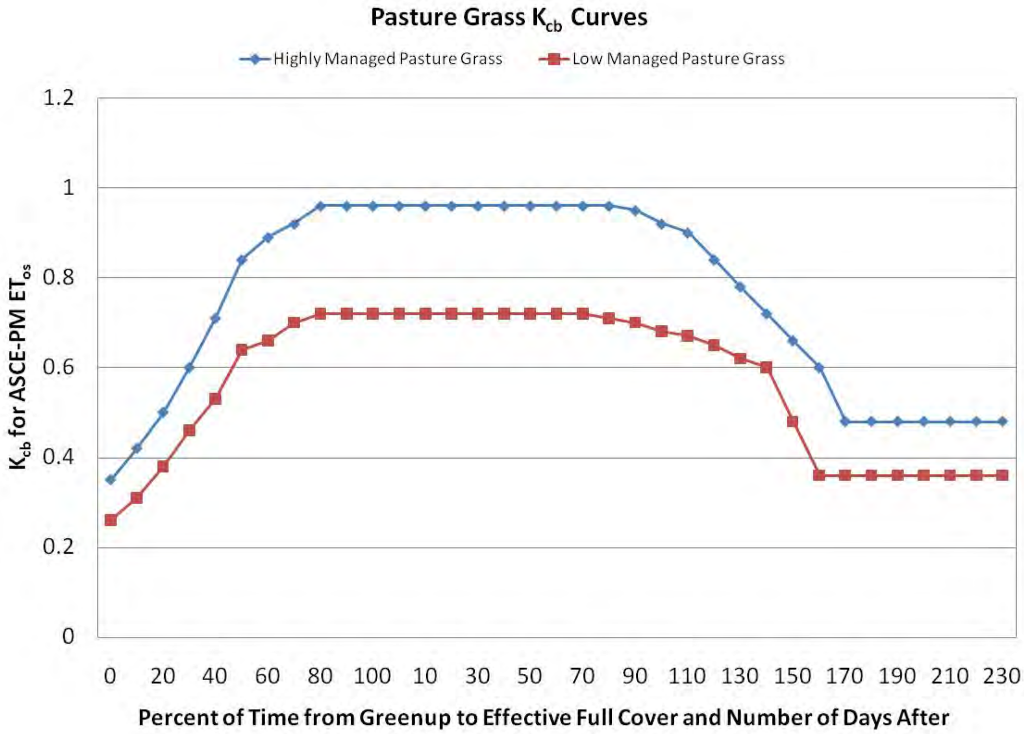

Figure 38. Pasture grass K_{cb} curves representing two classes of highly managed rotated grazing with significant re-growth height, and low management pasture grass with sustained lower grazing height.

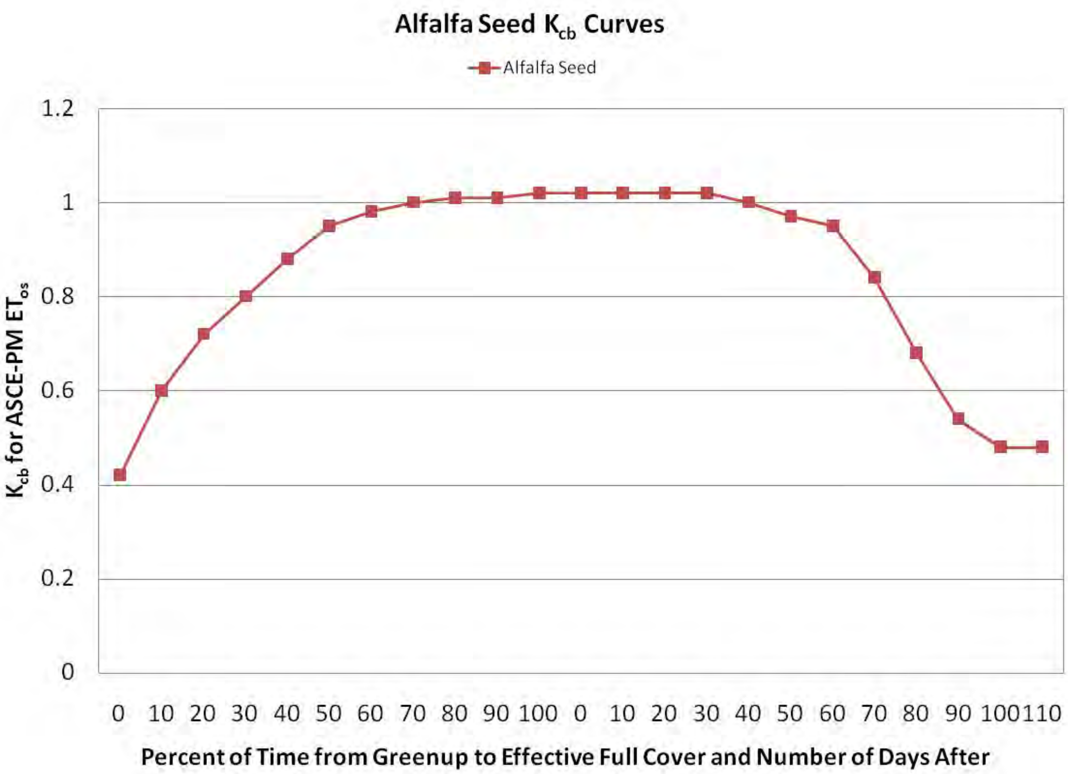

Figure 39. Alfalfa seed K_{cb} curve modified from Allen and Brockway (1983).

Termination and Killing Frosts

Killing frosts can terminate growing seasons prematurely for crops that grow late into fall or for crops that are sensitive to even light frosts. Temperatures for killing frosts were adopted from Allen and Robison (2007), which were derived from literature and internet searches, and personal field observations and notes from southern Idaho. Appendix 5 lists killing frost temperatures as well as all crop parameters used in this study.

Aridity Rating

Most NWS weather stations in Nevada are not located in agricultural areas. Local aridity of the area surrounding the weather station can elevate air temperature measurements above that expected within an agricultural field. This elevation in temperature can cause the progression of CGDD and NCGDD to over-accelerate. Therefore, to account for local aridity effects on CGDD and T_{30} impacting the computation of the beginning and ending of the growing season, the measured average daily temperature was reduced according to estimated station aridity. The amount of maximum adjustment to the measured average daily temperature is listed in Table 5, by month, where adjustments are in proportion to the % aridity. Aridity ratings for weather stations were computed following procedures outlined by Allen and Brockway (1983), where the station, local, and regional aridity is rated from 0-100 (0=irrigated and 100=completely arid), and the cumulative aridity is computed as 0.4(station aridity)+0.5(area aridity)+0.1(regional aridity). The qualitative analysis for assigning aridity ratings was based on NWS weather station photos requested from various NWS Nevada field offices and high resolution imagery, where the station location was analyzed in terms of the degree of aridity or lack of available moisture surrounding the stations. The local station aridity was based on land use within the immediate area of the station (~50m), area aridity of the station (~1500m), and regional aridity of the station (50km) following Allen and Pruitt (1986). The adjustment to temperature was to subtract the adjustment from both T_{max} and T_{min}.

Table 5. Aridity adjustments to the average temperature for stations having aridity ratings of 100% following Allen and Brockway (1983). A linear adjustment was assumed for stations having less than 100% aridity.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aridity Adjustment (^{o}C)	0	0	0	1	1.5	2	3.5	4.5	3	0	0	0

Aridity ratings for all weather stations used in this study are reported in Appendix 8. The aridity adjustment to the measured average daily temperature was applied before the calculation of CGDD since the CGDD thresholds 'expect' to have input from weather stations having relatively well-watered surroundings. Conversely, the aridity adjustment to the average daily temperature was made after computation of ET_{os} because the air temperature and dewpoint temperature used to calculate ET_{os} are already paired, based on K_o, as described earlier, so that the VPD in the ET_{os} calculation is generally representative of a reference condition (Allen et al., 1998; ASCE-EWRI 2005).

Non-growing Season Evapotranspiration

ET during the non-growing season varies widely depending on the availability of soil moisture, freezing of soils, snow cover, condition and amount of dormant vegetation, and availability of energy for ET. Estimation of non-growing season ET is important for maintaining the soil and root zone water balance and estimating the amount of non-growing season precipitation that accumulates during the non-growing season that is available during the start of the subsequent growing season.

Few studies have been performed where ET has been measured from dormant agricultural vegetation during the non-growing season. Wright (1991, 1993) conducted a series of non-growing season measurements of ET using the dual precision weighing lysimeter systems at Kimberly, ID, near Twin Falls, ID. The lysimeter surfaces included clipped fescue grass and bare soil conditions of disked wheat stubble, disked alfalfa, disked soil, dormant alfalfa, and winter wheat. Wright (1991, 1993) found that the K_{cmean} during the non-growing season rarely exceeded 1.0, for an alfalfa reference basis, even during periods having a constant supply of soil moisture from precipitation. Goodrich (1986) compiled water balance lysimeter measurements of non-growing season alfalfa ET at the Nevada Agricultural Experiment Station's Newlands Research Center in Fallon. Goodrich found that the average annual non-growing season (mid October – mid March) dormant alfalfa ET from 1974-1984 was 2.7 inches. Goodrich also reported that bare soil evaporation for the non-growing season of 1985-1986 was 1.2 inches. Unfortunately, no crop coefficients were developed in Goodrich's study.

Non-growing season K_{cb} of 0.12 was assumed in this study for bare soil conditions, surfaces covered with some amount of mulch, and for dormant turf. The K_{cb} represents conditions when these surfaces have a dry soil surface but with sufficient moisture at depth to supply some diffusive evaporation. The value was reduced during calculations if the soil moisture becomes overly dry during extended period of no precipitation. The evaporation component, K_e, is estimated separately in the daily soil water balance, where K_c max during the non-growing season was assumed to equal 1.1 for bare soil, 1.0 for mulched surfaces, and 0.96 for dormant grass cover. The lower value for grass is to account for insulation effects of the grass and higher albedo. The surface of mulch was used to represent surfaces that are part way between bare and grassed conditions. The assumed effective fraction of cover for estimation of K_e (discussed in Annex 1) was 0.7 for dormant grass, 0.4 for mulch, and 0 for bare soil.

The effective rooting zone of 0.10m was assumed during the non-growing season for mulch and dormant turf. A stress coefficient was applied during the non-growing season for all dormant mulch and dormant turf so that when the depletion of soil water dropped below the RAW for the upper 0.10m or effective root zone, the actual K_c was reduced below the K_{cb}, representing the condition when both the ground surface and subsurface soil was dry. The non-growing season was defined as the period beginning at the end of a K_{cb} curve representing the growing cycle for a specific crop or the occurrence of a killing frost, and ending at greenup or planting of the same crop the following season. All crop types were assigned one of the three non-growing season cover conditions of dormant grass, bare soil, or mulch for the estimation of ET during the non-growing season (Appendix 5).

During the non-growing season when ET demands are low, the depth of effective drying by evaporation decreases due to lower transport of heat into the soil profile and lower vapor pressures in the soil. This phenomena was accounted for following recommendations similar to those outlined in Allen et al., (2005) and Allen and Wright (2009), where if the 30 day average ET_{os} ending on the day in question was less than 4mm/day, then

$$TEW_{applied} = TEW\sqrt{\frac{ET_{os30}}{4}} \quad \text{Eq. 51}$$

and the value for REW was limited to less than or equal to 0.7($TEW_{applied}$). Using ET_{os} as a surrogate for temperature and radiation conditions, this adjustment is recommended to account for cool periods where less energy is available for evaporation and the total effective TEW representing a drying event will typically be smaller than during a warm period.

Snow cover information from NWS stations was used to adjust the K_{cb} value to account for higher albedo of snow and absorption of heat by melt. The following algorithms were applied following Allen and Robison (2007) and Allen and Wright (2009) for the adjustment of K_{cb} as

$$K_{c\_multiplier} = 1 - K_{radiation\_term\_winter} + \frac{(1 - albedo_{snow})}{(1 - albedo_{surface})} K_{radiation\_term\_winter} \quad \text{Eq. 52}$$

where the $K_{radiation\_term\_winter}$ represents the weighting of, or contribution to, winter time ET_{os} estimates by the radiation term of the ASCE-PM equation, $albedo_{snow}$ is the mean albedo of snow cover, and $albedo_{surface}$ is the mean albedo of the bare surface. Albedo of snow was assumed to be 0.8 and the albedo of the surface was set to 0.25. $K_{radiation\_term\_winter}$ is equivalent to

$$K_{raditation\_term\_winter} = \frac{\Delta}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \quad \text{Eq. 53}$$

where Δ is the slope of the saturation vapor pressure-temperature curve, γ is the psychrometric constant, r_s is the surface resistance to vapor flow, and r_a is the aerodynamic resistance to heat and vapor flow above the surface. The intent of Eq. 52 was to adjust the ET_{os} estimate, which is parameterized to estimate the potential ET for a vegetation surface, not a snow covered surface. The primary adjustment is for albedo of the surface, which is higher for snow cover. For ease of calculation, $K_{radiation\_term\_winter}$ is calculated as a function of day of year based on a relationship derived using full years of Kimberly, ID, weather data and the ASCE-PM equation as

$$K_{radiation\_term\_winter} = (2.2E-08)J^3 - (2.42E-05)J^2 + 0.006J + 0.011. \qquad \text{Eq. 54}$$

An additional reduction in evaporation of 30% was made to account for absorbed latent heat of fusion of any melting snow prior to evaporation.

Some of the NWS stations report daily snowfall but do not report observed accumulated snow depth. In these cases, estimated depth of snow on the ground was made by accumulating snowfall and applying a simple melt rate function, following Allen and Robison (2007), as

$$Snow\_accumulation_i = Snow\_accumulation_{i-1} + \frac{Snowfall}{2} - Melt_i \qquad \text{Eq. 55}$$

and

$$Melt = 4T_{\max} \qquad \text{Eq. 56}$$

where Snow_accumulation is the snow depth accumulation in mm, Snowfall is the reported snowfall depth for the day in mm, Melt is the melt rate in mm/day, and T_{max} is the daily maximum air temperature in ^oC. The snowfall amount is reduced by half in Eq. 55 as an approximation to settling of the snow. The snowmelt rate function was based on 50 years of snow cover and temperature observations in Ashton, ID by Allen and Robison (2007). The snow_accumulation parameter was calculated for all stations that reported snowfall.

Evaporation from Small Open Water Bodies

Small water bodies are common components to irrigation and municipal water supply systems. Estimating evaporation from open water bodies is complex. Energy balance variables that control the rate of evaporation include net radiation, heat storage, advection of heat into and out of the water body, and the transfer of sensible heat between the water and air. In addition, the aerodynamics of the water surface, turbidity of the water, and inflow and outflow rates control the rate of transfer between energy balance variables. For example, evaporation from a deep water body can be significantly lower than ET_{os} during the spring and summer due to the storage of heat from penetrating solar radiation beneath the water surface. An example of the effect of lake heat storage causing the lake evaporation to be lower than the ET_{os} in the summer and then higher than ET_{os} in the fall is shown for Walker Lake in Figure 40, where the Bowen ratio energy balance monthly estimated lake evaporation (Allander et al., 2009) is compared to

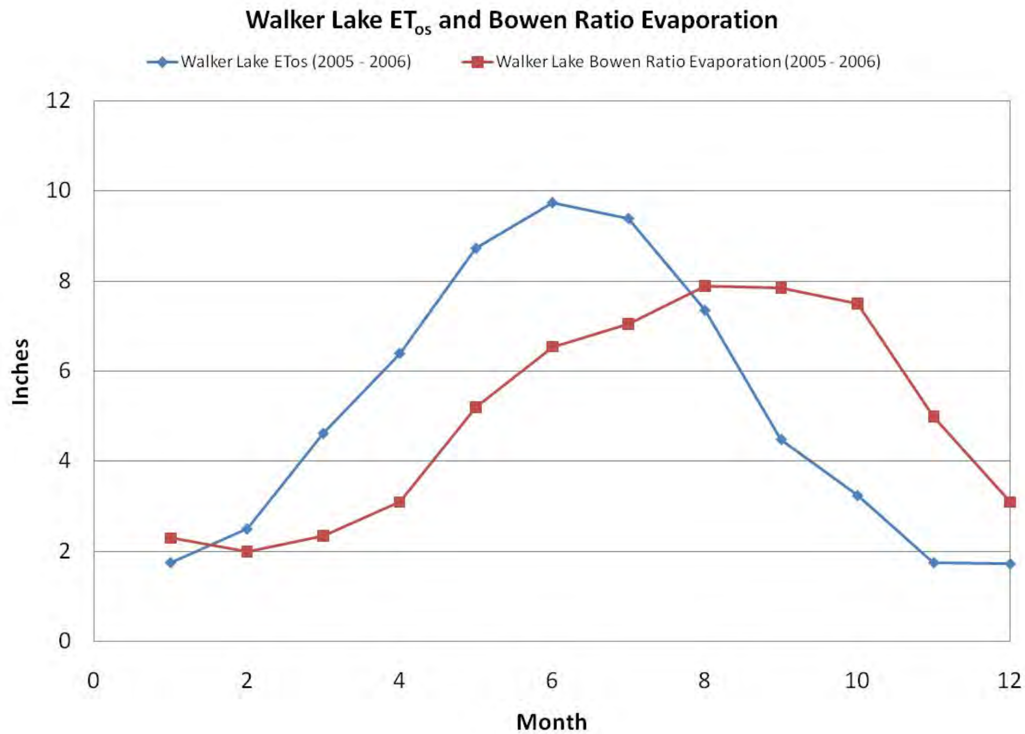

Figure 40. Walker Lake Bowen ratio energy balance estimated evaporation vs. calculated ET_{os} using Bowen ratio weather data. The illustrated shift in estimated Bowen ratio evaporation is due to heat storage in the summer months, and then the release of stored heat later in fall and winter.

the computed ET_{os} using weather variables measured at the Bowen ratio station. Later in the fall stored energy can be partitioned into evaporation, heating of the air, emission of long wave radiation, or advection of heat in the discharging water being released for irrigation. Because evaporation is a surface process, solar radiation stored as heat in the spring and summer months is not readily available for evaporation, rather heat storage is only available to the surface energy balance when transferred there by conduction or convection. During the conduction or convection of heat to the surface, air temperature is sometimes lower than the water temperature causing a large portion of energy to be partitioned from stored heat into sensible heat or long wave emission rather than evaporation, therefore reducing the total evaporation from the water body. In the example of Walker Lake, it appears that the heat stored in the summer is largely being partitioned into sensible heat in the fall when the water skin temperature is warmer than the air temperature. The skin temperature at the Bowen ratio station for respective time periods was estimated using MODIS (Moderate Resolution Imaging Spectrometer) satellite thermal imagery.

A number of recent studies have been conducted estimating evaporation from large open water bodies in Nevada and surrounding states (Allen and Tasumi, 2005; Allander et al., 2009; Westenburg et al., 2006; Trask, 2007). Estimating evaporation from large water bodies without significant amounts of field instrumentation is difficult due to the fact that each lake or reservoir has their own energy storage and energy exchange characteristics with the surrounding environment, which is a function of the hydrologic and physical characteristics of the water body, such as inflow and outflow volumes, water body depth and geometry, water turbidity, and topography and climate of the surrounding environment. For simplicity, this report only focuses on estimating open water evaporation from small, shallow (<5m) open water bodies, where impacts of energy storage are smaller and energy exchange with the surrounding environment is more similar to that of irrigated vegetation. Many studies have estimated evaporation from small, shallow water bodies using combination equations (i.e., combination of mass transfer and energy budget principles such as the Penman and Penman-Monteith equations). Such an approach was used in this report, where the ASCE-PM method was used to calculate the ET_{os}, and the ET_{os} was multiplied by a coefficient of 1.05 following recommendations outlined in FAO-56 (Allen et al., 1998). Evaporation estimates using the ET_{os} approach assume that no freezing occurs. The evaporation rate for open water will tend toward zero during periods of ice cover, therefore open water evaporation estimates in this study could be slightly inflated during winter months because ice coverage was not considered. In addition, deep open water systems could have significantly lower evaporation rates than those published in this report due to reasons summarized above. Additional measurements of evaporation using eddy correlation methods over a variety of open water surfaces are needed to characterize energy balance and physical properties of open water bodies so that more accurate estimates of open water evaporation using simplified methods can be developed and validated.

RESULTS

Reference ET, Actual Crop ET, and Net Irrigation Water Requirements

Reference evapotranspiration (ET_{os}), actual crop ET (ET_{act}), and the net irrigation water requirement (NIWR) were calculated for up to 34 different crop and land cover types at a daily time step using 190 weather stations shown (Figure 1) and the ASCE-PM grass reference equation and dual crop coefficient approach following methods outlined in FAO-56, Allen et al., (2005), and Allen and Robison (2007). Numerous ET and water balance related results for each weather station are organized by time series of daily, monthly, annual, and statistics files, which can be found on Nevada Division of Water Resources' website, water.nv.gov/NVET, and are also available by request. Details and definitions of variables included in daily, monthly, annual time series and statistics files are described in Appendix 9. For the purpose of assessing the amount of water available for water transfers from agriculture to some other use, the most useful result of this report is the mean annual NIWR. The NIWR is defined as the ET_{act} minus precipitation residing in the root zone, and represents the amount of additional water that the crop would evapotranspire beyond precipitation residing in the root zone. The NIWR is synonymous with the terms net consumptive use and precipitation deficit. Precipitation residing in the root zone, P_rz, is the amount of gross reported precipitation that infiltrates into the soil and that remains in the root zone for consumption by evaporation or transpiration. Although P_rz includes precipitation that is later evaporated and not "consumed" by the crop, it is important to note that because ET_{act} includes evaporation of precipitation, ET_{act} – P_rz represents the net irrigation water requirement, and not ET_{act} – P_rz that is effective toward transpiration only (see Appendix 9 for further details). P_rz was computed as P – Runoff – $DPerc_p$ where P is gross reported precipitation, Runoff is estimated surface runoff and $DPerc_p$ is deep percolation of any precipitation below the maximum root zone for the crop or land-use condition. A list of the crops for which ET_{act} and the NIWR were estimated at each weather station is presented in Appendix 10. Crops grown in limited areas in the state, such as onions, were only simulated at weather stations located near areas where they are known to be grown. Crops of alfalfa, pasture grass, grass hay, turf grass, and small shallow open water bodies were simulated at every weather station.

Examples of the daily estimated ET_{os}, ET_{bas}, and ET_{act} at Fallon, Yerington, and Minden for crops of alfalfa, onions, and pasture grass, respectively, are illustrated in Figures 41a-c. Also included in these figures are the simulated K_c and K_{cb} curves, simulated irrigations, and measured precipitation to illustrate the affect of cuttings and wetting events on the K_c curve (K_{cb}*K_s+K_e) and ET_{act}. The difference between the ET_{act} and the basal ET ($ET_{bas} = ET_{os} * K_{cb}$) represents the contribution of bare soil evaporation from irrigation and precipitation events. Using time series results for all stations and crops analyzed, the mean annual NIWR were computed for the last 30 years of record available, with a minimum of 4 complete years. Figure 42 illustrates the large spatial variation of the NIWR of alfalfa, which can be attributed to the spatial variability in ET_{os} (Figure 43), growing season length, and precipitation amount. In general, HAs located in southern parts of Nevada experience a NIWR that is larger than the typical permitted irrigation water right of 5ft/yr (1,524mm/yr), and in central and northern areas of Nevada the NIWR is less than the typical permitted irrigation water right of 4ft/yr (1,219mm/yr). Weather station estimates of the mean annual ET_{os} and ET_{act} are listed for alfalfa, grass hay, pasture grass, turf grass, and open water for each station sorted by weather station and HA name in Appendix 11a-b and the NIWR in Appendix 12a-b.

For purposes of estimating the mean annual NIWR per HA, weather stations located in upland and mountain block areas were omitted, and mean annual NIWR estimates for weather stations located on valley floor areas representative of potential agricultural areas were assigned to respective HAs based on single weather station estimates, or period of record weighted average estimates for HAs with multiple weather stations. For an example of the assignment, weighting procedure, and weather stations used in assigning or averaging the ET_{act} and NIWR for each HA, see Appendix 13. Several HAs include weather stations that are not located within the HA, but are near the boundary or considered representative, and therefore were used in assigning or computing the weighted average NIWR.

Of the 256 HAs in the state, 160 are absent of weather stations from which to estimate the ET_{act} and NIWR, therefore spatial interpolation of valley floor weather station estimates of ET_{act} and NIWR was performed for alfalfa, grass hay, pasture grass, turf grass, and small shallow open water bodies using the inverse distance weighting squared technique. Other spatial interpolation techniques that consider independent variables such as elevation were explored, however results were highly variable and inconsistent. Therefore, a simple inverse distance weighting technique was chosen where spatially interpolated surfaces of the ET_{act} and NIWR for the major crops previously discussed were averaged to each HA. Appendix 14 and 15 list the ET_{act} and NIWR of alfalfa, grass hay, pasture grass, turf grass, and small shallow open water bodies for each HA, and denotes the HAs for which the ET_{act} and NIWR were estimated using spatial interpolation. Plate 1 illustrates the estimated NIWR of alfalfa for each HA. The assignment and spatial interpolation of the NIWR for all HAs was limited to crops of alfalfa, grass hay, pasture grass, turf grass, and small shallow open water bodies. For HAs where the NIWR of specific crops are of interest, such as melons in Carson Desert, onions in Mason and Smith Valley, potatoes in Paradise Valley, etc., see Appendix 16 for a limited summary. For additional HAs and crops of interest, see electronic statistical summaries by station number. Descriptions of the statistical summaries are given in Appendix 9.

An interesting but not surprising result worth noting are the trends in simulated growing season lengths for alfalfa, as computed using a CGDD from Jan 1 of 300^{o}C-day and killing frost of -7^{o}C. Results of simulated growing season lengths indicate generally increasing trends over time due to increased average daily temperatures and minimum temperatures. Likewise simulated annual ET_{pot} ($ET_{pot} = ET_{os} * K_{cb} + K_e$) has also increased due to increased temperatures and growing season length. ET_{pot} was analyzed instead of ET_{act} to avoid the effects of any stress (K_s) caused by limiting water conditions that may occur during the non-growing season or early parts of the growing season. Examples of increases in simulated growing season lengths and annual ET_{pot} over time for alfalfa are illustrated in Figure 44a-e for selected weather stations in Nevada that have long periods of record. Several researchers have found similar results of increasing growing season lengths due to earlier spring greenup (Manzel and Fabian, 1999; Walther et al., 2002; Parmesan and Yohe, 2003) and later occurring frosts (Cooter and LeDuc, 1995; Easterling, 2002; Kunkel et al., 2004), resulting in increases in ET and intensification of the global water cycle (Brutsaert and Parlange, 1998; Golubev et al., 2001; Walter et al., 2004; Huntington, 2006). Although it is clear that the annual ET_{pot} is increasing through time for some stations, in this report the last 30 years of record was used to compute the average NIWR for purposes of evaluating the amount of water available for water transfers when converting existing irrigation water rights to some other use. Some of the observed trends in growing season length and ET_{pot} are caused by changes in relative dryness of the local or regional environment due to irrigation development or land-use change, by station location or relocation, or perhaps by change in overall climate. The last 30 years of usable record were considered to be more representative of expected future conditions than prior periods. The full records for each station are preserved in the daily, monthly, and annual time series files. Therefore, statistics for the full periods of record can be computed as needed from these data sets.

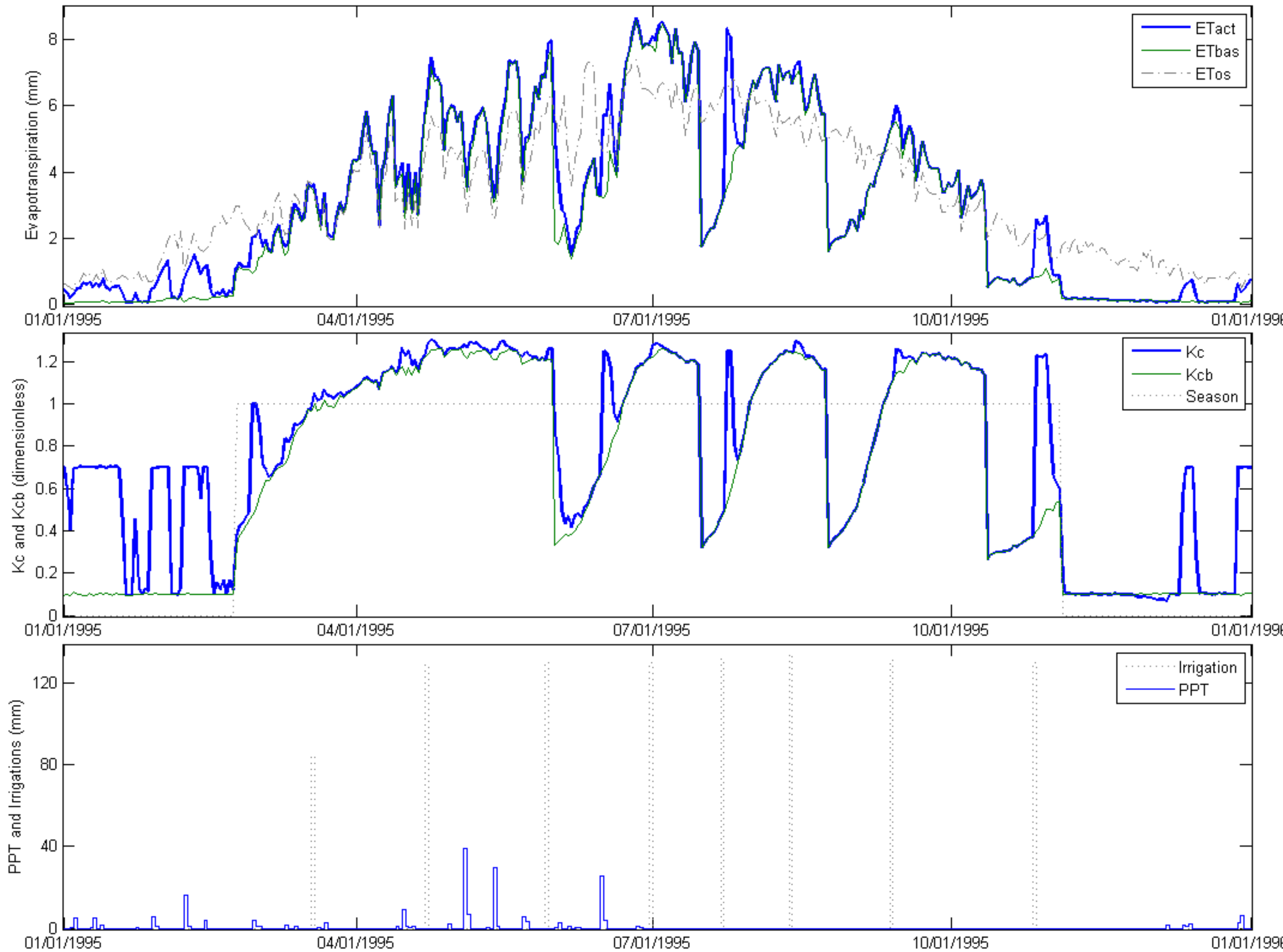

Figure 41a. Simulated alfalfa ET_{act} (top graph) and K_c (middle graph) using the NWS Fallon weather station. The simulated K_c curve, irrigations, and measured precipitation are shown to illustrate the response of the K_c curve and ET_{act} from cuttings and soil evaporation due to wetting events.

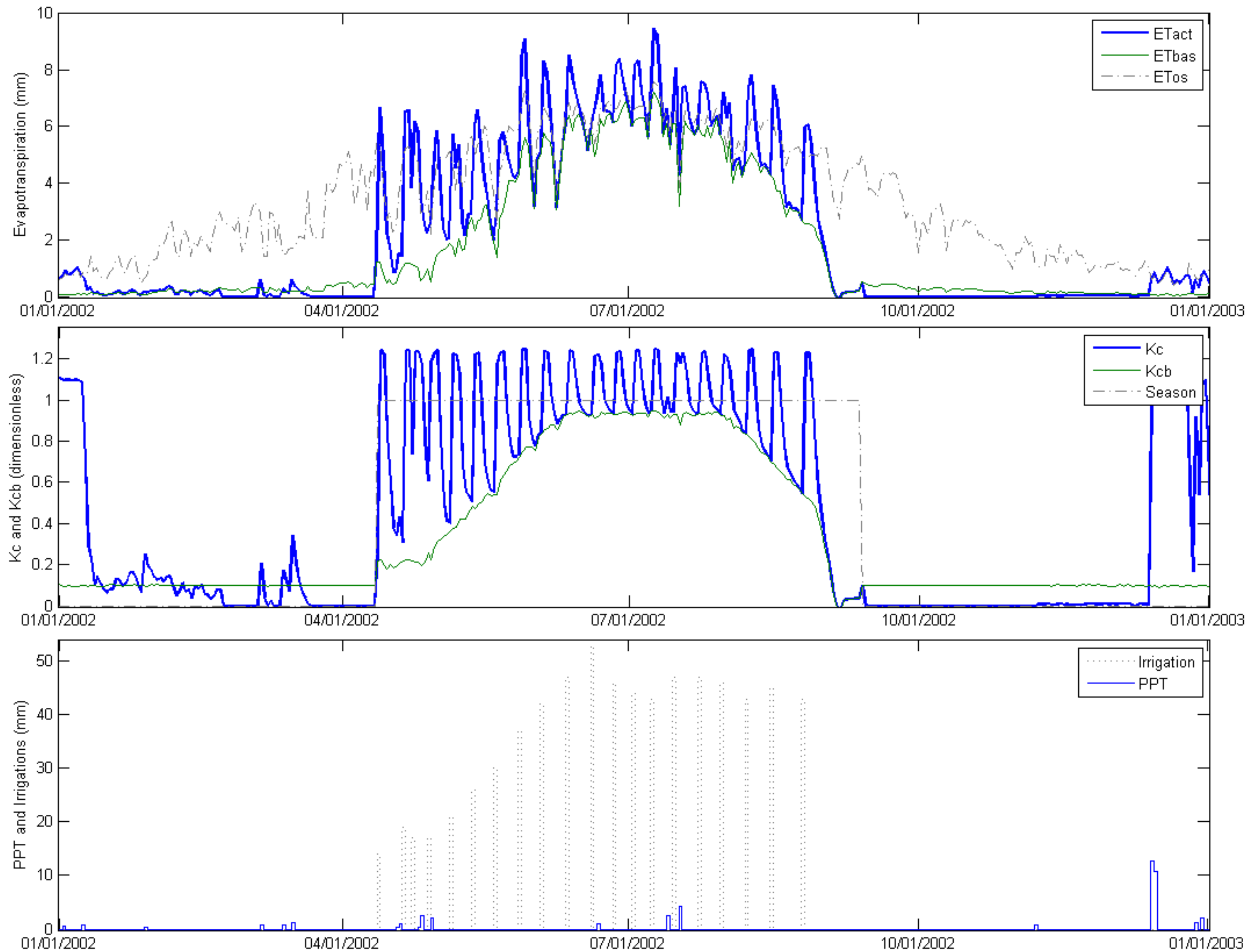

Figure 41b. Simulated onion ET_{act} (top graph) and K_c (middle graph) using the NWS Yerington weather station. Simulated K_c curve, irrigations, and measured precipitation are shown to illustrate the response of the K_c curve and ET_{act} from soil evaporation due to wetting events. More frequent irrigations are simulated compared to alfalfa as a result of the smaller root depth of onions and hence small amounts of available soil water.

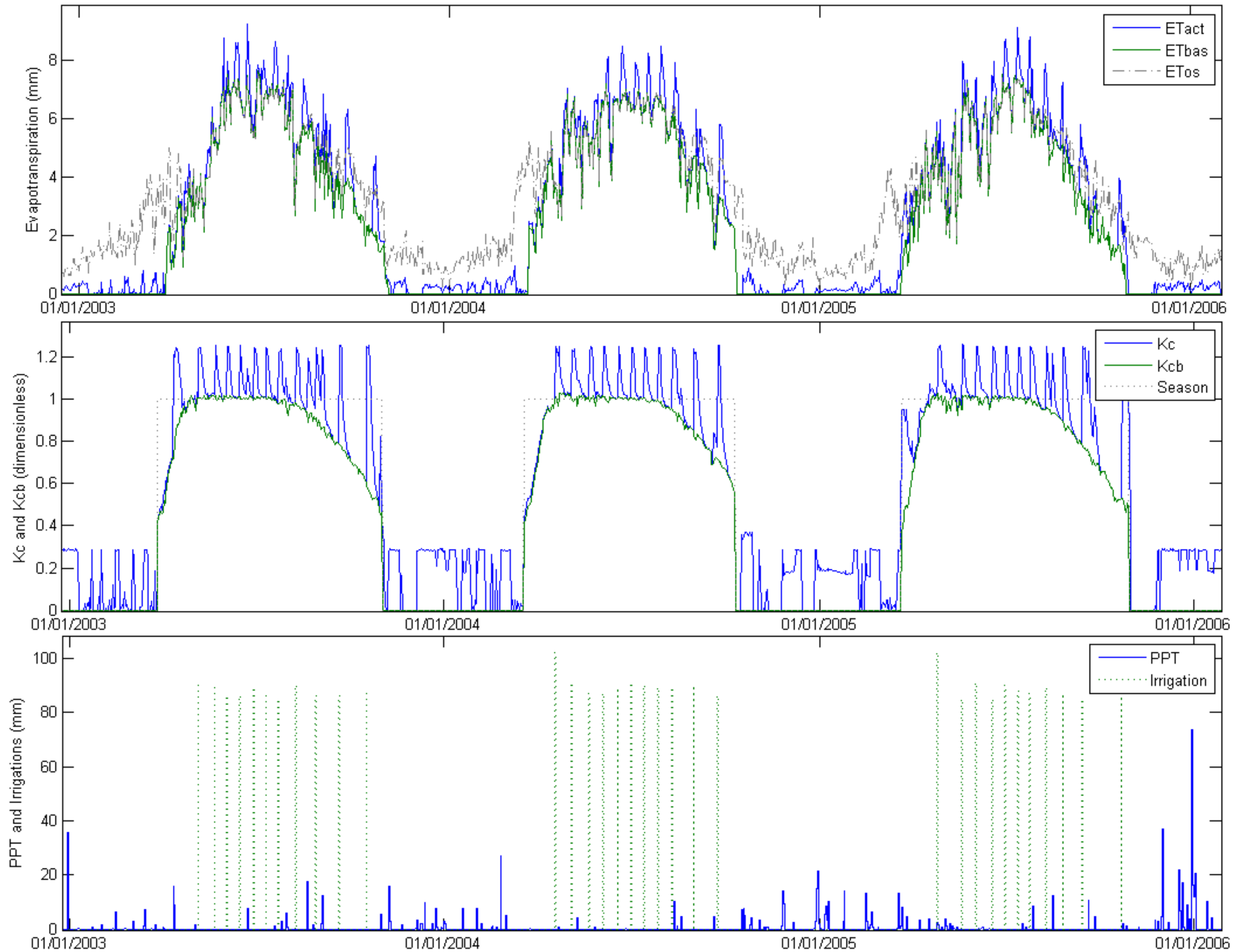

Figure 41c. Simulated pasture grass (highly managed type) ET_{act} (top graph) and K_c (middle graph) using the NWS Minden weather station. Multiple years are shown to illustrate non-growing season ET_{act} in response to precipitation events. Simulation of non-growing season ET_{act} allows for accounting soil moisture storage in the non-growing season and shows suppression of evaporation by dormant mulch.

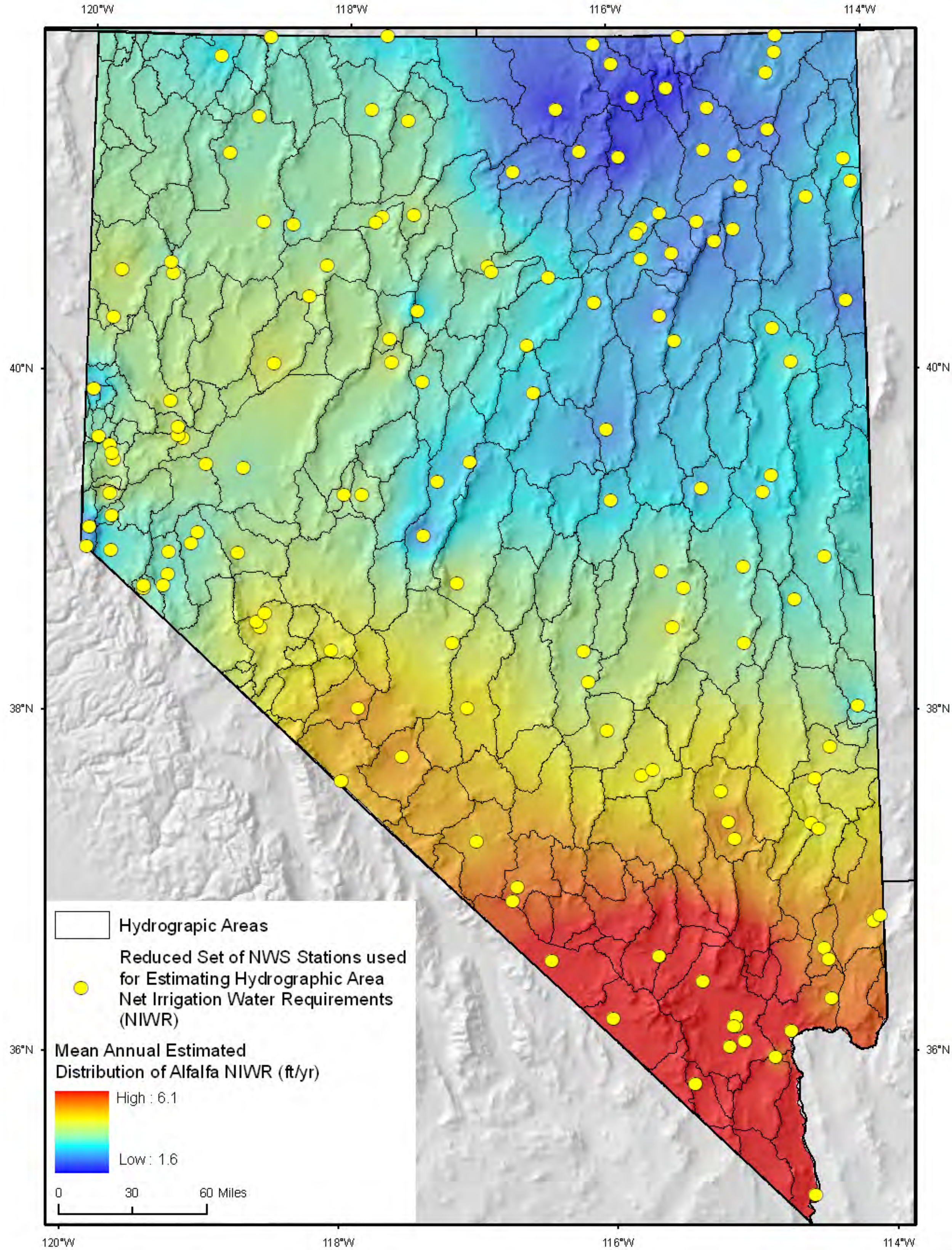

Figure 42. Spatially distributed mean annual alfalfa net irrigation water requirements (i.e. net consumptive use) and NWS stations used for computations and spatial interpolation.

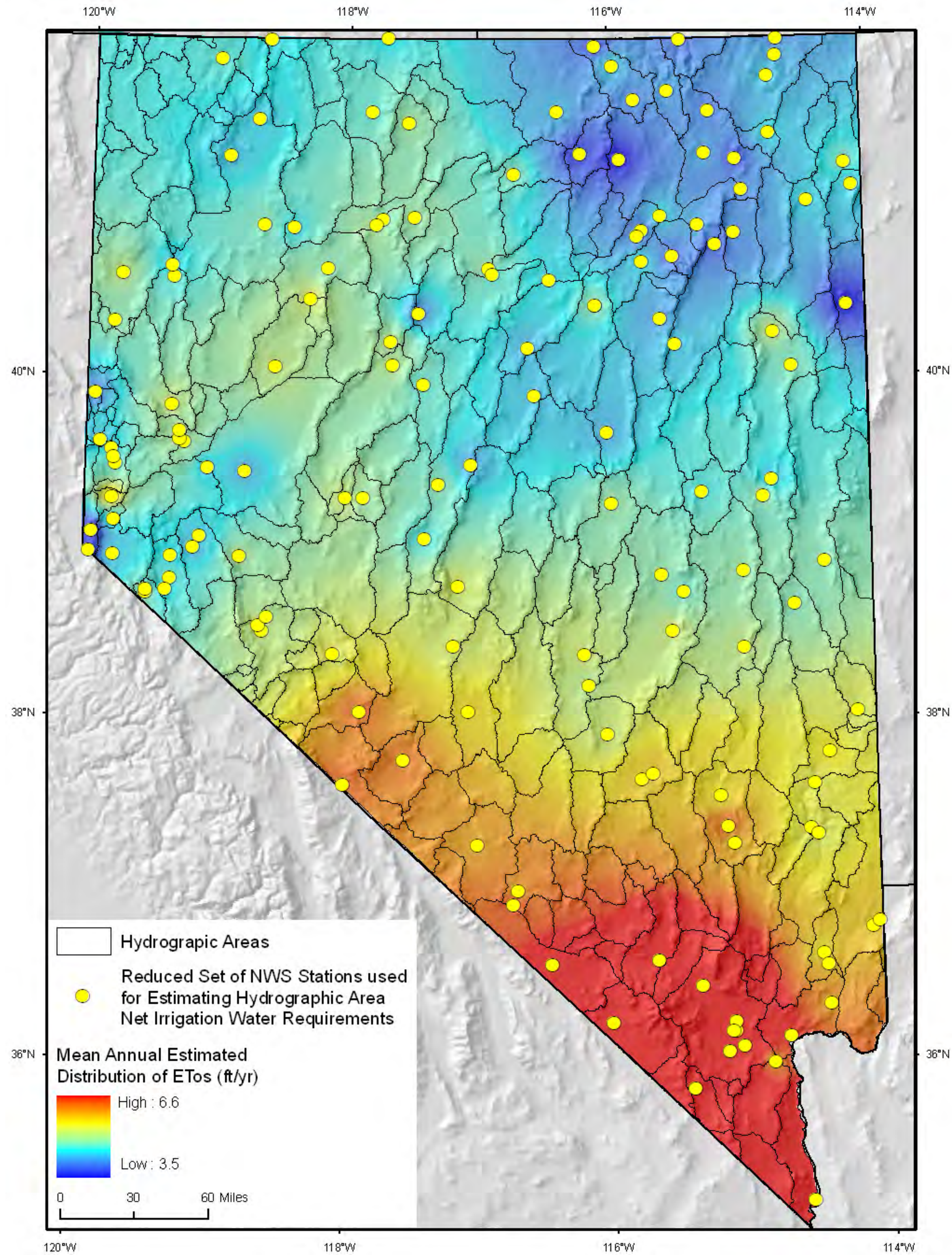

Figure 43. Spatially distributed mean annual ET_{os} using NWS stations used in estimating average hydrographic area net irrigation water requirements.

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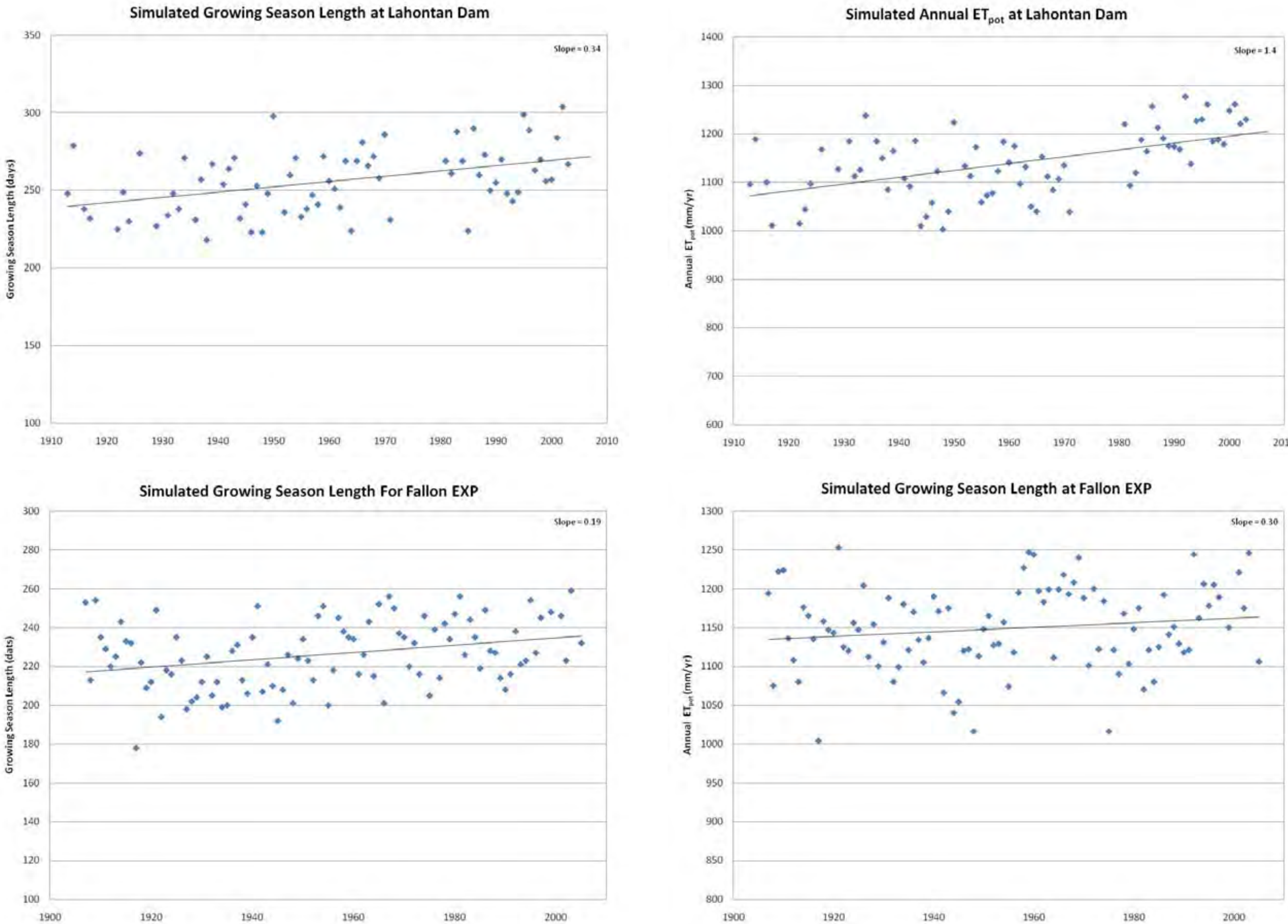
Comparison of Estimated ET_{os} vs. Calculated ET_{os}

Assessing the error in estimated ET_{os} using estimates of R_s, T_{dew}, and U_2, verses using measured data is of significant interest because estimation of these variables provides the ability to use NWS stations allowing for sufficient spatial coverage and statewide application. To address the accuracy of estimating these secondary parameters, a comparison was made between estimated ET_{os} at NWS stations and calculated ET_{os} at nearby stations located in irrigated areas that measure the full suite of weather variables. Results of the comparison indicate that the ratios of annual estimated ET_{os} to calculated ET_{os} range from 1.01 to 1.06, with an average of 1.03, and an average RMSE for daily estimated ET_{os} of 0.036 in/d (0.91 mm/d) (Table 6). These results are acceptable considering the overall uncertainty in the K_c x ET_{os} estimation procedures. The estimated ET_{os} was dependent on spatially interpolated K_o, U_2, and estimated R_s using T_{max} and T_{min}. Unfortunately very few weather stations exist that measure R_s, RH, and U_2 and are located in reference settings to compare estimated ET_{os}. As more weather stations become available that are located in agricultural areas the uncertainty in estimated ET_{os} can be better quantified.

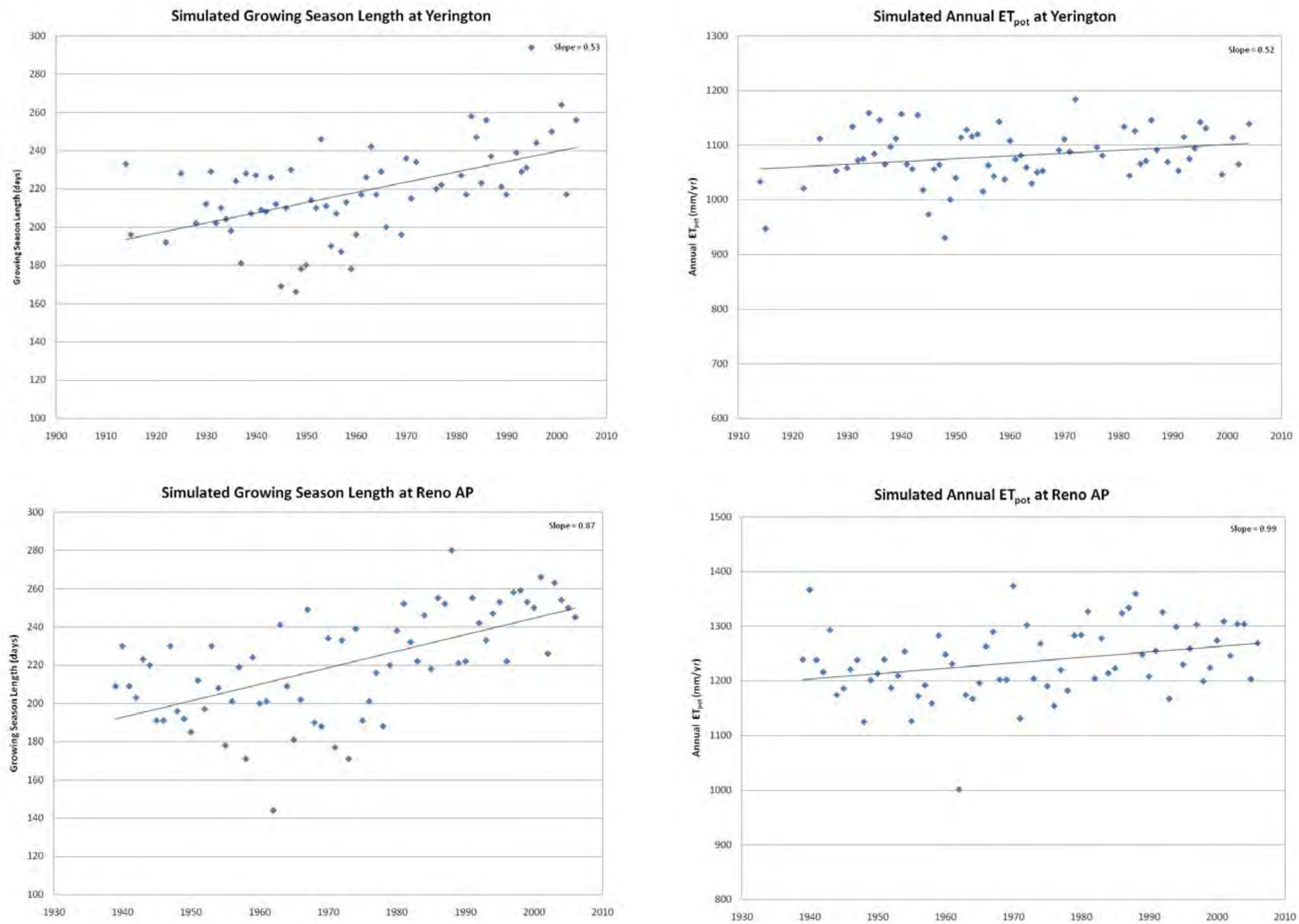
Table 6. ET_{os} from NWS stations where solar radiation, wind speed and dewpoint were estimated vs. ET_{os} at nearby irrigated area weather stations that measure the full suite of weather variables to calculate the 'full-suite' ET_{os}.

Name of NWS Station for ET_{os} Estimation	Basin of NWS Station Location	Name of ET_{os} full-suite Station	Basin of ET_{os} full-suite Station Location	Type of ET_{os} full-suite Station	Period of Record Used for Comparison	Ratio of Estimated Annual ET_{os} for NWS stations to Full-Suite Annual ET_{os}	RMSE for Daily Estimated ET_{os} (in/d)	Mean Annual ET_{os} (in) for full-suite station	Estimated Mean Annual ET_{os} (in)
Diamond Valley USDA	Diamond Valley	Eureka AGRIMET	Diamond Valley	AGRIMET	8/01 - 6/06	1.06	0.03	47.6	50.4
Fallon EXP STN	Carson Desert	Fallon AGRIMET	Carson Desert	AGRIMET	3/01 - 12/05	1.02	0.03	50.1	50.8
Laughlin	Colorado Valley	Mohave	Mohave Valley, AZ	AZMET	1/03 - 5/07	1.01	0.06	76.3	77.1
Yerington	Mason Valley	B11	Mason Valley	USGS Bowen Ratio	3/05 - 3/07	1.04	0.03	47.1	48.9
Minden	Carson Valley	ET-2	Carson Valley	USGS Bowen Ratio	4/03 - 11/04	1.05	0.03	50.2	52.4

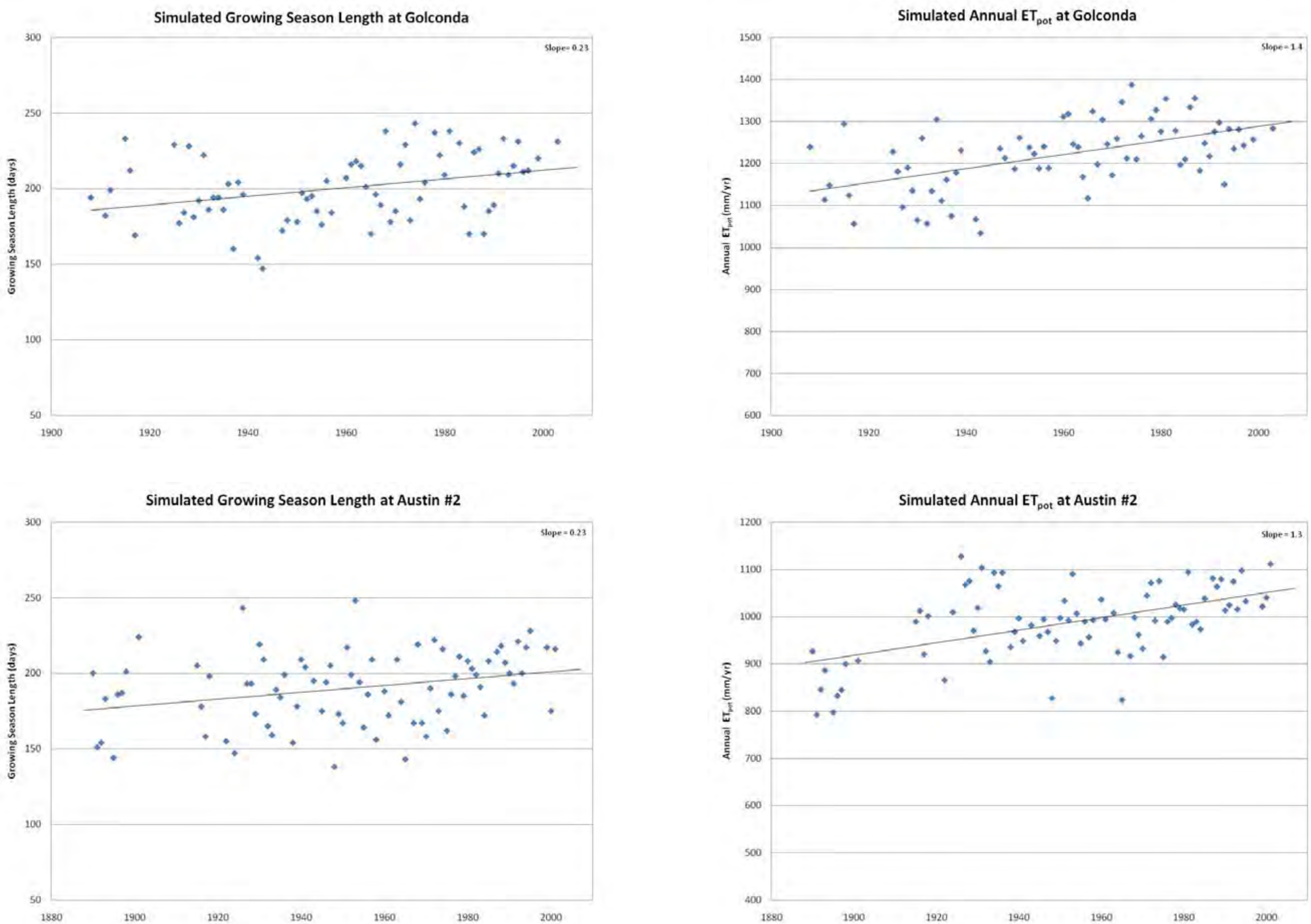
Average of Ratios and RMSE	**1.03**	**0.04**
Std. Dev. of Ratios and RMSE	**0.02**	**0.01**



Figures 44a. Alfalfa simulated growing season lengths and ET_{pot} for Lahontan Dam and Fallon NWS weather stations.



Figures 44b. Alfalfa simulated growing season lengths and ET_{pot} for Yerington and Reno AP NWS weather stations.



Figures 44c. Alfalfa simulated growing season lengths and ET_{pot} for Golconda and Austin NWS weather stations.

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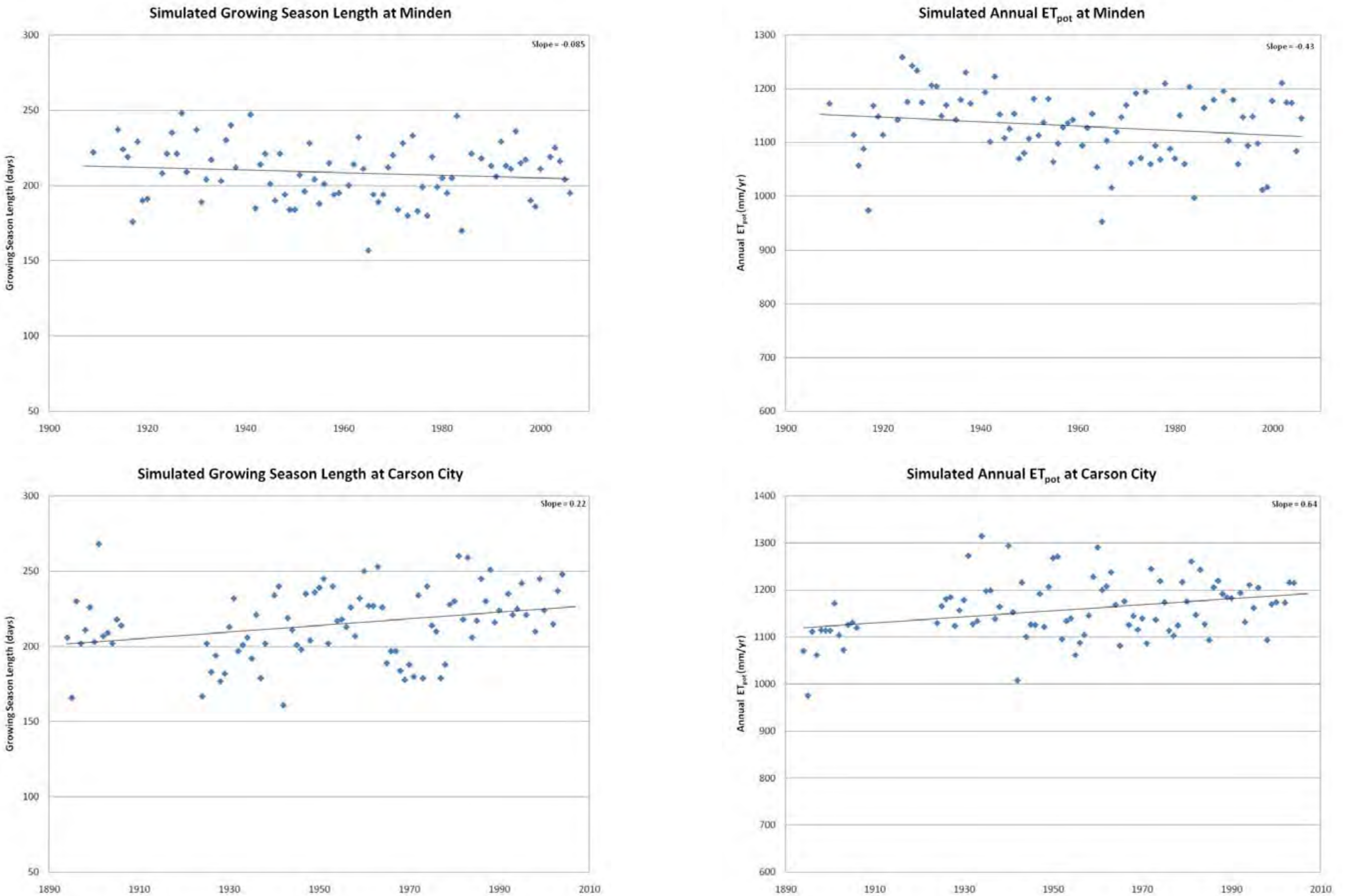
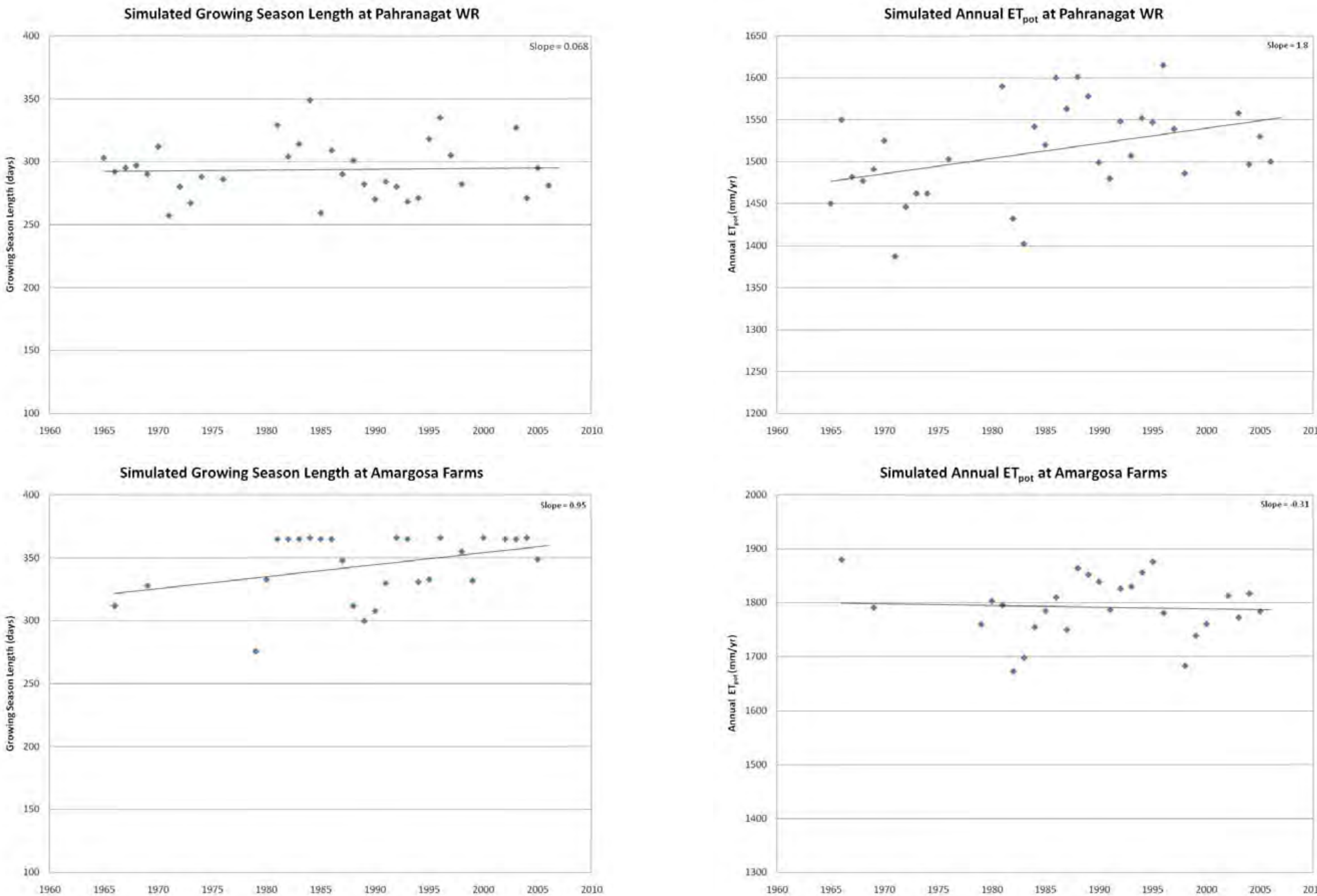


Figures 44d. Alfalfa simulated growing season lengths and ET_{pot} for Minden and Carson City NWS weather stations.



Figures 44e. Alfalfa simulated growing season lengths and ET_{pot} for Pahranagat WR and Amargosa Farms NWS weather stations.

Comparison of Estimated ET_{act} vs. Previously Reported ET_{act}

Many studies have investigated the ET of alfalfa in Nevada using multiple techniques such as water balance lysimeters, soil moisture depletion, and micrometeorological methods. Most of the studies were conducted from the 1950's through the 1980's with more recent applications of micrometeorological methods. Houston (1955) used two water balance tank lysimeters to investigate ET of alfalfa from 1951 to 1953 in the Truckee Meadows, at the University of Nevada Valley Road Farm. Houston's lysimeter experiments for 1951, 1952, and 1953 suggested that the estimated ET for alfalfa during the growing season was 42.7, 37.5 and 50 inches, with an oven dry weight yield of 2.5, 4.0, and 4.9 tons per acre, respectively.

Tovey (1963) investigated ET and crop yield of alfalfa in the Truckee Meadows, at the University of Nevada Main Station Farm during the 1959-1961 growing seasons, where he installed 63 water balance tank lysimeters and varied soil texture, lysimeter static water levels, and irrigation treatment (irrigated/non-irrigated). The ET_{act} of alfalfa was estimated by recording and adding the measured surface water irrigation volume applied to lysimeters, volume of water that maintained the static water level in the lysimeters, and volume of precipitation. Tovey (1963) reported an average seasonal ET_{act} of alfalfa to equal 42, 38, 40, and 31 inches, grown with lysimeter static water levels of 2, 4, 8 feet, and no static water level, respectively, where the growing season reported was from mid May to mid October. Yields associated with these ET_{act} estimates were 7.4, 7.1, 7.2, and 6.4 tons per acre, respectively, however it is unclear if these estimates represent the field weight or dry weight.

Many studies have been conducted evaluating lysimeter measurements of ET and crop yields of alfalfa in Fallon at the Nevada Agricultural Experiment Station's Newlands Research Center (Greil, 1974; Neyshabouri, 1976; Tuteur, 1976; Wilcox, 1978; Staubitz, 1978; Guitjens, 1982; Rashedi, 1983; Goodrich, 1986; Guitjens and Goodrich, 1994). These study objectives ranged from evaluating winter water use by seedling alfalfa, ET under conditions of a shallow water table and controlled irrigation, ET for maximum crop yields, crop yields from controlled irrigation, dormant season ET, development of alfalfa yield equations, and estimation of crop coefficients using different reference ET equations. Given that the ET rate will vary depending on the study design, goals and objectives, an average growing season ET rate is difficult to estimate from these studies. However, given that the crop yield of alfalfa is a function of the ET rate, a reported crop yield can be chosen to provide a fair evaluation of the respective ET rate. According to the USDA National Agriculture Statistics Service, the average yield for alfalfa hay for Churchill County, NV from 1969-2005 was 4.4 tons per acre, and the statewide average was 4 tons per acre from 1969-2005. The USDA National Agriculture Statistics Service crop yield estimates for Nevada are derived from mail and phone surveys in which approximately 85% of growers and farmers participated (USDA/Don Breazeale, 2006, verbal communication). Measurements of alfalfa yield from lysimeter studies conducted in Fallon (Greil, 1974; Neyshabouri, 1976; Tuteur, 1976; Wilcox, 1978; Staubitz, 1978; Rashedi, 1983; Goodrich, 1986) are reported to range from 5.0 to 10.5 tons per acre, with all of the years of measurement reporting substantially greater alfalfa yields than the USDA National Agriculture Statistics Service 1969-2005 average estimate for Churchill County, NV. Lysimeter studies conducted in Fallon reported alfalfa yield at the field weight, which is assumed to be at 12% moisture content (Tuteur, 1976). Possible reasons for the discrepancy between reported lysimeter yields and USDA reported statewide yields are 1) likely due to scaling the lysimeter yields from the small area of the lysimeter to 1 acre, 2) lysimeter studies were conducted under excellent agronomic practices and pristine crop conditions, and 3) no dry matter loss occurred, where dry matter loss can be a significant factor in reported low yields (Guitjens, 2006, verbal communication). For the purposes of comparison, 12 lysimeter measurements of ET during the growing season (average of mid March to mid October), summarized by Rashedi (1983, Table 11), were compiled and averaged to produce an average growing season ET of 43 inches and average yield of 9.3 tons per acre from 1974-1982.

Mahannah (1979) summarized multiple multiyear alfalfa ET studies that have been conducted in Carson Valley as part of a written report for U.S. District Court case United States vs. Alpine Land and Reservoir Company. Annual ET estimates for alfalfa and pasture grass were derived using class A evaporation pans, application of various empirical equations (i.e. Blaney Criddle, radiation method, Penman, etc.), and soil moisture depletion techniques (Guitjens and Mahannah, 1977). Findings of the multiyear study (1971-1975) estimated a mean annual ET rate of 43, 44, and 42 inches, using the class A pan, various empirical methods, and soil moisture depletion methods, respectively, and recommended that 44 inches be representative of annual alfalfa and pasture grass ET in Carson Valley. Mahannah (1979) also estimated the NIWR, or the annual ET_{act} minus the effective precipitation, using an ET estimation type approach and valley wide depletion approach. Mahannah (1979) assumed that 54% of the long term precipitation of 9.4 inches was effective, making the NIWR equal to 39 inches. Mahannah's valley wide depletion estimate was 28 inches, however this estimate was qualified as likely being low respective to what the potential consumptive use could be due to water supply and priority issues.

Kimbell et al., (1990) performed a multiyear experiment of alfalfa ET_{act} near Wadsworth, located in the Tracy Segment HA. Like Guitjens' and Mahannah's studies in the Carson Valley, soil moisture depletion methods were used to estimate the annual ET_{act} and associated crop for various water application rates. Findings from the study estimated that the annual alfalfa ET_{act} of 45 inches produced maximum yields of 7.5 tons/acre.

The US Geological Survey has conducted numerous ET studies to estimate the ET_{act} from agricultural areas. Maurer et al., (2005) deployed several micrometeorological stations in Carson Valley from 2003-2004 to quantify ET_{act} from various alfalfa and pasture grass fields. Results from the study suggest that the annual ET_{act} for flood irrigated alfalfa may range from 36 – 37 inches, and annual ET for flood irrigated pasture grass may range from 34 – 52 inches. As part of a water resource study of the Walker River basin, Allander et al., (2009) deployed several micrometeorological stations, two of which were located in alfalfa fields in Mason Valley and operated from 2005-2007. Results from Allander's study suggest that the ET_{act} from the monitored alfalfa may range from 40 - 49 inches.

Table 7 summarizes the comparison of previous estimates of alfalfa and pasture ET_{act} and ET_{act} simulated in this study. Comparisons were made at NWS weather stations near study areas for respective time periods. The average ratio of simulated ET_{act} to the average of previously published ET_{act} is 1.04, and standard deviation of the ratios is 0.12. Results generally agree however there are significant differences in some instances. For example, Carson Valley alfalfa annual ET_{act} of 36 – 37 inches, estimated by Maurer et al., (2005), does not compare well with the simulated alfalfa ET_{act} of 47 inches. There could be several reasons for this discrepancy. Given that pasture ET_{act} from the same study was estimated at 52 inches, the most likely reason for the discrepancy is that the 2 alfalfa fields monitored were water limited and not under optimal agronomic management. It is important to note that simulated ET_{act} in this study represents the ET that would occur under near-pristine crop conditions and not limited by water supply. In practice, this condition is difficult to achieve unless the water supply is not limited, and excellent irrigation system designs and agronomic management strategies are practiced.

Uncertainties of the accuracy of reported ET estimates exist and are not quantifiable in most cases. The accuracy of water balance lysimeters is limited to the accuracy of measuring individual water budget components, of which the most uncertain are soil moisture measurements used to calculate the change in soil moisture storage over time and how representative the lysimeter vegetation and immediate environment are to the surrounding field condition. Allen et al., (1991) described a range of management problems with lysimeters that impact the ET measurement, including bloom or clothesline effects that can cause substantial overstatement of ET. Likewise, the soil moisture depletion technique is limited by the accuracy of the soil moisture measurement and estimation of deep percolation past the root zone. Application of the Bowen ratio energy balance technique calculates ET as a residual of the radiation energy balance, transferring all the uncertainty and bias from net radiation and soil heat flux measurements into the estimate of ET. If all energy balance variables are measured, uncertainty in the ET estimate using the eddy correlation technique, where the ET calculated from vapor flux measurements, can be compared to the ET calculated as a residual of the energy balance. The uncertainty in ET estimates from micrometeorological sites used for comparisons made in this study is assumed to be accurate to within about 12 percent (Allander et al., 2009; Maurer et al., 2006). The most accurate and least uncertain measurement of ET is obtained using well-managed precision weighing lysimeter techniques, however no precision weighing lysimeter measurements exist in Nevada.

Table 7. Previously reported alfalfa and pasture ET_{act} based from measurement techniques vs. estimated alfalfa and pasture ET_{act} made in this study. Comparisons are made for respective time periods and hydrographic areas.

Reference	Period of Study	Location	Method	Crop	Yield (tons/acre)	Ranges of Reported ET_{act} (in)	Average of Reported ET_{act} (in)	ET_{act} From This Study (in)	Ratio of Estimated to Average of Reported ET_{act}	Weather Station Used for Comparison	Notes on ET_{act} Estimated in This Study Used for Comparisons
Houston (1955)	1951-1953	Truckee Meadows	Water Balance Lysimeters	Alfalfa	2.5 - 4.9	37.5 - 50 (Growing Season)	43.4	44	1.01	Reno AP	Average simulated growing season ET_{act} from 1951-1953
Tovey (1963)	1959-1961	Truckee Meadows	Water Balance Lysimeters	Alfalfa	6.4 - 7.4	31 - 42 (Growing Season)	37.9	46.3	1.22	Reno AP	Average simulated growing season ET_{act} from 1959-1961
Mahannah (1979)	1971-1975	Carson Valley	Soil Moisture Depletion	Alfalfa	NA	42.2 (Annual)	42.2	42.8	1.01	Minden	Average simulated annual ET_{act} from 1971-1975
Rashedi (1983)	1974-1982	Carson Desert	Water Balance Lysimeters	Alfalfa	8.1 - 10.5	36.8 - 55.1 (Growing Season)	42.7	40.5	0.95	Fallon EXP	Average simulated growing season ET_{act} from 1974-1982
Goodrich (1990)	1974-1986	Carson Desert	Water Balance Lysimeters	Alfalfa	NA	1.2 - 3.6 (Non-Growing Season)	2.6	2.5	0.96	Fallon EXP	Average simulated non-growing season ET_{act} of 1.6 and 3.5 inches from 1974-1986, which represent simulated ET_{act} during simulated non-growing dates, and simulated ETact during Goodrich's non-growing season dates, respectively
Kimbell et al., (1990)	1984-1986	Tracy Segment	Soil Moisture Depletion	Alfalfa	7.5	44.5 (Annual)	44.5	45.8	1.03	Wadsworth 4N	Average simulated annual ET_{act} from 1984-1986
Maurer et al., (2005)	2003-2004	Carson Valley	Bowen Ratio & Eddy Correlation	Alfalfa	NA	36.4 - 37.1 (Annual)	36.8	46.9	1.28	Minden	Average simulated annual ET_{act} from water year 2004
Maurer et al., (2005)	2003-2004	Carson Valley	Bowen Ratio & Eddy Correlation	Pasture	NA	33.6 - 52.2 (Annual)	41.3	41.7	1.01	Minden	Average simulated annual ET_{act} of low and highly managed pasture grass of 37.4 and 46.1 inches from water year 2004, respectively
Allender et al., (2009)	2005-2007	Mason Valley	Bowen Ratio	Alfalfa	NA	40.1 - 48.8 (Annual)	44.5	41.2	0.93	Yerington	Average simulated annual ET_{act} from 2005-2007

Average of Ratios	**1.04**
Std. Dev. Of Ratios	**0.12**

SUMMARY and CONCLUSIONS

Accurate estimates of evapotranspiration (ET) are becoming more important as increasing demands are placed on finite water supplies in Nevada and across the western U.S. Local, state, and federal water resource agencies require accurate crop ET (ET_{act}) and net irrigation water requirement (NIWR) estimates for evaluating irrigation development, transfers of irrigation water for municipal use, and litigation of water right applications and protests. The ET_{act} is equal to the reference ET multiplied by crop specific crop coefficients. In this study, the NIWR is equal to the annual ET_{act} minus precipitation that resides in the root zone that is available for evaporation or transpiration (i.e. ET_{act} – (PPT – runoff – deep percolation of precipitation)). The major objective of this study was to update estimates of ET_{act} and NIWR for Nevada. The methods for estimating the reference ET followed the new ASCE-EWRI Standardized Penman-Monteith approach, while the ET_{act} and NIWR was estimated using a dual crop coefficient and daily soil water balance. The dual crop coefficient and daily soil water balance approach allows for the consideration of evaporation from surface wetting by irrigation and precipitation in the computation of the crop coefficient value, which provides a more refined estimate of the ET_{act} and NIWR than previous studies. Estimates of the ET_{act} and NIWR for major crops grown in Nevada were made for daily, monthly, and annual time steps at 190 locations using National Weather Service weather stations located throughout the state for available periods of record. Evaporation from small shallow open water bodies was also estimated at all weather stations evaluated.

The ASCE standardized Penman-Monteith reference ET equation is a nationally standardized method (ASCE-EWRI 2005), is well regarded, and serves as a reproducible index approximating the climatic demand for water vapor. Reference ET is the ET rate from an extensive surface of reference vegetation having a standardized uniform height, is actively growing, completely shading the ground, has a dry but healthy and dense leaf surface, and is not short of water. The ASCE Penman-Monteith (ASCE-PM) equation was recently standardized by ASCE-EWRI (2005) for application to a tall full cover alfalfa crop and to a clipped grass reference. Because the grass reference is being widely applied by Arizona and California State agencies for computing ET_{act} (i.e. AZMET and CIMIS), as well as the U.S. Bureau of Reclamation for their Lower Colorado River Accounting System (LCRAS) model, the State of Nevada has adopted the daily time step grass reference evapotranspiration equation as the basis for computing the ET_{act} and NIWR in this study. Daily calculation time steps allow for the calculation and refined accounting of evaporation from wet soil surfaces following precipitation or irrigation events. ET_{act} for monthly, growing season, and annual periods were summed from the daily calculation results.

Because only maximum and minimum air temperature are observed at National Weather Service cooperative stations, solar radiation, humidity, and wind speed variables required in the ASCE-PM equation were estimated using methods similar to recommendations in ASCE-EWRI

(2005). Estimates of solar radiation were based on an empirical relationship of differences between daily maximum and minimum air temperature and solar radiation, where maximum air temperatures generally decrease during cloud cover, and the minimum temperature is increased due to increased downward emission of long wave radiation by clouds at night. Estimates of daily dewpoint temperature representative of agricultural areas were based on measured mean monthly differences between the daily minimum air temperature and the dewpoint temperature, otherwise known as the dewpoint depression, which was calculated at 17 weather stations located in agricultural areas in Nevada and neighboring states. Similarly, estimates of wind speed were based on measured mean monthly wind speed from 58 weather stations located in valley floor areas representative of where agriculture potentially occurs.

Greenup and planting dates and growing season lengths for most crops were determined year by year according to cumulative growing degree days following January 1, or according to mean air temperature over 30-day periods prior to the start date. Growing seasons were terminated by predicted maturation of the crop or by a killing frost. Basal crop coefficient curves (K_{cb}) used to scale the reference ET and to calculate the ET_{act} were expressed on relative time scales or relative thermal unit scales to allow K_{cb} curves to be scaled differently each year, according to weather conditions. Three different methods were used to express the base K_{cb} curves depending on the crop: 1) percent time from planting or greenup to harvest; 2) percent time from planting to effective full cover, with this ratio extended until termination; and 3) percent time from planting to effective full cover and then days after full cover. Basal crop coefficient curves were developed and organized for 34 crop and land cover types.

A modified FAO-56 dual crop coefficient method for estimating evaporation from bare soil was utilized, where a daily soil water balance was computed from the top 10 cm of soil to account for the reduction of evaporation as the soil surface dries. Irrigations were simulated to account for evaporation from wet soil surfaces. Scheduling of irrigations were made using a root zone water balance, where the root zone was estimated from a simple root growth model limited to specified maximum root depths, and the irrigation event was specified when the depletion of soil water exceeds the maximum allowable depletion level before plant stress occurred. Simulated irrigations are typically like those practiced with ‘low frequency’ surface irrigation such as hand line or wheel line sprinkler systems. Available water holding capacity and texture properties of soils for each station needed for parameterizing the soil and root zone water balance model were estimated from the USDA national STATSGO soils database using GIS. Runoff from precipitation was estimated using the USDA NRCS Curve Number method, where antecedent moisture was computed from the daily surface soil water balance. The curve number was estimated from soil texture based on the STATSGO soils GIS information at each station. Snow cover information was used to modify wintertime estimates of evaporation caused by high albedo of snow and energy required for heat of fusion and was also used during adjustment of cumulative growing degree days for winter wheat during winter.

Results of daily, monthly, and annual time series of the ET_{act} and NIWR were compiled into output files for each station, in addition to files containing tables of statistics describing the

ET_{act} and NIWR over the latest 30 years, or period of record available. These tables include means, standard deviations and 20 and 80% exceedence values that describe the expected variation within populations of the ET_{act} and NIWR. Statistics were computed for time period lengths of 3, 7, 15, and 30 days within each month. These period lengths were selected to encapsulate expected lengths of irrigation intervals or drying periods that are of interest in irrigation system design and operation. The statistics were computed over the most recent 30 years for stations having extensive periods of record rather than the entire period of record due to the fact that the periods of record vary widely from station to station and trends in air temperature and growing season length were evident. Some of these trends are caused by changes in relative dryness of the local or regional environment due to irrigation development or land-use change, by station location or relocation, or perhaps by change in overall climate. The last 30 years of usable record were considered to be more representative of expected future conditions than prior periods. The full records for each station were preserved in the daily, monthly, and annual time series files. Therefore, statistics for the full periods of record can be computed as needed from these data sets.

Assessment of error in estimated ASCE-PM reference ET using estimates of solar radiation, dewpoint, and wind speed, versus using measured data was done to determine whether estimation of these weather variables supports the use of NWS stations to provide sufficient spatial coverage and statewide application. To address this issue, a comparison was made between estimated reference ET at NWS stations and calculated reference ET at nearby stations located in irrigated areas that measure the full suite of weather variables. Results of the comparison indicate that the ratios of annual estimated reference ET to calculated reference ET range from 1.01 to 1.06, with an average of 1.03. These results are acceptable considering the overall error, and that estimated reference ET is entirely dependent on estimated dewpoint depression, wind speed, and solar radiation.

To explore the representativeness of estimated ET_{act} of alfalfa, a comparison was made to measured ET_{act} of alfalfa using results from previous studies for respective HAs and time periods. The average ratio of estimated ET_{act} to the average of the reported ET_{act} is 1.04, and the standard deviation of the ratios is 0.12 inches. Results generally agree well, however there are significant differences in some instances where published estimates of ET_{act} may have been impacted by water limiting conditions.

For purposes of estimating the mean annual ET_{act} and NIWR for each HA, the analysis was limited to weather stations on valley floor areas representative of potential agricultural areas. Mean annual values of the ET_{act} and NIWR were assigned to HAs if a single station was available, or if multiple stations were available, a period of record weighted average of the ET_{act} and NIWR was assigned to HAs. Of the 259 HAs in the state, 160 are absent of weather stations to estimate the ET_{act} and NIWR from, therefore spatial interpolation of valley floor weather station estimates of the mean annual ET_{act} and NIWR was performed for alfalfa, grass hay, pasture grass, turf grass, and small shallow open water bodies. Results of the NIWR per HA (Appendix 15 and Plate 1) indicate that in central and northern parts of Nevada, the NIWR for alfalfa is less than the typical permitted irrigation water right of 4 ac-ft/ac. However, in southern NV the NIWR may exceed the typical irrigation water right of 5 ac-ft/ac. These results represent the NIWR for pristine crop conditions under full water supply and should be considered the maximum.

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Appendix 1a. Weather stations used for estimating ET and net irrigation water requirements (sorted by station name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
ADAVEN	260046	38.12	-115.58	6250	1914	1981	53	Garden Valley	172
ALAMO*	260099	37.37	-115.17	3517	1921	1962	29	Pahranagat Valley	209
AMARGOSA FARMS-GAREY*	260150	36.57	-116.47	2450	1965	2006	28	Amargosa Desert	230
ANTELOPE VALLEY FARR*	260282	39.97	-117.43	4900	1984	1998	8	Antelope Valley	57
ARTHUR 4 NW*	260438	40.78	-115.18	6300	1963	2007	34	Ruby Valley	176
AUSTIN #2*	260507	39.50	-117.07	6780	1887	2007	82	Upper Reese River Valley	56
BASALT	260668	38.00	-118.27	6355	1941	1957	10	Teels Marsh Valley	114
BATTLE MTN*	260688	40.65	-116.93	4514	1898	1945	25	Clovers Area	64
BATTLE MTN AP*	260691	40.62	-116.90	4540	1944	2007	55	Lower Reese River Valley	59
BEATTY*	260715	36.92	-116.75	3304	1917	1972	32	Oasis Valley	228
BEATTY 8 N*	260718	37.00	-116.72	3550	1972	2007	28	Oasis Valley	228
BEOWAWE*	260795	40.58	-116.47	4700	1908	2007	60	Crescent Valley	54
BEOWAWE U OF N RCH*	260800	39.90	-116.58	5740	1972	2007	28	Grass Valley	138
BLUE EAGLE RCH HANKS*	260955	38.52	-115.55	4780	1978	2007	23	Railroad Valley	173B
BLUE JAY HWY STN*	260961	38.38	-116.22	5322	1963	1984	7	Hot Creek	156
BOULDER CITY*	261071	35.98	-114.85	2500	1931	2004	64	Eldorado Valley	167
BRINKERHOFF RCH*	261160	40.08	-117.67	3661	1966	1981	7	Dixie Valley	128
BUFFALO RCH*	261311	40.38	-117.47	5430	1966	1981	7	Buffalo Valley	131
BUNKERVILLE*	261327	36.77	-114.12	1550	1979	2007	6	Virgin River Valley	222
CALIENTE*	261358	37.62	-114.52	4400	1903	2007	22	Clover Valley	204
CALLVILLE BAY*	261371	36.13	-114.73	1270	1989	2007	8	Black Moutains Area	215
CARLIN NEWMONT MINE	261415	40.92	-116.32	6520	1966	2002	24	Boulder Flat	61
CARSON CITY*	261485	39.15	-119.77	4651	1893	2007	90	Eagle Valley	104
CATHEDRAL GORGE SP*	261590	37.80	-114.40	4830	2003	2007	4	Panaca Valley	203
CENTRAL NEVADA FLD LAB*	261630	39.38	-117.32	5950	1965	1986	13	Upper Reese River Valley	56
CHARLESTON*	261660	41.68	-115.53	5947	1961	2007	4	Bruneau River Area	38
CLOVER VALLEY*	261740	40.85	-115.03	5750	1900	2007	39	Clover Valley	177
COALDALE JUNCTION*	261755	38.05	-117.90	4603	1941	1965	6	Columbus Salt Marsh Valley	118
CONTACT*	261905	41.77	-114.75	5350	1949	1999	33	Salmon Falls Creek Area	40

Appendix 1a cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by station name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
CORTEZ GOLD MINE*	261975	40.18	-116.63	4905	1968	1979	10	Crescent Valley	54
CURRANT*	262078	38.75	-115.47	5184	1941	1949	4	Railroad Valley	173B
CURRANT HWY STN	262091	38.80	-115.35	6243	1963	1977	7	Railroad Valley	173B
CURRIE HWY STN*	262096	40.27	-114.75	5820	1961	1991	10	Steptoe Valley	179
DAGGET PASS	262119	38.98	-119.88	7334	1988	2007	5	Lake Tahoe Basin	90
DENIO*	262229	41.98	-118.63	4190	1951	2006	39	Pueblo Valley	1
DESERT NWR*	262243	36.43	-115.37	2920	1940	2007	60	Las Vegas Valley	212
DIABLO*	262276	37.92	-116.05	5105	1959	1978	10	Railroad Valley	173A
DIAMOND VALLEY USDA*	262296	39.68333	-116.0333	5970	1979	2007	19	Diamond Valley	153
DUCKWATER*	262390	38.85	-115.63	5550	1966	2003	19	Railroad Valley	173B
DUFURRENA*	262394	41.87	-119.02	4800	1959	2005	30	Virgin Valley	4
DYER*	262431	37.62	-118.02	4900	1903	2007	55	Fish Lake Valley	117
EASTGATE*	262477	39.30	-117.88	5023	1956	1964	4	Eastgate Valley Area	127
ECHO BAY*	262497	36.32	-114.43	1250	1989	2007	10	Black Moutains Area	215
ELGIN*	262557	37.35	-114.55	3420	1985	2007	20	Lower Meadow Valley Wash	205
ELGIN 3 SE*	262562	37.32	-114.50	3301	1965	1985	15	Lower Meadow Valley Wash	205
ELKO*	262570	40.87	-115.75	5235	1999	2007	6	Elko Segment	49
ELKO RGNL AP*	262573	40.83	-115.78	5050	1888	2007	94	Elko Segment	49
ELY 6 NE	262626	39.30	-114.83	6263	1999	2005	5	Steptoe Valley	179
ELY YELLAND FLD AP*	262631	39.30	-114.85	6262	1893	2005	68	Steptoe Valley	179
EMIGRANT PASS HWY STN	262656	40.65	-116.30	5760	1963	2001	27	Boulder Flat	61
EMPIRE*	262662	40.58	-119.35	3953	1951	1976	6	San Emidio Desert	22
EUREKA	262708	39.52	-115.97	6540	1888	2007	67	Diamond Valley	153
FALLON EXP STN*	262780	39.45	-118.78	3965	1903	2007	96	Carson Desert	101
FERGUSON SPRINGS HMS*	262820	40.42	-114.18	5840	1972	1982	7	Great Salt Lake Desert	192
FERNLEY*	262840	39.62	-119.25	4163	1907	1974	21	Fernley Area	76
FISH CREEK RCH*	262860	39.27	-116.00	6053	1943	1964	14	Little Smoky Valley	155A
GERLACH*	263090	40.65	-119.37	3950	1948	2007	27	San Emidio Desert	22
GEYSER RCH*	263101	38.67	-114.63	6020	1904	2002	19	Lake Valley	183

Appendix 1a cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by station name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
GIBBS RCH*	263114	41.57	-115.22	6000	1953	2007	43	Marys River Area	42
GLENBROOK*	263205	39.08	-119.93	6350	1909	2007	50	Lake Tahoe Basin	90
GOLCONDA*	263245	40.95	-117.50	4415	1906	2007	71	Winnemucca Segment	70
GOLDFIELD	263285	37.70	-117.23	5690	1906	2007	66	Alkali Spring Valley	142
GOODSPRINGS*	263316	35.83	-115.43	4000	1999	2007	6	Ivanpah Valley	164A
GREAT BASIN NP	263340	39.02	-114.23	6830	1987	2007	16	Snake Valley	195
HAWTHORNE*	263512	38.52	-118.63	4330	1954	2007	13	Walker Lake Valley	110C
HAWTHORNE AP*	263515	38.55	-118.67	4220	1888	1991	39	Walker Lake Valley	110C
HIKO*	263671	37.55	-115.22	3900	1989	2007	15	Pahranagat Valley	209
HUMBOLDT FLD	263853	40.08	-118.15	4160	1940	1947	7	Buena Vista Valley	129
I-L RCH*	263940	41.57	-116.40	5203	1962	1969	3	South Fork Owyhee River Area	35
IMLAY*	263957	40.65	-118.17	4260	1914	2007	56	Imlay Area	72
INDIAN SPRINGS*	263980	36.58	-115.68	3123	1913	1964	23	Indian Springs Valley	161
JACKPOT*	264016	41.98	-114.67	5290	1986	2007	15	Salmon Falls Creek Area	40
JARBRIDGE 4 N	264038	41.93	-115.43	6168	1916	1995	22	Jarbidge River Area	39
JARBIDGE 7 N*	264039	41.98	-115.43	6050	1995	2007	11	Jarbidge River Area	39
JIGGS 8 SSE ZAGA*	264095	40.35	-115.62	5800	1978	2007	19	Huntington Valley	47
JUNGO MEYER RCH*	264108	40.88	-118.43	4200	1968	1986	7	Desert Valley	31
KIMBERLY	264199	39.27	-115.03	7234	1928	1958	28	White River Valley	207
KNOLL CREEK FLD STN	264268	41.63	-114.73	6004	1971	1979	6	Salmon Falls Creek Area	40
KYLE CANYON RS	264314	36.25	-115.60	7205	1939	1948	4	Las Vegas Valley	212
LAGES*	264341	40.07	-114.62	5960	1984	2007	21	Steptoe Valley	179
LAHONTAN DAM*	264349	39.47	-119.07	4150	1911	2007	72	Churchill Valley	102
LAKE VALLEY STEWARD	264384	38.32	-114.65	6350	1971	1998	22	Lake Valley	183
LAMOILLE YOST*	264394	40.72	-115.52	5840	1975	2004	22	Lamoille Valley	45
LAMOILLE PH	264395	40.68	-115.47	6293	1916	1972	35	Lamoille Valley	45
LAS VEGAS*	264429	36.17	-115.13	2011	1895	1956	36	Las Vegas Valley	212
LAS VEGAS*	23112	36.17	-115.15	1867	1949	1970	22	Las Vegas Valley	212
LAS VEGAS WB AP*	264436	36.08	-115.07	2160	1948	2005	57	Las Vegas Valley	212

Appendix 1a cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by station name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
LAS VEGAS NWFO*	264439	36.05	-115.18	2170	1996	2007	9	Las Vegas Valley	212
LATHROP WELLS	264457	36.65	-116.40	2671	1942	1963	8	Fortymile Canyon	227A
LAUGHLIN*	264480	35.17	-114.58	605	1988	2007	10	Colorado Valley	213
LEHMAN CAVES NM	264514	39.00	-114.22	6826	1937	1987	44	Snake Valley	195
LEONARD CREEK RCH*	264527	41.52	-118.72	4224	1954	2007	44	Black Rock Desert	28
LEWERS RCH	264542	39.23	-119.85	5203	1893	1938	15	Washoe Valley	89
LITTLE RED ROCK	264600	36.15	-115.42	3802	1965	1970	4	Las Vegas Valley	212
LOGANDALE*	264651	36.62	-114.48	1410	1968	1992	20	Lower Moapa Valley	220
LOVELOCK DERBY FLD*	264700	40.07	-118.57	3902	1948	2005	49	Lovelock Valley	73
LUND*	264745	38.87	-115.02	5560	1957	2007	47	White River Valley	207
MALA VISTA RCH*	264824	41.32	-115.25	5594	1939	1965	16	Marys River Area	42
MARLETTE LAKE	264858	39.17	-119.92	8005	1916	1952	19	Lake Tahoe Basin	90
MCDERMITT*	264935	42.00	-117.72	4527	1892	2007	29	Quinn River Valley	33B
MCGILL*	264950	39.40	-114.78	6270	1892	2007	90	Steptoe Valley	179
MESQUITE*	265085	36.80	-114.07	1570	1942	2006	13	Virgin River Valley	222
METROPOLIS*	265092	41.28	-115.02	5800	1965	1995	18	Marys River Area	42
MIDAS 4 SE*	265105	41.20	-116.73	5203	1961	1969	4	Willow Creek Valley	63
MIDDLEGATE-LOWERY*	265132	39.30	-118.02	4600	1988	2007	15	Cowkick Valley	126
MINA*	265168	38.38	-118.10	4550	1896	2007	79	Soda Spring Valley	121A
MINDEN*	265191	38.95	-119.77	4720	1906	2007	86	Carson Valley	105
MONTELLO 2 SE*	265352	41.25	-114.17	4890	1902	2007	67	Thousand Springs Valley	189D
MONTGOMERY MNTC STN	265362	37.97	-118.32	7100	1960	1980	10	Queen Valley	116
MOORMAN RCH*	265371	39.33	-115.32	6539	2002	2007	4	Jakes Valley	174
MTN CITY RS*	265392	41.83	-115.97	5650	1955	1999	35	Owyhee River Area	37
MT CHARLESTON FS	265400	36.27	-115.65	7600	1949	2007	6	Las Vegas Valley	212
MT ROSE BOWL	265440	39.35	-119.87	7500	1973	1987	8	Pleasant Valley	88
NIXON*	265605	39.83	-119.35	3904	1928	1974	30	Pyramid Lake Valley	81
NORTH LAS VEGAS*	265705	36.22	-115.13	1888	1951	2007	20	Las Vegas Valley	212
OASIS*	265722	41.03	-114.47	5830	1987	2007	17	Goshute Valley	187
OLD RUTH	265760	39.27	-114.98	7034	1978	1985	5	Steptoe Valley	179

Appendix 1a cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by station name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
OROVADA 3 W*	265818	41.57	-117.83	4200	1911	2007	74	Quinn River Valley	33A
OVERTON*	265846	36.55	-114.45	1250	1939	2007	35	Lower Moapa Valley	220
OWYHEE*	265869	41.95	-116.10	5397	1948	1984	30	Owyhee River Area	37
PAHRANAGAT WR*	265880	37.27	-115.12	3400	1964	2007	33	Pahranagat Valley	209
PAHRUMP*	265890	36.22	-116.02	2700	1914	2007	42	Pahrump Valley	162
PAHUTE MEADOWS RCH*	265907	41.30	-118.93	4383	1963	1976	4	Black Rock Desert	28
PALMETTO	265931	37.47	-117.77	5906	1890	1911	14	Fish Lake Valley	117
PARADISE VALLEY 1 NW*	266005	41.50	-117.55	4675	1894	2007	47	Paradise Valley	69
PARIS RCH*	266055	40.22	-117.68	4140	1966	1991	22	Pleasant Valley	130
PENOYER VALLEY*	266130	37.65	-115.80	4800	1967	2006	5	Penoyer Valley	170
PEQUOP	266148	41.07	-114.53	6033	1959	1985	23	Goshute Valley	187
PILOT VALLEY-LEE*	266228	41.12	-114.12	4905	2000	2007	6	Pilot Creek Valley	191
PINE VALLEY BAILEY RCH*	266242	40.43	-116.12	5047	1982	2006	11	Pine Valley	53
PIOCHE	266252	37.95	-114.47	6180	1888	2006	61	Patterson Valley	202
QUINN RVR CROSSING	266504	41.57	-118.43	4091	1901	1951	10	Pine Forest Valley	29
RAND RCH PALISADE*	266574	40.43	-116.12	5046	1957	1982	19	Pine Valley	53
RATTLESNAKE	266630	38.45	-116.17	5915	1948	1966	13	Hot Creek	156
RED ROCK WC*	29999	39.892	-119.9345	4708	2004	2008	4	Red Rock Valley	99
RED ROCK CANYON SP	266691	36.08	-115.45	3780	1977	2007	20	Las Vegas Valley	212
REESE RIVER*	266746	39.07	-117.42	6550	1972	2007	26	Upper Reese River Valley	56
REESE VALLEY CARPER	266748	40.05	-117.23	4898	1976	1983	6	Middle Reese River Valley	58
RENO TAHOE INTL AP*	266779	39.48	-119.77	4410	1937	2007	69	Truckee Meadows	87
RENO WFO*	266791	39.57	-119.80	4974	1996	2007	10	Truckee Meadows	87
RUBY LAKE*	267123	40.20	-115.50	6010	1940	2007	61	Ruby Valley	176
RUTH	267175	39.28	-114.98	6850	1958	2007	30	Steptoe Valley	179
RYNDON*	267188	40.95	-115.60	5150	1999	2007	6	North Fork Area	44
RYE PATCH DAM*	267192	40.47	-118.30	4135	1935	2007	63	Imlay Area	72
SAND PASS*	267261	40.32	-119.80	3904	1913	1971	41	Smoke Creek Desert	21
SAN JACINTO*	267284	41.88	-114.68	5203	1904	1948	21	Salmon Falls Creek Area	40
SARCOBATUS*	267319	37.27	-117.02	4022	1941	1961	14	Sarcobatus Flat	146

Appendix 1a cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by station name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
SAVAL RCH*	267324	41.28	-115.92	6365	1960	1967	5	North Fork Area	44
SCHURZ*	267358	38.95	-118.82	4124	1920	1957	30	Walker Lake Valley	110A
SEARCHLIGHT	267369	35.47	-114.92	3540	1913	2007	73	Piute Valley	214
SEVENTY ONE RCH*	267397	40.90	-115.32	5453	1939	1952	4	Starr Valley Area	43
SHELDON	267443	41.85	-119.63	6506	1933	1972	35	Guano Valley	6
SHOSHONE 5 N*	267450	38.92	-114.40	5930	1988	2007	17	Spring Valley	184
SILVERPEAK*	267463	37.77	-117.57	4260	1967	2007	31	Clayton Valley	143
SMITH 1 N*	267609	38.82	-119.33	4754	1937	1966	23	Smith Valley	107
SMITH 6 N*	267612	38.95	-119.33	5000	1973	2007	23	Smith Valley	107
SMOKE CREEK ESPIL*	267618	40.60	-119.75	3850	1987	2006	14	Smoke Creek Desert	21
SMOKEY VALLEY*	267620	38.78	-117.17	5625	1949	2007	46	Big Smoky Valley	137B
SNOWBALL RCH	267640	39.03	-116.20	7160	1966	2002	33	Little Smoky Valley	155A
SOUTH FORK SP*	267690	40.68	-115.75	5270	1993	2007	8	Dixie Creek Tenmile	48
SPRING VALLEY SP*	267750	38.03	-114.18	5950	1974	2007	24	Spring Valley	201
STATELINE-HARRAH'S*	267806	38.97	-119.95	6248	1984	1998	13	Lake Tahoe Basin	90
STEAD*	267820	39.62	-119.88	5120	1985	2007	14	Lemmon Valley	92B
SULPHUR*	267873	40.90	-118.67	4042	1914	1953	21	Black Rock Desert	28
SUNNYSIDE*	267908	38.42	-115.02	5300	1891	2007	35	White River Valley	207
SUTCLIFFE	267953	39.95	-119.60	3900	1967	2007	27	Pyramid Lake Valley	81
TEMPIUTE 4 NW*	267983	37.68	-115.72	4889	1972	1985	12	Penoyer Valley	170
THORNE*	268034	38.60	-118.60	4203	1914	1950	24	Walker Lake Valley	110C
TONOPAH*	268170	38.05	-117.08	5395	1954	2005	49	Ralston Valley	141
TOPAZ LAKE 3N*	268186	38.73	-119.52	5105	1957	2007	19	Antelope Valley	106
TOPAZ LAKE 4 N*	268202	38.75	-119.52	5577	1986	2000	11	Antelope Valley	106
TUSCARORA*	268346	41.32	-116.22	6170	1958	2007	40	Independence Valley	36
TWIN SPRING FALLINI*	268443	38.20	-116.18	5300	1985	2005	10	Hot Creek	156
UNIV OF NEVADA EXP FM*	268500	39.52	-119.78	4514	1949	1954	4	Truckee Meadows	87
URSINE	268538	37.98	-114.22	5833	1964	1972	4	Eagle Valley	200
VALLEY OF FIRE SP	268588	36.43	-114.52	2000	1972	2007	33	Black Moutains Area	215
VIRGINIA CITY	268761	39.32	-119.65	6340	1887	2007	41	Dayton Valley	103
VYA	268810	41.58	-119.92	5663	1959	1980	14	Surprise Valley	14
WABUSKA 6 SE*	268822	39.07	-119.12	4300	1972	2007	27	Mason Valley	108

Appendix 1a cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by station name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
WADSWORTH*	268834	39.63	-119.28	4081	1902	1948	6	Tracy Segment	83
WADSWORTH 4 N*	268838	39.68	-119.28	4200	1974	2007	21	Dodge Flat	82
WASHOE VALLEY WC*	39999	39.285	-119.789	5050	2004	2008	4	Washoe valley	89
WELLINGTON RS*	268977	38.75	-119.37	4843	1942	1973	27	Smith Valley	107
WELLS*	268988	41.10	-114.97	5700	1895	2004	66	Marys River Area	42
WILDHORSE RSVR*	269072	41.63	-115.80	6226	1982	2007	18	Owyhee River Area	37
WILKINS*	269122	41.43	-114.75	5643	1948	1980	16	Thousand Springs Valley	189A
WILLOW SPRINGS*	269137	38.43	-117.20	6125	1941	1948	4	Big Smoky Valley	137A
WINNEMUCCA #2*	269168	40.93	-117.75	4300	1999	2007	6	Grass Valley	71
WINNEMUCCA MUNI AP*	269171	40.90	-117.80	4296	1949	2007	57	Winnemucca Segment	70
YERINGTON*	269229	39.00	-119.17	4380	1894	2007	66	Mason Valley	108

Appendix 1b. Weather stations used for estimating ET and net irrigation water requirements (sorted by basin name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
GOLDFIELD	263285	37.70	-117.23	5690	1906	2007	66	Alkali Spring Valley	142
AMARGOSA FARMS-GAREY*	260150	36.57	-116.47	2450	1965	2006	28	Amargosa Desert	230
ANTELOPE VALLEY FARR*	260282	39.97	-117.43	4900	1984	1998	8	Antelope Valley	57
TOPAZ LAKE 3N*	268186	38.73	-119.52	5105	1957	2007	19	Antelope Valley	106
TOPAZ LAKE 4 N*	268202	38.75	-119.52	5577	1986	2000	11	Antelope Valley	106
SMOKEY VALLEY*	267620	38.78	-117.17	5625	1949	2007	46	Big Smoky Valley	137B
WILLOW SPRINGS*	269137	38.43	-117.20	6125	1941	1948	4	Big Smoky Valley	137A
CALLVILLE BAY*	261371	36.13	-114.73	1270	1989	2007	8	Black Moutains Area	215
ECHO BAY*	262497	36.32	-114.43	1250	1989	2007	10	Black Moutains Area	215
VALLEY OF FIRE SP	268588	36.43	-114.52	2000	1972	2007	33	Black Moutains Area	215
LEONARD CREEK RCH*	264527	41.52	-118.72	4224	1954	2007	44	Black Rock Desert	28
PAHUTE MEADOWS RCH*	265907	41.30	-118.93	4383	1963	1976	4	Black Rock Desert	28
SULPHUR*	267873	40.90	-118.67	4042	1914	1953	21	Black Rock Desert	28
CARLIN NEWMONT MINE	261415	40.92	-116.32	6520	1966	2002	24	Boulder Flat	61
EMIGRANT PASS HWY STN	262656	40.65	-116.30	5760	1963	2001	27	Boulder Flat	61
CHARLESTON*	261660	41.68	-115.53	5947	1961	2007	4	Bruneau River Area	38
HUMBOLDT FLD	263853	40.08	-118.15	4160	1940	1947	7	Buena Vista Valley	129
BUFFALO RCH*	261311	40.38	-117.47	5430	1966	1981	7	Buffalo Valley	131
FALLON EXP STN*	262780	39.45	-118.78	3965	1903	2007	96	Carson Desert	101
MINDEN*	265191	38.95	-119.77	4720	1906	2007	86	Carson Valley	105
LAHONTAN DAM*	264349	39.47	-119.07	4150	1911	2007	72	Churchill Valley	102
SILVERPEAK*	267463	37.77	-117.57	4260	1967	2007	31	Clayton Valley	143
CALIENTE*	261358	37.62	-114.52	4400	1903	2007	22	Clover Valley	204
CLOVER VALLEY*	261740	40.85	-115.03	5750	1900	2007	39	Clover Valley	177
BATTLE MTN*	260688	40.65	-116.93	4514	1898	1945	25	Clovers Area	64
LAUGHLIN*	264480	35.17	-114.58	605	1988	2007	10	Colorado Valley	213
COALDALE JUNCTION*	261755	38.05	-117.90	4603	1941	1965	6	Columbus Salt Marsh Valley	118

Appendix 1b cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by basin name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
MIDDLEGATE-LOWERY*	265132	39.30	-118.02	4600	1988	2007	15	Cowkick Valley	126
BEOWAWE*	260795	40.58	-116.47	4700	1908	2007	60	Crescent Valley	54
CORTEZ GOLD MINE*	261975	40.18	-116.63	4905	1968	1979	10	Crescent Valley	54
VIRGINIA CITY	268761	39.32	-119.65	6340	1887	2007	41	Dayton Valley	103
JUNGO MEYER RCH*	264108	40.88	-118.43	4200	1968	1986	7	Desert Valley	31
DIAMOND VALLEY USDA*	262296	39.683	-116.03	5970	1979	2007	19	Diamond Valley	153
EUREKA	262708	39.52	-115.97	6540	1888	2007	67	Diamond Valley	153
SOUTH FORK SP*	267690	40.68	-115.75	5270	1993	2007	8	Dixie Creek Tenmile	48
BRINKERHOFF RCH*	261160	40.08	-117.67	3661	1966	1981	7	Dixie Valley	128
WADSWORTH 4 N*	268838	39.68	-119.28	4200	1974	2007	21	Dodge Flat	82
CARSON CITY*	261485	39.15	-119.77	4651	1893	2007	90	Eagle Valley	104
URSINE	268538	37.98	-114.22	5833	1964	1972	4	Eagle Valley	200
EASTGATE*	262477	39.30	-117.88	5023	1956	1964	4	Eastgate Valley Area	127
BOULDER CITY*	261071	35.98	-114.85	2500	1931	2004	64	Eldorado Valley	167
ELKO*	262570	40.87	-115.75	5235	1999	2007	6	Elko Segment	49
ELKO RGNL AP*	262573	40.83	-115.78	5050	1888	2007	94	Elko Segment	49
FERNLEY*	262840	39.62	-119.25	4163	1907	1974	21	Fernley Area	76
DYER*	262431	37.62	-118.02	4900	1903	2007	55	Fish Lake Valley	117
PALMETTO	265931	37.47	-117.77	5906	1890	1911	14	Fish Lake Valley	117
LATHROP WELLS	264457	36.65	-116.40	2671	1942	1963	8	Fortymile Canyon	227A
ADAVEN	260046	38.12	-115.58	6250	1914	1981	53	Garden Valley	172
OASIS*	265722	41.03	-114.47	5830	1987	2007	17	Goshute Valley	187
PEQUOP	266148	41.07	-114.53	6033	1959	1985	23	Goshute Valley	187
BEOWAWE U OF N RCH*	260800	39.90	-116.58	5740	1972	2007	28	Grass Valley	138
WINNEMUCCA #2*	269168	40.93	-117.75	4300	1999	2007	6	Grass Valley	71
FERGUSON SPRINGS HMS*	262820	40.42	-114.18	5840	1972	1982	7	Great Salt Lake Desert	192
SHELDON	267443	41.85	-119.63	6506	1933	1972	35	Guano Valley	6
BLUE JAY HWY STN*	260961	38.38	-116.22	5322	1963	1984	7	Hot Creek	156
RATTLESNAKE	266630	38.45	-116.17	5915	1948	1966	13	Hot Creek	156
TWIN SPRING FALLINI*	268443	38.20	-116.18	5300	1985	2005	10	Hot Creek	156
JIGGS 8 SSE ZAGA*	264095	40.35	-115.62	5800	1978	2007	19	Huntington Valley	47
IMLAY*	263957	40.65	-118.17	4260	1914	2007	56	Imlay Area	72

Appendix 1b cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by basin name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
RYE PATCH DAM*	267192	40.47	-118.30	4135	1935	2007	63	Imlay Area	72
TUSCARORA*	268346	41.32	-116.22	6170	1958	2007	40	Independence Valley	36
INDIAN SPRINGS*	263980	36.58	-115.68	3123	1913	1964	23	Indian Springs Valley	161
GOODSPRINGS*	263316	35.83	-115.43	4000	1999	2007	6	Ivanpah Valley	164A
MOORMAN RCH*	265371	39.33	-115.32	6539	2002	2007	4	Jakes Valley	174
JARBRIDGE 4 N	264038	41.93	-115.43	6168	1916	1995	22	Jarbidge River Area	39
JARBIDGE 7 N*	264039	41.98	-115.43	6050	1995	2007	11	Jarbidge River Area	39
DAGGET PASS	262119	38.98	-119.88	7334	1988	2007	5	Lake Tahoe Basin	90
GLENBROOK*	263205	39.08	-119.93	6350	1909	2007	50	Lake Tahoe Basin	90
MARLETTE LAKE	264858	39.17	-119.92	8005	1916	1952	19	Lake Tahoe Basin	90
STATELINE-HARRAH'S*	267806	38.97	-119.95	6248	1984	1998	13	Lake Tahoe Basin	90
GEYSER RCH*	263101	38.67	-114.63	6020	1904	2002	19	Lake Valley	183
LAKE VALLEY STEWARD	264384	38.32	-114.65	6350	1971	1998	22	Lake Valley	183
LAMOILLE YOST*	264394	40.72	-115.52	5840	1975	2004	22	Lamoille Valley	45
LAMOILLE PH	264395	40.68	-115.47	6293	1916	1972	35	Lamoille Valley	45
DESERT NWR*	262243	36.43	-115.37	2920	1940	2007	60	Las Vegas Valley	212
KYLE CANYON RS	264314	36.25	-115.60	7205	1939	1948	4	Las Vegas Valley	212
LAS VEGAS*	264429	36.17	-115.13	2011	1895	1956	36	Las Vegas Valley	212
LAS VEGAS*	23112	36.17	-115.15	1867	1949	1970	22	Las Vegas Valley	212
LAS VEGAS WB AP*	264436	36.08	-115.07	2160	1948	2005	57	Las Vegas Valley	212
LAS VEGAS NWFO*	264439	36.05	-115.18	2170	1996	2007	9	Las Vegas Valley	212
LITTLE RED ROCK	264600	36.15	-115.42	3802	1965	1970	4	Las Vegas Valley	212
MT CHARLESTON FS	265400	36.27	-115.65	7600	1949	2007	6	Las Vegas Valley	212
NORTH LAS VEGAS*	265705	36.22	-115.13	1888	1951	2007	20	Las Vegas Valley	212
RED ROCK CANYON SP	266691	36.08	-115.45	3780	1977	2007	20	Las Vegas Valley	212
STEAD*	267820	39.62	-119.88	5120	1985	2007	14	Lemmon Valley	92B
FISH CREEK RCH*	262860	39.27	-116.00	6053	1943	1964	14	Little Smoky Valley	155A
SNOWBALL RCH	267640	39.03	-116.20	7160	1966	2002	33	Little Smoky Valley	155A
LOVELOCK DERBY FLD*	264700	40.07	-118.57	3902	1948	2005	49	Lovelock Valley	73

Appendix 1b cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by basin name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
ELGIN*	262557	37.35	-114.55	3420	1985	2007	20	Lower Meadow Valley Wash	205
ELGIN 3 SE*	262562	37.32	-114.50	3301	1965	1985	15	Lower Meadow Valley Wash	205
LOGANDALE*	264651	36.62	-114.48	1410	1968	1992	20	Lower Moapa Valley	220
OVERTON*	265846	36.55	-114.45	1250	1939	2007	35	Lower Moapa Valley	220
BATTLE MTN AP*	260691	40.62	-116.90	4540	1944	2007	55	Lower Reese River Valley	59
GIBBS RCH*	263114	41.57	-115.22	6000	1953	2007	43	Marys River Area	42
MALA VISTA RCH*	264824	41.32	-115.25	5594	1939	1965	16	Marys River Area	42
METROPOLIS*	265092	41.28	-115.02	5800	1965	1995	18	Marys River Area	42
WELLS*	268988	41.10	-114.97	5700	1895	2004	66	Marys River Area	42
WABUSKA 6 SE*	268822	39.07	-119.12	4300	1972	2007	27	Mason Valley	108
YERINGTON*	269229	39.00	-119.17	4380	1894	2007	66	Mason Valley	108
REESE VALLEY CARPER	266748	40.05	-117.23	4898	1976	1983	6	Middle Reese River Valley	58
SOLDIERS MEADOW*	267682	41.35	-119.17	4554	1962	1966	8	Mud Meadow	26
RYNDON*	267188	40.95	-115.60	5150	1999	2007	6	North Fork Area	44
SAVAL RCH*	267324	41.28	-115.92	6365	1960	1967	5	North Fork Area	44
BEATTY*	260715	36.92	-116.75	3304	1917	1972	32	Oasis Valley	228
BEATTY 8 N*	260718	37.00	-116.72	3550	1972	2007	28	Oasis Valley	228
MTN CITY RS*	265392	41.83	-115.97	5650	1955	1999	35	Owyhee River Area	37
OWYHEE*	265869	41.95	-116.10	5397	1948	1984	30	Owyhee River Area	37
WILDHORSE RSVR*	269072	41.63	-115.80	6226	1982	2007	18	Owyhee River Area	37
ALAMO*	260099	37.37	-115.17	3517	1921	1962	29	Pahranagat Valley	209
HIKO*	263671	37.55	-115.22	3900	1989	2007	15	Pahranagat Valley	209
PAHRANAGAT WR*	265880	37.27	-115.12	3400	1964	2007	33	Pahranagat Valley	209
PAHRUMP*	265890	36.22	-116.02	2700	1914	2007	42	Pahrump Valley	162
CATHEDRAL GORGE SP*	261590	37.80	-114.40	4830	2003	2007	4	Panaca Valley	203
PARADISE VALLEY 1 NW*	266005	41.50	-117.55	4675	1894	2007	47	Paradise Valley	69
PIOCHE	266252	37.95	-114.47	6180	1888	2006	61	Patterson Valley	202

Appendix 1b cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by basin name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
PENOYER VALLEY*	266130	37.65	-115.80	4800	1967	2006	5	Penoyer Valley	170
TEMPIUTE 4 NW*	267983	37.68	-115.72	4889	1972	1985	12	Penoyer Valley	170
PILOT VALLEY-LEE*	266228	41.12	-114.12	4905	2000	2007	6	Pilot Creek Valley	191
QUINN RVR CROSSING	266504	41.57	-118.43	4091	1901	1951	10	Pine Forest Valley	29
PINE VALLEY BAILEY RCH*	266242	40.43	-116.12	5047	1982	2006	11	Pine Valley	53
RAND RCH PALISADE*	266574	40.43	-116.12	5046	1957	1982	19	Pine Valley	53
SEARCHLIGHT	267369	35.47	-114.92	3540	1913	2007	73	Piute Valley	214
MT ROSE BOWL	265440	39.35	-119.87	7500	1973	1987	8	Pleasant Valley	88
PARIS RCH*	266055	40.22	-117.68	4140	1966	1991	22	Pleasant Valley	130
DENIO*	262229	41.98	-118.63	4190	1951	2006	39	Pueblo Valley	1
NIXON*	265605	39.83	-119.35	3904	1928	1974	30	Pyramid Lake Valley	81
SUTCLIFFE	267953	39.95	-119.60	3900	1967	2007	27	Pyramid Lake Valley	81
MONTGOMERY MNTC STN	265362	37.97	-118.32	7100	1960	1980	10	Queen Valley	116
MCDERMITT*	264935	42.00	-117.72	4527	1892	2007	29	Quinn River Valley	33B
OROVADA 3 W*	265818	41.57	-117.83	4200	1911	2007	74	Quinn River Valley	33A
BLUE EAGLE RCH HANKS*	260955	38.52	-115.55	4780	1978	2007	23	Railroad Valley	173B
CURRANT*	262078	38.75	-115.47	5184	1941	1949	4	Railroad Valley	173B
CURRANT HWY STN	262091	38.80	-115.35	6243	1963	1977	7	Railroad Valley	173B
DIABLO*	262276	37.92	-116.05	5105	1959	1978	10	Railroad Valley	173A
DUCKWATER*	262390	38.85	-115.63	5550	1966	2003	19	Railroad Valley	173B
TONOPAH*	268170	38.05	-117.08	5395	1954	2005	49	Ralston Valley	141
RED ROCK WC*	29999	39.892	-119.9345	4708	2004	2008	4	Red Rock Valley	99
ARTHUR 4 NW*	260438	40.78	-115.18	6300	1963	2007	34	Ruby Valley	176
RUBY LAKE*	267123	40.20	-115.50	6010	1940	2007	61	Ruby Valley	176
CONTACT*	261905	41.77	-114.75	5350	1949	1999	33	Salmon Falls Creek Area	40
JACKPOT*	264016	41.98	-114.67	5290	1986	2007	15	Salmon Falls Creek Area	40
KNOLL CREEK FLD STN	264268	41.63	-114.73	6004	1971	1979	6	Salmon Falls Creek Area	40
SAN JACINTO*	267284	41.88	-114.68	5203	1904	1948	21	Salmon Falls Creek Area	40
EMPIRE*	262662	40.58	-119.35	3953	1951	1976	6	San Emidio Desert	22
GERLACH*	263090	40.65	-119.37	3950	1948	2007	27	San Emidio Desert	22

Appendix 1b cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by basin name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
SARCOBATUS*	267319	37.27	-117.02	4022	1941	1961	14	Sarcobatus Flat	146
SMITH 1 N*	267609	38.82	-119.33	4754	1937	1966	23	Smith Valley	107
SMITH 6 N*	267612	38.95	-119.33	5000	1973	2007	23	Smith Valley	107
WELLINGTON RS*	268977	38.75	-119.37	4843	1942	1973	27	Smith Valley	107
SAND PASS*	267261	40.32	-119.80	3904	1913	1971	41	Smoke Creek Desert	21
SMOKE CREEK ESPIL*	267618	40.60	-119.75	3850	1987	2006	14	Smoke Creek Desert	21
GREAT BASIN NP	263340	39.02	-114.23	6830	1987	2007	16	Snake Valley	195
LEHMAN CAVES NM	264514	39.00	-114.22	6826	1937	1987	44	Snake Valley	195
MINA*	265168	38.38	-118.10	4550	1896	2007	79	Soda Spring Valley	121A
I-L RCH*	263940	41.57	-116.40	5203	1962	1969	3	South Fork Owyhee River Area	35
SHOSHONE 5 N*	267450	38.92	-114.40	5930	1988	2007	17	Spring Valley	184
SPRING VALLEY SP*	267750	38.03	-114.18	5950	1974	2007	24	Spring Valley	201
SEVENTY ONE RCH*	267397	40.90	-115.32	5453	1939	1952	4	Starr Valley Area	43
CURRIE HWY STN*	262096	40.27	-114.75	5820	1961	1991	10	Steptoe Valley	179
ELY 6 NE	262626	39.30	-114.83	6263	1999	2005	5	Steptoe Valley	179
ELY YELLAND FLD AP*	262631	39.30	-114.85	6262	1893	2005	68	Steptoe Valley	179
LAGES*	264341	40.07	-114.62	5960	1984	2007	21	Steptoe Valley	179
MCGILL*	264950	39.40	-114.78	6270	1892	2007	90	Steptoe Valley	179
OLD RUTH	265760	39.27	-114.98	7034	1978	1985	5	Steptoe Valley	179
RUTH	267175	39.28	-114.98	6850	1958	2007	30	Steptoe Valley	179
VYA	268810	41.58	-119.92	5663	1959	1980	14	Surprise Valley	14
BASALT	260668	38.00	-118.27	6355	1941	1957	10	Teels Marsh Valley	114
MONTELLO 2 SE*	265352	41.25	-114.17	4890	1902	2007	67	Thousand Springs Valley	189D
WILKINS*	269122	41.43	-114.75	5643	1948	1980	16	Thousand Springs Valley	189A
WADSWORTH*	268834	39.63	-119.28	4081	1902	1948	6	Tracy Segment	83
RENO TAHOE INTL AP*	266779	39.48	-119.77	4410	1937	2007	69	Truckee Meadows	87
RENO WFO*	266791	39.57	-119.80	4974	1996	2007	10	Truckee Meadows	87
UNIV OF NEVADA EXP FM*	268500	39.52	-119.78	4514	1949	1954	4	Truckee Meadows	87
AUSTIN #2*	260507	39.50	-117.07	6780	1887	2007	82	Upper Reese River Valley	56

Appendix 1b cont. Weather stations used for estimating ET and net irrigation water requirements (sorted by basin name). * indicates station was used for basin average.

STATION NAME	STATION NUMBER	LAT (NAD83)	LONG (NAD83)	ELEVATION (feet)	DATA FILE START YEAR	DATA FILE END YEAR	NUMBER OF YEARS WITH INSIGNIFICANT MISSING DATA	BASIN NAME	BASIN NUMBER
CENTRAL NEVADA FLD LAB*	261630	39.38	-117.32	5950	1965	1986	13	Upper Reese River Valley	56
REESE RIVER*	266746	39.07	-117.42	6550	1972	2007	26	Upper Reese River Valley	56
BUNKERVILLE*	261327	36.77	-114.12	1550	1979	2007	6	Virgin River Valley	222
MESQUITE*	265085	36.80	-114.07	1570	1942	2006	13	Virgin River Valley	222
DUFURRENA*	262394	41.87	-119.02	4800	1959	2005	30	Virgin Valley	4
HAWTHORNE*	263512	38.52	-118.63	4330	1954	2007	13	Walker Lake Valley	110C
HAWTHORNE AP*	263515	38.55	-118.67	4220	1888	1991	39	Walker Lake Valley	110C
SCHURZ*	267358	38.95	-118.82	4124	1920	1957	30	Walker Lake Valley	110A
THORNE*	268034	38.60	-118.60	4203	1914	1950	24	Walker Lake Valley	110C
LEWERS RCH	264542	39.23	-119.85	5203	1893	1938	15	Washoe Valley	89
WASHOE VALLEY WC*	39999	39.285	-119.789	5050	2004	2008	4	Washoe valley	89
KIMBERLY	264199	39.27	-115.03	7234	1928	1958	28	White River Valley	207
LUND*	264745	38.87	-115.02	5560	1957	2007	47	White River Valley	207
SUNNYSIDE*	267908	38.42	-115.02	5300	1891	2007	35	White River Valley	207
MIDAS 4 SE*	265105	41.20	-116.73	5203	1961	1969	4	Willow Creek Valley	63
GOLCONDA*	263245	40.95	-117.50	4415	1906	2007	71	Winnemucca Segment	70
WINNEMUCCA MUNI AP*	269171	40.90	-117.80	4296	1949	2007	57	Winnemucca Segment	70

Appendix 2. Details of supplementary Washoe County weather data and modifications made to 2 NWS weather station data sets due to poor station siting.

Non NWS Weather Station Analysis

Two weather data sets from 'full sweet' weather stations not part of the NWS network were added to this analysis to provide ET and net irrigation water Requirement estimates in basins where information is needed to address current and future water rights applications. These stations are operated and maintained by Washoe County Department of Water Resources and are located in Washoe Valley and Redrock Valley. Weather data used from these stations were compiled and formatted to be used in the computer program developed to read NWS station data.

Measured daily wind speed, calculated daily dew point from measured RH, and measured precipitation for the Redrock weather station were used to calculate daily ET_{os} and the net irrigation water requirement for the period of record. After analyzing the dewpoint depression for the Redrock weather station it was determined that no adjustment was needed to reflect reference conditions due to the fact that the computed mean annual dewpoint depression was 2.5^{o}C, which generally represents near reference conditions.

Washoe Valley contains two weather stations that Washoe County maintains and operates. One of the weather stations is located near Old Franktown road on the west side of Washoe Valley, while the other is located near Washoe Lake on the east central side of Washoe Valley. The location of the weather station located near Old Franktown road is not ideal, as it is located in an area where the predominant upwind fetch is obstructed by tall timber. Conversely, the east side weather station is located downwind of Washoe Lake and experiences high winds, partly due to the smooth surface of the lake. Additionally, the precipitation gradient from the west side to the east side of the valley is large. According to the 800m version 2 PRISM (Parameter-elevation Regressions on Independent Slopes Model) precipitation map (Daly et al., 1996) the west side weather station averages 15.4 inches verses the east side weather station of 12.1 inches. Measured mean annual precipitation of 16 and 9 inches (2004-2008) from the west and east side weather stations, respectively, confirm this gradient. Because ET_{os} is a function of wind speed, and the net irrigation water requirement is a function of ET_{os} and the precipitation amount, averaging and developing basin wide representative variables of wind speed and precipitation was required to obtain one dataset that could be used to calculate the ET_{os} and the net irrigation water requirement that is representative of the entire valley. This approach was chosen rather than calculating separate net irrigation water requirement estimates for each station and averaging the two, due to the questionable quality and representativeness of measured wind speed, missing data, and having access to Nevada Department of Transportation (NDOT) weather data located near the center of the valley in a more valley wide representative area of pasture grass. The single weather dataset was constructed for the period of 2004-2008 and consisted of daily T_{max}, T_{min}, and calculated dew point collected from the east side weather station, mean monthly wind speed from the NDOT station, and daily precipitation, which was calculated by averaging daily measurements of precipitation from the west and east side weather stations. Average precipitation for 2004-2008 (i.e. average of east and west stations) was 12.7 inches, similar to the 1971-2000 PRISM 800m version 2 (Parameter-elevation Regressions on Independent Slopes Model) precipitation map (Daly et al., 1996) spatial average for the valley floor of 12.8 inches. Calculated mean annual dewpoint depression from the east side station represented near reference conditions of 2.4^{o}C, therefore no adjustment were made to the calculated dewpoint.

NWS Station Data Adjustment

Two NWS stations were identified in the Nevada dataset that had questionable temperature data. The first station identified was the Laughlin station (264480). Questionable temperature data were identified when comparing estimated solar radiation to measured solar radiation at a nearby weather station in Mohave, AZ. Figure AP1 and AP2 illustrate the estimated and measured solar radiation for Laughlin and Mohave, respectively, where it is obvious that the estimated solar radiation is below the measured solar radiation and does not ever approach the clear sky solar radiation "envelope" that it should for that elevation and latitude. Given that estimated R_s from T_{max} and T_{min} compares well with measurements at other stations, and that the estimated daily R_s is a function of the daily difference between T_{max} and T_{min}, investigation of Laughlin measured T_{max} and T_{min} was pursued to explain the underestimation. When comparing mean monthly measured T_{min} and T_{max} for Laughlin and Mohave it was evident that the maximum temperatures compared well but the Laughlin T_{min} was significantly higher than Mohave (Figure AP3).

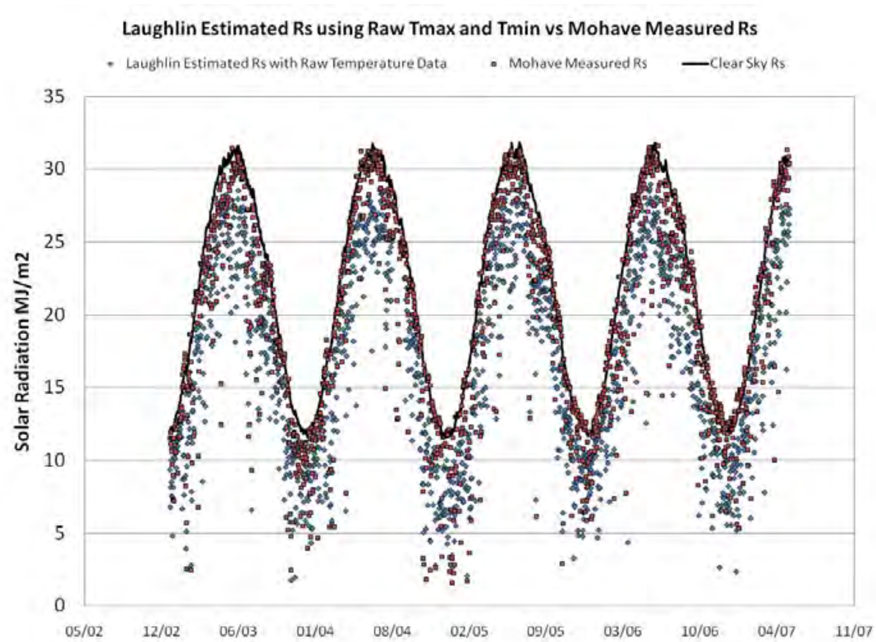

Figure AP1. Daily measured, estimated, and clear sky solar radiation for Mohave and Laughlin weather stations. The estimated solar radiation for Laughlin using T_{max} and T_{min} is underestimated when compared to the Mohave measured solar radiation.

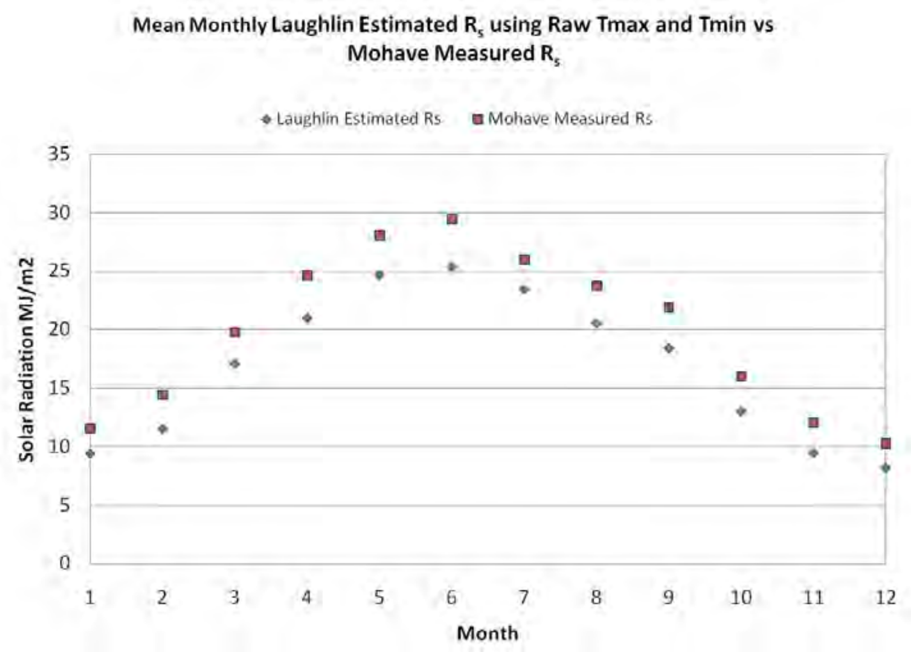

Figure AP2. Mean monthly measured and estimated solar radiation for Mohave and Laughlin weather stations.

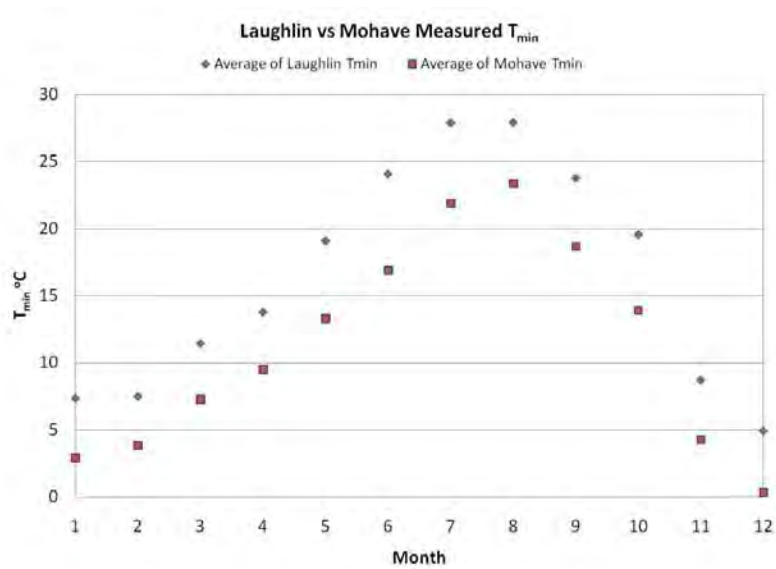

Figure AP3. Mean monthly T_{min} comparison between the Mohave and Laughlin weather stations.

The Mohave weather station is in an irrigated area along the Colorado River, so it is logical that there would be less sensible heat surrounding this station, which is illustrated in Figure AP4, where Mohave T_{max} is slightly lower than Laughlin in the spring and summer months due to evaporative cooling.

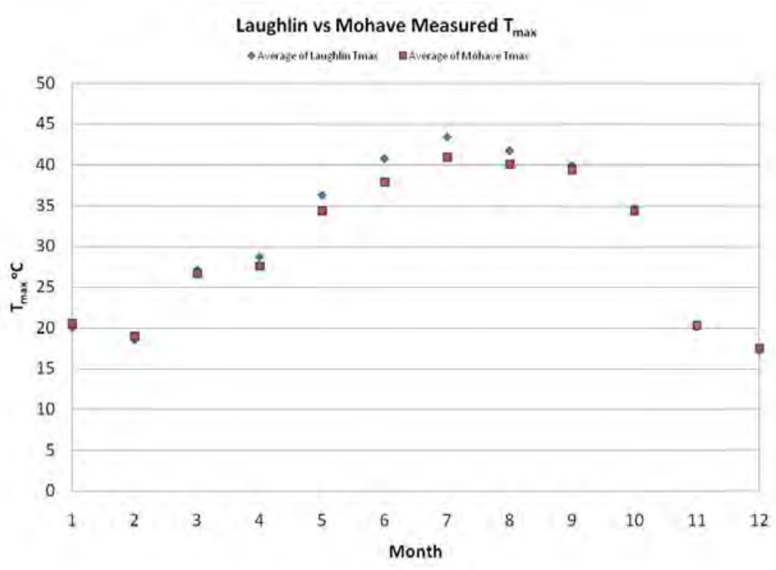

Figure AP4. Mean monthly T_{max} comparison between the Mohave and Laughlin weather stations.

The fact that Laughlin T_{min} is significantly higher than Mohave for all times of the year led to question if the area surrounding the Laughlin station could possibly be storing heat during the day and emitting it at night, such as from pavement or asphalt, thereby affecting the T_{min}. Photographs of the Laughlin station indicate that the station is indeed surrounded by asphalt and darker colored gravel (Figures AP5-AP6) perhaps having low thermal radiation emissivity and could be causing inflated T_{min} measurement. Miss calibration of the temperature sensor could also be causing inflated T_{min} measurement.

Figure AP5. Photo of the Laughlin weather station looking north.

Figure AP6. Photo of the Laughlin weather station looking south.

Artificially inflated T_{min} measurements are the primary reason why the estimated R_s did not compare well with the measured R_s nearby at the Mohave weather station. As previously mentioned, the empirical method used to estimate R_s (Thornton and Running, 1999) is based on the daily difference between T_{max} and T_{min}. The physical basis for the method is based from the fact that during cloud cover maximum air temperatures generally decrease and the minimum temperature is increased due to increased downward emission of reflection of long wave radiation by clouds at night (Allen, 1997). Because the T_{min} was abnormally inflated at Laughlin and not characteristic of an agricultural (evaporating) surface, the Thornton and Running equation, generally calibrated for more reference conditions, predicted that conditions were typically cloudy, when clearly from comparing to the Mohave measured R_s, it was not as cloudy as predicted in the region. To adjust the Laughlin T_{min} the mean monthly difference between the Laughlin and Mohave measured T_{min} was calculated and then subtracted from the Laughlin T_{min} time series for the period of record (1988-2007). After adjustment of the Laughlin T_{min} time series, estimated R_s compared well with measured R_s at the Mohave weather station.

During the QAQC process it was noted that the Minden weather station (265191) had significantly higher measured T_{max} than USGS micrometeorological weather station (ET-2) measured T_{max}, which was collected in a field of irrigated alfalfa when compared for respective time periods (Figure AP7). Measured T_{min} for both stations were very similar (Figure AP8). It is expected that the T_{max} measured over irrigated alfalfa would be somewhat lower due to less sensible heat and more ET occurring as compared to the area immediately surrounding Minden station which is a residential setting. However, the magnitudes of mean monthly differences of T_{max}, peaking at 7.8 ^{o}C in August for T_{max}, (Figure AP9) were considered significant given that the town of Minden is largely

Figure AP7. USGS Bowen Ratio micrometeorological weather station located in a field of irrigated alfalfa (modified from Maurer et al., 2005).

surrounded by irrigated alfalfa and pasture grass. These issues warranted an investigation of the area surrounding the Minden weather station. Figures AP10 and AP11 illustrate that the immediate area surrounding the Minden weather station is composed of a darker colored gravel, and is located within a residential area. Given that the Minden measured T_{min} compared well with measured T_{min} at the ET-2 site, the site surroundings of Mindin likely caused the increased T_{max} measurements. The affect of gravel surrounding the Minden weather station on T_{min} is smaller than the Laughlin station due to the limited extent of the gravel, where the Laughlin grave area immediately surrounding the station was large and included large areas of asphalt. In addition to the gravel surface in the vicinity of the Minden station, where there is no evaporative cooling to reduce air temperatures, there was probably substantial heat loading of the air temperature sensors due to thermal radiation emissions from the gravel, adjacent fence, and building shown in Figure AP11. The fence and building face the sun and would warm during the daytime, emitting substantial radiation toward the temperature shelter. In addition, the fence and building restricted air flow past the temperature shelter.

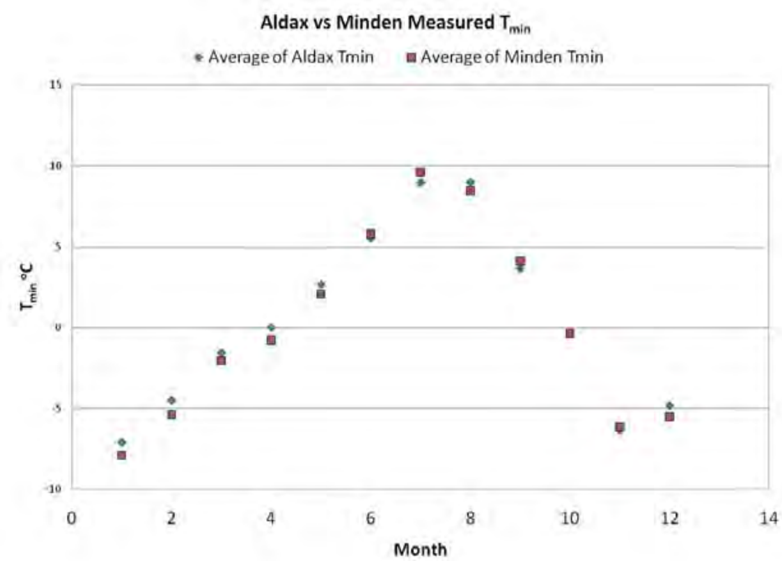

Figure AP8. Mean monthly T_{min} comparison between the ET-2 Aldax and Minden weather stations.

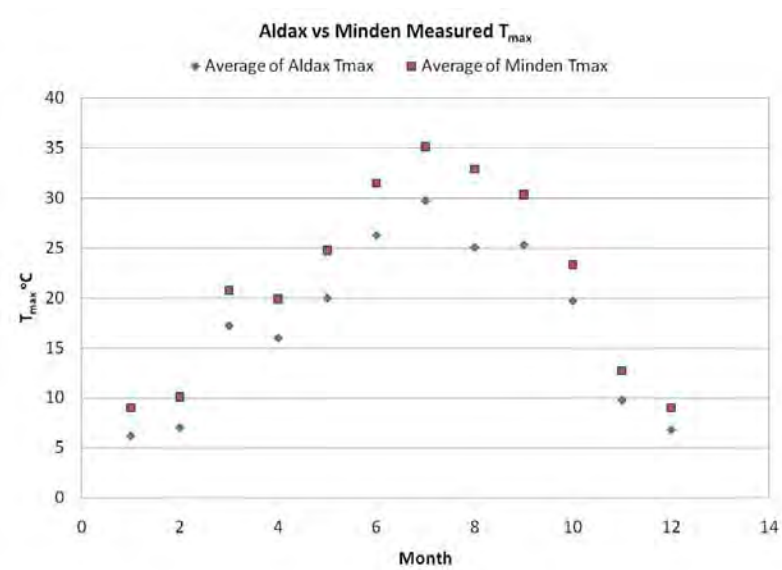

Figure AP9. Mean monthly T_{max} comparison between the ET-2 Aldax and Minden weather stations.

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Figure AP10. Gravel area surrounding the Minden NWS weather station looking northwest.

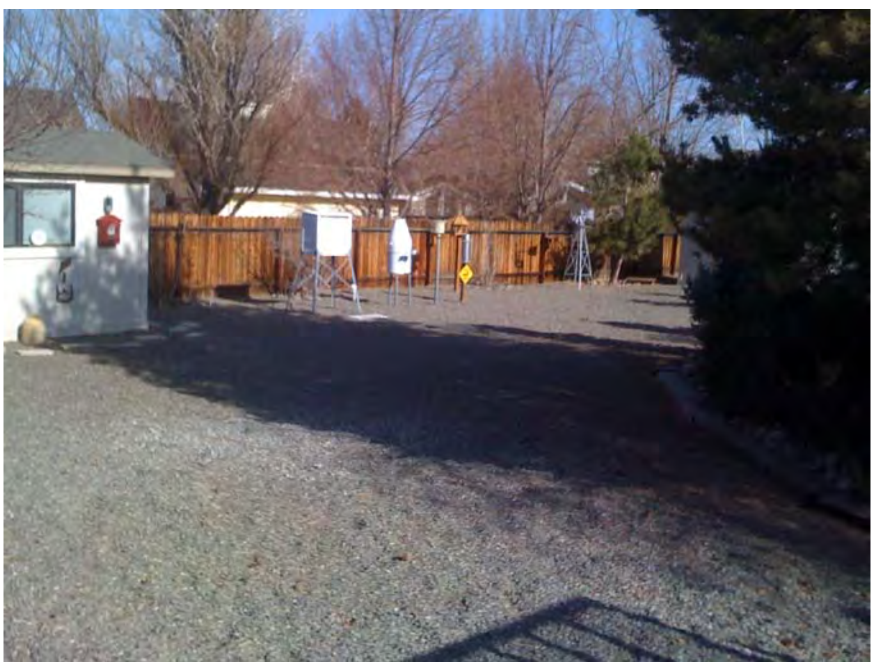

Figure AP11. Gravel area surrounding the Minden NWS weather station looking northeast

To adjust the Minden measured T_{max}, one half of the mean monthly difference between the Minden and the ET-2 site T_{max} were subtracted from the Minden T_{max} time series, beginning in 1991 when the station was relocated to the present site. Only one half of the T_{max} difference was used to adjust the Minden T_{max} time series based on findings that by using the full T_{max} difference produced unreasonable simulated greenup and harvest dates for Minden. Greenup and harvest date cumulative growing degree day parameters were calibrated to many areas of the state (see greenup and harvest date calibration section of report) using mostly NWS data that generally have a small amount of aridity bias due to siting near residential developments or non reference type settings. Therefore, the calibration may not perform well with T_{max} and T_{min} data collected in centers of irrigated fields that tend to run cooler. Because many NWS weather stations are not located in large irrigated areas, or directly over alfalfa or irrigated pasture grass, the adjustment was selected to replicate temperature measurements that would be more representative of typical NWS station site locations.

Appendix 3a. Mean monthly dew point depression (^{o}C) for stations used in spatial interpolation and assignment to NWS weather stations.

STATION	NETWORK	STATE	ELEVATION (ft)	LAT	LONG	PERIOD OF RECORD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Aberdeen, ID	BOR Agrimet	ID	4400	42.95	-112.83	1992-2004	-2.4	-2.2	-0.5	1.4	1.6	1.0	0.6	1.9	1.2	0.6	-1.6	-2.7	-0.1
Fairfield, ID	BOR Agrimet	ID	5038	43.31	-114.83	1990-2004	-4.3	-4.4	-2.4	0.5	0.8	0.4	1.4	2.2	1.6	0.5	-2.3	-4.2	-0.9
Malta, ID	BOR Agrimet	ID	4410	42.44	-113.41	1990-2002	-1.1	-1.3	0.1	1.1	0.9	1.3	2.5	2.9	1.3	0.8	-1.1	-1.7	0.5
Rupert, ID	BOR Agrimet	ID	4154	42.60	-113.84	1988-2008	-1.4	-1.0	0.4	1.5	1.7	1.3	1.2	2.0	1.2	0.8	-0.7	-1.4	0.5
Twin Falls, ID	BOR Agrimet	ID	3919	42.55	-114.35	1990-2008	-0.6	-0.3	1.3	2.0	2.4	3.0	3.3	3.0	2.6	1.9	0.0	-0.7	1.5
Grand View, ID	BOR Agrimet	ID	2579	42.91	-116.06	1993-2008	-1.6	-1.2	0.6	1.4	2.2	3.2	4.6	3.5	1.4	0.1	-1.3	-1.8	0.9
Bishop, CA	CIMIS	CA	4170	37.36	-118.40	1996-2007	1.6	2.0	4.3	5.0	4.4	4.4	4.0	3.7	2.7	2.5	2.0	2.0	3.2
Buntingville, CA	CIMIS	CA	4005	40.29	-120.43	1986-2007	-1.5	-0.6	0.4	0.9	0.9	2.2	3.3	4.0	2.4	0.6	-1.8	-1.8	0.7
Beryl Junction, UT	Utah Agmet	UT	5186	37.72	-113.70	2003-2007	-3.1	-1.4	0.5	2.4	3.1	5.8	4.3	2.9	3.1	1.2	0.3	-2.0	1.4
Drainage Farm, UT	Utah Agmet	UT	4430	41.83	-111.88	2003-2007	-1.9	-1.8	-1.6	2.0	2.5	2.9	4.4	3.8	1.7	0.0	-0.4	-1.3	0.9
Parowan, UT	Utah Agmet	UT	5754	37.86	-112.88	2004-2007	-3.3	-1.0	1.4	3.2	3.9	6.0	4.9	3.7	4.3	1.7	1.1	-1.9	2.0
Cedar City, UT	Utah Agmet	UT	5515	37.67	-113.14	2005-2007	-2.6	-0.3	1.2	3.4	4.7	8.1	6.5	4.7	4.8	2.2	2.9	-1.4	2.9
Flowell, UT	Utah Agmet	UT	4715	38.96	-112.42	2006-2007	-0.8	1.1	2.2	3.3	4.4	5.4	4.3	3.3	2.4	1.9	1.5	-3.7	2.1
Mason Valley, NV	USGS Bowen	NV	4322	39.11	-119.15	2005-2007	-0.4	0.7	2.3	2.2	1.6	2.3	3.6	2.4	1.4	0.6	-0.6	-0.7	1.3
Carson Valley, NV	USGS Bowen Ratio	NV	4686	39.01	-119.78	2003-2004	-0.1	2.0	2.3	3.0	1.9	2.4	2.4	1.8	2.5	1.9	0.2	-0.3	1.7
Eureka, NV	BOR Agrimet	NV	5897	39.69	-115.98	1989-2007	-3.6	-2.6	0.3	1.1	1.8	4.1	4.8	4.4	2.8	1.7	-0.9	-2.9	0.9
Fallon, NV	BOR Agrimet	NV	3965	39.46	-118.78	2001-2007	-1.0	1.0	4.6	5.6	6.7	9.6	8.3	5.9	4.9	3.2	0.3	-0.1	4.1
Lakeview, OR	BOR Agrimet	OR	4808	42.12	-120.52	1988-2007	-1.6	-1.4	-0.3	0.4	1.1	1.8	3.1	3.2	2.1	0.3	-1.5	-1.9	0.4
Lorella, OR	BOR Agrimet	OR	4130	42.08	-121.22	2001-2007	-1.7	-1.2	-1.0	-1.0	-0.2	0.1	0.7	0.3	-1.2	-2.4	-2.2	-1.6	-1.0
Mohave, AZ	AZMET	AZ	1581	34.97	-114.61	2003-2007	2.7	3.5	4.4	6.4	8.0	9.1	8.1	6.8	7.7	5.3	3.1	3.3	5.7

Appendix 3b. Interpolated or assigned basin average mean monthly dew point depression K_o (^oC) used for assignment to respective weather stations. Symbol * next to the basin name indicates the basins that were assigned the measured mean monthly dew point depression.

BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
142	Alkali Spring Valley	-0.2	0.9	2.9	3.8	3.8	4.8	4.6	3.8	3.1	2.1	0.9	0.1	2.5
111B	Alkali Valley	-0.2	1.1	3.0	3.5	3.3	4.2	4.3	3.4	2.7	1.8	0.4	0.1	2.3
230	Amargosa Desert	-0.5	0.8	2.7	3.9	4.3	5.7	5.1	4.1	3.8	2.4	1.2	0.0	2.8
57	Antelope Valley	-1.6	-0.3	2.0	2.7	3.0	4.7	4.9	4.0	2.9	1.7	-0.4	-1.2	1.9
106	Antelope Valley	-0.4	1.3	2.5	2.9	2.3	3.1	3.4	2.5	2.4	1.5	-0.1	-0.4	1.7
186B	Antelope Valley	-2.3	-1.4	0.4	1.9	2.4	3.6	3.8	3.4	2.4	1.3	-0.3	-2.3	1.1
137A	Big Smoky Valley	-0.6	0.7	2.8	3.6	3.6	4.9	4.7	3.8	3.0	2.0	0.6	-0.2	2.4
137B	Big Smoky Valley	-1.8	-0.5	1.9	2.7	3.0	4.8	4.9	4.0	3.0	1.8	-0.1	-1.4	1.9
215	Black Moutains Area	-0.6	0.8	2.4	4.1	5.0	6.9	5.9	4.7	4.9	2.8	1.7	0.0	3.2
28	Black Rock Desert	-1.3	-0.3	1.3	2.0	2.2	3.4	3.9	3.4	2.3	1.0	-0.9	-1.3	1.3
61	Boulder Flat	-2.1	-1.3	0.9	1.8	2.2	3.4	4.0	3.6	2.4	1.3	-0.8	-1.9	1.1
38	Bruneau River Area	-1.8	-1.4	0.3	1.6	2.0	2.5	3.2	3.1	1.9	0.9	-0.9	-1.9	0.8
129	Buena Vista Valley	-1.2	0.0	2.2	2.9	3.2	4.8	4.9	3.9	2.9	1.6	-0.5	-1.0	2.0
131	Buffalo Valley	-1.7	-0.6	1.5	2.3	2.6	4.0	4.4	3.7	2.6	1.4	-0.7	-1.4	1.5
101	Carson Desert*	-1.0	1.0	4.6	5.6	6.7	9.6	8.3	5.9	4.9	3.2	0.3	-0.4	4.1
105	Carson Valley*	-0.1	2.0	2.3	3.0	1.4	2.2	2.4	1.6	3.0	3.0	0.2	-0.3	1.7
102	Churchill Valley	-0.6	0.9	2.9	3.2	2.9	4.2	4.7	3.3	2.5	1.5	-0.3	-0.5	2.1
143	Clayton Valley	0.3	1.3	3.4	4.1	4.0	4.7	4.4	3.7	3.0	2.2	1.2	0.7	2.7
177	Clover Valley	-2.2	-1.5	0.4	1.8	2.2	3.2	3.6	3.3	2.2	1.2	-0.6	-2.1	1.0
204	Clover Valley	-2.7	-0.9	1.0	2.8	3.6	6.1	4.9	3.5	3.6	1.6	0.9	-1.8	1.9
64	Clovers Area	-1.9	-1.0	1.0	1.8	2.2	3.4	4.0	3.5	2.3	1.2	-0.9	-1.7	1.2
213	Colorado Valley	1.8	2.7	3.8	5.7	7.2	8.5	7.5	6.2	6.9	4.6	2.7	2.4	5.0
118	Columbus Salt Marsh Valley	0.1	1.2	3.2	3.9	3.8	4.6	4.4	3.7	2.9	2.1	0.9	0.4	2.6
126	Cowkick Valley	-1.0	0.6	3.1	3.8	4.1	6.0	5.8	4.3	3.4	2.1	-0.1	-0.5	2.6
54	Crescent Valley	-2.4	-1.4	1.0	1.8	2.3	4.0	4.4	3.9	2.7	1.5	-0.7	-2.0	1.3
103	Dayton Valley	-0.4	1.3	2.5	2.9	2.3	3.2	3.6	2.6	2.4	1.5	-0.2	-0.5	1.8
31	Desert Valley	-1.4	-0.5	1.3	2.0	2.2	3.4	3.9	3.4	2.3	1.0	-0.9	-1.4	1.3
153	Diamond Valley*	-3.6	-2.6	0.3	1.1	1.8	4.1	4.8	4.4	2.8	1.7	-0.9	-2.9	0.9
48	Dixie Creek-Tenmile Creek Area	-2.4	-1.6	0.6	1.7	2.2	3.6	4.0	3.7	2.4	1.3	-0.7	-2.2	1.0
128	Dixie Valley	-1.1	0.3	2.8	3.5	3.9	5.7	5.6	4.2	3.3	2.0	-0.2	-0.7	2.4
82	Dodge Flat	-0.8	0.8	2.9	3.5	3.6	5.2	5.2	3.9	3.1	1.9	-0.3	-0.5	2.4
104	Eagle Valley	-0.2	1.8	2.3	2.9	2.0	2.6	2.7	2.0	2.5	1.8	0.1	-0.3	1.7
200	Eagle Valley	-2.7	-1.0	0.9	2.8	3.6	6.1	4.8	3.4	3.5	1.5	0.8	-1.9	1.8

Appendix 3b cont. Interpolated or assigned basin average mean monthly dew point depression K_o (^oC).

BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
127	Eastgate Valley Area	-1.0	0.5	2.9	3.6	3.9	5.7	5.6	4.2	3.3	2.0	-0.1	-0.6	2.5
167	Eldorado Valley	0.9	2.0	3.3	5.1	6.3	7.8	6.8	5.6	6.1	3.9	2.3	1.5	4.3
49	Elko Segment	-2.2	-1.5	0.6	1.7	2.2	3.4	3.8	3.5	2.3	1.3	-0.7	-2.1	1.0
76	Fernley Area	-0.8	0.9	3.4	4.0	4.2	6.1	5.8	4.2	3.4	2.1	-0.1	-0.4	2.7
117	Fish Lake Valley	0.7	1.5	3.7	4.4	4.1	4.5	4.2	3.7	2.9	2.3	1.4	1.1	2.9
227A	Fortymile Canyon	-0.7	0.6	2.5	3.7	4.1	5.6	5.0	4.1	3.7	2.3	1.1	-0.2	2.7
122	Gabbs Valley	-0.8	0.7	2.9	3.5	3.6	5.1	5.1	3.8	3.0	1.9	0.0	-0.5	2.4
172	Garden Valley	-1.9	-0.3	1.7	3.0	3.6	5.6	4.9	3.9	3.5	1.9	0.7	-1.4	2.1
187	Goshute Valley	-2.2	-1.4	0.3	1.7	2.2	3.2	3.5	3.3	2.2	1.2	-0.4	-2.1	1.0
71	Grass Valley	-1.5	-0.4	1.6	2.3	2.6	3.9	4.3	3.6	2.5	1.3	-0.7	-1.3	1.5
138	Grass Valley	-2.6	-1.5	1.1	1.9	2.4	4.4	4.7	4.1	2.8	1.7	-0.6	-2.1	1.4
192	Great Salt Lake Desert	-2.1	-1.3	0.3	1.8	2.4	3.4	3.5	3.3	2.3	1.2	-0.3	-2.1	1.0
6	Guano Valley	-1.6	-1.0	0.2	0.8	1.2	2.0	3.0	2.8	1.6	0.1	-1.4	-1.7	0.5
156	Hot Creek	-1.7	-0.3	1.9	2.9	3.3	5.1	4.9	4.0	3.2	1.9	0.4	-1.2	2.0
24	Hualapai Flat	-1.3	-0.3	1.1	1.7	1.9	3.0	3.7	3.3	2.2	0.8	-1.1	-1.3	1.1
47	Huntington Valley	-2.9	-1.9	0.6	1.5	2.1	4.0	4.5	4.0	2.7	1.5	-0.7	-2.5	1.1
72	Imlay Area	-1.3	-0.1	1.8	2.5	2.8	4.1	4.4	3.6	2.6	1.4	-0.6	-1.1	1.7
36	Independence Valley	-1.9	-1.4	0.4	1.6	2.0	2.8	3.5	3.3	2.0	1.0	-1.0	-1.9	0.9
161	Indian Springs Valley	-1.0	0.5	2.2	3.7	4.3	6.1	5.3	4.2	4.1	2.4	1.3	-0.4	2.7
135	Ione Valley	-0.9	0.5	2.7	3.4	3.5	5.0	4.9	3.8	3.0	1.9	0.1	-0.6	2.3
164A	Ivanpah Valley	0.7	1.8	3.1	4.9	6.0	7.5	6.6	5.3	5.7	3.7	2.1	1.2	4.0
174	Jakes Valley	-2.8	-1.5	0.9	1.9	2.5	4.5	4.7	4.0	2.9	1.7	-0.2	-2.3	1.4
39	Jarbidge River Area	-1.7	-1.3	0.3	1.6	2.0	2.4	3.0	3.0	1.8	1.0	-0.9	-1.8	0.8
30A	Kings River Valley	-1.6	-0.9	0.7	1.4	1.8	2.7	3.5	3.1	1.9	0.6	-1.1	-1.6	0.9
90	Lake Tahoe Basin	-0.3	1.7	2.3	2.9	2.1	2.7	2.7	2.1	2.5	1.8	0.1	-0.3	1.7
183	Lake Valley	-2.3	-0.7	1.2	2.8	3.6	5.8	4.9	3.7	3.5	1.7	0.9	-1.8	2.0
45	Lamoille Valley	-2.2	-1.5	0.5	1.7	2.2	3.3	3.8	3.5	2.2	1.2	-0.7	-2.1	1.0
212	Las Vegas Valley	-0.4	0.9	2.5	4.2	5.0	6.8	5.9	4.7	4.8	2.9	1.6	0.2	3.3
92A	Lemmon Valley	-0.8	0.6	2.1	2.6	2.4	3.5	3.9	3.3	2.6	1.4	-0.6	-0.8	1.7
92B	Lemmon Valley	-0.8	0.7	2.2	2.7	2.5	3.6	4.0	3.2	2.6	1.5	-0.5	-0.7	1.8
155A	Little Smoky Valley	-2.9	-1.7	0.9	1.8	2.3	4.4	4.8	4.2	2.9	1.7	-0.5	-2.3	1.3
73	Lovelock Valley	-1.0	0.4	2.7	3.4	3.7	5.4	5.3	4.1	3.1	1.8	-0.4	-0.7	2.3
205	Lower Meadow Valley Wash	-2.2	-0.4	1.4	3.1	3.9	6.2	5.1	3.8	3.8	1.9	1.1	-1.4	2.2
220	Lower Moapa Valley	-1.6	0.0	1.8	3.5	4.4	6.5	5.5	4.1	4.2	2.3	1.4	-0.9	2.6
59	Lower Reese River Valley	-1.9	-0.9	1.3	2.1	2.5	3.9	4.4	3.8	2.6	1.5	-0.7	-1.6	1.4
52	Marys Creek Area	-2.3	-1.4	0.8	1.8	2.2	3.6	4.0	3.7	2.4	1.4	-0.8	-2.1	1.1
42	Marys River Area	-1.9	-1.4	0.4	1.7	2.1	2.7	3.2	3.1	2.0	1.1	-0.8	-1.9	0.9

Appendix 3b cont. Interpolated or assigned basin average mean monthly dew point depression K_o (^oC).

BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
108	Mason Valley*	-0.4	0.7	2.3	2.2	1.6	2.3	3.6	2.4	1.4	0.6	-0.6	-0.7	1.3
225	Mercury Valley	-0.7	0.6	2.4	3.8	4.3	5.9	5.3	4.2	4.0	2.4	1.3	-0.2	2.8
58	Middle Reese River Valley	-1.9	-0.7	1.6	2.3	2.7	4.3	4.6	3.9	2.8	1.6	-0.5	-1.5	1.6
26	Mud Meadow	-1.4	-0.5	1.0	1.6	1.9	2.9	3.6	3.2	2.1	0.7	-1.1	-1.4	1.0
44	North Fork Area	-1.9	-1.4	0.5	1.7	2.1	2.9	3.4	3.2	2.0	1.1	-0.8	-2.0	0.9
228	Oasis Valley	-0.6	0.7	2.6	3.7	4.0	5.3	4.8	3.9	3.5	2.2	1.1	-0.1	2.6
37	Owyhee River Area	-1.8	-1.4	0.3	1.5	2.0	2.6	3.3	3.1	1.9	0.9	-1.0	-1.9	0.8
209	Pahranagat Valley	-1.9	-0.3	1.6	3.2	3.9	6.0	5.1	3.9	3.7	1.9	1.0	-1.3	2.2
162	Pahrump Valley	-0.3	1.0	2.6	4.1	4.8	6.4	5.7	4.5	4.5	2.8	1.5	0.2	3.2
203	Panaca Valley	-2.6	-0.8	1.0	2.8	3.6	6.1	4.9	3.5	3.6	1.6	0.9	-1.8	1.9
69	Paradise Valley	-1.7	-0.9	0.9	1.7	2.1	3.1	3.8	3.3	2.1	0.9	-1.0	-1.6	1.1
202	Patterson Valley	-2.5	-0.8	1.1	2.9	3.6	6.0	4.9	3.6	3.6	1.7	0.9	-1.8	1.9
170	Penoyer Valley	-1.5	-0.1	1.9	3.2	3.7	5.6	5.0	3.9	3.5	2.0	0.8	-1.0	2.2
191	Pilot Creek Valley	-1.9	-1.4	0.2	1.7	2.1	2.8	3.2	3.1	2.0	1.1	-0.5	-2.0	0.9
29	Pine Forest Valley	-1.6	-0.8	0.7	1.5	1.8	2.8	3.5	3.1	1.9	0.6	-1.1	-1.6	0.9
53	Pine Valley	-2.9	-1.9	0.7	1.6	2.1	4.0	4.5	4.1	2.7	1.6	-0.7	-2.4	1.1
214	Piute Valley	2.0	2.9	3.9	5.9	7.3	8.6	7.6	6.3	7.1	4.7	2.8	2.6	5.1
88	Pleasant Valley	-0.4	1.3	2.4	2.9	2.3	3.1	3.3	2.6	2.5	1.6	-0.1	-0.5	1.8
130	Pleasant Valley	-1.4	-0.2	1.9	2.6	2.9	4.4	4.7	3.8	2.7	1.5	-0.5	-1.2	1.8
1	Pueblo Valley	-1.6	-0.9	0.6	1.3	1.7	2.6	3.3	3.0	1.8	0.5	-1.2	-1.6	0.8
65	Pumpernickel Valley	-1.7	-0.7	1.3	2.0	2.4	3.7	4.1	3.5	2.4	1.2	-0.8	-1.5	1.3
81	Pyramid Lake Valley	-1.0	0.4	2.1	2.7	2.7	4.2	4.5	3.7	2.8	1.4	-0.7	-0.9	1.8
116	Queen Valley	0.6	1.4	3.5	4.2	3.9	4.4	4.2	3.6	2.8	2.2	1.2	1.0	2.7
33A	Quinn River Valley	-1.6	-0.9	0.8	1.6	1.9	2.9	3.6	3.2	2.0	0.8	-1.1	-1.6	1.0
33B	Quinn River Valley	-1.7	-1.0	0.6	1.5	1.9	2.8	3.5	3.1	1.9	0.7	-1.1	-1.7	0.9
173A	Railroad Valley	-1.4	0.0	2.0	3.2	3.6	5.4	4.9	3.9	3.4	2.0	0.7	-1.0	2.2
173B	Railroad Valley	-2.2	-0.8	1.4	2.5	3.1	5.1	4.8	4.0	3.2	1.8	0.2	-1.7	1.8
141	Ralston Valley	-0.9	0.4	2.5	3.4	3.6	5.0	4.8	3.9	3.1	2.0	0.6	-0.5	2.3
176	Ruby Valley	-2.7	-1.7	0.5	1.7	2.3	3.9	4.2	3.8	2.6	1.4	-0.6	-2.3	1.1
40	Salmon Falls Creek Area	-1.6	-1.2	0.4	1.6	2.0	2.4	2.9	2.9	1.9	1.1	-0.7	-1.7	0.8
22	San Emidio Desert	-1.2	0.0	1.6	2.1	2.3	3.5	4.0	3.6	2.5	1.1	-0.9	-1.1	1.5
146	Sarcobatus Flat	-0.2	0.9	2.9	3.9	4.0	5.1	4.7	3.9	3.3	2.2	1.1	0.2	2.6
107	Smith Valley	-0.4	1.1	2.5	2.8	2.3	3.1	3.7	2.7	2.2	1.3	-0.2	-0.5	1.7
21	Smoke Creek Desert	-1.3	-0.3	1.1	1.6	1.7	2.9	3.6	3.5	2.3	0.8	-1.2	-1.3	1.1
195	Snake Valley	-2.3	-0.7	1.1	2.6	3.4	5.3	4.6	3.7	3.1	1.6	0.6	-2.1	1.7
121A	Soda Spring Valley	-0.5	0.8	2.9	3.5	3.4	4.7	4.6	3.6	2.9	1.9	0.3	-0.2	2.3
46	South Fork Area	-2.5	-1.6	0.6	1.7	2.2	3.6	4.0	3.7	2.4	1.3	-0.7	-2.3	1.0

Appendix 3b cont. Interpolated or assigned basin average mean monthly dew point depression K_o (^oC).

BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
35	South Fork Owyhee River Area	-1.9	-1.4	0.4	1.5	2.0	2.7	3.5	3.2	1.9	0.8	-1.1	-1.9	0.8
184	Spring Valley	-2.4	-0.9	1.1	2.5	3.2	5.1	4.6	3.7	3.1	1.6	0.4	-2.1	1.7
201	Spring Valley	-2.6	-0.8	1.0	2.8	3.6	6.1	4.9	3.5	3.6	1.6	0.9	-1.8	1.9
43	Starr Valley Area	-2.1	-1.4	0.5	1.7	2.2	3.1	3.5	3.3	2.1	1.2	-0.7	-2.0	0.9
179	Steptoe Valley	-2.5	-1.3	0.8	2.1	2.7	4.5	4.5	3.8	2.8	1.5	0.0	-2.2	1.4
149	Stone Cabin Valley	-1.2	0.2	2.3	3.2	3.5	5.1	4.8	3.9	3.2	2.0	0.5	-0.8	2.2
14	Surprise Valley	-1.5	-0.9	0.2	0.8	1.2	2.1	3.0	2.8	1.6	0.1	-1.4	-1.6	0.5
114	Teels Marsh Valley	0.1	1.2	3.2	3.8	3.6	4.4	4.3	3.6	2.8	2.0	0.8	0.4	2.5
189A	Thousand Springs Valley	-1.8	-1.3	0.3	1.7	2.0	2.6	3.0	3.0	2.0	1.1	-0.7	-1.9	0.8
189D	Thousand Springs Valley	-1.7	-1.3	0.2	1.6	2.0	2.5	2.9	2.9	1.9	1.0	-0.6	-1.8	0.8
83	Tracy Segment	-0.6	1.0	2.7	3.2	2.9	4.2	4.4	3.3	2.7	1.7	-0.2	-0.5	2.0
91	Truckee Canyon Segment	-0.6	1.1	2.3	2.8	2.3	3.2	3.5	2.8	2.5	1.6	-0.3	-0.6	1.7
87	Truckee Meadows	-0.6	1.1	2.4	2.9	2.4	3.4	3.7	2.9	2.5	1.6	-0.2	-0.6	1.8
56	Upper Reese River Valley	-1.6	-0.3	2.1	2.8	3.2	4.9	5.0	4.0	3.0	1.8	-0.2	-1.2	2.0
222	Virgin River Valley	-2.2	-0.4	1.4	3.2	4.0	6.4	5.2	3.8	3.9	1.9	1.2	-1.4	2.3
4	Virgin Valley	-1.5	-0.9	0.4	1.1	1.5	2.4	3.2	2.9	1.7	0.3	-1.3	-1.6	0.7
110A	Walker Lake Valley	-0.6	0.8	2.8	3.1	2.9	4.2	4.7	3.3	2.4	1.4	-0.3	-0.5	2.0
110C	Walker Lake Valley	-0.4	1.0	2.9	3.4	3.2	4.3	4.5	3.4	2.7	1.7	0.2	-0.2	2.2
89	Washoe Valley	-0.3	1.5	2.4	2.9	2.2	2.9	3.0	2.3	2.5	1.7	0.0	-0.4	1.7
207	White River Valley	-2.3	-0.8	1.3	2.6	3.2	5.2	4.8	3.9	3.3	1.8	0.4	-1.8	1.8
63	Willow Creek Valley	-1.9	-1.2	0.7	1.7	2.1	3.0	3.6	3.4	2.2	1.1	-0.9	-1.8	1.0
70	Winnemucca Segment	-1.6	-0.6	1.3	2.0	2.3	3.5	4.0	3.5	2.3	1.1	-0.8	-1.4	1.3
159	Yucca Flat	-1.0	0.4	2.3	3.5	4.0	5.7	5.0	4.0	3.7	2.2	1.1	-0.5	2.5

Appendix 4a. Mean monthly 2 meter equivalent wind speed (m/s) for stations used in spatial interpolation and assignment to weather NWS weather stations.

STATION NAME	LAT	LONG	ELEVATION (FT)	STATE	NETWORK	BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
AMARGOSA VALLEY	36.57	-116.46	2425	NV	CEMP	230	Amargosa Desert	1.8	2.2	2.3	3.0	2.7	2.9	2.9	2.8	2.3	2.0	1.7	1.7	2.4
ANTELOPE LAKE	41.68	-116.76	5459	NV	RAWS	34	Little Owyhee River Area	2.8	2.8	3.1	3.0	3.0	2.8	2.7	2.8	2.6	2.7	2.9	2.9	2.8
B11 WALKER BOWEN	39.11	-119.15	4321	NV	USGS	108	Mason Valley	1.4	2.1	2.0	2.2	1.8	1.5	1.4	1.4	1.4	1.3	1.5	1.5	1.6
BAKER FLAT	39.00	-114.22	6841	NV	RAWS	195	Snake Valley	1.5	1.4	1.8	2.0	2.0	2.1	2.0	2.0	1.9	1.6	1.5	1.5	1.8
BEACON LIGHT	40.56	-116.76	4800	NV	RAWS	59	Lower Reese River Valley	1.3	1.7	2.0	2.1	2.2	2.2	2.1	2.0	1.9	1.5	1.4	1.4	1.8
BENTON	37.84	-118.48	5449	CA	RAWS	NA	NA	1.8	2.2	2.4	2.6	2.3	2.1	1.9	1.9	1.8	1.9	2.0	1.9	2.1
BIG SMOKEY VALLEY	39.05	-117.00	5840	NV	DRI	137B	Big Smoky Valley	2.0	2.4	2.9	3.3	3.0	3.2	2.9	2.7	2.5	2.4	2.4	2.3	2.7
BLUEWING MOUNTAIN	40.50	-119.12	4570	NV	RAWS	79	Kumiva Valley	1.7	2.0	2.3	2.6	2.7	2.5	2.4	2.3	2.2	2.0	1.9	1.8	2.2
BUFFALO CREEK	40.58	-119.79	2795	NV	RAWS	21	Smoke Creek Desert	1.5	2.0	2.5	2.9	2.9	2.9	2.8	2.6	2.4	2.2	1.8	1.6	2.3
CARSON VALLEY	39.00	-119.78	4685	NV	NVDOT	105	Carson Valley	1.7	1.8	2.6	2.6	2.4	2.2	1.9	1.7	1.8	1.6	1.7	1.8	2.0
CATNIP MOUNTAIN	41.92	-119.50	5741	NV	RAWS	6	Guano Valley	3.6	3.2	3.4	3.3	3.0	2.9	2.6	2.5	2.4	2.8	3.3	3.5	3.0
CATTLE CAMP	38.90	-114.81	7024	NV	RAWS	179	Steptoe Valley	2.1	2.1	2.2	2.4	2.4	2.5	2.3	2.4	2.2	2.2	2.1	2.1	2.3
CEDARVILLE	41.59	-120.17	4600	CA	AGRIMET	NA	NA	2.1	2.1	2.5	2.4	2.2	2.0	1.9	1.9	1.8	1.8	2.1	2.1	2.1
COYOTE WASH	38.28	-114.76	5771	NV	RAWS	181	Dry Lake Valley	1.7	1.9	2.1	2.3	2.4	2.4	2.2	2.1	2.1	2.0	1.8	1.8	2.1
CURRANT CREEK	38.76	-115.41	5751	NV	RAWS	173B	Railroad Valley	1.8	2.2	2.6	2.9	2.8	2.9	2.7	2.8	2.6	2.3	1.9	1.7	2.4
DESATOYA MOUNTAIN	39.30	-117.58	6201	NV	RAWS	134	Smith Creek	2.2	2.4	2.5	2.5	2.5	2.5	2.4	2.3	2.1	2.0	2.2	2.3	2.3
DOYLE	40.03	-120.11	4239	CA	RAWS	NA	NA	1.9	2.2	2.3	2.3	2.3	2.1	2.1	2.1	2.0	2.0	2.0	2.0	2.1
DUCKWATER	38.92	-115.70	5463	NV	DRI	173B	Railroad Valley	2.6	2.6	3.1	3.5	3.1	3.3	2.7	2.7	2.8	2.8	2.6	2.4	2.8

Appendix 4a cont. Mean monthly 2 meter equivalent wind speed (m/s) for stations used in spatial interpolation and assignment to weather stations used for computing ET and net irrigation water requirements.

STATION NAME	LAT	LONG	ELEVATION (FT)	STATE	NETWORK	BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
DYER - WALLACE FARMS	37.61	-117.99	4882	NV	DRI	117	Fish Lake Valley	3.2	3.8	3.8	4.1	3.2	3.2	2.9	2.8	2.8	3.1	3.1	3.3	3.3
EDWARDS CREEK VALLEY	39.53	-117.75	5194	NV	DRI	133	Edwards Creek Valley	1.7	1.9	2.1	2.4	2.4	2.4	2.4	2.3	2.1	1.9	1.8	1.8	2.1
ELKO WB AIRPORT	40.83	-115.78	5050	NV	AIRPORT	49	Elko Segment	1.6	1.8	2.1	2.3	2.2	2.2	2.1	1.9	1.8	1.6	1.7	1.6	1.9
ELY WBO	39.30	-114.85	6262	NV	AIRPORT	179	Steptoe Valley	3.0	3.1	3.3	3.4	3.4	3.4	3.3	3.3	3.2	3.1	3.0	3.1	3.2
EUREKA	39.69	-115.98	5896	NV	AGRIMET	153	Diamond Valley	1.7	1.9	2.6	3.0	2.3	2.2	1.9	1.8	1.8	1.8	1.9	2.0	2.1
FAIRVIEW VALLEY	39.32	-118.22	4236	NV	DRI	124	Fairview Valley	1.7	2.1	2.3	2.7	2.8	2.6	2.6	2.3	2.1	1.9	1.9	1.7	2.2
FALLON	39.46	-118.78	3967	NV	AGRIMET	101	Carson Desert	1.3	1.7	2.0	2.2	1.8	1.8	1.4	1.3	1.3	1.1	1.3	1.5	1.6
GARDEN VALLEY	38.03	-115.44	5167	NV	CEMP	172	Garden Valley	1.1	1.3	1.6	1.9	1.8	1.8	1.7	1.6	1.5	1.2	1.1	1.1	1.5
GARDNERVILLE	38.89	-119.72	4797	NV	NVDOT	105	Carson Valley	1.5	1.5	2.2	2.4	2.2	1.9	1.7	1.8	1.6	1.5	1.5	1.7	1.8
GOLDFIELD	37.71	-117.24	5627	NV	CEMP	142	Alkali Spring Valley	2.8	3.1	3.3	3.5	3.1	3.1	2.8	2.8	2.7	2.6	2.7	2.7	2.9
IMMIGRATION WASH	37.92	-114.17	6230	NV	RAWS	198	Dry Valley	2.2	2.4	2.8	3.1	3.2	3.3	2.9	2.8	2.8	2.6	2.3	2.2	2.7
LAS VEGAS WSO AIRPORT	36.23	-115.03	1883	NV	AIRPORT	212	Las Vegas Valley	2.4	2.8	3.3	3.6	3.7	3.6	3.3	3.1	2.9	2.6	2.5	2.4	3.0
LOVELOCK FAA AIRPORT	40.07	-118.57	3902	NV	AIRPORT	73	Lovelock Valley	1.8	2.2	2.5	2.9	3.0	2.9	2.6	2.4	2.2	2.0	1.8	1.7	2.3
LOWER BIG SMOKEY VALLEY	38.37	-117.47	5036	NV	DRI	137A	Big Smoky Valley	3.2	3.5	3.9	4.3	4.1	4.2	3.5	3.4	3.5	3.6	3.4	3.0	3.6
MEDLINS RANCH	37.40	-115.54	4475	NV	CEMP	169A	Tikapoo Valley	2.5	2.5	2.8	3.2	3.1	3.0	2.7	2.6	2.7	2.5	2.3	2.3	2.7
MESQUITE	36.81	-114.05	1768	NV	CEMP	222	Virgin River Valley	1.4	1.4	1.5	1.7	1.7	1.6	1.7	1.5	1.6	1.3	1.2	1.2	1.5
MOHAVE	34.97	-114.61	479	AZ	AZMET	NA	NA	2.6	2.7	2.7	2.8	2.6	2.2	1.8	1.7	1.6	1.9	2.3	2.9	2.3
MOREY CREEK	41.45	-117.62	5499	NV	RAWS	69	Paradise	2.1	2.3	3.0	3.0	2.9	2.9	2.9	2.8	2.6	2.5	2.3	2.1	2.6
NYALA	38.25	-115.73	4826	NV	CEMP	173B	Railroad Valley	1.3	1.5	1.9	2.4	2.3	2.4	2.3	2.2	1.9	1.6	1.4	1.2	1.9
ORIENTAL WASH	37.24	-117.50	4101	NV	RAWS	232	Oriental W.	3.1	3.2	3.4	3.6	3.6	3.6	3.4	3.4	3.4	3.5	3.2	3.1	3.4

Appendix 4a cont. Mean monthly 2 meter equivalent wind speed (m/s) for stations used in spatial interpolation and assignment to weather stations used for computing ET and net irrigation water requirements.

STATION NAME	LAT	LONG	ELEVATION (FT)	STATE	NETWORK	BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
OVERTON	36.55	-114.45	1260	NV	CEMP	220	Lower Moapa Valley	1.4	1.5	1.6	1.9	1.8	1.8	1.5	1.6	1.5	1.4	1.3	1.3	1.5
PANCAKE	38.30	-116.19	5200	NV	RAWS	156	Hot Creek	1.4	1.8	2.3	2.6	2.6	2.6	2.4	2.3	2.1	1.9	1.7	1.6	2.1
PYRAMID LAKE FISHERIES	39.94	-119.59	3809	NV	DRI	81	Pyramid Lake Valley	2.5	2.7	3.0	3.2	2.7	2.5	2.3	2.5	2.5	2.5	2.8	3.2	2.7
RACHEL	37.64	-115.74	4849	NV	CEMP	170	Penoyer Valley	1.9	2.3	2.5	3.1	2.9	3.0	2.9	2.8	2.4	2.1	1.9	1.8	2.5
RED BUTTE	39.98	-117.32	5049	NV	RAWS	57	Antelope Valley	1.6	2.0	2.2	2.5	2.6	2.5	2.2	2.1	2.0	1.8	1.7	1.7	2.1
RED ROCK	39.90	-119.94	4715	NV	WASHOE COUNTY	99	Red Rock Valley	1.2	1.3	1.8	2.1	2.0	1.8	1.7	1.7	1.5	1.3	1.5	1.5	1.6
RENO WSFO AIRPORT	39.48	-119.77	4410	NV	AIRPORT	87	Truckee Meadows	1.6	2.0	2.5	2.8	2.8	2.7	2.5	2.3	2.0	1.7	1.8	1.7	2.2
ROCK SPRING CREEK	41.64	-114.44	5400	NV	RAWS	189B	Thousand Springs Valley	2.0	2.2	2.5	2.7	2.7	2.8	2.6	2.5	2.3	2.3	2.1	2.2	2.4
RUBY LAKE	40.17	-115.49	5971	NV	RAWS	176	Ruby Valley	2.5	2.7	3.0	3.2	3.0	2.9	2.5	2.5	2.5	2.5	2.6	2.6	2.7
SARCOBATUS FLATS	37.28	-117.02	4016	NV	CEMP	146	Sarcobatus Flat	2.3	2.4	2.6	2.7	2.2	2.3	2.2	2.0	1.9	1.9	2.0	2.2	2.2
SHO-PAI	42.02	-116.21	5351	ID	RAWS	NA	NA	2.8	2.8	3.3	3.2	3.1	2.9	2.9	2.8	2.7	2.6	3.1	3.0	2.9
SIARD	40.39	-117.63	4600	NV	RAWS	130	Pleasant Valley	1.7	1.9	2.3	2.4	2.5	2.5	2.3	2.2	2.1	1.9	1.8	1.8	2.1
SPRUCE MOUNTAIN	40.44	-114.81	6099	NV	RAWS	187	Goshute Valley	2.5	2.4	2.8	3.1	3.0	3.0	2.8	2.7	2.5	2.4	2.4	2.4	2.7
STEAD GOLF	39.63	-119.89	5140	NV	DRI	92A	Lemmon Valley	1.6	2.2	2.4	2.9	2.7	2.7	2.6	2.5	2.2	1.9	1.9	2.3	2.3
TONOPAH AIRPORT	38.05	-117.08	5395	NV	AIRPORT	141	Ralston Valley	3.0	3.3	3.6	3.9	3.7	3.5	3.1	3.1	3.0	3.1	3.1	3.0	3.3
TRACY CLARK	39.57	-119.53	4501	NV	NVDOT	83	Tracy Segment	1.5	2.1	2.4	3.1	2.8	2.5	2.4	2.3	2.1	1.8	1.9	1.7	2.2
WALKER	38.57	-119.46	5440	CA	RAWS	NA	NA	1.9	2.1	2.6	2.9	2.8	2.7	2.5	2.4	2.4	1.9	2.0	2.3	2.4
WASHOE VALLEY	39.27	-119.82	5043	NV	NVDOT	89	Washoe Valley	2.3	2.1	3.1	3.4	2.9	2.3	2.3	2.1	2.1	1.9	2.4	3.0	2.5
WASHOEVALLEY_EAST	39.29	-119.79	5040	NV	WASHOE COUNTY	89	Washoe Valley	2.8	3.1	4.4	5.2	5.1	4.3	4.2	4.5	4.5	3.7	3.1	3.8	4.0
WINNEMUCCA WSO AIRPORT	40.90	-117.80	4296	NV	AIRPORT	70	Winnemucca Segment	2.5	2.8	2.8	2.9	2.9	2.9	2.8	2.6	2.5	2.4	2.5	2.5	2.7

Appendix 4b. Interpolated or assigned basin average mean monthly wind speed (m/s) used for assignment to respective NWS weather stations. Symbol * next to the basin name indicates that the basins was assigned the measured mean monthly wind speed.

BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
142	Alkali Spring Valley*	2.8	3.1	3.3	3.5	3.1	3.1	2.8	2.8	2.7	2.6	2.7	2.7	2.9
111B	Alkali Valley	2.0	2.3	2.7	2.9	2.6	2.5	2.2	2.2	2.1	2.0	2.1	2.2	2.3
230	Amargosa Desert*	1.8	2.2	2.3	3.0	2.7	2.9	2.9	2.8	2.3	2.0	1.7	1.7	2.4
57	Antelope Valley*	1.6	2.0	2.2	2.5	2.6	2.5	2.2	2.1	2.0	1.8	1.7	1.7	2.1
106	Antelope Valley	1.9	2.1	2.6	2.9	2.8	2.7	2.5	2.4	2.4	1.9	2.0	2.3	2.4
186B	Antelope Valley	2.4	2.4	2.7	3.0	2.8	2.9	2.6	2.6	2.4	2.4	2.3	2.3	2.6
137A	Big Smoky Valley*	3.2	3.5	3.9	4.3	4.1	4.2	3.5	3.4	3.5	3.6	3.4	3.0	3.6
137B	Big Smoky Valley*	2.0	2.4	2.9	3.3	3.0	3.2	2.9	2.7	2.5	2.4	2.4	2.3	2.7
215	Black Moutains Area	1.8	2.0	2.3	2.6	2.5	2.5	2.2	2.2	2.1	1.9	1.8	1.7	2.1
28	Black Rock Desert	2.0	2.2	2.6	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.1	2.4
61	Boulder Flat	1.7	2.0	2.3	2.5	2.4	2.4	2.3	2.2	2.0	1.8	1.8	1.8	2.1
38	Bruneau River Area	2.4	2.5	2.9	2.9	2.8	2.8	2.7	2.6	2.4	2.4	2.6	2.5	2.6
129	Buena Vista Valley	1.8	2.1	2.4	2.6	2.6	2.6	2.4	2.3	2.1	2.0	1.9	1.9	2.2
131	Buffalo Valley	1.8	2.0	2.3	2.5	2.5	2.5	2.3	2.3	2.1	1.9	1.9	1.8	2.2
101	Carson Desert*	1.3	1.7	2.0	2.2	1.8	1.8	1.4	1.3	1.3	1.1	1.3	1.5	1.6
105	Carson Valley*	1.6	1.6	2.4	2.5	2.3	2.0	1.8	1.7	1.7	1.6	1.6	1.8	1.9
102	Churchill Valley	1.6	2.0	2.3	2.6	2.3	2.1	1.9	1.8	1.8	1.6	1.8	1.8	2.0
143	Clayton Valley	2.8	3.2	3.4	3.6	3.2	3.2	2.9	2.8	2.8	2.8	2.8	2.8	3.0
177	Clover Valley	2.3	2.3	2.7	2.9	2.8	2.8	2.6	2.5	2.3	2.3	2.3	2.3	2.5
204	Clover Valley	1.9	2.0	2.3	2.7	2.6	2.7	2.5	2.4	2.4	2.1	1.9	1.8	2.3
64	Clovers Area	1.9	2.1	2.5	2.6	2.6	2.5	2.4	2.3	2.2	2.0	2.0	1.9	2.2
213	Colorado Valley	2.6	2.7	2.7	2.8	2.6	2.2	1.8	1.7	1.6	1.9	2.3	2.9	2.3
118	Columbus Salt Marsh Valley	2.6	3.0	3.2	3.5	3.1	3.0	2.7	2.6	2.6	2.7	2.7	2.6	2.8
126	Cowkick Valley	1.8	2.1	2.3	2.6	2.6	2.5	2.5	2.3	2.1	1.9	1.9	1.9	2.2
54	Crescent Valley	1.6	1.9	2.3	2.4	2.4	2.4	2.2	2.1	2.0	1.8	1.7	1.7	2.1
103	Dayton Valley	1.8	2.0	2.6	2.9	2.6	2.3	2.2	2.0	2.0	1.8	2.0	2.1	2.2
31	Desert Valley	2.2	2.4	2.7	2.8	2.8	2.8	2.6	2.5	2.4	2.3	2.3	2.2	2.5
153	Diamond Valley*	1.7	1.9	2.6	3.0	2.3	2.2	1.9	1.8	1.8	1.8	1.9	2.0	2.1
48	Dixie Creek-Tenmile Creek Area	1.8	2.0	2.3	2.5	2.4	2.4	2.2	2.1	2.0	1.9	1.9	1.9	2.1
128	Dixie Valley	1.7	2.0	2.3	2.6	2.6	2.5	2.4	2.2	2.1	1.9	1.9	1.8	2.1

Appendix 4b cont. Interpolated or assigned basin average mean monthly wind speed (m/s) used for assignment to respective weather stations. Symbol * next to the basin name indicates that the basins was assigned the measured mean monthly wind speed.

BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
82	Dodge Flat	1.7	2.1	2.5	2.9	2.7	2.4	2.3	2.2	2.1	1.8	2.0	2.1	2.2
104	Eagle Valley	2.0	2.0	2.7	3.0	2.7	2.3	2.2	2.0	2.0	1.8	2.1	2.4	2.3
200	Eagle Valley	2.1	2.4	2.7	3.1	3.1	3.3	2.9	2.8	2.8	2.5	2.3	2.2	2.7
127	Eastgate Valley Area	1.9	2.2	2.3	2.6	2.6	2.5	2.4	2.3	2.1	1.9	2.0	2.0	2.2
167	Eldorado Valley	2.2	2.5	2.8	3.1	3.1	3.0	2.7	2.6	2.4	2.3	2.2	2.2	2.6
49	Elko Segment	1.6	1.8	2.1	2.3	2.2	2.2	2.1	1.9	1.8	1.6	1.7	1.6	1.9
76	Fernley Area	1.7	2.1	2.4	2.8	2.6	2.3	2.2	2.1	1.9	1.7	1.9	2.0	2.1
117	Fish Lake Valley*	3.2	3.8	3.8	4.1	3.2	3.2	2.9	2.8	2.8	3.1	3.1	3.3	3.3
227A	Fortymile Canyon	2.0	2.3	2.5	3.1	2.8	2.9	2.8	2.7	2.3	2.2	1.9	1.9	2.4
122	Gabbs Valley	2.0	2.4	2.6	2.9	2.8	2.7	2.5	2.3	2.2	2.1	2.2	2.1	2.4
172	Garden Valley*	1.1	1.3	1.6	1.9	1.8	1.8	1.7	1.6	1.5	1.2	1.1	1.1	1.5
187	Goshute Valley*	2.5	2.4	2.8	3.1	3.0	3.0	2.8	2.7	2.5	2.4	2.4	2.4	2.7
71	Grass Valley	2.1	2.3	2.6	2.7	2.7	2.7	2.6	2.5	2.3	2.2	2.2	2.1	2.4
138	Grass Valley	1.8	2.1	2.4	2.7	2.6	2.5	2.3	2.2	2.1	2.0	1.9	1.9	2.2
192	Great Salt Lake Desert	2.3	2.3	2.7	2.9	2.8	2.8	2.6	2.5	2.4	2.3	2.3	2.3	2.5
6	Guano Valley	3.6	3.2	3.4	3.3	3.0	2.9	2.6	2.5	2.4	2.8	3.3	3.5	3.0
156	Hot Creek*	1.4	1.8	2.3	2.6	2.6	2.6	2.4	2.3	2.1	1.9	1.7	1.6	2.1
156	Hot Creek	1.4	1.8	2.3	2.6	2.6	2.6	2.4	2.3	2.1	1.9	1.7	1.6	2.1
24	Hualapai Flat	1.9	2.1	2.5	2.8	2.7	2.6	2.5	2.4	2.2	2.1	2.0	2.0	2.3
47	Huntington Valley	2.2	2.4	2.7	3.0	2.8	2.7	2.4	2.4	2.3	2.3	2.3	2.3	2.5
72	Imlay Area	2.0	2.3	2.5	2.7	2.7	2.7	2.5	2.4	2.3	2.1	2.1	2.0	2.4
72	Imlay Area	2.0	2.3	2.5	2.7	2.7	2.7	2.5	2.4	2.3	2.1	2.1	2.0	2.4
36	Independence Valley	2.2	2.3	2.7	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.3	2.3	2.4
161	Indian Springs Valley	2.0	2.2	2.5	2.9	2.8	2.8	2.7	2.5	2.3	2.1	2.0	1.9	2.4
135	Ione Valley	2.4	2.7	2.9	3.2	3.1	3.1	2.8	2.6	2.6	2.5	2.5	2.4	2.7
164A	Ivanpah Valley	2.2	2.5	2.9	3.2	3.2	3.1	2.8	2.7	2.5	2.3	2.3	2.2	2.7
174	Jakes Valley	2.3	2.5	2.8	3.0	2.9	2.9	2.7	2.7	2.6	2.5	2.4	2.4	2.6
39	Jarbidge River Area	2.3	2.4	2.8	2.9	2.8	2.8	2.6	2.5	2.4	2.3	2.5	2.4	2.6
30A	Kings River Valley	2.3	2.4	2.9	2.9	2.8	2.8	2.7	2.6	2.4	2.4	2.4	2.3	2.6
90	Lake Tahoe Basin	1.9	2.0	2.7	2.9	2.6	2.3	2.1	2.0	2.0	1.8	2.0	2.3	2.2
183	Lake Valley	1.9	2.0	2.3	2.5	2.5	2.6	2.4	2.3	2.2	2.1	1.9	1.9	2.2
45	Lamoille Valley	1.9	2.0	2.4	2.6	2.5	2.4	2.3	2.2	2.1	1.9	2.0	1.9	2.2
212	Las Vegas Valley	2.4	2.8	3.3	3.6	3.7	3.6	3.3	3.1	2.9	2.6	2.5	2.4	3.0
92A	Lemmon Valley*	1.6	2.2	2.4	2.9	2.7	2.7	2.6	2.5	2.2	1.9	1.9	2.3	2.3
92B	Lemmon	1.6	2.2	2.4	2.9	2.7	2.7	2.6	2.5	2.2	1.9	1.9	2.3	2.3

Appendix 4b cont. Interpolated or assigned basin average mean monthly wind speed (m/s) used for assignment to respective weather stations. Symbol * next to the basin name indicates that the basins was assigned the measured mean monthly wind speed.

BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
	Valley													
155A	Little Smoky Valley	2.1	2.3	2.7	3.1	2.8	2.8	2.5	2.5	2.4	2.3	2.2	2.1	2.5
73	Lovelock Valley*	1.8	2.2	2.5	2.9	3.0	2.9	2.6	2.4	2.2	2.0	1.8	1.7	2.3
205	Lower Meadow V. W	1.7	1.8	2.1	2.4	2.3	2.3	2.2	2.1	2.0	1.8	1.7	1.6	2.0
220	Lower Moapa Valley*	1.4	1.5	1.6	1.9	1.8	1.8	1.5	1.6	1.5	1.4	1.3	1.3	1.5
59	Lower Reese River Valley*	1.3	1.7	2.0	2.1	2.2	2.2	2.1	2.0	1.9	1.5	1.4	1.4	1.8
52	Marys Creek Area	1.8	2.0	2.3	2.5	2.4	2.4	2.3	2.2	2.0	1.9	1.9	1.8	2.1
42	Marys River Area	2.1	2.3	2.6	2.8	2.7	2.7	2.5	2.4	2.3	2.2	2.2	2.2	2.4
108	Mason Valley*	1.4	2.1	2.0	2.2	1.8	1.5	1.4	1.4	1.4	1.3	1.5	1.5	1.6
225	Mercury Valley	2.0	2.2	2.5	3.0	2.8	2.9	2.8	2.6	2.3	2.1	1.9	1.9	2.4
58	Middle Reese River Valley	1.7	2.0	2.3	2.5	2.5	2.5	2.3	2.1	2.0	1.9	1.8	1.8	2.1
26	Mud Meadow	2.2	2.3	2.7	2.8	2.7	2.6	2.5	2.4	2.2	2.2	2.3	2.3	2.4
44	North Fork Area	2.0	2.2	2.5	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.1	2.1	2.3
228	Oasis Valley	2.3	2.5	2.7	3.1	2.7	2.8	2.7	2.5	2.3	2.3	2.2	2.2	2.5
37	Owyhee River Area	2.5	2.6	3.0	3.0	2.9	2.8	2.7	2.7	2.5	2.4	2.8	2.7	2.7
209	Pahranagat Valley	2.0	2.1	2.4	2.8	2.7	2.7	2.5	2.4	2.3	2.1	1.9	1.9	2.3
162	Pahrump Valley	2.1	2.4	2.7	3.1	2.9	3.0	2.8	2.6	2.4	2.2	2.1	2.0	2.5
203	Panaca Valley	1.9	2.1	2.5	2.8	2.8	2.9	2.6	2.5	2.5	2.2	2.0	1.9	2.4
69	Paradise Valley*	2.1	2.3	3.0	3.0	2.9	2.9	2.9	2.8	2.6	2.5	2.3	2.1	2.6
202	Patterson Valley	1.9	2.1	2.4	2.7	2.7	2.8	2.5	2.5	2.4	2.2	2.0	1.9	2.4
170	Penoyer Valley*	1.9	2.3	2.5	3.1	2.9	3.0	2.9	2.8	2.4	2.1	1.9	1.8	2.5
191	Pilot Creek Valley	2.2	2.3	2.6	2.8	2.7	2.8	2.6	2.5	2.4	2.3	2.3	2.3	2.5
29	Pine Forest Valley	2.3	2.5	2.8	2.9	2.8	2.8	2.6	2.5	2.4	2.3	2.4	2.4	2.6
53	Pine Valley	1.9	2.1	2.5	2.7	2.5	2.5	2.3	2.2	2.1	2.0	2.0	2.0	2.2
214	Piute Valley	2.6	2.7	2.7	2.8	2.6	2.2	1.8	1.7	1.6	1.9	2.3	2.9	2.3
88	Pleasant Valley	2.1	2.3	2.8	3.1	2.9	2.6	2.4	2.3	2.2	2.0	2.3	2.6	2.5
130	Pleasant Valley*	1.7	1.9	2.3	2.4	2.5	2.5	2.3	2.2	2.1	1.9	1.8	1.8	2.1
1	Pueblo Valley	2.5	2.5	2.9	2.9	2.8	2.8	2.6	2.5	2.4	2.4	2.5	2.5	2.6
65	Pumpernickel Valley	2.0	2.2	2.5	2.7	2.7	2.7	2.5	2.4	2.3	2.1	2.1	2.0	2.3
81	Pyramid Lake Valley*	2.5	2.7	3.0	3.2	2.7	2.5	2.3	2.5	2.5	2.5	2.8	3.2	2.7
116	Queen Valley	2.0	2.3	2.6	2.8	2.4	2.3	2.1	2.0	2.0	2.0	2.1	2.1	2.2
33A	Quinn River Valley	2.2	2.3	2.9	2.9	2.9	2.9	2.8	2.7	2.5	2.4	2.4	2.2	2.6
33B	Quinn River	2.3	2.4	2.9	2.9	2.9	2.8	2.7	2.6	2.5	2.4	2.4	2.3	2.6

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BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
	Valley													
173A	Railroad Valley	1.8	2.1	2.4	2.8	2.7	2.7	2.5	2.4	2.2	2.0	1.9	1.8	2.3
173B	Railroad Valley*	1.9	2.1	2.5	2.9	2.7	2.8	2.6	2.6	2.4	2.2	2.0	1.8	2.4
141	Ralston Valley*	3.0	3.3	3.6	3.9	3.7	3.5	3.1	3.1	3.0	3.1	3.1	3.0	3.3
176	Ruby Valley*	2.5	2.7	3.0	3.2	3.0	2.9	2.5	2.5	2.5	2.5	2.6	2.6	2.7
40	Salmon Falls Creek Area	2.1	2.3	2.6	2.8	2.7	2.8	2.6	2.5	2.3	2.3	2.2	2.2	2.5
22	San Emidio Desert	1.7	2.0	2.4	2.7	2.7	2.6	2.4	2.3	2.2	2.0	1.9	1.9	2.2
146	Sarcobatus Flat*	2.3	2.4	2.6	2.7	2.2	2.3	2.2	2.0	1.9	1.9	2.0	2.2	2.2
107	Smith Valley	1.5	1.7	2.1	2.4	2.2	2.0	1.9	1.8	1.8	1.5	1.6	1.7	1.8
21	Smoke Creek Desert*	1.5	2.0	2.5	2.9	2.9	2.9	2.8	2.6	2.4	2.2	1.8	1.6	2.3
195	Snake Valley*	1.5	1.4	1.8	2.0	2.0	2.1	2.0	2.0	1.9	1.6	1.5	1.5	1.8
121A	Soda Spring Valley	2.4	2.8	3.0	3.3	3.0	3.0	2.7	2.6	2.5	2.5	2.5	2.4	2.7
46	South Fork Area	2.1	2.2	2.5	2.8	2.6	2.6	2.4	2.3	2.2	2.1	2.2	2.1	2.3
35	South Fork Owyhee River Area	2.6	2.7	3.0	3.0	3.0	2.8	2.7	2.7	2.5	2.5	2.8	2.7	2.7
184	Spring Valley	2.1	2.2	2.5	2.7	2.6	2.7	2.5	2.5	2.4	2.2	2.1	2.1	2.4
201	Spring Valley	2.0	2.2	2.5	2.8	2.8	2.9	2.7	2.6	2.5	2.3	2.1	2.0	2.5
43	Starr Valley Area	2.0	2.2	2.5	2.7	2.6	2.6	2.4	2.3	2.2	2.1	2.1	2.1	2.3
179	Steptoe Valley	2.6	2.6	2.8	2.9	2.9	2.9	2.8	2.8	2.7	2.6	2.5	2.6	2.7
149	Stone Cabin Valley	2.3	2.6	2.9	3.2	3.1	3.1	2.8	2.7	2.5	2.4	2.4	2.3	2.7
14	Surprise Valley	2.3	2.3	2.6	2.6	2.4	2.3	2.1	2.1	2.0	2.0	2.2	2.3	2.3
114	Teels Marsh Valley	2.2	2.6	2.8	3.1	2.7	2.6	2.3	2.3	2.2	2.3	2.3	2.3	2.5
189A	Thousand Springs Valley	2.1	2.3	2.6	2.8	2.7	2.8	2.6	2.5	2.3	2.3	2.2	2.2	2.4
189D	Thousand Springs Valley	2.1	2.2	2.6	2.8	2.7	2.8	2.6	2.5	2.3	2.3	2.2	2.2	2.4
83	Tracy Segment*	1.5	2.1	2.4	3.1	2.8	2.5	2.4	2.3	2.1	1.8	1.9	1.7	2.2
91	Truckee Canyon Segment	1.9	2.2	2.6	3.0	2.8	2.6	2.4	2.3	2.2	1.9	2.1	2.3	2.3
87	Truckee Meadows*	1.6	2.0	2.5	2.8	2.8	2.7	2.5	2.3	2.0	1.7	1.8	1.7	2.2
56	Upper Reese River Valley	2.0	2.3	2.6	2.8	2.7	2.7	2.5	2.4	2.3	2.1	2.1	2.1	2.4
222	Virgin River Valley	1.4	1.4	1.5	1.7	1.7	1.6	1.7	1.5	1.6	1.3	1.2	1.2	1.5
4	Virgin Valley	3.0	2.8	3.1	3.1	2.9	2.7	2.5	2.5	2.4	2.5	2.9	3.0	2.8
110A	Walker Lake Valley	1.6	2.0	2.3	2.5	2.3	2.0	1.9	1.8	1.8	1.6	1.7	1.8	1.9
110C	Walker Lake Valley	2.0	2.4	2.7	2.9	2.6	2.5	2.3	2.2	2.1	2.0	2.1	2.2	2.3

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BASIN NUMBER	BASIN NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
89	Washoe Valley*	2.6	2.6	3.7	4.3	4.0	3.3	3.2	3.3	3.3	2.8	2.8	3.4	3.3
207	White River Valley	1.9	2.1	2.4	2.7	2.6	2.7	2.5	2.5	2.4	2.2	2.0	1.9	2.3
63	Willow Creek Valley	2.2	2.4	2.7	2.8	2.7	2.7	2.5	2.5	2.3	2.3	2.3	2.3	2.5
70	Winnemucca Segment*	2.5	2.8	2.8	2.9	2.9	2.9	2.8	2.6	2.5	2.4	2.5	2.5	2.7
159	Yucca Flat	2.1	2.3	2.6	3.0	2.8	2.9	2.7	2.6	2.4	2.2	2.1	2.0	2.5

Appendix 5. Crop parameter table listing all parameters used in estimating crop ET, planting or greenup, harvest, killing frost, and runoff.

Parameter	Explanation	Alfalfa Hay	Grass Hay	Beans Fresh	Beans Dry	Field Corn	Silage Corn	Sweet Corn - early	Sweet Corn - late	Spring Grain	Winter Grain
Days after planting or greenup for earliest irrigation		0	0	0	0	0	0	0	0	20	155
Winter surface class	1=bare, 2=mulch, 3=turf	2	3	1	1	1	1	1	1	2	2
MAD during initial and development stage	Maximum Allowable Depletion of soil moisture in percent	60	50	60	60	60	60	60	60	60	60
MAD during midseason and late season	Maximum Allowable Depletion of soil moisture in percent	60	50	50	50	50	50	50	50	50	50
Initial effective rooting depth, m	On alfalfa, 2nd cycle, start at max.	0.7	0.3	0.12	0.12	0.12	0.12	0.12	0.12	0.25	0.25
Maximum effective rooting depth, m		1.8	1.1	1.2	1.2	1.5	1.5	1	1	1.8	1.8
End of root growth, as a fraction of time from planting or greenup to EFC		0.5	0.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Starting crop height, m		0.1	0.1	0.05	0.05	0.1	0.1	0.1	0.1	0.05	0.05
Maximum Crop height, m		0.6	0.6	0.35	0.35	3	3.5	1.5	1.5	1	1
Crop Kcb curve number		13	19	12	11	9	9	10	10	1	2
Crop curve type	1=NCGDD, 2=%PL-EC, 3=%PL-EC,daysafter	1	1	1	1	1	1	1	1	1	1
Flag for means to estimate Greenup	1=CGDD, 2=T30, 3=date, 4 is on all the time	1	2	2	2	2	2	2	2	2	3
T30 for Greenup or CGDD for Greenup	30 day moving average, Degree C	300	7	11	11	9	9	9	12	5	
Date of Greenup (can be blank)	A negative values is an offset to the prior row, pos is months (fraction)										10
For NCGDD based curves: Tbase:	Mean Temp Base Degree C	0	0	5	5	-10	-10	-10	-10	0	0
CGDD for EFC	Cumulative Degree C days from Jan 1	880	1200	670	670	540	540	540	540	840	1080
CGDD for termination		740	3600	1150	1350	1400	1300	1000	1000	1600	1800
time for harvest (neg to extend until frost)	Use as max length for CGDD crops									180	
Killing frost temperature	Degrees C	-7	-5	-2	-2	-5	-4	-4	-5	-100	-100
Invoke Stress	1 yes, 0 no, 2 yes and will recover after severe stress (Ks<0.05)	2	2	1	1	1	1	1	1	2	2
NRCS runoff curve number - coarse soil		60	60	67	67	67	67	67	67	63	65
NRCS runoff curve number - medium soil		68	68	75	75	75	75	75	75	75	75
NRCS runoff curve number - fine soil		77	77	85	85	85	85	85	85	85	85

Appendix 5 cont. Crop parameter table listing all parameters used in estimating crop ET, planting or greenup, harvest, killing frost, and runoff.

Parameter	Explanation	Grass Pasture - high management	Grass Pasture - low management	Grass - Turf	Orchards - Apples and Cherries w/ground cover	Orchards - Apples and Cherries no ground cover	Garden Vegetables - general
Days after planting or greenup for earliest irrigation		0	0	0	0	0	0
Winter surface class	1=bare, 2=mulch, 3=turf	3	3	3	2	1	1
MAD during initial and development stage	Maximum Allowable Depletion of soil moisture in percent	60	60	60	50	50	50
MAD during midseason and late season	Maximum Allowable Depletion of soil moisture in percent	50	50	50	50	50	40
Initial rooting depth, m	On alfalfa, 2nd cycle, start at max.	0.3	0.3	0.3	1.5	1.5	0.12
Maximum rooting depth, m		1	1	0.6	1.5	1.5	0.6
End of root growth, as a fraction of time from planting or greenup to EFC		0.4	0.4	0.4	0.5	0.5	1.2
Starting crop height, m		0.1	0.1	0.05	4	4	0.1
Maximum Crop height, m		0.25	0.15	0.1	4	4	0.4
Crop Kcb curve number		30	31	29	24	25	20
Crop curve type	1=NCGDD, 2=%PL-EC, 3=%PL-EC,daysafter	3	3	2	2	2	2
Flag for means to estimate Greenup	1=CGDD, 2=T30, 3=date, 4 is on all the time	2	2	2	2	2	2
T30 for Greenup or CGDD for Greenup	30 day moving average, Degree C	5	5	5	6	6	10
Time for EFC	Days after planting or greenup	40	50	70	55	55	80
time for harvest (neg to extend until frost)	Use as max length for CGDD crops	-220	-220	-270	-260	-260	200
Killing frost temperature	Degrees C	-5	-5	-5	-5	-5	-2
Invoke Stress	1 yes, 0 no, 2 yes and will recover after severe stress (Ks<0.05)	2	2	2	1	1	1
NRCS runoff curve number - coarse soil		40	40	40	60	65	72
NRCS runoff curve number - medium soil		70	70	70	68	72	80
NRCS runoff curve number - fine soil		82	82	82	70	82	88

Appendix 5 cont. Crop parameter table listing all parameters used in estimating crop ET, planting or greenup, harvest, killing frost, and runoff.

Parameter	Explanation	Onions	Melons	Wine Grapes	Alfalfa Seed	Peas-fresh	Peas-seed	Potatoes-processing (early harvest)	Potatoes-cold pack (late harvest)
Days after planting or greenup for earliest irrigation		0	0	20	0	0	0	0	0
Winter surface class	1=bare, 2=mulch, 3=turf	1	1	1	2	1	1	1	1
MAD during initial and development stage	Maximum Allowable Depletion of soil moisture in percent	50	50	70	70	60	60	50	50
MAD during midseason and late season	Maximum Allowable Depletion of soil moisture in percent	40	50	70	70	50	50	40	40
Initial rooting depth, m	On alfalfa, 2nd cycle, start at max.	0.2	0.2	1	0.7	0.2	0.2	0.3	0.3
Maximum rooting depth, m		0.8	1.2	2	1.5	1	1	0.8	0.8
End of root growth, as a fraction of time from planting or greenup to EFC		1.2	1.2	1	0.5	1	1	1	1
Starting crop height, m		0.1	0.05	1.5	0.1	0.05	0.05	0.05	0.05
Maximum Crop height, m		0.4	0.3	1.5	0.6	0.3	0.3	0.4	0.4
Crop Kcb curve number		20	22	21	33	4	3	7	6
Crop curve type	1=NCGDD, 2=%PL-EC, 3=%PL-EC,daysafter	2	2	2	3	1	1	1	1
Flag for means to estimate Greenup	1=CGDD, 2=T30, 3=date, 4 is on all the time	2	2	2	1	2	2	2	2
T30 for Greenup or CGDD for Greenup	30 day moving average, Degree C	7.5	10	8	240	5	5	5	5
For NCGDD based curves: Tbase:	Temp Min. Degree C				0	0	0	5	5
CGDD for EFC	Cumulative Degree C days from Jan 1					640	640	700	740
CGDD for termination						1000	1620	1350	1900
Time for EFC	Days after planting or greenup	70	70	80	80				
time for harvest (neg to extend until frost)	Use as max length for CGDD crops	220	145	-270	100				
Killing frost temperature	Degrees C	-2	-2	-3	-7	-4	-4	-5	-5
Invoke Stress for rainfed agriculture	1 yes, 0 no, 2 yes and will recover after severe stress (Ks<0.05)	1	1	1	1	1	1	1	1
NRCS runoff curve number - coarse soil		72	72	65	60	63	63	70	70
NRCS runoff curve number - medium soil		80	80	72	68	70	70	76	76
NRCS runoff curve number - fine soil		88	88	82	77	82	82	88	88

Appendix 5 cont. Crop parameter table listing all parameters used in estimating crop ET, planting or greenup, harvest, killing frost, and runoff.

Parameter	Explanation	Sugar beets	Hops	Sunflower	Safflower	Canola
Days after planting or greenup for earliest irrigation		0	0	0	0	0
Winter surface class	1=bare, 2=mulch, 3=turf	1	1	1	2	2
MAD during initial and development stage	Maximum Allowable Depletion of soil moisture in percent	50	50	60	60	60
MAD during midseason and late season	Maximum Allowable Depletion of soil moisture in percent	50	50	60	60	60
Initial rooting depth, m	On alfalfa, 2nd cycle, start at max.	0.15	1	0.2	0.2	0.2
Maximum rooting depth, m		1.3	1.5	2.5	2.5	1.6
End of root growth, as a fraction of time from planting or greenup to EFC		1.2	1	1.2	1.2	1.2
Starting crop height, m		0.05	1	0.1	0.1	0.1
Maximum Crop height, m		0.35	6	2	1	1
Crop Kcb curve number		5	23	28	28	27
Crop curve type	1=NCGDD, 2=%PL-EC, 3=%PL-EC,daysafter	1	2	2	2	2
Flag for means to estimate Greenup	1=CGDD, 2=T30, 3=date, 4 is on all the time	2	1	2	2	2
T30 for Greenup or CGDD for Greenup	30 day moving average, Degree C	8	600	10	8	8
For NCGDD based curves: Tbase:	Temp Min. Degree C	0	0			
CGDD for EFC	Cumulative Degree C days from Jan 1	970				
CGDD for termination		2600				
Time for EFC	Days after planting or greenup		100	70	70	55
time for harvest (neg to extend until frost)	Use as max length for CGDD crops		170	170	170	170
Killing frost temperature	Degrees C	-4	-2	-4	-4	-4
Invoke Stress	1 yes, 0 no, 2 yes and will recover after severe stress (Ks<0.05)	1	1	1	1	1
NRCS runoff curve number - coarse soil		67	65	58	58	58
NRCS runoff curve number - medium soil		74	72	72	72	72
NRCS runoff curve number - fine soil		86	82	83	83	83

Appendix 5 cont. Crop parameter table listing all parameters used in estimating crop ET, planting or greenup, harvest, killing frost, and runoff.

Parameter	Explanation	Garlic	Bare soil	Mulched soil - including wheat stubble	Dormant Turf (winter time)	Open water - shallow systems
Days after planting or greenup for earliest irrigation		0	NA	NA	NA	NA
Winter surface class	1=bare, 2=mulch, 3=turf	1	1	2	3	NA
MAD during initial and development stage	Maximum Allowable Depletion of soil moisture in percent	50	60	60	60	NA
MAD during midseason and late season	Maximum Allowable Depletion of soil moisture in percent	40	60	60	60	NA
Initial rooting depth, m	On alfalfa, 2nd cycle, start at max.	0.2	0.08	0.08	0.08	NA
Maximum rooting depth, m		0.8	0.08	0.08	0.08	NA
End of root growth, as a fraction of time from planting or greenup to EFC		1.2	1	1	1	NA
Starting crop height, m		0.1	0.05	0.05	0.05	NA
Maximum Crop height, m		0.4	0.05	0.05	0.05	NA
Crop Kcb curve number		20	0	0	0	NA
Crop curve type	1=NCGDD, 2=%PL-EC, 3=%PL-EC,daysafter	2	NA	NA	NA	NA
Flag for means to estimate Greenup	1=CGDD, 2=T30, 3=date, 4 is on all the time	2	4	4	4	NA
T30 for Greenup or CGDD for Greenup	30 day moving average, Degree C	7.5				
Time for EFC	Days after planting or greenup	70				
time for harvest (neg to extend until frost)	Use as max length for CGDD crops	200				
Killing frost temperature	Degrees C	-2	-50	-50	-50	NA
Invoke Stress	1 yes, 0 no, 2 yes and will recover after severe stress (Ks<0.05)	1	2	2	2	NA
NRCS runoff curve number - coarse soil		72	58	58	40	NA
NRCS runoff curve number - medium soil		80	72	72	70	NA
NRCS runoff curve number - fine soil		88	83	83	82	NA

Appendix 6. Basal crop coefficient (K_{cb}) curve values for crop types simulated.

Type of K_{cb} Curve	1	1	1	1	1	1	1
X axis = NCGDD*100 (type 1)	Spring Wheat	Winter Wheat	Peas, seed	Peas, fresh	Sugar Beets	Potatoes--cold pack (late harvest)	Potatoes--processing (early harvest)
0	0.18	0.14	0.14	0.14	0.18	0.18	0.18
10	0.18	0.14	0.17	0.17	0.18	0.18	0.18
20	0.24	0.18	0.18	0.18	0.19	0.18	0.18
30	0.34	0.24	0.19	0.19	0.2	0.2	0.2
40	0.48	0.32	0.24	0.24	0.22	0.28	0.28
50	0.6	0.48	0.38	0.38	0.25	0.42	0.42
60	0.71	0.86	0.55	0.55	0.48	0.58	0.58
70	0.98	1.12	0.76	0.76	0.68	0.74	0.74
80	1.14	1.19	0.92	0.92	0.88	0.83	0.83
90	1.19	1.24	1.02	1.02	1.06	0.89	0.89
100	1.24	1.24	1.1	1.1	1.24	0.92	0.92
110	1.24	1.24	1.1	1.1	1.24	0.92	0.92
120	1.24	1.24	1.1	1.1	1.24	0.92	0.91
130	1.24	1.24	1.09	1.09	1.24	0.9	0.86
140	1.24	1.22	1.01	1.01	1.22	0.86	0.84
150	1.24	1.2	0.94	0.94	1.21	0.84	0.82
160	1.24	0.86	0.85	0.85	1.19	0.82	0.78
170	1.21	0.52	0.78	0.78	1.16	0.79	0.76
180	1.16	0.3	0.7		1.14	0.77	0.71
190	1.06	0.18	0.62		1.09	0.73	0.65
200	0.77	0.12	0.54		1.04	0.7	0.48
210	0.49	0.06	0.46		0.98	0.65	0.12
220	0.34		0.37		0.92	0.58	
230	0.19		0.32		0.88	0.19	
240	0.12		0.26		0.83	0.12	
250	0.06		0.22		0.76		
260			0.17		0.68		
270			0.12		0.12		

Appendix 6 cont. Basal crop coefficient (K_{cb}) curve values for crop types simulated.

Type of K_{cb} Curve	1	1	1	1	1	1	1	1
X axis = NCGDD*100 (type 1)	Field Corn	Sileage Corn	Sweet Corn	Snap Beans-dry	Snap Beans-fresh	Alfalfa 1st cycle	Alfalfa Int cycle	Alfalfa Last cycle
0	0.18	0.18	0.18	0.18	0.18	0.3	0.3	0.3
10	0.18	0.18	0.18	0.19	0.19	0.61	0.4	0.35
20	0.18	0.18	0.18	0.23	0.23	0.88	0.54	0.46
30	0.2	0.2	0.2	0.28	0.28	1.01	0.96	0.67
40	0.23	0.23	0.23	0.46	0.46	1.08	1.12	0.95
50	0.34	0.34	0.34	0.59	0.59	1.18	1.19	1.09
60	0.5	0.5	0.5	0.72	0.72	1.2	1.2	1.15
70	0.65	0.65	0.65	0.89	0.89	1.2	1.19	1.2
80	0.88	0.88	0.88	1.03	1.03	1.19	1.16	1.19
90	1.03	1.03	1.03	1.13	1.13	1.16	1.15	1.15
100	1.15	1.15	1.15	1.14	1.14	1.15	1.13	1.13
110	1.15	1.15	1.15	1.14	1.14			
120	1.15	1.15	1.14	1.14	1.14			
130	1.15	1.15	1.13	1.12	1.12			
140	1.15	1.15	1.12	1.08	1.08			
150	1.13	1.13	1.08	1.02	1.02			
160	1.08	1.08	1.03	0.9	0.9			
170	1.03	1.03	0.98	0.77				
180	0.98	0.98		0.59				
190	0.94	0.94		0.41				
200	0.88	0.88		0.23				
210	0.78	0.78		0.1				
220	0.53	0.24						
230	0.26	0.12						
240	0.16	0.12						

Appendix 6 cont. Basal crop coefficient (K_{cb}) curve values for crop types simulated.

Type of K_{cb} Curve	1	1	1	2	2	2	2	2	2	2
X axis = NCGDD*100 or % Time to EFC (type 1 and 2)	Lentils	Mint	Grass Hay	Onions	Garlic	Wine grapes	Melons	Hops	Orchard w/GC	Orchard w/no GC
0	0.18	0.42	0.24	0.18	0.18	0.19	0.18	0.12	0.18	0.18
10	0.18	0.61	0.55	0.18	0.18	0.22	0.18	0.12	0.24	0.18
20	0.22	0.88	0.82	0.18	0.18	0.26	0.2	0.12	0.29	0.22
30	0.3	1.01	0.95	0.29	0.29	0.31	0.24	0.14	0.4	0.3
40	0.43	1.08	1.02	0.4	0.4	0.44	0.29	0.16	0.53	0.42
50	0.54	1.18	1.12	0.49	0.49	0.67	0.37	0.38	0.66	0.53
60	0.64	1.2	1.14	0.62	0.62	0.78	0.53	0.66	0.79	0.68
70	0.89	1.2	1.14	0.74	0.74	0.78	0.67	0.83	0.92	0.79
80	1.03	1.19	1.13	0.85	0.85	0.78	0.78	0.95	1.01	0.86
90	1.07	1.16	1.1	0.9	0.9	0.78	0.78	1.04	1.04	0.9
100	1.12	1.15	1.09	0.9	0.9	0.78	0.78	1.15	1.08	0.9
110	1.12	0.3	0.6	0.9	0.9	0.78	0.78	1.2	1.08	0.9
120	1.12	0.4	0.66	0.9	0.9	0.78	0.78	1.2	1.08	0.9
130	1.12	0.54	0.84	0.9	0.9	0.78	0.78	1.2	1.08	0.9
140	1.12	0.9	0.9	0.9	0.9	0.78	0.78	1.16	1.08	0.9
150	1.12	0.9	0.9	0.9	0.78	0.78	0.78	1.07	1.08	0.9
160	1.12	0.9	0.9	0.9	0.67	0.78	0.78	0.85	1.08	0.9
170	1.09	0.9	0.9	0.78	0.56	0.78	0.78	0.62	1.08	0.9
180	1.04	0.9	0.9	0.67	0.46	0.78	0.78	0.36	1.08	0.9
190	0.95	0.9	0.84	0.56		0.72	0.78	0.31	1.08	0.9
200	0.7	0.9	0.84	0.46		0.72	0.78	0.26	1.08	0.9
210	0.44	0.9	0.84			0.72	0.78		1.08	0.9
220	0.3	0.9	0.78			0.72	0.78		0.88	0.84
230	0.19	0.9	0.78			0.72	0.78		0.66	0.66
240	0.12	0.9	0.78			0.72	0.78		0.66	0.66
250		0.9	0.72			0.72	0.78		0.66	0.66
260		0.9	0.66			0.72	0.78		0.66	0.66
270		0.9	0.6			0.72	0.78		0.66	0.66
280			0.54							
290			0.54							
300			0.54							

Appendix 6 cont. Basal crop coefficient (K_{cb}) curve values for crop types simulated.

Type of K_{cb} Curve		2	2	2	3	3	3
X axis = % Time to EFC (type 2)	X axis = % Time to EFC then days after (type 3)	Canola	Sunflower/ Safflower	Turf	Grass Pasture - high management	Grass Pasture - low management	Alfalfa Seed
0	0	0.18	0.18	0.18	0.35	0.26	0.42
10	10	0.18	0.18	0.3	0.42	0.31	0.6
20	20	0.18	0.18	0.46	0.5	0.38	0.72
30	30	0.23	0.23	0.58	0.6	0.46	0.8
40	40	0.35	0.35	0.71	0.71	0.53	0.88
50	50	0.79	0.67	0.78	0.84	0.64	0.95
60	60	1.02	0.9	0.84	0.89	0.66	0.98
70	70	1.14	1.02	0.84	0.92	0.7	1
80	80	1.16	1.04	0.84	0.96	0.72	1.01
90	90	1.16	1.04	0.84	0.96	0.72	1.01
100	100	1.16	1.04	0.84	0.96	0.72	1.02
110	0	1.16	1.04	0.84	0.96	0.72	1.02
120	10	1.16	1.04	0.84	0.96	0.72	1.02
130	20	1.16	1.04	0.84	0.96	0.72	1.02
140	30	1.15	1.03	0.84	0.96	0.72	1.02
150	40	0.97	0.85	0.84	0.96	0.72	1
160	50	0.7	0.58	0.84	0.96	0.72	0.97
170	60	0.43	0.37	0.84	0.96	0.72	0.95
180	70	0.3	0.24	0.84	0.96	0.72	0.84
190	80	0.12	0.12	0.84	0.96	0.71	0.68
200	90			0.84	0.95	0.7	0.54
210	100			0.84	0.92	0.68	0.48
220	110			0.84	0.9	0.67	0.48
230	120			0.84	0.84	0.65	
240	130			0.84	0.78	0.62	
250	140			0.84	0.72	0.6	
260	150			0.84	0.66	0.48	
270	160			0.84	0.6	0.36	
	170				0.48	0.36	
	180				0.48	0.36	
	190				0.48	0.36	
	200				0.48	0.36	
	210				0.48	0.36	
	220				0.48	0.36	
	230				0.48	0.36	

Appendix 7. Description of greenup and harvest information used in calibrating the cumulative growing degree day and T30 parameters controlling simulated greenup and harvest dates.

The calibration of parameters T_{30}, CGDD, controlling the greenup or planting dates and harvest dates was accomplished by comparing simulated mean annual dates to documented and typical dates of greenup or planting, and cutting and harvest dates for major crops grown in valleys discussed in the paragraphs below. Table 4 in the main body outlines the calibration information used for multiple crops.

Alfalfa grown in Carson Valley, Douglas County, typically greens up in early April and the typical beef hay alfalfa farmer gets a first cutting in the second week of June, second cutting in the first week of August, and last cutting in mid September. After the third cutting the crop is left for grazing and it is not irrigated, usually due to a shortage of water. Typical beef hay yields range between 4 and 4.5 tons per acre (Andy Aldax, verbal communication, 2008). The dairy hay farmer that irrigates with center pivots usually sees greenup occur in early April and the alfalfa usually reaches full cover by the mid May, and as a rule of thumb makes the first cutting at the end of May with 28-35 days between cuttings. The fourth and last cutting usually takes more time and occurs in mid September. Typical yields for dairy hay average about 5.5 tons per acre (Jim Usher, Bently Farms, verbal communication, 2008).

In the Boulder Flat hydrographic area, located in Eureka County, dairy and beef alfalfa hay is the primary crop and is largely irrigated from water derived from dewatering activities at surrounding mine sites. The greenup and harvest times of are very similar to Carson Valley where greenup occurs around the first of April and is first cut around the end of May to the beginning of June, with approximately 30-35 days in between cuttings. Some years however a fourth cutting is not attainable due to weather conditions of the season (Dan Gralian, TS Ranch, written communication, 2008).

In the Mason and Smith Valley hydrographic areas, located in Lyon County, beef and dairy hay are the primary crops grown, however the valleys are famous for producing some of the best quality onions in the country. Alfalfa greenup dates in Mason and SmithValley typically occur in mid to late March to early April and cutting dates usually occurs every 35 to 45 days beginning in the end of May to early June (John Snyder, verbal communication, 2009). Onion crops in Mason Valley are typically planted in mid March and greenup occurs 3 to 4 weeks after planting. Harvest of onions usually takes place in late August and continues throughout September depending on the variety. After harvest the fields are fallow until the next seasons planting (Peri and Sons, verbal communication, 2008, John Snyder, verbal communication, 2009). Garlic is commonly grown in Mason Valley and is typically harvested 2-3 weeks before onions. Irrigation is usually ceased by early to mid August to allow drying of the garlic (John Snyder, verbal communication, 2009).

Fallon, located in the Carson Desert hydrographic area, Churchill County, is well known for producing beef and dairy hay alfalfa and melons. Melons are a 90 day crop and are typically planted in early May, greenup occurs 10-12 days after planting, and harvest occurs in the middle of August (Workman Farms & Latin Farms, verbal communication, 2008). Fresh beans are typically planted in the middle of May and are harvested in the middle of August. Sweet corn being a 70-90 day crop is planted around the first of May and is harvested by the middle August to early September, and silage corn is planted at the same time as sweet corn but is grown longer and harvested around the middle to late September (Latin Farms, verbal communication, 2008). Alfalfa greenup usually occurs at the end of March with cuttings beginning in early to mid June, with 30 – 40 days between cuttings, and ending in late September to mid October with 3 to 4 cuttings.

Paradise Valley, located in Humboldt County, is a large agricultural area that is well known for its potatoes, but also produces wheat and dairy and beef alfalfa hay. Potatoes are grown for the processing and fresh market industry and are typically planted around early April to mid May. Processing potatoes are harvested beginning in mid August through mid September while fresh potatoes are harvested beginning in September through mid October (Verbal Communication, Shane Cheyne, Winnemucca Farms, 2008). Winter wheat is typically planted during the mid part of September through October and is harvested in mid to late July. Spring wheat is typically planted in late March, greens up in mid April, and is harvested in mid July to mid August.

Lake Valley, located in Lincoln County and White Pine counties, is home to Atlanta Farms, which produces large quantities of dairy and beef alfalfa hay and fresh potatoes. Greenup of alfalfa usually occurs in mid April, with the first cutting in mid June, and subsequent cuttings every 35-45 days after, with 3-4 cuttings. Potatoes are planted in mid April to mid May and harvest usually occurs in mid September through early October (Verbal Communication, Joseph Harker, Atlanta Farms, 2009).

Antelope Valley, located in Lander County, primarily produces dairy hay alfalfa. Typical greenup occurs between April 1 – 15, with effective full cover occurring around the mid to end of May, the first cutting occurring between June 15, the second cutting occurring near the beginning of August, and the last and third cutting occurring near Sept 15. Spring wheat is grown as a rotation crop is planted in mid April and is harvested in middle to late July (verbal communication, Allen Farr, Farr Farms, 2008).

In Moapa Valley, located in Clark County, dairy hay alfalfa is the primary crop grown and typically greens up near mid February, where the first cutting is generally within the first week of April and a 30 day period between cuttings with typically 7 cutting per year. The last cutting usually occurs in the mid part of November (verbal communication, Glenn Hardy, 2007). Typical annual alfalfa yields were stated to be about 8 tons per acre. After 3 to 4 years of alfalfa production Sudan grass and winter wheat are the typical rotation crops.

Appendix 8. Weather station aridity ratings following Allen and Brockway (1983), estimated from station photos, and high resolution image analysis (0= irrigated area, 100=completely arid).

Station Name	NOAA #	Station Aridity	Area Aridity	Regional Aridity	Cumulative Aridity
ADAVEN	260046	30	70	100	57
ALAMO	260099	30	60	80	50
AMARGOSA FARMS-GAREY	260150	90	90	100	91
ANTELOPE VALLEY FARR	260282	50	60	80	58
ARTHUR 4 NW	260438	50	60	70	57
AUSTIN #2	260507	90	80	80	84
BASALT	260668	100	100	100	100
BATTLE MTN	260688	80	70	70	74
BATTLE MTN AP	260691	100	80	70	87
BEATTY	260715	100	80	90	89
BEATTY 8 N	260718	90	90	100	91
BEOWAWE	260795	90	60	70	73
BEOWAWE U OF N RCH	260800	20	40	80	36
BLUE EAGLE RCH HANKS	260955	30	50	90	46
BLUE JAY HWY STN	260961	100	100	100	100
BOULDER CITY	261071	100	90	90	94
BRINKERHOFF RCH	261160	100	90	100	95
BUFFALO RCH	261311	90	90	90	90
BUNKERVILLE	261327	70	70	90	72
CALIENTE	261358	60	70	90	68
CALLVILLE BAY	261371	100	70	90	84
CARLIN NEWMONT MINE	261415	100	100	90	99
CARSON CITY	261485	100	80	70	87
CATHEDRAL GORGE SP	261590	90	90	90	90
CENTRAL NEVADA FLD LAB	261630	70	60	90	67
CHARLESTON	261660	70	60	80	66
CLOVER VALLEY	261740	20	30	90	32
COALDALE JUNCTION	261755	100	100	100	100
CONTACT	261905	100	80	90	89
CORTEZ GOLD MINE	261975	100	100	100	100
CURRANT	262078	50	30	90	44
CURRANT HWY STN	262091	100	100	100	100
CURRIE HWY STN	262096	80	70	90	76

Appendix 8 cont. Weather station aridity ratings following Allen and Brockway (1983), estimated from station photos, and high resolution image analysis (0= irrigated area, 100=completely arid).

Station Name	NOAA #	Station Aridity	Area Aridity	Regional Aridity	Cumulative Aridity
DAGGET PASS	262119	70	60	60	64
DENIO	262229	70	60	80	66
DESERT NWR	262243	80	90	100	87
DIABLO	262276	100	100	100	100
DIAMOND VALLEY USDA	262296	70	20	40	42
DUCKWATER	262390	60	60	80	62
DUFURRENA	262394	80	60	90	71
DYER	262431	90	90	90	90
EASTGATE	262477	90	90	100	91
ECHO BAY	262497	100	80	70	87
ELGIN	262557	60	90	90	78
ELGIN 3 SE	262562	60	90	90	78
ELKO	262570	70	70	90	72
ELKO RGNL AP	262573	100	70	80	83
ELY 6 NE	262626	90	90	90	90
ELY YELLAND FLD AP	262631	100	100	90	99
EMIGRANT PASS HWY STN	262656	90	90	100	91
EMPIRE	262662	70	90	100	83
EUREKA	262708	90	90	100	91
FALLON EXP STN	262780	50	70	50	60
FERGUSON SPRINGS HMS	262820	90	90	90	90
FERNLEY	262840	100	100	100	100
FISH CREEK RCH	262860	20	40	80	36
GERLACH	263090	100	90	100	95
GEYSER RCH	263101	60	70	90	68
GIBBS RCH	263114	50	50	70	52
GLENBROOK	263205	50	70	70	62
GOLCONDA	263245	100	100	100	100
GOLDFIELD	263285	100	100	100	100
GOODSPRINGS	263316	80	100	100	92
GREAT BASIN NP	263340	70	80	100	78
HAWTHORNE	263512	90	100	100	96
HAWTHORNE AP	263515	80	90	100	87
HIKO	263671	50	50	70	52
HUMBOLDT FLD	263853	90	100	100	96
I-L RCH	263940	80	80	90	81
IMLAY	263957	90	90	100	91
INDIAN SPRINGS	263980	100	100	100	100
JACKPOT	264016	70	90	100	83

Appendix 8 cont. Weather station aridity ratings following Allen and Brockway (1983), estimated from station photos, and high resolution image analysis (0= irrigated area, 100=completely arid).

Station Name	NOAA #	Station Aridity	Area Aridity	Regional Aridity	Cumulative Aridity
JARBRIDGE 4 N	264038	100	100	100	100
JARBIDGE 7 N	264039	40	70	100	61
JIGGS 8 SSE ZAGA	264095	70	90	100	83
JUNGO MEYER RCH	264108	80	90	100	87
KIMBERLY	264199	100	100	100	100
KNOLL CREEK FLD	264268	60	60	100	64
KYLE CANYON RS	264314	80	80	100	82
LAGES	264341	90	100	100	96
LAHONTAN DAM	264349	100	90	100	95
LAKE VALLEY STEWARD	264384	80	90	100	87
LAMOILLE YOST	264394	80	100	90	91
LAMOILLE PH	264395	80	90	90	86
LAS VEGAS	264429	100	100	100	100
LAS VEGAS WB AP	264436	100	100	100	100
LAS VEGAS NWFO	264439	100	100	100	100
LATHROP WELLS	264457	90	100	100	96
LAUGHLIN	264480	100	100	100	100
LEHMAN CAVES NM	264514	80	100	100	92
LEONARD CREEK RCH	264527	60	80	100	74
LEWERS RCH	264542	20	30	40	27
LITTLE RED ROCK	264600	100	100	100	100
LOGANDALE	264651	60	60	60	60
LOVELOCK DERBY FLD	264700	100	100	100	100
LUND	264745	60	60	80	62
MALA VISTA RCH	264824	60	50	80	57
MARLETTE LAKE	264858	80	80	80	80
MCDERMITT	264935	80	80	100	82
MCGILL	264950	80	90	100	87
MESQUITE	265085	70	70	80	71
METROPOLIS	265092	60	70	90	68
MIDAS 4 SE	265105	60	70	90	68
MIDDLEGATE-LOWERY	265132	100	100	100	100
MINA	265168	100	100	100	100
MINDEN	265191	10	30	30	22
MONTELLO 2 SE	265352	60	70	80	67
MONTGOMERY MNTC STN	265362	100	100	100	100
MOORMAN RCH	265371	100	100	100	100
MTN CITY RS	265392	70	80	90	77
MT CHARLESTON	265400	70	80	90	77

Appendix 8 cont. Weather station aridity ratings following Allen and Brockway (1983), estimated from station photos, and high resolution image analysis (0= irrigated area, 100=completely arid).

Station Name	NOAA #	Station Aridity	Area Aridity	Regional Aridity	Cumulative Aridity
FS					
MT ROSE BOWL	265440	70	80	90	77
NIXON	265605	90	80	100	86
NORTH LAS VEGAS	265705	100	100	100	100
OASIS	265722	70	70	90	72
OLD RUTH	265760	100	100	100	100
OROVADA 3 W	265818	30	60	60	48
OVERTON	265846	70	70	80	71
OWYHEE	265869	60	30	60	45
PAHRANAGAT WR	265880	60	60	60	60
PAHRUMP	265890	100	100	100	100
PAHUTE MEADOWS RCH	265907	40	60	90	55
PALMETTO	265931	100	100	100	100
PARADISE VALLEY 1 NW	266005	70	70	80	71
PARIS RCH	266055	60	70	90	68
PENOYER VALLEY	266130	60	20	70	41
PEQUOP	266148	100	100	100	100
PILOT VALLEY-LEE	266228	70	90	100	83
PINE VALLEY BAILEY RCH	266242	60	50	80	57
PIOCHE	266252	100	100	100	100
QUINN RVR CROSSING	266504	50	50	70	52
RAND RCH PALISADE	266574	60	40	80	52
RATTLESNAKE	266630	100	100	100	100
RED ROCK CANYON SP	266691	50	80	100	70
REESE RIVER	266746	60	80	90	73
REESE VALLEY CARPER	266748	60	50	60	55
RENO TAHOE INTL AP	266779	100	90	80	93
RENO WFO	266791	100	100	100	100
RUBY LAKE	267123	60	60	70	61
RUTH	267175	70	70	100	73
RYNDON	267188	60	50	70	56
RYE PATCH DAM	267192	70	60	90	67
SAND PASS	267261	70	80	100	78
SAN JACINTO	267284	70	50	60	59
SARCOBATUS	267319	50	60	90	59
SAVAL RCH	267324	90	90	100	91
SCHURZ	267358	60	70	70	66
SEARCHLIGHT	267369	100	100	100	100

Appendix 8 cont. Weather station aridity ratings following Allen and Brockway (1983), estimated from station photos, and high resolution image analysis (0= irrigated area, 100=completely arid).

Station Name	NOAA #	Station Aridity	Area Aridity	Regional Aridity	Cumulative Aridity
SEVENTY ONE RCH	267397	20	40	60	34
SHELDON	267443	50	50	80	53
SHOSHONE 5 N	267450	50	90	90	74
SILVERPEAK	267463	60	60	90	63
SMITH 1 N	267609	60	40	40	48
SMITH 6 N	267612	100	70	60	81
SMOKE CREEK ESPIL	267618	80	80	90	81
SMOKEY VALLEY	267620	70	80	90	77
SNOWBALL RCH	267640	100	100	100	100
SOUTH FORK SP	267690	90	90	90	90
SPRING VALLEY SP	267750	20	40	70	35
STATELINE-HARRAH'S	267806	20	30	30	26
STEAD	267820	100	90	100	95
SULPHUR	267873	100	100	100	100
SUNNYSIDE	267908	100	100	100	100
SUTCLIFFE	267953	70	80	90	77
TEMPIUTE 4 NW	267983	100	100	100	100
THORNE	268034	100	100	100	100
TONOPAH	268170	100	100	100	100
TOPAZ LAKE 3N	268186	70	90	100	83
TOPAZ LAKE 4 N	268202	70	90	100	83
TUSCARORA	268346	100	100	100	100
TWIN SPRING FALLINI	268443	100	100	100	100
UNIV OF NEVADA EXP FM	268500	50	70	80	63
URSINE	268538	40	60	80	54
VALLEY OF FIRE SP	268588	100	100	100	100
VIRGINIA CITY	268761	70	80	100	78
VYA	268810	100	100	100	100
WABUSKA 6 SE	268822	100	70	80	83
WADSWORTH	268834	100	70	90	84
WADSWORTH 4 N	268838	100	70	90	84
WELLINGTON RS	268977	60	70	70	66
WELLS	268988	70	80	100	78
WILDHORSE RSVR	269072	100	100	100	100
WILKINS	269122	70	70	90	72
WILLOW SPRINGS	269137	100	100	100	100
WINNEMUCCA #2	269168	70	90	90	82
WINNEMUCCA MUNI AP	269171	100	100	100	100
YERINGTON	269229	50	60	50	55

Appendix 8 cont. Weather station aridity ratings following Allen and Brockway (1983), estimated from station photos, and high resolution image analysis (0= irrigated area, 100=completely arid).

Station Name	NOAA #	Station Aridity	Area Aridity	Regional Aridity	Cumulative Aridity
LAS VEGAS	23112	100	100	100	100
RED ROCK WC	29999	90	30	40	55
WASHOE VALLEY WC	39999	60	30	30	42

Appendix 9. Descriptions of daily, monthly, annual, and statistical summaries of ET, net irrigation water requirement, and effective precipitation.

Daily Time Series

The daily ET_c time series files are assembled as one file per station and contain daily information for entire periods of record. The daily ET_c time series file has ET_c information for up to 34 crops or land use conditions. Any missing data in the daily ET_c files are denoted as –99. Generally, missing data occurred due to missing air temperature data for a day that precluded the calculation of ET_{os}. Often, entire months were missing from NWS files obtained from the NOAA-NCDC system. The daily ET_c files can be large, exceeding 50mb for some stations having long periods of record and many crop types. The total crop types that are included for each station are listed in Appendix 10.

The names of the ET_c files for the National Weather Service (NWS) stations contain the NCDC station ID number, for example, 262780 for the Fallon Exp station. The extension to these files is '*.dat*.' For example, the name Fallon Exp station is 262780ETca.dat. The daily ET_c files are 'flat' text (i.e., ASCII) files with all columns of data separated by one or more blank spaces. The daily ETc files contain daily ETc data for the full period of record for the particular station, with some files dating to the late 1800's. All NWS files conclude at 12/31/2007 or earlier, as the end of 2007 was the last period for which data were obtained for most stations. The full list of weather station names along with assigned file numbers are provided in Appendix 1a and 1b.

The daily files contain reference ET and reported precipitation in units of mm/day, along with the computed 30-day average daily mean air temperature (T30), and crop ET for different crop types. The value for T30 is for the 30-day period ending on the particular date. T30 was used to estimate starts of growth periods for many types of crops. The file header is comprised of five lines that describe the date of computation, the station ID number and internal station 'ET number' as well as the station latitude, longitude and elevation (in decimal degrees and feet). The fourth line of the header lists the total number of crop or land cover types in the specific file as well as a listing of each crop type. Each crop or land cover type is listed beginning with its specific number (1 through 34) followed by a short character description of the crop or land use. The last line in the header describes each data column. The first seven columns, headed by "*Year DoY Mo Dy PMETo Pr.mm T30*" represent the year, day of year (1-366), month, day of month, grass reference ET computed by the ASCE Penman-Monteith ETos method, gross precipitation, and 30-day mean air temperature. Following these seven columns, seven columns appear for each crop or land cover: "*ETact ETpot ETbas Irrn Seasn Runof DPerc*" These columns are defined as follows:

ETact (*actual daily* ET_c) - ET_{act} represents the total estimated flux of ET given any reduction in actual ET caused by soil water shortage or soil surface dryness. ET_{act} is computed as $ET_{act} = K_s\, ET_{bas} + K_e\, ET_{os}$, where ET_{os} is grass reference ET, K_s is a stress factor (0 – 1 where 1 means no stress) and K_e is the evaporation coefficient. ET_{bas} is defined below. ET_{act} is occasionally less than ET_{pot} for irrigated crops prior to the growing season when a low-level, basal crop coefficient for the non-growing season cover cannot be sustained by precipitation, or early in the growing season prior to initiation of irrigation. <u>ET_{act} includes evaporation from the soil surface from both precipitation and any simulated irrigation.</u>

ETpot (p*otential daily ET_c)* - ET_{pot} represents the total estimated flux of ET that would occur if there were no moisture stress imposed by soil water shortage in the root zone. ET_{pot} includes evaporation from the soil surface from both precipitation and any simulated irrigation. ET_{pot} is computed as $ET_{pot} = ET_{bas} + K_e ET_{os}$, where ET_{os} is the grass reference ET.

ETbas (*basal daily ET_c)* - ET_{bas} represents the ET that would occur under no water stress and with no surface wetting by precipitation or irrigation. In other words, ET_{bas} represents potential ET_c (ET_{pot}) for a dry soil surface. ET_{bas} should not be used to estimate irrigation water requirements, and is included to provide an indication of the amount of *ET* that is primarily 'transpiration', as opposed to any amount that is from evaporation of water from the soil surface layer. ET_{bas} is calculated as K_{cb} ET_{os} where K_{cb} is the basal crop coefficient and ET_{os} is the grass reference ET.

Irrn (*irrigations)* - Irrigation timing and amount is simulated using a daily soil water balance. Irrigations are simulated when the root zone dries to the specified threshold point (i.e. the maximum allowable depletion) where stress will begin to occur (listed in appendix 5). The simulated irrigation frequency and depth per irrigation is a function of the crop type and available water holding capacity.

Seasn (*growing or non-growing season*) - The *Seasn* column contains a 'flag' that is 1 when the date is inside the estimated growing season and 0 when outside the growing season. The growing season is defined as the time from first green-up or planting of the crop type until the time of harvest, senescence, or killing frost. The season start and end varies from year to year for crops where the season start is estimated using T30, cumulative growing degree days, and/or where season length is estimated using cumulative growing degree days, or is terminated by frost specified by a killing frost temperature. In the case of the four land cover types (bare soil, mulch, dormant turf, and small open water bodies), the season flag is always on.

Runof (*surface runoff from precipitation)* - Surface runoff is estimated during precipitation events using the NRCS curve number as described in the main body of text.

DPerc (*deep percolation below the root zone)* - *DPerc* represents water, in mm/day, percolating below the maximum root zone depth for the crop or land cover type. This water is considered to be unrecoverable for fulfilling any ET requirements. There are no estimates for upward capillary fluxes into the root zone from below the root zone. The *DPerc* during irrigation events may contain 10% of the irrigation depth (the amount of water required to refill the root zone). This 10% was included to provide recharge to depths in the soil profile that are above the maximum rooting depth, and below the current rooting depth of the crop. This was necessary to simulate buildup of soil water during irrigation events that is used later in the season as roots may deepen. This phenomenon is typical in practice.

Monthly Time Series

Files for monthly ET_c time series have names that follow the same convention for daily ET_c files. The latter portion of the name carries the label '*ETc_monthly.dat*', for example, the Fallon Exp station is "*262780ETc_monthly.dat.*" The monthly files are assembled as one file per station. Each file has ETc information for up to 34 crops or land use conditions. The monthly ET_c time series files have 10 lines of header information that contain similar information as for the daily time series files. The header notes the time and date of computation of the original daily ET_c information as well as the time and date of computation of the monthly summaries (series). The first three columns of data contain the year, the month number (1-12) and the number of 'valid' days in the month (*V.Dys*). *V.Dys* represents valid days (that do not have a –999 flag in the daily ET_c file caused by lack of weather data). The next two columns are average reference ET (ET_{os}) and average daily precipitation (*Prec*). Any missing data in the monthly ET_c time series files are denoted as –999. Generally, a monthly period in a time series was marked as missing if air temperature data were missing for all days in that month. Entire months were frequently missing from NWS files obtained as from the NOAA-NCDC system. All units are mm/day averaged over the month.

There are six columns of data presented for each crop or land cover that are defined as follow:

ETact (*actual monthly* ET_c) - ET_{act} represents the total estimated flux of ET given any reduction in actual ET caused by soil water shortage or soil surface dryness. ET_{act} is computed as $ET_{act} = K_s\ ET_{bas} + K_e\ ET_{os}$, where ET_{os} is grass reference ET, K_s is a stress factor (0 – 1 where 1 means no stress) and K_e is the evaporation coefficient. ET_{bas} is defined below. ET_{act} is occasionally less than ET_{pot} for irrigated crops prior to the growing season when a low-level, basal crop coefficient for the non-growing season cover cannot be sustained by precipitation, or early in the growing season prior to initiation of irrigation. ET_{act} includes evaporation from the soil surface from both precipitation and any simulated irrigation.

ETpot (p*otential monthly* ET_c*)* - ET_{pot} represents the total estimated flux of ET that would occur if there were no moisture stress imposed by soil water shortage in the root zone. ET_{pot} includes evaporation from the soil surface from both precipitation and any simulated irrigation. ET_{pot} is computed as $ET_{pot} = ET_{bas} + K_e ET_{os}$, where ET_{os} is the grass reference ET.

NIWR (*Net Irrigation Water Requirement AKA precipitation deficit)* - The NIWR is the difference between the actual ET (ET_{act}) and the amount of precipitation that resides in the root zone (*P_rz*) and is available for ET. *NIWR* is calculated as $ET_{act} – P\_rz$. *NIWR* represents the amount of additional water that the crop would consume (evapotranspire) beyond *P_rz* if that water were made available at the right time during the growing or non-growing season. The ET_{act} estimate includes soil evaporation from precipitation and simulated irrigation events. The *NIWR*, if summed only during the growing season, does not include the impact of the *NIWR* during the non-growing season in providing stored soil moisture that may offset irrigation requirements during the growing season. Conversely, if summed on an annual time step, the *NIWR* does include stored soil moisture from non-growing season precipitation, and represents what has historically been called the ***net consumptive use***, and is being termed the ***net irrigation water requirement*** in this report. All available precipitation in the root zone is considered when computing the *NIWR* because ET_{act} is used, where ET_{act} is the actual ET that is calculated from a daily soil water balance, and includes evaporation from precipitation. Because ET_{act} includes evaporation of precipitation *P_rz* must be subtracted from ET_{act}.

P_rz (*precipitation residing in the root zone)* - *P_rz* is the amount of gross reported precipitation less any surface runoff or deep percolation that resides in the soil and is available for consumption by evaporation or transpiration. *P_rz* is computed as *P – Runoff – DPerc* where *P* is gross reported precipitation, *Runoff* is estimated surface runoff and *DPerc* is deep percolation of any precipitation below the maximum root zone for the crop or land cover type. The difference between *P_rz* and ET_{act} during the non-growing season represents the amount of 'recharge' or 'build-up' of moisture to the root zone during the non-growing season (i.e., increase in soil water storage) that would be available at the start of the growing season to later partially fulfill plant water requirements. The ratio of ($P\_rz – ET_{act}$)/*P* computed during the non-growing period represents the 'efficiency' or effectiveness of gross precipitation in building soil water for use during the growing season.

P_efT (*precipitation residing in the root zone that is available for transpiration)* - *P_efT* is the amount of gross reported precipitation less any surface runoff or deep percolation that resides in the soil and is available for consumption by transpiration. *P_efT* does not include the amount of infiltrated precipitation that evaporates from the surface evaporation layer (upper 100 mm of soil). The *P_efT* parameter is useful in estimating the amount of precipitation during the non-growing season that is stored and made available for transpiration requirements during the growing season. *P_efT* is always less than *P_rz.* When analyzed during the growing season, *P_efT* is useful for estimating how 'efficient' precipitation is in fulfilling transpiration requirements of crops, as opposed to simply 'burning off' as evaporation from the soil surface. *P_efT* was calculated as *P_efT = P_rz - surface evaporation losses = P – Runoff – DPerc - surface evaporation losses*, where *P_rz* is precipitation infiltrating and residing in the maximum root zone for the crop, *P* is gross reported precipitation, *Runoff* is estimated surface runoff, and *DPerc* is deep percolation of any precipitation below the maximum root zone for the crop or land cover type.

SeDys (number of *growing season days* within the particular month) - *SeDys is* computed by summing the *Seasn* flag contained in the daily ETc files.

Annual Time Series

The annual ET_c time series files contain the same information as the monthly ET_c time series files. The annual files have names that follow the same convention for daily ET_c files previously described. The latter portion of the name carries the label '*ETc_annual.dat*', for example, for Fallon Exp, the name for the annual file is "*262780ETc_annual.dat*". Each file has ET_c information for up to 34 crops and land cover conditions. All units are in mm/year.

The annual ET_c time series files have 10 lines of header information that contain similar information as for the monthly and daily time series files. The header notes the time and date of computation of the original daily ET_c information as well as the time and date of computation of the annual summaries. The first four columns of data contain the year and the number of 'valid' days in the year (*V.Days*). *V.Days* represents those days that do not have a –999 flag in the daily ET_c file caused by lack of weather data. The next two columns are total reference ET (ET_{os}) and total precipitation (*Prec.*) for the calendar year, both expressed as mm over the year. It is important to note that both ET_{os} and *Prec.* represent the entire calendar year (365 or 366 days), including winter periods. Any years that had less than 350 days of valid data or more than 5 days of missing data during the growing season (defined as the growing period for grass hay) were reported as –999. Years having one to fifteen missing days during the year (and fewer than 6 missing days during the growing season) had annual values for ET and precipitation deficit adjusted by multiplying by 365 or 366 divided by the number of valid days. Any years that had more than 5 days of missing data during the growing season for a crop were reported as –999 for the seasonal ET totals.

There are six columns of annual data presented for each crop that are defined as follow:

ETac (*actual ETc) -* ET_{act} summed over the year. ET_{act} represents the total estimated flux of ET given any reduction in actual ET caused by soil water shortage or soil surface dryness. ET_{act} is computed as $ET_{act} = K_s\ ET_{bas} + K_e\ ET_{os}$, where ET_{os} is grass reference ET, K_s is a stress factor (0 – 1 where 1 means no stress) and K_e is the evaporation coefficient. ET_{bas} is defined below. ET_{act} is occasionally less than ET_{pot} for irrigated crops prior to the growing season when a low-level, basal crop coefficient for the non-growing season cover cannot be sustained by precipitation, or early in the growing season prior to initiation of irrigation. ET_{act} includes evaporation from the soil surface from both precipitation and any simulated irrigation.

ETpt (*potential* ET_c*) -* ET_{pot} summed over the year. ET_{pot} represents the total estimated flux of ET that would occur if there were no moisture stress imposed by soil water shortage in the root zone. ET_{pot} includes evaporation from the soil surface from both precipitation and any simulated irrigation. ET_{pot} is computed as $ET_{pot} = ET_{bas} + K_e ET_{os}$, where ET_{os} is the grass reference ET.

NIWR (*Net Irrigation Water Requirement AKA precipitation deficit)* – NIWR summed over the year. The NIWR is the difference between the actual ET (ET_{act}) and the amount of precipitation that resides in the root zone and is available for ET. *NIWR* is calculated as ET_{act} – *P_rz*. *NIWR* represents the amount of additional water that the crop would consume (evapotranspire) beyond *P_rz* if that water were made available at the right time during the growing or non-growing season. The ET_{act} estimate includes soil evaporation for precipitation and simulated irrigation events. Summed on an annual time step, *NIWR* does include stored soil moisture from non-growing season precipitation, and represents what has historically been called the ***net consumptive use***, and is being termed the ***net irrigation water requirement*** in this report. Although P_rz includes precipitation that is later evaporated and not "consumed" by the crop, it is important to note that because ET_{act} includes water that is consumed by evaporation of precipitation, that ET_{act} – P_rz, represents the net irrigation water requirement, and not ET_{act} minus root zone water that is effective toward transpiration only.

P_rz (p*recipitation residing in the root zone)* - *P_rz* is the amount of gross reported precipitation less any surface runoff or deep percolation that resides in the soil and is available for consumption by evaporation or transpiration. *P_rz* is computed as *P – Runoff – DPerc* where *P* is gross reported precipitation, *Runoff* is estimated surface runoff and *DPerc* is deep percolation of any precipitation below the maximum root zone for the crop or land cover type.

P_efT (*precipitation residing in the root zone that is available for transpiration)* - *P_efT* is the amount of gross reported precipitation less any surface runoff or deep percolation that resides in the soil and is available for consumption by transpiration. *P_efT* does not include the amount of infiltrated precipitation that evaporates from the surface evaporation layer (upper 100 mm of soil). The *P_efT* parameter is useful in estimating the amount of precipitation that is stored and made available for transpiration requirements. *P_efT* is always less than *P_rz. P_efT* is useful for estimating how 'efficient' precipitation is in fulfilling transpiration requirements of crops, as opposed to simply 'burning off' as evaporation from the soil surface. *P_efT* was calculated as *P_efT* = *P_rz - surface evaporation losses* = *P – Runoff – DPerc - surface evaporation losses*, where *P_rz* is precipitation infiltrating and residing in the maximum root zone for the crop, *P* is gross reported precipitation, *Runoff* is estimated surface runoff, and *DPerc* is deep percolation of any precipitation below the maximum root zone for the crop or land cover type.

DSn – The *number of growing season days* within the calendar year. *DSn* was computed by summing the *Seasn* flag contained in the daily ETc files over the calendar year.

Statistics Files

Perhaps the most useful results from this study are the statistics describing long-term mean values for ET_c on monthly, growing season, and annual bases, as well as standard deviations and 20% and 80% exceedence values that describe the expected variation of the populations of ET_c. These statistics have been computed for the following lengths of time periods within each month; 3, 7, 15, and 30 days. These period lengths were selected to include expected lengths of irrigation intervals or drying periods that are of interest in irrigation system design and operation. For example, a potato crop may be irrigated each 3 days during the peak month of July, so that users may be interested in reviewing the statistics describing the 3 day periods within the month of July for irrigation systems design. Or, for example, if a crop of alfalfa having a deeper effective root zone is irrigated on average each two weeks during August, then users may be interested in reviewing the statistics describing 15 day periods within the month of August for irrigation systems design.

There are four 'statistics' files per weather station. These files contain statistical summaries for 1) *actual ET*; 2) *potential ET*; 3) *basal ET*; and 4) *precipitation deficit* (i.e., *net irrigation water requirement*). The files have names beginning with the station coop number and ending with '*ETcact_stats.dat*', '*ETcpot_stats.dat*', '*ETcbas_stats.dat*' or '*NIWR_stats.dat*'. For example, in the case of the Fallon Exp station, the four files are named *262780ETcact_stats.dat*, *262780ETcpot_stats.dat*, *262780ETcbas_stats.dat* and *262780NIWR_stats.dat*. The *ETcact* represents actual ET, *ETcpot* represents potential ET, *Etcbas* represents basal ET, and *NIWR* represents the Net Irrigation Water Requirement (i.e. precipitation deficit, *P_def*). All of these terms have been defined under the daily, monthly, annual time series sections above. The *NIWR* is summarized for both growing season and annual time periods. The four files all contain headers comprised of 12 lines containing similar information including the time and date of the original calculation of daily ET and the time and date of the calculation of the statistical summaries. The headers also contain the station latitude and longitude in decimal degrees and station elevation in feet. Each crop or land cover type that was processed for a station is contained in the statistics files, following a single entry for reference ET (in the '*ETcact_stats*' file), for gross precipitation (in the '*ETcpot_stats*' file), or for 30 day average daily mean air temperature (in the '*ETcbas_stats*' file).

The statistics were computed over the most recent 30 years of valid (non-missing) data or over shorter periods if less than 30 years of valid data were available (minimum of 4 years). The span of the 30 year 'normals' are listed for each crop, but may not necessarily contain 30 years depending on the station period of record or number of missing days. The span of the normal periods can change with crop type, depending on the timing of any missing data (inside or outside growing periods). The span of the normal period can also exceed 30 years if some intervening years were omitted due to missing data.

The 30 year normal or shorter periods available were used to generate means and other statistics describing the behavior of the ET data rather than the entire periods of record (i.e. greater than 30 years) for two reasons. One, lengths of station records vary widely from station to station, ranging from as few as 4 years from 2005-2008, to 112 years from 1893-2004. Secondly, trends in air temperature and growing season lengths are apparent, and consequently ET trends exist. Some of these trends are caused by changes in relative dryness of the local or regional environment due to irrigation development or land-use change, by specific station location, or perhaps by change in overall climate. The last 30 years of usable record are considered to be more representative of expected future conditions than prior periods. The full record for each station is preserved in the daily, monthly and annual time series files. Therefore, statistics for the full periods of record can be computed as needed from these series.

For each crop, the following data columns are reported for each month, for the calendar year ('Ann.' row) and for the growing season ('Sea.' row):

Mean (*mean value) - Mean value* for the month and over the 'normal' period of record for the location. *Mean* represents either *ETcact, ETcpot, ETcbas* or *NIWR*, depending on the file. Units are in mm/day for monthly periods and mm/year annual and seasonal periods. The '*nyr*' column represents the number of years that had 'valid' entries for the month and that were included in the mean. Generally, if a full normal period was available, *nyr* = 30. The actual period of record for the station may have been much longer and is preserved in the time series files. Values for means are reported for the monthly, 15, 7, and 3 day averaging periods within each month. In general, these four means are nearly the same, and are reported only for documentation. Means for the 15, 7 and 3 day periods can deviate from those for the entire month because some information near the beginning and end of the month may not have the same weight. This was caused by the requirement that each 3, 7 or 15 day period considered for a month must have all of its member days residing within the month evaluated. For example, for the 15 day statistics, generally 13 to 16 separate 15 day averages were computed and considered for a specific month and year. The member days for the 15-day averages were days 1-15, days 2-16, days 3-17, ……, days 14-28, days 15-29, days 16-30, and days 17-31. Therefore, days nearer to the beginning and end of a period appeared fewer times in the computed means for the month. Thus, some differences in monthly means occurred between the 3, 7, 15 and monthly periods. Differences were generally small.

Stdev (*standard deviation) - Standard devieation* of the variable for the month over the normal period of record. The *Stdev* entry for a particular month was computed using one value (the observation mean) per year for the month. Units are in mm/day for monthly periods and mm for annual and seasonal periods.

Skew (*skew of the distribution of values)* - The *skew* is shown for the variable for each month for the monthly means (only) over the period of record. The skew for a particular month was computed using one value (the observation mean) per year for the month. A value for skew near zero indicates that the underlying distribution approximates a normal (Gaussian) and symmetrical distribution. A skew near 1.0 indicates that the underlying distribution approximates a lognormal distribution. The values for skew, standard deviation and mean can be used to parameterize a variety of probability density functions such as the normal, lognormal, Pearson, and Gamma distributions.

Kurt. (*Kurtosis) - Kurtosis* is a measurement of the 'slenderness' of the underlying distribution; in other words, the 'height to width ratio' of the probability density function. A normal (Gaussian) distribution has a kurtosis of 3. The higher the number, the taller and more slender the distribution is. A high kurtosis indicates that many of the observations in the distribution have very similar values. Kurtosis was calculated for monthly averages only over the normal period.

20%Ex *(20% exceedence)* **-** The *20%Ex* value represents the value for the parameter (actual, potential or basal ET or the precipitation deficit) *that has a 20% chance of being exceeded* that month during any particular year. Conversely, there is an 80% chance that the value of the parameter (for the particular length of averaging period) will be less than the *20%Ex* value. The *20%Ex* value is commonly used in design of capacity for irrigation and water supply systems. Units for *20%Ex* are in mm/day for monthly periods and mm for annual and seasonal periods. The *20%Ex* values were computed assuming a 'distribution free' probability density function. The values were selected by ranking the highest 3-, 7-, 15- or 30-day value within the month for *ETact, ETpot, ETbas* or *NIWR* for each year of the 30 year normal period and selecting the value that was positioned 20% of the way down from the highest value. There were '*nyrs*' values that were ranked (one for each year). In this way, the *20%Ex* value represents that value for the parameter (*ETact, ETpot*, *ETbas* or *NIWR*) that, when averaged over any 3-, 7-, 15- or 30- day period within the month, would have only a 20% chance of being exceeded at any time during that month for the given year. Thus, if an irrigation system were designed with capacity to provide the *20%Ex* amount of *NIWR* over a 7-day period, for example, the system's 'net' output (less any incidental leakage, spray drift or uniformity 'losses') would exceed the actual precipitation deficit (i.e., the ET less any Prz) 8 years out of 10. During two years out of any 10 year period, the ET less any Prz would exceed the net system capacity during at least one 7 day period during the particular month by some amount. The amount of the exceedence might range from only a millimeter to perhaps 15 to 20 mm over the period.

AveHi *(average hi)* - The *AveHi* parameter complements the *20%Ex* parameter, where *AveHi* represents the average (over the normal period) of the highest value for the parameter within the 3, 7, or 15 day period for each month. Therefore, each month of each year was assigned one 'highest' value for the parameter for the 3, 7 or 15 day averaging length. Then, for each month of the year, the values over the normal period were averaged to obtain *AveHi*. The value for *AveHi* for 3, 7 and 15 day periods is always greater than the average for the month itself (i.e., the mean), since the *AveHi* is the mean of the highest value for the 3, 7, or 15 day period within the month. The value for *AveHi* increases as the length of the averaging period (3, 7 or 15 days) decreases. The same values used to calculate *AveHi* were used in calculating the *20%Ex* value.

80%Ex *(20% exceedence)* **-** The *80%Ex* value represents the *value* for the parameter (actual, potential, basal ET, or the precipitation deficit) *that has an 80% chance of being exceeded* that month during any particular year. Conversely, there is a 20% chance that the value of the parameter (for the particular length of averaging period) will be less than the *80%Ex* value. The *80%Ex* value is commonly used in design of land application systems where water application may need to be limited to amounts that have at least 80% chance of being consumed. Units for *80%Ex* are in mm/day for monthly periods and mm for annual and seasonal periods. The *80%Ex* values were computed assuming a 'distribution free' probability density function. The values were selected by ranking the lowest 3-, 7-, 15- or 30-day value during the month for *ETact, ETpot, ETbas* or *NIWR* for each year and selecting the value that was positioned 80% of the way down from the highest value. There were 'nyrs' values that were ranked (one for each year). In this way, the 80%Ex value represents that value for the parameter (*ETact, ETpot, ETbas* or *NIWR*) that, when averaged over any 3-, 7-, 15- or 30- day period within the month, would have an 80% chance of being exceeded at all times during that month for the given year. Thus, if a land application system were designed with capacity to provide the *80%Ex* amount of *NIWR* over a 7-day period, for example, then the systems 'net' output (less any incidental leakage, spray drift or uniformity 'losses') would exceed the actual precipitation deficit (i.e., the ET less any Prz) during 2 years out of a 10 year period. During eight years out of any 10 year period, the ET less any Prz would exceed the application amount during all 7 day periods during the particular month by some amount. The amount of the exceedence might range from only a millimeter to perhaps 15 to 20 mm.

AveLo *(average low)* **-** The *AveLo* parameter complements the *80%Ex* parameter, where *AveLo* represents the average (over the normal period) of the lowest value for the parameter within the 3, 7, or 15 day period for each month. Therefore, each month of each year was assigned one 'lowest' value for the parameter for the 3, 7 or 15 day averaging length. Then, for each month of the year, the values over the normal period were averaged to obtain *AveLo*. The value for *AveLo* for 3, 7 and 15 day periods is always less than the average for the month itself (i.e., the 'mean'), since the *AveLo* is the mean of the lowest value for the 3, 7, or 15 day period within the month. The value for *AveLo* decreases as the length of the averaging period (3, 7 or 15 days) decreases. The same values used to calculate *AveLo* were used in calculating the *80%Ex* value. On an annual or growing season basis, the mean, *20%Ex* and *80%Ex* values are computed only for annual or growing season totals and represent the distribution of annual or growing season values (rather than for specific months).

Appendix 10. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Alfalfa Hay	Grass Hay	Snap and Dry Beans - fresh	Snap and Dry Beans - seed	Field Corn	Silage Corn	Sweet Corn-- early	Sweet Corn-- late	Spring Grain - irrigated	Winter Grain - irrigated
ADAVEN	260046	1	1								
ALAMO	260099	1	1			1	1	1	1	1	1
AMARGOSA FARMS-GAREY	260150	1	1			1	1	1	1	1	1
ANTELOPE VALLEY FARR	260282	1	1								
ARTHUR 4 NW	260438	1	1			1	1	1	1	1	1
AUSTIN #2	260507	1	1								
BASALT	260668	1	1								
BATTLE MTN	260688	1	1			1	1	1	1	1	1
BATTLE MTN AP	260691	1	1			1	1	1	1	1	1
BEATTY	260715	1	1			1	1	1	1	1	1
BEATTY 8 N	260718	1	1			1	1	1	1	1	1
BEOWAWE	260795	1	1								
BEOWAWE U OF N RCH	260800	1	1								
BLUE EAGLE RCH HANKS	260955	1	1								
BLUE JAY HWY STN	260961	1	1								
BOULDER CITY	261071	1	1			1	1	1	1	1	1
BRINKERHOFF RCH	261160	1	1								
BUFFALO RCH	261311	1	1								
BUNKERVILLE	261327	1	1			1	1	1	1	1	1
CALIENTE	261358	1	1			1	1	1	1	1	1
CALLVILLE BAY	261371	1	1								
CARLIN NEWMONT MINE	261415	1	1								
CARSON CITY	261485	1	1								
CATHEDRAL GORGE SP	261590	1	1			1	1	1	1	1	1
CENTRAL NEVADA FLD LAB	261630	1	1			1	1	1	1	1	1
CHARLESTON	261660	1	1								
CLOVER VALLEY	261740	1	1			1	1	1	1	1	1
COALDALE JUNCTION	261755	1	1								
CONTACT	261905	1	1								
CORTEZ GOLD MINE	261975	1	1								
CURRANT	262078	1	1			1	1	1	1	1	1
CURRANT HWY STN	262091	1	1								
CURRIE HWY STN	262096	1	1								
DAGGET PASS	262119	1	1								
DENIO	262229	1	1			1	1	1	1	1	1
DESERT NWR	262243	1	1								
DIABLO	262276	1	1								
DIAMOND VALLEY USDA	262296	1	1			1	1	1	1	1	1
DUCKWATER	262390	1	1			1	1	1	1	1	1
DUFURRENA	262394	1	1								
DYER	262431	1	1			1	1	1	1	1	1
EASTGATE	262477	1	1								
ECHO BAY	262497	1	1								
ELGIN	262557	1	1			1	1	1	1	1	1
ELGIN 3 SE	262562	1	1			1	1	1	1	1	1

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Alfalfa Hay	Grass Hay	Snap and Dry Beans - fresh	Snap and Dry Beans - seed	Field Corn	Silage Corn	Sweet Corn-- early	Sweet Corn-- late	Spring Grain - irrigated	Winter Grain - irrigated
ELKO	262570	1	1			1	1	1	1	1	1
ELKO RGNL AP	262573	1	1			1	1	1	1	1	1
ELY 6 NE	262626	1	1			1	1	1	1	1	1
ELY YELLAND FLD AP	262631	1	1			1	1	1	1	1	1
EMIGRANT PASS HWY STN	262656	1	1								
EMPIRE	262662	1	1			1	1	1	1	1	1
EUREKA	262708	1	1								
FALLON EXP STN	262780	1	1	1	1	1	1	1	1	1	1
FERGUSON SPRINGS HMS	262820	1	1								
FERNLEY	262840	1	1	1	1	1	1	1	1	1	1
FISH CREEK RCH	262860	1	1			1	1	1	1	1	1
GERLACH	263090	1	1			1	1	1	1	1	1
GEYSER RCH	263101	1	1			1	1	1	1	1	1
GIBBS RCH	263114	1	1								
GLENBROOK	263205	1	1								
GOLCONDA	263245	1	1								
GOLDFIELD	263285	1	1								
GOODSPRINGS	263316	1	1								
GREAT BASIN NP	263340	1	1								
HAWTHORNE	263512	1	1								
HAWTHORNE AP	263515	1	1								
HIKO	263671	1	1			1	1	1	1	1	1
HUMBOLDT FLD	263853	1	1								
I-L RCH	263940	1	1								
IMLAY	263957	1	1								
INDIAN SPRINGS	263980	1	1								
JACKPOT	264016	1	1								
JARBRIDGE 4 N	264038	1	1								
JARBIDGE 7 N	264039	1	1								
JIGGS 8 SSE ZAGA	264095	1	1								
JUNGO MEYER RCH	264108	1	1								
KIMBERLY	264199	1	1								
KNOLL CREEK FLD STN	264268	1	1								
KYLE CANYON RS	264314	1	1								
LAGES	264341	1	1								
LAHONTAN DAM	264349	1	1								
LAKE VALLEY STEWARD	264384	1	1								
LAMOILLE YOST	264394	1	1			1	1	1	1	1	1
LAMOILLE PH	264395	1	1			1	1	1	1	1	1
LAS VEGAS	264429	1	1			1	1	1	1	1	1
LAS VEGAS WB AP	264436	1	1			1	1	1	1	1	1
LAS VEGAS NWFO	264439	1	1			1	1	1	1	1	1
LATHROP WELLS	264457	1	1			1	1	1	1	1	1
LAUGHLIN	264480	1	1			1	1	1	1	1	1
LEHMAN CAVES NM	264514	1	1			1	1	1	1	1	1
LEONARD CREEK RCH	264527	1	1			1	1	1	1	1	1
LEWERS RCH	264542	1	1								
LITTLE RED ROCK	264600	1	1								

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Alfalfa Hay	Grass Hay	Snap and Dry Beans - fresh	Snap and Dry Beans - seed	Field Corn	Silage Corn	Sweet Corn-- early	Sweet Corn-- late	Spring Grain - irrigated	Winter Grain - irrigated
LOGANDALE	264651	1	1	1	1	1	1	1	1	1	1
LOVELOCK DERBY FLD	264700	1	1	1	1	1	1	1	1	1	1
LUND	264745	1	1			1	1	1	1	1	1
MALA VISTA RCH	264824	1	1			1	1	1	1	1	1
MARLETTE LAKE	264858	1	1								
MCDERMITT	264935	1	1			1	1	1	1	1	1
MCGILL	264950	1	1			1	1	1	1	1	1
MESQUITE	265085	1	1			1	1	1	1	1	1
METROPOLIS	265092	1	1			1	1	1	1	1	1
MIDAS 4 SE	265105	1	1								
MIDDLEGATE-LOWERY	265132	1	1								
MINA	265168	1	1								
MINDEN	265191	1	1			1	1	1	1	1	1
MONTELLO 2 SE	265352	1	1			1	1	1	1	1	1
MONTGOMERY MNTC STN	265362	1	1								
MOORMAN RCH	265371	1	1								
MTN CITY RS	265392	1	1								
MT CHARLESTON FS	265400	1	1								
MT ROSE BOWL	265440	1	1								
NIXON	265605	1	1			1	1	1	1	1	1
NORTH LAS VEGAS	265705	1	1			1	1	1	1	1	1
OASIS	265722	1	1								
OLD RUTH	265760	1	1								
OROVADA 3 W	265818	1	1	1	1	1	1	1	1	1	1
OVERTON	265846	1	1	1	1	1	1	1	1	1	1
OWYHEE	265869	1	1			1	1	1	1	1	1
PAHRANAGAT WR	265880	1	1			1	1	1	1	1	1
PAHRUMP	265890	1	1			1	1	1	1	1	1
PAHUTE MEADOWS RCH	265907	1	1								
PALMETTO	265931	1	1								
PARADISE VALLEY 1 NW	266005	1	1			1	1	1	1	1	1
PARIS RCH	266055	1	1								
PENOYER VALLEY	266130	1	1								
PEQUOP	266148	1	1								
PILOT VALLEY-LEE	266228	1	1								
PINE VALLEY BAILEY RCH	266242	1	1			1	1	1	1	1	1
PIOCHE	266252	1	1			1	1	1	1	1	1
QUINN RVR CROSSING	266504	1	1			1	1	1	1	1	1
RAND RCH PALISADE	266574	1	1			1	1	1	1	1	1
RATTLESNAKE	266630	1	1								
RED ROCK CANYON SP	266691	1	1								
REESE RIVER	266746	1	1			1	1	1	1	1	1
REESE VALLEY CARPER	266748	1	1								
RENO TAHOE INTL AP	266779	1	1			1	1	1	1	1	1
RENO WFO	266791	1	1			1	1	1	1	1	1
RUBY LAKE	267123	1	1			1	1	1	1	1	1
RUTH	267175	1	1								
RYNDON	267188	1	1			1	1	1	1	1	1

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Alfalfa Hay	Grass Hay	Snap and Dry Beans - fresh	Snap and Dry Beans - seed	Field Corn	Silage Corn	Sweet Corn--early	Sweet Corn--late	Spring Grain - irrigated	Winter Grain - irrigated
RYE PATCH DAM	267192	1	1								
SAND PASS	267261	1	1								
SAN JACINTO	267284	1	1								
SARCOBATUS	267319	1	1								
SAVAL RCH	267324	1	1								
SCHURZ	267358	1	1								
SEARCHLIGHT	267369	1	1								
SEVENTY ONE RCH	267397	1	1			1	1	1	1	1	1
SHELDON	267443	1	1								
SHOSHONE 5 N	267450	1	1								
SILVERPEAK	267463	1	1								
SMITH 1 N	267609	1	1			1	1	1	1	1	1
SMITH 6 N	267612	1	1			1	1	1	1	1	1
SMOKE CREEK ESPIL	267618	1	1								
SMOKEY VALLEY	267620	1	1			1	1	1	1	1	1
SNOWBALL RCH	267640	1	1								
SOUTH FORK SP	267690	1	1			1	1	1	1	1	1
SPRING VALLEY SP	267750	1	1								
STATELINE-HARRAH'S	267806	1	1								
STEAD	267820	1	1			1	1	1	1	1	1
SULPHUR	267873	1	1								
SUNNYSIDE	267908	1	1								
SUTCLIFFE	267953	1	1								
TEMPIUTE 4 NW	267983	1	1								
THORNE	268034	1	1								
TONOPAH	268170	1	1			1	1	1	1	1	1
TOPAZ LAKE 3N	268186	1	1			1	1	1	1	1	1
TOPAZ LAKE 4 N	268202	1	1			1	1	1	1	1	1
TUSCARORA	268346	1	1								
TWIN SPRING FALLINI	268443	1	1								
UNIV OF NEVADA EXP FM	268500	1	1			1	1	1	1	1	1
URSINE	268538	1	1								
VALLEY OF FIRE SP	268588	1	1								
VIRGINIA CITY	268761	1	1			1	1	1	1	1	1
VYA	268810	1	1								
WABUSKA 6 SE	268822	1	1			1	1	1	1	1	1
WADSWORTH	268834	1	1			1	1	1	1	1	1
WADSWORTH 4 N	268838	1	1								
WELLINGTON RS	268977	1	1			1	1	1	1	1	1
WELLS	268988	1	1			1	1	1	1	1	1
WILDHORSE RSVR	269072	1	1								
WILKINS	269122	1	1								
WILLOW SPRINGS	269137	1	1								
WINNEMUCCA #2	269168	1	1			1	1	1	1	1	1
WINNEMUCCA MUNI AP	269171	1	1			1	1	1	1	1	1
YERINGTON	269229	1	1			1	1	1	1	1	1
LAS VEGAS	23112	1	1			1	1	1	1	1	1
RED ROCK WC	29999	1	1			1	1	1	1	1	1
WASHOE VALLEY WC	39999	1	1			1	1	1	1	1	1

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Grass Pasture - high management	Grass Pasture - low management	Grass - Turf	Orchards - Apples and Cherries w/ground cover	Orchards - Apples and Cherries w/no ground cover	Garden Vegetables - general	Onions	Melons
ADAVEN	260046	1	1	1					
ALAMO	260099	1	1	1	1	1	1	1	
AMARGOSA FARMS-GAREY	260150	1	1	1	1	1	1	1	
ANTELOPE VALLEY FARR	260282	1	1	1					
ARTHUR 4 NW	260438	1	1	1	1	1			
AUSTIN #2	260507	1	1	1					
BASALT	260668	1	1	1					
BATTLE MTN	260688	1	1	1	1	1	1	1	
BATTLE MTN AP	260691	1	1	1	1	1	1	1	
BEATTY	260715	1	1	1	1	1	1	1	
BEATTY 8 N	260718	1	1	1	1	1	1	1	
BEOWAWE	260795	1	1	1					
BEOWAWE U OF N RCH	260800	1	1	1					
BLUE EAGLE RCH HANKS	260955	1	1	1					
BLUE JAY HWY STN	260961	1	1	1					
BOULDER CITY	261071	1	1	1	1	1	1		
BRINKERHOFF RCH	261160	1	1	1					
BUFFALO RCH	261311	1	1	1					
BUNKERVILLE	261327	1	1	1	1	1	1	1	
CALIENTE	261358	1	1	1	1	1	1	1	
CALLVILLE BAY	261371	1	1	1					
CARLIN NEWMONT MINE	261415	1	1	1					
CARSON CITY	261485	1	1	1					
CATHEDRAL GORGE SP	261590	1	1	1	1	1	1	1	
CENTRAL NEVADA FLD LAB	261630	1	1	1	1	1	1		
CHARLESTON	261660	1	1	1					
CLOVER VALLEY	261740	1	1	1	1	1	1		
COALDALE JUNCTION	261755	1	1	1					
CONTACT	261905	1	1	1					
CORTEZ GOLD MINE	261975	1	1	1					
CURRANT	262078	1	1	1	1	1	1	1	
CURRANT HWY STN	262091	1	1	1					
CURRIE HWY STN	262096	1	1	1					
DAGGET PASS	262119	1	1	1					
DENIO	262229	1	1	1	1	1	1	1	
DESERT NWR	262243	1	1	1					
DIABLO	262276	1	1	1					
DIAMOND VALLEY USDA	262296	1	1	1	1	1	1		
DUCKWATER	262390	1	1	1	1	1	1	1	
DUFURRENA	262394	1	1	1					
DYER	262431	1	1	1	1	1	1	1	
EASTGATE	262477	1	1	1					
ECHO BAY	262497	1	1	1					
ELGIN	262557	1	1	1	1	1	1	1	
ELGIN 3 SE	262562	1	1	1	1	1	1	1	
ELKO	262570	1	1	1	1	1	1		

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Grass Pasture - high management	Grass Pasture - low management	Grass - Turf	Orchards - Apples and Cherries w/ground cover	Orchards - Apples and Cherries w/no ground cover	Garden Vegetables - general	Onions	Melons
ELKO RGNL AP	262573	1	1	1	1	1	1		
ELY 6 NE	262626	1	1	1	1	1	1		
ELY YELLAND FLD AP	262631	1	1	1	1	1	1		
EMIGRANT PASS HWY STN	262656	1	1	1					
EMPIRE	262662	1	1	1	1	1	1	1	
EUREKA	262708	1	1	1					
FALLON EXP STN	262780	1	1	1	1	1	1	1	1
FERGUSON SPRINGS HMS	262820	1	1	1					
FERNLEY	262840	1	1	1	1	1	1	1	1
FISH CREEK RCH	262860	1	1	1	1	1	1		
GERLACH	263090	1	1	1	1	1	1	1	
GEYSER RCH	263101	1	1	1	1	1	1	1	
GIBBS RCH	263114	1	1	1					
GLENBROOK	263205	1	1	1					
GOLCONDA	263245	1	1	1					
GOLDFIELD	263285	1	1	1					
GOODSPRINGS	263316	1	1	1					
GREAT BASIN NP	263340	1	1	1					
HAWTHORNE	263512	1	1	1					
HAWTHORNE AP	263515	1	1	1					
HIKO	263671	1	1	1	1	1	1	1	
HUMBOLDT FLD	263853	1	1	1					
I-L RCH	263940	1	1	1					
IMLAY	263957	1	1	1					
INDIAN SPRINGS	263980	1	1	1					
JACKPOT	264016	1	1	1					
JARBRIDGE 4 N	264038	1	1	1					
JARBIDGE 7 N	264039	1	1	1					
JIGGS 8 SSE ZAGA	264095	1	1	1					
JUNGO MEYER RCH	264108	1	1	1					
KIMBERLY	264199	1	1	1					
KNOLL CREEK FLD STN	264268	1	1	1					
KYLE CANYON RS	264314	1	1	1					
LAGES	264341	1	1	1					
LAHONTAN DAM	264349	1	1	1					
LAKE VALLEY STEWARD	264384	1	1	1					
LAMOILLE YOST	264394	1	1	1	1	1			
LAMOILLE PH	264395	1	1	1	1	1			
LAS VEGAS	264429	1	1	1	1	1	1		
LAS VEGAS WB AP	264436	1	1	1	1	1	1		
LAS VEGAS NWFO	264439	1	1	1	1	1	1		
LATHROP WELLS	264457	1	1	1	1	1	1	1	
LAUGHLIN	264480	1	1	1	1	1	1		
LEHMAN CAVES NM	264514	1	1	1	1	1	1		
LEONARD CREEK RCH	264527	1	1	1	1	1	1	1	
LEWERS RCH	264542	1	1	1					
LITTLE RED ROCK	264600	1	1	1					
LOGANDALE	264651	1	1	1	1	1	1	1	

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Grass Pasture - high management	Grass Pasture - low management	Grass - Turf	Orchards - Apples and Cherries w/ground cover	Orchards - Apples and Cherries w/no ground cover	Garden Vegetables - general	Onions	Melons
LOVELOCK DERBY FLD	264700	1	1	1	1	1	1	1	
LUND	264745	1	1	1	1	1	1	1	
MALA VISTA RCH	264824	1	1	1	1	1	1	1	
MARLETTE LAKE	264858	1	1	1					
MCDERMITT	264935	1	1	1	1	1	1	1	
MCGILL	264950	1	1	1	1	1	1	1	
MESQUITE	265085	1	1	1	1	1	1	1	
METROPOLIS	265092	1	1	1	1	1	1	1	
MIDAS 4 SE	265105	1	1	1					
MIDDLEGATE-LOWERY	265132	1	1	1					
MINA	265168	1	1	1					
MINDEN	265191	1	1	1	1	1	1	1	
MONTELLO 2 SE	265352	1	1	1	1	1	1	1	
MONTGOMERY MNTC STN	265362	1	1	1					
MOORMAN RCH	265371	1	1	1					
MTN CITY RS	265392	1	1	1					
MT CHARLESTON FS	265400	1	1	1					
MT ROSE BOWL	265440	1	1	1					
NIXON	265605	1	1	1	1	1	1	1	
NORTH LAS VEGAS	265705	1	1	1	1	1	1		
OASIS	265722	1	1	1					
OLD RUTH	265760	1	1	1					
OROVADA 3 W	265818	1	1	1	1	1	1	1	
OVERTON	265846	1	1	1	1	1	1	1	1
OWYHEE	265869	1	1	1	1	1	1		
PAHRANAGAT WR	265880	1	1	1	1	1	1	1	
PAHRUMP	265890	1	1	1	1	1	1	1	
PAHUTE MEADOWS RCH	265907	1	1	1					
PALMETTO	265931	1	1	1					
PARADISE VALLEY 1 NW	266005	1	1	1	1	1	1	1	
PARIS RCH	266055	1	1	1					
PENOYER VALLEY	266130	1	1	1					
PEQUOP	266148	1	1	1					
PILOT VALLEY-LEE	266228	1	1	1					
PINE VALLEY BAILEY RCH	266242	1	1	1	1	1	1		
PIOCHE	266252	1	1	1	1	1	1	1	
QUINN RVR CROSSING	266504	1	1	1	1	1	1	1	
RAND RCH PALISADE	266574	1	1	1	1	1	1	1	
RATTLESNAKE	266630	1	1	1					
RED ROCK CANYON SP	266691	1	1	1					
REESE RIVER	266746	1	1	1	1	1	1	1	
REESE VALLEY CARPER	266748	1	1	1					
RENO TAHOE INTL AP	266779	1	1	1	1	1	1	1	
RENO WFO	266791	1	1	1	1	1	1	1	
RUBY LAKE	267123	1	1	1	1	1	1		
RUTH	267175	1	1	1					
RYNDON	267188	1	1	1	1	1	1	1	
RYE PATCH DAM	267192	1	1	1					

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Grass Pasture - high management	Grass Pasture - low management	Grass - Turf	Orchards - Apples and Cherries w/ground cover	Orchards - Apples and Cherries w/no ground cover	Garden Vegetables - general	Onions	Melons
SAND PASS	267261	1	1	1					
SAN JACINTO	267284	1	1	1					
SARCOBATUS	267319	1	1	1					
SAVAL RCH	267324	1	1	1					
SCHURZ	267358	1	1	1					
SEARCHLIGHT	267369	1	1	1					
SEVENTY ONE RCH	267397	1	1	1	1	1			
SHELDON	267443	1	1	1					
SHOSHONE 5 N	267450	1	1	1					
SILVERPEAK	267463	1	1	1					
SMITH 1 N	267609	1	1	1	1	1	1	1	
SMITH 6 N	267612	1	1	1	1	1	1	1	
SMOKE CREEK ESPIL	267618	1	1	1					
SMOKEY VALLEY	267620	1	1	1	1	1	1		
SNOWBALL RCH	267640	1	1	1					
SOUTH FORK SP	267690	1	1	1	1	1	1	1	
SPRING VALLEY SP	267750	1	1	1					
STATELINE-HARRAH'S	267806	1	1	1					
STEAD	267820	1	1	1	1	1	1		
SULPHUR	267873	1	1	1					
SUNNYSIDE	267908	1	1	1					
SUTCLIFFE	267953	1	1	1					
TEMPIUTE 4 NW	267983	1	1	1					
THORNE	268034	1	1	1					
TONOPAH	268170	1	1	1	1	1	1	1	
TOPAZ LAKE 3N	268186	1	1	1	1	1	1	1	
TOPAZ LAKE 4 N	268202	1	1	1	1	1	1	1	
TUSCARORA	268346	1	1	1					
TWIN SPRING FALLINI	268443	1	1	1					
UNIV OF NEVADA EXP FM	268500	1	1	1	1	1	1	1	
URSINE	268538	1	1	1					
VALLEY OF FIRE SP	268588	1	1	1					
VIRGINIA CITY	268761	1	1	1	1	1	1	1	
VYA	268810	1	1	1					
WABUSKA 6 SE	268822	1	1	1	1	1	1	1	
WADSWORTH	268834	1	1	1	1	1	1	1	
WADSWORTH 4 N	268838	1	1	1					
WELLINGTON RS	268977	1	1	1	1	1	1	1	
WELLS	268988	1	1	1	1	1			
WILDHORSE RSVR	269072	1	1	1					
WILKINS	269122	1	1	1					
WILLOW SPRINGS	269137	1	1	1					
WINNEMUCCA #2	269168	1	1	1	1	1	1		
WINNEMUCCA MUNI AP	269171	1	1	1	1	1	1		
YERINGTON	269229	1	1	1	1	1	1	1	
LAS VEGAS	23112	1	1	1	1	1	1		
RED ROCK WC	29999	1	1	1	1	1	1		
WASHOE VALLEY WC	39999	1	1	1	1	1	1		

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Grapes--wine	Alfalfa Seed	Peas--fresh	Peas--seed	Potatoes--processing (early harvest)	Potatoes--cold pack (late harvest)	Sugar beets	Hops
ADAVEN	260046								
ALAMO	260099		1			1	1	1	
AMARGOSA FARMS-GAREY	260150		1			1	1	1	
ANTELOPE VALLEY FARR	260282								
ARTHUR 4 NW	260438		1						
AUSTIN #2	260507								
BASALT	260668								
BATTLE MTN	260688		1			1	1		
BATTLE MTN AP	260691		1			1	1		
BEATTY	260715		1			1	1	1	
BEATTY 8 N	260718		1			1	1	1	
BEOWAWE	260795								
BEOWAWE U OF N RCH	260800								
BLUE EAGLE RCH HANKS	260955								
BLUE JAY HWY STN	260961								
BOULDER CITY	261071		1						
BRINKERHOFF RCH	261160								
BUFFALO RCH	261311								
BUNKERVILLE	261327		1			1	1	1	
CALIENTE	261358		1			1	1	1	
CALLVILLE BAY	261371								
CARLIN NEWMONT MINE	261415								
CARSON CITY	261485								
CATHEDRAL GORGE SP	261590		1			1	1	1	
CENTRAL NEVADA FLD LAB	261630		1						
CHARLESTON	261660								
CLOVER VALLEY	261740		1						
COALDALE JUNCTION	261755								
CONTACT	261905								
CORTEZ GOLD MINE	261975								
CURRANT	262078		1			1	1	1	
CURRANT HWY STN	262091								
CURRIE HWY STN	262096								
DAGGET PASS	262119								
DENIO	262229		1			1	1	1	
DESERT NWR	262243								
DIABLO	262276								
DIAMOND VALLEY USDA	262296		1						
DUCKWATER	262390		1			1	1	1	
DUFURRENA	262394								
DYER	262431		1			1	1	1	
EASTGATE	262477								
ECHO BAY	262497								
ELGIN	262557		1			1	1	1	
ELGIN 3 SE	262562		1			1	1	1	

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Grapes--wine	Alfalfa Seed	Peas--fresh	Peas--seed	Potatoes--processing (early harvest)	Potatoes--cold pack (late harvest)	Sugar beets	Hops
ELKO	262570		1						
ELKO RGNL AP	262573		1						
ELY 6 NE	262626		1						
ELY YELLAND FLD AP	262631		1						
EMIGRANT PASS HWY STN	262656								
EMPIRE	262662		1			1	1	1	
EUREKA	262708								
FALLON EXP STN	262780	1	1	1	1	1	1	1	
FERGUSON SPRINGS HMS	262820								
FERNLEY	262840	1	1	1	1	1	1	1	
FISH CREEK RCH	262860		1						
GERLACH	263090		1			1	1	1	
GEYSER RCH	263101		1			1	1	1	
GIBBS RCH	263114								
GLENBROOK	263205								
GOLCONDA	263245								
GOLDFIELD	263285								
GOODSPRINGS	263316								
GREAT BASIN NP	263340								
HAWTHORNE	263512								
HAWTHORNE AP	263515								
HIKO	263671		1			1	1	1	
HUMBOLDT FLD	263853								
I-L RCH	263940								
IMLAY	263957								
INDIAN SPRINGS	263980								
JACKPOT	264016								
JARBRIDGE 4 N	264038								
JARBIDGE 7 N	264039								
JIGGS 8 SSE ZAGA	264095								
JUNGO MEYER RCH	264108								
KIMBERLY	264199								
KNOLL CREEK FLD STN	264268								
KYLE CANYON RS	264314								
LAGES	264341								
LAHONTAN DAM	264349								
LAKE VALLEY STEWARD	264384								
LAMOILLE YOST	264394		1						
LAMOILLE PH	264395		1						
LAS VEGAS	264429		1						
LAS VEGAS WB AP	264436		1						
LAS VEGAS NWFO	264439		1						
LATHROP WELLS	264457		1						
LAUGHLIN	264480		1						
LEHMAN CAVES NM	264514		1			1	1		
LEONARD CREEK RCH	264527		1			1	1	1	
LEWERS RCH	264542								
LITTLE RED ROCK	264600								

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Grapes--wine	Alfalfa Seed	Peas--fresh	Peas--seed	Potatoes--processing (early harvest)	Potatoes--cold pack (late harvest)	Sugar beets	Hops
LOGANDALE	264651	1	1	1	1	1	1	1	1
LOVELOCK DERBY FLD	264700	1	1	1	1	1	1	1	1
LUND	264745		1			1	1	1	1
MALA VISTA RCH	264824		1			1	1	1	
MARLETTE LAKE	264858								
MCDERMITT	264935		1			1	1	1	1
MCGILL	264950		1			1	1	1	1
MESQUITE	265085		1			1	1	1	
METROPOLIS	265092		1			1	1	1	
MIDAS 4 SE	265105								
MIDDLEGATE-LOWERY	265132								
MINA	265168								
MINDEN	265191		1			1	1	1	1
MONTELLO 2 SE	265352		1			1	1	1	1
MONTGOMERY MNTC STN	265362								
MOORMAN RCH	265371								
MTN CITY RS	265392								
MT CHARLESTON FS	265400								
MT ROSE BOWL	265440								
NIXON	265605		1			1	1	1	1
NORTH LAS VEGAS	265705		1						
OASIS	265722								
OLD RUTH	265760								
OROVADA 3 W	265818		1	1	1	1	1	1	1
OVERTON	265846	1	1	1	1	1	1	1	1
OWYHEE	265869		1						1
PAHRANAGAT WR	265880		1			1	1	1	
PAHRUMP	265890		1			1	1	1	1
PAHUTE MEADOWS RCH	265907								
PALMETTO	265931								
PARADISE VALLEY 1 NW	266005		1			1	1	1	1
PARIS RCH	266055								
PENOYER VALLEY	266130								
PEQUOP	266148								
PILOT VALLEY-LEE	266228								
PINE VALLEY BAILEY RCH	266242		1						
PIOCHE	266252		1			1	1	1	
QUINN RVR CROSSING	266504		1			1	1	1	
RAND RCH PALISADE	266574		1			1	1	1	
RATTLESNAKE	266630								
RED ROCK CANYON SP	266691								
REESE RIVER	266746		1			1	1	1	
REESE VALLEY CARPER	266748								
RENO TAHOE INTL AP	266779	1	1			1	1		
RENO WFO	266791	1	1			1	1		
RUBY LAKE	267123		1						
RUTH	267175								
RYNDON	267188		1			1	1	1	

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Grapes--wine	Alfalfa Seed	Peas--fresh	Peas--seed	Potatoes--processing (early harvest)	Potatoes--cold pack (late harvest)	Sugar beets	Hops
RYE PATCH DAM	267192								
SAND PASS	267261								
SAN JACINTO	267284								
SARCOBATUS	267319								
SAVAL RCH	267324								
SCHURZ	267358								
SEARCHLIGHT	267369								
SEVENTY ONE RCH	267397		1						
SHELDON	267443								
SHOSHONE 5 N	267450								
SILVERPEAK	267463								
SMITH 1 N	267609	1	1			1	1		
SMITH 6 N	267612	1	1			1	1		
SMOKE CREEK ESPIL	267618								
SMOKEY VALLEY	267620		1						
SNOWBALL RCH	267640								
SOUTH FORK SP	267690		1			1	1	1	
SPRING VALLEY SP	267750								
STATELINE-HARRAH'S	267806								
STEAD	267820		1						
SULPHUR	267873								
SUNNYSIDE	267908								
SUTCLIFFE	267953								
TEMPIUTE 4 NW	267983								
THORNE	268034								
TONOPAH	268170		1			1	1		
TOPAZ LAKE 3N	268186		1			1	1		
TOPAZ LAKE 4 N	268202		1			1	1		
TUSCARORA	268346								
TWIN SPRING FALLINI	268443								
UNIV OF NEVADA EXP FM	268500		1			1	1		
URSINE	268538								
VALLEY OF FIRE SP	268588								
VIRGINIA CITY	268761		1			1	1		
VYA	268810								
WABUSKA 6 SE	268822		1			1	1		
WADSWORTH	268834		1			1	1		
WADSWORTH 4 N	268838								
WELLINGTON RS	268977		1			1	1		
WELLS	268988		1						
WILDHORSE RSVR	269072								
WILKINS	269122								
WILLOW SPRINGS	269137								
WINNEMUCCA #2	269168		1			1	1		
WINNEMUCCA MUNI AP	269171		1			1	1		
YERINGTON	269229		1			1	1		
LAS VEGAS	23112		1						
RED ROCK WC	29999		1			1	1		
WASHOE VALLEY WC	39999		1			1	1		

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Sunflower -irrigated	Safflower -irrigated	Canola	Garlic	Bare soil	Mulched soil, including wheat stubble	Dormant turf (winter time)	Open water - shallow systems/ponds
ADAVEN	260046					1	1	1	1
ALAMO	260099	1	1	1	1	1	1	1	1
AMARGOSA FARMS-GAREY	260150	1	1	1		1	1	1	1
ANTELOPE VALLEY FARR	260282					1	1	1	1
ARTHUR 4 NW	260438					1	1	1	1
AUSTIN #2	260507					1	1	1	1
BASALT	260668					1	1	1	1
BATTLE MTN	260688					1	1	1	1
BATTLE MTN AP	260691					1	1	1	1
BEATTY	260715	1	1	1	1	1	1	1	1
BEATTY 8 N	260718	1	1	1	1	1	1	1	1
BEOWAWE	260795					1	1	1	1
BEOWAWE U OF N RCH	260800					1	1	1	1
BLUE EAGLE RCH HANKS	260955					1	1	1	1
BLUE JAY HWY STN	260961					1	1	1	1
BOULDER CITY	261071	1	1	1		1	1	1	1
BRINKERHOFF RCH	261160					1	1	1	1
BUFFALO RCH	261311					1	1	1	1
BUNKERVILLE	261327	1	1	1	1	1	1	1	1
CALIENTE	261358	1	1	1	1	1	1	1	1
CALLVILLE BAY	261371					1	1	1	1
CARLIN NEWMONT MINE	261415					1	1	1	1
CARSON CITY	261485					1	1	1	1
CATHEDRAL GORGE SP	261590	1	1	1		1	1	1	1
CENTRAL NEVADA FLD LAB	261630					1	1	1	1
CHARLESTON	261660					1	1	1	1
CLOVER VALLEY	261740					1	1	1	1
COALDALE JUNCTION	261755					1	1	1	1
CONTACT	261905					1	1	1	1
CORTEZ GOLD MINE	261975					1	1	1	1
CURRANT	262078	1	1	1		1	1	1	1
CURRANT HWY STN	262091					1	1	1	1
CURRIE HWY STN	262096					1	1	1	1
DAGGET PASS	262119					1	1	1	1
DENIO	262229	1	1	1	1	1	1	1	1
DESERT NWR	262243					1	1	1	1
DIABLO	262276					1	1	1	1
DIAMOND VALLEY USDA	262296					1	1	1	1
DUCKWATER	262390	1	1	1	1	1	1	1	1
DUFURRENA	262394					1	1	1	1
DYER	262431	1	1	1	1	1	1	1	1
EASTGATE	262477					1	1	1	1
ECHO BAY	262497					1	1	1	1
ELGIN	262557	1	1	1	1	1	1	1	1

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Sunflower -irrigated	Safflower -irrigated	Canola	Garlic	Bare soil	Mulched soil, including wheat stubble	Dormant turf (winter time)	Open water - shallow systems/ponds
ELGIN 3 SE	262562	1	1	1	1	1	1	1	1
ELKO	262570					1	1	1	1
ELKO RGNL AP	262573					1	1	1	1
ELY 6 NE	262626					1	1	1	1
ELY YELLAND FLD AP	262631					1	1	1	1
EMIGRANT PASS HWY STN	262656					1	1	1	1
EMPIRE	262662	1	1	1	1	1	1	1	1
EUREKA	262708					1	1	1	1
FALLON EXP STN	262780	1	1	1	1	1	1	1	1
FERGUSON SPRINGS HMS	262820					1	1	1	1
FERNLEY	262840	1	1	1	1	1	1	1	1
FISH CREEK RCH	262860					1	1	1	1
GERLACH	263090	1	1	1	1	1	1	1	1
GEYSER RCH	263101	1	1	1	1	1	1	1	1
GIBBS RCH	263114					1	1	1	1
GLENBROOK	263205					1	1	1	1
GOLCONDA	263245					1	1	1	1
GOLDFIELD	263285					1	1	1	1
GOODSPRINGS	263316					1	1	1	1
GREAT BASIN NP	263340					1	1	1	1
HAWTHORNE	263512					1	1	1	1
HAWTHORNE AP	263515					1	1	1	1
HIKO	263671	1	1	1		1	1	1	1
HUMBOLDT FLD	263853					1	1	1	1
I-L RCH	263940					1	1	1	1
IMLAY	263957					1	1	1	1
INDIAN SPRINGS	263980					1	1	1	1
JACKPOT	264016					1	1	1	1
JARBRIDGE 4 N	264038					1	1	1	1
JARBIDGE 7 N	264039					1	1	1	1
JIGGS 8 SSE ZAGA	264095					1	1	1	1
JUNGO MEYER RCH	264108					1	1	1	1
KIMBERLY	264199					1	1	1	1
KNOLL CREEK FLD STN	264268					1	1	1	1
KYLE CANYON RS	264314					1	1	1	1
LAGES	264341					1	1	1	1
LAHONTAN DAM	264349					1	1	1	1
LAKE VALLEY STEWARD	264384					1	1	1	1
LAMOILLE YOST	264394					1	1	1	1
LAMOILLE PH	264395					1	1	1	1
LAS VEGAS	264429	1	1	1		1	1	1	1
LAS VEGAS WB AP	264436	1	1	1		1	1	1	1
LAS VEGAS NWFO	264439	1	1	1		1	1	1	1
LATHROP WELLS	264457	1	1	1		1	1	1	1
LAUGHLIN	264480	1	1	1		1	1	1	1
LEHMAN CAVES NM	264514					1	1	1	1
LEONARD CREEK RCH	264527	1	1	1		1	1	1	1
LEWERS RCH	264542					1	1	1	1

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Sunflower -irrigated	Safflower -irrigated	Canola	Garlic	Bare soil	Mulched soil, including wheat stubble	Dormant turf (winter time)	Open water - shallow systems/ponds
LITTLE RED ROCK	264600					1	1	1	1
LOGANDALE	264651	1	1	1		1	1	1	1
LOVELOCK DERBY FLD	264700	1	1	1	1	1	1	1	1
LUND	264745				1	1	1	1	1
MALA VISTA RCH	264824	1	1	1		1	1	1	1
MARLETTE LAKE	264858					1	1	1	1
MCDERMITT	264935					1	1	1	1
MCGILL	264950					1	1	1	1
MESQUITE	265085	1	1	1		1	1	1	1
METROPOLIS	265092	1	1	1		1	1	1	1
MIDAS 4 SE	265105					1	1	1	1
MIDDLEGATE-LOWERY	265132					1	1	1	1
MINA	265168					1	1	1	1
MINDEN	265191				1	1	1	1	1
MONTELLO 2 SE	265352				1	1	1	1	1
MONTGOMERY MNTC STN	265362					1	1	1	1
MOORMAN RCH	265371					1	1	1	1
MTN CITY RS	265392					1	1	1	1
MT CHARLESTON FS	265400					1	1	1	1
MT ROSE BOWL	265440					1	1	1	1
NIXON	265605				1	1	1	1	1
NORTH LAS VEGAS	265705	1	1	1		1	1	1	1
OASIS	265722					1	1	1	1
OLD RUTH	265760					1	1	1	1
OROVADA 3 W	265818				1	1	1	1	1
OVERTON	265846	1	1	1	1	1	1	1	1
OWYHEE	265869					1	1	1	1
PAHRANAGAT WR	265880	1	1	1	1	1	1	1	1
PAHRUMP	265890	1	1	1	1	1	1	1	1
PAHUTE MEADOWS RCH	265907					1	1	1	1
PALMETTO	265931					1	1	1	1
PARADISE VALLEY 1 NW	266005	1	1	1	1	1	1	1	1
PARIS RCH	266055					1	1	1	1
PENOYER VALLEY	266130					1	1	1	1
PEQUOP	266148					1	1	1	1
PILOT VALLEY-LEE	266228					1	1	1	1
PINE VALLEY BAILEY RCH	266242					1	1	1	1
PIOCHE	266252	1	1	1	1	1	1	1	1
QUINN RVR CROSSING	266504	1	1	1		1	1	1	1
RAND RCH PALISADE	266574	1	1	1		1	1	1	1
RATTLESNAKE	266630					1	1	1	1
RED ROCK CANYON SP	266691					1	1	1	1
REESE RIVER	266746	1	1	1		1	1	1	1
REESE VALLEY CARPER	266748					1	1	1	1
RENO TAHOE INTL AP	266779				1	1	1	1	1
RENO WFO	266791				1	1	1	1	1
RUBY LAKE	267123					1	1	1	1
RUTH	267175					1	1	1	1

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Sunflower -irrigated	Safflower -irrigated	Canola	Garlic	Bare soil	Mulched soil, including wheat stubble	Dormant turf (winter time)	Open water - shallow systems/ponds
RYNDON	267188	1	1	1		1	1	1	1
RYE PATCH DAM	267192					1	1	1	1
SAND PASS	267261					1	1	1	1
SAN JACINTO	267284					1	1	1	1
SARCOBATUS	267319					1	1	1	1
SAVAL RCH	267324					1	1	1	1
SCHURZ	267358					1	1	1	1
SEARCHLIGHT	267369					1	1	1	1
SEVENTY ONE RCH	267397					1	1	1	1
SHELDON	267443					1	1	1	1
SHOSHONE 5 N	267450					1	1	1	1
SILVERPEAK	267463					1	1	1	1
SMITH 1 N	267609	1	1	1	1	1	1	1	1
SMITH 6 N	267612	1	1	1	1	1	1	1	1
SMOKE CREEK ESPIL	267618					1	1	1	1
SMOKEY VALLEY	267620					1	1	1	1
SNOWBALL RCH	267640					1	1	1	1
SOUTH FORK SP	267690				1	1	1	1	1
SPRING VALLEY SP	267750					1	1	1	1
STATELINE-HARRAH'S	267806					1	1	1	1
STEAD	267820					1	1	1	1
SULPHUR	267873					1	1	1	1
SUNNYSIDE	267908					1	1	1	1
SUTCLIFFE	267953					1	1	1	1
TEMPIUTE 4 NW	267983					1	1	1	1
THORNE	268034					1	1	1	1
TONOPAH	268170				1	1	1	1	1
TOPAZ LAKE 3N	268186				1	1	1	1	1
TOPAZ LAKE 4 N	268202				1	1	1	1	1
TUSCARORA	268346					1	1	1	1
TWIN SPRING FALLINI	268443					1	1	1	1
UNIV OF NEVADA EXP FM	268500					1	1	1	1
URSINE	268538					1	1	1	1
VALLEY OF FIRE SP	268588					1	1	1	1
VIRGINIA CITY	268761					1	1	1	1
VYA	268810					1	1	1	1
WABUSKA 6 SE	268822					1	1	1	1
WADSWORTH	268834					1	1	1	1
WADSWORTH 4 N	268838					1	1	1	1
WELLINGTON RS	268977	1	1	1	1	1	1	1	1
WELLS	268988					1	1	1	1
WILDHORSE RSVR	269072					1	1	1	1
WILKINS	269122					1	1	1	1
WILLOW SPRINGS	269137					1	1	1	1
WINNEMUCCA #2	269168					1	1	1	1
WINNEMUCCA MUNI AP	269171					1	1	1	1
YERINGTON	269229	1	1	1	1	1	1	1	1
LAS VEGAS	23112					1	1	1	1

Appendix 10 cont. Crop or land cover class simulated for each station (1 = yes, 0 = no).

Station Name	Station Number	Sunflower -irrigated	Safflower -irrigated	Canola	Garlic	Bare soil	Mulched soil, including wheat stubble	Dormant turf (winter time)	Open water - shallow systems/ponds
RED ROCK WC	29999					1	1	1	1
WASHOE VALLEY WC	39999					1	1	1	1

Appendix 11a. Mean annual ET_{os} and ET_{act} for each NWS weather station, sorted by station name. * Station was used in averaging or assigning ET_{os} and ET_{act} to respective hydrographic areas. Number of years used for average and start and end years listed are for alfalfa and may vary slightly for other crop types due to possible missing data within crop specific growing seasons. See statistic data files for further details.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
260046	ADAVEN	Garden Valley	172	30	1947	1978	3.8	3.1	3.1	2.5	2.9	2.9	4.0
260099	ALAMO*	Pahranagat Valley	209	29	1923	1958	5.6	5.0	4.5	3.6	4.2	4.6	5.8
260150	AMARGOSA FARMS-GAREY*	Amargosa Desert	230	28	1966	2005	5.8	5.6	4.8	3.9	3.7	5.6	6.1
260282	ANTELOPE VALLEY FARR*	Antelope Valley	57	8	1985	1998	4.4	3.6	3.6	3.0	3.5	3.5	4.6
260438	ARTHUR 4 NW*	Ruby Valley	176	30	1972	2007	3.8	3.1	3.0	2.5	2.9	2.8	4.0
260507	AUSTIN #2*	Upper Reese River Valley	56	30	1972	2007	4.1	3.4	3.3	2.7	3.1	3.1	4.3
260668	BASALT	Teels Marsh Valley	114	10	1942	1957	4.4	3.4	3.4	2.7	3.3	3.2	4.7
260691	BATTLE MTN AP*	Lower Reese River Valley	59	30	1974	2006	4.3	3.8	3.7	3.1	3.5	3.6	4.5
260688	BATTLE MTN*	Clovers Area	64	25	1903	1944	4.6	4.0	3.9	3.2	3.7	3.8	4.8
260718	BEATTY 8 N*	Oasis Valley	228	28	1973	2004	5.3	4.9	4.3	3.5	4.1	4.8	5.6
260715	BEATTY*	Oasis Valley	228	30	1925	1972	5.6	5.2	4.6	3.7	4.2	5.1	5.9
260800	BEOWAWE U OF N RCH*	Grass Valley	138	28	1973	2007	4.2	3.5	3.4	2.8	3.3	3.3	4.4
260795	BEOWAWE*	Crescent Valley	54	30	1976	2006	4.3	3.6	3.6	3.0	3.5	3.5	4.5

Appendix 11a cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
260955	BLUE EAGLE RCH HANKS*	Railroad Valley	173B	23	1979	2007	4.8	4.4	4.3	3.6	4.2	4.3	5.0
260961	BLUE JAY HWY STN*	Hot Creek	156	7	1964	1983	4.8	3.9	3.9	3.2	3.7	3.7	5.0
261071	BOULDER CITY*	Eldorado Valley	167	30	1969	2004	5.4	5.1	4.3	3.5	3.1	5.0	5.7
261160	BRINKERHOFF RCH*	Dixie Valley	128	7	1967	1979	4.7	4.2	4.1	3.4	4.0	4.1	4.9
261311	BUFFALO RCH*	Buffalo Valley	131	7	1967	1978	4.0	3.7	3.5	2.9	3.3	3.5	4.2
261327	BUNKERVILLE*	Virgin River Valley	222	6	1980	2007	5.1	4.8	4.0	3.3	3.1	4.7	5.4
261358	CALIENTE*	Clover Valley	204	22	1904	2006	4.9	4.5	4.2	3.5	3.9	4.1	5.2
261371	CALLVILLE BAY*	Black Moutains Area	215	8	1990	2006	5.7	5.3	4.5	3.6	2.9	5.3	5.9
261415	CARLIN NEWMONT MINE	Boulder Flat	61	24	1967	1999	3.3	2.7	2.6	2.2	2.5	2.5	3.4
261485	CARSON CITY*	Eagle Valley	104	30	1974	2007	4.3	3.8	3.6	3.0	3.5	3.6	4.6
261590	CATHEDRAL GORGE SP*	Panaca Valley	203	4	2003	2007	5.0	4.7	4.4	3.7	4.3	4.3	5.3
261630	CENTRAL NEVADA FLD LAB*	Upper Reese River Valley	56	13	1966	1985	4.5	3.3	3.1	2.6	3.0	2.9	4.7
261660	CHARLESTON*	Bruneau River Area	38	4	1962	2005	4.1	2.3	2.0	1.7	1.7	1.8	4.3
261740	CLOVER VALLEY*	Clover Valley	177	30	1926	2007	4.0	3.3	3.3	2.7	3.1	3.1	4.2
261755	COALDALE JUNCTION*	Columbus Salt Marsh Valley	118	6	1942	1958	5.5	4.7	4.4	3.6	4.3	4.3	5.8

Appendix 11a cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
261905	CONTACT*	Salmon Falls Creek Area	40	30	1958	1998	4.2	3.4	3.2	2.7	3.0	3.0	4.4
261975	CORTEZ GOLD MINE*	Crescent Valley	54	10	1969	1979	4.1	3.6	3.5	2.9	3.4	3.3	4.3
262091	CURRANT HWY STN	Railroad Valley	173B	7	1964	1977	4.3	3.0	3.0	2.4	2.7	2.7	4.5
262078	CURRANT*	Railroad Valley	173B	4	1942	1946	4.4	3.8	3.8	3.1	3.7	3.6	4.6
262096	CURRIE HWY STN*	Steptoe Valley	179	10	1962	1989	4.7	3.2	3.1	2.5	2.9	2.8	4.9
262119	DAGGET PASS	Lake Tahoe Basin	90	5	1989	2005	3.3	2.3	2.2	1.7	2.0	2.0	3.4
262229	DENIO*	Pueblo Valley	1	30	1970	2005	4.3	3.7	3.6	3.0	3.5	3.5	4.5
262243	DESERT NWR*	Las Vegas Valley	212	30	1976	2007	6.2	5.9	5.1	4.1	4.2	5.7	6.5
262276	DIABLO*	Railroad Valley	173A	10	1960	1978	4.8	4.2	4.1	3.4	4.0	4.1	5.0
262296	DIAMOND VALLEY USDA*	Diamond Valley	153	19	1980	2006	4.1	3.2	3.1	2.5	3.0	2.9	4.3
262390	DUCKWATER*	Railroad Valley	173B	19	1967	1998	4.5	3.9	3.8	3.1	3.7	3.6	4.7
262394	DUFURRENA*	Virgin Valley	4	30	1967	2004	4.4	3.3	3.1	2.6	3.0	2.9	4.6
262431	DYER*	Fish Lake Valley	117	30	1974	2007	5.5	4.6	4.4	3.6	4.3	4.3	5.8
262477	EASTGATE*	Eastgate Valley Area	127	4	1957	1963	4.5	3.9	3.9	3.2	3.9	3.8	4.8
262497	ECHO BAY*	Black Moutains Area	215	10	1990	2003	5.3	5.0	4.2	3.4	2.8	4.9	5.6

Appendix 11a cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
262562	ELGIN 3 SE*	Lower Meadow Valley Wash	205	15	1966	1985	4.9	4.6	3.9	3.2	3.5	4.5	5.1
262557	ELGIN*	Lower Meadow Valley Wash	205	20	1986	2006	4.9	4.6	4.1	3.3	3.8	4.5	5.2
262573	ELKO RGNL AP*	Elko Segment	49	30	1978	2007	4.0	3.3	3.2	2.7	3.1	3.0	4.2
262570	ELKO*	Elko Segment	49	6	2000	2007	3.9	3.3	3.3	2.7	3.2	3.1	4.1
262626	ELY 6 NE	Steptoe Valley	179	5	2000	2005	4.8	4.0	3.9	3.3	3.7	3.7	5.1
262631	ELY YELLAND FLD AP*	Steptoe Valley	179	30	1976	2005	4.5	3.5	3.3	2.7	3.2	3.0	4.7
262656	EMIGRANT PASS HWY STN	Boulder Flat	61	27	1964	1999	3.8	3.2	3.2	2.6	3.0	3.0	4.0
262662	EMPIRE*	San Emidio Desert	22	6	1951	1976	4.4	3.9	3.9	3.2	3.8	3.9	4.6
262708	EUREKA	Diamond Valley	153	30	1975	2007	3.6	2.9	2.8	2.2	2.6	2.5	3.8
262780	FALLON EXP STN*	Carson Desert	101	30	1973	2005	4.1	3.6	3.5	2.9	3.5	3.5	4.3
262820	FERGUSON SPRINGS HMS*	Great Salt Lake Desert	192	7	1973	1982	3.6	2.9	2.9	2.3	2.7	2.7	3.7
262840	FERNLEY*	Fernley Area	76	21	1908	1974	4.6	3.9	3.8	3.1	3.6	3.7	4.8
262860	FISH CREEK RCH*	Little Smoky Valley	155A	14	1944	1964	4.5	3.1	3.1	2.5	2.9	2.9	4.8
263090	GERLACH*	San Emidio Desert	22	27	1963	2006	4.2	3.8	3.7	3.0	3.6	3.7	4.4
263101	GEYSER RCH*	Lake Valley	183	19	1972	2002	4.5	3.6	3.4	2.8	3.3	3.2	4.7

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263114	GIBBS RCH*	Marys River Area	42	30	1973	2007	3.9	3.0	2.9	2.4	2.8	2.8	4.1
263205	GLENBROOK*	Lake Tahoe Basin	90	30	1969	2007	3.5	2.9	2.7	2.2	2.5	2.5	3.7
263245	GOLCONDA*	Winnemucca Segment	70	30	1970	2005	4.6	4.0	3.9	3.2	3.8	3.8	4.8
263285	GOLDFIELD	Alkali Spring Valley	142	30	1951	2004	4.5	3.8	3.7	3.0	3.6	3.6	4.7
263316	GOODSPRINGS*	Ivanpah Valley	164A	6	2000	2006	5.9	5.7	4.9	4.0	4.1	5.6	6.2
263340	GREAT BASIN NP	Snake Valley	195	16	1988	2007	3.7	3.1	3.0	2.5	2.9	2.9	3.8
263515	HAWTHORNE AP*	Walker Lake Valley	110C	30	1948	1990	4.7	4.2	3.9	3.2	3.8	4.0	5.0
263512	HAWTHORNE*	Walker Lake Valley	110C	13	1955	2007	4.8	4.3	4.0	3.2	3.7	3.9	5.0
263671	HIKO*	Pahranagat Valley	209	15	1990	2006	5.0	4.5	4.2	3.4	3.8	4.4	5.2
263853	HUMBOLDT FLD	Buena Vista Valley	129	7	1940	1947	4.4	3.8	3.7	3.0	3.6	3.5	4.6
263940	I-L RCH*	South Fork Owyhee River Area	35	3	1963	1967	4.2	3.0	2.9	2.4	2.8	2.7	4.4
263957	IMLAY*	Imlay Area	72	30	1964	2007	4.5	4.0	3.9	3.2	3.8	3.8	4.7
263980	INDIAN SPRINGS*	Indian Springs Valley	161	23	1914	1964	6.0	5.4	4.9	4.0	4.2	5.3	6.3
264016	JACKPOT*	Salmon Falls Creek Area	40	15	1987	2004	3.9	3.2	3.2	2.6	3.0	3.0	4.1
264039	JARBIDGE 7 N*	Jarbidge River Area	39	11	1996	2006	3.9	3.3	3.0	2.5	2.9	2.8	4.1

Appendix 11a cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
264038	JARBRIDGE 4 N	Jarbidge River Area	39	22	1965	1995	3.8	3.1	2.6	2.2	2.3	2.4	4.0
264095	JIGGS 8 SSE ZAGA*	Huntington Valley	47	19	1979	2007	4.0	3.2	3.0	2.5	2.8	2.8	4.2
264108	JUNGO MEYER RCH*	Desert Valley	31	7	1969	1985	4.3	3.8	3.7	3.0	3.5	3.6	4.5
264199	KIMBERLY	White River Valley	207	28	1929	1958	3.9	3.0	2.9	2.4	2.8	2.7	4.1
264268	KNOLL CREEK FLD STN	Salmon Falls Creek Area	40	6	1972	1979	4.0	2.9	2.7	2.1	2.5	2.4	4.2
264314	KYLE CANYON RS	Las Vegas Valley	212	4	1940	1948	4.5	3.4	3.0	2.4	3.2	2.7	4.7
264341	LAGES*	Steptoe Valley	179	21	1984	2006	4.5	3.6	3.5	2.8	3.3	3.2	4.7
264349	LAHONTAN DAM*	Churchill Valley	102	30	1969	2007	4.2	3.8	3.6	3.0	3.5	3.7	4.4
264384	LAKE VALLEY STEWARD	Lake Valley	183	22	1971	1998	3.8	3.2	3.1	2.5	3.0	2.9	4.0
264395	LAMOILLE PH	Lamoille Valley	45	30	1934	1972	3.6	3.1	2.9	2.4	2.8	2.8	3.8
264394	LAMOILLE YOST*	Lamoille Valley	45	22	1976	2003	3.9	3.0	2.8	2.3	2.7	2.6	4.1
264439	LAS VEGAS NWFO*	Las Vegas Valley	212	9	1997	2007	5.8	5.5	4.6	3.7	3.3	5.3	6.1
264436	LAS VEGAS WB AP*	Las Vegas Valley	212	30	1976	2005	5.8	5.6	4.9	4.0	3.4	5.7	6.0
23112	LAS VEGAS*	Las Vegas Valley	212	22	1949	1970	6.0	5.8	5.1	4.1	3.7	5.9	6.3
264429	LAS VEGAS*	Las Vegas Valley	212	30	1921	1956	6.6	6.4	5.6	4.6	4.3	6.5	6.9
264457	LATHROP WELLS	Fortymile Canyon	227A	8	1943	1963	5.8	5.4	4.7	3.8	3.9	5.4	6.0

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264480	LAUGHLIN*	Colorado Valley	213	10	1989	2006	6.5	6.2	5.3	4.3	3.7	6.1	6.9
264514	LEHMAN CAVES NM	Snake Valley	195	30	1958	1987	3.6	2.9	2.8	2.3	2.7	2.6	3.8
264527	LEONARD CREEK RCH*	Black Rock Desert	28	30	1971	2004	4.2	3.9	3.8	3.2	3.7	3.8	4.4
264542	LEWERS RCH	Washoe Valley	89	15	1893	1913	4.5	3.9	3.6	2.9	3.5	3.4	4.7
264600	LITTLE RED ROCK	Las Vegas Valley	212	4	1966	1970	5.1	4.8	4.1	3.3	3.6	4.6	5.4
264651	LOGANDALE*	Lower Moapa Valley	220	20	1969	1991	5.0	4.7	4.1	3.4	3.2	4.9	5.2
264700	LOVELOCK DERBY FLD*	Lovelock Valley	73	30	1970	2005	4.7	4.1	4.1	3.4	4.0	4.0	4.9
264745	LUND*	White River Valley	207	30	1977	2007	4.5	3.9	3.8	3.2	3.7	3.7	4.8
264824	MALA VISTA RCH*	Marys River Area	42	16	1940	1965	4.1	3.1	2.9	2.4	2.8	2.7	4.3
264858	MARLETTE LAKE	Lake Tahoe Basin	90	19	1917	1952	2.9	1.8	1.7	1.3	1.6	1.5	3.0
264935	MCDERMITT*	Quinn River Valley	33B	29	1974	2007	4.3	3.4	3.2	2.7	2.9	3.0	4.5
264950	MCGILL*	Steptoe Valley	179	30	1977	2007	4.2	3.6	3.5	2.9	3.3	3.3	4.4
265085	MESQUITE*	Virgin River Valley	222	13	1942	2006	5.1	5.0	4.4	3.6	3.3	5.0	5.4
265092	METROPOLIS*	Marys River Area	42	18	1966	1994	3.7	3.2	3.1	2.6	3.0	3.0	3.9
265105	MIDAS 4 SE*	Willow Creek Valley	63	4	1962	1967	4.4	3.1	3.1	2.6	2.9	2.9	4.7
265132	MIDDLEGATE-LOWERY*	Cowkick Valley	126	15	1989	2007	4.8	3.8	3.5	2.9	3.4	3.3	5.0

Appendix 11a cont.

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265168	MINA*	Soda Spring Valley	121A	30	1978	2007	4.9	4.3	4.1	3.3	3.9	4.1	5.1
265191	MINDEN*	Carson Valley	105	30	1975	2007	4.3	3.6	3.5	2.9	3.3	3.4	4.5
265352	MONTELLO 2 SE*	Thousand Springs Valley	189D	30	1971	2007	4.4	3.5	3.4	2.7	3.2	3.1	4.6
265362	MONTGOMERY MNTC STN	Queen Valley	116	10	1961	1978	4.1	2.8	2.7	2.1	2.4	2.5	4.3
265371	MOORMAN RCH*	Jakes Valley	174	4	2003	2007	4.3	3.2	3.1	2.5	2.9	2.8	4.5
265400	MT CHARLESTON FS	Las Vegas Valley	212	6	1949	2007	4.4	3.4	2.7	2.1	3.1	2.4	4.7
265440	MT ROSE BOWL	Pleasant Valley	88	8	1974	1984	3.3	2.0	2.0	1.6	1.9	1.8	3.5
265392	MTN CITY RS*	Owyhee River Area	37	30	1965	1998	4.2	2.8	2.5	2.1	2.4	2.3	4.4
265605	NIXON*	Pyramid Lake Valley	81	30	1931	1973	4.8	4.1	4.0	3.2	3.8	3.9	5.0
265705	NORTH LAS VEGAS*	Las Vegas Valley	212	20	1952	2006	6.5	6.2	5.5	4.5	4.1	6.4	6.8
265722	OASIS*	Goshute Valley	187	17	1988	2006	4.2	3.4	3.2	2.6	3.1	2.9	4.5
265760	OLD RUTH	Steptoe Valley	179	5	1979	1985	3.8	2.9	2.9	2.3	2.7	2.6	4.0
265818	OROVADA 3 W*	Quinn River Valley	33A	30	1973	2006	4.4	3.9	3.8	3.1	3.6	3.6	4.6
265846	OVERTON*	Lower Moapa Valley	220	30	1953	2007	5.2	4.9	4.3	3.6	3.2	5.1	5.5
265869	OWYHEE*	Owyhee River Area	37	30	1954	1984	3.8	3.2	3.1	2.6	3.0	2.9	4.0

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265880	PAHRANAGAT WR*	Pahranagat Valley	209	30	1970	2006	5.2	4.8	4.3	3.5	3.7	4.6	5.4
265890	PAHRUMP*	Pahrump Valley	162	30	1976	2007	5.7	5.4	4.8	4.0	4.1	5.5	6.0
265907	PAHUTE MEADOWS RCH*	Black Rock Desert	28	4	1964	1974	4.2	3.6	3.6	2.9	3.5	3.5	4.4
265931	PALMETTO	Fish Lake Valley	117	14	1891	1907	4.9	3.5	3.4	2.7	3.1	3.1	5.2
266005	PARADISE VALLEY 1 NW*	Paradise Valley	69	30	1973	2007	4.6	3.8	3.6	3.0	3.5	3.4	4.8
266055	PARIS RCH*	Pleasant Valley	130	22	1967	1990	4.6	4.2	4.1	3.4	3.9	4.0	4.9
266130	PENOYER VALLEY*	Penoyer Valley	170	5	1968	2004	5.1	4.3	4.3	3.5	4.2	4.2	5.4
266148	PEQUOP	Goshute Valley	187	23	1960	1985	4.1	3.1	3.0	2.4	2.8	2.7	4.3
266228	PILOT VALLEY-LEE*	Pilot Creek Valley	191	6	2000	2007	4.2	3.4	3.3	2.7	3.1	3.1	4.4
266242	PINE VALLEY BAILEY RCH*	Pine Valley	53	11	1983	2003	4.5	3.4	3.2	2.7	3.0	3.0	4.7
266252	PIOCHE	Patterson Valley	202	30	1968	2006	4.1	3.6	3.4	2.8	3.3	3.3	4.3
266504	QUINN RVR CROSSING	Pine Forest Valley	29	10	1902	1950	4.5	3.6	3.5	2.8	3.4	3.3	4.8
266574	RAND RCH PALISADE*	Pine Valley	53	19	1958	1981	4.3	3.0	3.0	2.5	2.8	2.8	4.6
266630	RATTLESNAKE	Hot Creek	156	13	1949	1961	4.3	3.6	3.6	2.9	3.5	3.4	4.5
266691	RED ROCK CANYON SP	Las Vegas Valley	212	20	1978	2006	5.4	5.2	4.6	3.8	3.9	5.2	5.7
29999	RED ROCK WC*	Red Rock Valley	99	4	2004	2007	4.0	3.1	2.9	2.4	2.9	2.7	4.2

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266746	REESE RIVER*	Upper Reese River Valley	56	26	1973	2006	4.3	3.0	2.8	2.2	2.6	2.5	4.5
266748	REESE VALLEY CARPER	Middle Reese River Valley	58	6	1977	1983	4.3	3.5	3.3	2.8	3.2	3.1	4.5
266779	RENO TAHOE INTL AP*	Truckee Meadows	87	30	1978	2007	4.4	4.0	3.8	3.2	3.8	3.9	4.7
266791	RENO WFO*	Truckee Meadows	87	10	1997	2007	4.2	3.9	3.7	3.0	3.6	3.8	4.4
267123	RUBY LAKE*	Ruby Valley	176	30	1976	2007	4.2	3.5	3.4	2.8	3.3	3.2	4.4
267175	RUTH	Steptoe Valley	179	30	1963	2007	4.3	3.0	2.7	2.3	2.6	2.5	4.5
267192	RYE PATCH DAM*	Imlay Area	72	30	1973	2007	4.8	4.2	4.1	3.4	4.0	4.0	5.0
267188	RYNDON*	North Fork Area	44	6	2000	2007	4.3	3.5	3.1	2.6	3.0	2.9	4.5
267284	SAN JACINTO*	Salmon Falls Creek Area	40	21	1905	1947	4.1	3.2	3.0	2.5	2.9	2.8	4.3
267261	SAND PASS*	Smoke Creek Desert	21	30	1931	1970	4.5	4.0	4.0	3.3	3.9	3.9	4.7
267319	SARCOBATUS*	Sarcobatus Flat	146	14	1942	1961	5.3	4.4	4.3	3.4	3.9	4.3	5.5
267324	SAVAL RCH*	North Fork Area	44	5	1961	1965	3.5	2.6	2.3	1.9	2.3	2.1	3.7
267358	SCHURZ*	Walker Lake Valley	110A	30	1921	1955	4.6	3.9	3.9	3.2	3.8	3.9	4.9
267369	SEARCHLIGHT	Piute Valley	214	30	1976	2006	5.0	4.7	4.1	3.3	3.3	4.7	5.2
267397	SEVENTY ONE RCH*	Starr Valley Area	43	4	1940	1951	4.1	3.3	2.9	2.4	2.8	2.7	4.3

Appendix 11a cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
267443	SHELDON	Guano Valley	6	30	1942	1972	3.5	2.5	2.3	1.9	2.2	2.2	3.6
267450	SHOSHONE 5 N*	Spring Valley	184	17	1989	2007	4.5	3.7	3.6	3.0	3.5	3.5	4.7
267463	SILVERPEAK*	Clayton Valley	143	30	1975	2007	5.5	4.7	4.6	3.8	4.2	4.7	5.7
267609	SMITH 1 N*	Smith Valley	107	23	1938	1966	4.4	3.6	3.5	2.9	3.3	3.4	4.6
267612	SMITH 6 N*	Smith Valley	107	23	1974	2007	4.3	3.7	3.6	3.0	3.4	3.5	4.5
267618	SMOKE CREEK ESPIL*	Smoke Creek Desert	21	14	1988	2004	4.7	4.2	4.1	3.4	4.0	4.0	4.9
267620	SMOKEY VALLEY*	Big Smoky Valley	137B	30	1975	2007	4.8	4.1	4.0	3.2	3.9	3.7	5.1
267640	SNOWBALL RCH	Little Smoky Valley	155A	30	1972	2002	4.0	3.0	2.8	2.3	2.6	2.6	4.2
267690	SOUTH FORK SP*	Dixie Creek - Tenmile	48	8	1994	2007	4.3	3.4	3.3	2.7	3.0	3.1	4.5
267750	SPRING VALLEY SP*	Spring Valley	201	24	1975	2007	4.9	3.6	3.5	2.8	3.3	3.2	5.1
267806	STATELINE-HARRAH'S*	Lake Tahoe Basin	90	13	1985	1998	3.6	2.9	2.8	2.3	2.6	2.7	3.7
267820	STEAD*	Lemmon Valley	92B	14	1986	2006	4.2	3.7	3.6	3.0	3.5	3.6	4.4
267873	SULPHUR*	Black Rock Desert	28	21	1915	1953	4.5	3.8	3.8	3.1	3.7	3.6	4.7
267908	SUNNYSIDE*	White River Valley	207	30	1974	2007	4.7	4.0	3.8	3.1	3.6	3.6	4.9
267953	SUTCLIFFE	Pyramid Lake Valley	81	27	1968	2006	3.9	3.7	3.4	2.8	3.3	3.6	4.1
267983	TEMPIUTE 4 NW*	Penoyer Valley	170	12	1973	1984	5.1	4.4	4.4	3.6	4.3	4.3	5.4

Appendix 11a cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
268034	THORNE*	Walker Lake Valley	110C	24	1915	1950	4.6	4.1	3.9	3.1	3.8	3.9	4.8
268170	TONOPAH*	Ralston Valley	141	30	1975	2005	5.1	4.4	4.3	3.6	4.3	4.3	5.3
268186	TOPAZ LAKE 3N*	Antelope Valley	106	19	1958	2005	4.7	3.9	3.7	3.1	3.5	3.6	5.0
268202	TOPAZ LAKE 4 N*	Antelope Valley	106	11	1987	1997	4.3	3.7	3.6	3.0	3.6	3.6	4.5
268346	TUSCARORA*	Independence Valley	36	30	1973	2006	3.7	3.0	2.8	2.3	2.6	2.6	3.9
268443	TWIN SPRING FALLINI*	Hot Creek	156	10	1986	2005	4.7	3.9	3.9	3.1	3.8	3.7	4.9
268500	UNIV OF NEVADA EXP FM*	Truckee Meadows	87	4	1949	1954	4.4	4.0	3.8	3.2	3.8	3.9	4.6
268538	URSINE	Eagle Valley	200	4	1965	1972	4.8	4.3	4.2	3.5	4.1	4.1	5.1
268588	VALLEY OF FIRE SP	Black Moutains Area	215	30	1977	2007	5.1	4.7	3.9	3.1	2.7	4.6	5.3
268761	VIRGINIA CITY	Dayton Valley	103	30	1975	2007	3.5	2.9	2.8	2.3	2.7	2.7	3.7
268810	VYA	Surprise Valley	14	14	1960	1975	3.6	2.7	2.5	2.1	2.4	2.3	3.8
268822	WABUSKA 6 SE*	Mason Valley	108	27	1973	2006	4.2	3.5	3.4	2.8	3.3	3.3	4.4
268838	WADSWORTH 4 N*	Dodge Flat	82	21	1975	2002	4.6	3.9	3.8	3.1	3.7	3.7	4.8
268834	WADSWORTH*	Tracy Segment	83	6	1902	1947	4.6	4.1	3.8	3.1	3.5	3.6	4.9
39999	WASHOE VALLEY WC*	Washoe Valley	89	5	2004	2008	5.2	4.4	4.2	3.4	4.0	3.9	5.5
268977	WELLINGTON RS*	Smith Valley	107	27	1943	1972	4.2	3.6	3.5	2.9	3.4	3.5	4.4

Appendix 11a cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
268988	WELLS*	Marys River Area	42	30	1975	2004	4.0	3.1	2.9	2.4	2.8	2.7	4.2
269072	WILDHORSE RSVR*	Owyhee River Area	37	18	1983	2006	4.0	2.5	2.1	1.8	2.1	2.0	4.2
269122	WILKINS*	Thousand Springs Valley	189A	16	1949	1964	4.3	2.9	2.8	2.3	2.7	2.5	4.5
269137	WILLOW SPRINGS*	Big Smoky Valley	137A	4	1942	1948	4.8	3.9	3.8	3.0	3.8	3.5	5.0
269168	WINNEMUCCA #2*	Grass Valley	71	6	2000	2007	4.4	3.9	3.8	3.1	3.6	3.7	4.7
269171	WINNEMUCCA MUNI AP*	Winnemucca Segment	70	30	1978	2007	4.7	3.9	3.8	3.1	3.6	3.6	4.9
269229	YERINGTON*	Mason Valley	108	30	1970	2007	4.1	3.5	3.4	2.8	3.3	3.5	4.3

Appendix 11b. Mean annual ET_{os} and ET_{act} for each NWS weather station, sorted by basin name. * Station was used in averaging or assigning ET_{os} and ET_{act} to respective hydrographic areas. Number of years used for average and start and end years listed are for alfalfa and may vary slightly for other crop types due to possible missing data within crop specific growing seasons. See statistic data files for further details.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
263285	GOLDFIELD	Alkali Spring Valley	142	30	1951	2004	4.5	3.8	3.7	3.0	3.6	3.6	4.7
260150	AMARGOSA FARMS-GAREY*	Amargosa Desert	230	28	1966	2005	5.8	5.6	4.8	3.9	3.7	5.6	6.1
260282	ANTELOPE VALLEY FARR*	Antelope Valley	57	8	1985	1998	4.4	3.6	3.6	3.0	3.5	3.5	4.6
268186	TOPAZ LAKE 3N*	Antelope Valley	106	19	1958	2005	4.7	3.9	3.7	3.1	3.5	3.6	5.0
268202	TOPAZ LAKE 4 N*	Antelope Valley	106	11	1987	1997	4.3	3.7	3.6	3.0	3.6	3.6	4.5
267620	SMOKEY VALLEY*	Big Smoky Valley	137B	30	1975	2007	4.8	4.1	4.0	3.2	3.9	3.7	5.1
269137	WILLOW SPRINGS*	Big Smoky Valley	137A	4	1942	1948	4.8	3.9	3.8	3.0	3.8	3.5	5.0
261371	CALLVILLE BAY*	Black Moutains Area	215	8	1990	2006	5.7	5.3	4.5	3.6	2.9	5.3	5.9
262497	ECHO BAY*	Black Moutains Area	215	10	1990	2003	5.3	5.0	4.2	3.4	2.8	4.9	5.6
268588	VALLEY OF FIRE SP	Black Moutains Area	215	30	1977	2007	5.1	4.7	3.9	3.1	2.7	4.6	5.3
264527	LEONARD CREEK RCH*	Black Rock Desert	28	30	1971	2004	4.2	3.9	3.8	3.2	3.7	3.8	4.4

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
265907	PAHUTE MEADOWS RCH*	Black Rock Desert	28	4	1964	1974	4.2	3.6	3.6	2.9	3.5	3.5	4.4
267873	SULPHUR*	Black Rock Desert	28	21	1915	1953	4.5	3.8	3.8	3.1	3.7	3.6	4.7
261415	CARLIN NEWMONT MINE	Boulder Flat	61	24	1967	1999	3.3	2.7	2.6	2.2	2.5	2.5	3.4
262656	EMIGRANT PASS HWY STN	Boulder Flat	61	27	1964	1999	3.8	3.2	3.2	2.6	3.0	3.0	4.0
261660	CHARLESTON*	Bruneau River Area	38	4	1962	2005	4.1	2.3	2.0	1.7	1.7	1.8	4.3
263853	HUMBOLDT FLD	Buena Vista Valley	129	7	1940	1947	4.4	3.8	3.7	3.0	3.6	3.5	4.6
261311	BUFFALO RCH*	Buffalo Valley	131	7	1967	1978	4.0	3.7	3.5	2.9	3.3	3.5	4.2
262780	FALLON EXP STN*	Carson Desert	101	30	1973	2005	4.1	3.6	3.5	2.9	3.5	3.5	4.3
265191	MINDEN*	Carson Valley	105	30	1975	2007	4.3	3.6	3.5	2.9	3.3	3.4	4.5
264349	LAHONTAN DAM*	Churchill Valley	102	30	1969	2007	4.2	3.8	3.6	3.0	3.5	3.7	4.4
267463	SILVERPEAK*	Clayton Valley	143	30	1975	2007	5.5	4.7	4.6	3.8	4.2	4.7	5.7
261358	CALIENTE*	Clover Valley	204	22	1904	2006	4.9	4.5	4.2	3.5	3.9	4.1	5.2
261740	CLOVER VALLEY*	Clover Valley	177	30	1926	2007	4.0	3.3	3.3	2.7	3.1	3.1	4.2
260688	BATTLE MTN*	Clovers Area	64	25	1903	1944	4.6	4.0	3.9	3.2	3.7	3.8	4.8
264480	LAUGHLIN*	Colorado Valley	213	10	1989	2006	6.5	6.2	5.3	4.3	3.7	6.1	6.9

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261755	COALDALE JUNCTION*	Columbus Salt Marsh Valley	118	6	1942	1958	5.5	4.7	4.4	3.6	4.3	4.3	5.8
265132	MIDDLEGATE-LOWERY*	Cowkick Valley	126	15	1989	2007	4.8	3.8	3.5	2.9	3.4	3.3	5.0
260795	BEOWAWE*	Crescent Valley	54	30	1976	2006	4.3	3.6	3.6	3.0	3.5	3.5	4.5
261975	CORTEZ GOLD MINE*	Crescent Valley	54	10	1969	1979	4.1	3.6	3.5	2.9	3.4	3.3	4.3
268761	VIRGINIA CITY	Dayton Valley	103	30	1975	2007	3.5	2.9	2.8	2.3	2.7	2.7	3.7
264108	JUNGO MEYER RCH*	Desert Valley	31	7	1969	1985	4.3	3.8	3.7	3.0	3.5	3.6	4.5
262296	DIAMOND VALLEY USDA*	Diamond Valley	153	19	1980	2006	4.1	3.2	3.1	2.5	3.0	2.9	4.3
262708	EUREKA	Diamond Valley	153	30	1975	2007	3.6	2.9	2.8	2.2	2.6	2.5	3.8
267690	SOUTH FORK SP*	Dixie Creek - Tenmile	48	8	1994	2007	4.3	3.4	3.3	2.7	3.0	3.1	4.5
261160	BRINKERHOFF RCH*	Dixie Valley	128	7	1967	1979	4.7	4.2	4.1	3.4	4.0	4.1	4.9
268838	WADSWORTH 4 N*	Dodge Flat	82	21	1975	2002	4.6	3.9	3.8	3.1	3.7	3.7	4.8
261485	CARSON CITY*	Eagle Valley	104	30	1974	2007	4.3	3.8	3.6	3.0	3.5	3.6	4.6
268538	URSINE	Eagle Valley	200	4	1965	1972	4.8	4.3	4.2	3.5	4.1	4.1	5.1
262477	EASTGATE*	Eastgate Valley Area	127	4	1957	1963	4.5	3.9	3.9	3.2	3.9	3.8	4.8
261071	BOULDER CITY*	Eldorado Valley	167	30	1969	2004	5.4	5.1	4.3	3.5	3.1	5.0	5.7
262573	ELKO RGNL AP*	Elko Segment	49	30	1978	2007	4.0	3.3	3.2	2.7	3.1	3.0	4.2

Appendix 11b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
262570	ELKO*	Elko Segment	49	6	2000	2007	3.9	3.3	3.3	2.7	3.2	3.1	4.1
262840	FERNLEY*	Fernley Area	76	21	1908	1974	4.6	3.9	3.8	3.1	3.6	3.7	4.8
262431	DYER*	Fish Lake Valley	117	30	1974	2007	5.5	4.6	4.4	3.6	4.3	4.3	5.8
265931	PALMETTO	Fish Lake Valley	117	14	1891	1907	4.9	3.5	3.4	2.7	3.1	3.1	5.2
264457	LATHROP WELLS	Fortymile Canyon	227A	8	1943	1963	5.8	5.4	4.7	3.8	3.9	5.4	6.0
260046	ADAVEN	Garden Valley	172	30	1947	1978	3.8	3.1	3.1	2.5	2.9	2.9	4.0
265722	OASIS*	Goshute Valley	187	17	1988	2006	4.2	3.4	3.2	2.6	3.1	2.9	4.5
266148	PEQUOP	Goshute Valley	187	23	1960	1985	4.1	3.1	3.0	2.4	2.8	2.7	4.3
260800	BEOWAWE U OF N RCH*	Grass Valley	138	28	1973	2007	4.2	3.5	3.4	2.8	3.3	3.3	4.4
269168	WINNEMUCCA #2*	Grass Valley	71	6	2000	2007	4.4	3.9	3.8	3.1	3.6	3.7	4.7
262820	FERGUSON SPRINGS HMS*	Great Salt Lake Desert	192	7	1973	1982	3.6	2.9	2.9	2.3	2.7	2.7	3.7
267443	SHELDON	Guano Valley	6	30	1942	1972	3.5	2.5	2.3	1.9	2.2	2.2	3.6
260961	BLUE JAY HWY STN*	Hot Creek	156	7	1964	1983	4.8	3.9	3.9	3.2	3.7	3.7	5.0
266630	RATTLESNAKE	Hot Creek	156	13	1949	1961	4.3	3.6	3.6	2.9	3.5	3.4	4.5
268443	TWIN SPRING FALLINI*	Hot Creek	156	10	1986	2005	4.7	3.9	3.9	3.1	3.8	3.7	4.9
264095	JIGGS 8 SSE ZAGA*	Huntington Valley	47	19	1979	2007	4.0	3.2	3.0	2.5	2.8	2.8	4.2
263957	IMLAY*	Imlay Area	72	30	1964	2007	4.5	4.0	3.9	3.2	3.8	3.8	4.7

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267192	RYE PATCH DAM*	Imlay Area	72	30	1973	2007	4.8	4.2	4.1	3.4	4.0	4.0	5.0
268346	TUSCARORA*	Independence Valley	36	30	1973	2006	3.7	3.0	2.8	2.3	2.6	2.6	3.9
263980	INDIAN SPRINGS*	Indian Springs Valley	161	23	1914	1964	6.0	5.4	4.9	4.0	4.2	5.3	6.3
263316	GOODSPRINGS*	Ivanpah Valley	164A	6	2000	2006	5.9	5.7	4.9	4.0	4.1	5.6	6.2
265371	MOORMAN RCH*	Jakes Valley	174	4	2003	2007	4.3	3.2	3.1	2.5	2.9	2.8	4.5
264039	JARBIDGE 7 N*	Jarbidge River Area	39	11	1996	2006	3.9	3.3	3.0	2.5	2.9	2.8	4.1
264038	JARBRIDGE 4 N	Jarbidge River Area	39	22	1965	1995	3.8	3.1	2.6	2.2	2.3	2.4	4.0
262119	DAGGET PASS	Lake Tahoe Basin	90	5	1989	2005	3.3	2.3	2.2	1.7	2.0	2.0	3.4
263205	GLENBROOK*	Lake Tahoe Basin	90	30	1969	2007	3.5	2.9	2.7	2.2	2.5	2.5	3.7
264858	MARLETTE LAKE	Lake Tahoe Basin	90	19	1917	1952	2.9	1.8	1.7	1.3	1.6	1.5	3.0
267806	STATELINE-HARRAH'S*	Lake Tahoe Basin	90	13	1985	1998	3.6	2.9	2.8	2.3	2.6	2.7	3.7
263101	GEYSER RCH*	Lake Valley	183	19	1972	2002	4.5	3.6	3.4	2.8	3.3	3.2	4.7
264384	LAKE VALLEY STEWARD	Lake Valley	183	22	1971	1998	3.8	3.2	3.1	2.5	3.0	2.9	4.0
264395	LAMOILLE PH	Lamoille Valley	45	30	1934	1972	3.6	3.1	2.9	2.4	2.8	2.8	3.8
264394	LAMOILLE YOST*	Lamoille Valley	45	22	1976	2003	3.9	3.0	2.8	2.3	2.7	2.6	4.1
262243	DESERT NWR*	Las Vegas Valley	212	30	1976	2007	6.2	5.9	5.1	4.1	4.2	5.7	6.5

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264314	KYLE CANYON RS	Las Vegas Valley	212	4	1940	1948	4.5	3.4	3.0	2.4	3.2	2.7	4.7
264439	LAS VEGAS NWFO*	Las Vegas Valley	212	9	1997	2007	5.8	5.5	4.6	3.7	3.3	5.3	6.1
264436	LAS VEGAS WB AP*	Las Vegas Valley	212	30	1976	2005	5.8	5.6	4.9	4.0	3.4	5.7	6.0
23112	LAS VEGAS*	Las Vegas Valley	212	22	1949	1970	6.0	5.8	5.1	4.1	3.7	5.9	6.3
264429	LAS VEGAS*	Las Vegas Valley	212	30	1921	1956	6.6	6.4	5.6	4.6	4.3	6.5	6.9
264600	LITTLE RED ROCK	Las Vegas Valley	212	4	1966	1970	5.1	4.8	4.1	3.3	3.6	4.6	5.4
265400	MT CHARLESTON FS	Las Vegas Valley	212	6	1949	2007	4.4	3.4	2.7	2.1	3.1	2.4	4.7
265705	NORTH LAS VEGAS*	Las Vegas Valley	212	20	1952	2006	6.5	6.2	5.5	4.5	4.1	6.4	6.8
266691	RED ROCK CANYON SP	Las Vegas Valley	212	20	1978	2006	5.4	5.2	4.6	3.8	3.9	5.2	5.7
267820	STEAD*	Lemmon Valley	92B	14	1986	2006	4.2	3.7	3.6	3.0	3.5	3.6	4.4
262860	FISH CREEK RCH*	Little Smoky Valley	155A	14	1944	1964	4.5	3.1	3.1	2.5	2.9	2.9	4.8
267640	SNOWBALL RCH	Little Smoky Valley	155A	30	1972	2002	4.0	3.0	2.8	2.3	2.6	2.6	4.2
264700	LOVELOCK DERBY FLD*	Lovelock Valley	73	30	1970	2005	4.7	4.1	4.1	3.4	4.0	4.0	4.9
262562	ELGIN 3 SE*	Lower Meadow Valley Wash	205	15	1966	1985	4.9	4.6	3.9	3.2	3.5	4.5	5.1
262557	ELGIN*	Lower Meadow Valley Wash	205	20	1986	2006	4.9	4.6	4.1	3.3	3.8	4.5	5.2

Appendix 11b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
264651	LOGANDALE*	Lower Moapa Valley	220	20	1969	1991	5.0	4.7	4.1	3.4	3.2	4.9	5.2
265846	OVERTON*	Lower Moapa Valley	220	30	1953	2007	5.2	4.9	4.3	3.6	3.2	5.1	5.5
260691	BATTLE MTN AP*	Lower Reese River Valley	59	30	1974	2006	4.3	3.8	3.7	3.1	3.5	3.6	4.5
263114	GIBBS RCH*	Marys River Area	42	30	1973	2007	3.9	3.0	2.9	2.4	2.8	2.8	4.1
264824	MALA VISTA RCH*	Marys River Area	42	16	1940	1965	4.1	3.1	2.9	2.4	2.8	2.7	4.3
265092	METROPOLIS*	Marys River Area	42	18	1966	1994	3.7	3.2	3.1	2.6	3.0	3.0	3.9
268988	WELLS*	Marys River Area	42	30	1975	2004	4.0	3.1	2.9	2.4	2.8	2.7	4.2
268822	WABUSKA 6 SE*	Mason Valley	108	27	1973	2006	4.2	3.5	3.4	2.8	3.3	3.3	4.4
269229	YERINGTON*	Mason Valley	108	30	1970	2007	4.1	3.5	3.4	2.8	3.3	3.5	4.3
266748	REESE VALLEY CARPER	Middle Reese River Valley	58	6	1977	1983	4.3	3.5	3.3	2.8	3.2	3.1	4.5
267188	RYNDON*	North Fork Area	44	6	2000	2007	4.3	3.5	3.1	2.6	3.0	2.9	4.5
267324	SAVAL RCH*	North Fork Area	44	5	1961	1965	3.5	2.6	2.3	1.9	2.3	2.1	3.7
260718	BEATTY 8 N*	Oasis Valley	228	28	1973	2004	5.3	4.9	4.3	3.5	4.1	4.8	5.6
260715	BEATTY*	Oasis Valley	228	30	1925	1972	5.6	5.2	4.6	3.7	4.2	5.1	5.9
265392	MTN CITY RS*	Owyhee River Area	37	30	1965	1998	4.2	2.8	2.5	2.1	2.4	2.3	4.4

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
265869	OWYHEE*	Owyhee River Area	37	30	1954	1984	3.8	3.2	3.1	2.6	3.0	2.9	4.0
269072	WILDHORSE RSVR*	Owyhee River Area	37	18	1983	2006	4.0	2.5	2.1	1.8	2.1	2.0	4.2
260099	ALAMO*	Pahranagat Valley	209	29	1923	1958	5.6	5.0	4.5	3.6	4.2	4.6	5.8
263671	HIKO*	Pahranagat Valley	209	15	1990	2006	5.0	4.5	4.2	3.4	3.8	4.4	5.2
265880	PAHRANAGAT WR*	Pahranagat Valley	209	30	1970	2006	5.2	4.8	4.3	3.5	3.7	4.6	5.4
265890	PAHRUMP*	Pahrump Valley	162	30	1976	2007	5.7	5.4	4.8	4.0	4.1	5.5	6.0
261590	CATHEDRAL GORGE SP*	Panaca Valley	203	4	2003	2007	5.0	4.7	4.4	3.7	4.3	4.3	5.3
266005	PARADISE VALLEY 1 NW*	Paradise Valley	69	30	1973	2007	4.6	3.8	3.6	3.0	3.5	3.4	4.8
266252	PIOCHE	Patterson Valley	202	30	1968	2006	4.1	3.6	3.4	2.8	3.3	3.3	4.3
266130	PENOYER VALLEY*	Penoyer Valley	170	5	1968	2004	5.1	4.3	4.3	3.5	4.2	4.2	5.4
267983	TEMPIUTE 4 NW*	Penoyer Valley	170	12	1973	1984	5.1	4.4	4.4	3.6	4.3	4.3	5.4
266228	PILOT VALLEY-LEE*	Pilot Creek Valley	191	6	2000	2007	4.2	3.4	3.3	2.7	3.1	3.1	4.4
266504	QUINN RVR CROSSING	Pine Forest Valley	29	10	1902	1950	4.5	3.6	3.5	2.8	3.4	3.3	4.8
266242	PINE VALLEY BAILEY RCH*	Pine Valley	53	11	1983	2003	4.5	3.4	3.2	2.7	3.0	3.0	4.7
266574	RAND RCH PALISADE*	Pine Valley	53	19	1958	1981	4.3	3.0	3.0	2.5	2.8	2.8	4.6
267369	SEARCHLIGHT	Piute Valley	214	30	1976	2006	5.0	4.7	4.1	3.3	3.3	4.7	5.2
265440	MT ROSE BOWL	Pleasant Valley	88	8	1974	1984	3.3	2.0	2.0	1.6	1.9	1.8	3.5

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
266055	PARIS RCH*	Pleasant Valley	130	22	1967	1990	4.6	4.2	4.1	3.4	3.9	4.0	4.9
262229	DENIO*	Pueblo Valley	1	30	1970	2005	4.3	3.7	3.6	3.0	3.5	3.5	4.5
265605	NIXON*	Pyramid Lake Valley	81	30	1931	1973	4.8	4.1	4.0	3.2	3.8	3.9	5.0
267953	SUTCLIFFE	Pyramid Lake Valley	81	27	1968	2006	3.9	3.7	3.4	2.8	3.3	3.6	4.1
265362	MONTGOMERY MNTC STN	Queen Valley	116	10	1961	1978	4.1	2.8	2.7	2.1	2.4	2.5	4.3
264935	MCDERMITT*	Quinn River Valley	33B	29	1974	2007	4.3	3.4	3.2	2.7	2.9	3.0	4.5
265818	OROVADA 3 W*	Quinn River Valley	33A	30	1973	2006	4.4	3.9	3.8	3.1	3.6	3.6	4.6
260955	BLUE EAGLE RCH HANKS*	Railroad Valley	173B	23	1979	2007	4.8	4.4	4.3	3.6	4.2	4.3	5.0
262091	CURRANT HWY STN	Railroad Valley	173B	7	1964	1977	4.3	3.0	3.0	2.4	2.7	2.7	4.5
262078	CURRANT*	Railroad Valley	173B	4	1942	1946	4.4	3.8	3.8	3.1	3.7	3.6	4.6
262276	DIABLO*	Railroad Valley	173A	10	1960	1978	4.8	4.2	4.1	3.4	4.0	4.1	5.0
262390	DUCKWATER*	Railroad Valley	173B	19	1967	1998	4.5	3.9	3.8	3.1	3.7	3.6	4.7
268170	TONOPAH*	Ralston Valley	141	30	1975	2005	5.1	4.4	4.3	3.6	4.3	4.3	5.3
29999	RED ROCK WC*	Red Rock Valley	99	4	2004	2007	4.0	3.1	2.9	2.4	2.9	2.7	4.2
260438	ARTHUR 4 NW*	Ruby Valley	176	30	1972	2007	3.8	3.1	3.0	2.5	2.9	2.8	4.0
267123	RUBY LAKE*	Ruby Valley	176	30	1976	2007	4.2	3.5	3.4	2.8	3.3	3.2	4.4

Appendix 11b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
261905	CONTACT*	Salmon Falls Creek Area	40	30	1958	1998	4.2	3.4	3.2	2.7	3.0	3.0	4.4
264016	JACKPOT*	Salmon Falls Creek Area	40	15	1987	2004	3.9	3.2	3.2	2.6	3.0	3.0	4.1
264268	KNOLL CREEK FLD STN	Salmon Falls Creek Area	40	6	1972	1979	4.0	2.9	2.7	2.1	2.5	2.4	4.2
267284	SAN JACINTO*	Salmon Falls Creek Area	40	21	1905	1947	4.1	3.2	3.0	2.5	2.9	2.8	4.3
262662	EMPIRE*	San Emidio Desert	22	6	1951	1976	4.4	3.9	3.9	3.2	3.8	3.9	4.6
263090	GERLACH*	San Emidio Desert	22	27	1963	2006	4.2	3.8	3.7	3.0	3.6	3.7	4.4
267319	SARCOBATUS*	Sarcobatus Flat	146	14	1942	1961	5.3	4.4	4.3	3.4	3.9	4.3	5.5
267609	SMITH 1 N*	Smith Valley	107	23	1938	1966	4.4	3.6	3.5	2.9	3.3	3.4	4.6
267612	SMITH 6 N*	Smith Valley	107	23	1974	2007	4.3	3.7	3.6	3.0	3.4	3.5	4.5
268977	WELLINGTON RS*	Smith Valley	107	27	1943	1972	4.2	3.6	3.5	2.9	3.4	3.5	4.4
267261	SAND PASS*	Smoke Creek Desert	21	30	1931	1970	4.5	4.0	4.0	3.3	3.9	3.9	4.7
267618	SMOKE CREEK ESPIL*	Smoke Creek Desert	21	14	1988	2004	4.7	4.2	4.1	3.4	4.0	4.0	4.9
263340	GREAT BASIN NP	Snake Valley	195	16	1988	2007	3.7	3.1	3.0	2.5	2.9	2.9	3.8
264514	LEHMAN CAVES NM	Snake Valley	195	30	1958	1987	3.6	2.9	2.8	2.3	2.7	2.6	3.8

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
265168	MINA*	Soda Spring Valley	121A	30	1978	2007	4.9	4.3	4.1	3.3	3.9	4.1	5.1
263940	I-L RCH*	South Fork Owyhee River Area	35	3	1963	1967	4.2	3.0	2.9	2.4	2.8	2.7	4.4
267450	SHOSHONE 5 N*	Spring Valley	184	17	1989	2007	4.5	3.7	3.6	3.0	3.5	3.5	4.7
267750	SPRING VALLEY SP*	Spring Valley	201	24	1975	2007	4.9	3.6	3.5	2.8	3.3	3.2	5.1
267397	SEVENTY ONE RCH*	Starr Valley Area	43	4	1940	1951	4.1	3.3	2.9	2.4	2.8	2.7	4.3
262096	CURRIE HWY STN*	Steptoe Valley	179	10	1962	1989	4.7	3.2	3.1	2.5	2.9	2.8	4.9
262626	ELY 6 NE	Steptoe Valley	179	5	2000	2005	4.8	4.0	3.9	3.3	3.7	3.7	5.1
262631	ELY YELLAND FLD AP*	Steptoe Valley	179	30	1976	2005	4.5	3.5	3.3	2.7	3.2	3.0	4.7
264341	LAGES*	Steptoe Valley	179	21	1984	2006	4.5	3.6	3.5	2.8	3.3	3.2	4.7
264950	MCGILL*	Steptoe Valley	179	30	1977	2007	4.2	3.6	3.5	2.9	3.3	3.3	4.4
265760	OLD RUTH	Steptoe Valley	179	5	1979	1985	3.8	2.9	2.9	2.3	2.7	2.6	4.0
267175	RUTH	Steptoe Valley	179	30	1963	2007	4.3	3.0	2.7	2.3	2.6	2.5	4.5
268810	VYA	Surprise Valley	14	14	1960	1975	3.6	2.7	2.5	2.1	2.4	2.3	3.8
260668	BASALT	Teels Marsh Valley	114	10	1942	1957	4.4	3.4	3.4	2.7	3.3	3.2	4.7
265352	MONTELLO 2 SE*	Thousand Springs Valley	189D	30	1971	2007	4.4	3.5	3.4	2.7	3.2	3.1	4.6

Appendix 11b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
269122	WILKINS*	Thousand Springs Valley	189A	16	1949	1964	4.3	2.9	2.8	2.3	2.7	2.5	4.5
268834	WADSWORTH*	Tracy Segment	83	6	1902	1947	4.6	4.1	3.8	3.1	3.5	3.6	4.9
266779	RENO TAHOE INTL AP*	Truckee Meadows	87	30	1978	2007	4.4	4.0	3.8	3.2	3.8	3.9	4.7
266791	RENO WFO*	Truckee Meadows	87	10	1997	2007	4.2	3.9	3.7	3.0	3.6	3.8	4.4
268500	UNIV OF NEVADA EXP FM*	Truckee Meadows	87	4	1949	1954	4.4	4.0	3.8	3.2	3.8	3.9	4.6
260507	AUSTIN #2*	Upper Reese River Valley	56	30	1972	2007	4.1	3.4	3.3	2.7	3.1	3.1	4.3
261630	CENTRAL NEVADA FLD LAB*	Upper Reese River Valley	56	13	1966	1985	4.5	3.3	3.1	2.6	3.0	2.9	4.7
266746	REESE RIVER*	Upper Reese River Valley	56	26	1973	2006	4.3	3.0	2.8	2.2	2.6	2.5	4.5
261327	BUNKERVILLE*	Virgin River Valley	222	6	1980	2007	5.1	4.8	4.0	3.3	3.1	4.7	5.4
265085	MESQUITE*	Virgin River Valley	222	13	1942	2006	5.1	5.0	4.4	3.6	3.3	5.0	5.4
262394	DUFURRENA*	Virgin Valley	4	30	1967	2004	4.4	3.3	3.1	2.6	3.0	2.9	4.6
263515	HAWTHORNE AP*	Walker Lake Valley	110C	30	1948	1990	4.7	4.2	3.9	3.2	3.8	4.0	5.0
263512	HAWTHORNE*	Walker Lake Valley	110C	13	1955	2007	4.8	4.3	4.0	3.2	3.7	3.9	5.0
267358	SCHURZ*	Walker Lake Valley	110A	30	1921	1955	4.6	3.9	3.9	3.2	3.8	3.9	4.9

Appendix 11b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
268034	THORNE*	Walker Lake Valley	110C	24	1915	1950	4.6	4.1	3.9	3.1	3.8	3.9	4.8
264542	LEWERS RCH	Washoe Valley	89	15	1893	1913	4.5	3.9	3.6	2.9	3.5	3.4	4.7
39999	WASHOE VALLEY WC*	Washoe Valley	89	5	2004	2008	5.2	4.4	4.2	3.4	4.0	3.9	5.5
264199	KIMBERLY	White River Valley	207	28	1929	1958	3.9	3.0	2.9	2.4	2.8	2.7	4.1
264745	LUND*	White River Valley	207	30	1977	2007	4.5	3.9	3.8	3.2	3.7	3.7	4.8
267908	SUNNYSIDE*	White River Valley	207	30	1974	2007	4.7	4.0	3.8	3.1	3.6	3.6	4.9
265105	MIDAS 4 SE*	Willow Creek Valley	63	4	1962	1967	4.4	3.1	3.1	2.6	2.9	2.9	4.7
263245	GOLCONDA*	Winnemucca Segment	70	30	1970	2005	4.6	4.0	3.9	3.2	3.8	3.8	4.8
269171	WINNEMUCCA MUNI AP*	Winnemucca Segment	70	30	1978	2007	4.7	3.9	3.8	3.1	3.6	3.6	4.9

Appendix 12a. Mean annual Net Irrigation Water Requirement (NIWR) for each NWS weather station, sorted by station name. * Station was used in averaging or assigning NIWR to respective hydrographic areas. Number of years used for average and start and end years listed are for alfalfa and may vary slightly for other crop types due to possible missing data within crop specific growing seasons. See statistic data files for further details.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
260046	ADAVEN	Garden Valley	172	30	1947	1978	2.5	2.6	2.0	2.5	2.4	2.9
260099	ALAMO*	Pahranagat Valley	209	29	1922	1958	4.6	4.2	3.3	3.9	4.3	5.3
260150	AMARGOSA FARMS-GAREY*	Amargosa Desert	230	28	1966	2005	5.3	4.5	3.6	3.6	5.3	5.8
260282	ANTELOPE VALLEY FARR*	Antelope Valley	57	8	1985	1998	3.0	3.1	2.4	3.0	3.0	3.9
260438	ARTHUR 4 NW*	Ruby Valley	176	30	1971	2007	2.3	2.3	1.8	2.3	2.2	2.7
260507	AUSTIN #2*	Upper Reese River Valley	56	30	1972	2007	2.7	2.7	2.1	2.6	2.5	3.1
260668	BASALT	Teels Marsh Valley	114	10	1942	1957	3.2	3.2	2.5	3.1	3.0	4.2
260691	BATTLE MTN AP*	Lower Reese River Valley	59	30	1973	2006	3.0	3.1	2.4	2.9	3.0	3.8
260688	BATTLE MTN*	Clovers Area	64	25	1899	1944	3.5	3.4	2.8	3.3	3.3	4.3
260718	BEATTY 8 N*	Oasis Valley	228	28	1973	2004	4.5	3.9	3.1	3.8	4.5	5.1
260715	BEATTY*	Oasis Valley	228	30	1921	1972	4.9	4.3	3.4	4.0	4.8	5.5
260800	BEOWAWE U OF N RCH*	Grass Valley	138	28	1973	2006	2.7	2.8	2.2	2.7	2.7	3.5
260795	BEOWAWE*	Crescent Valley	54	30	1976	2006	2.9	3.0	2.4	2.9	2.9	3.7

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
260955	BLUE EAGLE RCH HANKS*	Railroad Valley	173B	23	1979	2007	3.7	3.7	2.9	3.5	3.7	4.3
260961	BLUE JAY HWY STN*	Hot Creek	156	7	1964	1983	3.3	3.4	2.6	3.3	3.2	4.3
261071	BOULDER CITY*	Eldorado Valley	167	30	1968	2004	4.6	3.9	3.1	2.9	4.6	5.1
261160	BRINKERHOFF RCH*	Dixie Valley	128	7	1967	1979	3.6	3.5	2.8	3.4	3.6	4.3
261311	BUFFALO RCH*	Buffalo Valley	131	7	1967	1978	2.8	2.8	2.2	2.7	2.8	3.0
261327	BUNKERVILLE*	Virgin River Valley	222	6	1980	2007	4.3	3.7	2.9	2.9	4.3	4.9
261358	CALIENTE*	Clover Valley	204	22	1904	2005	3.8	3.7	2.9	3.4	3.6	4.4
261371	CALLVILLE BAY*	Black Moutains Area	215	8	1990	2003	4.9	4.1	3.3	2.8	4.9	5.5
261415	CARLIN NEWMONT MINE	Boulder Flat	61	24	1967	1999	2.0	2.0	1.6	1.9	1.9	2.3
261485	CARSON CITY*	Eagle Valley	104	30	1973	2007	3.2	3.1	2.5	3.0	3.1	3.7
261590	CATHEDRAL GORGE SP*	Panaca Valley	203	4	2003	2007	3.7	3.6	2.8	3.5	3.5	4.2
261630	CENTRAL NEVADA FLD LAB*	Upper Reese River Valley	56	13	1966	1985	2.7	2.6	2.0	2.5	2.4	4.1
261660	CHARLESTON*	Bruneau River Area	38	4	1962	2005	1.6	1.5	1.1	1.2	1.3	3.3
261740	CLOVER VALLEY*	Clover Valley	177	30	1923	2007	2.5	2.6	2.1	2.5	2.5	3.1
261755	COALDALE JUNCTION*	Columbus Salt Marsh Valley	118	6	1942	1957	4.4	4.2	3.3	4.1	4.1	5.4

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
261905	CONTACT*	Salmon Falls Creek Area	40	30	1956	1998	2.6	2.4	1.9	2.3	2.3	3.5
261975	CORTEZ GOLD MINE*	Crescent Valley	54	10	1969	1979	2.9	2.9	2.3	2.8	2.8	3.5
262091	CURRANT HWY STN	Railroad Valley	173B	7	1964	1977	2.5	2.5	2.0	2.3	2.3	3.8
262078	CURRANT*	Railroad Valley	173B	4	1942	1946	3.3	3.4	2.6	3.2	3.2	4.1
262096	CURRIE HWY STN*	Steptoe Valley	179	10	1962	1989	2.8	2.7	2.1	2.5	2.5	4.3
262119	DAGGET PASS	Lake Tahoe Basin	90	5	1989	2005	1.9	1.9	1.4	1.7	1.7	1.3
262229	DENIO*	Pueblo Valley	1	30	1969	2005	3.1	3.1	2.5	3.0	3.0	3.7
262243	DESERT NWR*	Las Vegas Valley	212	30	1974	2007	5.5	4.7	3.7	4.0	5.4	6.1
262276	DIABLO*	Railroad Valley	173A	10	1960	1978	3.7	3.7	3.0	3.5	3.7	4.5
262296	DIAMOND VALLEY USDA*	Diamond Valley	153	19	1980	2006	2.5	2.5	2.0	2.4	2.4	3.5
262390	DUCKWATER*	Railroad Valley	173B	19	1967	1998	3.3	3.3	2.6	3.2	3.1	4.1
262394	DUFURRENA*	Virgin Valley	4	30	1965	2004	2.8	2.7	2.1	2.6	2.5	4.0
262431	DYER*	Fish Lake Valley	117	30	1974	2007	4.2	4.1	3.2	4.1	4.0	5.4
262477	EASTGATE*	Eastgate Valley Area	127	4	1957	1963	3.4	3.4	2.7	3.4	3.4	4.2
262497	ECHO BAY*	Black Moutains Area	215	10	1990	2003	4.5	3.8	3.0	2.6	4.6	5.1
262562	ELGIN 3 SE*	Lower Meadow Valley Wash	205	15	1966	1985	3.8	3.2	2.5	2.9	3.8	3.9

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
262557	ELGIN*	Lower Meadow Valley Wash	205	20	1986	2006	3.9	3.4	2.7	3.3	3.9	4.2
262573	ELKO RGNL AP*	Elko Segment	49	30	1978	2007	2.6	2.6	2.1	2.5	2.5	3.3
262570	ELKO*	Elko Segment	49	6	2000	2007	2.6	2.7	2.1	2.6	2.5	3.2
262626	ELY 6 NE	Steptoe Valley	179	5	2000	2005	3.4	3.4	2.7	3.1	3.2	4.4
262631	ELY YELLAND FLD AP*	Steptoe Valley	179	30	1976	2005	2.8	2.7	2.1	2.6	2.5	3.9
262656	EMIGRANT PASS HWY STN	Boulder Flat	61	27	1964	1999	2.4	2.5	2.0	2.4	2.4	2.9
262662	EMPIRE*	San Emidio Desert	22	6	1951	1976	3.5	3.5	2.8	3.4	3.5	4.1
262708	EUREKA	Diamond Valley	153	30	1975	2007	2.3	2.3	1.7	2.2	2.1	2.8
262780	FALLON EXP STN*	Carson Desert	101	30	1973	2005	3.2	3.2	2.5	3.1	3.2	3.9
262820	FERGUSON SPRINGS HMS*	Great Salt Lake Desert	192	7	1973	1982	2.3	2.4	1.9	2.3	2.2	3.1
262840	FERNLEY*	Fernley Area	76	21	1908	1974	3.5	3.4	2.7	3.3	3.3	4.3
262860	FISH CREEK RCH*	Little Smoky Valley	155A	14	1944	1964	2.8	2.8	2.2	2.6	2.6	4.4
263090	GERLACH*	San Emidio Desert	22	27	1963	2006	3.1	3.2	2.5	3.1	3.2	3.7
263101	GEYSER RCH*	Lake Valley	183	19	1905	2002	3.0	2.9	2.3	2.7	2.7	4.0
263114	GIBBS RCH*	Marys River Area	42	30	1972	2006	2.3	2.3	1.8	2.2	2.1	3.2
263205	GLENBROOK*	Lake Tahoe Basin	90	30	1969	2007	2.3	2.2	1.7	2.1	2.1	2.2
263245	GOLCONDA*	Winnemucca Segment	70	30	1970	2005	3.4	3.4	2.7	3.3	3.4	4.2

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263285	GOLDFIELD	Alkali Spring Valley	142	30	1951	2004	3.4	3.3	2.6	3.2	3.2	4.2
263316	GOODSPRINGS*	Ivanpah Valley	164A	6	2000	2006	5.2	4.4	3.5	3.7	5.1	5.6
263340	GREAT BASIN NP	Snake Valley	195	16	1988	2007	2.3	2.4	1.8	2.3	2.3	2.7
263515	HAWTHORNE AP*	Walker Lake Valley	110C	30	1947	1990	3.8	3.6	2.8	3.5	3.6	4.6
263512	HAWTHORNE*	Walker Lake Valley	110C	13	1955	2007	3.9	3.6	2.8	3.4	3.6	4.6
263671	HIKO*	Pahranagat Valley	209	15	1990	2006	4.1	3.7	2.9	3.5	3.9	4.6
263853	HUMBOLDT FLD	Buena Vista Valley	129	7	1940	1947	3.2	3.2	2.5	3.1	3.1	4.0
263940	I-L RCH*	South Fork Owyhee River Area	35	3	1963	1967	1.8	1.9	1.5	2.0	1.8	3.1
263957	IMLAY*	Imlay Area	72	30	1964	2007	3.4	3.3	2.6	3.2	3.3	4.0
263980	INDIAN SPRINGS*	Indian Springs Valley	161	23	1914	1964	5.2	4.7	3.7	4.1	5.0	6.0
264016	JACKPOT*	Salmon Falls Creek Area	40	15	1987	2004	2.5	2.5	2.0	2.4	2.4	3.3
264039	JARBIDGE 7 N*	Jarbidge River Area	39	11	1996	2006	2.3	2.3	1.7	2.2	2.1	2.7
264038	JARBRIDGE 4 N	Jarbidge River Area	39	22	1917	1995	2.1	1.9	1.4	1.7	1.7	2.3
264095	JIGGS 8 SSE ZAGA*	Huntington Valley	47	19	1979	2007	2.4	2.4	1.8	2.2	2.2	3.0
264108	JUNGO MEYER RCH*	Desert Valley	31	7	1969	1985	3.1	3.2	2.5	3.1	3.1	3.8
264199	KIMBERLY	White River Valley	207	28	1929	1958	2.4	2.4	1.9	2.3	2.2	3.0

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264268	KNOLL CREEK FLD STN	Salmon Falls Creek Area	40	6	1972	1979	2.4	2.3	1.7	2.1	2.0	3.6
264314	KYLE CANYON RS	Las Vegas Valley	212	4	1940	1948	2.8	2.6	2.0	2.7	2.3	3.1
264341	LAGES*	Steptoe Valley	179	21	1984	2006	3.0	3.0	2.3	2.9	2.8	4.0
264349	LAHONTAN DAM*	Churchill Valley	102	30	1966	2003	3.4	3.2	2.6	3.1	3.4	4.0
264384	LAKE VALLEY STEWARD	Lake Valley	183	22	1971	1998	2.4	2.5	1.9	2.4	2.3	2.7
264395	LAMOILLE PH	Lamoille Valley	45	30	1934	1972	2.1	2.2	1.7	2.1	2.1	2.2
264394	LAMOILLE YOST*	Lamoille Valley	45	22	1976	2003	2.3	2.3	1.8	2.2	2.1	2.9
264439	LAS VEGAS NWFO*	Las Vegas Valley	212	9	1997	2007	5.1	4.3	3.3	3.2	5.0	5.6
264436	LAS VEGAS WB AP*	Las Vegas Valley	212	30	1976	2005	5.2	4.5	3.7	3.2	5.4	5.7
23112	LAS VEGAS*	Las Vegas Valley	212	22	1949	1970	5.5	4.8	3.9	3.6	5.6	6.0
264429	LAS VEGAS*	Las Vegas Valley	212	30	1915	1955	6.1	5.3	4.2	4.1	6.2	6.5
264457	LATHROP WELLS	Fortymile Canyon	227A	8	1943	1963	5.2	4.6	3.6	3.8	5.3	5.8
264480	LAUGHLIN*	Colorado Valley	213	10	1989	2006	5.8	5.0	3.9	3.6	5.8	6.4
264514	LEHMAN CAVES NM	Snake Valley	195	30	1958	1987	2.1	2.2	1.7	2.1	2.0	2.6
264527	LEONARD CREEK RCH*	Black Rock Desert	28	30	1971	2004	3.2	3.2	2.5	3.1	3.2	3.6
264542	LEWERS RCH	Washoe Valley	89	15	1893	1913	3.2	3.1	2.4	3.1	2.9	2.7

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264600	LITTLE RED ROCK	Las Vegas Valley	212	4	1966	1970	4.3	3.7	2.8	3.3	4.2	4.7
264651	LOGANDALE*	Lower Moapa Valley	220	20	1969	1991	4.3	3.7	3.0	2.9	4.5	4.8
264700	LOVELOCK DERBY FLD*	Lovelock Valley	73	30	1970	2005	3.7	3.7	3.0	3.6	3.6	4.5
264745	LUND*	White River Valley	207	30	1977	2007	3.1	3.1	2.4	2.9	2.9	3.9
264824	MALA VISTA RCH*	Marys River Area	42	16	1940	1965	2.4	2.3	1.8	2.2	2.2	3.5
264858	MARLETTE LAKE	Lake Tahoe Basin	90	19	1917	1952	1.4	1.5	1.1	1.4	1.3	0.7
264935	MCDERMITT*	Quinn River Valley	33B	29	1916	2007	2.8	2.7	2.1	2.3	2.5	3.8
264950	MCGILL*	Steptoe Valley	179	30	1977	2007	2.9	2.8	2.2	2.7	2.7	3.6
265085	MESQUITE*	Virgin River Valley	222	13	1942	2006	4.4	3.9	3.1	2.9	4.5	4.8
265092	METROPOLIS*	Marys River Area	42	18	1966	1994	2.4	2.4	1.9	2.4	2.3	2.8
265105	MIDAS 4 SE*	Willow Creek Valley	63	4	1962	1967	2.4	2.5	2.0	2.4	2.4	3.9
265132	MIDDLEGATE-LOWERY*	Cowkick Valley	126	15	1989	2007	3.4	3.2	2.5	3.1	3.0	4.5
265168	MINA*	Soda Spring Valley	121A	30	1978	2007	3.9	3.7	2.9	3.6	3.7	4.6
265191	MINDEN*	Carson Valley	105	30	1975	2007	3.0	3.0	2.4	2.9	3.0	3.7
265352	MONTELLO 2 SE*	Thousand Springs Valley	189D	30	1971	2007	2.9	2.9	2.2	2.8	2.6	4.0

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265362	MONTGOMERY MNTC STN	Queen Valley	116	10	1961	1978	2.3	2.3	1.8	2.1	2.1	3.6
265371	MOORMAN RCH*	Jakes Valley	174	4	2003	2007	2.7	2.6	2.0	2.5	2.4	3.7
265400	MT CHARLESTON FS	Las Vegas Valley	212	6	1949	2007	2.8	2.3	1.8	2.7	2.1	3.2
265440	MT ROSE BOWL	Pleasant Valley	88	8	1974	1984	1.6	1.7	1.3	1.6	1.5	1.0
265392	MTN CITY RS*	Owyhee River Area	37	30	1965	1998	2.1	2.0	1.6	1.9	1.8	3.3
265605	NIXON*	Pyramid Lake Valley	81	30	1931	1973	3.6	3.5	2.8	3.4	3.5	4.4
265705	NORTH LAS VEGAS*	Las Vegas Valley	212	20	1952	2006	5.9	5.2	4.2	3.9	6.0	6.4
265722	OASIS*	Goshute Valley	187	17	1988	2006	2.8	2.7	2.1	2.6	2.5	3.7
265760	OLD RUTH	Steptoe Valley	179	5	1979	1985	2.1	2.3	1.7	2.1	2.0	2.8
265818	OROVADA 3 W*	Quinn River Valley	33A	30	1971	2006	3.1	3.1	2.5	3.0	3.1	3.7
265846	OVERTON*	Lower Moapa Valley	220	30	1950	2007	4.6	4.0	3.2	2.9	4.7	5.1
265869	OWYHEE*	Owyhee River Area	37	30	1953	1984	2.3	2.4	1.9	2.3	2.2	2.8
265880	PAHRANAGAT WR*	Pahranagat Valley	209	30	1968	2006	4.3	3.8	3.0	3.5	4.2	4.9
265890	PAHRUMP*	Pahrump Valley	162	30	1973	2006	5.0	4.4	3.6	3.8	5.1	5.6
265907	PAHUTE MEADOWS RCH*	Black Rock Desert	28	4	1964	1974	3.2	3.2	2.6	3.2	3.1	3.8

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265931	PALMETTO	Fish Lake Valley	117	14	1891	1907	2.8	2.8	2.2	2.5	2.6	3.7
266005	PARADISE VALLEY 1 NW*	Paradise Valley	69	30	1972	2007	3.2	3.2	2.5	3.0	3.0	4.0
266055	PARIS RCH*	Pleasant Valley	130	22	1967	1990	3.5	3.4	2.8	3.3	3.4	4.1
266130	PENOYER VALLEY*	Penoyer Valley	170	5	1968	2004	3.9	4.0	3.2	3.8	3.9	4.9
266148	PEQUOP	Goshute Valley	187	23	1960	1985	2.4	2.3	1.8	2.3	2.1	3.2
266228	PILOT VALLEY-LEE*	Pilot Creek Valley	191	6	2000	2007	2.9	2.8	2.2	2.7	2.6	3.6
266242	PINE VALLEY BAILEY RCH*	Pine Valley	53	11	1983	2003	2.7	2.6	2.0	2.3	2.4	3.8
266252	PIOCHE	Patterson Valley	202	30	1968	2006	2.8	2.7	2.1	2.6	2.6	3.1
266504	QUINN RVR CROSSING	Pine Forest Valley	29	10	1902	1950	3.1	3.1	2.4	3.0	3.0	4.3
266574	RAND RCH PALISADE*	Pine Valley	53	19	1958	1981	2.3	2.3	1.8	2.2	2.2	3.7
266630	RATTLESNAKE	Hot Creek	156	13	1949	1961	3.2	3.3	2.6	3.2	3.1	4.1
266691	RED ROCK CANYON SP	Las Vegas Valley	212	20	1978	2006	4.4	3.9	3.1	3.4	4.5	4.7
29999	RED ROCK WC*	Red Rock Valley	99	4	2004	2007	2.6	2.6	2.0	2.5	2.4	3.4
266746	REESE RIVER*	Upper Reese River Valley	56	26	1973	2006	2.5	2.4	1.8	2.2	2.1	3.9
266748	REESE VALLEY CARPER	Middle Reese River Valley	58	6	1977	1983	2.8	2.8	2.2	2.6	2.6	3.7
266779	RENO TAHOE INTL AP*	Truckee Meadows	87	30	1978	2007	3.5	3.4	2.7	3.3	3.5	4.0

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266791	RENO WFO*	Truckee Meadows	87	10	1997	2007	3.3	3.2	2.6	3.2	3.4	3.7
267123	RUBY LAKE*	Ruby Valley	176	30	1975	2007	2.8	2.8	2.2	2.7	2.6	3.3
267175	RUTH	Steptoe Valley	179	30	1963	2007	2.3	2.2	1.7	2.1	2.0	3.5
267192	RYE PATCH DAM*	Imlay Area	72	30	1973	2007	3.6	3.5	2.8	3.4	3.4	4.3
267188	RYNDON*	North Fork Area	44	6	2000	2007	2.6	2.6	2.0	2.5	2.4	3.6
267284	SAN JACINTO*	Salmon Falls Creek Area	40	21	1905	1947	2.6	2.4	1.9	2.3	2.3	3.6
267261	SAND PASS*	Smoke Creek Desert	21	30	1930	1970	3.5	3.6	2.8	3.4	3.6	4.2
267319	SARCOBATUS*	Sarcobatus Flat	146	14	1942	1961	4.2	4.0	3.2	3.7	4.2	5.2
267324	SAVAL RCH*	North Fork Area	44	5	1961	1965	1.8	1.7	1.3	1.7	1.6	2.7
267358	SCHURZ*	Walker Lake Valley	110A	30	1920	1955	3.5	3.5	2.8	3.4	3.5	4.4
267369	SEARCHLIGHT	Piute Valley	214	30	1976	2006	4.2	3.6	2.8	3.0	4.2	4.6
267397	SEVENTY ONE RCH*	Starr Valley Area	43	4	1940	1945	2.4	2.3	1.8	2.2	2.2	3.3
267443	SHELDON	Guano Valley	6	30	1942	1972	1.8	1.8	1.4	1.7	1.7	2.6
267450	SHOSHONE 5 N*	Spring Valley	184	17	1989	2007	3.0	3.0	2.4	2.9	2.9	3.9
267463	SILVERPEAK*	Clayton Valley	143	30	1974	2007	4.4	4.3	3.4	3.9	4.4	5.3
267609	SMITH 1 N*	Smith Valley	107	23	1938	1966	3.0	3.0	2.4	2.8	2.9	4.0
267612	SMITH 6 N*	Smith Valley	107	23	1974	2007	3.1	3.1	2.5	3.0	3.1	4.0
267618	SMOKE CREEK ESPIL*	Smoke Creek Desert	21	14	1988	2004	3.6	3.6	2.9	3.5	3.6	4.3

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267620	SMOKEY VALLEY*	Big Smoky Valley	137B	30	1975	2007	3.6	3.5	2.8	3.5	3.4	4.5
267640	SNOWBALL RCH	Little Smoky Valley	155A	30	1972	2002	2.4	2.3	1.7	2.1	2.1	3.5
267690	SOUTH FORK SP*	Dixie Creek - Tenmile	48	8	1994	2007	2.8	2.7	2.1	2.4	2.6	3.7
267750	SPRING VALLEY SP*	Spring Valley	201	24	1975	2006	3.0	2.9	2.3	2.8	2.6	4.1
267806	STATELINE-HARRAH'S*	Lake Tahoe Basin	90	13	1985	1998	2.4	2.4	1.9	2.3	2.3	2.7
267820	STEAD*	Lemmon Valley	92B	14	1986	2006	3.1	3.1	2.5	3.0	3.1	3.4
267873	SULPHUR*	Black Rock Desert	28	21	1915	1953	3.4	3.4	2.7	3.4	3.3	4.2
267908	SUNNYSIDE*	White River Valley	207	30	1973	2007	3.3	3.3	2.5	3.1	3.1	4.1
267953	SUTCLIFFE	Pyramid Lake Valley	81	27	1968	2006	3.1	2.9	2.3	2.9	3.1	3.5
267983	TEMPIUTE 4 NW*	Penoyer Valley	170	12	1973	1984	3.8	3.8	3.1	3.7	3.8	4.7
268034	THORNE*	Walker Lake Valley	110C	24	1915	1950	3.8	3.7	2.9	3.6	3.7	4.6
268170	TONOPAH*	Ralston Valley	141	30	1975	2005	4.0	3.9	3.1	3.9	3.9	4.8
268186	TOPAZ LAKE 3N*	Antelope Valley	106	19	1958	1980	3.3	3.3	2.6	3.1	3.1	4.2
268202	TOPAZ LAKE 4 N*	Antelope Valley	106	11	1987	1997	3.2	3.1	2.5	3.2	3.2	3.7
268346	TUSCARORA*	Independence Valley	36	30	1973	2006	2.2	2.2	1.7	2.1	2.0	2.8
268443	TWIN SPRING FALLINI*	Hot Creek	156	10	1986	2005	3.5	3.5	2.8	3.4	3.3	4.4

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268500	UNIV OF NEVADA EXP FM*	Truckee Meadows	87	4	1949	1954	3.4	3.3	2.7	3.3	3.5	3.9
268538	URSINE	Eagle Valley	200	4	1965	1972	3.4	3.6	2.8	3.4	3.5	4.0
268588	VALLEY OF FIRE SP	Black Moutains Area	215	30	1977	2007	4.2	3.5	2.7	2.6	4.2	4.7
268761	VIRGINIA CITY	Dayton Valley	103	30	1974	2007	2.4	2.4	1.8	2.3	2.3	2.6
268810	VYA	Surprise Valley	14	14	1960	1975	2.0	1.9	1.5	1.8	1.8	2.7
268822	WABUSKA 6 SE*	Mason Valley	108	27	1973	2006	3.1	3.0	2.4	2.9	3.0	4.0
268838	WADSWORTH 4 N*	Dodge Flat	82	21	1975	2002	3.5	3.4	2.7	3.3	3.3	4.3
268834	WADSWORTH*	Tracy Segment	83	6	1902	1947	3.6	3.4	2.7	3.1	3.3	4.3
39999	WASHOE VALLEY WC*	Washoe Valley	89	5	2004	2008	3.7	3.8	2.9	3.5	3.5	4.7
268977	WELLINGTON RS*	Smith Valley	107	27	1943	1972	3.0	3.0	2.4	2.9	3.0	3.7
268988	WELLS*	Marys River Area	42	30	1975	2004	2.5	2.4	1.9	2.3	2.2	3.4
269072	WILDHORSE RSVR*	Owyhee River Area	37	18	1983	2006	1.8	1.7	1.3	1.6	1.5	3.0
269122	WILKINS*	Thousand Springs Valley	189A	16	1949	1964	2.2	2.2	1.7	2.1	2.0	3.6
269137	WILLOW SPRINGS*	Big Smoky Valley	137A	4	1942	1948	3.7	3.6	2.9	3.6	3.4	4.7
269168	WINNEMUCCA #2*	Grass Valley	71	6	2000	2007	3.3	3.4	2.6	3.2	3.2	4.0

Appendix 12a cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
269171	WINNEMUCCA MUNI AP*	Winnemucca Segment	70	30	1978	2007	3.4	3.3	2.6	3.1	3.2	4.2
269229	YERINGTON*	Mason Valley	108	30	1965	2007	3.1	3.0	2.4	2.9	3.1	3.8

Appendix 12b. Mean annual Net Irrigation Water Requirement (NIWR) for each NWS weather station, sorted by basin name.
* Station was used in averaging or assigning NIWR to respective hydrographic areas. Number of years used for average and start and end years listed are for alfalfa and may vary slightly for other crop types due to possible missing data within crop specific growing seasons.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
263285	GOLDFIELD	Alkali Spring Valley	142	30	1951	2004	3.4	3.3	2.6	3.2	3.2	4.2
260150	AMARGOSA FARMS-GAREY*	Amargosa Desert	230	28	1966	2005	5.3	4.5	3.6	3.6	5.3	5.8
260282	ANTELOPE VALLEY FARR*	Antelope Valley	57	8	1985	1998	3.0	3.1	2.4	3.0	3.0	3.9
268186	TOPAZ LAKE 3N*	Antelope Valley	106	19	1958	1980	3.3	3.3	2.6	3.1	3.1	4.2
268202	TOPAZ LAKE 4 N*	Antelope Valley	106	11	1987	1997	3.2	3.1	2.5	3.2	3.2	3.7
267620	SMOKEY VALLEY*	Big Smoky Valley	137B	30	1975	2007	3.6	3.5	2.8	3.5	3.4	4.5
269137	WILLOW SPRINGS*	Big Smoky Valley	137A	4	1942	1948	3.7	3.6	2.9	3.6	3.4	4.7
261371	CALLVILLE BAY*	Black Moutains Area	215	8	1990	2003	4.9	4.1	3.3	2.8	4.9	5.5
262497	ECHO BAY*	Black Moutains Area	215	10	1990	2003	4.5	3.8	3.0	2.6	4.6	5.1
268588	VALLEY OF FIRE SP	Black Moutains Area	215	30	1977	2007	4.2	3.5	2.7	2.6	4.2	4.7
264527	LEONARD CREEK RCH*	Black Rock Desert	28	30	1971	2004	3.2	3.2	2.5	3.1	3.2	3.6

Appendix 12b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
265907	PAHUTE MEADOWS RCH*	Black Rock Desert	28	4	1964	1974	3.2	3.2	2.6	3.2	3.1	3.8
267873	SULPHUR*	Black Rock Desert	28	21	1915	1953	3.4	3.4	2.7	3.4	3.3	4.2
261415	CARLIN NEWMONT MINE	Boulder Flat	61	24	1967	1999	2.0	2.0	1.6	1.9	1.9	2.3
262656	EMIGRANT PASS HWY STN	Boulder Flat	61	27	1964	1999	2.4	2.5	2.0	2.4	2.4	2.9
261660	CHARLESTON*	Bruneau River Area	38	4	1962	2005	1.6	1.5	1.1	1.2	1.3	3.3
263853	HUMBOLDT FLD	Buena Vista Valley	129	7	1940	1947	3.2	3.2	2.5	3.1	3.1	4.0
261311	BUFFALO RCH*	Buffalo Valley	131	7	1967	1978	2.8	2.8	2.2	2.7	2.8	3.0
262780	FALLON EXP STN*	Carson Desert	101	30	1973	2005	3.2	3.2	2.5	3.1	3.2	3.9
265191	MINDEN*	Carson Valley	105	30	1975	2007	3.0	3.0	2.4	2.9	3.0	3.7
264349	LAHONTAN DAM*	Churchill Valley	102	30	1966	2003	3.4	3.2	2.6	3.1	3.4	4.0
267463	SILVERPEAK*	Clayton Valley	143	30	1974	2007	4.4	4.3	3.4	3.9	4.4	5.3
261358	CALIENTE*	Clover Valley	204	22	1904	2005	3.8	3.7	2.9	3.4	3.6	4.4
261740	CLOVER VALLEY*	Clover Valley	177	30	1923	2007	2.5	2.6	2.1	2.5	2.5	3.1
260688	BATTLE MTN*	Clovers Area	64	25	1899	1944	3.5	3.4	2.8	3.3	3.3	4.3
264480	LAUGHLIN*	Colorado Valley	213	10	1989	2006	5.8	5.0	3.9	3.6	5.8	6.4
261755	COALDALE JUNCTION*	Columbus Salt Marsh Valley	118	6	1942	1957	4.4	4.2	3.3	4.1	4.1	5.4

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
265132	MIDDLEGATE-LOWERY*	Cowkick Valley	126	15	1989	2007	3.4	3.2	2.5	3.1	3.0	4.5
260795	BEOWAWE*	Crescent Valley	54	30	1976	2006	2.9	3.0	2.4	2.9	2.9	3.7
261975	CORTEZ GOLD MINE*	Crescent Valley	54	10	1969	1979	2.9	2.9	2.3	2.8	2.8	3.5
268761	VIRGINIA CITY	Dayton Valley	103	30	1974	2007	2.4	2.4	1.8	2.3	2.3	2.6
264108	JUNGO MEYER RCH*	Desert Valley	31	7	1969	1985	3.1	3.2	2.5	3.1	3.1	3.8
262296	DIAMOND VALLEY USDA*	Diamond Valley	153	19	1980	2006	2.5	2.5	2.0	2.4	2.4	3.5
262708	EUREKA	Diamond Valley	153	30	1975	2007	2.3	2.3	1.7	2.2	2.1	2.8
267690	SOUTH FORK SP*	Dixie Creek - Tenmile	48	8	1994	2007	2.8	2.7	2.1	2.4	2.6	3.7
261160	BRINKERHOFF RCH*	Dixie Valley	128	7	1967	1979	3.6	3.5	2.8	3.4	3.6	4.3
268838	WADSWORTH 4 N*	Dodge Flat	82	21	1975	2002	3.5	3.4	2.7	3.3	3.3	4.3
261485	CARSON CITY*	Eagle Valley	104	30	1973	2007	3.2	3.1	2.5	3.0	3.1	3.7
268538	URSINE	Eagle Valley	200	4	1965	1972	3.4	3.6	2.8	3.4	3.5	4.0
262477	EASTGATE*	Eastgate Valley Area	127	4	1957	1963	3.4	3.4	2.7	3.4	3.4	4.2
261071	BOULDER CITY*	Eldorado Valley	167	30	1968	2004	4.6	3.9	3.1	2.9	4.6	5.1
262573	ELKO RGNL AP*	Elko Segment	49	30	1978	2007	2.6	2.6	2.1	2.5	2.5	3.3
262570	ELKO*	Elko Segment	49	6	2000	2007	2.6	2.7	2.1	2.6	2.5	3.2
262840	FERNLEY*	Fernley Area	76	21	1908	1974	3.5	3.4	2.7	3.3	3.3	4.3
262431	DYER*	Fish Lake Valley	117	30	1974	2007	4.2	4.1	3.2	4.1	4.0	5.4

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
265931	PALMETTO	Fish Lake Valley	117	14	1891	1907	2.8	2.8	2.2	2.5	2.6	3.7
264457	LATHROP WELLS	Fortymile Canyon	227A	8	1943	1963	5.2	4.6	3.6	3.8	5.3	5.8
260046	ADAVEN	Garden Valley	172	30	1947	1978	2.5	2.6	2.0	2.5	2.4	2.9
265722	OASIS*	Goshute Valley	187	17	1988	2006	2.8	2.7	2.1	2.6	2.5	3.7
266148	PEQUOP	Goshute Valley	187	23	1960	1985	2.4	2.3	1.8	2.3	2.1	3.2
260800	BEOWAWE U OF N RCH*	Grass Valley	138	28	1973	2006	2.7	2.8	2.2	2.7	2.7	3.5
269168	WINNEMUCCA #2*	Grass Valley	71	6	2000	2007	3.3	3.4	2.6	3.2	3.2	4.0
262820	FERGUSON SPRINGS HMS*	Great Salt Lake Desert	192	7	1973	1982	2.3	2.4	1.9	2.3	2.2	3.1
267443	SHELDON	Guano Valley	6	30	1942	1972	1.8	1.8	1.4	1.7	1.7	2.6
260961	BLUE JAY HWY STN*	Hot Creek	156	7	1964	1983	3.3	3.4	2.6	3.3	3.2	4.3
266630	RATTLESNAKE	Hot Creek	156	13	1949	1961	3.2	3.3	2.6	3.2	3.1	4.1
268443	TWIN SPRING FALLINI*	Hot Creek	156	10	1986	2005	3.5	3.5	2.8	3.4	3.3	4.4
264095	JIGGS 8 SSE ZAGA*	Huntington Valley	47	19	1979	2007	2.4	2.4	1.8	2.2	2.2	3.0
263957	IMLAY*	Imlay Area	72	30	1964	2007	3.4	3.3	2.6	3.2	3.3	4.0
267192	RYE PATCH DAM*	Imlay Area	72	30	1973	2007	3.6	3.5	2.8	3.4	3.4	4.3
268346	TUSCARORA*	Independence Valley	36	30	1973	2006	2.2	2.2	1.7	2.1	2.0	2.8
263980	INDIAN SPRINGS*	Indian Springs Valley	161	23	1914	1964	5.2	4.7	3.7	4.1	5.0	6.0

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263316	GOODSPRINGS*	Ivanpah Valley	164A	6	2000	2006	5.2	4.4	3.5	3.7	5.1	5.6
265371	MOORMAN RCH*	Jakes Valley	174	4	2003	2007	2.7	2.6	2.0	2.5	2.4	3.7
264039	JARBIDGE 7 N*	Jarbidge River Area	39	11	1996	2006	2.3	2.3	1.7	2.2	2.1	2.7
264038	JARBRIDGE 4 N	Jarbidge River Area	39	22	1917	1995	2.1	1.9	1.4	1.7	1.7	2.3
262119	DAGGET PASS	Lake Tahoe Basin	90	5	1989	2005	1.9	1.9	1.4	1.7	1.7	1.3
263205	GLENBROOK*	Lake Tahoe Basin	90	30	1969	2007	2.3	2.2	1.7	2.1	2.1	2.2
264858	MARLETTE LAKE	Lake Tahoe Basin	90	19	1917	1952	1.4	1.5	1.1	1.4	1.3	0.7
267806	STATELINE-HARRAH'S*	Lake Tahoe Basin	90	13	1985	1998	2.4	2.4	1.9	2.3	2.3	2.7
263101	GEYSER RCH*	Lake Valley	183	19	1905	2002	3.0	2.9	2.3	2.7	2.7	4.0
264384	LAKE VALLEY STEWARD	Lake Valley	183	22	1971	1998	2.4	2.5	1.9	2.4	2.3	2.7
264395	LAMOILLE PH	Lamoille Valley	45	30	1934	1972	2.1	2.2	1.7	2.1	2.1	2.2
264394	LAMOILLE YOST*	Lamoille Valley	45	22	1976	2003	2.3	2.3	1.8	2.2	2.1	2.9
262243	DESERT NWR*	Las Vegas Valley	212	30	1974	2007	5.5	4.7	3.7	4.0	5.4	6.1
264314	KYLE CANYON RS	Las Vegas Valley	212	4	1940	1948	2.8	2.6	2.0	2.7	2.3	3.1
264439	LAS VEGAS NWFO*	Las Vegas Valley	212	9	1997	2007	5.1	4.3	3.3	3.2	5.0	5.6
264436	LAS VEGAS WB AP*	Las Vegas Valley	212	30	1976	2005	5.2	4.5	3.7	3.2	5.4	5.7
23112	LAS VEGAS*	Las Vegas Valley	212	22	1949	1970	5.5	4.8	3.9	3.6	5.6	6.0

Appendix 12b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
264429	LAS VEGAS*	Las Vegas Valley	212	30	1915	1955	6.1	5.3	4.2	4.1	6.2	6.5
264600	LITTLE RED ROCK	Las Vegas Valley	212	4	1966	1970	4.3	3.7	2.8	3.3	4.2	4.7
265400	MT CHARLESTON FS	Las Vegas Valley	212	6	1949	2007	2.8	2.3	1.8	2.7	2.1	3.2
265705	NORTH LAS VEGAS*	Las Vegas Valley	212	20	1952	2006	5.9	5.2	4.2	3.9	6.0	6.4
266691	RED ROCK CANYON SP	Las Vegas Valley	212	20	1978	2006	4.4	3.9	3.1	3.4	4.5	4.7
267820	STEAD*	Lemmon Valley	92B	14	1986	2006	3.1	3.1	2.5	3.0	3.1	3.4
262860	FISH CREEK RCH*	Little Smoky Valley	155A	14	1944	1964	2.8	2.8	2.2	2.6	2.6	4.4
267640	SNOWBALL RCH	Little Smoky Valley	155A	30	1972	2002	2.4	2.3	1.7	2.1	2.1	3.5
264700	LOVELOCK DERBY FLD*	Lovelock Valley	73	30	1970	2005	3.7	3.7	3.0	3.6	3.6	4.5
262562	ELGIN 3 SE*	Lower Meadow Valley Wash	205	15	1966	1985	3.8	3.2	2.5	2.9	3.8	3.9
262557	ELGIN*	Lower Meadow Valley Wash	205	20	1986	2006	3.9	3.4	2.7	3.3	3.9	4.2
264651	LOGANDALE*	Lower Moapa Valley	220	20	1969	1991	4.3	3.7	3.0	2.9	4.5	4.8
265846	OVERTON*	Lower Moapa Valley	220	30	1950	2007	4.6	4.0	3.2	2.9	4.7	5.1
260691	BATTLE MTN AP*	Lower Reese River Valley	59	30	1973	2006	3.0	3.1	2.4	2.9	3.0	3.8

Appendix 12b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
263114	GIBBS RCH*	Marys River Area	42	30	1972	2006	2.3	2.3	1.8	2.2	2.1	3.2
264824	MALA VISTA RCH*	Marys River Area	42	16	1940	1965	2.4	2.3	1.8	2.2	2.2	3.5
265092	METROPOLIS*	Marys River Area	42	18	1966	1994	2.4	2.4	1.9	2.4	2.3	2.8
268988	WELLS*	Marys River Area	42	30	1975	2004	2.5	2.4	1.9	2.3	2.2	3.4
268822	WABUSKA 6 SE*	Mason Valley	108	27	1973	2006	3.1	3.0	2.4	2.9	3.0	4.0
269229	YERINGTON*	Mason Valley	108	30	1965	2007	3.1	3.0	2.4	2.9	3.1	3.8
266748	REESE VALLEY CARPER	Middle Reese River Valley	58	6	1977	1983	2.8	2.8	2.2	2.6	2.6	3.7
267188	RYNDON*	North Fork Area	44	6	2000	2007	2.6	2.6	2.0	2.5	2.4	3.6
267324	SAVAL RCH*	North Fork Area	44	5	1961	1965	1.8	1.7	1.3	1.7	1.6	2.7
260718	BEATTY 8 N*	Oasis Valley	228	28	1973	2004	4.5	3.9	3.1	3.8	4.5	5.1
260715	BEATTY*	Oasis Valley	228	30	1921	1972	4.9	4.3	3.4	4.0	4.8	5.5
265392	MTN CITY RS*	Owyhee River Area	37	30	1965	1998	2.1	2.0	1.6	1.9	1.8	3.3
265869	OWYHEE*	Owyhee River Area	37	30	1953	1984	2.3	2.4	1.9	2.3	2.2	2.8
269072	WILDHORSE RSVR*	Owyhee River Area	37	18	1983	2006	1.8	1.7	1.3	1.6	1.5	3.0
260099	ALAMO*	Pahranagat Valley	209	29	1922	1958	4.6	4.2	3.3	3.9	4.3	5.3
263671	HIKO*	Pahranagat Valley	209	15	1990	2006	4.1	3.7	2.9	3.5	3.9	4.6
265880	PAHRANAGAT WR*	Pahranagat Valley	209	30	1968	2006	4.3	3.8	3.0	3.5	4.2	4.9

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265890	PAHRUMP*	Pahrump Valley	162	30	1973	2006	5.0	4.4	3.6	3.8	5.1	5.6
261590	CATHEDRAL GORGE SP*	Panaca Valley	203	4	2003	2007	3.7	3.6	2.8	3.5	3.5	4.2
266005	PARADISE VALLEY 1 NW*	Paradise Valley	69	30	1972	2007	3.2	3.2	2.5	3.0	3.0	4.0
266252	PIOCHE	Patterson Valley	202	30	1968	2006	2.8	2.7	2.1	2.6	2.6	3.1
266130	PENOYER VALLEY*	Penoyer Valley	170	5	1968	2004	3.9	4.0	3.2	3.8	3.9	4.9
267983	TEMPIUTE 4 NW*	Penoyer Valley	170	12	1973	1984	3.8	3.8	3.1	3.7	3.8	4.7
266228	PILOT VALLEY-LEE*	Pilot Creek Valley	191	6	2000	2007	2.9	2.8	2.2	2.7	2.6	3.6
266504	QUINN RVR CROSSING	Pine Forest Valley	29	10	1902	1950	3.1	3.1	2.4	3.0	3.0	4.3
266242	PINE VALLEY BAILEY RCH*	Pine Valley	53	11	1983	2003	2.7	2.6	2.0	2.3	2.4	3.8
266574	RAND RCH PALISADE*	Pine Valley	53	19	1958	1981	2.3	2.3	1.8	2.2	2.2	3.7
267369	SEARCHLIGHT	Piute Valley	214	30	1976	2006	4.2	3.6	2.8	3.0	4.2	4.6
265440	MT ROSE BOWL	Pleasant Valley	88	8	1974	1984	1.6	1.7	1.3	1.6	1.5	1.0
266055	PARIS RCH*	Pleasant Valley	130	22	1967	1990	3.5	3.4	2.8	3.3	3.4	4.1
262229	DENIO*	Pueblo Valley	1	30	1969	2005	3.1	3.1	2.5	3.0	3.0	3.7
265605	NIXON*	Pyramid Lake Valley	81	30	1931	1973	3.6	3.5	2.8	3.4	3.5	4.4
267953	SUTCLIFFE	Pyramid Lake Valley	81	27	1968	2006	3.1	2.9	2.3	2.9	3.1	3.5
265362	MONTGOMERY MNTC STN	Queen Valley	116	10	1961	1978	2.3	2.3	1.8	2.1	2.1	3.6

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264935	MCDERMITT*	Quinn River Valley	33B	29	1916	2007	2.8	2.7	2.1	2.3	2.5	3.8
265818	OROVADA 3 W*	Quinn River Valley	33A	30	1971	2006	3.1	3.1	2.5	3.0	3.1	3.7
260955	BLUE EAGLE RCH HANKS*	Railroad Valley	173B	23	1979	2007	3.7	3.7	2.9	3.5	3.7	4.3
262091	CURRANT HWY STN	Railroad Valley	173B	7	1964	1977	2.5	2.5	2.0	2.3	2.3	3.8
262078	CURRANT*	Railroad Valley	173B	4	1942	1946	3.3	3.4	2.6	3.2	3.2	4.1
262276	DIABLO*	Railroad Valley	173A	10	1960	1978	3.7	3.7	3.0	3.5	3.7	4.5
262390	DUCKWATER*	Railroad Valley	173B	19	1967	1998	3.3	3.3	2.6	3.2	3.1	4.1
268170	TONOPAH*	Ralston Valley	141	30	1975	2005	4.0	3.9	3.1	3.9	3.9	4.8
29999	RED ROCK WC*	Red Rock Valley	99	4	2004	2007	2.6	2.6	2.0	2.5	2.4	3.4
260438	ARTHUR 4 NW*	Ruby Valley	176	30	1971	2007	2.3	2.3	1.8	2.3	2.2	2.7
267123	RUBY LAKE*	Ruby Valley	176	30	1975	2007	2.8	2.8	2.2	2.7	2.6	3.3
261905	CONTACT*	Salmon Falls Creek Area	40	30	1956	1998	2.6	2.4	1.9	2.3	2.3	3.5
264016	JACKPOT*	Salmon Falls Creek Area	40	15	1987	2004	2.5	2.5	2.0	2.4	2.4	3.3
264268	KNOLL CREEK FLD STN	Salmon Falls Creek Area	40	6	1972	1979	2.4	2.3	1.7	2.1	2.0	3.6
267284	SAN JACINTO*	Salmon Falls Creek Area	40	21	1905	1947	2.6	2.4	1.9	2.3	2.3	3.6
262662	EMPIRE*	San Emidio Desert	22	6	1951	1976	3.5	3.5	2.8	3.4	3.5	4.1
263090	GERLACH*	San Emidio Desert	22	27	1963	2006	3.1	3.2	2.5	3.1	3.2	3.7

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
267319	SARCOBATUS*	Sarcobatus Flat	146	14	1942	1961	4.2	4.0	3.2	3.7	4.2	5.2
267609	SMITH 1 N*	Smith Valley	107	23	1938	1966	3.0	3.0	2.4	2.8	2.9	4.0
267612	SMITH 6 N*	Smith Valley	107	23	1974	2007	3.1	3.1	2.5	3.0	3.1	4.0
268977	WELLINGTON RS*	Smith Valley	107	27	1943	1972	3.0	3.0	2.4	2.9	3.0	3.7
267261	SAND PASS*	Smoke Creek Desert	21	30	1930	1970	3.5	3.6	2.8	3.4	3.6	4.2
267618	SMOKE CREEK ESPIL*	Smoke Creek Desert	21	14	1988	2004	3.6	3.6	2.9	3.5	3.6	4.3
263340	GREAT BASIN NP	Snake Valley	195	16	1988	2007	2.3	2.4	1.8	2.3	2.3	2.7
264514	LEHMAN CAVES NM	Snake Valley	195	30	1958	1987	2.1	2.2	1.7	2.1	2.0	2.6
265168	MINA*	Soda Spring Valley	121A	30	1978	2007	3.9	3.7	2.9	3.6	3.7	4.6
263940	I-L RCH*	South Fork Owyhee River Area	35	3	1963	1967	1.8	1.9	1.5	2.0	1.8	3.1
267450	SHOSHONE 5 N*	Spring Valley	184	17	1989	2007	3.0	3.0	2.4	2.9	2.9	3.9
267750	SPRING VALLEY SP*	Spring Valley	201	24	1975	2006	3.0	2.9	2.3	2.8	2.6	4.1
267397	SEVENTY ONE RCH*	Starr Valley Area	43	4	1940	1945	2.4	2.3	1.8	2.2	2.2	3.3
262096	CURRIE HWY STN*	Steptoe Valley	179	10	1962	1989	2.8	2.7	2.1	2.5	2.5	4.3
262626	ELY 6 NE	Steptoe Valley	179	5	2000	2005	3.4	3.4	2.7	3.1	3.2	4.4
262631	ELY YELLAND FLD AP*	Steptoe Valley	179	30	1976	2005	2.8	2.7	2.1	2.6	2.5	3.9
264341	LAGES*	Steptoe Valley	179	21	1984	2006	3.0	3.0	2.3	2.9	2.8	4.0

Appendix 12b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
264950	MCGILL*	Steptoe Valley	179	30	1977	2007	2.9	2.8	2.2	2.7	2.7	3.6
265760	OLD RUTH	Steptoe Valley	179	5	1979	1985	2.1	2.3	1.7	2.1	2.0	2.8
267175	RUTH	Steptoe Valley	179	30	1963	2007	2.3	2.2	1.7	2.1	2.0	3.5
268810	VYA	Surprise Valley	14	14	1960	1975	2.0	1.9	1.5	1.8	1.8	2.7
260668	BASALT	Teels Marsh Valley	114	10	1942	1957	3.2	3.2	2.5	3.1	3.0	4.2
265352	MONTELLO 2 SE*	Thousand Springs Valley	189D	30	1971	2007	2.9	2.9	2.2	2.8	2.6	4.0
269122	WILKINS*	Thousand Springs Valley	189A	16	1949	1964	2.2	2.2	1.7	2.1	2.0	3.6
268834	WADSWORTH*	Tracy Segment	83	6	1902	1947	3.6	3.4	2.7	3.1	3.3	4.3
266779	RENO TAHOE INTL AP*	Truckee Meadows	87	30	1978	2007	3.5	3.4	2.7	3.3	3.5	4.0
266791	RENO WFO*	Truckee Meadows	87	10	1997	2007	3.3	3.2	2.6	3.2	3.4	3.7
268500	UNIV OF NEVADA EXP FM*	Truckee Meadows	87	4	1949	1954	3.4	3.3	2.7	3.3	3.5	3.9
260507	AUSTIN #2*	Upper Reese River Valley	56	30	1972	2007	2.7	2.7	2.1	2.6	2.5	3.1
261630	CENTRAL NEVADA FLD LAB*	Upper Reese River Valley	56	13	1966	1985	2.7	2.6	2.0	2.5	2.4	4.1
266746	REESE RIVER*	Upper Reese River Valley	56	26	1973	2006	2.5	2.4	1.8	2.2	2.1	3.9
261327	BUNKERVILLE*	Virgin River Valley	222	6	1980	2007	4.3	3.7	2.9	2.9	4.3	4.9

Appendix 12b cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	NUMBER OF YEARS USED FOR AVERAGE	START YEAR	END YEAR	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
265085	MESQUITE*	Virgin River Valley	222	13	1942	2006	4.4	3.9	3.1	2.9	4.5	4.8
262394	DUFURRENA*	Virgin Valley	4	30	1965	2004	2.8	2.7	2.1	2.6	2.5	4.0
263515	HAWTHORNE AP*	Walker Lake Valley	110C	30	1947	1990	3.8	3.6	2.8	3.5	3.6	4.6
263512	HAWTHORNE*	Walker Lake Valley	110C	13	1955	2007	3.9	3.6	2.8	3.4	3.6	4.6
267358	SCHURZ*	Walker Lake Valley	110A	30	1920	1955	3.5	3.5	2.8	3.4	3.5	4.4
268034	THORNE*	Walker Lake Valley	110C	24	1915	1950	3.8	3.7	2.9	3.6	3.7	4.6
264542	LEWERS RCH	Washoe Valley	89	15	1893	1913	3.2	3.1	2.4	3.1	2.9	2.7
39999	WASHOE VALLEY WC*	Washoe Valley	89	5	2004	2008	3.7	3.8	2.9	3.5	3.5	4.7
264199	KIMBERLY	White River Valley	207	28	1929	1958	2.4	2.4	1.9	2.3	2.2	3.0
264745	LUND*	White River Valley	207	30	1977	2007	3.1	3.1	2.4	2.9	2.9	3.9
267908	SUNNYSIDE*	White River Valley	207	30	1973	2007	3.3	3.3	2.5	3.1	3.1	4.1
265105	MIDAS 4 SE*	Willow Creek Valley	63	4	1962	1967	2.4	2.5	2.0	2.4	2.4	3.9
263245	GOLCONDA*	Winnemucca Segment	70	30	1970	2005	3.4	3.4	2.7	3.3	3.4	4.2
269171	WINNEMUCCA MUNI AP*	Winnemucca Segment	70	30	1978	2007	3.4	3.3	2.6	3.1	3.2	4.2

Appendix 13. Example of assignment and weighting of the mean annual Net Irrigation Water Requirement (NIWR) of alfalfa for respective HAs. Values of the NIWR were either assigned or averaged for HAs with multiple stations according to valid period of record for each station used in computing the annual average. The NIWR is listed in order of HA name, with shaded areas denoting the weighted average, and respective HA name and number.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
260150	AMARGOSA FARMS-GAREY*	Amargosa Desert	230	5.3	1966	2005	28	1.00	5.3	5.3
260282	ANTELOPE VALLEY FARR*	Antelope Valley	57	3.0	1985	1998	8	1.00	3.0	3.0
268186	TOPAZ LAKE 3N*	Antelope Valley	106	3.3	1958	1980	19	0.63	2.1	
268202	TOPAZ LAKE 4 N*	Antelope Valley	106	3.2	1987	1997	11	0.37	1.2	3.3
269137	WILLOW SPRINGS*	Big Smoky Valley	137A	3.7	1942	1948	4	1.00	3.7	3.7
267620	SMOKEY VALLEY*	Big Smoky Valley	137B	3.6	1975	2007	30	1.00	3.6	3.6
261371	CALLVILLE BAY*	Black Moutains Area	215	4.9	1990	2003	8	0.44	2.2	
262497	ECHO BAY*	Black Moutains Area	215	4.5	1990	2003	10	0.56	2.5	4.7
263090	GERLACH*	San Emidio Desert	22	3.1	1963	2006	27	0.33	1.0	
264527	LEONARD CREEK RCH*	Black Rock Desert	28	3.2	1971	2004	30	0.37	1.2	
265907	PAHUTE MEADOWS RCH*	Black Rock Desert	28	3.2	1964	1974	4	0.05	0.2	
267873	SULPHUR*	Black Rock Desert	28	3.4	1915	1953	21	0.26	0.9	3.2

Appendix 13 cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
261660	CHARLESTON*	Bruneau River Area	38	1.6	1962	2005	4	1.00	1.6	1.6
261311	BUFFALO RCH*	Buffalo Valley	131	2.8	1967	1978	7	1.00	2.8	2.8
264349	LAHONTAN DAM*	Churchill Valley	102	3.4	1966	2003	30	0.50	1.7	
262780	FALLON EXP STN*	Carson Desert	101	3.2	1973	2005	30	0.50	1.6	3.3
265191	MINDEN*	Carson Valley	105	3.0	1975	2007	30	1.00	3.0	3.0
262780	FALLON EXP STN*	Carson Desert	101	3.2	1973	2005	30	0.50	1.6	
264349	LAHONTAN DAM*	Churchill Valley	102	3.4	1966	2003	30	0.50	1.7	3.3
267463	SILVERPEAK*	Clayton Valley	143	4.4	1974	2007	30	1.00	4.4	4.4
261740	CLOVER VALLEY*	Clover Valley	177	2.5	1923	2007	30	1.00	2.5	2.5
261358	CALIENTE*	Clover Valley	204	3.8	1904	2005	22	1.00	3.8	3.8
260691	BATTLE MTN AP*	Lower Reese River Valley	59	3.0	1973	2006	30	0.55	1.7	
260688	BATTLE MTN*	Clovers Area	64	3.5	1899	1944	25	0.45	1.6	3.2
264480	LAUGHLIN*	Colorado Valley	213	5.8	1989	2006	10	1.00	5.8	5.8
261755	COALDALE JUNCTION*	Columbus Salt Marsh Valley	118	4.4	1942	1957	6	1.00	4.4	4.4
265132	MIDDLEGATE-LOWERY*	Cowkick Valley	126	3.4	1989	2007	15	1.00	3.4	3.4
260795	BEOWAWE*	Crescent Valley	54	2.9	1976	2006	30	0.75	2.2	
261975	CORTEZ GOLD MINE*	Crescent Valley	54	2.9	1969	1979	10	0.25	0.7	2.9
264108	JUNGO MEYER RCH*	Desert Valley	31	3.1	1969	1985	7	1.00	3.1	3.1

Appendix 13 cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
262296	DIAMOND VALLEY USDA*	Diamond Valley	153	2.5	1980	2006	19	1.00	2.5	2.5
267690	SOUTH FORK SP*	Dixie Creek - Tenmile	48	2.8	1994	2007	8	1.00	2.8	2.8
261160	BRINKERHOFF RCH*	Dixie Valley	128	3.6	1967	1979	7	1.00	3.6	3.6
262840	FERNLEY*	Fernley Area	76	3.5	1908	1974	21	0.44	1.5	
268834	WADSWORTH*	Tracy Segment	83	3.6	1902	1947	6	0.13	0.5	
268838	WADSWORTH 4 N*	Dodge Flat	82	3.5	1975	2002	21	0.44	1.5	3.5
261485	CARSON CITY*	Eagle Valley	104	3.2	1973	2007	30	1.00	3.2	3.2
262477	EASTGATE*	Eastgate Valley Area	127	3.4	1957	1963	4	1.00	3.4	3.4
261071	BOULDER CITY*	Eldorado Valley	167	4.6	1968	2004	30	1.00	4.6	4.6
262570	ELKO*	Elko Segment	49	2.6	2000	2007	6	0.17	0.4	
262573	ELKO RGNL AP*	Elko Segment	49	2.6	1978	2007	30	0.83	2.2	2.6
268838	WADSWORTH 4 N*	Dodge Flat	82	3.5	1975	2002	21	0.44	1.5	
268834	WADSWORTH*	Tracy Segment	83	3.6	1902	1947	6	0.13	0.5	
262840	FERNLEY*	Fernley Area	76	3.5	1908	1974	21	0.44	1.5	3.5
262431	DYER*	Fish Lake Valley	117	4.2	1974	2007	30	1.00	4.2	4.2
265722	OASIS*	Goshute Valley	187	2.8	1988	2006	17	1.00	2.8	2.8
269171	WINNEMUCCA MUNI AP*	Winnemucca Segment	70	3.4	1978	2007	30	0.83	2.8	
269168	WINNEMUCCA #2*	Grass Valley	71	3.3	2000	2007	6	0.17	0.5	3.3

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
260800	BEOWAWE U OF N RCH*	Grass Valley	138	2.7	1973	2006	28	1.00	2.7	2.7
262820	FERGUSON SPRINGS HMS*	Great Salt Lake Desert	192	2.3	1973	1982	7	1.00	2.3	2.3
260961	BLUE JAY HWY STN*	Hot Creek	156	3.3	1964	1983	7	0.41	1.4	
268443	TWIN SPRING FALLINI*	Hot Creek	156	3.5	1986	2005	10	0.59	2.0	3.4
264095	JIGGS 8 SSE ZAGA*	Huntington Valley	47	2.4	1979	2007	19	1.00	2.4	2.4
263957	IMLAY*	Imlay Area	72	3.4	1964	2007	30	0.50	1.7	
267192	RYE PATCH DAM*	Imlay Area	72	3.6	1973	2007	30	0.50	1.8	3.5
268346	TUSCARORA*	Independence Valley	36	2.2	1973	2006	30	1.00	2.2	2.2
263980	INDIAN SPRINGS*	Indian Springs Valley	161	5.2	1914	1964	23	1.00	5.2	5.2
263316	GOODSPRINGS*	Ivanpah Valley	164A	5.2	2000	2006	6	1.00	5.2	5.2
265371	MOORMAN RCH*	Jakes Valley	174	2.7	2003	2007	4	1.00	2.7	2.7
264039	JARBIDGE 7 N*	Jarbidge River Area	39	2.3	1996	2006	11	1.00	2.3	2.3
263205	GLENBROOK*	Lake Tahoe Basin	90	2.3	1969	2007	30	0.70	1.6	
267806	STATELINE-HARRAH'S*	Lake Tahoe Basin	90	2.4	1985	1998	13	0.30	0.7	2.3
263101	GEYSER RCH*	Lake Valley	183	3.0	1905	2002	19	1.00	3.0	3.0
264394	LAMOILLE YOST*	Lamoille Valley	45	2.3	1976	2003	22	1.00	2.3	2.3
23112	LAS VEGAS*	Las Vegas Valley	212	5.5	1949	1970	22	0.16	0.9	
262243	DESERT NWR*	Las Vegas Valley	212	5.5	1974	2007	30	0.21	1.2	

Appendix 13 cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
264429	LAS VEGAS*	Las Vegas Valley	212	6.1	1915	1955	30	0.21	1.3	
264436	LAS VEGAS WB AP*	Las Vegas Valley	212	5.2	1976	2005	30	0.21	1.1	
264439	LAS VEGAS NWFO*	Las Vegas Valley	212	5.1	1997	2007	9	0.06	0.3	
265705	NORTH LAS VEGAS*	Las Vegas Valley	212	5.9	1952	2006	20	0.14	0.8	5.6
267820	STEAD*	Lemmon Valley	92B	3.1	1986	2006	14	1.00	3.1	3.1
262860	FISH CREEK RCH*	Little Smoky Valley	155A	2.8	1944	1964	14	1.00	2.8	2.8
264700	LOVELOCK DERBY FLD*	Lovelock Valley	73	3.7	1970	2005	30	1.00	3.7	3.7
264651	LOGANDALE*	Lower Moapa Valley	220	4.3	1969	1991	20	0.24	1.0	
265846	OVERTON*	Lower Moapa Valley	220	4.6	1950	2007	30	0.35	1.6	
262557	ELGIN*	Lower Meadow Valley Wash	205	3.9	1986	2006	20	0.24	0.9	
262562	ELGIN 3 SE*	Lower Meadow Valley Wash	205	3.8	1966	1985	15	0.18	0.7	4.2
264651	LOGANDALE*	Lower Moapa Valley	220	4.3	1969	1991	20	0.40	1.7	
265846	OVERTON*	Lower Moapa Valley	220	4.6	1950	2007	30	0.60	2.7	4.5
260688	BATTLE MTN*	Clovers Area	64	3.5	1899	1944	25	0.45	1.6	
260691	BATTLE MTN AP*	Lower Reese River Valley	59	3.0	1973	2006	30	0.55	1.7	3.2
263114	GIBBS RCH*	Marys River Area	42	2.3	1972	2006	30	0.32	0.7	

Appendix 13 cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
264824	MALA VISTA RCH*	Marys River Area	42	2.4	1940	1965	16	0.17	0.4	
265092	METROPOLIS*	Marys River Area	42	2.4	1966	1994	18	0.19	0.5	
268988	WELLS*	Marys River Area	42	2.5	1975	2004	30	0.32	0.8	2.4
268822	WABUSKA 6 SE*	Mason Valley	108	3.1	1973	2006	27	0.47	1.5	
269229	YERINGTON*	Mason Valley	108	3.1	1965	2007	30	0.53	1.6	3.1
267188	RYNDON*	North Fork Area	44	2.6	2000	2007	6	0.55	1.4	
267324	SAVAL RCH*	North Fork Area	44	1.8	1961	1965	5	0.45	0.8	2.2
260715	BEATTY*	Oasis Valley	228	4.9	1921	1972	30	0.52	2.5	
260718	BEATTY 8 N*	Oasis Valley	228	4.5	1973	2004	28	0.48	2.2	4.7
265392	MTN CITY RS*	Owyhee River Area	37	2.1	1965	1998	30	0.38	0.8	
265869	OWYHEE*	Owyhee River Area	37	2.3	1953	1984	30	0.38	0.9	
269072	WILDHORSE RSVR*	Owyhee River Area	37	1.8	1983	2006	18	0.23	0.4	2.1
260099	ALAMO*	Pahranagat Valley	209	4.6	1922	1958	29	0.39	1.8	
263671	HIKO*	Pahranagat Valley	209	4.1	1990	2006	15	0.20	0.8	
265880	PAHRANAGAT WR*	Pahranagat Valley	209	4.3	1968	2006	30	0.41	1.7	4.4
265890	PAHRUMP*	Pahrump Valley	162	5.0	1973	2006	30	1.00	5.0	5.0
261358	CALIENTE*	Clover Valley	204	3.8	1904	2005	22	0.85	3.2	
261590	CATHEDRAL GORGE SP*	Panaca Valley	203	3.7	2003	2007	4	0.15	0.6	3.8

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
266005	PARADISE VALLEY 1 NW*	Paradise Valley	69	3.2	1972	2007	30	1.00	3.2	3.2
266130	PENOYER VALLEY*	Penoyer Valley	170	3.9	1968	2004	5	0.29	1.2	
267983	TEMPIUTE 4 NW*	Penoyer Valley	170	3.8	1973	1984	12	0.71	2.7	3.9
266228	PILOT VALLEY-LEE*	Pilot Creek Valley	191	2.9	2000	2007	6	1.00	2.9	2.9
266242	PINE VALLEY BAILEY RCH*	Pine Valley	53	2.7	1983	2003	11	0.37	1.0	
266574	RAND RCH PALISADE*	Pine Valley	53	2.3	1958	1981	19	0.63	1.5	2.5
266055	PARIS RCH*	Pleasant Valley	130	3.5	1967	1990	22	1.00	3.5	3.5
262229	DENIO*	Pueblo Valley	1	3.1	1969	2005	30	1.00	3.1	3.1
265605	NIXON*	Pyramid Lake Valley	81	3.6	1931	1973	30	1.00	3.6	3.6
265818	OROVADA 3 W*	Quinn River Valley	33A	3.1	1971	2006	30	1.00	3.1	3.1
264935	MCDERMITT*	Quinn River Valley	33B	2.8	1916	2007	29	1.00	2.8	2.8
262276	DIABLO*	Railroad Valley	173A	3.7	1960	1978	10	1.00	3.7	3.7
260955	BLUE EAGLE RCH HANKS*	Railroad Valley	173B	3.7	1979	2007	23	0.50	1.8	
262078	CURRANT*	Railroad Valley	173B	3.3	1942	1946	4	0.09	0.3	
262390	DUCKWATER*	Railroad Valley	173B	3.3	1967	1998	19	0.41	1.4	3.5
268170	TONOPAH*	Ralston Valley	141	4.0	1975	2005	30	1.00	4.0	4.0
29999	RED ROCK WC*	Red Rock Valley	99	2.6	2004	2007	4	1.00	2.6	2.6

Appendix 13 cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
260438	ARTHUR 4 NW*	Ruby Valley	176	2.3	1971	2007	30	0.50	1.1	
267123	RUBY LAKE*	Ruby Valley	176	2.8	1975	2007	30	0.50	1.4	2.5
261905	CONTACT*	Salmon Falls Creek Area	40	2.6	1956	1998	30	0.45	1.2	
264016	JACKPOT*	Salmon Falls Creek Area	40	2.5	1987	2004	15	0.23	0.6	
267284	SAN JACINTO*	Salmon Falls Creek Area	40	2.6	1905	1947	21	0.32	0.8	2.6
262662	EMPIRE*	San Emidio Desert	22	3.5	1951	1976	6	0.18	0.6	
263090	GERLACH*	San Emidio Desert	22	3.1	1963	2006	27	0.82	2.6	3.2
267319	SARCOBATUS*	Sarcobatus Flat	146	4.2	1942	1961	14	1.00	4.2	4.2
267609	SMITH 1 N*	Smith Valley	107	3.0	1938	1966	23	0.32	1.0	
267612	SMITH 6 N*	Smith Valley	107	3.1	1974	2007	23	0.32	1.0	
268977	WELLINGTON RS*	Smith Valley	107	3.0	1943	1972	27	0.37	1.1	3.1
263090	GERLACH*	San Emidio Desert	22	3.1	1963	2006	27	0.38	1.2	
267261	SAND PASS*	Smoke Creek Desert	21	3.5	1930	1970	30	0.42	1.5	
267618	SMOKE CREEK ESPIL*	Smoke Creek Desert	21	3.6	1988	2004	14	0.20	0.7	3.4
265168	MINA*	Soda Spring Valley	121A	3.9	1978	2007	30	1.00	3.9	3.9
263940	I-L RCH*	South Fork Owyhee River Area	35	1.8	1963	1967	3	1.00	1.8	1.8
267450	SHOSHONE 5 N*	Spring Valley	184	3.0	1989	2007	17	1.00	3.0	3.0

Appendix 13 cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
267750	SPRING VALLEY SP*	Spring Valley	201	3.0	1975	2006	24	1.00	3.0	3.0
267397	SEVENTY ONE RCH*	Starr Valley Area	43	2.4	1940	1945	4	1.00	2.4	2.4
262096	CURRIE HWY STN*	Steptoe Valley	179	2.8	1962	1989	10	0.11	0.3	
262631	ELY YELLAND FLD AP*	Steptoe Valley	179	2.8	1976	2005	30	0.33	0.9	
264341	LAGES*	Steptoe Valley	179	3.0	1984	2006	21	0.23	0.7	
264950	MCGILL*	Steptoe Valley	179	2.9	1977	2007	30	0.33	0.9	2.9
269122	WILKINS*	Thousand Springs Valley	189A	2.2	1949	1964	16	1.00	2.2	2.2
265352	MONTELLO 2 SE*	Thousand Springs Valley	189D	2.9	1971	2007	30	1.00	2.9	2.9
262840	FERNLEY*	Fernley Area	76	3.5	1908	1974	21	0.44	1.5	
268838	WADSWORTH 4 N*	Dodge Flat	82	3.5	1975	2002	21	0.44	1.5	
268834	WADSWORTH*	Tracy Segment	83	3.6	1902	1947	6	0.13	0.5	3.5
266779	RENO TAHOE INTL AP*	Truckee Meadows	87	3.5	1978	2007	30	0.68	2.4	
266791	RENO WFO*	Truckee Meadows	87	3.3	1997	2007	10	0.23	0.8	
268500	UNIV OF NEVADA EXP FM*	Truckee Meadows	87	3.4	1949	1954	4	0.09	0.3	3.4
260507	AUSTIN #2*	Upper Reese River Valley	56	2.7	1972	2007	30	0.43	1.2	
261630	CENTRAL NEVADA FLD LAB*	Upper Reese River Valley	56	2.7	1966	1985	13	0.19	0.5	

Appendix 13 cont.

STATION NUMBER	STATION NAME	BASIN NAME	BASIN NUMBER	ALFALFA NIWR (ft)	START YEAR	END YEAR	NUMBER OF YEARS IN AVERAGE	WEIGHT BASED ON NUMBER OF YEARS USED IN AVERAGE	WEIGHT x ALFALFA NIWR (ft)	WEIGHTED AVERAGE ALFALFA NIWR (ft)
266746	REESE RIVER*	Upper Reese River Valley	56	2.5	1973	2006	26	0.38	0.9	2.6
261327	BUNKERVILLE*	Virgin River Valley	222	4.3	1980	2007	6	0.32	1.4	
265085	MESQUITE*	Virgin River Valley	222	4.4	1942	2006	13	0.68	3.0	4.4
262394	DUFURRENA*	Virgin Valley	4	2.8	1965	2004	30	1.00	2.8	2.8
267358	SCHURZ*	Walker Lake Valley	110A	3.5	1920	1955	30	1.00	3.5	3.5
263512	HAWTHORNE*	Walker Lake Valley	110C	3.9	1955	2007	13	0.19	0.8	
263515	HAWTHORNE AP*	Walker Lake Valley	110C	3.8	1947	1990	30	0.45	1.7	
268034	THORNE*	Walker Lake Valley	110C	3.8	1915	1950	24	0.36	1.4	3.8
39999	WASHOE VALLEY WC*	Washoe Valley	89	3.7	2004	2008	5	1.00	3.7	3.7
264745	LUND*	White River Valley	207	3.1	1977	2007	30	0.50	1.6	
267908	SUNNYSIDE*	White River Valley	207	3.3	1973	2007	30	0.50	1.7	3.2
265105	MIDAS 4 SE*	Willow Creek Valley	63	2.4	1962	1967	4	1.00	2.4	2.4
269168	WINNEMUCCA #2*	Grass Valley	71	3.3	2000	2007	6	0.09	0.3	
263245	GOLCONDA*	Winnemucca Segment	70	3.4	1970	2005	30	0.45	1.6	
269171	WINNEMUCCA MUNI AP*	Winnemucca Segment	70	3.4	1978	2007	30	0.45	1.5	3.4

Appendix 14. Mean annual reference (ET_{os}) and actual crop evapotranspiration (ET_{act}) of alfalfa, grass hay, pasture grass, turf grass, and small shallow open water bodies for all HAs. Values of the ET_{os} and ET_{act} for each HA were either assigned for HAs with single stations, computed using a valid period of record weighted average for HAs with multiple stations, or estimated from spatial interpolation for HAs with no stations. * indicates that the ET_{os} and ET_{act} was estimated using spatial interpolation.

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Adobe Valley*	115	Central Region	5.0	4.3	4.1	3.3	3.9	4.0	5.2
Alkali Spring Valley*	142	Central Region	5.2	4.5	4.4	3.6	4.2	4.4	5.5
Alkali Valley*	111A	Central Region	4.7	4.1	3.9	3.1	3.7	3.9	4.9
Alkali Valley*	111B	Central Region	4.7	4.1	3.9	3.1	3.7	3.9	4.9
Amargosa Desert	230	Death Valley Basin	5.8	5.6	4.8	3.9	3.7	5.6	6.1
Antelope Valley	57	Humboldt River Basin	4.4	3.6	3.6	3.0	3.5	3.5	4.6
Antelope Valley	106	Walker River Basin	4.6	3.8	3.7	3.0	3.6	3.6	4.8
Antelope Valley*	186B	Central Region	4.1	3.2	3.1	2.5	2.9	2.9	4.3
Antelope Valley*	186A	Central Region	4.2	3.3	3.2	2.6	3.1	3.0	4.4
Antelope Valley*	93	Western Region	4.3	3.7	3.6	2.9	3.5	3.5	4.5
Antelope Valley*	151	Central Region	4.4	3.3	3.3	2.7	3.1	3.0	4.6
Bedell Flat*	94	Western Region	4.1	3.4	3.3	2.7	3.2	3.1	4.3
Big Smoky Valley	137B	Central Region	4.8	4.1	4.0	3.2	3.9	3.7	5.1
Big Smoky Valley	137A	Central Region	4.8	3.9	3.8	3.0	3.8	3.5	5.0
Black Moutains Area	215	Colorado River Basin	5.5	5.1	4.4	3.5	2.8	5.1	5.7
Black Rock Desert	28	Black Rock Desert Region	4.3	3.8	3.7	3.1	3.7	3.7	4.5
Boulder Flat*	61	Humboldt River Basin	4.2	3.5	3.4	2.8	3.3	3.3	4.4
Boulder Valley*	15	Northwest Region	4.3	3.8	3.7	3.0	3.6	3.6	4.6
Bradys Hot Springs Area*	75	West Central Region	4.5	3.9	3.8	3.1	3.6	3.7	4.8
Bruneau River Area	38	Snake River Basin	4.1	2.3	2.0	1.7	1.7	1.8	4.3

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Buena Vista Valley*	129	Central Region	4.6	4.1	3.9	3.3	3.8	3.9	4.8
Buffalo Valley	131	Central Region	4.0	3.7	3.5	2.9	3.3	3.5	4.2
Butte Valley*	178A	Central Region	4.3	3.3	3.1	2.6	3.0	2.9	4.5
Butte Valley*	178B	Central Region	4.3	3.4	3.3	2.7	3.1	3.1	4.5
Cactus Flat*	148	Central Region	5.0	4.3	4.2	3.4	4.0	4.2	5.3
California Wash*	218	Colorado River Basin	5.5	5.2	4.5	3.7	3.3	5.3	5.7
Carico Lake Valley*	55	Humboldt River Basin	4.3	3.6	3.5	2.9	3.4	3.4	4.5
Carson Desert	101	Carson River Basin	4.2	3.7	3.6	2.9	3.5	3.6	4.4
Carson Desert*	101A	Carson River Basin	4.6	4.1	4.0	3.3	3.8	3.9	4.8
Carson Valley	105	Carson River Basin	4.3	3.6	3.5	2.9	3.3	3.4	4.5
Cave Valley*	180	Central Region	4.6	3.9	3.7	3.0	3.5	3.5	4.8
Churchill Valley	102	Carson River Basin	4.2	3.7	3.6	2.9	3.5	3.6	4.4
Clayton Valley	143	Central Region	5.5	4.7	4.6	3.8	4.2	4.7	5.7
Clover Valley	177	Central Region	4.0	3.3	3.3	2.7	3.1	3.1	4.2
Clover Valley	204	Colorado River Basin	4.9	4.5	4.2	3.5	3.9	4.1	5.2
Clovers Area	64	Humboldt River Basin	4.4	3.8	3.8	3.1	3.6	3.7	4.7
Coal Valley*	171	Central Region	5.0	4.4	4.2	3.4	4.0	4.2	5.2
Cold Spring Valley*	100	Western Region	4.2	3.7	3.6	3.0	3.5	3.6	4.4
Cold Spring Valley*	100A	Western Region	4.2	3.6	3.4	2.8	3.4	3.4	4.4
Coleman Valley*	11	Northwest Region	4.3	3.7	3.6	2.9	3.4	3.4	4.5
Colorado Valley	213	Colorado River Basin	6.5	6.2	5.3	4.3	3.7	6.1	6.9
Columbus Salt Marsh Valley	118	Central Region	5.5	4.7	4.4	3.6	4.3	4.3	5.8
Continental Lake Valley*	2	Northwest Region	4.3	3.6	3.5	2.9	3.4	3.4	4.5
Cowkick Valley	126	Central Region	4.8	3.8	3.5	2.9	3.4	3.3	5.0
Coyote spring Valley*	210	Colorado River Basin	5.4	5.1	4.5	3.6	3.7	5.0	5.7

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Crater Flat*	229	Death Valley Basin	5.6	5.2	4.6	3.7	4.0	5.1	5.9
Crescent Valley	54	Humboldt River Basin	4.2	3.6	3.6	3.0	3.4	3.4	4.4
Dayton Valley*	103	Carson River Basin	4.4	3.8	3.7	3.0	3.5	3.6	4.6
Deep Creek Valley*	193	Great Salt Lake Basin	4.2	3.3	3.2	2.6	3.1	3.0	4.4
Delamar Valley*	182	Central Region	5.1	4.6	4.2	3.4	3.9	4.4	5.4
Desert Valley	31	Black Rock Desert Region	4.3	3.8	3.7	3.0	3.5	3.6	4.5
Diamond Valley	153	Central Region	4.1	3.2	3.1	2.5	3.0	2.9	4.3
Dixie Creek-Tenmile Creek Area	48	Humboldt River Basin	4.3	3.4	3.3	2.7	3.0	3.1	4.5
Dixie Valley	128	Central Region	4.7	4.2	4.1	3.4	4.0	4.1	4.9
Dodge Flat	82	Truckee River Basin	4.6	3.9	3.8	3.1	3.7	3.7	4.8
Dry Lake Valley*	181	Central Region	4.9	4.3	4.1	3.3	3.8	4.0	5.1
Dry Valley*	19	Black Rock Desert Region	4.5	4.0	3.9	3.2	3.8	3.9	4.7
Dry Valley*	95	Western Region	4.1	3.4	3.2	2.6	3.2	3.1	4.3
Dry Valley*	198	Colorado River Basin	4.9	4.2	4.0	3.3	3.8	3.9	5.2
Duck Lake Valley*	16	Northwest Region	4.4	3.9	3.8	3.1	3.7	3.7	4.6
Eagle Valley	104	Carson River Basin	4.3	3.8	3.6	3.0	3.5	3.6	4.6
Eagle Valley*	200	Colorado River Basin	4.9	3.8	3.6	2.9	3.4	3.3	5.1
East Walker Area*	109	Walker River Basin	4.6	3.9	3.8	3.1	3.6	3.8	4.8
Eastgate Valley Area	127	Central Region	4.5	3.9	3.9	3.2	3.9	3.8	4.8
Edwards Creek Valley*	133	Central Region	4.5	3.7	3.6	2.9	3.5	3.4	4.7
Eldorado Valley	167	Central Region	5.4	5.1	4.3	3.5	3.1	5.0	5.7
Elko Segment	49	Humboldt River Basin	4.0	3.3	3.2	2.7	3.1	3.0	4.2
Emigrant Valley*	158A	Central Region	5.3	4.7	4.4	3.6	4.1	4.5	5.5
Emigrant Valley*	158B	Central Region	5.5	5.0	4.5	3.7	4.1	4.8	5.8
Escalante Desert*	197	Escalante Desert	4.9	4.3	4.0	3.3	3.8	4.0	5.2

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Fairview Valley*	124	Central Region	4.6	3.8	3.6	3.0	3.5	3.5	4.8
Fernley Area	76	West Central Region	4.6	3.9	3.8	3.1	3.7	3.7	4.8
Fireball Valley*	77	West Central Region	4.6	4.0	3.8	3.1	3.7	3.7	4.8
Fish Lake Valley	117	Central Region	5.5	4.6	4.4	3.6	4.3	4.3	5.8
Fortymile Canyon*	227B	Death Valley Basin	5.4	4.9	4.5	3.6	4.0	4.8	5.7
Fortymile Canyon*	227A	Death Valley Basin	5.6	5.3	4.6	3.8	4.0	5.2	5.9
Frenchman Flat*	160	Central Region	5.7	5.3	4.7	3.8	4.1	5.2	6.0
Gabbs Valley*	122	Central Region	4.7	4.0	3.8	3.0	3.6	3.7	4.9
Garden Valley*	172	Central Region	4.9	4.2	4.1	3.4	4.0	4.1	5.1
Garfield Flat*	120	Central Region	4.8	4.3	4.0	3.2	3.9	4.0	5.1
Garnet Valley*	216	Colorado River Basin	5.9	5.6	4.9	4.0	3.6	5.6	6.2
Gold Butte Area*	223	Colorado River Basin	5.4	5.1	4.4	3.5	3.1	5.1	5.6
Gold Flat*	147	Central Region	5.2	4.5	4.3	3.5	4.0	4.4	5.4
Goose Creek Area*	41	Snake River Basin	4.1	3.2	3.1	2.6	3.0	2.9	4.3
Goshute Valley	187	Central Region	4.2	3.4	3.2	2.6	3.1	2.9	4.5
Granite Basin*	23	Black Rock Desert Region	4.3	3.8	3.8	3.1	3.7	3.7	4.5
Granite Springs Valley*	78	West Central Region	4.6	4.0	3.9	3.2	3.8	3.8	4.8
Grapevine Canyon*	231	Death Valley Basin	5.4	4.7	4.4	3.5	4.0	4.6	5.6
Grass Valley	71	Humboldt River Basin	4.6	3.9	3.8	3.1	3.6	3.6	4.9
Grass Valley	138	Central Region	4.2	3.5	3.4	2.8	3.3	3.3	4.4
Greasewood Basin*	224	Colorado River Basin	5.3	5.1	4.4	3.6	3.1	5.1	5.6
Great Salt Lake Desert	192	Great Salt Lake Basin	3.6	2.9	2.9	2.3	2.7	2.7	3.7
Gridley Lake Valley*	3	Northwest Region	4.3	3.7	3.6	2.9	3.5	3.5	4.5
Grouse Creek Valley*	190	Great Salt Lake Basin	4.2	3.3	3.2	2.6	3.0	3.0	4.4
Guano Valley*	6	Northwest Region	4.3	3.6	3.5	2.8	3.3	3.3	4.5

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Hamlin Valley*	196	Great Salt Lake Basin	4.6	3.8	3.7	3.0	3.5	3.5	4.9
Hardscrabble Area*	68	Humboldt River Basin	4.4	3.7	3.6	2.9	3.4	3.4	4.7
Hidden Valley*	217	Colorado River Basin	5.9	5.6	4.9	3.9	3.6	5.6	6.2
Hidden Valley*	166	Central Region	5.9	5.7	4.9	4.0	3.6	5.6	6.2
High Rock Lake Valley*	25	Black Rock Desert Region	4.3	3.8	3.7	3.0	3.6	3.6	4.5
Honey Lake Valley*	97	Western Region	4.4	3.8	3.7	3.0	3.6	3.6	4.6
Hot Creek	156	Central Region	4.7	3.9	3.9	3.2	3.8	3.7	4.9
Hualapai Flat*	24	Black Rock Desert Region	4.3	3.9	3.8	3.1	3.7	3.7	4.6
Huntington Valley	47	Humboldt River Basin	4.0	3.2	3.0	2.5	2.8	2.8	4.2
Huntoon Valley*	113	Central Region	4.9	4.2	4.0	3.2	3.8	4.0	5.1
Imlay Area	72	Humboldt River Basin	4.7	4.1	4.0	3.3	3.9	3.9	4.9
Independence Valley	36	Snake River Basin	3.7	3.0	2.8	2.3	2.6	2.6	3.9
Independence Valley*	188	Central Region	4.1	3.2	3.1	2.5	3.0	2.9	4.3
Indian Springs Valley	161	Central Region	6.0	5.4	4.9	4.0	4.2	5.3	6.3
Ione Valley*	135	Central Region	4.7	3.8	3.6	2.9	3.5	3.5	4.9
Ivanpah Valley	164A	Central Region	5.9	5.7	4.9	4.0	4.1	5.6	6.2
Ivanpah Valley*	164B	Central Region	5.9	5.7	4.9	4.0	3.7	5.7	6.2
Jakes Valley	174	Central Region	4.3	3.2	3.1	2.5	2.9	2.8	4.5
Jarbidge River Area	39	Snake River Basin	3.9	3.3	3.0	2.5	2.9	2.8	4.1
Jean Lake Valley*	165	Central Region	5.9	5.7	4.9	4.0	3.7	5.6	6.2
Jersey Valley*	132	Central Region	4.4	4.0	3.9	3.2	3.7	3.8	4.7
Kane Springs Valley*	206	Colorado River Basin	5.0	4.7	4.1	3.4	3.7	4.5	5.3
Kawich Valley*	157	Central Region	5.1	4.5	4.3	3.5	4.1	4.4	5.4
Kelley Creek Area*	66	Humboldt River Basin	4.4	3.7	3.6	3.0	3.4	3.4	4.7
Kings River Valley*	30A	Black Rock Desert Region	4.3	3.7	3.6	3.0	3.5	3.5	4.6

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Kings River Valley*	30B	Black Rock Desert Region	4.4	3.8	3.7	3.0	3.5	3.6	4.6
Kobeh Valley*	139	Central Region	4.2	3.4	3.3	2.7	3.1	3.1	4.4
Kumiva Valley*	79	West Central Region	4.4	3.9	3.9	3.2	3.7	3.8	4.7
Lake Tahoe Basin	90	Truckee River Basin	3.6	2.9	2.7	2.2	2.6	2.6	3.7
Lake Valley	183	Central Region	4.5	3.6	3.4	2.8	3.3	3.2	4.7
Lamoille Valley	45	Humboldt River Basin	3.9	3.0	2.8	2.3	2.7	2.6	4.1
Las Vegas Valley	212	Colorado River Basin	6.2	6.0	5.2	4.2	3.9	6.0	6.5
Lemmon Valley	92B	Western Region	4.2	3.7	3.6	3.0	3.5	3.6	4.4
Lemmon Valley*	92A	Western Region	4.2	3.7	3.6	3.0	3.5	3.6	4.4
Lida Valley*	144	Central Region	5.3	4.6	4.4	3.5	4.1	4.4	5.6
Little Fish Lake Valley*	150	Central Region	4.6	3.7	3.7	3.0	3.5	3.5	4.8
Little Humboldt Valley*	67	Humboldt River Basin	4.4	3.5	3.4	2.8	3.2	3.2	4.6
Little Owyhee River Area*	34	Snake River Basin	4.2	3.3	3.1	2.6	3.0	2.9	4.4
Little Smoky Valley	155A	Central Region	4.5	3.1	3.1	2.5	2.9	2.9	4.8
Little Smoky Valley*	155C	Central Region	4.6	3.9	3.8	3.1	3.7	3.7	4.9
Little Smoky Valley*	155B	Central Region	4.6	3.8	3.7	3.0	3.6	3.5	4.8
Long Valley*	9	Northwest Region	4.3	3.7	3.6	3.0	3.5	3.5	4.5
Long Valley*	175	Central Region	4.3	3.4	3.2	2.7	3.1	3.0	4.5
Lovelock Valley	73	Humboldt River Basin	4.7	4.1	4.1	3.4	4.0	4.0	4.9
Lovelock Valley*	73A	Humboldt River Basin	4.7	4.2	4.0	3.3	3.9	3.9	4.9
Lower Meadow Valley Wash	205	Colorado River Basin	5.0	4.7	4.2	3.4	3.4	4.8	5.3
Lower Moapa Valley	220	Colorado River Basin	5.1	4.9	4.3	3.5	3.2	5.0	5.4
Lower Reese River Valley	59	Humboldt River Basin	4.4	3.8	3.8	3.1	3.6	3.7	4.7
Macy Flat*	10	Northwest Region	4.3	3.6	3.5	2.9	3.4	3.4	4.5
Maggie Creek Area*	51	Humboldt River Basin	4.0	3.2	3.0	2.5	2.9	2.8	4.2

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Marys Creek Area*	52	Humboldt River Basin	4.2	3.5	3.3	2.8	3.2	3.2	4.4
Marys River Area	42	Humboldt River Basin	3.9	3.1	3.0	2.5	2.9	2.8	4.1
Mason Valley	108	Walker River Basin	4.1	3.5	3.4	2.8	3.3	3.4	4.4
Massacre Lake Valley*	8	Northwest Region	4.3	3.7	3.6	2.9	3.5	3.5	4.5
Mercury Valley*	225	Death Valley Basin	5.9	5.5	4.9	4.0	4.0	5.5	6.2
Mesquite Valley*	163	Central Region	5.9	5.7	4.9	4.0	3.9	5.7	6.2
Middle Reese River Valley*	58	Humboldt River Basin	4.3	3.8	3.7	3.0	3.5	3.6	4.6
Monitor Valley*	140A	Central Region	4.4	3.5	3.4	2.8	3.3	3.2	4.7
Monitor Valley*	140B	Central Region	4.7	3.8	3.7	3.0	3.6	3.5	4.9
Mono Valley*	112	Central Region	4.8	4.1	3.9	3.2	3.8	3.9	5.0
Monte Cristo Valley*	136	Central Region	5.0	4.3	4.1	3.3	4.0	4.1	5.3
Mosquito Valley*	12	Northwest Region	4.3	3.7	3.6	2.9	3.5	3.5	4.5
Mud Meadow*	26	Black Rock Desert Region	4.3	3.7	3.7	3.0	3.6	3.6	4.5
Muddy River Springs Area*	219	Colorado River Basin	5.4	5.1	4.4	3.6	3.4	5.1	5.6
Newark Valley*	154	Central Region	4.3	3.3	3.2	2.7	3.1	3.0	4.5
Newcomb Lake Valley*	96	Western Region	4.2	3.5	3.4	2.8	3.3	3.2	4.4
North Fork Area	44	Humboldt River Basin	4.0	3.1	2.8	2.3	2.7	2.6	4.2
Oasis Valley	228	Death Valley Basin	5.5	5.1	4.5	3.6	4.1	5.0	5.7
Oriental Wash*	232	Death Valley Basin	5.3	4.6	4.4	3.5	4.1	4.5	5.6
Owyhee River Area	37	Snake River Basin	4.0	2.9	2.7	2.2	2.5	2.4	4.2
Pahranagat Valley	209	Colorado River Basin	5.3	4.8	4.4	3.5	3.9	4.6	5.6
Pahroc Valley*	208	Colorado River Basin	4.9	4.4	4.1	3.4	3.9	4.1	5.2
Pahrump Valley	162	Central Region	5.7	5.4	4.8	4.0	4.1	5.5	6.0
Painter Flat*	18	Black Rock Desert Region	4.5	4.0	3.9	3.2	3.8	3.8	4.7
Panaca Valley	203	Colorado River Basin	4.9	4.5	4.2	3.5	4.0	4.1	5.2

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Paradise Valley	69	Humboldt River Basin	4.6	3.8	3.6	3.0	3.5	3.4	4.8
Patterson Valley*	202	Colorado River Basin	4.9	4.1	3.9	3.2	3.7	3.7	5.1
Penoyer Valley	170	Central Region	5.1	4.4	4.4	3.6	4.2	4.3	5.4
Pilgrim Flat*	17	Black Rock Desert Region	4.4	3.9	3.8	3.2	3.7	3.8	4.7
Pilot Creek Valley	191	Great Salt Lake Basin	4.2	3.4	3.3	2.7	3.1	3.1	4.4
Pine Forest Valley*	29	Black Rock Desert Region	4.3	3.8	3.7	3.0	3.5	3.5	4.5
Pine Valley	53	Humboldt River Basin	4.4	3.2	3.1	2.5	2.9	2.9	4.6
Piute Valley*	214	Colorado River Basin	6.1	5.8	5.0	4.0	3.6	5.8	6.4
Pleasant Valley	130	Central Region	4.6	4.2	4.1	3.4	3.9	4.0	4.9
Pleasant Valley*	194	Great Salt Lake Basin	4.3	3.4	3.3	2.7	3.2	3.1	4.5
Pleasant Valley*	88	Truckee River Basin	4.7	4.1	3.9	3.2	3.8	3.8	5.0
Pueblo Valley	1	Northwest Region	4.3	3.7	3.6	3.0	3.5	3.5	4.5
Pumpernickel Valley*	65	Humboldt River Basin	4.5	3.9	3.8	3.1	3.6	3.7	4.7
Pyramid Lake Valley	81	Truckee River Basin	4.8	4.1	4.0	3.2	3.8	3.9	5.0
Queen Valley*	116	Central Region	5.1	4.4	4.2	3.4	4.0	4.1	5.4
Quinn River Valley	33B	Black Rock Desert Region	4.3	3.4	3.2	2.7	2.9	3.0	4.5
Quinn River Valley	33A	Black Rock Desert Region	4.4	3.9	3.8	3.1	3.6	3.6	4.6
Railroad Valley	173B	Central Region	4.6	4.1	4.1	3.3	3.9	4.0	4.9
Railroad Valley	173A	Central Region	4.8	4.2	4.1	3.4	4.0	4.1	5.0
Ralston Valley	141	Central Region	5.1	4.4	4.3	3.6	4.3	4.3	5.3
Rawhide Flats*	123	Central Region	4.4	3.8	3.7	3.0	3.6	3.7	4.7
Red Rock Valley	99	Western Region	4.0	3.1	2.9	2.4	2.9	2.7	4.2
Rhodes Salt Marsh Valley*	119	Central Region	5.0	4.4	4.1	3.3	4.0	4.1	5.3
Rock Creek Valley*	62	Humboldt River Basin	4.3	3.4	3.3	2.7	3.1	3.1	4.5
Rock Valley*	226	Death Valley Basin	5.8	5.4	4.8	3.9	3.9	5.4	6.1

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Rose Valley*	199	Colorado River Basin	4.9	4.0	3.8	3.1	3.6	3.6	5.2
Ruby Valley	176	Central Region	4.0	3.3	3.2	2.6	3.1	3.0	4.2
Sage Hen Valley*	5	Northwest Region	4.3	3.4	3.3	2.7	3.2	3.1	4.6
Salmon Falls Creek Area	40	Snake River Basin	4.1	3.3	3.1	2.6	3.0	2.9	4.3
San Emidio Desert	22	Black Rock Desert Region	4.2	3.8	3.7	3.1	3.6	3.7	4.4
Sano Valley*	20	Black Rock Desert Region	4.5	4.0	3.9	3.2	3.8	3.8	4.7
Sarcobatus Flat	146	Central Region	5.3	4.4	4.3	3.4	3.9	4.3	5.5
Silver State Valley*	32	Black Rock Desert Region	4.5	3.9	3.8	3.1	3.6	3.6	4.7
Skedaddle Creek Valley*	98	Western Region	4.5	4.0	3.9	3.2	3.8	3.8	4.7
Smith Creek*	134	Central Region	4.5	3.5	3.3	2.7	3.2	3.2	4.7
Smith Valley	107	Walker River Basin	4.3	3.6	3.5	2.9	3.4	3.5	4.5
Smoke Creek Desert	21	Black Rock Desert Region	4.4	4.0	3.9	3.2	3.8	3.8	4.6
Snake Valley*	195	Great Salt Lake Basin	4.4	3.6	3.5	2.9	3.4	3.3	4.7
Soda Spring Valley	121A	Central Region	4.9	4.3	4.1	3.3	3.9	4.1	5.1
Soda Spring Valley*	121B	Central Region	4.7	4.1	3.9	3.2	3.8	3.9	5.0
South Fork Area*	46	Humboldt River Basin	4.1	3.3	3.1	2.5	2.9	2.9	4.3
South Fork Owyhee River Area	35	Snake River Basin	4.2	3.0	2.9	2.4	2.8	2.7	4.4
Spanish Springs Valley*	85	Truckee River Basin	4.4	3.9	3.7	3.1	3.6	3.7	4.6
Spring Valley	184	Central Region	4.5	3.7	3.6	3.0	3.5	3.5	4.7
Spring Valley	201	Colorado River Basin	4.9	3.6	3.5	2.8	3.3	3.2	5.1
Starr Valley Area	43	Humboldt River Basin	4.1	3.3	2.9	2.4	2.8	2.7	4.3
Steptoe Valley	179	Central Region	4.4	3.5	3.4	2.8	3.2	3.2	4.6
Stevens Basin*	152	Central Region	4.3	3.2	3.2	2.6	3.0	3.0	4.5
Stingaree Valley*	125	Central Region	4.7	3.8	3.6	2.9	3.5	3.4	4.9
Stone Cabin Valley*	149	Central Region	4.9	4.1	4.1	3.3	3.9	3.9	5.1

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Stonewall Flat*	145	Central Region	5.2	4.5	4.3	3.5	4.1	4.4	5.5
Summit Lake Valley*	27	Black Rock Desert Region	4.3	3.7	3.6	3.0	3.5	3.5	4.5
Sun Valley*	86	Truckee River Basin	4.2	3.9	3.7	3.0	3.6	3.8	4.5
Surprise Valley*	14	Northwest Region	4.3	3.8	3.7	3.0	3.6	3.6	4.6
Susie Creek Area*	50	Humboldt River Basin	4.0	3.3	3.1	2.6	3.0	2.9	4.2
Swan Lake Valley*	7	Northwest Region	4.3	3.6	3.5	2.9	3.4	3.3	4.5
Teels Marsh Valley*	114	Central Region	5.0	4.3	4.1	3.3	3.9	4.1	5.2
Thousand Springs Valley	189D	Great Salt Lake Basin	4.4	3.5	3.4	2.7	3.2	3.1	4.6
Thousand Springs Valley	189A	Great Salt Lake Basin	4.3	2.9	2.8	2.3	2.7	2.5	4.5
Thousand Springs Valley*	189B	Great Salt Lake Basin	4.2	3.2	3.1	2.5	2.9	2.8	4.4
Thousand Springs Valley*	189C	Great Salt Lake Basin	4.2	3.3	3.1	2.6	3.0	2.9	4.4
Three Lakes Valley*	168	Central Region	5.7	5.3	4.7	3.8	4.0	5.2	6.0
Three Lakes Valley*	211	Colorado River Basin	6.0	5.6	5.0	4.0	4.0	5.5	6.3
Tikapoo Valley*	169A	Central Region	5.2	4.6	4.3	3.5	4.0	4.4	5.5
Tikapoo Valley*	169B	Central Region	5.5	5.0	4.5	3.7	3.9	4.9	5.7
Tippett Valley*	185	Central Region	4.3	3.4	3.3	2.7	3.2	3.1	4.5
Tracy Segment	83	Truckee River Basin	4.6	3.9	3.8	3.1	3.7	3.7	4.8
Truckee Canyon Segment*	91	Truckee River Basin	4.4	3.9	3.7	3.0	3.6	3.7	4.6
Truckee Meadows	87	Truckee River Basin	4.4	3.9	3.8	3.1	3.7	3.8	4.6
Tule Desert*	221	Colorado River Basin	5.0	4.7	4.1	3.4	3.5	4.6	5.3
Upper Reese River Valley	56	Humboldt River Basin	4.2	3.2	3.0	2.5	2.9	2.8	4.5
Virgin River Valley	222	Colorado River Basin	5.1	4.9	4.3	3.5	3.2	4.9	5.4
Virgin Valley	4	Northwest Region	4.4	3.3	3.1	2.6	3.0	2.9	4.6
Walker Lake Valley	110A	Walker River Basin	4.6	3.9	3.9	3.2	3.8	3.9	4.9
Walker Lake Valley	110C	Walker River Basin	4.7	4.1	3.9	3.2	3.8	3.9	4.9

Appendix 14 cont.

BASIN NAME	BASIN NUMBER	BASIN REGION	REFERENCE ET_{os} (ft)	ALFALFA ET_{act} (ft)	HIGHLY MANAGED PASTURE GRASS ET_{act} (ft)	LOW MANAGED PASTURE GRASS ET_{act} (ft)	GRASS HAY ET_{act} (ft)	TURF GRASS ET_{act} (ft)	SHALLOW OPEN WATER E_{act} (ft)
Walker Lake Valley*	110B	Walker River Basin	4.6	4.0	3.9	3.1	3.7	3.9	4.9
Warm Springs Valley*	84	Truckee River Basin	4.4	3.8	3.6	3.0	3.5	3.6	4.6
Warner Valley*	13	Northwest Region	4.3	3.7	3.6	2.9	3.5	3.5	4.5
Washoe Valley	89	Truckee River Basin	5.2	4.4	4.2	3.4	4.0	3.9	5.5
Whirlwind Valley*	60	Humboldt River Basin	4.3	3.7	3.6	3.0	3.5	3.5	4.5
White Plains*	74	Humboldt River Basin	4.5	4.0	3.9	3.2	3.7	3.8	4.8
White River Valley	207	Colorado River Basin	4.6	4.0	3.8	3.2	3.7	3.6	4.9
Willow Creek Valley	63	Humboldt River Basin	4.4	3.1	3.1	2.6	2.9	2.9	4.7
Winnemucca Lake Valley*	80	Truckee River Basin	4.5	3.9	3.8	3.1	3.7	3.7	4.7
Winnemucca Segment	70	Humboldt River Basin	4.6	4.0	3.8	3.2	3.7	3.7	4.8
Yucca Flat*	159	Central Region	5.5	4.9	4.5	3.7	4.1	4.8	5.7

Appendix 15. Mean annual Net Irrigation Water Requirement (NIWR) of alfalfa, grass hay, pasture grass, turf grass, and small shallow open water bodies for all HAs. Values of the NIWR for each HA were either assigned for HAs with single stations, computed using a valid period of record weighted average for HAs with multiple stations, or estimated from spatial interpolation for HAs with no stations. * indicates that the NIWR was estimated using spatial interpolation.

BASIN NAME	BASIN NUMBER	BASIN REGION	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
Adobe Valley*	115	Central Region	3.9	3.8	3.0	3.6	3.7	4.8
Alkali Spring Valley*	142	Central Region	4.2	4.0	3.2	3.9	4.0	5.1
Alkali Valley*	111A	Central Region	3.7	3.5	2.8	3.4	3.5	4.5
Alkali Valley*	111B	Central Region	3.7	3.5	2.8	3.4	3.5	4.5
Amargosa Desert	230	Death Valley Basin	5.3	4.5	3.6	3.6	5.3	5.8
Antelope Valley	57	Humboldt River Basin	3.0	3.1	2.4	3.0	3.0	3.9
Antelope Valley	106	Walker River Basin	3.3	3.2	2.5	3.1	3.2	4.0
Antelope Valley*	186B	Central Region	2.6	2.6	2.0	2.5	2.4	3.6
Antelope Valley*	186A	Central Region	2.7	2.7	2.1	2.6	2.5	3.7
Antelope Valley*	93	Western Region	3.1	3.1	2.5	3.0	3.1	3.7
Antelope Valley*	151	Central Region	2.8	2.8	2.2	2.7	2.6	4.0
Bedell Flat*	94	Western Region	2.9	2.9	2.3	2.8	2.8	3.6
Big Smoky Valley	137B	Central Region	3.6	3.5	2.8	3.5	3.4	4.5
Big Smoky Valley	137A	Central Region	3.7	3.6	2.9	3.6	3.4	4.7
Black Moutains Area	215	Colorado River Basin	4.7	4.0	3.1	2.7	4.7	5.2
Black Rock Desert	28	Black Rock Desert Region	3.2	3.2	2.6	3.2	3.2	3.8
Boulder Flat*	61	Humboldt River Basin	2.8	2.8	2.2	2.7	2.7	3.6
Boulder Valley*	15	Northwest Region	3.3	3.2	2.6	3.2	3.2	3.9
Bradys Hot Springs Area*	75	West Central Region	3.5	3.4	2.7	3.3	3.3	4.2
Bruneau River Area	38	Snake River Basin	1.6	1.5	1.1	1.2	1.3	3.3

Appendix 15 cont.

BASIN NAME	BASIN NUMBER	BASIN REGION	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
Buena Vista Valley*	129	Central Region	3.4	3.4	2.7	3.3	3.3	4.1
Buffalo Valley	131	Central Region	2.8	2.8	2.2	2.7	2.8	3.0
Butte Valley*	178A	Central Region	2.6	2.6	2.0	2.5	2.4	3.6
Butte Valley*	178B	Central Region	2.8	2.7	2.1	2.6	2.5	3.7
Cactus Flat*	148	Central Region	3.9	3.8	3.1	3.7	3.9	4.8
California Wash*	218	Colorado River Basin	4.8	4.1	3.3	3.1	4.9	5.3
Carico Lake Valley*	55	Humboldt River Basin	3.0	3.0	2.3	2.8	2.9	3.7
Carson Desert	101	Carson River Basin	3.3	3.2	2.6	3.1	3.3	3.9
Carson Desert*	101A	Carson River Basin	3.5	3.5	2.8	3.4	3.4	4.2
Carson Valley	105	Carson River Basin	3.0	3.0	2.4	2.9	3.0	3.7
Cave Valley*	180	Central Region	3.2	3.1	2.4	3.0	2.9	4.0
Churchill Valley	102	Carson River Basin	3.3	3.2	2.6	3.1	3.3	3.9
Clayton Valley	143	Central Region	4.4	4.3	3.4	3.9	4.4	5.3
Clover Valley	177	Central Region	2.5	2.6	2.1	2.5	2.5	3.1
Clover Valley	204	Colorado River Basin	3.8	3.7	2.9	3.4	3.6	4.4
Clovers Area	64	Humboldt River Basin	3.2	3.2	2.6	3.1	3.1	4.0
Coal Valley*	171	Central Region	3.8	3.7	2.9	3.5	3.7	4.6
Cold Spring Valley*	100A	Western Region	3.0	3.0	2.4	2.9	3.0	3.6
Cold Spring Valley*	100	Western Region	3.1	3.1	2.5	3.0	3.1	3.6
Coleman Valley*	11	Northwest Region	3.1	3.1	2.4	3.0	3.0	3.9
Colorado Valley	213	Colorado River Basin	5.8	5.0	3.9	3.6	5.8	6.4
Columbus Salt Marsh Valley	118	Central Region	4.4	4.2	3.3	4.1	4.1	5.4
Continental Lake Valley*	2	Northwest Region	3.0	3.0	2.4	2.9	2.9	3.8
Cowkick Valley	126	Central Region	3.4	3.2	2.5	3.1	3.0	4.5
Coyote spring Valley*	210	Colorado River Basin	4.6	4.1	3.2	3.4	4.6	5.1

BASIN NAME	BASIN NUMBER	BASIN REGION	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
Crater Flat*	229	Death Valley Basin	4.8	4.2	3.4	3.8	4.8	5.4
Crescent Valley	54	Humboldt River Basin	2.9	3.0	2.4	2.9	2.9	3.7
Dayton Valley*	103	Carson River Basin	3.3	3.2	2.6	3.1	3.2	3.9
Deep Creek Valley*	193	Great Salt Lake Basin	2.7	2.7	2.1	2.6	2.5	3.6
Delamar Valley*	182	Central Region	4.1	3.7	2.9	3.4	3.9	4.6
Desert Valley	31	Black Rock Desert Region	3.1	3.2	2.5	3.1	3.1	3.8
Diamond Valley	153	Central Region	2.5	2.5	2.0	2.4	2.4	3.5
Dixie Creek-Tenmile Creek Area	48	Humboldt River Basin	2.8	2.7	2.1	2.4	2.6	3.7
Dixie Valley	128	Central Region	3.6	3.5	2.8	3.4	3.6	4.3
Dodge Flat	82	Truckee River Basin	3.5	3.4	2.7	3.3	3.3	4.3
Dry Lake Valley*	181	Central Region	3.7	3.5	2.7	3.3	3.5	4.3
Dry Valley*	19	Black Rock Desert Region	3.5	3.5	2.8	3.4	3.5	4.1
Dry Valley*	95	Western Region	2.9	2.9	2.3	2.7	2.7	3.6
Dry Valley*	198	Colorado River Basin	3.5	3.3	2.6	3.2	3.2	4.2
Duck Lake Valley*	16	Northwest Region	3.3	3.3	2.6	3.2	3.3	4.0
Eagle Valley	104	Carson River Basin	3.2	3.1	2.5	3.0	3.1	3.7
Eagle Valley*	200	Colorado River Basin	3.1	3.0	2.4	2.9	2.8	4.1
East Walker Area*	109	Walker River Basin	3.5	3.4	2.7	3.3	3.4	4.3
Eastgate Valley Area	127	Central Region	3.4	3.4	2.7	3.4	3.4	4.2
Edwards Creek Valley*	133	Central Region	3.2	3.1	2.4	3.0	3.0	4.0
Eldorado Valley	167	Central Region	4.6	3.9	3.1	2.9	4.6	5.1
Elko Segment	49	Humboldt River Basin	2.6	2.6	2.1	2.5	2.5	3.3
Emigrant Valley*	158A	Central Region	4.2	4.0	3.2	3.7	4.1	5.0
Emigrant Valley*	158B	Central Region	4.6	4.2	3.3	3.8	4.5	5.3
Escalante Desert*	197	Escalante Desert	3.6	3.4	2.7	3.2	3.4	4.3

BASIN NAME	BASIN NUMBER	BASIN REGION	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
Fairview Valley*	124	Central Region	3.4	3.2	2.6	3.2	3.2	4.3
Fernley Area	76	West Central Region	3.5	3.4	2.7	3.3	3.3	4.3
Fireball Valley*	77	West Central Region	3.5	3.4	2.7	3.3	3.4	4.3
Fish Lake Valley	117	Central Region	4.2	4.1	3.2	4.1	4.0	5.4
Fortymile Canyon*	227B	Death Valley Basin	4.6	4.1	3.3	3.8	4.5	5.3
Fortymile Canyon*	227A	Death Valley Basin	4.9	4.3	3.4	3.8	4.9	5.5
Frenchman Flat*	160	Central Region	4.9	4.4	3.5	3.9	4.9	5.6
Gabbs Valley*	122	Central Region	3.5	3.4	2.7	3.3	3.3	4.4
Garden Valley*	172	Central Region	3.7	3.6	2.9	3.5	3.6	4.5
Garfield Flat*	120	Central Region	3.9	3.7	2.9	3.5	3.7	4.7
Garnet Valley*	216	Colorado River Basin	5.2	4.5	3.6	3.4	5.3	5.7
Gold Butte Area*	223	Colorado River Basin	4.7	4.0	3.2	2.9	4.7	5.2
Gold Flat*	147	Central Region	4.1	3.9	3.1	3.7	4.1	5.0
Goose Creek Area*	41	Snake River Basin	2.5	2.5	1.9	2.4	2.3	3.5
Goshute Valley	187	Central Region	2.8	2.7	2.1	2.6	2.5	3.7
Granite Basin*	23	Black Rock Desert Region	3.3	3.3	2.6	3.2	3.3	3.9
Granite Springs Valley*	78	West Central Region	3.5	3.5	2.8	3.4	3.4	4.2
Grapevine Canyon*	231	Death Valley Basin	4.4	4.1	3.3	3.8	4.3	5.3
Grass Valley	71	Humboldt River Basin	3.3	3.3	2.6	3.2	3.2	4.2
Grass Valley	138	Central Region	2.7	2.8	2.2	2.7	2.7	3.5
Greasewood Basin*	224	Colorado River Basin	4.6	4.0	3.2	2.9	4.7	5.1
Great Salt Lake Desert	192	Great Salt Lake Basin	2.3	2.4	1.9	2.3	2.2	3.1
Gridley Lake Valley*	3	Northwest Region	3.1	3.1	2.4	3.0	3.0	3.8
Grouse Creek Valley*	190	Great Salt Lake Basin	2.7	2.6	2.0	2.5	2.4	3.6
Guano Valley*	6	Northwest Region	3.0	3.0	2.4	2.9	2.9	3.9

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Hamlin Valley*	196	Great Salt Lake Basin	3.0	3.0	2.4	2.9	2.9	4.0
Hardscrabble Area*	68	Humboldt River Basin	3.1	3.0	2.4	2.9	2.9	3.8
Hidden Valley*	217	Colorado River Basin	5.2	4.5	3.6	3.4	5.3	5.8
Hidden Valley*	166	Central Region	5.2	4.5	3.6	3.4	5.3	5.7
High Rock Lake Valley*	25	Black Rock Desert Region	3.2	3.2	2.6	3.2	3.2	3.9
Honey Lake Valley*	97	Western Region	3.3	3.3	2.6	3.2	3.3	4.0
Hot Creek	156	Central Region	3.4	3.5	2.7	3.4	3.3	4.4
Hualapai Flat*	24	Black Rock Desert Region	3.3	3.3	2.6	3.3	3.3	3.9
Huntington Valley	47	Humboldt River Basin	2.4	2.4	1.8	2.2	2.2	3.0
Huntoon Valley*	113	Central Region	3.9	3.7	2.9	3.5	3.7	4.7
Imlay Area	72	Humboldt River Basin	3.5	3.4	2.7	3.3	3.4	4.2
Independence Valley	36	Snake River Basin	2.2	2.2	1.7	2.1	2.0	2.8
Independence Valley*	188	Central Region	2.5	2.5	2.0	2.4	2.4	3.4
Indian Springs Valley	161	Central Region	5.2	4.7	3.7	4.1	5.0	6.0
Ione Valley*	135	Central Region	3.4	3.2	2.6	3.2	3.1	4.4
Ivanpah Valley	164A	Central Region	5.2	4.4	3.5	3.7	5.1	5.6
Ivanpah Valley*	164B	Central Region	5.3	4.5	3.6	3.5	5.3	5.8
Jakes Valley	174	Central Region	2.7	2.6	2.0	2.5	2.4	3.7
Jarbidge River Area	39	Snake River Basin	2.3	2.3	1.7	2.2	2.1	2.7
Jean Lake Valley*	165	Central Region	5.2	4.5	3.6	3.5	5.3	5.7
Jersey Valley*	132	Central Region	3.3	3.2	2.6	3.1	3.2	3.8
Kane Springs Valley*	206	Colorado River Basin	4.0	3.6	2.8	3.2	4.0	4.4
Kawich Valley*	157	Central Region	4.1	3.9	3.1	3.7	4.0	4.9
Kelley Creek Area*	66	Humboldt River Basin	3.0	3.1	2.4	2.9	2.9	3.9
Kings River Valley*	30A	Black Rock Desert Region	3.1	3.1	2.4	2.9	3.0	3.8

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Kings River Valley*	30B	Black Rock Desert Region	3.1	3.1	2.5	3.0	3.0	3.8
Kobeh Valley*	139	Central Region	2.7	2.7	2.1	2.6	2.6	3.6
Kumiva Valley*	79	West Central Region	3.4	3.4	2.7	3.3	3.4	4.1
Lake Tahoe Basin	90	Truckee River Basin	2.3	2.3	1.8	2.1	2.2	2.4
Lake Valley	183	Central Region	3.0	2.9	2.3	2.7	2.7	4.0
Lamoille Valley	45	Humboldt River Basin	2.3	2.3	1.8	2.2	2.1	2.9
Las Vegas Valley	212	Colorado River Basin	5.6	4.8	3.9	3.7	5.7	6.1
Lemmon Valley	92B	Western Region	3.1	3.1	2.5	3.0	3.1	3.4
Lemmon Valley*	92A	Western Region	3.1	3.1	2.5	3.0	3.1	3.6
Lida Valley*	144	Central Region	4.3	4.1	3.3	3.8	4.2	5.2
Little Fish Lake Valley*	150	Central Region	3.2	3.2	2.5	3.1	3.1	4.2
Little Humboldt Valley*	67	Humboldt River Basin	2.8	2.8	2.2	2.6	2.6	3.7
Little Owyhee River Area*	34	Snake River Basin	2.5	2.5	2.0	2.4	2.4	3.5
Little Smoky Valley	155A	Central Region	2.8	2.8	2.2	2.6	2.6	4.4
Little Smoky Valley*	155C	Central Region	3.3	3.3	2.6	3.2	3.2	4.2
Little Smoky Valley*	155B	Central Region	3.2	3.2	2.5	3.1	3.1	4.2
Long Valley*	9	Northwest Region	3.2	3.2	2.5	3.1	3.1	3.9
Long Valley*	175	Central Region	2.7	2.7	2.1	2.6	2.5	3.7
Lovelock Valley	73	Humboldt River Basin	3.7	3.7	3.0	3.6	3.6	4.5
Lovelock Valley*	73A	Humboldt River Basin	3.5	3.4	2.8	3.3	3.4	4.2
Lower Meadow Valley Wash	205	Colorado River Basin	4.2	3.7	2.9	3.0	4.3	4.6
Lower Moapa Valley	220	Colorado River Basin	4.5	1.8	1.5	1.4	2.2	2.4
Lower Reese River Valley	59	Humboldt River Basin	3.2	3.2	2.6	3.1	3.1	4.0
Macy Flat*	10	Northwest Region	3.1	3.1	2.4	3.0	2.9	3.9
Maggie Creek Area*	51	Humboldt River Basin	2.4	2.4	1.9	2.3	2.3	3.3

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Marys Creek Area*	52	Humboldt River Basin	2.7	2.7	2.2	2.6	2.6	3.6
Marys River Area	42	Humboldt River Basin	2.4	2.4	1.8	2.3	2.2	3.2
Mason Valley	108	Walker River Basin	3.1	3.0	2.4	2.9	3.0	3.9
Massacre Lake Valley*	8	Northwest Region	3.1	3.1	2.5	3.0	3.0	3.9
Mercury Valley*	225	Death Valley Basin	5.2	4.6	3.6	3.8	5.2	5.8
Mesquite Valley*	163	Central Region	5.3	4.5	3.6	3.7	5.3	5.7
Middle Reese River Valley*	58	Humboldt River Basin	3.1	3.1	2.4	2.9	3.0	3.8
Monitor Valley*	140A	Central Region	2.9	2.9	2.3	2.8	2.7	4.0
Monitor Valley*	140B	Central Region	3.3	3.3	2.6	3.2	3.1	4.3
Mono Valley*	112	Central Region	3.8	3.6	2.8	3.5	3.6	4.5
Monte Cristo Valley*	136	Central Region	4.0	3.8	3.0	3.7	3.7	4.9
Mosquito Valley*	12	Northwest Region	3.1	3.1	2.5	3.0	3.0	3.9
Mud Meadow*	26	Black Rock Desert Region	3.2	3.2	2.6	3.2	3.2	3.9
Muddy River Springs Area*	219	Colorado River Basin	4.7	4.0	3.2	3.1	4.7	5.1
Newark Valley*	154	Central Region	2.7	2.7	2.1	2.6	2.6	3.8
Newcomb Lake Valley*	96	Western Region	3.0	3.0	2.4	2.9	2.9	3.7
North Fork Area	44	Humboldt River Basin	2.2	2.2	1.7	2.1	2.0	3.2
Oasis Valley	228	Death Valley Basin	4.7	4.1	3.3	3.9	4.7	5.3
Oriental Wash*	232	Death Valley Basin	4.3	4.1	3.3	3.8	4.2	5.2
Owyhee River Area	37	Snake River Basin	2.1	2.1	1.6	2.0	1.9	3.1
Pahranagat Valley	209	Colorado River Basin	4.4	4.0	3.1	3.6	4.2	5.0
Pahroc Valley*	208	Colorado River Basin	3.8	3.6	2.8	3.4	3.6	4.4
Pahrump Valley	162	Central Region	5.0	4.4	3.6	3.8	5.1	5.6
Painter Flat*	18	Black Rock Desert Region	3.5	3.4	2.7	3.4	3.4	4.1
Panaca Valley	203	Colorado River Basin	3.8	3.6	2.9	3.4	3.6	4.4

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Paradise Valley	69	Humboldt River Basin	3.2	3.2	2.5	3.0	3.0	4.0
Patterson Valley*	202	Colorado River Basin	3.4	3.3	2.6	3.1	3.1	4.2
Penoyer Valley	170	Central Region	3.9	3.9	3.1	3.8	3.8	4.8
Pilgrim Flat*	17	Black Rock Desert Region	3.4	3.4	2.7	3.3	3.4	4.0
Pilot Creek Valley	191	Great Salt Lake Basin	2.9	2.8	2.2	2.7	2.6	3.6
Pine Forest Valley*	29	Black Rock Desert Region	3.1	3.1	2.5	3.0	3.1	3.8
Pine Valley	53	Humboldt River Basin	2.5	2.4	1.9	2.3	2.3	3.8
Piute Valley*	214	Colorado River Basin	5.4	4.6	3.7	3.5	5.4	6.0
Pleasant Valley	130	Central Region	3.5	3.4	2.8	3.3	3.4	4.1
Pleasant Valley*	194	Great Salt Lake Basin	2.8	2.8	2.2	2.7	2.6	3.8
Pleasant Valley*	88	Truckee River Basin	3.5	3.5	2.7	3.3	3.3	4.2
Pueblo Valley	1	Northwest Region	3.1	3.1	2.5	3.0	3.0	3.7
Pumpernickel Valley*	65	Humboldt River Basin	3.3	3.3	2.6	3.1	3.2	4.0
Pyramid Lake Valley	81	Truckee River Basin	3.6	3.5	2.8	3.4	3.5	4.4
Queen Valley*	116	Central Region	4.1	3.9	3.1	3.8	3.8	5.0
Quinn River Valley	33B	Black Rock Desert Region	2.8	2.7	2.1	2.3	2.5	3.8
Quinn River Valley	33A	Black Rock Desert Region	3.1	3.1	2.5	3.0	3.1	3.7
Railroad Valley	173B	Central Region	3.5	3.5	2.8	3.4	3.4	4.2
Railroad Valley	173A	Central Region	3.7	3.7	3.0	3.5	3.7	4.5
Ralston Valley	141	Central Region	4.0	3.9	3.1	3.9	3.9	4.8
Rawhide Flats*	123	Central Region	3.4	3.3	2.6	3.2	3.3	4.2
Red Rock Valley	99	Western Region	2.6	2.6	2.0	2.5	2.4	3.4
Rhodes Salt Marsh Valley*	119	Central Region	4.0	3.8	3.0	3.7	3.8	4.8
Rock Creek Valley*	62	Humboldt River Basin	2.7	2.7	2.1	2.6	2.6	3.7
Rock Valley*	226	Death Valley Basin	5.1	4.5	3.5	3.8	5.1	5.7

Appendix 15 cont.

BASIN NAME	BASIN NUMBER	BASIN REGION	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
Rose Valley*	199	Colorado River Basin	3.3	3.2	2.5	3.0	3.0	4.2
Ruby Valley	176	Central Region	2.5	2.6	2.0	2.5	2.4	3.0
Sage Hen Valley*	5	Northwest Region	2.9	2.8	2.2	2.7	2.7	3.9
Salmon Falls Creek Area	40	Snake River Basin	2.6	2.5	1.9	2.3	2.3	3.5
San Emidio Desert	22	Black Rock Desert Region	3.2	3.2	2.6	3.2	3.2	3.8
Sano Valley*	20	Black Rock Desert Region	3.5	3.5	2.8	3.4	3.5	4.1
Sarcobatus Flat	146	Central Region	4.2	4.0	3.2	3.7	4.2	5.2
Silver State Valley*	32	Black Rock Desert Region	3.3	3.3	2.6	3.1	3.2	4.0
Skedaddle Creek Valley*	98	Western Region	3.5	3.5	2.8	3.4	3.5	4.1
Smith Creek*	134	Central Region	3.0	2.9	2.3	2.8	2.7	4.1
Smith Valley	107	Walker River Basin	3.1	3.0	2.4	2.9	3.0	3.9
Smoke Creek Desert	21	Black Rock Desert Region	3.4	3.4	2.7	3.3	3.4	4.0
Snake Valley*	195	Great Salt Lake Basin	3.0	2.9	2.3	2.8	2.8	3.9
Soda Spring Valley	121A	Central Region	3.9	3.7	2.9	3.6	3.7	4.6
Soda Spring Valley*	121B	Central Region	3.8	3.6	2.8	3.5	3.6	4.6
South Fork Area*	46	Humboldt River Basin	2.5	2.5	1.9	2.3	2.3	3.2
South Fork Owyhee River Area	35	Snake River Basin	1.8	1.9	1.5	2.0	1.8	3.1
Spanish Springs Valley*	85	Truckee River Basin	3.3	3.3	2.6	3.2	3.3	3.9
Spring Valley	184	Central Region	3.0	3.0	2.4	2.9	2.9	3.9
Spring Valley	201	Colorado River Basin	3.0	2.9	2.3	2.8	2.6	4.1
Starr Valley Area	43	Humboldt River Basin	2.4	2.3	1.8	2.2	2.2	3.3
Steptoe Valley	179	Central Region	2.9	2.8	2.2	2.7	2.6	3.9
Stevens Basin*	152	Central Region	2.7	2.7	2.1	2.6	2.5	3.9
Stingaree Valley*	125	Central Region	3.4	3.2	2.5	3.1	3.0	4.4
Stone Cabin Valley*	149	Central Region	3.7	3.7	2.9	3.6	3.6	4.6

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Stonewall Flat*	145	Central Region	4.2	4.0	3.2	3.8	4.0	5.0
Summit Lake Valley*	27	Black Rock Desert Region	3.1	3.1	2.5	3.1	3.1	3.8
Sun Valley*	86	Truckee River Basin	3.3	3.2	2.6	3.2	3.3	3.7
Surprise Valley*	14	Northwest Region	3.2	3.2	2.6	3.1	3.2	3.9
Susie Creek Area*	50	Humboldt River Basin	2.5	2.5	2.0	2.4	2.4	3.3
Swan Lake Valley*	7	Northwest Region	3.1	3.0	2.4	2.9	2.9	3.9
Teels Marsh Valley*	114	Central Region	4.0	3.8	3.0	3.7	3.8	4.8
Thousand Springs Valley	189D	Great Salt Lake Basin	2.9	2.9	2.2	2.8	2.6	4.0
Thousand Springs Valley	189A	Great Salt Lake Basin	2.2	2.2	1.7	2.1	2.0	3.6
Thousand Springs Valley*	189B	Great Salt Lake Basin	2.5	2.5	1.9	2.4	2.3	3.5
Thousand Springs Valley*	189C	Great Salt Lake Basin	2.6	2.6	2.0	2.5	2.4	3.6
Three Lakes Valley*	168	Central Region	4.9	4.4	3.5	3.8	4.9	5.6
Three Lakes Valley*	211	Colorado River Basin	5.3	4.7	3.7	3.9	5.2	6.0
Tikapoo Valley*	169A	Central Region	4.2	3.9	3.1	3.7	4.0	4.9
Tikapoo Valley*	169B	Central Region	4.6	4.1	3.3	3.6	4.5	5.2
Tippett Valley*	185	Central Region	2.8	2.8	2.2	2.7	2.6	3.8
Tracy Segment	83	Truckee River Basin	3.5	3.4	2.7	3.2	3.3	4.3
Truckee Canyon Segment*	91	Truckee River Basin	3.3	3.2	2.6	3.1	3.2	3.8
Truckee Meadows	87	Truckee River Basin	3.4	3.4	2.7	3.3	3.5	4.0
Tule Desert*	221	Colorado River Basin	4.0	3.5	2.8	3.1	4.0	4.4
Upper Reese River Valley	56	Humboldt River Basin	2.6	2.5	2.0	2.4	2.3	3.6
Virgin River Valley	222	Colorado River Basin	4.4	3.8	3.0	2.9	4.5	4.8
Virgin Valley	4	Northwest Region	2.8	2.7	2.1	2.6	2.5	4.0
Walker Lake Valley	110A	Walker River Basin	3.5	3.5	2.8	3.4	3.5	4.4
Walker Lake Valley	110C	Walker River Basin	3.8	3.6	2.9	3.5	3.7	4.6

BASIN NAME	BASIN NUMBER	BASIN REGION	ALFALFA NIWR (ft)	HIGHLY MANAGED PASTURE GRASS NIWR (ft)	LOW MANAGED PASTURE GRASS NIWR (ft)	GRASS HAY NIWR (ft)	TURF GRASS NIWR (ft)	SHALLOW OPEN WATER NIWR (ft)
Walker Lake Valley*	110B	Walker River Basin	3.7	3.5	2.8	3.4	3.5	4.5
Warm Springs Valley*	84	Truckee River Basin	3.3	3.2	2.6	3.1	3.2	4.0
Warner Valley*	13	Northwest Region	3.1	3.1	2.5	3.0	3.0	3.9
Washoe Valley	89	Truckee River Basin	3.7	3.8	2.9	3.5	3.5	4.7
Whirlwind Valley*	60	Humboldt River Basin	3.0	3.0	2.4	2.9	2.9	3.7
White Plains*	74	Humboldt River Basin	3.5	3.4	2.8	3.3	3.4	4.3
White River Valley	207	Colorado River Basin	3.2	3.2	2.5	3.0	3.0	4.0
Willow Creek Valley	63	Humboldt River Basin	2.4	2.5	2.0	2.4	2.4	3.9
Winnemucca Lake Valley*	80	Truckee River Basin	3.5	3.4	2.7	3.3	3.4	4.2
Winnemucca Segment	70	Humboldt River Basin	3.4	3.4	2.7	3.2	3.3	4.2
Yucca Flat*	159	Central Region	4.6	4.2	3.3	3.8	4.5	5.3

Appendix 16. Mean annual Net Irrigation Water Requirement (NIWR) for selected HAs and crops. Values of the NIWR were either assigned or averaged for HAs with multiple stations according to the number of valid years used in computing the station annual average NIWR. The NIWR for corn is the average of silage, field, and sweet corn crops. For other areas and crops of interest, see electronic statistical summaries. Descriptions of the electronic statistical summaries are given in Appendix 9.

Basin Name	Basin Number	Garden Vegetables (general) NIWR (ft)	Corn NIWR(ft)	Spring Wheat NIWR (ft)	Winter Wheat NIWR (ft)	Garlic NIWR (ft)	Onion NIWR (ft)	Potatoes (baking-late harvest) NIWR (ft)	Potatoes (processing -early harvest) NIWR (ft)	Grapes NIWR (ft)	Melons NIWR (ft)
Carson Desert	101	2.8	2.6	2.0	2.1					2.4	1.7
Carson Valley	105	2.7	2.5	1.9	2.2						
Diamond Valley	153	2.2	2.2	2.0	2.1						
Lovelock Valley	73	3.4	3.1	2.3	2.5			2.9	2.5		
Mason Valley	108	2.7	2.4	1.9	2.0	2.3	2.4				
Paradise Valley	69	2.6	2.8	2.3	2.5	2.5	2.6	2.7	2.4		
Smith Valley	107	2.6	2.5	2.0	2.2	2.4	2.5				
Lake Valley	183	2.3	2.4	2.2	2.5	2.5	2.5	2.6	2.4		

Annex 1.

FAO-56 Dual Crop Coefficient Method for Estimating Evaporation from Soil and Application Extensions

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Abstract: Crop coefficient curves provide simple, reproducible means to estimate crop evapotranspiration (ET) from weather-based reference ET values. The dual crop coefficient (K_c) method of the Food and Agricultural Organization of the United States (FAO) Irrigation and Drainage Paper No. 56 (*FAO-56*) is intended to improve daily simulation of crop ET by considering separately the contribution of evaporation from soil. The dual method utilizes "basal" crop coefficients representing ET from crops having a dry soil surface and separately predicts evaporation from bare soil based on a water balance of the soil surface layer. Three extensions to the evaporation calculation procedure are described here that are intended to improve accuracy when applications warrant the extra complexity. The first extension uses parallel water balances representing the portion of the soil surface wetted by irrigation and precipitation together and the portion wetted by precipitation alone. The second extension uses three "stages" for surface drying and provides for application to deep cracking soils. The third extension predicts the extraction of the transpiration component from the soil surface layer. Sensitivity and analyses and illustrations indicate moderate sensitivity of daily calculated ET to application of the extensions. The dual K_c procedure, although relatively simple computationally and structurally, estimates daily ET as measured by lysimeter relatively well for periods of bare soil and partial and full vegetation cover.

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CE Database subject headings: Evapotranspiration; Evaporation; Crops; Crop moisture index; Soil water.

Introduction

A commonly used approach for estimating consumptive use of water by irrigated crops is the crop coefficient—reference evapotranspiration (K_c ET_0) procedure. Reference evapotranspiration (ET_0) is computed for a grass or alfalfa reference crop and is then multiplied by an empirical crop coefficient (K_c) to estimate crop evapotranspiration (ET_c) (Jensen et al. 1971; Doorenbos and Pruitt 1977; Wright 1981, 1982). In general, three primary characteristics distinguish ET from a crop from ET from the reference surface: aerodynamic roughness of the crop; general resistance within the crop canopy and soil to the flow of heat and water vapor; and reflectance of the crop and soil surface to short wave radiation. Because ET_0 represents nearly all effects of weather, K_c varies predominately with specific crop characteristics and only a small amount with climate. This enables the transfer of standard values and curves for K_c between locations and climates. This transfer has led to the widespread acceptance and usefulness of the K_c approach.

In situations where K_c has not been derived by ET measurement, it can be estimated from fraction of ground cover or leaf area index (Allen et al. 1998). K_c varies during the growing season as plants develop, as the fraction of ground covered by vegetation changes, and as plants age and mature (Fig. 1). K_c varies according to the wetness of the soil surface, especially when there is little vegetation cover. Under bare soil conditions, K_c has a high value when soil is wet and its value steadily decreases as the soil dries.

This paper describes the dual K_c procedure of FAO published as *FAO Irrigation and Drainage Paper No. 56* (Allen et al. 1998) and provides a brief rationale for various components of the procedure along with selected sensitivity analyses. Extensions to the original procedure are introduced that may improve accuracy of applications for special situations.

FAO-56 K_c Procedure

The *FAO-56* crop coefficients are intended for use with grass reference ET_0 similar to that predicted by the *FAO-56* Penman–Monteith method (Allen et al. 1998). The *FAO-56* Penman–Monteith equation predicts ET_0 from a hypothetical grass reference surface that is 0.12 m in height having a surface resistance of 70 s m^{-1} for 24 h time steps and albedo of 0.23. Standardized equations for computing parameters in the *FAO-56* Penman–Monteith equation are given in Allen et al. (1998, 1994) as well

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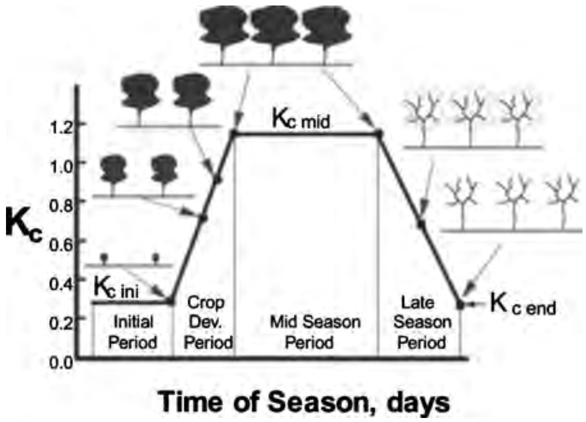

Fig. 1. Schematic showing generalized shape of Food and Agricultural Organization (FAO) K_c curve with four crop stages and three K_c (or K_{cb}) values and relative development of vegetation

as in Smith et al. (1991), Pereira et al. (1998), Pereira and Allen (1999), and ASCE (2002).

Crop Coefficient

Fundamentally, the crop coefficient is defined as the ratio of ET from any specific crop or soil surface to some reference ET as defined by weather data. In *FAO-56* nomenclature

$$K_c = \frac{\mathrm{ET}_c}{\mathrm{ET}_0} \tag{1}$$

In *FAO-56*, values listed for K_c represent ET under growing conditions having a high level of management and with little or no water or other ET reducing stresses and thus represent what are referred to as potential levels for crop ET

$$\mathrm{ET}_c = K_c \mathrm{ET}_0 \tag{2}$$

Actual ET_c can be less than the potential ET_c for a crop under nonideal growing conditions including those having water stress or high soil salinity. In this paper, ET_c representing ET under any condition, ideal or nonideal, is termed "actual ET_c" and is denoted as $\mathrm{ET}_{c\ \mathrm{act}}$. The $\mathrm{ET}_{c\ \mathrm{act}}$ was termed "adjusted ET_c" ($\mathrm{ET}_{c\ \mathrm{adj}}$) in *FAO-56*. The terms are synonymous and

$$\mathrm{ET}_{c\ \mathrm{act}} = K_{c\ \mathrm{act}} \mathrm{ET}_0 \tag{3}$$

where $K_{c\ \mathrm{act}}$ = "actual" crop coefficient that includes any effects of environmental stresses.

A linearized form for mean K_c and basal K_c curves in *FAO-56* was introduced in *FAO-24* (Doorenbos and Pruitt 1977) where the FAO K_c curve is comprised of four straight line segments representing the initial period, the development period, the midseason period, and the late season period (Fig. 1). These segments are defined by three primary K_c values: K_c during the initial period ($K_{c\ \mathrm{ini}}$), K_c during the midseason (full cover) period ($K_{c\ \mathrm{mid}}$), and K_c at harvest (or at the end of the late season) ($K_{c\ \mathrm{end}}$). The $K_{c\ \mathrm{ini}}$ defines the horizontal portion of the K_c curve during the initial period until approximately 10% of the ground is covered by vegetation. The $K_{c\ \mathrm{mid}}$ defines the value for K_c during the peak period for the crop, which is normally when the crop is at "effective full cover." This period is described by a horizontal line extending through $K_{c\ \mathrm{mid}}$. The development period is defined by a sloping line that connects the initial and midseason periods. The late season has a sloping line that connects the end of the midseason period with the harvest (end) date.

In *FAO-56*, two forms for K_c are presented: the "singular" K_c form used in *FAO-24* and the "dual" $K_c = K_{cb} + K_e$ form introduced in *FAO-56*, where K_{cb} is the basal crop coefficient and K_e is the soil evaporation coefficient. In the dual form, K_{cb} represents the ratio of ET_c to ET_0 under conditions when the soil surface layer is dry, but where the average soil water content of the root zone is adequate to sustain full plant transpiration. Under basal conditions, small amounts of evaporation from the surface soil layer occur by diffusion and are included in K_{cb} (and thus $K_{cb\ \mathrm{ini}}$ is usually not set to zero during the growing cycle). The majority of evaporation from soil following wetting by precipitation or irrigation is represented by the separate K_e. The total, actual $K_{c\ \mathrm{act}}$ is the sum of K_{cb} and K_e, reduced by any occurrence of soil water stress

$$K_{c\ \mathrm{act}} = K_s K_{cb} + K_e \tag{4}$$

where K_{cb} and K_e range from [0 to ~1.4]. The stress reduction coefficient K_s [0–1], reduces K_{cb} when the average soil water content or salinity level of the root zone are not conducive to sustain full plant transpiration. K_s for soil water stress is described later and the function for salinity induced stress is described in Allen et al. (1998). The sum of K_{cb} and K_e cannot exceed some maximum value for a crop–soil complex (generally ~1.4 for *FAO-56* based ET_0), based on energy limitations. The form and principle of Eq. (4) was developed by Jensen et al. (1971), Wright and Jensen (1978), and Wright (1981, 1982).

The K_{cb} curve has the same shape as in Fig. 1 and three benchmark values for K_{cb} are used to construct the curve, namely $K_{cb\ \mathrm{ini}}$, $K_{cb\ \mathrm{mid}}$, and $K_{cb\ \mathrm{end}}$. Because K_{cb} can include "diffusive" or residual evaporation from soil for potentially long periods following wetting, $K_{cb\ \mathrm{ini}}$ is generally set to 0.15 in *FAO-56* for annual crops for the period from planting to before 10% ground cover. However, under dry conditions with long periods between wetting events or during the nongrowing season, $K_{cb\ \mathrm{ini}}$ can be set equal to 0. This is illustrated later.

FAO-56 describes the procedure for applying the dual method on a daily basis, with specific estimation of evaporation from wet soil. The dual approach is well suited for predicting the effects of day to day variation in soil water evaporation and the effectiveness of precipitation.

Adjustment for Climate

FAO-24 (Doorenbos and Pruitt 1977) presented, for each crop listing, four values for singular midseason and end-of-season crop coefficients, termed in *FAO-56* as $K_{c\ \mathrm{mid}}$ and $K_{c\ \mathrm{end}}$. The four values represented four climatic cases of wind and humidity that impact the value for K_c. In contrast, *FAO-56* includes only single entries for $K_{c\ \mathrm{mid}}$ and for $K_{c\ \mathrm{end}}$, or, in the case of K_{cb}, for $K_{cb\ \mathrm{mid}}$ and for $K_{cb\ \mathrm{end}}$. The single entries correspond to K_c or K_{cb} values associated with a standard subhumid climate having average daytime minimum relative humidity ($\mathrm{RH}_{\mathrm{min}}$) of about 45% and having calm to moderate wind speeds of 1–3 $\mathrm{m\ s^{-1}}$, averaging 2 $\mathrm{m\ s^{-1}}$. K_c and K_{cb} values are listed for about 80 crops in *FAO-56*. These can be accessed on the FAO web site (FAO 1998).

For climates where mean $\mathrm{RH}_{\mathrm{min}}$ is different from 45% or where wind speed at 2 m (u_2) is different from 2.0 $\mathrm{m\ s^{-1}}$, $K_{cb\ \mathrm{mid}}$ values from *FAO-56* are adjusted as

$$K_{\text{cb mid}} = K_{\text{cb mid (standard climate)}} + [0.04(u_2 - 2) - 0.004(\text{RH}_{\min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (5)$$

where $K_{\text{cb mid(standard climate)}}$=value for $K_{\text{cb mid}}$ from Table 17 of *FAO-56*; u_2=mean daily wind speed at 2 m height (m s^{-1}); $\text{RH}_{\min}$=mean daily minimum relative humidity (%) during the midseason period; and h=mean plant height during the midseason period (m). The adjustment in Eq. (5) accounts for impacts of differences in aerodynamic roughness between crops and the grass reference with changing climate and closely replicates the range in K_c values for the four climatic classes of *FAO-24*. Justification for Eq. (5) is given in Allen et al. (1998). Similar adjustment is made to $K_{\text{cb end}}$ when values for $K_{\text{cb end}} > 0.45$. Eq. (5) can be applied daily using daily values for u_2 and $\text{RH}_{\min}$ or can be applied for the midseason in total using averages for u_2 and $\text{RH}_{\min}$ for the period with relatively small loss in accuracy. When only mean daily dewpoint temperature or vapor pressure is known, $\text{RH}_{\min}$ can be approximated as $\text{RH}_{\min} \sim 100e_a/e^0(T_{\max})$, where e_a is actual vapor pressure and $e^0(T_{\max})$ is saturation vapor at daily maximum air temperature. The crop height adjustment in Eq. (5) is applied to both the wind and the $\text{RH}_{\min}$ terms because both terms appear in the aerodynamic term of the Penman–Monteith equation and both factors influence ET in some proportion to aerodynamic roughness.

Evaporation from Soil

The approach of *FAO-56* is similar to that of Ritchie (1972), Saxton et al. (1974), and Wright (1982) where evaporation from soil beneath a canopy or inbetween plants is predicted by estimating the amount of energy at the soil surface in conjunction with energy consumed by transpiration. When the soil is wet, evaporation is predicted to occur at some maximum rate and the sum $K_c = K_{\text{cb}} + K_e$ is limited by some maximum value $K_{c\,\max}$.

As the surface soil layer dries, a reduction in evaporation occurs, and K_e is simulated as

$$K_e = K_r(K_{c\,\max} - K_{\text{cb}}) \leqslant f_{\text{ew}} K_{c\,\max} \quad (6)$$

where $K_{c\,\max}$=maximum value of K_c following rain or irrigation; K_r=dimensionless evaporation reduction coefficient and is dependent on the cumulative depth of water depleted (evaporated); and f_{ew}=fraction of the soil that is both exposed to solar radiation and that is wetted. Evaporation is restricted by the energy available at the exposed soil fraction, i.e., K_e cannot exceed $f_{\text{ew}} K_{c\,\max}$. The *FAO-56* dual procedure differs from Ritchie (1972) and Saxton et al. (1974) in that the FAO procedure gives K_e (as limited by $f_{\text{ew}} K_{c\,\max}$) equal priority to transpiration (as represented by K_{cb}) in regard to energy consumption, whereas the Ritchie and Saxton approaches give transpiration priority over evaporation.

$K_{c\,\max}$ represents an upper limit on evaporation and transpiration from the cropped surface and is introduced to reflect the natural constraints on available energy. $K_{c\,\max}$ ranges from about 1.05 to 1.30 when using the grass reference ET_0

$$K_{c\,\max} = \max\left(\left\{1.2 + [0.04(u_2 - 2) - 0.004(\text{RH}_{\min} - 45)]\left(\frac{h}{3}\right)^{0.3}\right\}, \{K_{\text{cb}} + 0.05\}\right) \quad (7)$$

where h=mean plant height during the period of calculation (initial, development, mid-season, or late-season) (m), and the max () function indicates the selection of the maximum of values separated by the comma. Eq. (7) ensures that $K_{c\,\max}$ is always greater than or equal to the sum $K_{\text{cb}}+0.05$, suggesting that wet soil always increases the K_c value above K_{cb} by 0.05 following complete wetting of the soil surface, even during periods of full ground cover. The value 1.2 represents the impact of reduced albedo of wet soil and the contribution of heat stored in dry soil prior to wetting events that are separated by more than 3 or 4 days. The value also considers the effect of increased aerodynamic roughness of surrounding crops during development, midseason, and late season growth stages which can increase the turbulent transfer of vapor from the exposed soil surface. Bonachela et al. (2001) noted $K_{c\,\max}$ of over 1.5 for soil evaporation from a drip-irrigated olive orchard caused by microadvection of heat from dry surface areas to wet surface areas. Under complete surface wetting, $K_{c\,\max}$ would be expected to be lower, for example ranging from 1.0 to 1.2. In addition, if irrigation or precipitation events are more frequent than 3 days each, for example daily or 2 days each, then the soil has less opportunity to absorb heat between wetting events, and the 1.2 value can be reduced to about 1.1.

The surface soil layer is presumed to dry to an air dry water content approximated as halfway between wilting point θ_{WP} and oven dry. The amount of water that can be removed by evaporation during a complete drying cycle is estimated as

$$\text{TEW} = 1000(\theta_{\text{FC}} - 0.5\theta_{\text{WP}})Z_e \quad (8)$$

where (total evaporable water) (TEW)=maximum depth of water that can be evaporated from the surface soil layer when the layer has been initially completely wetted (mm). Field capacity θ_{FC} and θ_{WP} are expressed in (m^3 m^{-3}) and Z_e(m)=effective depth of the surface soil subject to drying to 0.5 θ_{WP} by way of evaporation. Typical values for θ_{FC}, θ_{WP}, and TEW are given in Table 1 for various soil types. Z_e is an empirical value based on observation. *FAO-56* recommended values for Z_e of 0.10–0.15 m, with 0.1 m recommended for coarse soils and 0.15 m recommended for fine textured soils. However, the user should select the value for Z_e, or even TEW, that represents evaporation amounts observed over complete drying cycles via gravimetric or other measurement. Some evaporation or soil drying will be observed to occur below the Z_e depth.

Evaporation from exposed soil is presumed to take place in two stages: an energy limiting stage (Stage 1), and a falling rate stage (Stage 2) (Philip 1957 and Ritchie 1972). During Stage 1, the soil surface remains wet and evaporation is predicted to occur at the maximum rate limited only by energy availability at the soil surface and therefore, K_r=1. As the soil surface dries, the evaporation rate decreases below the potential evaporation rate (defined as $K_{c\,\max} - K_{\text{cb}}$), and K_r becomes less than one. K_r becomes zero when no water is left for evaporation in the evaporation layer.

Stage 1 holds until the cumulative depth of evaporation D_e is such that the hydraulic properties of the upper soil become limiting and water cannot be transported to near the soil surface at a rate to supply the demand. At the end of Stage 1 drying, D_e is equal to readily evaporable water (REW). Readily evaporable water normally ranges from 5 to 12 mm and is highest for medium and fine textured soils (Ritchie 1972; Ritchie et al. 1989).

The second stage, where K_r is decreasing, begins when D_e exceeds REW. At this point, the soil surface is visibly dry, and evaporation from the exposed soil decreases in proportion to the amount of water remaining in the surface soil layer. Most early Stage 2 models (Philip 1957; Ritchie 1972) proportion the evaporation rate according to the square root of time since the begin-

Table 1. Typical Soil Water Characteristics for Different Soil Types (from *FAO-56*)

Soil type (USDA soiltexture classification)	Soil water characteristics θ_{FC} $m^3\,m^{-3}$	θ_{WP} $m^3\,m^{-3}$	$(\theta_{FC}\text{-}\theta_{WP})$ $m^3\,m^{-3}$	Evaporation parameters: Amount of water that can be depleted by evaporation — Stage 1 REW (mm)	Stages 1 and 2 TEW[a] (Z_e=0.10 m) (mm)	Stages 1 and 2 TEW[a] (Z_e=0.15 m) (mm)
Sand	0.07–0.17	0.02–0.07	0.05–0.11	2–7	6–12	9–13
Loamy sand	0.11–0.19	0.03–0.10	0.06–0.12	4–8	9–14	13–21
Sandy loam	0.18–0.28	0.06–0.16	0.11–0.15	6–10	15–20	22–30
Loam	0.20–0.30	0.07–0.17	0.13–0.18	8–10	16–22	24–33
Silt loam	0.22–0.36	0.09–0.21	0.13–0.19	8–11	18–25	27–37
Silt	0.28–0.36	0.12–0.22	0.16–0.20	8–11	22–26	33–39
Silt clay loam	0.30–0.37	0.17–0.24	0.13–0.18	8–11	22–27	33–40
Silty clay	0.30–0.42	0.17–0.29	0.13–0.19	8–12	22–28	33–42
Clay	0.32–0.40	0.20–0.24	0.12–0.20	8–12	22–29	33–43

Note: USDA=United States Department of Agriculture; REW=readily evaporated water; and TEW=totally evaporated water.

[a]TEW=$(\theta_{FC}-0.5\theta_{WP})Z_e$.

ning of Stage 2. This requires manipulation of time terms as new water enters the system. Moreover, the proportionality factor changes with ET_0 demand and therefore requires frequent recalibration (Snyder et al. 2000). In the *FAO-56* model, the reduction in evaporation during Stage 2 is proportional to the cumulative evaporation from the surface soil layer, resulting in a more simple, easily managed computation procedure that is based on a soil–water balance and that does not require recalibration

$$K_r = \frac{\text{TEW} - D_{e,j-1}}{\text{TEW} - \text{REW}} \tag{9}$$

for $D_{e,j-1} > \text{REW}$, where $D_{e,j-1}$=cumulative depletion from the soil surface layer at the end of day $j-1$ (the previous day) (mm); and TEW and REW are in millimeters (REW<TEW). The general form for the K_r function is illustrated in Fig. 2. The prediction by Eq. (9) is similar to that predicted by a square-root-of-time Stage 2 model, and differences are in general smaller than the uncertainties caused by the continuously changing effects of soil

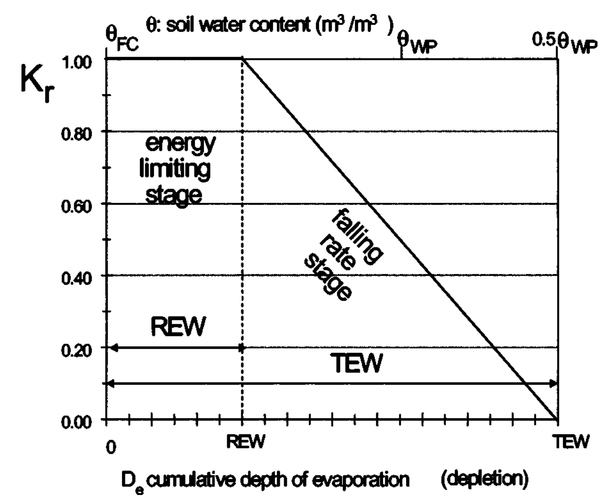

Fig. 2. General function for soil evaporation reduction coefficient K_r for two-stage *FAO-56* model (from *FAO-56*)

hydraulic properties, tillage, soil temperature, wetting characteristics, and root extraction. Saxton et al. (1974) used a nonlinear proportionality based on water content of the surface layer that had similar behavior as Eq. (9). A three-stage drying process can be applied to cracking soils as described in a following section. Mutziger et al. (2001) found good agreement between K_r predicted using the *FAO-56* dual method using REW and TEW from Table 1 (with Z_e=0.1 m) and relative evaporation measurements published by Chanzy and Bruckler (1993) for loam, silty clay loam, and clay soils.

In crops having partial ground cover, evaporation from the soil usually occurs nonuniformly over the surface, and is greater between plants having dense canopies near the ground where exposure to sunlight occurs and where more air ventilation is able to transport vapor from the soil surface to above the canopy. This is especially true where only part of the soil surface is wetted by irrigation. While it is recognized that both the locations and the fractions of the soil surface exposed to sunlight and ventilation may change with the time of day and depend on row orientation and near surface canopy density, the procedure of *FAO-56* predicts a general, averaged fraction of soil surface from which the majority of evaporation is expected to occur. Most evaporation from the soil beneath the crop canopy, occurring at a slower rate, is in many situations included in the basal K_{cb} coefficient.

Table 2. Common Values for Fraction of Soil Surface Wetted by Irrigation or Precipitation (after *FAO-56*)

Wetting event	f_w
Precipitation	1.0
Sprinkler irrigation, field crops	1.0
Sprinkler irrigation, orchards	0.7–1.0
Basin irrigation	1.0
Border irrigation	1.0
Furrow irrigation (every furrow), narrow bed	0.6–1.0
Furrow irrigation (every furrow), wide bed	0.4–0.6
Furrow irrigation (alternated furrows)	0.3–0.5
Microspray irrigation, orchards	0.5–0.8
Trickle (drip) irrigation	0.3–0.4

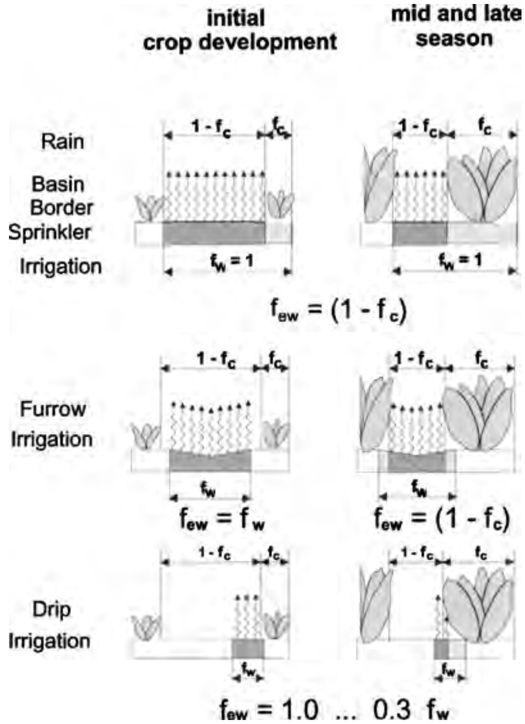

Fig. 3. Determination of f_{ew} (greyed areas) as function of fraction of ground surface coverage (f_c) and fraction of surface wetted (f_w) (from *FAO-56*)

In the *FAO-56* model, the term f_w is defined as the fraction of the surface wetted by irrigation and/or precipitation. This term defines the potential spatial extent of evaporation. Common values for f_w are listed in Table 2. An extension to Eq. (10) is described later.

When the soil surface is completely wetted, as by precipitation or sprinkler, f_{ew} of Eq. (6) is set equal to $(1-f_c)$, where f_c is the fraction of soil surface effectively covered by vegetation and $(1-f_c)$ represents the approximate fraction of soil surface that is effectively exposed to evaporation energy. For irrigation systems where only a fraction of the ground surface (f_w) is wetted, f_{ew} is limited to f_w

$$f_{ew} = \min(1 - f_c, f_w) \tag{10}$$

Both $1-f_c$ and f_w, for numerical stability, have limits of [0.01–1]. The limitation imposed by Eq. (10) presumes the fraction of soil wetted by irrigation occurs within the primary fraction of soil exposed to sunlight and ventilation. This is generally the case, except with some drip irrigation (Fig. 3). In the case of drip irrigation, Allen et al. (1998) recommended multiplying f_w by $[1-(2/3)f_c]$. Pruitt et al. (1984) and Bonachela et al. (2001) have described evaporation patterns and extent under drip irrigation.

Predicting Fraction of Surface Cover

The difference $(1-f_c)$ represents the fraction of the soil effectively exposed to sunlight and air ventilation and serves as the site where the majority of evaporation is expected to occur. The value for f_c is limited to <0.99 for numerical stability and is generally determined by visual observation. For purposes of estimating f_{ew}, f_c can be estimated from K_{cb} as

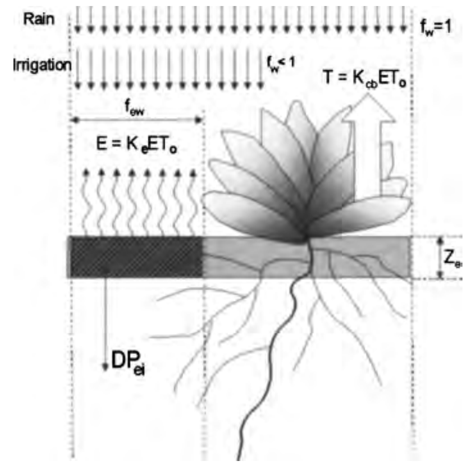

Fig. 4. Water balance of soil surface layer (from *FAO-56*)

$$f_c = \left(\frac{K_{cb} - K_{c\,min}}{K_{c\,max} - K_{c\,min}} \right)^{(1+0.5h)} \tag{11}$$

where f_c is limited to [0–0.99] and $K_{c\,min}$=minimum K_c for dry bare soil with no ground cover. Eq. (11) assumes that the value for K_{cb} is largely governed by the fraction of vegetation cover. The $1+0.5h$ exponent in Eq. (11) represents the impact of plant height on shading of the soil surface and in increasing the value for K_{cb} given a specific value for f_c. The difference $K_{cb}-K_{c\,min}$ is limited to $\geqslant 0.01$ for numerical stability. The value for f_c will change daily as K_{cb} changes. $K_{c\,min}$ ordinarily has the same value as $K_{cb\,ini}$ used for annual crops under nearly bare soil conditions (i.e., $K_{c\,min} \sim 0.15$). The value for f_c decreases during the late season period in proportion to K_{cb} to account for local transport of sensible heat from senescing leaves to the soil surface.

Under vegetation having an open canopy near the ground surface, for example some types of orchards, a large proportion, if not all, of the ground surface is effectively exposed to evaporative energy (Bonachela et al. 2001). In these situations, $1-f_c$ does not have large impact on f_{ew}, and $f_{ew}=f_w$ can be applied. The decision in assigning values for f_c and f_{ew} should be based on field observation of drying patterns.

Water Balance of Soil Surface Layer

Calculation of K_e requires a daily water balance for the f_{ew} fraction of the surface soil layer. The daily soil water balance equation is (Fig. 4)

$$D_{e,j} = D_{e,j-1} - (P_j - RO_j) - \frac{I_j}{f_w} + \frac{E_j}{f_{ew}} + T_{ei,j} + DP_{ei,j} \tag{12}$$

where $D_{e,j-1}$ and $D_{e,j}$=cumulative depletion depth at the ends of days $j-1$ and j (mm); P_j and RO_j=precipitation and precipitation runoff from the soil surface on day j (mm); I_j=irrigation depth on day j that infiltrates the soil (mm); E_j=evaporation on day j (i.e., $E_j=K_e ET_0$) (mm); $T_{ei,j}$=depth of transpiration from the exposed and wetted fraction of the soil surface layer on day j (mm); and $DP_{ei,j}$=deep percolation from the soil surface layer on day j if soil water content exceeds field capacity (mm). Assuming that the surface layer is at field capacity following heavy rain or irrigation, the minimum value for $D_{e,j}$ is zero and limits imposed are $0 \leqslant D_{e,j} \leqslant TEW$. It is recognized that water content of the soil surface layer can exceed TEW for short periods of time while drainage is occurring. However, because the length of time that this occurs varies with soil texture, wetting depth, and tillage, $D_{e,j} \geq 0$ is assumed. Additionally, it is recognized that some drainage in soil occurs at very small rates at water contents below field capacity. To some extent, impacts of these simple assumptions can be compensated for, if needed, in setting the value for Z_e or TEW.

RO_j can be computed using the USDA curve number procedure (Hawkins et al. 1985). The irrigation depth I_j is divided by f_w to approximate the infiltration depth to the f_w portion of the soil surface. Similarly, E_j is divided by f_{ew} because it is assumed that all E_j (other than residual evaporation implicit to the K_{cb} coefficient) is taken from the f_{ew} fraction of the surface layer.

Except for shallow rooted crops, where the depth of the maximum rooting is less than 0.5–0.6 m, the amount of transpiration extracted from the f_{ew} portion of the surface soil layer is small and can be ignored (i.e., $T_{ei}=0$). Where transpiration is known to extract water from the f_{ew} fraction of the surface layer, but is not considered in Eq. (12), *FAO-56* advises that the depth of the surface layer Z_e be decreased to compensate for the quicker drying. Estimation of T from the f_{ew} fraction of the surface layer is described in a following section.

Following heavy rain or irrigation, the soil water content in the surface layer (Z_e layer) might exceed field capacity for short time periods until excess water moves into the root zone and perhaps even deeper. In the simple water balance procedure used in *FAO-56*, however, it is assumed that the soil water content is limited to $\leq \theta_{FC}$ on the day of a complete wetting event. This is a reasonable assumption considering the shallowness of the surface layer. Downward drainage (percolation) of water from the surface layer is calculated as

$$DP_{e,j} = (P_j - RO_j) + \frac{I_j}{f_w} - D_{e,j-1} \geq 0 \qquad (13)$$

As long as the soil water content in the evaporation layer is below field capacity (i.e., $D_{e,j} > 0$), the surface layer is assumed to not drain, and $DP_{e,j}=0$.

Initialization of Water Balance

To initiate the water balance for the evaporating layer, the user can assume that the soil surface layer is near θ_{FC} following a heavy rain or irrigation so that $D_{e,j-1}=0$. Where a long period of time has elapsed since the last wetting, the user can assume that all evaporable water has been depleted from the evaporation layer at the beginning of calculations so that $D_{e,j-1}=\text{TEW}=1{,}000(\theta_{FC} - 0.5\ \theta_{WP})\ Z_e$.

Order of Calculation

Calculations for the *FAO-56* dual $K_{cb}+K_e$ procedure, for example when using a spreadsheet, proceed in the following order: K_{cb}, h, $K_{c\ max}$, f_c, f_w, f_{ew}, K_r, K_e, E, DP_e, D_e, I, K_c, and ET_c.

Extensions to FAO-56 Procedure

The evaporation component of the *FAO-56* dual K_c procedure was intended for routine application under a wide range of conditions. The procedure constitutes a balance between simplicity, understandability, and completeness and is recommended for most applications. The following three extensions to the *FAO-56* procedure may increase accuracy and definition of the total evaporation and drying process under special conditions.

Separate Prediction of Evaporation from Soil Wetted by Precipitation Only

The evaporation component is assumed to be fully concentrated in the exposed and wetted fraction of the surface layer. The slower rate of evaporation occurring from beneath the vegetation canopy is generally included in K_{cb} and is therefore not explicitly quantified. E is computed as $K_e\ ET_0$. The quotient E/f_{ew} in Eq. (12) describes the concentration of evaporation over the fraction of the soil that is both exposed and wetted.

Parameter $f_w=1$ for precipitation but is often <1 for some types of surface irrigation and micro irrigation. *FAO-56* recommended a procedure for calculating f_w according to the type of last wetting event and its extent. However, this determination can be subjective and uncertain. This section describes an extension to *FAO-56* that incorporates a separate water balance and procedure for K_r for the fraction of soil that is wetted by precipitation only (i.e., not by irrigation). The extension reduces uncertainty in determining the value for f_w and has been applied by Mutziger et al. (2005) in estimating annual evaporation losses from agricultural areas in California.

In the extension to the *FAO-56* procedure, the evaporation calculation is divided into two separate calculations. One calculation is made for the exposed fraction of soil wetted by both irrigation and precipitation and one calculation is made for the exposed fraction of soil wetted by precipitation only. The coefficient K_e is calculated as

$$K_e = K_{ei} + K_{ep} \qquad (14)$$

where K_{ei}=evaporation coefficient for the exposed fraction of the soil wetted by both irrigation and by precipitation and K_{ep}=evaporation coefficient for the exposed fraction of the soil wetted by precipitation only.

The modification to Eq. (6) that applies to the fraction wetted by both irrigation and by precipitation is

$$K_{ei} = K_{ri} W (K_{c\ max} - K_{cb}) \leq f_{ewi} K_{c\ max} \qquad (15)$$

and the application of Eq. (6) to the fraction of soil that is exposed and wetted by precipitation only is

$$K_{ep} = K_{rp}(1 - W)(K_{c\ max} - K_{cb}) \leq f_{ewp} K_{c\ max} \qquad (16)$$

where f_{ewi}=fraction of soil wetted by both irrigation and precpitation and is exposed to rapid drying due to exposure to solar radiation and/or ventilation; f_{ewp}=fraction of soil exposed to rapid drying and is wetted by precipitation only; W=weighting coefficient for partitioning the energy available for evaporation into the f_{ewi} and f_{ewp} soil fractions, depending on water availability; K_{ri} and K_{rp}=evaporation reduction coefficients for the f_{ewi} and f_{ewp} fractions; and f_{ewp} is calculated as

$$f_{ewp} = 1 - f_c - f_{ewi} \qquad (17)$$

and f_{ewp} and f_{ewi} are limited to 0.001–1.0. Eq. (10) is reexpressed for f_{ewi} as

$$f_{ewi} = \min(1 - f_c, f_w) \qquad (18)$$

where $1-f_c$ has limits of [0.01–1] and f_w=average fraction of soil surface wetted by irrigation, only [0.01–1].

The weighting factor W is calculated according to water availability in the two wetted, exposed fractions of the surface layer

$$W = \frac{1}{1 + \frac{f_{\text{ewp}}}{f_{\text{ewi}}} \frac{(\text{TEW} - D_{\text{ep}})}{(\text{TEW} - D_e)}} \quad (19)$$

where D_e=cumulative depletion depth (mm) from the evaporating layer for the f_{ewi} fraction of soil; and D_{ep}=cumulative depletion depth (mm) from the evaporating layer for the f_{ewp} fraction of soil. The limits D_e and $D_{\text{ep}} < \text{TEW}$; D_e and $D_{\text{ep}} \geq 0$; and $f_{\text{ewi}}(\text{TEW} - D_e) > 0.001$ are imposed for numerical stability.

An associated water balance is computed for the fraction of the evaporation layer wetted by precipitation, but not by irrigation, and is in the exposed portion of the soil

$$D_{\text{ep},j} = D_{\text{ep},j-1} - (P_j - \text{RO}_j) + \frac{E_{p,j}}{f_{\text{ewp}}} + T_{\text{ep},j} + \text{DP}_{\text{ep},j} \quad (20)$$

where $D_{\text{ep},j-1}$ and $D_{\text{ep},j}$=cumulative depletion depths at the ends of days $j-1$ and j in the f_{ewp} fraction of the surface (mm); $E_{p,j}$ =evaporation from f_{ewp} fraction on day j ($E_{p,j}=K_{\text{ep}}\,\text{ET}_0$) (mm); $T_{\text{ep},j}=T_e$ from f_{ewp} fraction of the evaporation layer on day j (mm); ($T_{\text{ep},j}$ can be set equal to zero for simplification); and $\text{DP}_{\text{ep},j}$=deep percolation from the f_{ewp} fraction of the evaporation layer on day j if soil water content exceeds θ_{FC} (mm). The limits on $D_{\text{ep},j}$ are $0 \leq D_{\text{ep},j} \leq \text{TEW}$. The $E_{p,j}$ is divided by f_{ewp} because it is assumed that all E_p is taken from the f_{ewp} fraction of the surface layer.

Eq. (12) is expressed for the f_{ewi} fraction as

$$D_{e,j} = D_{e,j-1} - (P_j - \text{RO}_j) - \frac{I_j}{f_w} + \frac{E_j}{f_{\text{ewi}}} + T_{\text{ei},j} + \text{DP}_{\text{ei},j} \quad (21)$$

where f_w=fraction of soil surface wetted by irrigation.

Eq. (9) is expressed for the f_{ewi} and f_{ewp} fractions as

$$K_{\text{ri}} = \frac{\text{TEW} - D_{e,j-1}}{\text{TEW} - \text{REW}} \quad (22)$$

and

$$K_{\text{rp}} = \frac{\text{TEW} - D_{\text{ep},j-1}}{\text{TEW} - \text{REW}} \quad (23)$$

for $D_{e,j-1}$ and $D_{\text{ep},j-1} \geq 0$.

The total evaporation rate from the exposed fraction of the surface is $E=K_e\,\text{ET}_0=(K_{\text{ei}}+K_{\text{ep}})\,\text{ET}_0$. K_{ei} and K_{ep} are both constrained so that $K_{\text{ei}} \geq 0$ and $K_{\text{ep}} \geq 0$

Eq. (13) is expressed for the f_{ewi} fraction of the surface layer as

$$\text{DP}_{\text{ei},j} = (P_j - \text{RO}_j) + \frac{I_j}{f_w} - D_{\text{ei},j-1} \geq 0 \quad (24)$$

As long as the soil water content in the evaporation layer is below field capacity (i.e., $D_{\text{ei},j} > 0$), the soil will not drain and $\text{DP}_{\text{ei},j}$ =0. For the fraction of exposed soil that is wetted by precipitation but not by irrigation

$$\text{DP}_{\text{ep},j} = (P_j - \text{RO}_j) - D_{\text{ep},j-1} \geq 0 \quad (25)$$

Transpiration from Surface Layer

The amount of transpiration extracted from the f_{ew} fraction of the evaporating soil layer is generally small and can be ignored. However, for shallow-rooted annual crops where the depth of the maximum rooting is less than about 0.5 m, T_e may have significant effect on the water balance of the surface layer and therefore on prediction of the evaporation component, especially for the period midway through the development period.

Under conditions of uniform water availability within the soil profile, the ratio of T extracted from the evaporation layer to total T is presumed proportional to $(Z_e/Z_r)^{0.6}$ (Allen et al. 1996), where Z_e is the depth of the surface evaporation layer and Z_r is the effective depth of the root zone ($Z_e \leq Z_r$ and Z_e is contained in Z_r). This relationship is based on the commonly used 40–30–20–10% root extraction pattern for quartile rooting depths (top to bottom) of the root zone for moist soils.

In this extension, it is assumed that the previous extension using f_{ewi} and f_{ewp} is applied. If this is not the case, then only T_{ei} is used and all occurrences of f_{ewi} are set to f_{ew}. The equation for T_e from the f_{ewi} fraction of the evaporation layer T_{ei} is

$$T_{\text{ei}} = K_{\text{ti}} K_{\text{cb}} K_s \text{ET}_0 \quad (26)$$

where K_{ti}, $[0-1]$=proportion of basal $\text{ET}(=K_{\text{cb}}\text{ET}_0)$ extracted as transpiration from the f_{ewi} fraction of the surface soil layer, and K_s=soil water stress factor computed for the root zone [0–1]. K_{ti} is determined by comparing relative water availability in the Z_e and Z_r layers along with the presumed rooting distribution. For the f_{ewi} fraction

$$K_{\text{ti}} = \left(\frac{1 - \frac{D_e}{\text{TEW}}}{1 - \frac{D_r}{\text{TAW}}} \right) \left(\frac{Z_e}{Z_r} \right)^{0.6} \quad (27)$$

where the numerator and denominator of the first expression of Eq. (27) are limited to ≥ 0.001 and TAW is total available water in the root zone [see Eq. (33) introduced later]. In addition, the value for K_{ti} is limited to ≤ 1.0 to limit T_{ei} to $\leq \text{ET}_c$. A value of $K_{\text{ti}} \sim 1.0$ would represent conditions where the soil profile is near wilting point, but the shallow surface layer is partially or fully rehydrated by a light precipitation or irrigation event, or where the root zone is very shallow.

Transpiration from the f_{ewp} fraction of the soil T_{ep} is calculated as

$$T_{\text{ep}} = K_{\text{tp}} K_{\text{cb}} K_s \text{ET}_0 \quad (28)$$

where

$$K_{\text{tp}} = \left(\frac{1 - \frac{D_{\text{ep}}}{\text{TEW}}}{1 - \frac{D_r}{\text{TAW}}} \right) \left(\frac{Z_e}{Z_r} \right)^{0.6} \quad (29)$$

where K_{tp}, $[0-1]$=proportion of basal $\text{ET}(=K_{\text{cb}}\text{ET}_0)$ extracted as transpiration from the f_{ewp} fraction of the surface soil layer. The same limitations apply as for Eq. (27).

When there is Stage 3 evaporation, as defined in the next section, TEW in Eqs. (27) and (29) is set equal to TEW_3, the upper limit for evaporable water.

Stage Three Evaporation

The third extension to the *FAO-56* procedure applies to soils that crack substantially upon drying, thereby exposing progressively deeper depths of soil to drying by evaporation. This progressive drying continues at a low rate for an extended period of time. Drying to depths as deep as 0.5 m is possible for severely cracking soils containing large amounts of montmorillinite clay where cracks can extend as deep as 1 m (Pettry and Switzer 1996).

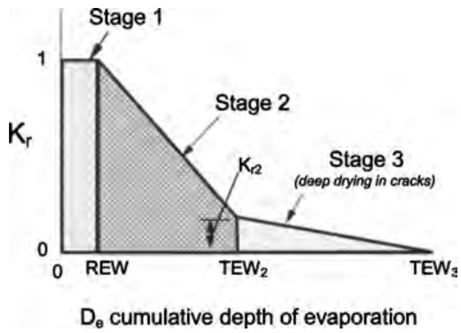

Fig. 5. General schematic showing evaporation reduction coefficient K_r as function of depth of water evaporated (depleted) from surface soil layer for cracking soil having three-stage evaporation.

In the extension for cracking soils, the evaporation process is expanded from two to three stages. The three stages are illustrated in Fig. 5. For normal agricultural soils that do not crack or only mildly crack, only Stage 1 and Stage 2 drying is applied. For cracking soils that have Stage 3 drying, Stage 3 is presumed to begin when K_r reduces to a threshold value labeled K_{r2}.

For three-stage drying, K_r is calculated for the second stage as

$$K_r = K_{r2} + (1 - K_{r2})\frac{\text{TEW}_2 - D_{e,j-1}}{\text{TEW}_2 - \text{REW}}$$

$$\text{for REW} < D_{e,j-1} < \text{TEW}_2 \qquad (30)$$

where TEW_2 = maximum cumulative depth of evaporation (depletion) from the soil surface layer when $K_r = K_{r2}$ (point at which evaporation transitions into stage three drying) (mm), and K_{r2} = value for K_r at the junction of Stage 2 and Stage 3 drying. Generally, the value for K_{r2} should be some relatively low value between about 0.1 and 0.4, depending on the nature and degree of cracking as the soil dries. Allen et al. (1998) recommended $K_{r2} \sim 0.2$. Mutziger et al. (2001) found best fit values for K_{r2} for two cracking soils in Texas to be 0.3 and 0.2 when comparing against lysimeter measurements of evaporation for a black clay and clay loam.

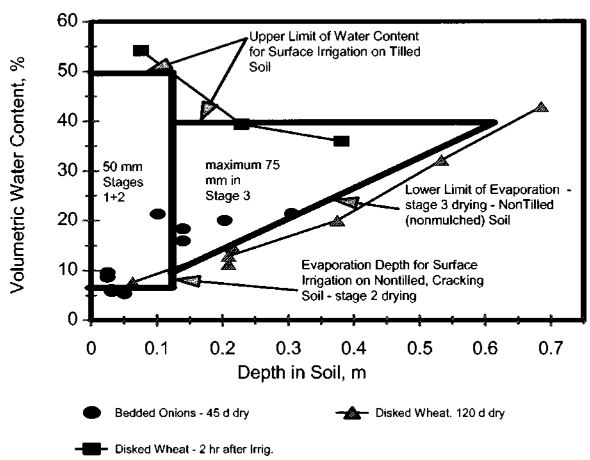

Fig. 6. Field measurements of volumetric water content for cracking soils in Imperial Irrigation District when wet (square symbols) and after 45 and 120 days of drying (circles and triangles). Superimposed on data are abstracted water content profiles associated with Stages 1 and 2 and with Stage 3 evaporation components

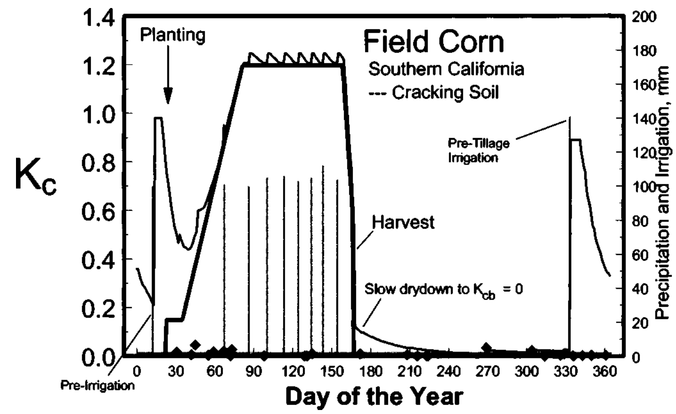

Fig. 7. Simulated K_{cb} (heavy line) and $K_{cb}+K_e$ (light line) curves for crop of field corn planted in late January in southern California on cracking soil having REW = 8 mm, TEW_2 = 50 mm, TEW_3 = 100 mm, K_{r2} = 0.2, and f_w = 0.7 for growing period irrigations and f_w = 1.0 for preirrigations. Bars denote predicted timing and depths of irrigation and diamonds denote rainfall

K_r is calculated for the third stage as

$$K_r = K_{r2}\frac{\text{TEW}_3 - D_{e,j-1}}{\text{TEW}_3 - \text{TEW}_2}$$

$$\text{for TEW}_2 \leq D_{e,j-1} \qquad (31)$$

where TEW_3 = maximum cumulative depth of evaporation (depletion) from the soil surface layer when the soil is dry and no further evaporation occurs (K_r = 0) (mm). The value TEW_3 includes REW and TEW_2. For application of the three-stage drying extension with the first extension, Eqs. (22) and (23) are expanded using Eqs. (30) and (31), with each application (I + P) and (P) having its own water balance.

The three stage drying extension has been applied to cracking heavy clay soils in the Imperial Irrigation District of California (Allen et al. 2005) and to two cracking or partially cracking soils in Texas (Mutziger et al. 2001). Values used for the Imperial soils were REW = 8 mm, TEW_2 = 50 mm, TEW_3 = 100 mm, and K_{r2}

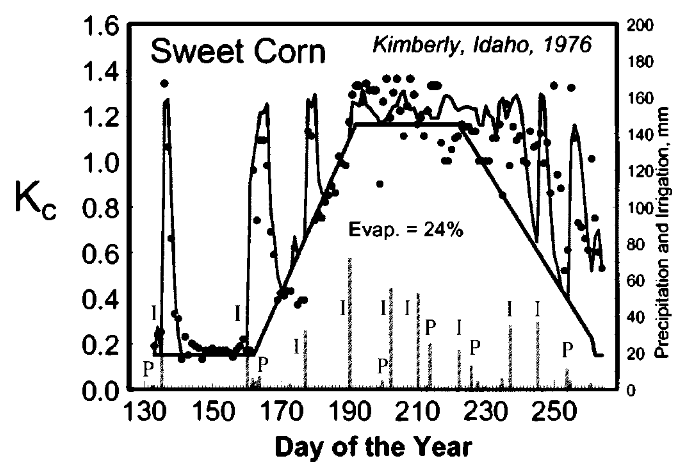

Fig. 8. Daily crop coefficients based on measured evapotranspiration and simulated using *FAO-56* dual K_c approach at Kimberly, Id. for a crop of sweet corn (lysimeter data from Wright 1982, personal communication 1990).

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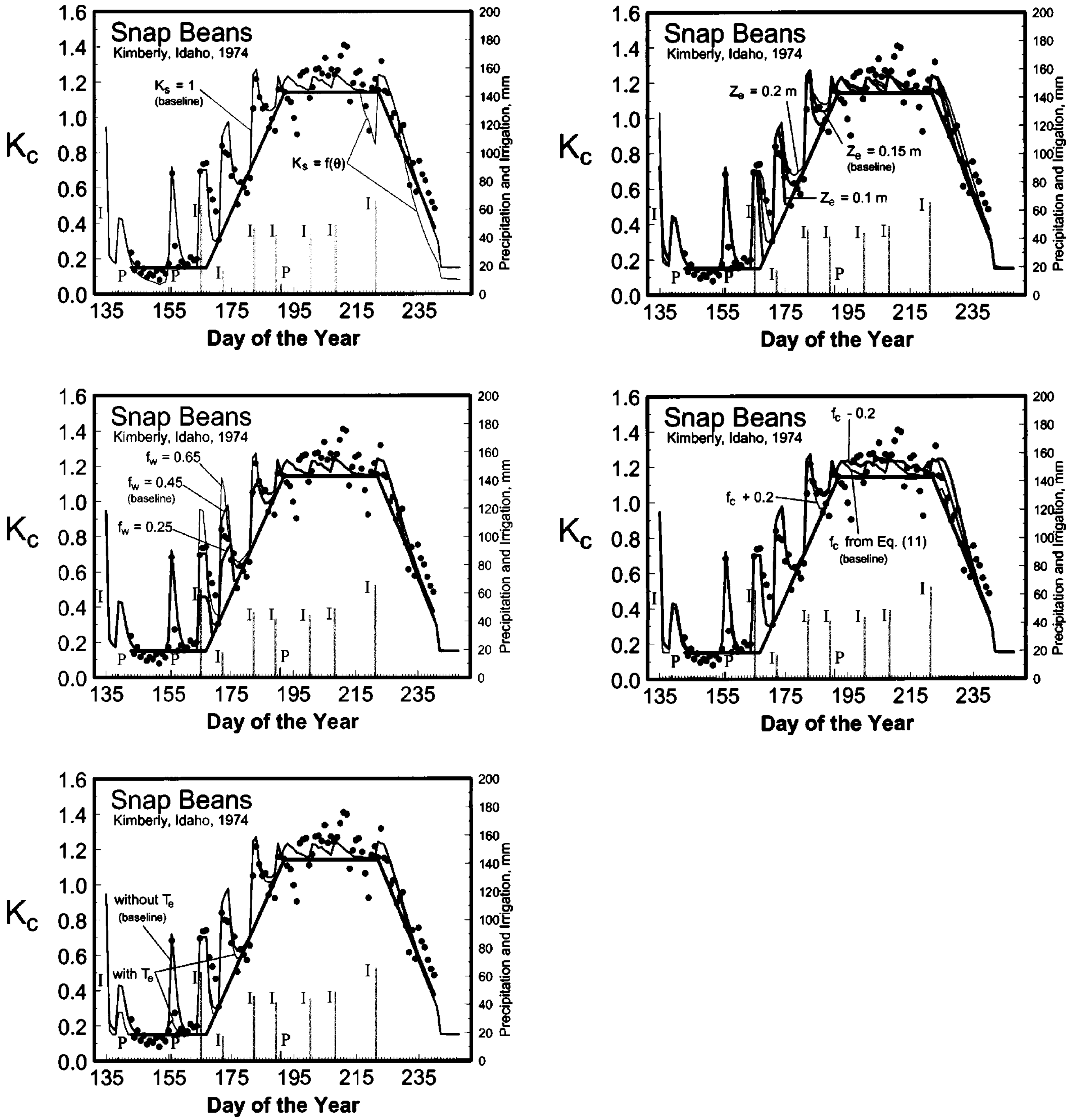

Fig. 9. Sensitivity of daily $K_{c\ \mathrm{act}}$ estimation for snap bean crop near Kimberly, Id. (lysimeter data from J. L. Wright, unpublished) to: (a) application of water stress function [Eq. (32)] (thin line) with comparison to K_c predicted using $K_s=1$ (medium line), K_{cb} (thick line), and measured K_c (symbols); (b) value for f_w; (c) application of T_e in Eq. (12); (d) value for Z_e; and (e) value for f_c

=0.2. Best fit values (to lysimeter evaporation measurements) for the Houston black clay and Pullman clay loam soils evaluated by Mutziger were REW=7 mm; TEW_2=30 and 22 mm; and TEW_3 =50 and 45 mm.

TEW_2 and TEW_3 for the Imperial Valley soils were estimated from sampled soil water contents at the beginning and end of drying cycles in fallow fields as shown in Fig. 6. The sampling sites were in an area of mixed Imperial silty clay and Imperial-Glenbar silty clay loam soil. Cracks penetrated to about 1 m on drying on an approximately 0.5 to 2 m grid and average crack width was 10 mm. Moisture was gravimetrically determined from cored samples. In the case of sampling the dry profile where the soil was deeply cracked, samples were taken approximately 0.3 m in from the face of cracks. The areas between the upper horizontal and the lower horizontal or diagonal lines in the figure suggest the equivalent depth of water evaporated during Stages 1 and 2 and during Stage 3 from the cracking soil. The sampling indicated drying to a depth of more than 0.5 m due to cracking. Even though the apparent depletable depth from 0.12 to 0.6 m shown in Fig. 6 was about 75 mm, a value of 50 mm for Stage 3 drying

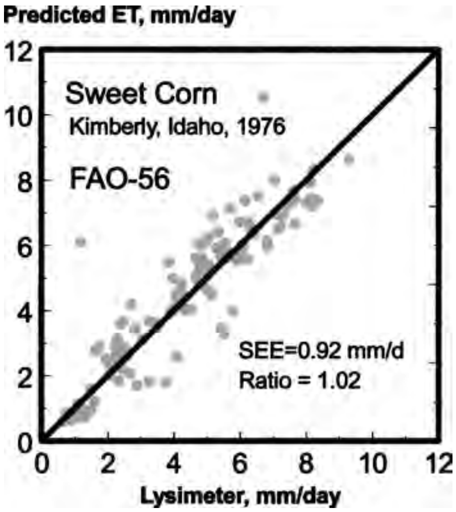

Fig. 10. Daily measured and estimated evapotranspiration for sweet corn near Kimberly, Id. using *FAO-56* dual K_c procedure (data from Wright 1982, personal communication 1990).

(so that $TEW_3 = 50 + 50 = 100$ mm) was selected for routine application in the Imperial Valley to account for dampening effects of disking and other tillage on creating a surface soil mulch and any effects of water extraction by roots (Allen et al. 2005).

The net impact of Stage 3 drying is to prolong the time for K_r to decrease to zero, thereby creating a prolonged "base-line" evaporation rate. As shown in Fig. 7, where the *FAO-56* $K_{cb}+K_e$ method was applied with Stage 3 drying, base-line evaporation was prolonged following harvest for more than 60 days, even when time between wetting events was large. Without the Stage 3 drying, $K_{c\ act}$ reduced to zero within 5–10 days following harvest. The K_{cb} prior to planting and following harvest was set to zero to allow evaporation (and total ET) to approach zero during extended dry periods.

Impacts of Water Stress

The final component in Eq. (4) is the water stress coefficient K_s used to reduce K_{cb} under conditions of water stress or salinity stress. Allen et al. (1998) describes the salinity stress function and computation. The water stress function is described here and is illustrated later. Mean water content of the root zone in the *FAO-56* procedure is expressed by root zone depletion, D_r, i.e., water shortage relative to field capacity. At field capacity, $D_r = 0$. Stress is presumed to initiate when D_r exceeds RAW, the depth of readily available water in the root zone. For $D_r > \text{RAW}$, K_s is

$$K_s = \frac{\text{TAW} - D_r}{\text{TAW} - \text{RAW}} = \frac{\text{TAW} - D_r}{(1-p)\text{TAW}} \tag{32}$$

where TAW = total available soil water in the root zone (mm), and p = fraction of TAW that a crop can extract from the root zone without suffering water stress. When $D_r \leq \text{RAW}$, $K_s = 1$. The total available water in the root zone is estimated as the difference between the water content at field capacity and wilting point

$$\text{TAW} = 1000(\theta_{FC} - \theta_{WP})Z_r \tag{33}$$

where Z_r = effective rooting depth (m) and Z_r contains Z_e. RAW is estimated as

$$\text{RAW} = p\text{TAW} \tag{34}$$

where RAW has units of TAW (mm). *FAO-56* contains recommended values for p for 60 crops and describes several means to model the development (increase) in Z_r with time for annual crops including in proportion to development of K_{cb} and in proportion to time. Other methods for Z_r development include a sine function of time (Borg and Grimes 1986), an exponential function of time dampened by soil temperature and soil moisture (Danuso et al. 1995), and a full root growth simulation model by Jones et al. (1991).

Example Applications and Sensitivity Analyses

Illustrative applications of the *FAO-56* procedure are given in Fig. 8 for a sweet corn crop and in Fig. 9 for a snap bean crop grown near Kimberly, Id. during 1976 and 1974 by Wright (1982). Daily ET was measured using a precision weighing lysimeter planted to and immediately surrounded by a specific crop. Fetch of the lysimeter was at least 50 m in all directions for the specific crop and resolution of the lysimeter system was about 0.05 mm (Wright 1982). The daily measured K_c values in the figures were calculated by dividing daily lysimeter measurements by ET_0 as computed by Eq. (1). Weather data were assembled from a grassed weather station located about 1 km north of the lysimeter site. Dates for planting and harvest and for precipitation and irrigation were based on field notes (Wright, personal communication 1990; Vanderkimpen 1991). Values for K_{cb} were taken from *FAO-56*. Dates for beginning of development, midseason and late season periods for the *FAO-56* procedure were selected to fit the lysimeter data.

The application used the original *FAO-56* procedure with extension for T_e. The Portneuf silt loam soil at Kimberly was modeled using two-stage drying with Z_e set to 0.15 m and REW = 8 mm and TEW = 34 mm. The value for f_w was 0.6 for the furrow-irrigated sweet corn and 0.45 for alternate furrow-irrigated beans.

For the application to beans, ranges in values for parameters K_s, f_w, T_e, Z_e, and f_c were applied to illustrate the sensitivity of the *FAO-56* model predictions to these parameters. In the case of K_s and T_e, the sensitivity was with and without the inclusion of functions for these parameters.

Results

Simulated daily K_{cb} and $K_{c\ act}$ and measured $K_{c\ act}$ for the growing period for the sweet corn crop shown in Fig. 8 indicate relatively

Table 3. Standard Error of Estimate (SEE) and Ratio of Estimated to Measured Daily Evapotranspiration for Full Season of Snap Beans in 1974 near Kimberly, Id. (n = 98 days), where Baseline Conditions were $f_w = 0.45$, $T_e = 0$, $K_s = 1$, $Z_e = 0.15$ m, and f_c from Eq. (11)

	Baseline	$f_w = 0.25$	$f_w = 0.65$	with T_e	with K_s	$Z_e = 0.10$ m	$Z_e = 0.20$ m	$f_c - 0.2$	$f_c + 0.2$
SEE (mm day^{-1})	0.63	0.74	0.68	0.67	0.78	0.76	0.61	0.66	0.68
Ratio to measured	1.00	0.96	1.03	0.98	0.96	0.96	1.04	1.03	0.95

good agreement between simulated and measured values. The peak spikes in $K_{c\ \mathrm{act}}$ following wetting agreed well with measurements as did the rate of decay of the K_e curve. There was some underestimation of $K_{c\ \mathrm{act}}$ during the midseason period which may have been caused by underestimation of ET_0 by Eq. (1) or underestimation of the midseason K_{cb} for corn by *FAO-56*. The $K_{c\ \mathrm{act}}$ predicted during the late season overestimated measured $K_{c\ \mathrm{act}}$ for some days and underestimated over two 5 day periods. Much of the under- and overestimation during the senescence period was probably caused by uncertainty in the estimation of f_c during that period and the impact of ground shading on the wetted portion of the soil surface.

The unadjusted standard error of estimate (SEE) between the estimated and lysimeter-measured daily ET (Fig. 10) was $0.92\ \mathrm{mm\ day}^{-1}$ and the seasonal ratio of predicted ET to measured ET was 1.02. Total seasonal evaporation for the sweet corn crop was estimated to be 24% of the total seasonal ET. Because the lysimeter measurements provide only integrated values of ET, the separate estimation of evaporation cannot be evaluated for accuracy. Estimates of soil evaporation do not include the evaporation from soil that occurs as a diffusive component of K_{cb} over time.

Sensitivity of the $K_{cb}+K_e$ procedure of *FAO-56* to invocation of a K_s soil moisture stress function under conditions where mild stress may have occurred is shown in Fig. 9(a) for the 1974 snap bean crop. Without the K_s function (thus $K_s=1.0$), the $K_{c\ \mathrm{act}}$ curve (medium gage line) "bottomed" against the K_{cb} curve (heavy line). With the K_s function [Eq. (32)], drying below the p level of the root zone was predicted during the development period, late midseason, and latter part of the late season. These predictions were based on actual irrigation dates and values for soil water holding properties from Table 1 ($AW=160\ \mathrm{mm\ m}^{-1}$), and $p=70\%$ during the initial period and $p=55\%$ for the other three periods, and maximum rooting depth of 1.6 m, based on measurements by Wright (unpublished data, 2000). The application of the K_s function improved estimation of $K_{c,\mathrm{act}}$ for some dates and caused underestimation for others. No visual or measured stress by the lysimeter crop in 1974 was noted by Wright (1982).

Figure 9(b) illustrates the impact that f_w, the fraction of soil surface wetted by irrigation, has on the $K_{c\ \mathrm{act}}$ estimate. Higher values for f_w extended the magnitudes and time lengths of drydown for K_e "spikes" during the development period when the value $1-f_c$ in Eq. (10) was large. During midseason period, $1-f_c$ in Eq. (10) limited the value for f_{ew} regardless of range in f_w. Thus, sensitivity to f_w is generally prominent only during the initial and development periods.

The inclusion of the T_e function for extraction for transpiration from the Z_e layer impacted the estimation for K_c during the initial and development periods and had no impact during the mid and late season periods when the evaporation layer was largely shaded. The T_e function reduced the prediction of K_e for the precipitation event on Day 156 [Fig. 9(b)] because T_e extraction during prior days increased D_e so that the 6 mm precipitation depth was absorbed into the Stage 2 depletion reservoir, rather than adding to Stage 1 drying. This illustrates a weakness of the *FAO-56* model in that any light precipitation event is subtracted from the total D_e for the Z_e depth, rather than left on the soil skin for immediate evaporation. D_e was increased during the initial period with the application of the T_e function because all of the K_{cb} value [0.15 in Fig. 9(b)] is assigned to basal transpiration in the dual procedure, even though the 0.15 value may contain significant amounts of diffusive evaporation. There is danger in assigning too large a value for K_{cb} in the dual method, including the method of Wright (1982), since no limit is placed on K_{cb} extraction from a shallow, initial root depth unless the K_s function is invoked. The fact that inclusion of the T_e function did not improve predictions for the snap beans may reflect the tillage practices for beans, where open spaces between rows are cultivated two to three times during the growing season, thus reducing root activity there and thus extraction by transpiration. The $1-f_c$ parameter in Eq. (10) represents these open spaces.

The impact of the value assigned to Z_e, the effective depth of the evaporating layer, is illustrated in Fig. 9(d). With all other parameters fixed, the impact of greater Z_e is to extend the lengths of drydown periods and to increase the estimated evaporation component of ET. The impact of Z_e was pronounced during all periods.

Sensitivity to the estimation of fraction of surface covered by vegetation is illustrated in Fig. 9(e), where 0.2 was added and subtracted from the value for f_c predicted by Eq. (11). The impact of value for f_c was negligible for the initial and most of the development period when $1-f_c$ exceeded the value assigned to f_w. In this case, f_w controlled the estimate of evaporation. As f_c increased, its value began to control f_{ew} from Eq. (10) and impact on K_e and K_c increased. The smaller value for f_c (i.e., $f_c-0.2$) during late development and mid season tended to improve estimates during those periods.

Table 3 lists summary statistics for the five sensitivity tests. The smallest SEE ($0.61\ \mathrm{mm\ day}^{-1}$) occurred when Z_e was increased from 0.15 to 0.20 m, however, the reduction in SEE over the baseline was very small. The impact by the individual ranges in the parameters on the ratio of estimated seasonal ET to measured ET ranged from −5 to +4%.

Summary and Conclusions

The *FAO-56* dual K_c procedure was established to provide daily estimates of evaporation from wet soil in conjunction with crop transpiration. The procedure uses a daily water balance of the soil surface layer and accounts for the fraction of soil surface wetted by irrigation or by precipitation and exposed to radiation and ventilation. Three optional extensions to the original method are described. The first is the establishment of a separate water balance for the fraction of the surface wetted by precipitation, only, and for the fraction wetted by both irrigation and precipitation. The second extension is a procedure to approximate the drying of the surface layer by transpiration in addition to evaporation. The third extension provides for the application to deep cracking soils. The dual K_c procedure is useful when short term estimates of evapotranspiration are needed, for example in research and in irrigation scheduling for individual fields as well as in estimation of total consumption of water where impacts of wetting frequency are important.

The sensitivity analysis indicates that inclusion of a function to estimate transpiration from the evaporating layer may not substantially impact or improve estimates, especially for crops having periodic cultivation. Calculations are moderately sensitive to values specified for the depth of the evaporation layer and fraction of surface wetted by irrigation, and to the estimation of fraction of ground cover.

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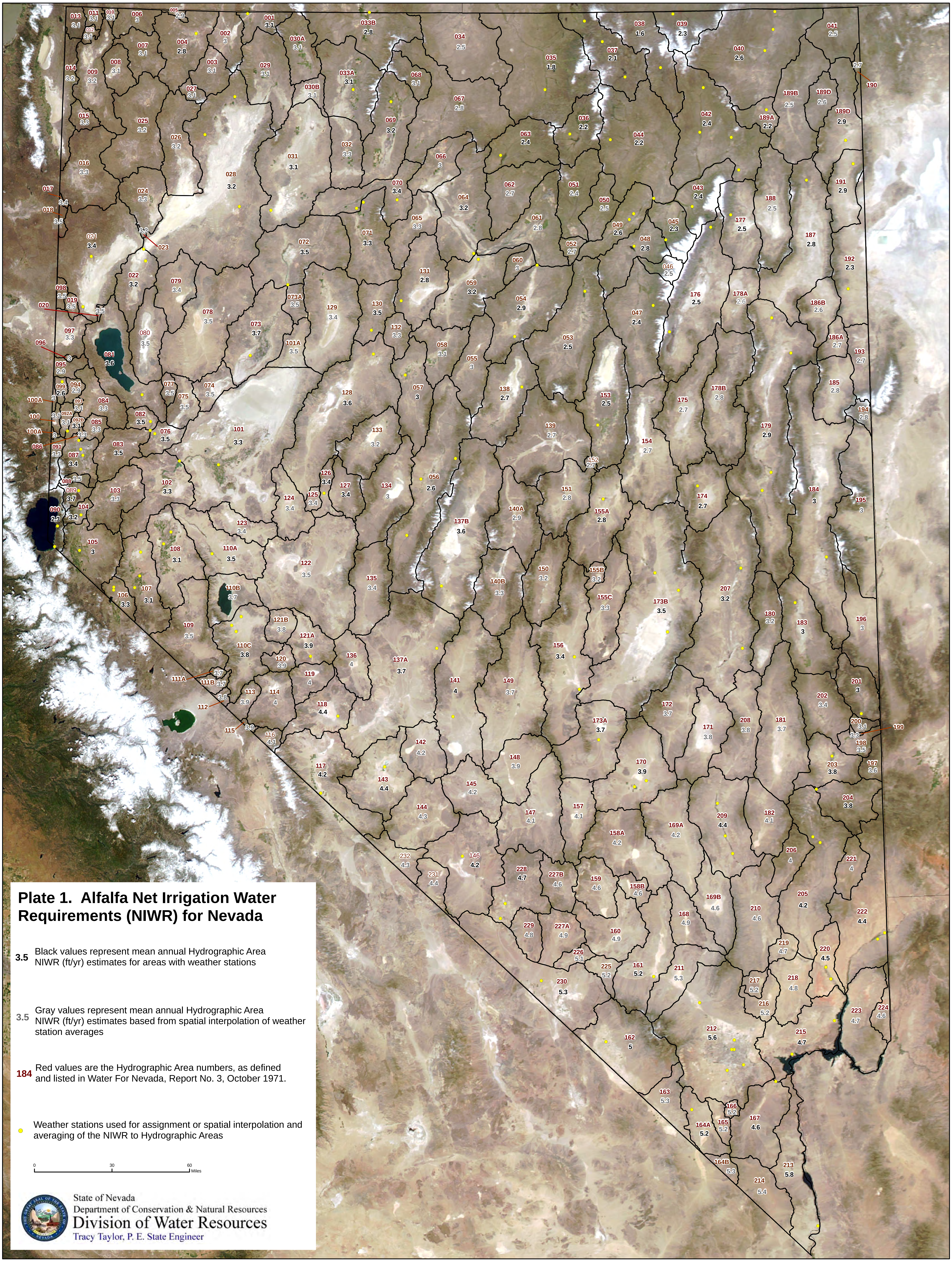

Plate 1. Alfalfa Net Irrigation Water Requirements (NIWR) for Nevada

SE ROA 54538

JA_18676

JIM GIBBONS
Governor

STATE OF NEVADA

LEO DROZDOFF
Acting Director

JASON KING, P.E.
State Engineer

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Re: Applications 54055-54059, 63272-63276, 63867-63876, 54076; Order No. 1169

Study Participants:

This letter is intended as follow-up to the meeting held June 22, 2010, and to address outstanding issues and reporting requirements related to State Engineer's Order No. 1169, in particular the critical pumping test portion of the Order. Order No. 1169, which was signed on March 8, 2002, holds in abeyance all pending carbonate-rock aquifer system groundwater applications and new filings to appropriate water in Coyote Spring Valley (Basin 210), Black Mountains Area (Basin 215), Garnet Valley (Basin 216), Hidden Valley (Basin 217), Muddy River Springs aka as Upper Moapa Valley (Basin 219), and Lower Moapa Valley (Basin 220) until further information is obtained by stressing the aquifer by the pumping of those water right permits already issued in Coyote Spring Valley. Application 54076 in California Wash was also held in abeyance until the test was completed.

The entities initially required to participate in the study included: Las Vegas Valley Water District (LVVWD), Southern Nevada Water Authority (SNWA), Coyote Springs Investment, LLC, Nevada Power Company, and the Moapa Valley Water District (MVWD). The Moapa Band of Paiutes recently requested and was granted status as a participant.

The Order calls for a minimum five-year hydrological study during which at least 50% of the existing water rights in Coyote Spring Valley must be pumped for at least two consecutive years. The permitted groundwater rights of the study participants in Coyote Spring Valley total

16,100 acre-feet annually (afa); therefore, the amount that must be pumped each year for two consecutive years is 8,050 afa. The water may be pumped from any of the currently permitted points of diversion of the participants. Pumped water must be put to beneficial use within Coyote Spring Valley or exported from the hydrographic basins subject of Order No. 1169.

A hydrologic report, prepared by Mifflin and Associates, Inc. (MAI) and forwarded to this office by the Moapa Band of Paiutes, presented information supporting a conclusion that pumping from Coyote Spring Valley would reduce Muddy River spring flows at a 1:1 rate just nine months after pumping occurs. In its report and in a presentation at the June 22, 2010 meeting, MAI concluded:

- The pumping that has occurred to date in Coyote Spring Valley has produced results that effectively satisfy the objectives of Order No. 1169.
- Pumping in Coyote Spring Valley in 2007 was coincident with, and possibly responsible for, a 60% decrease in the Moapa dace population.
- Flows in the Warm Springs area would not be adequately protected by the Memorandum of Understanding agreed to by the U.S. Fish and Wildlife Service (USFWS), the SNWA, the MVWD, and the Moapa Band of Paiutes.

MAI recommended that the pumping test not proceed until the cause of the dace population decline is better known, minimum flows for their habitat are established, and a pumping test designed to protect those minimum flows is developed. However, comments by the USFWS did not concur with the MAI view that the low flows during that period of time were responsible for the decrease in dace population, and the USFWS recommended that the pumping test take place as outlined in Order No. 1169. At the end of the meeting, it was decided that the pumping test should be carried out to the extent possible. Modifications to the test, reporting and subsequent studies are outlined below.

Section 7 of the Order requires the study participants to file a report within 180 days of the end of the fifth year detailing the results of the study. Section 8 requires that at the end of the study period, LVVWD/SNWA are to update Exhibit 54 from the July 2001 hearing to show the State Engineer the effects, if any, of production of water under Applications 54055 - 54059. The State Engineer was to then make a determination if he had sufficient information to proceed with ruling on those additional applications in Coyote Spring Valley for which hearings had already been conducted, and other pending applications in these basins.

For various reasons, eight years have passed since the State Engineer issued Order No. 1169, and the pumping requirements of the Order have not yet begun. SNWA's present plan is to pump only the MX-5 well and pipe that water to Lower Moapa Valley, where it will be allowed to flow into Lake Mead for the benefit of SNWA. However, maximum pumping rates from MX-5, even when combined with Coyote Springs Investment, LLC's ongoing pumping, may not meet the 8,050 afa minimum pumping requirement of the Order. As established in the Order, final reports and the update to Exhibit 54 are only required after completion of the pumping test. However, decisions regarding future appropriations in the basins subject to Order No. 1169 cannot be deferred indefinitely. Therefore, in accordance with NRS 533.368, 533.375 and 534.110, and regardless of whether the 8,050 afa minimum requirement is met or not, the study participants shall comply with the reporting requirements of Sections 7 and 8 from Order No. 1169. SNWA shall submit a report detailing the results of the first two years of the pumping. The two-year time period will start when pumping and water export from well MX-5 commences. The report shall be due 180 days after completion of two years of pumping from well MX-5, in other words, the report is due to be filed with the State Engineer $2^1/_2$ years after initiation of the MX-5 pumping and export of water. In addition, SNWA shall submit model simulation results using the SNWA Pipeline EIS groundwater flow model, or a suitable alternative, showing the predicted effects of pumping both existing water rights and current applications in Lower Meadow Valley Wash (Basin 205), Kane Springs Valley (Basin 206), Coyote Spring Valley (Basin 210), Black Mountains Area (Basin 215), Garnet Valley (Basin 216), Hidden Valley (Basin 217), California Wash (Basin 218), Muddy River Springs aka as Upper Moapa Valley (Basin 219), and Lower Moapa Valley (Basin 220). The modeling report shall clearly tabulate and illustrate the modeled effects of the various pumping rates on the monitored groundwater levels, spring flow, and Muddy River flow.

In Section 6 of the Order, the State Engineer ordered the Las Vegas Valley Water District, Southern Nevada Water Authority, Coyote Springs Investment, LLC, Nevada Power Company, Moapa Valley Water District, Dry Lake Water Company, LLC, Republic Environmental Technologies, Inc., Chemical Lime Co., Nevada Cogeneration Associates, or their successors, who presently hold water rights authorized for appropriation from the carbonate-rock aquifer, to provide the other parties to the study and the State Engineer with data on a quarterly basis as to the rate at which water was diverted under the specific water right permits issued, total acre-feet diverted per month, and monthly water level measurements. Multiple parties have expressed a need for daily pumpage data from major producers. Therefore, each of the entities identified in Order No. 1169 Section 3 - the Las Vegas Valley Water District, Southern Nevada Water Authority, Coyote Springs Investment, LLC, Nevada Power Company, the Moapa Valley Water District and the Moapa Band of Paiutes, shall report pumpage on a daily basis for any wells that pump more than ten (10) acre feet in a given month. Those wells without automated monitoring and data recording systems (SCADA) systems must record and report when the wells are in operation on a daily basis, so that when combined with monthly total pumpage it will be possible to ascertain with reasonable accuracy the daily pumpage amounts from the well. Production wells and their required monitoring frequency are shown in the attachment.

The pumping test is expected to begin in August or September of this year. Therefore, all parties are hereby notified that all monitoring activities as outlined in this letter must be in place no later than August 1, 2010.

All reporting shall occur on a quarterly basis. Reports are due to the State Engineer's office within 30 days of the end of each calendar quarter. Water levels and pumpage data are to be submitted to the State Engineer's office in electronic format. Monitoring data will be available to the parties and public to view or download from the Division of Water Resources website http://water.nv.gov/. If you have questions concerning test procedures or reporting, please contact Rick Felling at (775) 684-2866 or rfelling@water.nv.gov.

Sincerely,

P.E.

Jason King, P.E.
State Engineer

JK/ml
Attachment
c: Rick Felling - Email
Susan Joseph Taylor - Email
Kelvin Hickenbottom - Email
John Guillory - Email

Order No. 1169 Monitoring Sites

Groundwater Level Monitoring:

Basin_no	Name	Alias1	WellType	Hydrogeologic Unit	Agency	WL Measurement Frequency	UTM_X	UTM_Y
205	MVWD MW-1		Monitor	Valley Fill	MVWD	Monthly	707906	4087860
205	EH-6		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	717058	4062265
205	EH-8A		Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly	716453	4061395
205	EH-8B		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	716453	4061395
205	NPC-4A		Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly	716557	4062678
205	NPC-5 OLD		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	715288	4064185
205	TH-12		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	716322	4062680
205	TH-31		Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly	715626	4061638
205	TH-35		Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly	717055	4061095
205	TH-8		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	716648	4061854
205	NPC-2		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	716321	4061107
210	CSI-1		Production	Carbonate	CSI/SNWA	Continuous	686043	4074459
210	CSI-2		Production	Carbonate	CSI/SNWA	Continuous	687083	4075781
210	CSI-3		Production	Carbonate	CSI/SNWA	Monthly/Cont.	685813	4077531
210	CSI-4		Production	Carbonate	CSI/SNWA	Monthly/Cont.	682366	4080185
210	CSV-RW2	RW-2	Production	Carbonate	NPC (NVEnergy)	Continuous	687862	4074082
210	CE-VF-1	365232114554401	Monitor	Valley Fill	SNWA	Monthly	683025	4083038
210	CE-VF-2	365227114554401	Monitor	Carbonate	SNWA	Continuous	683007	4082892
210	CSV-3	364127114553001	Monitor	Valley Fill	SNWA	Monthly	685222	4062583
210	CSV3009X		Monitor	Valley Fill	SNWA	Continuous	681075	4094893
210	CSV3011X		Monitor	Valley Fill	SNWA	Continuous	684065	4094870
210	CSVM-1	PAHRANAGAT WASH	Monitor	Carbonate	SNWA	Continuous	688602	4073793
210	CSVM-2	SOUTH PASS	Monitor	Carbonate	SNWA	Continuous	685625	4059370
210	CSVM-3	NORTH PASS	Monitor	Carbonate	SNWA	Continuous	679319	4102600
210	CSVM-4	STINGRAY RIDGE	Monitor	Carbonate	SNWA	Continuous	688086	4095971
210	CSVM-5	MORMON WELL ROAD	Monitor	Carbonate	SNWA	Continuous	680295	4068774
210	CSVM-6	DUTCHFLAT 2	Monitor	Carbonate	SNWA	Continuous	686453	4078333

Order No. 1169 Monitoring Sites

Groundwater Level Monitoring:

Basin_no	Name	Alias1	WellType	Hydrogeologic Unit	Agency	WL Measurement Frequency	UTM_X	UTM_Y
210	CSVM-7	Williams Well	Monitor	Valley Fill	SNWA	Monthly	678234	4101968
210	DF-1	DUTCHFLAT	Monitor	Valley Fill	SNWA	Monthly	686980	4078687
210	MX-5	CE-DT-5	Production	Carbonate	SNWA	Continuous	688084	4074219
210	MX-4	CE-DT-4	Monitor	Carbonate	SNWA/USGS	Continuous	688003	4074277
215	EBM-3		Monitor	Carbonate	Nevada Cogen.	Monthly	689605	4018529
215	BM-DL-1	BM-1	Monitor	Carbonate	SNWA	Monthly	689926	4019483
215	BM-DL-2	BM-2	Monitor	Carbonate	SNWA	Monthly	689270	4019591
215	BM-ONCO-1		Monitor	Clastic Rock	SNWA	Quarterly	702650	4010748
215	BM-ONCO-2		Monitor	Clastic Rock	SNWA	Quarterly	702054	4010722
216	CRYSTAL 1		Grounding	Carbonate	NPC (NVEnergy)	Continuous	694389	4039716
216	CRYSTAL 2		Grounding	Carbonate	NPC (NVEnergy)	Continuous	694146	4039284
216	GV-RW1	RW-1	Production	Carbonate	NPC (NVEnergy)	Quarterly	692928	4036645
216	WELL #1	RS-1	Production	Clastic Rock	Republic Env. Tech.	Monthly	690790	4028841
216	GARNET		Monitor	Valley Fill	SNWA	Monthly	693046	4036387
216	GV-1		Monitor	Carbonate	SNWA	Continuous	682983	4034143
216	GV-2		Monitor	Carbonate	SNWA	Monthly	686226	4025690
216	GV-DUKE-WS1		Production	Carbonate	SNWA	Monthly	686197	4029178
216	GV-MIRANT1		Production	Carbonate	SNWA	Monthly	683115	4032318
216	GV-PW-MW1	PINNACLE WEST MW-1	Monitor	Carbonate	SNWA	Continuous	683460	4031730
216	GV-PW-MW2	PINNACLE WEST MW-2	Monitor	Carbonate	SNWA	Monthly	682652	4031488
216	GV-PW-WS1	PINNACLE WEST WS-1	Production	Carbonate	SNWA	Monthly	682854	4031460
216	GV-DUKE-WS2		Production	Carbonate	SNWA/NPC (NVEnergy)	Monthly	686185	4029177
217	SHV-1	HIDDEN	Monitor	Valley Fill	SNWA/USGS	Continuous	685751	4047256
218	PAIUTES-ECP1	ECP-1	Monitor	Carbonate	MBPI	Continuous	696729	4046590
218	PAIUTES-ECP2	ECP-2	Monitor	Carbonate	MBPI	Quarterly	696723	4046742
218	PAIUTES-ECP3	ECP-3	Monitor	Carbonate	MBPI	Quarterly	696714	4046984
218	PAIUTES-M1	M-1	Monitor	Carbonate	MBPI	Continuous	704517	4057109

Order No. 1169 Monitoring Sites

Groundwater Level Monitoring:

Basin_no	Name	Alias1	WellType	Hydrogeologic Unit	Agency	WL Measurement Frequency	UTM_X	UTM_Y
218	PAIUTES-M2	M-2	Monitor	Carbonate	MBPI	Continuous	695836	4040876
218	PAIUTES-M3	M-3	Monitor	Carbonate	MBPI	Continuous	691536	4044302
218	PAIUTES-TH2	TH-2	Monitor	Carbonate	MBPI	Continuous	697684	4049916
218	BYRON		Production	Carbonate	SNWA	Monthly	710994	4051282
219	ARROW_CANYON		Production	Carbonate	MVWD	Continuous	701104	4067755
219	ARROW CANYON 2		Production	Carbonate	MVWD	Continuous	701103	4067788
219	MX-6	CE-DT-6	Production	Carbonate	MVWD	Monthly	697482	4071381
219	ABBOTT	UM7	Monitor	Valley Fill	NPC (NVEnergy)	Monthly	706443	4065657
219	BEHMER-MW		Monitor	Valley Fill	NPC (NVEnergy)	Monthly	706031	4065280
219	EH-4		Monitor	Carbonate	NPC (NVEnergy)	Continuous	703929	4064736
219	EH-5B		Monitor	Carbonate	NPC (NVEnergy)	Continuous	701569	4067619
219	LDS CENTRAL	UM49	Production	Valley Fill	NPC (NVEnergy)	Monthly	704114	4066544
219	LDS EAST	UM50	Production	Valley Fill	NPC (NVEnergy)	Monthly	704479	4066594
219	LDS WEST	UM18	Production	Valley Fill	NPC (NVEnergy)	Monthly	702746	4067063
219	LEWIS 1 OLD	UM55	Monitor	Valley Fill	NPC (NVEnergy)	Monthly	702077	4068229
219	LEWIS 2	UM74	Production	Valley Fill	NPC (NVEnergy)	Continuous	702339	4067921
219	LEWIS NORTH	UM45	Monitor	Valley Fill	NPC (NVEnergy)	Continuous	701589	4067872
219	LEWIS SOUTH	UM43	Monitor	Valley Fill	NPC (NVEnergy)	Continuous	702737	4067266
219	PERKINS OLD	UM15	Monitor	Valley Fill	NPC (NVEnergy)	Continuous	705637	4065223
219	PERKINS PRODUCTION		Production	Valley Fill	NPC (NVEnergy)	Monthly	705693	4065206
219	CSV-1	364601114514301	Monitor	Valley Fill	SNWA	Monthly	691378	4071630
219	UMVM-1	DEADMAN WASH	Monitor	Carbonate	SNWA	Continuous	694305	4070248
219	CSV-2	364650114432001	Monitor	Carbonate	SNWA/USGS/NV Energy	Continuous	703217	4072967
220	EH-3		Monitor	Carbonate	NPC (NVEnergy)	Continuous	721085	4063300
220	EH-7		Monitor	Carbonate	NPC (NVEnergy)	Continuous	720660	4060990

Order No. 1169 Monitoring Sites

Spring and Stream Flow Monitoring:

Basin_no	Name	Alias1	TYPE	Hydrogeologic Unit	Agency	Production/Flow Data Frequency	Will Monitor for duration of Order 1169 Test	UTM_X	UTM_Y
215	BLUE POINT SPRING		Spring	Stream Gage	NPS	Continuous	Yes	730353	4030271
215	ROGERS SPRING		Spring	Stream Gage	NPS	Continuous	Yes	729420	4028891
219	BALDWIN SPRING BOX		Spring	Flow Meter	MVWD	Continuous	Yes	703257	4066270
219	JONES SPRING BOX		Spring	Flow Meter	MVWD	Continuous	Yes	703714	4065661
219	PEDERSON EAST SPRING GAGE	PLAYBOY POOL GAGE	Spring	Flume	SNWA/USGS	Continuous	Yes	704034	4065063
219	PEDERSON SPRING GAGE		Spring	Weir	SNWA/USGS	Continuous	Yes	704008	4065089
219	WARM SPRINGS WEST GAGE		Spring	Flume	SNWA/USGS	Continuous	Yes	704211	4065272
219	IVERSON FLUME		Stream	Flume	SNWA/USGS	Continuous	Yes	704570	4065296
219	MUDDY SPRING GAGE		Spring	Flume	SNWA/USGS	Continuous	Yes	704018	4066348
219	MOAPA GAGE		Stream	Stream Gage	USGS	Continuous	Federally Funded	705823	4065350
220	LEWIS AVENUE NEAR OVERTON GAGE		Stream	Stream Gage	SNWA/USGS	Continuous	Yes	730091	4046454
220	GLENDALE GAGE		Stream	Stream Gage	USGS	Continuous	Federally Funded	719897	4058057

Order No. 1169 Monitoring Sites

Groundwater Pumpage:

Basin_no	Name	Alias1	Agency	Hydrogeologic Unit	Production / Flow Data Fequency	Permit	UTM_X	UTM_Y
210	CSI-1		CSI/SNWA	Carbonate	Daily	70430	686043	4074459
210	CSI-2		CSI/SNWA	Carbonate	Daily	70429	687083	4075781
210	CSI-3		CSI/SNWA	Carbonate	Daily	74094	685813	4077531
210	CSI-4		CSI/SNWA	Carbonate	Daily	74095	682366	4080185
210	CSV-RW2	RW-2	NPC (NV Energy)	Carbonate	Daily	77164	687862	4074082
210	MX-5	CE-DT-5	SNWA	Carbonate	Daily	77292	688084	4074219
215	EBP-2		Nevada Cogen.	Carbonate	Monthly	55269	689628	4018599
215	EGV-3		Nevada Cogen.	Carbonate	Monthly	58031	689858	4018999
215	EBM-4		Nevada Cogen.	Carbonate	Monthly	58032	689784	4018826
216	OLD		Chemical Lime Co.	Valley Fill	Monthly	63261	687941	4029333
216	NEW		Chemical Lime Co.	Carbonate	Monthly	64880	687748	4026563
216	GV-2	Central Well	Dry Lake Water Co.	Carbonate	Monthly	66784	686226	4025690
216	GV-RW1	RW-1	NPC (NV Energy)	Carbonate	Daily	74399	692928	4036645
216	WELL #2		Republic Env. Tech.	Carbonate	Monthly	67716	690674	4027890
216	WELL #5		Republic Env. Tech.	Carbonate	Monthly	67715	691053	4029626
216	WELL #6		Republic Env. Tech.	Carbonate	Monthly	67718	690552	4026318
216	GV-DUKE-WS1		SNWA	Carbonate	Daily	73149	686197	4029178
216	GV-MIRANT1		SNWA	Carbonate	Daily	68822	683115	4032318
216	GV-PW-WS1	PINNACLE WEST WS-1	SNWA	Carbonate	Daily	72798	682654	4031460
216	GV-DUKE-WS2		SNWA/NPC NV Energy	Carbonate	Daily	73150	686185	4029177
218	TH-1		MBPI	Carbonate	Daily	76643	697233	4044981
218	PAIUTES-ECP-1	South	MBPI	Carbonate	Daily	70257	696729	4046590
218	PAIUTES-ECP-2	Middle	MBPI	Carbonate	Daily	70259	696723	4046742

Order No. 1169 Monitoring Sites

Groundwater Pumpage:

Basin_no	Name	Alias1	Agency	Hydrogeologic Unit	Production / Flow Data Fequency	Permit	UTM_X	UTM_Y
218	PAIUTES-ECP-3	North	MBPI	Carbonate	Daily	70258	696729	4046590
219	MX-6	CE-DT-6	MVWD	Carbonate	Daily	46932	697482	4071381
219	ARROW_CANYON		MVWD	Carbonate	Daily	52520	701104	4067755
219	ARROW CANYON 2		MVWD	Carbonate	Daily	66043	701103	4067768
219	BEHMER	UM14	NPC (NV Energy)	Valley Fill	Daily	29296	706031	4065080
219	LDS CENTRAL	UM49	NPC (NV Energy)	Valley Fill	Daily	50732	704114	4066544
219	LDS EAST	UM50	NPC (NV Energy)	Valley Fill	Daily	50723	704479	4066594
219	LDS WEST	UM18	NPC (NV Energy)	Valley Fill	Daily	50724	702746	4067083
219	LEWIS 1		NPC (NV Energy)	Valley Fill	Daily	24186	702182	4068043
219	LEWIS 2	UM74	NPC (NV Energy)	Valley Fill	Daily	24186	702339	4067921
219	LEWIS 3		NPC (NV Energy)	Valley Fill	Daily	22633	701956	4068021
219	LEWIS 4		NPC (NV Energy)	Valley Fill	Daily	22636	702028	4067620
219	LEWIS 5		NPC (NV Energy)	Valley Fill	Daily	22632	702196	4067485
219	PERKINS PRODUCTION		NPC (NV Energy)	Valley Fill	Daily	50272	705693	4065206

Note: If pumping from a given well is les than 10 acre feet per month, daily pumpage reporting is not required.

THE CHURCH OF
JESUS CHRIST
OF LATTER-DAY SAINTS

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STATE ENGINEERS OFFICE

MEETINGHOUSE FACILITIES DEPARTMENT
Real Estate Services Division
50 East North Temple Street
Salt Lake City, Utah 84150-0012
Phone: 1-801-240-3840
Facsimile: 1-801-240-2913

Dear State Engineer Wilson,

As you know, The Church of Jesus Christ of Latter-day Saints, a Utah corporation sole (the "Church") holds various surface and groundwater rights in the Lower White River Flow System ("LWRFS"). To date, the Church's Grant Cooper, Ph.D., P.E. has participated in many of the stakeholder sessions organized by your office.

For purposes of a clear record, the Church joins in the technical evidentiary submissions (initial and rebuttal), made by the City of North Las Vegas. Although the Church joins and agrees with the analysis and conclusions contained in these submissions, the Church does not request an allotment of time to present evidence or to cross-examine witnesses during the two week hearing scheduled to commence on September 23, 2019. The Church will continue to monitor these proceedings and offer the City of North Las Vegas any assistance it may request.

Should the State Engineer undertake further proceedings with respect to the LWRFS, the Church would reserve its right to offer evidence and testimony, as well as its right to cross-examine witnesses, on subjects outside of those being considered under Interim Order 1303, including but not limited to subjects such as overall water policy and purported interference between groundwater and surface water, which were topics identified as not being a part of the upcoming two week hearing, during the Pre-Hearing Conference on August 8, 2019.

Thank you for considering the technical reports and testimony submitted by the City of North Las Vegas.

Sincerely yours,

Roy McDaniel

Roy McDaniel
Water Resources Manager
Natural Resource Services Section
The Church of Jesus Christ of Latter-day Saints

Letter to SE re LWRFS

MOAPA BAND OF PAIUTES

MOAPA RIVER INDIAN RESERVATION
BOX 340
MOAPA, NEVADA 89025
TELEPHONE (702) 865-2787

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STATE ENGINEERS OFFICE

May 26, 2010

Jason King, P.E., State Engineer
Nevada Division of Water Resources
901 South Stewart St., Suite 2002
Carson City, NV 89701

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Nevada Field Office
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U.S. National Park Service
601 Nevada Way
Boulder City, NV 89005

Re: Order 1169 Study

To Whom It May Concern:

The Moapa Band of Paiutes has recently been recognized as a participant in the upcoming water study called for under State Engineer's Order 1169. The Tribe is also a signatory to the Memorandum of Agreement dated April 20, 2006, which is designed to provide protection to the endangered Moapa dace, including protection from pumping of regional groundwater in a manner which may harm Muddy Springs, the dace's habitat.

We recently received the enclosed unsolicited report from MAI, Inc., the Tribe's hydrogeologic consultants. MAI's analysis concludes that the pump test itself will likely impact the dace, and that such impact will persist long enough that the protective features of the MOA may not be adequate to protect the dace from harm. To avoid the potential risk to the dace projected by MAI, the most prudent course may be to reduce or phase in the pump test while the effects of the mitigation now specified in the MOA are carefully monitored. As the scope of the pump test is mandated by Order 1169, any reduction or phase-in would have to be approved by the State Engineer.

The Tribe, and Marty Mifflin and Cady Johnson of MAI, wish to share the MAI report with you so that you may promptly independently evaluate the report and its conclusions regarding the effectiveness of the pumping cut-backs in wells up-gradient of the Muddy River Springs, specified in the MOA as mitigation measures. We request that we all then participate in a timely, pre-pump-test meeting to discuss how best to proceed.

The Tribe also has an independent pending request to the State Engineer to require real-time monitoring of certain wells, particularly wells maintained by Nevada Energy, which we believe will improve monitoring.

We appreciate the responsibilities associated with participation in the MOA and Order 1169 processes, and look forward to working with you. Please feel free to contact us, or MAI directly at (702) 395-8451, if you have any questions or concerns about the report.

Very truly yours,

MOAPA BAND OF PAIUTES

Darren Daboda
Chairperson

Encl.

Order 1169 Impacts

Mifflin & Associates, Inc.
Las Vegas, Nevada

May 27, 2010

Preface by Dr. Martin Mifflin

The Moapa Band of Paiutes' (MBP) hydrogeologic contractor, Mifflin and Associates Inc (MAI) has conducted comprehensive analyses of monitoring records in preparation for the Order 1169 test. Order 1169 was issued to validate the Las Vegas Valley Water District (LVVWD) model docketed as Exhibit 54 (LVVWD, 2001) in the 2001 State Engineer hearing on LVVWD's applications. Based on past analyses of Muddy River Springs area (MRSA) pumpage, 1:1 pumping impacts on Muddy River flows have been shown to occur through water-balance accounting (Johnson and Mifflin, 2006) but specific sources of impacts had been very difficult to confidently identify and measure due to several data-related problems. However, with longer monitoring records now available and better documentation of region-wide annual and multi-year water-level fluctuations, a new analytical strategy – presented here – has been developed by MAI that has proven successful well beyond expectations. The large CSI pumping stresses that began in 2006 have been identified and their impacts confidently resolved in the MRSA monitoring records; the analyses demonstrate 1:1 impacts developing 9-10 months after pumping during the first three years of Coyote Springs Investments (CSI) groundwater development in Coyote Spring Valley. The analytical objectives of Order 1169 have been met: the magnitude and rate of development of impacts have been estimated in the MRSA. Reduction of the monitoring databases into useful formats for analyses has been labor-intensive, but the analytical strategies are straightforward and reproducible.

The results of the MAI analyses are consistent with independent lines of evidence gathered over many years. All developed hydrogeologic evidence, beginning in the 1960's (Eakin, 1966; Mifflin, 1968) indicated Coyote Spring Valley is a direct source basin for Muddy River Springs flow. Databases confirming the transmissive characteristics of the carbonate-rock aquifer and small hydraulic gradients were established by Fugro/Ertec during the MX Program (Ertec Western, 1981) and extended geographically by new CSI production wells, SNWA monitoring wells, and associated monitoring records within Coyote Spring Valley. As far north (and into) Kane Springs Valley, all databases have combined to document a highly transmissive carbonate-rock aquifer in close hydraulic continuity with the Muddy River Springs discharge area. Pump anywhere upgradient of the Springs within this interconnected transmissive zone and 1:1 impacts will develop on flows in the Muddy River Springs discharge area - and now there is a good measure of timing for the rate of development of impacts to a full 1:1 ratio from pumpage in southeastern Coyote Spring Valley.

The rate and magnitude of impacts resulting from CSI pumping stresses applied in Coyote Spring Valley indicate a potential for highly undesirable consequences from the currently proposed design of the Order 1169 pump test. Reduced flows in already marginal Moapa Dace habitats in the Springs area, including in several of the tributary reaches that historically provided the best habitats, and the recent (synchronous with the first large CSI pumping impact) drop in population counts by approximately 60% from 2007 to 2008 (USFWS, 2008) indicate that a choice may exist between development of 50% of permits for two years, as prescribed by Order 1169, or maintaining flows required for the remaining quality Dace habitats. The 2006 Memorandum of Agreement (MOA) between regional water users and the U.S. Fish and Wildlife Service, with mandated pumping reductions designed to limit existing Dace habitat-flow declines at the Springs to specified trigger levels, is ineffective because of the full development of 1:1 impacts from pumping upgradient from the Springs. Just as important, the impacts persist long after MOA-prescribed actions reduce pumping stresses.

The MOA stipulations related to trigger-level flows and actions to protect in-stream flows of Dace habitat reaches would fail to accomplish such objectives during execution of Order 1169 as currently planned with 8050 ac-ft/yr (11.12 cfs) pumping stress. In fact, MOA stipulations assure that, whatever level of pumping stresses may be adopted for the Order 1169 test, the 1:1 level of impacts from the full initial pumping stress would be acting for many months in the Springs area, perhaps for well over a year even if the final trigger level of 2.7 cfs at the Warm Springs West gage were to be reached or significantly exceeded (as could occur with 11.12 cfs of constant stress and would be even more likely if pumping varies seasonally to achieve an annualized 11.12 cfs). If it requires 9 months for full development of 1:1 impacts in the Springs area flows, it also will take 9 months for the stipulated actions of decreases or termination of the pumping stress in Coyote Spring Valley to fully register in the Springs area flows. Further adding to the problem are the 45- or 90-day periods stipulated before actions are taken, and the number of trigger-level actions required before the pumping stresses in Coyote Spring Valley begin to be reduced. Contrary to the intent of the MOA, the MOA stipulations would act to wipe out Dace habitats and local Dace populations if the initial pumping stress selected for the Order 1169 test proved to be too large. As there seems to be considerable uncertainly in flow requirements, a very cautious approach in applying the initial pumping stresses is warranted.

With these anticipated problems stemming from full-scale Order 1169 implementation, and given that 1:1 impacts are already evident in the existing monitoring records, alternative strategies warrant careful consideration and would be wise in light of these new findings. MAI urges the participants to approach the production requirement of Order 1169 in a step-wise fashion by delaying full-scale pumping until the analyses presented herein have been competently reviewed. Participants are unlikely to accept the MAI analyses without the opportunity for comprehensive review and rebuttal, and will require adequate time for such reviews. The ramifications of the MAI findings are far-reaching, and Order 1169 is effectively in process with lower-level but useful pumping stresses providing sufficient data for impact analyses. Higher-resolution pumping and streamflow data would allow MAI results to be refined, particularly with respect to features that are presently hidden within the very coarse monthly pumping tabulations from production wells near the most important monitoring localities, some of which record measurements at 15-minute intervals and others hourly. Adding on comprehensive documentation of real-time pumping activity and continuous gauging of individual low-flow Dace-habitat reaches would provide useful additional information to support a decision of whether the full production level planned in Coyote Spring Valley is necessary, wise, or desirable.

We are confident the results of MAI analyses are as reliable as the existing databases allow. One of the reasons for confidence is internally consistent results obtained from independent analytical steps in the scaling evaluation. Further, one does not need to be an expert in hydrograph analyses to recognize the marked change in pattern of the Muddy River flows and the marked lows in River flows that began during 2007, and continue to the end of data availability. We have recommended refinements in monitoring database collections that would allow more refined analyses. Also, some information used in our analyses (for example, reported daily production from the CSI1 well that at times exceeds the tested capacity of the well) is suspect.

Annual Muddy River flows have declined in lock-step with groundwater production in the MRSA since the early 1960s. Monitoring records now demonstrate the same level of system response to Coyote Spring Valley pumpage. It is not acceptable to ignore these Muddy River Springs-area responses if the remaining Moapa Dace habitats and populations are to be maintained. The issued but undeveloped permits in the Coyote Spring Valley groundwater basin essentially equal the remaining flows of the Muddy River and Muddy River Springs.

Figures 1 and 2, and Figure 16 of the following section tell the story perhaps as well as the analytical methodology and quantitative results. Figure 1 illustrates a period of flows between 1913 and 1918 in the Muddy River at the Moapa gage before flows began to respond to local groundwater development (note peak winter flows at 51-53 cfs). Figure 2 illustrates the current flow regime as well as the various diversions that have prevented water flows from exceeding 40 cfs in recent years. The key relationship that doesn't require an expert to recognize is the change in the pattern of Muddy River flows after 2006. The markedly reduced summer flows occurred during a period when the totals of non-CSI diversions are generally smaller than in previous years. The new pattern of low summer flows begins in the summer of 2007, after the first season of CSI pumping in 2006. Figure 16 of the following section illustrates how the River hydrograph responded to production by CSI, and is quantified in our analyses and derivations of full 1:1 impacts about 9 months (Warm Springs West gage) and 10 months (Muddy River at Moapa gage) after pumping occurs in southeastern Coyote Spring Valley.

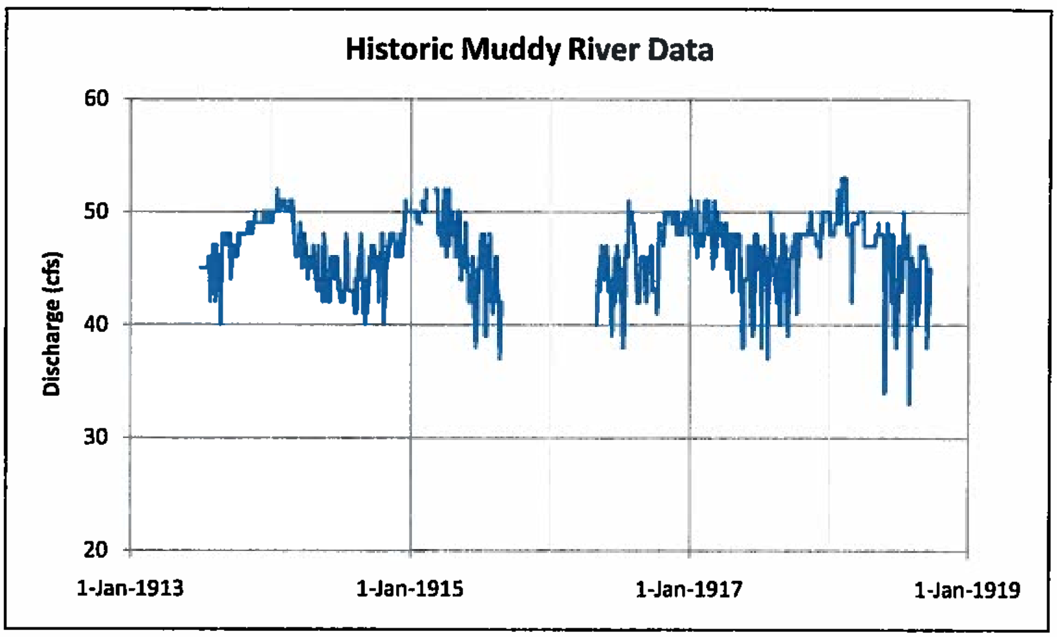

Figure 1. Recorded daily flows of the Muddy River between 1913 and 1918, prior to any known groundwater production from wells. Minor data gaps represent storm surges that have been removed (censored) from the record. Note the effects of irrigation diversions during the summer months. [file MuddyRivQ_1913-1918.xls, Sheet NarrowCensor]

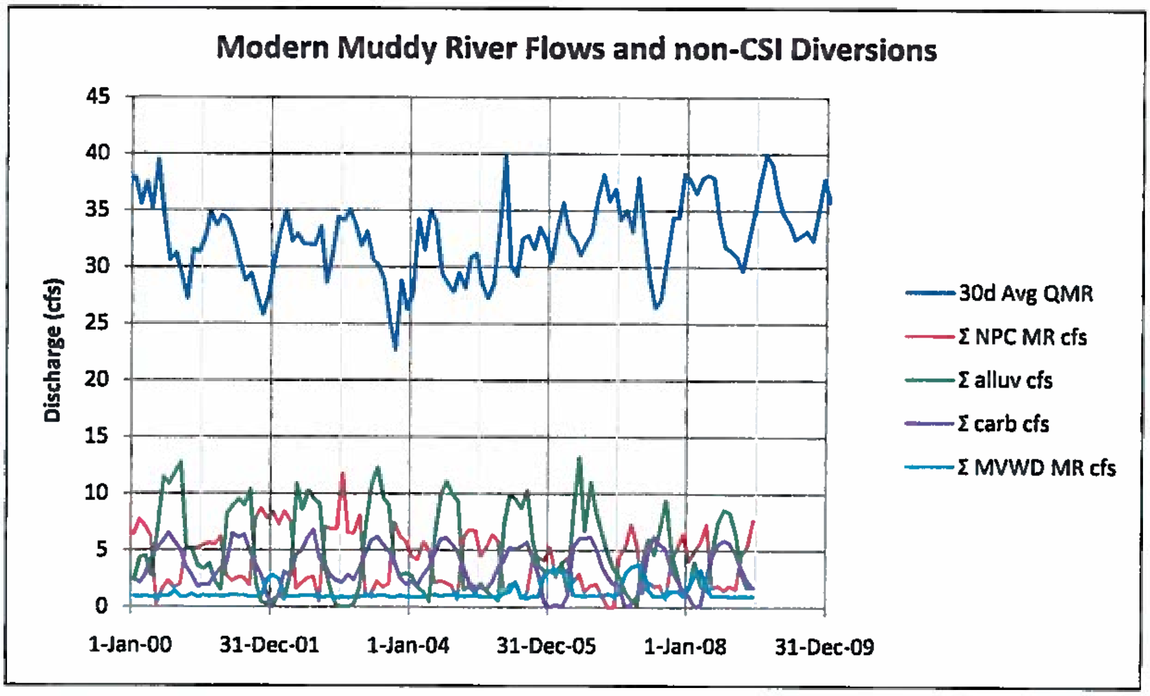

Figure 2. Average monthly flows in the Muddy River from 2000 through 2009, with municipal (MVWD) and industrial (NPC) diversions. Data associated with rain days and associated storm surges have been censored (removed) from the record. "alluv" indicates the alluvial aquifer, "carb" indicates the carbonate-rock aquifer, and "MR" indicates diversions directly from the River or its tributaries. [File MuddyRivQ_2000-2010b.xlsx, Sheet 'MonthlyRaw']

MAI offers the following analytical methodology and results to other Order 1169 Participants in anticipation of their independent and in-depth analyses, followed by technical exchanges on results. MAI also suggests all involved directly with the Order 1169 pump test should make independent reviews of the implications of MAI analytical results with respect to how effectively the MOA would serve to limit impacts. Perhaps attention should also be focused on the 60% Dace population crash that apparently occurred sometime in 2007 (and continued similar population counts). The CSI pumping resulted in 1:1 impacts in 2007 after the first large CSI production year of 2006 and that have continued in subsequent years.

Approach and Analyses by Dr. Cady Johnson

Mifflin & Associates, Inc. (MAI) has carefully analyzed ten years of water-level records from MBP's 5-well monitoring network, water levels from the USGS CE-DT-4 (MX-4) and Nevada Energy Company (NPC/NEC) EH-5b monitoring wells, springflow records from Big Muddy Spring and Warm Springs West, stream-gauging data for the Muddy River, production records from NEC and and Moapa Valley Water District (MVWD) plus four years of drilling, development, and production records from Coyote Springs Investments (CSI) (Figures 3a, 3b).

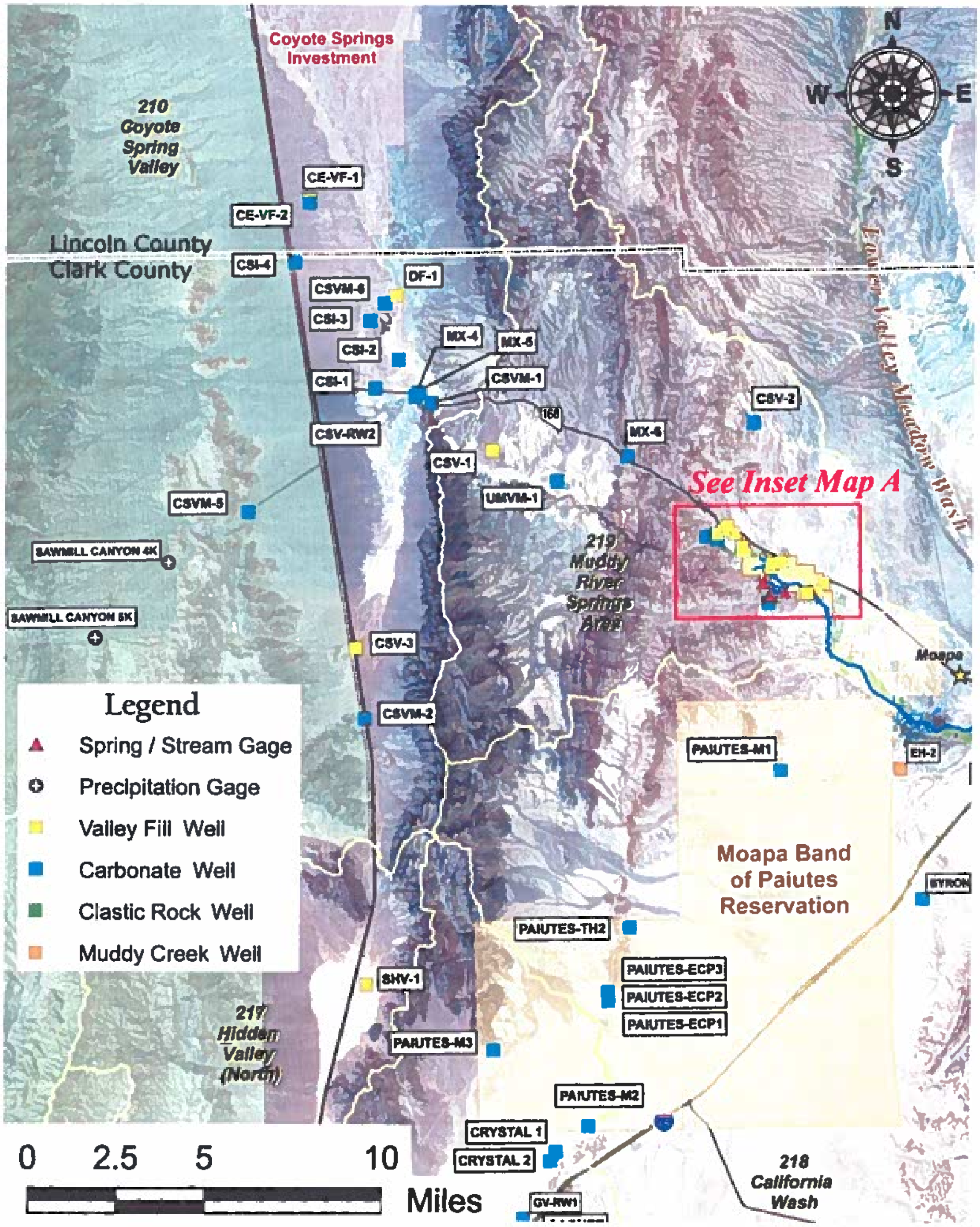

Figure 3a. Location of study area; map and "Insert Map A" (Figure 3b herein) have been modified and corrected from source file "CSI_Monitor_Points_Map.pdf", which is stored in the SNWA Common Data Repository at www.snwawatershed.org/portal. (file MonitoringPtMapSmallGR83.jpg)

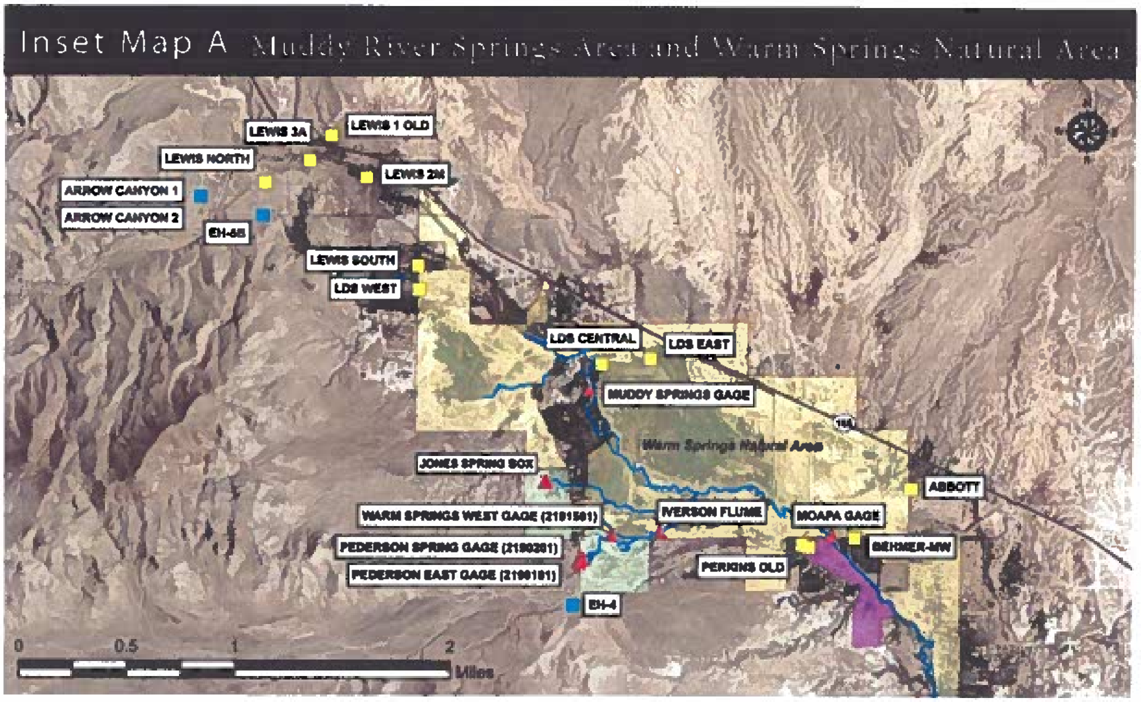

Figure 3b. Detail area from Figure 3a; Legend from Figure 3a applies. Unmodified from source, same as Figure 3a. (file MonitoringPtMapInsetAGR83.jpg)

From the inception of the MBP monitoring program in 2000 until late 2004, yearly-average water levels in the five MBP monitoring wells and several other monitoring wells in the region including MX-4 (monitored by the USGS) and EH-5b (monitored by NVE) were decreasing, with generally sinusoidal, seasonal variations about linear long-term decline trends (Mayer and Congdon, 2008). Seasonal water-level cycles that track those at MX-4, and follow the same pattern as long-term discharge rates at Warm Springs West, dominate the hydrographs. The origins of the sinusoidal component of the MBP hydrographs has long been an issue, but the absence of systematic phase differences or attenuation with distance from known pumping wells suggested that pumping effects were absent, and that climate was solely responsible for the seasonal water-level variations in the MBP wells (Johnson and Mifflin, 2006). The winter of 2004-2005 was unusually wet, and was followed by two years of rising water levels and increasing springflow in upper Moapa Valley. This climatic impulse produced distinctive responses in the hydrographs of the region, and the expectation that climatic responses are more uniform in space than pumping effects presents the opportunity to resolve these two primary influences on water levels using new approaches that we begin to explore here.

The fundamental premise in the following analyses is that springflow is deterministically responsive to regional water levels. There is no other underlying assumption. In a new analytical approach, described below, MAI has developed a *Synthetic Reference Hydrograph* (SRH) based on comparison of the ECP-1 and TH-2 hydrographs with that from MX-4. Subtraction of paired (hourly or daily) data points filters the climatic component from this composite record, producing a *difference* hydrograph (DH) so perturbations in either area can be recognized as a departure from the typical closely-correlated relationship.

The first potential perturbation to be considered was pumping at the MVWD Arrow Canyon #1 Well (ACW) which is usually pumped at about 5 cfs during the peak (summer) season. It was observed that maxima and minima of the ECP-1/MX-4 difference hydrograph bear a close correspondence to the pattern of pumping at ACW until about 2006, and was so similar in 2001-2004 (before CSI activities began) that fortuitous similarity is unlikely (Figure 4). Furthermore, comparison of the best-defined peaks in ACW production and DH response reveals a 4-week lag between cause and effect (caveat: production data are currently reported *monthly*, and although we interpolated to weekly values for this analysis and a 4-week lag is indicated, we do not imply week-scale precision of the lag estimate). Notably, there is a *positive* correlation between the signals illustrated in Figure 4; as pumping increases at the ACW, the difference between MX-4 and ECP-1 water levels also increases. Since pumping would be unlikely to cause the water level in another well to rise systematically, it appears that ECP-1 (which has the lower water level elevation) is experiencing a seasonal drawdown effect from ACW.

Possible influences of NPC/NEC pumping seasonally from the alluvial aquifer of upper Moapa Valley on the DH hydrograph were investigated next. The years 2001-2002 are of particular interest, since the ACW was shut down for most of January, 2002, an atypical event at that time. During the summers of 2001 and 2002 Nevada Power Company (NPC) operated its Lewis and LDS well fields analogously to a square-wave impulse to the hydrologic system that was twice as strong and more sustained than the pattern of pumping by MVWD (Figure 5). The fact that the sawtooth pattern of the DH that was maintained in 2001-2002 demonstrates little or no effect of alluvial pumping on ECP-1, consistent with Johnson and Mifflin (2006). Incorporating the good correspondence that exists between ACW production, lagged four weeks, and the DH, the linear relationship (Figure 6) that explains variations in head difference between MX-4 and ECP-1 as responses to ACW pumping was used to adjust the ECP-1 hydrograph for the ACW effect. This is the Synthetic Reference Hydrograph or SRH (Figure 7) a tool that is particularly useful for understanding excursions of springflow from "normal" trends.

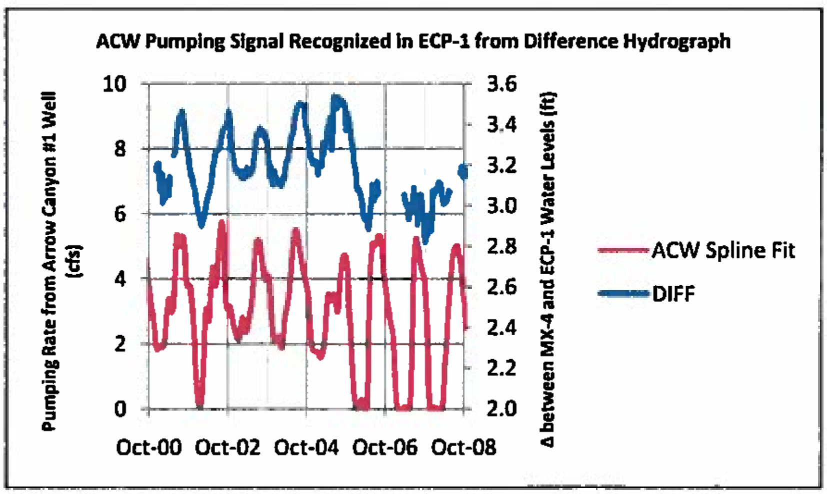

Figure 4. Difference hydrograph, obtained by subtracting weekly average water levels in ECP-1 from those in MX-4, compared with pumping rate of Arrow Canyon #1 well. The monthly well production totals were interpolated to weekly values with a cubic spline approximation. The relationship indicates that as well production increases the difference between the reference hydrographs increases, meaning that water levels in ECP-1 are being lowered relative to MX-4. [file ACW_QmonthsToWeeks.xls, Sheet 'AllWeeks']

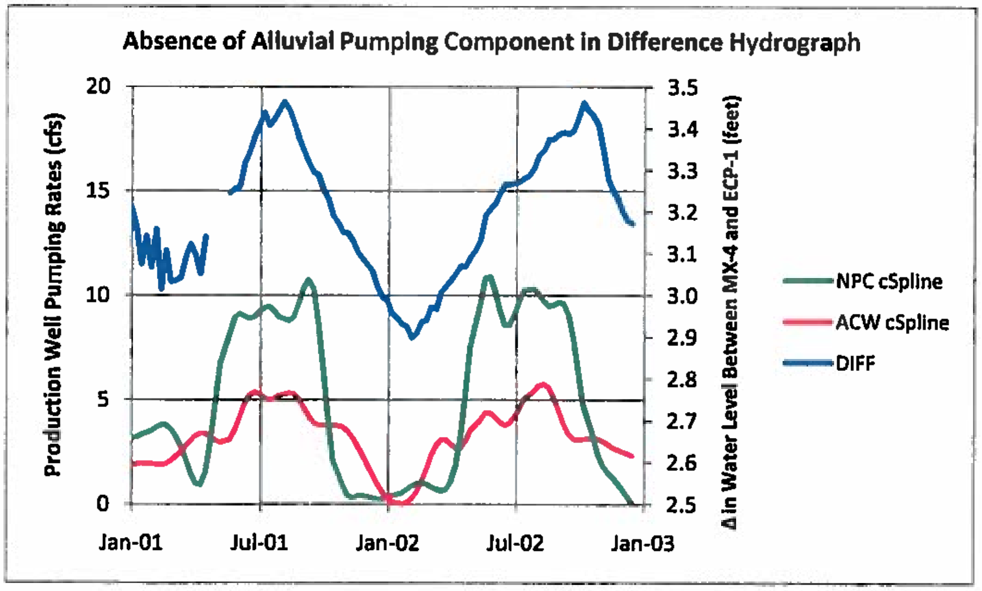

Figure 5. The sawtooth pattern of the difference hydrograph in 2001-2002 closely mimics the pattern of seasonal pumping from the Arrow Canyon #1 well, and is almost completely unaffected by the square-wave alluvial pumping signal that is roughly twice as strong and seasonally more sustained. The data gap in the difference hydrograph is where MX-4 data are missing. Monthly production data were interpolated to weekly values by a cubic spline approximation. [file Production.xls, Sheet 'Diffs00-02']

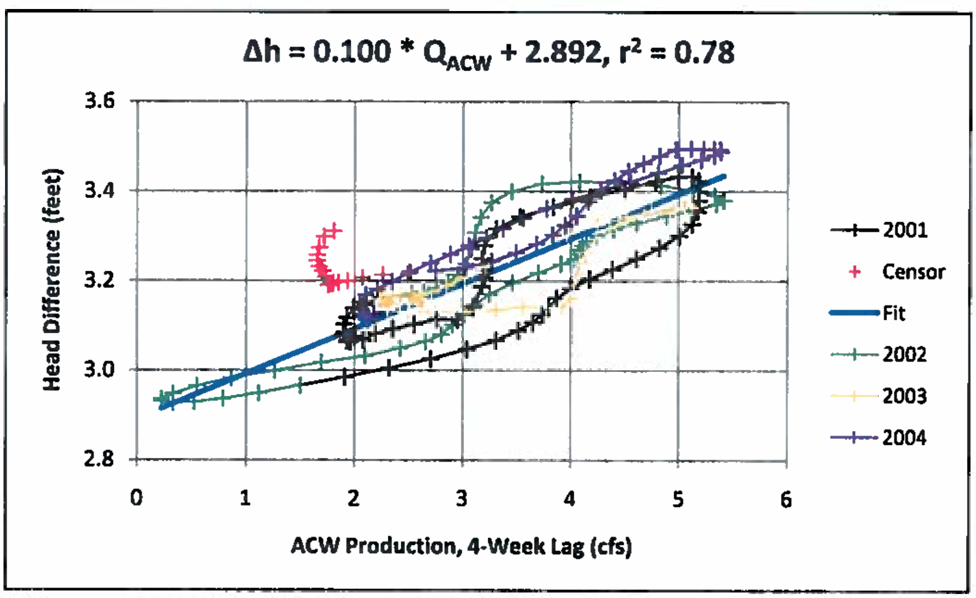

Figure 6. Correlation relations between Arrow Canyon #1 production and head difference between MX-4 and ECP-1 for 2001 through 2004. "Censor" indicates data from late 2004 not considered in the regression; heavy precipitation in that time frame may have caused a water-level rise in MX-4.

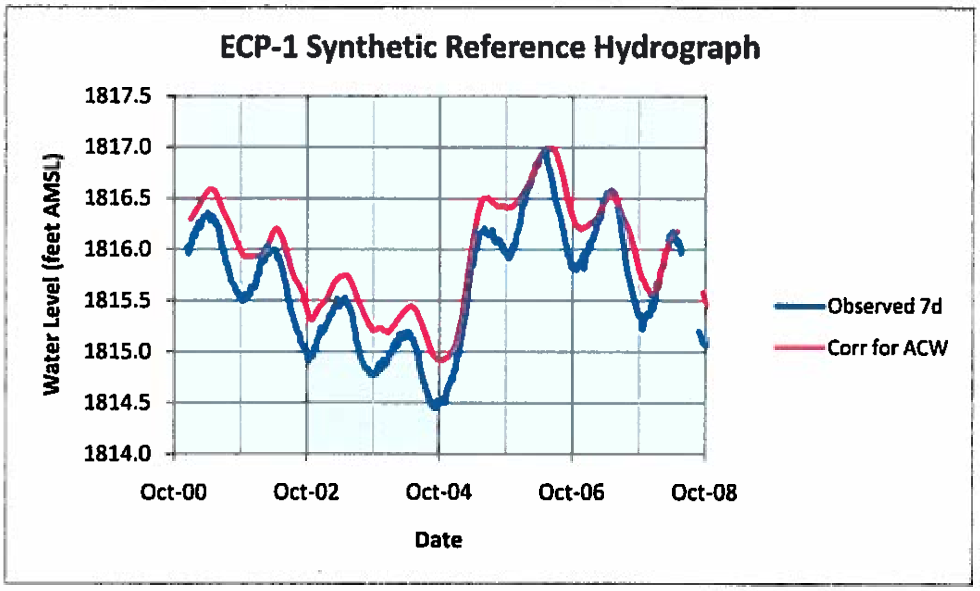

Figure 7. Synthetic reference hydrograph developed from differences in 7-day average ECP-1 water levels relative to the MX-4 monitoring well, with adjustment for pumping stress attributable to the Arrow Canyon #1 well. [file Production.xls, Sheet 'SyntheticHydrograph')

Transformations of the SRH are useful as indicators of baseline flow conditions in individual springs and the Muddy River, after censoring (adjusting) discharge records to eliminate data from rain days (River) and operational disturbances (springs). In the case of the Muddy River, effects of winter precipitation are particularly difficult to remove from the discharge record without introducing large data gaps, resulting in annual maxima that are less uniform in the reconstituted record than annual minima. Details of how basic data were scrubbed for representativeness are not elaborated here.

Warm Springs West Trend

To utilize the SRH as a reference discharge indicator for springflow, it is necessary to detrend and scale the long-term hydrograph (which has a length dimension) to be proportional to the discharge measurements (volumetric flow rate) by a linear transformation (Figure 8). The process is exploratory, requiring a choice of the time interval that contains the antecedent trends in the hydrographs being compared, then additional choices of how to align the detrended hydrographs in scale (such as fitting maxima or minima) and time (by shifting time scales to account for lags between stimulus and response). These linear transformations are non-unique, but ultimately preserve the form of the original data and provide a basis for quantitative comparison of discharge records and water levels. Appropriately-scaled head data can be considered to be cfs-equivalents in this approach. When fitted to springflow maxima, the scaled SRH should tightly drape the springflow record, matching at times when spring discharge is unaffected by pumping activity. The drape-fit of the SRH on the springflow record (Figure 9) demonstrates a discharge deficit at Warm Springs West after 2006, the year CSI began producing from their CSI1 well. Discharge plotted in Figure 9 is partially reconstituted to account for the influence of the ACW, derived by minimizing the amplitude of the 2001-2004 hydrograph (Figure 10). A scale factor of 0.015, derived interactively by trial-and-error, indicates that for each 1 cfs pumped from the ACW, 0.015 cfs (1.5%) is accounted for by capture from Warm Springs West.

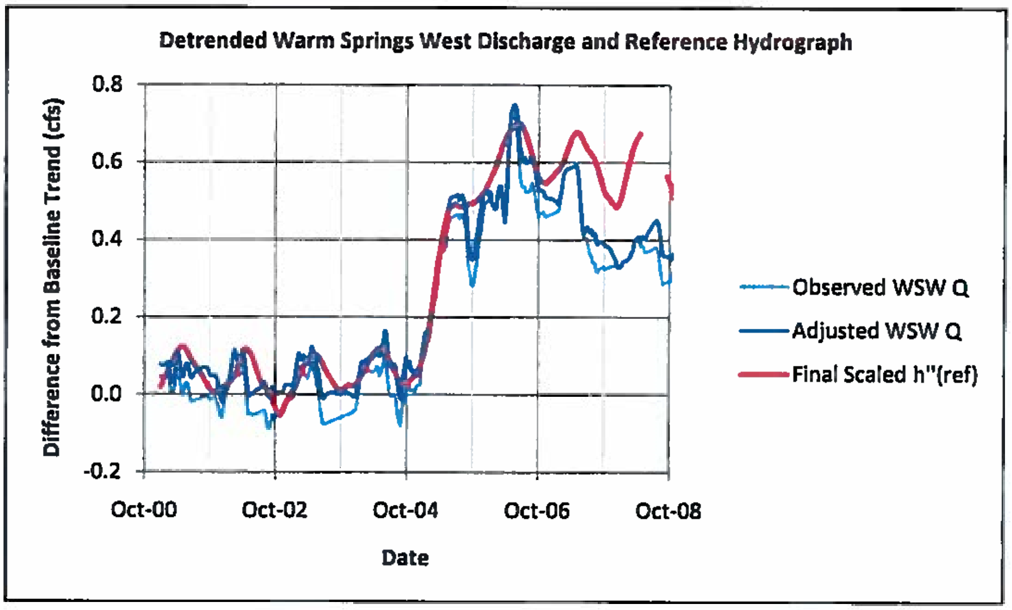

Figure 8. Detrended hydrographs, expressed as differences from their baseline (2001-2004) trends, with synthetic reference hydrograph (SRH) scaled to drape springflow. The adjustment to Warm Springs West discharge removes the effect of the Arrow Canyon #1 well. [File CSI&ACWimpacts3.xls, Sheet Scaling3]

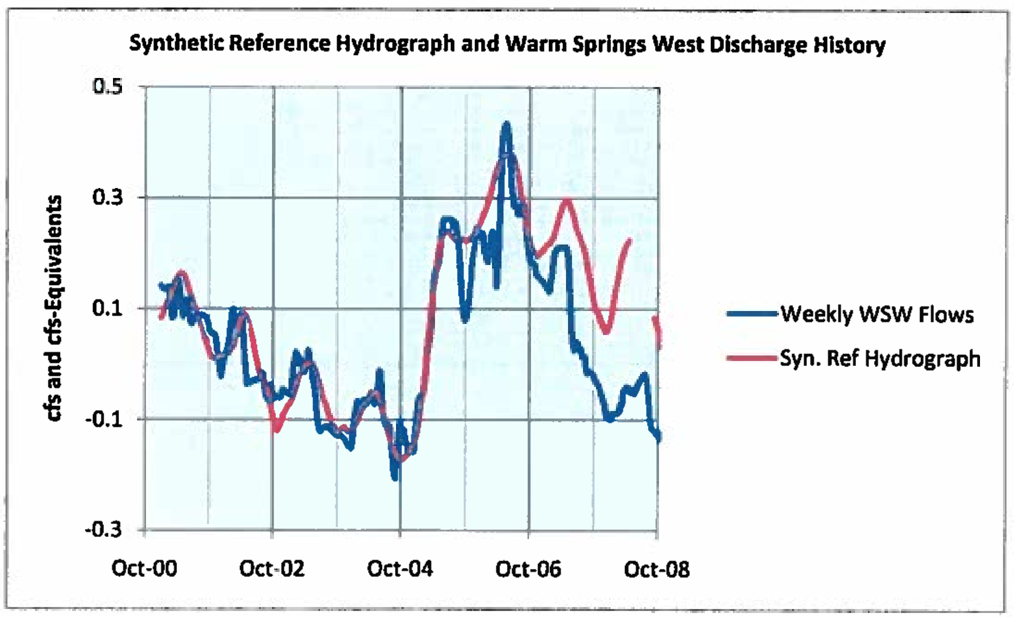

Figure 9. Re-trended hydrographs, showing progressive divergence of Warm Springs West discharge from Synthetic Reference Hydrograph beginning in late 2006, the year that continuous production by Coyote Springs Investments began. [file CSI&ACWimpacts2.xls, Sheet 'Scaling3']

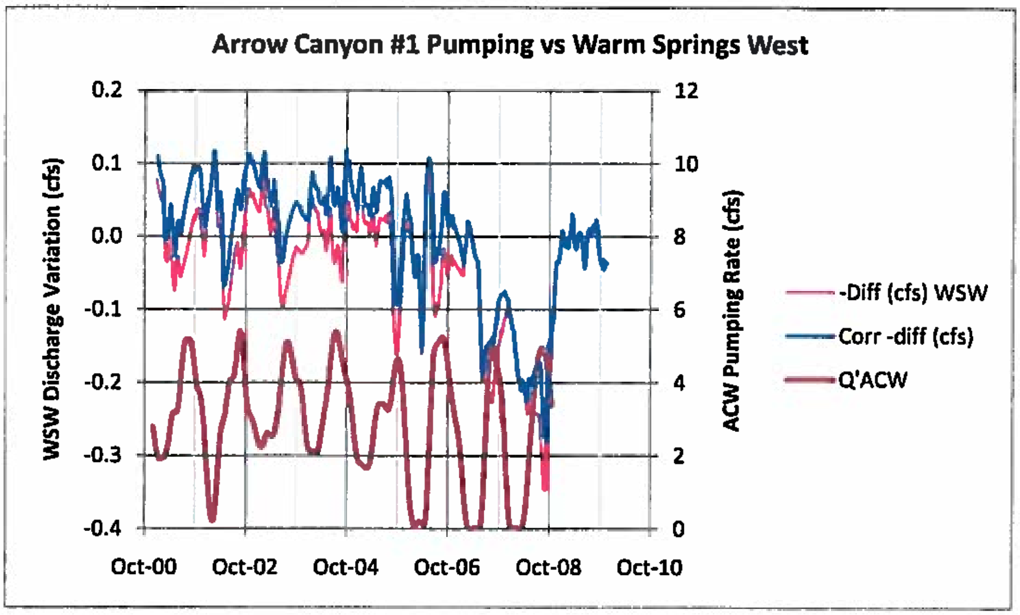

Figure 10. Scale factor of 0.015 minimizes the effects of the Arrow Canyon #1 well on Warm Springs West discharge; for each 1 cfs pumped from the well, 0.015 cfs is accounted for by capture from the Springs. (file CSI&ACWimpacts2.xls, Sheet 'ACWfineTuning')

CSI Impacts at Warm Springs West

Three production wells operated by Coyote Springs Investments were considered as having the potential to capture flow from Warm Springs West. Weekly production data were compiled from records submitted to the Nevada State Engineer; additional information pertaining to well-development activities is available in reports by Johnson (2005a,b; 2007). Weekly averages were prepared from the production records, since generally the totalizing meters were not read on a daily basis.

Well CSI1 was completed in May of 2005, with development and production testing occurring in the latter half of that same month. CSI1 entered service in January of 2006, primarily for grading and dust control, according to information on file with the State Engineer. CSI2 was completed in August of 2005; development pumping began on August 29 and production testing ended on October 1. CSI2 entered service in July of 2006. CSI3 was completed in August of 2006, with development and production testing taking place between August 10 and September 14. CSI3 entered service in June of 2007. Johnson (2007, p. A-13) reports development activity at a Well #4, but production from this facility was minor and intermittent through 2008.

The CSI pumping signal is well-expressed in the Warm Springs West discharge record, and lags the actual pumping by 9 months (Figure 11). The proportional reduction of Spring discharge is 5.8%, meaning Springs discharge is reduced by 5.8% of pumpage with a 9 month delay (Figure 12). "Raw CSIT" on the Figure 11 chart represents the time the pumping occurred; "Lag CSIT" presents the pumping data 9 months later to illustrate correspondence of the lagged signal with changes in springflow.

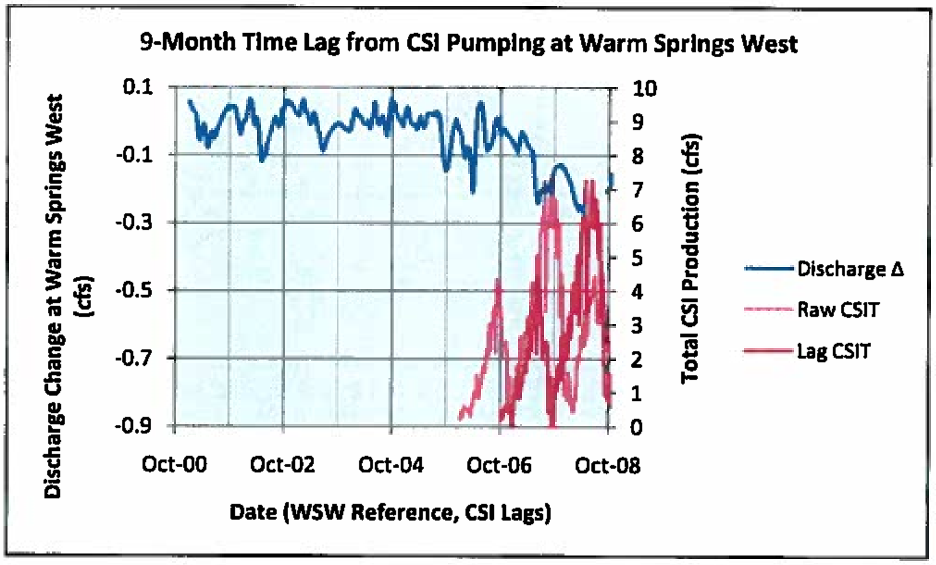

Figure 11. Pumping effects at Warm Springs West attriutable to CSI activity, accounting for the 9-month lag that provides the best correspondence between peaks. [file CSI&ACWimpacts3.xls, Sheet 'CSIimpacts')

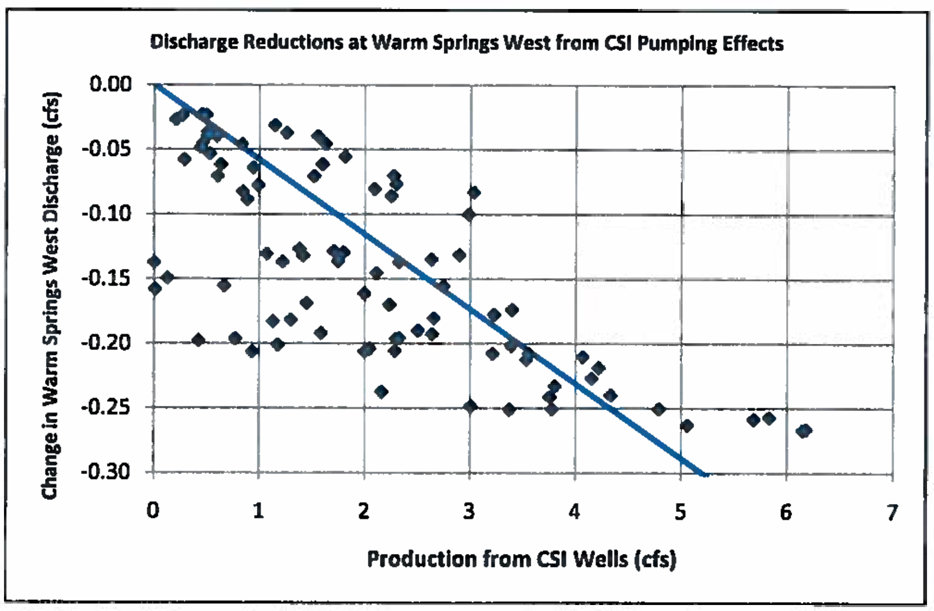

Figure 12. Proportional reduction of discharge at Warm Springs West with respect to groundwater production in Coyote Spring Valley, lagged 9 months; the constant of proportionality is 0.058 cfs reduction per cfs pumped, or 5.8%. [file CSI&ACWimpacts3.xls, Sheet 'CSIimpacts']

Scaling of Results to the Muddy River Headwaters Area

Discharge of the Muddy River at the Moapa gage is roughly twice as great as the sum of tributary flows derived directly from springs (Eakin, 1968; Beck et al., 2006). The alluvial aquifer, recharged by distributed flux from the carbonate-rock aquifer, stores groundwater and contributes to the base flow of the River in the headwaters area. Storage effects delay the impacts of alluvial pumping on measured River discharge. Adding present-day diversions to the modern, reduced flows of the Muddy River (Figure 2) reproduces the annual cycle seen in 1913-1918 (Figure 1) if appropriate time lags are applied to represent the effects of groundwater storage (Johnson and Mifflin, 2006). In reconstituting the Muddy River to match historic flows, surface-water diversions were applied in the month they are reported, diversions from the carbonate-rock aquifer (MX-6 and Arrow Canyon wells) were lagged one month, and diversions from the alluvial aquifer (Lewis and LDS well fields) were lagged five months. Johnson and Mifflin (2006) analyzed records from 1997-2002, and in the present analysis from 2001-2008 with comparable results. The finding of both analyses is the same, that the net effect of all diversions is a 1:1 reduction of Muddy River discharge, and each category of diversion has a unique imprint upon the discharge record based on the delayed responses of the River.

Mayer and Congdon (2008) hypothesized that higher-elevation springs would prove to be most sensitive to pumping effects based on the assumption that Darcy's law applies in the discharge conduits. Big Muddy Spring is the largest (8 cfs prior to 2005) and lowest elevation spring in the MRSA, with a measuring station elevation of 1745.34 feet AMSL about 0.1 mile downstream from the spring pool (Beck et al., 2006). Detrended discharge from 2001-2002 correlates well with production from the Arrow Canyon #1 well (Figure 13; slope = -0.08669 cfs/cfs or 8.7%, intercept = 8.606 cfs), allowing the discharge record from Big Muddy Spring to be adjusted for the ACW impact effects in subsequent years (Figure 14). We note that the proportional impacts from Arrow Canyon Well pumpage are substantially greater (8.7% of pumpage) at Big Muddy Spring than at Warm Springs West, where ACW impacts are only 1.5% of pumpage, and for which Beck et al. (2006) report a station elevation of 1770.04 feet AMSL.

NOTE: There is inconsistency in usage of the name "Warm Springs West". Beck et al. (2006, Table 4) refer to USGS site 09415920, and their reported elevation of 1770.04 feet corresponds to a staff plate reading of 0.91 feet in the 1-ft Parshall flume at that measurement location, which monitors total flow discharging from all springs associated with the Pederson Springs Groups. Mayer and Congdon (2008, Table 1 and Fig. 10), however, appear to consider Warm Springs West to be "Lower Elevation Springs" (an average of 5 elevations, 1797.9 feet) and Pederson and Pederson East "Higher Elevation Springs". Spring elevations are immaterial to the present analysis, so we leave it to Mayer and Congdon to clarify the confusion.

The average production of the ACW from September 2000 to October 2008 was 2.9 cfs, 5.7% of the estimated 51 cfs total groundwater flux to the MRSA, the 1:1 impact on the overall system in accordance with the water balance of Johnson and Mifflin (2006). Recognition of non-uniform pumping effects from the ACW in the MRSA raises the question of how CSI impacts are distributed. Identification of the spatially variable impacts of the ACW on individual springs and River flows is important because superposed CSI pumping impacts are now incorporated into the gauging records, and the opportunity to consider individual well impact effects in isolation (with other pumping sources "quiet") is no longer available.

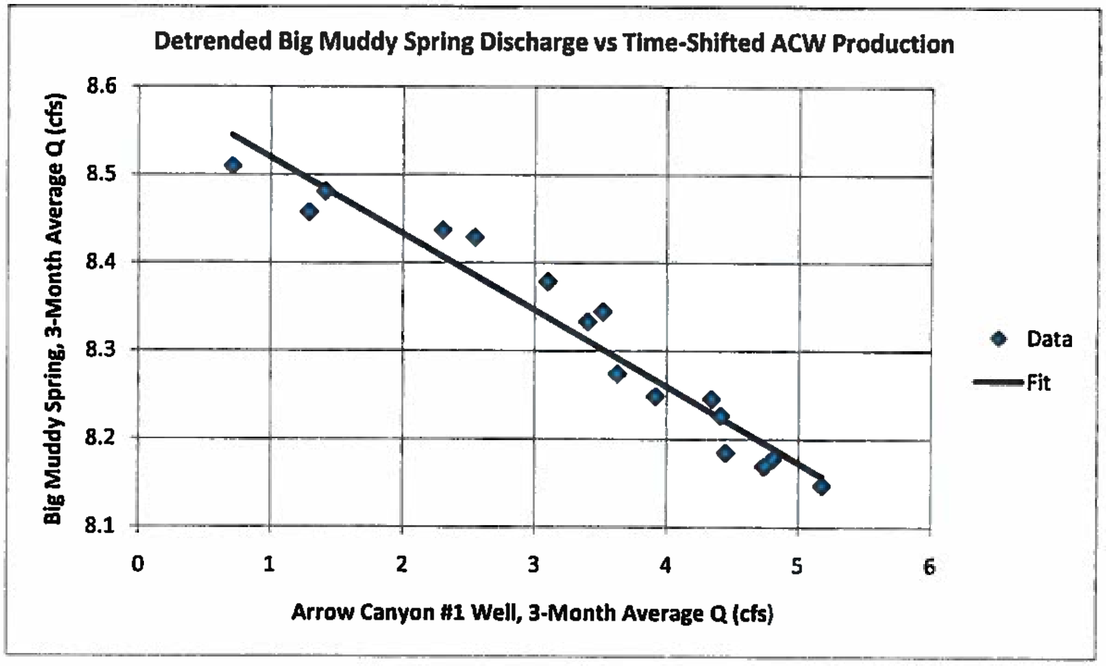

Figure 13. Proportional decreases in discharge from Big Muddy Spring, May 2001 – August 2002. [File FinalSpringflowComponents.xls, Sheet 'Re-startWithACW']

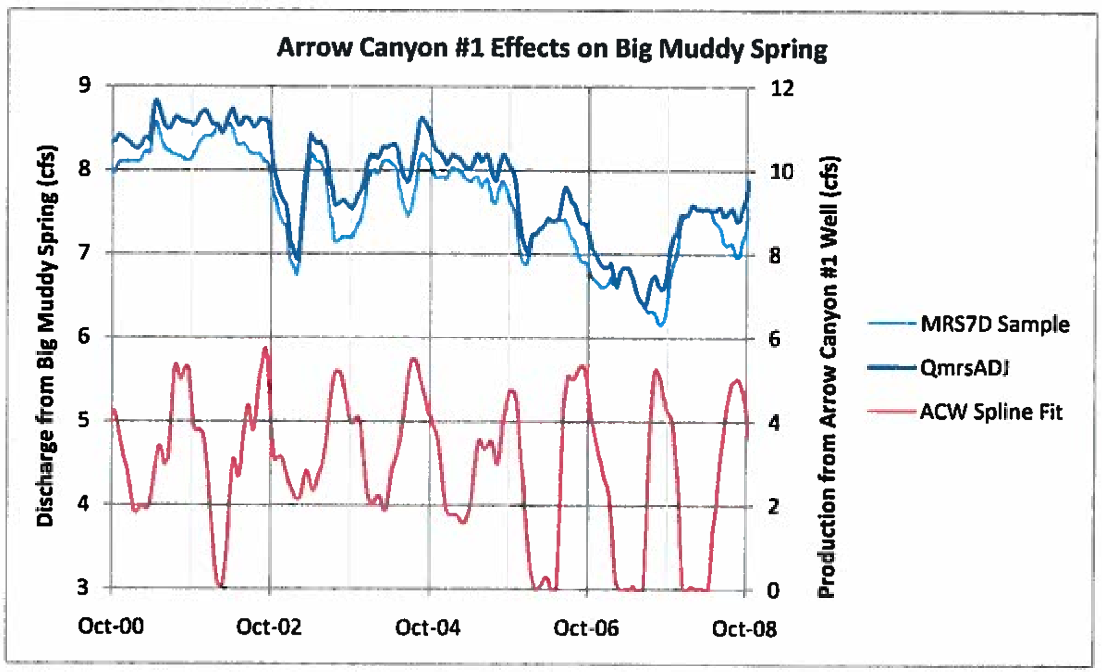

Figure 14. Adjustment of the 7-day average Big Muddy Spring discharge record to remove effects of the Arrow Canyon #1 well. [File BigMuddyLongTerm.xls, Sheet 'WeeklyACW']

As a result of seepage gains from the alluvial aquifer, the Muddy River as a whole might be considered to be dominated by "lower-elevation" discharge, in the parlance of Mayer and Congdon (2008). At an average discharge rate of about 3.7 cfs, Warm Springs West represents only about 7.3% of the 51 cfs long-term average total flux to the Muddy River headwaters in upper Moapa Valley. If the CSI impact results from Warm Springs West (5.8% of CSI pumpage; Figure 12) prove representative of CSI pumping impacts distributed throughout the MRSA, groundwater diverted in Coyote Spring Valley would be manifested as a reduction of the total flux in the proportion of 51 cfs / 3.7 cfs, or about 14 times the impact at Warm Springs West. To date, diversions from Coyote Spring Valley have occurred as three distinct seasonal pulses peaking at approximately 3.7, 6.0, and 3.9 cfs in 2006, 2007, and 2008, respectively (Figure 11). Total CSI diversions are of sufficient magnitude that if pumping effects calculated for Warm Springs West are representative of the MRSA as a whole, it should be possible to measure the total impacts of CSI diversions that have already occurred in the post-2006 record of Muddy River discharge. In other words, if local estimates of pumping impacts derived from springflow data are proportionally representative, these 1:1 impacts would be apparent in Muddy River flows.

To develop a CSI pumping-impact estimate for the MRSA as a whole, the synthetic reference hydrograph (Figure 7) and censored Muddy River hydrograph were detrended based on the 2000-2004 record, and the SRH was conservatively scaled to match the minima of the River hydrograph. When comparing River flows with the history of groundwater production from Coyote Spring Valley, there would be a correspondence of River and SRH peaks if the pumping impacts from 2006 lag the actual pumping by 10 months (Figure 15). Moreover, since scaling the SRH to the River hydrograph produces a measure of differences in cfs-equivalents; deficits in River flow have the units of cfs and can be compared directly with the pumping stress suspected of creating the discharge deficits. In the case of the 2006 CSI pumping stresses, the July and August 2007 River discharge deficits have 1:1 correspondence with the CSI pumping stress 10 months earlier. The calculated Warm Springs West impact estimate scales up to the Muddy River as a whole, and the full 1:1 impacts of diversions within and nearer the MRSA (Johnson and Mifflin, 2006) also apply to groundwater extracted from southeastern Coyote Spring Valley in 2006.

The raw hydrograph of the Muddy River illustrates changed flow patterns in 2007-2009 that do not require detailed or sophisticated analyses to appreciate (Figure 16). The large production peak from 2007 is primarily due to pumping from the CSI2 well, and appears to be expressed in the River hydrograph with a lag time greater than one year.

Conclusion

Flows at Warm Springs West would be reduced by 0.64 cfs as a direct result of an 11 cfs Order 1169 experiment, 17% of the historic 10-year average of 3.7 cfs or 19% of the minimum flows of 2004. These estimates are subject to considerable uncertainty due to the scatter of data in the regression relation (Figure 12), and the CSI impact would be superposed on seasonal discharge reductions that are attributable to the Arrow Canyon wells and climate effects. The CSI-related pumping impacts detected at Warm Springs West are proportional to impacts derived by reconstituting Muddy River flows; if full-scale groundwater production in Coyote Spring Valley of 22 cfs were to occur as a uniform pumping stress, elimination of that full amount from the regional flux to the MRSA would be the result. This discharge reduction would translate directly to flow reductions that approach the minimum flows recorded in 2003, and are well over half the average seasonal minima of the past 10 years. If, however, seasonal pumping typical of the region were to occur, periodic impacts transmitted to the Springs area would be far greater.

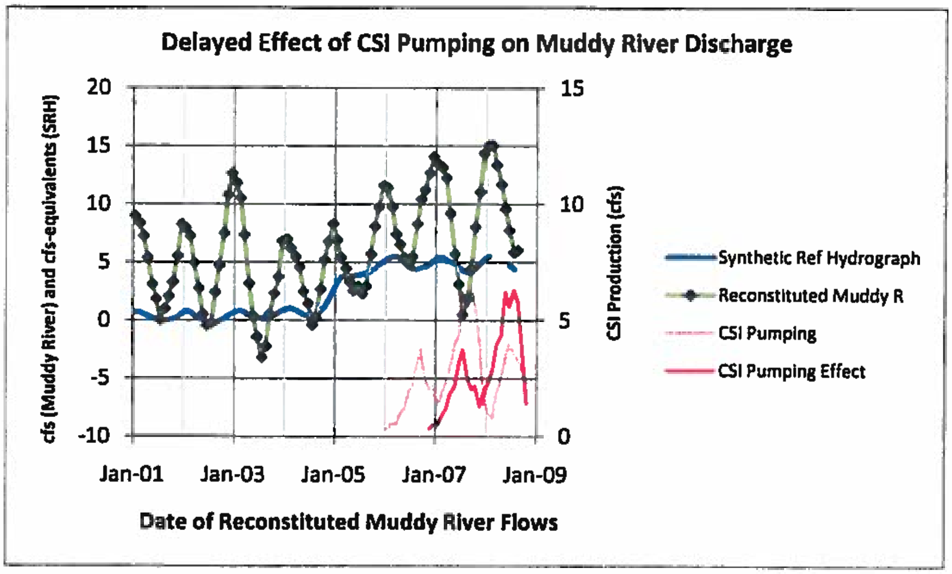

Figure 15. Divergence of reconstituted Muddy River discharge from baseline trend between April and September of 2007, corresponding (in terms of cfs-equivalents), to the production rate from CSI wells that first peaked in September of 2006, indicating a ten-month lag between cause and effect in the first phase of pumping. Zero reference is average of peak minima from 2002-2005. [file MuddyRivQ_2000-2010a.xls, Sheet 'CSImonthly']

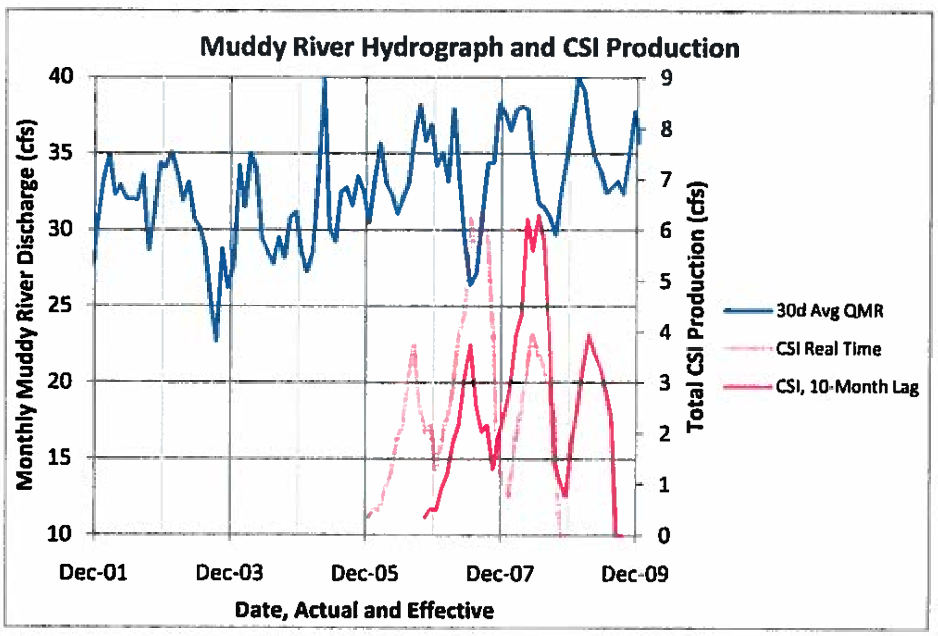

Figure 16. Raw Muddy River hydrograph, monthly samples of 30-day moving average, censored for rain days, and CSI production history. [file MuddyRivQ_2000-2010a.xls, Sheet 'Narrow')

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USFWS, Request for Formal and Informal Consultation on the Kane Springs Valley Groundwater Development Project in Lincoln County, Nevada (Biological Opinion), October 29, 2008 (File Nos. 84320-2008-F-007 and 84320-2008-I-0216).

IN THE OFFICE OF THE STATE ENGINEER
OF THE STATE OF NEVADA

IN THE MATTER OF APPLICATIONS 54075 AND 54076 FILED TO APPROPRIATE UNDERGROUND WATER FROM THE CALIFORNIA WASH HYDROGRAPHIC AREA (218), CLARK COUNTY, NEVADA	)))))	**RULING** **#5115**

GENERAL

I.

Application 54075 was filed on October 17, 1989, by the Las Vegas Valley Water District ("LVVWD") to appropriate 10 cubic feet per second (cfs) of the water from the "underground rock aquifer" within the California Wash Hydrographic Area for municipal and domestic purposes within Clark, Lincoln, Nye and White Pine Counties, as more specifically described and defined within NRS § 243.035-243.040 (Clark), 243.210-243.225 (Lincoln), 243.365-243.385 (White Pine) and 243.275-243.315 (Nye). The proposed point of diversion is described as being located within the NE¼ SW¼ of Section 4, T.16S., R.66E., M.D.B.& M.[1] In Item 12, the remarks section of the application, it indicates that the water sought under the application shall be placed to beneficial use within the Las Vegas Valley Water District service area as set forth in Chapter 752, Statutes of Nevada 1989, or as may be amended. Further, that the water may also be served and beneficially used by lawful users within Lincoln, Nye and White Pine Counties, and that water would be commingled with other water rights owned or served by the applicant or its designee. By letter dated March 22, 1990, the applicant further indicated, in reference to Item 12, that the approximate number of persons to be served is 800,000 in addition to the current service for approximately 618,000 persons, that the applications seek all the unappropriated water within the particular groundwater basins in the which water rights are sought and that the projected

[1] File No. 54075, official records in the Office of the State Engineer.

population of the Clark County service area at the time of the 1990 letter was estimated to be 1,400,000 persons by the year 2020.

II.

Application 54076 was filed on October 17, 1989, by the LVVWD to appropriate 10 cfs of the water from the underground rock aquifer within the California Wash Hydrographic Area for municipal and domestic purposes within the Clark, Lincoln, Nye and White Pine Counties. The proposed point of diversion is described as being located within the NW¼ NW¼ of Section 16, T.15S., R.64E., M.D.B.& M.[2] The Item 12 remarks are the same as those found under Application 54075.

III.

By letter dated March 26, 2002, the LVVWD requested the State Engineer proceed with action on Applications 54075 and 54076 filed to appropriate a total of 14,480 acre-feet annually.[3] The LVVWD requested that, in the event the permits are issued for less than the amount requested, the State Engineer withhold final action on the remaining portion of the ground water applied for until such time as definitive data on the availability of additional ground water in Basin 218 is available.

The LVVWD indicated that it intends to make any permits issued under these applications available to the Moapa Band of Paiutes provided that a settlement agreement between the Tribe and the LVVWD has been finalized. The LVVWD further provided that, although these two applications were filed as part of what has come to be known as the Cooperative Water Project, development needs along the I-15 corridor and continued growth in the northern section of the Las Vegas Valley have caused the LVVWD and Southern

[2] File No. 54076, official records in the Office of the State Engineer.

[3] Letter dated March 26, 2002, from David Donnelly to State Engineer. File Nos. 54075 and 54076, official records in the Office of the State Engineer.

Nevada Water Authority ("SNWA)" to evaluate resource opportunities in relative proximity to these areas separately from the Cooperative Water Project, as reflected in the 2002 SNWA Resource Plan.[4]

IV.

Application 54075 was protested by the Unincorporated Town of Pahrump, the United States Department of Interior, National Park Service, the United States Fish and Wildlife Service, the United States Department of Interior, Bureau of Land Management, the County of Nye, the County of White Pine and the City of Ely, the Moapa Band of Paiute Indians, Fred Landau, the Ely Shoshone Tribe, the City of Caliente, and the Lincoln County Board of Commissioners.

Application 54076 was protested by the Unincorporated Town of Pahrump, the United States Department of Interior, National Park Service, the United States Fish and Wildlife Service, the United States Department of Interior, Bureau of Land Management, the County of Nye, the County of White Pine and the City of Ely, the Moapa Band of Paiute Indians, Walter Galloway, the Toiyabe Chapter of the Sierra Club, and the Lincoln County Board of Commissioners.

The applications were protested on many grounds, including:

1. The applications were some of the 146 applications to appropriate water filed by the LVVWD, which combined seek 864,195 acre-feet annually of underground and surface water, and diversion of such a quantity of water would deprive the area of origin of water needed to protect and enhance its environment and economic well being, and would unnecessarily destroy environmental, ecological, scenic and recreational values the State holds in trust for its citizens.
2. The applications should not be granted in the absence of comprehensive planning.

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[4] Ibid.

3. Approval of the applications would sanction and encourage the willful waste and inefficient use of water in the Las Vegas Valley.

4. The LVVWD has not obtained rights-of-way from the United States Department of Interior, Bureau of Land Management.

5. The LVVWD lacks the financial capability for developing the project.

6. The applications fail to include statutorily required information, specifically, a description of the place of use, the proposed works, the estimated cost of such works and the estimated time required to go to beneficial use.

7. The applications fail to contain sufficient information for the State Engineer to safeguard the public interest and that a publicly-reviewable assessment must be done of the cumulative impacts of the proposed extraction, mitigation measures needed and alternatives to the proposed extraction.

8. The population projection numbers are unrealistic.

9. The applications would allow the LVVWD to "lock up" vital water resources for possible use in the distant future beyond current planning horizons.

10. The applications substantially overstate future water demand needs.

11. Further study is needed because the potential effects are impossible to anticipate.

12. The granting of the applications would destroy the economic and growth potential of the hydrographic basin.

13. The public interest will not be served if the water and water-related resources in the Death Valley National Monument and the Lake Mead National Recreational Area are diminished or impaired as a result of the appropriations.

14. The applications will eventually reduce or eliminate the flows from springs, which are discharge areas for a regional groundwater flow system upon which the National Park Service

claims senior appropriative and implied Federal reserved water rights.

15. The proposed diversions are from the carbonate-rock province of Nevada that is typified by complex, interbasin, regional-flow systems that include both basin-fill and carbonate-rock aquifers along with interbasin flows that are poorly defined, and the diversions will reduce the interbasin flows, and modify the direction of groundwater movement in adjoining and hydraulically connected basins thereby reducing spring and stream flows.

16. The available scientific literature is not adequate to reasonably assure that the proposed diversions will not impact senior rights and water resources.

17. As of December 1988 the committed diversions in California Wash were 510 acre-feet annually (afa) with an estimated perennial yield of 100 afa and the sum of the applications and the committed diversions will exceed the perennial yield of the groundwater basin; therefore, there is no water available for appropriation.

18. It is unclear whether the amount contemplated in the applications is necessary and reasonably required for the proposed purposes.

19. The granting of the applications will lower the water table, sanction water mining, degrade water quality, cause negative hydraulic gradient influences, threaten springs and seeps and phreatophytes, which provide water and habitat critical to the survival of wildlife including, endangered species and grazing livestock.

20. The applications would create air contamination and pollution in violation of State and Federal statutes.

21. The applications will cause water rates to go up thereby causing demand to go down thereby rendering the water unnecessary.

22. Previous applications from California Wash Hydrographic Basin have been denied.

23. The applications will negatively impact Nevada's environment.

24. The LVVWD has not shown a need for the water or that the project is feasible.
25. Until the claims under the Treaty of Ruby Valley (1863) are adjudicated the applications are premature.

FINDINGS OF FACT

I.

By letter dated April 5, 2002, legal counsel for the Federal agencies, U.S. Department of Interior, Bureau of Land Management, Fish and Wildlife Service and National Park Service requested that the State Engineer hold a public administrative hearing before acting on the applications, because they have scientific information on water availability in California Wash. The request for a public hearing appears to be contradictory to other comments in the letter, which indicate the Federal agencies want to discuss settlement with the Las Vegas Valley Water District. If they settle, the information would not be presented at the administrative hearing.

In July and August of 2001, nearly four weeks of public administrative hearings were conducted on applications filed by the Las Vegas Valley Water District (Applications 54055-54059, inclusive) and Coyote Springs Investment, LLC (Applications 63272-63276, inclusive, and 63867-63876, inclusive), which together request to appropriate approximately 135,000 acre-feet of water annually within the Coyote Springs Valley Hydrographic Basin. Those hearings were on applications that requested to appropriate water from a regional source of water, the carbonate-rock aquifer system, the same source the applicant hopes to tap under these applications.[5] The result of those hearings was the issuance of

[5] Transcript, public administrative hearings before the State Engineer, July 16-24, August 20-24, 27-28, 31, 2001, official records Office of the State Engineer.

State Engineer's Order No. 1169[6], pursuant to which the State Engineer ordered holding in abeyance applications for additional water rights from the carbonate-rock aquifer in most of the basins surrounding California Wash. The basis for the Order was that there is insufficient scientific evidence to proceed with additional appropriations until those water rights that have been permitted are pumped and monitored, thereby providing evidence of the effect of the exercise of the water rights already issued. Nothing has changed since the issuance of that order, which the State Engineer believes will provide additional evidence of value other rather than just adding to the theoretical evidence already presented.

Nevada Revised Statute § 533.365 provides that the State Engineer shall consider a protest timely filed, but that it is within his discretion whether or not to hold an administrative hearing as to any particular water right application. The State Engineer finds that he does not believe an administrative hearing will add to the knowledge already held. The scientific evidence previously presented was not definitive as to the availability of water within the carbonate-rock aquifer and the effects of pumping. The State Engineer finds there is sufficient information available in the records of the Division of Water Resources and in reports prepared by the United States Geological Survey in conjunction with the State of Nevada, Las Vegas Valley Water District, City of North Las Vegas, U.S. National Park Service, U.S. Fish and Wildlife Service, U.S. Bureau of Land Management, Desert Research Institute, U.S. Bureau of Reclamation, U.S. Air Force and U.S. Bureau of Indian Affairs, and in conjunction with the weeks of public administrative hearings held in the summer of 2001 to review these specific applications, and that an administrative hearing in this instance is not necessary.

[6] State Engineer's Order No. 1169, dated March 8, 2002, official records in the Office of the State Engineer.

However, the State Engineer finds the decision not to hold a hearing does not preclude the need for additional study.

II.

When the State Engineer analyzes whether water is available for appropriation from the underground sources of water in Nevada, the first analysis addresses the perennial yield of the particular groundwater basin. The perennial yield of a hydrologic basin may be defined as the maximum amount of ground water that can be salvaged over the long term without depleting the groundwater reservoir. Perennial yield is ultimately limited to the maximum amount of natural recharge that can be salvaged for beneficial use. If the perennial yield is continually exceeded, groundwater levels will decline.[7] Withdrawals of ground water in excess of the perennial yield contribute to adverse conditions such as water quality degradation, storage depletion, diminishing yield of wells, increased economic pumping lifts, land subsidence and possible reversal of groundwater gradients, which could result in significant changes in the recharge-discharge relationship. Presently, scientists can estimate the perennial yield of a groundwater basin by two distinct methods: recharge to the groundwater basin from precipitation, and discharge from the groundwater basin by spring/surface discharge, interbasin flow, consumption by plants tapping the ground water and consumption by man.

Reconnaissance Report 50 estimates that California Wash has an annual recharge of less than 100 acre-feet from precipitation and that no water comes into the valley-fill reservoir from subsurface inflow.[8] The Report provides that inflow is

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[7] State Engineer's Office, Water for Nevada, State of Nevada Water Planning Report No. 3, p. 13, Oct. 1971.

[8] F.E. Rush, Water Resources-Reconnaissance Series Report 50, Water-Resources Appraisal of the Lower Moapa-Lake Mead Area, Clark County, Nevada, United States Geological Survey, pp. 25,26, 28, 41 (1968).

contributed to California Wash from Garnet Valley (Basin 216), Muddy River Springs area (Basin 219), and Lower Meadow Valley Wash (Basin 205) through the alluvium and carbonate rocks.[9] Reconnaissance Report 50 studied the region in which California Wash is located and indicated the following.

> All the areas included in this report[10] apparently drain in the subsurface to either the Muddy River or directly to Lake Mead... Hidden Valley probably drains to Garnet Valley, which in turn probably drains eastward toward California Wash...Subsurface drainage may be both northeastward from California Wash Area toward the Muddy River and southeastward toward Lake Mead... Ground water may enter the report area at several places: (1) along Meadow Valley Wash, flowing through alluvium, (2) along the Muddy River, flowing through alluvium, and (3) from Las Vegas Valley, near Lake Mead Base..., flowing through carbonate rocks, and (4) from Las Vegas Valley, along Las Vegas Wash flowing through alluvium. All these flow quantities are probably small.[11]

However, the "possibility of salvaging all or part of the outflow by pumping is dependent upon the nature and extent of the transmitting lithology, which is generally unknown. For the purpose of this reconnaissance it is assumed that the subsurface geohydrologic controls might permit salvage of half of the outflow by pumping."[12]

Testimony and evidence from the July and August 2001 hearings previously referenced indicated that using the standard Maxey-

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[9] Id. at 26.

[10] The Reconnaissance Series Report 50 covered the Lower Moapa-Lake Mead Area of Clark County, Nevada, including Hidden, Garnet, and Lower Moapa Valleys, Black Mountains and Gold Butte Areas, California Wash and Greasewood Basin. F.E. Rush, Water Resources-Reconnaissance Series Report 50, Water-Resources Appraisal of the Lower Moapa-Lake Mead Area, Clark County, Nevada, United States Geological Survey, at 1 (1968).

[11] Id. at 13.

[12] Id. at 49-51.

Eakin technique for estimation of groundwater recharge from precipitation, the recharge for the Coyote Springs Valley, Muddy River Springs, Hidden Valley, Garnet Valley, Black Mountains, and Lower Moapa Valley areas combined is approximately 3,550 acre-feet annually. Using the modified Maxey-Eakin technique introduced at the administrative hearing (known as the Donovan-Katzer 2000 technique), the recharge is estimated at approximately 6,761 acre-feet annually for the combined areas.[13] California Wash adds an additional 100 to 311 acre-feet under the two techniques.

The State Engineer finds using the Maxey-Eakin method of estimating recharge, the recharge to the area comprised of Coyote Springs Valley, Muddy River Springs, Hidden Valley, Garnet Valley, Black Mountains, Lower Moapa Valley and California Wash is approximately 3,650 acre-feet annually. The Donovan-Katzer 2000 technique estimates the recharge to be approximately 7,072 acre-feet annually for the combined areas.

III.

Another method for estimating the total quantity of water available for appropriation uses interbasin flow and discharge flow as a method to approximate the annual safe yield. Ground water is discharged by the natural processes of transpiration of vegetation, evaporation from the soil and free-water surfaces, and possible underflow from one groundwater basin to another. This method is addressed in the context of the discussion below.

The applications indicate the water proposed for appropriation under these applications is from a source known as a carbonate-rock aquifer, which is a source that was not generally considered in the analysis of water available for appropriation in these particular groundwater basins. In 1984, the Water Resources Division of the United States Department of Interior, Geological Survey proposed a 10-year investigation of the entire Carbonate

[13] See, testimony of Terry Katzer and David Donovan; Exhibit 54, p. 4-25, public administrative hearing before the State Engineer, July 16-24, 2001.

Terrane.[14] The study was proposed because, the water resources of the Carbonate Terrane were not well defined, the data was sparse and the hydrology and geology of the area are complex. It has been known since 1984 that to arrive at some reasonable understanding of the carbonate-rock aquifer system, substantial amounts of money would be required to develop the science, a significant period of study would be required, and that "unless this understanding is reached, the development of carbonate water is risky and the resultant effects may be disastrous for the developers and current users."[15]

It was believed that developing a better scientific understanding would identify possible additional water resources that could be developed, would further the attempts to define the perennial yield of this water source, would protect current users, would allow the State Engineer to better understand the system, which would allow management for the benefit of all the people, and would further the knowledge needed by the Federal agencies for protection of their water rights and water-resource related interests.

It was noted in the proposal referenced above, that this was not the first time a comprehensive investigation of the hydrology of the Carbonate Terrane in Nevada was considered, and that area-wide studies had been conducted by four different organizations to date.[16] The 1984 United States Geological Survey memo indicates

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[14] Memorandum dated August 3, 1984, from Terry Katzer, Nevada Office Chief, Water Resources Division, United States Department of Interior Geological Survey, Carson City, Nevada, to Members of the Carbonate Terrane Society.

[15] Ibid.

[16] Those organizations were identified as:
(1) the Desert Research Institute (Mifflin 1968, Hess and Mifflin 1978);
(2) the United States Air Force (M-X Multiple Protective Shelter Water Resources Program 1983);
(3) the United States Geological Survey (Great Basin Regional Aquifer System Analysis, Harrill and others 1982), and;
(4) the United States Bureau of Reclamation (Southern Nevada Deep Carbonate

that given the "myriad possible avenues of hydrologic connection between the various aquifers and flow systems and the uncertainties of recharge and discharge mechanisms and processes, an investigation of the hydrology of the carbonate-rock aquifers in Nevada is undoubtedly a difficult undertaking."[17]

An investigation of the carbonate-rock aquifer system is additionally complicated by factors including:

- basic hydrologic data such as groundwater levels in both the basin-fill aquifers and carbonate-rock aquifers, and reliable flow measurements for important springs and major streams are scarce or infrequently obtained in much of the area;
- secondary hydrologic and other data, such as hydraulic parameters, geophysical and geochemical, are lacking in many areas;
- the geometry, properties, and boundaries of the carbonate-rock and basin-fill reservoirs are generally unknown, and definition of these properties can be expensive and difficult;
- climatic conditions today are inadequately defined (particularly at higher altitudes) and conditions during the development of the flow paths within the deep-rock aquifers and flow paths within the

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Aquifer Study 1984).

These studies were based on many smaller scale studies, including:
(1) the early studies of the White River flow system by Maxey and Eakin 1949, and Eakin 1966);
(2) the numerous studies in the area between, and including, the Nevada Test Site and Death Valley by Hunt and Robinson 1960, Eakin and other 1963, Winograd and Thordarson 1975, Classen 1983, and;
(3) the investigations of the geohydrology of Central Nevada associated with the Atomic Energy Commission's Central Nevada Test Area, Fiero and Illian 1968 and 1969.

Numerous other studies of individual or small groups of basins have also been conducted by private and public organizations, and information has been gathered from drilling for oil and mineral exploration.

[17] Memorandum dated August 3, 1984, from Terry Katzer, Nevada Office Chief, Water Resources Division, United States Department of Interior Geological Survey, Carson City, Nevada, to Members of the Carbonate Terrane Society, Attachment at 7.

carbonate-rock aquifer are even more uncertain;
-uncertainties and inaccuracies exist in current methods of estimating precipitation;
- uncertainties and inaccuracies exist in current methods of estimating groundwater inflow and recharge;
- uncertainties and inaccuracies exist in current methods of estimating groundwater outflow and evaporative discharge;
- only a small number of wells tap the deep carbonate rocks;
- because there has been no significant historical pumping of ground water from the carbonate-rock aquifer system, groundwater models can only be used as a limited predictive tool for estimating the principle location and magnitude of impact of pumping ground water from the system;
- limited stresses on the water resources of the area under current development conditions allow hydrologists information only on the narrow band of system responses to natural conditions; and
- the relationship between geothermal systems and the deep carbonate-rock aquifers and groundwater flow systems is not well understood.

The State Engineer finds that as of 1984 the carbonate-rock aquifers were known to exist, not much specific data existed on the carbonate-rock aquifers or their relationship to the basin-fill/alluvial aquifers and it was well known that further study was needed to understand the water systems. The State Engineer finds that not much has changed to the present time.

IV.

In 1985, the Nevada Legislature authorized a program for the study and testing of the carbonate-rock aquifers of eastern and southern Nevada. The program was a cooperative effort between the State of Nevada and the Federal Government. The overall plan for the program was to study the carbonate-rock aquifers of southern, east-central, and northeastern Nevada as separate phases of work, with a summary of findings to be prepared at the end of each phase. A report, Distribution of Carbonate-Rock Aquifers in Southern Nevada and the Potential for their Development, Summary of Findings, 1985-1988,[18] summarized the findings of the first phase of the study, which assessed the resources of the carbonate-rock aquifers of southern Nevada. The summary brought together results from more than 20 technical reports produced during the study and indicated that:

> The rocks that compose the carbonate-rock aquifers are layers of limestone and dolomite that were deposited hundreds of millions of years ago in much of the eastern Great Basin. Subsequently, the carbonate rocks were much deformed; as a result, they no longer exist as continuous layers beneath the region. Instead, they have been pulled apart to form a few large areas of thick and relatively continuous carbonate rocks. Separating these areas are noncarbonate rocks, within which are isolated mountain-sized blocks of carbonate rock.
>
> Beneath southern Nevada, the thick carbonate-rock layers are continuous enough to transmit ground water at regional scales only beneath a north-south "corridor" 60-90 miles wide that extends southward from east-central Nevada to and beyond the Spring Mountains area west of Las Vegas. Within this corridor are the two major regional flow systems of southern Nevada: the Ash Meadows-Death Valley system and the White River-Muddy River Springs system. These flow systems link the ground water beneath dozens of valleys and over distances exceeding 200 miles. Flow in these systems probably is concentrated along highly transmissive zones associated with (1) recently active faults and (2) confluences of flow near major warm-water springs. Outside of the corridor, the carbonate rocks are present primarily as isolated blocks that form aquifers of limited extent, recharged mostly by local precipitation.

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[18] Michael D. Dettinger, Distribution of Carbonate-Rock Aquifers in Southern Nevada and the Potential for their Development, Summary of Findings, 1985-1988, Summary Report No. 1, United States Geological Survey, Department of Interior and Desert Research Institute, University of Nevada System, Forward, 1989.

> Large-scale development (sustained withdrawals) of water from the carbonate-rock aquifers would result in water-level declines and cause the depletion of large quantities of stored water. Ultimately, these declines would cause reductions in the flow of warm-water springs that discharge from the regional aquifers. Storage in other nearby aquifers also might be depleted, and water levels in those other aquifers could decline. In contrast, isolated smaller ground-water developments, or developments that withdraw ground water for only a shorttime, may result in water-level declines and springflow reductions of manageable or acceptable magnitude.
>
> Confidence in predictions of the effects of development, however, is low; and it will remain low until observations of the initial hydrologic results of development are analyzed. A strategy of staging developments gradually and adequately monitoring the resulting hydrologic conditions would provide information that eventually could be used to improve confidence in the predictions.[19]

The committed groundwater resource in the form of permits and certificates issued by the State Engineer to appropriate underground water from the California Wash Hydrographic Basin currently exceeds 567 acre feet annually.[20] The State Engineer has previously granted groundwater permits, which authorize use of underground water in an area underlain by the carbonate-rock aquifer system or directly from the carbonate-rock aquifer system in the following quantities:

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[19] Id. at 1-2.

[20] Hydrographic Basin Abstract, Basin 218, official records in the Office of the State Engineer, April 9, 2002. It should be noted that only 477 acre-feet is for the permanent use of water, the other water use permitted is for environmental clean-up and mining and milling, which are considered non-permanent uses of water.

Coyote Springs Valley (Basin 210)	16,300	acre-feet
Black Mountain (Basin 215)	10,216	acre-feet
Garnet Valley (Basin 216)	3,380	acre-feet
Hidden Valley (Basin 217)	2,200	acre-feet[21]
Muddy River Springs aka Upper Moapa Valley (Basin 219)	14,756	acre-feet
Lower Moapa Valley (Basin 220)	5,813	acre-feet
California Wash (Basin 218)	477	acre-feet
Total	50,942	acre-feet

The State Engineer finds, in a straight perennial yield analysis, that existing groundwater rights in the California Wash groundwater basin exceed the perennial yield of the groundwater basin. However, the State Engineer further finds that appropriations from the carbonate-rock aquifer are being requested, and evidence has been presented to him that new estimates of the system yield need to be established. The State Engineer finds, given the complexities of the carbonate-rock aquifer system, further site specific information (one valley at a time) is needed and will provide information not presently available due to the limited development of the resource. The State Engineer finds that due to the complexities of the system and potential interaction between the carbonate-rock aquifer and the alluvial aquifer, further analysis is required in order to understand what potential, if any, exists for the appropriation of more water from the California Wash groundwater basin.

The State Engineer finds because assurances that the adverse effects of development will not overshadow the benefits cannot be made with a high degree of confidence, development of the carbonate-rock aquifer system must be undertaken in gradual stages together with adequate monitoring in order to predict the effects

[21] This 2,200 acre-feet is combined with 2,200 acre-feet issued in Garnet Valley for a total of 2,200 afa between the two basins.

of continued or increased development with a higher degree of confidence.

V.

The State Engineer finds that staging development gradually means not developing the resources in one large step, but rather starting with small projects that are possibly augmented gradually if conditions and confidence warrant. This approach allows the effects of development to be observed and analyzed continually, so that the benefits and adverse effects of development can be judged and the effects reversed or mitigated if they prove to be detrimental to existing rights and the environment. This approach would hopefully avoid the havoc that could be created by the curtailment of water use by those who have come to rely on it if impacts occur requiring curtailment of the water use.

VI.

The 1995 Water-Resources Investigations Report 91-4146[22] estimates the total water budget of all southern Nevada aquifers from the natural recharge to the mountains and subsurface inflow to the study area[23] to be about 160,000 acre-feet annually, and discharges from major discharge areas to be about 77,000 acre-feet annually.[24] However, it is believed that all of the recharge and subsurface inflow cannot be captured for use.

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[22] Michael D. Dettinger, et al., Distribution of Carbonate-Rock Aquifers and the Potential for Their Development, Southern Nevada and Adjacent Parts of California, Arizona and Utah, U.S. Geological Survey, Water-Resources Investigations Report 91-4146, p. 50, 1995.

[23] The study area is defined on p. 5 of Water-Resources Investigations Report 91-4146 to be most of southern Nevada south of Tonopah and Pioche.

[24] Discharge areas are identified as Muddy River Springs 36,000 acre-feet annually (afa) of spring flow, Blue Point Spring 240 afa of spring flow, Rogers Spring 920 afa of spring flow, Frenchman Mountain 2,100 afa of underflow toward Colorado River, Pahrump Valley 18,000 afa of underflow to California, Ash Meadows 17,000 afa of spring flow and evapotranspiration, Amargosa Desert 3,000 afa of underflow to Death Valley, and Grapevine Canyon 400 afa of underflow to Death Valley. Water-Resources Investigations Report 91-4146 at 53.

As previously noted, the testimony and evidence from the July and August 2001 administrative hearings on Coyote Springs Valley Hydrographic Basin indicated that the groundwater recharge from precipitation for the Coyote Springs Valley, Muddy River Springs, Hidden Valley, Garnet Valley, Black Mountains, Lower Moapa Valley and California Wash areas combined is approximately 3,650 acre-feet up to 7,072 acre-feet annually depending on the method used for calculation.

Testimony and evidence from those hearings further indicated that approximately 50,000 acre-feet of groundwater inflow comes into the Coyote Springs Valley from northern groundwater basins and approximately 53,000 acre-feet annually outflows[25] of which a portion may be available for capture from the underflow. While testimony presented indicated a belief that significant quantities of water may be available for capture from storage, it is unknown what quantity that would be, and if any underground water could be appropriated without unreasonable and irreversible impacts.[26] The testimony and evidence indicated that a portion of the groundwater outflow from Coyote Springs Valley is believed to discharge at a rate of approximately 37,000 acre-feet annually at the Muddy River Springs area and approximately 16,000 to 17,000 acre-feet annually flows to groundwater basins further south, possibly to Garnet Valley, Hidden Valley and California Wash Hydrographic Basins.[27]

The approximately 37,000 acre-feet annually of water discharged from the large springs located near the central part of the Upper Moapa Valley (aka as the Muddy River Springs area - hydrographic basin 219) is fully appropriated pursuant to the

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[25] Taking into account for 4,000 afa of in-basin recharge and 1,000 afa of evapotranspiration.

[26] See, testimony of Terry Katzer and David Donovan, public administrative hearing before the State Engineer, July 16-24, 2001.

[27] Ibid.

Muddy River Decree,[28] and, therefore, is not available for appropriation. It is believed that the source of water discharged originates mainly from the carbonate-rock aquifer system, but it is unknown if the discharge originates solely from the White River Flow System or is also influenced by discharge from the Meadow Valley Flow System or if there is influence from the alluvial aquifer. Further, there are listed endangered and/or potential threatened species that exist in the Muddy Springs/Muddy River area.

The testimony and evidence from the hearing on the LVVWD's applications in Coyote Springs Valley indicated that their own expert witnesses were unable to make a suggestion to the State Engineer as to what part of the water budget could be captured without a great deal of uncertainty, and that the question cannot be resolved without stressing the system.[29] Further, the State Engineer's ability to determine if development of the carbonate-rock aquifer system will impact existing rights is dependent on how the water rights are brought "on-line" and monitored.[30] Today, little is still known about the hydrologic connectivity between the groundwater basins, virtually nothing is known about the mountain blocks, estimates of recharge to the area can vary by a factor of two, there is probably some connectivity between the water in the carbonate-rock aquifers and the alluvial groundwater basins,[31] there is still little data available, and not much has changed from the information known in 1984.

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[28] Judgment and Decree, In the Matter of the Determination of the Relative Rights In and To the Waters of the Muddy River and Its Tributaries in Clark County, State of Nevada, March 12, 1920, Tenth Judicial District Court of the State of Nevada, In and For the County of Clark.

[29] See, testimony of Terry Katzer and David Donovan, public administrative hearing before the State Engineer, July 16-24, 2001.

[30] Ibid.

[31] Ibid.

As previously noted, on March 8, 2002, the State Engineer issued State Engineer's Order No. 1169[32] by which he ordered that all applications pending and any new filings for the appropriation of water from the carbonate-rock aquifer system in Coyote Springs Valley (Basin 210), Black Mountains Area (Basin 215), Garnet Valley (Basin 216), Hidden Valley (Basin 217), Muddy River Springs aka as Upper Moapa Valley (Basin 219), and Lower Moapa Valley (Basin 220) would be held in abeyance until further information is obtained by stressing the aquifer by the pumping of the water under those water right permits already issued to appropriate water from the carbonate-rock aquifer system. While the studies proposed in 1985 were a beginning, those studies indicated that large-scale developments with sustained withdrawals of water from the carbonate-rock aquifers would result in water-level declines and depletion of stored water, but that isolated smaller groundwater developments or developments of limited duration may result in water-level declines and springflow reductions of manageable and acceptable magnitudes. However, very little additional information based on hard science has been produced since that time.

The State Engineer informed applicants for additional water from the above-referenced hydrographic basins of the need for additional study before a final determination can be made on carbonate-rock aquifer system water right applications in the referenced basins. The purpose of the study is to analyze the effect of pumping under those water rights already issued for appropriation of water from the carbonate-rock aquifer. The entities ordered to participate in the study are at a minimum to include: the LVVWD, SNWA, Coyote Springs Investment, LLC, Nevada Power Company, and Moapa Valley Water District. The study is to cover a 5-year minimum period during which at least 50% of the

[32] Official records in the Office of the State Engineer.

water rights currently permitted in the Coyote Springs Valley groundwater basin are pumped for at least 2 consecutive years.

During the administrative hearings in the summer of 2001, evidence was presented by witnesses for the Moapa Band of Paiute Indians indicating a belief that additional water comes into California Wash above the previous estimates of perennial yield. But, their testimony also indicated a belief there is already a downward trend in water levels for the carbonate-rock aquifer during periods of heavy pumping at the Arrow Canyon well, as was shown in the Las Vegas Valley Water District's model presented at the hearing[33], and they are seeing carryover drawdown, which will impact the carbonate-rock aquifer, which is filling the alluvial aquifer. However, the witnesses further indicated that there may be a substantial quantity of water available in the carbonate-rock aquifer, but if for one reason or another a drawdown in caused near the Muddy River springs, spring flow will be influenced independent of the availability of water. These witnesses testified that future development of the carbonate-rock aquifer should be approached by pumping "whatever you can without getting into trouble," but that water should not just be appropriated upgradient of the Muddy River springs, but also downgradient in the California Wash Hydrographic Basin.[34] "[A]t this point all we have is ideas and concepts and yet no proof about where that inflow occurs."[35] These witnesses for the Moapa Band of Paiutes postulated that 6,000 acre-feet "upwells" or enter in the area of California Wash, which they believe explains isotopic data in the area.[36] If 16,000 to 17,000 acre-feet is believed to by-pass the

[33] See, testimony of Martin Mifflin, Henk Haitjema and Cady Johnson, public administrative hearing before the State Engineer, July 16-24, 2001, pp. 820-831.

[34] Id. at 925-930.

[35] Id. at 943.

[36] Id. at 944-947.

Muddy River Springs area, the water right permits already issued in Coyote Springs Valley alone equal the estimate of the amount of carbonate flow that by-passes the region, and is not part of the flow discharged from the Muddy River Springs area. These 16,000 to 17,000 acre-feet perhaps flow through Hidden Valley, Garnet Valley and California Wash. But the witnesses for the Moapa Band of Paiutes believe there is additional water in the area of California Wash, but that evidence is speculative.

When the State Engineer issued Order No. 1169, the California Wash Hydrographic Basin was notably left out. This was done in recognition that perhaps this is the next basin in which the pumping of a small quantity of water could be permitted for stressing the carbonate-rock aquifer system, because it is downgradient of the Muddy River Springs. As the tribal witnesses believed should be done, this will enable the system to be stressed downgradient of the Muddy River Springs area in order to study the reactions to pumping from this portion of the region in conjunction with the other areas, which are to be studied under State Engineer's Order No. 1169.

The State Engineer finds that little is known as to what yield exists from the carbonate-rock aquifer and its impact on the alluvial aquifers or discharge springs of the regional area. However, based on the scientific studies to date, the experts believe there is some water that can be developed from the system, but only through slow, staged development of small amounts accompanied by significant monitoring, studying and reporting, with plans for mitigation if impacts to existing water rights are shown. The State Engineer finds while he has concerns over development of the carbonate-rock aquifer system, lack of knowledge should not stop the development of the carbonate-rock aquifers in light of their potential as a significant resource in one of the driest places in the nation. However, development should proceed in relatively small quantities and cautiously.

Therefore, the State Engineer finds he will not consider granting both applications as requested or granting any one application for the diversion rate or quantity requested.

VII.

As noted, by letter dated March 26, 2002, the LVVWD requested the State Engineer proceed with action on Applications 54075 and 54076, which were filed to appropriate 14,480 acre-feet annually.[37] The LVVWD requested that in the event the permits are issued for less than the amount requested, that the State Engineer withhold final action on the remaining portion of the ground water applied for until such time as definitive data on the availability of additional ground water in Basin 218 is available. The LVVWD indicated that it intends to make any permits issued under these applications available to the Moapa Band of Paiutes provided that a settlement agreement[38] between the Tribe and the LVVWD has been finalized. The settlement agreement indicates the Tribe wishes to develop the Reservation, including without limitation the development of a natural gas-fired power plant. However, the LVVWD further provided that, although these two applications were filed as part of what has come to be known as the Cooperative Water Project, development along the I-15 corridor and continued growth in the north section of Las Vegas have caused the LVVWD and SNWA to evaluate resource opportunities in relative proximity to these areas separately from the Cooperative Water Project, as reflected in the 2002 SNWA Resource Plan.

In State Engineer's Ruling No. 5008, which addressed the LVVWD's request to appropriate water in Hidden and Garnet Valleys,

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[37] Letter dated March 26, 2002, from David Donnelly to State Engineer. File Nos. 54075 and 54076, official records in the Office of the State Engineer.

[38] See, Draft Settlement Agreement attached to letter from David Donnelly to State Engineer, dated March 26, 2002. File Nos. 54075 and 54076, official records in the Office of the State Engineer.

the State Engineer noted that the national news of late is filled with stories as to the lack of sufficient power generating resources in the western United States. Ruling No. 5008 includes significant discussion about the power situation, as it was believed to exist one year ago, and references Governor Guinn's February 22, 2001, energy plan for Nevada, which includes expediting the construction of some of the proposed power plants and negotiating for some of that power to remain in Nevada.[39] State Engineer's Ruling No. 5008 was premised on that immediate need for power generation, and that action on the applications in Hidden and Garnet Valleys would allow the LVVWD to provide water resources for the construction of realistic power generation projects, which will use water efficient, air-cooled technology, in exchange for a portion of the energy remaining in Nevada. In Ruling No. 5008, the State Engineer found that evidence indicated a power crisis was on the horizon for Southern Nevada.

In the LVVWD's request that the State Engineer act on Applications 54075 and 54076, it indicates that it is the LVVWD's intention to make any permits issued under these applications available to the Moapa Band of Paiutes under a proposed settlement, which addresses ground water and surface water issues of the Tribe. The proposed settlement indicates that the Tribe wishes to develop a natural-gas fired power plant on its reservation, but seeks an initial use of at least 10,000 acre-feet annually, indicating the Tribe is likely planning a water-cooled power plant.

Technology is available, which can produce significant amounts of electricity using air-cooled systems. This technology uses significantly less quantities of water. The State Engineer recognizes there are unique issues when dealing with tribal

[39] Letter from David Donnelly, Deputy General Manager, Las Vegas Valley Water District to Hugh Ricci, State Engineer, dated March 5, 2001. File Nos. 54073 and 54074, official records of the Office of the State Engineer.

claims, but does not believe it is prudent to use substantial quantities of newly appropriated ground water for water-cooled power plants in one of the driest places in the nation, particularly with the uncertainty as to what quantity of water is available from the resource, if any. However, the State Engineer notes that his analysis may not be the same in the context of a change application of water rights that had previously been placed to beneficial use. The State Engineer finds that until a determination can be made as to the quantity of water available, any amount granted for appropriation must be limited as was done in State Engineer's Ruling No. 5008 and State Engineer's Order No. 1169.

The State Engineer finds there is no definitive evidence of a substantial quantity of water being available from the groundwater resources of the California Wash Hydrographic Basin. The State Engineer finds from the evidence and testimony presented during the July and August 2001 administrative hearings that California Wash is perhaps the next best place to begin stressing the carbonate-rock aquifer system, but with the same small quantity of water, monitoring and mitigation provisions as set forth in State Engineer's Ruling No. 5008. The State Engineer finds that whether the applicant decides to pursue a settlement agreement with the Moapa Band of Paiutes is not presently before him, but further finds there are sufficient reasons to grant the LVVWD a municipal water right for a small quantity of water from this groundwater basin.

VIII.

Many of the protestants alleged that these applications were two of the 146 filed by the Las Vegas Valley Water District, which when combined, sought a quantity of water that would deprive the area of origin of water needed to protect and enhance its environment and economic well being, and that the diversion would unnecessarily destroy environmental, ecological, scenic and recreational values the State holds in trust for its citizens.

The State Engineer finds the manner and place of use under the applications as filed is for municipal and domestic purposes within Clark, Lincoln, Nye and White Pine Counties. The State Engineer finds that the service area of the Las Vegas Valley Water District is solely Clark County.[40] The State Engineer finds there is evidence from the July 2001 administrative hearings and the 2002 SNWA Resource Plan,[41] which indicates that the LVVWD must pursue other water resource options. The State Engineer finds, until more is known about whether the carbonate-rock aquifer area is a significant source of ground water or not available, it is impossible to address whether there is a need to protect and enhance the environment and economic well being of the area of origin. The State Engineer finds, until more is known about whether the carbonate-rock aquifer is a significant source of ground water that can be appropriated on a sustained basis, it is impossible to address whether the diversion would unnecessarily destroy environmental, ecological, scenic and recreational values the protestants allege the State holds in trust for its citizens.

The State Engineer finds that by issuing one of the permits requested, for a limited amount of water, and holding the other application in abeyance, progress can be made toward information gathering, while hopefully protecting the resource and other areas of concern. The State Engineer finds that the requirements of monitoring and mitigation being imposed will provide the needed information as to whether the appropriation is environmentally sound from a hydrologic standpoint. The State Engineer finds,

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[40] Nevada Revised Statutes, Text of Special and Local Acts, Vol. 11, pp. 283-295.

[41] Letter dated March 26, 2002, from David Donnelly to State Engineer. File Nos. 54075 and 54076, official records in the Office of the State Engineer.

since he is only going to grant one application for a reduced quantity and is holding the other application in abeyance until the study ordered in State Engineer's Order No. 1169 is completed, he does not believe use of the water will unduly limit future growth and development in the California Wash groundwater basin but, rather will enhance growth in the basin.

IX.

Some of the protestants alleged that the applications should not be granted in the absence of comprehensive planning. The State Engineer finds there is no provision in Nevada Water Law which requires comprehensive water resource development planning prior to the granting of a water right application, and further as discussed below, that the LVVWD and the SNWA have engaged in long-range planning.

X.

Some protestants alleged that the approval of the applications would sanction and encourage the willful waste and inefficient use of water in Las Vegas Valley.

> In Las Vegas, the role of conservation is critical to the region's water planning efforts. In 1990, the local water and wastewater agencies completed an extensive supply and demand projection process that resulted in public realization that the region would run out of water in fifteen years even with conservation. The need for conservation was quickly acknowledged by the public and widespread conservation efforts began in the summer of 1991. Creation of artificial lakes was banned, water waste ordinances were adopted, and lawn watering was restricted during the hotter time of the day.
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> * * *
>
> To begin the shift to water-conserving rates, local water purveyors switched from flat rates to increasing block rates.
>
> From 1991 through 1994, conservation education and water rates slowly increased. During the IRP [Integrated Resource Plan] process in 1994 and 1995, it became obvious that conservation could extend the time

> frames when additional resources and facilities are needed. As a result, the Board adopted recommendations on conservation, including one that required a 10 to 15 percent reduction in maximum day water usage by summer 2000.[42]

Further activity towards conservation in the Las Vegas Valley has encompassed public education to reduce peak summer usage, agreeing to follow the Bureau of Reclamation's conservation measures called "Best Management Practices", waste water reuse and a xeriscape study. "A recent survey by the City of Austin, Texas of water purveyors around the nation shows the Authority's overall program is among the most comprehensive in the country."[43]

The State Engineer finds the SNWA is taking conservation seriously as part of its overall water management plan.

XI.

Some of the protestants alleged that the LVVWD has not obtained rights-of-way from the BLM. The State Engineer finds every water right permit is conditioned on the applicant obtaining any necessary right-of-way and these applicants will not be treated any differently.

XII.

Some of the protestants alleged that the LVVWD lacks the financial capability for developing the project. This protest allegation is more relevant if the State Engineer were considering all the applications filed for the Cooperative Water Project together as one project. The State Engineer finds the issue of financial ability to develop the massive project of all the LVVWD filings is not currently relevant.

XIII.

Some of the protestants alleged that the applications failed to include statutorily required information, specifically a

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[42] Southern Nevada Water Authority 1999 Water Resource Plan, at 7-10, October 1999.

[43] Id. at 8.

description of the place of use, the proposed works, the estimated cost of such works and the estimated time required to go to beneficial use. The State Engineer finds he has sufficient information to address the applications.

XIV.

Some of the protestants alleged that the applications failed to contain sufficient information for the State Engineer to safeguard the public interest and that a publicly-reviewable assessment must be done of the cumulative impacts of the proposed extraction, mitigation measures needed and alternatives to the proposed extraction. The State Engineer finds that the process envisioned by allowing relatively small amounts of water to be appropriated along with staged development and significant monitoring addresses this protest concern; however, there is nothing in the Nevada Water Law, which requires a public review assessment process. The records of the State Engineer are always available for public review.

XV.

Some of the protestants alleged that the population projection numbers are unrealistic. The applicant projected a population 1,400,000 people by the year 2020. The present population of Clark County is approximately 1,400,000 people; therefore, the State Engineer finds the population projections were not unrealistic, but rather underestimated the projected population.

XVI.

Some protestants alleged that these applications, among the others, would allow the LVVWD to "lock up" vital water resources for possible use in the distant future beyond current planning horizons, and further alleged that the applications substantially overstate future water demand needs. These applications were filed in 1989. In 1989, the LVVWD believed it was running out of additional water resources in the very near future.

In 1987, the Nevada Legislature enacted the first water laws providing for projects, which recharge, store and recover water.[44] Recharge by the LVVWD began around 1989. In 1991, the LVVWD issued a moratorium, which prohibited any new hookups to the water system. Thus, the future water demands were not beyond current planning horizons.

Since the filing of the applications, the LVVWD, along with and as a member of the SNWA, has been involved in many varied programs to plan for the future resources of the Las Vegas Valley. In 1991, the SNWA was formed, and the SNWA purveyors agreed that any new contract with the Secretary of the Interior for remaining unallocated water from the Colorado River would be with the SNWA and would deliver water to purveyor members and they agreed on the method of allocating any water received.[45] The remaining Colorado River water was contracted for in 1992.

In 1993 and 1994, the SNWA obtained additional Colorado River water through agreements with Southern California Edison and Basic Management, Inc., and agreements have been reached regarding reclaimed water.[46] Beginning in 1996, the Secretary of Interior declared a surplus condition on the Colorado River every year (up to the date of the October 1999 Water Resource Plan), and under the excess surplus criteria this had provided additional water for Southern Nevada.[47] Since then, the Department of Interior has issued a record of decision making the Interim Surplus Guidelines effective beginning in 2002, which will provide Colorado River water for the SNWA purveyors through 2016,[48] if a surplus is

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[44] Nevada Revised Statutes § 534.250 - 534.340.

[45] Southern Nevada Water Authority 1999 Water Resource Plan, at 14-15, October 1999, p. 14.

[46] Id. at 14-15.

[47] Id. at 20-21, 31-36.

[48] Letter from David Donnelly, Deputy General Manager, Las Vegas Valley

available and other factors tied into California cutting down on its use of the Colorado River are in place by the end of 2002. Planning for the reuse of reclaimed water has taken place over the last decade and thousands of acre-feet of water are now used in power plants and on golf courses.[49] Furthermore, there now exists the possibility of using the Arizona Water Banking program, an option that did not exist at the time of the filing of the applications.[50] Nevada is very close to, if not there, for having used its full allotment of Colorado River water.

The State Engineer finds as to these applications, the amount requested under the applications is not substantially overstated as to future planning needs for the Las Vegas Valley. The State Engineer finds that Nevada is a prior appropriation state, that is, first in time, first in right. The State Engineer further finds all water belongs to the public subject to appropriation pursuant to law.[51] The applicant is moving forward with a use for the water requested for appropriation under these applications; therefore, there is a reasonable expectation to go to beneficial use within a reasonable amount of time. The State Engineer finds the LVVWD's need for future resources is not beyond the current planning horizon.

XVII.

Some of the protestants alleged that the granting of the applications would destroy the economic and growth potential of the hydrographic basin. The State Engineer finds Nevada is a prior appropriation state, that is first in time is first in right. The State Engineer finds these applications would not

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Water District to Hugh Ricci, State Engineer, dated March 5, 2001. File Nos. 54073 and 54074, official records of the Office of the State Engineer.

[49] Southern Nevada Water Authority 1999 Water Resource Plan, pp. 16-17, October 1999.

[50] Id. at 36-38.

[51] NRS § 533.025, 533.030.

destroy the economic and growth potential of the hydrographic basin, but rather growth is occurring in the area, and the water use is also for the area since growth is occurring along the I-15 corridor.

XVIII.

Some of the protestants alleged that further study is needed because the potential effects are impossible to anticipate, that the public interest will not be served if the water and water-related resources in the Death Valley National Monument and the Lake Mead National Recreational Area are diminished or impaired as a result of the appropriations, and that the applications will eventually reduce or eliminate the flows from springs which are discharge areas for a regional groundwater flow system upon which the National Park Service claims senior appropriative and implied Federal reserved water rights. The State Engineer finds that gradual, staged appropriations of smaller quantities of water with sufficient monitoring and mitigation will deal with these protest issues, and there are too many unknowns to be able to address this issue without developing additional science. The approach being taken by the State Engineer in Ruling No. 5008, and Order No. 1169 is that of further study.

XIX.

Some of the protestants alleged that the proposed diversions are from the carbonate-rock province of Nevada that is typified by complex, interbasin, regional-flow systems that includes both basin-fill and carbonate-rock aquifers along with interbasin flows that are poorly defined, and the diversions will reduce the interbasin flows, modify the direction of groundwater movement in adjoining and hydraulically connected basins thereby reducing spring and stream flows. The State Engineer finds this is the reasoning behind gradual, staged development, which is to develop further knowledge that it lacking at this time as to how the complex carbonate-rock aquifer system works. The State Engineer further finds it is not known whether the diversions will reduce the interbasin flows, modify the direction of groundwater movement in adjoining and hydraulically connected basins reducing spring and stream flows; thus, the reasoning behind gradual development, monitoring, and mitigation, if necessary.

XX.

Some of the protestants alleged that the available scientific literature is not adequate to reasonably assure that the proposed diversions will not impact senior rights and water resources. The State Engineer finds this statement to be true, and again; thus, the reasoning behind gradual development, monitoring and mitigation, if necessary. The data will never be obtained through "literature," but only through the development of science based on real facts. The State Engineer further finds without development of the resource the knowledge will not be obtained to even explore whether development of the resource is feasible or not.

XXI.

Some of the protestants alleged that as of December 1988 the sum of Applications 54075 and 54076 and the committed diversions will exceed the perennial yield of the groundwater basin; therefore, there is no water available for appropriation. The State Engineer finds the water requested for appropriation under these applications is from the carbonate-rock aquifer and at this time it is unknown what contribution if any the carbonate-rock aquifer has to the estimated perennial yield of the California Wash groundwater basin.

XXII.

Some of the protestants alleged that it is unclear whether the amount contemplated in the applications is necessary and reasonably required for the proposed purposes. The State Engineer finds since he is taking these applications basin by basin and the amount permitted under one application is being reduced, with the other application being held in abeyance, it is a reasonable amount for the municipal use envisioned.

XXIII.

Some of the protestants alleged that the granting of the applications will lower the water table, sanction water mining, degrade the water quality, cause negative hydraulic gradient influences, threaten springs and seeps and phreatophytes, which provide water and habitat critical to the survival of wildlife, including endangered species and grazing livestock. They further alleged that the applications would create air contamination and pollution in violation of State and Federal statutes.

The State Engineer finds these protest claims directly relate to the discussion above as to gradual, staged development with sufficient monitoring to explore the capacity of the system, and air quality issues are addressed by the Clark County Health Department. Furthermore, the State Engineer finds that as a municipality with access to resources such as the Colorado River or the Muddy River, the LVVWD has sufficient resources to plan for any necessary mitigation.

XXIV.

Some protestants alleged that the applications will cause water rates to go up thereby causing demand to go down thereby rendering the water unnecessary. The State Engineer finds this protest claim to be completely hypothetical and not within his scope of review.

XXV.

One protestant alleged that until the claims under the Treaty of Ruby Valley (1863) are adjudicated the applications are premature. The State Engineer finds issues as to the Treaty of Ruby Valley are not within his jurisdiction and all water right permits are issued subject to existing rights.

XXVI.

The State Engineer finds that if any significant impacts to existing water rights are detected the LVVWD or any assignee will be required to mitigate those impacts.

CONCLUSIONS OF LAW

I.

The State Engineer has jurisdiction over the parties and the subject matter of this action and determination.[52]

II.

The State Engineer is prohibited by law from granting a permit under an application to appropriate the public waters where:[53]

A. there is no unappropriated water in the proposed source;
B. the proposed use or change conflicts with existing rights;
C. the proposed use or change conflicts with protectible interests in existing domestic wells as set forth in NRS § 533.024; or
D. the proposed use or change threatens to prove detrimental to the public interest.

III.

The State Engineer concludes that the expert scientific evidence found in the reports prepared over the last decade leads him to believe there is possibly some unappropriated water in the carbonate-rock aquifer system, but that further knowledge is necessary before any amount can be quantified. The State Engineer concludes that only by gradual, staged development can the additional science be obtained, which will allow a better understanding of the carbonate-rock aquifer(s).

IV.

The State Engineer concludes that little is known as to what

[52] NRS chapters 533 and 534.

[53] NRS § 533.370(3).

yield exists from the carbonate-rock aquifer, if any. The State Engineer concludes it is impossible to say if there will be any impacts on the alluvial aquifers of the area groundwater basins or existing water rights within those groundwater basins. The State Engineer concludes that by providing safeguards, such as monitoring and mitigation, there are some assurances that any impacts can be quantified and, if necessary, mitigated.

V.

The State Engineer concludes that Nevada Water Law does not require comprehensive planning before the granting of a water right application.

VI.

The State Engineer concludes the evidence does not indicate that appropriation of water from the carbonate-rock aquifers will automatically conflict with existing water rights. The complexity and unknowns of the system make such a determination extremely difficult. Only by allowing some development to proceed will the additional science be obtained to provide further knowledge as to how the carbonate-rock aquifer and alluvial aquifer systems are connected, if they are. The State Engineer concludes that the available scientific literature is not adequate to reasonably assure that the proposed diversions will not impact senior rights and water resources; thus, the requirements of monitoring and mitigation, if necessary. The State Engineer concludes that the evidence to date indicates that generalizations cannot be made applicable to specific basins because, they may not be applicable to any particular basin. Individual basins may react completely differently to the pumping of the carbonate-rock aquifer.

VII.

The State Engineer concludes that the protest issue that the applications would encourage willful waste and inefficient use of water in the Las Vegas Valley is not a protest issue warranting consideration, and the LVVWD has been proactive in conservation planning.

VIII.

The State Engineer concludes if the applicant needs to obtain the approval of the United States Department of Interior, Bureau of Land Management for any necessary rights-of-way, that is any issue for the applicant to address with the Bureau of Land Management. The granting of a water right permit does not waive the requirements of other State or Federal laws.

IX.

The State Engineer concludes the applications contain sufficient information for the State Engineer to safeguard the public interest. The State Engineer concludes that it does not threaten to prove detrimental to the public interest to allow smaller quantities of water to be developed from the carbonate-rock aquifer system, but the development must be staged and in conjunction with sufficient monitoring, and plans for mitigation of impacts, if necessary. The State Engineer concludes it does not threaten to prove detrimental to the public interest to allow some development of this resource to proceed. The State Engineer concludes that the LVVWD has sufficient resources to plan for any necessary mitigation, and any possible assignee must also have mitigation resources available and will be subject to all permit terms.

X.

The State Engineer concludes that Nevada Water Law does not require a publicly-reviewable assessment of the cumulative impacts of the proposed appropriation.

XI.

The State Engineer concludes he is only acting on Applications 54075 and 54076 under this ruling and since the applicant has proposed a plan for the beneficial use of the water in the near future, the issue of "locking-up" the resource beyond current planning horizons is moot. The State Engineer concludes the carbonate-rock aquifer system is so complex and unsure that pending applications cannot be acted on quickly due to the caution in development that must be exercised.

XII.

The State Engineer concludes that granting the applications will not destroy the economic and growth potential of the hydrographic basin because, it is development along the I-15 corridor, which includes the hydrographic basin, that has prompted the request to act on the applications.

XIII.

The State Engineer concludes that the required monitoring and mitigation protect the water-related interests of the Death Valley National Monument and the Lake Mead Recreational Area.

XIV.

The State Engineer concludes that it is unknown, without further analysis through development of the resource, if these appropriations will reduce interbasin flows or modify the direction of groundwater movement thereby reducing spring and stream flows. The State Engineer concludes it is because of these unknowns that he will require monitoring and mitigation, if necessary.

XV.

The State Engineer concludes that while the existing rights in the California Wash groundwater basin exceed the estimated perennial yield, that analysis did not contemplate the carbonate-rock aquifer resource as perhaps changing the analysis of the water available for appropriation and only by stressing the system can such a determination be made.

XVI.

The State Engineer concludes it would threaten to prove detrimental to the public interest to allow the appropriation of the full quantity requested under the applications at this time, since no determination can be made that there is even unappropriated water available.

XVII.

The State Engineer concludes that by granting of these water right applications he is not sanctioning water mining; and thus, the requirement for monitoring and mitigation.

XVIII.

The State Engineer concludes that the issue of air contamination or pollution is within the authority of the Clark County Health Department.

XIX.

The State Engineer concludes that the protest issue that the applications will cause water rates to go up causing demand to go down is without merit.

XX.

The State Engineer concludes that any issues as to the Treaty of Ruby Valley are not within his jurisdiction and all water right permits are issued subject to existing rights.

RULING

The protests to Application 54075 is upheld in part and overruled in part. They are being upheld in that more information is necessary before the appropriation of large quantities of water from the groundwater basin can proceed. They are being overruled in that development of a smaller quantity of water is being permitted. Application 54076 is being held in abeyance until at least the study ordered under State Engineer's Order No. 1169 has been completed. Application 54075 is hereby granted subject to:

1. Existing rights;
2. Payment of the statutory fees;
3. A monitoring program approved by the State Engineer prior to the diversion of any water permitted under these

applications prepared in conjunction with the study ordered in State Engineer's Order No. 1169.

4. The total duty under Permit 54075 shall be limited to 2,500 acre-feet annually with a diversion rate of 5.0 cfs, no additional water will be granted under this application; and

5. If impacts to existing rights are demonstrated, the applicant or any assignee will be required to mitigate the same.

Respectfully submitted,

Hugh Ricci, P.E.

HUGH RICCI, P.E.
State Engineer

HR/SJT/jm

Dated this 18th day of April, 2002.

Additional comments from Technichrome.

In my previous submission Technichrome asserted that reducing well withdrawals across the entire LWRFS designated area would not accomplish the desired goals. There is no evidence to suggest it might. The evidence suggests that a LWRFS area wide reduction would have no impact on the Pederson Springs. Massive reductions in pumping at the two nearby well sites had no effect on the flow of the springs, so there is no support to the theory that a LWRFS area wide reduction would have any impact on the springs or Dace habitats. Their is probably some effect localized reductions with an immediate and direct hydrologic connection to the springs would have.

Technichrome now wants to cover the damage a system wide reduction in allocated rights would have.

Many large businesses, particularly in the Apex Industrial Park, rely on well water. There are several gypsum/drywall and building material plants in the area (Pabco, Georgia Pacific, and Lhoist) that rely on well water. There are multiple electric generation plants, for example Nevada Cogen Associates 1 and 2 who require a lot of water. The city of North Las Vegas has represented that “Up to 20,000 direct jobs and 56,000 support jobs could be created when Apex is fully developed,” This requires water. (see https://www.ktnv.com/news/north-las-vegas-apex-industrial-park-to-finally-get-water) And there is the Apex landfill which requires water to manage its waste.

A LWRFS reorganization of priorities based on first use would put the agricultural uses ahead of all industrial uses, since they have earlier first use dates. This is contrary to the State Engineers previous determinations (e.g. order 1025) that Industrial uses are prioritized over ag uses.

If the LWSFS water rights were prioritized by date of first use and a basin wide reduction was required, this would result in the industrial users losing their water rights. This could be an economic disaster for the affected businesses. If it interferes with the development of the Apex park, it would also have a major impact on employment and the well being of the citizens of North Las Vegas.

It is unlikely that reorganizing water right priorities would stand up in court since there is rational reason for it.

Technichrome suspects that many of the wells supplying the various plants have not pulled out 100% of their allocated water, so they have not been able to prove their Beneficial use. Hopefully with these proposed changes, those who did not use 100% of their allocated rights do not get punished for their conservation of water.

Another concern Technichrome has is that eliminating the basin barriers within the LWSFS would allow unfettered movement of water rights within the larger LWRFS basin. For example NV Energy could transfer all of their water rights from the closing Reid Gardner station in Moapa to the Harry Allen station in Apex (Garnet Basin). There would be nothing to prevent this. Multiple other users could acquire rights from current agricultural users and transfer the rights to the users in Apex. Many additional thousands of acre feet could now be pumped out of the Garnet basin, which according to the State Engineer is already oversubscribed. By removing the existing basin boundaries, nothing would stop this. These rights would be mostly unused existing rights.
This has both a good side and a bad side. The good side is that existing rights holders in other LWRFS currently designated basins could get premium prices for their unused rights. More water would be available to users in the Apex Park. The down side is that the Garnet basin could not support the added water use. The problem is the State Engineer loses control to manage or prevent this.

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RESPONSE TO INTERIM ORDER #1303
SUBMITEED BY TECHNICHROME

Having reviewed the order, Technichrome makes the following comments.

Technichrome does not object to considering basins 210, 215, 216, 217, 219 and 220 as a "joint administrative basin."

It is likely that in addition to these basins other basins are hydrologically connected to the LWRFS. The Journal of the Nevada Water Association Fall 2004 states "That portion of the flow system contributory to the Muddy Springs is interpreted to be primarily derived from recharge on the mountain ranges along the White River Flow System (WRFS), extending approximately 200 to 300 miles to the north (Eakin, 1966) and perhaps from the Meadow Valley Flow System immediately to the east of the WRFS (Thomas and others, 2001; LVWD, 2001.)" It is unclear why these additional basins are excluded from the Joint Administrative basin. Sources upstream from the Pederson Springs are more likely to have an impact on the springs than wells just a few miles away to the west and even the included downstream withdrawals. It is understood that the above ground portion of the White River disappears for many miles north of Parhranagat Valley. However, there is probably a direct underground hydrologic link between the various portions of the White River.
Another area of interest is the Meadow Valley Wash, designated basin 205. This stream, although partly underground, feeds directly into the lower Muddy River. and has been called the East Fork Muddy River (Bancroft's Map of California and Nevada: 1868). Therefore, the request is to consider at least Basin 205, the Meadow Valley Wash, for inclusion into the Joint Administrative Basin since it is clearly part of the LWRFS.

Secondly, the interim order 1303 states the LWRFS "must be administered as a joint administrative unit, including the administration of all water rights based upon the date of priority of such rights in relation to the priority of rights in the other basins." (page 10). Technichrome notes that combining all water rights into a single unit where withdrawals are based on the date of priority of such rights gives the State Engineer less control over withdrawals than what he currently has. It gives him less ability to preserve water flows in the springs and to save the Moapa Dace. This seems contrary to what he is trying to accomplish.

The State Engineer should have the ability to control usage within small areas. With his proposed change he will only be able to control usage over a much wider area. Any order in reduction would be based on seniority across the whole LWRFS. If the State Engineer were to decide that the area around Petersen Springs consisted of a single shallow aquifer and that withdrawals need to be reduced in the vicinity of this shallow aquifer, he would not be able to reduce pumping without ordering wells 25 miles away to also reduce pumping. Every well in the basin with a later priority date would be affected, when just the ones closest to the springs need to be curtailed. If he reduced the grid size to a few miles squares he could more easily control pumping in local areas. As proposed, increasing it to 50 miles defeats the purpose of the change.
It like watching tv. A low resolution tv gives one a bad image quality, so bad at times it is hard to discriminate the picture. Whereas a high resolution TV (4k) gives a vastly superior quality. In technology, engineers always try to provide the best resolution possible. Here the State Engineer seems to be headed toward low resolution and loss of control.
In medicine, drugs that just target the cancerous cells are much more effective than drugs that indiscriminately target cells in the whole body. Targeted solutions are almost always better solutions.

There is evidence that the reduction in flow measured in the Order 1169 Aquifer test and cited in this Interim Order #1303 is a localized effect. The report mentions that the closure of turbines at Reid Gardner resulted in a reduction of 5000 AFA in withdrawal from the aquifer starting in 2015 and continuing until this day. The graph on page 5 and the summation shows that there was no increase in outflow of the Pederson Springs from 2015 through 2018. There was actually a decrease in outflow from 2016 to 2018. This indicates no correlation (and possibly a reverse correlation) between the Reid Gardner well withdrawals and the Pederson Springs output. Reid Gardner is five miles from the Pederson Springs. The entire combined basin well withdrawals during the test were 14,535 AFA (page 4). The Reid Gardner reduction was a 35% reduction over the entire basin withdrawals with no effect on the Pederson wells. It is unlikely that wells much further away have any impact on the flow of Pederson Springs.

According to the Journal of the Nevada Water Resources Association (Fall 2004), the Moapa Valley Water District well at Arrow Canyon increased withdrawals from 750 AFA to 2500 AFA around 1998 (page 83) with little impact on the flow at Pederson Spring "suggesting a lack of direct hydraulic connection between the Arrow Canyon well and Pederson spring." (page 83) and "suggesting a hydraulic discontinuity between the pumping well and spring." (Pae 76) The distance between the well and Muddy Springs area appears to be less than two miles, yet parts of the new Joint Administrative Basin are more than 50 miles apart. There is no evidence supporting that reducing well flows 25 miles to the west of the Pederson Springs (and still within the LWRFS) would have any impact on the Springs.
The ultimate solution may be to just reduce flow in wells and river withdrawals that directly impact the flow of the Pederson Springs. The State Engineer should have the ability to implement this targeted solution.

Assuming that correlation is causation, the best one could hypothesize from the draw-down study is that some withdrawals have an effect on the Pederson springs, but certainly not all. Those drawdowns that have an effect are those with a direct and probably proximal hydrological connection, most likely just upstream and downstream from the springs. Possibly only within the shallow basin where the springs reside.

The conclusion the LWRFS “must be administered as a joint administrative unit, including the administration of all water rights based upon the date of priority of such rights in relation to the priority of rights in the other basins” has no basis in evidence. Even with dramatic increases and decreases in pumping levels at nearby wells to the Pederson Spings, little influence is seen on the Springs. How the State Engineer gets to the statement that all rights must be administered as a single basin is a mystery. Shotguns are not the best tools for killing fleas.

Whatever the State Engineer decides, it would be useful for him to have the ability to impact just the wells that will give him the outcome he is looking for. If that means the whole Administrative basin, then he should be able to do that. However, if it just means a small portion of the basin, he should have that authority as well. The current science does not support a Joint Administrative basin wide reduction. The best hope for the Moapa Dace is a targeted solution.

Water reductions in the LWRFS should not be based on priority dates of permits. That will not provide the control the State Engineer needs to save the Moapa Dace and Pederson Springs.

Nigel Macrae
Vice President
Technichrome

United States Department of the Interior

GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
Room 227, Federal Building
705 North Plaza Street
Carson City, Nevada 89701

August 3, 1984

MEMORANDUM

TO: Members of the Carbonate Terrane Society

FROM: Terry Katzer, Nevada Office Chief, WRD, Carson City, NV

SUJBECT: Carbonate Terrane Study

In response to our last meeting, we have prepared the enclosed project proposal for a 10-year investigation of the entire Carbonate Terrane, which will serve as a point of discussion for our August 13th meeting. We have probably overlooked some elements, however, I'm sure they will fall into place during the course of the study. There is a large degree of uncertainty on projecting cost for ten years. For one thing, the inflation rate is unknown. Also, the budget, while it may seem ambitious, may in all actuality, be deficient. Another large item not estimated here are the costs of an exploratory drilling program with subsequent development/production drilling; these costs will probably dwarf all the investigative cost. And finally, we realize that ultimately, the availability of funds will be a controlling factor in the investigative process.

To briefly summarize the proposal, it is important to understand that the water resources of the carbonate terrane are not well defined, for the data are sparse, and the hydrology and geology are complex. It will take a lot of money and a long time to arrive at some reasonable understanding of the system. Unless this understanding is reached, the development of carbonate water is risky, and the resultant effects may be disastrous for the developers and current users.

Water resource planning based on a scientific understanding of the hydrology will have many benefits. From the Las Vegas Valley water users perspective, it will mean knowing that the additional water for their expanding needs is really available, and that it will be possible to quantify that additional water.

From the perspective of the current water users throughout the Carbonate Terrane, including the potential White Pine Power Project users, it will mean ensuring a safeguard on their already appropriated ground-water rights, and it will allow the allocation of unallocated waters to proceed toward a much better defined perennial yield.

From the State's perspective, an understanding of the system will allow its optimum management for the benefit of all the people. From the Federal agencies perspective and, in particular the Department of Interior's Water and Science, an understanding of the system is essential prior to beginning resource development.

See you on Monday, August 13 at 10:00 a.m. in Rick Holmes' shop.

Terry

Terry Katzer

Enclosure

TK:tf

PROJECT PROPOSAL
for
INVESTIGATION OF CARBONATE-ROCK AQUIFERS IN
EASTERN AND SOUTHERN NEVADA

U.S. Geological Survey
Water Resources Division
Carson City, Nevada

July 1984

PROJECT PROPOSAL
for
INVESTIGATION OF CARBONATE-ROCK AQUIFERS IN
EASTERN AND SOUTHERN NEVADA

Problem

Most of the known water resources of Nevada, which includes virtually all surface water and most of the ground water in basin-fill reservoirs, are used or appropriated to (or beyond) the extent of current estimates of their perennial yield. For development to continue in some of the more intensely developed basins, "new" sources of water or new methods of managing the existing sources will be necessary. In this context, the aquifers of the deep carbonate rocks of eastern and southern Nevada are often cited as potential "new" sources of water. At the same time, the hydrology of the Carbonate Terrane, and in particular the carbonate-rock aquifers, is the least understood in the Great Basin. Large-scale and long-term investigations will be needed to overcome this knowledge deficiency.

This proposal is not the first to consider a comprehensive investigation of the hydrology of the Carbonate Terrane in Nevada (fig. 1). Area-wide studies have been conducted by four different organizations to date (area-wide here indicates an interest in the Carbonate Terrane as a whole or at least over an area large enough to include more than one of the major regional flow systems within the Terrane). The organizations are 1) the Desert Research Institute (Mifflin, 1968, Hess and Mifflin, 1973), 2) the U.S. Air Force (M-X Multiple Protective Shelter Water Resources Program 1983), 3) the U.S. Geological Survey (Great Basin Regional Aquifer System Analysis, Harrill and others, 1982), and 4) the U.S. Bureau of Reclamation (Southern Nevada Deep Carbonate Aquifer Study, 1984). Each of the studies by these organiza-

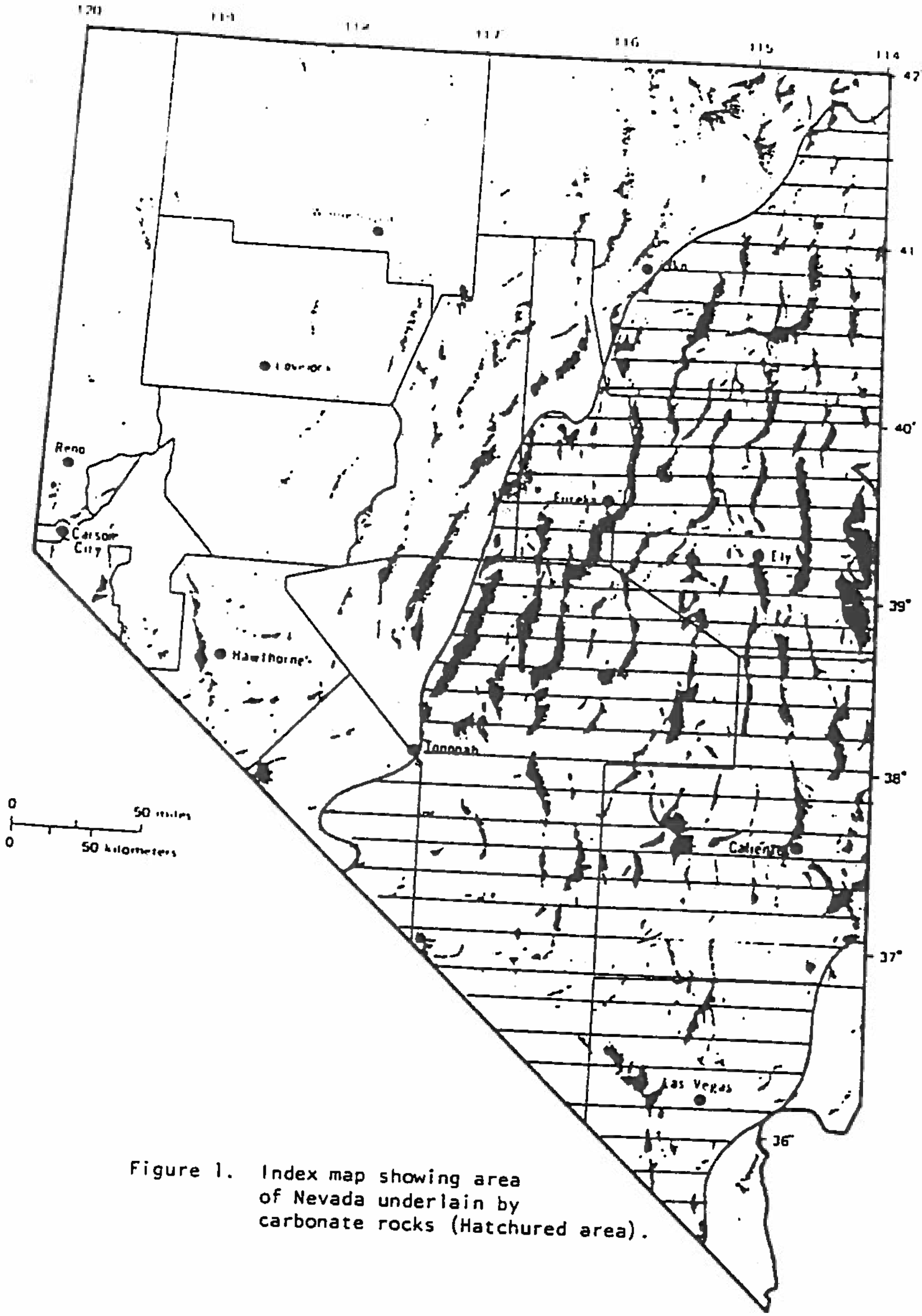

Figure 1. Index map showing area of Nevada underlain by carbonate rocks (Hatchured area).

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tions was concerned with the development of appropriate and feasible methods for the investigation of the hydrology of the Terrane, and to varying extents, each is concerned with the development of well-constructed plans for long-term studies to support and (or) assess development of the resources of the deep carbonate-rock aquifer

The large-scale investigations have been, and will continue to be, built on smaller scale studies. Important among the small-scale investigations are studies that have dealt primarily with the delineation and description of individual regional flow systems. These include 1) the early studies of the White River flow system by Maxey and Eakin (1949) and Eakin (1966); 2) the numerous studies in the area between, and including, the Nevada Test Site and Death Valley by Hunt and Robinson (1960), Eakin and others (1963), Winograd and Thordarson (1975), and Classen (1983); and, 3) the investigations of the geohydrology of Central Nevada associated with the Atomic Energy Commission's Central Nevada Test Area (Fiero and Illian, 1968 and 1969). Numerous studies of the hydrology of individual or small groups of basins have also been conducted by both private and public organizations and will provide their conceptual foundations to planned large-scale studies. Major sources of information for comprehensive investigations come from outside the hydrologic profession. Deep drill-hole information has been collected in the course of drilling deep test wells for oil exploration, and much of the geophysical data in the Carbonate Terrane was developed in support of mineral exploration.

The Carbonate Terrane of eastern and southern Nevada lies in an area in which local climates are primarily dependent on altitude. Annual preciptation totals range from less than 3 inches in some of the southern valleys (e.g., Amargosa Desert and Death Valley) to greater than 30 inches in some of the highest mountain ranges in the northeast (e.g., the Ruby Mountains). Precipitation on most valley floors range from 5 to 12 inches per year (Hardman, 1936). The most humid parts of the Carbonate Terrane, with local exceptions, lie in the vicinity of 38 degrees latitude where the valley floors are often more than 5,000 feet above sea level. The Utah and southern Nevada parts of the Terrane are the most arid. The temporal distribution of precipitation in the region is dependent on which of several storm tracks are influential in a particular area, but generally precipitation on valley floors throughout much of the Terrane is relatively evenly distributed between the winter and summer (Quiring, 1965, figures 2 and 3). Summer precipitation occurs mostly during thunderstorms.

Water deposited by precipitation within the Carbonate Terrane or on the bordering mountain blocks is the only water, so far as is known, that recharges the hydrologic systems of the Carbonate Terrane. Most of the precipitation on the valley floors is evaporated or transpired without entering the ground-water systems of either the basin-fill aquifers or the deep carbonate-rock aquifers. Thus, most of the recharg to basins and deep carbonate-rock aquifers is presumed to derive ultimately from precipitation in the mountains in and adjacent to the Carbonate Terrane. The processes by which this recharge occurs are poorly understood. In some basins, for example southern Ruby Valley (Johnson 1980, pages 17-180) and the Ash Meadows flow system (Winograd and Thordarson, 1975, page 92), recharge to the basin-fill aquifers, and to carbonate-rock aquifers, is believed to occur primarily as deep percolation of water into and through the mountain block materials. In other valleys and systems, for example the Amargosa Desert (Claasen, 1983, page 1), much of the recharge appears to have occurred primarily as a result of the percolation of surface runoff from snowmelt in the adjacent mountains, and took place in flood channels along alluvial fans and the basin floor during wetter climatic conditions 12,000 to 18,000 years ago. The percent of recharge water following one of these paths or the other must depend to a large extent on the topography and large-scale permeability of the mountain block.

Flow patterns within the basin-fill reservoirs of the Carbonate Terrane can be complex, but most often entail flow from the recharge areas at the base of the moutain blocks "down" the basin to one or more discharge areas. The water at these discharge areas either 1) evaporates at a playa or free-water surface fed by springs, 2) is evapotranspired by phreatophytes where the water table is relatively near land surface, 3) flows into another basin or flow system, or 4) leaves the system through some combination of the above modes of discharge. The location of these discharge areas within a basin is determined by some combination of geologic, topographic, and hydraulic factors.

The hydraulic and hydrologic connections between the basin-fill reservoirs and underlying carbonate-rock aquifers are poorly understood at this time. Studies in Ash Meadows (Bateman and others, 1972; Bateman and others, 1974) and in the Upper Moapa Valley (Maxey and others, 1966) have shown that in some cases very intimate connections between the two aquifers may exist while in other cases, the aquifers may behave as independent systems. The factors that may ultimately control the extent of interconnections are the presence of aquitards between the two types of aquifers and the extent to which hydraulic gradients exist which might induce interaquifer flow. The aquitards that may occur in this context are — in order of increasing age — layers of fine-grained sediments within the basin fill, thick layers of lava-flow materials, and (or) tuffs of Tertiary age, and fine-grained consolidated rocks (for example, the siltstones and shales of Mesozoic age that overlie some Paleozoic sections). Where such aquitards lie between the basin-fill aquifers and underlying carbonate-rock aquifers over a large area, flow and hydraulic connection between the two systems may be prevented or greatly modified.

The connection between the ground-water systems of mountain blocks and adjacent basin-fill aquifers -- and between adjacent basins through the intervening mountain blocks -- is also controlled at least in part by the presence of aquitards and by the existence of favorable hydraulic gradients. Where the normal faulting that created the basin and range topographically has left Tertiary volcanics or some poorly permeable unit along a large portion of the contact surface between the mountain block and basin-fill sediments, the capacity for recharge water that has percolated deep into the mountain block to leak into and recharge the basin-fill aquifers may be severely impaired. The presence of such an aquitard, or the presence of an intrusive body or other type of aquitard beneath the mountain block may also prevent inter-basin flow though the mountain block. Another barrier to interbasin flow that has been suggested in several cases is the presence of a mound of recharge water beneath mountain blocks (Eakin, 1963, page 15). Beneath ranges that receive a substantial amount of deep percolating recharge water, the hydraulic heads may be raised above the head in either of the adjacent valleys. As a result, water cannot flow towards or through the mountain block from either of the valleys. The amount of deep-percolating recharge necessary to create a hydraulic barrier must depend on the permeability of the mountain block (Eakin, 1966, pages 268-269; Mifflin, 1968, pages 15-20).

Mountain blocks at depth are not hydrologically distinct geologically from the carbonate rock as a whole. The exposed part of the mountain block is the same lithogically, as that part of the block of consolidated rock underlying the area. As such mountain-block hydrology at depth is no different from the hydrology of the consolidated rock beneath the basins. Both are dominated by the secondary and tertiary porosity -- and resulting permeability -- of the consolidated rocks. Secondary porosity is the porosity associated with fractures in the aquifer medium. Tertiary porosity is the porosity associated with dissolution features such as caves and modified fractures. Tertiary porosity and permeability is limited to the carbonate rocks, and, at depths where overburden pressures may tend to seal simple fractures, may be the most important avenue of ground-water flow (Eakin, 1966, pages 266 and 268). Dissolution of carbonate rock is generally concentrated near the water table or in the unsaturated portions of the carbonate rocks, where the water is still unsaturated with respect to the carbonate minerals. Within a short distance of entering carbonate rocks, the ground waters of the Carbonate Terrane are fully saturated with respect to those minerals. Caves occur most often in the mountain blocks and in specific parts of the Paleozoic section, but solution features may be present at great depth (Hess and Mifflin, 1978, pages 26-31).

The physics of flow of ground water through secondary-permeability terranes is such that water flow is very easy along the path of the fracture and solution features, and difficult perpendicular to these features. At a small scale then, flow direction need not parallel the local or regional hydraulic gradients. At large scales, depending on the degrees to which the fracture patterns are isotropic and sufficiently random, flow directions may or may not parallel large-scale hydraulic gradients. Instead, large-scale flow and discharge patterns may tend to parallel major structural features. This results in conditions in which large hydraulic gradients can persist with little actual flow.

Ground-water flow within the Carbonate Terrane at regional scales depends on the presence of fracture zones, the occurrence of intrusives and other local geologic barriers, the impacts of large-scale linear geologic features such as the Cortez Rift, the locations of topographic lows and other discharge areas, recharge distribution, and the configuration of aquitards and aquifers. Many large springs are associated with major faults in the carbonate terrane, and faults can act to expedite flow or act as barriers to flow (e.g., Winograd and Thordarson, 1975, pages 81 and 29). Ground-water discharge areas are commonly found in the areas that are lowest topographically, whether in a basin, a regional system or on the side of a mountain block. Recharge distribution can result in hydraulic barriers and ultimately drive the flow systems.

Given the myriad possible avenues of hydrologic connection between the various aquifers and flow systems and the uncertainties of recharge and discharge mechanisms and processes, an investigation of the hydrology of the carbonate-rock aquifers in Nevada is undoubtedly a difficult undertaking. Additional complicating factors include:

- Basic hydrologic data (ground-water levels in both the basin-fill and carbonate-rock aquifers, flow measurements for important springs, and flow measurements for major streams) are scarce or infrequently obtained in much of the area.
- Secondary hydrologic and other data, such as hydraulic parameters, geophysical and geochemical data, are lacking in many areas.
- Only a small number of wells and drill holes tap the deep carbonate rocks.
- The geology of the Great Basin in general, and the Carbonate Terrane in particular, is complicated.

- Uncertainties and inaccuracies exist in current methods of estimating ground-water inflow and recharge.
- Uncertainties and inaccuracies exist in current methods of estimating ground-water outflow and evaporative discharge.
- The geometry, properties, and boundaries of the carbonate-rock and basin-fill reservoirs are generally unknown, and definition of these properties can be expensive and difficult.
- Climatic conditions today are inadequately defined (particularly at higher altitudes) and conditions during the development of the flow paths within the deep-rock aquifers and flow paths are even more uncertain.
- Limited stresses on the water resources of the area under current development conditions, allow hydrologists information only on the narrow band of system responses to natural conditions.
- The relationship between geothermal systems and the deep carbonate-rock aquifers and ground-water flow systems is not well understood.
- The area underlain by significant carbonate-rock sequences in Nevada is over 40,000 square miles of sparsely populated land, and includes 106 hydrographic areas and basins.

A comprehensive investigation of the hydrology of the Carbonate Terrane will have to be at least ambitious enough to deal in some manner or other with each of these complications and uncertainties.

Objective

The objective of the proposed project is to understand the hydrology, specifically the ground-water hydrology, of the Carbonate Terrane of the Great

Basin. Initially the project will concentrate on delineating, defining, describing, and understanding the carbonate-rock aquifers and associated flow systems in eastern and southern Nevada.

Approach

A comprehensive long-term program of investigation of the Nevada Carbonate Terrane will have to be based on a series of related and interdependent shorter term small-scale studies designed to address and resolve, insofar as possible, specific problems. Because of the large number of hydrologic problems that exist and the scope, remoteness, and complexity of the Carbonate Terrane, it is unlikely that a single, large-scale comprehensive study of the Carbonate Terrane as a whole could be pursued or even funded at appropriate levels by any one of the interested agencies and organizations. It is unlikely that all of the interested agencies taken together could pursue an adequate plan of study unless the issues and investigations are pursued on a more local level. A rational program of investigation requires the division of studies among limited, but key, subareas of the Carbonate Terrane; critical hydrologic processses; and those agencies most capable of pursuing it. The choice of study areas must be based on hydrologic continuity, on relative uniformity of conditions and processes, on interest in development of the resources or processes specific to an area, and on logistical feasibility. They must be scaled to include some significant part of a regional or subregional flow system so that problems of true interest--e.g. interbasin flow mechanisms and the yield potential of the carbonate-rock aquifers--are addressed.

Initially these studies may be conducted independently, concurrently, or in tandem, as time, manpower, and resources allow. Even in the early stages there will be a need for a large-scale overview and integration of all hydrologic and geologic interpretations with an eye toward transfer of information, regionalization of interpretations, and analysis of topics that are inherently too large-scaled to fall within the scope of any of the subarea studies. At some point the regionalization must be funded as a major project in its own right.

Principal methods available for continuing and future investigations of the Carbonate Terrane are: (1) geophysical studies to locate hydraulic boundaries, define rock properties, and delineate aquifer geometries, (2) interpretation of geochemical data to define the sources and histories of waters encountered in the carbonate-rock aquifers and surrounding media, (3) re-evaluation of water budgets for basins and mountain blocks in the Carbonate Terrane, and the development of more innovative methods of developing these budgets, (4) evaluation of physical and chemical analyses of deep wells and regional springs, (5) analysis of the lineaments and large-scale structural features of this part of the Great Basin, (6) geomorphic analysis of major landforms to assist in determining past hydrologic environments, (7) investigations of paleoclimates and their significance to current and future conditions, as well as to the history and geography of cavern development, and (8) analysis of hydraulic, lithologic, geophysical, and chemical data from deep wells and other holes.

Geophysical methods of study that may prove very useful include seismic refraction and (or) reflection surveys surface and downhole gravity measurements, and aeromagnetic surveys. Seismic methods may be used to identify major faults and geometries of local geologic structures. Gravity may be used to estimate depths to consolidated rock beneath valley-fill materials and density of consolidated rocks (and hence, indirectly, fracture density). Interpretation of aeromagnetic data may allow detection of metamorphic structures and intrusive bodies that may act as hydraulic barriers. Interpretation of chemical, temperature and isotopic variations along (and among) flow systems can be useful in delineating and assessing the limits and potential of those flow systems (Mifflin, 1968, pages 31-39; Johnson, 1980; Claasen, 1983). Linements analyses can be accomplished using Landsat imagery, and may be useful in identifying hydrologically significant structural features such as local shear zones with their attendant fracture systems or brecciation.

As basin and mountain block water budgers are better defined a level of confidence in the amounts of water that are flowing through the carbonate-rock aquifers and the connections between this water and the waters of the basin-fill aquifers may be developed. Improvement of these estimated budgets will require development of more accurate and precise estimates of rates of recharge and discharge.

Determination of piezometric heads at springs associated with the carbonate-rock aquifers and wells open to the carbonate rocks helps to define flow directions and can be useful in identifying hydraulic connections between rock units. Regional springs and deep wells also provide the main avenue for determination of chemical conditions in the deep rock aquifers.

Geomorphic research focused initially on the White River system will place the landforms of that area into a geomorphic/geologic time series that broadly defines its complex history in terms of paleohydrology. The mapping and age dating of soils, surficial geology, and stratigraphy will provide the means for the ultimate quantification of the landscaping processes. This will involve gathering the appropriate soil surveys made by the Soil Conservation Service and interpreting these findings in a geomorphic-hydrologic perspective. Additionally, all geologic and geomorphic (if available) literature will be put into a common data base. After this evaluation is made, areas will be selected for a second phase of intense investigation based on their importance in understanding todays hydrologic flow system. The second phase studies will be site specific (one valley at a time) and involve very detailed mapping and corresponding age dating. As a data base is built in one area, chronologies will be extended to other appropriate areas, and in this fashion, the entire White River system will be analyzed. During this second phase, areas outside the White River system may require similar efforts if it seems important to understand a cause-effect relationship that bears on the White River system.

Paleoclimate research is of significance because of the long travel times for water in regional systems; for example in the White River flow system water as much as 10,000 to 20,000 years old are encountered (Alan Welch, U.S. Geological Survey, personal communication, 1984). Understandng of the conditions under which this water was recharged, flowed, and discharged may depend on the development of histories of climate in the Great Basin. These factors may, in turn, influence assessments of the renewability of the waters of the carbonate-rock aquifers.

Finally, the most direct, but generally most expensive method of investigation of the carbonate-rock aquifers is drilling of deep holes into the rocks. The information gained at each hole is only a small increment of the total information required for the rational development of the aquifers, but the cost of drilling and properly teting holes limits the number of deep holes that will be available. Thus, the wells that are drilled have to be placed and designed carefully to maximize their scientific worth. This will require packer tests on each porosity zone encountered to determine productivities and specific aquifer properties; development of careful lithologic logs based on cuttings and careful, detailed borehole geophysical measurements; and determinations of water chemistries and rock properties by stratigraphic unit.

Major tasks to be performed in conducting a comprehensive investigation of the hydrology of the carbonate terrane will include:

1) Basic data collection, compilation and analysis;

2) Research on key hydrologic processes and parameters, and development of specific methods for system definition;

3) Investigation and analysis of conditions and processes in important subareas;

4) Delineation and definition of flow systems and resources of the carbonate terrane; and

5) Regionalization of results.

Data Collection

Crucial to the study of the carbonate terrane is the development and continuation of historical records of hydrologic conditions in the area. Current data collection efforts are inadequate to define the hydrologic conditions throughout the area. Basic data collection programs will be initiated and (or) extended, as resources permit, to measure:

--Streamflow from important watersheds and springs

--Ground-water levels in each basin

--The chemistry of water in all parts of the carbonate terrane (surface water and ground water)

--Precipitation rates at all altitudes encountered in the carbonate terrane

--Other climatic parameters as necessary to estimate of evapotranspiration under conditions encountered in the carbonate terrane, and

--Land- and water-use data, as well as water supply sources and rates. Figure 2 shows the location of continuous streamflow and springflow gaging stations operating in and near the carbonate terrane. Installation and maintenance of these additional gaging stations will bring the level of surface-water discharge data in the carbonate terrane up to minimum regional levels. Specific surface-water gaging sites will be chosen to be representative of regional runoff characteristics, to help define specific basin and interbasin water budgets, and (or) to provide data for the delineation of mountain-block or regional-spring hydrology.

Figure 3 shows the location of continuous ground-water level gaging stations and regularly monitored wells in the carbonate terrane. Relatively few continuous gaging stations are necessary on a regional scale to define the slow and fast response cycles of ground-water levels, but regular measurement of a larger number of wells is desirable. Much more important is the canvassing of basins to update and improve the areal coverage provided by the historical database. This canvassing provides well locations, well descriptions, and water-level data at new and existing wells in many basins that otherwise would not be available to future investigations. Canvassing of basins should be repeated approximately every three to five years. The entire southern half of the carbonate terrane, excepting Las Vegas and the Nevada Test Site, should be canvassed soon to fill this data requirement.

Geochemical interpretations of the sources and histories of waters in the carbonate terrane are, of course, dependent on the availability of chemical, physical, and isotopic analyses of samples from an adequate number and distribution of sources. The U.S. Geological Survey Great Basin Regional

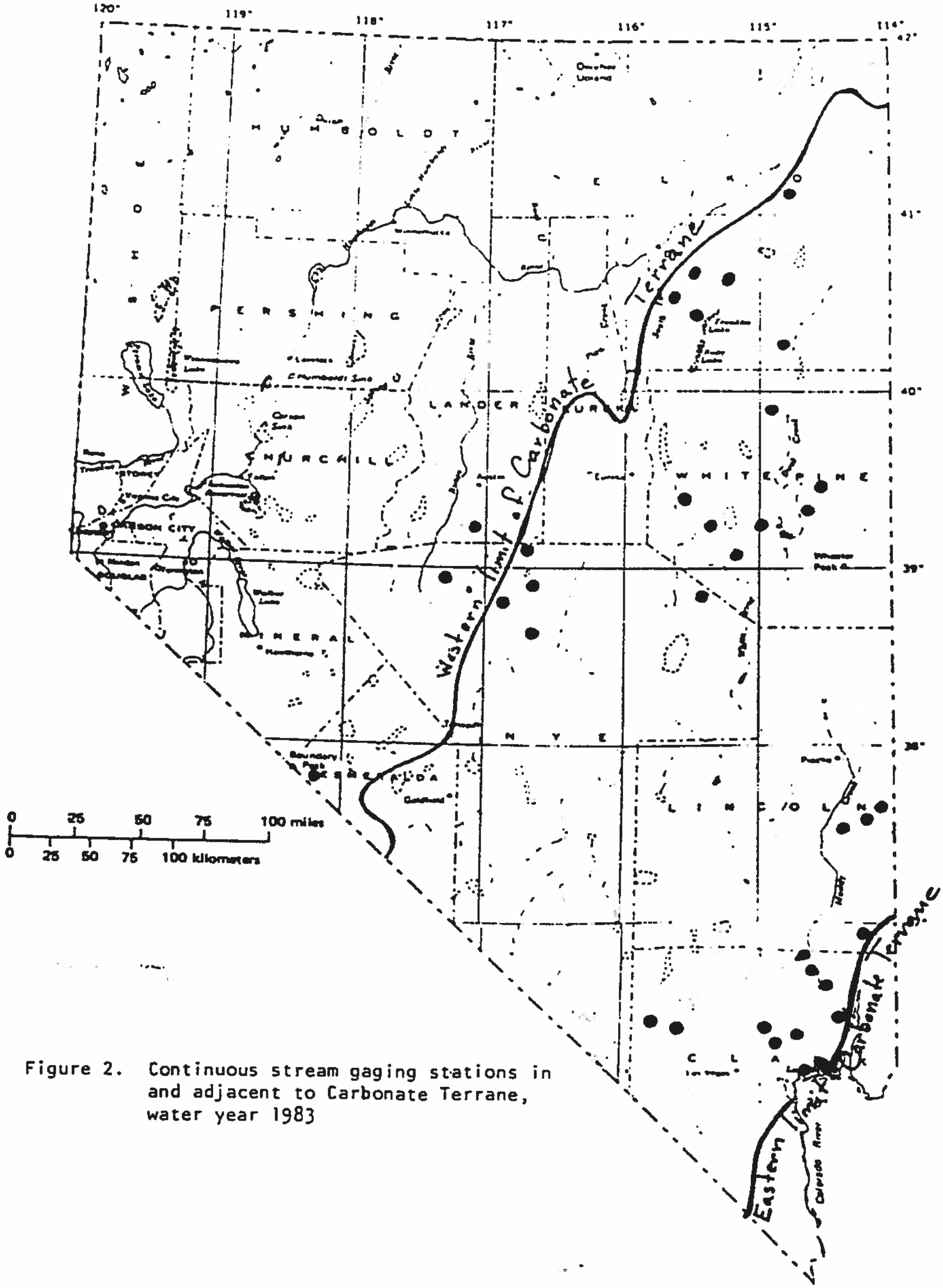

Figure 2. Continuous stream gaging stations in and adjacent to Carbonate Terrane, water year 1983

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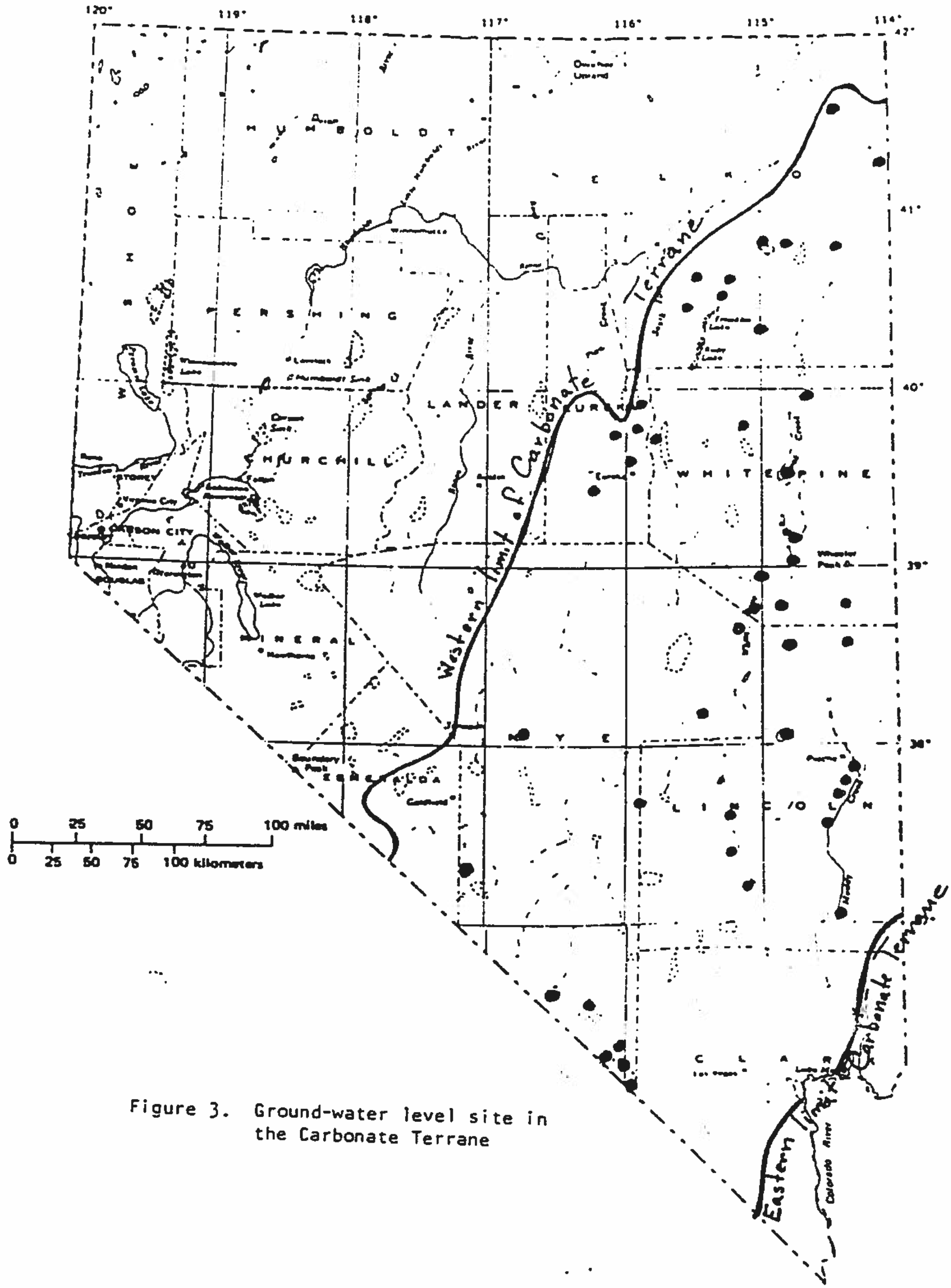

Figure 3. Ground-water level site in the Carbonate Terrane

Aquifer System Analysis has collected a wealth of chemical and isotopic data on the major regional springs of the carbonate terrane. Reliable chemical and isotopic data for water from the streams, mountain-block streams, and basin-fill ground waters of the carbonate terrane are not so readily available, and should be augumented as part of the basic data collection program.

A key factor in the development of recharge estimates is the estimated precipitation rates in areas that act as recharge centers. The areal distribution of precipitation stations is probabaly adequate at valley-floor elevations in the Carbonate Terrane. At high altitudes, where most of the precipitation takes place, however, coverage needs considerable improvement. Recent installation of ten high-altitude precipitation storage gages in eastern Nevada has raised the upper limit on precipitation measurements in that area from about 8,500 to 10,500 feet. Figure 4 shows the distribution of high-altitude precipitation measurement sites in the carbonate terrane.

A key parameter in the development of discharge estimates for water budgets is the rate of evapotranspiration by phreatophyes, from bare soil, and from free water surfaces. At present, precise measurements to estimate these rates are being made only in southwestern Nevada, near Beatty and at the Nevada Test Site. A wide variety of climatic, vegetative, and topographic conditions in the carbonate terrane limit the transfer value of these data collection efforts. The basic data collection program will therefore include the installation and maintenance of at least ten additional measurement sites, selected for wide areal coverage, coverage at a wide range of elevations, and for coverage of the entire range of ecologic settings encountered in the

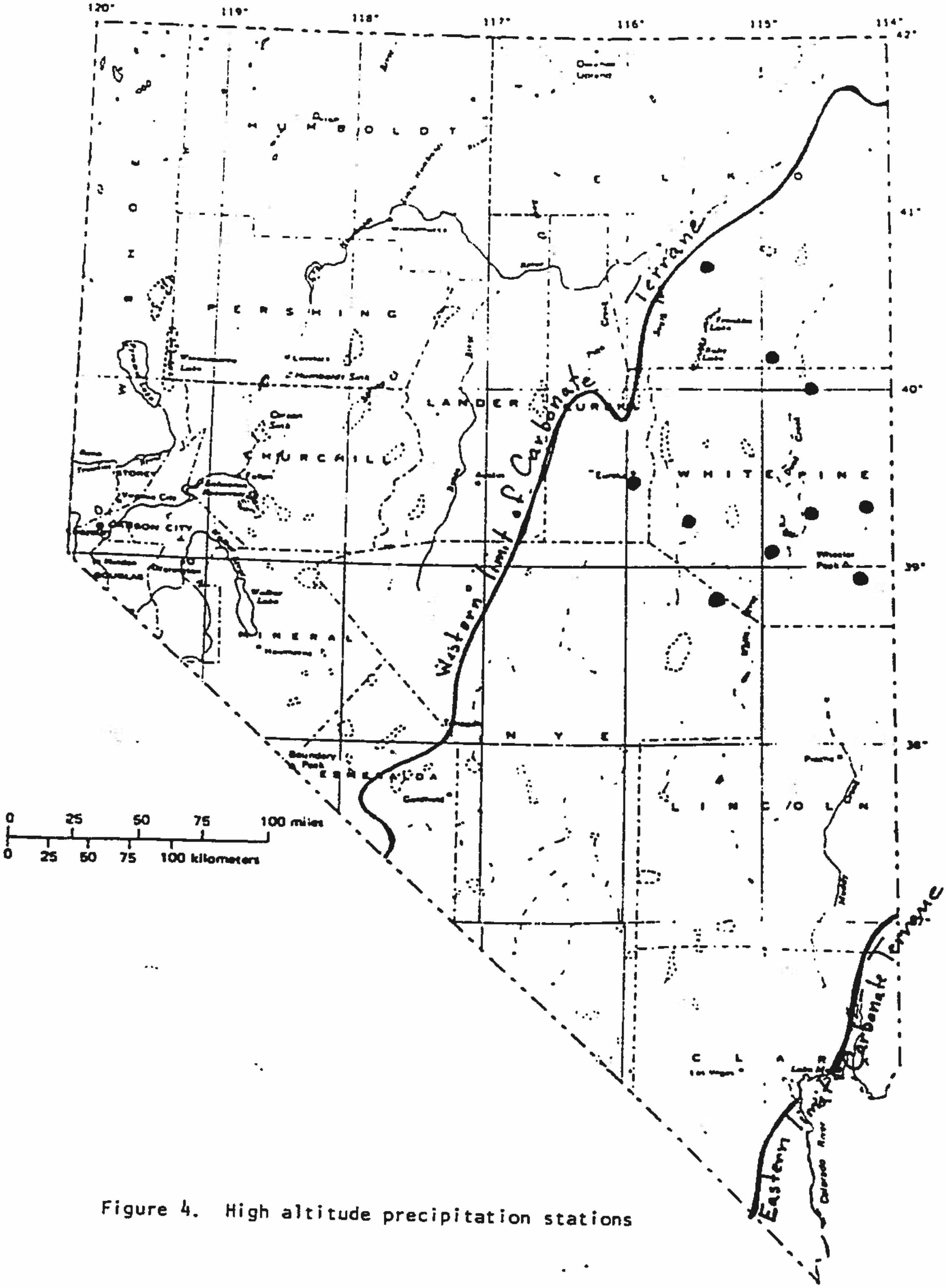

Figure 4. High altitude precipitation stations

Carbonate Terrane.

Finally, land-use and water-use data and measurements are necessary to the definition of water budgets in the carbonate terrane. Current efforts in this area are generally limited to efforts by the State Engineer to document water use in valleys that are either designated (restricted development) or approaching that status. Such efforts would be useful in essentially all of the developed basins in the area. It is probably not necessary that data be collected every year (except in the heavily impacted valleys that would be monitored anyway under current policy), rather collection could be integrated with the ground-water levels canvasing discussed above on a three- to five-year cycle.

It is crucial that each of these components of the basic data collection be granted a long-term commitment of funding and staffing independent of other parts of the comprehensive investigation. A single year or even several years of data in any of these areas will be of limited use. The various data networks should be implemented as soon as possible and will be reviewed periodically. Improvements to the networks are to be a goal of these reviews and, where necessary or appropriate, reductions or expansions of the networks will be implemented.

Critical hydrologic processes and paramenters that require investigation and research in the carbonate terrane are:

--Local, basin-wide, and deep-rock recharge processes.

--Evapotranspiration under that range of topographic, ecologic, and climatic settings encountered in the Carbonate Terrane.

--Role and definition of geologic barriers to ground-water flow.

--determination of hydraulic properties of shallow basin-fill aquifers, deep, basin-fill aquifers, carbonate-rock aquifers, and the other aquifers and aquitards in the area.

Research conerning proper application and interpretation of the following methods will also be necessary:

--Correlation of surface geophysical measurements to aquifer geometry.

--Correlation of borehole geophysical meaurements, lithologies, and well test results to aquifer/aquitard hydraulic properties.

--Correlation of selected isotopic and geochemical parameters to flow-path delineation and flow-rate estimation.

--Definition of water budgets more precise and accurate than the current reconnaissance estimates.

--Correlation of lineament analyses with regional, geologic, structural, and hydrologic features.

Research in these areas will utilize historical data, data developed under the basic data program, and specially collected data as necessary, and will be associated with ongoing investigations where possible to ensure that the efforts are tied very closely to the issues at hand. At the same time, the research will be designed for wide-spread application of results.

The carbonate terrane might be divided into key areas as follows in general order of hydrologic interest and priority:

--Southern Nevada

--Nevada Test Site, Nellis Gunnery and Bombing Range, and Amargosa Desert area

--East-central Nevada in the vicinity of White Pine County

--Diamond Valley/Kobeh Valley area

--Pahrump Valley

--Central Nevada -- (a) the Railroad Valley, (b) Kobeh-Monitor Valley, and (c) Clayton Valley multibasin flow systems

--Areas peripheral to the carbonate terrane -- (a) Big Smoky Valley and (b) the basins of the Humboldt River drainage within the carbonate terrane

—The upper White River flow system

--North-eastern Nevada -- the Great Salt Lake Desert flow system

Figure 5 indicates the nine general areas referred to above.

The southern Nevada area is listed as a high interest and priority area because it includes the discharge areas of several major regional flow systems, and interest in developing the water of the carbonate-rock aquifers is greatest in that area. The Test Site Amargosa Desert area includes three flow systems whose boundaries and interactions are still uncertain after more than 20 years of hydrologic investigations. Information concerning regional flow is greatest there as a result of these long-term hydrologic investigations. The White Pine County area is a high-altitude part of the cabonate terrane (figure 5) with basins and mountains that are generally subhumid. Much of the recharge in the carbonate terrane is localized there. The Diamond Valley - Kobeh Valley area is of interest because it provides an opportunity to observe the effects of stressing the basin-fill aquifers in one of the basins of the carbonate terrane. Diamond Valley is experiencing a considerable overdraft condition under current pumping regimes (Harrill, 1968). Pahrump Valley provides another opportunity to observe the workings of carbonate-terrane hydrology under stressed conditions and has the advantage that several excellent studies in the area provide a basis for future investigations (Harrill, 1982). The moderate-size interbasin flow system of central Nevada are of interest because their connections to surrounding major flow systems is not completely defined and because they may provided clues to

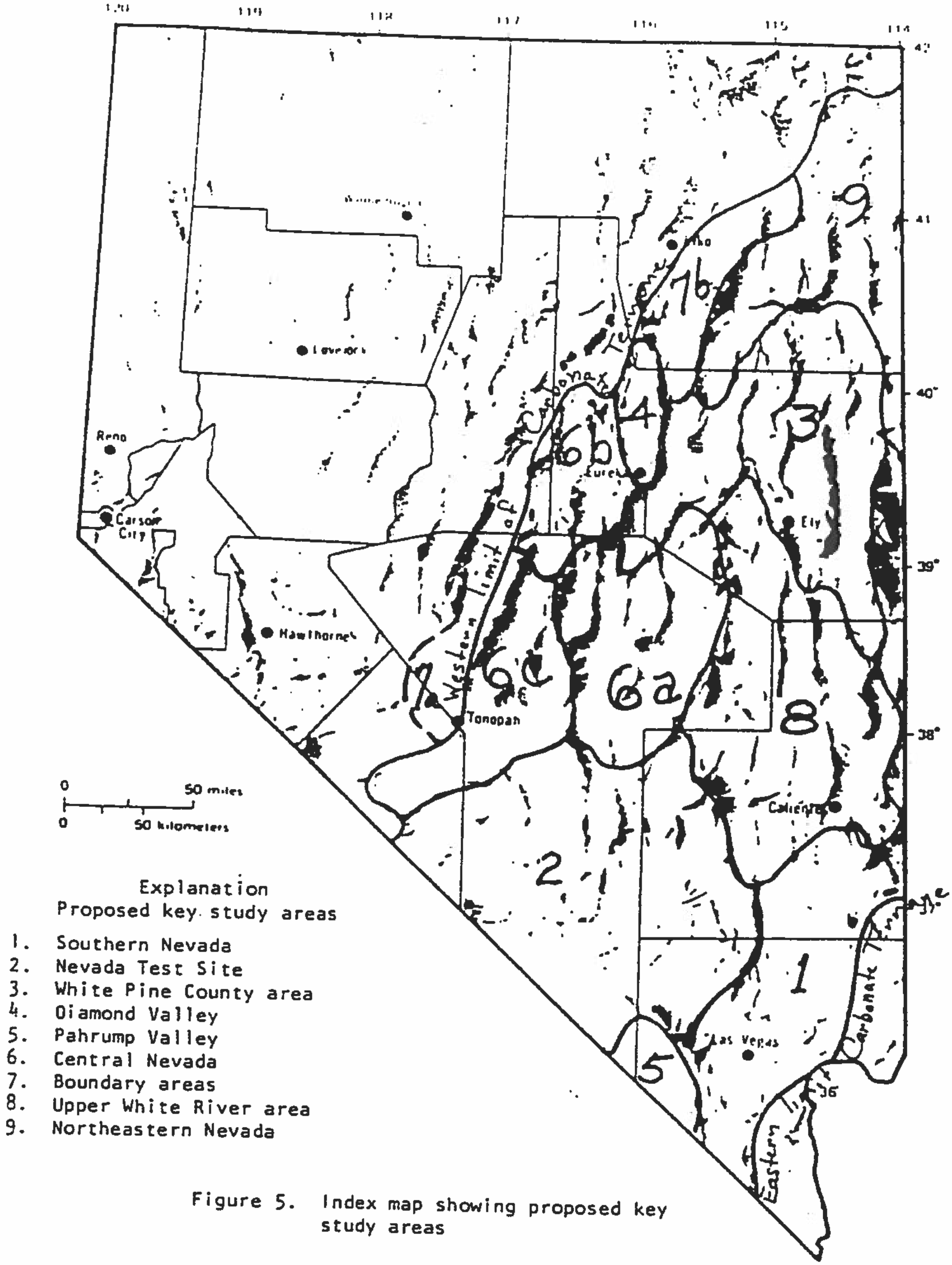

Figure 5. Index map showing proposed key study areas

the workings of carbonate-rock aquifer hydrologies at a more manageable scale than the larger flow systems. Studies along the periphery of the carbonate terrane will be, at least in part, designed to help define what are the true hydrologic boundaries of the carbonate terrane and (or) the carbonate-rock aquifer system. Finally, the northern two-thirds of the White River flow system and the basins of north-eastern Nevada are the headwaters of two of the major flow systems in the carbonate terrane of eastern Nevada.

The key area investigations should address the following issues:

--Geologic structural setting

--Recharge conditions, process and rates

--Ground water occurrence and movement in basin-fill reservoirs

--Ground water occurrence and movement in consolidated-rock reservoirs

--Physical and geologic controls on ground-water movement

--Ground-water discharge conditions, processes and rates

--Aquifer/aquitard geometries

--Hydrologic barriers and controls on ground-water movement

--Mountain-block recharge/mountain-block runoff processes and rates

--Water Budgets

--Analysis and observation of impacts of resource development

--Special topics important in the individual areas

Simulation analysis will be used as necessary and warranted; both as a tool for testing the feasibility of conceptual models and as an investigative and, potentially, a predictive tool for integrating information on the working of the flow system.

Exploratory drilling can be expected to play an important role in several of these studies.

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Program elements and budget summary FY85-89

Program element		TOTAL	Total
Data networks			
	Surface water	$1,250,000	
	Ground water	$750,000	
	Water quality	$750,000	
	Precipitation	$400,000	
	Data compilations	$200,000	
	Data management	$400,000	
			$3,750,000
Hydrogeologic Studies			
	Geophysics	$400,000	
	Geophysics Data	$50,000	
	Lineaments/Fractures	$240,000	
	Stratigraphy	$160,000	
			$850,000
Hydrologic Studies			
	Recharge mechanisms	$360,000	
	Discharge/Evapotrans	$540,000	
	Recon drilling	$270,000	
	Well testing	$110,000	
	Hydraulic properties	$75,000	
	Aquifer geometry	$160,000	
	Paleoclimates	$620,000	
	Paleohydrology	$415,000	
	Environ. science	$150,000	
	Water budget eval.	$415,000	
	Geologic barriers	$320,000	
	Aquifer interconnect	$360,000	
	Water use	$300,000	
			$4,095,000
Geochemical Studies			
	General geochem	$465,000	
	Isotopes	$160,000	
			$625,000
Area Studies			
	White R Sys.	$260,000	
	Diamond Valley	$360,000	
	Steptoe Valley	$220,000	
	Central Nevada	$400,000	
	Terrane boundary	$360,000	
			$1,600,000
Program Management		$800,000	
			$800,000
Regional Synthesis		$400,000	
			$400,000
Total		$12,120,000	$12,120,000

Program elements and budgets for Carbonate Terrane Program FY85-89

Program element	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	TOTAL	Total
Data networks												$3,750,000
Surface water	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$125,000	$1,250,000	
Ground water	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$750,000	
Water quality	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$750,000	
Precipitation	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$400,000	
Data compilations	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$200,000	
Data management	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$400,000	
Hydrogeologic Studies												$850,000
Geophysics	$50,000	$50,000	$80,000	$80,000	$80,000	$60,000					$400,000	
Geophysics Data	$30,000	$20,000									$50,000	
Lineaments/Fractures	$80,000	$60,000	$40,000	$40,000	$20,000						$240,000	
Stratigraphy		$40,000	$40,000	$40,000	$40,000						$160,000	
Hydrologic Studies												$4,095,000
Recharge mechanisms	$40,000	$80,000	$80,000	$80,000	$80,000						$360,000	
Discharge/Evapotrans	$40,000	$100,000	$80,000	$80,000	$80,000	$80,000	$80,000				$540,000	
Recon drilling	$30,000	$60,000	$60,000			$60,000	$60,000				$270,000	
Well testing	$10,000	$30,000	$30,000			$20,000	$20,000				$110,000	
Hydraulic properties		$15,000	$20,000	$40,000							$75,000	
Aquifer geometry		$30,000	$50,000	$80,000							$160,000	
Paleoclimates	$60,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000			$620,000	
Paleohydrology	$50,000	$65,000	$80,000	$80,000	$80,000	$60,000					$415,000	
Environ. science	$50,000	$50,000	$50,000								$150,000	
Water budget eval.				$40,000	$80,000	$80,000	$80,000	$75,000	$60,000		$415,000	
Geologic barriers					$40,000	$80,000	$80,000	$60,000	$60,000		$320,000	
Aquifer interconnect					$40,000	$80,000	$80,000	$80,000	$80,000		$360,000	
Water use			$80,000	$80,000	$40,000	$20,000	$20,000	$20,000	$20,000	$20,000	$300,000	
Geochemical Studies												$625,000
General geochem	$65,000	$50,000	$75,000	$75,000	$60,000	$60,000	$20,000	$60,000			$465,000	
Isotopes		$40,000	$60,000	$60,000							$160,000	
Area Studies												$1,600,000
White R Sys.			$40,000	$80,000	$80,000	$60,000					$260,000	
Diamond Valley				$40,000	$80,000	$80,000	$80,000	$80,000			$360,000	
Steptoe Valley	$80,000	$80,000	$60,000								$220,000	
Central Nevada					$80,000	$80,000	$80,000	$80,000	$80,000		$400,000	
Terrane boundary					$40,000	$80,000	$80,000	$80,000	$80,000		$360,000	
Program Management	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$800,000	$800,000
Regional Synthesis						$80,000	$80,000	$80,000	$80,000	$80,00C	$400,000	$400,000
Total	$1,040,000	$1,305,000	$1,460,000	$1,430,000	$1,455,000	$1,515,000	$1,295,000	$1,150,000	$915,000	$555,000	$12,120,000	$12,120,000

All costs in 1986 dollars [illegible]

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Distribution of carbonate-rock aquifers in southern Nevada and the potential for their development: summary of findings, 1985-88

1 author:

Michael D. Dettinger
United States Geological Survey

SE ROA 54945

JA_18783

Distribution of Carbonate-Rock Aquifers in Southern Nevada and the Potential for their Development

Summary of Findings, 1985-88

PROGRAM FOR THE STUDY AND TESTING OF CARBONATE-ROCK AQUIFERS IN EASTERN AND SOUTHERN NEVADA

Summary Report No. 1

This report is based on work by the
U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR
and the
DESERT RESEARCH INSTITUTE, UNIVERSITY OF NEVADA SYSTEM

Prepared in cooperation with the
STATE OF NEVADA
and the
LAS VEGAS VALLEY WATER DISTRICT

COVER PHOTOGRAPH: View to northwest from flank of Sheep Range between Rye Patch Spring and mouth of Picture Canyon, in late afternoon of November 9, 1984. In foreground are northernmost Black Hills; in distance are Desert Range and Pintwater Range. Photograph by Michael D. Dettinger.

Distribution of Carbonate-Rock Aquifers in Southern Nevada and the Potential for their Development

Summary of Findings, 1985-88

By Michael D. Dettinger, U.S. Geological Survey

PROGRAM FOR THE STUDY AND TESTING OF CARBONATE-ROCK AQUIFERS IN EASTERN AND SOUTHERN NEVADA

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Carson City, Nevada
1989

FOREWORD

The 1985 Nevada Legislature authorized a program for the study and testing of carbonate-rock aquifers of eastern and southern Nevada. The program is a cooperative effort by the State of Nevada and the Federal Government, and the study is being made by an informal coalition of U.S. Department of the Interior agencies (the U.S. Geological Survey and the U.S. Bureau of Reclamation) and the Desert Research Institute, University of Nevada System. Progress and plans for the study are evaluated regularly by a committee of representatives that was created in the authorizing legislation and that represents a wide range of interests throughout the State. The chairman of the evaluation committee has reported findings and recommendations to the Legislature's Interim Finance Committee four times since 1985.

The overall plan for the program is to study the carbonate-rock aquifers of southern, east-central, and northeastern Nevada as separate phases of work, with a summary of findings prepared at the end of each phase. An overall summary would be prepared at the completion of all three phases of study.

This report summarizes findings of the first phase of study, which assessed the resources of the carbonate-rock aquifers of southern Nevada. The summary brings together results from more than 20 technical reports produced during the study to date. It describes the location, magnitude, and resource potential of the carbonate-rock aquifers from a regional perspective and provides information needed to support management and development strategies for meeting southern Nevada's future needs.

Paul R. Fenske, Chairman
Committee to Evaluate Progress
of the Carbonate-Aquifer Study

Agencies represented on the evaluation committee:

- Desert Research Institute, University of Nevada System
- Nevada Department of Conservation and Natural Resources
- Las Vegas Valley Water District
- Colorado River Commission
- Nevada Association of Counties
- Nevada League of Cities
- Nevada Water Resources Association
- U.S. Geological Survey (non-voting member)
- U.S. Bureau of Reclamation (non-voting member)

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

"Inch-pound" units of measure used in this report may be converted to metric units by using the following factors:

Multiply	*By*	*To obtain*
Acre-feet	1,233	Cubic meters
Acre-feet per month	1,233	Cubic meters per month
Acre-feet per year	0.001233	Cubic hectometers per year
Cubic feet	0.02832	Cubic meters
Feet	0.3048	Meters
Feet squared per day	0.0929	Meters squared per day
Gallons per minute	0.06309	Liters per second
Miles	1.609	Kilometers
Square miles	2.590	Square kilometers

ALTITUDE DATUM

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929), which is derived from a general adjustment of the first-order leveling networks of both the United States and Canada.

DISTRIBUTION OF CARBONATE-ROCK AQUIFERS IN SOUTHERN NEVADA AND THE POTENTIAL FOR THEIR DEVELOPMENT

SUMMARY OF FINDINGS, 1985-88

By Michael D. Dettinger

I. OVERVIEW

Studies of the ground-water resources of carbonate-rock aquifers in southern Nevada by the U.S. Geological Survey, Desert Research Institute, and U.S. Bureau of Reclamation during 1985-88 have helped to answer the following questions:

- Where is water potentially available in the aquifers?
- How much water potentially can be withdrawn from the aquifers?
- What effects might result from development of the aquifers?

The studies included hydrologic-data collection, geologic mapping, well drilling and testing, geophysical measurements, and geochemistry.

The rocks that compose the carbonate-rock aquifers are layers of limestone and dolomite that were deposited hundreds of millions of years ago in much of the eastern Great Basin. Subsequently, the carbonate rocks were much deformed; as a result, they no longer exist as continuous layers beneath the region. Instead, they have been pulled apart to form a few large areas of thick and relatively continuous carbonate rocks. Separating these areas are noncarbonate rocks, within which are isolated mountain-sized blocks of carbonate rock.

Beneath southern Nevada, the thick carbonate-rock layers are continuous enough to transmit ground water at regional scales only beneath a north-south "corridor" 60-90 miles wide that extends southward from east-central Nevada to and beyond the Spring Mountains area west of Las Vegas. Within this corridor are the two major regional flow systems of southern Nevada: the Ash Meadows-Death Valley system and the White River-Muddy River Springs system. These flow systems link the ground water beneath dozens of valleys and over distances exceeding 200 miles. Flow in these systems probably is concentrated along highly transmissive zones associated with (1) recently active faults and (2) confluences of flow near major warm-water springs. Outside of the corridor, the carbonate rocks are present primarily as isolated blocks that form aquifers of limited extent, recharged mostly by local precipitation.

The sources of ground-water flow in the aquifers of southern Nevada are (1) recharge from precipitation in the mountains and (2) regional inflow from carbonate-rock aquifers farther north. The total contribution from these sources to all the aquifers of southern Nevada--both carbonate and noncarbonate--is about 160,000 acre-feet per year. About 80 percent (130,000 acre-feet per year) passes beneath the central corridor; this includes nearly all flow in the major regional systems. At present, the fraction of the recharge that enters the carbonate-rock aquifers cannot be estimated because the controlling processes are poorly understood and because the available data are insufficient to describe these processes.

Some of the total flow beneath the area discharges through the basin-fill sedimentary aquifers that partly fill valleys, some flows from carbonate-rock aquifers at warm-water springs, and the rest flows out of Nevada into adjacent states (mostly to California) through the carbonate-rock aquifers. Discharge from the springs plus the outflow from Nevada through the carbonate rocks total about 77,000 acre-feet per year. The total rate of flow through the regional carbonate-rock aquifers of southern Nevada is equal to this 77,000 acre-feet per year plus some unknown quantity of ground water that leaks up into basin-fill aquifers.

A much larger quantity of water--on the order of 800 million acre-feet--is stored in the carbonate-rock aquifers. This is because the aquifers underlie about 10,000 square miles and probably are, on the average, about 12,000 feet thick in the central corridor. On the order of 6 million acre-feet of water, the quantity stored in the upper 100 feet of the aquifers, might be economically accessible. However, this volume is equivalent to decades or centuries of recharge; if depleted, it would be replenished very slowly or not at all.

Large-scale development (sustained withdrawals) of water from the carbonate-rock aquifers would result in water-level declines and cause the depletion of large quantities of stored water. Ultimately, these declines would cause reductions in flow of warm-water springs that discharge from the regional aquifers. Storage in other nearby aquifers also might be depleted, and water levels in those other aquifers could decline. In contrast, isolated smaller ground-water developments, or developments that withdraw ground water for only a short time, may result in water-level declines and springflow reductions of manageable or acceptable magnitude.

Confidence in predictions of the effects of development, however, is low; and it will remain low until observations of the initial hydrologic results of development are analyzed. A strategy of staging developments gradually and adequately monitoring the resulting hydrologic conditions would provide information that eventually could be used to improve confidence in the predictions.

II. INTRODUCTION

Rocks that were consolidated from layers of ancient marine sediments underlie many of the basins and mountains of a 50,000-square-mile area of southern and eastern Nevada that is referred to as the carbonate-rock province (**fig. 1**). These rocks, which are dominated by limestone and dolomite (two common carbonate-rock types), also extend beneath western Utah and into southeastern Idaho and eastern California. Large springs--many with discharges greater than 1,000 gallons per minute--are associated with these carbonate rocks, and several wells drilled into fractured zones in the rocks have been pumped at high rates with little water-level decline. The large area underlain by the rocks, together with their capacity to transmit large volumes of water, suggests that the carbonate-rock province of Nevada contains aquifer systems of regional scale and significance (Hess and Mifflin, 1978, p. viii).

Nevada, the most arid State in the Nation, is facing rapid population growth and increasing demands for water. Historic sources of water--surface water in streams and lakes and ground water in localized sand-and-gravel aquifers--are used or appropriated nearly to (and in some valleys, beyond) their estimated perennial yields in many parts of the State. The possibility, therefore, that the largely unexplored carbonate-rock aquifers of Nevada are an untapped source of water supply has sparked considerable interest in recent years.

In 1985, the State of Nevada entered into a cooperative effort with the U.S. Department of the Interior to study and test the carbonate-rock aquifers to assess the potential for developing these ground-water resources. These studies were proposed in a report by the U.S. Department of the Interior (1985) and funded through Nevada State Senate bills S.B. 277 (in 1985) and S.B. 209 (in 1987). Technical work toward this end was funded by several agencies (**table 1**) and done by the U.S. Geological Survey, the Desert Research Institute, and the U.S. Bureau of Reclamation.

TABLE 1.--Agencies participating in the Nevada Carbonate Aquifers Program

Agency	Contributions	Years
State of Nevada	Funding, advisory	1985-88
U.S. Geological Survey	Funding, technical studies	1984-88
U.S. Bureau of Reclamation	Funding, technical studies	1984-87
Desert Research Institute	Funding, technical studies	1985-88
Las Vegas Valley Water District	Funding	1985-88
City of North Las Vegas	Funding	1985

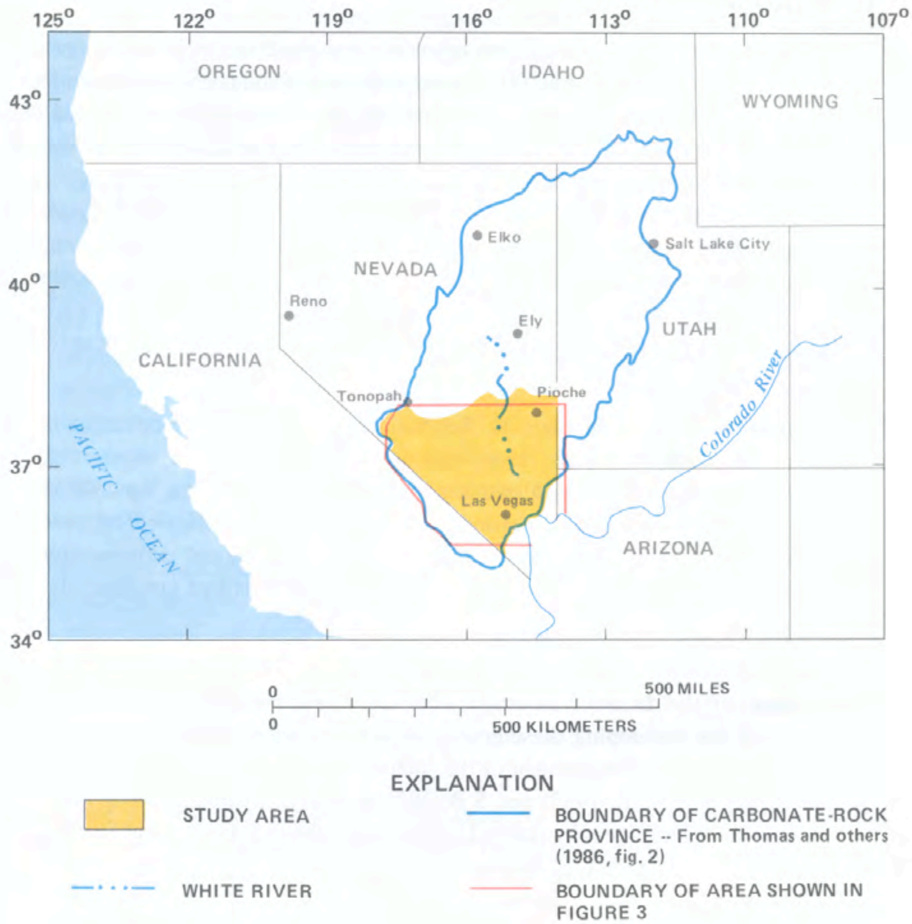


FIGURE 1.--Location of carbonate-rock province, southern Nevada study area, White River, and area shown in figure 3.

During 1985-88, the technical studies were focused on southern Nevada, mostly north of Las Vegas and south of Pioche and Tonopah, although some activities--notably basic-data collection and geochemical analyses--extended farther to the north in Nevada and into adjacent states. **Figure 1** shows the southern Nevada study area in relation to the carbonate-rock province as a whole.

The technical studies were intended to address the following basic concerns:

1. Where are appreciaole quantities of water potentially available for development in the carbonate-rock aquifers?
2. How much water potentially can be withdrawn from these aquifers for development?
3. What might be the effects of short-term and long-term development of the aquifers?

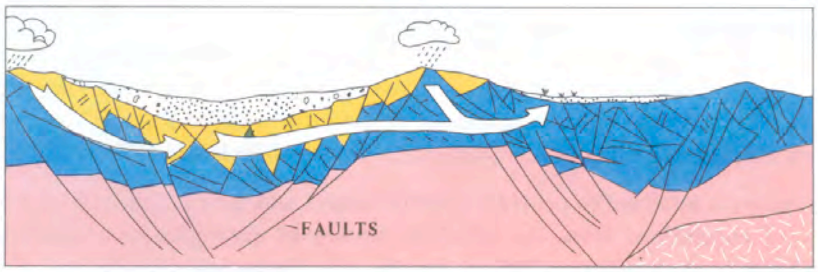
Plans for studies beyond 1988 address the same concerns in east-central Nevada and, by 1992, in northeastern Nevada. During 1985-87, the Bureau of Reclamation pursued an additional objective of evaluating the economic feasibility of specific resource-management alternatives that could be used to supply peak demands for water in the Las Vegas urban area during summer months in the near future (U.S. Bureau of Reclamation, 1988).

This report is intended to provide water managers and policy makers with a brief summary of conclusions from the scientific studies of carbonate-rock aquifers in southern Nevada made during 1985-88 by the U.S. Geological Survey and Desert Research Institute. The report is organized to address the three basic concerns listed above. These conclusions are documented in detailed reports resulting from specific study elements. These additional reports include 20 that are highlighted in the "References Cited" section at the end of this report.

III. WHAT ARE THE CARBONATE-ROCK AQUIFERS?

The carbonate rocks of southern Nevada were deposited as layers of ancient marine sediment that cumulatively were as much as 40,000 feet thick on the continental shelf off the ancestral west coast of North America between about 570 million and 280 million years ago (during that period, the west coast of the continent was in present-day Utah). The carbonate rocks--limestone and dolomite--were deposited on even older, noncarbonate sediments and crystalline basement rocks. Within and between layers of carbonate rock are noncarbonate layers of shale, quartzite, chert, and siltstone, but the overall accumulation is dominated by carbonate rock. In aggregate, these rocks are massive and widely distributed; as a consequence, the aquifers that they comprise provide avenues for ground-water flow beneath much of the area shown in **figure 1**. All the ancient sedimentary rocks, where deformed and fractured, may transmit some ground-water flow, but **the carbonate-rock layers within the rocks--because of their brittleness and tendency to dissolve into flowing water--are believed to be the principal water-bearing (or aquifer) zones.**

Fiero (1986) presents a general background on the geology of these sedimentary sequences, and the various older and younger noncarbonate rocks in southern and eastern Nevada. Plume and Carlton (1988) describe the general water-bearing properties of these rocks and the regional distribution of exposures of the various rock types.



EXPLANATION

SAND AND GRAVEL -- Basin-fill aquifer

CLAY AND SILT -- Basin-fill deposits that impede ground-water flow

VOLCANIC ROCKS -- Aquifers as well as layers that impede flow

CARBONATE ROCKS -- Aquifers

OLDER, NONCARBONATE SEDIMENTARY ROCKS -- Impede flow

CRYSTALLINE BASEMENT -- Impedes flow

GROUND-WATER FLOW PATH

PLAYAS, SPRINGS, AND NATIVE VEGETATION

RAIN AND SNOW IN MOUNTAINOUS AREAS

FIGURE 2.--Schematic hydrogeologic section across mountain ranges and intervening basins, showing configuration at depth of aquifers and rocks that impede flow. (Modified from Anderson and others, 1983, fig. 10.) Approximate width and depth of schematic section, 30 miles by 8 miles.

The carbonate-rock aquifers have complex shapes and are connected to aquifers of other rock types. Volcanic activity and erosion of rock fragments from ancient and present-day mountain ranges have resulted in the deposition of younger rocks atop the carbonate rocks. Among these younger rocks are sand-and-gravel aquifers that partly fill the basins of Nevada and that are the sources of most of the ground water now used in the State. (These water-bearing sediments are referred to as "basin-fill aquifers.") Although the carbonate rocks were deposited as widespread layers, geologic forces subsequently deformed the rocks into innumerable "blocks" of rock that are bounded by faults, and folded rock masses of all sizes. Because of this deformation, **rocks of widely differing geologic age are intermingled, and the distribution of rocks that constitute aquifers is greatly complicated (as are the paths followed by ground-water flow through the rocks). Figure 2** shows the typical distribution of rocks beneath valleys of southern Nevada. The rocks that compose some of the blocks may be highly productive aquifers, whereas other rocks may transmit only moderate quantities of water, and still others may impede flow altogether. The numerous faults shown in **figure 2** facilitate ground-water flow under some conditions and impede flow under others.

Water in the carbonate-rock aquifers flows away from areas where water has infiltrated the land surface and moves down to the water table (this water is called "ground-water recharge"). Most recharge to the aquifers of southern Nevada (both carbonate-rock and basin-fill) originates in the high mountain ranges, where rainfall and snowfall rates are greatest and where large accumulations of springtime snowmelt release large quantities of water on the land surface over a sustained period of time. Rain that falls directly on the valley floors provides only meager quantities of recharge. Under natural conditions, recharge from the mountains flows within the aquifers toward springs or areas where plants extract and use it or where the water evaporates directly through the overlying soil. The springflow, use by plants, and evaporation are together termed "ground-water discharge." **Along its path from recharge to discharge, water may flow through basin-fill aquifers, carbonate-rock aquifers, or both.** Water flows between aquifers to connect the ground-water systems in some places [for example, in Pahrump Valley (Harrill, 1986, p. 27) and at Ash Meadows (Dudley and Larson, 1976, p. 48)]. As a result, the large flow systems in southern Nevada typically include both basin-fill and carbonate-rock aquifers (Harrill and others, 1988).

IV. HOW ARE THE CARBONATE-ROCK AQUIFERS BEING STUDIED?

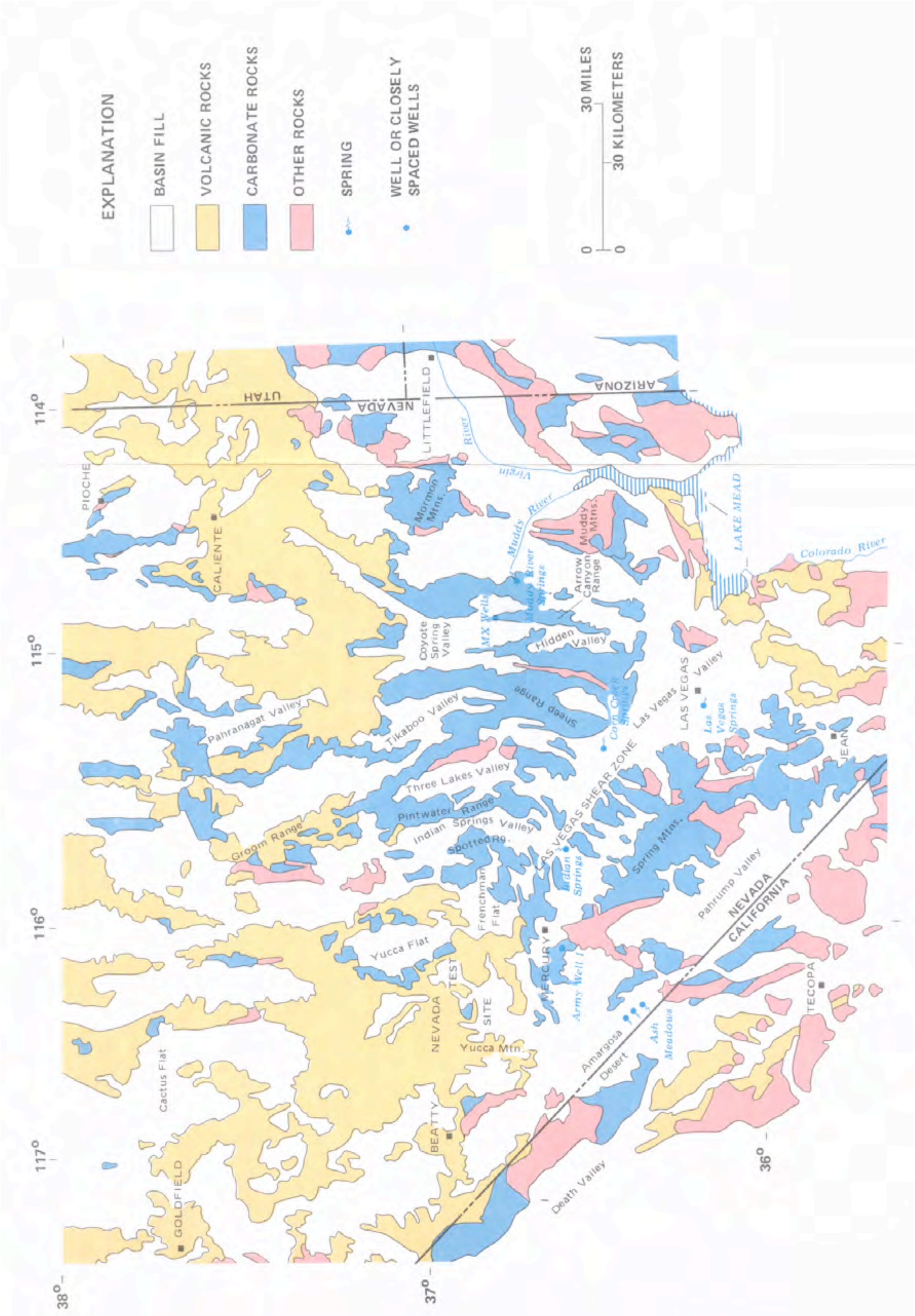
Accurate definition of the potential for developing carbonate-rock aquifers requires an understanding of the configuration and physical properties of the carbonate and intervening noncarbonate rocks, coupled with estimates of the volume of water contained in and moving through them. To develop the required understanding, the following activities were undertaken in 1985-88.

Several types of **basic hydrologic data were collected** in eastern and southern Nevada, including semiannual measurements of cumulative rain and snowfall at 15 high-altitude sites; continuous measurements of discharge at 8 representative springs; regularly scheduled measurements of discharge at 59 other springs; continuous measurements of water levels in 4 wells open to the carbonate-rock aquifers; regularly scheduled measurements of water levels at 11 other wells; and measurements of meteorological conditions at 2 sites used to estimate evaporation rates and water consumption by native plants.

Continuous measurements (data in Pupacko and others, 1988, p. 48, 50, 61; and Pupacko and others, 1989, p. 45-47, 57) indicate that the discharge from two of the larger of the Muddy River Springs remains nearly uniform at the rates (totaling about 8,000 acre-feet per year) reported by Eakin (1964, p. 17) and that the discharge from Corn Creek Springs also is nearly uniform at about the rate measured during 1947-55--about 200 acre-feet per year (Malmberg, 1965, p. 60). (The location of these springs and all other sites and features specifically mentioned in this section is shown in **figure 3**.) The continuing long-term and short-term uniformity of these discharges indicate that the springs have not been affected measurably by the pumping of nearby wells. Small, short-term fluctuations in spring discharge and water levels in carbonate wells, however, are observed; they represent responses to atmospheric pressure change, tides, local precipitation, and other natural stresses. Water levels in some wells, for example, fluctuate about 0.2 foot seasonally.

Geology was mapped for an area of about 1,800 square miles north of Las Vegas and centered on the Sheep Range. The mapping emphasized carbonate rocks and younger sediments, and was based on detailed field observations (Guth, 1986; Guth and others, 1988), interpretation of geophysical measurements (Blank, 1988), and correlation of observations with aerial photography and satellite imagery (McBeth, 1986).

Results of the mapping indicate that small openings through which small volumes of water can flow probably are common throughout the region. These openings resulted from region-wide geologic forces that fractured the rocks. Along certain recently active, steeply dipping faults (such as those that form the steep margins of mountain ranges), rocks were fractured and fragmented under conditions that allowed them to develop and maintain larger openings through which large volumes of water can flow. These fault zones may constitute the principal paths through which most ground water flows in the carbonate rocks. In contrast, rocks that were fractured and fragmented along older, flat-dipping fault zones subsequently resolidified into rock masses that now can impede ground-water flow (Dwight L. Schmidt, U.S. Geological Survey, written communication, 1987).



EXPLANATION
BASIN FILL
VOLCANIC ROCKS
CARBONATE ROCKS
OTHER ROCKS
SPRING
WELL OR CLOSELY SPACED WELLS
0 30 MILES
0 30 KILOMETERS
38°
37°
36°
117°
116°
115°
114°
UTAH
NEVADA
ARIZONA
CALIFORNIA
PIOCHE
CALIENTE
LITTLEFIELD
GOLDFIELD
BEATTY
MERCURY
LAS VEGAS
JEAN
TECOPA
Virgin River
Muddy River
Colorado River
LAKE MEAD
Mormon Mtns.
Muddy Mtns.
Arrow Canyon Range
Muddy River Springs
MX Wells
Coyote Spring Valley
Hidden Valley
Sheep Range
Corn Creek Springs
Las Vegas Valley
Las Vegas Springs
Pahranagat Valley
Tikaboo Valley
Three Lakes Valley
Pintwater Range
Indian Springs Valley
Groom Range
Spotted Ra.
LAS VEGAS SHEAR ZONE
Indian Springs
Spring Mtns.
Frenchman Flat
Yucca Flat
NEVADA TEST SITE
Yucca Mtn.
Army Well 1
Ash Meadows
Amargosa Desert
Pahrump Valley
Cactus Flat
Death Valley

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Land-surface geophysical measurements were made to estimate thicknesses of basin-fill aquifers overlying the carbonate-rock aquifers and to locate faults deep beneath land surface. Measurements detected spatial variations in the density, strength, and electrical properties of rocks in the subsurface. This effort included collection of about 200 gravity measurements, 7 seismic-refraction profiles, and more than 65 geoelectrical measurements of the resistivity of rock far below the land surface using direct-current, audiomagnetotelluric, and magnetotelluric methods (Pierce and Hoover, 1986).

Interpretation of these measurements shows that thicknesses of basin fill overlying carbonate rocks range from less than 500 feet in Hidden Valley to about 1,000 feet in Coyote Spring Valley, about 2,000-3,000 feet in northwestern Las Vegas Valley, and more than 6,000 feet beneath southern Tikaboo Valley (Donald H. Schaefer, U.S. Geological Survey, written communication, 1988). Estimates of thickness are critical in siting exploration wells in these valleys. The geoelectrical measurements also showed that the highly productive wells drilled in Coyote Spring Valley during the Air Force's MX Missile-Siting program during 1980-81 (referred to as MX wells hereafter) penetrate a fault zone along the east edge of the Arrow Canyon Range, rather than the more visible fault zone on the steep west side of the range (Pierce and Hoover, 1986, fig. 2).

Water samples were collected and analyzed to characterize ground water and delineate flow paths in terms of physical and chemical properties of the water. Samples were collected from 209 springs, streams, and wells during 1985-88. Hundreds of analyses from previous studies also were compiled.

Geochemical balances and models were used to update water budgets and to identify flow and mixing rates in six parts of southern Nevada, including the Spring Mountains, Las Vegas Valley, Ash Meadows area, and Muddy River Springs area (Emme, 1986; Hershey and others, 1987; Kirk and Campana, 1988; Lyles and Hess, 1988; Noack, 1988; Thomas, 1988). The results alter previous concepts of regional flow beneath southern Nevada by indicating that most recharge from the Sheep Range flows toward the Muddy River Springs rather than radially toward other adjacent valleys including Las Vegas Valley (Thomas, 1988). Also, flow in the basin-fill aquifers of the Las Vegas shear zone--a complicated geologic feature extending from the northeastern part of Las Vegas Valley nearly to Mercury, Nev., beneath the valley floors–was shown to be impeded in some areas and enhanced in others, presumably by the influence of deeply buried geologic structures (Lyles and Hess, 1988). The studies of Emme (1986), Schroth (1987), Kirk and Campana (1988), and Thomas (1988) generally verify the overall water budgets developed by previous investigators (Rush, 1964; Eakin, 1966; Winograd and Friedman, 1972) for regional flow beneath the White River drainage in east-central Nevada (**fig. 1**). A broad reconnaissance of water quality in southern Nevada demonstrated that aquifers beneath and east of Las Vegas Valley and elsewhere in southeasternmost Nevada are likely to contain water of inadequate quality for many uses (Lyles and others, 1986; Schroth, 1987, p. iii).

Wells were drilled, logged, and tested in the basin-fill and carbonate-rock aquifers to provide direct observations of aquifer characteristics (Lyles, 1987; Berger and others, 1988; Morin and others, 1988). Nine wells were drilled (a total of about 4,500 feet in basin fill and 5,500 feet in carbonate rocks) and two abandoned wells in key locations were rehabilitated. Borehole-geophysical logs were collected from selected depth intervals in all these wells and in four MX wells. The aquifers were tested at three of the new wells and at three of the MX wells during 1985-88 to determine transmissivity (the capacity of the aquifers to transmit water). Results from reports of specialized tests in 13 oil-test wells (McKay and Kepper, 1988, p. 21, 39) and aquifer tests at 33 other wells in the carbonate-rock aquifers of Nevada were compiled.

The capacity of the carbonate-rock aquifers to transmit water ranges from low to very high, depending on location. Whereas the transmissivity of aquifers at the MX wells in Coyote Spring Valley is extremely high (about 200,000 feet squared per day) and productivity also is high [3,400 gallons per minute pumped with only 12 feet of water-level decline (Ertec Western, Inc., 1981, p. 51)], most other wells drilled in carbonate-rocks are much less productive. In fact, the aquifer at the MX wells is somewhat more transmissive than at any other site for which test results are available. The average aquifer properties, as reported in compiled tests at water wells, are similar to those at Army Well 1 near Mercury, where 455 gallons per minute can be pumped for long periods of time with 85 feet of water-level decline (drawdown) in the well. The transmissivity at Army Well 1 is estimated to be between 5,000 and 11,000 feet squared per day (Winograd and Thordarson, 1975, table 3, well 67-68).

Geophysical logging in the wells measured rock properties that are dependent on primary porosity (open spaces between grains in the rocks) and secondary porosity (fracture and dissolution cavities). These porosities are important in determining the quantity of water contained in a given volume of aquifer material. The total porosities--primary plus secondary--estimated from the geophysical logging were similar to those reported from laboratory measurements of rocks collected at the Nevada Test Site (Winograd and Thordarson, 1975, p. C17), which averaged 5.5 percent. Secondary porosity, as estimated from the logs in zones where many fractures are present, locally may constitute almost half of that total (David L. Berger, U.S. Geological Survey, written communication, 1988).

All these activities provided useful information about the movement of water in aquifers near and immediately north of Las Vegas. To address the regional distribution of the carbonate-rock aquifers throughout southern Nevada and their potential for development, however, an additional effort synthesized the results from all of these activities, together with results from many other hydrogeologic and geologic investigations. The following sections report on the results of that synthesis in terms of the three basic concerns listed earlier: the location of water in the aquifers, the quantity of water, and the potential effects of development.

V. WHERE IS WATER POTENTIALLY AVAILABLE IN THE CARBONATE-ROCK AQUIFERS?

Understanding where water potentially could be developed from the carbonate-rock aquifers requires an understanding of where the carbonate rocks are present, and where they are continuous enough to form local and regional aquifers. Although the carbonate rocks are widespread and originally were very thick (up to 40,000 feet thick in some places), subsequent geologic forces disrupted and partly or completely removed these sedimentary rocks from large parts of southern Nevada. As a result of the action of those forces, much of present-day southern Nevada is underlain by areas where the carbonate rocks remain only as isolated blocks having dimensions that range up to miles on a side. In contrast, **the central third of southern Nevada is underlain by a north-south corridor of thick, laterally continuous carbonate rocks.** Even within the central corridor, the thickness of carbonate rocks was reduced to between about 3,000 and 19,000 feet. **Figure 4** shows the location of the central corridor of thick carbonate rocks and **figure 5** shows cutaway views of subsurface geology along several lines across southern Nevada. **Line A-A'** coincides approximately with the Clark-Lincoln County boundary, and shows a very nonuniform thickness of carbonate rocks (the blue shaded zones). Within the central corridor, two areas are underlain by thick and relatively continuous carbonate rocks--the Pintwater-Spotted Range area (Guth, 1988) and Coyote Spring Valley area (Guth, 1988; Wernicke and Axen, 1988a, p. 1749). These two areas are connected to a similarly thick carbonate-rock mass described 60 miles farther north by Bartley and others (1988, p. 1). The thick carbonate rocks probably contain the principal conduits for regional flow from east-central Nevada into southern Nevada, with the flow ultimately discharging at Ash Meadows and Death Valley, and at the Muddy River Springs (Dettinger, 1987). Thus, **these thick and continuous carbonate-rock masses largely constitute the regional carbonate-rock aquifers**. East and west of the central corridor are blocks of carbonate rock (west of Yucca Mountain and beneath the Mormon Mountains) that are thick but largely isolated from carbonate-rock aquifers in other areas by noncarbonate materials of low transmissivity (Wernicke and others, 1985, fig. 15; Blank, 1988; Carr, 1988; Hamilton, 1988, p. 57, 61, 79; Scott, 1988; Wernicke and Axen, 1988b, fig. 2). The blocks are much thinner both north and south of the section shown, and, as a result, do not receive regional inflow. These carbonate rocks therefore transmit little water.

Farther south, **line B-B'** shows the rocks beneath a short line of section just north of Las Vegas and indicates the presence of thick carbonate rocks east of the Sheep Range (Guth, 1980, plate 2). At moderate depths, the carbonate-rock aquifers beneath the Sheep Range are underlain by noncarbonate rock. The uppermost noncarbonate rocks are at high enough altitude along the west side of the range to impede westward flow of water that recharges the range. This barrier provides geologic support for geochemical balances developed during this study which suggest that nearly all the water recharging the Sheep Range flows to the north and east toward Muddy River Springs (Thomas, 1988)

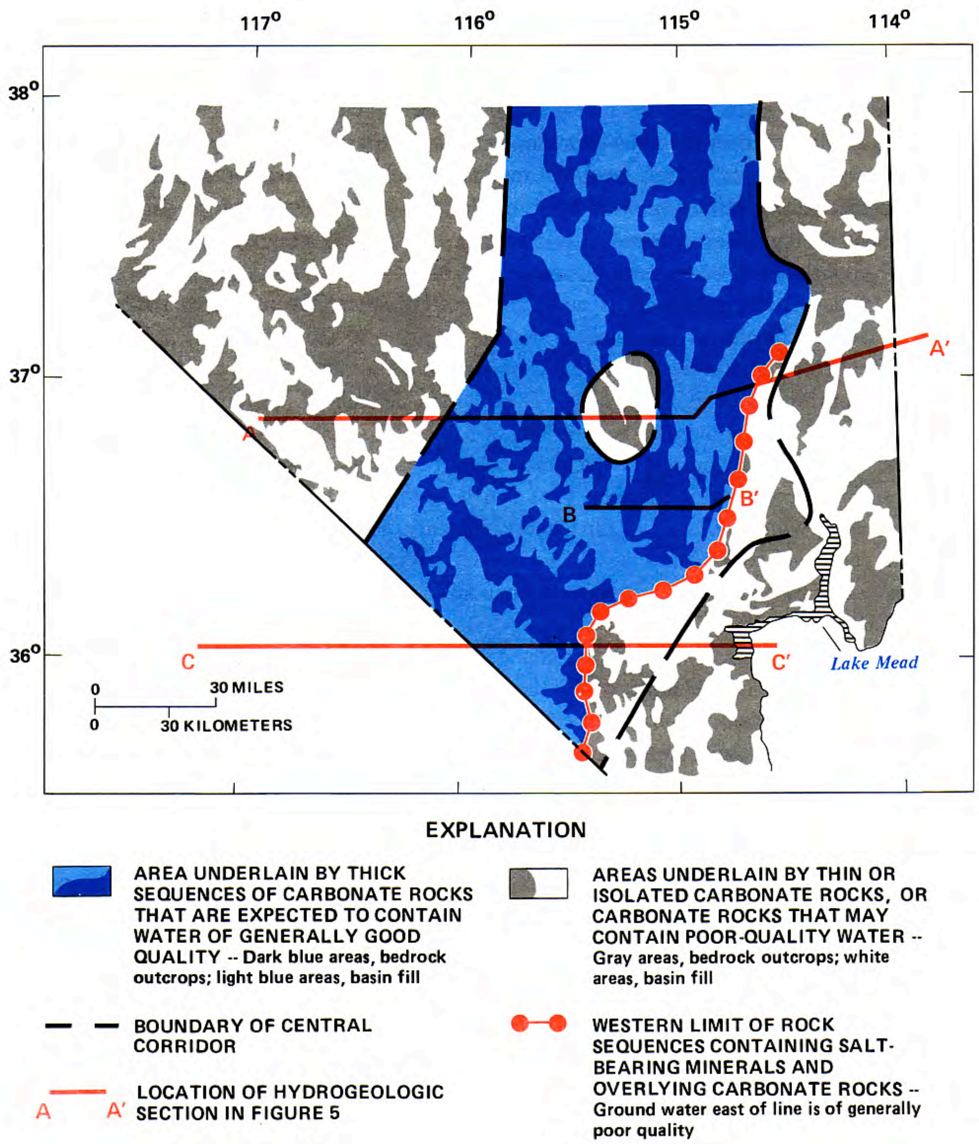


FIGURE 4.--Central corridor of thick carbonate rocks that contain water of generally good quality (that is, water suitable for most uses). Delineation of bedrock and basin fill from Stewart and Carlson, 1978.

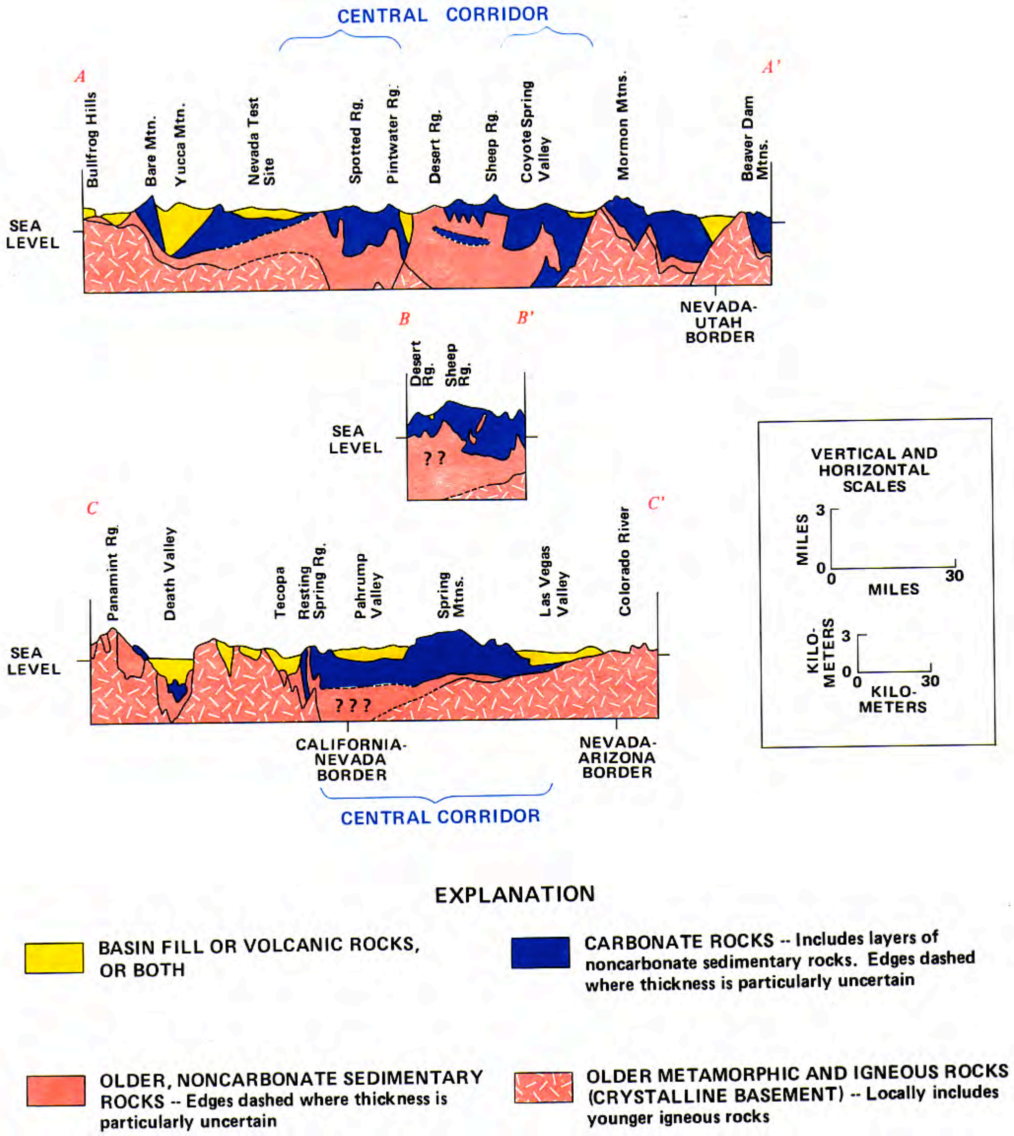


FIGURE 5.--Hydrogeologic sections across southern Nevada. Section A-A' is based on work of Scott and Whitney (1987), Guth (1988), P.L. Guth (U.S. Naval Academy, written communication, 1988), and G.L. Axen (Harvard University, written communication, 1988). Section B-B' is based on work of Guth (1980) and D.L. Schmidt (U.S. Geological Survey, written communication, 1986). Section C-C' is based on work of Wright and others (1981) and Smith and others (1987).

Line C-C' shows a single, continuous corridor of thick carbonate rocks that is surrounded by noncarbonate rocks and a few small and isolated blocks of carbonate rock (as on the western edge of Death Valley). At this latitude, the central corridor underlies the Spring Mountains-Pahrump Valley area (Wright and others, 1981). The carbonate rocks beneath Las Vegas Valley are believed to thin abruptly to the east toward Lake Mead (Smith and others, 1987, p. 38). Water flowing through the corridor at this latitude is derived mostly from recharging snowmelt in the Spring Mountains. This recharge moves radially away from the high-altitude areas of the Spring Mountains to discharge near Tecopa, in Pahrump Valley, at Indian Springs, and (in the past) at Las Vegas Springs (Hershey and others, 1987).

Some zones within the central corridor are highly transmissive, as indicated by large spring discharges that are fed by parts of the aquifers having imperceptibly sloping water tables, and by geologic mapping of ancestral flow paths. The highly transmissive zones may act as large-scale drains, collecting water from adjacent, less transmissive rock that underlies most of the study area. The drains would ultimately conduct much of the flow that discharges at large regional springs. This hypothesis is supported by field observations of a few flow tubes--resembling very long, narrow caves--that evidently formed during transmission of large volumes of water prior to being lifted up to the present-day land surface by geologic forces (Dwight L. Schmidt and Alan M. Preissler, U.S. Geological Survey, written communications, 1986). The few tubes observed are located along major fault zones around the Muddy River Springs area and are surrounded by large volumes of rock containing myriad small, sealed fractures that evidently never developed into important flow conduits after they were opened long ago.

In addition to suggesting a relation between highly transmissive zones and regional springs, the present study has hypothesized that **such zones may stay highly transmissive only if large volumes of water continue to flow through them.** Otherwise, openings in the rocks gradually fill with minerals and the rocks resolidify. Many of the small, filled fractures observed in outcrops of the carbonate rocks throughout the area appear to have been sealed while still below the water table, and they generally show no evidence of prior mineral dissolution from the fracture walls. In contrast, the flow tubes along major fault zones exhibit numerous characteristics of wall dissolution by flowing ground water. This dissolution widened the openings and enhanced what probably were already fairly high transmissivities. Results from tests of carbonate-rock aquifers throughout eastern and southern Nevada indicate that within 10 miles of regional springs, aquifers are an average of 25 times more transmissive than they are farther away. These are areas where flow is converging and flow rates are locally high. The high transmissivities near regional springs could reflect the presence of structures that were more recently active than elsewhere (although that is not demonstrated by the present study), or they may be a further indication that the large volumes of flow concentrated upgradient from the springs are enhancing or maintaining the high transmissivities.

If these hypotheses prove true, then wells that tap conduits of concentrated regional flow probably will be most productive. Certain faults--especially recently active range-bounding faults--are most likely to create openings in the rocks through which concentrations of flow can be transmitted, as noted previously. Maps of recently active faults and delineations of regional flow confluences might be used to systematically locate the most productive structure beneath areas being considered for development.

A natural transition exists between (1) areas in southeasternmost Nevada where the carbonate rocks commonly intermingle with other rocks containing thick or numerous layers of salts (evaporite minerals such as gypsum and halite), and (2) areas elsewhere in southern Nevada where these other rocks are nearly absent (**fig. 4**). The evaporite-bearing rocks east of the transition are younger than most of the carbonate rocks and older than the volcanic rocks and basin-fill aquifers (Longwell and others, 1965, p. 38; Tschanz and Pampeyan, 1970, p. 60-63). The complex geologic history of the area has placed these younger rocks in complicated and unpredictable juxtaposition with the carbonate rocks. **The present investigation minimized study efforts in southeasternmost Nevada because development of the carbonate-rock aquifers there risks the encounter of ground water that is unsuitable for many uses (Lyles and others, 1986).**

VI. HOW MUCH WATER POTENTIALLY CAN BE WITHDRAWN FROM THE CARBONATE-ROCK AQUIFERS?

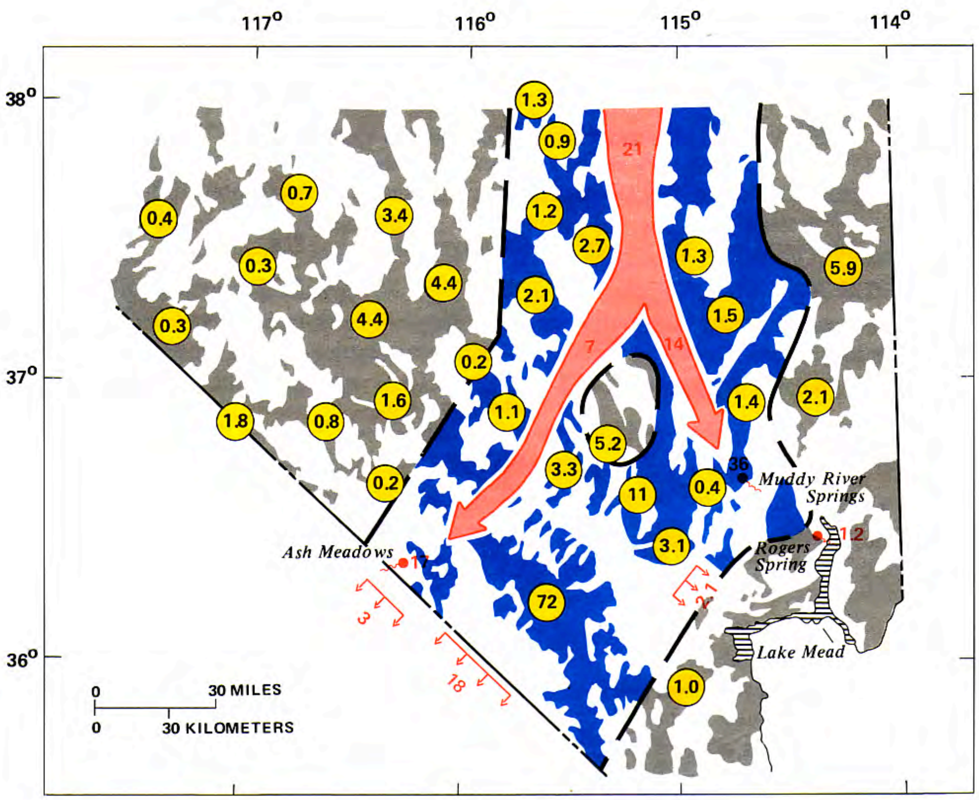
The water resource of the carbonate-rock aquifers is the sum of the perennial yield of the aquifers and the reserve of water stored in them. The perennial yield is the quantity of water that can be extracted for use each year over an indefinite period of time without depleting the ground-water reservoir (Scott and others, 1971, p. 13). The perennial yield can be no greater than the total rate of flow through the aquifers, and it probably is less. For the estimates presented herein, the quantity of water that goes into the aquifers (as recharge and inflow from other areas) is assumed, on average, to equal the quantity that discharges. Under this assumption, the rate of flow within the aquifer is equal to the total income (recharge) and the total output (discharge) of the aquifers. At present (1989), the total rate of flow through the carbonate-rock aquifers cannot be estimated directly, but rather must be bracketed by other rates that can be estimated. The total flow is assumed equal to the recharge to the carbonate-rock aquifers alone, which is less than the total rate of recharge to all the aquifers of southern Nevada, both carbonate and noncarbonate. Because the fraction recharging the carbonate-rock aquifers alone cannot be estimated, the total recharge will be estimated to provide an upper limit on estimates of total flow. The total rate of flow through the carbonate-rock aquifers is greater than the rate of land-surface discharge directly from the carbonate-rock aquifers, because some discharge from the carbonate-rock aquifers is by unseen subsurface leakage of water into adjacent basin-fill aquifers. The rate of land-surface discharge from the carbonate-rock aquifers therefore provides a lower limit on estimates of total flow. Thus, the total flow rate is bracketed between a regional total-recharge rate and a land-surface discharge rate.

Natural recharge in the mountains of southern Nevada has been estimated to total about 140,000 acre-feet annually, of which about 110,000 acre-feet is generated within the central corridor of thick carbonate-rock aquifers (**fig. 6**). The estimates are based mostly on previous studies that range from reconnaissance investigations to numerical models of ground-water flow (Harrill, 1976, p. 50; Harrill, 1986, p. 46; Harrill and others, 1988, sheet 2). The principal insights from the present study define where recharge may be entering regionally extensive aquifers.

In addition to ground-water recharge in southern Nevada, geochemical balances computed in the present study show that **another 21,000 acre-feet per year is supplied to southern Nevada by inflow through carbonate-rock aquifers from east-central Nevada** (Kirk and Campana, 1988; Thomas, 1988). Together recharge plus inflow totals about 160,000 acre-feet per year.

Part of the total ground-water income (recharge plus inflow) flows directly or indirectly into the carbonate-rock aquifers and discharges (1) at regional springs, (2) by flowing out of the study area through carbonate rocks that extend into California, or (3) by leaking into basin-fill aquifers. **The first two mechanisms discharge about 77,000 acre-feet directly from carbonate-rock aquifers of the central corridor**, as summarized in **figure 6** (Harrill, 1976, p. 50; Hess and Mifflin, 1978, appendix II; Harrill, 1986, p. 46; Harrill and others, 1988, sheet 2; and springflow measurements made during this study). The remaining water either leaks upward into the basin fill or directly recharges the basin fill, and ultimately discharges at local springs, playas, meadows, and streams. Previous studies have estimated natural discharge from basin-fill aquifers in the central corridor to be about 50,000 acre-feet per year (Scott and others, 1971, table 3); natural discharge from the basin fill is primarily by evaporation or use by native plants excluding those supplied by regional springs.

The various inflows to and outflows from all aquifers of the central corridor are summarized in **table 2**, which shows that about 130,000 acre-feet may be entering the aquifers each year. Under natural conditions, an equal quantity was discharged from springs, streams, and playas in southern Nevada and nearby parts of California each year.



EXPLANATION

BASIN FILL

BEDROCK OUTSIDE CENTRAL CORRIDOR

BEDROCK WITHIN CENTRAL CORRIDOR

BOUNDARY OF CENTRAL CORRIDOR

1.0 GROUND-WATER RECHARGE, BY MOUNTAIN RANGE -- Number is thousands of acre-feet per year (modified from Scott and others, 1971; Harrill 1976, 1986)

7 GENERAL DIRECTION OF REGIONAL GROUND-WATER INFLOW -- Number is thousands of acre-feet per year (from Thomas, 1988)

36 REGIONAL SPRINGS -- Number is discharge, in thousands of acre-feet per year (from Hess and Mifflin, 1978; and measurements made during this study)

3 REGIONAL GROUND-WATER OUTFLOW -- Number is thousands of acre-feet per year (from Scott and others, 1971; Harrill, 1976, 1986)

FIGURE 6.--Components of regional ground-water budget.

TABLE 2.--Water budget for the central corridor of carbonate-rock aquifers
[All rates are in thousands of acre-feet per year]

Recharge source	Rate	Discharge mechanism	Rate
Mountains of southern Nevada	110	Regional springs	54
Regional ground-water inflow	21	Regional ground-water outflow	about 23
		Discharge from basin-fill under natural conditions	about 50
TOTAL RECHARGE (ROUNDED)	130	TOTAL DISCHARGE (ROUNDED)	130

As a result of this equilibrium between income and output, future wells that continuously extract any part of the annual recharge eventually can be expected to decrease the discharge from one or more of the aquifers. This equality between observed rates of discharge and inferred rates of recharge can be wrong only if the present-day system is not in a natural equilibrium or if some component of discharge has been overlooked. A review of aquifer conditions within and along the boundaries of the central corridor suggests that **only along the California border are the carbonate-rock aquifers continuous enough to transmit large quantities of water to areas where its discharge at land surface could be overlooked in this study.** In particular, no large, currently unidentified quantities of water are likely to be flowing out of southern Nevada to the Colorado River or Arizona.

The perennial yield of the carbonate-rock aquifers cannot exceed the total flow through them. However, part of this flow discharges by leaking into adjacent basin-fill aquifers. This component of flow probably is accounted for already in the water budgets (and estimated perennial yields) of those basins and cannot be included properly in estimates of the perennial yield of the carbonate-rock aquifers unless it is first subtracted from the basin-fill budgets. The perennial yield of the carbonate-rock aquifers of southern Nevada, therefore, should be defined in terms of the remainder of the total flow: **For practical purposes, the perennial yield is no more than the combined rates of discharge at regional springs in southern Nevada and at discharge areas in the Death Valley region (total, about 77,000 acre-feet per year).**

The actual rate at which water can be withdrawn without continual depletion of the ground-water reservoir may depend on how the resource is developed. This is because practical strategies to capture spring flow and outflow may entail inefficiencies that allow part of the flow to avoid capture. These inefficiencies will depend on where and how the water is withdrawn. For example, Harrill (1986, p. 43) used a computer model to show that ground water flowing toward regional springs near Tecopa, Calif. (**fig. 3**), would be difficult to capture at pumping sites upgradient in Pahrump Valley. Thus, **if wells some distance from regional springs are pumped in an effort to capture the spring flows at logistically convenient locations, the sustainable rates of withdrawal may be considerably less than the present flow rates from the regional springs and discharge areas.**

If the basin-fill and carbonate-rock aquifers were managed together, then the overall perennial yield still could not be more than the total recharge to the area. Management of both aquifer types together would not lessen overall effects on natural discharge, but rather it would permit tradeoffs as to what effects would be allowed and where. **Ground-water flow beneath southern Nevada totals about 160,000 acre-feet per year**--about 110,000 recharges mountains in the central corridor, about 30,000 recharges mountains outside the central corridor, and about 21,000 originates in east-central Nevada. **This ground water flows through the carbonate rocks or basin fill, or (along many flow paths) both. Managing the aquifers separately will not increase the total resource.**

The other component of the carbonate-rock water resources is the large volume of water stored in the rocks. Because of the areal extent (10,000 square miles; **fig. 4**) and great thickness of the carbonate rocks in the central corridor (between 3,000 and 19,000 feet and averaging about 12,000 feet), the total volume of rock is enormous. Carbonate rocks that might store and transmit water south of the latitude of Pioche and Tonopah are estimated to total about 20,000 cubic miles. Borehole geophysical measurements made during 1985-88 suggest that the total amount of open space within these rocks may be on the order of 1 to 10 percent, and previous studies at the Nevada Test Site (Winograd and Thordarson, 1975, table 2) suggest that about one-fifth of that space is connected and will allow ground water to move through it. Therefore, if the water stored in selected parts of the carbonate-rock aquifers were extracted, the volume obtained might be on the order of 1 percent of the aquifer volume. Assuming the same percentage of recoverable water in each cubic foot of aquifer, the total quantity of water stored in the rocks south of Pioche and Tonopah would be on the order of 800 million acre-feet. For practical purposes, not all this water can be extracted. However, **if all the water stored in the upper 100 feet of the aquifer's thickness could be extracted, the central corridor could yield on the order of 6 million acre-feet of stored water.**

Stored water is by far the largest part of the water resource of the carbonate-rock aquifers; that is, the total volume of water stored in the carbonate-rock aquifers of southern Nevada greatly exceeds the annual rate of flow through the aquifers. For example, the current rate of spring discharge and subsurface outflow from the carbonate-rock aquifers (about 77,000 acre-feet per year) is only about one ten-thousandth of the estimated total volume of storage and one one-hundredth of the water stored in the upper 100 feet of aquifer. The water stored in the upper 100 feet, if depleted regionally, would be replenished only by the equivalent of decades or centuries of recharge. In contrast, if stored water were depleted only locally, adverse effects might be manageable, especially if well fields were sited to take advantage of geologic barriers that could partly or wholly prevent the large-scale spread of effects. Regional and local depletions of stored water can be expected to decrease discharge from the aquifers eventually, but the magnitude and timing of even these decreases may be manageable by advantageous choices of well sites.

The volumes of water moving through and stored in the carbonate-rock aquifers can be compared in magnitude to other water resources in southern Nevada:

- The recharge rate to all aquifers in the central corridor south of Pioche and Tonopah (about 110,000 acre-feet per year) is equal to about one-third of Nevada's allocation for consumptive use of Colorado River water (300,000 acre-feet per year, according to URS Company and Converse Ward Davis Dixon, 1982, p. 74).
- The rate of discharge directly from the carbonate-rock aquifers (77,000 acre-feet per year) is 2.6 times the estimated natural recharge rate to the basin-fill aquifers of Las Vegas Valley as given by Harrill (1976, p. 50).
- The volume of water stored in the upper 100 feet of the carbonate-rock aquifers of the central corridor (on the order of 6 million acre-feet) is equivalent to about one-quarter of the usable storage volume of water in Lake Mead, about 8 months of average flow in the Colorado River (as given by Pupacko and others, 1988, p. 78-80), and about 23 years of Nevada's allocation for consumptive use of Colorado River water.
- Finally, the volume of water stored in the upper 100 feet of carbonate-rock aquifers is about one-sixth of the quantity stored in the upper 100 feet of basin-fill aquifers overlying the central corridor (the latter as compiled from Scott and others, 1971, table 1).

Ultimately, long-term development of the carbonate-rock aquifers would deplete stored water, or would capture water that otherwise would discharge from the aquifers of southern Nevada and vicinity, or both. In many places, development may extract water from both carbonate-rock and basin-fill aquifers. Reasonable tradeoffs among these alternative sources may be possible given (1) better local understanding of the aquifers and effects of development, and (2) careful planning of the developments.

VII. WHAT EFFECTS MIGHT RESULT FROM DEVELOPMENT OF THE CARBONATE-ROCK AQUIFERS?

Possible effects of developing the carbonate-rock aquifers include declining water levels, decreasing spring-flow rates, drying up of some streams, playas, and meadows, and changing water chemistry. These effects are direct or indirect responses to water-level changes associated with aquifer development, and are related to disturbances of the natural equilibrium between aquifer recharge and discharge.

Sustained effects within the carbonate-rock aquifers resulting from development of those aquifers have not been observed to date, but this reflects more the lack of aquifer development than a lack of potential for effects if such development were undertaken. The magnitude and extent of water-level changes and, eventually, changes in spring-flow rates caused by development would depend on the geometry of the aquifers and their capacity to transmit and store water. Such effects can be predicted roughly by using either engineering-style hydraulic calculations or more complex computer models of ground-water flow. The hydraulic equations--such as those of Theis (1935)--ignore much of the complex structure of the carbonate-rock aquifers but still can provide useful insight into the probable extent of water-level declines on the basis of the observed capacity of the aquifer to transmit and store water.

Hydraulic calculations such as those made by using the Theis equation involve many restrictive assumptions that are only loosely applicable to southern Nevada, but they nonetheless indicate that **water-level declines associated with a pumped well in a carbonate-rock aquifer may be moderate to small in most locations where the aquifer is unconfined, but would be much larger where the aquifer is confined.**[1] Water-level declines in extensive, unconfined carbonate-rock aquifers commonly would be between about 1 and 70 feet within 1 mile of a production well after 10 years of pumping at 1,000 gallons per minute. This predicted range is calculated by assuming that the range of transmissivities includes the middle two-thirds of those calculated on the basis of measurements at 39 carbonate-rock wells in Nevada; the particular values assumed were between 700 and 114,000 feet squared per day. Also assumed is a storage coefficient of 1 percent under unconfined conditions. Applying these assumptions further, calculated water-level declines 10 miles from the pumped well in an unconfined part of the aquifers would be between a fraction of a foot and several feet. If, instead, the developed aquifer is confined

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[1] Heath (1983, p. 6) describes unconfined aquifers as those in which water only partly fills the transmissive rocks, so that the upper surface of water in the openings in the rock can rise and decline in response to pumping. In contrast, confined aquifers are those in which water completely fills the entire thickness of transmissive rock up to an overlying layer that restricts vertical flow of ground water. In confined aquifers, water pressure, not water level, rises and declines in response to pumping.

(assuming a storage coefficient of 0.01 percent with all other assumptions unchanged), then the predicted water-level declines after 10 years would range between about 1 foot and about 200 feet at 1 mile from the pumped well, and between about 1 and 70 feet at 10 miles.

These calculated drawdowns range over hundreds of feet, reflecting broad uncertainties. The calculations, however, demonstrate the important difference between developing unconfined parts of the aquifers rather than confined parts. Until more experience is gained with stressed carbonate-rock aquifers, site-specific predictions of the degree of confinement exhibited by a selected part of the carbonate-rock aquifers will be accurate only where based on direct observation of water-level fluctuations and analysis of short-term effects of development. Still, a preliminary review of hydrogeologic conditions leads to the hypothesis that water levels in the aquifers will respond to development over tens of years and at long distances from pumping as if the aquifers were unconfined. Continuous, low-permeability layers that might confine the aquifers over large distances are expected to be uncommon because the carbonate-rock aquifers have been deformed along steep faults in so many places. If so, adverse effects may be restricted to relatively small areas around a development.

Neither set of calculations (for unconfined and confined conditions) accounts for the large directional influence on declines that would be expected if the well were drawing water from narrow, highly transmissive zones such as those hypothesized in an earlier section. As a consequence, the calculated declines around wells drawing water from these zones may be underestimated along the zones and overestimated away from the zones. The calculated declines therefore are only general indications of the magnitude of effects that might be expected, and are subject to large revisions when nonuniform properties of the aquifers can properly be taken into account.

The carbonate rocks do not form a single, thick layer beneath southern Nevada, but rather are distributed as corridors and blocks. The preceding calculations of drawdown around aquifer developments assume that the aquifer extends far beyond the area affected by pumping. Currently (1989), data that accurately account for the influence of aquifer geometry are not available to support detailed predictions of potential effects of development. The study discussed herein did not attempt to model development effects at any specific localities, but several previous studies have included computer models that provide insight into the problems of prediction. A review of those models suggests primarily that flow in the aquifers varies complexly at every scale. Regardless of whether the effect of pumping near Devils Hole is being modeled at a small scale (Bateman and others, 1974; Rojstaczer, 1987) or whether the flow toward Death Valley is being simulated at a regional scale (Bedinger and others, in press), **the geologic complexity of southern Nevada is hydrologically important and must be considered in predicting development effects.** The numerous fault-zone orientations, differing aquifer thicknesses, and difficult-to-delineate masses of noncarbonate rock that are barriers to flow require (1) that detailed aquifer descriptions be available before accurate site-specific predictions can be made, and probably (2) that those predictions be based on effective use of sophisticated computer models. An alternative that may be adequate in some areas of relatively simple aquifer geometry is the application of hydraulic equations using boundary representations, of the sort described by Bear (1979, section 8-10).

The potential for adverse effects in adjacent aquifers resulting from development of the carbonate-rock aquifers is another concern. Available methods for hydraulic calculation of effects in an aquifer that overlies a second, stressed aquifer--similar in style and simplicity to the Theis equations of 1935--probably are not applicable to the complex geologic setting in southern Nevada. However, historical experience with such conditions is available at two areas in southern Nevada that have undergone ground-water development from basin-fill aquifers adjacent to carbonate-rock aquifers: Ash Meadows and Muddy River Springs. Observations in these areas provide information concerning the potential for interaction of aquifers near pumped wells. However, the historical conditions at Ash Meadows and Muddy River Springs, where the basin-fill aquifers were developed instead of underlying carbonate-rock aquifers, are the reverse of the type of development being assessed herein. **At Ash Meadows, direct connections between pumping from basin-fill aquifers and water-level declines in the carbonate rocks were demonstrated (fig. 3).** Withdrawals from irrigation wells near Devils Hole drew down water levels by more than a foot in the carbonate-rock aquifers between 1969-72 (**fig. 7**; Bateman and others, 1974; Dudley and Larson, 1976). The water levels recovered slowly but steadily over a period of about 15 years after pumping ceased (**fig. 7**). Pumping water from some of the wells also resulted in rapid declines of flow from nearby springs that discharge from the carbonate-rock aquifers. **Around the Muddy River Springs (fig. 3), in contrast, varying levels of development of ground water from basin-fill aquifers over the last 20 years have resulted in minimal changes in water levels of the carbonate-rock aquifers** (Martin D. Mifflin, Mifflin and Associates, Inc., written communication, 1987; Pohlmann and others, 1988, p. 14). These small changes are difficult to quantify or to attribute to specific development activities. No long-term changes in spring flow have been measured or recognized during this study. The difference between historical responses at these two areas probably could not have been predicted before the aquifers were pumped and early effects observed. Thus, experience with aquifer development at the Ash Meadows and Muddy River Springs areas indicates that the potential for adverse effects on both basin-fill and carbonate-rock aquifers can be assessed only on a site-by-site basis. **Different hydrogeologic settings in southern Nevada can be expected to respond differently to aquifer development.**

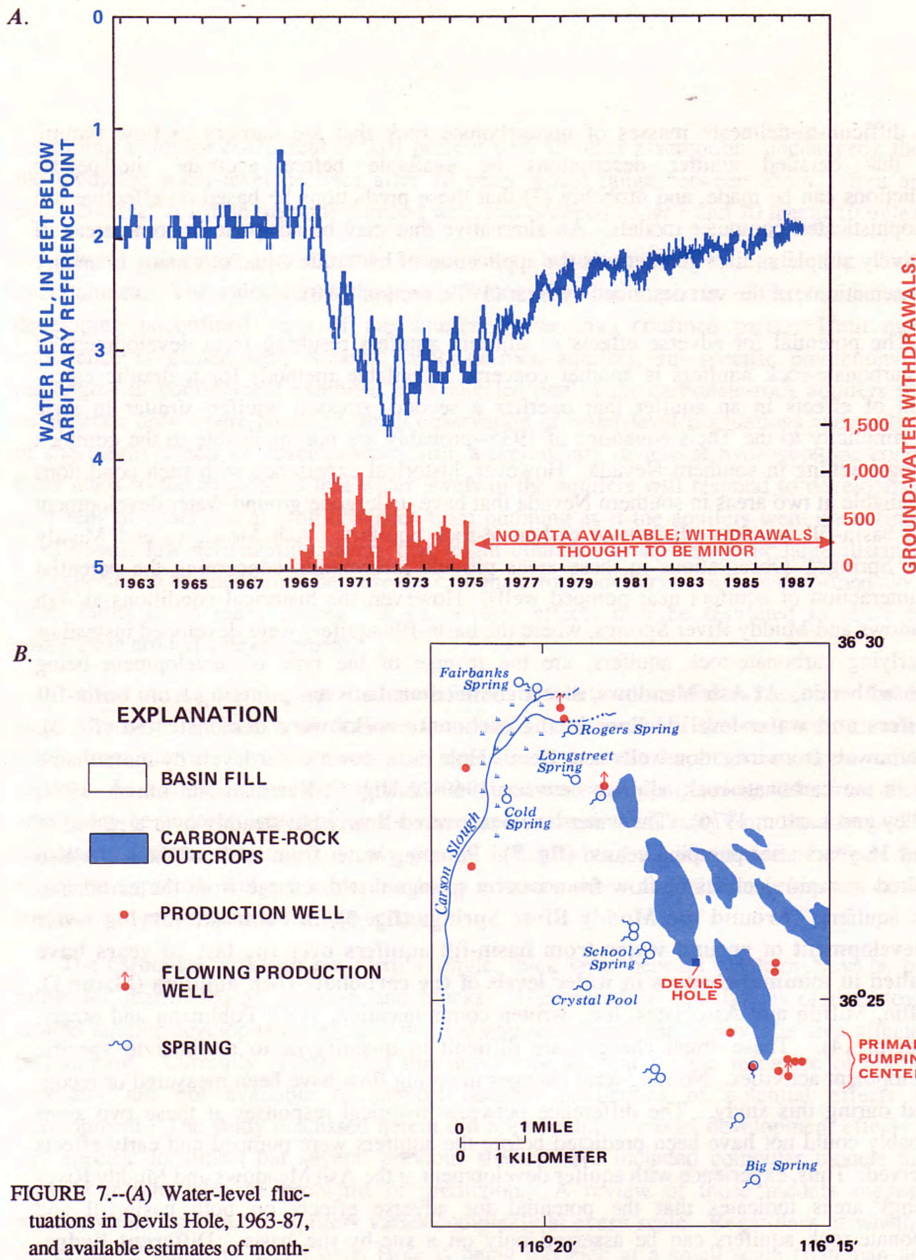

FIGURE 7.--(*A*) Water-level fluctuations in Devils Hole, 1963-87, and available estimates of monthly ground-water withdrawals for irrigation in Ash Meadows area.
Water-level data from U.S. Geological Survey files; pumpage estimates from Bateman and others (1974), Larson (1974a, 1974b, and 1975), and Dudley and Larson (1976). (*B*) Location of Devils Hole, production wells, and springs in Ash Meadows area (see fig. 3). Modified from Larson (1974b, fig. 2).

Simple predictions of water-level declines in the carbonate-rock aquifers, together with a review of historical experiences with the effects of drawing water from basin-fill aquifers that are adjacent to carbonate-rock aquifers, suggest that the carbonate-rock aquifers might be developed in some areas with acceptable effects. In other areas--for example, where a stressed aquifer is fully confined or where adjacent aquifers are closely connected--effects could be more severe. The effects of depletion of stored water and capture of water that otherwise would discharge from the aquifers would depend on site-specific conditions around areas where water is withdrawn from the aquifers. **Confidence in the prediction of effects that might result from development of the carbonate-rock aquifers will remain limited until observations are available that document changes as the aquifers respond locally to long-term pumping stresses.**

Initially, assurances that the adverse effects of development will not overshadow benefits cannot be made with a high degree of confidence. However, **if staged development were undertaken together with adequate monitoring, effects of continued or increased development could be estimated with progressively higher degrees of confidence.** Staging means not developing the resources in one large step but rather starting with small projects that are augmented gradually as conditions and confidence warrant. This approach allows the effects of development to be observed and analyzed continually, so that the benefits and adverse effects of development can be judged and the effects reversed or mitigated if they prove to be too costly (in economic and environmental terms). Adequate monitoring means monitoring that provides data for a timely and sound judgment of benefits and adverse effects. Monitoring of all aquifers that may be affected, and all hydrologic conditions that may reflect these effects, should provide a basis for sound judgments. Regular or continuous monitoring that permits the recognition of early signs of effects of development and that allows these effects to be distinguished from natural fluctuations, would provide information for timely judgments.

VIII. WHAT ISSUES REMAIN TO BE RESOLVED?

In southern Nevada (**fig. 8**), studies during 1985-88 have advanced the understanding of ground-water flow in the carbonate-rock aquifers, but the foundations of this new understanding still are of a qualitative and regional nature. Uncertainties remain concerning some regional flow components and most site-specific issues. Despite these limitations, the studies provide a groundwork for future resource evaluations of local areas and for site-specific studies intended to locate and design production well fields.

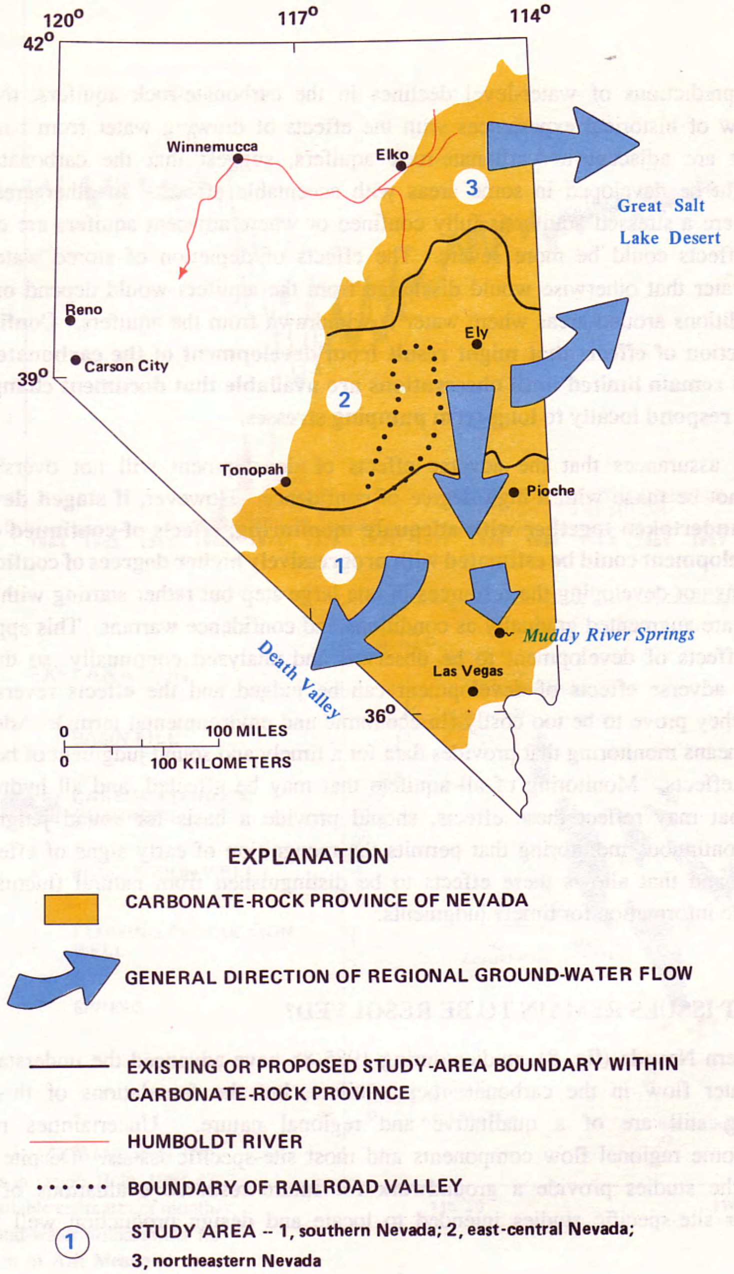

FIGURE 8.--Location of existing southern Nevada study area (1985-88) and proposed east-central and northeastern study areas, in relation to directions of regional ground-water flow and other features.

Future studies could productively include drilling and testing beyond that done for the studies described herein (for instance, to locally identify flow systems that would be *penetrated by production wells, to determine engineering-design requirements for such* wells, and to address other site-specific issues such as whether the aquifer is confined or unconfined). In contrast, additional regional-scale investigations in this part of the State reasonably could be postponed until after some of these localized investigations. Consequently, **work in southern Nevada in the near future could focus productively on localized drilling and testing programs, whereas regional-scale studies and resource evaluations could focus productively on the central and northeastern parts of the State.**

Higher altitudes and more northern location make east-central Nevada (**fig. 8**) much wetter than southern Nevada. As a result of this greater wetness, some components of the water budgets of the carbonate-rock aquifers may be as yet undetected or underestimated. In fact, **if water unaccounted for in present water-budget estimates is to be found anywhere in the carbonate-rock aquifers, it most likely is in east-central Nevada.** This area is the source of most regional ground-water flow throughout the carbonate-rock province. Regional flow systems originating in east-central Nevada discharge both to the south into southern Nevada and to the northeast into Utah (**fig. 8**; Harrill and others, 1988). In addition, a smaller interbasin flow system discharges tens of thousands of acre-feet per year in Railroad Valley (**fig. 8**; Van Denburgh and Rush, 1974, tables 8 and 9).

Studies in east-central Nevada could focus on defining the areas that contribute recharge to regional flow systems and on further quantifying the regional outflow. These studies also could determine which areas contribute recharge to the more localized flow systems. This focus would help improve estimates of regional flow rates into southern Nevada and western Utah. Most of the same methods discussed in this report could be applied also to studies of regional ground-water flow in east-central Nevada. One complicating factor, however, is the widespread presence of volcanic rocks that form thick subregional aquifers (Fiero, 1968; Winograd, 1971, fig. 1; Stewart and Carlson, 1976). Thus, ground water in east-central Nevada would have to be considered in three aquifer types--basin fill, volcanic rocks, and carbonate rocks.

Studies in northeastern Nevada (**fig. 8**) could focus on locating and delineating supplies for regional water-management plans--for example, the combined water resources of the Humboldt River, the adjacent basin-fill aquifers, and the carbonate-rock aquifers. Other studies could be designed to address the potential for developing water supplies from the carbonate-rock aquifers for uses such as mining, power plants, and small municipalities. Regional-scale flow in northeastern Nevada is believed to be generally eastward toward the Great Salt Lake Desert in Utah. This regional flow, combined with outflow to Utah from east-central Nevada, has been estimated to total about 50,000 acre-feet per year (Harrill and others, 1988). Studies could address which part of this water might be developed with little or no adverse effect in Nevada or western Utah.

IX. CONCLUSIONS

The carbonate-rock aquifers of Nevada are widely distributed, fractured and solution-modified rocks that transmit water beneath mountains and basins. In southern Nevada, the aquifers are thick enough and continuous enough to collect and transmit regional ground-water flow only within a north-south corridor centered under Pahranagat Valley, the Sheep Range and Spotted Range areas, and Spring Mountains. Outside of this corridor, carbonate rocks are present mostly as isolated mountain-sized blocks that do not form regional aquifers.

About 130,000 acre-feet of water recharges to and discharges from aquifers of all types (carbonate and non-carbonate) in the central corridor each year. Of that total, about 77,000 acre-feet discharges each year directly from the carbonate-rock aquifers; nearly all this discharge occurs in Ash Meadows and at Muddy River Springs in Nevada and in Death Valley and vicinity in California. Because regional aquifers are limited to the central corridor, little additional, currently unidentified outflow from the carbonate-rock aquifers of southern Nevada is likely; in particular, the Colorado River does not receive large quantities of outflow from the carbonate-rock aquifers.

Because of the great thickness and extent of the carbonate-rock aquifers and the long distances between the high-altitude recharge areas and the lower-altitude discharge areas, water that discharges today has spent thousands of years flowing through the aquifers. Thus, the quantity of water present in the aquifers at any particular moment is far greater than the quantity entering or leaving the aquifer in a single year. The quantity of water in transit through the aquifers at present may be on the order of 800 million acre-feet, and the quantity stored in just the top 100 feet of the aquifers may be on the order of 6 million acre-feet.

Sustained withdrawal of water from the carbonate-rock aquifers would entail (1) depleting some of the large store of water in transit through the aquifers and (2) capturing some water that would otherwise discharge from the Ash Meadows, Muddy River Springs, and Death Valley areas. These depletions can be expected to result in (1) water-level declines in the carbonate-rock aquifers and, under some circumstances, in the basin-fill aquifers, and, ultimately, (2) spring-flow reductions. The magnitude and geographic range of these effects, however, is largely unpredictable at present. Confidence in predicting effects of specific plans for developing the aquifers is likely to be increased only through a gradual (staged) approach to aquifer development, together with adequate monitoring and interpretation of short-term effects.

In southern Nevada, a regional-scale framework has been developed during the present study that can be used as a basis for site-specific studies in support of actual aquifer developments. Consequently, in the immediate future, regional-scale studies might be focused most productively in wetter areas farther north in the carbonate-rock province.

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Drought

What is a drought?

A **drought** is a period of drier-than-normal conditions that results in water-related problems. **Precipitation** (rain or snow) falls in uneven patterns across the country. The amount of precipitation at a particular location varies from year to year but, over a period of years, the average amount is fairly constant. In the deserts of the Southwest, the average precipitation is less than 3 inches per year. In contrast, the average yearly precipitation in some parts of the Northwest is more than 150 inches.

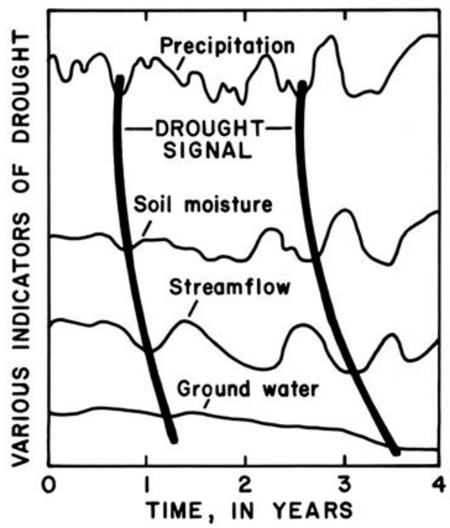
The amount of rain and snow also varies with the seasons. In some areas, most of the yearly precipitation falls in early spring. In the Southeast, most of the yearly precipitation falls during the hurricane seasons in late summer and fall. Even if the total amount of rainfall for a year is about average, rainfall shortages can occur during a period when moisture is crucially needed for plant growth.

When no rain or only a very small amount of rain falls, soils can dry out and plants can die. When rainfall is less than normal for several weeks, months, or years, the flow of streams and rivers declines, water levels in lakes and reservoirs fall, and the depth to water in wells increases. If dry weather persists and water-supply problems develop, the dry period can become a **drought**.

When does a drought begin?

The beginning of a drought is difficult to determine. Several weeks, months, or even years may pass before people know that a drought is occurring. The end of a drought can occur as gradually as it began. Dry periods can last for 10 years or more. During the 1930's, most of the United States was much drier than normal. In California, the drought extended from 1928 to 1937. In Missouri, the drought lasted from 1930 to 1941. That extended dry period produced the "Dust Bowl" of the 1930's when dust storms destroyed crops and farms.

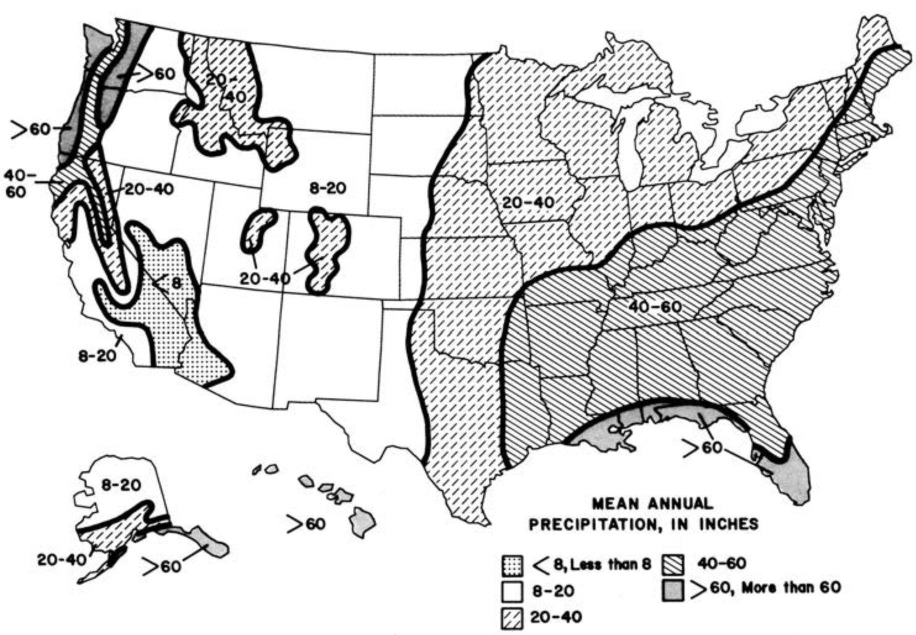
The first evidence of drought usually is seen in records of rainfall. Within a short period of time, the amount of moisture in soils can begin to decrease. The effects of a drought



on flow in streams and rivers or on water levels in lakes and reservoirs may not be noticed for several weeks or months. Water levels in wells may not reflect a shortage of rainfall for a year or more after a drought begins.

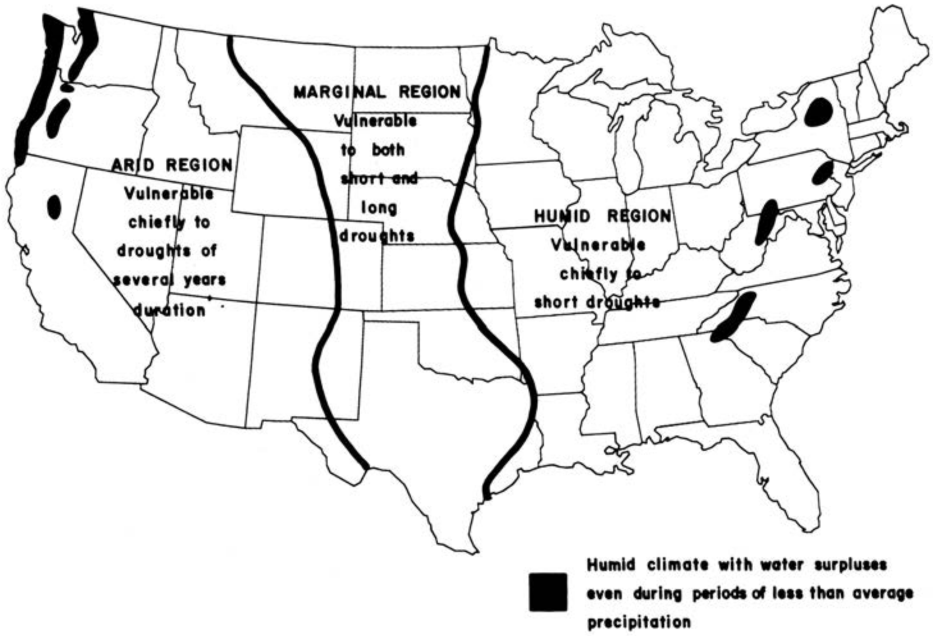
Does a shortage of rain mean a drought will occur?

A period of below-normal rainfall does not necessarily result in drought conditions. Some rain returns to the air as water vapor when water **evaporates** from water surfaces and from moist soil. Plant roots draw some of the moisture from the soil and return it to the air through a process called **transpiration**. The total amount of water returned to the air by these processes is called **evapotranspiration**. Sunlight, humidity, temperature, and wind affect the rate of evapotranspiration. When evapotranspiration rates are large, soils can lose moisture and dry conditions can develop. During cool, cloudy weather, evapotranspiration rates may be small enough to offset periods of below normal precipitation and a drought may be less severe or may not develop at all.



Where do droughts usually occur?

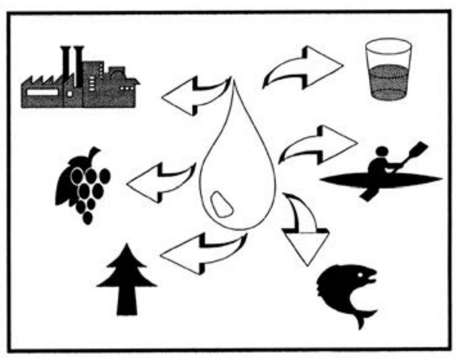
Some areas of the United States are more likely to have droughts than other areas. In **humid**, or wet regions, a drought of a few weeks is quickly reflected in a decrease in soil moisture and in declining flow in streams. People who use water from streams in these areas may face water shortages as soon as streamflow begins to decline. In **arid**, or dry regions, people rely on ground water and water in reservoirs to supply their needs. They are protected from short-term droughts, but may have severe problems during long dry periods because they may have no other water source if wells or reservoirs go dry.



What can be done to solve water problems during periods of drought?

When droughts occur, there is not enough water to supply all needs. If water is diverted from streams to irrigate crops, streamflow will decrease. Reservoirs that may already be at low levels will be drawn even lower to supply water for power generation, to supply water to downstream cities and towns, or to maintain river levels high enough for navigation. Decreasing water levels in rivers, lakes, and reservoirs may cause problems for fish and wildlife that depend on wetlands or water bodies to survive.

Balancing the needs of all the users of a water supply during a drought can be very difficult. Local, State, and Federal agencies must make decisions on how water will be used to satisfy the most critical needs and to reduce economic and environmental problems. In times of severe drought, water users must cooperate and share the limited amount of water available to protect the critical needs of people, fish and wildlife, agriculture, and industry.



Conserving water is very important during drought periods. Water saved by one user may be enough to protect the critical needs of others. Irrigation practices can be changed to use less water or crops that use less water can be planted. Cities and towns can ration water, factories can change manufacturing methods, and individuals can practice water-saving measures to reduce consumption. If everyone reduces water use during a drought, more water will be available to share.

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