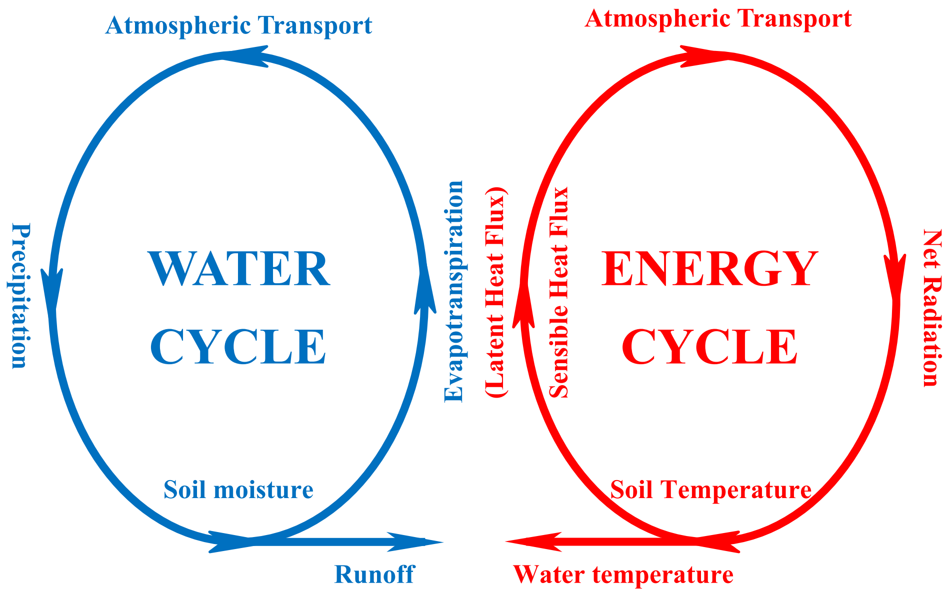


Atmospheric Transport
Precipitation
WATER
CYCLE
Evapotranspiration
Soil moisture
Runoff
Atmospheric Transport
(Latent Heat Flux)
Sensible Heat Flux
ENERGY
CYCLE
Net Radiation
Soil Temperature
Water temperature

Figure 13

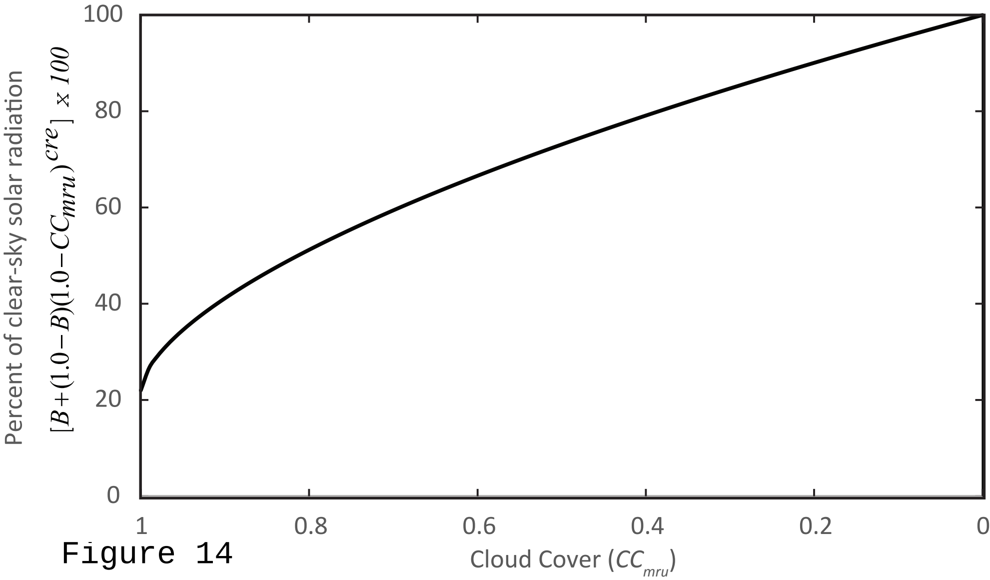

100
80
60
40
20
0
1
0.8
0.6
0.4
0.2
0
Percent of clear-sky solar radiation
$[B+(1.0-B)(1.0-CC_{mru})^{cre}] \times 100$
Cloud Cover (CC_{mru})

Figure 14

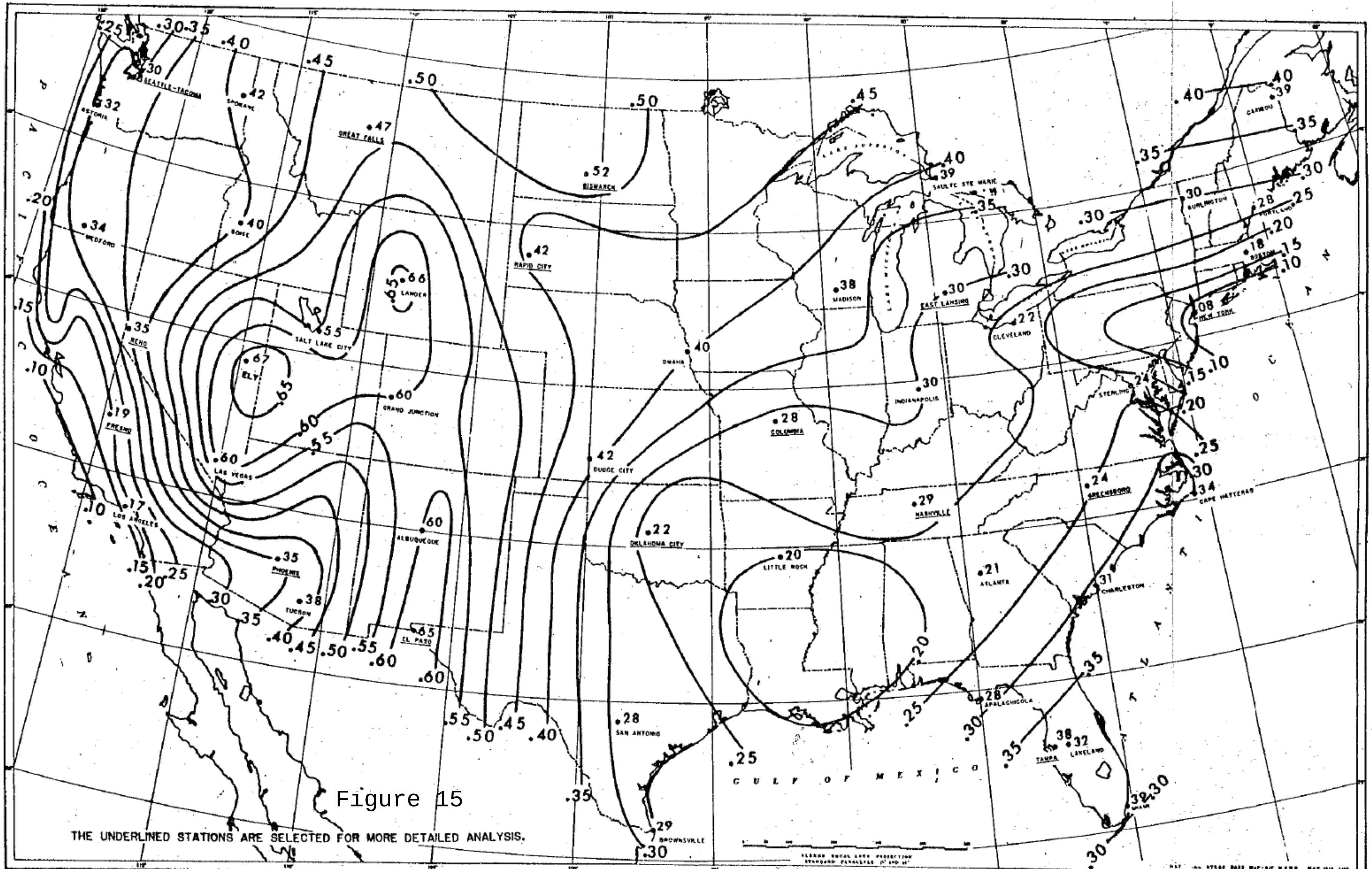
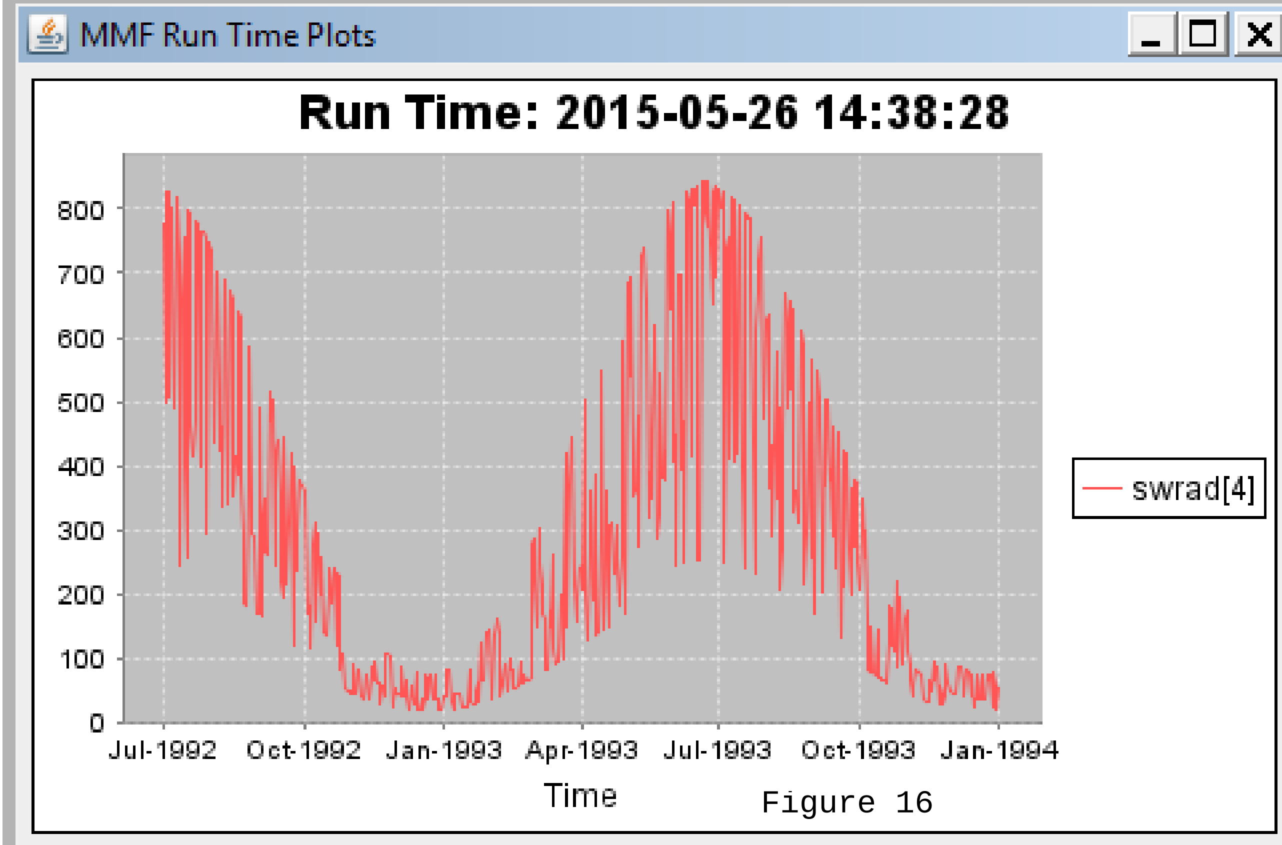
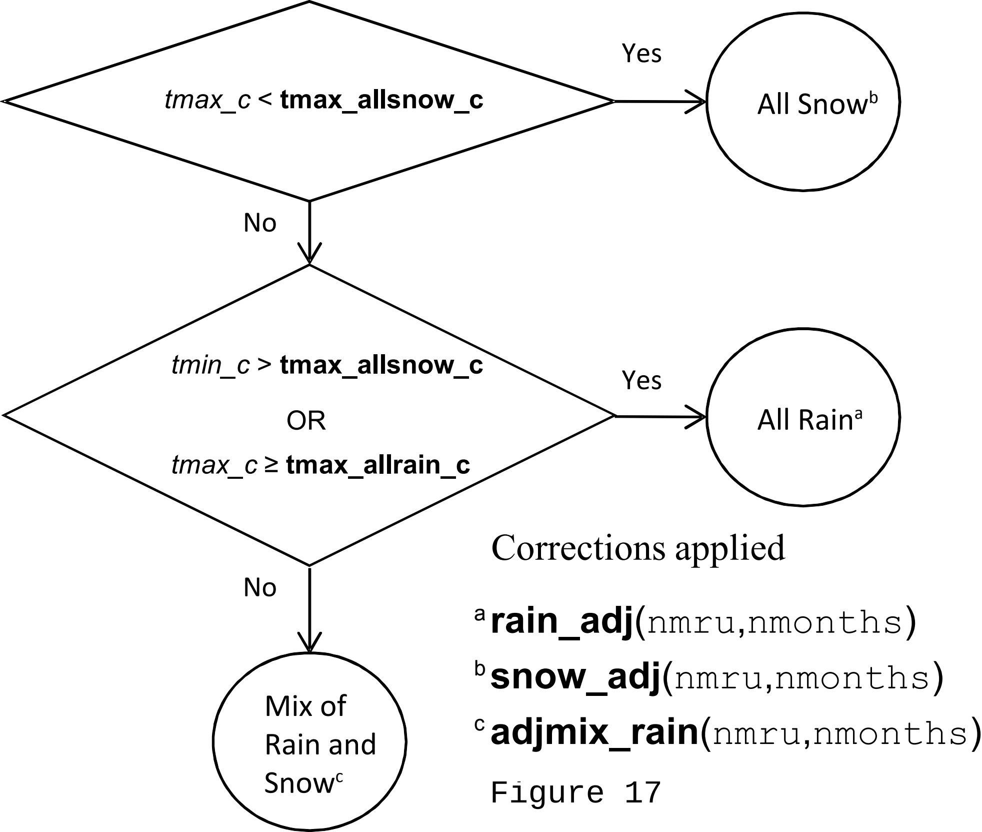


Figure 15

THE UNDERLINED STATIONS ARE SELECTED FOR MORE DETAILED ANALYSIS.


MMF Run Time Plots
Run Time: 2015-05-26 14:38:28
800
700
600
500
400
300
200
100
0
Jul-1992
Oct-1992
Jan-1993
Apr-1993
Jul-1993
Oct-1993
Jan-1994
Time
swrad[4]
Figure 16



tmax_c < tmax_allsnow_c
Yes
All Snow[b]
No
tmin_c > tmax_allsnow_c
OR
tmax_c ≥ tmax_allrain_c
Yes
All Rain[a]
No
Mix of Rain and Snow[c]
Corrections applied
[a] rain_adj(nmru,nmonths)
[b] snow_adj(nmru,nmonths)
[c] adjmix_rain(nmru,nmonths)

Figure 17

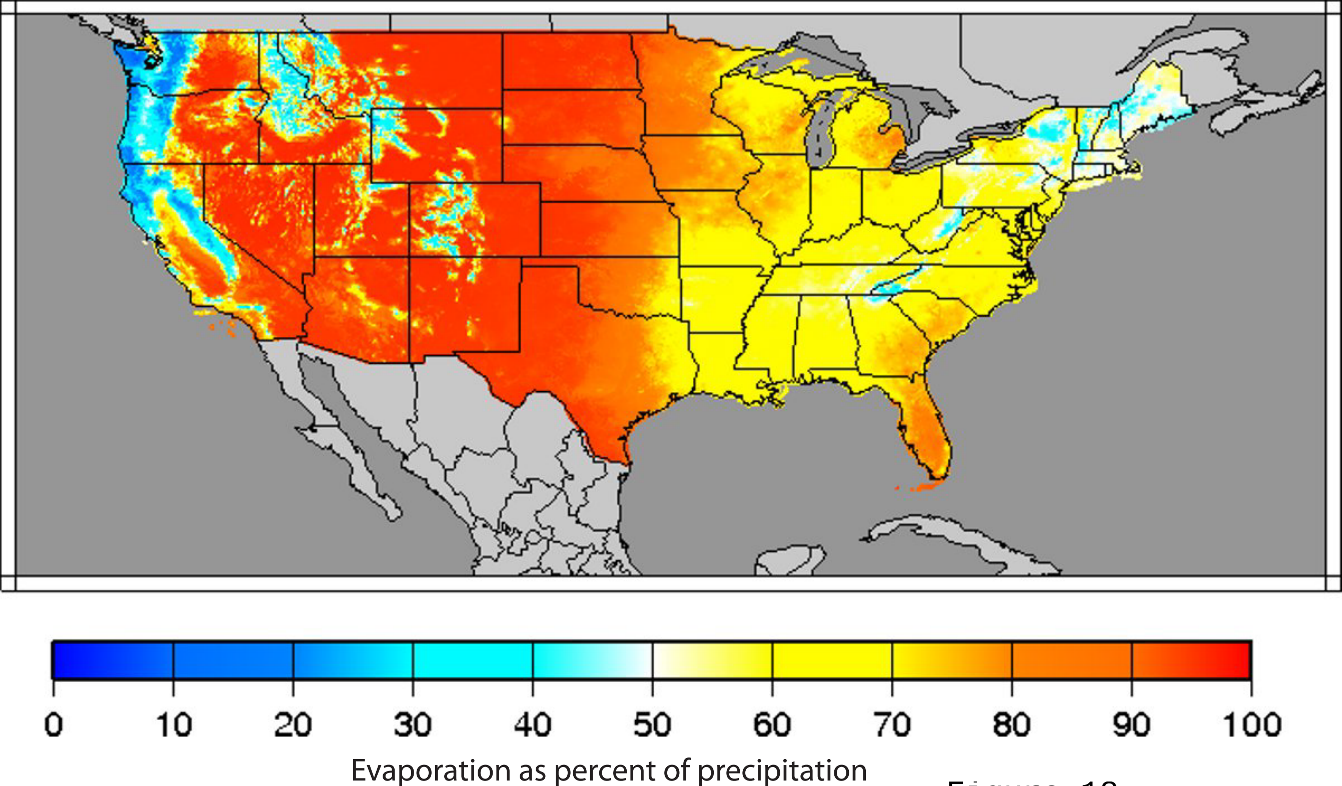
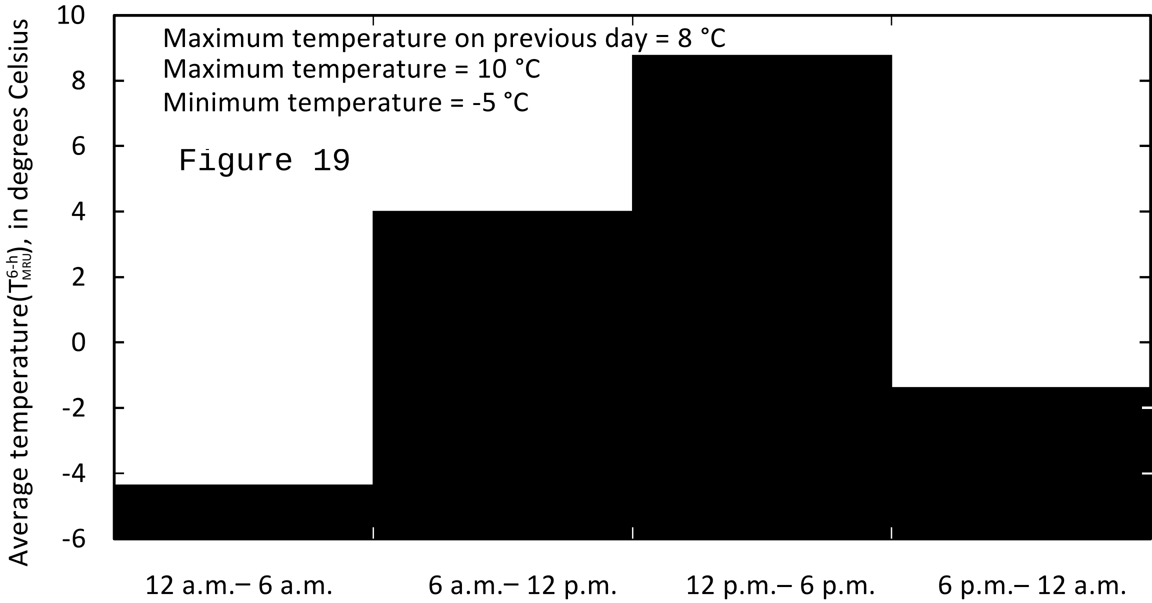

0
10
20
30
40
50
60
70
80
90
100
Evaporation as percent of precipitation

Figure 18


Maximum temperature on previous day = 8 °C
Maximum temperature = 10 °C
Minimum temperature = -5 °C
Figure 19
Average temperature($T_{MRU}^{6\text{-}h}$), in degrees Celsius
10
8
6
4
2
0
-2
-4
-6
12 a.m.– 6 a.m.
6 a.m.– 12 p.m.
12 p.m.– 6 p.m.
6 p.m.– 12 a.m.

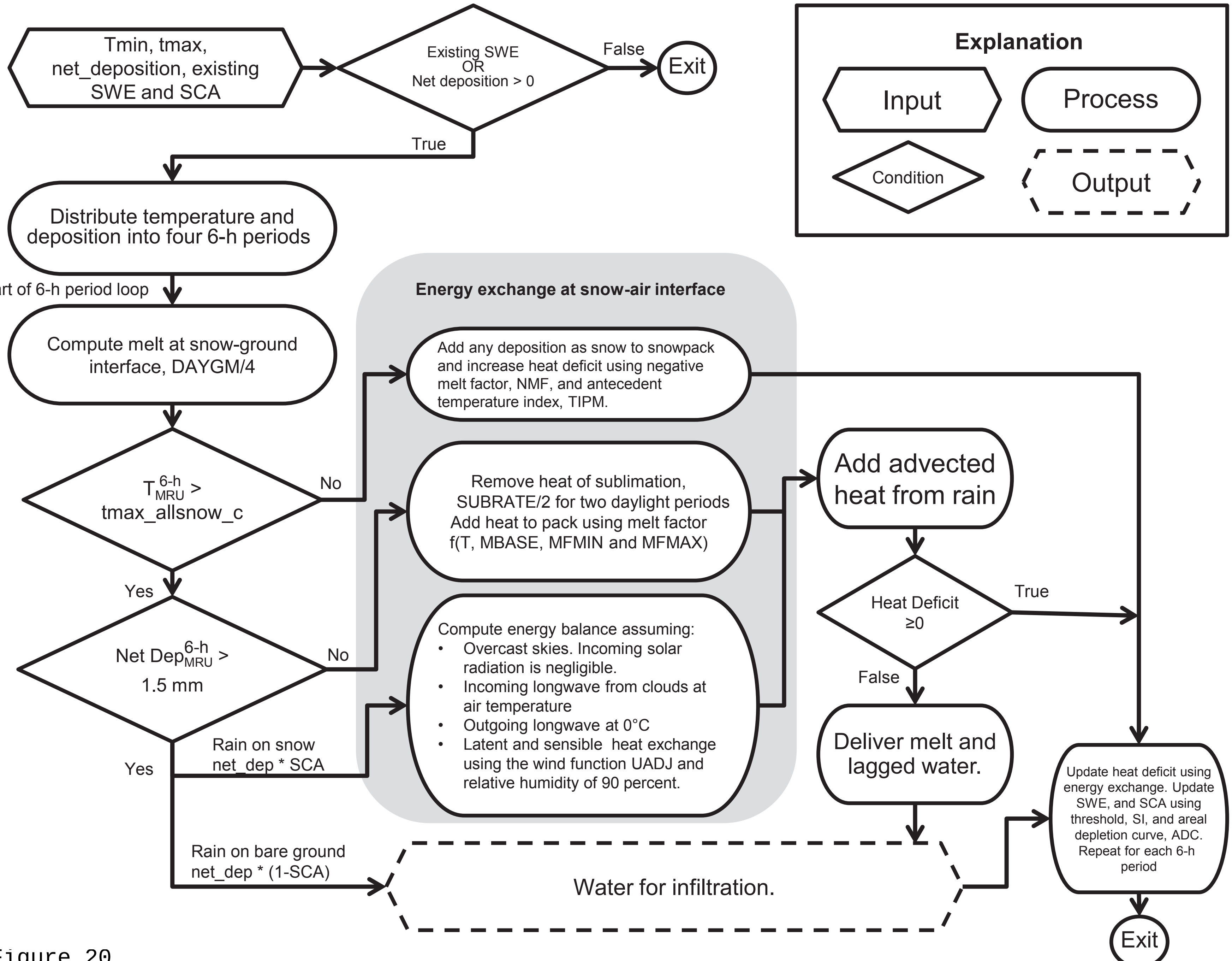
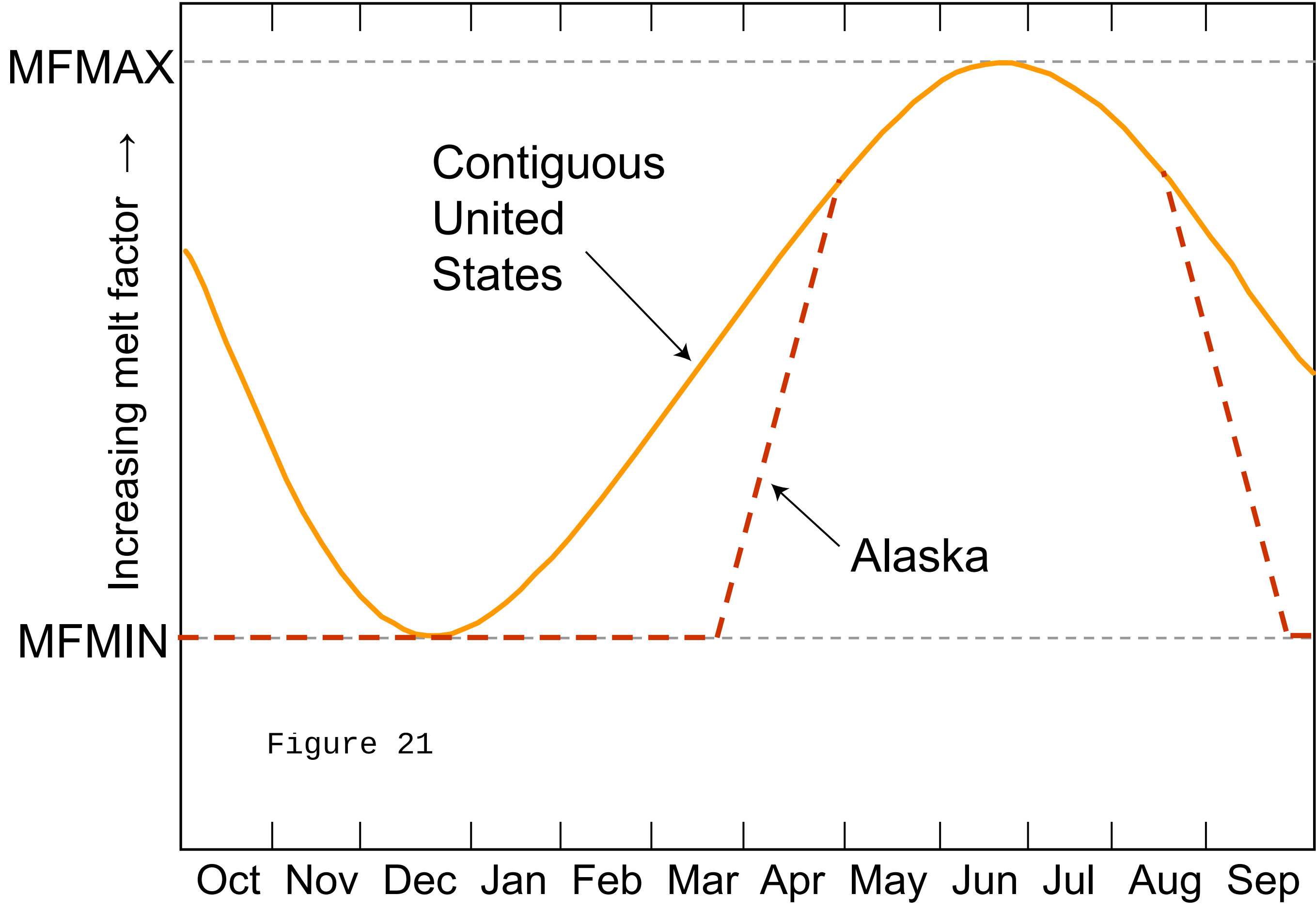

Tmin, tmax, net_deposition, existing SWE and SCA
Existing SWE OR Net deposition > 0
False
Exit
True
Explanation
Input
Process
Condition
Output
Distribute temperature and deposition into four 6-h periods
Start of 6-h period loop
Compute melt at snow-ground interface, DAYGM/4
$T_{MRU}^{6\text{-}h}$ > tmax_allsnow_c
No
Yes
Net $Dep_{MRU}^{6\text{-}h}$ > 1.5 mm
No
Yes
Energy exchange at snow-air interface
Add any deposition as snow to snowpack and increase heat deficit using negative melt factor, NMF, and antecedent temperature index, TIPM.
Remove heat of sublimation, SUBRATE/2 for two daylight periods Add heat to pack using melt factor f(T, MBASE, MFMIN and MFMAX)
Compute energy balance assuming:
• Overcast skies. Incoming solar radiation is negligible.
• Incoming longwave from clouds at air temperature
• Outgoing longwave at 0°C
• Latent and sensible heat exchange using the wind function UADJ and relative humidity of 90 percent.
Rain on snow net_dep * SCA
Rain on bare ground net_dep * (1-SCA)
Add advected heat from rain
Heat Deficit ≥0
True
False
Deliver melt and lagged water.
Water for infiltration.
Update heat deficit using energy exchange. Update SWE, and SCA using threshold, SI, and areal depletion curve, ADC. Repeat for each 6-h period
Exit

Figure 20


MFMAX
MFMIN
Increasing melt factor →
Contiguous
United
States
Alaska
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Figure 21

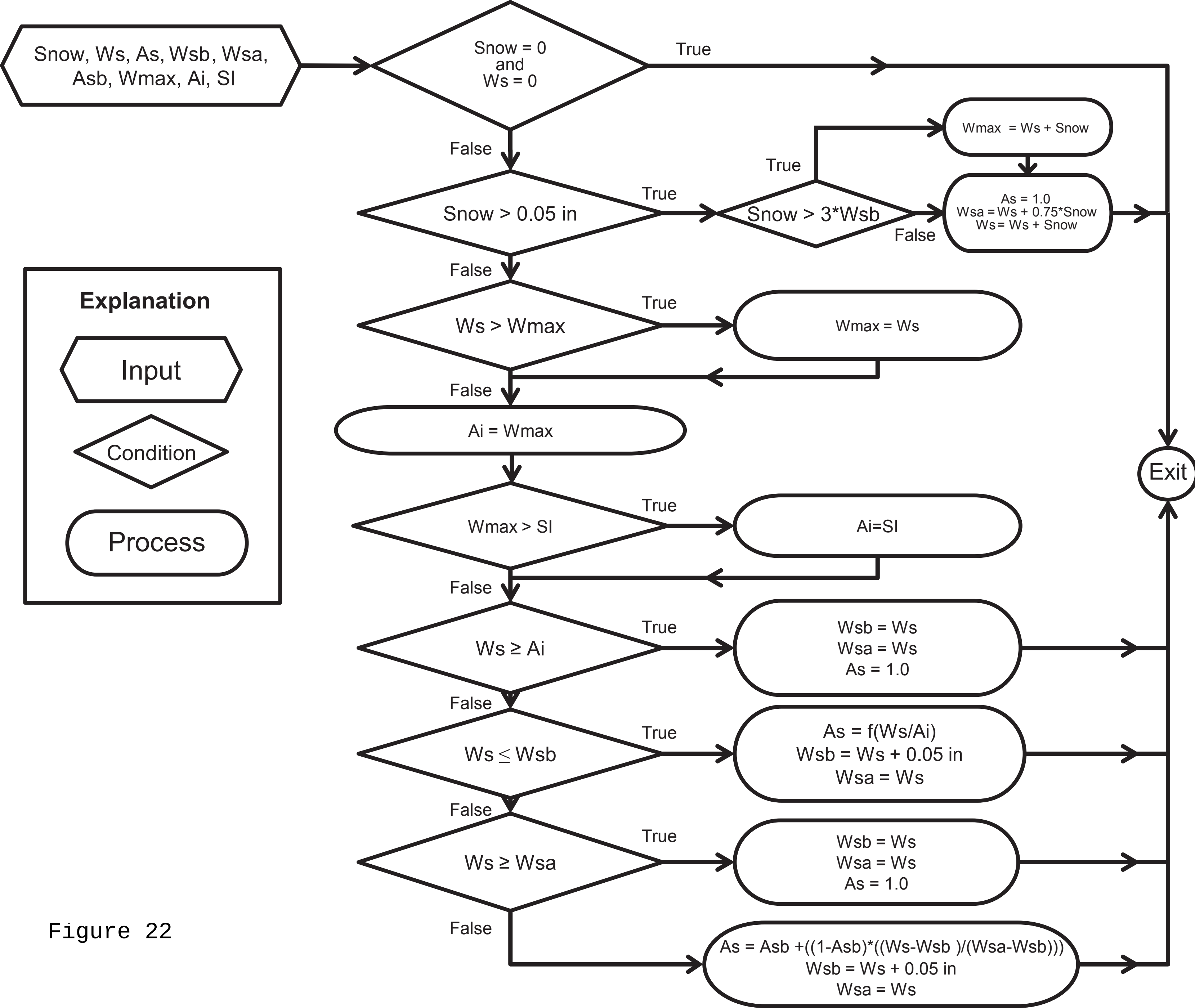
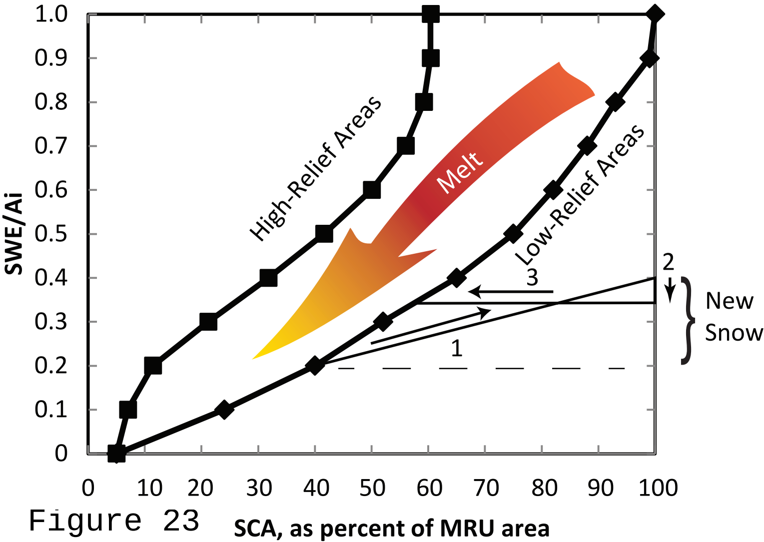

Snow, Ws, As, Wsb, Wsa, Asb, Wmax, Ai, SI
Snow = 0 and Ws = 0
True
False
Snow > 0.05 in
True
Snow > 3*Wsb
True
False
Wmax = Ws + Snow
As = 1.0
Wsa = Ws + 0.75*Snow
Ws = Ws + Snow
False
Ws > Wmax
True
Wmax = Ws
False
Ai = Wmax
Wmax > SI
True
Ai=SI
False
Ws ≥ Ai
True
Wsb = Ws
Wsa = Ws
As = 1.0
False
Ws ≤ Wsb
True
As = f(Ws/Ai)
Wsb = Ws + 0.05 in
Wsa = Ws
False
Ws ≥ Wsa
True
Wsb = Ws
Wsa = Ws
As = 1.0
False
As = Asb +((1-Asb)*((Ws-Wsb)/(Wsa-Wsb)))
Wsb = Ws + 0.05 in
Wsa = Ws
Exit
Explanation
Input
Condition
Process

Figure 22


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
SWE/Ai
High-Relief Areas
Melt
Low-Relief Areas
2
3
1
New
Snow
0
10
20
30
40
50
60
70
80
90
100
SCA, as percent of MRU area
Figure 23

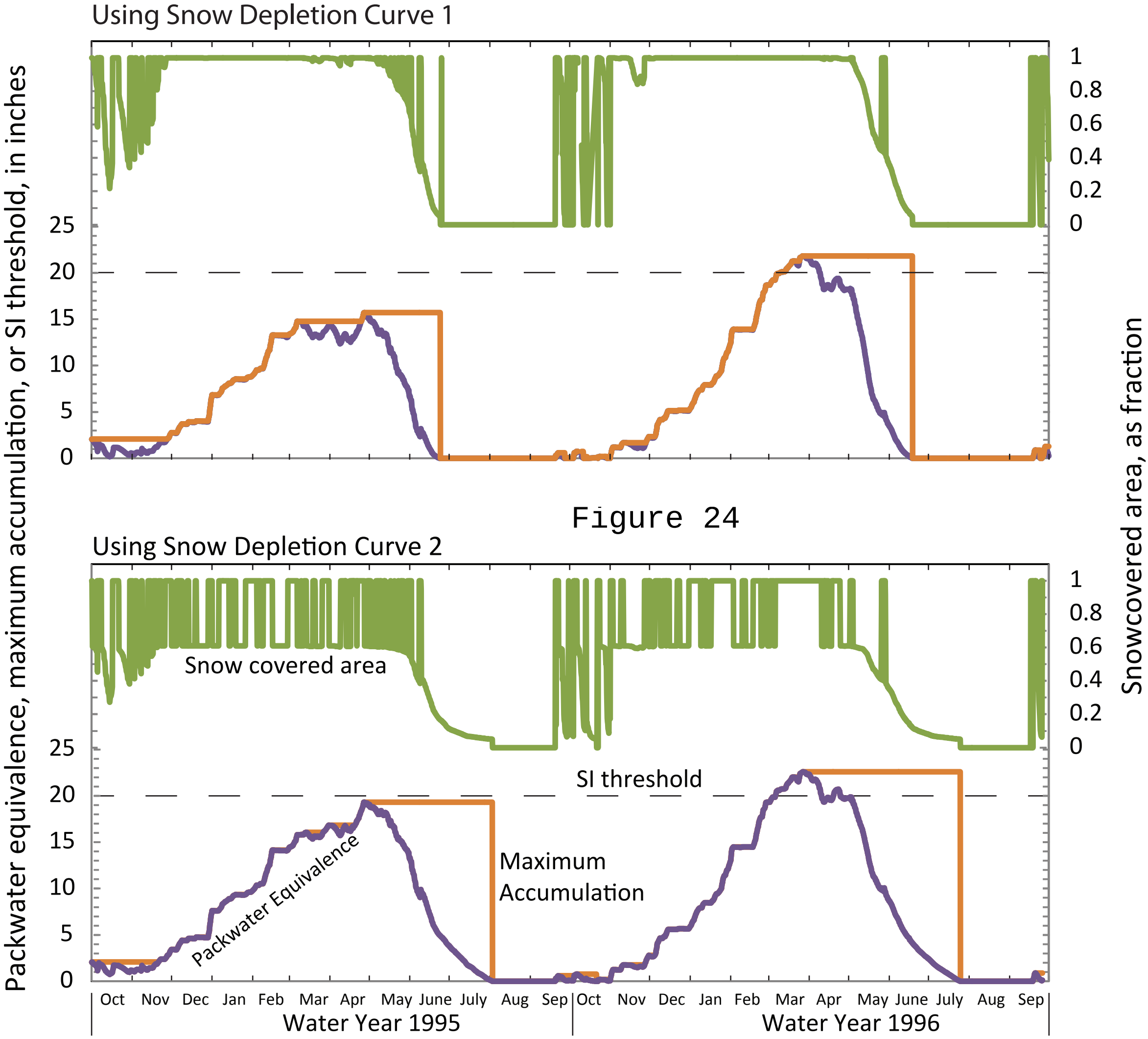
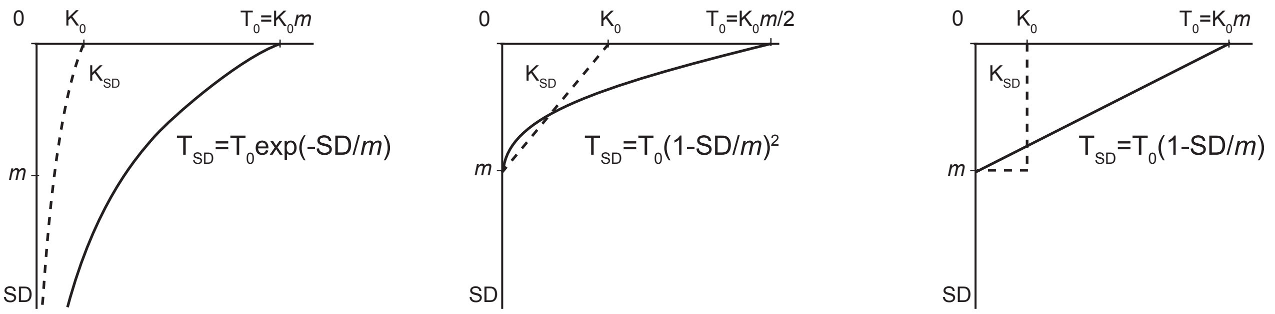

Using Snow Depletion Curve 1
Using Snow Depletion Curve 2
Snow covered area
SI threshold
Packwater Equivalence
Maximum
Accumulation
Packwater equivalence, maximum accumulation, or SI threshold, in inches
Snowcovered area, as fraction
0
5
10
15
20
25
0
0.2
0.4
0.6
0.8
1
Oct Nov Dec Jan Feb Mar Apr May June July Aug Sep
Water Year 1995
Water Year 1996

Figure 24

Types of transmissivity profiles. K_0, conductivity at saturation, in meters per hour; T_0, transmissivity at saturation [`T0`(nmru)], in square meters per hour; *m*, the recession parameter [`szm`(nmru)], in meters; SD, local saturation deficit [***sd***(nac,nmru)], in meters; K_{SD}, conductivity as a function of saturation deficit, in meters per hour; T_{SD} , transmissivity as a function of saturation deficit, in square meters per hour;

exponential	parabolic	linear
(`T_decay` = 0)	(`T_decay` = 1)	(`T_decay` = 2)



Transform of discharge, Q, for linear relation of base-flow recession with time. Q in m^3h^{-1} and time in h. The slope of the relation is α. ln, natural logarithm.

$1/Q$	$1/\sqrt{Q}$	$\ln(Q)$

Transformation of the Topographic Index ($a/\tan\beta$), TTI, for categorizing areas with similar hydrologic behavior. a, upslope area; $\tan\beta$, tangent of the slope.

$\ln(a/\tan\beta)$	$\sqrt{a/\tan\beta}$	$a/\tan\beta$

Relation of the slope of the transformed recession curve, α, the transmissivity at saturation, T_0, and the recession parameter, *m* , where A is MRU area in m^2, λ_l is the mean $\ln(a/\tan\beta)$, λ_r is the mean $\sqrt{a/\tan\beta}$, and λ_s is the mean $a/\tan\beta$. The selected lambda is the parameter `TL`(nmru).

$m=1/A\alpha$ and T_0 free	$\sqrt{T_0}/m=\alpha\sqrt{A}\lambda_r$	$T_0/m=\alpha\lambda_s$

Local saturation deficit, SD [***sd***(nac,nmru)]. Dunnian overland flow [***qofs***(nmru)] can occur where SD < 0, where ST is the maximum value of the TTI for a given area of hydrologic similarity [`st`(nac,nmru)] and S is the mean saturation deficit.[***sbar***(nmru)]

$SD=S+m(\lambda_l-ST)$	$SD=m-ST((m-S)/\lambda_r)$	$SD=m-ST((m-S)/\lambda_s)$

Base flow

$Q_b = Q_0\exp(-S/m)$	$Q_b = Q_0(1-(S/m))^2$	$Q_b = Q_0(1-(S/m))$

where Qb is the baseflow [***qb***(nmru)], in meters, and Q_0 is the discharge when the mean relative deficit (S/m) is equal to zero.

$Q_0 = AT_0\exp(-\lambda_l)$	$Q_0 = AT_0\lambda_r^{-2}$	$Q_0 = AT_0\lambda_s^{-1}$

Figure 25

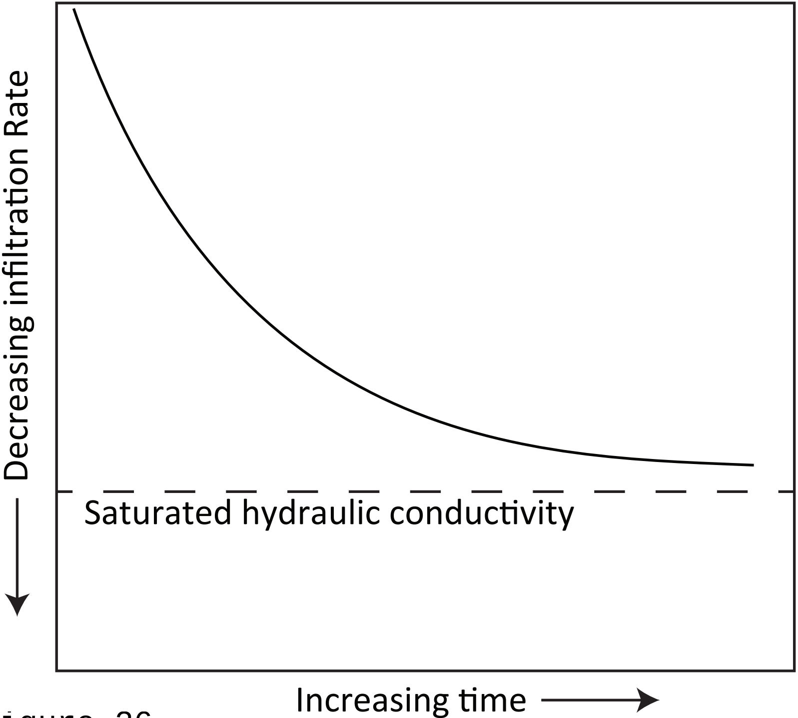

Decreasing infiltration Rate
Saturated hydraulic conductivity
Increasing time

Figure 26

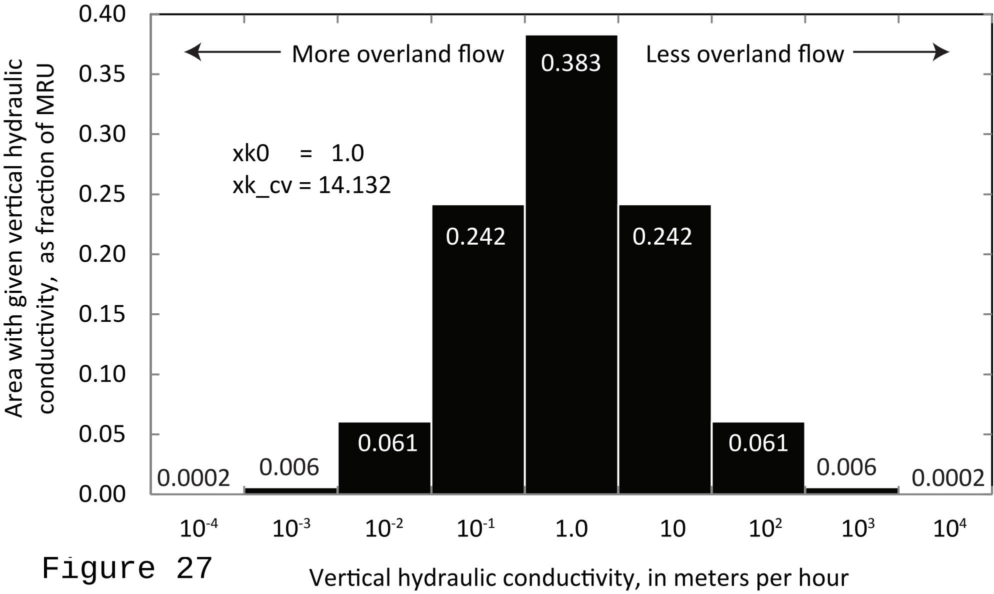

0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Area with given vertical hydraulic conductivity, as fraction of MRU
More overland flow
Less overland flow
xk0 = 1.0
xk_cv = 14.132
0.0002
0.006
0.061
0.242
0.383
0.242
0.061
0.006
0.0002
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1.0
10
10^{2}
10^{3}
10^{4}
Vertical hydraulic conductivity, in meters per hour

Figure 27

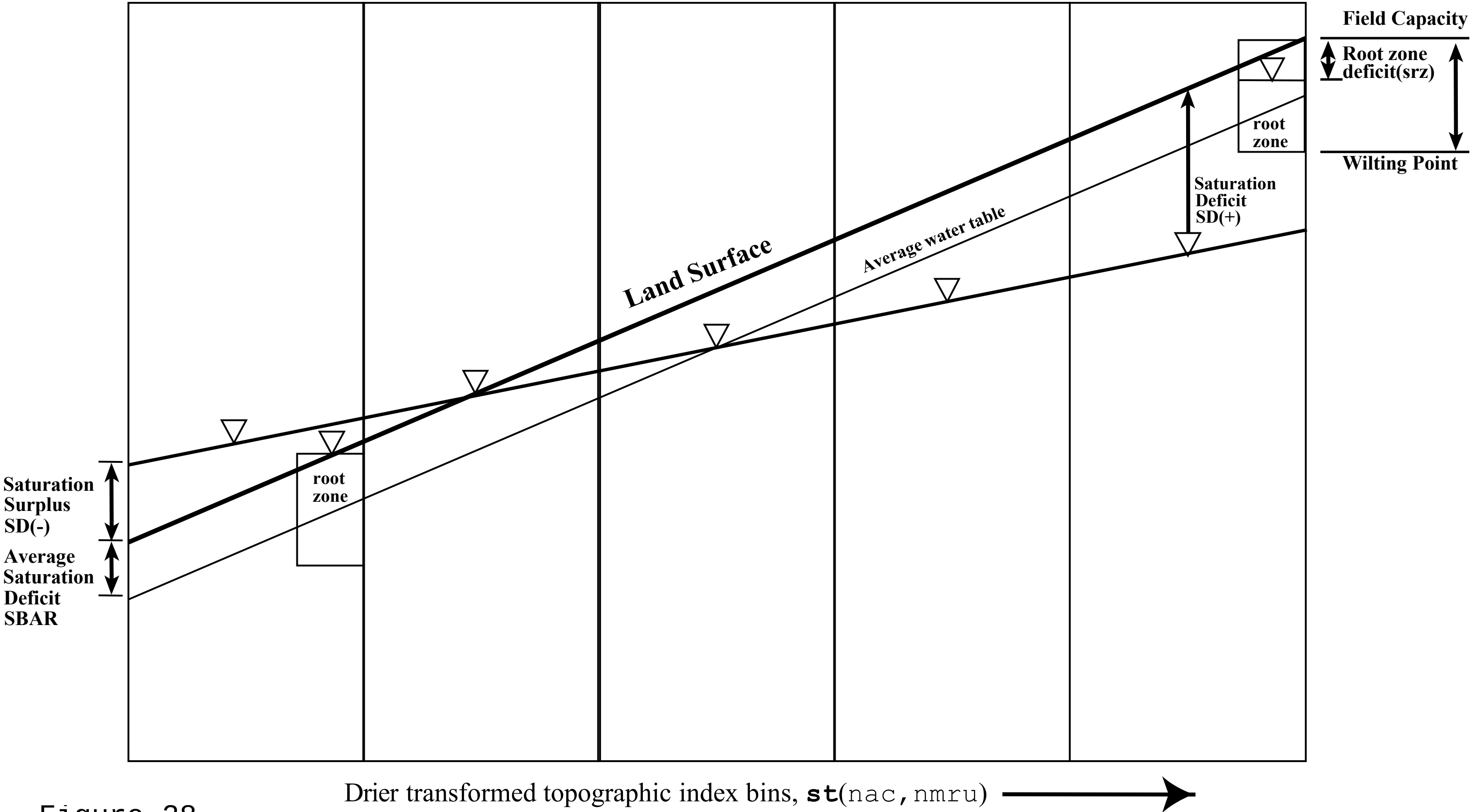

Field Capacity
Root zone
deficit(srz)
root
zone
Wilting Point
Saturation
Deficit
SD(+)
Average water table
Land Surface
Saturation
Surplus
SD(-)
root
zone
Average
Saturation
Deficit
SBAR
Drier transformed topographic index bins, st(nac, nmru)

Figure 28

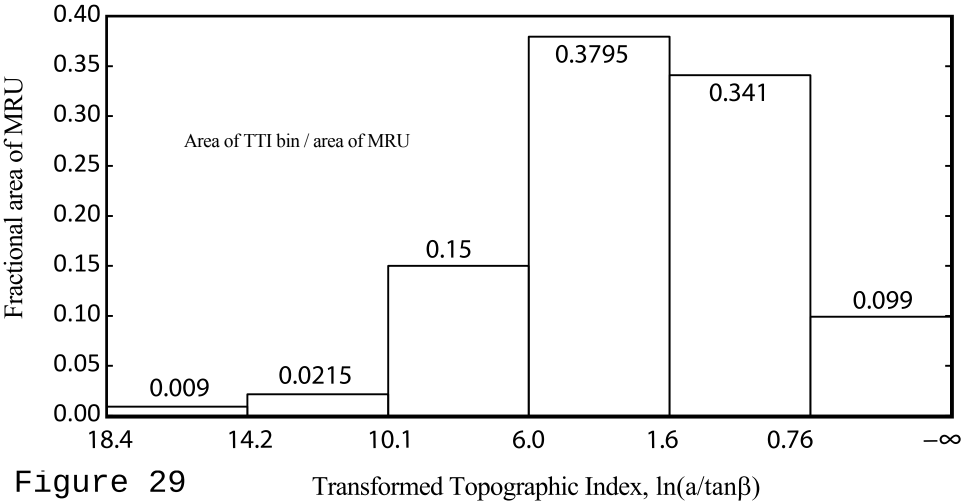

0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Fractional area of MRU
Area of TTI bin / area of MRU
0.3795
0.341
0.15
0.099
0.0215
0.009
18.4
14.2
10.1
6.0
1.6
0.76
−∞
Transformed Topographic Index, ln(a/tanβ)

Figure 29

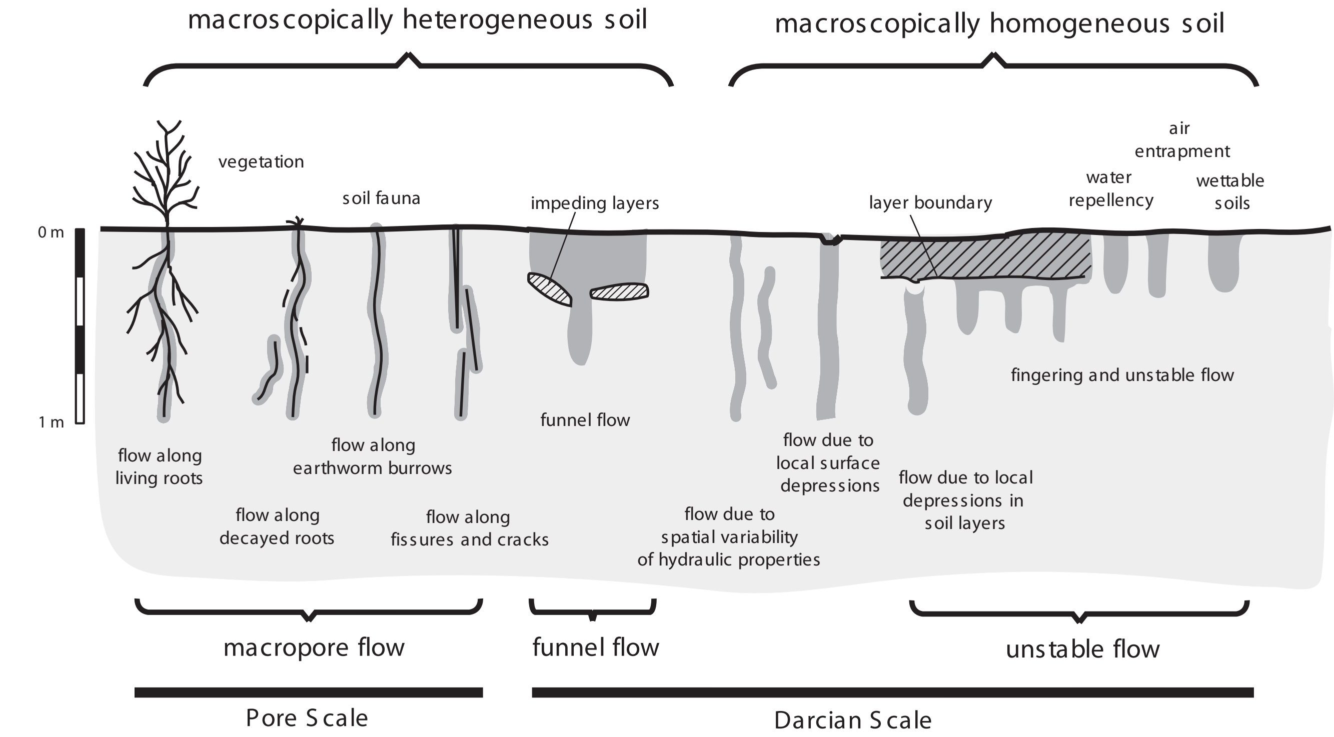
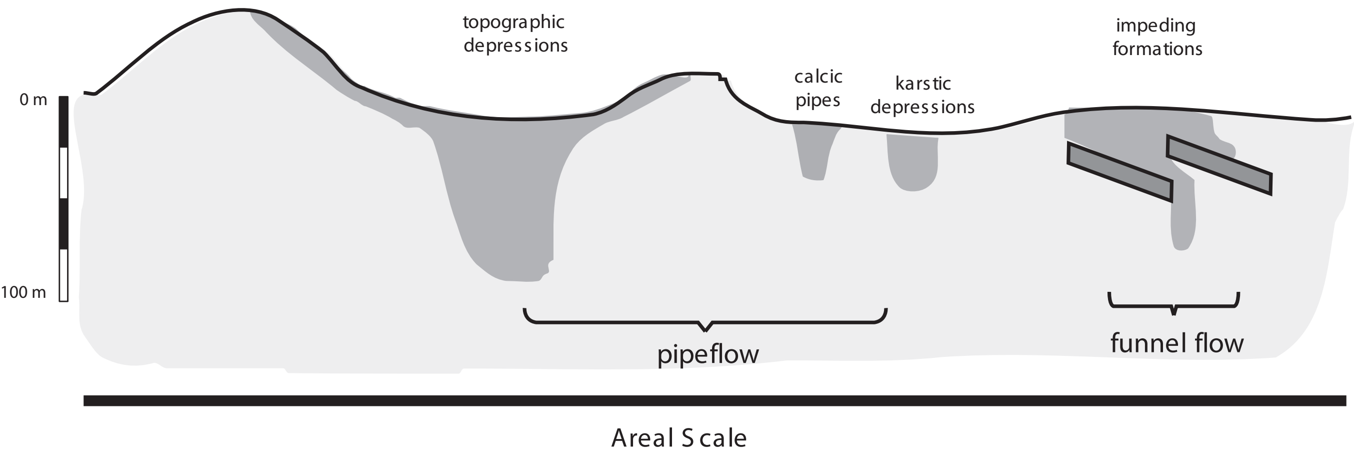
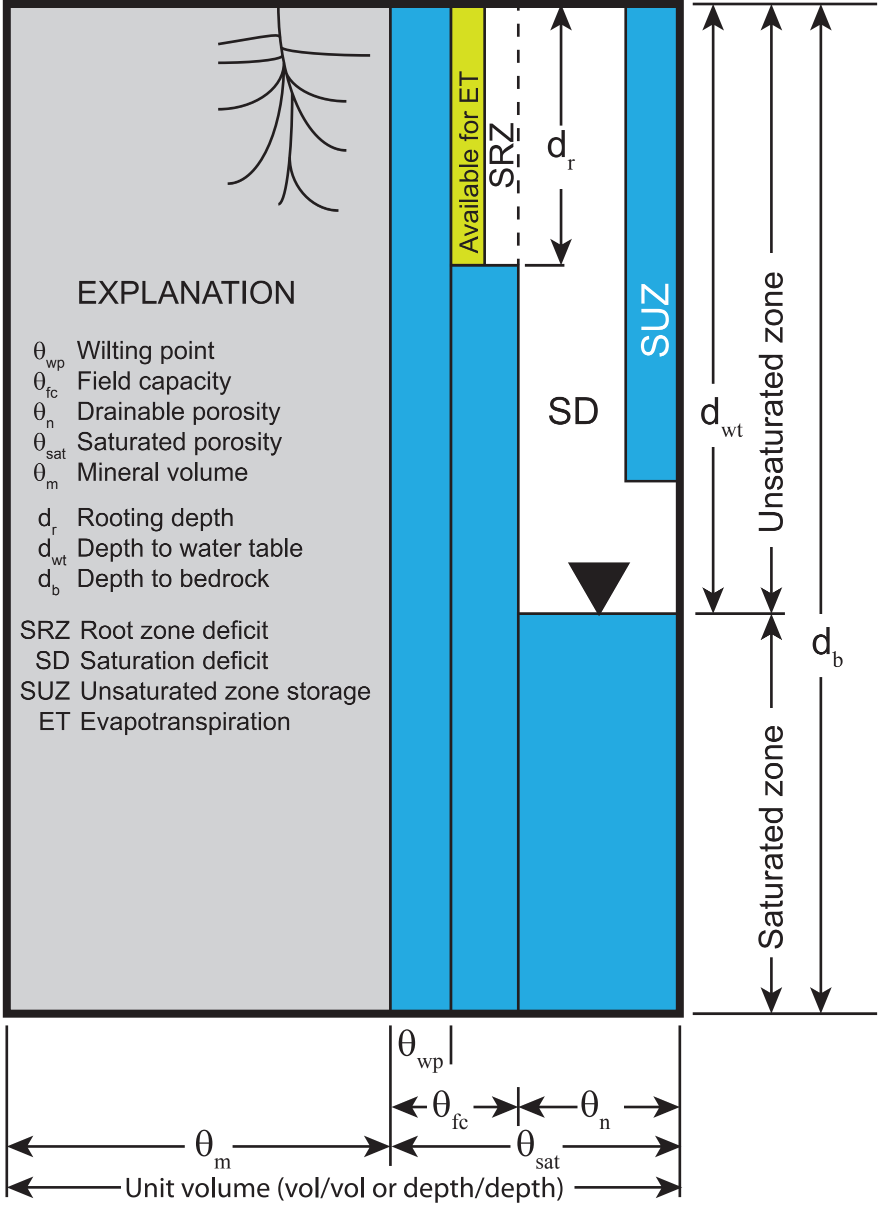

macroscopically heterogeneous soil
macroscopically homogeneous soil
vegetation
soil fauna
impeding layers
layer boundary
water
repellency
air
entrapment
wettable
soils
0 m
1 m
fingering and unstable flow
funnel flow
flow along
living roots
flow along
earthworm burrows
flow along
decayed roots
flow along
fissures and cracks
flow due to
local surface
depressions
flow due to local
depressions in
soil layers
flow due to
spatial variability
of hydraulic properties
macropore flow
funnel flow
unstable flow
Pore Scale
Darcian Scale

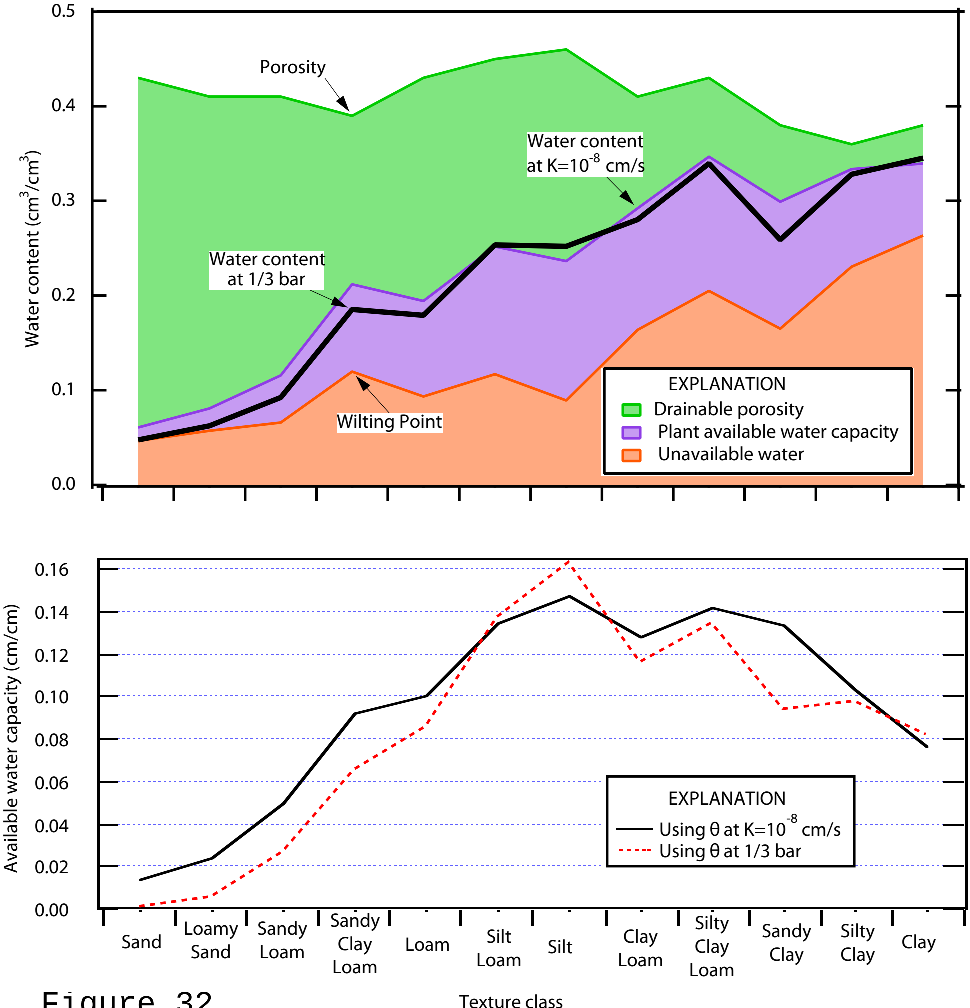
Figure 30


topographic
depressions
calcic
pipes
karstic
depressions
impeding
formations
0 m
100 m
pipeflow
funnel flow
Areal Scale



Available for ET
SRZ
d_r
SUZ
SD
d_{wt}
Unsaturated zone
d_b
Saturated zone
EXPLANATION
θ_{wp} Wilting point
θ_{fc} Field capacity
θ_n Drainable porosity
θ_{sat} Saturated porosity
θ_m Mineral volume
d_r Rooting depth
d_{wt} Depth to water table
d_b Depth to bedrock
SRZ Root zone deficit
SD Saturation deficit
SUZ Unsaturated zone storage
ET Evapotranspiration
θ_{wp}
θ_{fc}
θ_n
θ_m
θ_{sat}
Unit volume (vol/vol or depth/depth)

Figure 31



Porosity
Water content at K=10^-8 cm/s
Water content at 1/3 bar
Wilting Point
EXPLANATION
Drainable porosity
Plant available water capacity
Unavailable water
Water content (cm^3/cm^3)
0.0
0.1
0.2
0.3
0.4
0.5
Available water capacity (cm/cm)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
EXPLANATION
Using θ at K=10^-8 cm/s
Using θ at 1/3 bar
Sand
Loamy Sand
Sandy Loam
Sandy Clay Loam
Loam
Silt Loam
Silt
Clay Loam
Silty Clay Loam
Sandy Clay
Silty Clay
Clay
Texture class

Figure 32

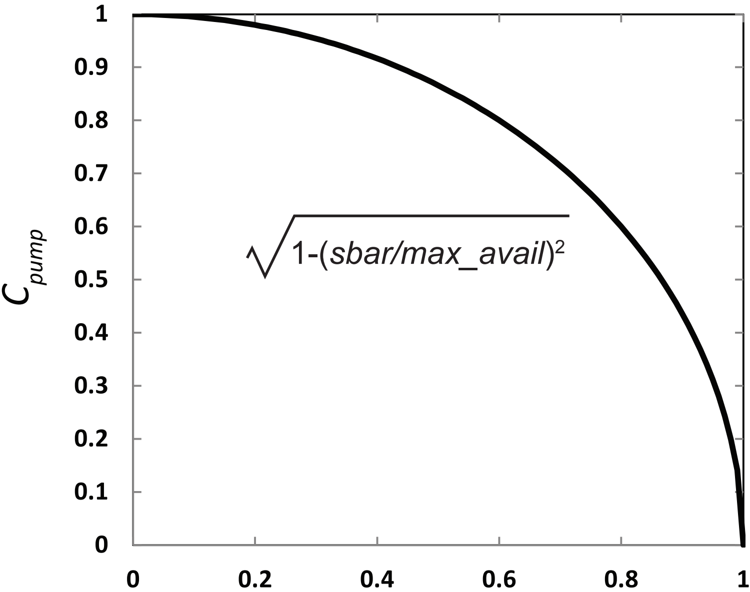
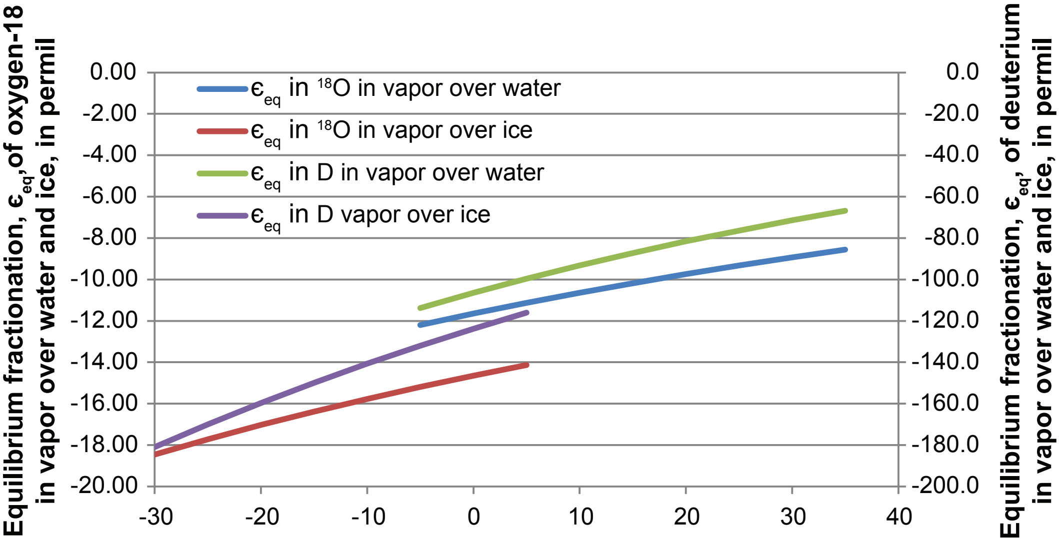

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
C_{pump}
$\sqrt{1-(sbar/max\_avail)^2}$
0
0.2
0.4
0.6
0.8
1
sbar/max_avail

Figure 33



Equilibrium fractionation, ϵeq, of oxygen-18 in vapor over water and ice, in permil
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
ϵeq in 18O in vapor over water
ϵeq in 18O in vapor over ice
ϵeq in D in vapor over water
ϵeq in D vapor over ice
-30
-20
-10
0
10
20
30
40
Temperature, in degrees Celsius
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
-200.0
Equilibrium fractionation, ϵeq, of deuterium in vapor over water and ice, in permil

Figure 34

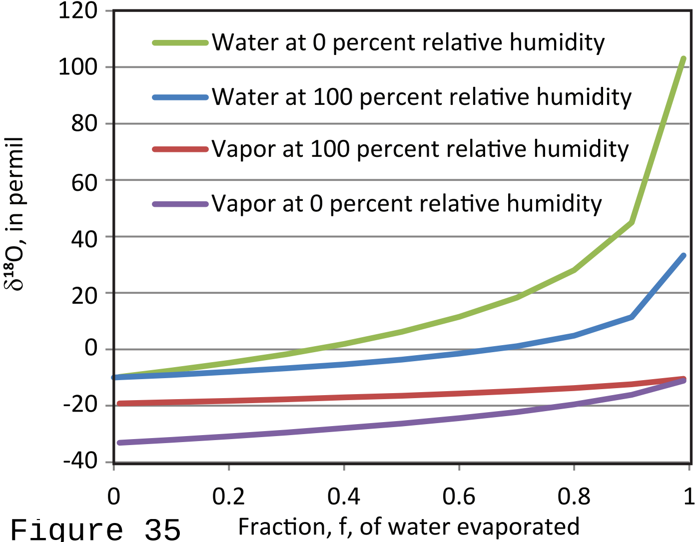
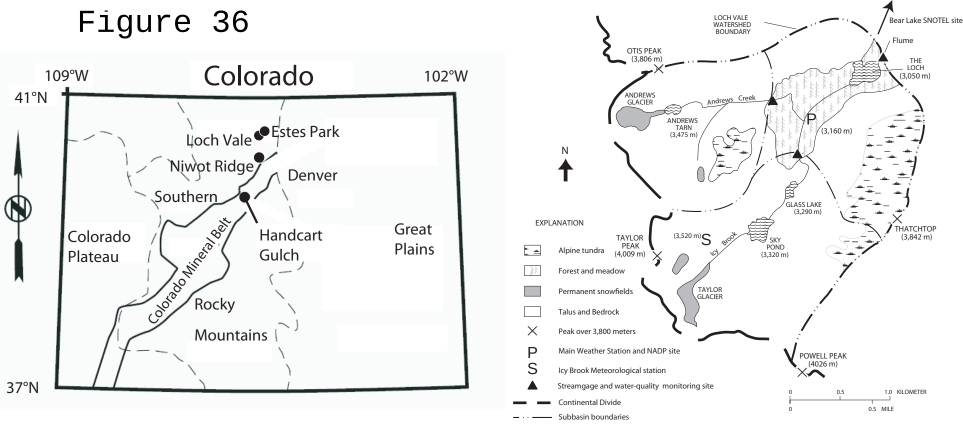
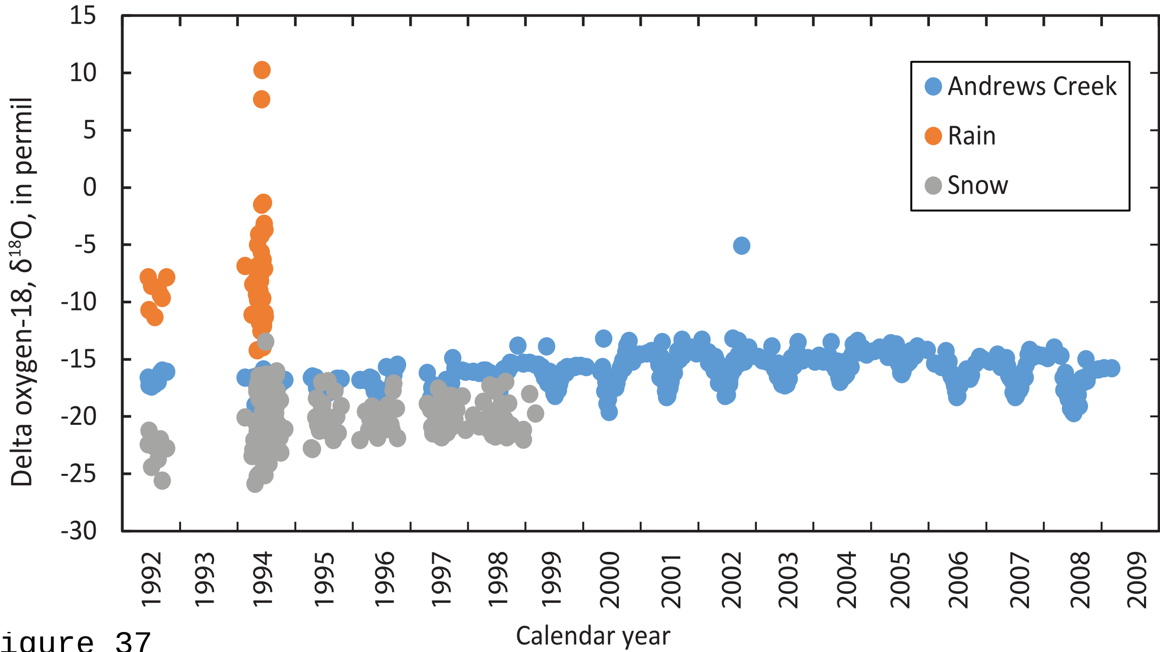

Water at 0 percent relative humidity
Water at 100 percent relative humidity
Vapor at 100 percent relative humidity
Vapor at 0 percent relative humidity
δ¹⁸O, in permil
120
100
80
60
40
20
0
-20
-40
0
0.2
0.4
0.6
0.8
1
Fraction, f, of water evaporated

Figure 35

Figure 36


Colorado
109°W
102°W
41°N
37°N
Loch Vale
Estes Park
Niwot Ridge
Denver
Southern
Colorado Plateau
Colorado Mineral Belt
Handcart Gulch
Great Plains
Rocky Mountains
N
LOCH VALE WATERSHED BOUNDARY
Bear Lake SNOTEL site
Flume
OTIS PEAK (3,806 m)
THE LOCH (3,050 m)
ANDREWS GLACIER
Andrews Creek
ANDREWS TARN (3,475 m)
P
(3,160 m)
GLASS LAKE (3,290 m)
THATCHTOP (3,842 m)
TAYLOR PEAK (4,009 m)
(3,520 m) S
Icy Brook
SKY POND (3,320 m)
TAYLOR GLACIER
POWELL PEAK (4026 m)
EXPLANATION
Alpine tundra
Forest and meadow
Permanent snowfields
Talus and Bedrock
Peak over 3,800 meters
Main Weather Station and NADP site
Icy Brook Meteorological station
Streamgage and water-quality monitoring site
Continental Divide
Subbasin boundaries
0 0.5 1.0 KILOMETER
0 0.5 MILE



Andrews Creek
Rain
Snow
Delta oxygen-18, $\delta^{18}O$, in permil
15
10
5
0
-5
-10
-15
-20
-25
-30
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Calendar year

Figure 37

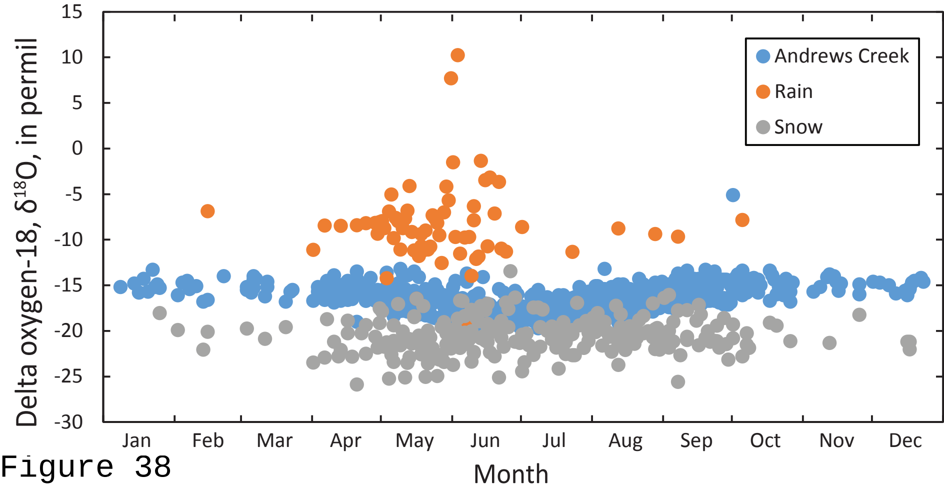
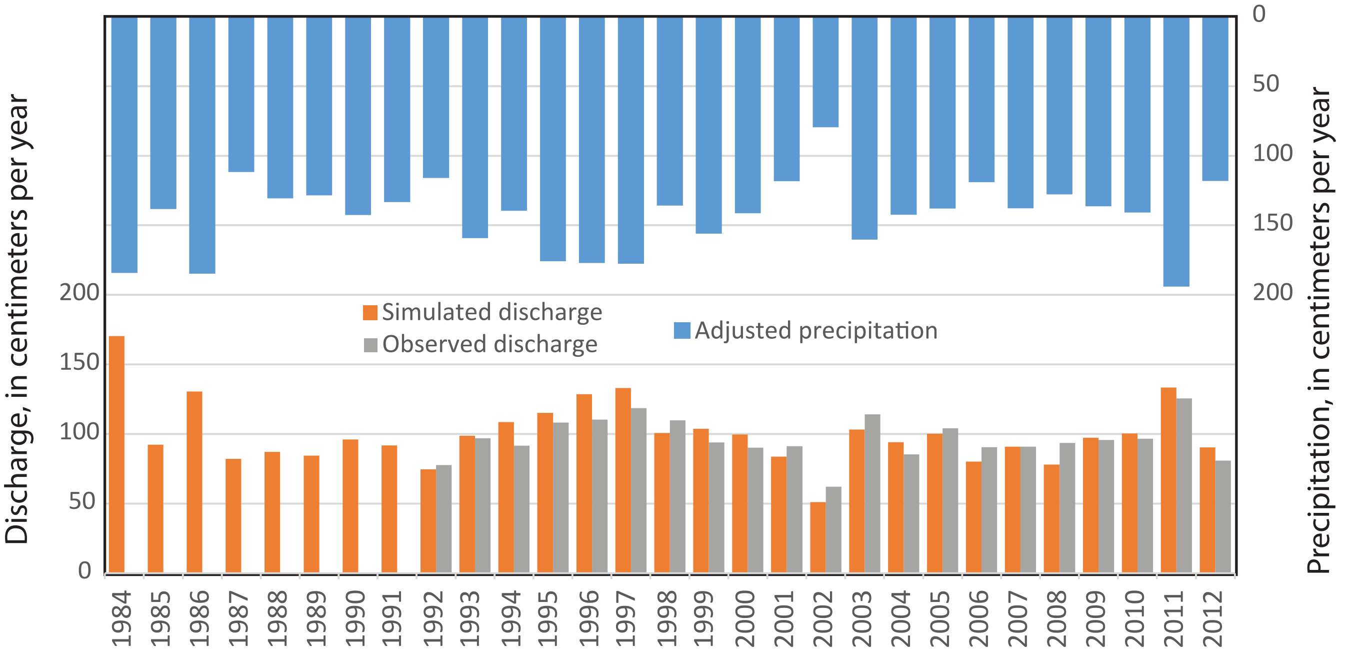
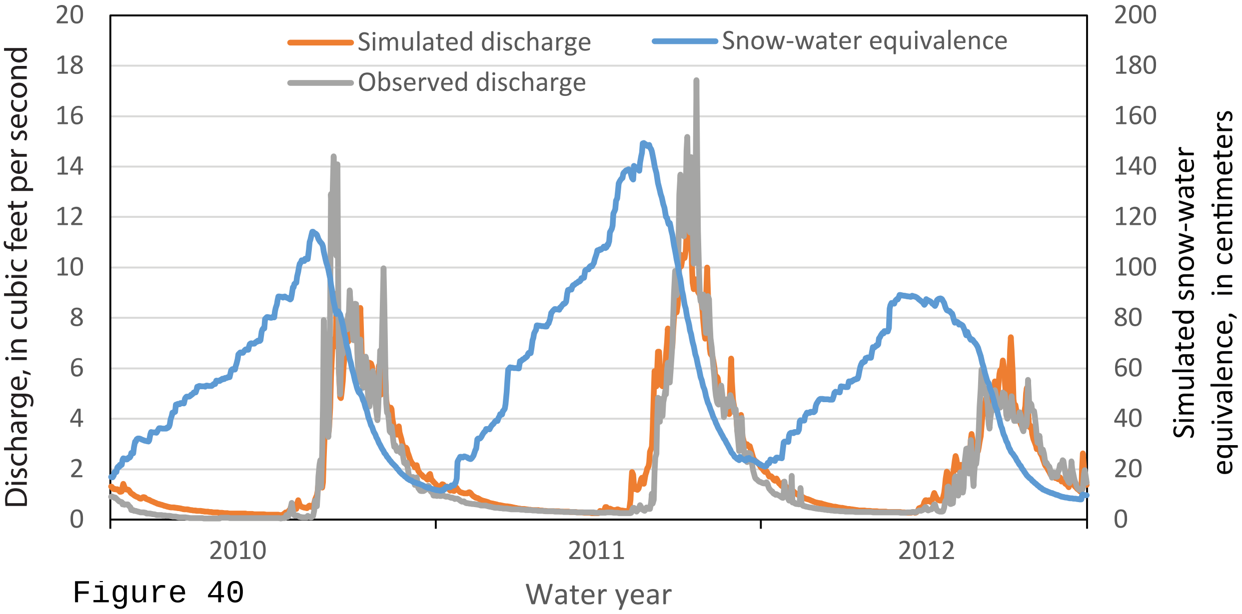

Delta oxygen-18, δ18O, in permil
15
10
5
0
-5
-10
-15
-20
-25
-30
Andrews Creek
Rain
Snow
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 38



Simulated discharge
Observed discharge
Adjusted precipitation
Discharge, in centimeters per year
Precipitation, in centimeters per year
0
50
100
150
200
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Water year

Figure 39



Simulated discharge
Snow-water equivalence
Observed discharge
Discharge, in cubic feet per second
Simulated snow-water equivalence, in centimeters
0
2
4
6
8
10
12
14
16
18
20
0
20
40
60
80
100
120
140
160
180
200
2010
2011
2012
Water year

Figure 40

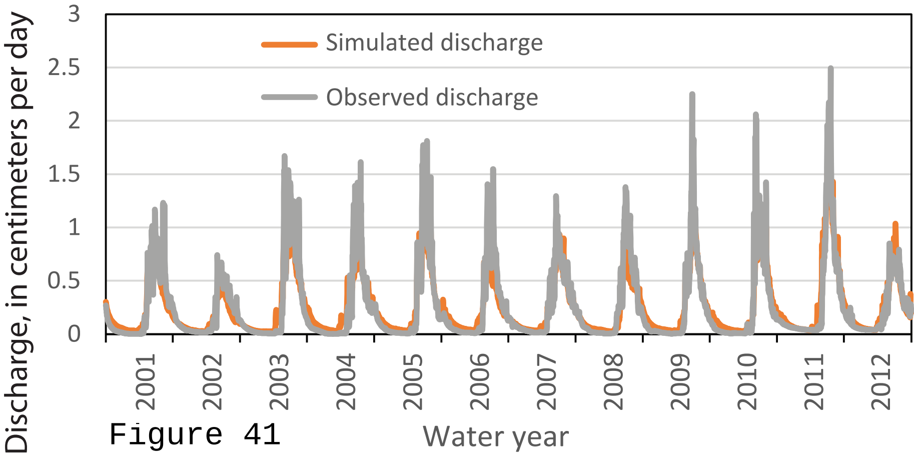

Simulated discharge
Observed discharge
Discharge, in centimeters per day
3
2.5
2
1.5
1
0.5
0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Water year

Figure 41

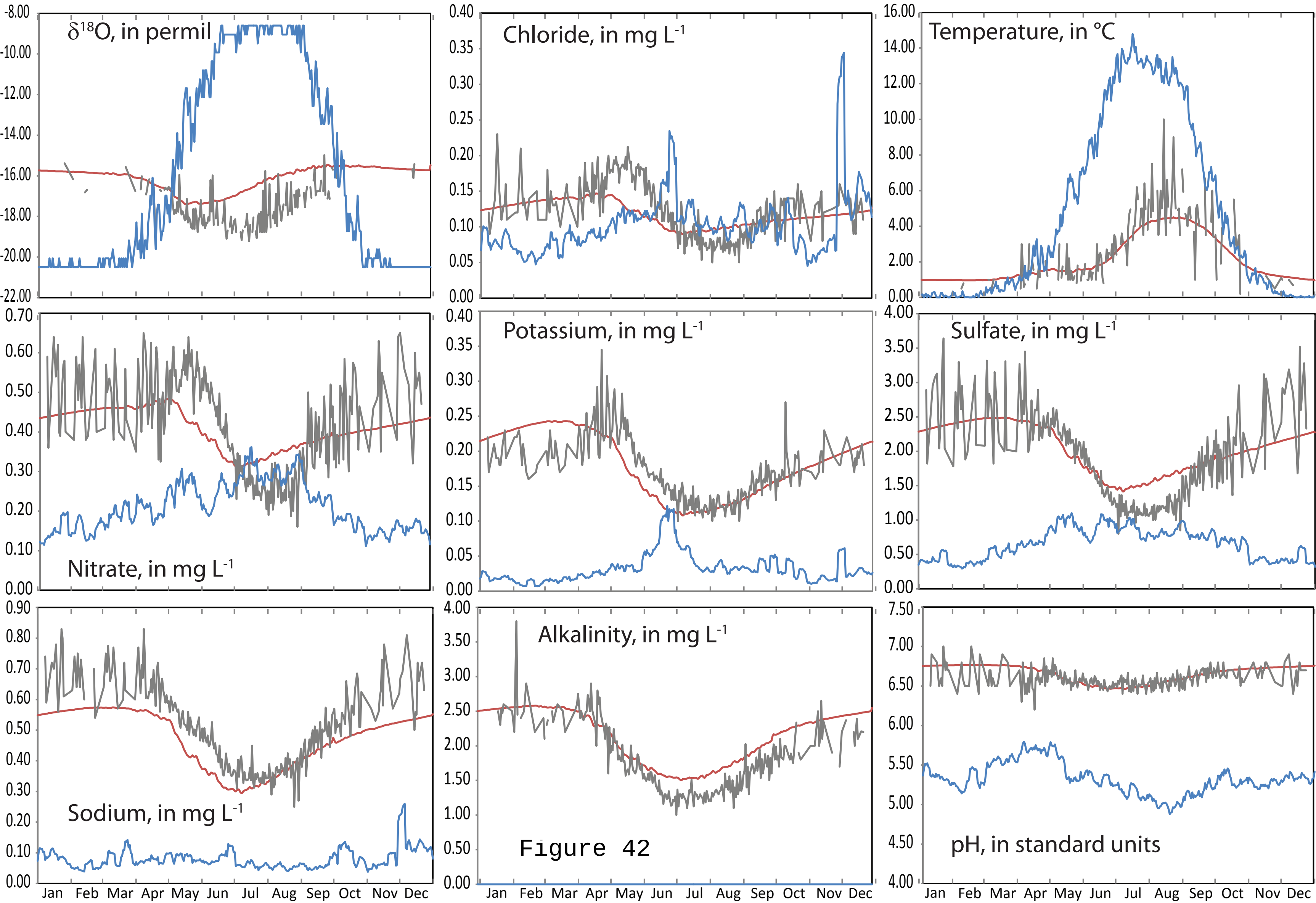
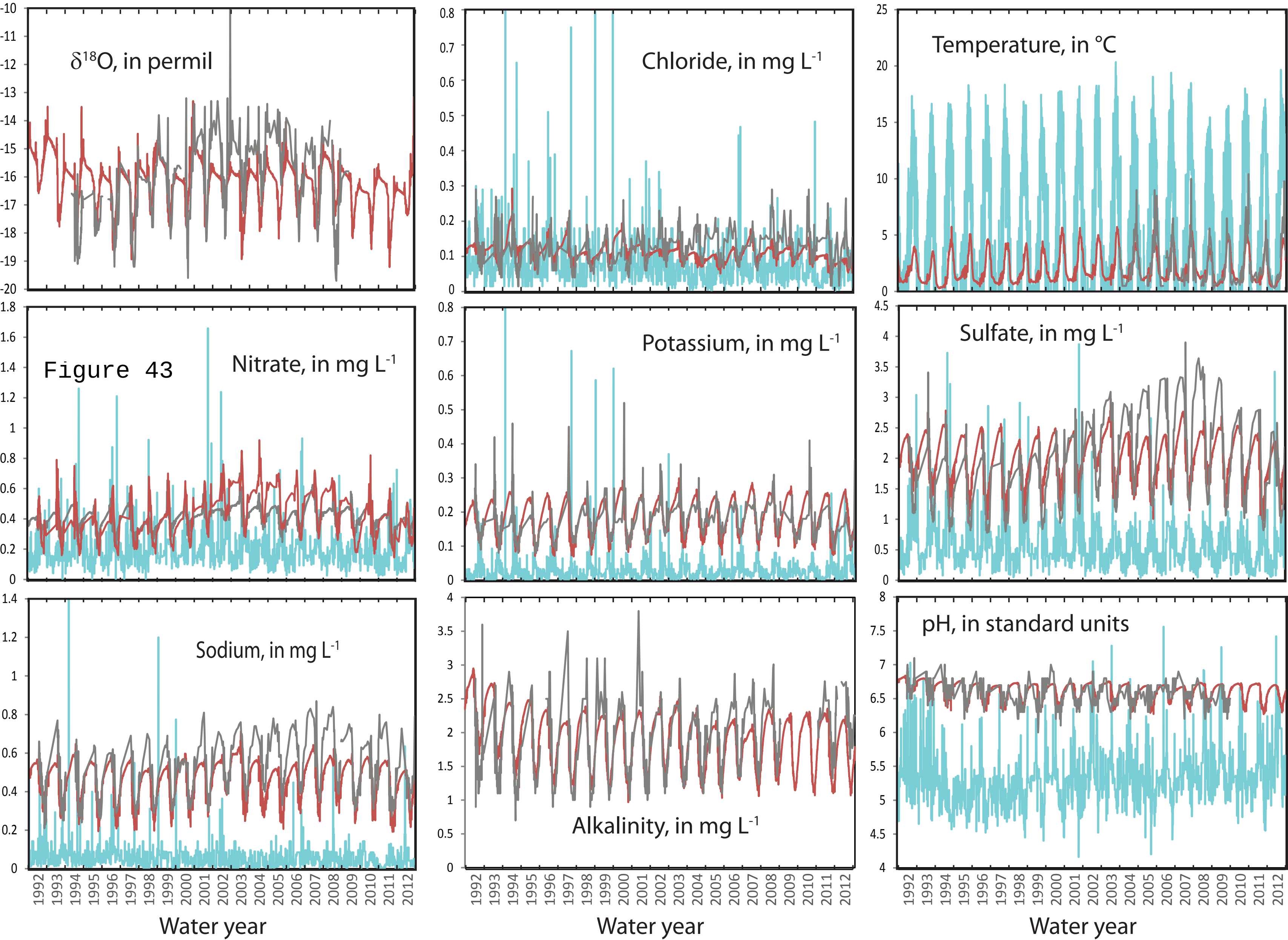

δ18O, in permil
Chloride, in mg L-1
Temperature, in °C
Nitrate, in mg L-1
Potassium, in mg L-1
Sulfate, in mg L-1
Sodium, in mg L-1
Alkalinity, in mg L-1
pH, in standard units
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Figure 42


δ18O, in permil
Chloride, in mg L-1
Temperature, in °C
Figure 43
Nitrate, in mg L-1
Potassium, in mg L-1
Sulfate, in mg L-1
Sodium, in mg L-1
Alkalinity, in mg L-1
pH, in standard units
Water year
Water year
Water year

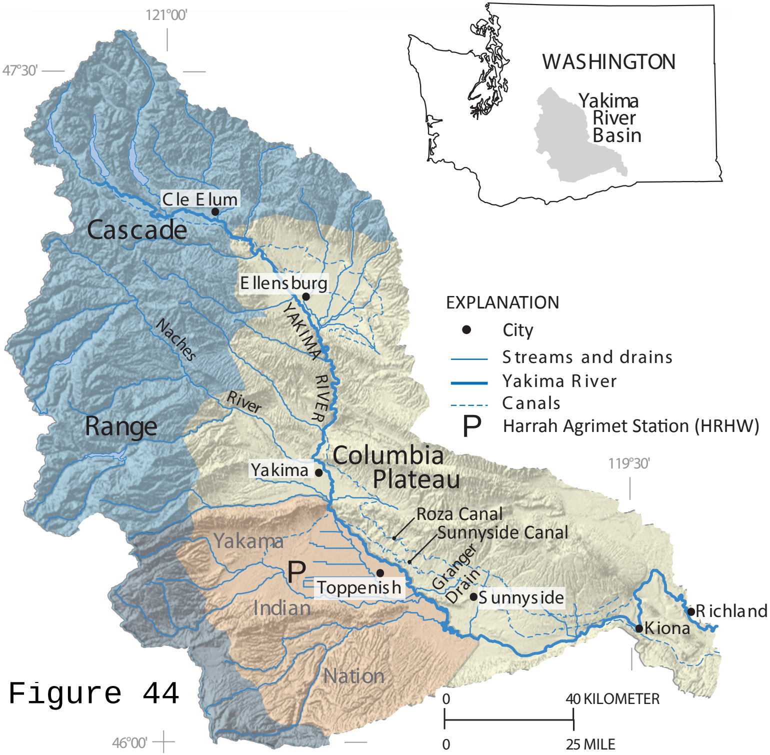
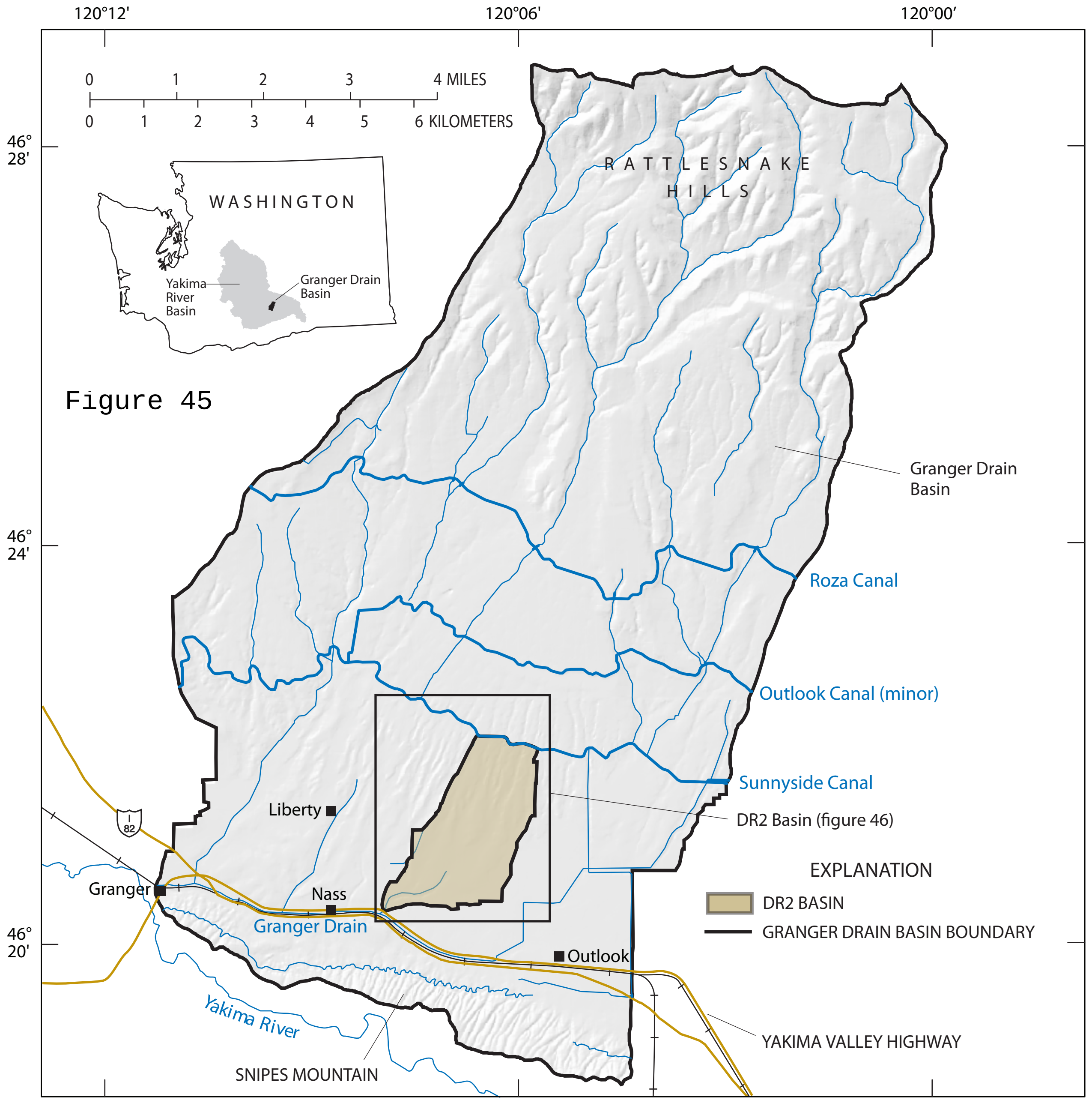

121°00'
47°30'
WASHINGTON
Yakima River Basin
Cle Elum
Cascade
Ellensburg
YAKIMA RIVER
Naches River
Range
EXPLANATION
City
Streams and drains
Yakima River
Canals
P Harrah Agrimet Station (HRHW)
Columbia Plateau
Yakima
119°30'
Roza Canal
Sunnyside Canal
Granger Drain
Yakama Indian Nation
P
Toppenish
Sunnyside
Richland
Kiona
0 40 KILOMETER
0 25 MILE
46°00'

Figure 44



Albers projection, False_Easting: 0.00000000, False_Northing: 0.00000000, Central_Meridian: -119.00000000, Standard_Parallel_1: 29.50000000, Standard_Parallel_2: 45.50000000, Latitude_Of_Origin: 23.00000000, Linear Unit: Meter.
Shaded-relief base from 1:100,000-scale Digital Elevation Model based on the North American Datum of 1983.

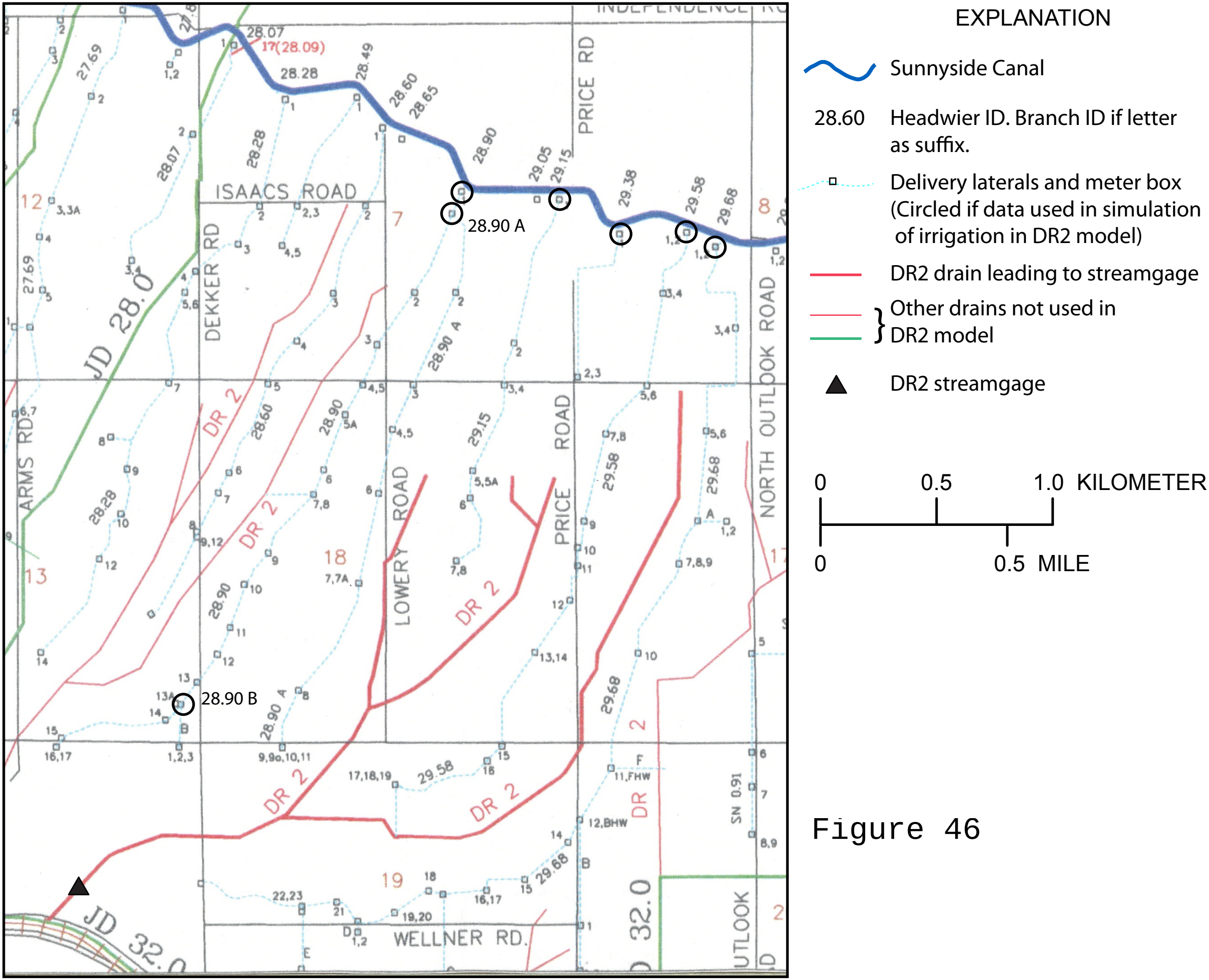
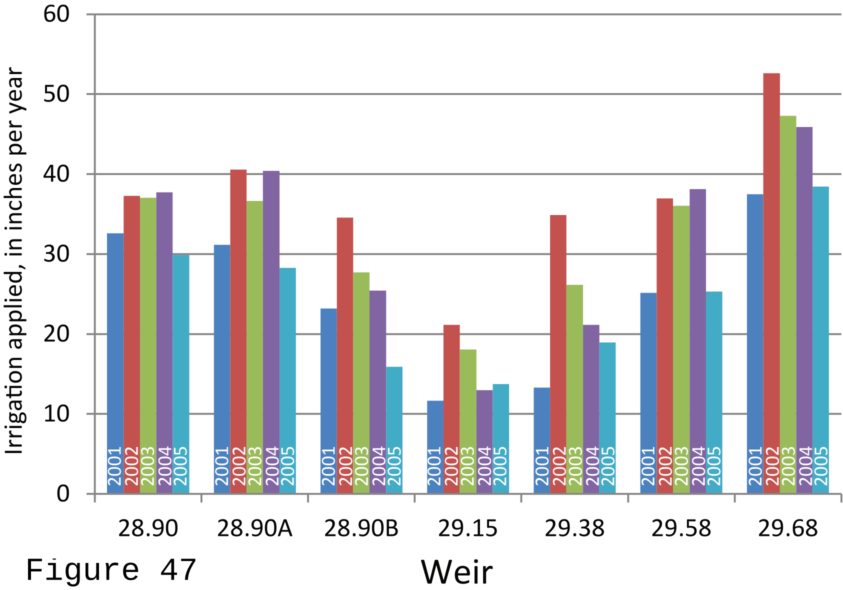

EXPLANATION
Sunnyside Canal
28.60 Headwier ID. Branch ID if letter as suffix.
Delivery laterals and meter box (Circled if data used in simulation of irrigation in DR2 model)
DR2 drain leading to streamgage
Other drains not used in DR2 model
DR2 streamgage
0 0.5 1.0 KILOMETER
0 0.5 MILE
ISAACS ROAD
DEKKER RD
PRICE RD
PRICE ROAD
LOWERY ROAD
NORTH OUTLOOK ROAD
ARMS RD
WELLNER RD.
JD 28.0
JD 32.0
DR 2
28.90 A
28.90 B

Figure 46



60
50
40
30
20
10
0
Irrigation applied, in inches per year
2001
2002
2003
2004
2005
28.90
28.90A
28.90B
29.15
29.38
29.58
29.68
Weir

Figure 47

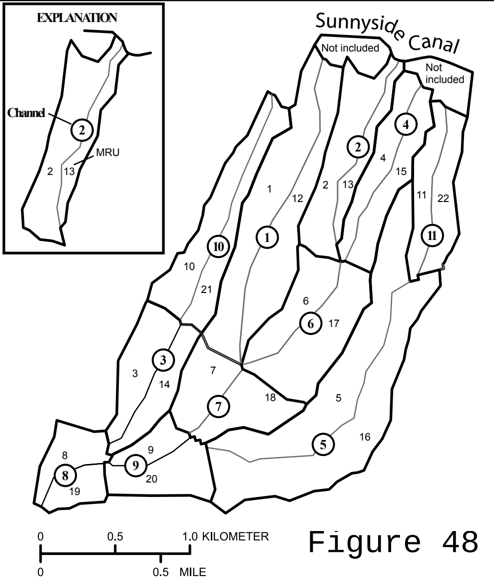

EXPLANATION
Channel
2
MRU
2
13
Sunnyside Canal
Not included
Not included
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
0.5
1.0 KILOMETER
0
0.5
MILE

Figure 48

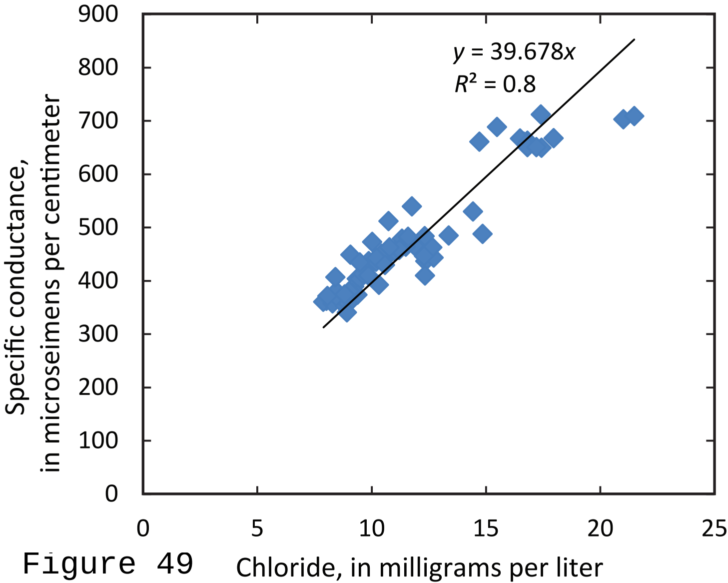
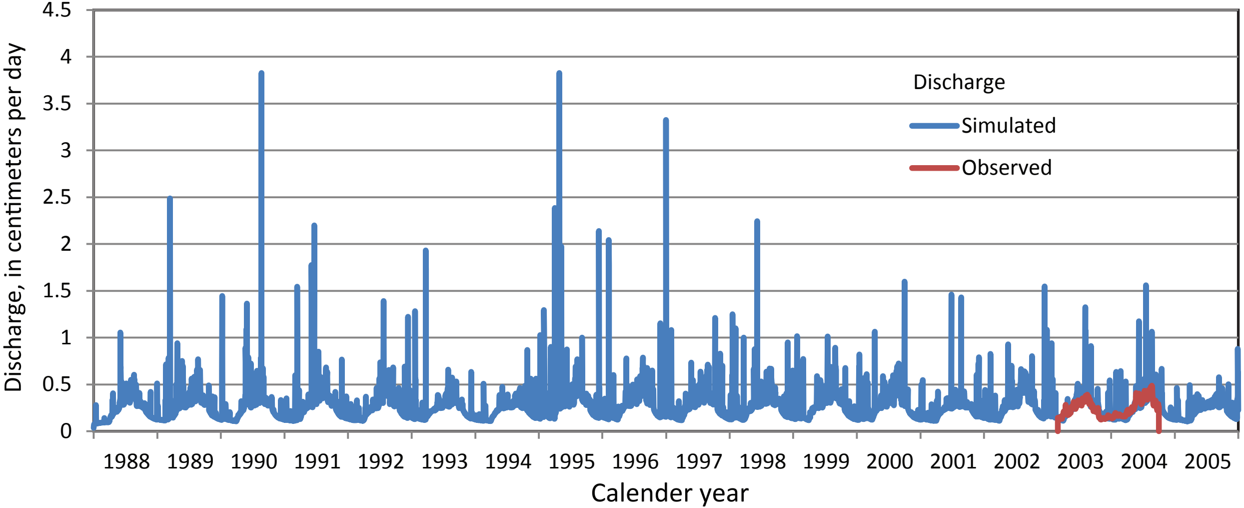
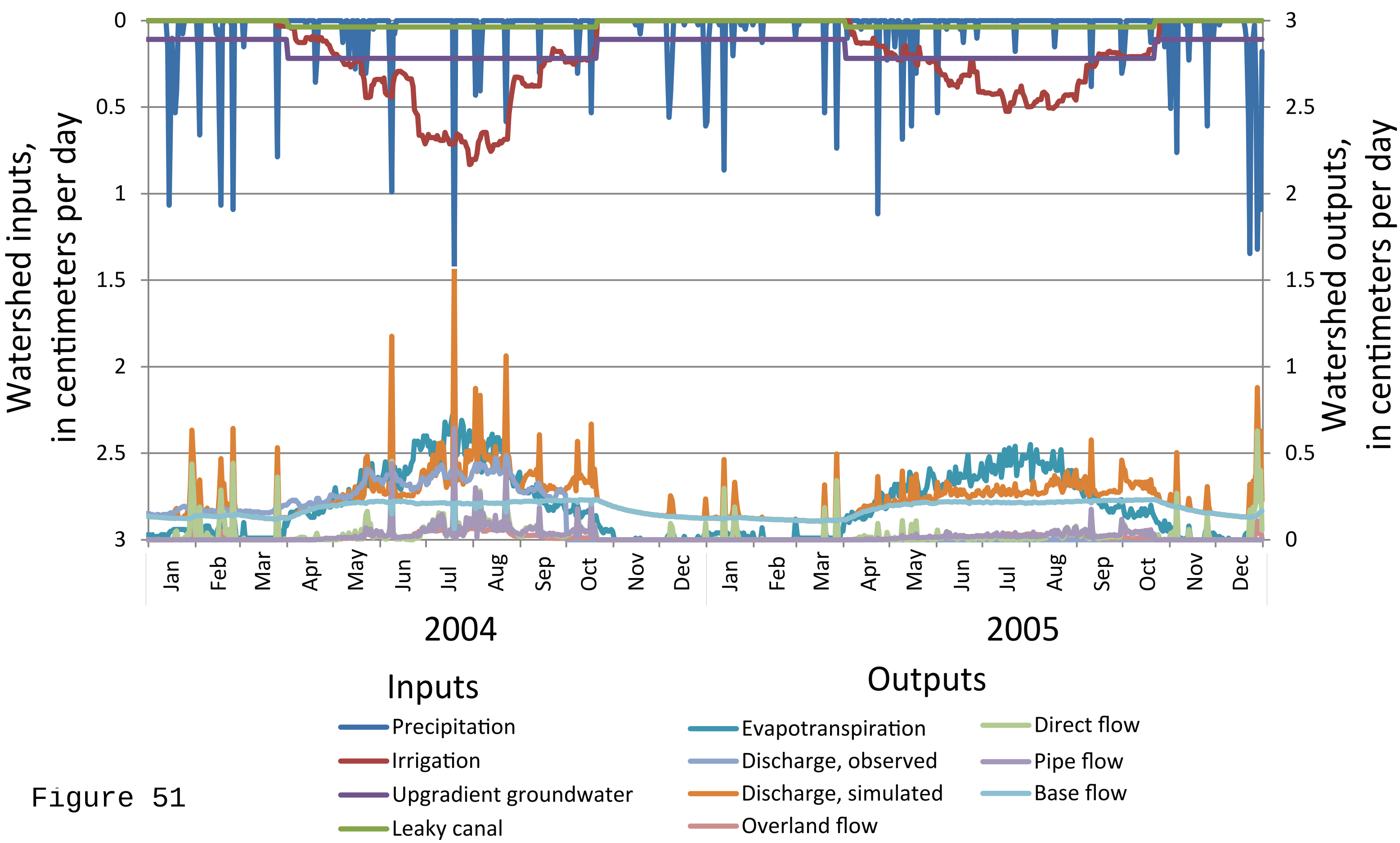

y = 39.678x
R² = 0.8
Specific conductance, in microseimens per centimeter
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
Chloride, in milligrams per liter

Figure 49



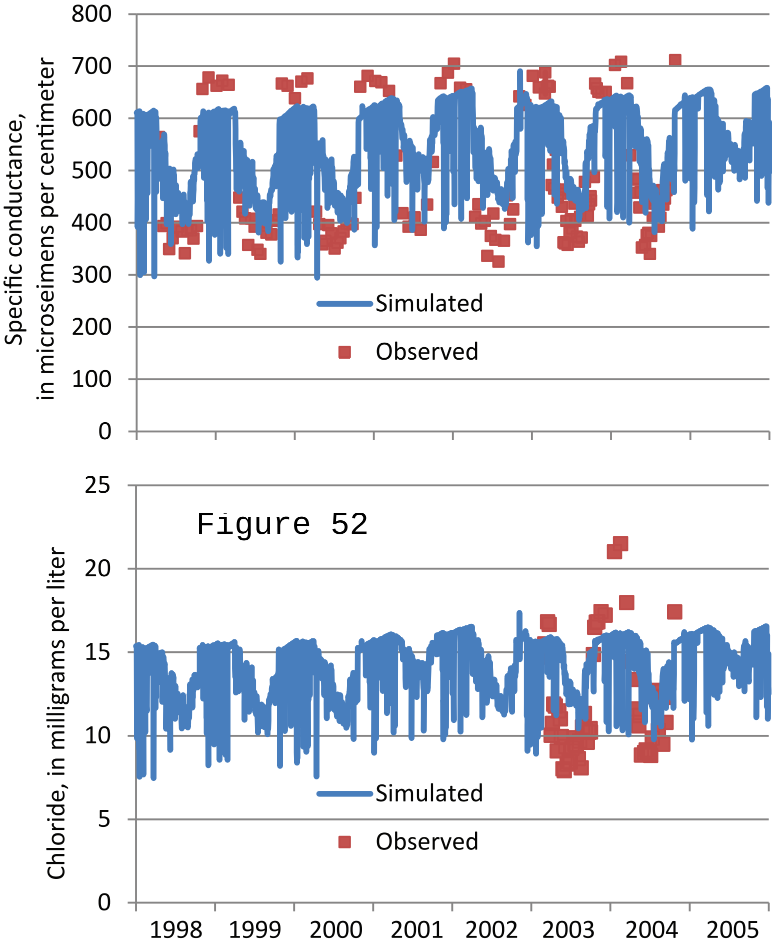
Discharge, in centimeters per day
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Discharge
Simulated
Observed
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Calender year

Figure 50



0
0.5
1
1.5
2
2.5
3
3
2.5
2
1.5
1
0.5
0
Watershed inputs, in centimeters per day
Watershed outputs, in centimeters per day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2004
2005
Inputs
Outputs
Precipitation
Irrigation
Upgradient groundwater
Leaky canal
Evapotranspiration
Discharge, observed
Discharge, simulated
Overland flow
Direct flow
Pipe flow
Base flow

Figure 51



Specific conductance, in microseimens per centimeter
in milligrams per centimeter
800
700
600
500
400
300
200
100
0
Simulated
Observed
Chloride, in milligrams per liter
25
20
15
10
5
0
Simulated
Observed
1998
1999
2000
2001
2002
2003
2004
2005

Figure 52