R software has been used for questions 1, 4, 5 and 6 which are included following the solution or a plot. Handwritten solutions are attached for questions 2 and 4.

1. Sensitivity of tp wrt to S and ap

First, reference values for S, ap, A, sig are obtained. To find ap’s effect, S is kept constant and ap values are changed +5% five times abut its reference value. Similar procedure to see S’s effect.



S=1.74e17

ap=0.3

A=5.10e14

sig=5.78e-8

for(i in 1:5){

S=append(S, S[i]\*1.05)

}

tp=(S\*(1-ap)/(sig\*A))^1/4

plot(S/S[1],tp/tp[1],type="l")

#wrt ap, keeping S constant

ap=0.3

for(i in 1:5){

ap=append(ap, ap[i]\*1.05)

}

tp=(S\*(1-ap)/(sig\*A))^1/4

plot(ap/ap[1],tp/tp[1],col = 3)

1. ##2. (Refer handwritten notes)
2. ##3. (Refer handwritten notes)
3. Sensitivity of Ts wrt to f

First, reference values for ku, kl, f, W, Qe and Qh are obtained. To find f’s effect, f is varied +5% five times about its reference value



ku=0.18

kl=0.075

f=0.95

W=1.07e13

Qe=4.08e16

Qh=8.67e15

for(i in 1:5){

f=append(f, f[i]\*1.05)

}

Ts=(((3-3\*ap-2\*ku-kl)\*S-1.5\*Qe-Qh+2\*W)/(3-2\*f)\*sig\*A)^(1/4)

plot(f/f[1],Ts/Ts[1],type="l")

1. a)#Precipitation

For a watershed around Cherry creek, Denver, CO, PRISM annual precipitation data from 1990 to 2015 is obtained. Its then averaged to obtain long term precipitation average

**ppt\_avg = 410.7396 mm/yr**

ppt = read.csv("usu/usu-coursework/cee6400phyhydro/hw/hw2/PRISM\_ppt\_stable\_4km\_1990\_2015\_39.7577\_-105.0108.csv", skip = 10)

ppt\_avg = mean(unlist(ppt[2]))

a)#Runoff

Runoff data is obtained from USGS (previous homework, and the drainage area from StremStats

**ro\_avg = 1.811747 mm/yr**

siteNo <- "06713500"

pCode <- "00060"

start.date <- "1990-01-01"

end.date <- "2015-12-31"

cherry\_creek = readNWISdv(siteNo,"00060",start.date,end.date)

Q=cherry\_creek$X\_00060\_00003

dt=cherry\_creek$Date

yy=as.numeric(format.Date(dt,"%Y")) #year

mo=as.numeric(format.Date(dt,"%m")) #month

#wy=ifelse(mo>=10,yy+1,yy) Not doing for water years but instead regular for now

yrseq=unique(yy) #unique years

Qmean=rep(NA,length(yrseq)) #Annual Flow

for(i in 1:length(yrseq)){

yr=yrseq[i]

#Average annual flow

Qmean[i]=mean(Q[yy==yr])

}

cherry\_creek\_area = 7040 #mi2, from WaterStats ?? or just 4km2?

ro = (Qmean/(cherry\_creek\_area\*(5280)^2))\*86400\*365\*12\*25.4

ro\_avg = mean(ro)

a)#Evapotranspiration

**et\_avg = 408.9279mm/yr**

et = ppt[2] - ro

et\_avg = mean(unlist(et))

b)# Seasonal runoff and precipitation

Seasonal runoff



c)#c Runoff ratio (w)

**w = 0.0044**

w = mean(ro)/mean(unlist(ppt[2]))

1. For a watershed
2. Mean annual temperature and PET

**pet\_avg = 1048.676mm/yr**

**meanannualtemp\_avg = 11.09615C**

meanannualtemp = read.csv("usu/usu-coursework/cee6400phyhydro/hw/hw2/PRISM\_tmean\_stable\_4km\_1990\_2015\_39.7577\_-105.0108.csv", skip = 10)

pet = 1.2e10\*exp((-4620)/(meanannualtemp[2]+273.15))

pet\_avg = mean(unlist(pet))

meanannualtemp\_avg = mean(unlist(meanannualtemp[2]))

b. Best fit value for w

**w = 4.615171e-06**

fs <- function(w,y) {(ppt\_avg\*(1-((ppt\_avg)/((ppt\_avg^w)+(pet\_avg^w))^(1/w))))-y}

w=uniroot(fs,y=ro\_avg,lower=-10,upper=10)[1]

(INCORRECT method above)

(To implement following code, but ran into R errors)

#assume w = 0.1

w=0.1

rop1=ppt[2]\*(1-((pet\_avg)/((ppt[2]^w)+(pet\_avg^w))^(1/w)))

et1 = ppt[2]-rop1

plot(as.vector(rep(pet\_avg,length(ppt[2]))/ppt[2]),as.vector(et1/ppt[2]))

#assume w = 0.2

w=0.2

rop2=ppt[2]\*(1-((pet\_avg)/((ppt[2]^w)+(pet\_avg^w))^(1/w)))

et2 = ppt[2]-rop1

plot(as.vector(rep(pet\_avg,length(ppt[2]))/ppt[2]),as.vector(et2/ppt[2]))

#assume w = 0.4

w=0.3

rop1=ppt[2]\*(1-((pet\_avg)/((ppt[2]^w)+(pet\_avg^w))^(1/w)))

et1 = ppt[2]-rop1

plot(as.vector(rep(pet\_avg,length(ppt[2]))/ppt[2]),as.vector(et1/ppt[2]))

#assume w = 0.4

w=0.4

rop1=ppt[2]\*(1-((pet\_avg)/((ppt[2]^w)+(pet\_avg^w))^(1/w)))

et1 = ppt[2]-rop1

plot(as.vector(rep(pet\_avg,length(ppt[2]))/ppt[2]),as.vector(et1/ppt[2]))

#Plot all w lines, then obtain a point (pet\_avg/ppt\_avg, et\_avg/ppt\_avg) and see where the point #lies wrt to each w. The closest w value is the answer

c. Elasticity of runoff to precipitation (based on w from first method)

**el = 1**

Elasticity means how runoff and precipitation are related to each other. Similar to sensitivity

numr = 1-(1/(1+(ppt\_avg/pet\_avg)^w)^(1+1/w))

denr = 1-(pet\_avg/(ppt\_avg^w+pet\_avg^w)^(1/w))

el = numr/denr

d. Relative change in runoff (based on w from first method)

**rc ~0**

meanannualtempk = mean(unlist(meanannualtemp[2])) + 273.15

numra1=5.54e13\*exp(-4620/mean(unlist(meanannualtempk)))

denmra1=(mean(unlist(meanannualtemp))^2)\*ppt\_avg\*(1+(pet\_avg/ppt\_avg)^w)^(1+(1/w))

denmra2=(1-(pet\_avg/(ppt\_avg^w+pet\_avg^w)^(1/w)))

rc=-1\*(numra1/(denmra2\*denmra1))