

Hydrologic Responses to Drought in the Barton Creek
Segment of the Edwards Aquifer

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INTRODUCTION

This project is an analysis of precipitation and stream flow across the Barton Springs segment of the Edwards Aquifer. By comparing precipitation and stream flow at various points across the contributing and recharge zones of the Barton Springs segment, we can infer differences in hydrologic response to climate between the contributing and recharge zones of the aquifer. More specifically, by comparing hydrologic response during times of drought and times of non-drought across the two zones of the aquifer, we can better understand how drought affects recharge to the aquifer.

BACKGROUND

The Edwards Aquifer is a large aquifer in central Texas that provides water for over 2 million people (Figure 1; Smith and Hunt, 2004). As populations rise in the areas served, it becomes increasingly important to understand how the aquifer responds to climate and to environmental conditions, especially droughts that periodically afflict central Texas. The aquifer consists of three primary hydrologic zones: the contributing zone, the recharge zone, and the artesian zone. The contributing zone includes watersheds that will eventually recharge the aquifer, but do not overlay outcrops of the aquifer. The recharge zone is where the Balcones Fault Zone (BFZ) has brought the aquifer to the ground surface. Streams that cross the recharge zone are generally losing streams, where stream flow decreases downstream. The third zone, the artesian zone, is where the aquifer becomes confined. Streams do not recharge the aquifer once they cross into the artesian zone. In order to understand how recharge to the Edwards Aquifer changes during drought conditions, it is important to understand how stream hydrology over the contributing and recharge zones respond to drought conditions.

The Barton Springs Segment of the Edwards Aquifer is an important segment between the San Antonio segment to the south and the Colorado River to the north, immediately south of downtown Austin. The Barton Springs segment is about 400 km² in area, and primarily discharges through Barton Springs, a

popular recreational site near the Colorado River. The Barton Springs segment is crossed by Onion Creek, Slaughter Creek, and Barton Creek, as well as several small intermittent streams. Several of these streams have water level gages maintained by the National Oceanic and Atmospheric Association (NOAA). Tables of these water levels are available online.

OBJECTIVE

This project aims to compare NOAA World Weather Online (WWO) stream gage data and North American National Land Data Assimilation System (NLDAS) Noah model precipitation across the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer during times of drought and non-drought. By comparing drought and non-drought stream responses of these two zones to precipitation, we can infer how recharge to the aquifer responds to drought conditions.



Figure 1: Edwards Aquifer in central Texas.

DATA

Data was collected from four primary sources: the NLDAS Noah model, NOAA WWO stream gage data, the USGS National Elevation Dataset (NED30m) and the NOAA National Climatic Data Center (NCDC). The NLDAS Noah model provides a land surface water balance that is forced by physical measurements such as rainfall and temperature. These data are provided as averages of 1/8th degree grid squares on either a monthly or hourly basis. For the purposes of this project, monthly rainfall, snowfall, and evapotranspiration (ET) were collected. The NOAA WWO stream gages provide gage depth averaged over a day. Some provide additional information such as maximum and minimum gage depths for each day, but for this project, these data were ignored. The NED30m provides elevation at a 30m resolution. Finally, Palmer Drought Severity Index (PDSI) values were downloaded from the NOAA NCDC for each month of the study. PDSI is based on modeled soil water supply and demand and is based on measured temperature and precipitation.

METHODS

Based on PDSI values, the water years (October to October) of 2005-2011 were chosen as the focus of the study. These provided three periods totaling 63 months of drought and two periods totaling 21 months of non-drought conditions (Figure 2). By choosing a contiguous sample, effects of change in land use could be minimized.

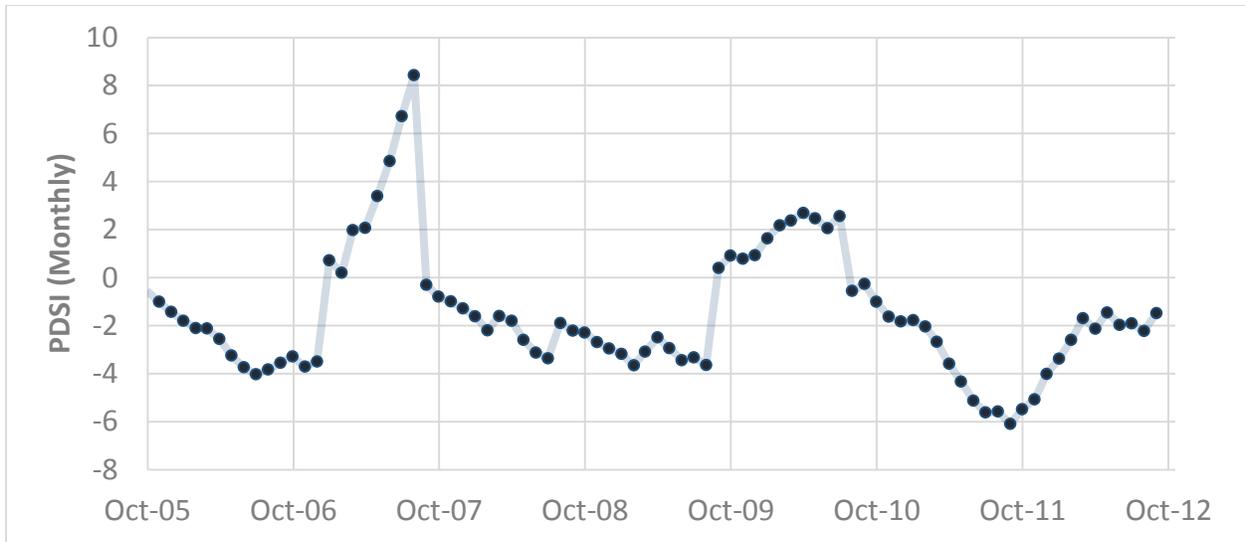


Figure 2: Monthly Palmer Drought Severity Index (PDSI) values for the Edwards Plateau October 2005 to October 2012. Negative values indicate drought conditions, while positive values indicate non-drought conditions.

Eight stream gages were chosen from the set of WWO gages. These gages had data for the period October 2005 to October 2012, and were near either the boundary of the contributing and recharge zones or the boundary of the recharge and artesian zones (Figure 3). The three gages in the contributing zone were each paired with a downstream gage near the boundary of the recharge and artesian zones. Two additional gages draw primarily from the recharge zone.

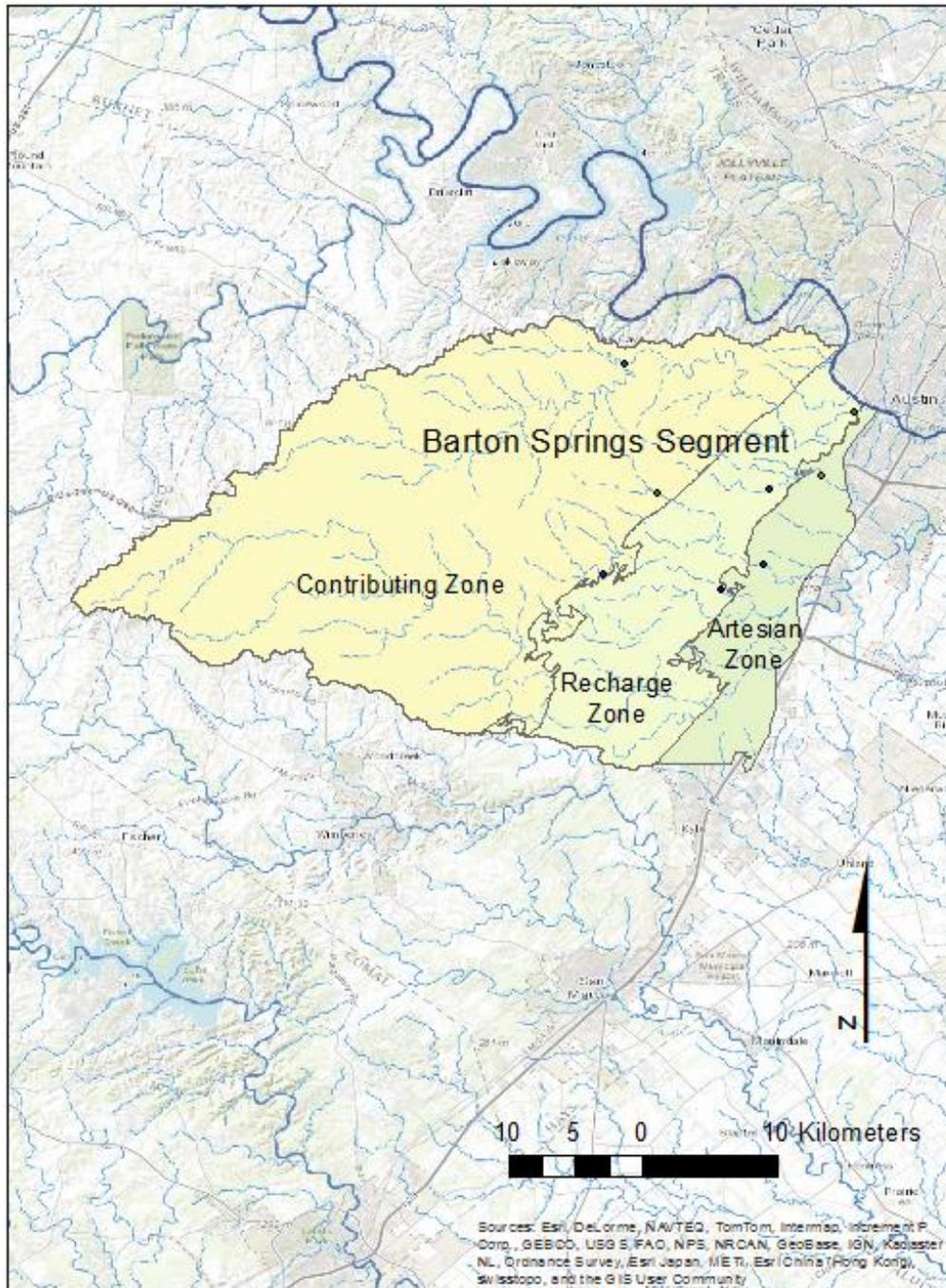


Figure 3: Contributing, Recharge, and Artesian zones of the Barton Springs Segment. Points represent studied stream gages.

Once gages were chosen, NED30m data were used to estimate a watershed for each gage. These watersheds were then intersected with the zones of the aquifer (Figure 4).

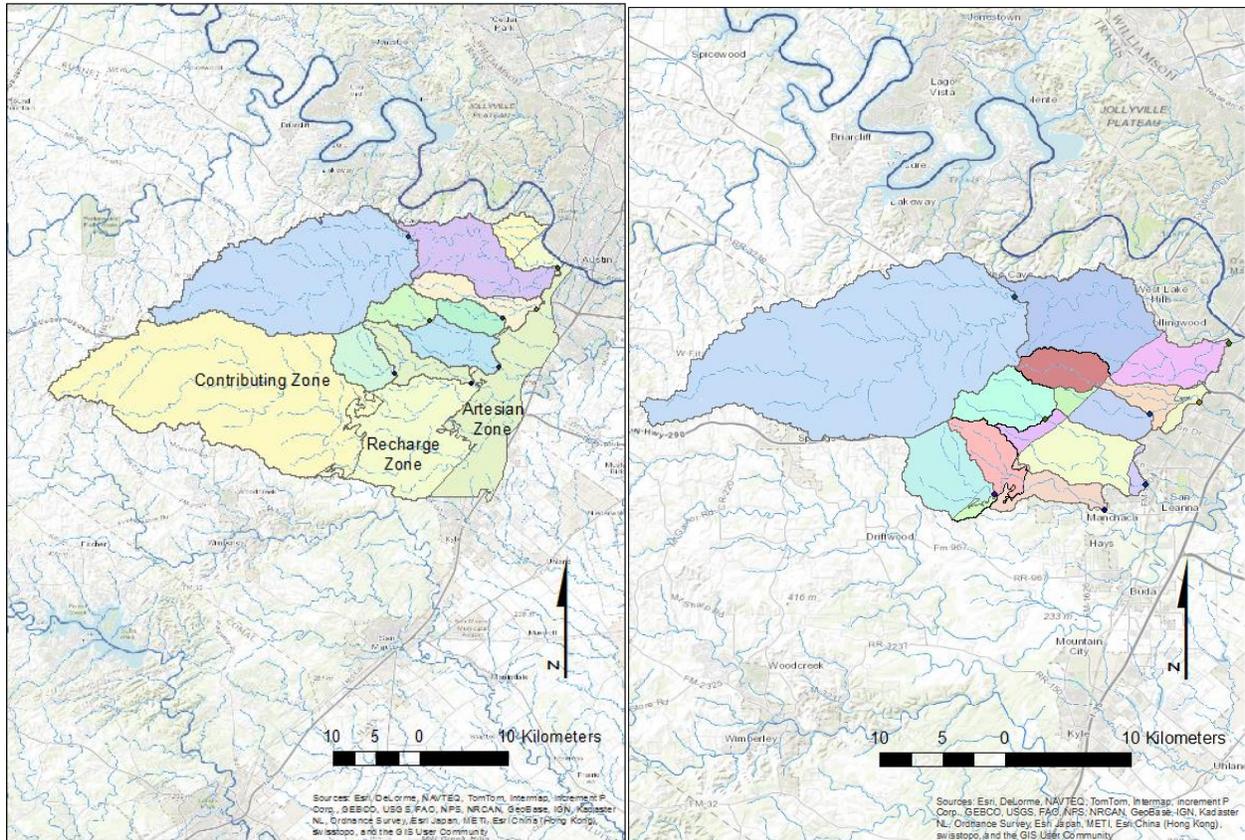


Figure 4: Left: gage watersheds calculated using NED30m data. Right: These same watersheds intersected with the contributing, recharge, and artesian zones of the Edwards Aquifer.

NLDAS Noah rainfall, snowfall, and ET data for the studied time period were then downloaded for each watershed zone using a Python program that called the NOAH Downloader tool (Appendix A). A similar approach, using Python to run ArcGIS zonal averaging for each parameter in each watershed zone was attempted, but ultimately failed due to difficulties with the ArcPy handling of tables. In order to calculate these zonal averages, the watersheds were further divided to intersect with the $1/8^{\text{th}}$ degree grid lines used by the NLDAS models (Figure 5).

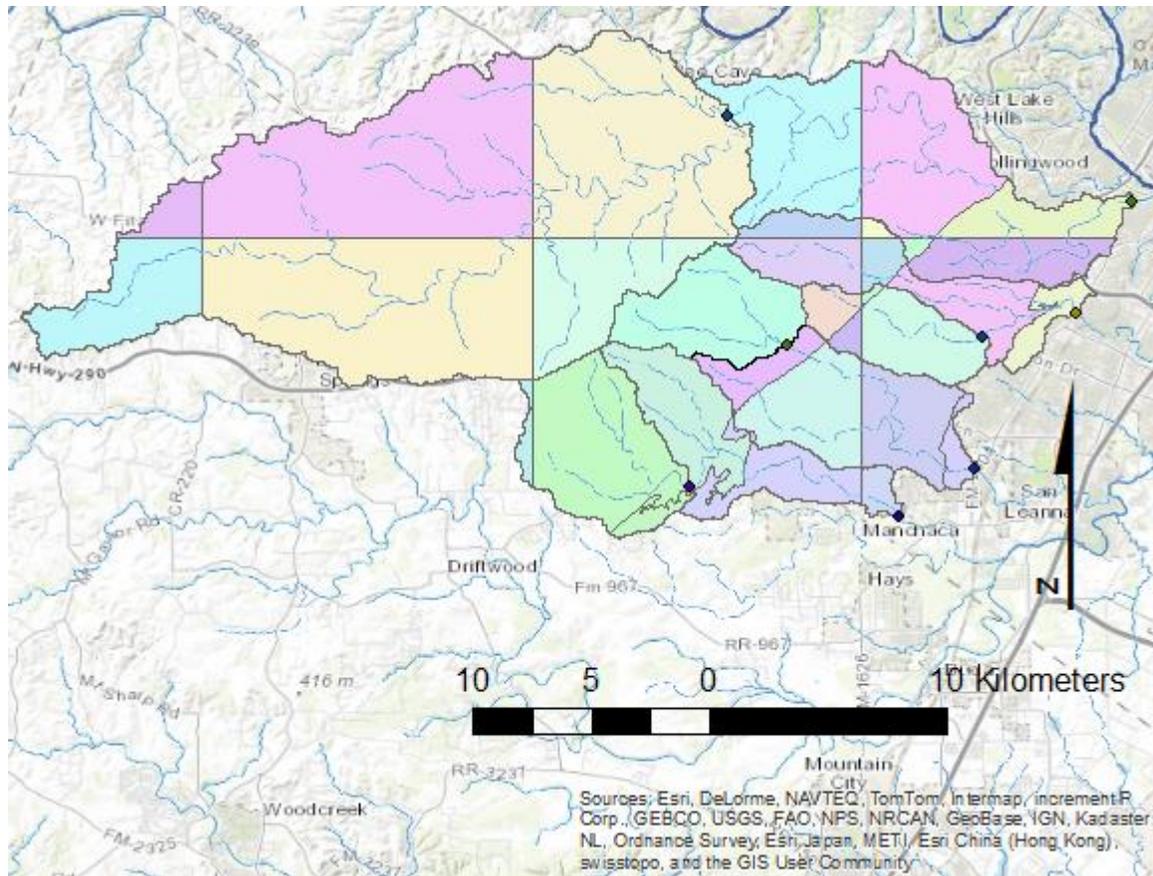


Figure 5: Gage watersheds intersected with aquifer contributing, recharge, and artesian zones, as well as the 1/8th degree grid lines that are used by the NLDAS Noah models.

Areas from these new, subdivided watershed zones were used to calculate Recharge Area/Contributing Area (R/C) ratios for each watershed, and to calculate zonal averaging coefficients for each watershed zone. A new python program was designed that uses these coefficients to calculate zonal averages from the *.asc files generated by downloading the NLDAS data (Appendix B). Daily stream gage data was downloaded from the US Geological Service website and averaged by month. These monthly stream flows were compared to the sum of monthly averages of rainfall and snowfall.

RESULTS

The correlation between precipitation volume over the watershed versus the gage flow out of the watershed was surprisingly low for all gages analyzed (Figure 6). There was no significant relationship between the proportion of the watershed that was over the recharge zone and how it responded to precipitation when all points were considered. When monthly gage flow during draught conditions was separated from monthly gage flow during non-draught conditions, R/C of each watershed became more significant (Figure 7). During non-drought conditions, there is little to no correlation between rainfall and gage flow in watersheds that are primarily in the contributing zone, but correlation between rainfall and gage flow in watersheds over the recharge zone. During drought conditions, there is a similar correlation between precipitation and gage flow for all gages (Figure 8).

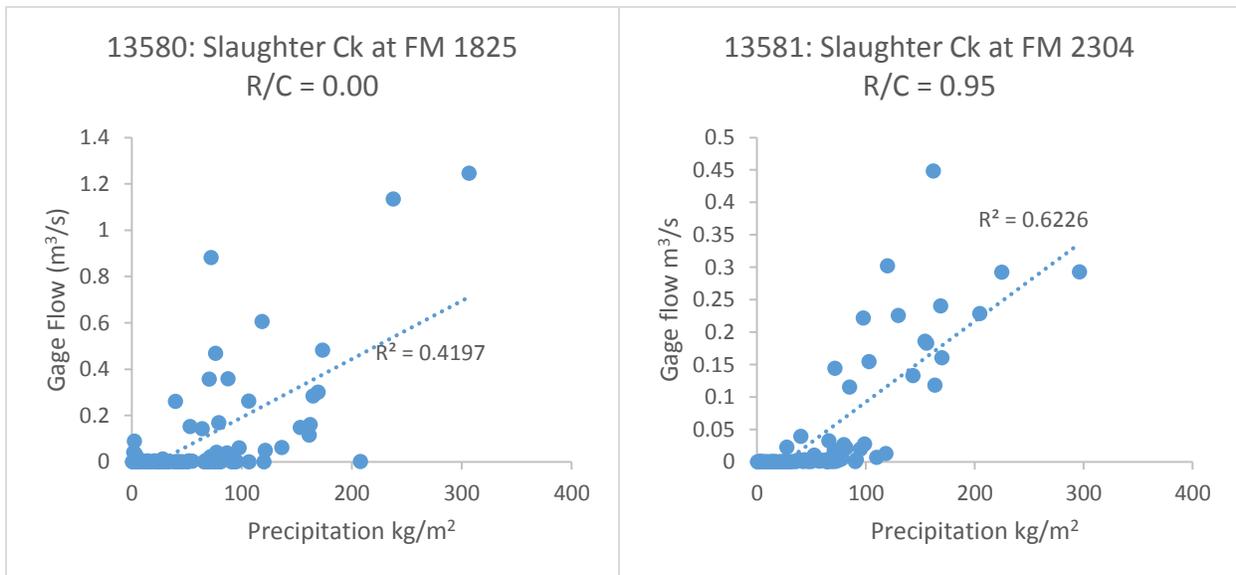


Figure 6: Monthly gage flow compared to precipitation for two representative gages.

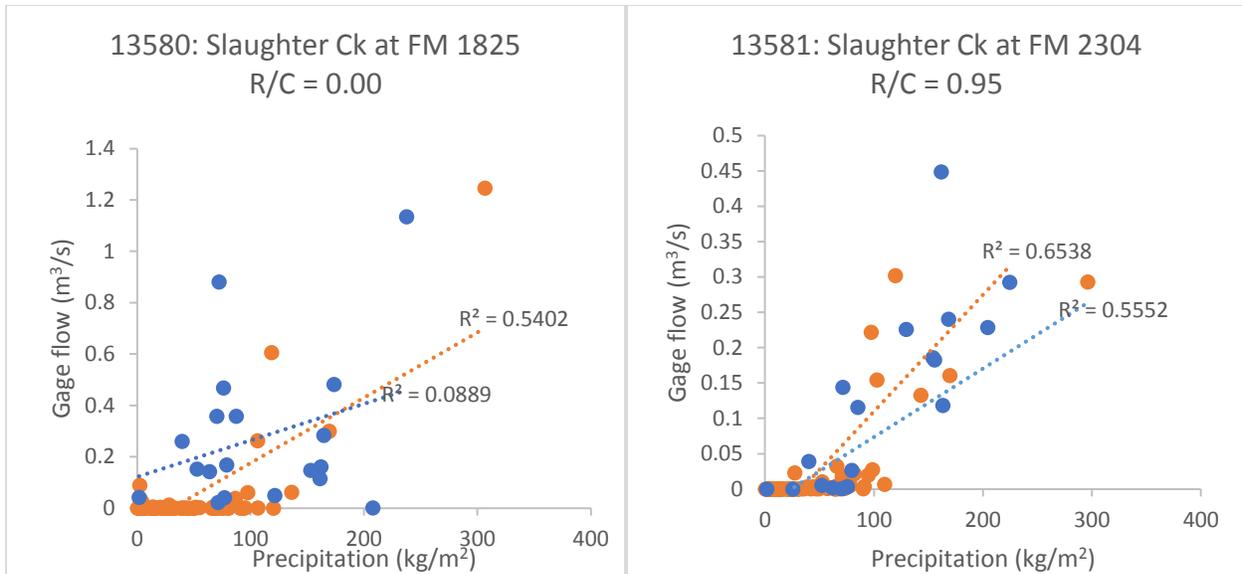


Figure 7: Gage flow compared to precipitation separated by PDSI for two representative gages. Drought conditions are represented by orange symbols, and non-drought by blue.

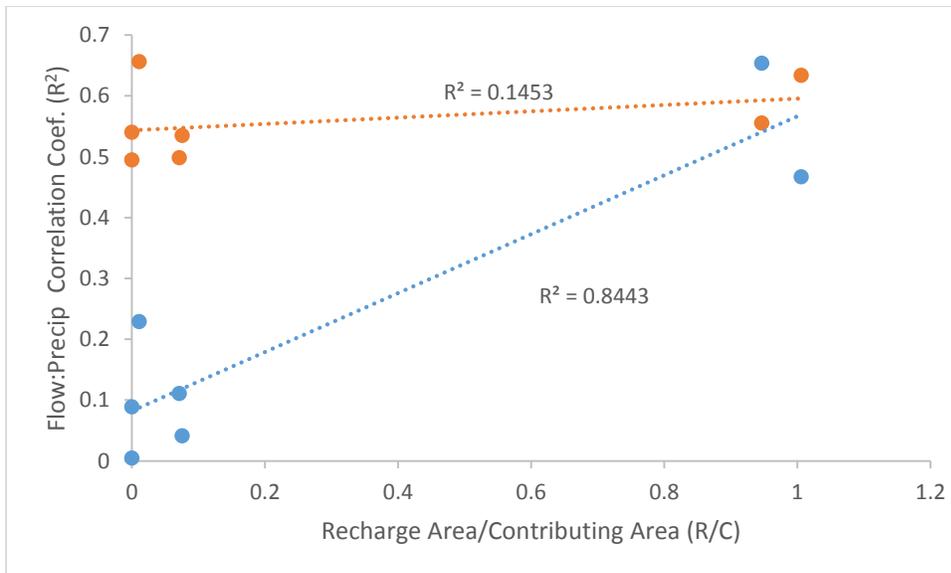


Figure 8: Correlation between gage flow and precipitation versus R/C, separated by PDSI drought conditions. Drought conditions are represented by orange symbols, and non-drought conditions by blue symbols.

DISCUSSION

The general lack of strong correlation between precipitation and gage flow over the Barton Springs segment of the Edwards Aquifer could be due primarily to our method of estimating precipitation. The watersheds are generally small compared to the size of the 1/8th degree grids used to estimate rainfall over the area. Rainfall in central Texas can occur in highly localized storms. This could lead to situations where the precipitation from a storm event is averaged over a much larger area than the storm itself, leading to recorded precipitation over watersheds that saw no rainfall. Similarly, this method of estimating precipitation can underestimate actual rainfall over a watershed. If the watershed is smaller than the grid square, but is large enough to receive the entirety of the precipitation from the storm event, grid averaging could reallocate precipitation away from that watershed. The complete lack of correlation of rainfall to gage flow during wet conditions in the contributing zone could be due to these types of zonal averaging.

The higher correlation between rainfall and gage flow in the contributing zone during dry conditions and the generally higher correlation between rainfall and gage flow in the recharge zone are more difficult to account for. They could imply that some sort of physical buffering is occurring that mirrors the effects of the zonal averaging of rainfall. In the recharge zone, this may be accounted for by the recharge of water into the aquifer. High rainfall would lead to higher infiltration of groundwater in the recharge zone. This would have a damping effect on the gage flow response that could be similar to potential underestimation of precipitation in a watershed by zonal averaging. In the contributing zone, this correlation during dry seasons could potentially be due to changes in soil properties that affect runoff or changes in plant utilization of water during dry conditions. It is unknown why these effects would differ between the contributing and recharge zones. Other effects could highly alter these signals, including changes in land use, differences in vegetative cover between contributing and recharge zones, watershed size effects, intermittency in streams, and variations in volume and timing of rain events.

CONCLUSIONS

Watersheds in the contributing zone have hydrologic responses to precipitation that varies based on drought versus non-drought conditions, while drought does not affect how watersheds in the recharge zone respond to rain events. The reasons for this distinction are not clear, but merit further, more rigorous study. This study was unable to account for several factors that may affect watershed response to precipitation. It also showed that for the scale of small catchments in the Edwards Aquifer, the NLDAS Noah precipitation grids are likely too large to accurately represent small storm events over the watershed. Future studies could attempt to account for variation in timing and amount of rainfall during drought, difference in land use, or watershed size and network topology. A much more rigorous statistical analysis of these results than provided here is also warranted.

CITATIONS

Capitol Area Council of Governments. **2013**. Barton Springs Edwards Aquifer Conservation District Hydrologic Zones. Retrieved Dec 02, 2013.

National Climatic Data Center. **2013**. Climate at a glance: Timeseries. Retrieved Dec 09, 2013.

http://www.ncdc.noaa.gov/cag/time-series/us/41/4/pdsi/1/1/1895-1901?base_prd=true&firstbaseyear=1901&lastbaseyear=2000&filter=true

Smith, B.B., and B.B. Hunt. **2004**. Evaluation of sustainable yield of the Barton Springs segment of the Edwards Aquifer, Hays and Travis Counties, central Texas. Barton Springs/Edwards Aquifer Conservation District.

APPENDIX A

```
# -----
# DownloadsMult.py
# Created on: 2013-12-03
# Peter Carlson
# Description:
# This script automates the repetitive downloads of NLDAS data over a list of watersheds
# The toolbox location needs to be edited for your system
# The file Downloads.csv needs to be edited to control the variables to download
# Based on Downloads.py by David Tarboton
# -----

# Import arcpy module
import arcpy, datetime, os
from arcpy import env

# Inputs -----
gdbname=r"Ex5\BaseLayers.gdb" # geodatabase
zoneslist= [r"Layers\R13555", r"Layers\C13555",
            r"Layers\R13578",r"Layers\C13578",r"Layers\R13577",r"Layers\C13577",r"Layers\T13580",r"Layers\R13583",r"Layers\C13583",r"La
            yers\R13586",r"Layers\A13586",r"Layers\R15384",r"Layers\C15384",r"Layers\R13585",r"Layers\C13585",r"Layers\A13586"] #
            Name of zone (basins) feature class in geodatabase
infile=r"Ex5\Downloads.csv"
# End of inputs -----

# Load the LDAS toolbox. Adjust this line to where it occurs in your system
arcpy.ImportToolbox(r"C:\Users\Peter\Documents\ArcGIS\Packages\LDASools\v101\application\LDAS tools.tbx")

# Local variables:
# Use the current working directory as the folder

Folder=os.getcwd() # or r"D:\Scratch\Ex5"
env.workspace = Folder

for zones in zoneslist:
    print zones
    Basin = Folder+os.sep+gdbname+os.sep+zones
    Outfold=Folder+os.sep+"NLDAS"+os.sep+zones
    # If this folder does not exist make it
    if not os.path.isdir(Outfold):
        os.makedirs(Outfold)

    f=open(infile)
    line=f.readline() # reads the header
    for line in f:
        print(line)
        cols=line.split(",")
        Outfolder=Outfold+os.sep+cols[0]
        if not os.path.isdir(Outfolder):
            os.makedirs(Outfolder)
        Dataset=cols[1]
        Var=cols[2]
        Begdate=cols[3]
        Enddate=cols[4]
        arcpy.LDASNOAHdownloader(Basin, Dataset,Var, Outfolder, Begdate, Enddate)
    f.close()
```

APPENDIX B:

```
# -----
# Desperation.py
# Created on: 2013-12-09
# Peter Carlson
# Description:
# This script uses a manually input table of zonal average coefficients to perform zonal averaging on NLDAS data *.asc files
# Outputs zonal averages to excel files.
# -----

# Python modules used
import sys
import csv
import arcpy, datetime, os, shutil
from arcpy import env
from arcpy.sa import *

# Inputs -----
gdbname=r"Ex5\BaseLayers.gdb" # geodatabase
zoneslist=["T13580", "R13586", "A13586"] # Name of zone (basins) feature class in geodatabase
outtableshort="zstats"

coefficients = [[[1.000000]],
                [[0.540146, 0.459854]],
                [[1.000000]]]

#End of inputs -----

# Use the current working directory as the folder to work in
Folder=os.getcwd() # or r"D:\Scratch\Ex5"
env.workspace = Folder
m=0
for zoneshort in zoneslist:
    print zoneshort
    outtable=outtableshort + zoneshort + ".csv"
    zones = "Layers" + os.sep + zoneshort
    # Full file paths
    zonestape=gdbname + os.sep + zones # Basin feature class
    WorkFolder = Folder+os.sep+r"NLDAS"+os.sep+zones # This is the folder used for input data
    TempFolder = Folder+os.sep+r"temp" # This is the folder where temporary tables are written
    if not os.path.isdir(TempFolder):
        os.makedirs(TempFolder)
    VarFolders=os.listdir(WorkFolder)
    tablenamefull=Folder+os.sep+"NLDAS"+os.sep+"Layers"+os.sep+outtable
    field0="ObjectID"
    field1="Vrcode"
    field2="Date"
    field3="Value"
    field4="TimeSupport"
    Header = [field0,field1,field2,field3,field4]
    with open(tablenamefull,'wb') as o:
        writer = csv.writer(o)
        writer.writerow(Header)
        i=1
    for VarFolder in VarFolders:
        print VarFolder
        VarFiles=os.listdir(WorkFolder+os.sep+VarFolder)
        for theFile in VarFiles:
            if theFile.endswith(".asc"): # Only ASC files
                print theFile
                if(theFile[-6:-4]=="00"): # This occurs for an hourly file
```

```

    dateString = theFile[-15:-7]
    timeSupport="Hour"
else:
    dateString = theFile[-10:-4]
    timeSupport="Month"
if timeSupport=="Hour":
    date=str(datetime.datetime.strptime(dateString,'%Y%m%d'))
else:
    date=str(datetime.datetime.strptime(dateString,'%Y%m'))
fullFile=WorkFolder+os.sep+VarFolder+os.sep+theFile
f=open(fullFile)
j=0
mean=0
for line in f:
    if j >= 6:
        list=line.split()
        if len(list) == 1:
            mean += float(list[0])
            print mean
        else:
            for k in range(len(list)):
                mean += float(list[k])*coefficients[m][j-6][k]
            print mean
        j+=1
    entry = [i,VarFolder, date, mean, timeSupport]
    writer.writerow(entry)
f.close()
i+=1
try:
    if os.path.isdir(TempFolder): # Remove temporary folder
        shutil.rmtree(TempFolder)
except:
    print "Unable to delete temporary folder: "+TempFolder
m+=1
print "Done"

```