

Evaluation of Southern Utah Aquifers

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CEE 6440 – GIS for Water Resources

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Photo credit: <http://www.parks.ca.gov/>

Introduction

Located in the south-west corner of the state of Utah, St. George City has long been a favorite vacation spot for Utah residents and attracts many senior citizens looking for an escape to warmer weather (see Figure 1). Urban development has boomed in recent years; the city's 2012 population was 75,560, which constitutes an increase of 52% since 2000 (Onboard Informatics, 2013). The Utah Governor's Office projects that this number will nearly double to 148,000 by 2030 (State of Utah, 2013). In addition to the rapid growth that is occurring, the area has also historically supported a large agricultural community. The proper management of water resources in this arid region of Utah will therefore be of critical importance to the community in coming years.

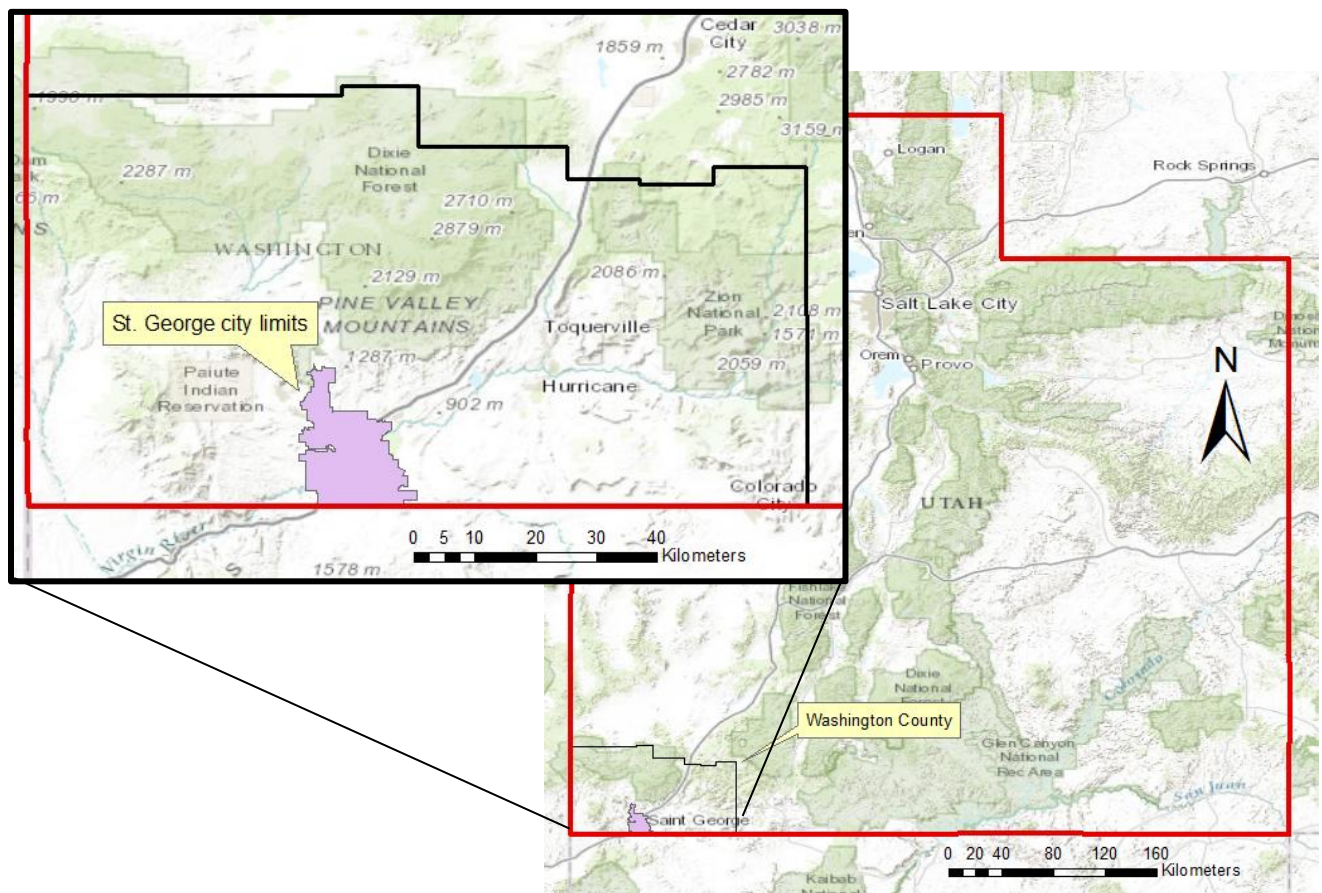


Figure 1: Map of Utah showing the location of Washington County in southern Utah. The inset shows a close up of Washington County with the shaded area giving the St. George city limits.

Much of the public water supply relies on groundwater to meet demand for drinking water. Many individual farmers also tap into groundwater sources to meet their irrigation needs. The majority of this groundwater is supplied by the Navajo/Kayenta and upper Ash Creek aquifers (see Figure 2). These aquifers underlie the greater St. George area, Hurricane, and several smaller communities. A more in-depth discussion on these aquifers can be found in the 2005 publication by Hansen, Allen, and Luce, Inc.

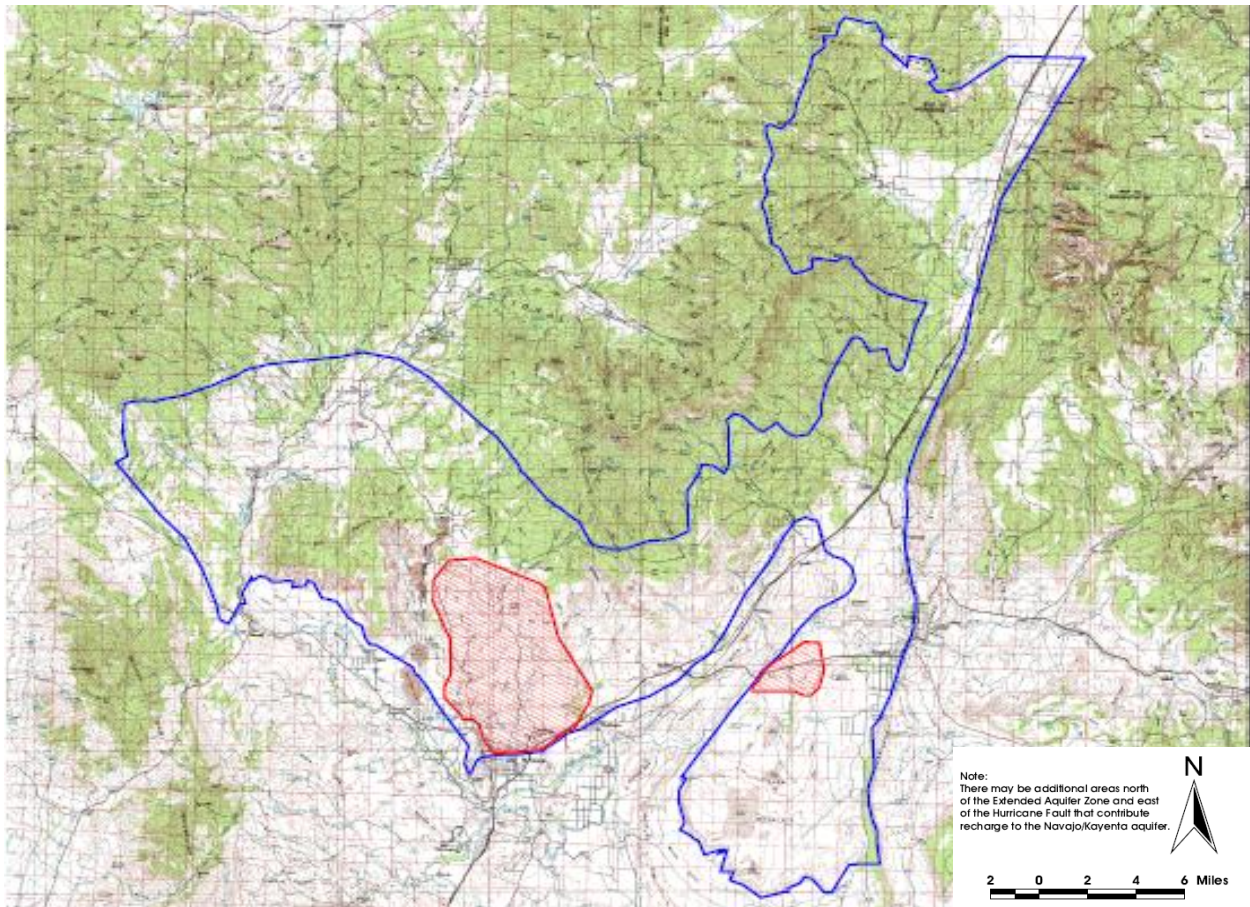


Figure 2: This figure shows the boundaries of the Navajo/Kayenta and upper Ash Creek aquifers; St. George is located in and adjacent to the large red-hatched area (Hansen, Allen, & Luce, Inc, 2005).

Project Objectives

The original objective of this project was to employ the various datasets and methods learned in the CEE 6440 class in order to identify trends in the groundwater that supplies the greater St. George area. In particular, the GRACE dataset would be used as a means of identifying changes to groundwater supplies through the use of gravitational anomalies. The project was approached under the assumption that, due to the area's arid climate, rapid urbanization, and strong agricultural sector, groundwater levels would eventually be shown to be declining. A second component to the project was then conceived in which geologic layers would be used along with aquifer maps in order to determine sites that would be suitable for artificial groundwater recharge projects.

An initial investigation resulted in the following challenges that would be faced in accomplishing these goals:

- No readily available well level data (USGS or otherwise)
- Lack of accessible shape files or data for the Navajo/Kayenta and upper Ash Creek aquifers
- Unexpected complexity of geologic features

In light of these potentially limiting factors, the project objectives were modified slightly in order to make them more attainable in a timely fashion. As the lack of well data made it impossible to correlate the GRACE results with actual water table levels, it was decided that the focus of the project would be shifted to analyzing the soil water changes produced by GRACE in a larger hydrologic context. This approach contrasted the GRACE results with estimated baseflows relevant to the aquifer in order to look for patterns and correlations that might help explain the changes to soil water.

Methods

The GRACE (Gravity Recovery and Climate Experiment) dataset described earlier is the result of a NASA satellite mission launched in 2002 which aimed at accurately mapping variations in the earth's gravitational field. The gravitational anomalies which occur over land surfaces are attributed to changes to groundwater storage in land masses (Netting, 2013). The GRACE dataset that was used for this project was accessed as a ArcGIS web service provided by the University of Texas at Austin at <http://crwr-arcgis01.austin.utexas.edu/arcgis/services>. A certain amount of preprocessing of the GRACE data has already been performed on this dataset, which provides the gravitational anomaly in terms of equivalent soil water content as a depth in centimeters. The value given is the change in total water storage for a given month, relative to the average value over the ten-year period (2003-2013) for which data has been collected.

Before the GRACE data could be analyzed for the project study area, a local copy in .tif format had to first be obtained from the server (the host provides it as an ArcMap Image Service, while we need it in raster form in order to perform spatial analysis techniques). Rather than manually download each of the monthly images, a python script was written to automate this process. The Image Service files were first copied from the GRACE attribute table to the Table of , then python script GraceExtractVR1.py was employed to import these into the geodatabase as a folder of .tif rasters. Figure 3 gives a diagram of the basic steps involved in this code.

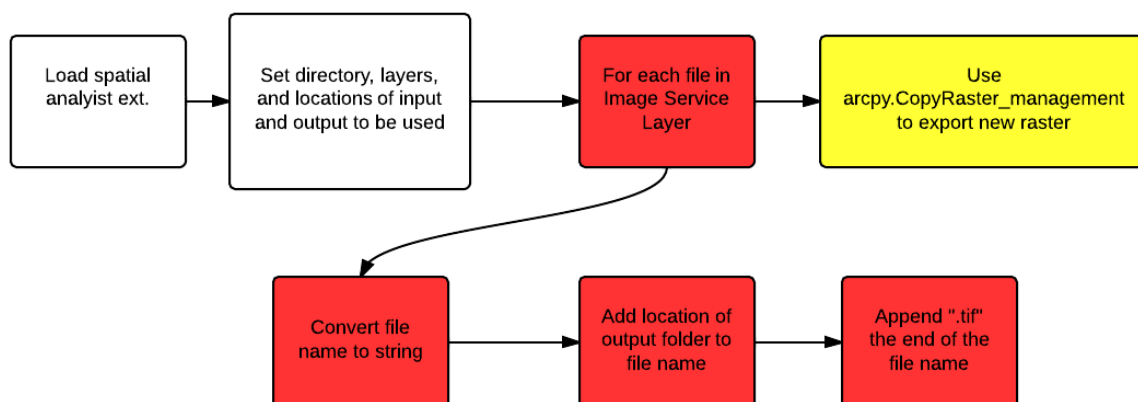


Figure 3: Schematic of GraceExtractVR1.py (full code in Appendix)

The GRACE image service obtained from the University of Texas at Austin provides averages of the gravitational anomaly over a one degree by one degree grid for the world's landmasses (Figure 4). In order to obtain a monthly average anomaly relevant to the St. George area, a zonal average of the dataset was taken. Per Dr. Maidment's instructions, GRACE data should not be interpreted over a space any smaller than a 200 km diameter. Accordingly, a raster was created that encompassed a 100 km radius around the St. George city limits (Figure 5).

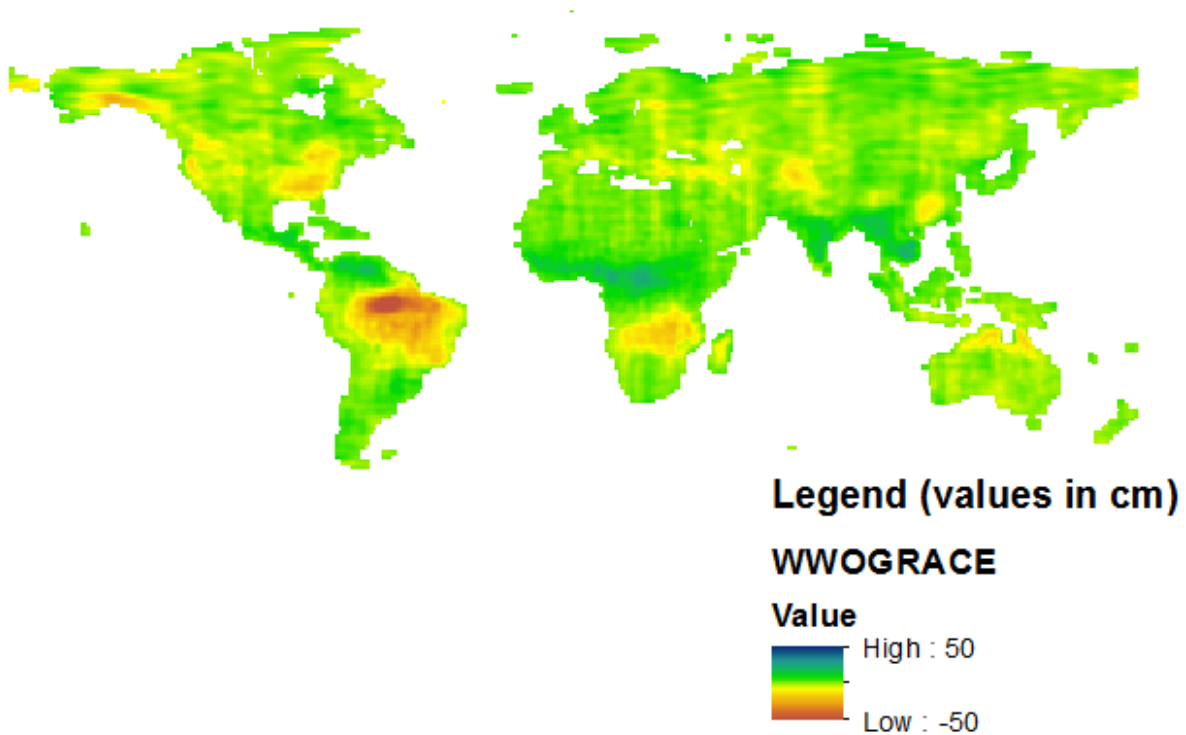


Figure 4: Example of GRACE data for a given month.

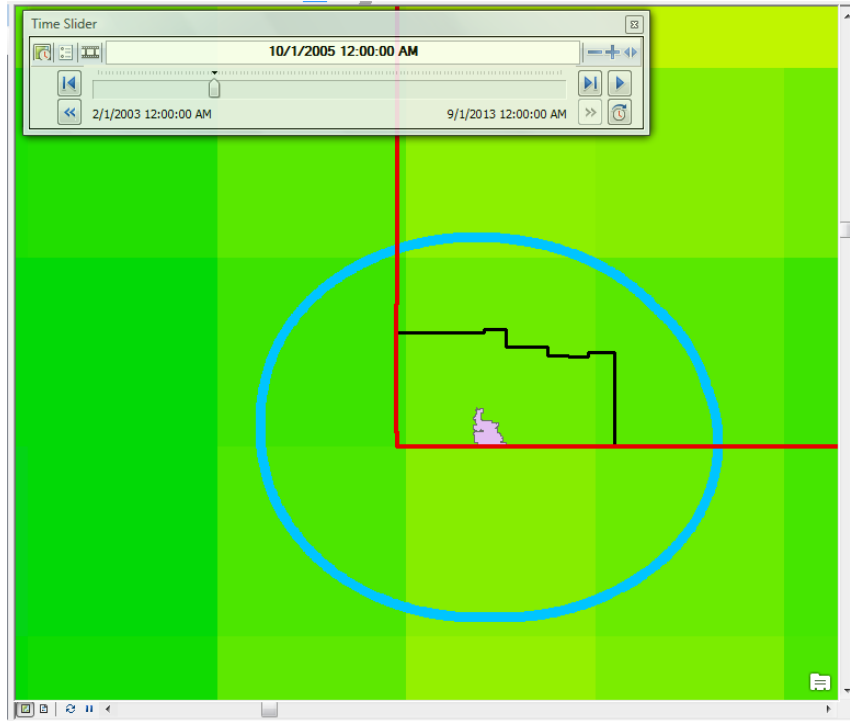


Figure 5: Screen capture of GRACE data for southern Utah and the 100km radius used for zonal average. One degree by one degree resolution of the data can also be seen.

To perform the zonal average, a python script was again utilized. As shown below in Figure 6, `ZonalAverageStGeorge.py` cycles through the raster produced previously for each time step and computes zonal statistics on the area encompassed by the specified zone. The mean value and date are both extracted from the raster and appended to an output table that can then be used to process the results further. This script is a variation of the script that was provided for Exercise 5 in the GIS for Water Resources class.

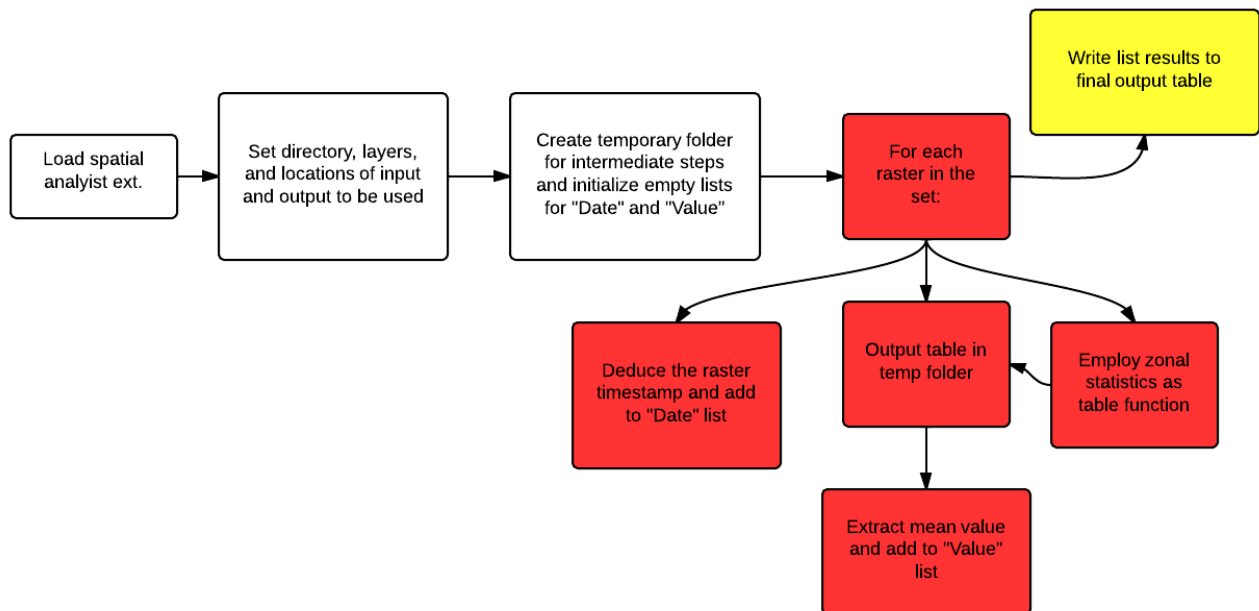


Figure 6: Basic schematic for ZonalAverageStGeorge.py (full code in Appendix).

Finally, stream data was collected for comparison to GRACE results. World Water Online (WVO), the web service provided by University of Texas at Austin, was utilized to easily obtain points features that are linked to USGS stream gages. From these linked features one can connect directly to the relevant graphs or data on the USGS website. In selecting a stream, it was desired to find a stream that originated within the one of the aquifers under consideration so that the base flow would be directly tied to contributions by the aquifer. The stream gage also needed to have recorded values for the same span of time as the GRACE dataset (2003-2013), and preferably be located upstream of any dams or diversions.

Unfortunately, very few stream gages met all of the above requirements. Many gages did not have recent enough data uploaded to coincide with the GRACE time period. USGS gage #09408135 ‘Virgin River above Quail Creek near Hurricane, UT’ was selected as this gage is located on the Virgin R. after it has entered the aquifer boundaries and is upstream of as many irrigation diversion points as possible (Figure 7). The tabulated table obtained from this stream gage was then imported into Excel for further analysis.

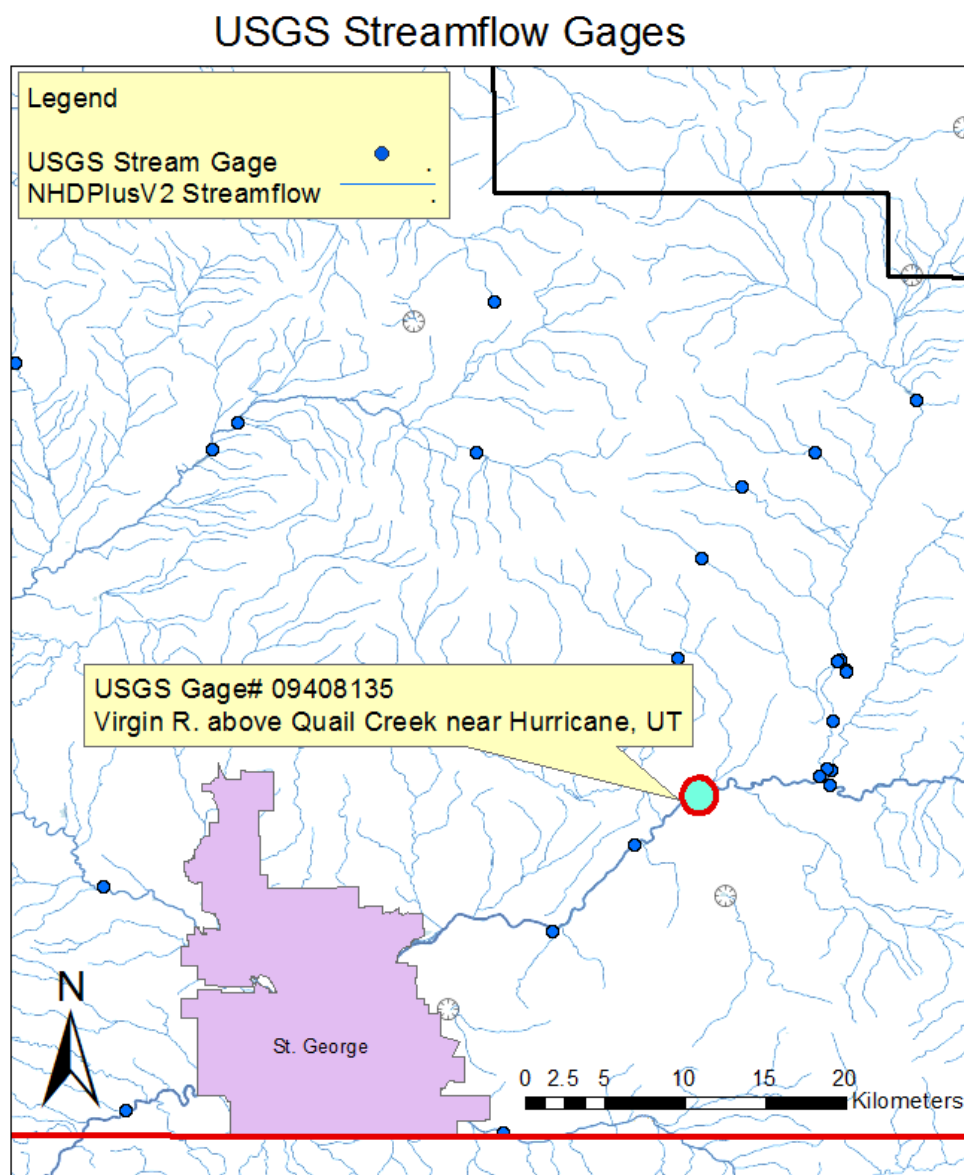


Figure 7: Map of the area surrounding St. George, showing USGS streamgages. Stream lines from the NHDPlusV2 data set were included to better visualize the streams.

Results

Excel was used to produce charts that help to better visualize the results. Figures 8-10 present plots of different quantities produced by further processing the GRACE zonal average.

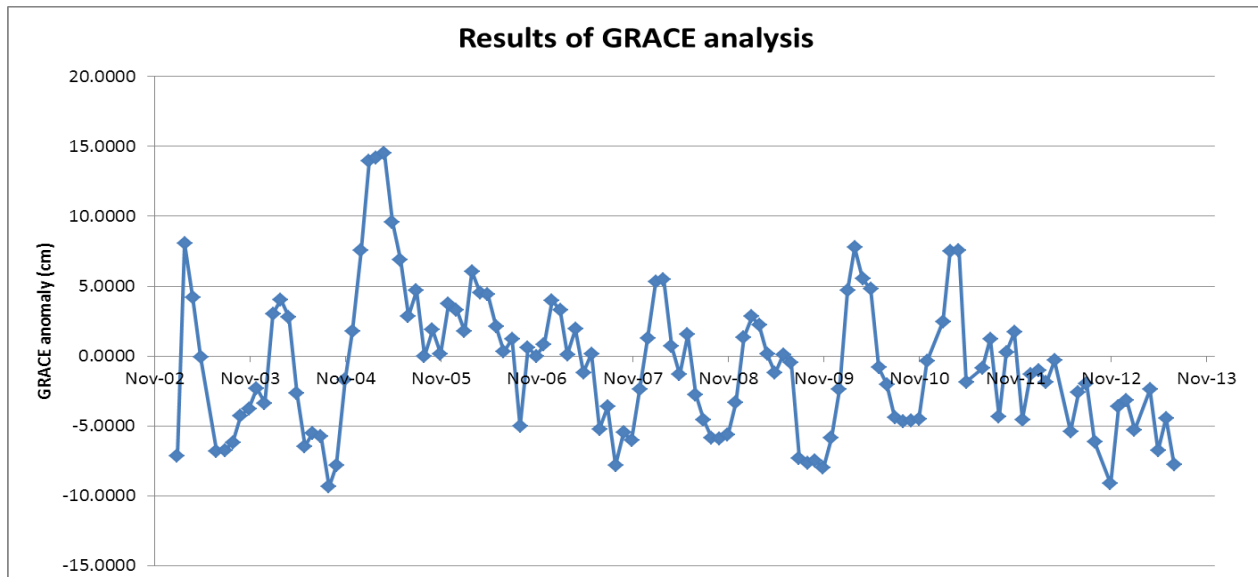


Figure 8: Plot of the GRACE anomaly over the ten-year time period. Note the seasonal cycles.

The change in net storage was calculated by subtracting the anomaly of the previous time step from the current time step and summing these monthly changes over a water year.

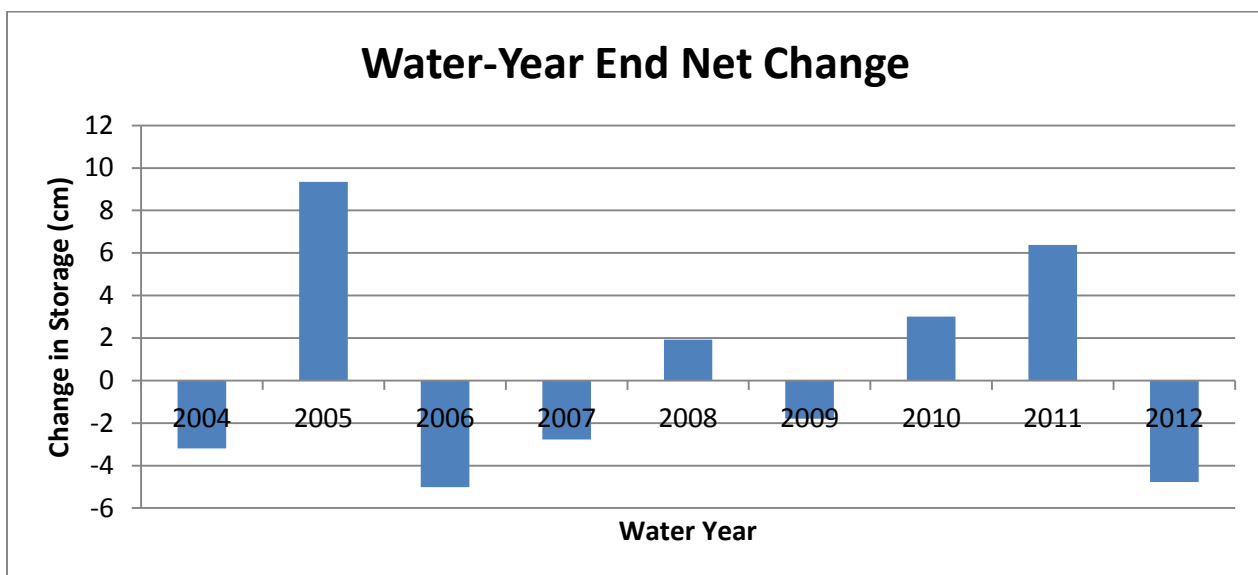


Figure 9: Total net change in storage over the course of each water year.

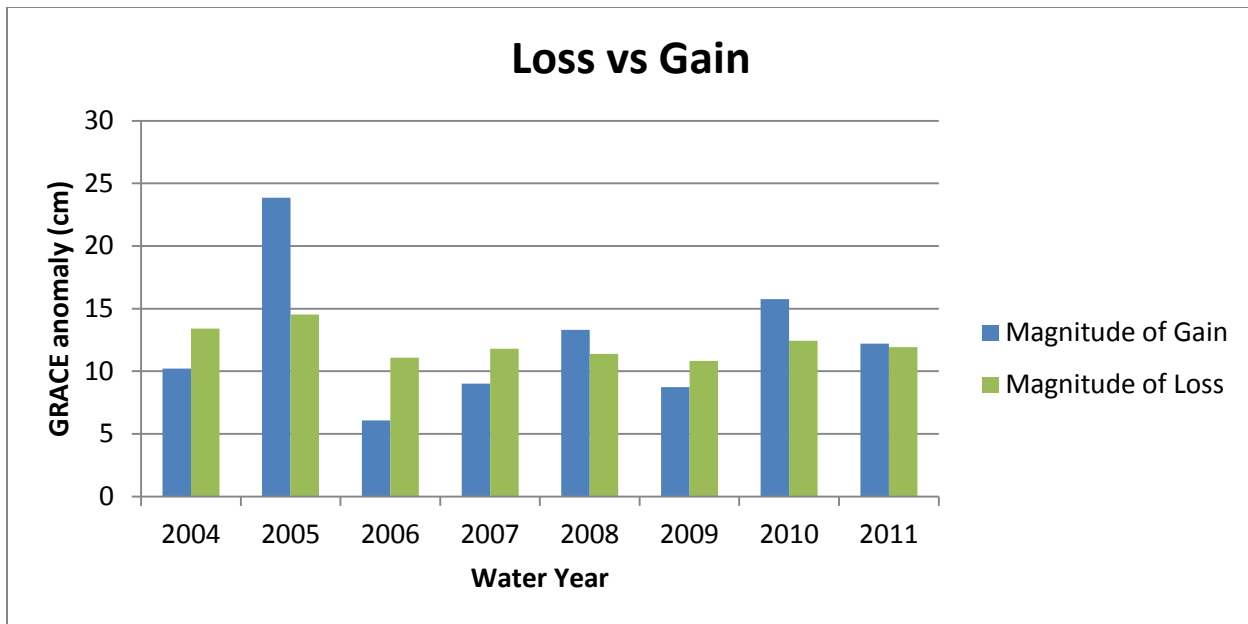


Figure 10: This chart reports the magnitude of each water year's period of recharge and period of decline (see Figure 8). Magnitudes for 2012 are not reported, as this year does not exhibit the typical seasonal pattern and therefore no clear period of recharge or decline was visible.

The daily stream flows obtained from USGS were broken into water years and the minimum daily flow for each year was assumed to approximate the base flow (Figure 11).

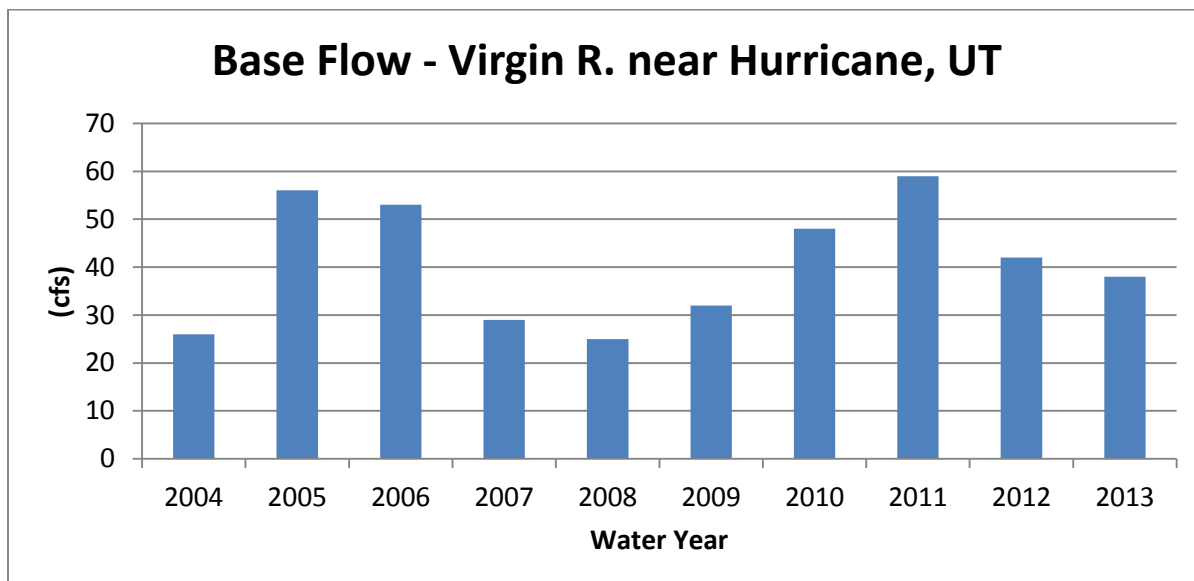


Figure 11: Base flows obtained from analysis of daily stream flows at USGS gage#09408135.

Discussion

The results of the GRACE analysis raise many questions; perhaps the most obvious being “what’s going on with the 2012-2013 data?” The seasonal cycle of recharging from October through March or April and declining during the summer months decays to the point that a loss/gain evaluation (Figure 10) cannot be performed. It is possible that the problem could be in the data, as neither the past weather nor the streamflows (Figure 11) reflect similar patterns. This ties in with the greatest limitation of using GRACE for analysis of this site – without reliable well data to compare against, there is no way to tell how directly the anomalies correlate with the actual groundwater levels.

Figures 8-10 show a large increase in water content for water year 2005. This aligns perfectly with the major flooding events that happened in the region in early spring of 2005, causing significant property damage and infrastructure issues. This is encouraging in that it at least shows that the GRACE data is connected to the greater hydrology of the area.

It was thought that a comparison with baseflows for streams in the study area would help to provide some greater connectivity between the results and other aspects of hydrology. The assumption was made that flow in all of the perennial streams in this arid region is primarily the result of baseflow contributed by the aquifer. Therefore, if the aquifer was being heavily drawn down through agricultural or municipal extraction of groundwater, we would expect to see a similar trend in the baseflow. However, when comparing Figure 11 with Figure 9 or 10, there is no discernable connection between the two.

Even the GRACE data by itself does not seem to suggest any prevalent trend in groundwater storage, suggesting that perhaps the area’s aquifers are not as stressed as had been assumed. Many uncertainties present themselves in this analysis, however. The short time-span of the GRACE data does not lend itself well to predicting long-term trends. The baseflows obtained for the Virgin River could possibly be influenced by upstream control points and diversion. Again, since the Virgin spends a good deal of time outside of the Navajo/Kayenta aquifer, the analysis would be better if streamflow data for a stream exclusive to the aquifer’s drainage area could be found.

Conclusion

While the initial objective of identifying trends in southern Utah groundwater was not accomplished with any amount of certainty, there were other conclusions that can be pulled from the results. As was demonstrated by the flood of 2005, the GRACE dataset is apparently sensitive to the impacts of the other hydrologic factors it interacts with. A seasonal pattern of recharge and drawdown was observed for the study area that also describes patterns of water use. Further investigation into this issue will be required in order to provide more certain results. Possible tactics that were identified but not pursued due to time and resource limitations could include contrasting monthly rainfall with the results, a more detailed search for streams that originate within the aquifer drainage area, or contacting municipal units and individual water right holders to obtain well level information (if any exists) for the area.

References

- Hansen, Allen, & Luce, Inc. (2005). *Petition for classification of the Navajo/Kayenta and upper Ash Creek aquifers – Final Report*. Unpublished consultants report, Midvale, UT.
- Netting, Ruth (2013). “GRACE.” *NASA Science Missions*, <science.nasa.gov/missions/grace/> (6 Dec 2013).
- Onboard Informatics (2013). “St. George, Utah.” *City-Data.com*, <<http://www.city-data.com/city/St.-George-Utah.html>> (6 Dec 2013).
- State of Utah (2013). “Demographic and Economic Projections.” *Governor’s Office of Management and Budget*, <<http://governor.utah.gov/DEA/projections.html>> (6 Dec 2013).

Appendix

This appendix contains the full script for the two python codes used for this project.

GraceExtractVR1.py

```
import arcpy, datetime, os
from arcpy import env
# Check out the ArcGIS Spatial Analyst extension for using the IDW interpolation tool
arcpy.CheckOutExtension("spatial")

gdbname="TermProject.gdb" # geodatabase
Folder=os.getcwd() # Use the current working directory as the folder to work in
env.workspace = Folder
# Folder where rasters will be written. This must exist at start
rasterfolder=r"gracegrids2"
mxdname=Folder+os.sep+"Test1.mxd"
mxd = arcpy.mapping.MapDocument(mxdname)
df = arcpy.mapping.ListDataFrames(mxd, "Layers")[0]
# "Grasters" is the name of the image files copied to the Table of Contents
for lyr in arcpy.mapping.ListLayers(mxd, "Grasters", df):
    print lyr
    for lyr2 in arcpy.mapping.ListLayers(lyr):
        print lyr2
        cols=str(lyr2).split("\\")
        if(len(cols)>1):
            outname=rasterfolder+os.sep+cols[1] + ".tif"
            print outname
            arcpy.CopyRaster_management(lyr2,outname)

print "done running"
```

ZonalAverageStGeorge.py

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

# Inputs -----
gdbname="TermProject.gdb" # geodatabase
```

```

zones="WashingtonCo" # Name of zone (basins) feature class in geodatabase
mosaic = "Mosaic2" # Name of mosaiced layer in geodatabase that is to be zonally averaged
outtab = "GWtableWashCo" # Name of table for zonal averaged data to be written in
geodatabase. The script will create this file
tempfolder="temp" # name for temporary folder used for intermediate zone average tables
# End of inputs -----

arcpy.CheckOutExtension("spatial") # Check out a spatial analyst license
Folder=os.getcwd() # Use the current working directory as the folder to work in
env.workspace = Folder

# Establish proper paths
zonestape=gdbname + os.sep + zones # Basin feature class
theMosaic=gdbname + os.sep + mosaic # The mosaiced layer that is being zonally averaged

# If temporary folder does not exist, create it
if not os.path.isdir(tempfolder):
    os.makedirs(tempfolder)
else: # Write a message and exit
    print "A folder already exists at the location: " + tempfolder
    print "Delete or move this or use a different temporary folder location"
    quit()

dates=[] # list to hold dates
vals=[] # list to hold values
# Loop over all the mosaic values
with arcpy.da.UpdateCursor(theMosaic,["OBJECTID","Raster","YYYYMM"]) as cursor:
    for row in cursor:
        # Deduce date from the YYYYMM column and append it to our list
        dates=dates+[datetime.datetime.strptime(row[2],'%Y%m')]
        # Create an output table for zonal statistics in the temporary folder
        zonetable=Folder + os.sep + tempfolder + os.sep + "t" + row[2] # to keep unique name
        outZSaT = ZonalStatisticsAsTable(zonestape,"OBJECTID",row[1],zonetable,"", "MEAN")
        tableRow = arcpy.UpdateCursor(zonetable)
        # zone table only has one row. Extract its mean
        for linerow in tableRow:
            meanValue = linerow.MEAN
            vals=vals+[meanValue] # Append the mean to our list
# Clean up by removing unused objects to removes locks on the database
del linerow
del tableRow

# Write results to a table
tabnamefull=gdbname+os.sep+outtab
field1="Date"
field2="Value"

```

```
arcpy.CreateTable_management(gdbname, outtab, "", "") # Create Table
arcpy.AddField_management(tabnamefull, field1, "DATE", "", "", "", "", "") # Add date field
arcpy.AddField_management(tabnamefull, field2, "FLOAT", "", "", "", "", "") # Add Value field
rows = arcpy.InsertCursor(tabnamefull, "")
for i in range(len(vals)):
    line = rows.newRow()
    line.setValue(field1, dates[i])
    line.setValue(field2, vals[i])
    rows.insertRow(line)
    print str(dates[i])+", "+str(vals[i])

# Clean up
del line
del rows
try:
    if os.path.isdir(tempfolder): # Remove temporary folder
        shutil.rmtree(tempfolder)
except:
    print "Unable to delete temporary folder: "+tempfolder
print "Done"
```