Comparison of Streamflow and Precipitation in the Upper Provo River Watershed

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Introduction

Every year streams receive different amounts of precipitation that eventually contribute to streamflow. The Provo River is no exception, as the streamflow in the river can vary significantly depending on the amount of precipitation that falls. The Provo River originates in Summit County, Utah and eventually flows into Utah Lake. However, this river is unique in that it passes through two reservoirs before it reaches Utah Lake. The focus of this project was the Upper Provo River watershed which is the area upstream of Deer Creek Reservoir. The purpose of this project is to determine the variability of the runoff ratio within the Upper Provo River watershed. This variability will in turn show the difficulties with predicting yearly runoff ratios, yet the general trend in this watershed.

Methods to Determine Runoff Ratios

The first step was to determine what data was available to complete the analysis. The topography, streamflow, precipitation, and Jordanelle reservoir data were the data types needed. The first source that was used to locate data was the US Geological Survey (USGS), which includes stream gage information for streams around the United States. Along the Provo River, four gages were found upstream of Deer Creek Reservoir. All four gages started reading data at different years with the Hailstone gage starting in 1949, Woodland (1960), Charlestown (1991), and River Road (2001). The monthly average streamflow for each available year was downloaded and used in subsequent calculations. The exact locations of these gages were found from the USGS, which publishes the latitude and longitude coordinates. The coordinates provided were from the datum, North American 1927 (NAD27). Thus, the shapefiles of each stream gage point was projected to a Transverse Mercator Projection that was appropriate for the Provo watershed (NAD_1983_UTM_Zone_12N). The following map (Figure 1), created in ArcMap 10.1, shows the location of these stream gages.

Figure 1: Location of four streamgages used in the analysis.

Once it was determined that these stream gages contained sufficient streamflow data, the topography of the watershed was then found. A 30m digital elevation map (DEM) from the United States National Elevation Map website was located (USGS, 2012b). This DEM was downloaded as two files and the two files were then added to ArcMap where many tools were used to delineate the Upper Provo River watershed. The first tool was the *Mosaic* tool to combine the two DEM's into one workable DEM. The *Clip* tool was then used to create a more appropriate size for the watershed delineation. The new DEM wasn't projected properly, so the *Project Raster* tool was used to project this raster to the NAD_1983_UTM_Zone_12 projection. The cell size was also projected to 100 meters so that the calculation times of the future ArcMap tools would be minimal. Figure 2 shows the projected DEM:

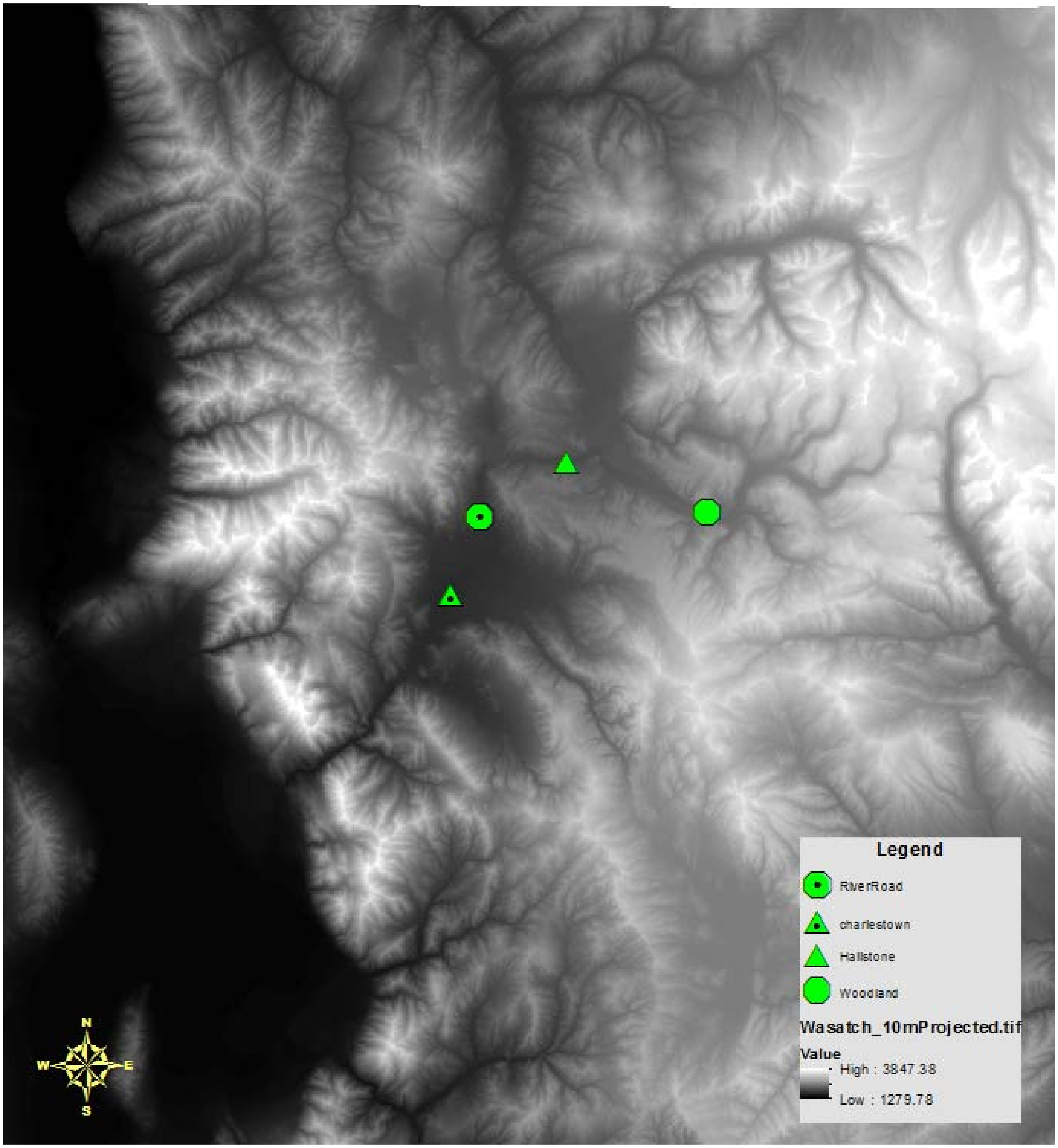
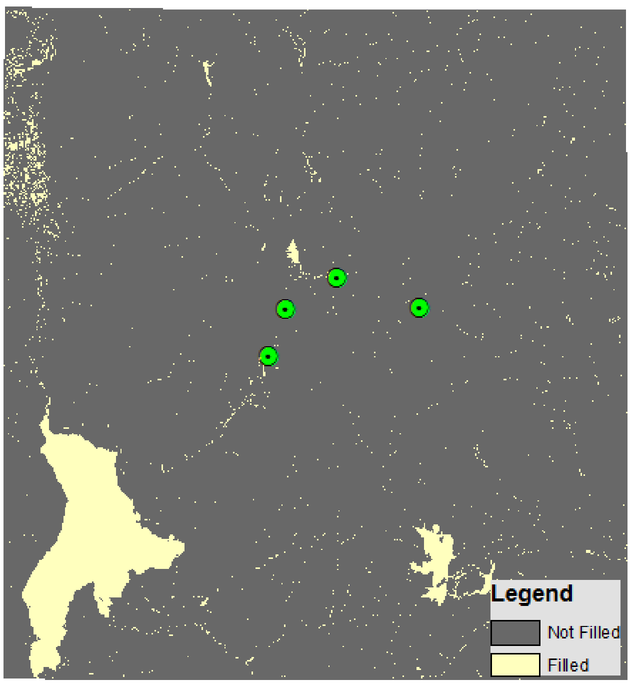


Figure 2: Projected DEM with Streamgages

Knowing that the cell size for subsequent calculations was 100 m X 100 m was very crucial for the interpretation of the results as will be shown in the results section. After the stream gage locations were found and the DEM properly projected; the watershed delineation could then be accomplished.

To delineate the watershed, tools from TauDEM were used. TauDEM is an abbreviation for Terrain Analysis Using Digital Elevation Models and was developed to analyze hydrologic features from a DEM (Utah State University Hydrology Research Group, 2010). The first tool used was called *Pit Remove*. This tool fills any areas of the DEM that may not drain to the river by filling them with an elevation to the lowest of their neighbors. This will allow the analysis to make the assumption that all cells will drain to a stream. Figure 3 shows the cells that were filled and the resulting DEM with the streamgages for reference.



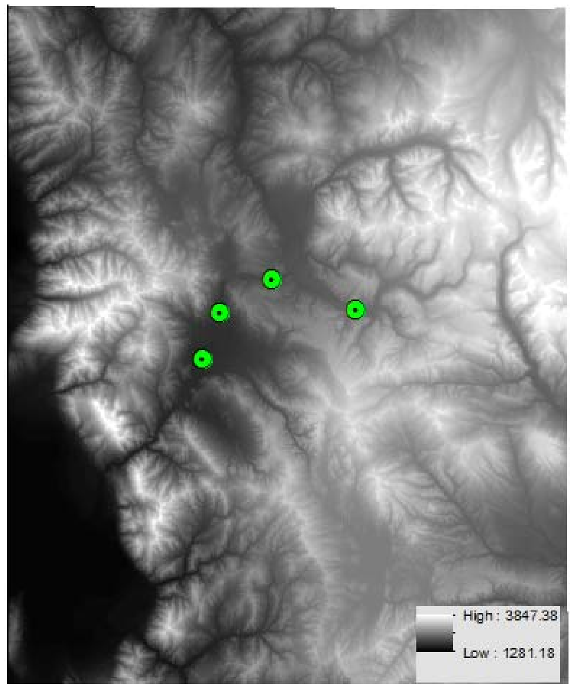


Figure 3: Cells that were filled with Pit Remove function and resulting DEM.

As can be seen from the above figure, the elevations now range from 1281.18 meters to 3847.28 meters. Whereas, the original DEM ranged from 1279.78 m to 3847.28 m. With the pits filled, the next tool used was the *D8 Flow Direction*.

The *D8 Flow Direction* shows the direction to its downslope neighbor. This tool creates directions ranging from 1 to 8. One represents east with the other numbers following in clockwise direction with 8 representing a northeast direction. Figure 4 shows the flow direction for the area of study.

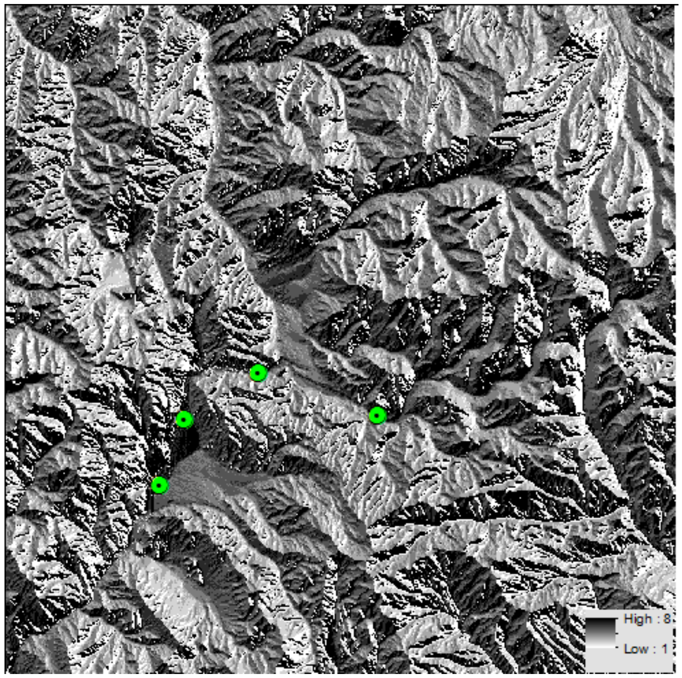


Figure 4: Flow Direction for the entire DEM.

The *D8 Flow Direction* also produces a raster of the slope. This is shown in figure 5.

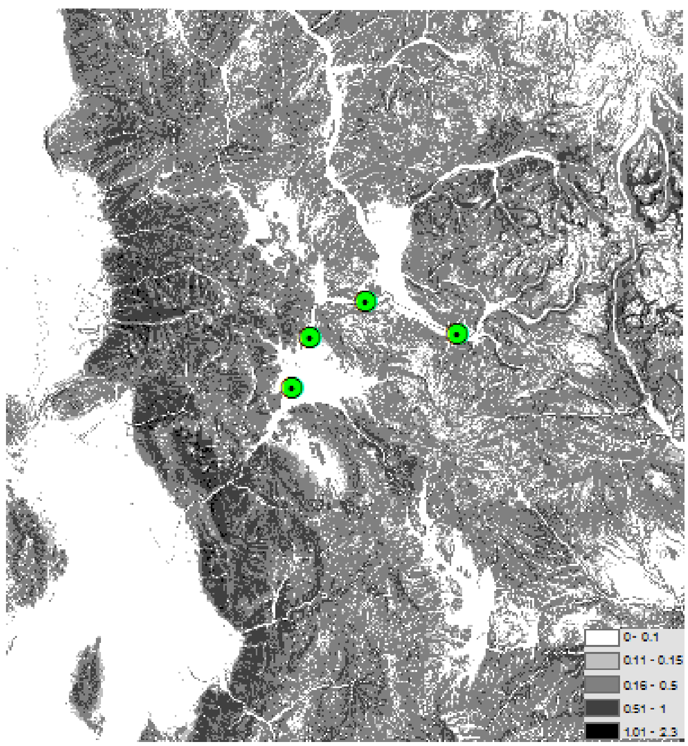


Figure 5: Slope Direction obtained from the D8 Flow Direction tool.

After the flow directions and slope were calculated, the *D8 Contributing Area* tool was used to calculate the contributing area for the entire DEM. This tool calculated the number of grid cells draining from each cell. The contributing area result was then used by the tool *Stream Definition by Threshold*, which creates a stream raster based on a minimum number of cells draining into a cell. For this step in the analysis a threshold of 500 was used to locate the streams. Below in Figure 6 is the result zoomed in near the stream gages.

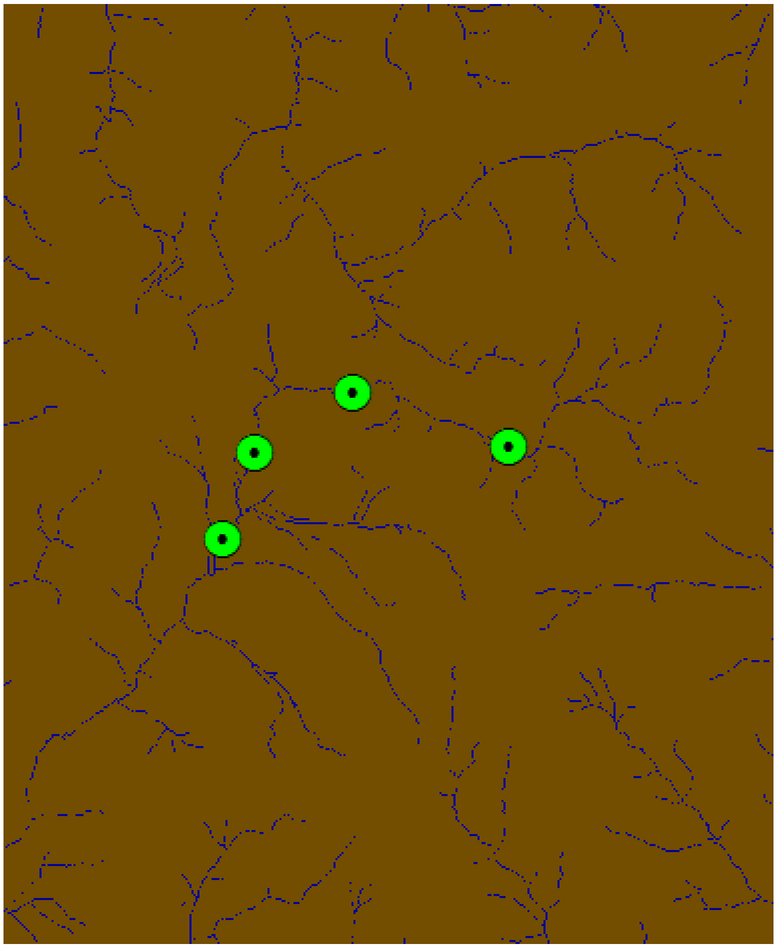


Figure 6: Streams shown, based on a threshold of 500 grid cells draining to a stream.

The above process was completed for the entire watershed, because the stream gages were slightly located off the streams. By moving the gages one or two cells, they were directly on the stream and the analysis could continue.

The *D8 Contributing Area* tool within TauDEM allows for an outlet point to be specified. When an outlet point is specified, then only the area upstream of the point will be calculated. This was completed for each of the four gages, with each resulting with a contributing area. Then, the stream definition by threshold tool was used for each gage. This time a threshold of 100 was used, meaning that a cell must have 100 cells draining to it before a stream is created.

After the above steps were successfully completed; the tool *Stream Reach and Watershed* was used to fully delineate the watershed above each gage (See Appendix A). Each stream and subwatershed was labeled with unique identifiers and the area of each watershed could now be computed by using the identify tool and clicking on the outlet points. This gave a number of cells that drains to each gage. This number was then multiplied by the cell size, 100 m * 100 m, which resulted in an area of square meters for each watershed. This value was then converted to square feet to provide for correct units. A summary of these results is shown in Table 1.

Table 1: Areas calculated from Watershed Delineations

Gage Station	*Number of Cells (Identify tool)*	*Upstream Area (m^2) (100 m X 100 m Grid Cells)*	*km^2*	*mi^2*	*ft^2*
Charlestown	96646	966460000	966.46	373.15	**1.04E+10**
RiverRoad	69705	697050000	697.05	269.13	**7.5E+09**
Hailstone	59149	591490000	591.49	228.38	**6.37E+09**
Woodland	44634	446340000	446.34	172.33	**4.8E+09**

The above steps led to the acquisition of streamflow data and watershed areas. However, precipitation data was also crucial to the analysis. The determination was made that monthly data would be sufficient for precipitation data as this project will show the yearly runoff ratios. By using monthly data, the averages attained for each year were determined to be adequate. Another consideration during the acquisition of precipitation data was the concern of error from conversions and interpolating. To reduce this error while still obtaining accurate monthly averages, it was determined that gridded data would be the best option; and PRISM data from Oregon State University would be the best source (Oregon State University, 2012).

The challenge of using PRISM data over a long period of time is the increased burden of downloading each month of data for many years. Since four gages and thus, four watersheds were used for this analysis; this could become a very tedious and time-consuming process. In order to reduce the download time, a script within the mathematical program, R, was used to download the necessary PRISM data for each watershed area. See Appendix B for a more detailed explanation involving this script.

The monthly precipitation averages for each watershed was collected and an average yearly value of precipitation was found by adding the monthly averages (See Appendix C). This value was then converted from mm/year to feet/year.

The streamflow data was determined in two ways. The flow in the gages at Woodland and Hailstone were acquired in monthly cubic feet per second (cfs) averages. These values were summed for each year and then divided by twelve to get a yearly average. This value was then converted to cubic feet per year. The other two gages are downstream of Jordanelle reservoir which causes the streamflow to be influenced by the reservoir. The analysis for this project was to determine the natural runoff ratio, so the most accurate value of streamflow at these points would be the Jordanelle reservoir inflows from the Provo River. The Bureau of Reclamation records the daily inflow and outflow during each day of the year. This information was obtained and an average value of streamflow for each month was calculated (Bureau of Reclamation, 2012b). These averages were summed and converted to give a yearly average in cubic feet per year for the River Road and Charlestown gages (See Appendix D).

The unit area discharge (q) was computed by taking the streamflow at each gage (cubic feet/year) and dividing it by the area of each watershed (square feet). To determine the runoff ratios (r) for each watershed, the unit area discharge was divided by the precipitation average (feet/year). This unit less runoff ratio was computed for every year that each stream gage had available data.

Results and Discussion

The runoff ratios that were calculated from the above analysis are summarized by the following graph (Figure 7). The runoff ratio is plotted on the y-axis with the years on the x-axis. All four gages are shown on the same graph.

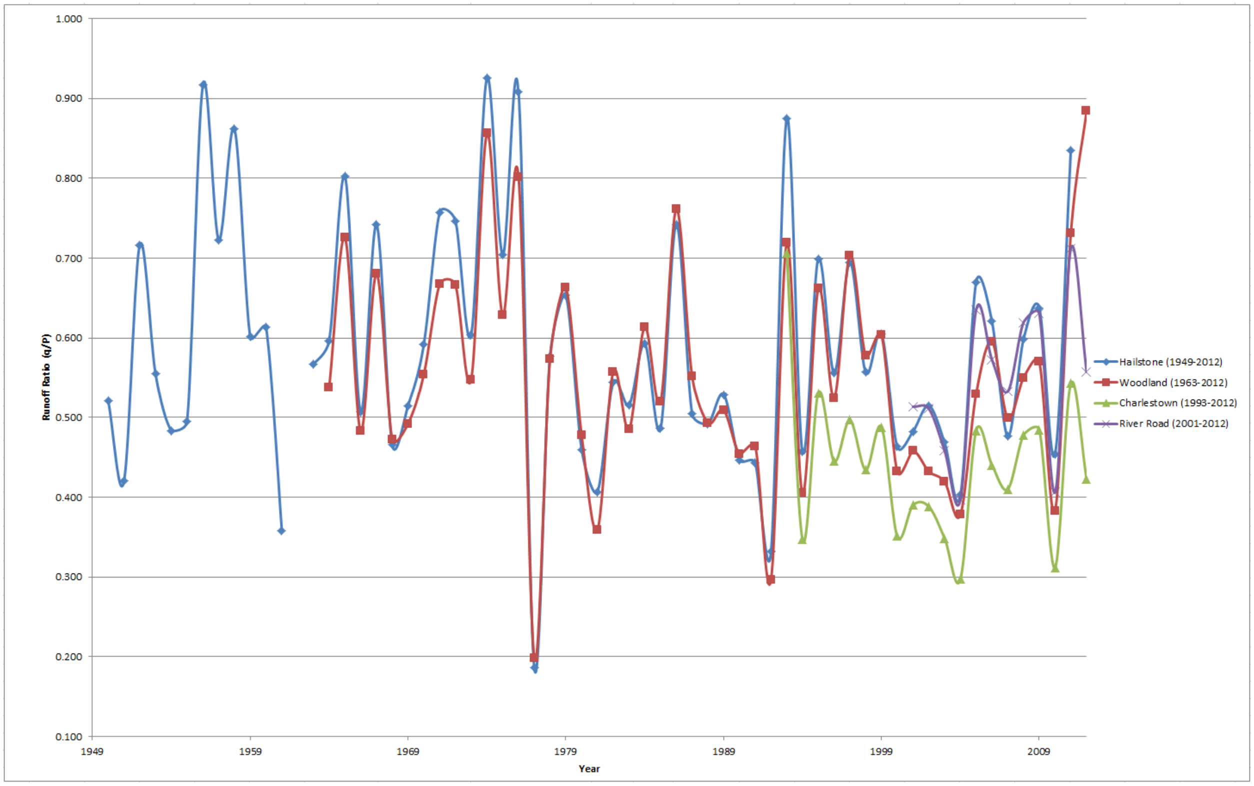


Figure 7: Runoff Ratios calculated for the Provo River Watershed.

As this graph illustrates, the runoff ratios from year to year vary significantly. However, each of the four gages seems to follow the same general trend. This shows that the soils in this region act similarly and that the whole watershed has similar characteristics. On any given year, the runoff ratio is very similar between gages. Although uniformity exists among the gages, values of 0.9 for a runoff ratio are too high for Utah. This shows that even though every precaution was taken to obtain the best precipitation data; that PRISM may even fall short in evaluating the precipitation in this area accurately.

A more likely source of the error however, is the streamflow data. Recently information was obtained that a six-mile long tunnel runs from the Duchesne River and connects to the Provo River. This tunnel has the capacity to deliver 630 cfs during the spring. However, the flows are usually substantially lower than the maximum capacity of the tunnel. For example, during the past month, the Duchesne Tunnel has only averaged a flow of 10.3 cfs (PRWUA, 2012). This amount of flow is minimal when compared with the yearly averages at the gages, which are around 200 cfs (See Appendix E). No historical data for flows at the Duchesne Tunnel could be obtained previous to November 6, 2012; thus, the assumption is made that slight errors in the streamflow have occurred because of neglecting the tunnels impact. The high runoff ratios could thus be explained from a combination of inaccurate PRISM data, and slightly higher than natural streamflow because of the tunnel.

Further investigation was explored as to how the runoff ratios have varied once the reservoir has been built. The assumption that the flow at the Charlestown streamgage was the reservoir inflow was explored in greater detail. The following figure, Figure 8, shows the runoff ratio computed from this assumption (green line), and the runoff ratio computed from the streamflow measurements by the streamgage (turquoise line).

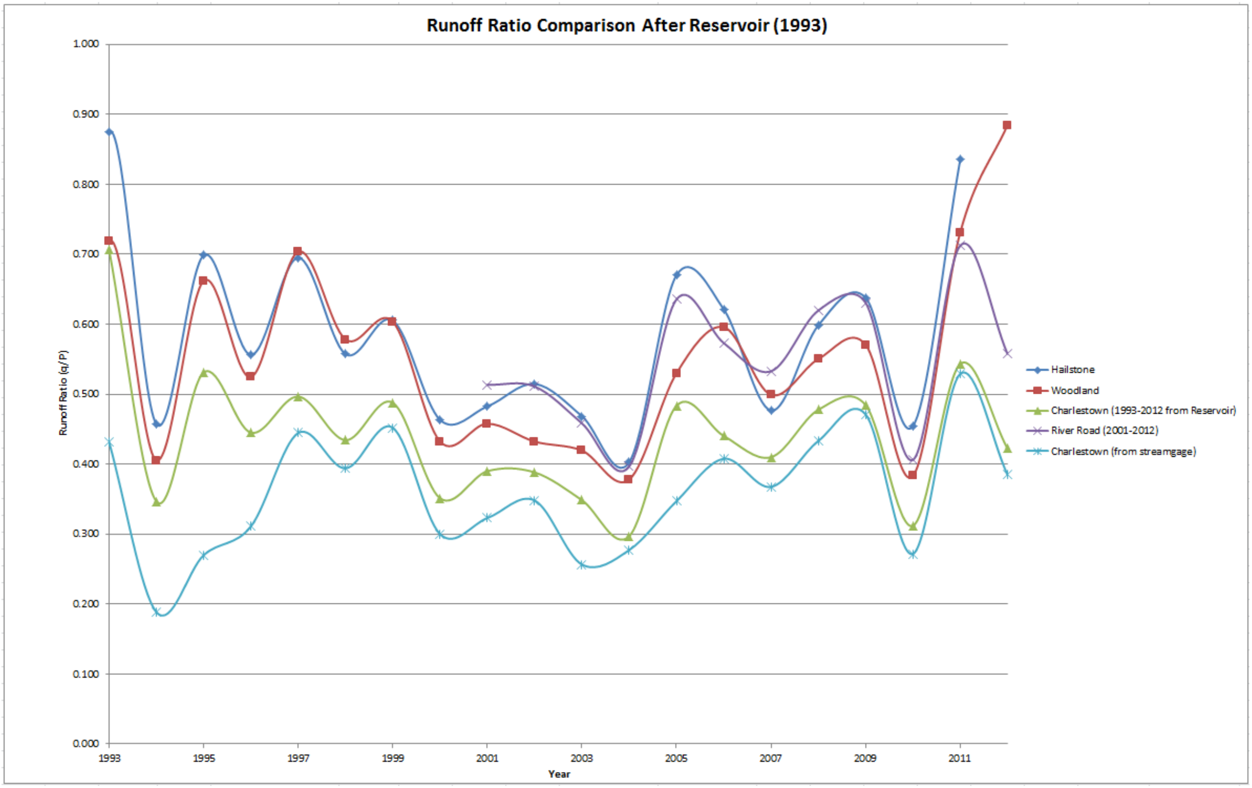


Figure 8: Runoff Ratio Comparison after Jordanelle was built with Charlestown gage showing both measured streamflow and reservoir assumption.

This graph shows that the runoff ratios calculated from the reservoir inflow are much closer to the other three gages. The flow measured by the streamgage at Charlestown is greatly influenced by the amount of water that is released by the reservoir, thus causing certain years to differ from the other gages significantly.

Conclusion

Through the use of ArcMap and other programs, comparisons of the runoff ratios in the Upper Provo River watershed were obtained. These runoff ratios were similar between all the gages, which shows that this watershed has similar characteristics. Some of the runoff ratios were unrealistic, which shows that some years of data may have errors in measurement. Whether the errors came from the PRISM data obtained or the streamgages is unknown. Overall, ArcMap is a powerful tool that can be used in the analysis of watersheds and runoff coefficients

References

Bureau of Reclamation (2012a). “Jordanelle Reservoir.”,<http://www.usbr.gov/projects/Facility.jsp?fac_Name=Jordanelle%20Dam> (26 November 2012).

Bureau of Reclamation (2012b). “Jordanelle Reservoir Inflow/Outflow.” <http://www.usbr.gov/uc/crsp/GetSiteInfo> (November 21, 2012).

Oregon State University (2012). “PRISM Products Matrix.” <http://www.prism.oregonstate.edu/products/matrix.phtml> (13 November 2012).

PRWUA (2012). “Duchesne Tunnel.” < http://www.prwua.org/provo-river-project-features/duchesne-tunnel-system/duchesne-tunnel.php> (5 December 2012).

USGS (2012a). “National Water Information System.” *USGS surface water statistics.* <http://waterdata.usgs.gov/ut/nwis/current/?type=flow> (1 November 2012).

USGS (2012b). “National Map Viewer.” 10 and 30 m Digital Elevation Models (DEM). <http://viewer.nationalmap.gov/viewer/> (15 November 2012).

Utah State University Hydrology Research Group (2010). “Terrain Analysis Using Digital Elevation Models (TAUDEM).” <http://www.prism.oregonstate.edu/products/matrix.phtml> (5 November 2012).

Appendix A: Watershed Delineation

This appendix shows the final watershed delineation of each of the four watersheds. The areas for these watersheds was obtained by using the identify tool at the outlet to determine the number of grid cells that drained into the gage location. By knowing the cell size to be 100 m X 100 m, the area of each watershed could be calculated. Figure A.1 shows the watershed delineated upstream of the Charlestown gage. The area was found to be 373.15 square miles.

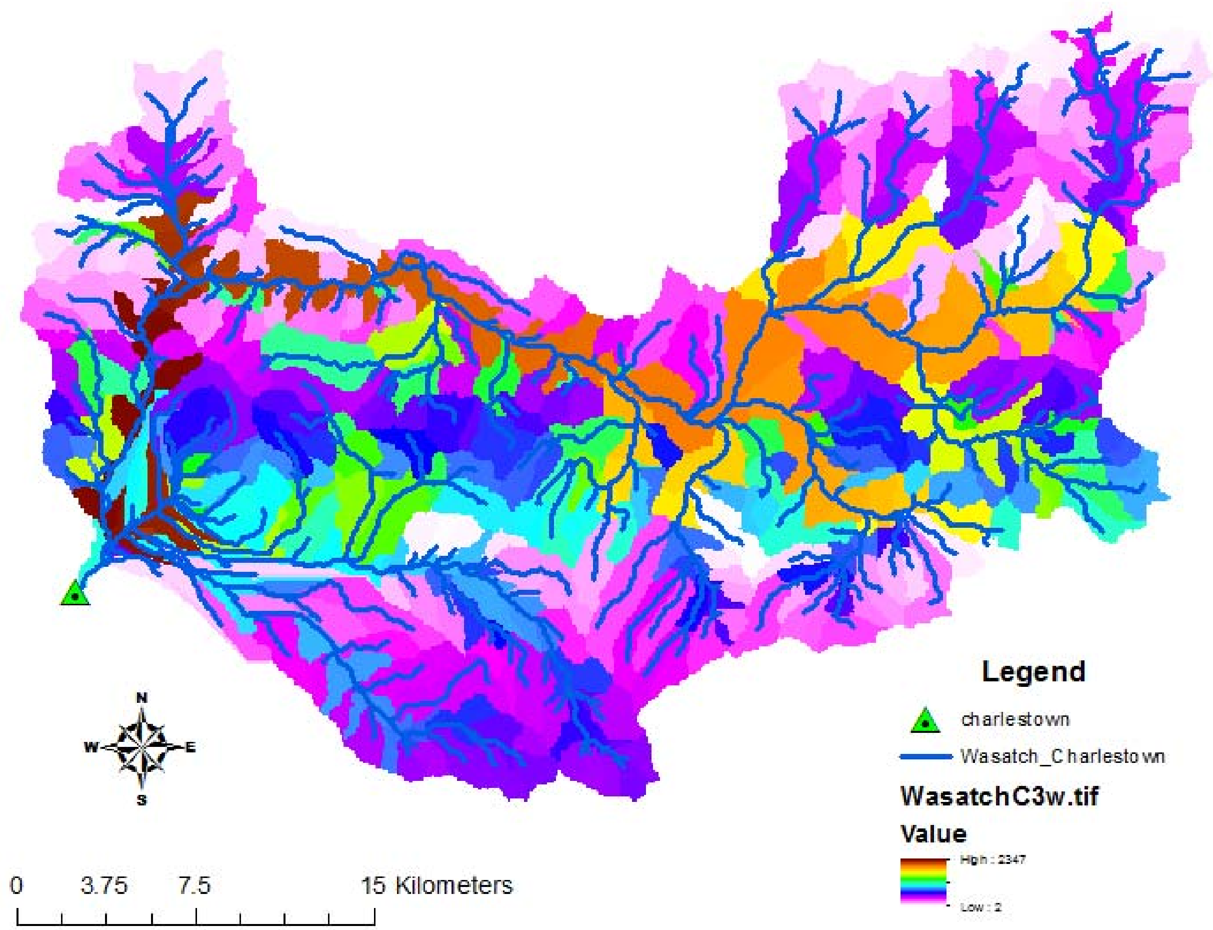


Figure A.1: Watershed Delineation upstream of Charlestown gage

The next watershed that was delineated was the one upstream of the river road gage. The result produced an area of 269.13 square miles for this watershed and the result is shown in figure A.2.

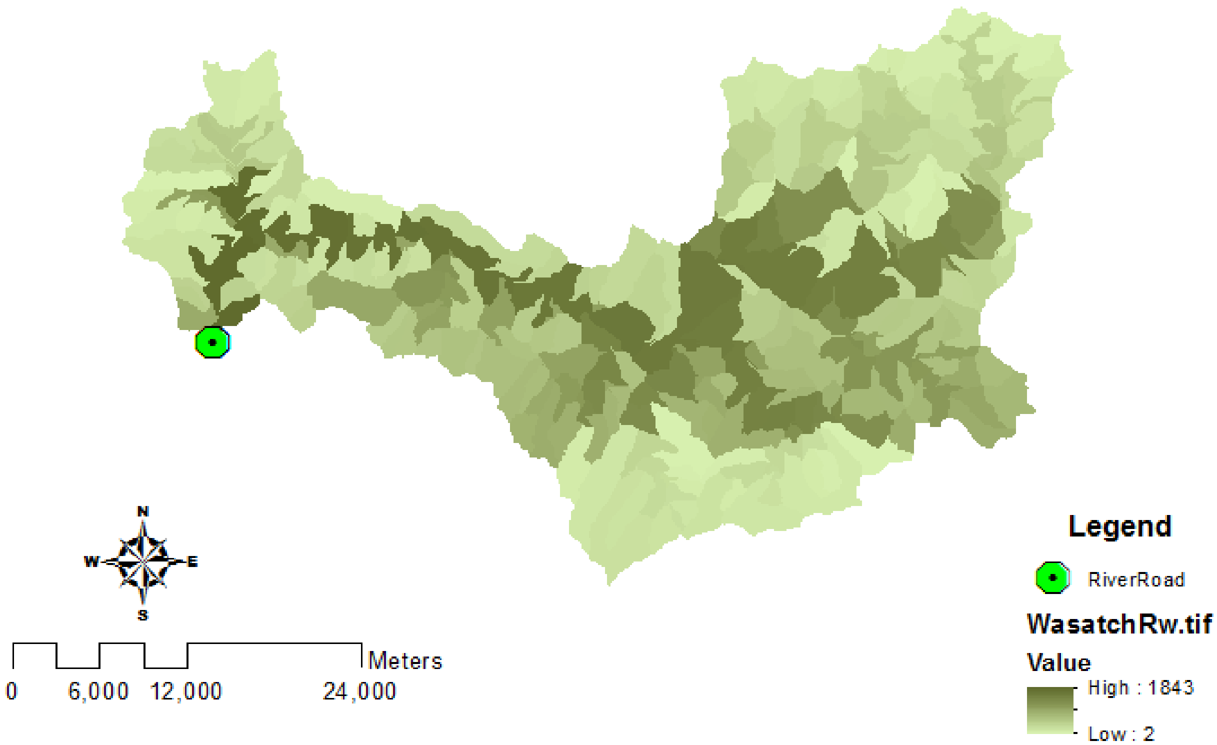


Figure A.2 Watershed delineation upstream of River Road gage.

The next two gages upstream were the hailstone gage and the woodland gage. The area upstream of the hailstone gage was found to be 228.38 square miles as shown in figure A.3. Then, the area upstream of the woodland gage was found to be 172.33 square miles as shown in figure A.4.

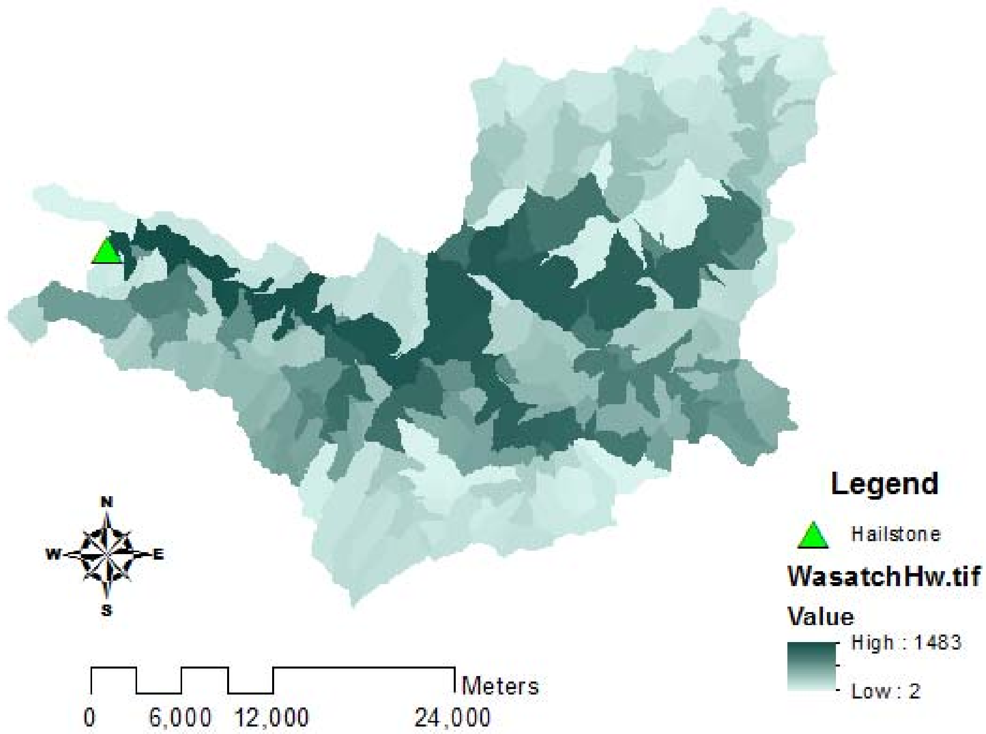


Figure A.3: Watershed delineation upstream of the Hailstone gage.

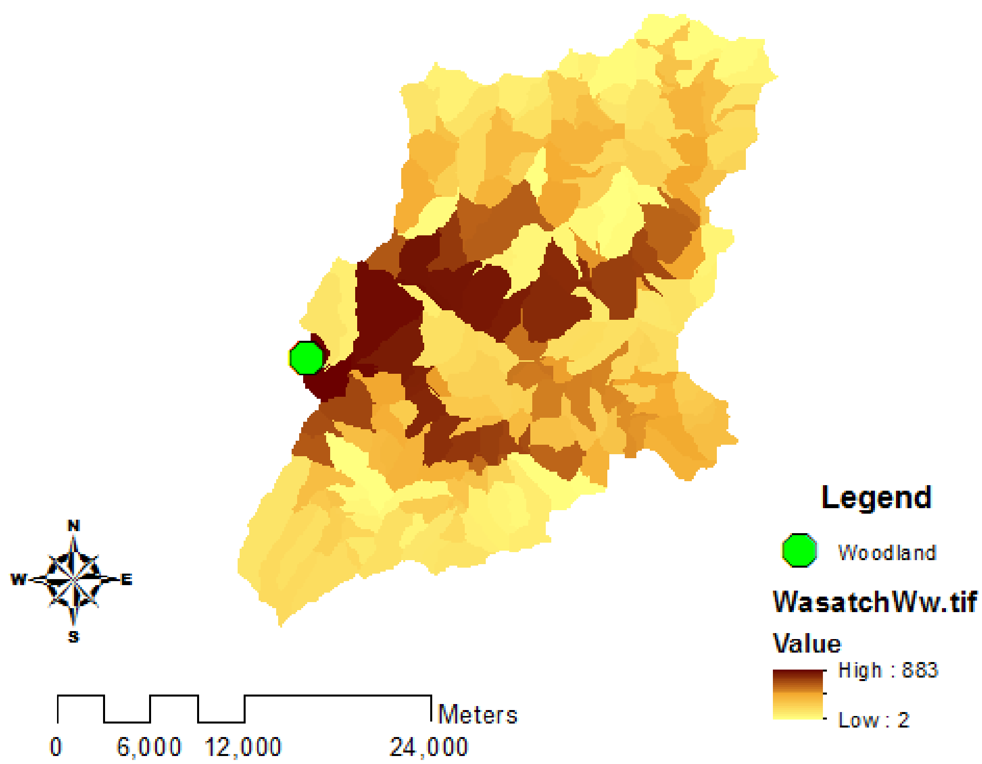


Figure A.4: Watershed delineation upstream of the Woodland gage.

Appendix B: R Script for downloading of PRISM data

This script was initially created by Dr. David Tarboton for the Great Salt Lake Basin. Through several modifications, the program was edited for use in the Provo River watershed. Before this script could be used, several items needed to be completed within ArcMap. First, the gridded data available from PRISM had to be downloaded as a shape file for the entire United States. Then, only the points within the watershed areas had to be selected so that the precipitation averages would only be calculated over the watershed. Thus, the Charlestown watershed had a larger amount of points to average the precipitation over than the other watersheds. Sequentially, the Woodland watershed had the least amount of points from which the precipitation would be averaged. Figure B.1 shows the points that were selected for the Charlestown watershed and figure B.2 shows the points that were selected for the Woodland watershed. Similar shapefiles were created for the Hailstone and River Road areas.

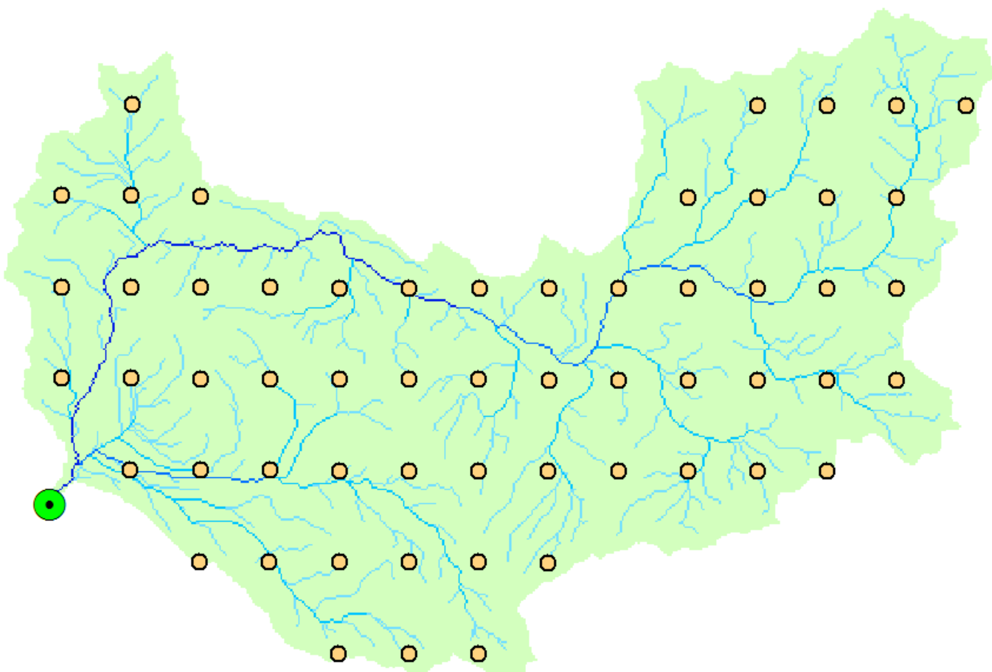


Figure B.1: PRISM points within the Charlestown watershed that were selected, from which a shapefile was created.

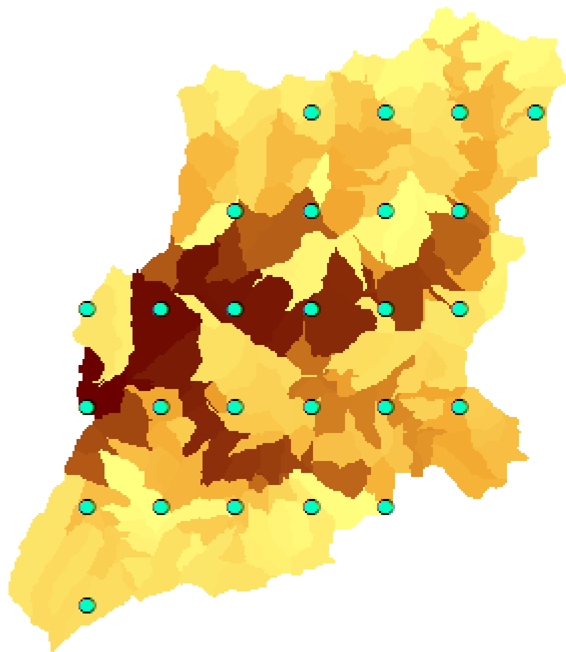


Figure B.2: PRISM points within the Woodland watershed that were selected, from which a shapefile was created.

Once the shapefiles were created for each watershed area, the years to acquire the data from PRISM were determined. PRISM data comes in folders every ten years, thus, the format to correctly reference these folders had to be followed. For example, the Woodland gage needed data from 1960-2012. Table B.1 shows how these years would be entered into a table that would be referenced by R.

Table B.1: Example of entering years of interest into a table that can be referenced by R.

folder	year_start	year_end
2010-2019	2010	2012
2000-2009	2000	2009
1990-1999	1990	1999
1980-1989	1980	1989
1970-1979	1970	1979
1960-1969	1960	1969

Once the above work is completed, then the script is ready to run. Within the script, the first section is a function that was created to reference a folder of years from which to download data. This function uses the RODBC library, which is most easily used in the 32-bit version of R. The second section within the script then references this function and extracts the data from only the shapefile that was created in ArcMap. Then the results are output in a table for readability and easy interpretation.

The following script is an example of the script used for the Woodland watershed. A location must be set for the data to be stored, for this example, the location is *G:/PRISM-DATA-2/Woodland*. The file, *PrismFoldersYrs2*, is the excel file that includes Table B.1 which has the years to extract the data. The file *Woodlandppt.dbf* is from the shapefile created within ArcMap that has the points within the Woodland watershed selected as shown in Figure B.2. The function is shown in Figure B.3 and the code for the operating of the program is shown in Figure B.4.

```
###function to download data from PRISM website
####The data is continental monthly precipitation
####the data resoultion is 2.5 arcmin with units millimeters
####scale factor is 100

setwd("G:/PRISM DATA-2/Woodland")


Get_Prism_Data=function(file="PrismFoldersYrs2.xlsx",dt="ppt",savefolder="precip")
{
#.xlsx contains info about the folders required for download
library(RODBC)
channel <- odbcConnectExcel2007(file)
tt<-sqlFetch(channel,"Sheet1")
odbcCloseAll()
Folder_Name<-tt$folder
year_start<-tt$year_start
year_end<-tt$year_end
#formatting the months for downloading
ss<-c(".01",".02",".03",".04",".05",".06",".07",".08",".09",".10",".11",".12")
# doing loop for each folder
kk<-length(Folder_Name)
for (i in 1:kk)
{
path<-paste("ftp://prism.oregonstate.edu//pub//prism//us//grids//",dt,"//",as.character(Folder_Name[i]),"//",sep="")
temp_files<-seq(year_start[i],year_end[i])
      for(j in 1:length(temp_files))
            {
            file<-temp_files[j]
                              for(k in 1:length(ss))
                                    {
                                    mo<-ss[k]
                                    path_2<-paste(as.character(path),"us_",dt,"_",as.character(file),as.character(mo),".gz",sep="")
                                    download.file(path_2,paste(getwd(),"/",savefolder,"/us_",dt,"_",as.character(file),as.character(mo),".gz",sep=""))
                                    }
            }
}
}
```

Figure B.3: Function within R that references years folder and extracts data from PRISM website.

```
# Get PRISM Data
Get_Prism_Data("PrismFoldersYrs2.xlsx")

####function to extract the climate data
Prism_extract=function(monthseq=seq(as.Date("1943/10/1"),as.Date("1991/11/1"),by="month"),filePrefix="./Precip/us_ppt_",GridDBF="../GIS/GSL_Climate_prism.dbf")
{
#  Given a filename prefix (that may contain folder), sequence of dates and dbf file containing grid locations to extract
#  return a vector of the precipitation
# The function reads the prism monthly zip files and outputs average values
# for specific points defined for the GSL basin taken from GridDBF
# this function can be used to get average Precip, minimum and maximum air temperatures as well as dew point temperature
library(RODBC)
library(foreign)
Prism_grids<-read.dbf(GridDBF)
months<-length(monthseq)# is number of months equal to the avaliable zip files
#GSL_list<-vector("list",months+1)
values=NA
result=NA
# this list will contain for each month the list of PRISM values matching grid cells in grids input
# the last entry in the list "months+1" will contain the mean of these as a vector for each month
# only the last is returned
ROWS<-Prism_grids$Row
COLS<-Prism_grids$Col
data<-matrix(NA,max(ROWS),max(COLS))
######extract the files and getting the precip time series
for (i in 1:months)
{
      gfile=paste(filePrefix,format(monthseq[i],"%Y.%m.gz"),sep="")
      print(gfile)
      flush.console()
      x<-readLines(zz <- gzfile(gfile))
      close(zz,x)
#reading the PRISM data upto the GSL Basin only!
      for(q in 1:(dim(data)[1]))
      {
            data[q,1:dim(data)[2]]<-as.numeric(strsplit(x[-(1:6)][[q]]," ")[[1]][2:(1+dim(data)[2])])
      }
            for(j in 1:(dim(Prism_grids)[1]))
            {
                  # GSL_list[[i]][j]<-data[ROWS[j],COLS[j]]/100 #here I scaled the record
                  values[j]=data[ROWS[j],COLS[j]]/100 #here I scaled the record
            }
result[i]=mean(values)
#GSL_list[[months+1]][i]<-mean(GSL_list[[i]])
}
#return(GSL_list[[months+1]])
return(result)
}

#  Extract designated months of PRISM data
month=seq(as.Date("1960/1/1"),as.Date("2012/10/1"),by="month")

temp=Prism_extract(month,filePrefix="./Precip/us_ppt_",GridDBF="./Woodlandppt.dbf")

df=data.frame(months=month,ppt=temp)
write.table(df,file="precipwoodlandtable.csv",sep=",",row.names=F,qmethod="double")
```

Figure B.4: Remaining code within R that extracts data from PRISM.

This script was used for each sub watershed to determine the monthly average precipitation for the years desired.

Appendix C: Summary of PRISM Data Collected

Within this Appendix is the PRISM data that was downloaded from the program R. The precipitation monthly averages were only used for the years that the streamgage existed. The PRISM data downloaded for the four watershed areas is shown in the following tables; Table C.1 (Charlestown), Table C.2 (RiverRoad), Table C.3 (Hailstone), and Table C.4 (Woodland). After this data was downloaded, the monthly averages for each year were added together in order to give a precipitation amount per year. This value in mm/year was then converted to ft/year to allow for calculations to be completed in feet.

Table C.1: Precipitation data for the Charlestown Watershed

CHARLESTOWN PRISM DATA SUMMARY in mm (Oregon State University, 2012)												
	January	February	March	April	May	June	July	August	September	October	November	December
1991	48.38	32.32	91.47	70.31	55.44	33.50	21.62	60.12	47.88	49.92	82.47	18.61
1992	14.00	47.71	38.69	26.44	55.08	29.78	26.04	27.46	17.10	66.01	80.16	96.61
1993	116.80	96.60	68.31	54.99	87.34	54.29	52.96	30.77	18.14	62.34	35.46	23.05
1994	34.73	96.42	46.55	68.45	36.26	3.91	9.47	47.10	32.50	91.37	90.12	43.71
1995	85.49	53.34	107.26	63.12	134.03	56.90	36.83	34.46	28.46	25.16	51.09	75.98
1996	151.92	76.97	82.55	65.87	40.37	21.67	20.66	6.65	54.25	61.50	95.05	149.12
1997	157.01	53.07	33.69	76.60	52.72	53.24	28.06	58.47	85.38	54.45	53.31	34.55
1998	130.88	97.28	78.15	58.16	61.76	106.68	41.04	40.86	35.91	50.87	58.28	32.39
1999	100.88	95.51	37.15	114.23	88.70	37.29	40.97	54.95	23.90	9.19	17.57	55.84
2000	119.66	100.66	55.31	35.41	47.65	19.24	10.09	60.75	49.44	68.45	48.15	70.81
2001	31.16	45.70	38.73	93.15	17.49	13.18	32.63	36.89	16.85	41.55	101.81	76.92
2002	36.38	30.09	64.85	44.61	28.96	7.91	22.58	8.90	93.66	53.04	56.80	49.79
2003	28.23	54.08	66.98	50.78	61.76	57.79	8.52	60.20	23.26	18.79	96.97	108.72
2004	46.48	69.22	30.27	54.53	33.80	40.77	40.38	37.91	25.33	162.08	46.57	87.02
2005	130.80	63.26	73.47	62.09	82.25	47.18	9.34	25.14	27.31	34.28	76.87	140.31
2006	107.96	47.00	90.23	66.56	23.56	27.44	26.34	36.56	71.05	74.89	72.05	40.87
2007	25.50	73.95	51.63	32.13	29.58	14.90	32.64	31.55	72.85	64.51	18.54	91.68
2008	127.36	87.05	49.81	41.00	60.54	21.04	9.53	41.60	44.82	29.34	60.40	92.13
2009	88.67	58.61	72.90	118.72	42.97	97.09	19.24	22.49	44.64	46.20	18.33	69.70
2010	51.65	31.42	55.60	108.28	75.29	52.88	19.62	70.01	13.31	107.31	97.42	195.57
2011	49.93	92.43	86.00	164.71	114.75	31.64	58.06	37.57	27.65	62.25	60.49	13.95
2012	68.81	57.56	58.17	59.80	29.81	0.06	44.29	20.20	43.86	37.30		

Table C.2: Precipitation data for the River Road Watershed

RIVER ROAD PRISM DATA SUMMARY in mm (Oregon State University, 2012)												
	January	February	March	April	May	June	July	August	Septembe	October	November	December
1990	88.75	76.97	60.12	60.61	42.80	50.76	18.99	25.41	53.38	45.69	47.91	52.48
1991	53.36	38.23	100.82	79.17	58.59	37.17	25.18	65.49	48.31	51.98	90.42	19.24
1992	15.35	48.88	41.99	30.26	59.29	31.68	26.92	30.81	16.98	65.16	86.40	104.55
1993	119.03	103.65	73.62	63.97	86.49	56.87	58.14	32.71	17.61	65.99	37.48	24.77
1994	38.94	101.50	50.20	76.51	38.79	4.09	10.12	50.10	33.97	91.32	95.04	44.72
1995	88.47	62.30	114.70	72.40	138.11	59.74	39.68	40.11	30.68	30.47	59.11	82.75
1996	162.36	78.79	88.08	72.55	41.49	22.18	20.93	6.95	55.38	65.85	96.68	163.94
1997	160.16	55.48	35.71	81.84	54.17	55.62	30.35	60.87	86.64	56.13	55.02	34.28
1998	136.91	99.65	81.20	61.68	64.43	110.34	44.42	42.66	38.28	51.58	60.25	33.03
1999	105.37	104.46	42.02	121.53	94.34	38.37	42.77	58.23	25.29	10.23	18.96	59.02
2000	126.32	104.04	58.63	37.97	50.74	20.70	11.47	66.08	51.65	69.51	50.65	74.54
2001	31.67	48.15	40.38	99.00	19.21	14.31	37.05	38.00	18.60	42.31	103.96	81.65
2002	39.00	32.77	69.26	47.07	30.96	8.75	24.37	9.83	98.09	54.64	57.42	51.10
2003	30.14	56.27	70.46	55.26	66.24	61.73	9.78	65.37	24.08	20.09	99.35	110.84
2004	48.48	70.12	32.60	56.77	36.21	42.87	44.95	41.19	25.99	162.26	48.58	89.12
2005	134.79	64.25	75.71	66.79	87.41	50.44	9.96	28.45	28.64	32.57	84.29	150.10
2006	112.13	50.64	92.03	72.10	26.37	29.80	27.69	39.83	74.98	79.23	79.46	43.82
2007	28.37	78.14	56.78	35.42	32.76	14.57	35.88	32.51	77.35	66.98	19.96	95.85
2008	134.69	92.04	53.89	46.35	66.84	23.04	8.60	45.77	46.39	30.21	63.08	98.34
2009	93.31	60.82	80.68	127.01	47.16	101.60	21.12	22.99	47.92	49.84	19.86	71.62
2010	53.13	33.12	59.05	120.46	87.18	57.33	20.74	71.70	13.76	112.77	104.59	200.05
2011	52.69	98.20	90.66	176.53	117.45	32.93	63.87	38.18	28.11	67.10	63.09	15.07
2012	70.16	59.16	61.83	64.23	31.82	0.09	47.66	22.02	44.64	38.66		

Table C.3: Precipitation data for the Hailstone Watershed

HAILSTONE PRISM DATA SUMMARY in mm (Oregon State University, 2012)												
	January	February	March	April	May	June	July	August	September	October	Novembe	December
1949	105.05	61.29	67.57	13.66	84.95	46.74	18.01	40.94	39.52	84.07	53.97	114.02
1950	146.72	62.34	92.72	45.65	72.70	21.02	22.91	4.21	38.04	28.35	104.32	94.33
1951	103.45	47.24	49.35	84.74	66.66	38.81	40.88	59.76	2.48	74.80	96.16	162.87
1952	104.94	60.21	135.48	58.31	57.42	50.79	32.84	57.82	20.46	0.67	25.34	51.10
1953	101.75	26.46	75.60	60.07	85.22	37.80	30.06	46.65	8.31	35.38	46.81	41.30
1954	75.44	34.35	71.34	38.78	34.30	51.38	36.67	26.17	54.57	30.77	50.84	47.69
1955	64.47	78.99	41.52	28.08	41.92	32.02	35.44	45.22	47.13	25.29	93.73	171.07
1956	118.71	39.90	10.23	51.49	57.00	13.52	26.68	11.71	7.68	52.69	20.54	122.24
1957	84.43	53.91	65.88	94.96	120.92	64.49	23.84	53.80	9.50	41.96	87.75	86.07
1958	39.44	86.97	93.68	52.88	34.62	15.53	1.29	35.48	35.88	7.18	54.55	27.38
1959	34.76	109.44	57.28	49.72	47.54	56.04	11.26	51.12	76.83	25.32	15.86	40.55
1960	32.55	86.71	71.28	57.86	34.47	17.86	20.43	13.12	48.79	60.33	70.01	14.03
1961	1.37	36.60	86.59	28.64	16.48	6.20	27.22	69.81	83.20	68.92	70.31	76.59
1962	96.23	102.27	70.66	84.79	70.38	35.20	21.68	8.22	17.77	38.11	27.27	21.04
1963	110.09	78.44	74.90	181.28	16.23	33.04	13.61	55.61	64.99	40.41	65.92	22.56
1964	69.64	23.31	76.27	112.51	65.45	92.28	14.07	26.02	15.45	11.60	91.15	238.74
1965	84.38	34.20	47.58	84.81	58.10	54.29	71.42	49.67	64.79	10.38	107.52	116.80
1966	34.11	138.05	42.69	38.52	56.87	14.69	25.50	41.22	46.67	54.75	56.46	139.52
1967	128.00	35.05	78.72	60.60	113.62	81.41	24.97	28.80	30.89	22.94	40.12	84.24
1968	52.42	136.25	77.97	132.71	90.39	65.59	33.09	105.12	18.85	46.65	62.54	71.71
1969	185.18	123.46	18.65	64.89	14.81	91.89	29.85	32.44	22.53	88.92	29.37	64.08
1970	73.95	30.98	49.72	72.69	43.88	57.99	34.24	48.12	53.70	47.12	109.03	109.93
1971	62.76	55.27	28.46	64.30	70.74	28.17	15.59	40.54	40.32	78.43	63.04	145.45
1972	64.25	25.04	38.79	99.82	20.35	48.75	10.58	27.40	42.56	138.81	58.79	103.47
1973	49.09	64.58	82.28	83.64	40.23	31.82	58.33	54.66	64.08	14.30	82.27	107.93
1974	74.34	26.58	42.43	136.45	6.77	9.96	24.44	12.97	4.04	81.57	37.57	50.53
1975	84.06	65.98	118.27	61.57	107.03	81.66	32.32	12.89	13.88	67.38	72.58	67.00
1976	34.86	90.46	57.74	59.18	47.92	24.71	17.91	18.48	23.19	14.84	3.56	6.78
1977	23.87	57.22	72.91	27.51	98.16	10.21	48.03	56.99	52.68	45.75	57.28	115.75
1978	79.13	78.39	126.97	135.70	33.22	17.82	1.53	37.73	48.97	3.33	100.12	82.78
1979	106.47	84.58	45.16	43.18	47.30	7.82	20.70	33.31	4.90	52.88	48.42	21.93
1980	219.86	153.71	91.48	42.45	67.15	27.69	21.95	47.91	33.23	68.44	30.55	48.84
1981	73.24	28.29	100.13	58.69	106.76	14.87	22.32	17.49	54.96	136.12	49.89	156.17
1982	130.71	51.34	142.30	85.37	48.10	27.08	42.81	31.76	158.04	57.63	103.60	61.65
1983	39.33	94.79	118.35	76.97	104.03	39.38	45.23	97.79	68.35	53.32	121.73	208.37
1984	19.82	29.65	64.35	87.24	37.63	84.65	58.20	90.89	69.69	87.50	110.21	83.60
1985	19.19	39.66	95.86	52.71	69.95	29.08	77.24	7.90	54.22	80.51	181.23	55.49
1986	56.74	224.81	79.20	136.41	68.50	20.87	37.05	42.03	65.01	51.63	44.11	13.70
1987	59.32	59.40	58.71	28.01	92.82	27.94	50.97	62.82	13.35	26.41	48.20	66.02
1988	74.68	36.62	58.91	67.69	53.85	15.85	11.54	19.53	15.39	10.22	112.22	47.36
1989	34.83	87.01	104.32	62.45	38.82	44.80	29.59	32.32	59.08	41.56	54.09	22.35
1990	93.15	81.63	65.81	65.96	46.11	55.03	19.79	27.58	58.33	47.84	52.60	56.66
1991	55.43	41.80	108.86	85.21	62.13	40.99	27.38	68.45	50.79	53.50	94.54	19.77
1992	16.01	50.57	44.79	31.90	62.83	33.74	27.98	33.10	17.55	67.10	87.53	112.61
1993	122.00	109.78	77.67	68.47	87.99	60.04	60.55	34.18	18.71	68.82	37.38	25.99
1994	40.24	105.98	52.28	82.70	40.59	4.22	10.78	52.01	36.65	93.38	97.35	46.86
1995	91.25	66.76	121.64	79.69	144.39	64.17	41.68	43.08	32.97	32.72	63.23	88.84
1996	168.63	81.43	93.54	77.65	42.65	23.35	21.57	6.89	58.35	70.48	97.25	176.97
1997	166.17	57.74	37.75	88.08	55.61	57.71	31.61	64.17	91.02	59.84	57.36	35.14
1998	142.62	104.92	85.70	66.85	66.58	111.44	46.63	45.31	40.59	53.34	62.68	33.97
1999	109.46	112.59	45.36	128.33	97.27	39.45	44.81	61.49	27.03	11.24	19.90	61.12
2000	132.47	110.81	62.20	40.18	52.36	22.63	12.16	69.26	53.33	71.96	52.50	78.09
2001	32.79	51.76	42.42	103.84	20.37	15.36	39.53	39.11	19.79	45.95	106.70	85.47
2002	40.78	35.59	73.17	49.71	32.66	9.41	25.67	10.61	104.13	57.36	59.92	52.82
2003	31.17	58.80	72.83	59.07	69.14	63.84	10.62	68.38	25.40	21.74	103.00	113.37
2004	50.88	73.22	33.95	59.80	36.83	45.24	47.22	43.50	28.90	168.43	49.95	93.12
2005	139.85	68.36	78.11	71.68	90.46	52.85	10.86	30.43	31.63	33.96	88.94	157.71
2006	116.95	53.90	96.51	77.02	26.84	31.60	29.02	41.27	77.41	83.20	83.70	45.91
2007	29.91	82.51	60.79	37.46	34.34	15.13	36.84	33.96	80.68	69.67	21.68	100.06
2008	141.79	97.42	57.50	50.03	69.08	24.19	8.98	48.28	47.20	31.83	65.23	104.34
2009	97.23	64.75	86.28	133.98	50.02	103.86	21.96	23.32	49.36	52.90	20.92	74.58
2010	56.29	34.51	61.82	128.96	92.25	59.91	21.53	75.03	14.17	118.30	109.19	208.01
2011	55.49	105.10	95.33	189.03	120.69	34.87	68.01	38.17	29.27	71.22	65.42	16.58
2012	72.19	61.61	65.87	69.16	33.64	0.10	50.61	23.57	46.16	40.37		

Table C.4: Precipitation data for the Woodland Watershed

WOODLAND PRISM DATA SUMMARY in mm (Oregon State University, 2012)												
	January	February	March	April	May	June	July	August	September	October	November	December
1960	34.08	93.94	75.61	64.35	38.01	19.21	22.08	13.45	54.47	65.56	73.67	14.14
1961	1.46	39.92	93.22	31.78	18.58	7.29	29.14	73.67	89.37	72.27	74.91	80.02
1962	102.46	111.95	77.25	93.48	73.00	37.08	22.98	9.60	20.57	41.51	28.15	21.40
1963	113.12	85.68	81.50	196.60	18.47	36.82	15.24	61.04	68.89	44.04	68.07	22.64
1964	71.47	25.34	81.83	126.41	69.98	95.56	14.18	28.95	17.37	12.73	96.30	257.92
1965	88.80	38.86	52.28	95.33	63.30	58.40	72.17	52.51	70.06	11.74	111.34	127.51
1966	33.77	137.76	46.93	42.67	62.00	15.75	28.19	44.57	50.50	58.93	57.26	150.17
1967	135.95	37.04	86.05	65.72	119.38	87.32	27.66	31.12	32.72	24.91	40.96	89.53
1968	54.80	142.66	83.22	144.33	95.41	70.80	33.08	109.58	20.28	48.44	63.22	74.87
1969	199.29	134.28	21.12	73.21	16.41	98.32	32.64	35.14	24.75	92.54	30.77	68.76
1970	78.08	33.52	53.91	78.23	47.82	60.88	36.23	51.54	57.37	49.11	113.01	117.28
1971	64.35	60.61	29.97	73.05	77.69	29.59	15.77	44.68	41.82	82.45	66.14	157.50
1972	68.23	27.85	41.77	108.88	23.70	54.13	11.56	28.86	45.38	147.36	61.95	110.12
1973	52.31	70.14	90.67	93.63	41.39	34.00	62.68	54.58	67.21	15.15	87.38	115.40
1974	80.16	28.67	44.21	148.54	7.58	10.11	27.85	14.31	4.58	87.17	38.11	51.30
1975	89.08	71.16	125.80	65.62	112.53	89.77	34.16	14.34	15.30	69.29	72.53	71.50
1976	35.05	99.36	61.95	66.86	53.02	26.59	19.59	20.52	26.63	15.94	3.93	6.53
1977	25.69	63.42	78.29	32.28	103.33	11.10	51.83	58.05	55.79	49.49	61.93	126.27
1978	85.74	86.85	138.78	151.92	35.81	19.86	1.91	39.68	50.47	4.14	102.61	90.48
1979	117.43	94.78	48.14	49.29	53.09	8.76	22.04	36.07	6.18	53.04	54.70	24.22
1980	231.65	164.18	98.78	49.32	65.51	33.76	24.72	54.84	36.21	74.93	29.48	51.44
1981	82.45	31.85	110.60	66.15	114.24	14.73	24.47	19.60	59.24	144.65	54.02	173.95
1982	143.77	57.00	160.06	95.44	53.33	29.32	45.15	35.48	161.12	62.06	112.06	65.15
1983	40.73	101.46	130.12	85.43	110.41	43.03	41.05	106.11	72.81	57.48	132.02	225.86
1984	20.50	32.98	69.09	98.82	40.18	89.26	62.02	99.94	74.79	94.02	120.70	89.86
1985	17.12	41.17	107.75	60.63	75.23	29.03	77.59	9.05	60.51	86.51	199.48	60.83
1986	63.40	254.48	86.87	149.31	75.44	22.40	39.28	42.06	67.66	57.64	49.11	13.74
1987	62.67	66.99	63.76	32.25	101.76	30.51	52.25	65.43	16.50	28.40	55.11	72.84
1988	80.76	42.11	66.99	75.89	60.69	18.03	13.13	21.53	16.83	11.17	121.02	48.13
1989	37.20	98.76	118.45	70.18	43.15	48.80	30.58	31.03	61.99	47.28	57.35	24.15
1990	101.85	91.02	74.44	76.12	51.10	60.69	19.57	30.00	64.07	51.96	58.54	60.59
1991	59.89	49.38	122.58	94.52	68.33	47.14	30.53	74.20	54.26	56.87	103.28	20.23
1992	16.73	55.62	48.21	35.90	67.60	37.38	30.06	38.18	19.53	70.97	93.15	122.50
1993	128.07	120.81	84.62	78.68	88.02	64.36	66.76	37.30	20.00	74.74	39.50	27.72
1994	44.17	115.28	56.03	92.86	43.63	4.61	11.18	56.99	40.37	96.29	102.84	50.43
1995	95.50	74.85	136.17	90.70	152.83	68.20	46.65	46.58	35.09	37.61	70.73	98.11
1996	184.39	90.06	100.37	87.06	45.02	24.68	22.64	7.61	62.21	78.66	101.08	198.71
1997	180.11	61.37	41.17	95.82	57.83	60.53	33.03	69.61	97.14	63.99	61.71	37.73
1998	156.12	113.41	92.93	74.58	71.54	112.71	50.25	49.51	44.12	54.84	68.07	36.34
1999	118.66	125.78	51.80	138.05	101.76	40.76	47.96	65.65	29.73	12.48	21.82	65.95
2000	146.93	121.69	67.74	44.11	55.20	25.55	13.46	74.53	54.99	76.61	56.08	86.10
2001	35.94	57.52	45.81	112.39	22.35	16.41	42.94	40.52	21.23	49.78	112.36	94.12
2002	45.63	39.20	79.05	52.85	36.18	10.39	26.05	11.85	111.86	59.20	64.53	56.91
2003	33.66	62.89	77.00	65.55	74.37	67.32	12.30	71.95	27.18	23.37	110.66	120.90
2004	56.52	77.88	36.15	63.90	38.25	47.75	49.54	47.10	31.93	176.91	53.03	102.92
2005	150.32	74.40	81.88	77.32	95.87	55.90	12.05	34.18	35.54	34.58	98.08	174.50
2006	128.36	59.20	103.86	83.91	27.89	34.39	32.32	44.18	81.28	89.44	91.33	49.82
2007	32.14	90.64	66.97	40.77	36.65	15.71	39.03	36.77	86.69	74.55	24.34	107.31
2008	154.66	106.71	64.25	56.05	73.40	26.62	10.09	52.88	48.39	34.46	69.61	114.19
2009	104.01	72.05	94.60	144.18	55.85	107.85	24.01	24.12	52.22	58.40	22.69	78.76
2010	61.51	36.50	65.39	141.67	101.17	64.97	24.13	81.04	15.31	127.49	117.30	222.49
2011	59.57	115.18	103.94	208.03	127.50	38.53	74.89	38.10	31.03	79.19	70.27	18.42
2012	75.90	65.53	72.51	77.11	37.15	0.13	54.89	26.43	48.83	44.40		

Appendix D: Jordanelle Reservoir Inflow Data used for Streamflow assumptions at River Road and Charlestown Gages.

This appendix shows the reservoir inflow data that was obtained from the Bureau of Reclamation (2012b). This was assumed to be the average streamflow at the River Road and Charlestown streamgages. This is an accurate assumption for the River Road gage as it is directly downstream of Jordanelle Reservoir. Alternately, this assumption for the Charlestown gage could cause some errors in the streamflow data. However, this error would be less than the error given by the actual streamgage at Charlestown as the values at this gage would be highly uncertain because of Jordanelle being upstream. Table D.1 shows the inflow values that were used as the flow in the Provo River downstream of the reservoir.

Table D.1: Jordanelle Reservoir Inflow Data that was used as the streamflow values at the River Road and Charlestown gages.

Jordanelle Reservoir Inflow Data			
Year	Total Inflow (cfs)	cubic feet/day	cubic feet/year
1993	150352.22	1.30E+10	4.74E+12
1994	82119.24	7.10E+09	2.59E+12
1995	157533.92	1.36E+10	4.97E+12
1996	145488.14	1.26E+10	4.59E+12
1997	145058.45	1.25E+10	4.57E+12
1998	135706.2	1.17E+10	4.28E+12
1999	130089.24	1.12E+10	4.10E+12
2000	95226.32	8.23E+09	3.00E+12
2001	83992.05	7.26E+09	2.65E+12
2002	76184.24	6.58E+09	2.40E+12
2003	87428.84	7.55E+09	2.76E+12
2004	79225.91	6.85E+09	2.50E+12
2005	147241.17	1.27E+10	4.64E+12
2006	118883.75	1.03E+10	3.75E+12
2007	87224.84	7.54E+09	2.75E+12
2008	125550.53	1.08E+10	3.96E+12
2009	133658.63	1.15E+10	4.22E+12
2010	108061.21	9.34E+09	3.41E+12
2011	171242.24	1.48E+10	5.40E+12
2012	62113.03	5.37E+09	1.96E+12

Appendix E: Calculation of Runoff Ratios and Streamflow Information at Woodland Streamgage

This appendix gives a summary of values that were used for the runoff ratio calculations. A similar pattern was completed for all four streamgages, but only the Woodland streamgage information is shown in full detail. The average yearly streamflows varied significantly; however, they were often around 200 cfs which shows that for most seasons of the year the Duchesne tunnel has a small percentage of flow that enters the Provo River. Figure E.1 shows a summary of the precipitation and streamflow data that was used to calculate the runoff ratio at the Woodland streamgage.

Woodland StreamGage								
Precipitation Summary and Unit Conversions					Streamflow Summary		q	Yearly Runoff Ratio
Years	Monthly Avg	Year Sum	Year Sum	Year Sum	Yearly Avg	Yearly Avg	Q/A	(q/P)
(1960-2012)	(mm)	(mm/year)	(in/year)	(ft/year)	cfs	(ft^3/yr)	(ft/year)	
1963	67.68	812.10	31.97	2.66	56.23	1.77E+09	0.37	0.139
1964	74.84	898.05	35.36	2.95	241.40	7.61E+09	1.58	0.538
1965	70.19	842.30	33.16	2.76	305.47	9.63E+09	2.01	0.726
1966	60.71	728.50	28.68	2.39	175.77	5.54E+09	1.15	0.483
1967	64.86	778.36	30.64	2.55	264.70	8.35E+09	1.74	0.680
1968	78.39	940.69	37.04	3.09	222.18	7.01E+09	1.46	0.473
1969	68.93	827.22	32.57	2.71	203.47	6.42E+09	1.34	0.492
1970	64.75	776.96	30.59	2.55	215.32	6.79E+09	1.41	0.554
1971	61.97	743.61	29.28	2.44	248.02	7.82E+09	1.63	0.667
1972	60.82	729.80	28.73	2.39	243.23	7.67E+09	1.60	0.667
1973	65.38	784.54	30.89	2.57	214.95	6.78E+09	1.41	0.548
1974	45.22	542.59	21.36	1.78	232.23	7.32E+09	1.52	0.856
1975	69.26	831.08	32.72	2.73	261.12	8.23E+09	1.71	0.629
1976	36.33	435.98	17.16	1.43	174.78	5.51E+09	1.15	0.802
1977	59.79	717.46	28.25	2.35	71.15	2.24E+09	0.47	0.198
1978	67.35	808.25	31.82	2.65	231.71	7.31E+09	1.52	0.574
1979	47.31	567.73	22.35	1.86	188.14	5.93E+09	1.23	0.663
1980	76.23	914.82	36.02	3.00	218.23	6.88E+09	1.43	0.477
1981	74.66	895.95	35.27	2.94	160.91	5.07E+09	1.06	0.359
1982	84.99	1019.92	40.15	3.35	284.37	8.97E+09	1.87	0.558
1983	95.54	1146.52	45.14	3.76	277.83	8.76E+09	1.82	0.485
1984	74.35	892.17	35.12	2.93	273.68	8.63E+09	1.80	0.614
1985	68.74	824.91	32.48	2.71	214.35	6.76E+09	1.41	0.520
1986	76.78	921.40	36.28	3.02	350.71	1.11E+10	2.30	0.762
1987	54.04	648.48	25.53	2.13	178.99	5.64E+09	1.17	0.552
1988	48.02	576.27	22.69	1.89	142.03	4.48E+09	0.93	0.493
1989	55.74	668.91	26.34	2.19	170.15	5.37E+09	1.12	0.509
1990	61.66	739.94	29.13	2.43	167.96	5.30E+09	1.10	0.454
1991	65.10	781.19	30.76	2.56	181.22	5.71E+09	1.19	0.464
1992	52.99	635.83	25.03	2.09	94.28	2.97E+09	0.62	0.297
1993	69.21	830.57	32.70	2.72	298.65	9.42E+09	1.96	0.719
1994	59.56	714.69	28.14	2.34	144.83	4.57E+09	0.95	0.405
1995	79.42	953.02	37.52	3.13	315.34	9.94E+09	2.07	0.662
1996	83.54	1002.50	39.47	3.29	262.86	8.29E+09	1.73	0.525
1997	71.67	860.04	33.86	2.82	302.53	9.54E+09	1.99	0.704
1998	77.04	924.42	36.39	3.03	267.18	8.43E+09	1.75	0.578
1999	68.37	820.40	32.30	2.69	247.55	7.81E+09	1.62	0.604
2000	68.58	822.99	32.40	2.70	177.83	5.61E+09	1.17	0.432
2001	54.28	651.36	25.64	2.14	149.07	4.70E+09	0.98	0.458
2002	49.47	593.69	23.37	1.95	128.28	4.05E+09	0.84	0.432
2003	62.26	747.16	29.42	2.45	156.63	4.94E+09	1.03	0.419
2004	65.16	781.89	30.78	2.57	147.76	4.66E+09	0.97	0.378
2005	77.05	924.62	36.40	3.03	244.94	7.72E+09	1.61	0.530
2006	68.83	825.97	32.52	2.71	245.98	7.76E+09	1.61	0.596
2007	54.30	651.57	25.65	2.14	162.52	5.13E+09	1.07	0.499
2008	67.61	811.31	31.94	2.66	223.14	7.04E+09	1.46	0.550
2009	69.89	838.72	33.02	2.75	239.23	7.54E+09	1.57	0.571
2010	88.25	1058.97	41.69	3.47	202.81	6.40E+09	1.33	0.383
2011	80.39	964.66	37.98	3.16	352.50	1.11E+10	2.31	0.731
2012	50.29	502.88	19.80	1.65	222.32	7.01E+09	1.46	0.885

Figure E.1: Summary of Yearly Statistics at the Woodland Streamgage.