MFL Technical Support – Lower Peace River

Update of Baseline Flow for Shell Creek

Final Report

April, 2016

Prepared for:

2379 Broad Street

Brooksville, FL 34604

Prepared by:

15711 Mapledale Boulevard, Suite B

Tampa, FL 33624

Table of Contents

List of Figures

List of Tables

Introduction

A baseline flow record was developed for the Shell Creek watershed (Figure 1) for daily flows at the Shell Creek near Punta Gorda gauge (SCPG, USGS 02298202) to support the establishment of Minimum Flows and Levels (MFLs) for the Lower Shell Creek. Several adjustments were made to the flow record at SCPG, i.e., the outfall of the City of Punta Gorda's reservoir (Hendrickson Dam), to account for missing records, withdrawals from the reservoir by the City of Punta Gorda, recorded zero flows at the SCPG gauge, and additional flows into the reservoir from excess irrigation in the watershed (SWFWMD 2010).

For this update, additional data collected since 2004 through September 2014 were added to the period of record (POR) analysis. Some modifications to the earlier data record were made based on additional information provided by the Southwest Florida Water Management District (District). In addition to updating the baseline record for the SCPG gauge, baseline flow records were developed for the Shell Creek gauge at Circle K Groves (SCCK, USGS 02297600) and the Prairie Creek gage near Ft Ogden (PCFO, USGS 02298123). Details of the USGS gauges in the area are summarized in Table 1.

Table 1 – USGS gauges summary

Station Name	Station ID	Date	Location
Shell Creek near Punta Gorda	02298202 Drainage Area: 373 sq. miles	01/01/1965-09/30/2014 Count-15,613	Lat: 26°59'04" Long: -81°56'09"
Shell Creek at Circle K Groves	02297600 Drainage Area: NA	10/01/2009-09/30/2014 Count-1,826	Lat: 26°58'02.44" Long: -81°49'35.89"
Shell Creek on CR 764	02297635 Drainage Area: 90.1 sq. miles	10/01/2009-09/30/2012 Count-1,096	Lat: 26°58'30" Long: -81°53'15"
Prairie Creek near Ft Ogden	02298123 Drainage Area: 233 sq. miles	10/01/1963-09/30/2014 Count-15,341	Lat: 27°03'06" Long: -81°47'05"
Prairie Creek Upstream of SR 31	02298110 Drainage Area: 63.5 sq. miles[1]	04/01/2007-09/30/2014 Count-2,740	Lat: 27°02'29.6" Long: -81°44'35.4"
Prairie Creek on CR 764	02298170 Drainage Area: 260 sq. miles	10/01/2009-07/22/2012 Count-1,026	Lat: 26°59'25" Long: -81°53'41"
Charlie Creek near Gardner FL	02296500 Drainage Area: 330 sq. miles	05/01/1950-09/30/2014 Count-23,529	Lat: 27°22'29" Long: -81°47'48"

[1] Area computed from District GIS shapefiles.

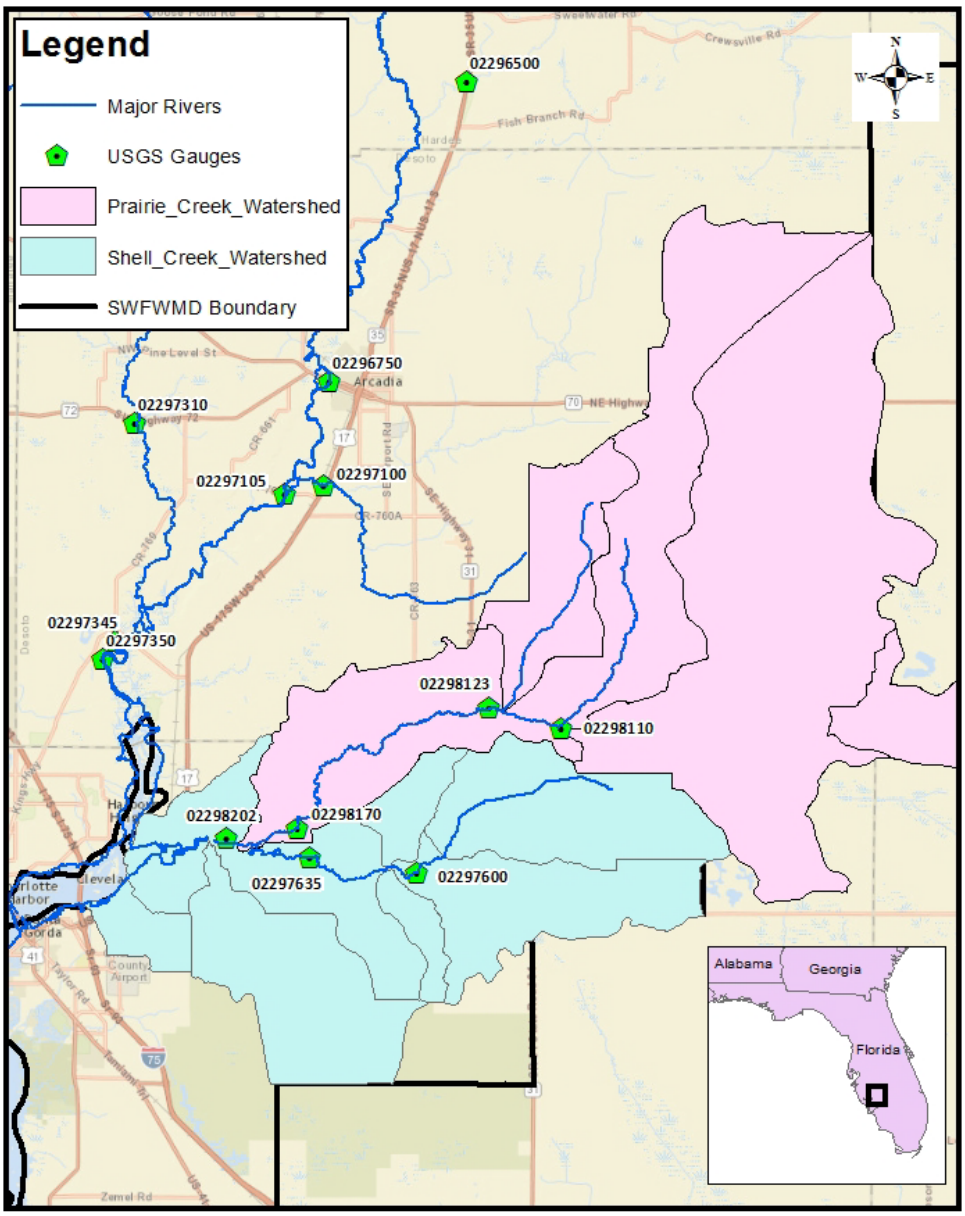

Figure 1 – Location Map

Baseline Flow for Shell Creek at the USGS Shell Creek near Punta Gorda Gauge (02298202)

The SCPG gauge is used to measure flow at the spillway of the Hendrickson Dam and not flow entering the reservoir. The measured discharge from the reservoir has been decreased by the City of Punta Gorda's withdrawal from the reservoir for public supply and increased by the addition of groundwater pumped for agricultural irrigation. Additionally, there is a 7-year gap in the gauge flow record. Adjustments were made to the observed record to account for these missing records, withdrawals, and additions.

Adjustment of Missing Records

The POR for the SCPG gauge is from Water Year (WY) 1966 to WY 2014. However, there is a period of missing records from October 1, 1987 to September 30, 1994 (Figure 2). The District used the 1987 USGS rating curve at the dam to infill these missing records (SWFWMD 2010). There were no additional days when flow was missing in the updated record (i.e., through September 2014).

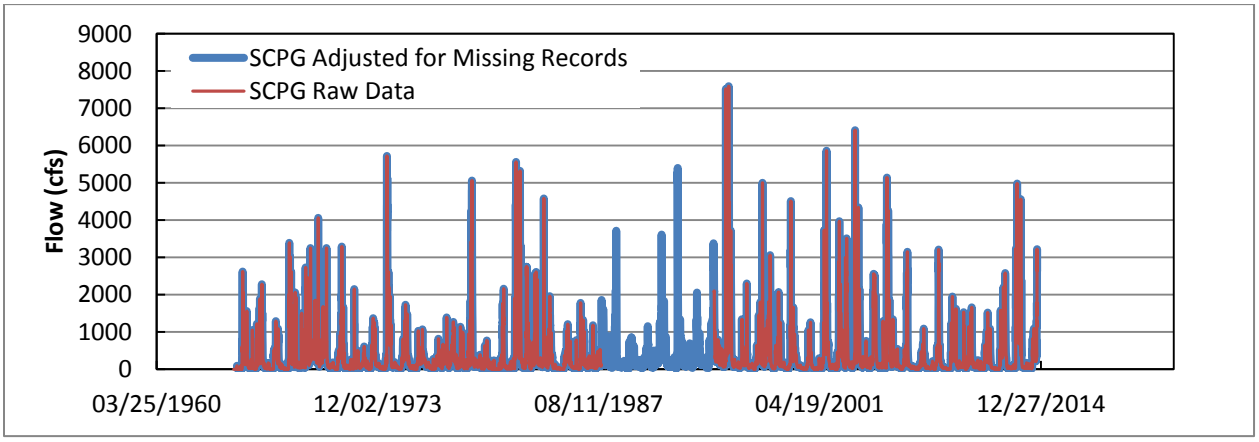

Figure 2 – Shell Creek near Punta Gorda (SCPG) missing flow records adjustment

Adjustment to Account for City of Punta Gorda Withdrawals

The observed discharge from the reservoir has been decreased by the City of Punta Gorda's withdrawal from the reservoir for public supply. Discharge records begin in 1972 when the mean annual withdrawal was 2.0 cfs during the first year. Between 1966 and 1972, the City's impact on flow over the dam is considered negligible (e.g. < 2 cfs) for purposes of correcting the discharge record (SWFWMD 2010).

Withdrawal records from the City of Punta Gorda, supplied by the District, were added to the SCPG to adjust the flow record for withdrawals from the reservoir, with the exception of days when recorded flow was 0.0. Days when flow recorded at the SCPG was zero may or may not reflect zero flow into the reservoir, depending on the storage in the reservoir.

Whenever the stage in the reservoir is below the outfall, gauged flow exiting the reservoir is recorded as 0.0 even when some water flow is entering the reservoir. For the POR (January 1, 1966 through September 30, 2014), there were 479 readings of 0.0 at the SCPG gauge while only 5 recordings of 0.0 occurred for the PCFO gauge during that time period. Recorded flows of 0.0 at the reservoir outfall were adjusted using regression equations developed with the SCPG flow, adjusted for withdrawals when recorded flow was not zero, and, in order of preference, flow recorded at the PCFO gauge ($SCPG_{(0)}$ = PCFO*1.554, Figure 3) or at the Charlie Creek near Gardner gauge (Charlie, USGS 02296500) ($SCPG_{(0)}$ = PCFO*1.002, Figure 4). The flow multiples are consistent with the relative watershed areas. Flows calculated in this manner were not subsequently adjusted for withdrawals since non zero discharge used in the regressions included withdrawals.

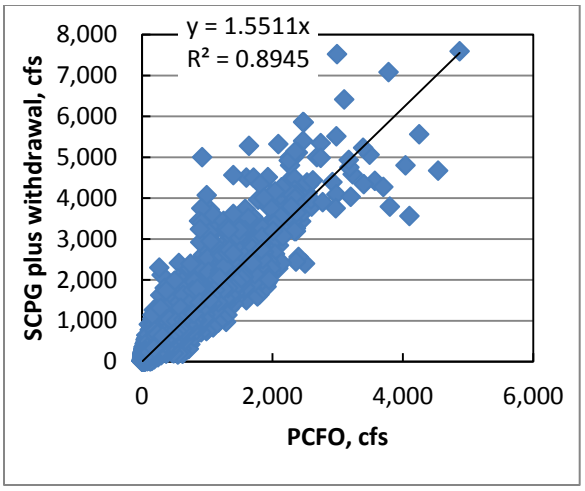

Figure 3 – Shell Creek near Punta Gorda (SCPG) and Prairie Creek near Fort Ogden (PCFO) regression

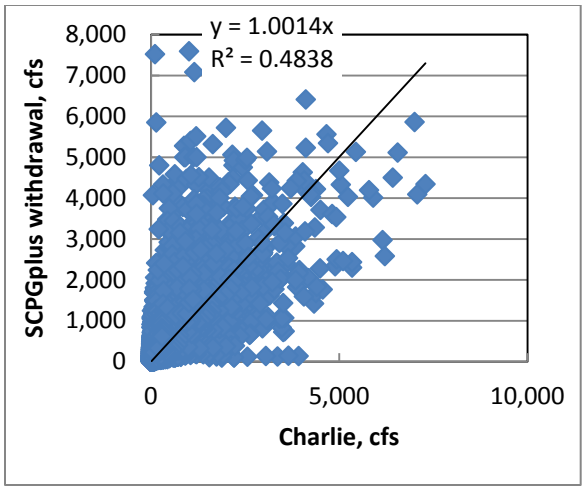

Figure 4 – Shell Creek near Punta Gorda (SCPG) and Charlie Creek near Gardner (Charlie) regression

Adjustment to Account for Anthropogenic Groundwater Discharges

Groundwater from the Floridan aquifer is used for irrigation in both Prairie and Shell Creek watersheds. Excess irrigation flow (irrigation water not lost to evapotranspiration) is carried through Shell and Prairie creeks to the reservoir, impacting the recorded flow at the SCPG gauge. The groundwater flow due to excess irrigation was estimated by computing water and chloride mass balance equations at the reservoir utilizing concentrations of chloride in (1) groundwater used for irrigation, (2) surface water (i.e., background concentration), and (3) reservoir storage. Mathematically, the impact of excess groundwater pumping is calculated using Equation 4, derived from mass balance equations 1 and 2.

For,

V_R	Volume in reservoir, current time period
C_R	Chloride concentration in reservoir, current time period
V_{R-1}	Volume in reservoir, prior time period
C_{R-1}	Chloride concentration in reservoir, prior time period
Q_S/V_S	Surface water flow/volume
C_S	Chloride concentration in surface water
Q_G/V_G	Groundwater flow/volume
C_G	Chloride concentration in groundwater
Q_D/V_D	Discharge flow/volume over the dam
C_D	Chloride concentration in discharge volume, assumed same as C_R
Q_W/V_W	Withdrawal flow/volume by City
C_W	Chloride concentration in withdrawal volume, assumed same as C_R
V_E	Volume of evaporation from reservoir, current time period
V_P	Volume of precipitation over reservoir, current time period

Water mass balance equation:

$$V_G + V_S + V_P = V_R - V_{R-1} + V_D + V_W + V_E$$

Equation 1

Change in Chloride mass in reservoir is $C_R V_R - C_{R-1} V_{R-1}$
Chloride addition to the reservoir is $C_S V_S + C_G V_G$
Chloride removal from reservoir is $C_R V_D + C_R V_W$

The chloride mass balance equation:
$C_R V_R - C_{R-1} V_{R-1} = C_S V_S + C_G V_G - C_R (V_D + V_W)$

Equation 2

Solving equations 1 and 2 yields:

$$V_G = \frac{(V_R + V_D + V_W)C_R - C_{R-1}V_{R-1} - (V_R - V_{R-1} + V_D + V_W + V_E - V_P)C_S}{C_G - C_S}$$

Equation 3

For a time period T:

$$Q_G = \frac{\left(\frac{V_R}{T} + Q_D + Q_W\right)C_R - \frac{C_{R-1}V_{R-1}}{T} - \left(\frac{V_R - V_{R-1}}{T} + Q_D + Q_W + \frac{V_E - V_P}{T}\right)C_S}{C_G - C_S}$$

Equation 4

For a monthly time period, average monthly flows and volumes in and through the reservoir were used in Equation 4 to calculate the monthly flow impact of excess groundwater on the SCPG record.

Average monthly rainfall (Figure 5) and evaporation (Figure 6) were derived from the District provided rainfall record for Site ID 2515, Punta Gorda 4 ESE NWS (11/1/1965 – 9/30/2014) and evaporation record for Site ID 24572, Peace River Water Plant ET (1/1/1984 – 3/31/1998).

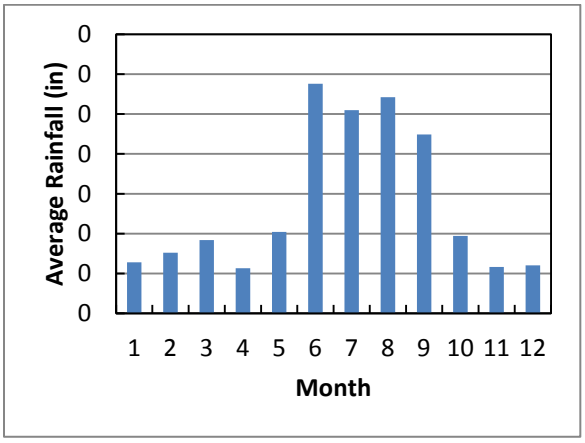

Figure 5 – Average monthly rainfall at reservoir

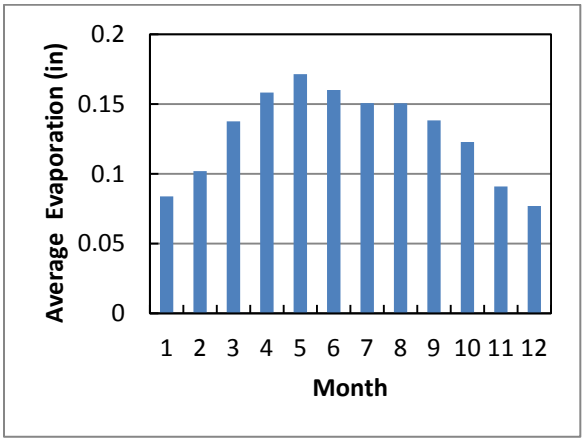

Figure 6 – Average monthly evaporation at reservoir

The average monthly discharge over Hendrickson Dam and City of Punta Gorda withdrawals (Table 2) are computed from the SCPG record and the City of Punta Gorda withdrawal data.

Table 2 – Average monthly SCPG discharge and City of Punta Gorda withdrawals

Month	Discharge (cu-ft)	Withdrawals (cu-ft)
1	147.16	4.81
2	157.00	4.94
3	215.98	5.06
4	103.36	5.27
5	79.25	5.15
6	488.40	4.16
7	688.19	4.03
8	722.86	4.36
9	822.38	4.44
10	442.37	5.14
11	171.33	5.47
12	141.81	4.96

Reservoir area-volume-stage relationships (Figures 7 and 8) were developed using District provided reservoir data (Table 3).

Table 3 – Reservoir area-volume-stage data

Level (ft)	Volume (cu-ft)	Area (sq-ft)	Volume (Gal)
1	14,544,444	14,544,444	108,792,445
2	41,387,500	20,693,750	309,578,501
3	71,920,139	23,973,380	537,962,641
4	101,664,063	25,416,016	760,447,190
5	137,209,723	27,441,945	1,026,328,726
6	174,974,480	29,162,413	1,308,809,109
7	217,324,480	31,046,354	1,625,587,110
7.75	246,894,619	31,857,370	1,846,771,749
8	259,621,008	32,452,626	1,941,965,138

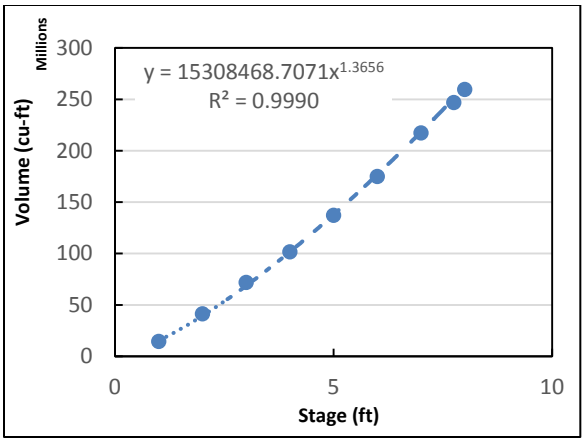

Figure 7 – Reservoir Volume-Stage Relationship

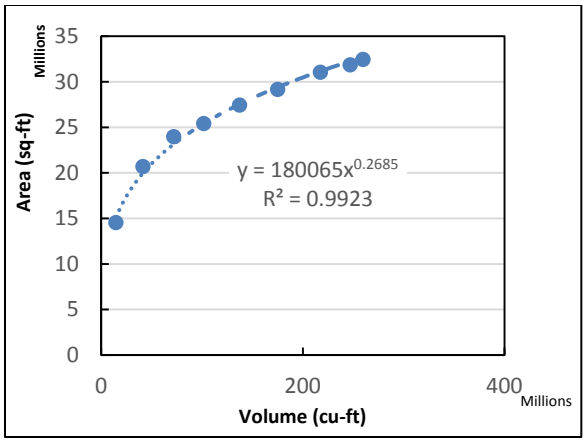

Figure 8 – Reservoir Area-Volume Relationship

Using these relationships and the recorded water level stage at the SCPG gauge, the average monthly reservoir volume and area (Table 4) were generated. Average monthly chloride concentration in the reservoir (Table 4) was generated using the data provided by the City of Punta Gorda, through the District, for the period from 1/1/1964 to 9/30/2014.

Table 4 – Average monthly reservoir stage, volume, area, and chloride concentration

Month	Stage (ft)	Volume (MG)	Area (ac)	Chloride (mg/l)
1	5.18	1081.96	641.69	137.52
2	5.21	1092.22	643.22	149.35
3	5.25	1101.75	644.60	151.51
4	5.15	1073.56	640.23	161.19
5	5.09	1057.32	637.62	164.22
6	5.36	1137.16	649.61	143.41
7	5.54	1187.97	657.59	107.03
8	5.57	1195.51	658.89	85.99
9	5.63	1213.56	661.38	73.76
10	5.36	1135.99	649.92	89.87
11	5.20	1088.94	642.77	111.58
12	5.17	1080.46	641.40	123.95

Chloride concentration in the reservoir is a function of the ratio of excess irrigation flow, i.e., groundwater flow, to surface water flow reaching the reservoir. Average excess irrigation flows (Table 5) were developed for Shell Creek (9.5 cfs) and Prairie Creek (7.6 cfs) agricultural areas based on application rates, periods, and irrigation inefficiencies taken from IFAS recommendations for nearby Manatee County (SWFWMD 2010). The chloride concentration in groundwater (Figure 9) averaged 942 mg/l for the shell Creek watershed (Station: ROMP 5 AVON PARK) and 376 mg/l for the Prairie Creek watershed (Station: ROMP 13 AVON PARK). An excess irrigation weighted average concentration of 691

mg/l, i.e., (9.5*942+7.6*376)/(9.5+7.6), was developed to represent the groundwater chloride concentration.

Table 5 – Excess irrigation

					Prairie Creek			Shell Creek		
Crop Type	Irrigation Inefficiency	Irrigation Period		Application Rates (in/d)	Area (ac)	Irrigation Rates (cfs)	Excess Flow (cfs)	Area (ac)	Irrigation Rates (cfs)	Excess Flow (cfs)
		Start	End							
Row Crops	40.0%	15-Jan	15-May	0.375	1,170	18.4	7.4	2,400	37.8	15.1
		15-Aug	14-Nov	0.272		13.4	5.3		27.4	11.0
		15-Nov	15-Dec	0.125		6.1	2.5		12.6	5.0
Citrus	15.0%	1-Apr	31-May	0.058	35,004	85.3	12.8	12,647	85.3	4.6
		1-Oct	15-Dec	0.032		47.1	7.1		47.1	2.6
				Average			7.6			9.5

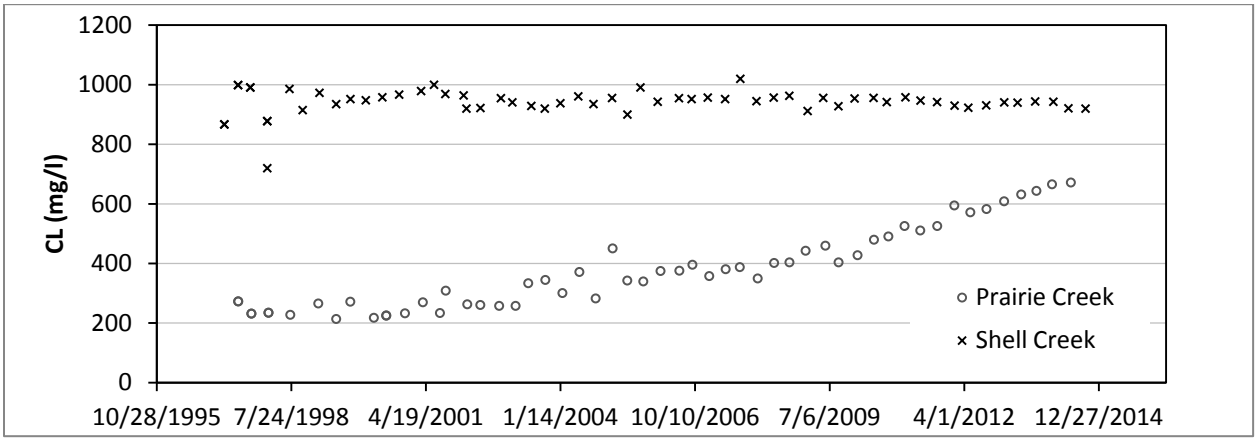

Figure 9 – Groundwater chloride concentration

Chloride concentration in surface water for Prairie Creek at SR 31 (Station ID 25020435) and Shell Creek at SR 31 (Station ID 25020555FTM) exhibit minimal groundwater impact between the months of July and October (Figure 10). A watershed area weighted concentration of 91 mg/l was developed to represent the surface water chloride concentration.

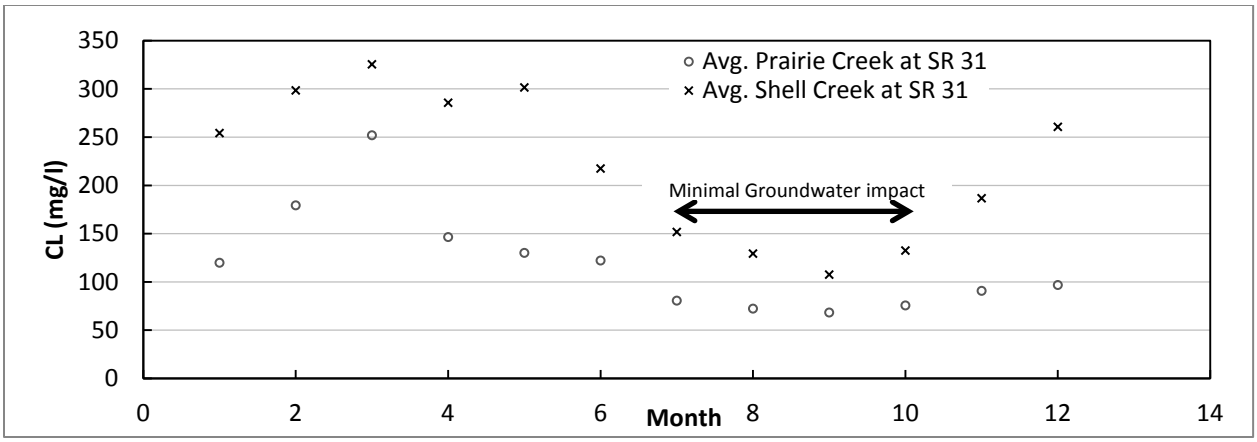

Figure 10 – Surface water chloride concentration

The monthly estimate of excess groundwater flow for SCPG (Table 6) was then computed using Equation 4. The estimated groundwater flow reaching the reservoir exhibits a pattern comparable to the flow based on irrigation rates and application inefficiencies (Figure 11) with lag potentially attributable to the travel time between irrigation location and location of the SCPG gauge. The monthly ratio of groundwater flow to surface water flow is consistent with observed chloride concentration in the reservoir (Figure 12).

Table 6 – Excess groundwater flow at SCPG

Month	No. of Days	Mid Month DOY	Average Rainfall over reservoir (in)	Average Evaporation from Reservoir (in)	Discharge over Reservoir Structure (cfs)	City of Punta Gorda Withdrawals (cfs)	Reservoir Stage (ft)	Reservoir Volume (MG)	Reservoir Area (ac)	Reservoir Chlorides Concentration (mg/l)	**Total Excess Groundwater flow at SCPG (02298202) (cfs)**
1	31	15	0.06	0.084	147.16	4.81	5.18	1082	642	137.52	**13.1**
2	29	45	0.08	0.102	157.00	4.94	5.21	1092	643	149.35	**17.0**
3	31	75	0.09	0.138	215.98	5.06	5.25	1102	645	151.51	**22.7**
4	30	106	0.06	0.158	103.36	5.27	5.15	1074	640	161.19	**13.5**
5	31	136	0.10	0.171	79.25	5.15	5.09	1057	638	164.22	**10.5**
6	30	167	0.29	0.160	488.40	4.16	5.36	1137	650	143.41	**41.8**
7	31	197	0.25	0.151	688.19	4.03	5.54	1188	658	107.03	**15.6**
8	31	228	0.27	0.151	722.86	4.36	5.57	1196	659	85.99	**0.0**
9	30	259	0.22	0.138	822.38	4.44	5.63	1214	661	73.76	**0.0**
10	31	289	0.10	0.123	442.37	5.14	5.36	1136	650	89.87	**1.1**
11	30	320	0.06	0.091	171.33	5.47	5.20	1089	643	111.58	**8.2**
12	31	350	0.06	0.077	141.81	4.96	5.17	1080	641	123.95	**9.3**

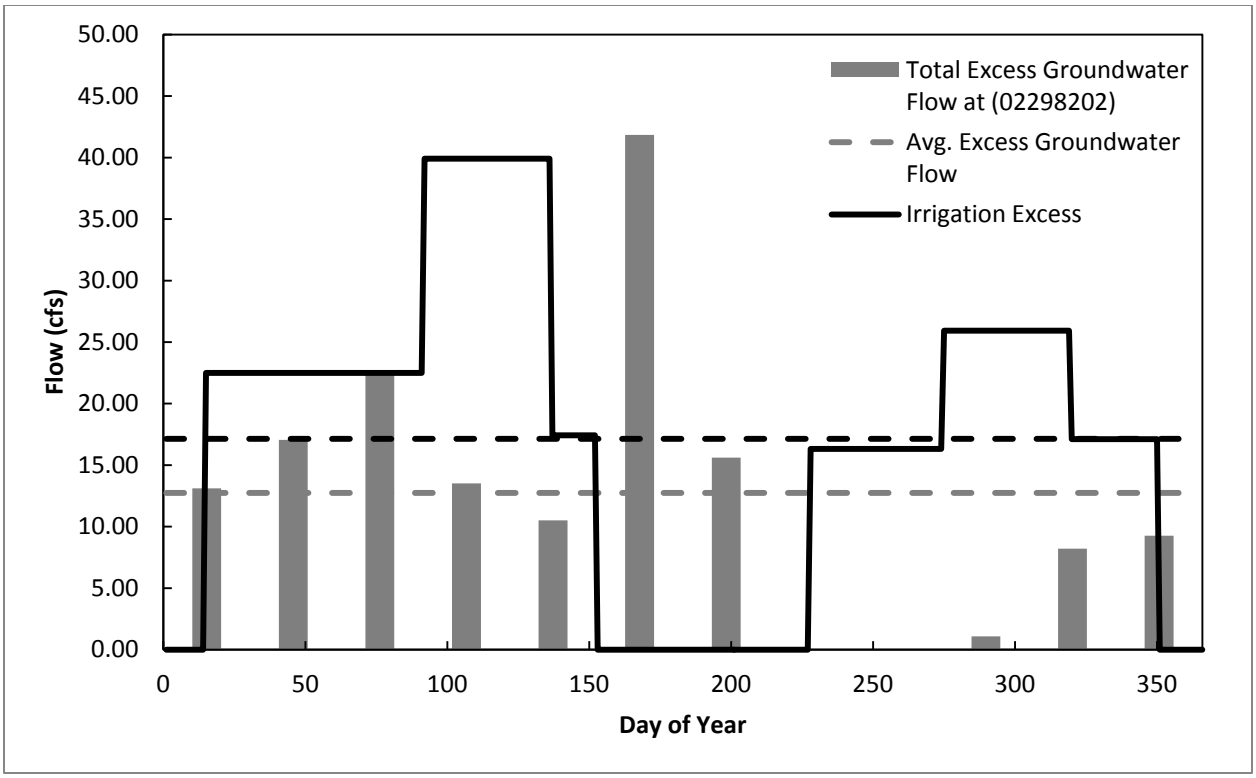

Figure 11 – Excess groundwater flow

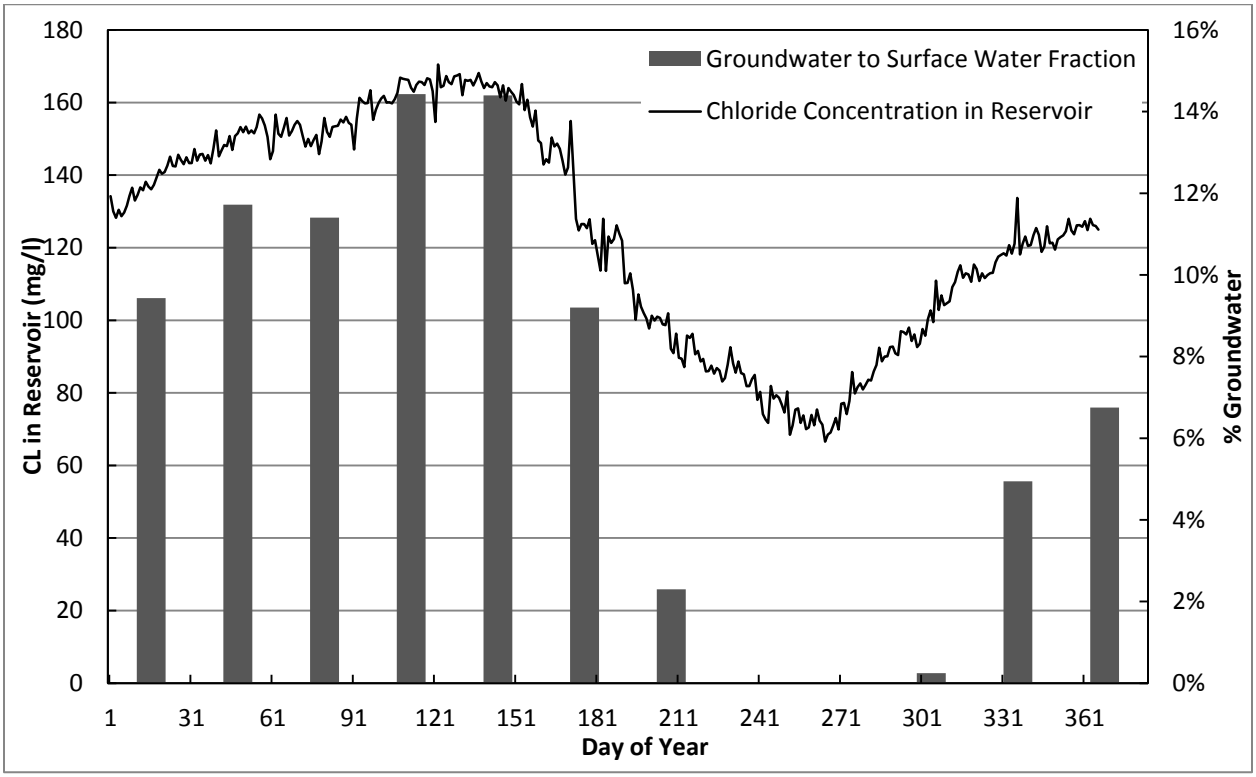

Figure 12 – Measured chloride in reservoir and estimated groundwater to surface water fraction

Baseline Shell Creek near Punta Gorda Flow Hydrographs

The SCPG discharge record – adjusted for missing values, water supply withdrawals from the reservoir, and groundwater flow due to excess irrigation – was used to develop hydrographs for the median and average baseline flows for Shell Creek near Punta Gorda (Figures 13 and 14).

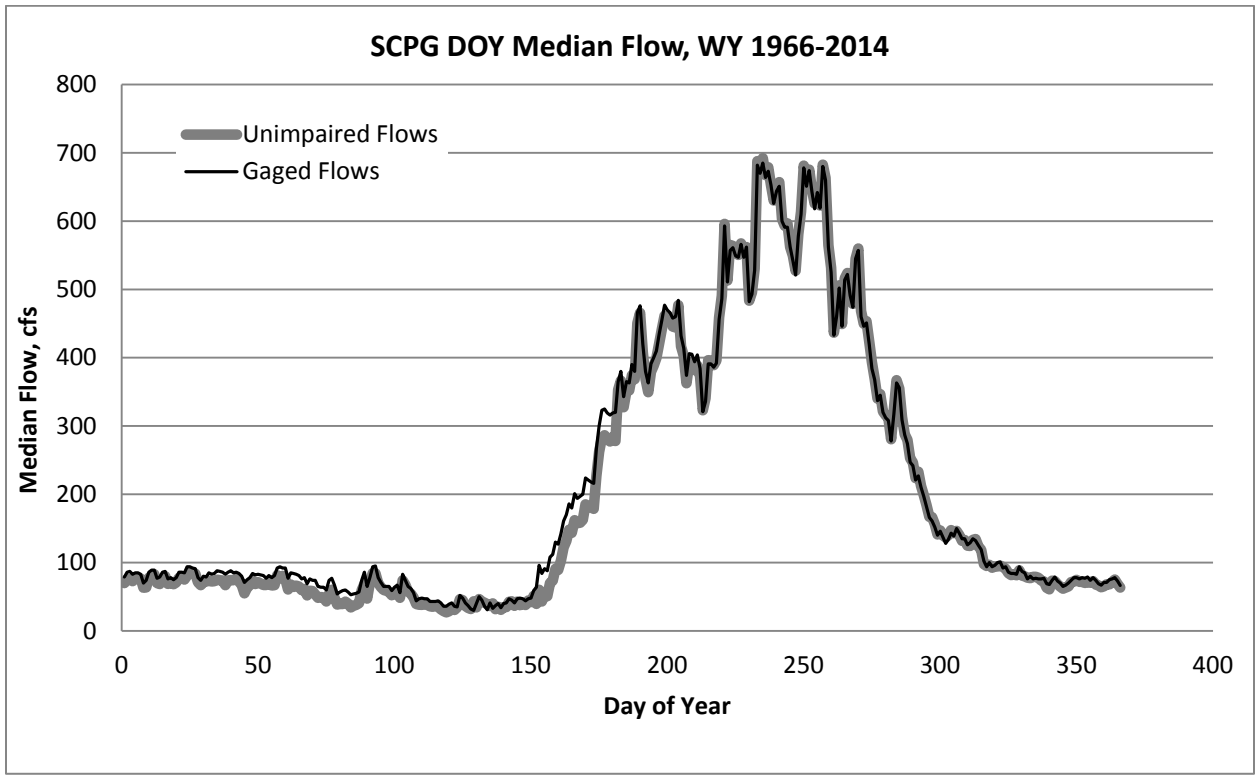

Figure 13 – Hydrographs of the median daily flows for Shell Creek near Punta Gorda (SCPG)

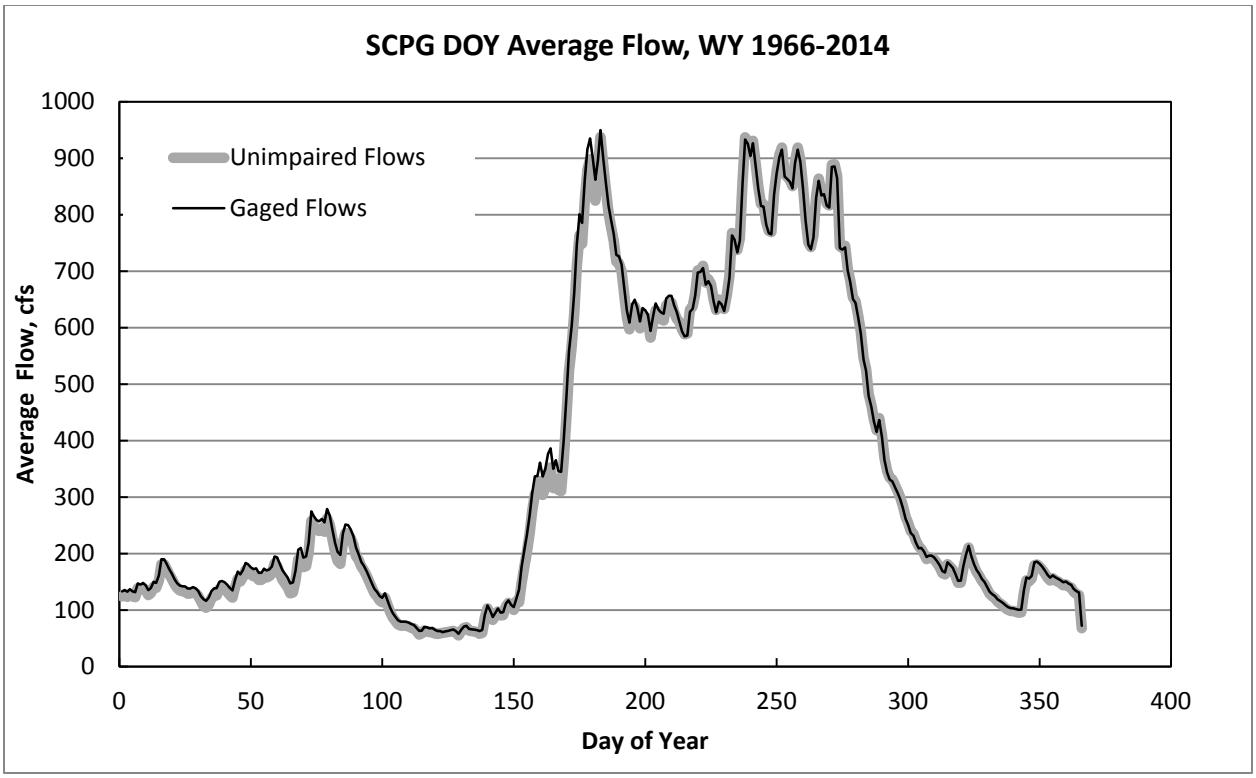

Figure 14 – Hydrographs of the average daily flows for Shell Creek near Punta Gorda (SCPG)

Baseline Flow for Prairie Creek at the USGS Prairie Creek near Ft. Ogden Gauge (02298123)

The PCFO is used to measure Prairie Creek flow about 12 miles upstream of the confluence of Prairie and Shell creeks. The measured discharge has been increased by the addition of groundwater pumped for agricultural irrigation. Additionally, there is a 9-year gap in the gauge flow record. Adjustments to the observed record were prepared to account for these missing records and additions.

Adjustment of Missing Records

The POR for the PCFO gauge is from WY 1963 to WY 2014. However, there is a period of missing records from October 1, 1968, to September 30, 1977 (Figure 15). Missing records were adjusted using regression equations developed with the flow recorded at the PCFO gauge and flow recorded at the SCPG, adjusted for missing records and withdrawals, (PCFO = SCPG*0.5971 – 2.052, Figure 16).

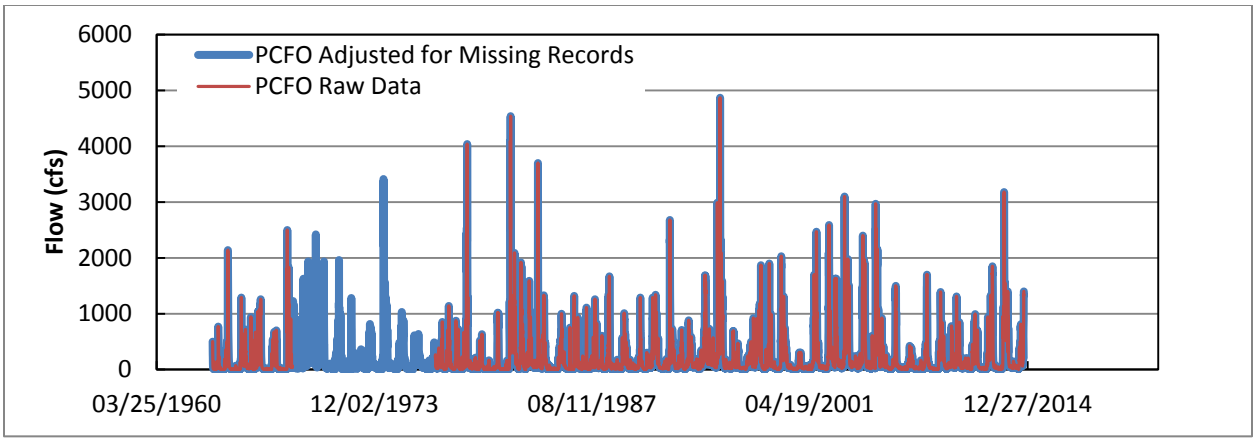

Figure 15 – Prairie Creek near Ft Ogden (PCFO) missing flow records adjustment

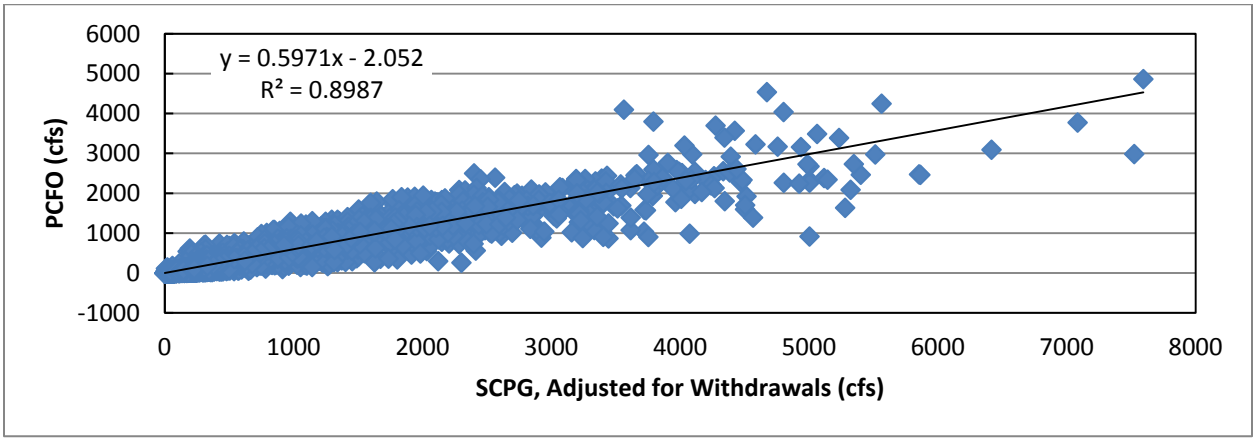

Figure 16 – Prairie Creek near Fort Ogden (PCFO) and Shell Creek near Punta Gorda (SCPG) regression

Adjustment to Account for Anthropogenic Groundwater Discharges

Excess groundwater derived for SCPG is apportioned to Shell Creek and Prairie Creek watersheds using their respective average excess irrigation of 7.6 cfs for Prairie Creek and 9.5 cfs for Shell Creek, i.e., Prairie = 7.6*SCPG/(7.6+9.5). The monthly groundwater at PCFO (Table 7) is then calculated as a ratio of the area of Prairie Creek watershed upstream of PCFO (233 sq-mi) to the area of the entire Prairie Creek watershed (264.2 sq-mi), i.e., PCFO = 233*Prairie/264.2.

Table 7 – Excess groundwater flow at PCFO

Month	Total Excess Groundwater Flow at SCPG (02298202) (cfs)	Entire Prairie Creek Excess Groundwater Flow(cfs)	**Excess Groundwater Flow at PCFO (02298123) (cfs)**
1	13.1	5.8	**5.1**
2	17.0	7.6	**6.7**
3	22.7	10.1	**8.9**
4	13.5	6.0	**5.3**
5	10.5	4.7	**4.1**
6	41.8	18.6	**16.4**
7	15.6	6.9	**6.1**
8	0.0	0.0	**0.0**
9	0.0	0.0	**0.0**
10	1.1	0.5	**0.4**
11	8.2	3.6	**3.2**
12	9.3	4.1	**3.6**

Baseline Prairie Creek near Ft Ogden Flow Hydrographs

The PCFO discharge record – adjusted for missing values and groundwater flow due to excess irrigation – was used to develop hydrographs for the median and average baseline flows for Prairie Creek Near Ft Ogden (Figures 17 and 18).

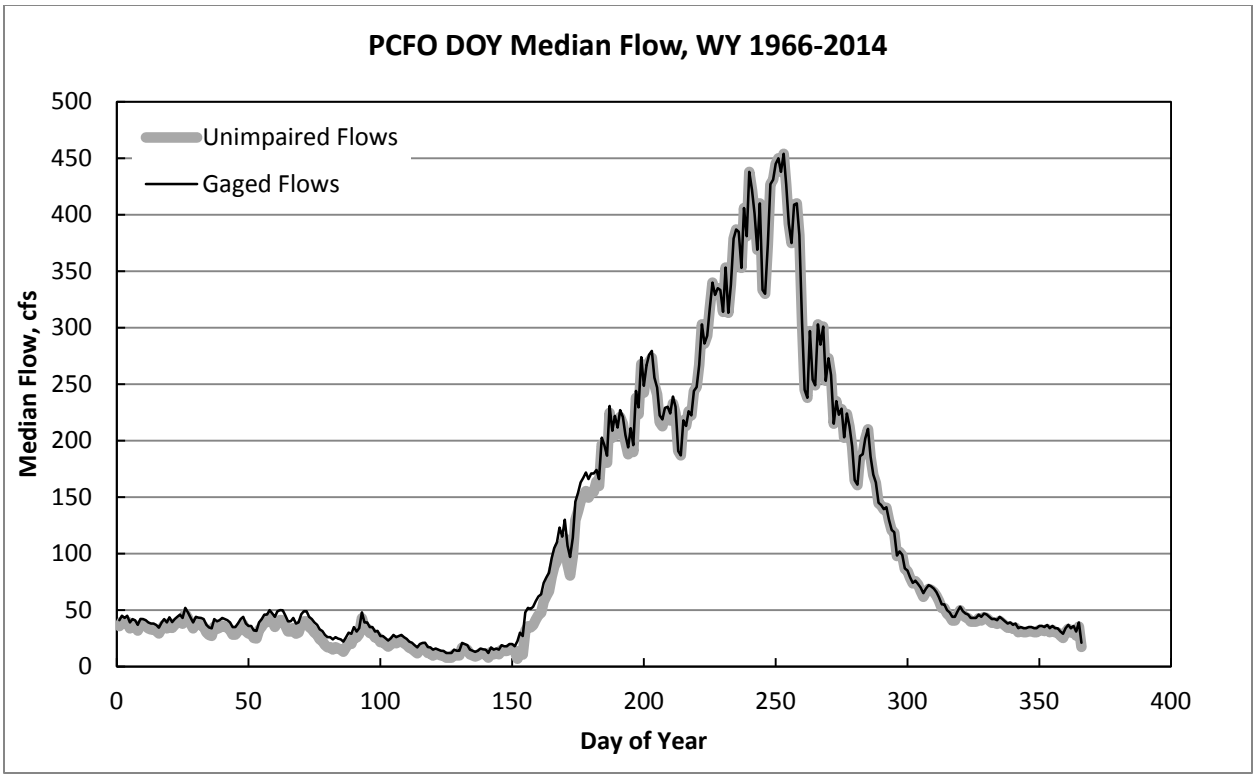

Figure 17 – Hydrographs of the median daily flows for Prairie Creek near Ft Ogden (PCFO)

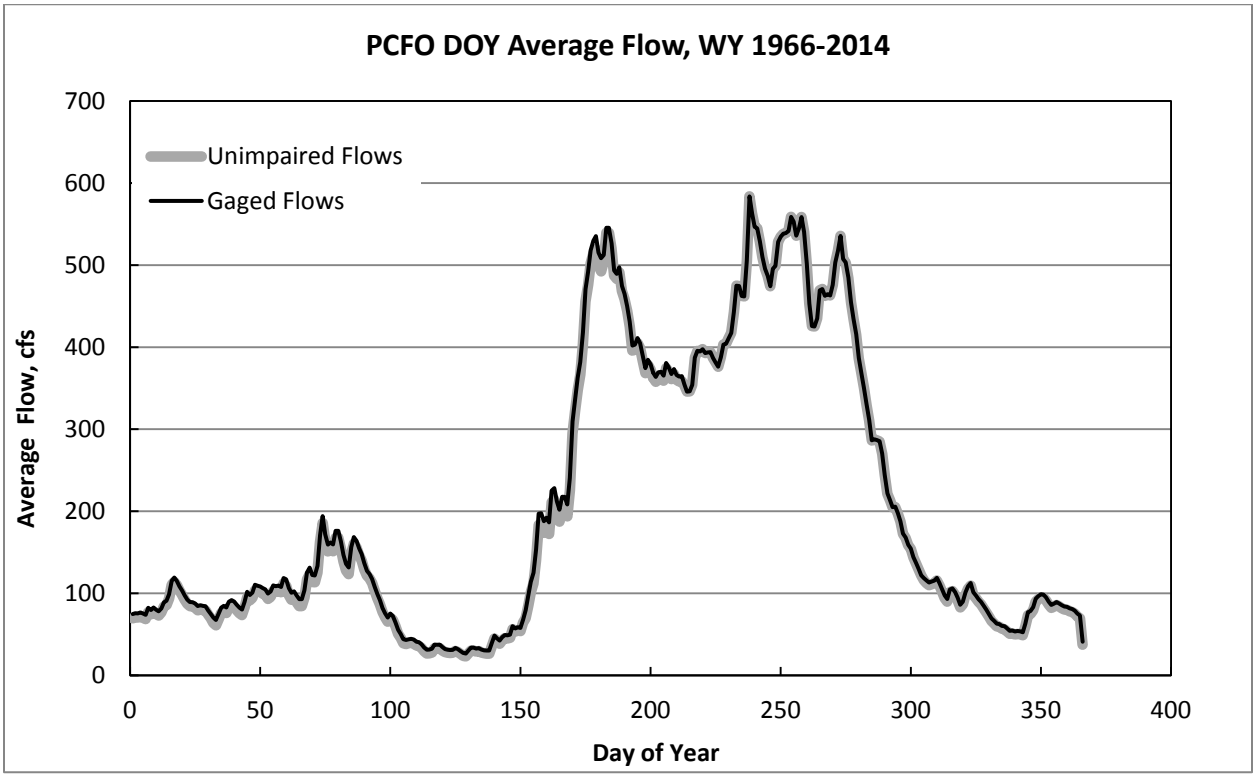

Figure 18 – Hydrographs of the average daily flows for Prairie Creek near Ft Ogden (PCFO)

Baseline Flow for Shell Creek at the USGS Shell Creek at Circle K Groves Gauge (02297600)

The SCCK gauge is used to measure Shell Creek flow about 8 miles upstream of the SCPG gauge. The measured discharge has been increased by the addition of groundwater pumped for agricultural irrigation. Additionally, the recorded flow period at the SCCK gauge is from WY 2010 to WY 2014 only. Adjustments to the observed record were prepared to cover a POR of WY 1966 to WY 2014 and to account for groundwater additions.

Adjustment to Extend SCCK Period of Record

The recorded flows at SCCK are from WY 2010 to WY 2014. To estimate SCCK flow values that date back to 10/1/1965, a multiple linear regression equation was developed with the flow recorded at the SCCK gauge, and SCPG flow, adjusted for missing records and withdrawals, and PCFO flow, adjusted for missing records (PCFO = SCPG*0.284-PCFO*0.149 + 0.343, Table 8 and Figure 19).

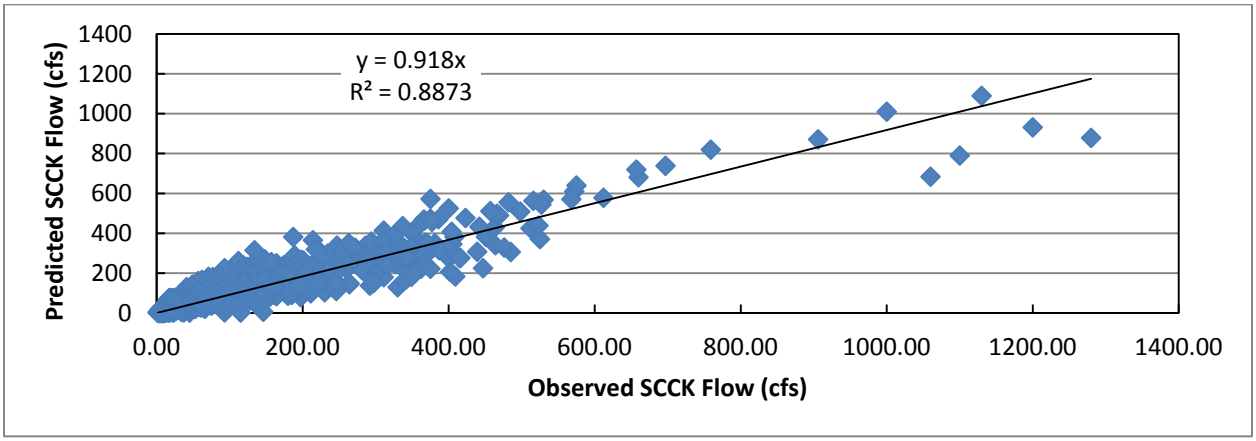

Figure 19 – Shell Creek at Circle K (SCCK) and Shell Creek near Punta Gorda (SCPG) and Prairie Creek near Ft Ogden (PCFO) multiple linear regression

Table 8 – Shell Creek at Circle K (SCCK) and Shell Creek near Punta Gorda (SCPG) and Prairie Creek near Ft Ogden (PCFO) multiple linear regression Statistics

SCCK and SCPG/PCFO Regression Statistics			
Multiple R	0.943727	Standard Error	39.91827
R Square	0.890621	Observations	1826
Adjusted R Square	0.890501		

Adjustment to Account for Anthropogenic Groundwater Discharges

Excess groundwater derived for SCPG is apportioned to Shell Creek and Prairie Creek watersheds using their respective average excess irrigation of 7.6 cfs for Prairie Creek and 9.5 cfs for Shell Creek, i.e., Shell = 9.5*SCPG/(7.6+9.5). The monthly SCCK groundwater (Table 9) is then calculated as a ratio of the area of Shell Creek watershed upstream of SCCK (63.5 sq-mi) to the area of the entire Shell Creek watershed (108.8 sq-mi), i.e., SCCK = 63.5*Shell/108.8.

Table 9 – Excess groundwater flow at SCCK

Month	Total Excess Groundwater Flow at SCPG (02298202) (cfs)	Entire Shell Creek Excess Groundwater Flow(cfs)	**Excess Groundwater Flow at SCCK (02297600) (cfs)**
1	13.1	7.3	**4.3**
2	17.0	9.5	**5.5**
3	22.7	12.6	**7.4**
4	13.5	7.5	**4.4**
5	10.5	5.8	**3.4**
6	41.8	23.3	**13.6**
7	15.6	8.7	**5.1**
8	0.0	0.0	**0.0**
9	0.0	0.0	**0.0**
10	1.1	0.6	**0.4**
11	8.2	4.6	**2.7**
12	9.3	5.1	**3.0**

Baseline Shell Creek at Circle K Groves Flow Hydrographs

The SCCK discharge record – adjusted for missing values and groundwater flow due to excess irrigation – was used to develop hydrographs for the median and average baseline flows for Shell Creek at Circle K Groves (Figures 20 and 21).

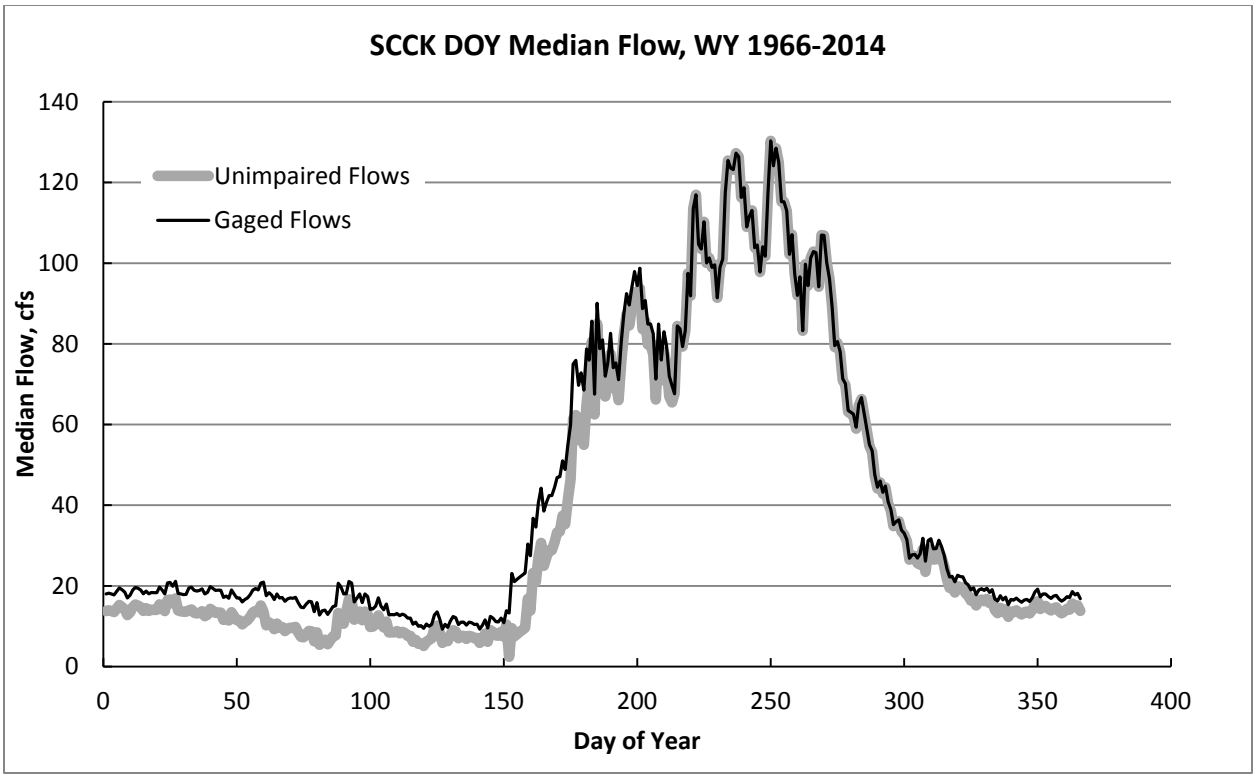

Figure 20 – Hydrographs of the median daily flows for Shell Creek at Circle K Groves (SCCK)

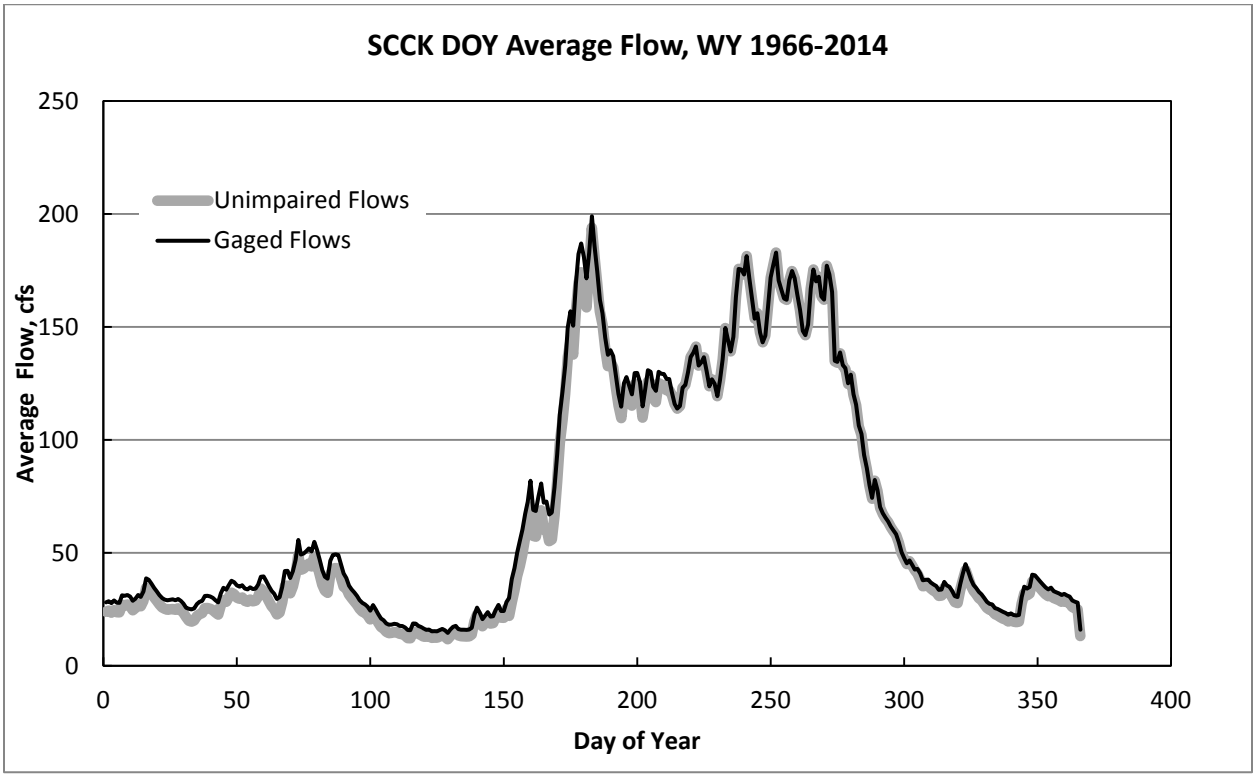

Figure 21 – Hydrographs of the average daily flows for Shell Creek at Circle K Groves (SCCK)

Summary

Flow duration curves (Figure 22) and hydrographs for the median (Figure 23) and average (Figure 24) baseline flow records were developed for the Shell Creek at Circle K Groves (SCCK, USGS 02297600) and the Prairie Creek near Ft Ogden (PCFO, USGS 02298123) to adjust recorded flows for missing records, withdrawals for public supply, and groundwater addition due to excess irrigation.

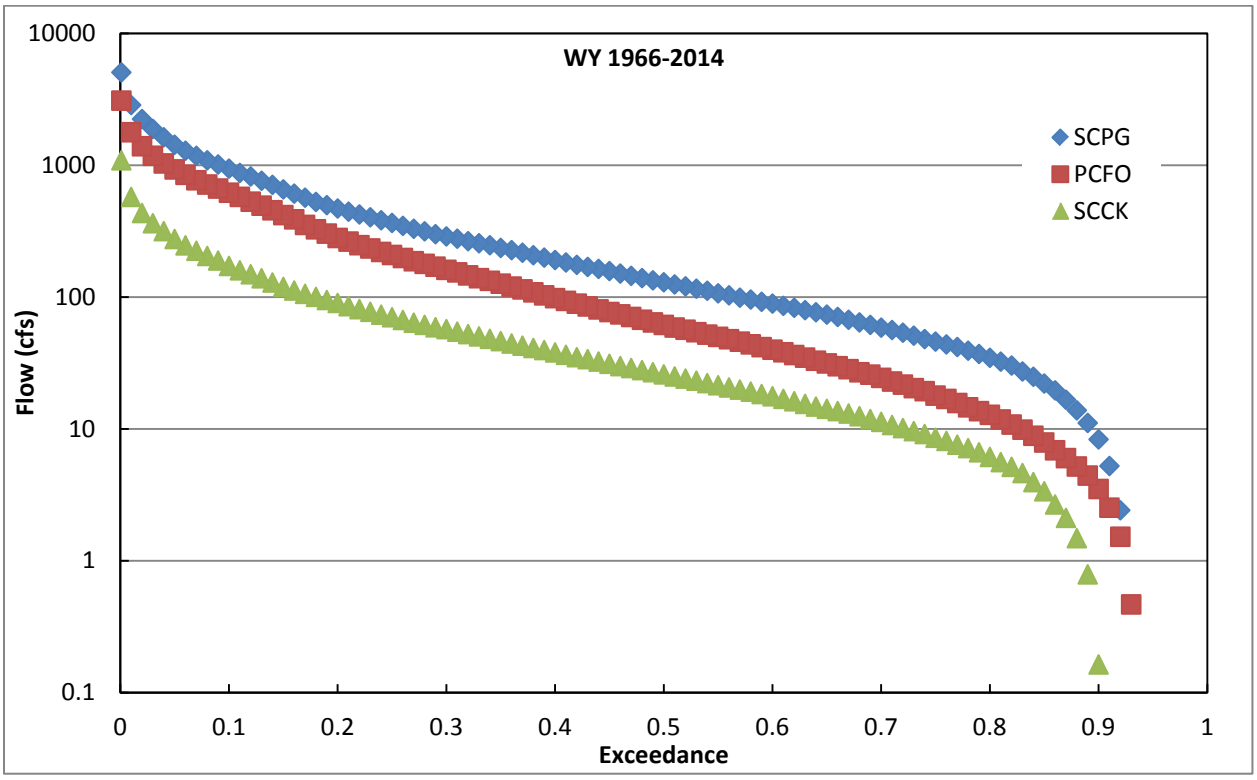

Figure 22 – Flow Duration Curves for Baseline Flow at Shell Creek near Punta Gorda (SCPG, USGS 02298202), Shell Creek at Circle K Groves (SCCK, USGS 02297600), and Prairie Creek near Ft Ogden (PCFO, USGS 02298123)

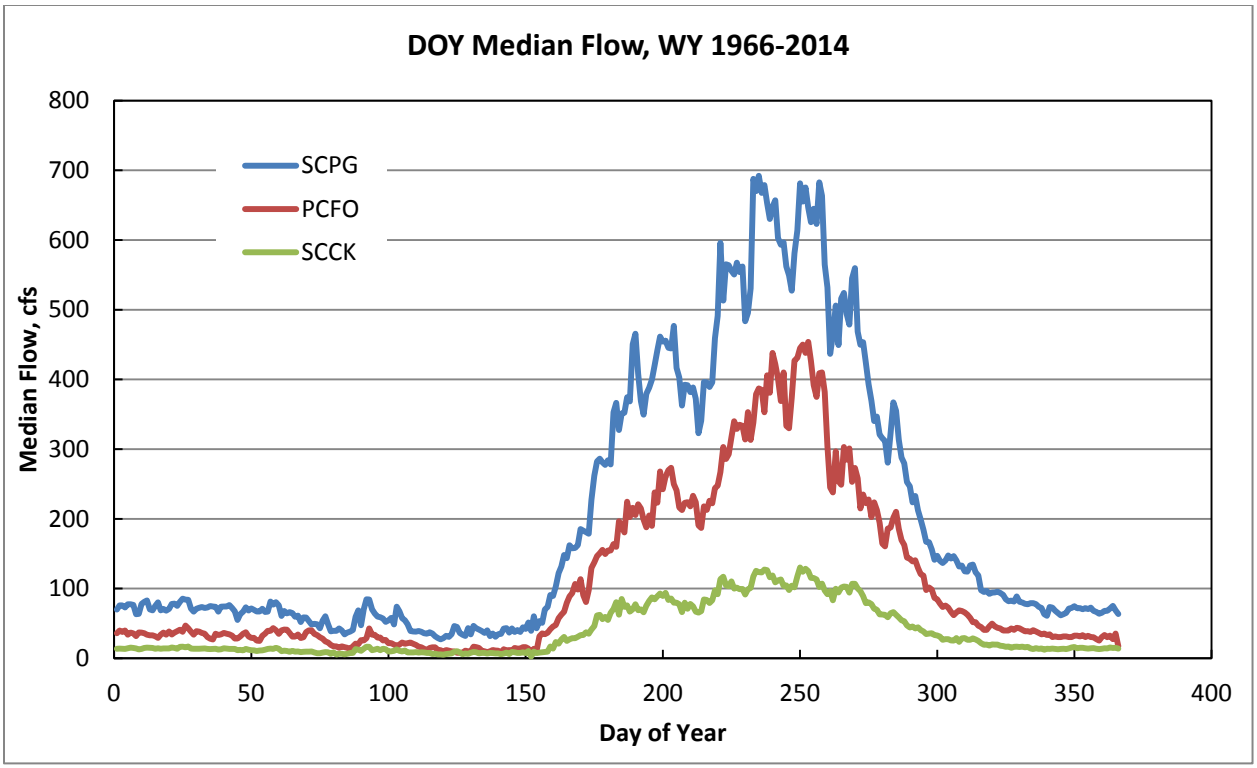

Figure 23 – Hydrographs for Median Baseline Flow at Shell Creek near Punta Gorda (SCPG, USGS 02298202), Shell Creek at Circle K Groves (SCCK, USGS 02297600), and Prairie Creek near Ft Ogden (PCFO, USGS 02298123)

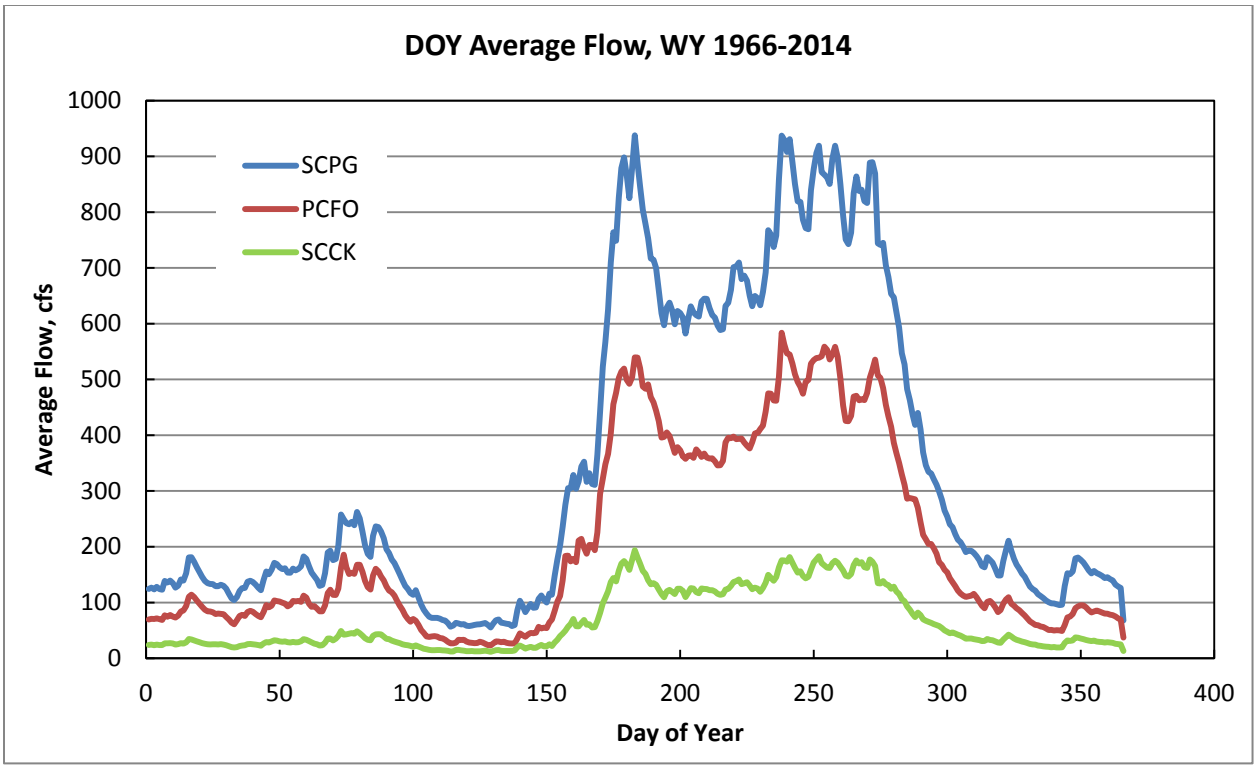

Figure 24 – Hydrographs for Average Baseline Flow at Shell Creek near Punta Gorda (SCPG, USGS 02298202), Shell Creek at Circle K Groves (SCCK, USGS 02297600), and Prairie Creek near Ft Ogden (PCFO, USGS 02298123)