Hydrograph Separation Methods Used to Estimate Groundwater Discharge for Assistance in Calibration of the Western Water Use Model

By

Jesse R. Bradley, Nebraska Department of Natural Resources

Thaddeus Kuntz, Adaptive Resources Inc.

Richard R. Luckey, High Plains Hydrology

Contents

Figures

Tables

1.0 Introduction

The Western Water Use Model (WWUM) is a groundwater flow model being collaboratively developed by the Nebraska Department of Natural Resources (NDNR), North Platte Natural Resources District (NPNRD), and South Platte Natural Resources District (SPNRD). The WWUM covers the central and southern panhandle in Western Nebraska and extends east to include Lake McConaughy and a small portion of the South Platte River (figure 1).

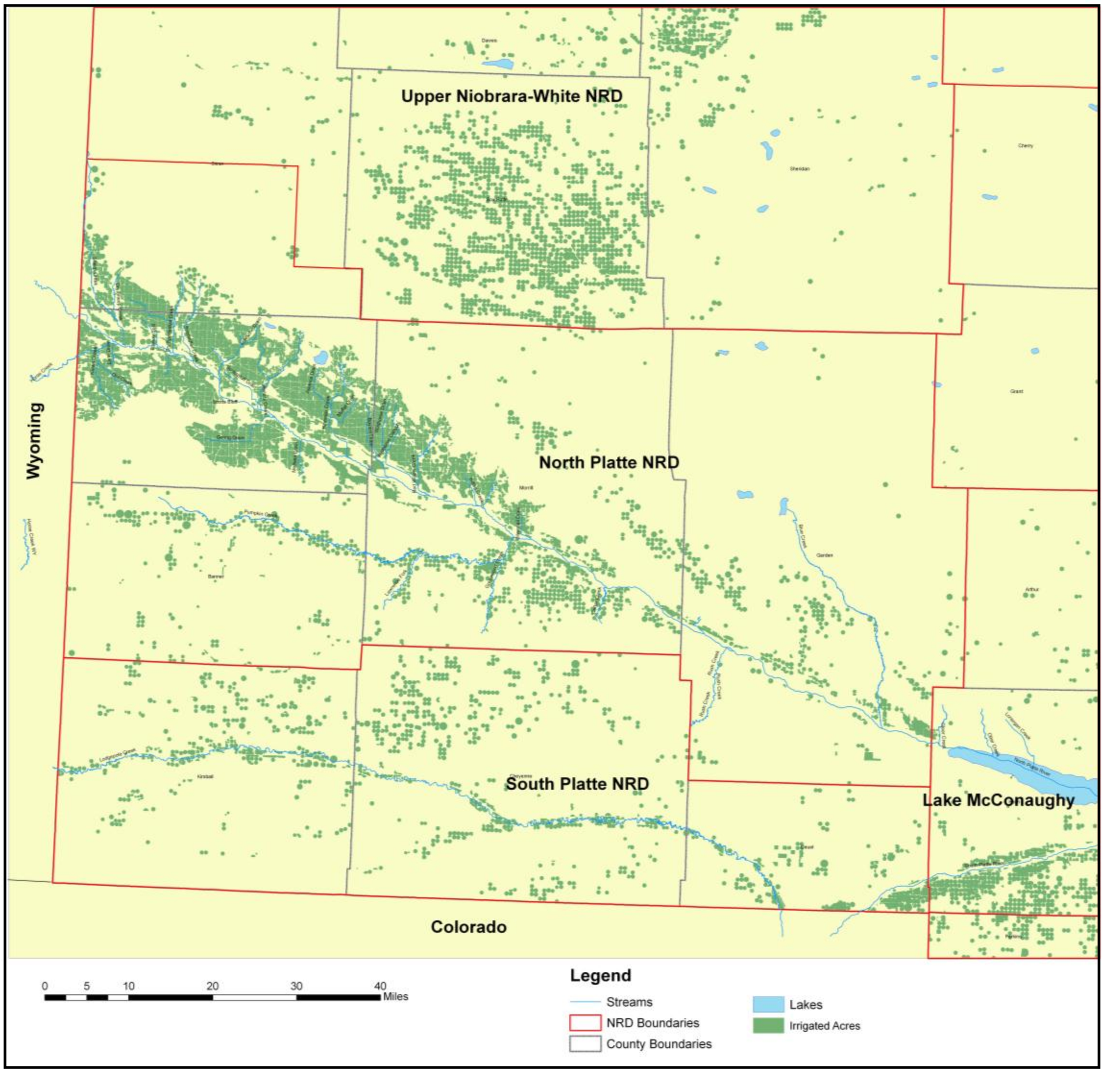


Figure 1. Map of WWUM study area

The WWUM builds on previous efforts conducted by the Cooperative Hydrology Study (COHYST) in addition to aquifer and canal characterization studies completed by the NPNRD and SPNRD. The goal of the WWUM project, in this phase of study, is to develop a calibrated groundwater model that can be utilized to assist the partnering agencies in measuring success toward the goals and objectives outlined in their Integrated Management Plans adopted in September 2009.

A key component in the development of the groundwater model is the development of calibration targets representative of the groundwater discharge to/from hydraulically connected streams. This groundwater discharge component is often referred to as baseflow. Baseflow is typically associated with groundwater discharge and discharge from other delayed sources (Hall, 1968) and represents the slow flow portion of the streamflow hydrograph (Schwartz, 2007).

In hydrograph separation, runoff is defined as the portion of the streamflow hydrograph that is in excess of baseflow. It is important that the user be aware of this distinction and understands that runoff determined through hydrograph separation techniques can be dominated by subsurface flow (Wittenberg and Sivapalan, 1999). Due to the various preconceived connotations for "runoff," this study will define the portion of the hydrograph that is in excess of baseflow as "*residual flow"* since this portion of the hydrograph represents those flows which are remaining after the baseflow component has been estimated. Residual flows can include contributions from overland flow and subsurface flows such as through flow and interflow.

Hydrograph separation techniques can range in complexity from manually drawn curves to automated algorithms. The purpose of hydrograph separation techniques is to divide a streamflow hydrograph into baseflow and residual flow (figure 2).

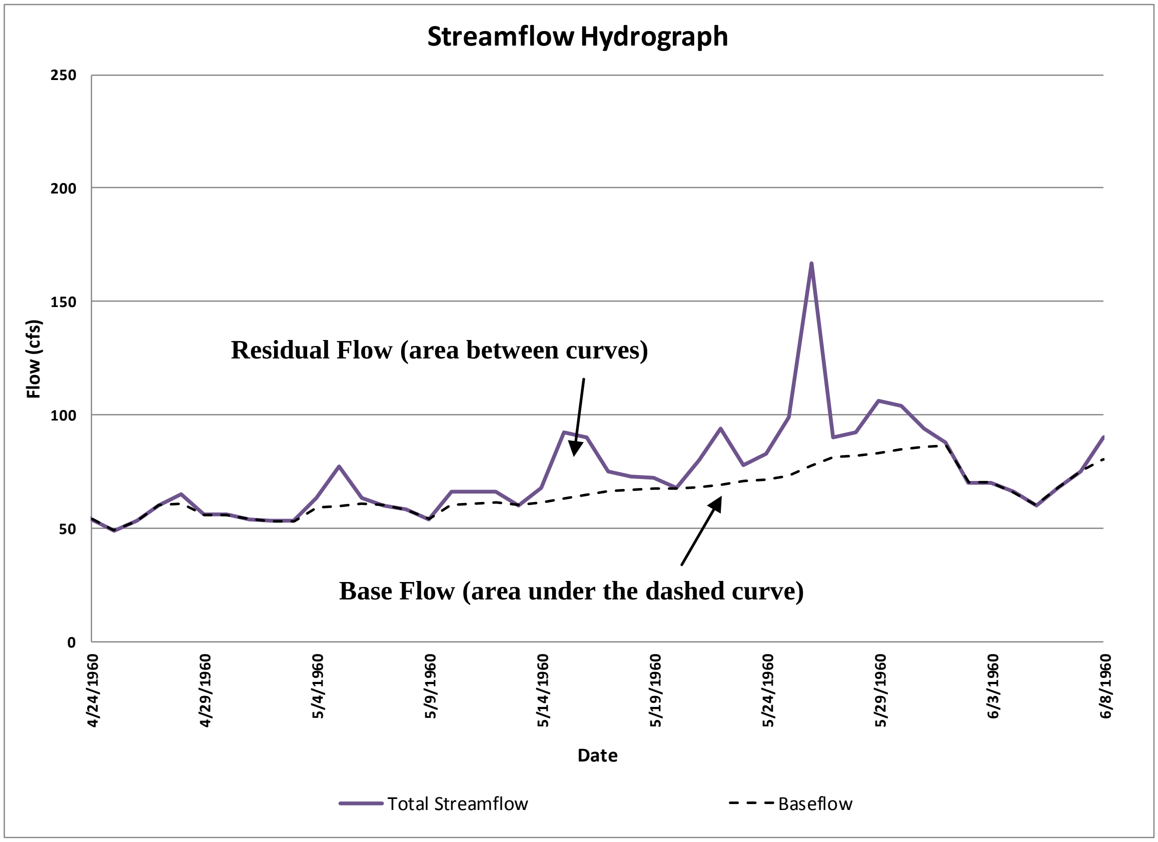


Figure 2. Example streamflow hydrograph and the various components of the hydrograph

The estimates provided through hydrograph separation are often used by hydrologists/hydrogeologists for estimating groundwater discharge/recharge, estimating flooding potential, calibrating models, and assessing impacts of water development.

Previous efforts conducted by the COHYST (Luckey, et al., 2001) focused on the use of low flow statistics to develop estimates of groundwater discharge for the study area. These estimates were utilized to assist in calibration of those earlier groundwater models developed by COHYST. The results from this hydrograph separation study will be used to provide guidance in developing calibration targets in support of the WWUM.

2.0 Methods

The methods section is divided into three subsections. Subsection one provides the overview and underlying assumptions that were utilized in the study. Subsection two details the methods used to process “raw” streamflow data for preparation in the hydrograph separation methods. Subsection three provides a summary of the hydrograph separation methods used in this study.

2.1 Overview and Assumptions

The goal of the hydrograph separation analysis conducted for this report was to develop techniques which could be implemented for the various types of streamflow conditions which occur across the WWUM study area. The focus in developing the techniques was to assess the baseflow for tributary stream gaging points and the baseflow “gain” for reaches of the North Platte River. Baseflow gain, for purposes of this report, refers to the volumetric increase or decrease in baseflow between two streamflow gages. The emphasis of the techniques was to develop methods capable of assessing the contribution of baseflow to total streamflow. Table 1 illustrates the gages evaluated in this report and the period of record utilized for each gage.

Table 1. Stream gages evaluated in this study

Gage ID	Name	Start Year	End Year	Notes
Tributary Gages				
06677500	Horse Creek near Lyman, NE	1931	2006	Includes Kiowa Creek
06678000	Sheep Creek near Morrill, NE	1931	2006	
06679000	Dry Spottedtail Creek at Mitchell, NE	1948	2006	
06680000	Tub Springs near Scottsbluff, NE	1948	2006	
06681000	Winters Creek near Scottsbluff, NE	1931	2006	
06681500	Gering Drain near Gering, NE	1931	2006	
06682500	Ninemile Drain near McGrew, NE	1932	2006	
06683000	Bayard Creek near Bayard, NE	1931	2006	
06684000	Red Willow Creek near Bayard, NE	1931	2006	
06685000	Pumpkin Creek near Bridgeport, NE	1931	2006	
06687000	Blue Creek near Lewellen, NE	1930	2006	
06677300	Kiowa Creek near Lyman, NE	1961	1965	
206000	Cleveland Drain near Bayard, NE	1955	1990	annual data for 1990, all other years May-Sept. only
207000	Coldwater Creek near Lisco, NE	1955	1989	May-Sept. only
209000	Upper Dugout Creek near Bridgeport, NE	1955	1990	annual data for 1979-1985, all other years May-Sept. only
217000	Indian Creek near Northport, NE	1955	1990	May-Sept. only
224000	Melbeta Drain near Melbeta, NE	1955	1990	May-Sept. only
230000	Silvernail Drain near Bridgeport, NE	1955	1989	annual data for 1979-1983, all other years May-Sept. only
204000	Cedar Creek near Broadwater, NE	1955	1989	annual data for 1979-1983, all other years May-Sept. only
North Platte River Gages				
06674500	North Platte River at Wyoming-Nebraska State Line	1929	2006	
06679500	North Platte River at Mitchell, NE	1930	2006	
06682000	North Platte River at Minatare, NE	1916	2006	
06684500	North Platte River at Bridgeport, NE	1930	2006	
06686000	North Platte River at Lisco, NE	1916	2006	
06687500	North Platte River at Lewellen, NE	1940	2006	

The methods developed as part of this study attempted to address the anthropogenic influences that alter streamflow hydrographs in the study area. These anthropogenic impacts include such items as direct diversion of streamflow, direct return of streamflow diverted from a different source or during a different timeframe, and the occurrence and use of stored water supplies, among others (table 2). While the results presented in this report were unable to address all of these anthropogenic impacts, largely due to incomplete or limited data, the methods presented are flexible in nature and provide reasonable estimates of baseflow quantities and trends in most time periods.

It is important to consider the occurrence of storage water introduced into a drainage system, such as which occurs in the study area, as it may cause baseflow estimates from the hydrograph separations to be artificially high. Deliveries for the use of surface water outside of the channel must also be accounted for to provide flow data without the influences of these anthropogenic impacts. Thus, methods to correct for the occurrence of storage water and out of channel uses of surface water had to be developed for baseflow estimates to have a higher degree of validity.

The process of separating the streamflow data using the hydrograph separation techniques typically requires several steps. These general steps are provided below.

1. Adjust streamflow records to account for diversions and storage releases.
2. Conduct hydrograph separations using manual and/or automated method.
3. Summarize data to monthly values.
4. Constrain monthly baseflow data by monthly reach gain data (if baseflow is greater than reach gain, constrain to reach gain).
5. Develop transient plots of baseflow targets.

Subsection two will provide further details on the methods utilized to adjust for the occurrence of storage water and out of channel use of storage water. Subsection three will address the methods used for hydrograph separations.

Table 2. List of anthropogenic factors influencing stream gages

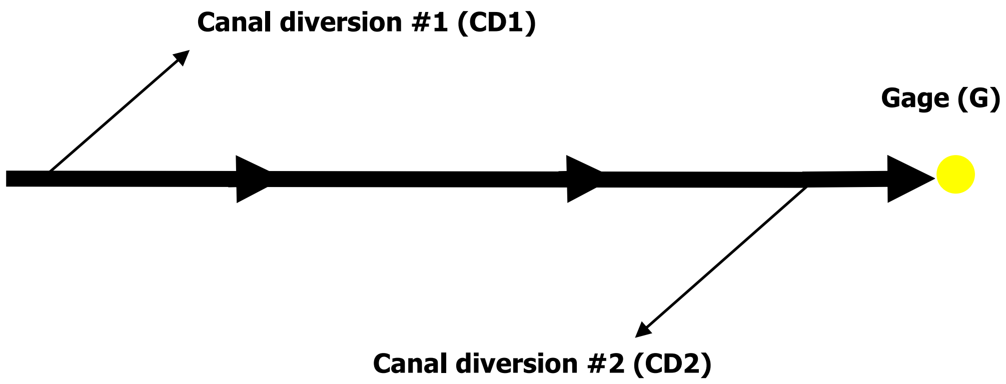
Name	**Anthropogenic Factors**
Tributary Gages	
Horse Creek near Lyman, NE	Owl Creek, Kiowa Creek, Mitchell Drain, Lane Drain
Sheep Creek near Morrill, NE	Interstate Canal, Tri-State Canal
Dry Spottedtail Creek at Mitchell, NE	Interstate Canal, Tri-State Canal, Enterprise Canal
Tub Springs near Scottsbluff, NE	Hiersch Drain (Lake Alice), Tri-State Canal, Enterprise Canal
Winters Creek near Scottsbluff, NE	Winters Creek Canal, High Line Canal, Lowline Canal, Winters Creek Lake, Tri-State Canal, Enterprise Canal, Sugar Factory Drain, Scottsbluff Drain #2
Gering Drain near Gering, NE	Mitchell Gering Canal, Fort Laramie Canal, Gooseneck Creek
Ninemile Drain near McGrew, NE	Nine-Mile Canal, Moffat Drain, Alliance Drain, Kelly Drain, Highline Canal, Minatare Drain, Tri-State Canal
Bayard Creek near Bayard, NE	Alliance Canal
Red Willow Creek near Bayard, NE	Alliance Canal, Lowline Canal, Tri-State Canal
Pumpkin Creek near Bridgeport, NE	Court House Rock Canal, Merideth-Ammer Canal, Last Chance Canal, Belmont Canal
Blue Creek near Lewellen, NE	Blue Creek Canal, Hooper Canal, Graf Canal, Union Canal, Paisley Canal
Kiowa Creek near Lyman, NE	
Cleveland Drain near Bayard, NE	Castle Rock Canal
Coldwater Creek near Lisco, NE	Lisco Canal
Upper Dugout Creek near Bridgeport, NE	Northport Canal
Indian Creek near Northport, NE	Northport Canal, Alliance Canal
Melbetta Drain near Melbeta, NE	Fort Laramie Canal, Mitchell Gering Canal
Silvernail Drain near Bridgeport, NE	Northport Canal
Cedar Creek near Broadwater, NE	Belmont Canal
North Platte River Gages	
North Platte River at Wyoming-Nebraska State Line	Storage releases from storage reservoirs located in Wyoming
North Platte River at Mitchell, NE	Enterprise Canal, Ramshorn Canal, Tri-State Canal, Sheep Creek, Morril Drain, Horse Creek, Lane Drain, Bald Peak Drain, Dry Spotted Tail Creek,
North Platte River at Minatare, NE	Castle Rock Canal, Central Canal, Minatare Canal, Winters Creek Canal, Toohey Spill, Wet Spotted Tail Creek, Tub Springs, Winters Creek, Scottbluff Drain #1 and #2, Gering Drain, Melbetta Drain, Spill # 3 (from Mitchell Gering Canal)
North Platte River at Bridgeport, NE	Empire Canal, Belmont Canal, Chimney Rock Canal, Shortline Canal Minatare Spill, Fairfield Seep, Ninemile Creek, Cleveland Drain, Bayard Drain, Chimney Rock Canal Spill, Wild Horse Creek, Red Willow Creek, DeGraw Drain, Indian Creek, Upper Dugout Creek
North Platte River at Lisco, NE	Beerline Canal, Lisco Canal, Brown Creek Canal, Silvernail Drain, Plum Creek, Browns Creek, Lower Dugout Creek, Pumpkin Creek, Cedar Creek, Sand Creek
North Platte River at Lewellen, NE	Midland Overland Canal, Coldwater Creek, Rush Creek, Blue Creek

* This table may not be complete for any given stream gage. This table was developed through evaluation of previous reports and conversations with NDNR field office personnel in the area.

2.2 Methods to Process Raw Streamflow Data into Hydrograph Estimated Baseflow and Residual Flow

The daily streamflow hydrograph represents the total streamflow that occurred at a given location each day. In many areas throughout the study area, these streamflow measurements are impacted by anthropogenic activities (irrigation, storage, etc.). To more accurately estimate the total streamflow that would have arrived at a stream gaging location naturally, efforts were made to account for the impacts from these anthropogenic activities.

Canal diversions, which divert directly from streamflow, have the effect of reducing downstream gaged streamflow. To account for canal diversions, the record of daily canal diversion data is added to the downstream streamflow gage data to create a diversion adjusted streamflow record. Figure 3 illustrates an example of the components of a hypothetical tributary along with the equations necessary to develop the adjusted streamflow record.



Assuming a one day travel time for flows occurring at CD1.
Gage (G) = $G_{date} + CD1_{date-1} + CD2_{date}$

Figure 3. Illustration of components and equations necessary to develop adjusted streamflow record.

In certain instances the canal diversions may have been far enough upstream of the stream gage that the canal diversion records are lagged by more than one day to account for downstream travel time.

The storage of streamflow within a drainage basin acts to preserve flows during periods of low precipitation and prevent high flows during periods of high precipitation. The mixture of storage water releases and naturally occurring streamflow complicate the hydrograph separation techniques and must be done exercising caution, as the release of storage water into a drainage basin typically increases the amount of water portioned to baseflow using hydrograph separation techniques.

The methods used in this analysis accounted for all data that were available for estimating the impacts from canal deliveries, tributary inflows, storage releases, and diversion returns. Unfortunately, not all of these impacts are measured and the effects of underestimating these impacts may cause the daily values within the adjusted streamflow record to be too high or low.

Due to the more complicated effects of storage water within the North Platte River during much of the study period, it was necessary to apportion it into various reaches and focus on the baseflow gain within the reaches. These reaches were determined largely based on the location of long-term streamflow gaging sites. An adjusted streamflow record for each reach was created for the downstream gage prior to conducting the hydrograph separations. The methods for developing the adjusted streamflow record follow those previously outlined for tributary streamflow gages. The adjusted streamflow record was then processed using the manual and automated hydrograph separation techniques.

2.3 Hydrograph Separation Methods Utilized

Various methods have been established for the separation of hydrograph data into baseflow and residual flow. These methods can be divided into two broad categories, manual methods and automated methods. Manual methods can be labor intensive and can provide results that are subject to the interpretation of the individual hydrologist. Automated methods use computers to remove some of the subjectivity and substantially reduce the time required for analysis of streamflow records (White and Slotto, 1990).

The methodology developed for this report focused on two hydrograph separation techniques, a manual method identified in this report as the pilot point method and an automated method described as the one parameter digital filter (Lyne and Hollick, 1979). The automated and manual methods were utilized in assessment of the five mainstem reaches of the North Platte River and major tributaries of the North Platte River which had year-round streamflow records. The one parameter digital filter was the only method used for smaller tributaries without year-round records.

The pilot point method typically requires the user to identify points that are believed to be representative of baseflow and then linearly interpolate between those points to develop a curve representing the portion of the hydrograph that represents baseflow. The pilot point method follows this premise by establishing a fixed interval at which baseflow points are identified by the user (60-days used in this study) and then linearly interpolates between points. The method allows the user to set a value representative of baseflow at the beginning and end of each interval and then linearly interpolates between the two points to provide a daily estimate of baseflow. Although daily estimates of baseflow are made, they are not intended to be representative of daily baseflow, but rather to capture the long-term (monthly or greater) baseflow portion of the hydrograph. Figure 4 illustrates a pilot point method hydrograph with an interpolated baseflow (green line). The daily baseflow estimates may be in excess of streamflow on any given day, however the intent is to capture the long-term baseflow trend.

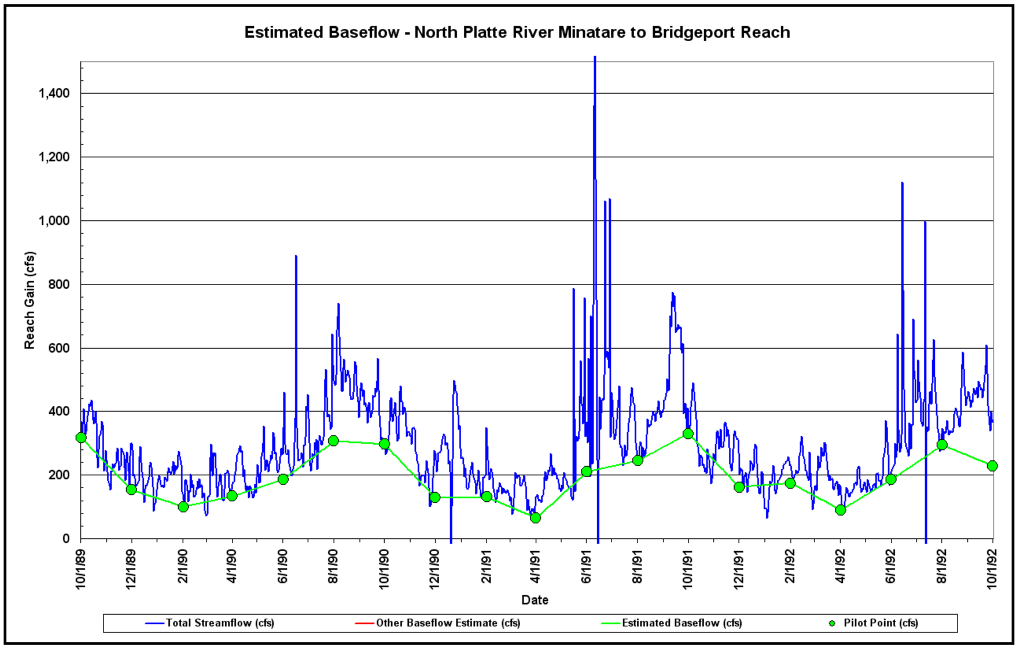


Figure 4. Illustration of pilot point method hydrograph separation.

The automated method utilized in this study was the one-parameter digital filter. The one-parameter digital filter utilizes filtering approaches used to separate high frequency signal from low frequency signal (Lyne and Hollick, 1979). The method can be applied to baseflow separation because high frequency waves can be associated with runoff and low frequency waves can be associated with baseflow (Eckhardt, 2005). The one-parameter digital filter may provide overestimates of baseflow during extend periods of runoff. The equation for the one-parameter digital filter is illustrated below:

$$q_t = \alpha * q_{t-1} + (1+\alpha)/2 * (Q_t - Q_{t-1})$$

Where:

q_t = the filtered direct runoff at the *t* time step
α = filter parameter (0.925 in this study)
q_{t-1} = filtered direct runoff at the *t-1* time step
Q_t = the total streamflow at the *t* time step
Q_{t-1} = the total streamflow at the *t-1* time step

The one parameter digital filter requires the user to provide an alpha parameter. Nathan and McMahon (1990) determined that an alpha parameter of 0.925 provides realistic results when compared to manual separation methods. The alpha parameter has an inverse relationship with the volume of baseflow estimated when using the one parameter digital filter (figure 5). The default value of 0.925 was used in evaluating all reaches and tributaries for this study.

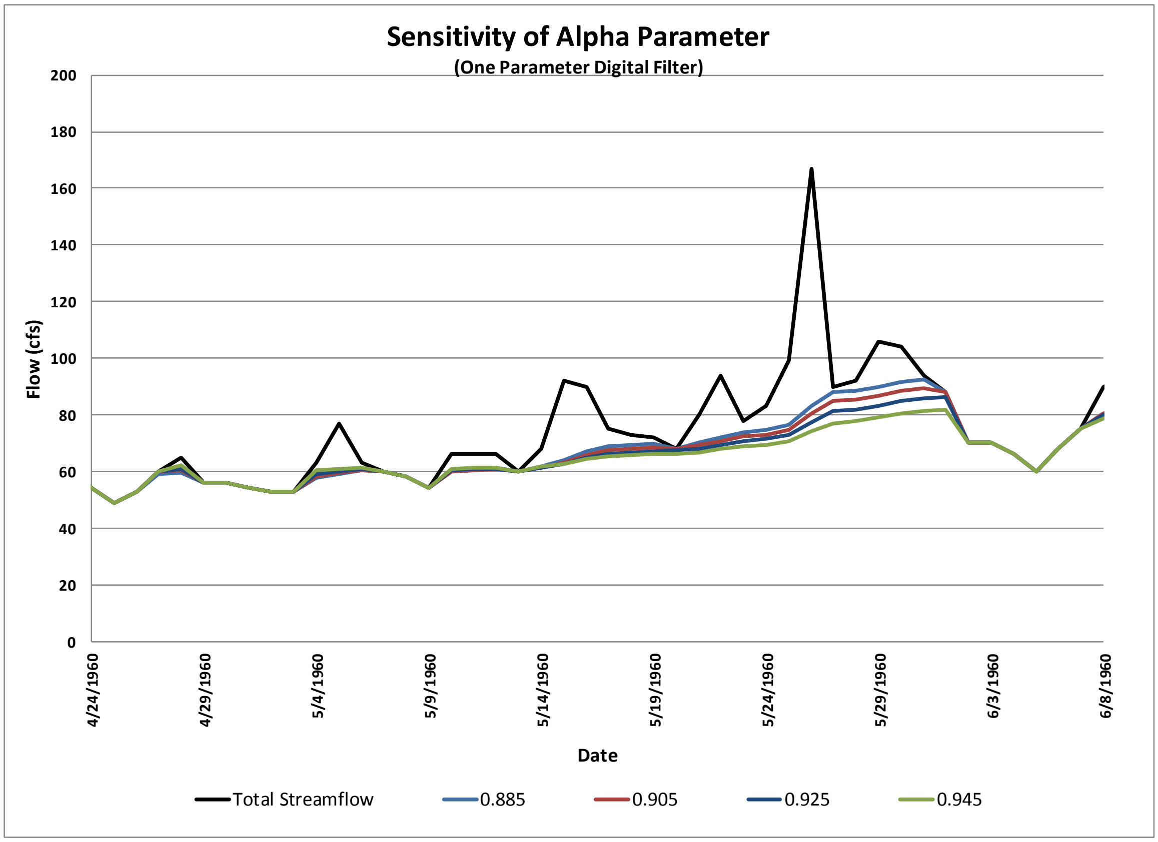


Figure 5. Illustration of the effects of varying the alpha parameter in the one-parameter digital filter

For adjusted tributary streamflow records the automated method was conducted by copying the data into a spreadsheet which utilized the one-parameter digital filtering algorithm, exporting out the separated data, and summarizing the data to a monthly total. In the event the streamflow records were not available throughout the entire study period (1950 – 2006) then only the portion that was available was utilized. The summarized baseflow values are presented in monthly and annual charts in addition to a plot of the mean, median, and plus/minus one standard deviation about the mean for each month.

The five North Platte River reaches were evaluated using both the automated and manual methods. The process for utilizing the automated methods consist of similar methods as outlined above for the tributary streamflow records with two key differences. The first difference is that specified reaches were used to identify the baseflow gain between upstream and downstream gages of a given reach. This was accomplished by subtracting the monthly hydrograph separated baseflow for the upstream streamflow record from the monthly hydrograph separated baseflow for the downstream adjusted streamflow record. This was done to reduce the influence of storage water releases on the baseflow gain estimates. The second difference is that the monthly total baseflow gain was compared to the monthly reach gain and constrained to ensure that it did not exceed the total reach gain. Once these constrained monthly baseflow values were calculated they were then summarized by month for the study period. The rest of the methods outlined for the tributary gages were unchanged.

The process for conducting the manual hydrograph separation (used only on the North Platte River reaches) was slightly different than that of the automated methods. The manual hydrograph separations were conducted using the reach gain data. The reach gain data was calculated by adding all diversions out of the channel to the downstream streamflow record and subtracting the upstream streamflow record from this total. The automated methods are not capable of separating the reach gain data due to presence of negative values in the dataset. Once the reach gain data was separated the data was summarized into monthly totals and compared against the monthly reach gain to ensure that it did not exceed the total reach gain in any one month. The results were then summarized and presented in monthly and annual charts in addition to a plot of the mean, median, and plus/minus one standard deviation about the mean for each month. Additionally, the results of the manual methods are summarized in comparison to the automated methods for the same corresponding reach.

3.0 Results

This report summarizes the methods used to estimate the baseflow and residual components for streamflow hydrographs within the WWUM study area. The results of this report (see appendix A) provide estimates of monthly and annual baseflow developed through hydrograph separation techniques for nineteen tributary streamflow gaging stations and five reaches of the North Platte River. Additionally, the monthly mean, median, and plus/minus one standard deviation about the mean were calculated and provided for each gage or reach evaluated.

The hydrograph separation results for the North Platte River reaches tend to indicate that the manual method provides a lower less variable estimate of annual baseflow with transient annual trends of both the manual method and automated methods being similar in character. Nearly all hydrograph separation results tend to indicate a wider standard deviation during the months May through September (typical irrigation season) than the months October through April. This is likely due to the increase in anthropogenic factors that are not measured influencing the streamflow records. Future efforts to refine these baseflow estimates should focus on further identification and characterization of these anthropogenic factors to evaluate their potential impact on the baseflow estimates.

References

Eckhardt K. 2005. How to construct recursive digital filters for baseflow separation. Hydrological Processes Journal 19(2):507-15.

Hall FR. 1968. Base-flow recessions—A review. Water Resour. Res. 4(5):973–83.

Luckey RR, Carney CP, Peterson SM. 2001. Estimated groundwater discharge to streams from the High Plains aquifer in the Western Model Unit of the Cooperative Hydrology Study area for the period prior to major groundwater irrigation. Platte River Cooperative Hydrology Study.

Lyne VD, Hollick M. 1979. Stochastic time-variable rainfall-runoff modeling. Hydrology and Water Resources Symposium. Institution of Engineers Australia, Perth, Australia. p. 89-92.

Nathan RJ, McMahon TA. 1990. Evaluation of automated techniques for baseflow and recession analysis. Wat. Resour. Res. 26(7):1465-73.

Schwartz SS. 2007. Automated algorithms for heuristic base-flow separation. Journal of the American Water Resources Association 43(6):1583-94.

White K, Slotto RA. 1990. Baseflow frequency characteristics of selected Pennsylvania streams. US Geological Survey Water-Resources Investigations Report 90-4160.

Wittenberg H, Sivapalan M. 1999. Watershed groundwater balance estimation using streamflow recession analysis and baseflow separation. Journal of Hydrology 219(1999):20-33.