Determining the Flow of Comal Springs at New Braunfels, Texas

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Abstract

A computerized base-flow separation method based on 2-day local minimums (the minimum discharge within each 2-day interval) was used to estimate springflow for Comal Springs from daily discharges for the Comal River at New Braunfels, Texas, for the 1933-93 water years. These estimates were compared to the historic estimates (manual separation). The annual springflow from the computer separation averaged about 0.4 percent less than manually-separated values. Daily estimates of springflow were also in good agreement. Thus, the computerized separation method appears to be a viable and objective method of defining the springflows from the river discharges. The study results also show that the water levels in the Comal County and Bexar County index wells are closely related (correlation coefficient of 0.98), and that it is possible to estimate the base flow of the springs from water levels in either well. The Comal County well, however, gave the better result (standard error of estimate of about 16 ft^3/s above 623 ft elevation and about 8 ft^3/s below).

Introduction

The Edwards aquifer is an important source of water for south-central Texas. In addition to providing water for agriculture, San Antonio and other cities in the area rely on the aquifer as a principal source of their municipal water supplies. Recharge occurs along the outcrop of the Edwards and associated limestones (*fig. 1*); streams that cross the outcrop lose much of their flow to the aquifer (Puente, 1978; Maclay and Land, 1988). Many studies of the geology and hydrology of the Edwards aquifer have been made. The report by Maclay and Land (1988) summarizes these studies and provides an overview of the interconnection of the aquifer and the springs that rise along faults between San Antonio and San Marcos.

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The largest of those springs, Comal Springs at New Braunfels, Texas, is the largest group of springs in Texas (Harden, 1988, p. 26) and one of the largest in the southwestern United States. In addition to providing agricultural and municipal water, Comal Springs supports a regional recreation and tourism industry and provides critical habit for the fountain darter (*Estheostoma fonticola*), an endangered fish that occurs at Comal Springs as well as in parts of the Comal and San Marcos Rivers. The U.S. Fish and Wildlife Service has determined that flows of less than 150 ft^3/s from Comal Springs will place the fountain darter in jeopardy (Moore, 1994). As springflows approach this level, users of water from the aquifer will be affected by aquifer management strategies designed to maintain the springflows.

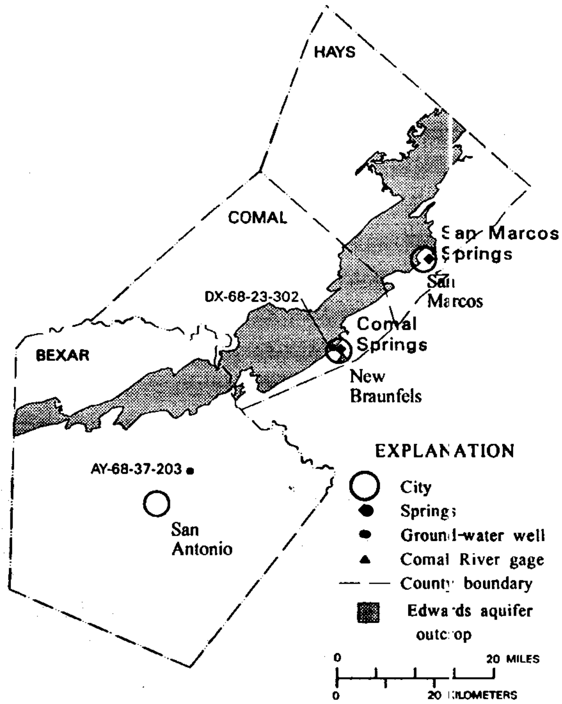

Figure 1. Location map of the study area.

Because Comal Springs rises in numerous orifices, some of which are submerged in pools, direct measurement of the discharge of Comal Springs is not feasible. Historically, estimates of daily springflow have been derived from the daily flow record for the U.S. Geological Survey (USGS) streamflow gaging station on the Comal River at New Braunfels (08169000) using manual methods of base-flow separation. About 95 percent of the time, all flow in the Comal River is derived from Comal Springs. Thunderstorms occasionally produce direct runoff to the river, which has a surface drainage area at the gaging station of 108 mi^2. The direct runoff is included in the gaged river discharge and must be subtracted from the total flow in order to arrive at the base flow derived from the springs.

There are now two somewhat separate needs for springflow data. Data are needed to define the long-term flow rates of the springs for archival purposes. In addition, there is a need to be able to estimate the real-time (present) flow of the springs. Base-flow separation methods can provide the data for archival purposes, but it is unlikely that those methods can provide real-time estimates of the springflow except during periods of no direct runoff. Therefore, alternative methods are needed, perhaps using local ground-water levels. The present study was undertaken to determine (1) whether computerized base-flow separation methods can provide the daily flow records needed for documentation and archival purposes, and (2) whether real-time estimates of the discharge of the springs during periods of direct runoff can be derived from ground-water levels.

Computerized Base-Flow Separation (BFI Program)

Manual base-flow separation methods are labor intensive and are generally not objective; different analysts given the same data would probably arrive at somewhat different values for base flow.

To overcome the lack of objectivity in manual base-flow separation methods, the Institute of Hydrology (1980a,b) proposed a set of procedures in which the water year is divided into 5-day increments, and the minimum flow during each 5-day period is identified. Minimums are then compared to adjacent minimums to determine turning points on the base-flow hydrograph. If 90 percent of a given minimum is less than both adjacent minimums, then that minimum is a turning point. Straight lines drawn between turning points (on semilogarithmic paper) define the base-flow hydrograph; the area beneath the hydrograph is an estimate of the volume of base flow for the period. The ratio of this volume to the total volume of streamflow for the period is defined as the base-flow index. Although these prodedures may not yield the true base flow of the stream, tests in Great Britain (Institute of Hydrology, 1980b), Canada (Swan and Condie, 1983), and the United States (Wahl and Wahl, 1988) suggest that the results are consistent and indicative of the base flow. The procedure is only appropriate for unregulated streams, and thus often cannot be applied to large watersheds.

In contrast to most manual procedures, computerized methods of base-flow separation can handle large amounts of data with relative ease and are objective. A FORTRAN program, BFI (Base Flow Index) that implements the Institute of Hydrology method was initially written for studies of base flow trends in the Oklahoma Panhandle (Wahl and Wahl, 1988) and has been further developed since that time.

How the BFI Program Works

The BFI program accepts data in USGS WATSTORE 2- and 3-card (80-column) format (Hutchinson, 1975) and can process multiple years of data from one or more gage sites. The program produces a table that includes the base flow, total streamflow, and the base-flow index for each water year, as well as summary statistics.

Several refinements have been made to the program to increase its usefulness and provide flexibility. To allow analysis of streams with zero-flow periods, the program uses a linear base-flow recession rather than the standard semilogarithmic relation if a base-flow turning point falls on a zero-flow day. The program can also process continuously through consecutive years so that data near the beginning and end of each water year are not excluded from the analysis. The program checks for errors in the input data, and although it will only calculate a base-flow index for years with complete data, all turning points, daily streamflow and base-flow values can be output to a file for further analysis.

The algorithm proposed by the Institute of Hydrology uses 5-day minimum streamflows and a factor of 0.9 for the test to identify base-flow turning points. Both of these parameters can be varied in the BFI program to permit tuning the algorithm for different watersheds or to match other base-flow separation methods. These parameters are termed *N* (number of days) and *f* (turning point test factor). If the year cannot be evenly divided into *N*-day periods, the last period in the year is lengthened to include the remaining days.

In some cases the method may estimate daily base flows that exceed the actual streamflow. This is often the result of random errors in reported streamflow discharge for streams dominated by base flow. The program makes no adjustments for this situation in its calculations of total annual base flow. However, the daily base-flow values printed in the output file are checked and limited to the actual daily streamflow.

Determining *N* and *f*

Tuning of the BFI program is accomplished by varying *N* and *f*. The parameter *N* has the most dramatic effect in most cases. As *N* is increased, higher-flow days are excluded, and the base flow estimated by the program is reduced. *Figure 2* shows the relation between the base-flow index and *N* for the Comal River at New Braunfels for each of the 1986-88 water years and for the 1933-93 average. The curves show two different behaviors. For 1988, a year with little direct runoff, the relation between BFI and *N* is basically linear. For the remaining curves, however, increasing *N* causes a dramatic drop in the estimated base flow as direct runoff is being eliminated. When a critical value of *N* is reached, all direct runoff has been eliminated, and the drop in estimated base flow becomes less pronounced and essentially linear with increasing *N*; any further increase of *N* causes the method to cut into base flow. Thus, the point of slope change indicates an appropriate value for *N*. For the Comal River at New Braunfels the slope change occurs at *N* = 2 days. This is consistent with the observation that direct runoff generally ceases within 1-2 days following a storm.

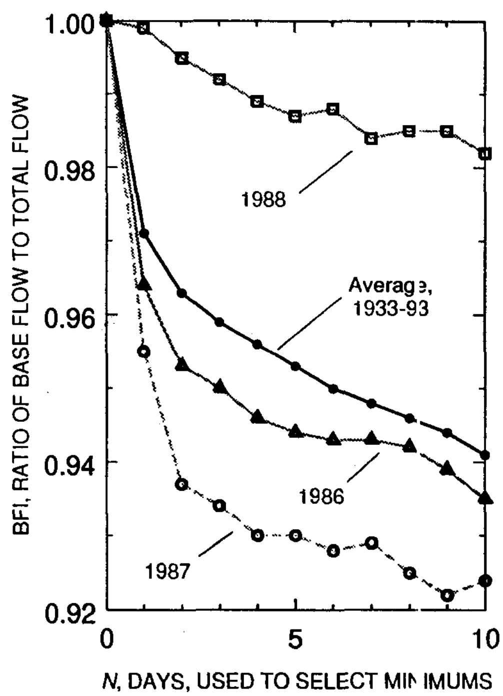

Figure 2. Relation between base flow (BFI) and number of days (*N*) used to select minimums.

The effect of the *f* parameter is less definite. If the interval in days between each potential turning point (*N*-day minimum) were a constant, the value of f associated with a given N would define limiting rising and recession slopes for the base-flow hydrograph. However, since minimum flows can occur anywhere within each N-day period, the interval between any two N-day minimums can vary from 1 to ($2N$-1), producing a wide range of slope limits imposed by f within the course of a single application of the program. In practice, the value of 0.9 seems appropriate in most applications for which the BFI method is suitable.

Comparison with Historic Springflow Estimates

The program was used to compute base-flow estimates for the Comal River at New Braunfels for water years 1933-1955 and 1958-1991, using an N of 2 days and an f of 0.9. Water years 1956 and 1957 were excluded because the Comal Springs went dry during these years, and the river flow was supplemented by ground-water pumping, which has not been excluded from the reported daily streamflow. The percentage differences between annual base-flow volumes estimated using the BFI program and the historic estimates based on manual-separation methods are shown in *figure 3A and 3B*. The annual results compare very favorably, with BFI producing about 0.4 percent less springflow, on average, than was estimated through the historic manual separation. While the annual differences average only about 0.4 percent, the differences appear to be systematically larger from the late 1970's to about 1992 (*fig. 3A*). These differences are independent of the magnitude of the annual discharge of the river (*fig. 3B*). This implies a difference in the manual base-flow separation method used to estimate springflow for that period.

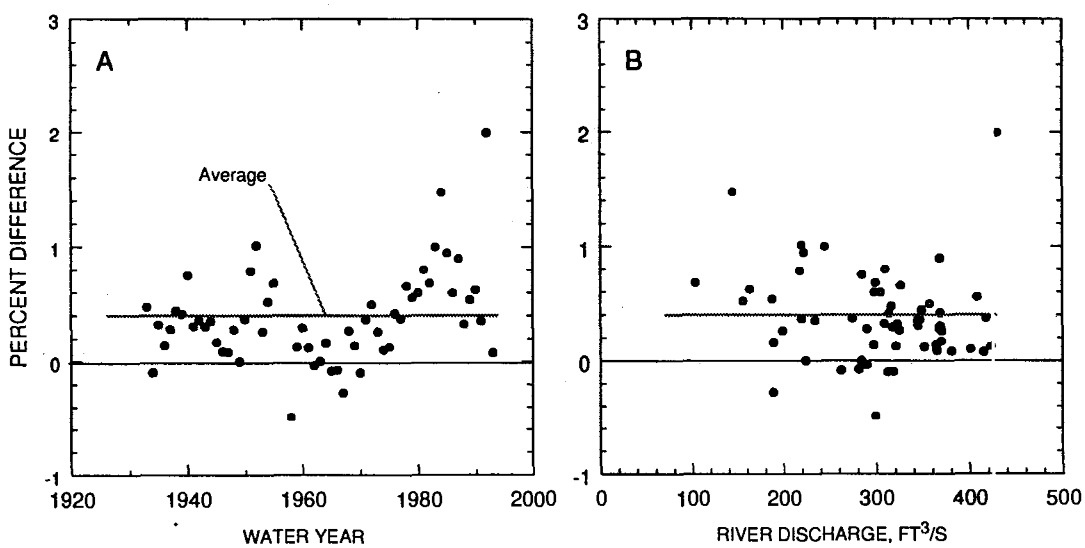

Figure 3. Percent difference between historic springflow estimates (manual separation method) and BFI results using N = 2 days as a function of (A) time, and (B) Discharge of the Comal River.

Daily base-flow estimates produced by the BFI program for water years 1986-90 are compared with manually-separated values in *figure 4.* The 1986-90 period was selected as a sample representative of the period of record. The correspondence between daily values is only approximate, confirming previous observations that the method may not yield the true base flow, but provides a consistent indication of longer-term base-flow variations. There is, of course, no assurance that the manually-separated base flows are the true springflows.

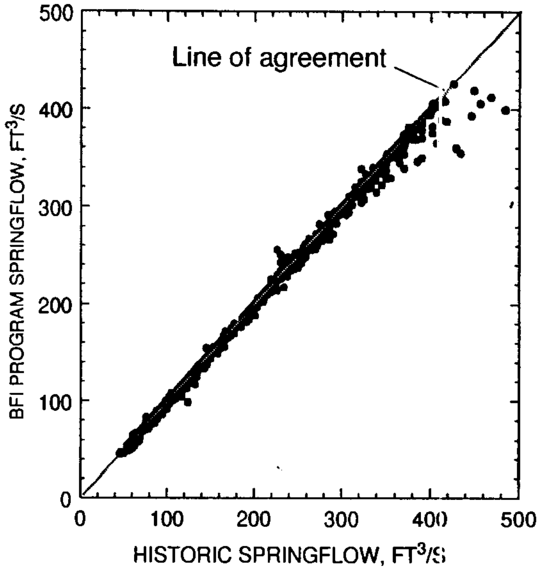

Figure 4. Comparison of daily springflow from the BFI program with historic estimates from manual separation, water years 1986-90.

Relations between Ground-Water Levels and Springflows

The flow of the springs has long been recognized to be directly related to the water levels in the Edwards aquifer. Maclay and Land (1988, p. 20) described the general movement of ground-water in the Edwards aquifer and noted that "Most of the flow in Comal Springs is sustained by ground water along the downthrown side of the Comal Springs fault." Espey (1988) showed the relation between river flows and base flows, and Harden (1988) described the general relation between water level in the aquifer and elevations of the principal springs that issue from the aquifer. However, the relations shown by both Espey (1988) and Harden (1988) were qualitative; no specific estimating relations were shown.

Puente (1976) defined regression relations between water levels in several index wells in the area as well as defining the relations between those water levels and springflow amounts. Among the wells he used were the Comal County index well (DX-68-23-302) located about 300 feet west of Comal Springs and the Bexar County index well (AY-68-37-203) located about 25 mi southwest of Comal Springs.

For the present study, regression relations were defined between the historic springflows (from base-flow separation) and the water-surface elevations of both the Comal County and Bexar County index wells. The Comal County well is nearby and would serve as a convenient index to the springflow. Although this well is near the springs, the well was completed on the upthrown side of the Comal Springs fault (George Ozuna, U.S. Geological Survey, written commun., 1994), and the springs are sustained by ground water along the downthrown side of the fault (Maclay and Land, 1988, p. 20). In addition, the head variation in the Comal County well (about 11 ft) is much less than in upgradient wells that are more distant from the fault and springs. Thus, a relatively small change in water-level elevation in the well could effect a relatively large change in springflow. The Bexar County well is a widely used index well with a larger range in water-level elevation (about 80 ft), but is located about 25 mi from the springs. The Bexar County well, however, is known to be influenced by development in the San Antonio area (Harden, 1988). Because of this development and the distance to the springs, the Bexar County well may not accurately reflect the hydraulic head driving Comal Springs.

The Relation Between Well Levels

Water-level data are available in computer files of the USGS for both the Comal County well and the Bexar County well. Several wells have served as the Bexar County index well since about 1911; water levels in the USGS computer files represent well AY-68-37-203 only since the spring of 1963. Thus, the current analysis of water levels for the Bexar County index well used data only after 1963.

Puente (1976) developed a linear regression relation between the monthly mean depths (in ft) to water below land surface in the Comal County (D_C) and in the Bexar County (D_B) index wells. The elevations of the land-surface datums are 642.7 ft and 730.81 ft, respectively. A similar relation was developed in the present study using 2,016 daily water-level readings for calendar years 1964-1993. Those relations as well as the equivalent present relation using water-level elevations (E_C and E_B) of the wells are shown in Table 1.

Table 1: Regression relations between water levels in the Comal County and Bexar County index wells.

Variable	Equation	R^2	Standard error, ft	Sample size	Data used
Monthly mean depth to water (Puente, 1976)	$D_C = 8.46 + 0.13\ D_B$	0.98	0.22	81	1964-73
Daily depth to water	$D_C = 8.48 + 0.1316\ D_B$	.97	.39	2,016	1964-93
Daily water-level elevation	$E_C = 538.1 + 0.1316\ E_B$	.97	.39	2,016	1964-93

The relations between the water-level elevation data are shown in *figure 5*. The excellent agreement between Puente's relation and those defined in the present study using more frequent readings and a longer period of record attest to the stability of the relation between these wells.

Relation between Springflow and Ground-Water Levels

Puente (1976) defined regression relations between the flow of Comal Springs and the ground-water levels in the Comal and Bexar County index wells. Daily and monthly flows were related to the Comal County well, and monthly and annual flows were related to the Bexar County well. Although his data covered the normal ranges of the variables, the daily-flow relations were based on a relatively small set of data (33 days). Puente concluded that springflow could be estimated accurately by a set of empirical equations. These wells were also used in the present study.

The elevation of Comal Springs is commonly given as 623 ft. That elevation, however, is for the topmost orifice. The springs went dry in 1956 as the water-level elevation in the Comal County well neared 619 ft; the springs remained dry while the water level in the well remained below about 619 ft. Therefore, the elevations of the various orifices of the springs can be assumed to cover a range of about 4 ft. The relation between the water levels in the well and springflow will change as the various orifices cease to flow over a water-level range of about 4 ft. Therefore, separate relations were developed depending on whether the water-level elevation in the Comal County well was above or below 623 ft. The corresponding elevation at the Bexar County well is 645 ft.

Daily springflow discharges (Q) determined from base-flow separation were related to the water levels in both the Comal County and Bexar County wells. Those relations are shown in Table 2 and the data and relations for the Comal County well are shown in *figure 6*. The lower relation for the Comal County well shows the springs to be dry when the water level in the well falls below about 619.3 ft and should not be used below that elevation. The Comal County well produced the better relations, probably by virtue of its proximity to the springs. The relation between the flow from Comal Springs and the Comal County well is good, but there appears to be some minor seasonal fluctuation in some years. That fluctuation may be a result of the response of the well to pumping in the vicinity of the well or to changes in the water level in Landa Lake, which would affect the head difference between the aquifer and the spring orifices.

Table 2: Regression relations between the average daily flow of Comal Springs and water-surface elevations in the Comal County and Bexar County index wells.

Equation	Conditions	R^2	Standard Error, ft^3/s	Sample Size
$Q = 36.82 + 36.96 (E_C - 619)$	$E_C > 623$	0.94	16.13	813
$Q = -17.03 + 50.5 (E_C - 619)$	$619.3 > E_C < 623$	.97	7.92	114
$Q = 52.31 + 4.932 (E_B - 619)$	$E_B > 645$	.92	19.22	813
$Q = 11.63 + 6.51 (E_B - 619)$	$619 > E_B < 645$	.93	12.52	114

Puente (1976) presented a relation between the daily springflow and the depth below land surface in the Comal County index well that was based on 33 daily values. His relation, recast in the form of the equations in Table 2 was

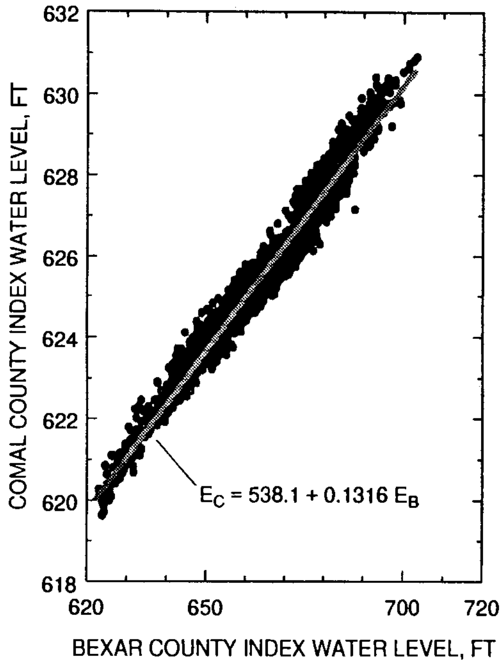

Figure 5. Relation between the water-level elevations in the Bexar and Comal County index wells (1964-93).

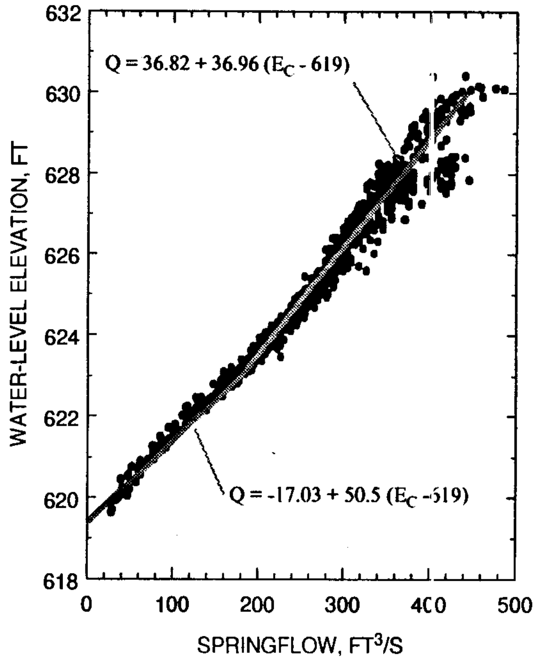

Figure 6. Relation between water level in Comal County index well and flow from Comal Springs (1977-91).

Q = 12.72 + 44.4 (E_C - 619). That equation produces comparable results to those in Table 2 for E_C = 623 ft; for E_C = 630 ft, Puente's equation gives about 13 percent more springflow.

Summary and Conclusions

The study shows that the springflows that have traditionally been computed by manual separation of the base flow from the daily discharges of the Comal River can be reproduced using a computerized method. The annual percentage differences between the model-produced results and the historic values averaged about 0.4 percent. The computerized method has advantages over the manual method in that the computerized method is fast and objective; that is, given the same set of input data, different analysts would produce the same base-flow (springflow) estimates using the model. There is some evidence that in the past, the methodology used in performing the manual separation has undergone some subtle changes that, while producing relatively small differences, could cause the results to suggest changes that may in fact be artifacts of the changes in methodology. The computer-based separated values do not show this feature.

The study results also show that it is possible to estimate the base flow of the springs from water levels in either the Comal County or the Bexar County index wells. The Comal County well gave the better result (standard error of estimate of about 16 ft^3/s above 623 ft elevation and about 8 ft^3/s below). Using the well record could be particularly useful when the rates of springflow are needed during periods of direct runoff to the river. During such periods, base-flow separation techniques, both manual and computerized, are ineffective until the river has returned to base-flow conditions.

A possible procedure that could be used to determine springflows in the future would be to (1) use the computerized method (*N*=2 days) to derive the springflows for archival purposes, and (2) use the relation with the water levels in the Comal County index well to estimate the flow in real time during periods of direct runoff. These latter values would be recognized as estimates that could be available immediately for management purposes, but that would be revised and replaced in the database with values from the computer model once the river flow had receded to base-flow conditions.

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