City of Austin
WATERSHED
PROTECTION

Response to Mr. Raymond Slade's Addendum to cause 2015003—Summary of Complaint against Nico Hauwert, PG #5171

Response Prepared by Nico Hauwert, Ph.D., P.G. #5171
City of Austin Watershed Protection Department
December 11, 2014

DR-15-06

Below is response material pertaining to an undated file provided by Raymond Slade entitled (pdf file sent was created November 20, 2014):
"Addendum to cause 2015009—Summary of complaint against Nico Hauwert, P.G. #5171*"*

Note that Mr. Slade misquotes the values I used to characterize recharge.
"*Hauwert published a report (Hauwert, 2014) claiming the interstream recharge rate from his 2009 small-basin (26-32% of precipitation) to represent that for the entire recharge area."*

What Hauwert & Sharp 2014 actually states is :
"Based on compilation of ET data from other flux towers in Central Texas under a wide variety of annual precipitation conditions, it can be estimated that under average precipitation conditions, 69% of rainfall leaves as ET; 28% of rainfall percolates as autogenic recharge into the Edwards Aquifer."

It is unclear what is referred to by the statement:
"Hauwert (2014) references only one site from one study that produced a recharge rate similar to his claim. However, that study is flawed and not pertinent to the Edwards aquifer as identified in item 8 of exhibit A."

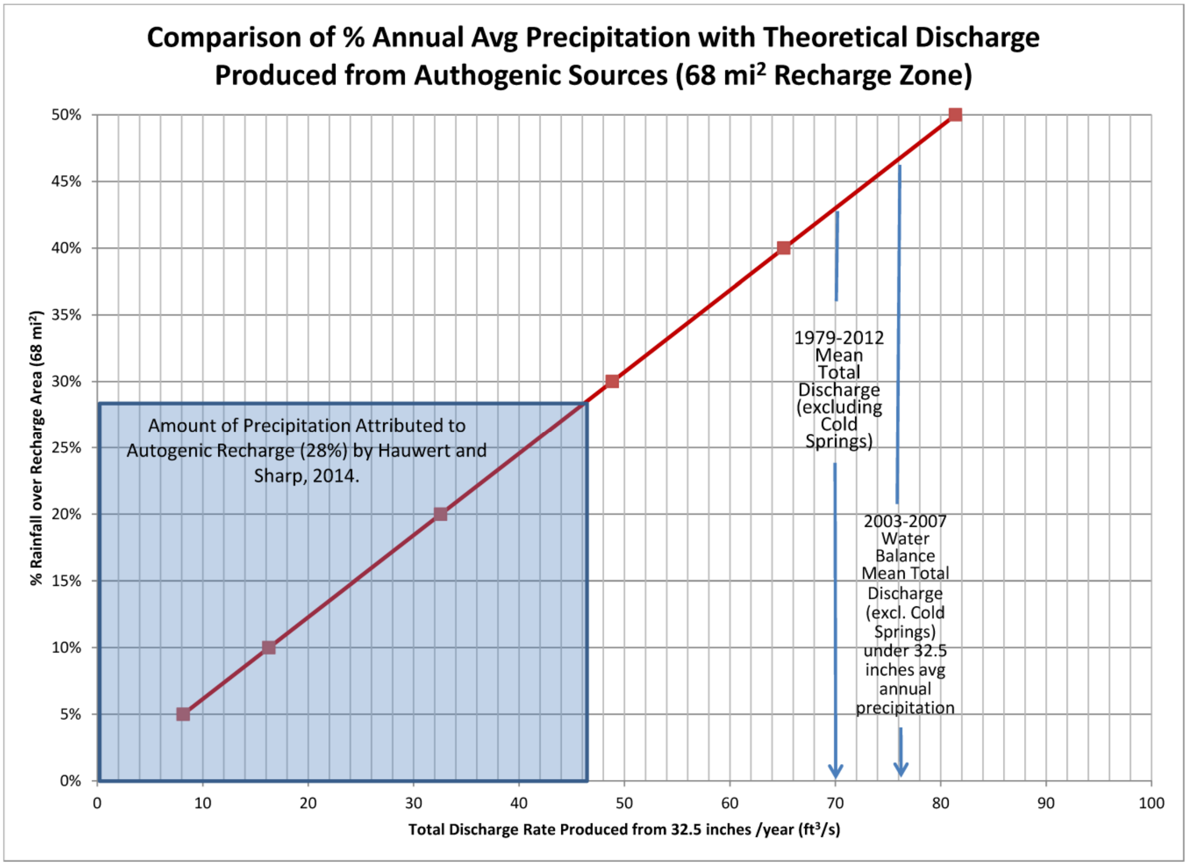
Could it be he is referring to Hauwert and Sharp 2014, where date from several site scaled climate towers across Central Texas is presented (not just one site)?

Exhibit 8 ("Edwards aquifer discharges other than Cold Springs to the Colorado River") references an April 1925 Colorado River low survey. According to Slade the TBWE notes that flow measurements taken April 23, April 24, and April 25 were noted to be under "Constant stage." However, the USGS Water Supply Paper for 1925 (attached) notes that at the Colorado River at Austin, discharge on April 23, 1925 was 188 ft3/s, on April 24, 1925 was 238 ft3/s, and on April 25, 1925 was 243 ft3/s. It is possible that TWBE noted “Constant” as a relative condition, although the 55 ft3/s change in discharge would have large potential error for comparing flow measurements along the Colorado River on different days. It is unclear how Slade attempts to use this might apply to measurements of recharge in Central Texas.

Mr. Slade uses “simple” calculations to evaluate the validity of upland recharge values that are prone to high potential error. I previously present data to suggest Mr. Slade selected the wrong values here. Is the arithmetic mean of Barton Springs discharge 50 or 70 ft^3/s? Is the groundwater basin for Barton Springs the recharge area combined with the contributing zone, and is it 350 square miles, 90 square miles or 68 square miles? If Cold Springs discharge is included in the balance is its discharge measureable, is it 3-4 ft^3/s, is it 6 ft^3/s or is it 15 to 30 ft3/s? How were the groundwater basins determined and what are their areas? Were all the creek sources to the springs measured? How was autogenic or upland sourced recharge measured if at all? Are there multiple methods of measuring recharge for comparison, given the large potential for error using creek flow loss alone?

Still, we show a calculation how much discharge could be theoretically produced by 32.5 inches of precipitation over a source area, based on the best available data (Figure 1). Based on tracing and surface geological mapping (Small, Hansen and Hauwert, 1995/Hauwert, 2009), I measure the recharge area to Barton Springs to be 82 square miles, although 14 square miles of this recharge area are overlain with confining units such as Del Rio Clay (described in Hauwert and Sharp, 2014, p. 871). To characterize the Edwards outcrop, I believe that a 68 square mile source area is most representative.

Figure 1.



Note, by allocating 28% of precipitation to autogenic recharge produces 46 ft^3/s over a 68 square mile area. Using mean total discharge (USGS reported Barton Springs discharge + BSEACD calculated pumpage+lower Barton Creek spring discharge) of 70 ft^3/s (mean from 1979 to 2012) to 77 ft^3/s (four year water balance under average rainfall conditions), there is 24 to 31 ft3/s of flow available from other sources such as allogenic recharge from the contributing zone. During the 2003 to 2007 water balance interval, allogenic recharge sources could be measured from upstream gauging stations to be roughly similar in magnitude to autogenic recharge.

Essentially the discrepancy between and those reported in Slade et al, 1986 (column A below), Barrett et al., 1996, and my recharge measurements (C in chart below) for intervening recharge can be attributed to different allocation of recharge from **Barton Creek channel**, along with lesser refinements for Blanco River contribution and addition of actual Little Bear Creek discharge data.

Table 1. Comparison of Sources to Barton Springs

Source	Total Barton Springs Flow			Total T. GW Disch.		Maximum Recharge Rate			
	A* (%)	B* (%)	C* (%)	A*	C* (%)	A* (cfs)	B* (cfs)	C* flood (cfs)	C* low-flow
Barton Upst 360	28	26	0	26	0	30-71	250	50	30
Barton Dnst 360	---	---	<12 (6 be*)	---	<11 (6 be*)	---	---	40	20
Williamson	7	3	1	6	1	14	13	20	13
Slaughter	12	5	8	11	7	53	52	85	28-55
Bear	11	6	7	10	6	32	33	35	28-33
Little Bear	11	6	4	10	4	28	33	35	25
Onion	35	39	37	32	33	120	120	250	20-100
Blanco River	0	0	9	0	6	---	---	250	10-18
Sum			57-78	94	**56-67%**				
Intervening Areas	15	15	---		33-44%^{E}	---	---	---	---

A* - source Slade et al., 1986, total watershed
B* - source Barrett et al., 1996, major stream channel
C* - This study, major stream channel
be* - best estimate

^{E} - Intervening Area recharge was calculated as water budget residual and includes other lesser leakage sources. Upland recharge was only directly measured at site scale in study C for comparison.
Other Potential Leakage Sources: Subsurface Trinity Aquifer Leakage, Urban Leakage, Saline Water Zone

The difference in groundwater basin delineation is that since 1996, I have participated in extensive dye tracing of Barton Creek, coupled with potentiometric surface mapping, whereas Slade et al 1986 had only data on hydraulic connection between Barton Springs pool and selected wells, data which is also incorporated into my delineation of groundwater basins. The groundwater basins used by Slade et al., 1986 are simply assumptions which contradict direct tracing data. I traced some sites on Barton Creek twice under both high and low springflow conditions, using creek flow to flush tracers in some cases.

In Slade et. al., 1986 and Barrett et al., 1996, Little Bear Creek recharge was simply assumed to be the same as Bear Creek, since discharge data was not available in 1986 during their study intervals. Discharge data for Little Bear Creek collected by City of Austin and Barton Springs/Edwards Aquifer Conservation District was used in a 2003 to 2007 water budget study.

I will attempt to describe the differences in the reports and studies on recharge.

1980s report

In a 1984 Austin Geological Society guidebook, Mr. Raymond Slade wrote an article describing a recharge study using monthly recharge values per watershed from July 1979 to December 1982, concluding that 85 percent of the total recharge originates in major creek channels and 15% originates in intervening tributaries and other recharge zone areas. The methodology for the recharge calculations and creek flow loss data was not presented in the article. Within the same guidebook a second article authored by Dr. C.M. Woodruff cites USGS gauging station data support further analysis of the creek flow loss as a percent of precipitation. Dr. Woodruff and Mr. Slade both claim that Mr. Slade was ghost writer for this article but the U.S. Geological Survey would not approve its release in time for publication. However, the analysis breaking down rainfall components of evapotranspiration and upland Edwards Aquifer recharge presented in Woodruff 1984 is not included in the U.S. Geological Survey final report on the recharge study (Slade et al. 1986) nor in subsequent USGS reports, and I presume it is because the USGS was not comfortable with extrapolation of a rainfall water budget based solely on stream flow gauging. By relying on a fraction of the water budget (9% of precipitation) to extrapolate the remainder, there is a large potential for error. Furthermore, as discussed below, continuous flow data was available from upstream gauging station alone for most of the major creeks, not upstream and downstream stations as described in Slade et al., 1986. The results from the Woodruff (1984) water budget are frequently cited, particularly to discount upland recharge for development projects and recent proposed Jeremiah Ventures development where wastewater irrigation was recently proposed for the recharge zone in Hays County. The use (or misuse) of this recharge data can potentially affect public health and safety, particularly downgradient water well users.

Summary of Stream Flow Recharge Studies

The Woodruff 1984 article was not specific in describing how recharge was calculated. Using USGS reported recharge values, it was calculated that 6% of rainfall across the recharge and contributing zones recharge, that 85% evapotranspirates, and 9% runs off downstream of the recharge zone. Much of the 6% of precipitation that recharged the aquifer originated as runoff from the contributing zone (allogenic recharge) and that only 15% of the 6% of precipitation recharged on intervening upland areas between the major creek channels. Dr. Woodruff states (1984, page 39):

> *"Moreover, the value commonly cited for the amount of recharge occurring in the streambottoms within the recharge zone (85 percent) applies only to the approximately 6 percent of incident rainfall that actually contributes to the recharge (based on the USGS figures cited above). Hence, on the average, the amount of recharge occurring on upland areas (that is, away from the main stream channels) amounts to a mere 15 percent of the 6 percent of the incident rainfall—or a value of 548 acre ft/mo (fig 11)."*

where 6% of 15 is 0.89%.

As paraphrased by Woodruff (2010) for the application of treated wastewater on Jeremiah Ventures proposal :

> *"A comprehensive water budget must include total rainfall, rates of surface water runoff from the uplands, and the water cycled via E/T, as well as recharge. For the 42-month period of study used by Slade and others (1986), total rainfall (integrated for the study area) totaled 2,577,120 acre ft (61,360 acre ft per month), which is somewhat higher than the long-term average, but that value represents weather conditions when the flow-loss studies were conducted. During that time, the two directly measured parts of the water budget were found to be 5.95% for recharge and 9.07% for runoff. Subtracting the sum of these percentages shows that E/T comprised*

> *85% of the total water budget. In other words, in this area vegetation is expected to cycle about 85% of incident rainfall back to the atmosphere, and most of this cycling occurs on the uplands.*
>
> *Of the recharge fraction, the average monthly volume entering the aquifer from within the main creek channels accounts for 3,102.5 acre ft of the recharge total (85%),* ***leaving 547.5 acre ft as the monthly fraction that enters the aquifer in all other areas beyond the main channels of the six through-flowing creeks (0.89% of rainfall).*** *As noted in a generalized (BSS aquifer-wide) water budget computed by Woodruff (1984), the modest fraction of recharge occurring on most of the recharge zone (outside the six main creek channels) is corroborated by Rugen and others (1977), who employed controlled vegetated plots with precisely measured irrigation volumes to compute monthly E/T values. The E/T rates obtained in this manner were about 7 percent higher than those computed for the BSS area-wide water budget using data from the 42-month study period. Nonetheless, the conclusions from both studies show the importance of E/T as (by far) the chief process cycling rainwater incident on the recharge zone.* ***A liberal estimate of recharge would allocate about 1% of total rainfall to enter the aquifer on uplands and along tributary watercourses.*** *Of course, the ability of specific localities to receive recharge is highly variable during short time intervals. Moreover, open caverns on the uplands could easily receive many times the average recharge rate, if water were directed to such features."*

While I do agree with Mr. Slade's assertion that the 1980's USGS data was insufficient to calculate upland recharge on the Edwards, I hold false Mr. Slade's assertion (from "9. Advantage of aquifer wide ET budget" in original complaint materials), that Dr. Woodruff's did not state that 6% of 15% of precipitation was estimated for upland intervening recharge:

> *"Hauwert's statement that "0.09% of the mean rainfall was estimated to recharge the aquifer through upland intervening areas of the recharge zone" is meaningless. Woodruff does not state such nor provide data or information that would even suggest such. Also Woodruff's budget includes the entire contributing and recharge area as a whole: separate budgets were not done for the contributing or recharge areas..It is obvious that Hauwert does not understand Woodruff's budget."*

Mr. Slade's assertion that I do not understand his Slade et al. 1986 or Slade 2014 methodology or Dr. Woodruff's 1984 budget may also be true to the extent that the methodology is referenced to various reports and even a thorough understanding of all the reports does not yield a clear and consistent methodology that applies to the analysis. To some extent my understanding is limited to what can be read in their original reports, as well as what the authors claim in discussion and other reports.

In Slade et al., 1986 the description of methodology in his study as:

"*The method of estimating surface recharge to the Edwards aquifer is presented by Garza (1962). Recharge consists of the infiltration of streamflow plus direct infiltration* *of runoff in the interstream areas.* ***The approach of estimating recharge in each stream basin is a water-balance equation, in which recharge within a stream basin is the difference between gaged streamflow upstream and downstream from the recharge area plus the estimated runoff in the intervening area.*** *The intervening area is the drainage area within the recharge area between the two streamflow-gaging stations in each stream basin. Runoff from that area is estimated on the basis of unit runoff from the area upstream from the recharge area." All hydrographs in this report present recharge in units of daily-mean values."* "***A water-budget analysis was done for the total inflow and outflow to the surface area which contributes recharge to the aquifer by using the precipitation, streamflow, and surface recharge data (Woodruff, 1984). This analysis was done so that the portion of precipitation which contributes to recharge and runoff from the recharge area could be put in perspective."***

On table 4 monthly recharge values are presented and summed from July 1979 to December 1982. Note this is not the same interval as the December 1979 to July 1982 referenced as the interval in other parts of the report, and that is significant because Barton Springs discharge was reported by U.S. Geological Survey to be 102 ft3/s on July 1, 1979 and 42 ft3/s on December 31, 1982, and there was considerable change in aquifer storage during the water budget interval.

The recent Slade 2014 (p. 13) recharge report refers back to his earlier report for methodology, except that downstream gauging stations are not used. It states: *"Recharge volumes are calculated as explained by Slade et al. (1986). Although the recharge calculations account for total recharge within the recharge area, they cannot distinguish among the individual components of recharge that occur in each of the 3 source areas of recharge: the main channels of the 6 major streams; the channels of tributaries to the main streambeds; and the overland flow area within the recharge area.*"

On p. 20: "*The daily-mean recharge for the water budget period (December 1979–July 1982) was calculated and summed for the main channels of 5 of the 6 major streams. Little Bear Creek was excluded from this calculation because a streamflow station was not installed at the upstream end of its recharge area. The recharge calculation is based on daily-mean streamflow values for the following stations near the upstream end of the recharge area: 08155200 Barton Creek at Highway 71, 08155240 Barton Creek at Lost Creek Boulevard, 08158920 Williamson Creek at Oak Hill, 08158840 Slaughter Creek at FM Road 1826, 08158810 Bear Creek below FM Road 1826, and 08158700 Onion Creek near Driftwood. The data are available from the USGS online at http://waterdata.usgs.gov/ tx/nwis/dv/?referred_module=sw*

"The calculation of recharge in the main streambeds is based on gaged streamflow at the upstream end of the recharge area and does not account for runoff entering the main channels from the recharge area. However, most recharge in the main channels is from the contributing area because this area is about 3 times larger than the recharge area."

So not only is the methodology vague exactly how recharge was calculated based on 1979 to 1982 USGS gauging data, particularly for the intervening areas of the recharge zone, but there are two different methodologies described, one using upstream and downstream gauging stations and estimating the intervening runoff, and the 2014 description that somehow calculates recharge using only the upstream gauging stations. This is probably because, although not reported in the 1986 report, most of the downstream gauging stations reported only a few days per year of flow data if at all during the 1979 to 1982 interval, as indicated by USGS annual hydrologic data reports. Even though Slade et al., 1986 refer to Woodruff 1984 for calculation of rainfall components like intervening recharge, in Slade 2014 it states that these recharge values cannot be distinguished.

The methodology for recharge calculation in Barrett et al., 1996 is fairly well described in the report. Using the upstream gauges on the major creeks, recharge up to the estimated maximum recharge rate was assumed to contribute to Barton Springs recharge. The study used the same groundwater basins assumed by Slade et al., 1986, prior to significant differences in sources from Barton Creek and the Blanco River by tracing initiated in 1996. Continuous gauging data was not available for Little Bear this study simply assumed that the recharge of Bear and Little Bear Creeks were the same. A Groundwater Loading Effects of Agricultural Management Practices (GLEAMS) model is used to calculate upland infiltration from soil and vegetation types, but does not seem to consider the karst nature of the underlying rock.

I conducted a stream flow loss water budget using 2003 to 2007 gauging data from upstream and downstream stations on the major creeks including Little Bear Creek. While still being published, Mr. Slade provided a draft copy of the paper submitted to the world lake conference in 2012.

Below is a summary of the recharge values from the various studies:

Comparison of Recharge Values from the Barton Springs Segment Derived from Various Studies

Water Balance Component	**2003-2007 Stream Flow Loss** Hauwert in prep	**Central Texas Site Scale Field Meas.** Hauwert & Sharp, 2014	1979-1982 Stream Flow Loss		GLEAMS model Barrett et al., 1996
			Woodruff, 1984	Slade 2014	
Authogenic Recharge	26%	28%	6%	<6.6%	6%
Intervening Authogenic	18%	---	1%	---	
Evapotranspiration	56%	69%	---	85.0%	
Downstream Runoff	18%	3%	---	9.0%	9%

References

Barrett, M. E., and Charbeneau, R. J., 1996, A parsimonious model for simulation of flow and transport in a karst aquifer: Technical Report Center for Research in Water Resources, Report No. 269, 149 p. http://www.crwr.utexas.edu/reports/pdf/1996/rpt96-3.pdf

Hauwert, Nico M., 2009, Groundwater Flow and Recharge within the Barton Springs Segment of the Edwards Aquifer, Southern Travis County and Northern Hays County, Texas: Ph.D. Diss., University of Texas at Austin, Texas. 328 p. http://repositories.lib.utexas.edu/handle/2152/14107

Hauwert, N.M. and Sharp, J.M. 2014. Measuring Autogenic Recharge over a Karst Aquifer Utilizing Eddy Covariance Evapotranspiration. *Journal of Water Resource and Protection*, 6, 869-879. http://dx.doi.org/10.4236/jwarp.2014.69081

Slade, R.M., Jr., 1984, Hydrogeology of the Edwards Aquifer Discharged by Barton Springs, in Woodruff, C. M., Jr., and Slade, R. M., Jr., eds., Hydrogeology of the Edwards aquifer-Barton Springs segment: Austin Geological Society Guidebook no. 6, p. 9-35.

Slade, R.M., Jr., Dorsey, M.E., and Stewart, S.L., 1986, Hydrology and water quality of Barton Springs and associated Edwards aquifer in the Austin area, Texas: U.S. Geological Survey Water-Resources Investigations Report 86-4036, ll7 p. http://pubs.er.usgs.gov/pubs/wri/wri864036

Slade, R.M., Jr., 2014, Documentation of a recharge-discharge water budget and main-streambed recharge volumes, and fundamental evaluation of groundwater tracer studies for the Barton Springs segment of the Edwards Aquifer: Texas Water Journal, Vol 5 No. 1. https://journals.tdl.org/twj/index.php/twj/article/view/6988

Woodruff, C. M., Jr., 1984, Water-budget analysis for the area contributing recharge to the Edwards aquifer, Barton Springs segment, in Woodruff, C. M., Jr., and Slade, R. M., Jr., eds., Hydrogeology of the Edwards aquifer-Barton Springs segment: Austin Geological Society Guidebook no. 6, p. 36-42.