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Cost-effective Stream Gage Installation and Data Use for Small Watersheds

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Abstract

One of the most important components of watershed monitoring is stream discharge. Currently small watershed monitoring is mostly limited to water quality sampling. Adding discharge measurements to current programs allows for the estimation of critical pollutant loading to the receiving stream. Additionally, discharge measurements can be used to establish a watershed water budget that in turn evaluates the status of groundwater storage in the watershed area. Flint Creek is a 59 square mile sub-watershed to the Fox River watershed in north eastern Illinois about 40 miles northwest of Chicago. Stream gages were constructed at five locations in the watershed. Once installed, the USGS conducted discharge measurements during various flow conditions to collect data to be used in stage-discharge relationship development. The resulting relationships were used to convert stage data recorded by the gages to discharge. At this point, stage-discharge data was used to estimate critical pollutant loading to the Fox River and the components of a water budget.

Keywords: Stream gages • Pollutant loading • Water budget

Introduction

Stream gage construction

A schematic of a gage installation is presented (Figure 1). Installation of a gage entailed drilling a six-inch diameter borehole to a depth of approximately 10 to 15 feet using an auger-drilling rig. A narrow trench was dug from the borehole to the stream to a depth equal to the bottom of the stream. The gage housing, constructed out of two-inch Schedule 80 PVC pipe, was put in place with the screen portion of the horizontal member lying exposed on the stream bottom. This horizontal member was secured to the streambed with two staples fashioned from three foot lengths of #3 rebar bent to shape. The trench and the annulus of the borehole was backfilled with excavated soil to a level 3 feet below the surface. A four-inch diameter protector casing with locking cap was installed over the gage stickup. An approximately 2-foot round by 6-inch thick concrete pad was constructed around the protector pipe. During the pad installation the remaining 3 feet of the borehole annulus was filled with concrete and the rest was backfilled with excavated soil. The concrete pad is flush with the ground surface and the protector pipe sticks up approximately 2 feet. The final step was the installation of the transducer that records the stream water levels and other data. The transducer was hung in the PVC pipe below the level of the stream bottom from a special cap.

Instrumentation: An *In-Situ* AquaTroll 200 data logger was installed as shown in Figure 1. The logger was set to take hourly readings.

Stage-discharge rating developments

To accurately measure the stage of the Flint Creek gages, the USGS installed a reference mark for use in determining the stage while discharge measurements were performed by Sauer VB and Turnipseed DP [1]. The reference gages were surveyed according to USGS policies to ensure the stability of the mark. All stage readings were referenced to a common datum, such as the National American Vertical Datum of 1988 (NAVD88). The establishment of the datum was completed according to Rydlund PH and Densmore BK [2]. Discharge measurements were event-based. Six or more discharge measurements at five sites were made to cover the range of observed flows at each location. Discharge measurements were made according to nationally established USGS techniques [3]. USGS data managers set up site station numbers and developed formatting for archival of the measurements and other station details. No measurements were taken during the winter months when the stream is affected by ice as these types of measurements are not used in stage-discharge rating development. Streamflow measurements were conducted using an Acoustic Doppler Current

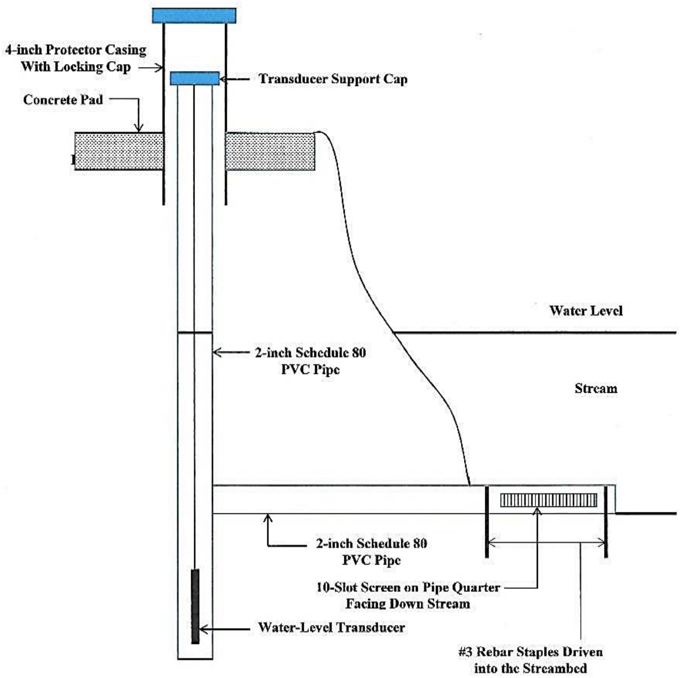

Figure 1. Stream gage installation schematic.

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Profiler (ADCP) (Figure 2). The elevations determined by the USGS did not coincide with the elevation Measurements recorded by the stream gages. Therefore, the USGS elevations were replaced by recorded elevations at the same time that discharge measurements were conducted. When this was completed, stage-discharge rating curves were developed for each gaging station by relating discharge as a function of the stream elevation (stage). A curve example for gaging station five is presented in Figure 3. Curve fitting analysis was performed to establish a relationship that best represented the curve configuration. This relationship is embedded in the graph presented in Figure 3. The R^2 value is a measure of residual standard error and has a value of 0.9976. Standard Error (SE) was calculated to be 0.275 and accuracy was estimated to be 99.72 percent. The law relationship for discharge accurately predicts discharge 99.7 percent of the time. Table 1 lists the stream discharge rating curve equations for each of the five stream gages along with their R^2s, standard error and estimated accuracy.

Methodology

Data preparation

The Stream Gage Five (SG-5) record was selected for analysis. SG-5 is located just above the confluence of Flint Creek with the Fox River. The record contains hourly readings of the stream stage in addition to several other parameters. The period of record extends from November 12, 2014, through October 21, 2021.

The first step of data analysis was to convert the hourly readings to average daily readings. The stage readings were converted to discharge values using the stage-discharge rating equation for SG-5 (Table 1).

Estimated pollutant load

The most common use of flow data by watershed groups is pollutant-load calculation. Pollutant loads are critical elements of Total Mean Daily Load (TMDL) development and implementation and reduction in pollutant load is often an important measure of success in nonpoint-source watershed projects. Nonpoint source pollutant loading was estimated as part of the baseline characteristics study [4]. This project obtained the highest accuracy possible in the measurement of stream discharge. Detailed scientific methods were used to estimate the sediment and/or pollutant loading in the watershed and the effectiveness of implemented BMPs. Pollutant loading to a stream is calculated using the following equation:

Where: L= 5.25AD

L= Load (lbs/Day)

A= Analyte Concentration (mg/L)

Figure 2. ADCP streamflow measurement.

D= Discharge (cfs)

Examples of loading estimates are presented in Table 2. Data collected at SG-5 were used in the example. Analyte concentrations were taken from the baseline report [4]. The discharge value of 31.64 cfs representing the average flow at SG-5 was also used. Loading was also calculated for the analyte criteria to determine the maximum allowable daily pollutant load in the amount the pollutant load needs to be reduced to meet the goals.

Results and Discussion

Data analysis

The Stream Gage Five (SG-5) record was selected for analysis. SG-5 is located just above the confluence of Flint Creek with the Fox River. The record contains hourly readings of the stream stage in addition to several other parameters. The period of record extends from November 12, 2014, through October 21, 2021.

The RECESS program was used to calculate streamflow recession during times when all flow can be considered to be groundwater discharge [5]. The average recession value over the period of record was calculated to be 4.08 days.

Monthly recharge was estimated using the RORA program [5]. This program uses the recession-curve-displacement method to estimate the recharge for each peak in the streamflow record. The average recharge over the period of record was 5.01 inches.

Water budget

The water budget is a measure of the change in groundwater storage that is equal to the inflows to the watershed minus the outflows. The water budget is represented by the following equation where the units of measurement for all the components are inches over the area of the watershed:

$$\Delta S = P - BE - RO - R - EGW - ENS$$

Where:

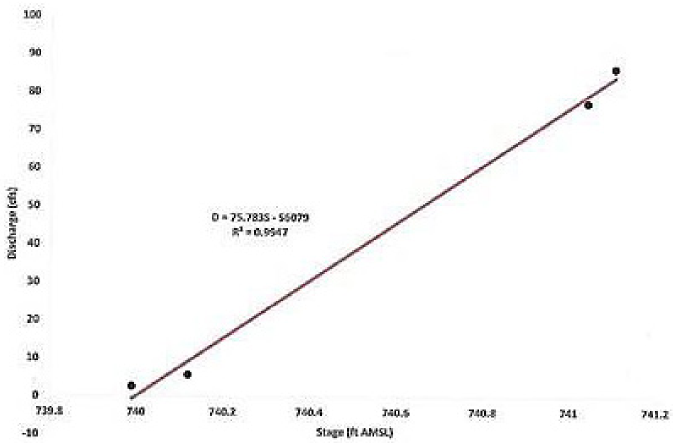

Figure 3. Stage-discharge relationship curve.

Table 1. Stream gage stage-discharge rating equations.

Stream Gage	Stage-discharge Rating	R^2	Standard Error	Accuracy (%)
SG-1	D=26.0225S-20563	0.9826	0.615	99.39
SG-2	D=53.0845S-41870	0.9811	0.644	99.36
SG-3	D=67.0445S-50169	0.9403	0.503	99.5
SG-4	D=22.6100S-16856	0.9847	3.939	96.06
SG-5	D=75.753S-56079	0.9976	0.275	99.72

Table 2. Example of total daily load calculations.

Analyte	Concentration (mg/L)	Discharge (cfs)	Loading (lbs/day)	Criteria (mg/L)	Loading Goals (lbs/day)	Load Reduction to Meet Goals (%)
Phosphorus	0.29	31.64	48.2	0.05	8.3	82.8
Orthophosphate	0.2	31.64	33.2	0.01	1.7	94.9
Chloride	245	31.64	40,700	250	41,500	0
Iron	0.49	31.64	81.4	0.3	49.8	38.8
TDS	800	31.64	1,33,000	500	83,000	37.6
Oxygen	9.4	31.64	1,560	>5.0	>830	0
BOD	4.77	31.64	792	<5.0	<830	0
E. coli	488	3.64	81,100	200	33,200	59.1

Table 3. Hydrologic cycle components and values.

Water Budget Components	Values (Inches)
Precipitation	39.27
Streamflow	7.22
Base Flow	3.93
Runoff	3.30
Recharge	5.01
Evapotranspiration, Total	29.26
Evapotranspiration, Ground Water	1.08
Evapotranspiration, Near Surface	28.18
Change in Storage	-2.23

∆S=Change in Storage

P=Precipitation

BF=Base Flow

RO=Runoff

R=Recharge

EGW=Evapotranspiration, Ground Water

ENS=Evapotranspiration, Near Surface

The values for the water budget components calculated using the entire data set collected from Stream Gage 5 (SG-5) are presented in Table 3. The values for streamflow, base flow, runoff and recharge were estimated using the USGS Groundwater Toolbox [6,7]. The average precipitation value was taken from the USGS current conditions record at the stream gage located in Gurney, Illinois [8]. Total evapotranspiration was estimated for the area using the method presented by Sanford WE and Selnick DL [9].

Conclusion

The groundwater evapotranspiration was estimated by calculating the value of recharge minus base flow and near-surface evapotranspiration was calculated by subtracting the evapotranspiration of groundwater from total evapotranspiration. The water budget change of storage (∆S) was estimated to be -2.23. The negative values for change in storage indicate a loss of groundwater over the period of record within the area of the watershed.

Acknowledgement

None.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

1. Sauer, Vernon B. and D. Phil Turnipseed. “Stage measurement at gaging stations.” *US Geol Surv* 2010.
2. Rydlund, Paul H. and Brenda K. Densmore. ‘’Methods of practice and guidelines for using survey-grade Global Navigation Satellite Systems (GNSS) to establish vertical datum in the United States Geological Survey.’’ *US Geol Surv* 2012.
3. Turnipseed, D. Phil and Vernon B. Sauer. “Discharge measurements at gaging stations.” *US Geol Surv* 2010.
4. https://flintcreekspringcreekwatersheds.org/wp-content/uploads/FSCWP-Baseline-Report-Final.pdf
5. Rutledge, Albert T. “Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records-update. *US Geol Surv* 1998.
6. Barlow, Paul M., William L. Cunningham, Tong Zhai and Mark Gray. “US Geological Survey groundwater toolbox, a graphical and mapping interface for analysis of hydrologic data (version 1.0): User guide for estimation of base flow, runoff and groundwater recharge from streamflow data.” *US Geol Surv* 2015.
7. Salmi, T., A. Määttä, P. Anttila and T. Ruoho-Airola, et al. "Makesens 1.0. Mann-Kendall test and Sen’s slope estimates for the trend of annual data." (2002).
8. https://waterdata.usgs.gov/nwis
9. Sanford, Ward E. and David L. Selnick. "Estimation of evapotranspiration across the conterminous United States using a regression with climate and land-cover data 1." *J Am Water Resour Assoc* 49 (2013): 217-230.

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