**Abstract (February 05, 2016)**

Indiana portion described below (repeated for MI, WI, IL.)

**Data (15 study watersheds, IN) for 1991 to 2012 (22 years)**

- Land use (NLCD 2006) ratio of study areas (for FLC, ULC, GLC, and ALC)

\*FLC (41, 42, and 43); ULC (21, 22, 23, 24, and 31); GLC (52, 71, and 81); ALC (82); Water (etc.)

- Flow (USGS): average annual streamflow (direct runoff + base flow)

\*base flow separation method: WHAT (default parameters; *a* 0.980, *BIFmax* 0.8)

base flow dominated flow: baseflow ≥ 90% of total flow

\*base flow dominated flow (BD flow) for base flow’s EMC (EMCb)

- WQ (IDEM): water quality samples for TN, TP, and TSS

\*average annual pollutant loads for total flow and BD flow from LOADEST

\* “-1” value for sample 🡪 (lower limit value)/2 (TN 0.05; TP 0.015; TSS 2.0)

**Basic equations**

**Q = Qdr + Qb = (Qdr(FLC)+Qdr(ULC)+Qdr(GLC)+Qdr(ALC)) + (Qb(FLC)+Qb(ULC)+Qb(GLC)+Qb(ALC))**

**Load = [Qdr(FLC)\*EMCdr (FLC) + Qdr(ULC)\*EMCdr (ULC) + Qdr(GLC)\*EMCdr (GLC) + Qdr(ALC)\*EMCdr (ALC)]**

**+ [Qb(FLC)\*EMCb (FLC) + Qb(ULC)\*EMCb (ULC) + Qb(GLC)\*EMCb (GLC) + Qb(ALC)\*EMCb (ALC)]**

**Regression analysis (least squares method)**

**(step 1) Flow coefficient; qb(FLC), qb(ULC), qb(GLC), and qb(ALC)**

for **Base flow** & **Base flow dominated flow**

**Qb = qb(FLC)\*AFLC + qb(ULC)\*AULC + qb(GLC)\*AGLC + qb(ALC)\*AALC**

\* *regression constraints*; CN ratio + forest constraint 450 mm/yr (from literatures)

: GLC ≤ 0.820866 \* FLC; ALC ≤ 0.742012 \* GLC; ULC ≤ 0.5547 \* ALC

\* Flow coefficient results

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Coefficient  (mm/yr) | Base flow | | | **Base flow dominated flow** | | |
| Calibration | Validation | Total period | Calibration | Validation | Total period |
| 1991 to 2001 | 2002 to 2012 | 1991 to 2001 | 2002 to 2012 |
| qb(FLC) | **450.0** | 450.0 | 450.0 | **426.5** | 426.5 | 336.9 |
| qb(ULC) | **0.0** | 0.0 | 72.7 | **30.3** | 30.3 | 40.5 |
| qb(GLC) | **321.9** | 321.9 | 334.0 | **73.7** | 73.7 | 98.4 |
| qb(ALC) | **238.8** | 238.8 | 247.8 | **54.7** | 54.7 | 73.0 |
| R2 | **0.96** | **0.96** | 0.96 | **0.81** | **0.82** | 0.82 |

 

**(step 2) Pollutant coefficient (TN and TP); EMCb(FLC), EMCb(ULC), EMCb(GLC), and EMCb(ALC)**

for **base flow and Base flow dominated flow are the same** (assumed)

**Loadb = Qb(FLC)\*EMCb (FLC) + Qb(ULC)\*EMCb (ULC) + Qb(GLC)\*EMCb (GLC) + Qb(ALC)\*EMCb (ALC)**

- Average annual pollutant loads for *base flow dominated flow* are used

- Flow coefficients (qb(FLC), qb(ULC), qb(GLC), and qb(ALC)); are considered with ratio

**Qb(obs) = [qb(FLC)\*AFLC + qb(ULC)\*AULC + qb(GLC)\*AGLC + qb(ALC)\*AALC] \* ratio**

\* *regression constraints*

WQ and flow data from previous research and Indiana & Michigan watersheds are investigated

: 4 literature sources: 5 agricultural (IN), 4 forest (MI), and 2 urban (MI) watershed data are applicable

TN: EMCb(FLC) ≤ 0.5463 \* EMCb(ULC); EMCb(ULC) ≤ 0.4125 \* EMCb(ALC); EMCb(GLC) ≤ EMCb(ALC)

TP: EMCb(FLC) ≤ 0.3411 \* EMCb(ULC); EMCb(ULC) ≤ 0.9120 \* EMCb(ALC); EMCb(GLC) ≤ EMCb(ALC);

EMCb(ALC) ≤ 0.1915

\* Pollutant coefficient results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Coefficient  (mg/L) | **TN** | | **TP** | |
| Calibration | Validation | Calibration | Validation |
| 1991 to 2001 | 2002 to 2012 | 1991 to 2001 | 2002 to 2012 |
| EMCb(FLC) | **0.77** | 0.77 | **0.037** | 0.037 |
| EMCb (ULC) | **2.55** | 2.55 | **0.175** | 0.175 |
| EMCb (GLC) | **5.09** | 5.09 | **0.192** | 0.192 |
| EMCb (ALC) | **6.99** | 6.99 | **0.192** | 0.192 |
| R2 | **0.90** | **0.94** | **0.76** | **0.67** |

 

 

 

 

\* Watersheds #5 (WUW160-0006) and #8 (WWU 090-0002) may cause high levels of nutrients in WQ due to relatively large amount of effluent from WWTP and stream impairments, respectively.

**(step 3) Flow coefficient; qdr(FLC), qdr(ULC), qdr(GLC), and qdr(ALC)**

for **Direct runoff flow**

**Qdr = qdr(FLC)\*AFLC + qdr(ULC)\*AULC + qdr(GLC)\*AGLC + qdr(ALC)\*AALC**

\* *regression constraints*; CN ratio (inversed maximum retention storage)

: ULC ≥ 1.802775 \* ALC; GLC ≥ 1.218226 \* FLC; ALC ≥ 1.347687 \* GLC

\* Flow coefficient results

|  |  |  |  |
| --- | --- | --- | --- |
| Coefficient  (mm/yr) | Direct runoff | | |
| Calibration | Validation | Total period |
| 1991 to 2001 | 2002 to 2012 |
| qdr(FLC) | **65.6** | 65.6 | 55.4 |
| qdr(ULC) | **456.0** | 456.0 | 646.5 |
| qdr(GLC) | **79.9** | 79.9 | 73.6 |
| qdr(ALC) | **107.7** | 107.7 | 99.2 |
| R2 | **0.93** | **0.86** | 0.90 |

**(step 4) Total flow prediction**

using estimated **qdr(FLC), qdr(ULC), qdr(GLC), qdr(ALC), qb(FLC), qb(ULC), qb(GLC) and qb(ALC)**

**Q = Qdr + Qb = (qdr(FLC)\*AFLC + qdr(ULC)\*AULC + qdr(GLC)\*AGLC + qdr(ALC)\*AALC)**

**+ (qb(FLC)\*AFLC + qb(ULC)\*AULC + qb(GLC)\*AGLC + qb(ALC)\*AALC)**

\* Flow coefficient (Total flow = Direct runoff flow + Base flow)

|  |  |  |  |
| --- | --- | --- | --- |
| Coefficient  (mm/yr) | Total flow (w constraints) | | |
| Calibration | Validation | Total period |
| 1991 to 2001 | 2002 to 2012 |
| qdr(FLC)/qb(FLC) | **65.6/450.0** | 65.6/450.0 | 55.4/450.0 |
| qdr(ULC)/qb(ULC) | **456.0/0.0** | 456.0/0.0 | 646.5/72.7 |
| qdr(GLC)/qb(GLC) | **79.9/321.9** | 79.9/321.9 | 73.6/334.0 |
| qdr(ALC)/qb(ALC) | **107.7/238.8** | 107.7/238.8 | 99.2/247.8 |
| R2 | **0.98** | **0.95** | 0.97 |

 

**(step 5) Pollutant coefficient (TN and TP); EMCdr(FLC), EMCdr(ULC), EMCdr(GLC), and EMCdr(ALC)**

For **Direct runoff flow**

**Load = [Qdr(FLC)\*EMCdr (FLC) + Qdr(ULC)\*EMCdr (ULC) + Qdr(GLC)\*EMCdr (GLC) + Qdr(ALC)\*EMCdr (ALC)]**

**+ [Qb(FLC)\*EMCb (FLC) + Qb(ULC)\*EMCb (ULC) + Qb(GLC)\*EMCb (GLC) + Qb(ALC)\*EMCb (ALC)]**

- Average annual pollutant loads for total streamflow are used

- Pollutant coefficients for *base flow dominated flow* are used for base flow loads

- Flow coefficients are considered with ratio

**Qdr(obs) = [qdr(FLC)\*AFLC + qb(ULC)\*AULC + qb(GLC)\*AGLC + qb(ALC)\*AALC] \* ratio**

**Qb(obs) = [qb(FLC)\*AFLC + qb(ULC)\*AULC + qb(GLC)\*AGLC + qb(ALC)\*AALC] \* ratio**

- Two cases of regression are tested (without and with constraints)

\* *regression constraints*

EMCdr(FLC) ≤ EMCdr(ULC); EMCdr(ULC) ≤ EMCdr(GLC); EMCdr(GLC) ≤ EMCdr(ALC)

\* Pollutant coefficient results (without constraints)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Coefficient  (mg/L) | **TN** | | **TP** | |
| Calibration | Validation | Calibration | Validation |
| 1991 to 2001 | 2002 to 2012 | 1991 to 2001 | 2002 to 2012 |
| EMCdr(FLC) | **0.16** | 0.16 | **0.114** | 0.114 |
| EMCdr (ULC) | **1.07** | 1.07 | **0.511** | 0.511 |
| EMCdr (GLC) | **0.12** | 0.12 | **0.082** | 0.082 |
| EMCdr (ALC) | **1.56** | 1.56 | **0.411** | 0.411 |
| R2 | **0.89** | **0.90** | **0.81** | **0.86** |

\* Pollutant coefficient results (with constraints)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Coefficient  (mg/L) | **TN** | | **TP** | |
| Calibration | Validation | Calibration | Validation |
| 1991 to 2001 | 2002 to 2012 | 1991 to 2001 | 2002 to 2012 |
| EMCdr(FLC) | **0.50** | 0.50 | **0.180** | 0.180 |
| EMCdr (ULC) | **0.98** | 0.98 | **0.341** | 0.341 |
| EMCdr (GLC) | **1.27** | 1.27 | **0.420** | 0.420 |
| EMCdr (ALC) | **1.54** | 1.54 | **0.486** | 0.486 |
| R2 | **0.89** | **0.90** | **0.80** | **0.84** |

 

 

 

 

**(step 6) Pollutant coefficient (TSS); EMC(FLC), EMC(ULC), EMC(GLC), and EMC(ALC)**

for **total streamflow**

**Load = (Qdr(FLC)+Qb(FLC))\*EMC(FLC) + (Qdr(ULC)+Qb(ULC))\*EMC(ULC) + (Qdr(GLC)+Qb(GLC))\*EMC(GLC)**

**+ (Qdr(ALC)+Qb(ALC))\*EMC(ALC)**

- Average annual TSS loads for total streamflow are used

- Flow coefficients are considered with ratio

**Q(obs) = [(qdr(FLC)+qb(FLC))\*AFLC + (qdr(ULC)+qb(ULC))\*AULC + (qdr(GLC)+qb(GLC))\*AGLC**

**+ (qdr(ALC)+qb(ALC))\*AALC] \* ratio**

\* *regression constraints*

EMC(FLC) = EMC(ULC) = EMC(GLC) = EMC(ALC)

\* Pollutant coefficient results

|  |  |  |
| --- | --- | --- |
| Coefficient  (mg/L) | **TN** | |
| Calibration | Validation |
| 1991 to 2001 | 2002 to 2012 |
| EMCdr(FLC) | **468.2** | 468.2 |
| R2 | **0.22** | **0.26** |

 

 

\* Total suspended solid

Amount of TSS loads are not directly related watershed size (area) since **severe storm (torrential rain) can generate larger amount of flow and high sediment concentration**. In other words, the watershed which has a larger amount of flow not always can have high concentration of sediment. It more related to characteristics of rainfall events (e.g. rainfall rate, etc.).

**Paper draft for Journal publication(in progress fall 2017)**

“A method for characterizing annual base flow quantity and quality for different land uses in Indiana watersheds”