**Estimation of P load from all tile discharge in JBW**

We estimated P loads from all tile drain discharge in the JBW using measured P loads from monitored fields JBT01 – JBT19. Monitored absolute loads (kg/yr) were converted to areal loads (kg/ha/yr) based on the assumption that the tile drainage area was equal to the surface area of each drained field. The areal loads appeared to conform to a normal distribution; no transformations were required. We chose median and 95% confidence interval annual areal TP and TDP loads from the group of monitored fields to provide representative areal loads to apply across the JBW. Finally, we used VT AAFM data on “presence of tile” for the entire JBW (2096 ha) with fields clipped to watershed boundaries, amounting to 845.5 ha.

We used two methods in computing estimates. Method 1 combined all monitoring data to apply median and 95% C.I. values to all tile drained fields in the JBW. Because previous analysis suggested significant difference in P loads from row crop (corn, soybeans) vs. hay (hay, alfalfa), Method 2 applied different median and 95% C.I. values to row crop and hayland areas, then summed for the entire JBW tile drained area.

Areal load values used in Method 1 are shown below:

|  |  |  |
| --- | --- | --- |
|  | **Areal TPx (kg/ha/yr)** | **Areal TDPx (kg/ha/yr)** |
| Range | 0.122 – 1.124 | 0.083 – 0.556 |
| Median | 0.541 | 0.199 |
| Mean | 0.555 | 0.272 |
| 95% C.I. | 0.368 – 0.743 | 0.166 – 0.378 |

Assuming the total JBW tile drained area is 845.5 ha, estimated P loads from combined tiled agricultural land in the JBW are:

|  |  |  |
| --- | --- | --- |
|  | **Median Export (kg/yr)** | **95% C.I. (kg/yr)** |
| TP | 458 | 311 - 638 |
| TDP | 168 | 140 - 320 |

Areal load values used in Method 2 (row crop and hay estimated separately) are shown below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **RC** | | **H** | |
| **Areal TPx (kg/ha/yr)** | **Areal TDPx (kg/ha/yr)** | **Areal TPx (kg/ha/yr)** | **Areal TDPx (kg/ha/yr)** |
| Range | 0.276 – 1.124 | 0.153 – 0.556 | 0.122 – 0.451 | 0.083 – 0.212 |
| Median | 0.650 | 0.289 | 0.249 | 0.101 |
| Mean | 0.649 | 0.318 | 0.274 | 0.132 |
| 95% C.I. | 0.441 – 0.857 | 0.191 – 0.445 | 0.138 – 0.686 | 0.042 – 0.306 |

To account for land reported as corn/hay rotation, we assumed a 50-50 split in an average year, resulting in a total of 614 ha of row crop land and 232 ha of hay land JBW tiled area (assuming 50-50 split of corn/hay rotation)

Estimated P loads from tiled agricultural land in the JBW when row crop and hayland are separated are:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **TP (kg/yr)** | | **TDP (kg/yr)** | |
|  | Median | 95% C.I. | Median | 95% C.I. |
| **RC** | 399 | 270.8 – 526.2 | 177 | 117.3 – 273.2 |
| **H** | 58 | 32.0 – 158.8 | 23 | 9.7 – 70.8 |
| **TOTAL** | 458 | 302.8 – 685.0 | 201 | 127.0 – 344.0 |

Estimates of TP export in tile drainage agree between the two approaches. Treating row crop and hayland separately yield a higher estimate of TDP export.

**Monitored P loads in Jewett Brook[[1]](#footnote-1)**

**Methods.** We estimated annual and monthly mean P loading rates from Jewett Brook for the period of May 2017 to April 2018 from stream discharge and P concentration measurements obtained during the period of January 2017 to September 2018. We chose this date range to provide an adequate P concentration sample size to support the development of loading regression models while limiting the data to recent months best representing agricultural management and other watershed features present during the tile drain monitoring period.

We obtained discharge measurements for use in estimating phosphorus loading in Jewett Brook from the U.S. Geological Survey (USGS) stream flow gage station on Jewett Brook (USGS Reference No. 0429810, 3.74 mi2 [969 ha] drainage area). Average daily flow rates in cubic feet per second (cfs) for the period of 1/1/2017 to 9/30/2018 were downloaded for this site on 10/1/2018 from the USGS National Water System website (<https://waterdata.usgs.gov/vt/nwis/uv?site_no=04292810>). Average daily flow values after 10/11/2017 were identified as provisional by the USGS. No flow values were reported on a total of 35 winter days between 12/28/2017 and 2/21/2018 due to intermittent ice effects at the gage site. These missing values due to ice effects were replaced for this analysis with flow rates representing the mean value from the two nearest adjoining dates that had flow data provided. Zero discharge rates were reported on 74 days during the dry summer months of 2018. These zero values were replaced for this analysis with values of 0.001 cfs in order to permit logarithmic transformation of the data.

We obtained TP and TDP concentrations measured in samples from Jewett Brook from the Vermont DEC, Lake Champlain Long-Term Monitoring website (<https://anrweb.vermont.gov/dec/_dec/LongTermMonitoringTributary.aspx>). We used results from a total of 29 TP samples and 21 TDP samples obtained under a range of flow conditions from 2/24/2017 to 9/11/2018 for this analysis.

We used the USGS program *LOADEST* (Runkel et al. 2004) to calculate phosphorus loading rates in Jewett Brook from the stream flow and P concentration data, and the utility program *LoadRunner* (Raymond et al. 2011) to automate runs of LOADEST.

*LOADEST* supports the development of regression models to calculate daily, monthly, and annual mean loads (with error estimates) from constituent concentration data and a time series of daily stream flow measurements. Several pre-defined regression model options are provided in *LOADEST* to predict loads from various combinations of stream flow and decimal time. For this analysis, *LOADEST* was allowed to automatically select the optimum regression model from the pre-defined list for both TP and TDP load estimation, based on a minimum value of the Akaike Information Criterion statistic.

Regression coefficients were fit by *LOADEST* using Maximum Likelihood Estimation, appropriate for uncensored data (no results below detection limits) and where regression residuals are normally distributed. Regression diagnostic procedures described in Runkel et al. (2004) were used to confirm that model residuals were independent, homoscedastic, and normally distributed.

**Results.** Application of the *LOADEST* program to the Jewett Brook data resulted in the selection of *LOADEST* regression model 2, described in equation 1, for both TP and TDP load estimation.

ln(L) = a0 + a1 ln(Q) + a2 ln(Q)2 (1)

where, ln(L) = natural log of the daily loading rate

ln(Q) = ln(daily stream flow rate) – center of ln(daily stream flow rate)

a0, a1, a2 are calibrated regression coefficients

Regression models calibrated from discharge and P concentration data obtained during the date range of 1/1/2017 to 9/30/2018 were used to estimate monthly and annual TP and TDP loading rates for the period of May 2017 to April 2018, which closely approximates the tile drain monitoring period. Loading estimates and their 95% confidence limits calculated by the *LOADEST* program are shown in Tables 1 and 2 for TP and TDP, respectively. These loading estimates apply at the location of the USGS stream gage station on Jewett Brook. No adjustments were made to account for the additional downstream watershed area.

Table 1. Monthly mean TP loading rates and their 95% confidence limits in Jewett Brook during the tile drain monitoring period.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Month | Year | N Days | Mean Flow (cfs) | Mean Load (kg/day) | Lower 95% Limit (kg/day) | Upper 95% Limit (kg/day) |
| May | 2017 | 31 | 5.69 | 5.24 | 4.06 | 6.66 |
| June | 2017 | 30 | 5.62 | 5.40 | 3.89 | 7.31 |
| July | 2017 | 31 | 3.91 | 3.56 | 2.70 | 4.61 |
| Aug. | 2017 | 31 | 0.52 | 0.46 | 0.34 | 0.62 |
| Sep. | 2017 | 30 | 0.93 | 0.83 | 0.58 | 1.14 |
| Oct. | 2017 | 31 | 0.64 | 0.56 | 0.40 | 0.76 |
| Nov. | 2017 | 30 | 2.92 | 2.58 | 2.00 | 3.27 |
| Dec. | 2017 | 31 | 1.13 | 0.98 | 0.75 | 1.26 |
| Jan. | 2018 | 31 | 9.04 | 8.67 | 6.60 | 11.18 |
| Feb. | 2018 | 28 | 12.25 | 11.32 | 9.23 | 13.74 |
| Mar. | 2018 | 31 | 9.52 | 8.98 | 6.97 | 11.38 |
| Apr. | 2018 | 30 | 15.23 | 14.99 | 11.59 | 19.07 |
| Period Total | | 365 | 5.55 | 5.24 | 4.46 | 6.12 |

Thus, we estimate that the TP load from the monitored portion of the JBW over the entire period was 1913kg/yr (1628 – 2234 kg/yr).

Table 2. Monthly mean TDP loading rates and their 95% confidence limits in Jewett Brook during the tile drain monitoring period.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Month | Year | N Days | Mean Flow (cfs) | Mean Load (kg/day) | Lower 95% Limit (kg/day) | Upper 95% Limit (kg/day) |
| May | 2017 | 31 | 5.69 | 3.90 | 2.79 | 5.30 |
| June | 2017 | 30 | 5.62 | 3.91 | 2.58 | 5.68 |
| July | 2017 | 31 | 3.91 | 2.70 | 1.88 | 3.74 |
| Aug. | 2017 | 31 | 0.52 | 0.39 | 0.26 | 0.56 |
| Sep. | 2017 | 30 | 0.93 | 0.66 | 0.42 | 0.98 |
| Oct. | 2017 | 31 | 0.64 | 0.46 | 0.30 | 0.68 |
| Nov. | 2017 | 30 | 2.92 | 2.02 | 1.44 | 2.75 |
| Dec. | 2017 | 31 | 1.13 | 0.81 | 0.56 | 1.13 |
| Jan. | 2018 | 31 | 9.04 | 6.23 | 4.38 | 8.60 |
| Feb. | 2018 | 28 | 12.25 | 8.31 | 6.29 | 10.78 |
| Mar. | 2018 | 31 | 9.52 | 6.53 | 4.71 | 8.83 |
| Apr. | 2018 | 30 | 15.23 | 10.57 | 7.54 | 14.42 |
| Period Total | | 365 | 5.55 | 3.83 | 3.05 | 4.75 |

We estimate that the TDP load from the monitored portion of the JBW over the entire period was 1398 kg/yr (1278 – 1734kg/yr).

**Estimation of JBW tile P load as a proportion of monitored P load in Jewett Brook**

Because P loads in Jewett Brook were computed at a station representing only a portion of the JBW, we took two approaches to estimate the contribution of tile discharge to JBW P loads. For both approaches, we used the areal P loads from tile discharge estimated by Method 1 above, wherein all tiled land is combined.

**Approach 1.** In this approach, we recomputed estimates for annual P loads from tile discharge for the tiled cropland within 969 ha captured at the USGS station on Lower Newton Rd. This allows direct comparison between annual P loads in Jewett Brook estimated from monitoring data with estimated annual P loads in tile discharge from the same area, although not from the entire JBW.

**Monitored P loads at USGS station on Lower Newton Rd, drainage area = 1180 ha)**

|  |  |  |
| --- | --- | --- |
|  | **Mean annual load (kg/yr)** | **95% C.I. (kg/yr)** |
| TP | 1913 | 1628 – 2234 |
| TDP | 1398 | 1278 - 1734 |

We recalculated estimated P loads in tile discharge for the 517 ha of tiled area cited in the VT AAFM data for JBW, representing the area of drained fields clipped to the “above” watershed boundaries. Annual estimated tile loads calculated as median tile P load x estimated tiled area using single P concentration because no assumptions of breakdown of row crop/hay required)

**Estimated P loads in tile discharge above USGS station, tiled area = 517 ha)**

|  |  |  |
| --- | --- | --- |
|  | **Mean annual load (kg/yr)** | **95% CI (kg/yr)** |
| TP | 280 | 190 – 384 |
| TDP | 103 | 86 - 195 |

We summarize the proportion of total JBW P loads represented by tile discharge as follows.

Mean tile load % of total is computed as the estimated median P load from tile discharge divided by the monitored Jewett Brook P load. An error range for this estimate was computed as the [low 95% C.I. of tile load]/[high 95% C.I. of monitored load] and the [high 95% C.I. of tile load]/[low 95% C.I. of monitored load]. These estimates are shown below:

|  |  |  |
| --- | --- | --- |
|  | **Tile load % of total** | **Range** |
| TP | 15% | 8.5 – 24% |
| TDP | 7% | 5 – 15% |

**Approach 2.** In this approach, we compared estimates of annual P loads from tile discharge for the 845.5 ha of tiled cropland within the entire JBW from the VTAAFM inventory against annual P loads in Jewett Brook extrapolated from the USGS monitored area (1180 ha) to the entire watershed (2096 ha) by a simple area ratio of 1.78.

**Jewett Brook P loads extrapolated to entire JBW, drainage area = 1180 ha)**

|  |  |  |
| --- | --- | --- |
|  | **Mean annual load (kg/yr)** | **95% C.I. (kg/yr)** |
| TP | 3404 | 2898 - 3976 |
| TDP | 2488 | 2275 - 3086 |

**Estimated P loads in tile discharge for entire JBW, tiled area = 846 ha)**

|  |  |  |
| --- | --- | --- |
|  | **Mean annual load (kg/yr)** | **95% CI (kg/yr)** |
| TP | 458 | 311 – 638 |
| TDP | 168 | 140 - 320 |

We summarize the proportion of total JBW P loads represented by tile discharge extrapolated for the entire watershed by the same methods as in Approach 1. These estimates are shown below:

|  |  |  |
| --- | --- | --- |
|  | **Tile load % of total** | **Range** |
| TP | 13% | 8 – 22% |
| TDP | 7% | 4.5 – 14% |

**References**

Raymond P., N.H. Oh, R.M. Holmes, and G. Booth. 2011. LoadRunner v1.2b. Yale School of Forestry and Environmental Science. <https://environment.yale.edu/loadrunner/>

Runkel, R.L., C.G. Crawford, and T.A. Cohen. 2004. Load estimator (LOADEST): A FORTRAN program for estimating constituent loads in streams and rivers. U.S. Geological Survey Techniques and Methods Book 4, Chapter A5. Reston, VA. <https://water.usgs.gov/software/loadest/>

1. Analysis by Eric Smeltzer [↑](#footnote-ref-1)