environments

*Supplementary Material*

# Potential Influence of Sewage Phosphorus and Wet and Dry Deposition Detected in Fish Collected in the Athabasca River North of Fort McMurray

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Script 1. Code to perform single bootstrapping (used to estimate within year variability for fish collected from 2011-2019).

```
B<-99999
newtest<-data to boostrap

#FULLParametric boostrap
mu1<-mean(newtest)
sig1<-sd(newtest)
SBS <- lapply(1:B, function(t)
rnorm(m,mu1,sig1))
medianSBS2<-sapply(SBS,median)
aa<-round(quantile(medianSBS2, 0.025),3)
bb<-round(quantile(medianSBS2, 0.5),3)
cc<-round(quantile(medianSBS2, 0.975),3)

#Semi-parametric single bootstrap
H<-dpik(newtest)
rkernel <- function(g) rnorm(10000, sd=H)
newtest2<-sample(newtest, 10000, replace=TRUE) + rkernel(10000)
SBS <- lapply(1:B, function(t){
sample(newtest2, m, replace=TRUE)})
medianSBS3<-sapply(SBS,median)
aa<-round(quantile(medianSBS3, 0.025),3)
bb<-round(quantile(medianSBS3, 0.5),3)
cc<-round(quantile(medianSBS3, 0.975),3)
```

Script 2. Code to perform double bootstrapping (used to estimate expected occurrence of medians in test years (2014-2016) from reference years (2011-2013) for each study location.

```
B<-4999
C<-999
DBSPtiles<-matrix(, nrow=B, nol=2)
newref<-data to bootstrap
n<-length(newref)
m<-sample size for test years
for (i in 1:B){
        } if ((n<15) & (m<15)){

#FULLPara
moo<-mean(newref)
sig<-sd(newref)
BS2 <-rnorm(m,moo,sig)
mean1<-mean(BS2)
sd1<-sd(BS2)
BS3<-lapply(1:C, function(j)
rnorm(m, mean1, sd1))
DBSPtiles[i,1]<-quantile(sapply(BS3,median),0.025)
DBSPtiles[i,2]<-quantile(sapply(BS3,median),0.975)
type<-'parapara'
        } else if ((n>14) & (m<15)){

# kernel/para
H<-dpik(newref)
rkernel <- function(g) rnorm(n, sd=H)
newref2<-sample(newref, n, replace=TRUE) + rkernel(n)
BS2<-sample(newref2, n, replace=TRUE)
H2<-dpik(BS2)
rkernel2 <- function(gg) rnorm(n, sd=H2)
newref3<-sample(BS2, n, replace=TRUE) + rkernel2(n)
mu1<-mean(newref2)
sd1<-sd(newref2)
BS3<-lapply(1:C,function(j)
rnorm(m, mu1, sd1))
DBSPtiles[i,1]<-quantile(sapply(BS3,median),0.025)
DBSPtiles[i,2]<-quantile(sapply(BS3,median),0.975)
type<-'kernelpara'
        }else if ((n<15) & (m>14)){
moo<-mean(newref)
sig<-sd(newref)
BS2 <-rnorm(m,moo,sig)
H2<-dpik(BS2)
rkernel3 <- function(gg) rnorm(m, sd=H2)
newref2<-sample(newref, m, replace=TRUE)
BS3<-lapply(1:C,function(j)
sample(newref2, m, replace=TRUE) + rkernel3(m))
DBSPtiles[i,1]<-quantile(sapply(BS3,median),0.025)
DBSPtiles[i,2]<-quantile(sapply(BS3,median),0.975)
        }else {

# n>15 and m>15
H<-dpik(newref)
rkernel <- function(g) rnorm(n, sd=H)
newref2<-sample(newref, n, replace=TRUE) + rkernel(n)
BS2<-sample(newref2, m, replace=TRUE)
H2<-dpik(BS2)
rkernel4 <- function(gg) rnorm(m, sd=H2)
newref3<-sample(BS2, m, replace=TRUE)
BS3<-lapply(1:C,function(j)
sample(newref3, m, replace=TRUE) + rkernel4(m))
DBSPtiles[i,1]<-quantile(sapply(BS3,median),0.025)
DBSPtiles[i,2]<-quantile(sapply(BS3,median),0.975)
 }
```

```
 }
#97.5 percentile of 97.5 percentile
round(quantile(DBSPtiles[,2], 0.975),3)

#50th percentile of 97.5 percentile
round(quantile(DBSPtiles[,2], 0.5),3)

#50th percentile of 2.5 percentile
round(quantile(DBSPtiles[,1], 0.5),3)

#2.5 percentile of 2.5 percentile
round(quantile(DBSPtiles[,1], 0.025),3)
```

**Table S1.** Female/male sample sizes of gonad (GW), liver (LW), and body (BW) weights per year and site; blanks indicate sites where no fish were collected; primary collection locations marked with *; additional sampling locations added in 2014 and 2016 (M7) and 2019 (OSPW DS1 and OSPW DS2) for parallel/supplementary studies; all samples in 2014 collected for analysis of tissue contaminants, but included opportunistically for the current study.

| **Year** | **2011** | | | **2012** | | | **2013** | | | **2014** | | | **2016** | | | **2019** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | GW | LW | BW | GW | LW | BW | GW | LW | BW | GW | LW | BW | GW | LW | BW | GW | LW | BW |
| DS M3* | 20/20 | 20/20 | 20/20 | 18/15 | 17/15 | 18/15 | 19/9 | 19/9 | 19/9 | 7/2 | 7/2 | 7/2 | 5/0 | 5/0 | 5/0 | 16/15 | 16/15 | 16/15 |
| OSPW DS1 | | | | | | | | | | | | | | | | 5/4 | 5/4 | 5/4 |
| OSPW DS2 | | | | | | | | | | | | | | | | 0/2 | 0/2 | 0/2 |
| US M4* | 20/20 | 20/20 | 20/20 | 16/18 | 16/18 | 16/18 | 12/13 | 12/13 | 12/13 | 5/4 | 5/4 | 5/4 | 4/2 | 4/2 | 4/2 | 2/2 | 2/2 | 2/2 |
| DS M4* | 20/20 | 19/19 | 20/20 | 15/20 | 15/20 | 15/20 | 16/22 | 16/22 | 16/22 | 5/5 | 5/5 | 5/5 | 3/3 | 3/3 | 3/3 | 7/12 | 7/12 | 7/12 |
| M7 | | | | | | | | | | 8/2 | 8/2 | 8/2 | 4/2 | 4/2 | 4/2 | | | |
| allOSR | 60/60 | 59/59 | 60/60 | 49/53 | 48/53 | 49/53 | 47/44 | 47/44 | 47/44 | 25/13 | 25/13 | 25/13 | 16/7 | 16/7 | 16/7 | 30/35 | 30/35 | 30/35 |

**Table S2.** Environmental covariates for fish analyses; discharge is a range because it is calculated for each day fish were collected.

| **Year** | **Median $Q_{60}$ Discharge ($m^3/s$)** | **Median Summer Air Temperature (°C)** | **Mean Summer Phosphorus (mg/L)** | **Mean Summer Precipitation (mm/day)** |
|---|---|---|---|---|
| 2011 | 912–931 | 17.95 | 0.463 | 0.883 |
| 2012 | 998–1125 | 18.75 | 0.253 | 1.988 |
| 2013 | 950.5–1002.5 | 17.70 | 0.187 | 2.953 |
| 2014 | 738.5 | 19.05 | 0.517 | 1.078 |
| 2016 | 838.5 | 18.35 | 0.125 | 2.218 |
| 2019 | 1317.57–1388.19 | 16.20 | 0.155 | 3.232 |

**Table S3.** AICs for original T+D models estimated per location in the Athabasca River; lowest AICs for each sex-site-measure models shown in bold; model numbers described in Table 1.

| Sex | Site | Weight measure | Model 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| F | DS M3 | Gonad | -109.83 | **-124.62** | -100.58 | -116.73 | -105.61 | -114.39 | -103.79 | -112.72 |
| | | Liver | -178.39 | -179.87 | -170.51 | -170.64 | -171.94 | **-180.15** | -171.44 | -179.5 |
| | | Body | -307.17 | -305.76 | -299 | -297.21 | -297.78 | **-306.62** | -298.16 | -306.02 |
| | US M4 | Gonad | -61.32 | **-71.92** | -54.27 | -65.19 | -58.68 | -64.61 | -54.92 | -60.75 |
| | | Liver | -121.13 | **-124.14** | -117.54 | -116.91 | -116.06 | -120.37 | -115.55 | -119.35 |
| | | Body | **-208.99** | -205.81 | -184.06 | -181.58 | -183.26 | -207.7 | -183.41 | -207.76 |
| | DS M4 | Gonad | -99.75 | -108.83 | -100.24 | -113.53 | **-115.53** | -110.81 | -107.6 | -105.31 |
| | | Liver | -118.4 | -122.23 | -116.81 | -122.95 | **-124.68** | -123.82 | -120.03 | -120.88 |
| | | Body | -234.82 | -236 | -232.84 | -234.44 | -232.35 | -234.34 | -234.77 | **-236.1** |
| | allOSR | Gonad | -286.44 | **-302.88** | -273.85 | -291.73 | -291.36 | -302.75 | -282.82 | -294.06 |
| | | Liver | -444.87 | **-447.29** | -428.61 | -430.98 | -431.09 | -445.04 | -427.75 | -443.21 |
| | | Body | **-776.93** | -775.61 | -738.56 | -736.8 | -738.28 | -776.44 | -737.36 | -774.99 |
| M | DS M3 | Gonad | **-132.67** | -131.15 | -129.41 | -127.76 | -127.41 | -130.93 | -128.89 | -132.17 |
| | | Liver | **-106.82** | -104.88 | -102.1 | -99.64 | -101.41 | -105.26 | -101.29 | -104.96 |
| | | Body | **-258.32** | -254.85 | -246.77 | -242.94 | -244.84 | -256.83 | -244.83 | -256.81 |
| | US M4 | Gonad | -94.7 | -100.04 | -89.6 | -93.14 | -94.33 | -99.71 | -95 | **-101.75** |
| | | Liver | **-120.5** | -118.02 | -117.49 | -114.94 | -116.93 | -119.81 | -116.94 | -120 |
| | | Body | **-204.02** | -203.73 | -193.13 | -193.2 | -194.05 | -203.84 | -192.6 | -202.44 |
| | DS M4 | Gonad | **-184** | -182.66 | -177.92 | -177.4 | -175.94 | -182.03 | -176.22 | -182.16 |
| | | Liver | -146.17 | -145.13 | **-149.44** | -148.63 | -148.57 | -145.34 | -147.87 | -144.67 |
| | | Body | -300.91 | -298.26 | **-303.16** | -301.44 | -301.17 | -299.18 | -301.98 | -300.2 |
| | allOSR | Gonad | **-436.02** | -433.96 | -417.9 | -416.88 | -415.92 | -434.04 | -416.19 | -434.14 |
| | | Liver | **-390.83** | -388.5 | -389.02 | -387.05 | -388.19 | -389.45 | -388.83 | -390.02 |
| | | Body | **-795.29** | -793.44 | -772.48 | -770.89 | -770.86 | -793.76 | -771.12 | -793.71 |

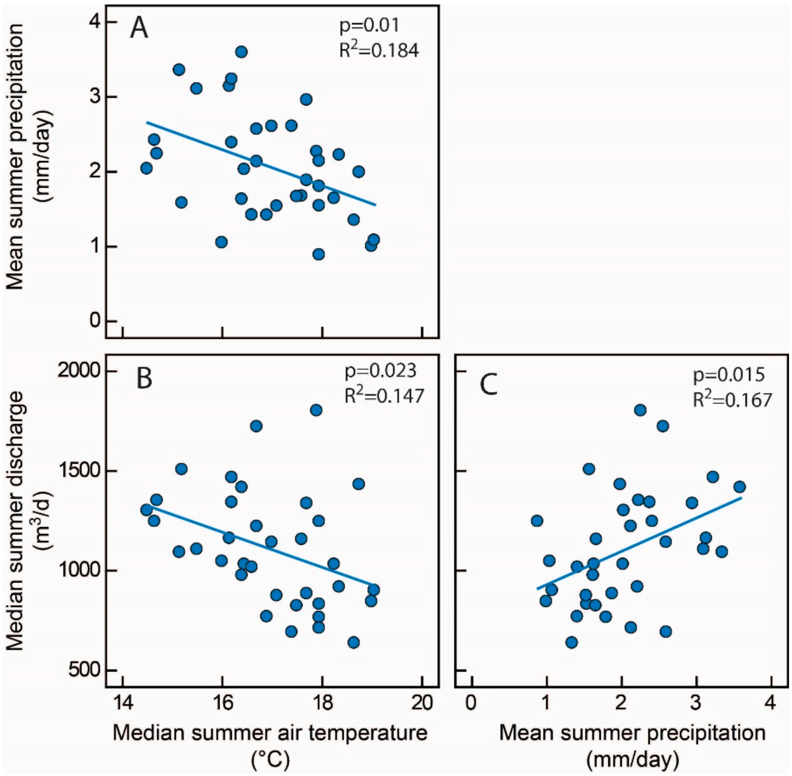


**Figure S1.** Regressions of (A) mean summer precipitation vs. median summer air temperature, (B) median summer discharge vs. median summer air temperature, and (C) median summer discharge vs. mean summer precipitation using hydrological data from the Fort McMurray gauging station and the Mildred Lake meteorological station; overlapping years included 1973-1980 and 1991-2018.

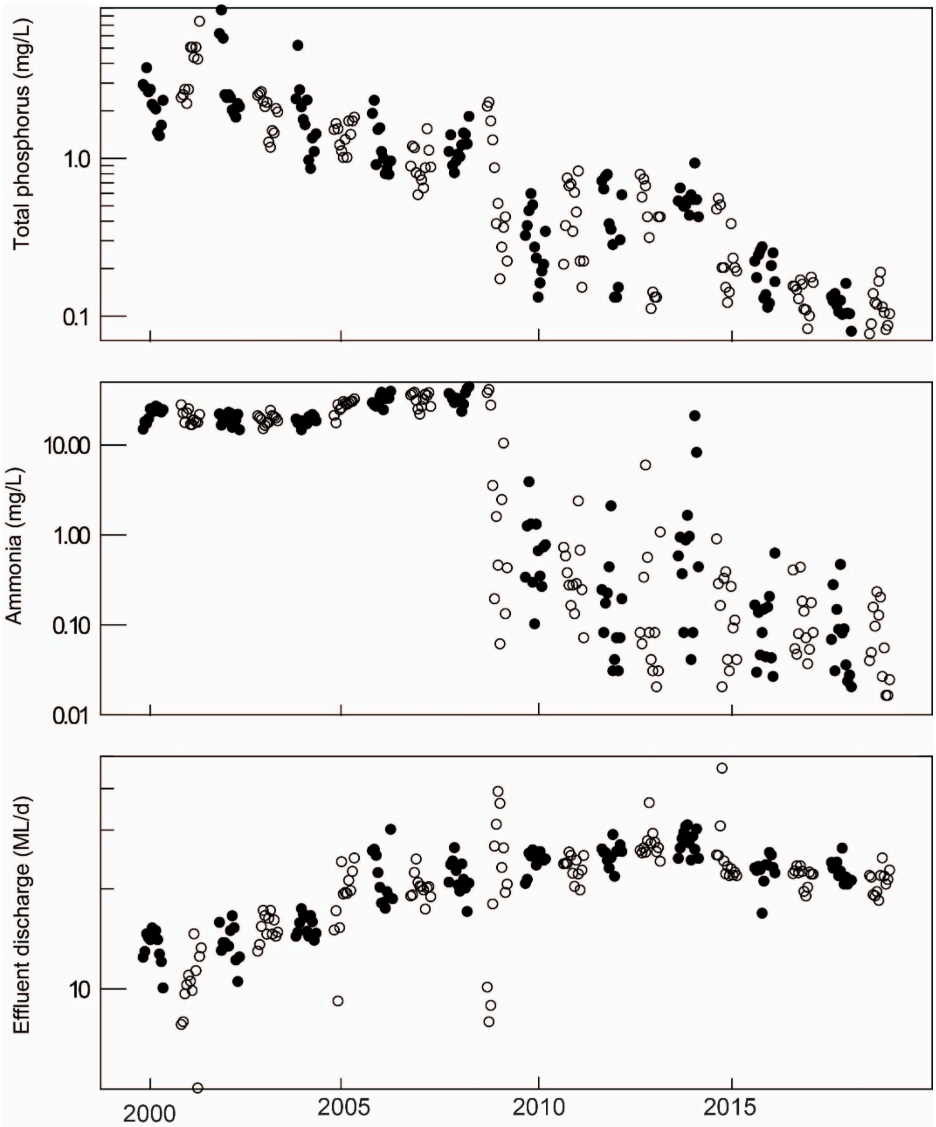


**Figure S2.** Total phosphorus (mg/L), total ammonia (mg/L), and volume of effluent (ML/d) discharged from the Fort McMurray Wastewater Treatment plant (FMM WWTP) between 2000 and 2019; data obtained from annual compliance reporting submitted to Alberta Environment and Parks.

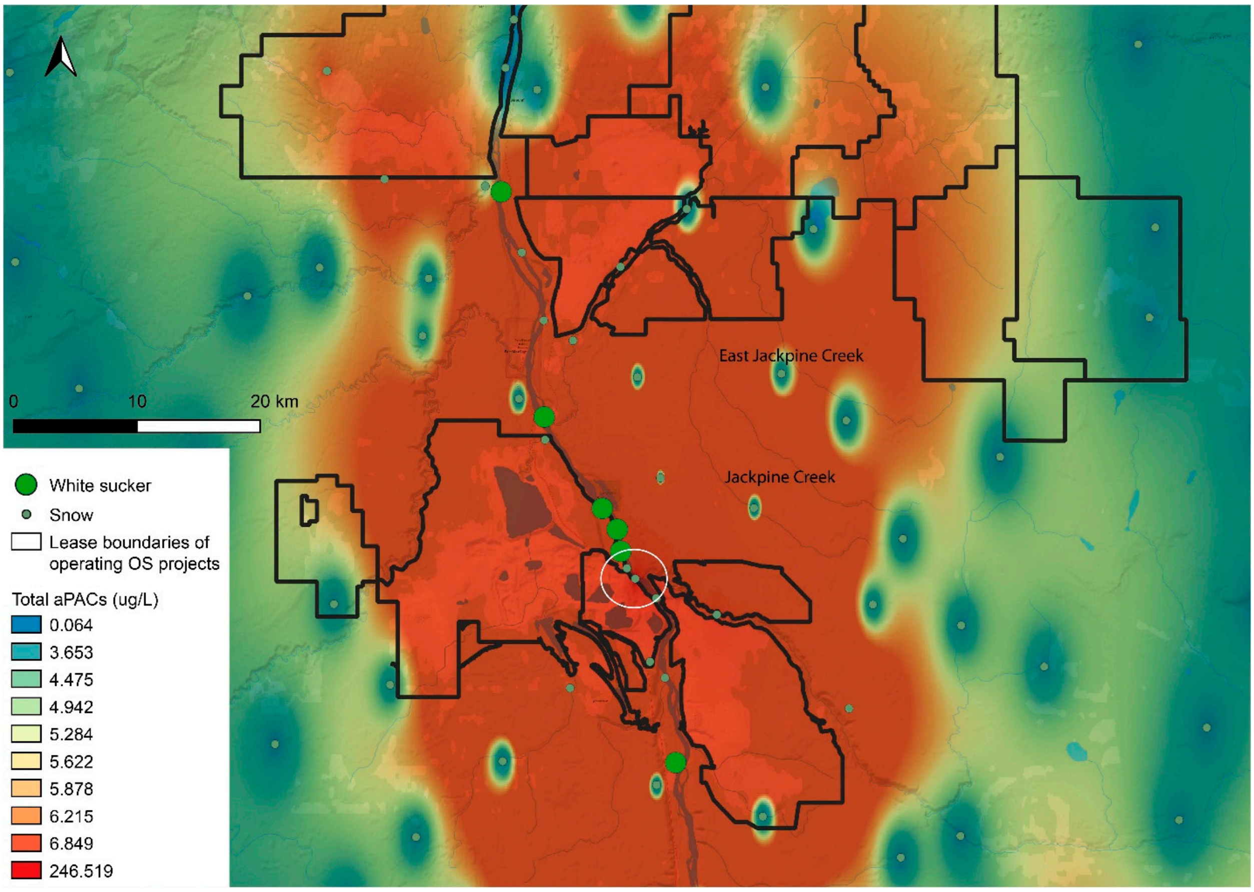


**Figure S3.** Estimated deposition patterns of total alkylated polyaromatic compounds (aPACs; ug/L) in snow collected in late winter 2014 grouped by deciles; Spatial interpolation used Inverse Distance Weighting with a power of 2; analyses performed using IDW algorithm in QGIS; Data obtained from: http://donnees.ec.gc.ca/data/substances/monitor/snow-and-wet-precipitation-oil-sands-region/snow-oil-sands-region/; highest area of deposition highlighted with white circle.

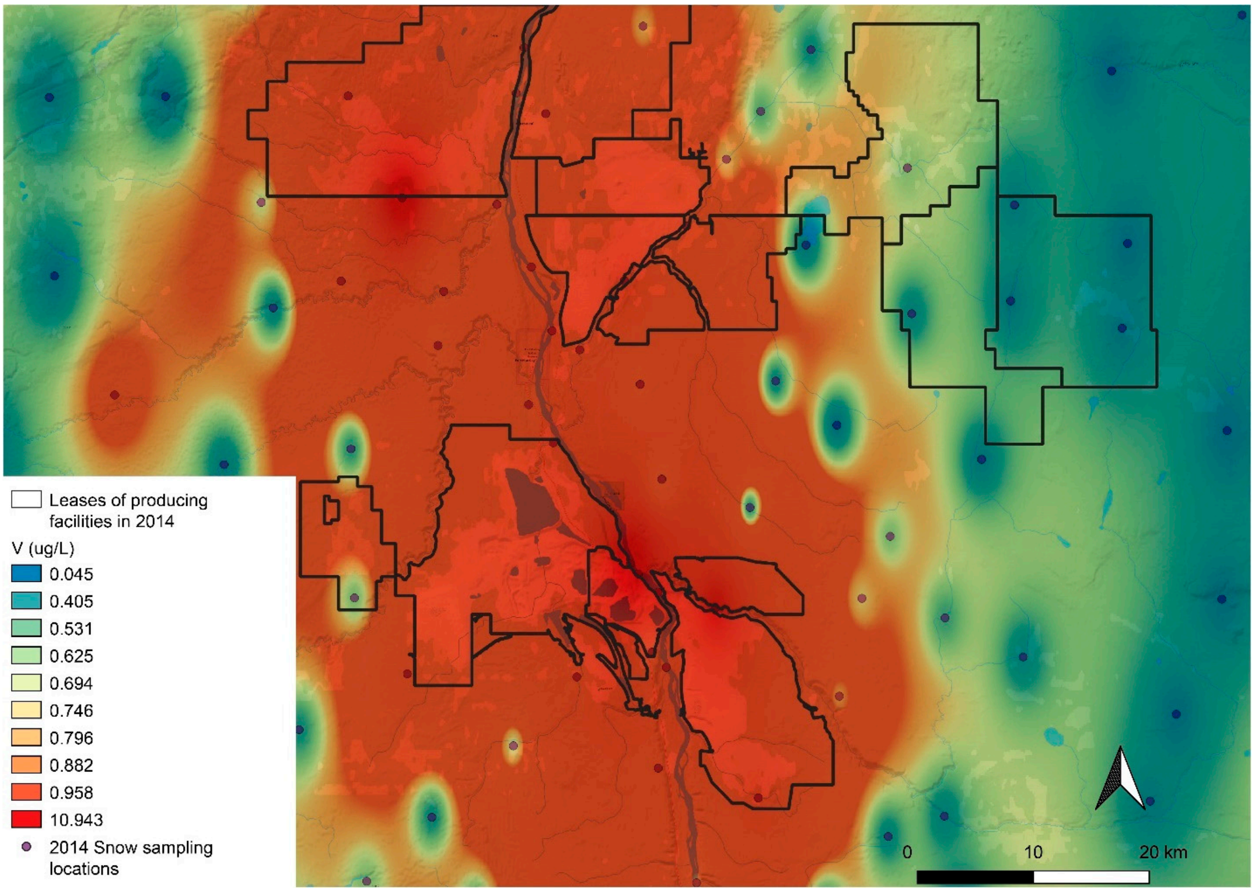


**Figure S4.** Estimated deposition patterns of Vanadium (V) in snow from 2014; grouped by deciles; Spatial interpolation used Inverse Distance Weighting with a power of 2; analyses performed using IDW algorithm in QGIS; Data obtained from: http://donnees.ec.gc.ca/data/substances/monitor/snow-and-wet-precipitation-oil-sands-region/snow-oil-sands-region/.

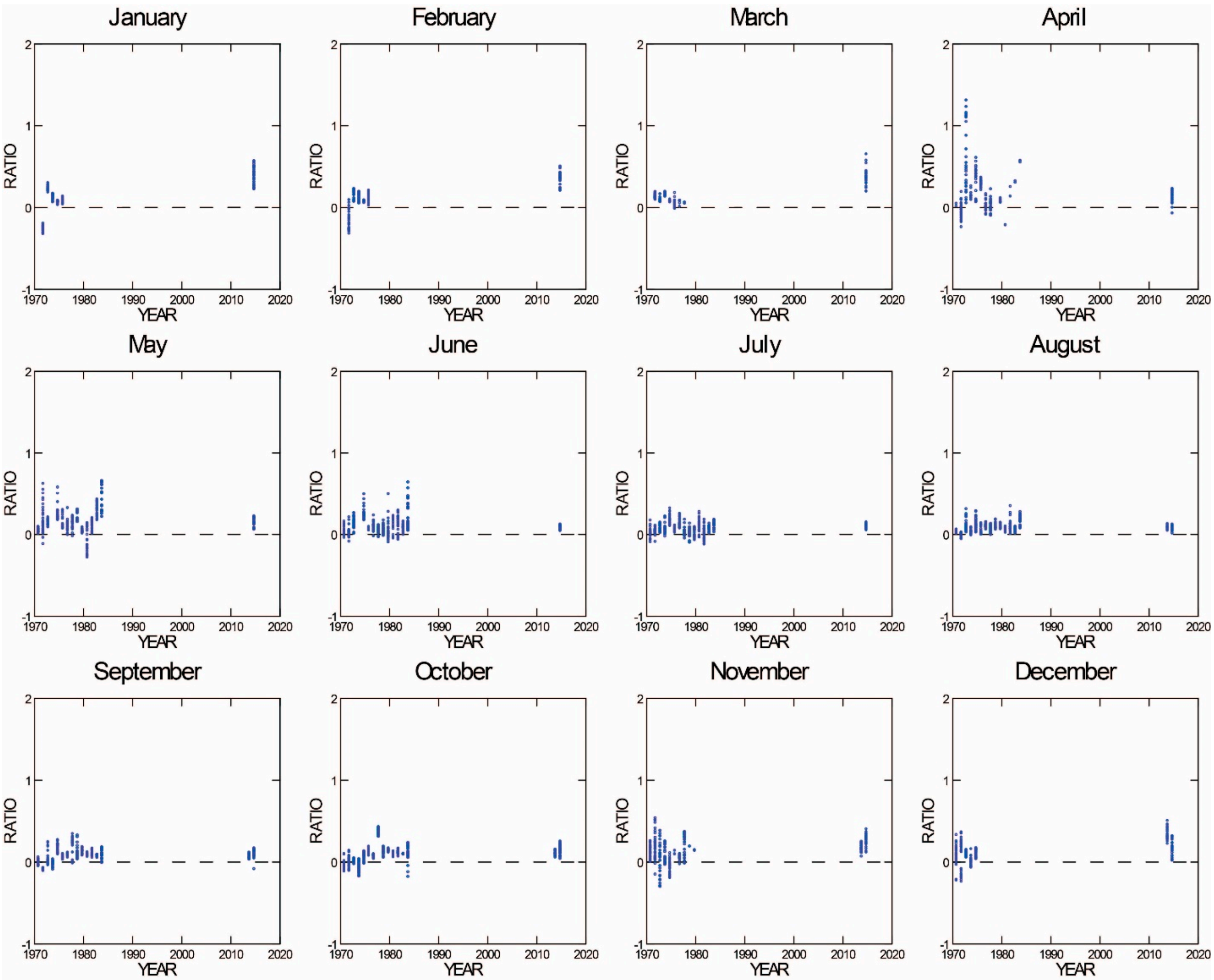


**Figure S5.** Differences in Athabasca River discharge at FMM and Embarras Airport downstream of all oil sands development expressed as ratio; positive numbers indicate increases in flow from US to DS stations; negative numbers indicate decrease in flows between stations.