



# Quantifying Phosphorus Losses from Tile Drained Agricultural Lands: Investigating the Influence of Preferential Flow

**Mohamed Chikhaoui & Mark Eastman**

Apurva Gollamudi, Chandra Madramootoo and Aubert Michaud

**Brace Centre for Water Resources Management  
Department of Bioresource Engineering**



**McGill University**



**Tile Drainage Workshop – W.H. Miner Institute  
January 15, 2008**



# PROBLEM

---

## Eutrophication:

- Eutrophication of Bay Missisquoi
- Algal blooms – cyanobacteria
- Loss of recreation
- Health hazards

## Non-Point Source Pollution:

- Agricultural industry
- Intensification/mechanization
  - Subsurface drainage

## Subsurface Drainage:

- P transport pathway?



# OBJECTIVES

---

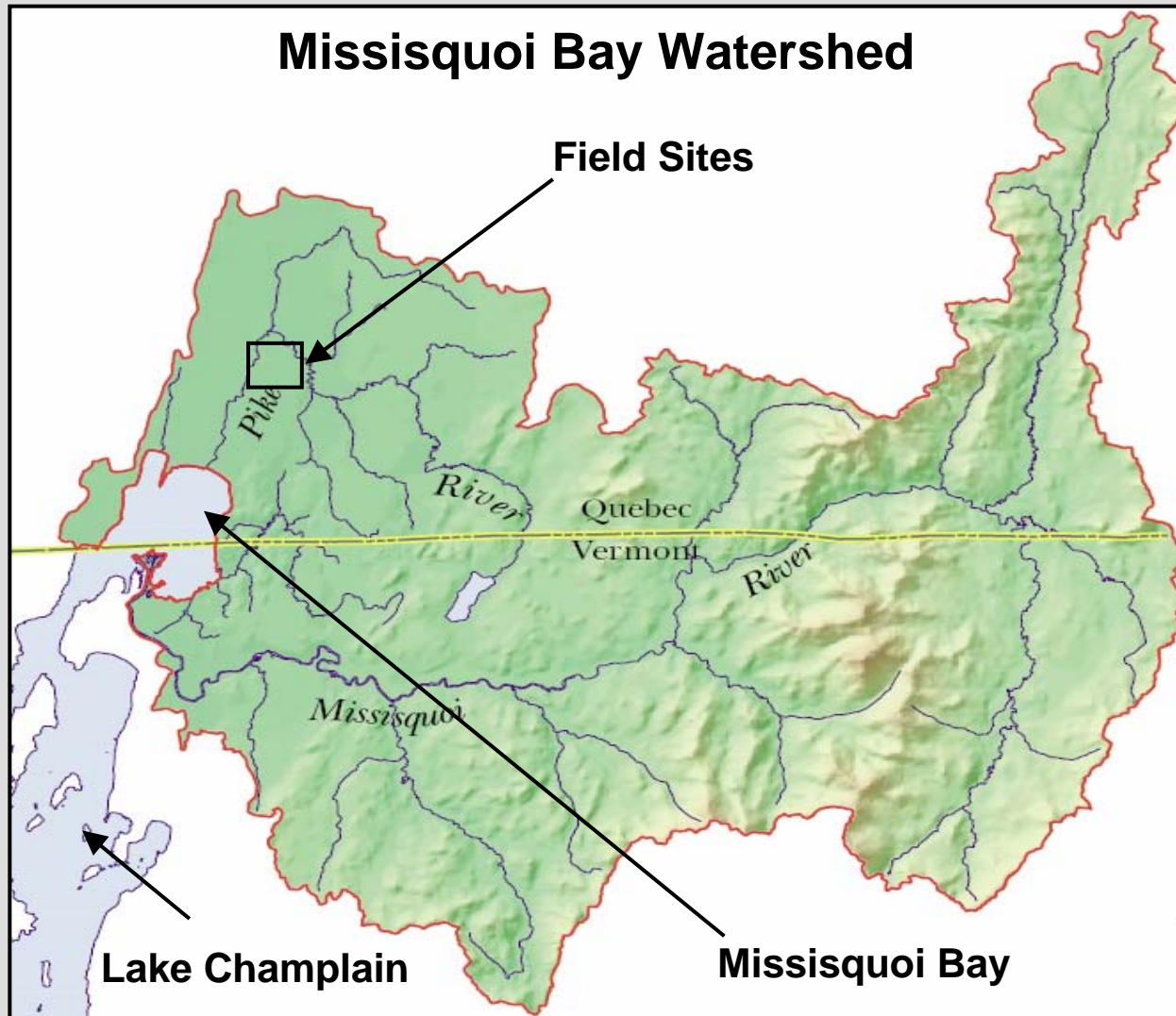
Quantify phosphorus loss from agricultural tile drainage systems under clay loam and sandy loam soils

Identify factors which influence the risk of P loss from subsurface drained fields under clay loam and sandy loam soils

Estimation of preferential flow (bypass) contributions to tile drains

# LOCATION

---



# FIELD SITES

---

## 4 Field Sites Instrumented

### – 2 Subsurface Drained Sites (2000)

- Site A (Gagnon) - Clay Loam (approx. 41% clay)
  - P-test = 145 kg ha<sup>-1</sup>, P-sat = 7%
- Site B (Marchand) - Sandy Loam (approx. 10% clay)
  - P-test = 289 kg ha<sup>-1</sup>, P-sat = 17%

**Accurate data available from 2002 onwards**



# INSTRUMENTATION

## Surface Hydrology

- Flumes
- Ultrasonic Depth Sensors
- Pressure Transducers
- Automatic Samplers



Depth  
Sensor



H - Flume



Composite  
Auto-Sampler

## Subsurface Hydrology

- Flow Meters
- Water Table Levelloggers
- Automatic Samplers



Water Table  
Measurement



Subsurface  
Flow meter

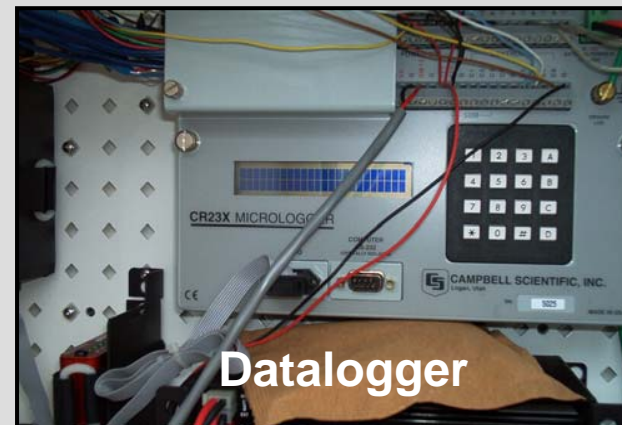
# INSTRUMENTATION

## Meteorological

- Temperature – Air and Soil
- Rain Gauges
- Barometric pressure
- Wind Speed
- Solar Radiation

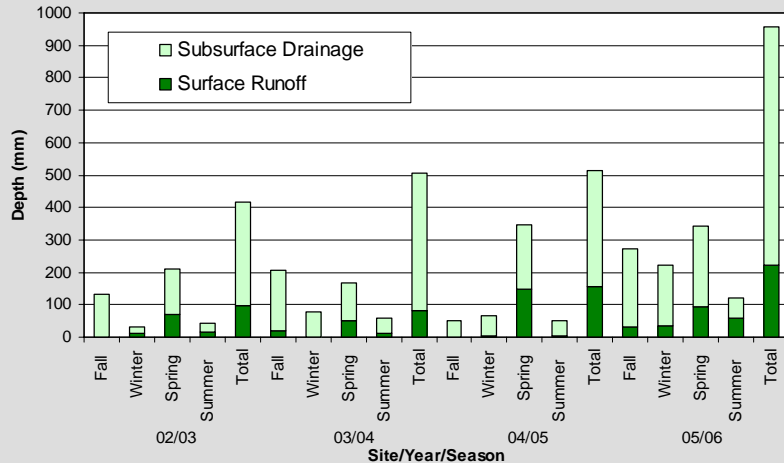
## Data Storage/Access

- Data loggers
- Radios
- Modems / Cell Phones

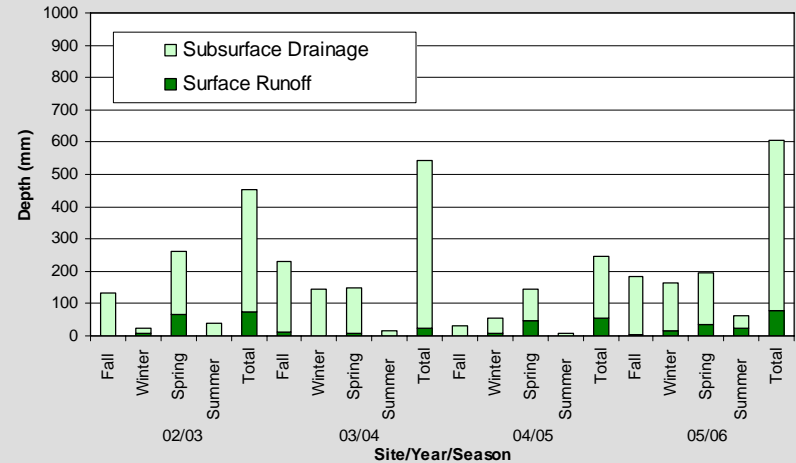


# HYDROLOGY RESULTS

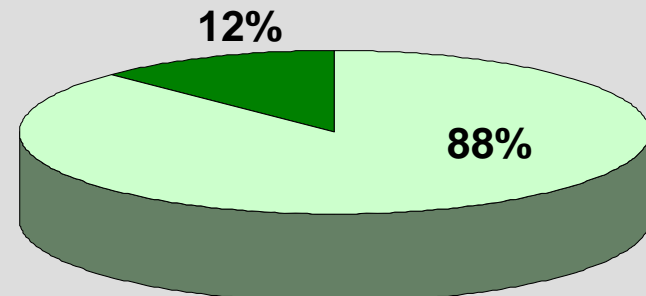
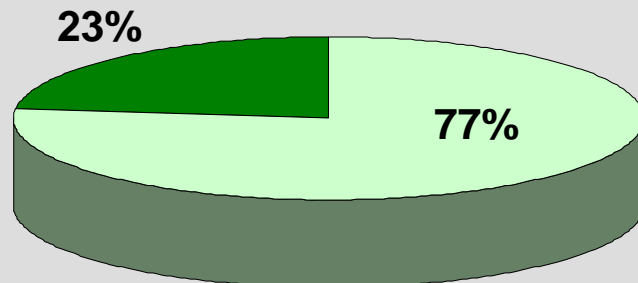
Site A Total Water Yield



Site B Total Water Yield

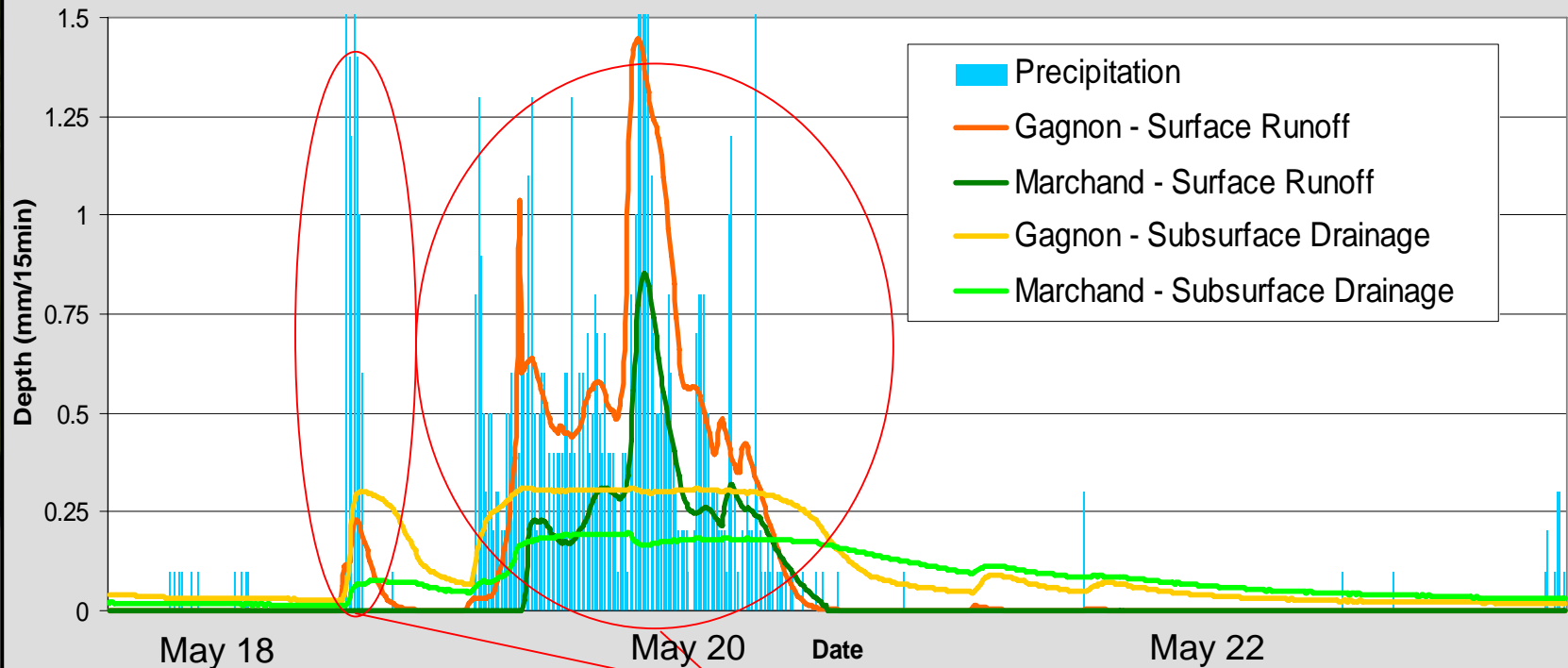


- Average subsurface drainage = 461mm and 405mm at sites A and B
- Average surface drainage = 139mm and 57mm at sites A and B



- Site A is much more hydrologically responsive – expected for surface runoff, but for subsurface drainage as well?

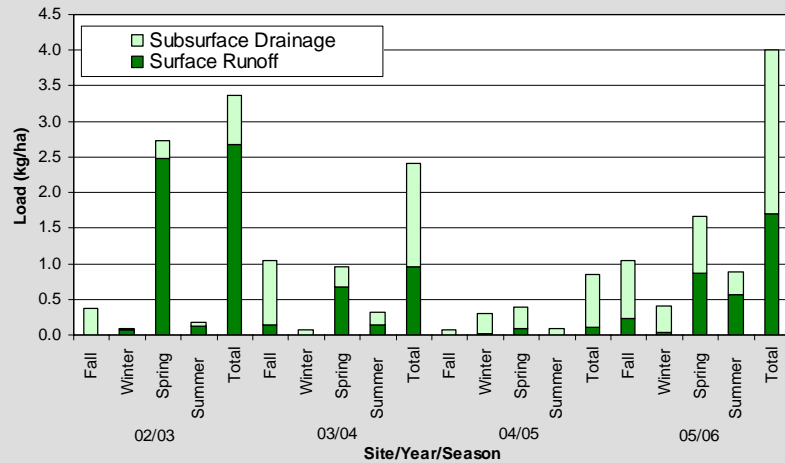
# EVENT ANALYSIS – May 18-23, 2006



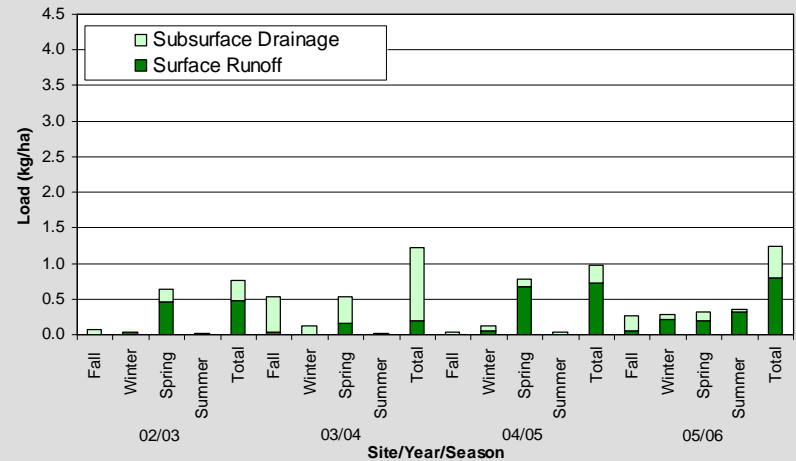
- Large rain event: fairly intense at times, long duration (3 days)
- Very short, intense rain event
- Rapid surface runoff and subsurface drainage response at Gagnon
- Rapid surface runoff and subsurface drainage response at Gagnon
- Less surface runoff and a slower subsurface drainage response at Marchand
- No surface runoff and a slow subsurface drainage response at Marchand
- Rapid subsurface response at Gagnon is a result of macropore/crack flow

# PHOSPHORUS RESULTS

Site A Total Phosphorus

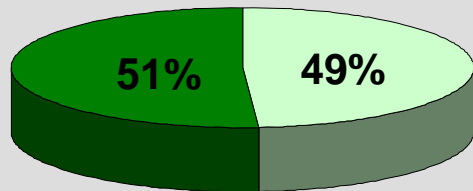


Site B Total Phosphorus



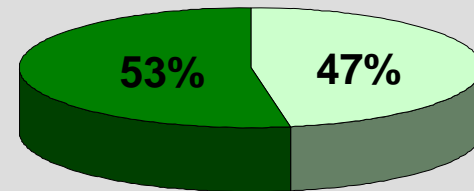
- Average annual Total P loads = 2.7 kg/ha at site A and 1.0 kg/ha at site B

Site A

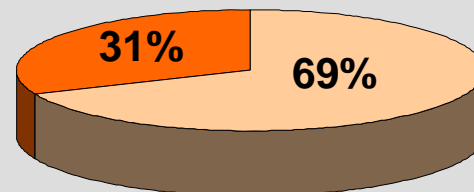
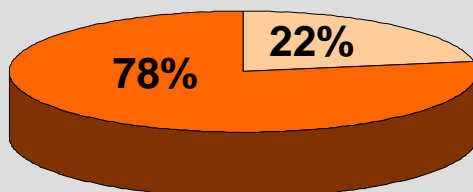


Total P Partitioning

Site B



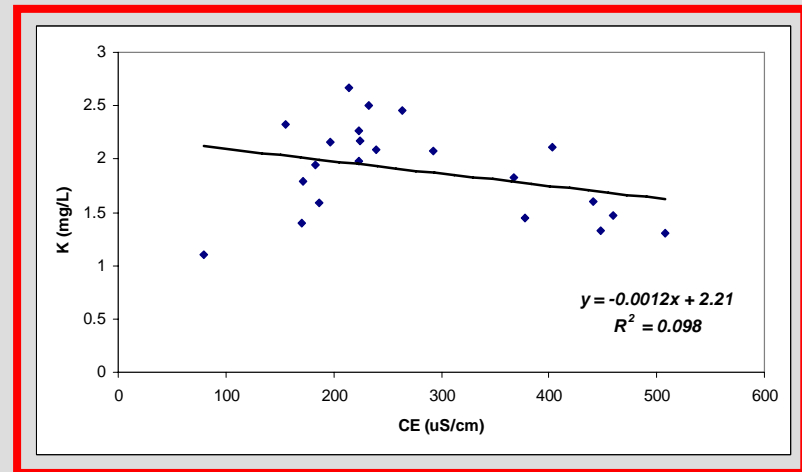
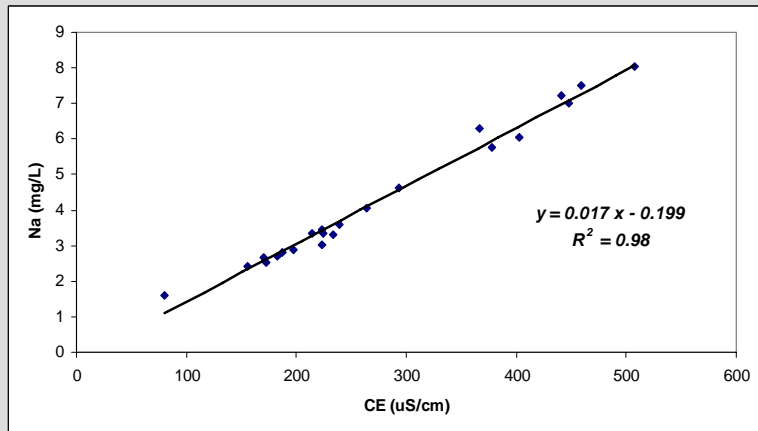
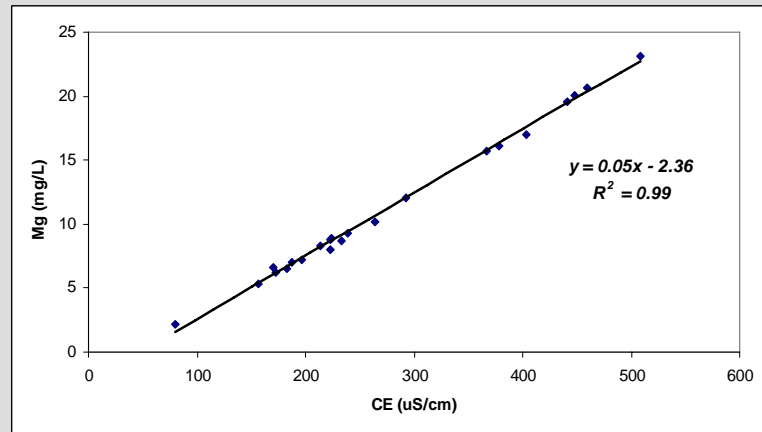
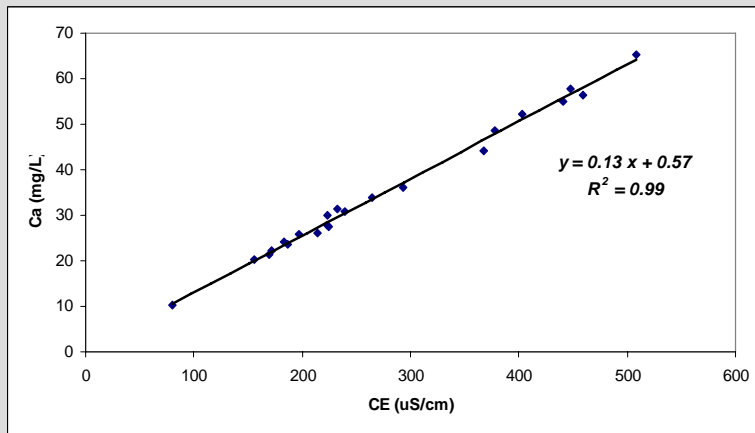
Subsurface P Form Partitioning



Particulate Phosphorus
  Total Dissolved Phosphorus

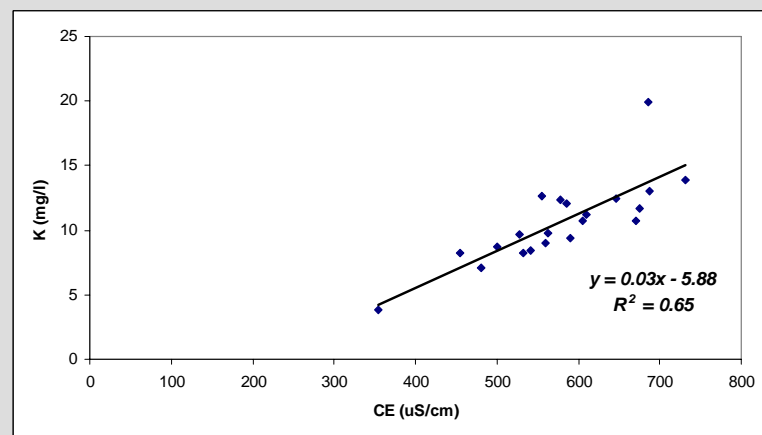
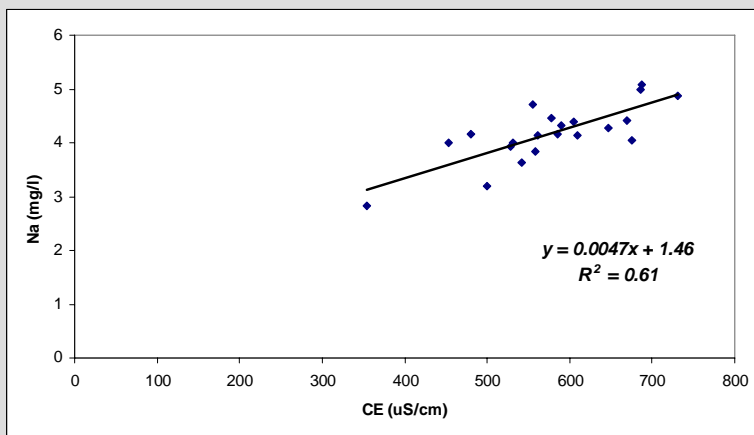
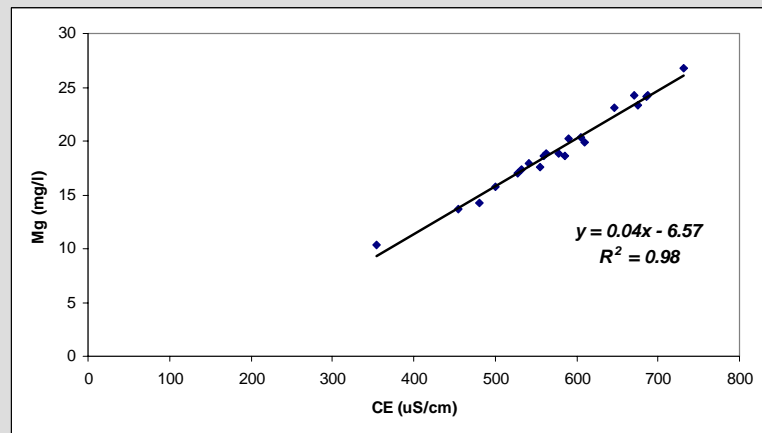
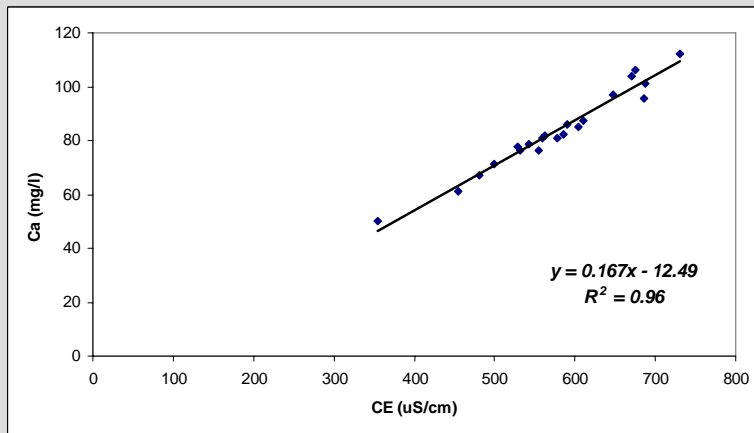
# ESTIMATION OF PREFERENTIAL FLOW

## Site A (Gagnon)



# ESTIMATION OF PREFERENTIAL FLOW

## Site B (Marchand)



# ESTIMATION OF PREFERENTIAL FLOW

---

## ➤ Conservation of mass equations

$$(Stone\ et\ Wilson,\ 2006) \left\{ \begin{array}{l} Q_d = Q_m + Q_p \\ Q_d C_d = Q_m C_m + Q_p C_p \end{array} \right.$$

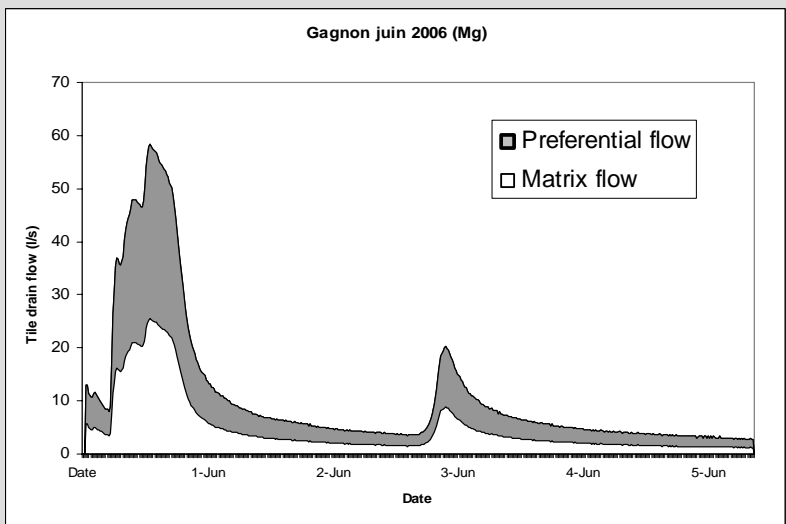
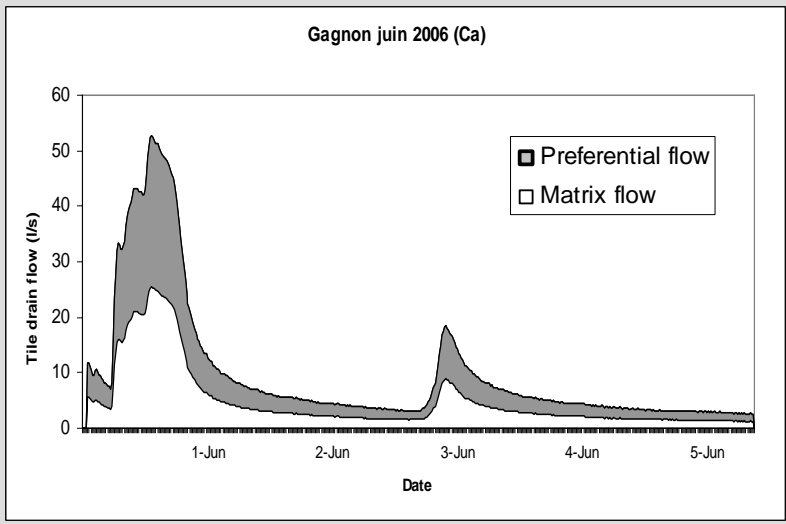
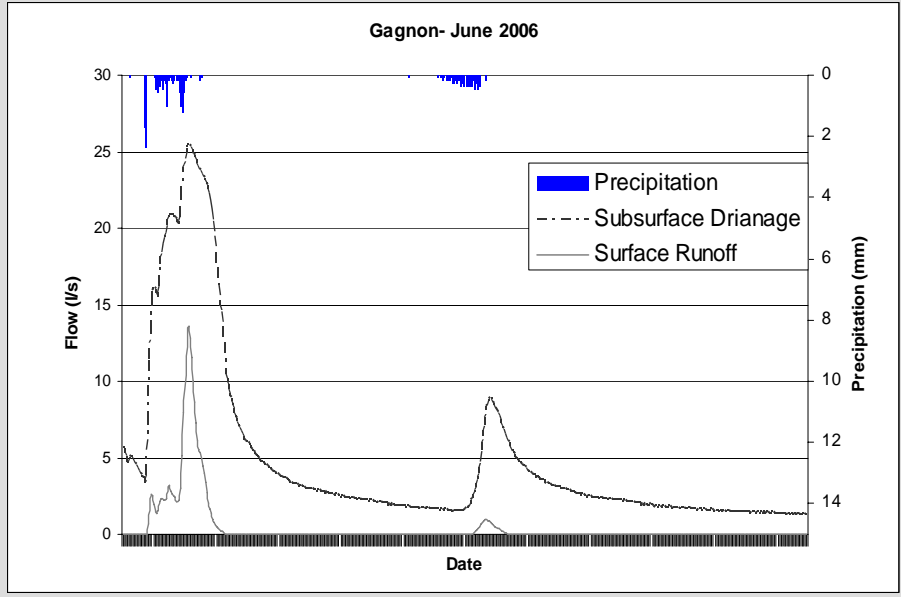
- 1- Preferential flow water reflects the chemistry of water from soil surface;
- 2- Matrix flow water reflects the chemistry of water that has more contact time with soil and base flow (Steenhuis et al., 1994).

$$Q_p = \frac{Q_d (C_d - C_m)}{(C_p - C_m)}$$

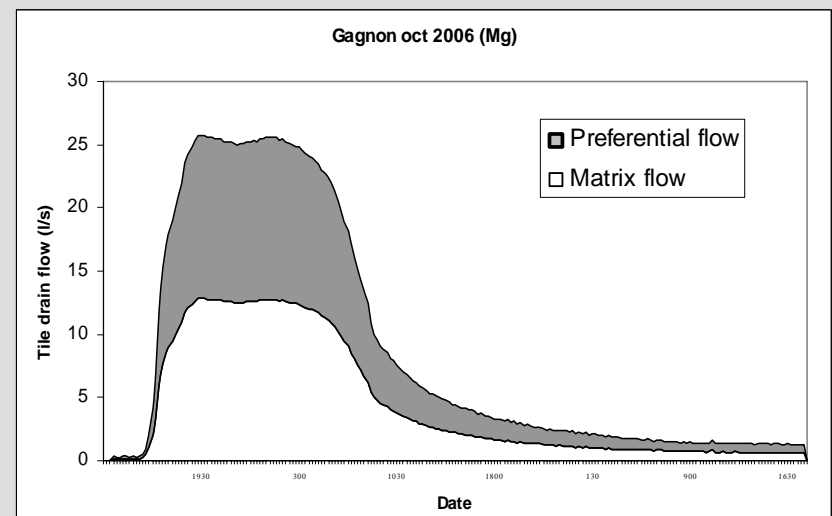
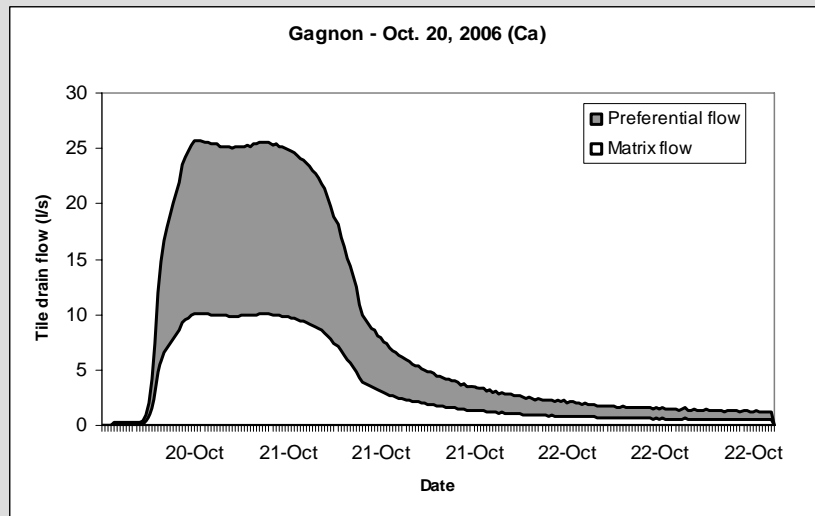
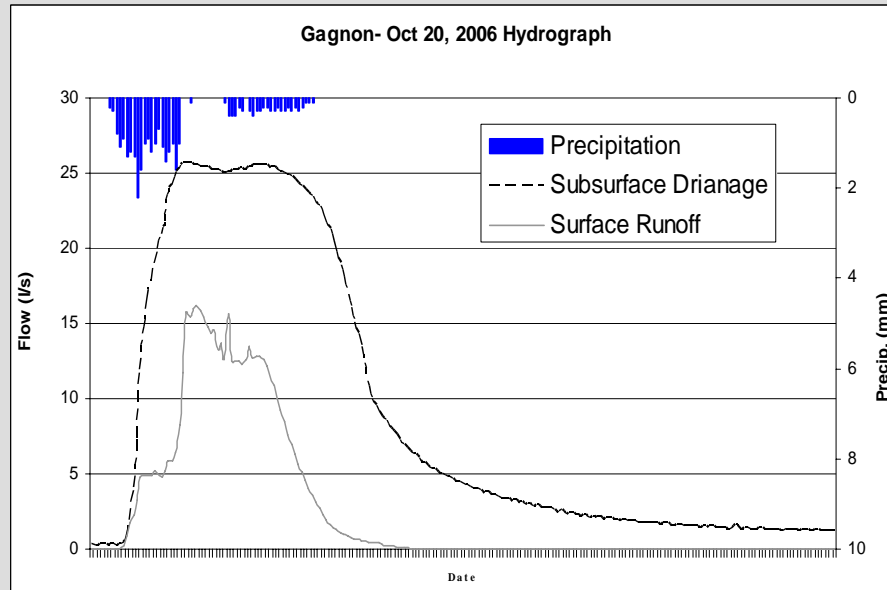
$$Q_m = \frac{Q_d (C_d - C_p)}{(C_m - C_p)}$$

# ESTIMATION OF PREFERENTIAL FLOW

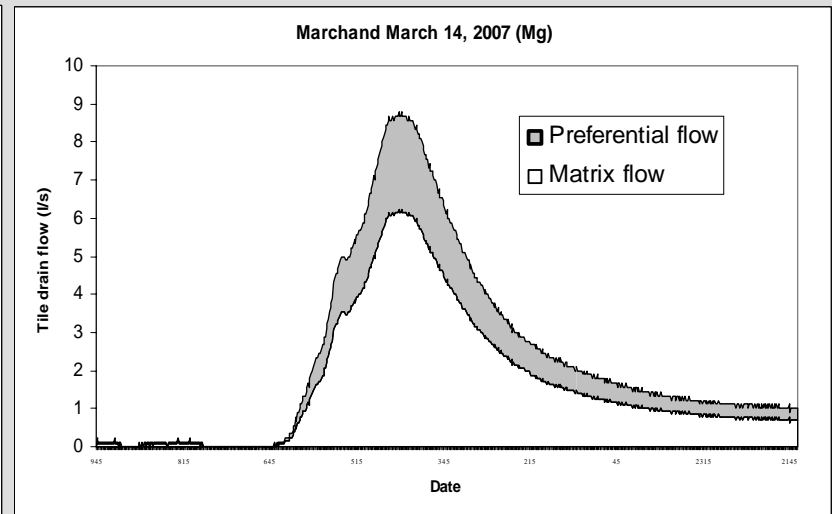
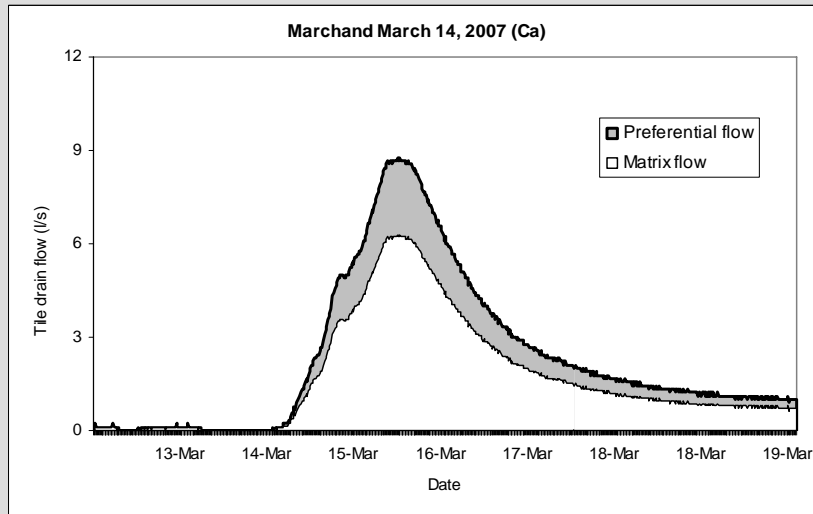
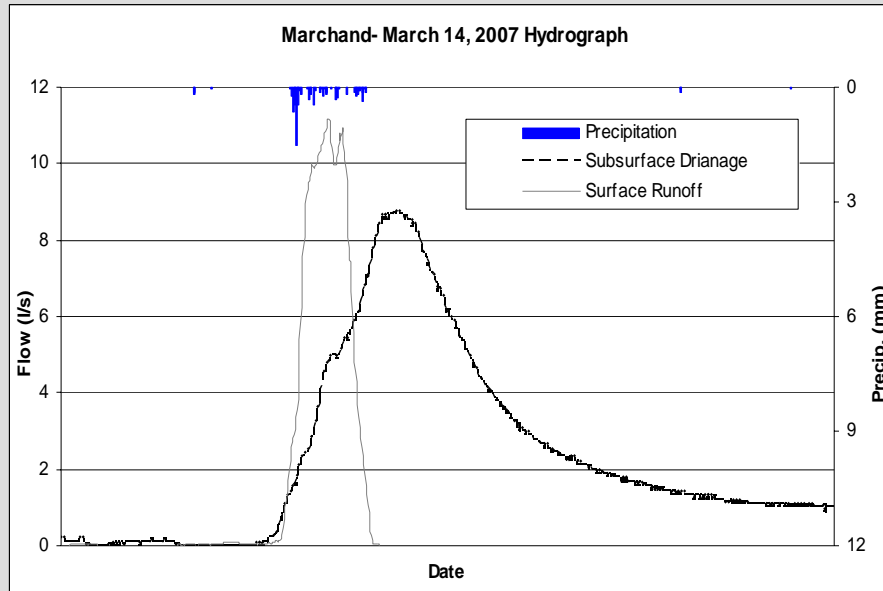
## ➤ Conservation of mass equations



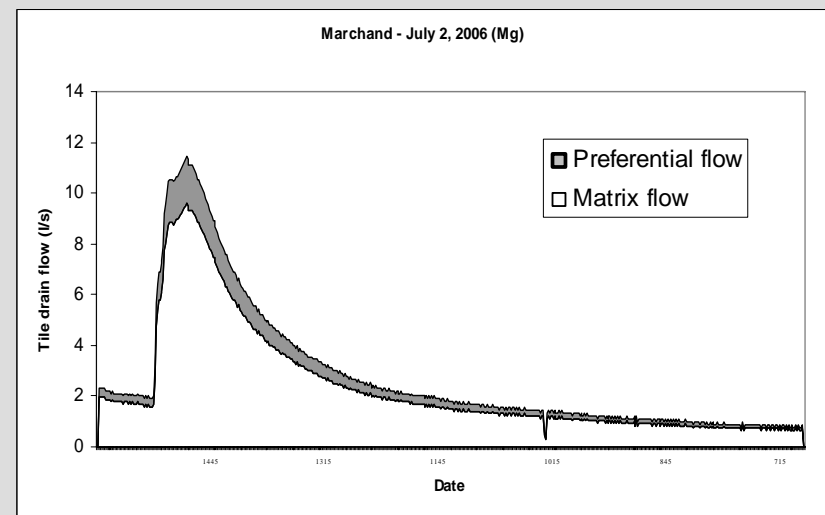
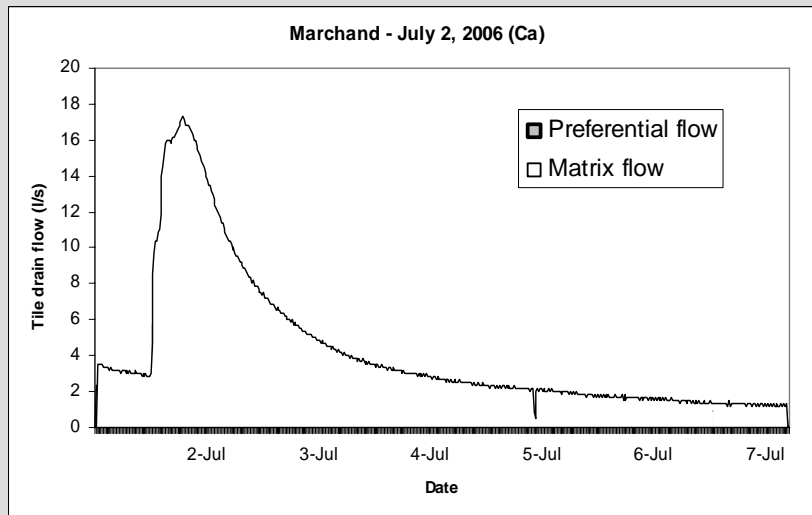
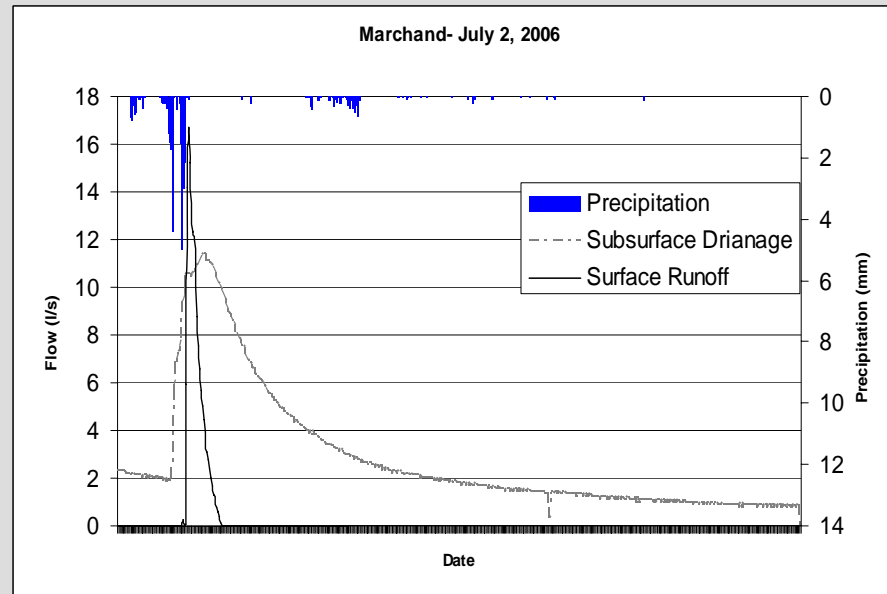
# ESTIMATION OF PREFERENTIAL FLOW



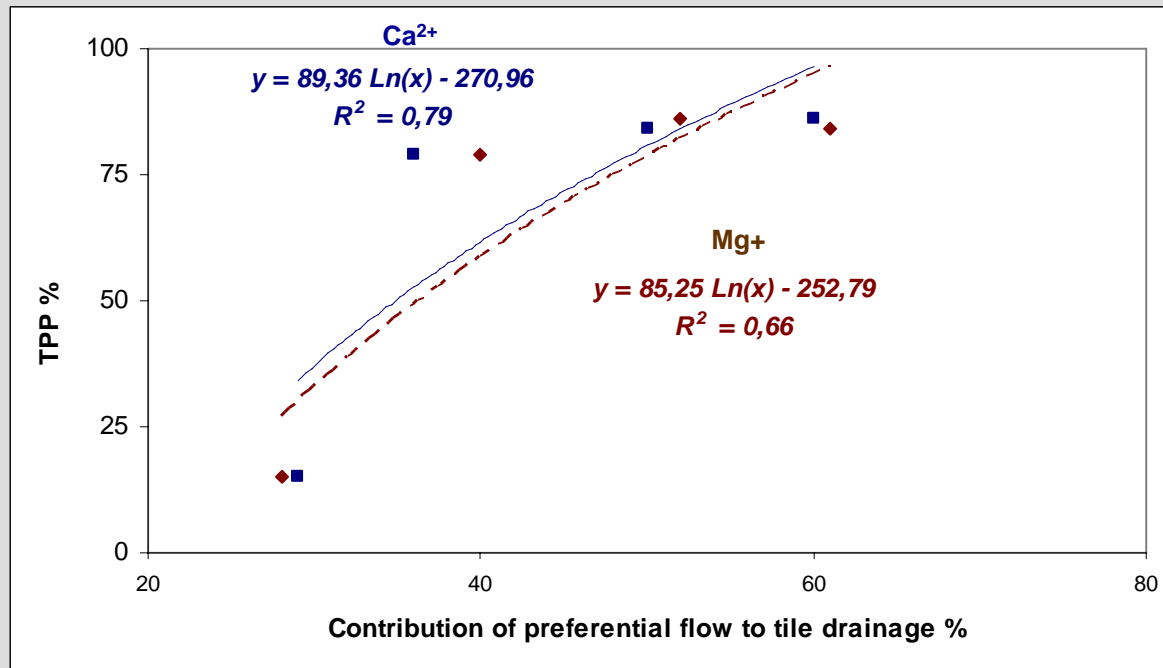
# ESTIMATION OF PREFERENTIAL FLOW



# ESTIMATION OF PREFERENTIAL FLOW



# ESTIMATION OF PREFERENTIAL FLOW



# CONCLUSION

---

- ✓ The clay loam site (site A) was more hydrologically responsive in terms of surface runoff and subsurface drainage than the sandy loam site;
- ✓ Preferential flow through a fine soil is dominant (70%);
- ✓ Matrix flow through a coarse soil is dominant (80%);



# CONCLUSION

---

- ✓ The peak of preferential flow coincided with the peak of tile drain;
- ✓ High intensity storms contribute larger proportions of preferential flow to tile drains than lower intensity storms (Kumar et al., 1997);
- ✓ Highest P loading occurred from one of the lowest P-test and P-Sat soils (Site A - 145 kg ha<sup>-1</sup>, 7%) and the lowest P loading occurred from the highest P-test and P-Sat soil (Site B - 289 kg ha<sup>-1</sup>, 17%)
- ✓ Preferential flow is an important transport mechanism for PP;
- ✓ Forms of P loads depend of type of flow and soil profile;
- ✓ The elements (Ca<sup>2+</sup>, Mg<sup>2+</sup>) satisfactorily predict the extent of preferential flow.



# ACKNOWLEDGEMENTS

---

## **Technical Support**

- IRDA
- MAPAQ
- Vermont Agency of Agriculture
- Corporation Bassin Versant Baie Missisquoi

## **Financial Support**

- FQRNT
- Max Bell Foundation

***THANK YOU!***

