Controlling THMs through Chlorine Demand Management:

A Newfoundland & Labrador Case Study

Government of
Newfoundland and Labrador

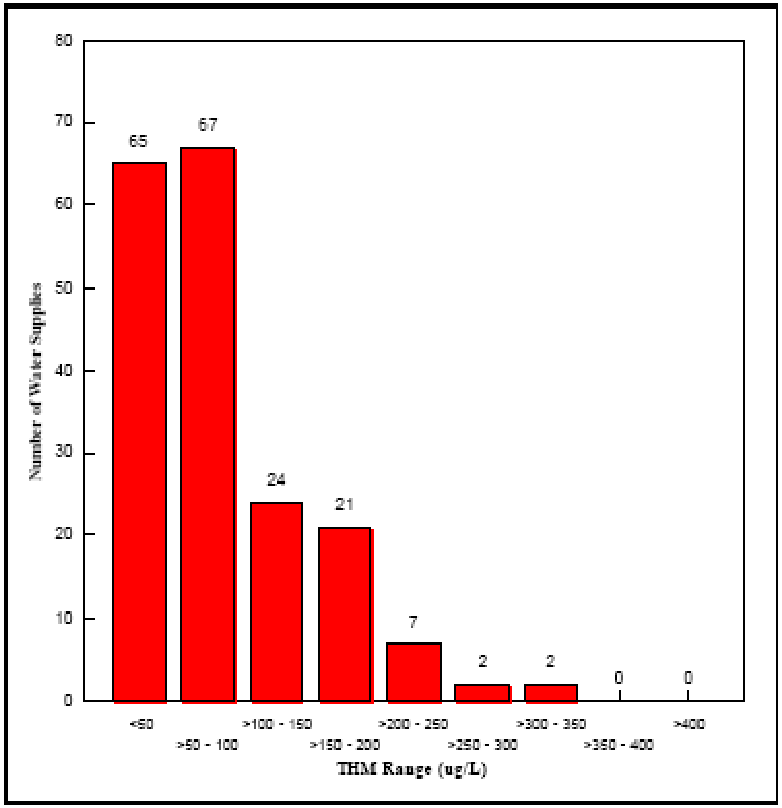
Water Resources Management Division
Department of Environment and Conservation

What is Chlorine Demand Management?

- Maintaining the required level of chlorine residual throughout the distribution system while at the same time minimizing the formation of Disinfection by-Products such as THMs

Why Chlorine Demand Management?

- 50% of surface drinking water sources are naturally predisposed to have medium to high THM formation potential
- Many communities throughout province already have high THMs



- Trihalomethanes (THMs) are a group of chemical compounds formed by chlorination of water and are a suspected human carcinogen

Why Chlorine Demand Management?

- Precursors of THMs include:
  - Chlorine, pH, water temperature, concentration of organic precursor compounds, colour, DOC, bromide, turbidity, contact time
- Chlorine treatment + Natural water quality = THM formation
- Size of communities makes cost of conventional water treatment plants unviable
- Option→ Optimize chlorine use to address THM issue
- How? → Distribution System Modeling

Scope of Modeling Work

- To develop 7 water quality models
- represent small, mid and large scale water distribution systems
- represent Eastern, Central, Western and Labrador regions
- run various scenarios
- use results to develop generic Chlorine Best Management Practices (BMPs) to reduce Disinfection-by-Products (DBPs) in problem water distribution systems
- work on this project first started in 2001

Distribution System Size and Type

- *Small systems*:
  - pop < 500
- *Mid-size system*:
  - 500 < pop < 5000
- *Large system*:
  - pop > 5000

- Long linear systems
- Fish plants or a very large demand in a small system
- Long T-type system
- Problematic tanks
- Operational problems

Communities Selected for Modeling

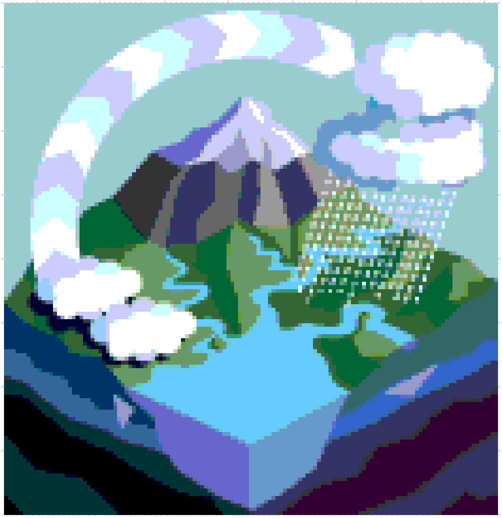
- Brighton (C)
- Burlington (W)
- Cartwright (L)
- Ferryland (E)
- Marystown (E)
- St. Pauls (W)
- Summerford (C)

- Why were these communities selected?
  - Representative communities
    - Population
    - Region
    - Distribution system type
  - All had THMs over Canadian Drinking Water Quality Guideline of 100 ug/L

	1	2	3	4	5
Pop less than 500	Brighton	Burlington	St. Paul’s		
Pop b/w 500-5000	Cartwright	Ferryland	Summerford		
Pop b/w 5000-10,000	Marystown				
Eastern	Marystown	Ferryland			
Central	Brighton	Summerford			
Western	Burlington	St. Paul’s			
Labrador	Cartwright				
Problamatic Tank	Brighton	St. Paul’s			
Long System	Brighton	Burlington	St. Paul’s	Cartwright	Ferryland
Long T-Branched System	Marystown	Summerford			
Fish Plant / Large Demand	Cartwright	Summerford	Marystown		
Operational Problems	Burlington				

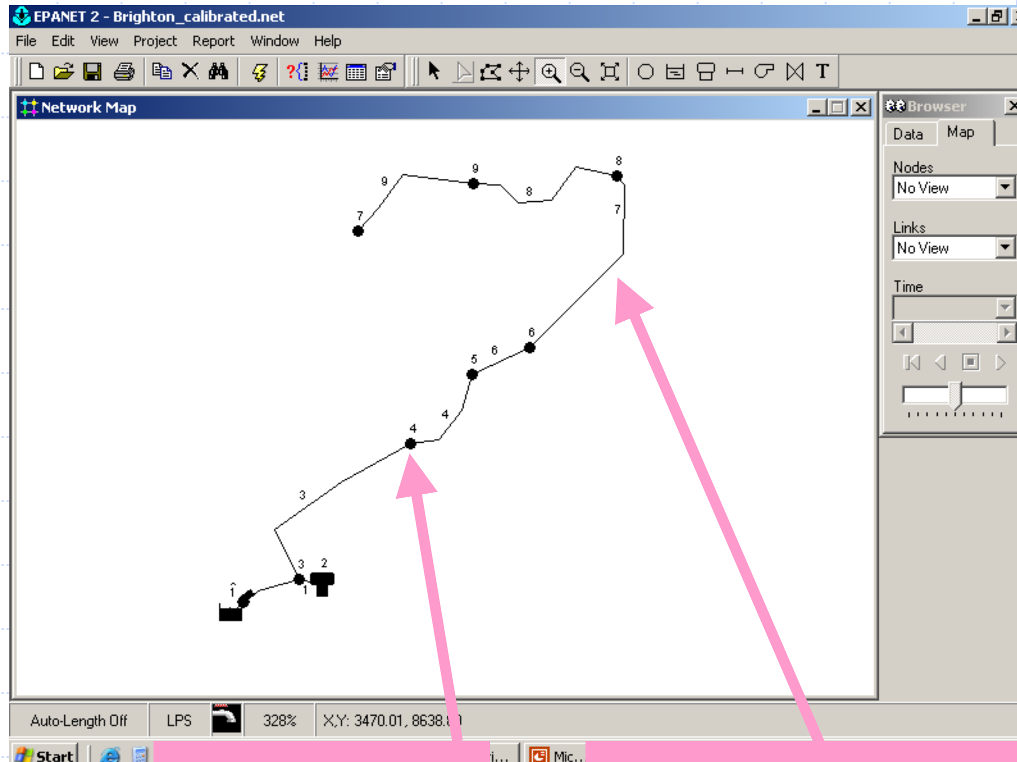
What is a Model?

- A representation of reality that helps us understand the complex world around us



Hydraulic/ Water Quality Modeling of Distribution Systems- EPANET

- Inputs:
  - Network layout
  - Elevations
  - Pipe size, material, length, etc.
  - Water demand
  - Reservoir, pumps, tank, valves, etc.
  - Initial water quality
  - Reaction rates
  - Time step



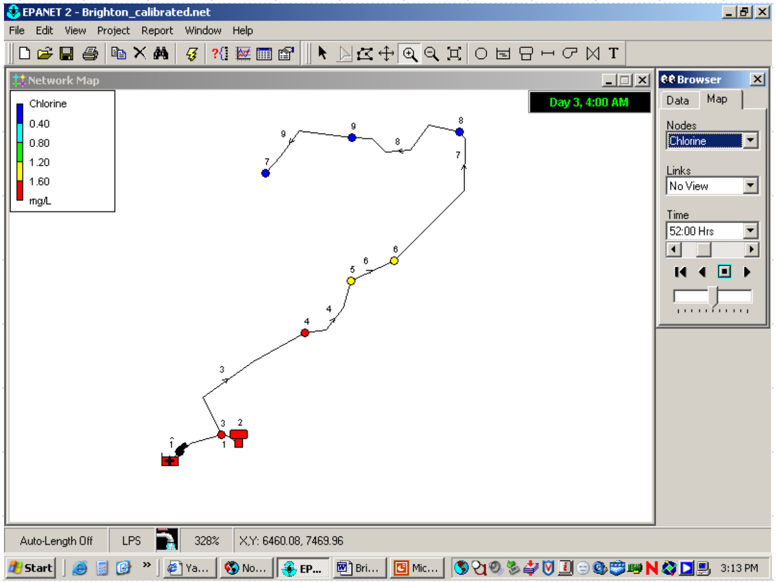
Junction:
-demand
-elevation

Link:
-pipe diameter
-pipe length

Hydraulic/ Water Quality Modeling of Distribution Systems- EPANET

- **Hydraulic Outputs**
  - Flow
  - Demand
  - Velocity
  - Pressure
  - Head
  - Headloss
  - Tank water elevation

- **Water Quality Outputs**
  - Water age
  - Chemical concentration
  - Average reaction rates



Objectives of CDM Models

- Water entering the distribution system shall have a 20 min contact time, and shall contain a free Cl residual of at least 0.3 mg/L at the first point of use
- Maintain detectable free Cl residual (0.05-0.10 mg/L) in all areas of the distribution system (ie. end points)
- Satisfy a maximum residual chlorine disinfectant level of 4.0 mg/L (USEPA)

Model Scenarios for Managing Chlorine/ Dealing with DBPs

- Change first point of chlorination
- Chlorine dosage
- Single point chlorination vs. multiple point (ie. chlorination boosters)
- Size of pipes
- Age of pipes (different C value for new/clean pipes)
- Network configuration- system looping, length of system from source to 1st user
- Regular flushing at dead ends
- Water usage ranges
- Tank operation- amount of storage in tank
- Tank location
- Multiple smaller tanks

Modeling Case Study: Brighton

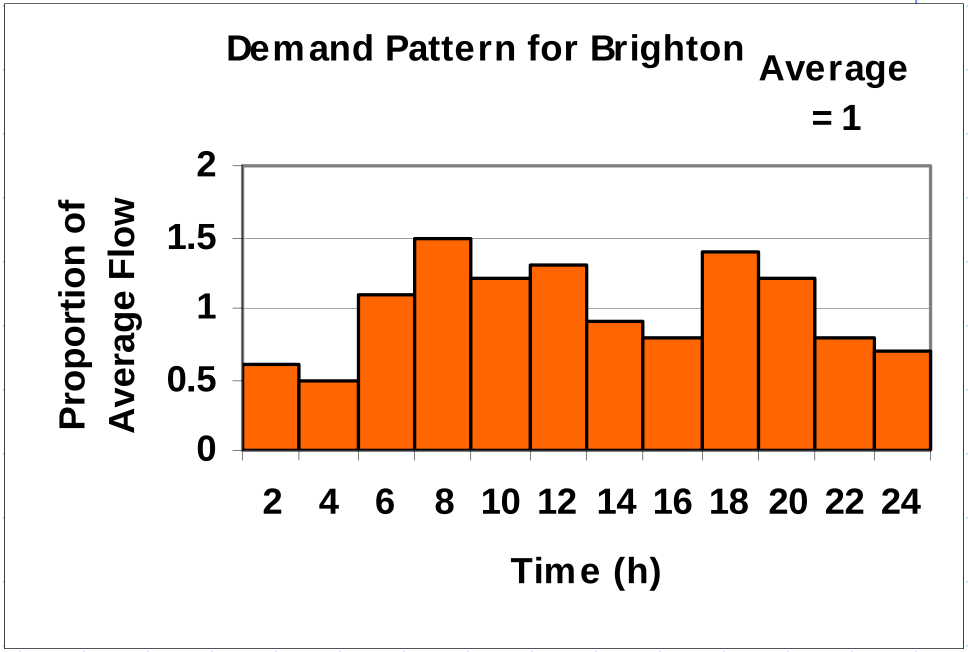
Classification of Brighton System

Region	System Size	Configuration / Problem	Secondary Problem
Central	Small	Long linear system	Tank

- High colour in source water
- Pump supplies community and tank
- Tank supplies community when pump offline
- Tank water levels trigger pump operation
- Liquid chlorination system

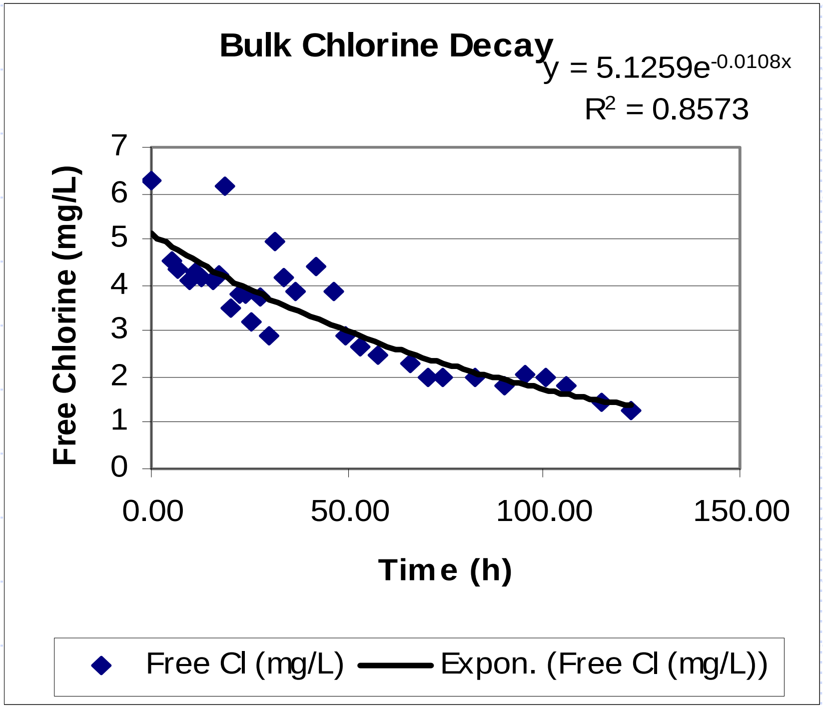
Brighton Water Demand

- Average daily demand= 92.8 m^3/d
- 104 water connections
- 2001 Population = 233
- Water Demand = 398 L/p/d
- Demand attributed to 6 nodes in network based on housing density surrounding that node
- Elevation of nodes: 7.2 m to 1.2 m above sea level



Brighton Chlorine Demand

- Liquid hypo-chlorination system
- Chlorinator cuts in when pump does
- Bulk chlorine decay coefficient of -0.3 d^{-1} from field test
- default wall decay coefficient of –1 m/day



Brighton Site Visit

- Sept 24, 2004
- gather data on the distribution system
  - Information from system operator
  - Pressure readings
  - Flow readings
  - Chlorine residuals

Brighton Chlorine and THM Data

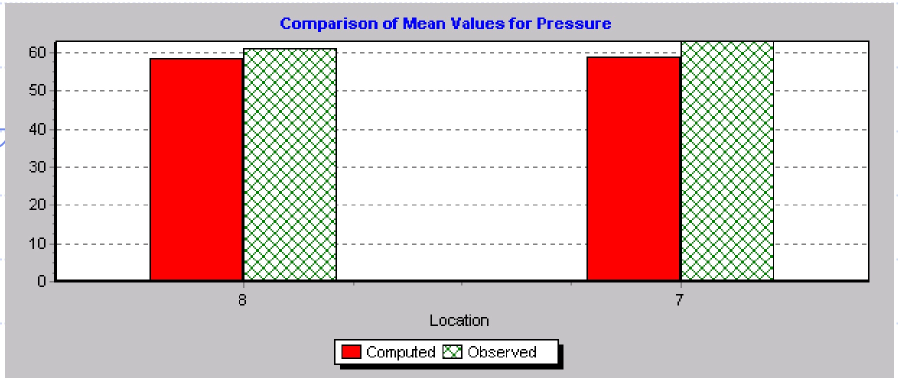
- Average Free Chlorine and THM results
- Canadian Drinking Water Quality Guideline for THMs = 100 ug/L

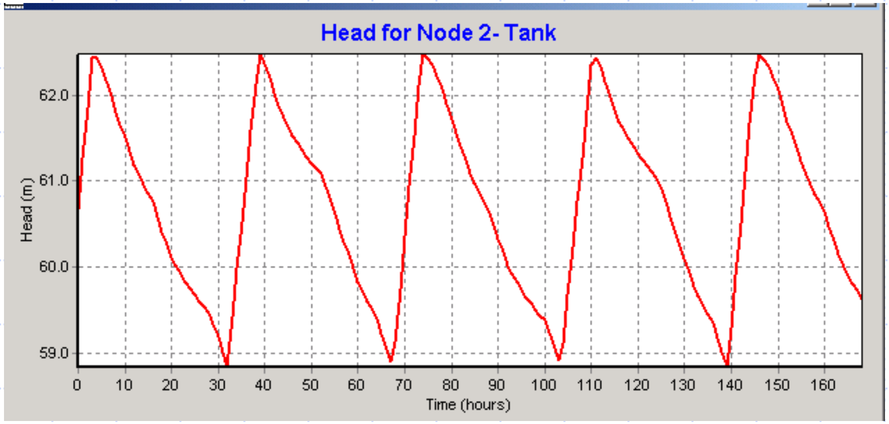
Location in Network	Junction	Free Chlorine-DoE (mg/L)	THM Total-DoE (ug/L)
Beginning	4	1.49	300
Middle	6	0.99	271
End	7	0.26	248

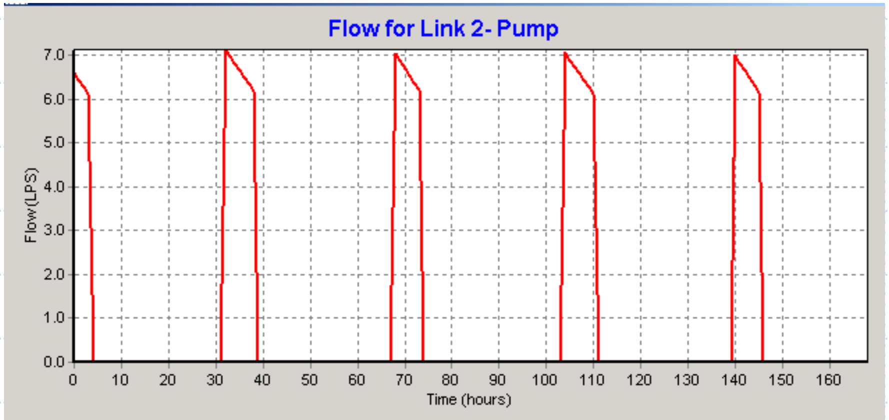
Calibrating the Brighton Model

- Model results were compared with the following datasets:
  - Flow data
  - Pressure data
  - Tank filling/emptying cycles
  - Chlorine residual data
- Adjustments made to model to correct for error
- Percent Error from model to field results:
  - Flow → 6% (down from 9%)
  - Pressure → 3-6 % (down from 10-12%)
  - Tank cycle → 3% (down from 17%)
  - Chlorine residuals →24 % average error (down from 28%)

Pressure, Tank and Flow Calibration





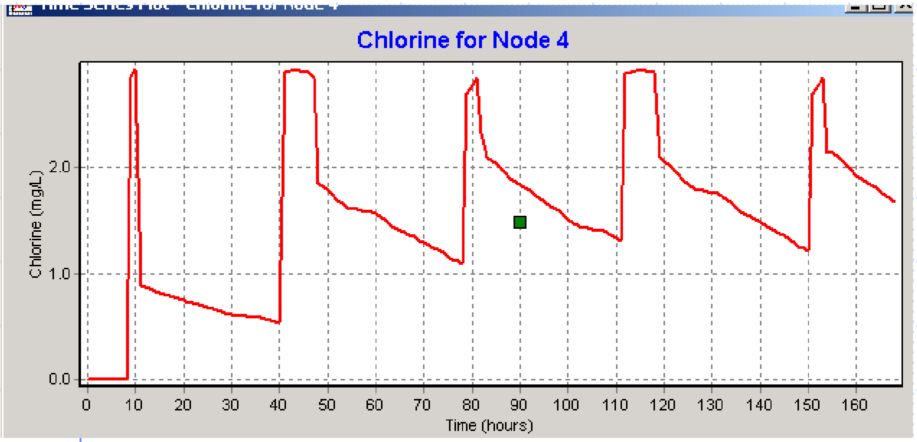


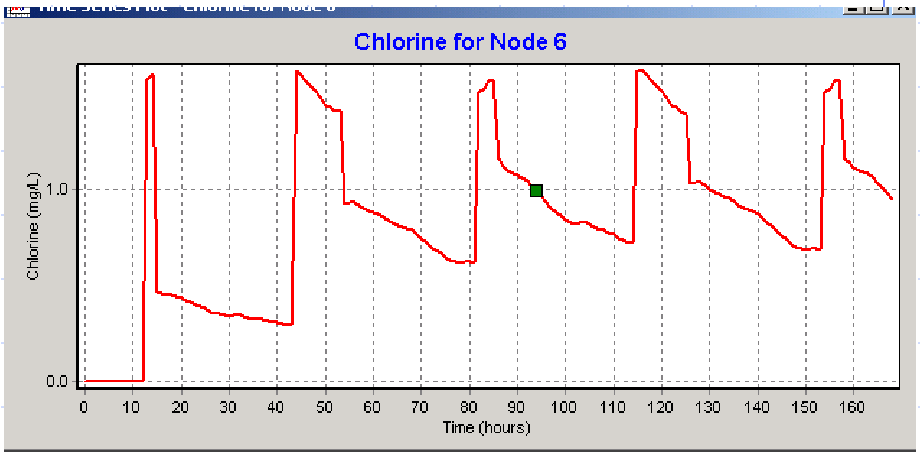
Correlation Between Means: 1.000

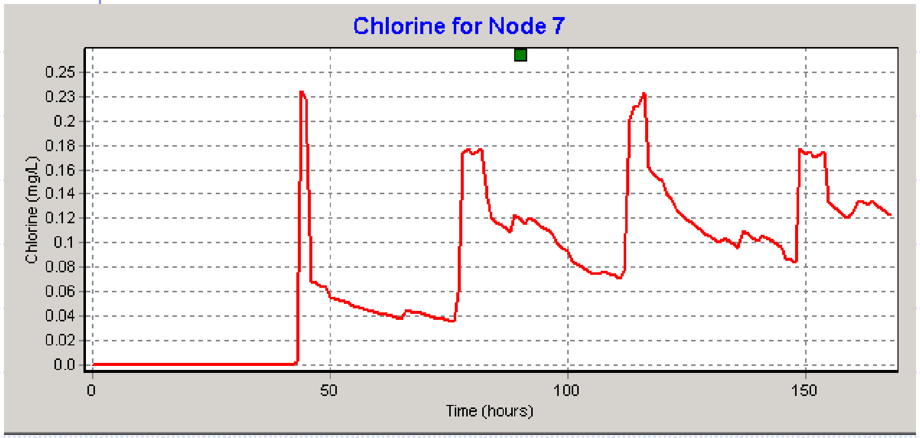
Tank is on an observed 36 hour filling/ emptying cycle.

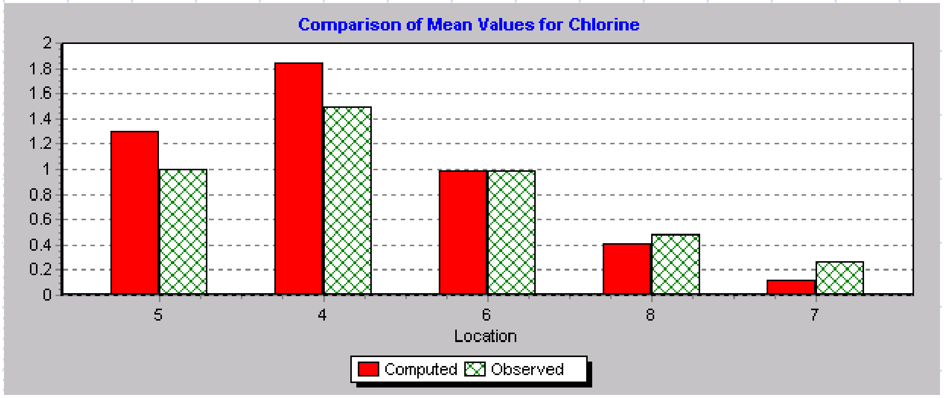
Instantaneous field flow reading of 7.15 L/s matched by model.

Chlorine Calibration





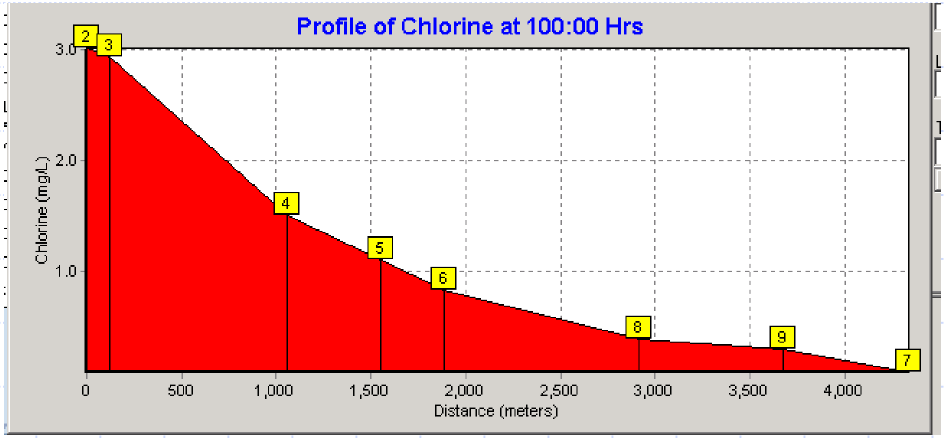


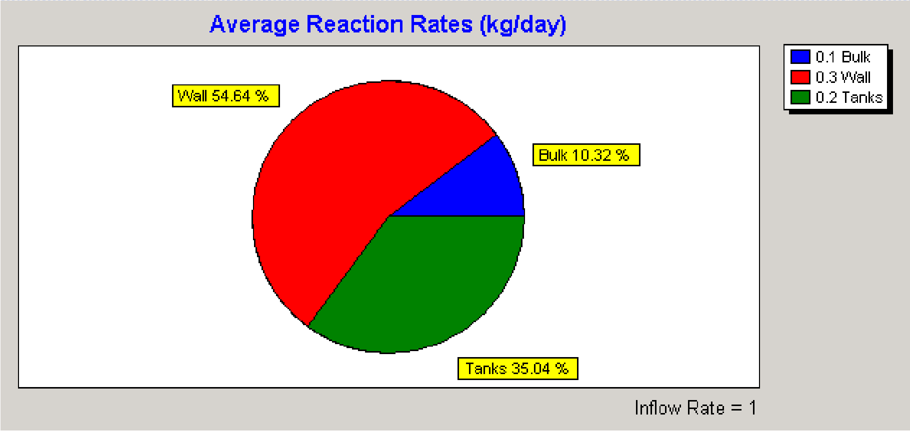


Correlation Between Means: 0.988

Problems with the Brighton Distribution System

- By establishing a calibrated baseline model, we were able to identify problems with how the system operates normally





Problems with the Brighton Distribution System

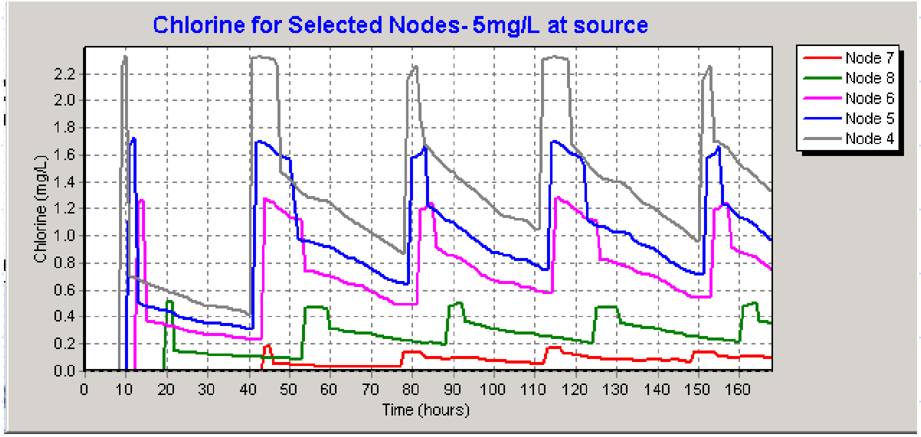
- Raw source water quality- high colour and DOC are precursors for THM formation
- Excess chlorine dosage at the beginning of the system (over 6 mg/L) in order to achieve an adequate residual at the end
- Overcapacity in the system
- Length of the distribution system- over 3 km
- Rapid chlorine decay at beginning of the system
- Excessive chlorine decay throughout the distribution system and in the tank
- Excessive water age in the tank (40 hrs) and distribution system (75 hrs)

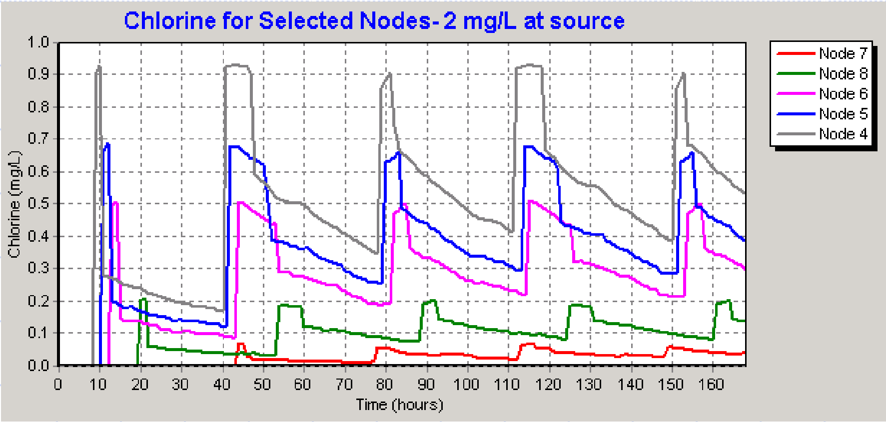
Possible Solutions to Problems with Brighton Distribution System

- Changing chlorine dosage at the beginning of the system
- Adding a chlorine booster
- Changing tank operation

Changing Chlorine Dosage

- To maintain an adequate chlorine residual at the end of the system chlorine dose must be kept above 5 mg/L
- To maintain a residual of 0.3 mg/L at the first point of use, chlorine dose must be kept above 2 mg/L.



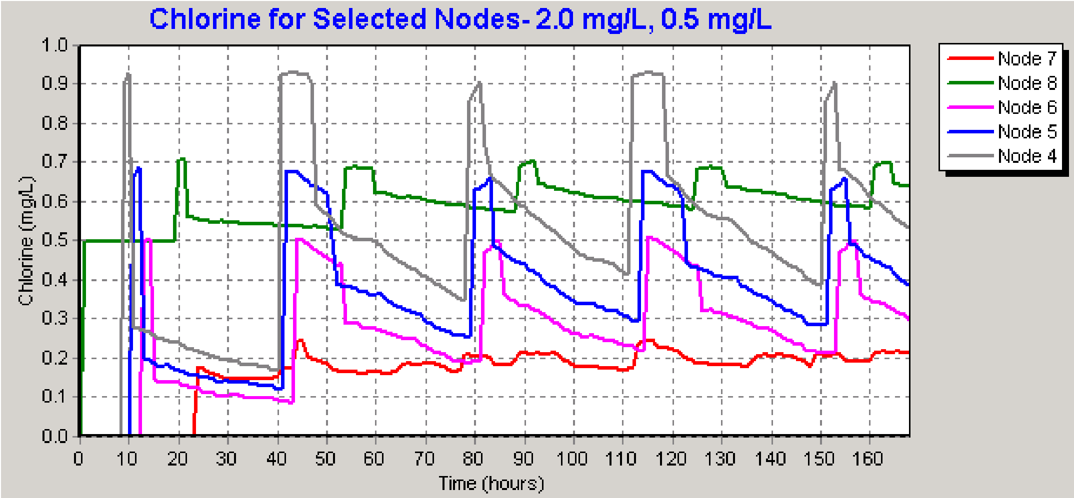


Adding a Chlorine Booster

- With a source chlorine dose of 2mg/L, the minimum chlorine residual at node 8 is 0.08 mg/L
- node 8 is the best site for our chlorine booster station

Adding a Chlorine Booster

- A source dose of 2 mg/L and booster dose of 0.5 mg/L at node 8 provides similarly adequate system results to just having a source dose of 5 mg/L.



Changing Tank Operation

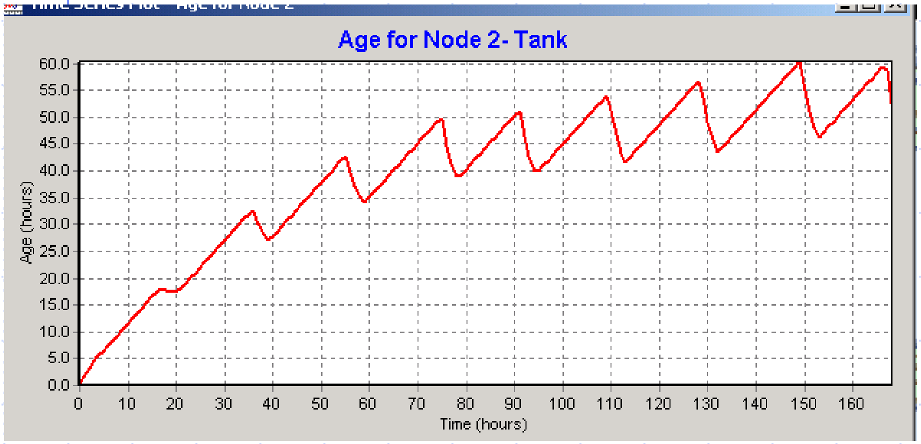
- At one-quarter full, the pump is supposed to turn on and at three-quarters full, the pump is supposed to turn off, actively utilizing 50% of the tank volume
- Water quality degrades as a result of long residence times in storage tanks
  - chlorine residuals decrease
  - (DBPs) such as THMs increase
- Average water age in the Brighton tank is approximately 40 hrs

Changing Tank Operation

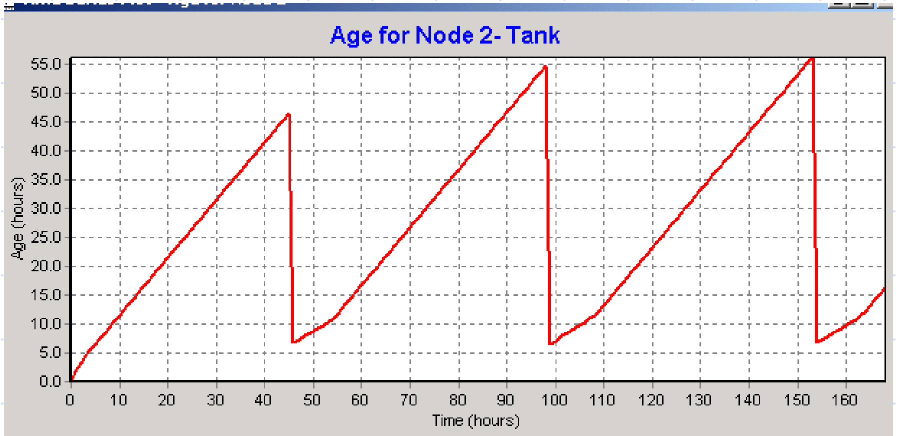
Tank Volume Used (%)	Water Age in Tank (hrs)
10	57
25	53
50	40
75	32

- The best option for reducing water age, and therefore THM formation potential in the Brighton system, is to increase the active volume of the tank.

Changing Tank Operation



Active Tank Volume = 25%



Active Tank Volume = 75%

Summary of Solution Options

Scenario Description	Effectiveness	Cost Reductions	Cost Increases	Comments
Cl dose of 5 mg/L or greater	Cl requirements met	Can use slightly less Cl than currently using		THM formation still high
Source Cl at 2 mg/L, booster Cl at 0.5 mg/L at node 8	Cl requirements met	Use half as much Cl	Booster Cl system	The use of less Cl will reduce THM formation
75% active tank volume	Cl requirements met and water age in tank reduced	Less pump usage and less Cl usage		Reduces water age in tank, reducing potential THM formation

Modeling Case Study: Ferryland

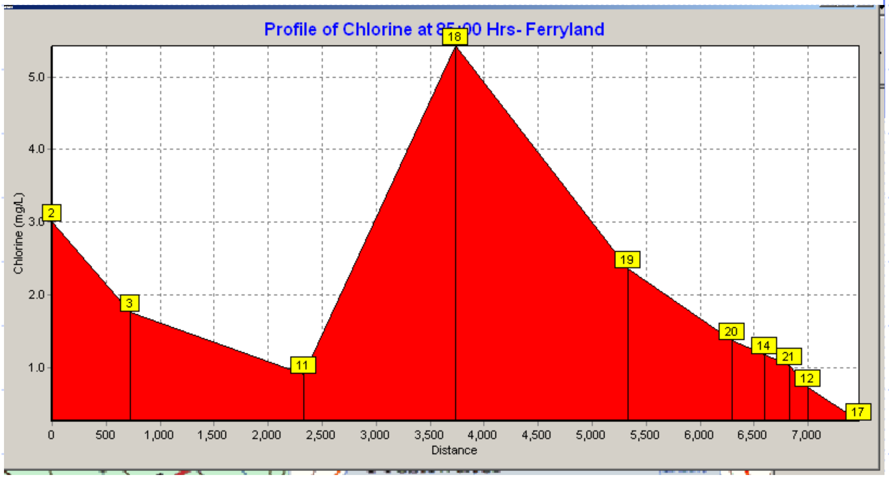
- Region:
  - Eastern
- System Size:
  - Mid
- Configuration/Problem:
  - Long linear system

Problems with the Ferryland Distribution System

- Raw source water quality- high colour and DOC
- Inadequate chlorine dosage
- Length of system- over 6 km
- Rapid chlorine decay
- Overcapacity in system

Possible Solutions to Problems with Ferryland Distribution System

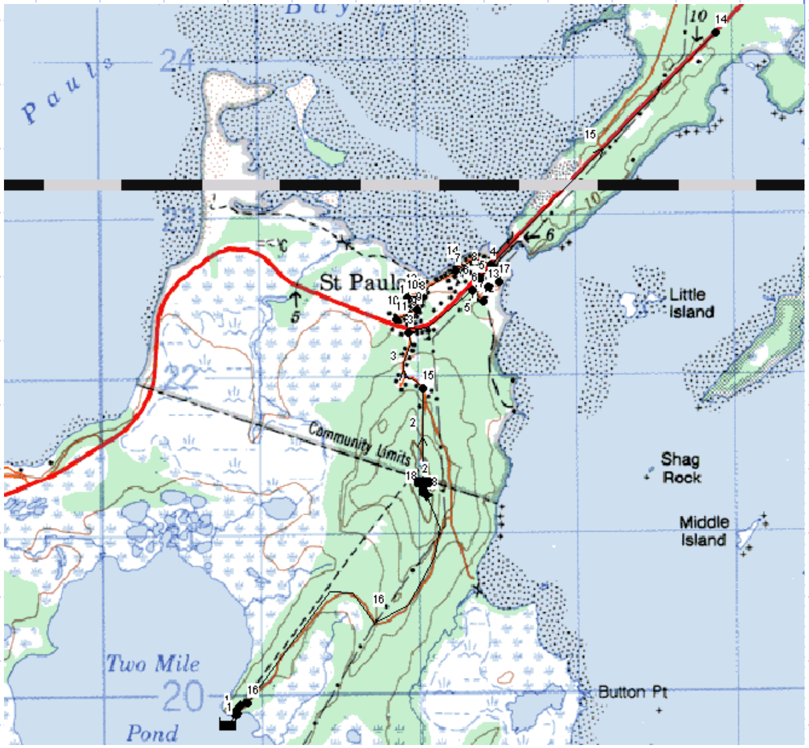
- Changing chlorine dosage at the beginning of the system
- Adding a chlorine booster
- Reducing pipe diameter throughout the system



- scenario 2 meets all stated objectives, uses less chlorine, reduces THM formation potential

Modeling Case Study: St. Paul’s

- Region:
  - Western
- System Size:
  - Small
- Configuration/Problem:
  - Long linear system
- Secondary Problem:
  - Problematic Tank

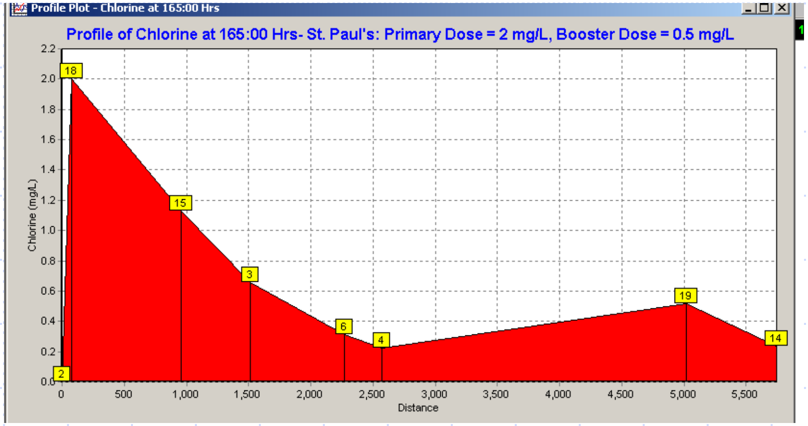


Problems with the St. Paul's Distribution System

- Raw source water quality- high colour, DOC, turbidity
- Inadequate chlorine dosage to achieve end of system Cl residuals
- High chlorine dose (26 mg/L)
- Wide variation in chlorine residuals due to tank filling cycle
- Excessive chlorine decay in tank
- Length of system- over 6 km
- Rapid decay of chlorine in first half of system
- Overcapacity in system
- Lack of demand at system end
- Large inactive volume of water in tank

Possible Solutions to Problems with St. Paul's Distribution System

- Changing chlorine dosage at the beginning of the system
- Adding a chlorine booster
- Locating primary chlorination system at outlet of tank
- Locating primary chlorination system at outlet of tank with chlorine booster
- Changing tank operation



- Scenarios 2, 4 and 5 meet objectives

Practical Application of Models

- To assist smaller communities with limited resources in managing their water distribution systems
- To identify problems and possible solutions
- To take recommendations from models to make improvements to individual systems
- To reduce THMs
- To develop generic Chlorine Best Management Practices (BMPs) to help maintain effective chlorine residuals in typical problem distribution systems and to help reduce Disinfection-by-Products (DBPs)

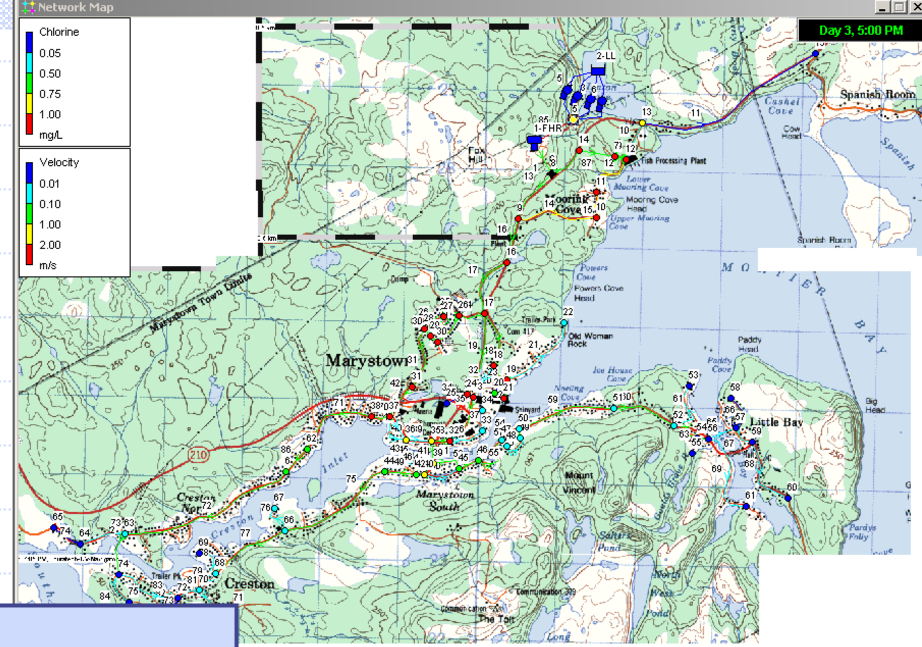
Conclusions

- THM control through CDM is a workable option when conventional water treatment is not a viable and sustainable option
- Without source water treatment, only factors controllable are chlorine and contact time
- CDM is the most cost effective option to help deal with THMs in smaller systems
- CDM would be our first option for smaller communities with high THMs
- If CDM is not effective other conventional options will have to be considered

Path Forward

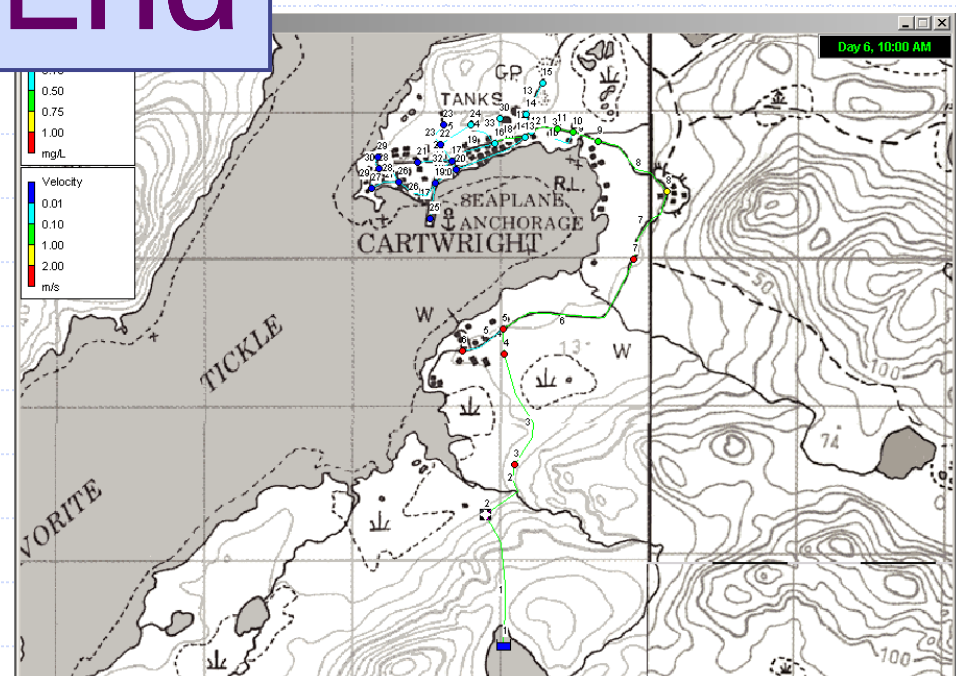
- Model THM growth
- Complete technical report on distribution system modeling of 7 selected communities
- Use results from models to develop generic Chlorine Demand Management (CDM) Guidelines
- Share information with Dept of Municipal Affaires and Communities
- Implement CDM guidelines
- Continue with site specific modeling where generic guidelines not applicable


Network Map
Day 5, 2:00 PM
Chlorine
0.20
0.40
0.60
0.80
mg/L
Velocity
0.01
0.10
1.00
2.00
m/s
lebar unit = 0.5 km
and 01-N-02, 2/1/2005, 2:00:48 PM, Touratech-QV-Navigator
Deep Cove
Calvert
Foul Cove
Broad Cove
Lance Cove
Stone Islands
Deep Cove Pond
Scoggins Head
Bay
Freshwater Cove
Goose Island
Brimstone Hill
Sunny Hill
Cornfield
The Grove
Coldeast Point
Battery
Fox Hill
The Gaze
Ferryland
Forge Hill
RCMP
Museum
Fish Packing Plant
Wrens Island
Costellos Island
Ship Island
Bois Island
Ferryland
Harbour
Sandy Cove
Hills
Riverhead Pond
Quarry Pond
River
Ball Park
Backside
The Downs
Freshwater
Medical


Network Map
Day 3, 5:00 PM
Chlorine
0.05
0.50
0.75
1.00
mg/L
Velocity
0.01
0.10
1.00
2.00
m/s
Spanish Room
Cashel Cove
Fish Processing Plant
Marystown
Little Bay
Marystown South
Creston
Mount Vincent
Shipyard

The End


Network Map
Chlorine
0.25
0.50
0.75
1.00
mg/L
Velocity
0.01
0.10
1.00
2.00
m/s
Municipal Hall
Burlington
Burlington Community Limits
Northwest
Arm
Winterhouse Cove
Rix I
Rix C
Rix Pt
Young Cove
413


Day 6, 10:00 AM
0.50
0.75
1.00
mg/L
Velocity
0.01
0.10
1.00
2.00
m/s
TANKS
SEAPLANE ANCHORAGE
CARTWRIGHT
TICKLE