Influence of Land-Use and Precipitation on Regional Hydrology and Public Health: A Feasibility Study

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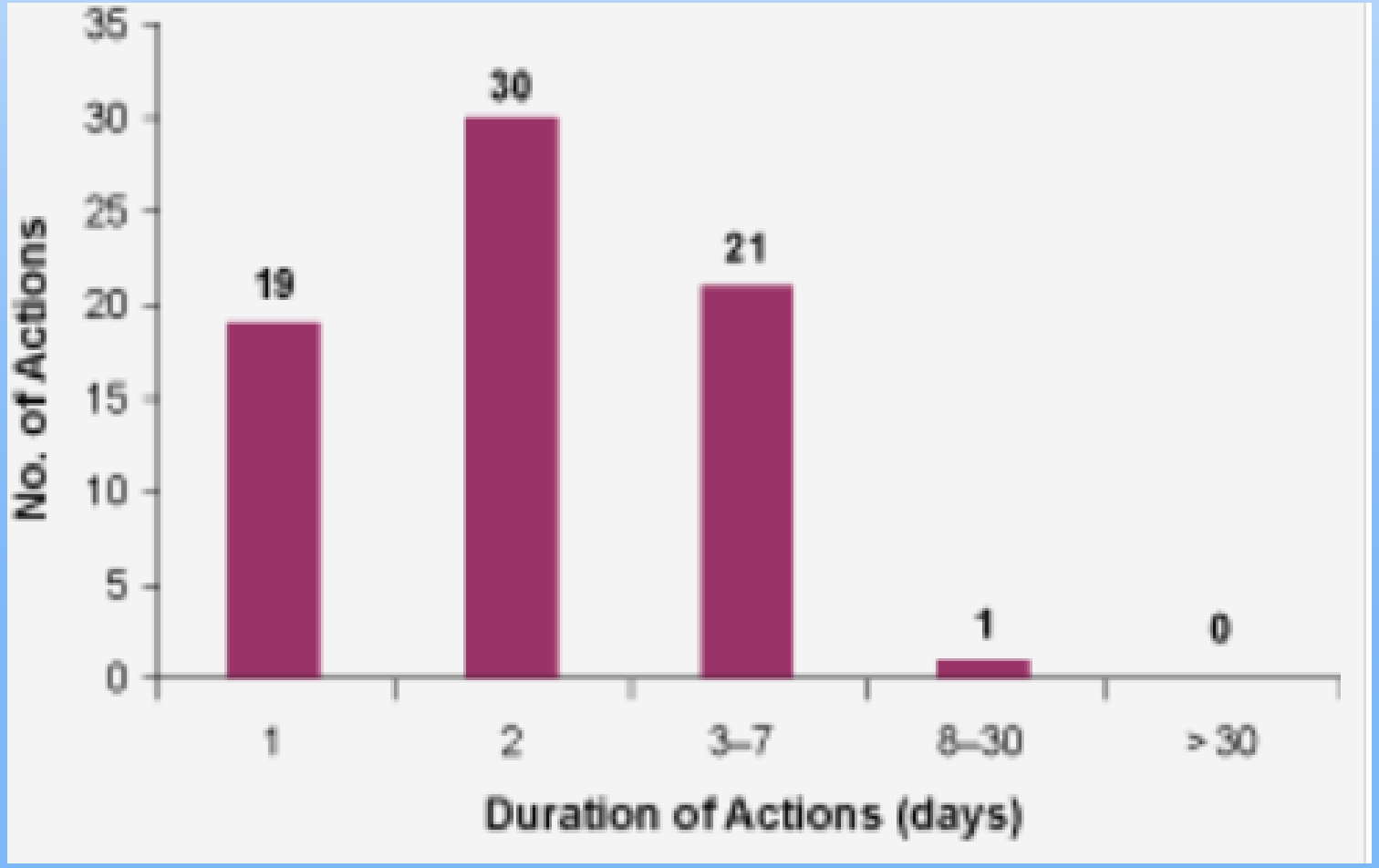
Backdrop

- Heavy rainfall events are more likely to lead to a decline in microbiological quality of inland and marine recreational waters and drinking water supplies as a result of heavy runoff
- These pollutants travel downstream with river flow to the coastal ocean and adjacent waters, which results in Reduced Water Quality Events (RWQEs).

Backdrop

- Beach Actions in Maine 2010



Backdrop

- Maine Beach Actions

Table 2. Beach notification actions, 2008–2010.

Year	2008	2009	2010
Number of monitored beaches	60	60	59
Number of beaches affected by notification actions	22	36	29
Percentage of beaches affected by notification actions	37%	60%	49%
Percentage of beach days affected by notification actions	3%	4%	4%

Backdrop

- Nationwide

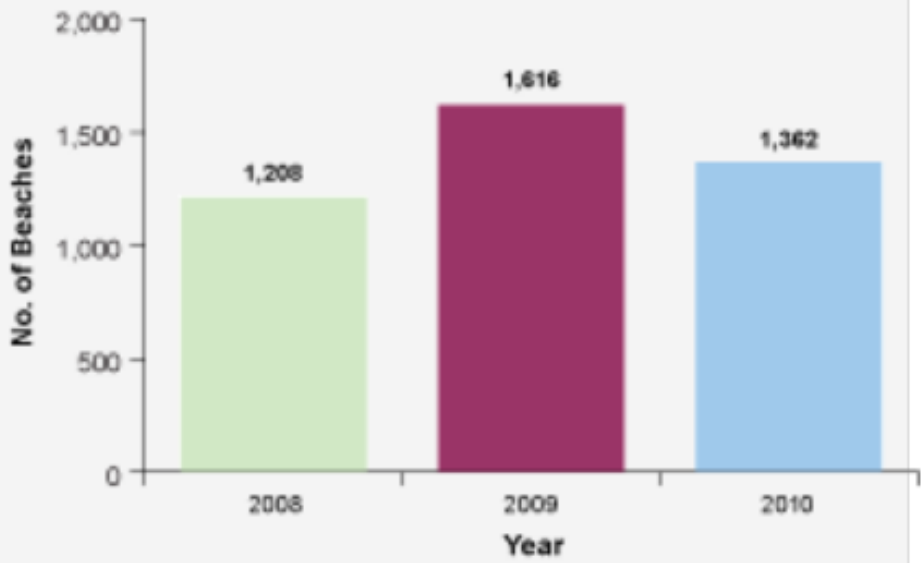


Figure 2: Number of beaches with notification actions from 2008 to 2010.

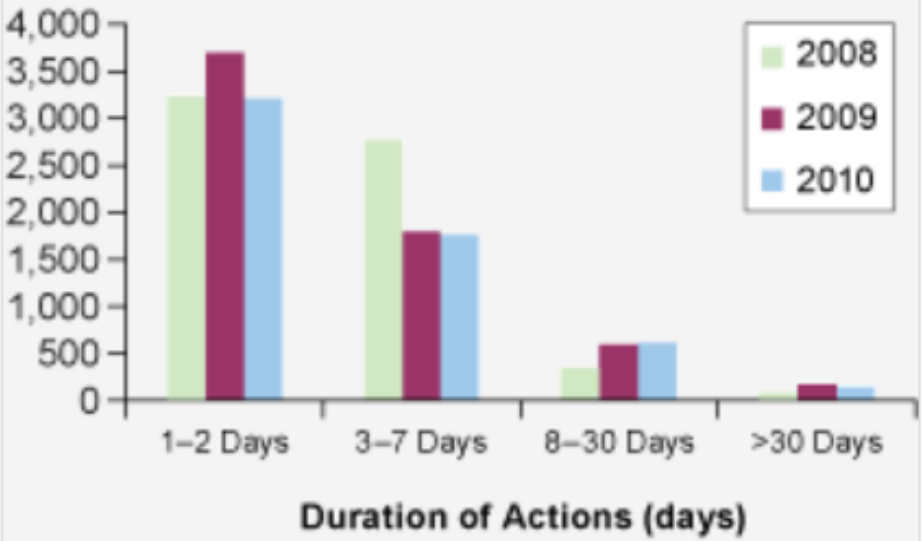


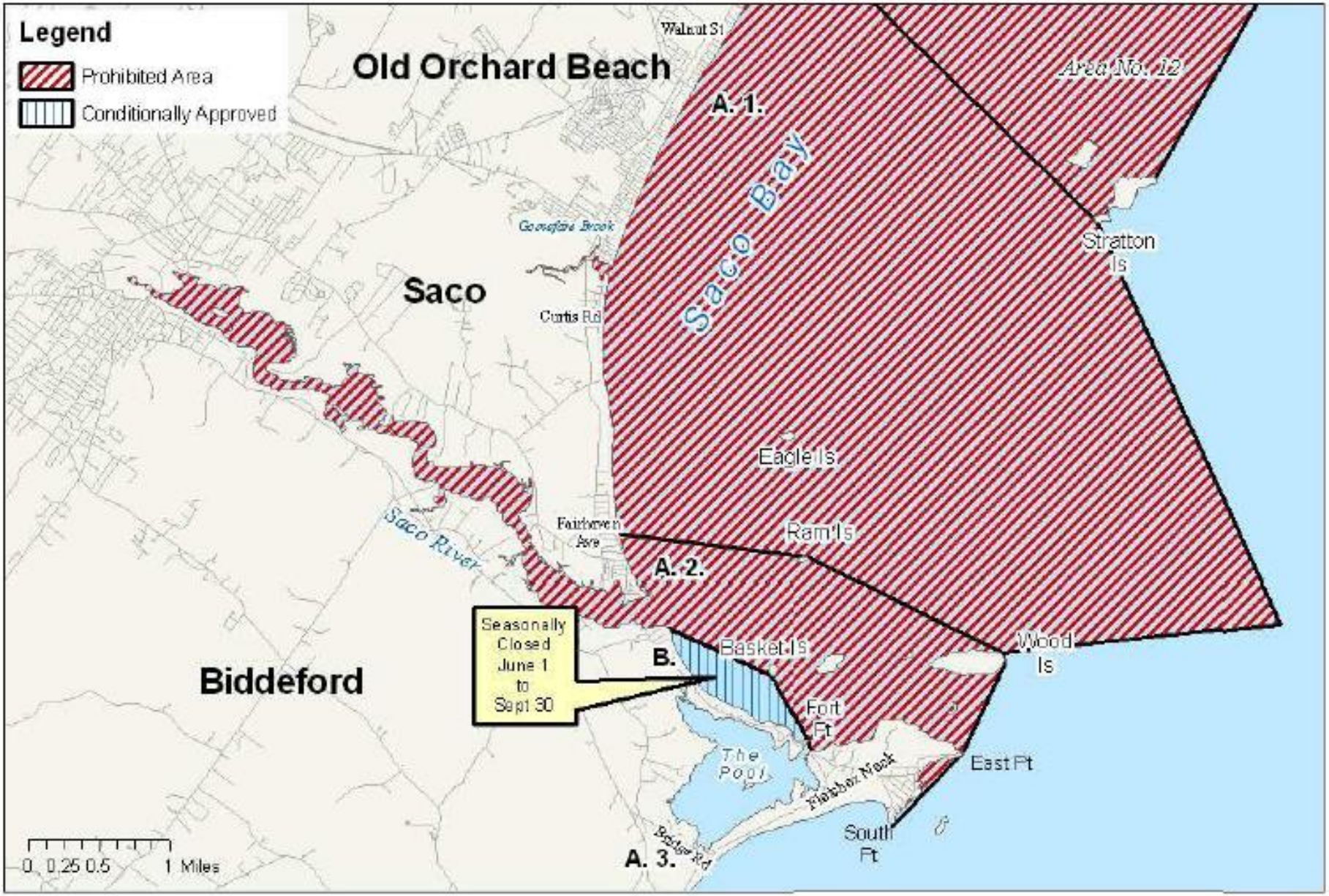
Figure 3: Duration of beach notification actions from 2008 to 2010.

Maine Department of Marine Resources

Pollution Area No. 10

Saco River and Saco Bay (Biddeford, Saco, Old Orchard Beach)

09.29.09

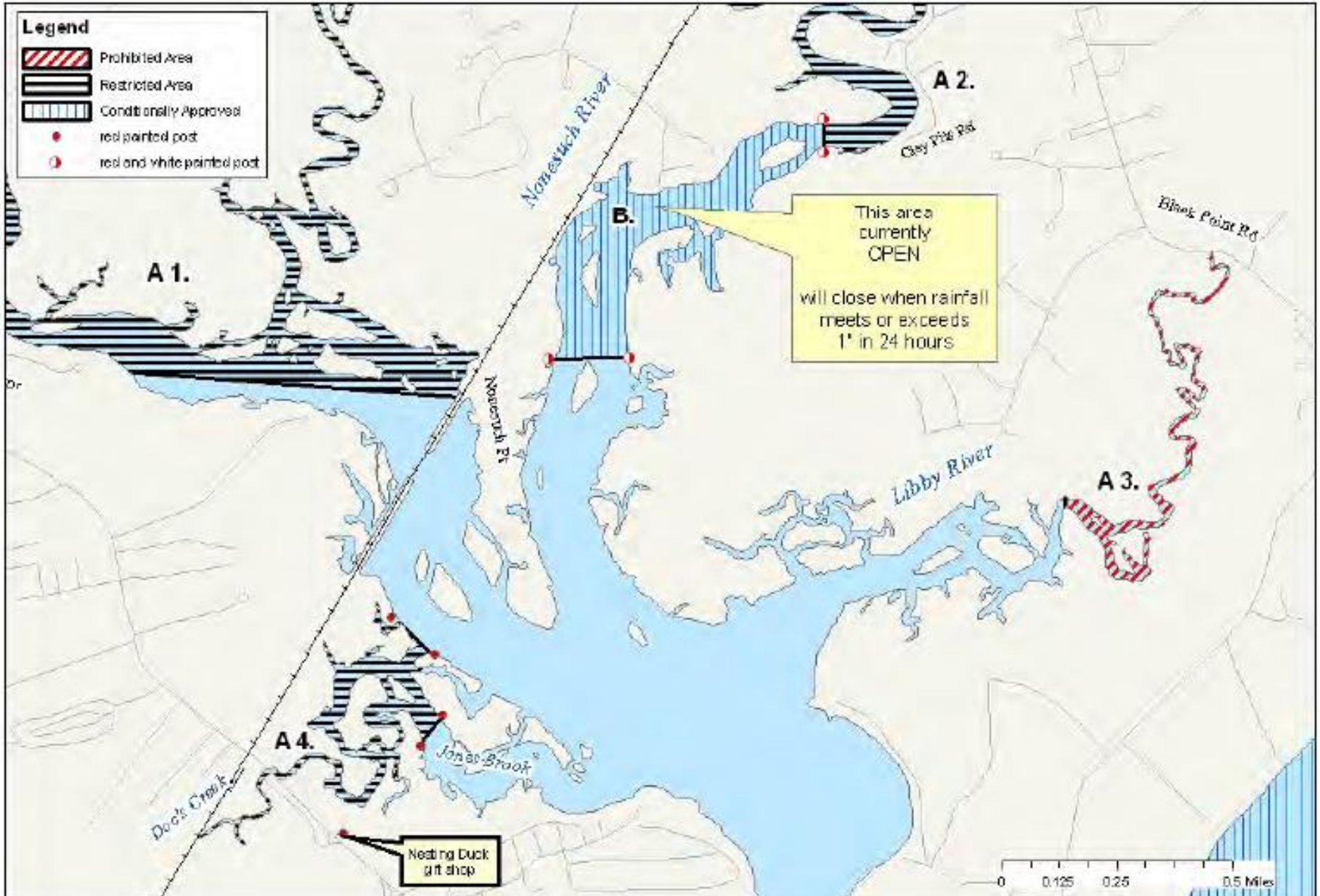


Maine Department of Marine Resources

Pollution Area No. 11

Scarborough River

9/12/11



Decision Making Activities

- **States need a low cost, rapid method for estimating water quality to protect human health.**
  - A number of states are unable to quickly test for harmful bacteria in coastal waters
  - States are unable to warn their citizens of harmful water quality.

Decision Making Activities

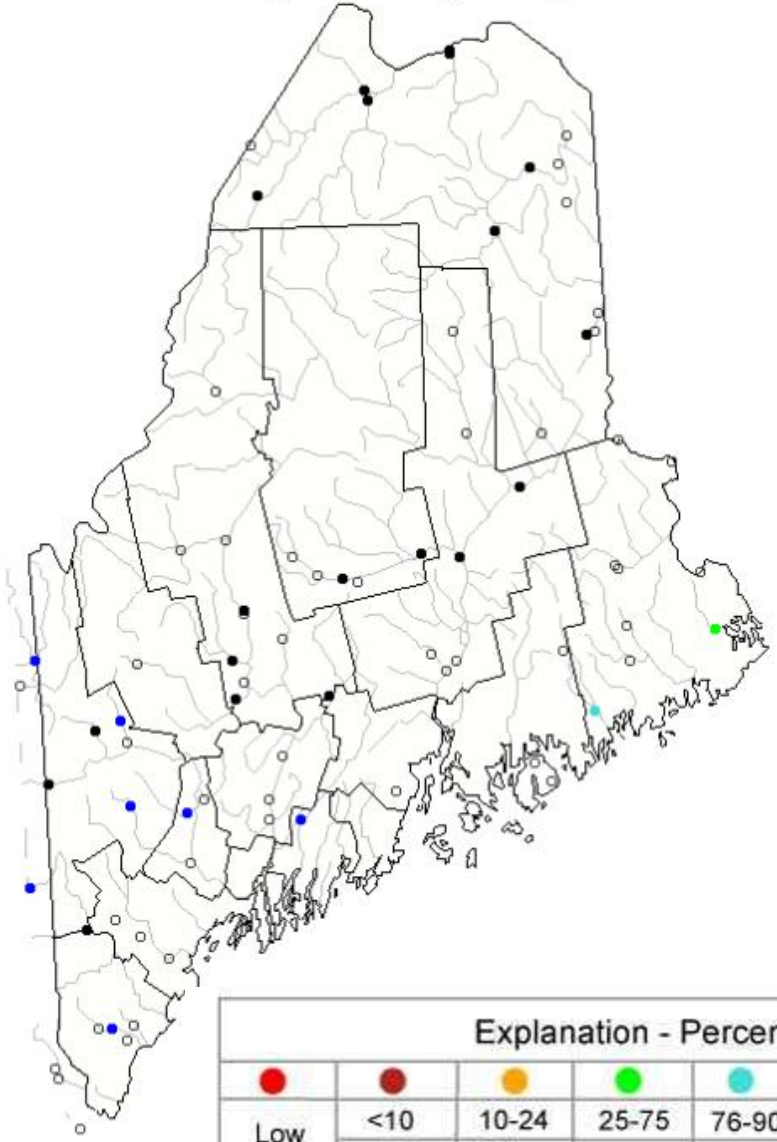
- Current Dept of Marine Resources management strategy
  - Each river is assigned a discharge that will result in a predicted reduced water quality event.
  - When river discharge exceeds this value, shellfish beds and recreational areas are closed and testing of the region begins.

Decision Making Activities

- Reliance on Discharge Rates from USGS gaging stations
- Close swimming areas and shellfish beds when measured discharge exceeds a given value

Real-Time Discharge, in cfs

Thursday, September 08, 2011 16:30ET



Explanation - Percentile classes							
Low	<10	10-24	25-75	76-90	>90	High	Not-ranked
	Much below normal	Below normal	Normal	Above normal	Much above normal		

USGS

Temp | Cond | pH | D.O. | Turb | Nitrate | Disch

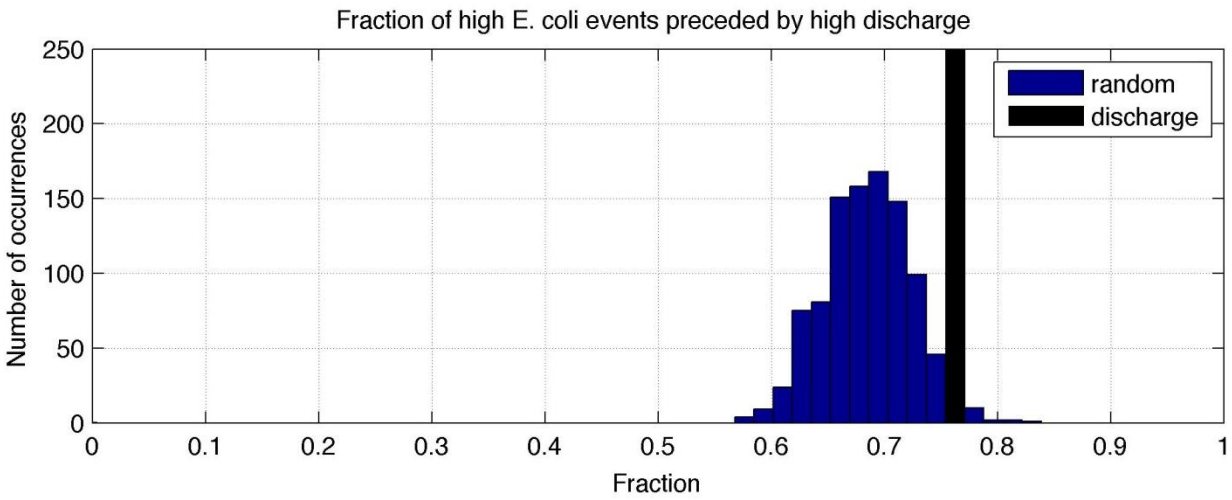
The Issue

- Current methods of forecasting unhealthy levels of contaminants such as coliform bacteria are unreliable
  - Result in too many false alarms
- Traditional microbiological techniques are too slow
  - *E. coli* testing takes 18 hours to complete, plus sampling time.

Does Maine's method work?

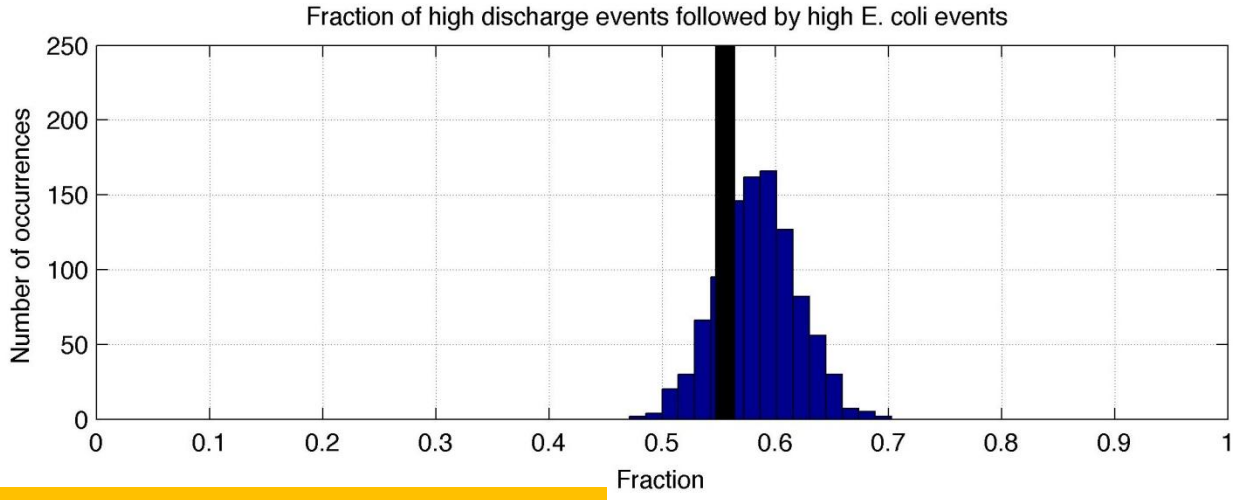
How often is a high *E. coli* event preceded by high discharge?

76.3% of the time



How often is high discharge followed by a high *E. coli* event?

55.6% of the time.



44.4% of the time, this method results in a false alarm!

Need for Change in SOP

- Resource managers need **accurate** prediction of reduced water quality
- Fisherman and local economies need **minimum number of false alarms**

New Methods

- We demonstrate that using near-real time satellite data is a statistically better predictor of contaminant levels
- These data are rapidly available, and are cost effective for managers

Proposed Solution

- We developed a method to use satellite-derived precipitation data that more accurately predicts when levels of contamination exceed statutory limits.

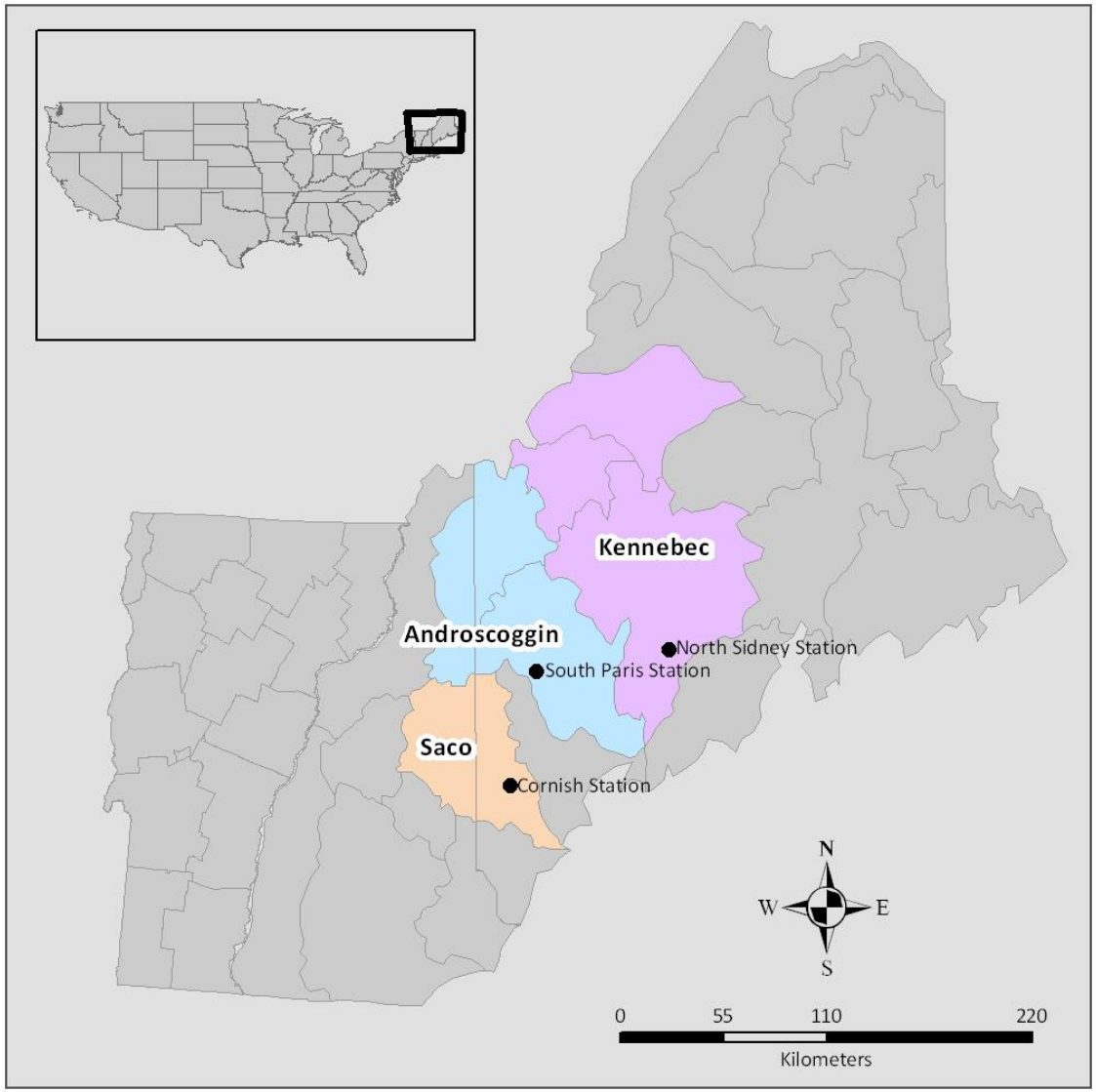
Project Hypotheses

- Coastal water quality is driven by precipitation, land use, and discharge from watersheds.
  - NASA products for land use and precipitation can be used to more accurately predict water quality.
- Projected climate and land use changes will lead to robust variations in precipitation and river discharge.
- Changes in discharge will lead to decreased water quality in the coastal environment.
  - Output from NASA climate models and land use prediction models will allow for accurate predictions of discharge and water quality

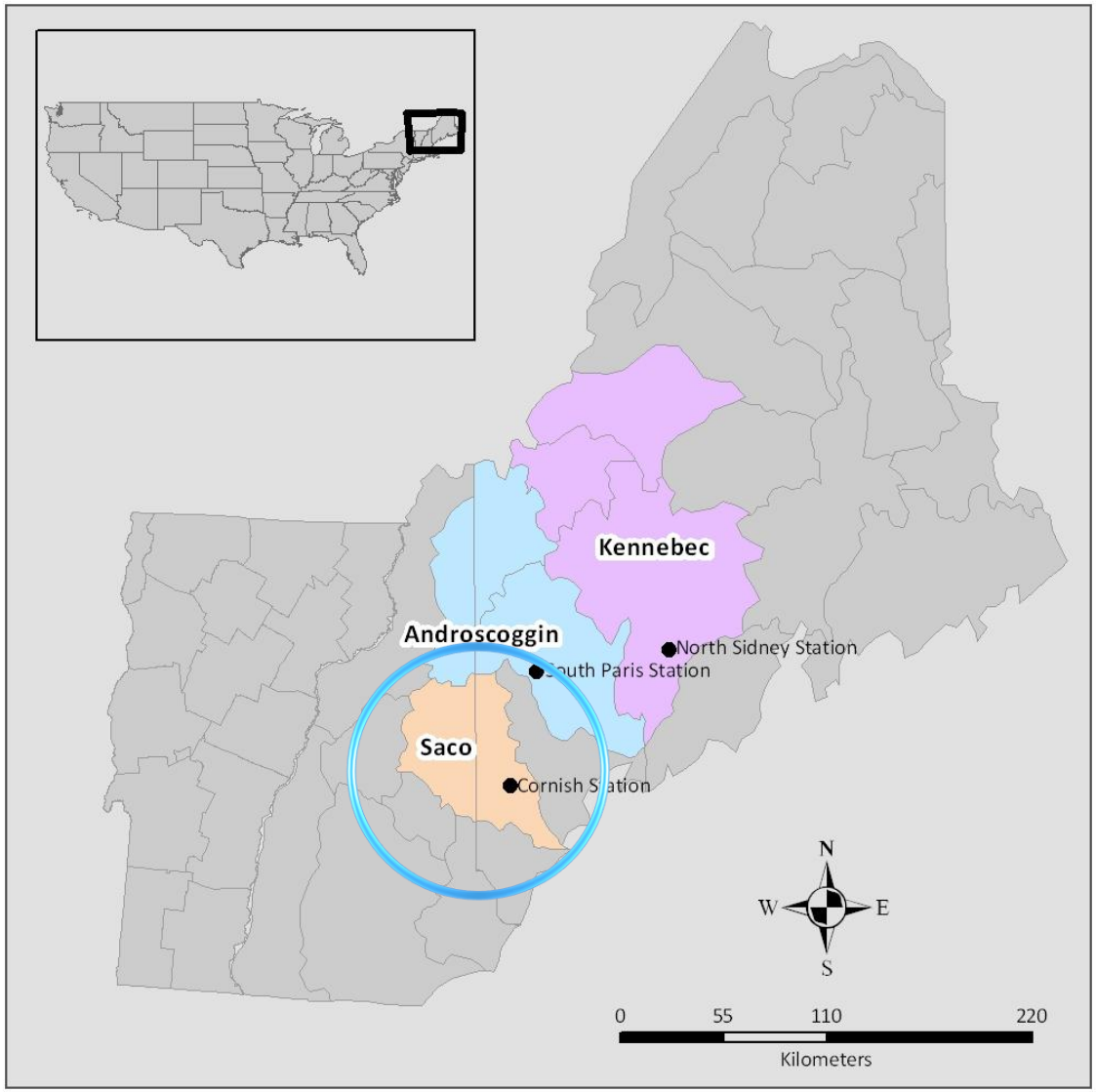
Tropical Rainfall Measuring Mission

- TRMM-based precipitation estimates
  - A series of quasi-global, near-real-time estimates
  - Estimates are on a 0.25 °x 0.25 ° grid over the latitude band 50 ° N-S
  - Available within about seven hours of observation time.
  - Three products are available:
    - A TRMM-calibrated merger of all available TMI, AMSR-E, SSM/I, and AMSU-B precipitation estimates (three-hourly accumulations);
    - a geosynchronous infrared estimate which is calibrated by the merged-microwave data (hourly estimates);
    - and a combination of the first two fields (three-hourly accumulations).

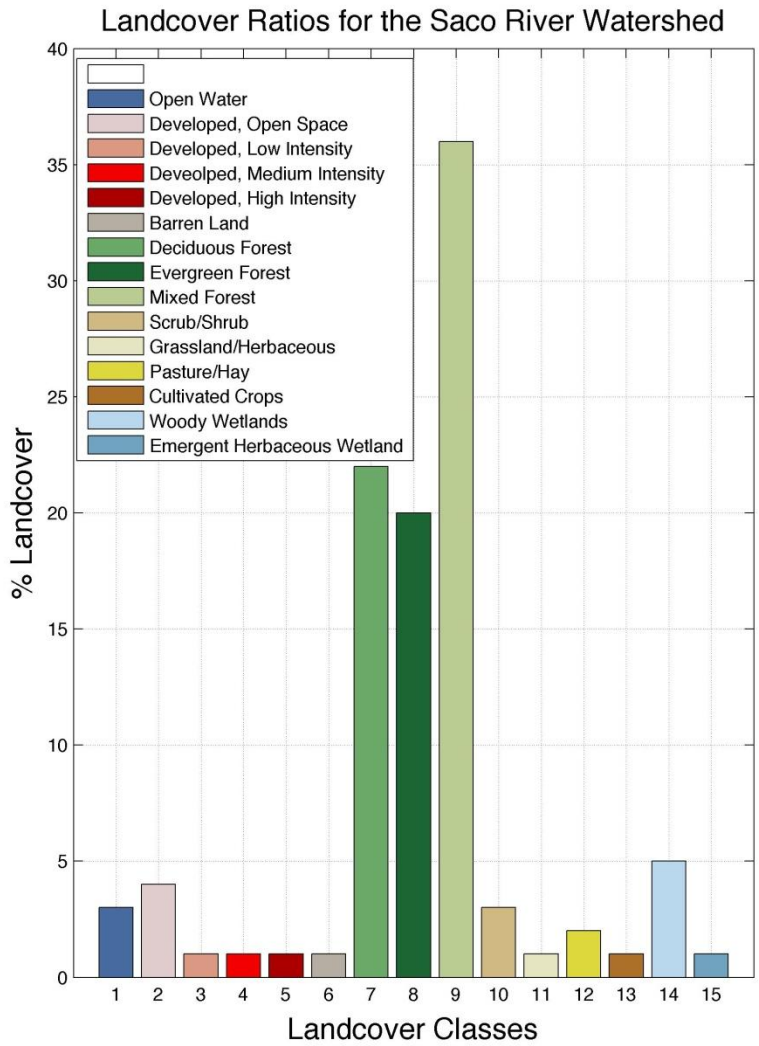
Test Case: Three watersheds in Maine

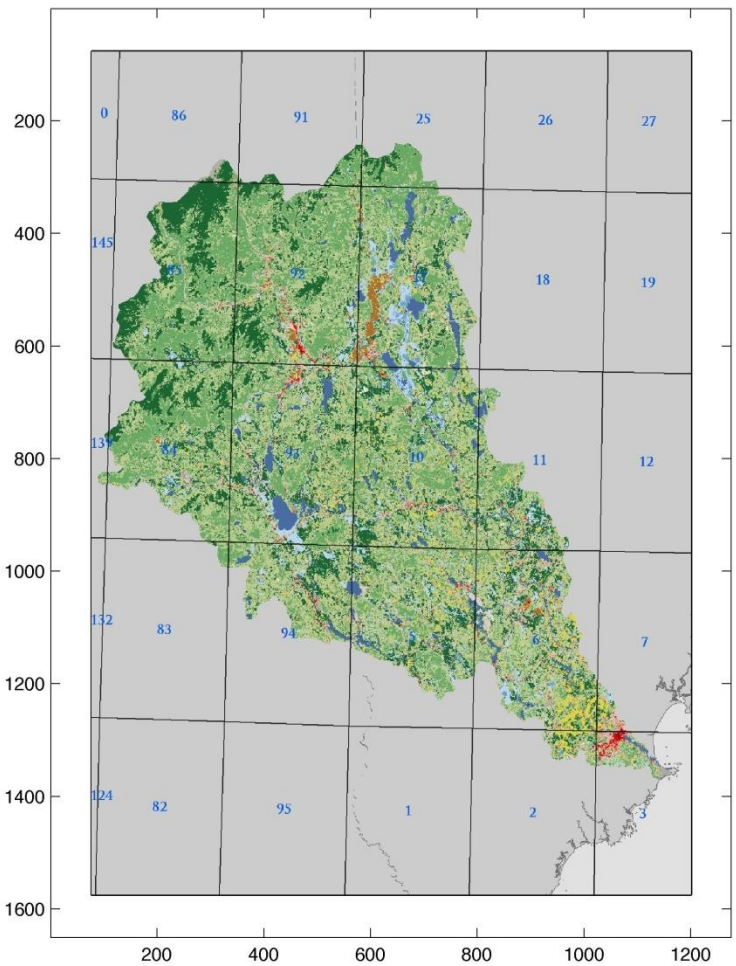


Test Case: Three watersheds in Maine



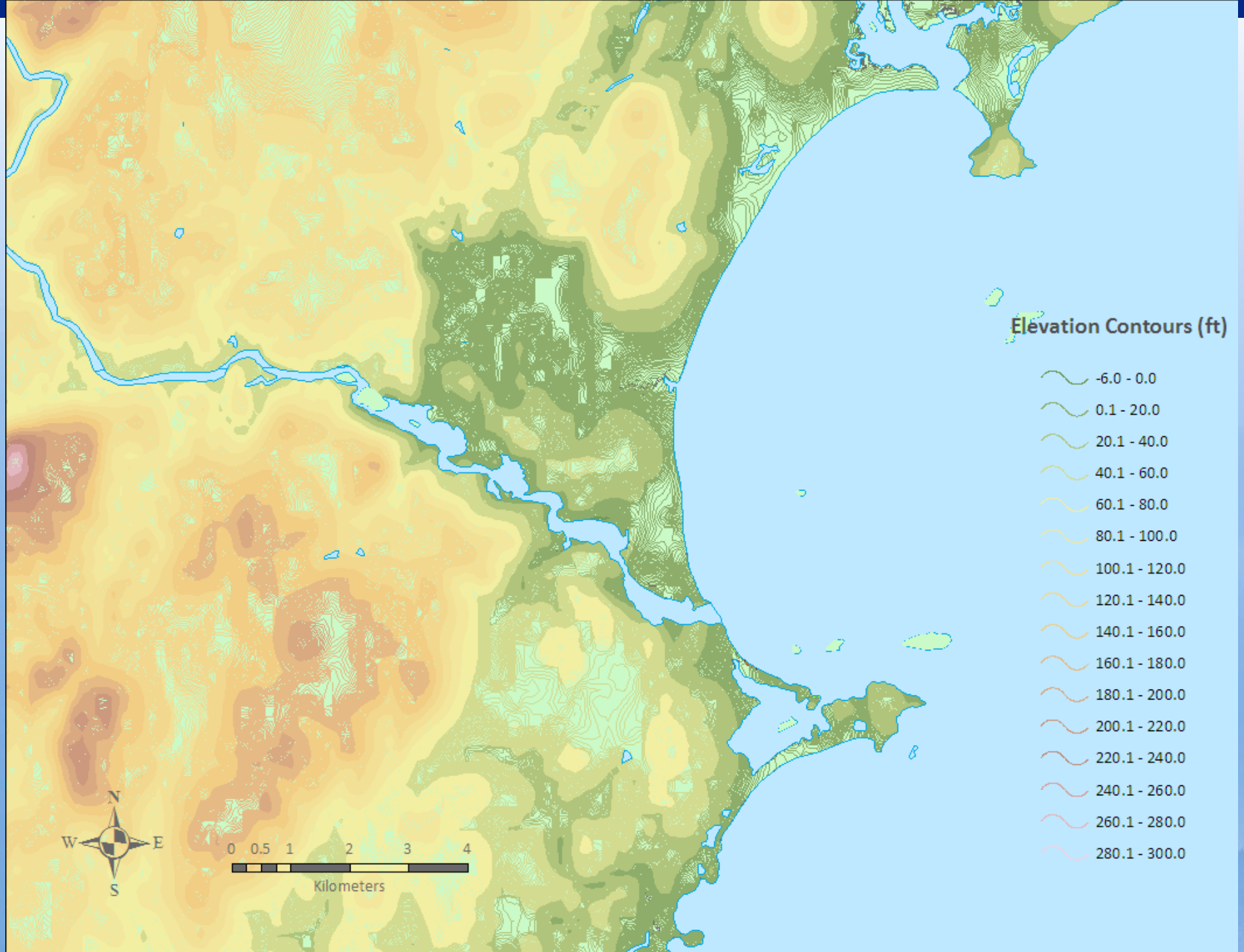
Land use in Saco River Watershed





4,410 km^2 area

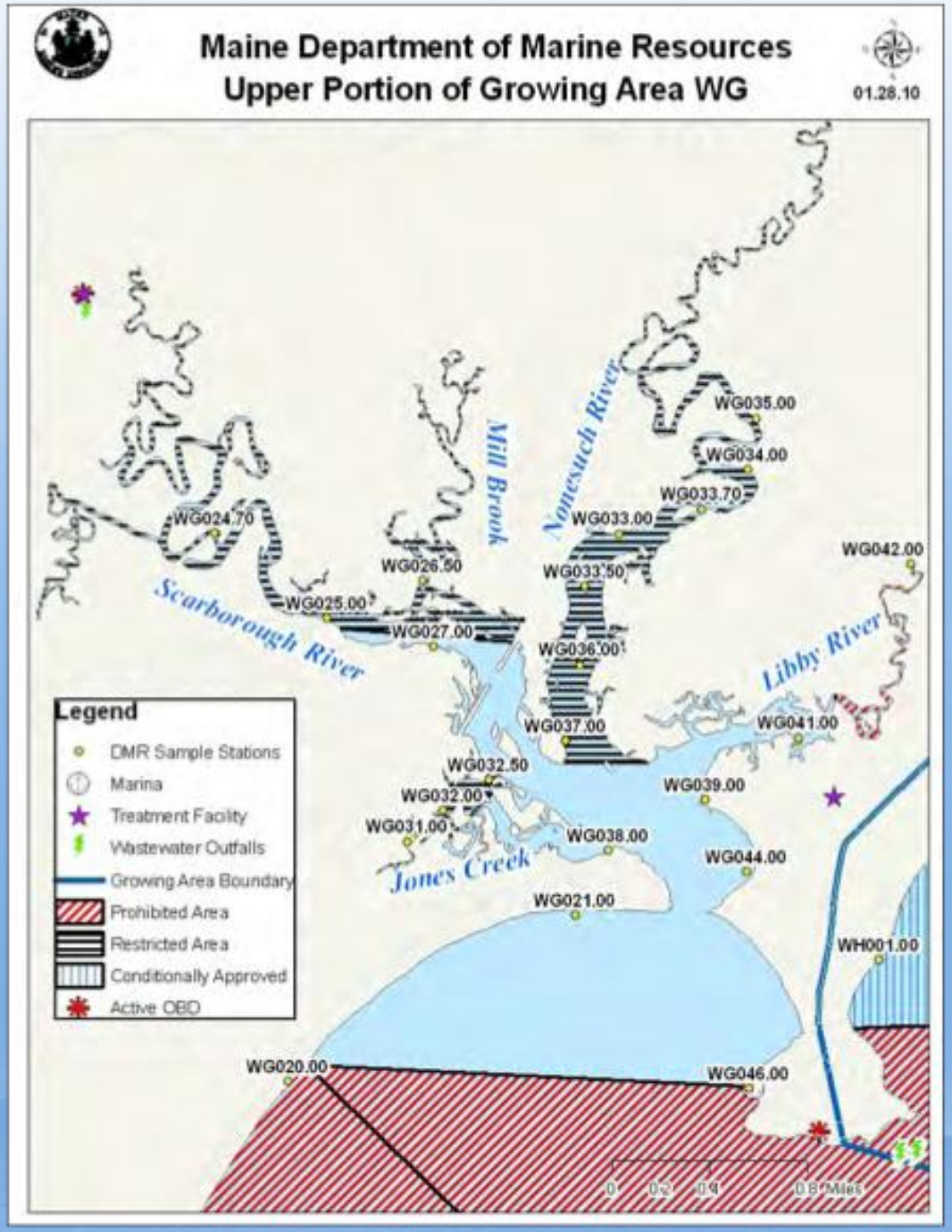
mean discharge = 90 m^3/s


Elevation Contours (ft)
-6.0 - 0.0
0.1 - 20.0
20.1 - 40.0
40.1 - 60.0
60.1 - 80.0
80.1 - 100.0
100.1 - 120.0
120.1 - 140.0
140.1 - 160.0
160.1 - 180.0
180.1 - 200.0
200.1 - 220.0
220.1 - 240.0
240.1 - 260.0
260.1 - 280.0
280.1 - 300.0
N
W
E
S
0 0.5 1 2 3 4
Kilometers

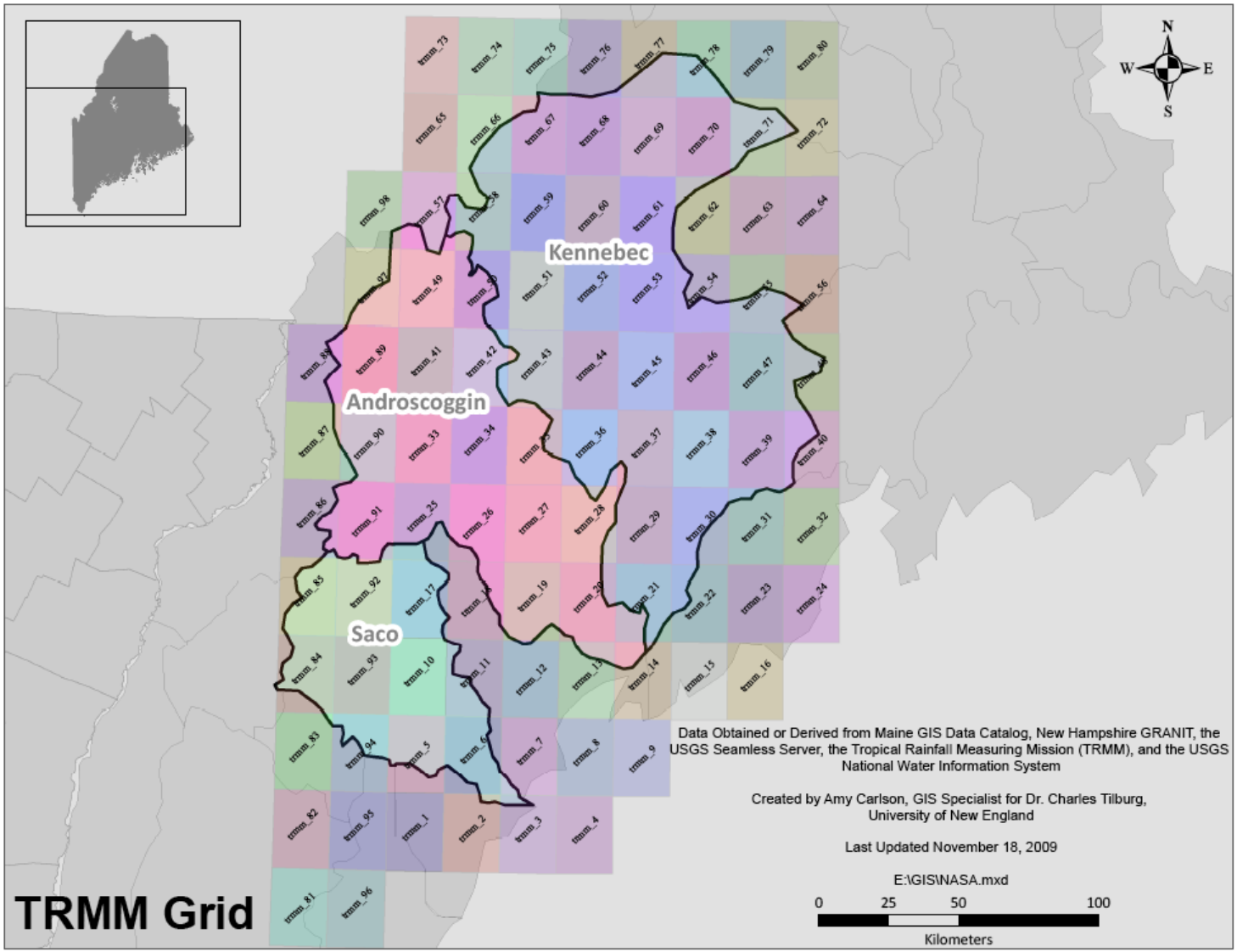
Growing Area WG

This map was updated August 28, 2008

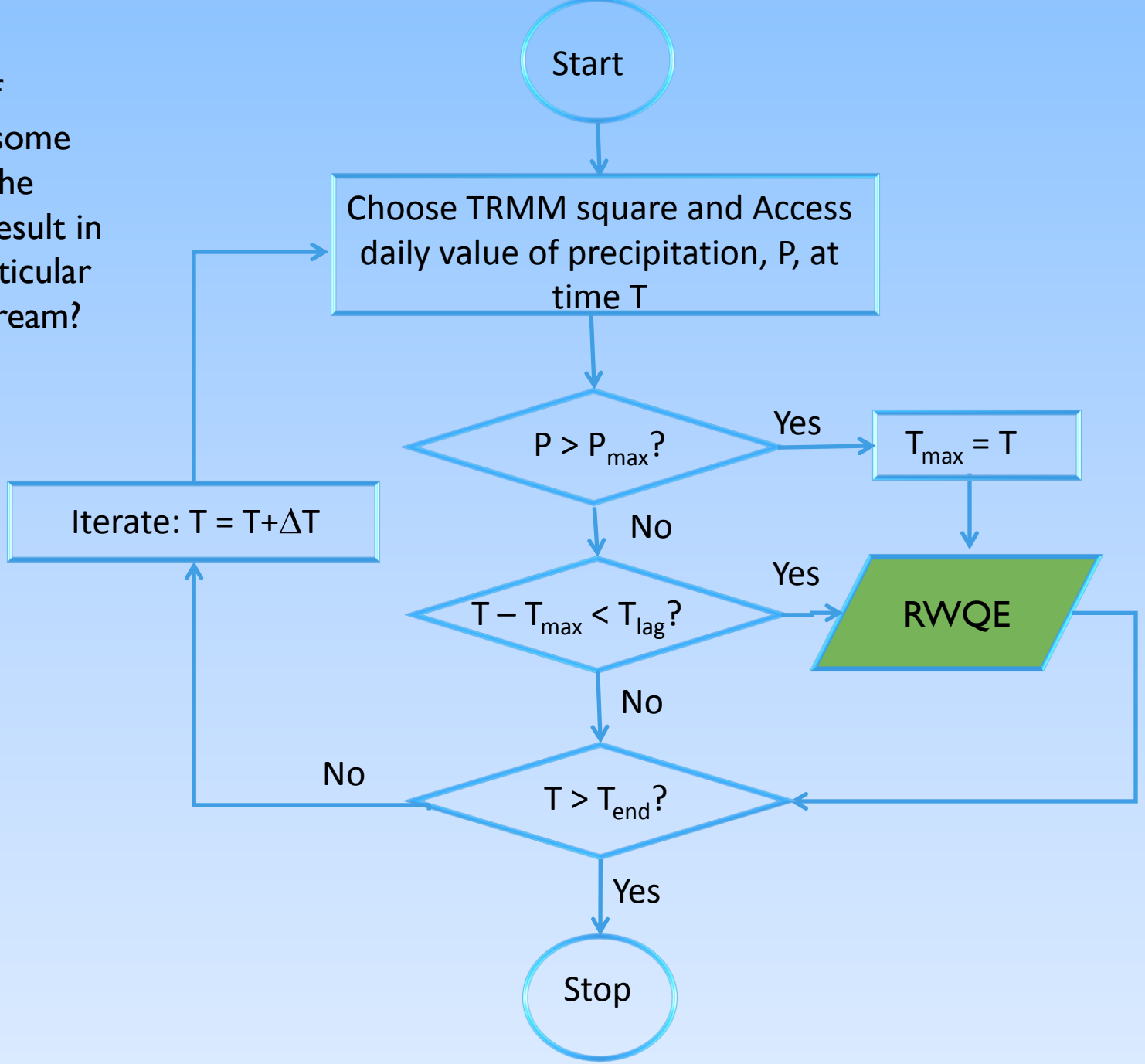
Figure 2. Growing Area WG, with Active Water Stations – Upper Portion



TRMM Grid Squares and Basins



What amount of precipitation at some location within the watershed will result in RWQEs at a particular location downstream?



Model Parameters

- To determine the optimum settings to predict RWQEs, we varied:
  - **P_{max}**, the amount of rainfall that defines a RWQE-producing precipitation event (range 2-20 mm/d).
  - The location of precipitation event (i.e. the TRMM square)
  - **T_{lag}**, the time period over which a particular precipitation event affects a region (range 3-7 d).

Comparison

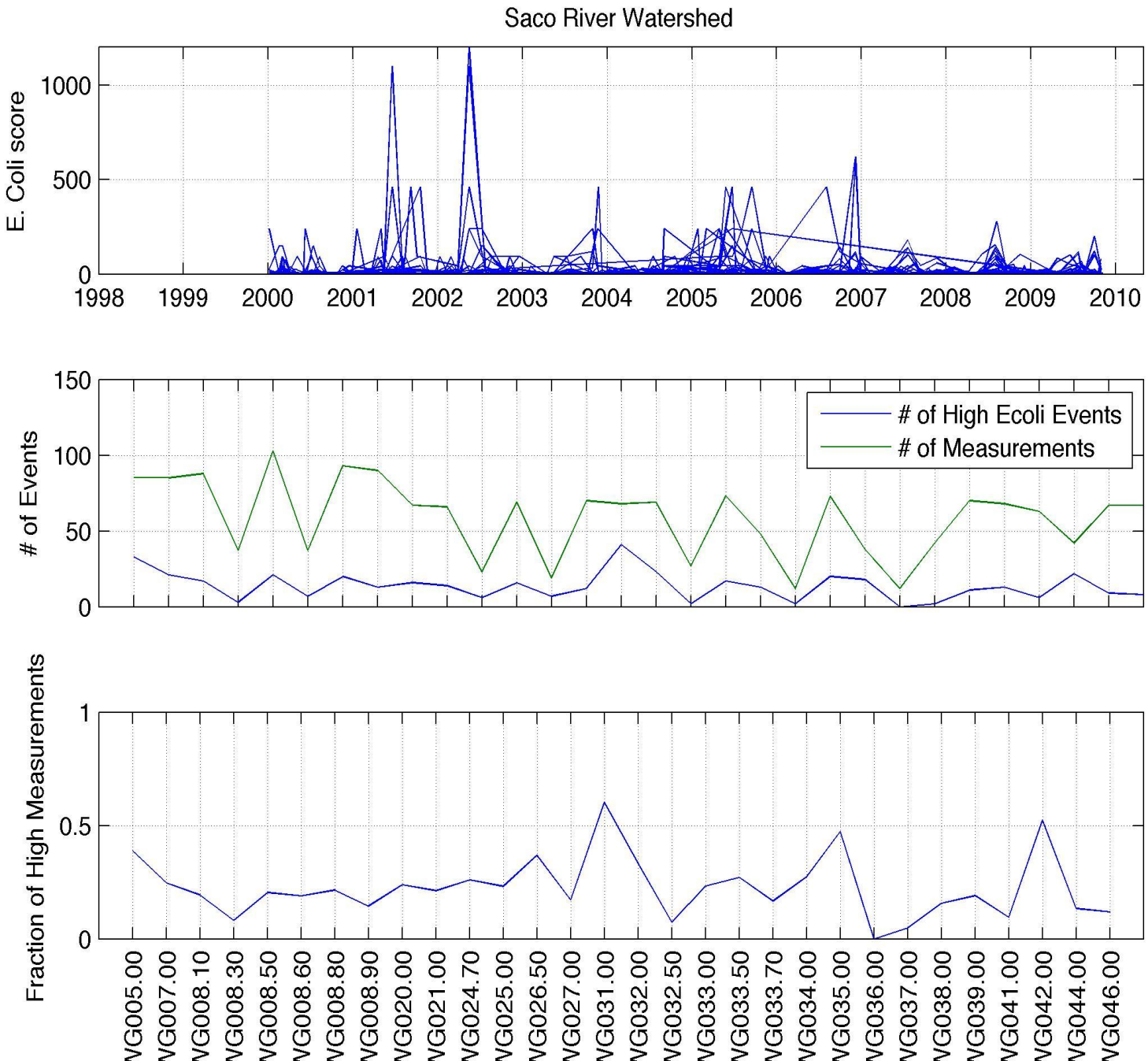
- We examined the ability of the model to predict known RWQEs determined with the current method (river discharge), and to avoid false alarms.
- These tests enabled us to
  - Measure the accuracy of the model
  - Determine the optimum amount of precipitation, ideal location, and time lag of precipitation for each water quality site.

Model Skill

- Precipitation is likely to trigger a RWQE
- However, there will be a number of precipitation events that do not result in RWQEs as well as RWQEs that occur even after no rainfall.
- We use a randomization test by using a large number of synthetic data sets.
  - Compare the ability of model to 1) predict events, and 2) avoid false alarms.

Synthetic Data

- The synthetic data sets were constructed by determining the number of different precipitation events in the observed data set that exceeded $\mathbf{P_{max}}$ (i.e. *n* events) and then randomly placing those *n* events throughout the time period.
- The random data set is then used to predict RWQEs.
- A frequency distribution of the percentage of predicted RWQEs and false alarms is then constructed from a large number.


Saco River Watershed
E. Coli score
1000
500
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
# of Events
150
100
50
0
# of High Ecoli Events
# of Measurements
Fraction of High Measurements
1
0.5
0
VG005.00
VG007.00
VG008.10
VG008.30
VG008.50
VG008.60
VG008.80
VG008.90
VG020.00
VG021.00
VG024.70
VG025.00
VG026.50
VG027.00
VG031.00
VG032.00
VG032.50
VG033.00
VG033.50
VG033.70
VG034.00
VG035.00
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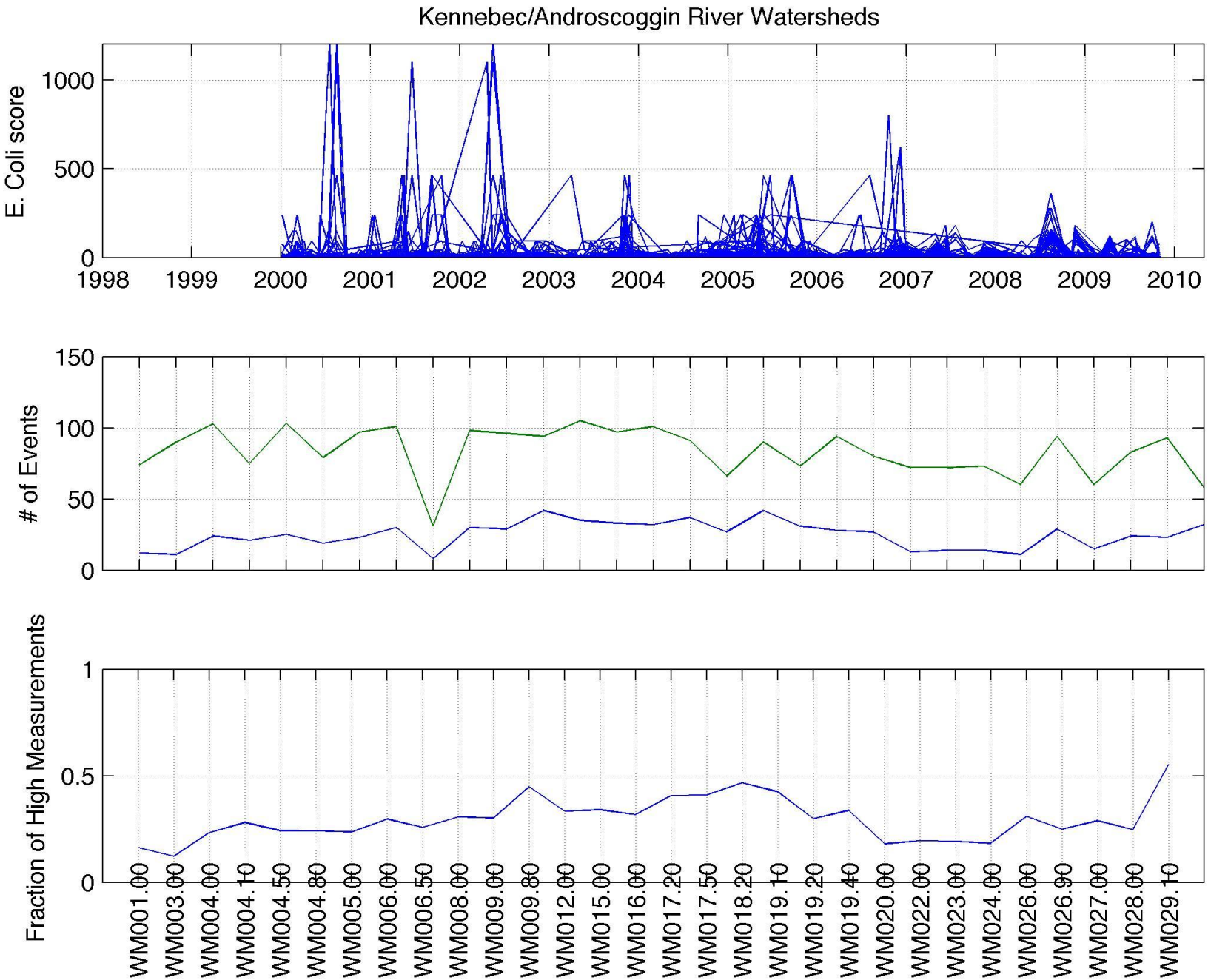
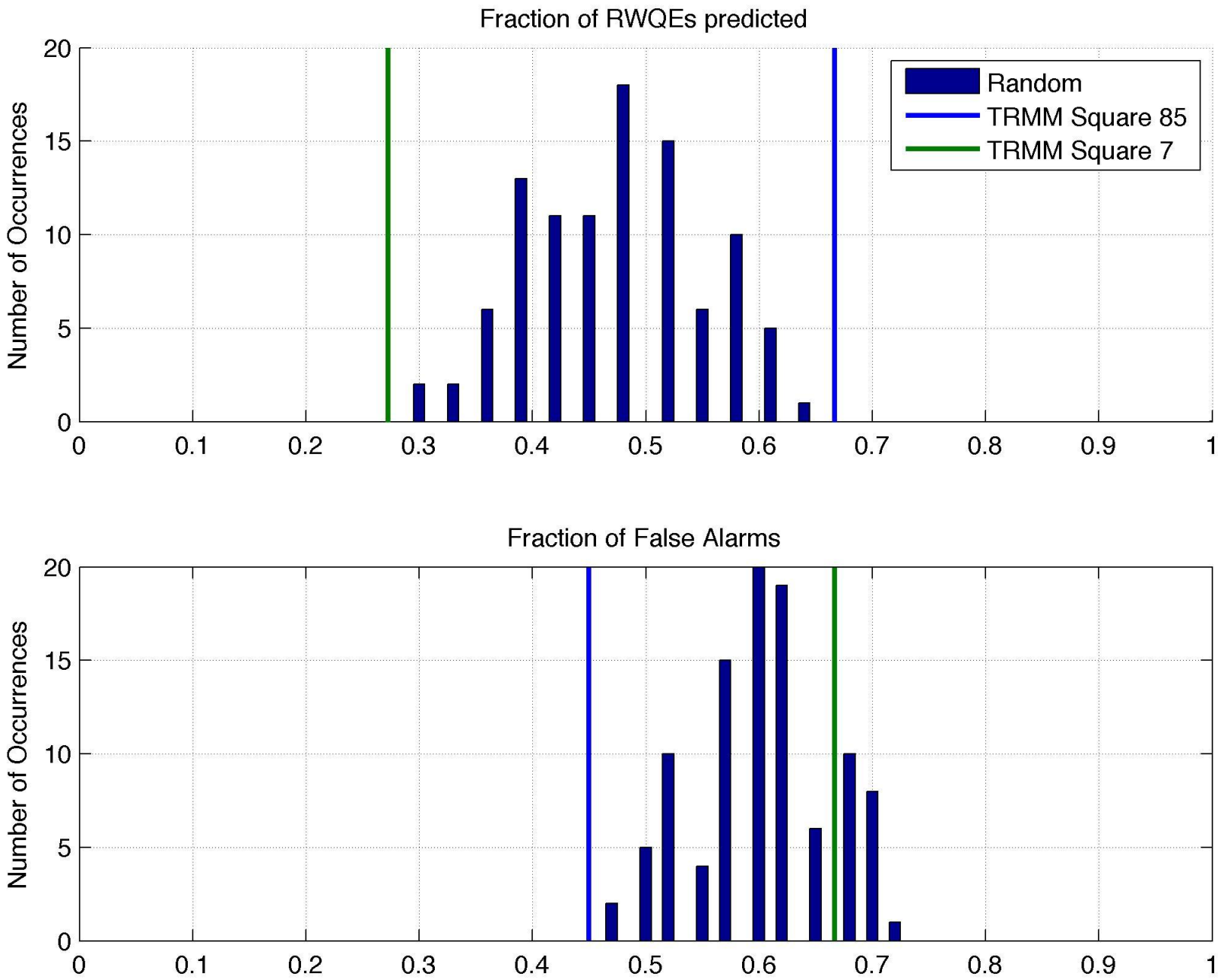
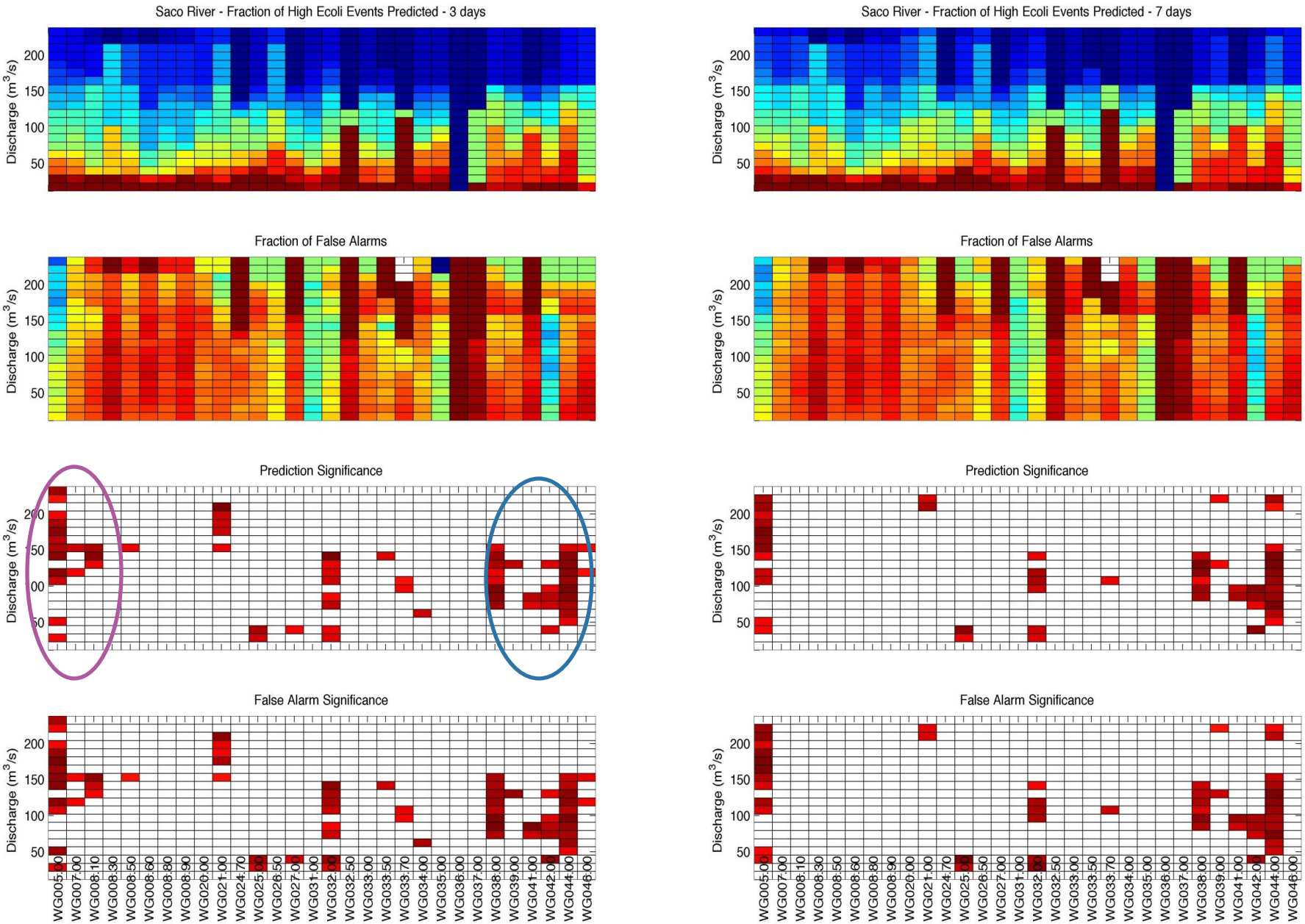
VG042.00
VG044.00
VG046.00


Kennebec/Androscoggin River Watersheds
E. Coli score
1000
500
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
# of Events
150
100
50
0
Fraction of High Measurements
1
0.5
0
WM001.00
WM003.00
WM004.00
WM004.10
WM004.50
WM004.80
WM005.00
WM006.00
WM006.50
WM008.00
WM009.00
WM009.80
WM012.00
WM015.00
WM016.00
WM017.20
WM017.50
WM018.20
WM019.10
WM019.20
WM019.40
WM020.00
WM022.00
WM023.00
WM024.00
WM026.00
WM026.90
WM027.00
WM028.00
WM029.10

Model Skill

- Comparison of the model predicted RWQEs with the distribution from the synthetic data set provides an estimate of the significance of the model skill
- A model prediction that is greater than 95% of the synthetic prediction percentage indicates that the model skill outperforms random chance at a significance of 95%.
- Model false alarms that are less than 95% of the synthetic data set false alarms indicates that the model outperforms random chance at a significance of 95%.

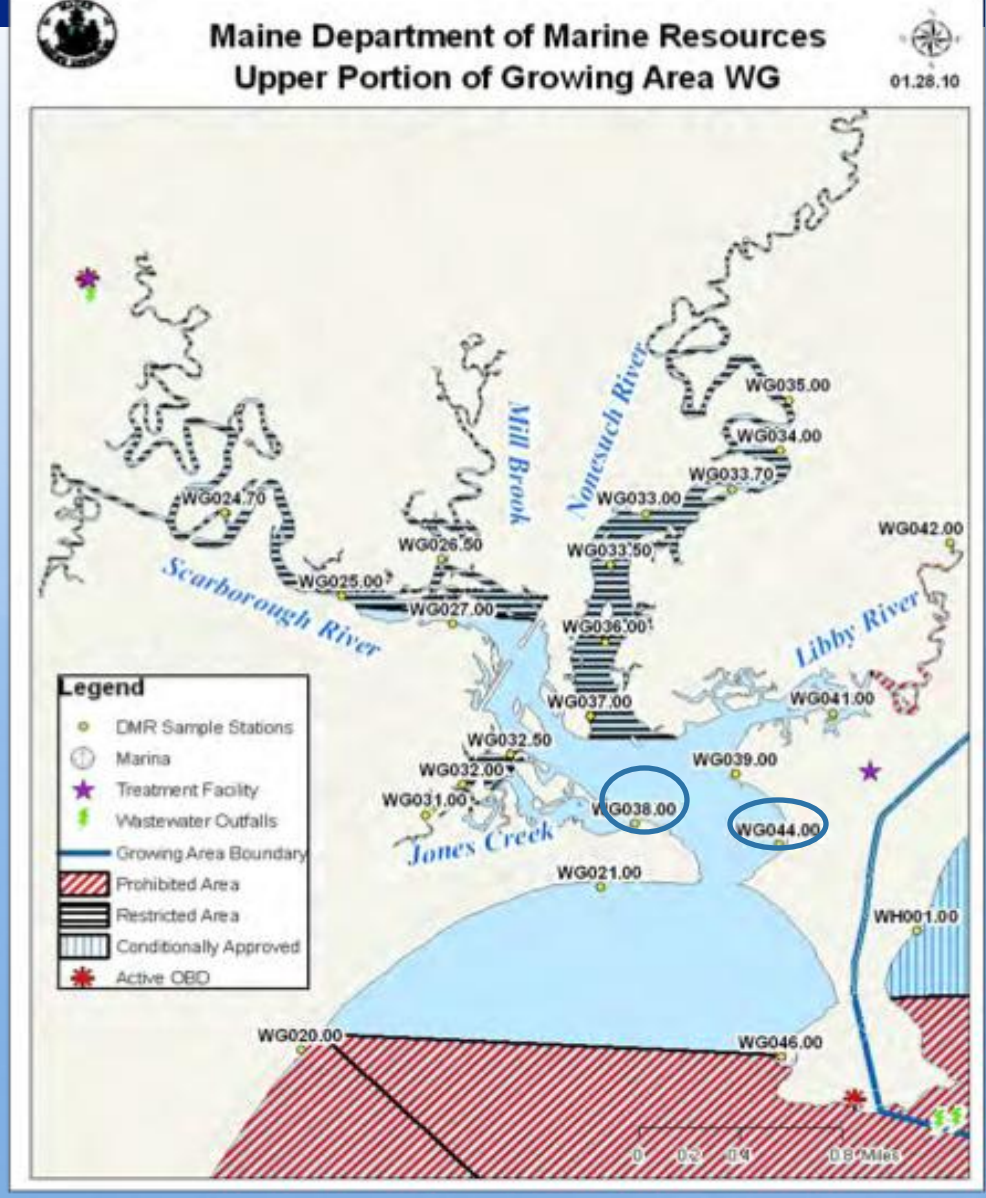

Fraction of RWQEs predicted
Number of Occurrences
Random
TRMM Square 85
TRMM Square 7
0
5
10
15
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Fraction of False Alarms
Number of Occurrences
0
5
10
15
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Discharge based predictions

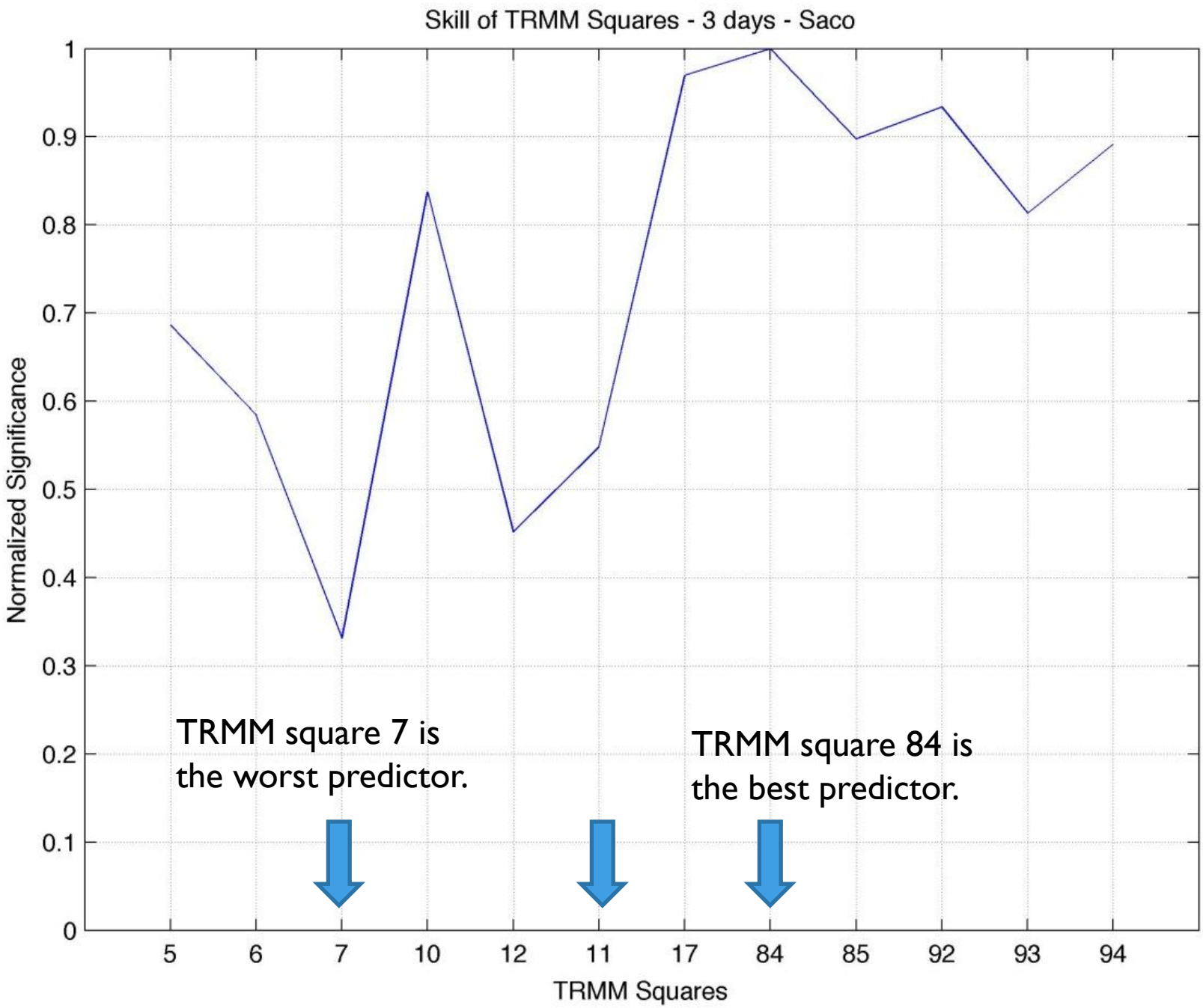
Growing Area WG

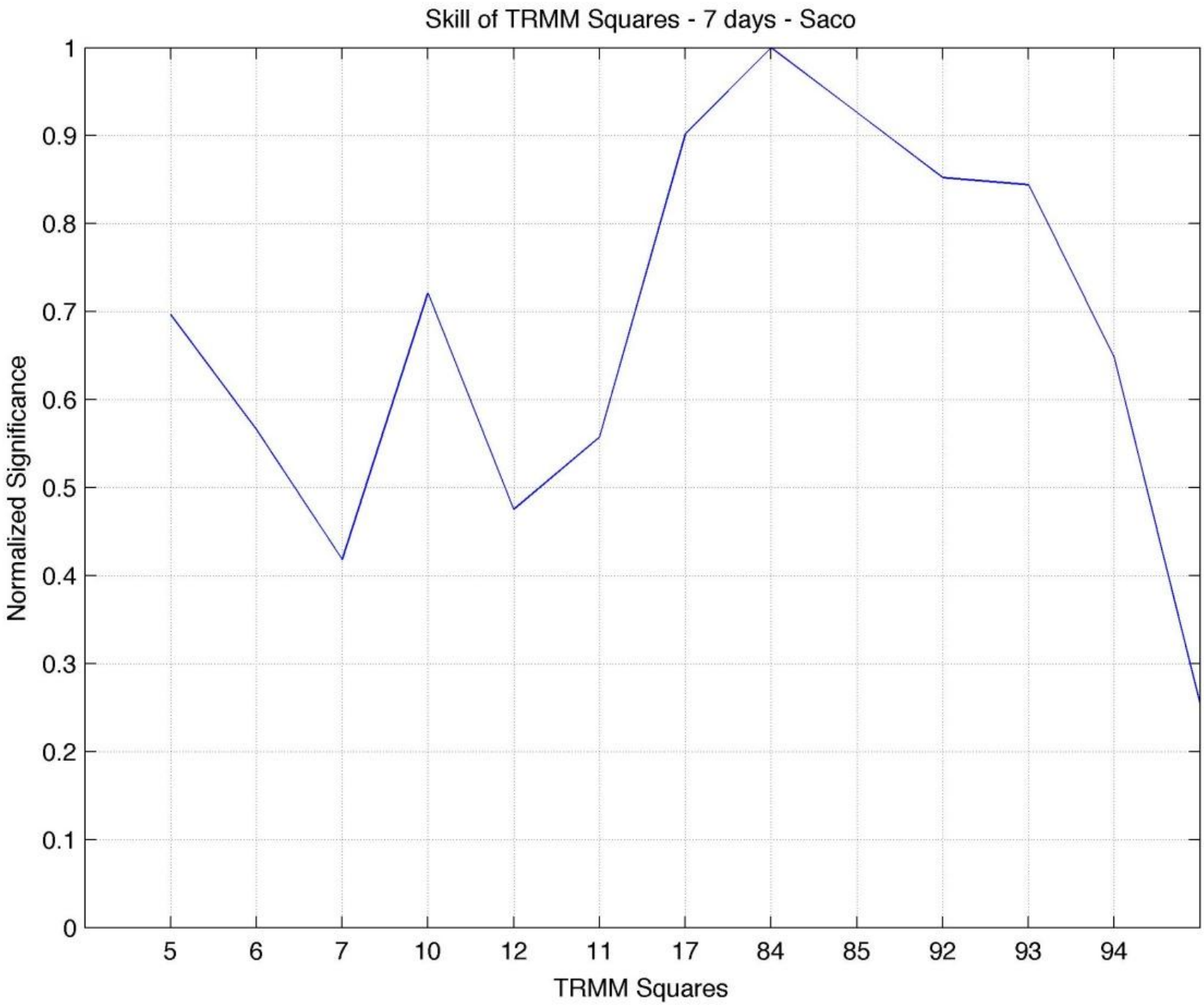
This map was updated August 28, 2008



Lets compare to TRMM

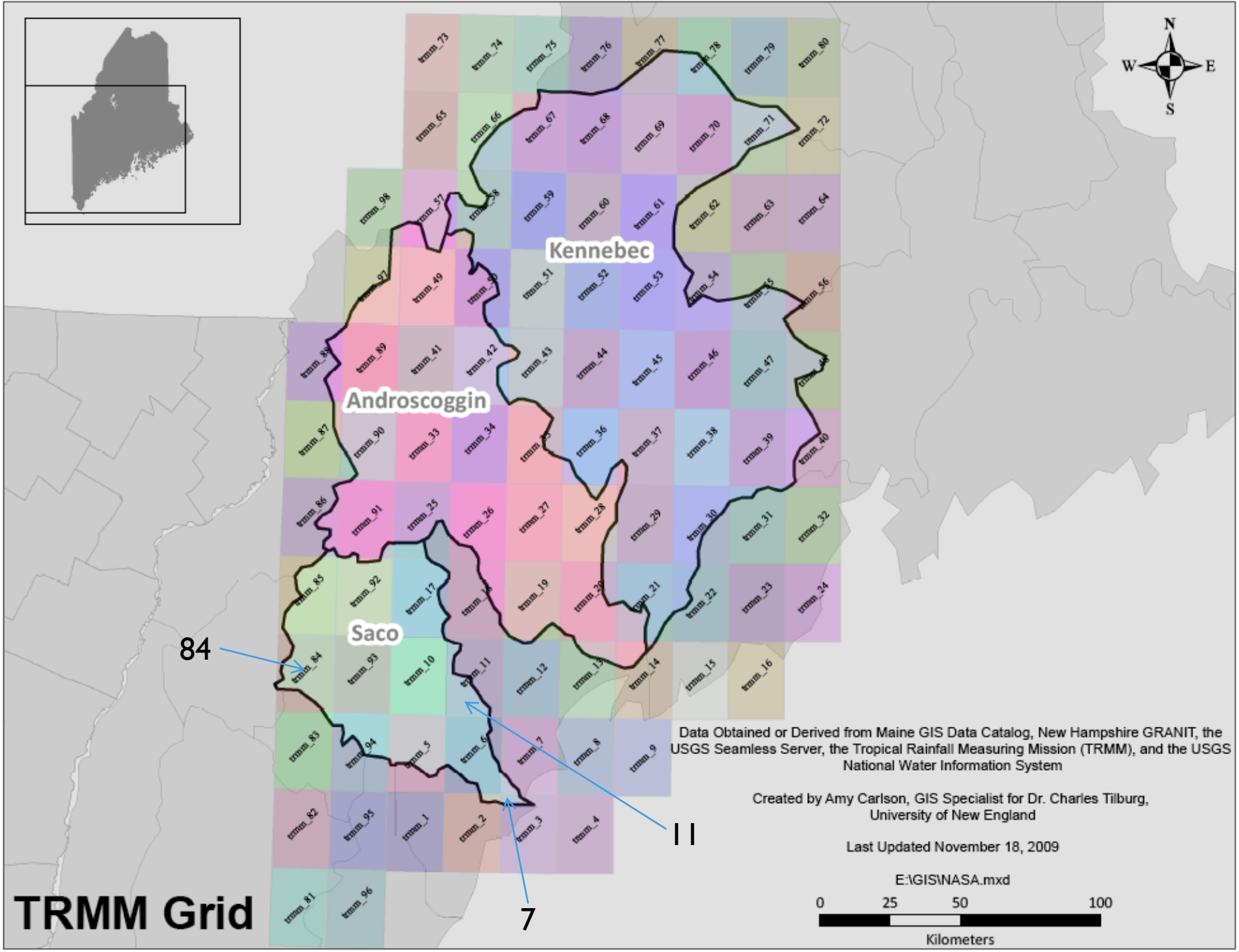
- Next we quantify the results using TRMM precipitation predictions.


Skill of TRMM Squares - 3 days - Saco
Normalized Significance
TRMM Squares
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5
6
7
10
12
11
17
84
85
92
93
94
TRMM square 7 is
the worst predictor.
TRMM square 84 is
the best predictor.

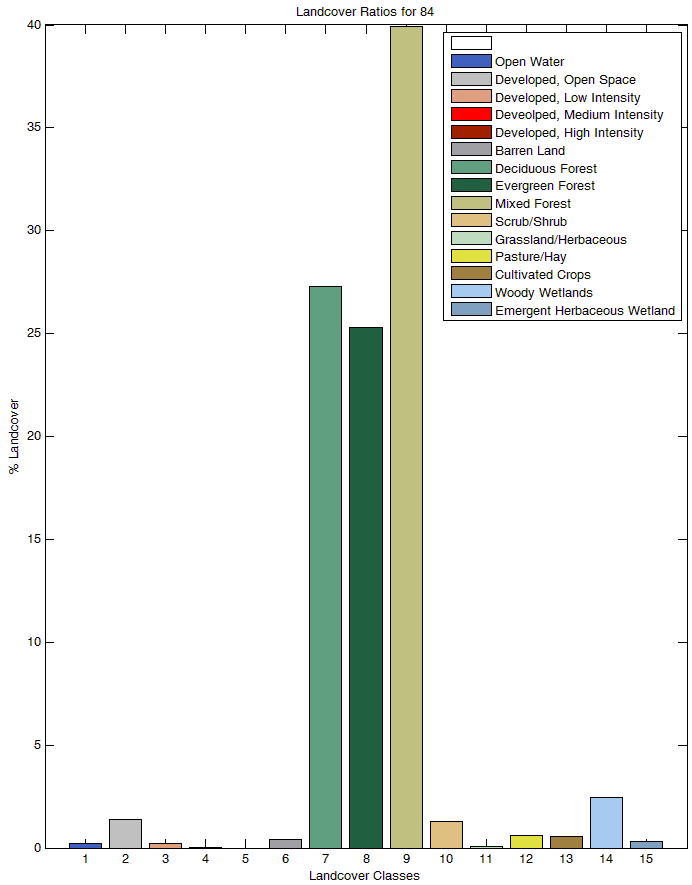

Skill of TRMM Squares - 7 days - Saco
Normalized Significance
TRMM Squares
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5
6
7
10
12
11
17
84
85
92
93
94

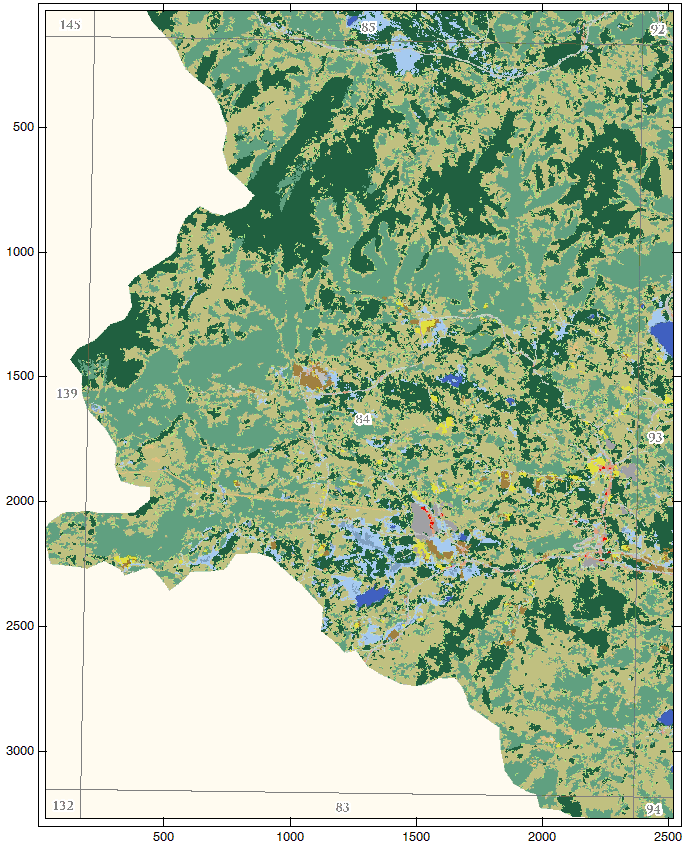
Lets compare to TRMM

- The differential capability of the TRMM squares as predictors of bacterial contamination at the ocean is possibly related to land cover.

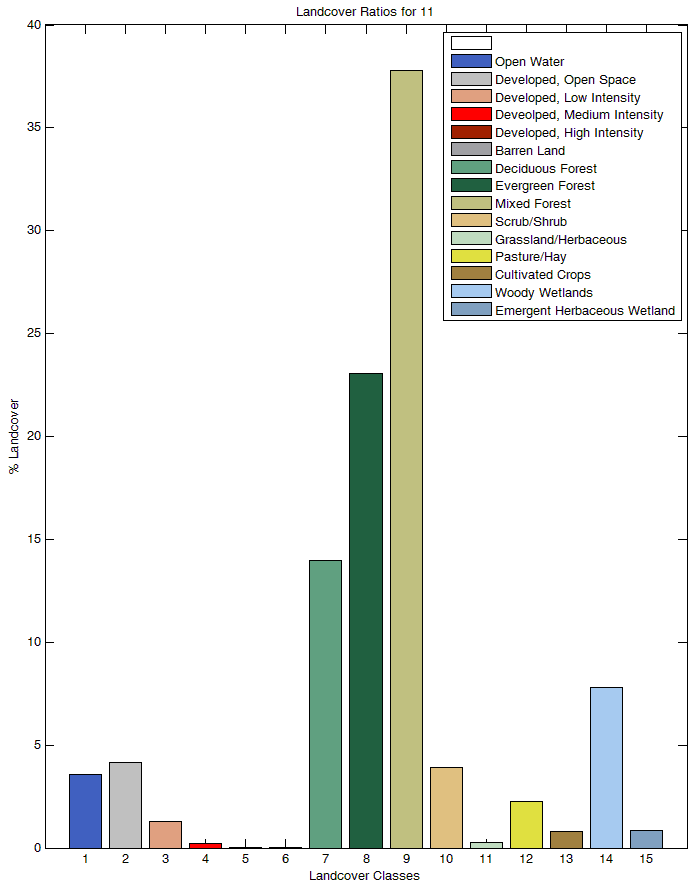

Kennebec
Androscoggin
Saco
84
11
7
N
W
E
S
Data Obtained or Derived from Maine GIS Data Catalog, New Hampshire GRANIT, the USGS Seamless Server, the Tropical Rainfall Measuring Mission (TRMM), and the USGS National Water Information System
Created by Amy Carlson, GIS Specialist for Dr. Charles Tilburg, University of New England
Last Updated November 18, 2009
E:\GIS\NASA.mxd
0 25 50 100
Kilometers

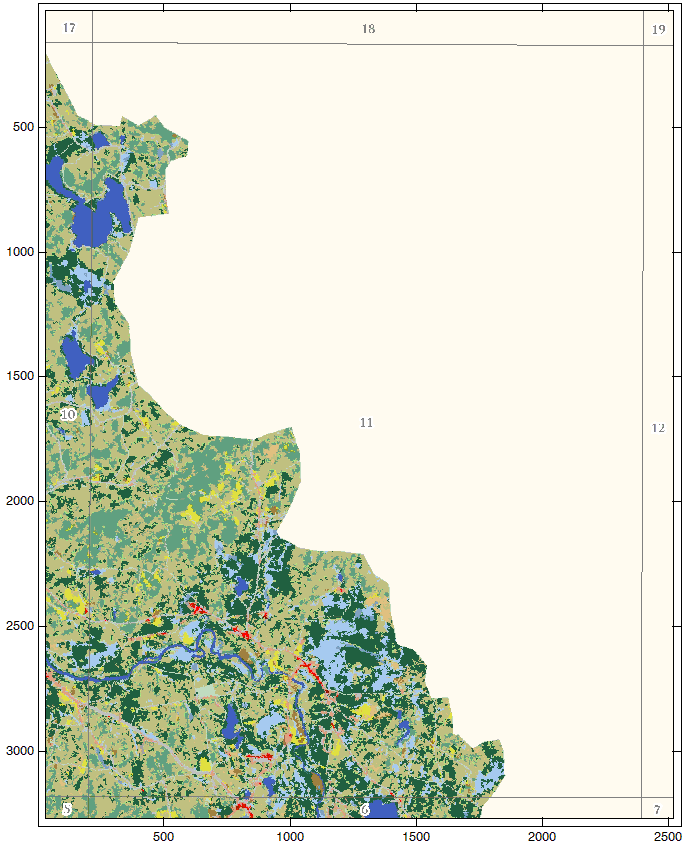
TRMM Grid



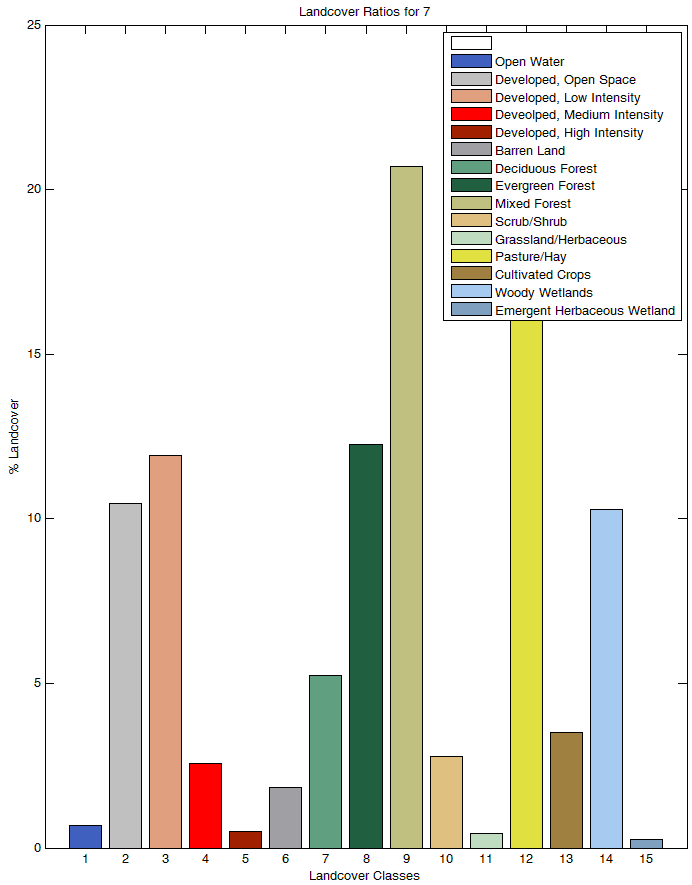


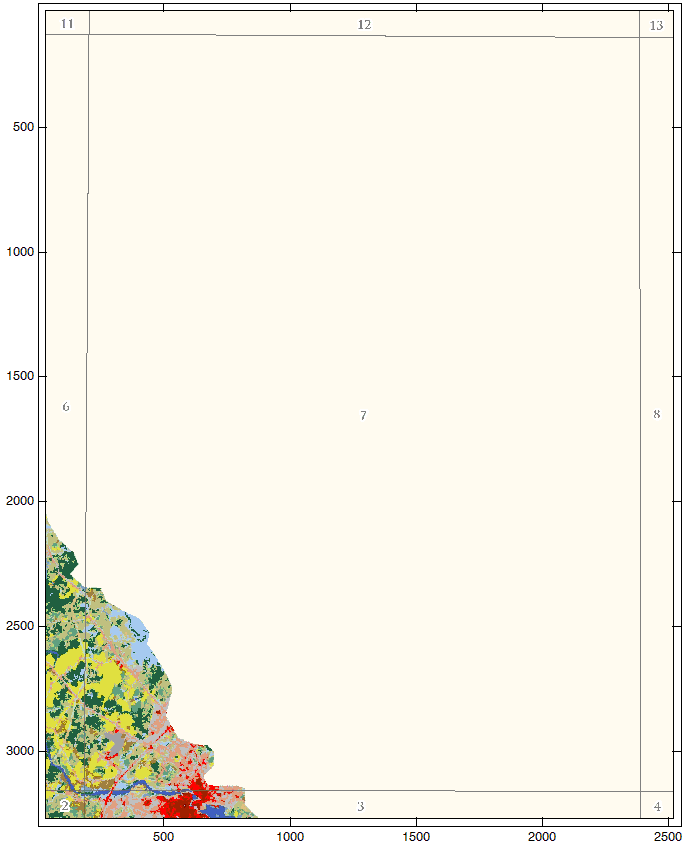
TRMM square 84





TRMM square 11

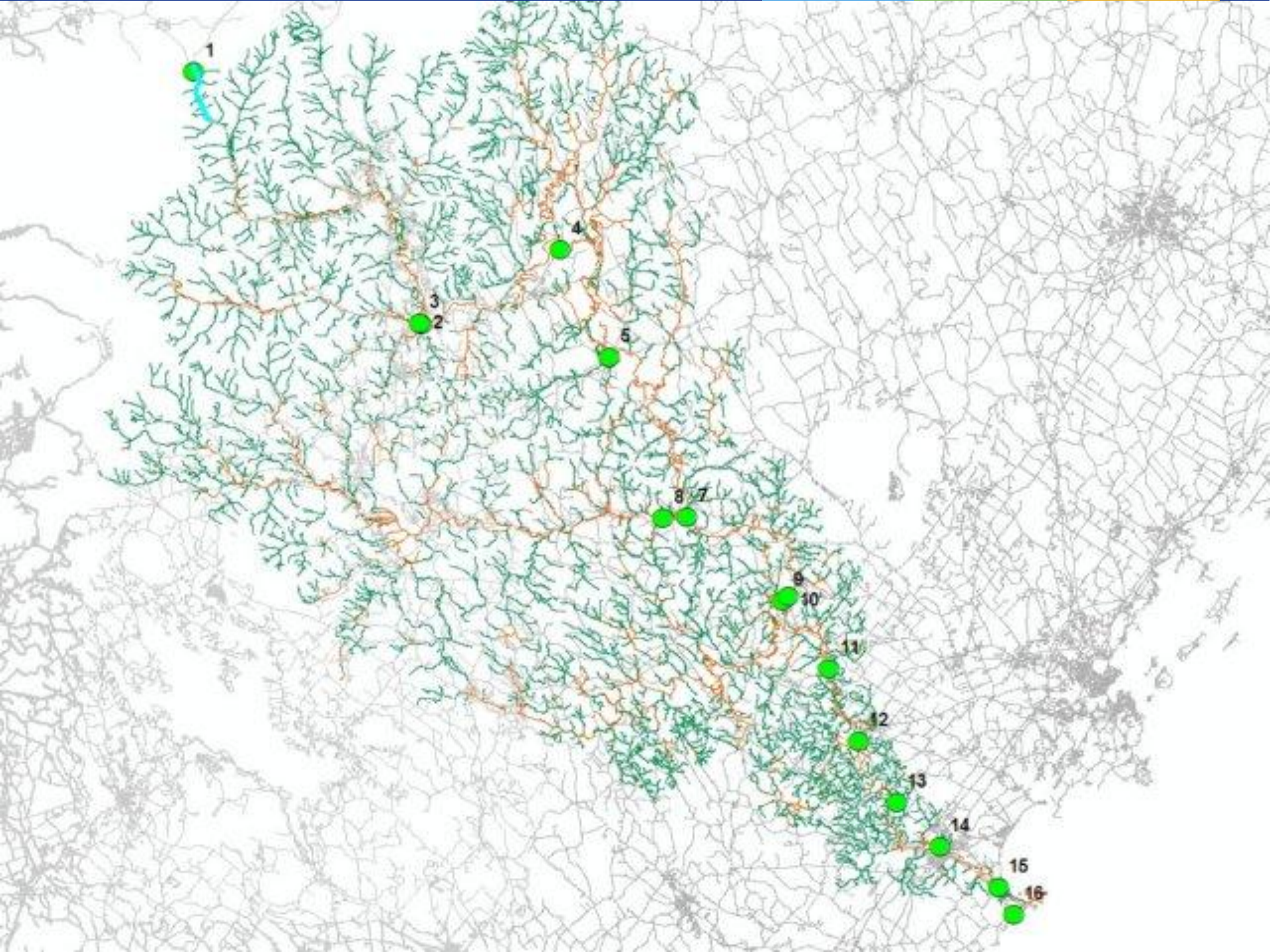


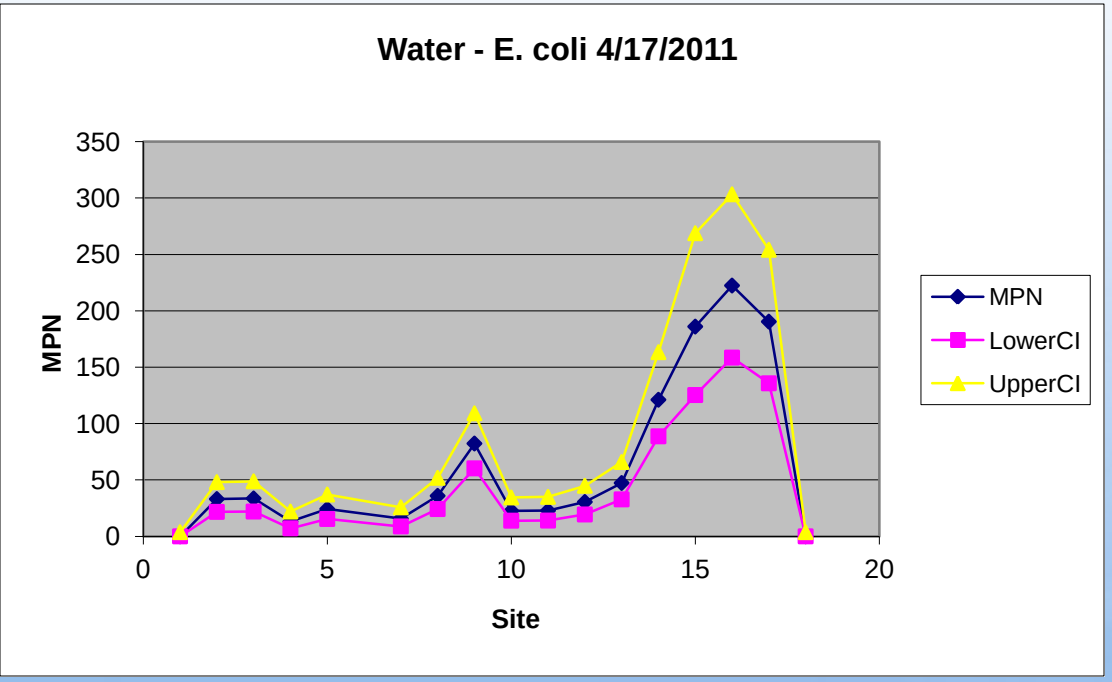


TRMM square 7

Lets compare to TRMM

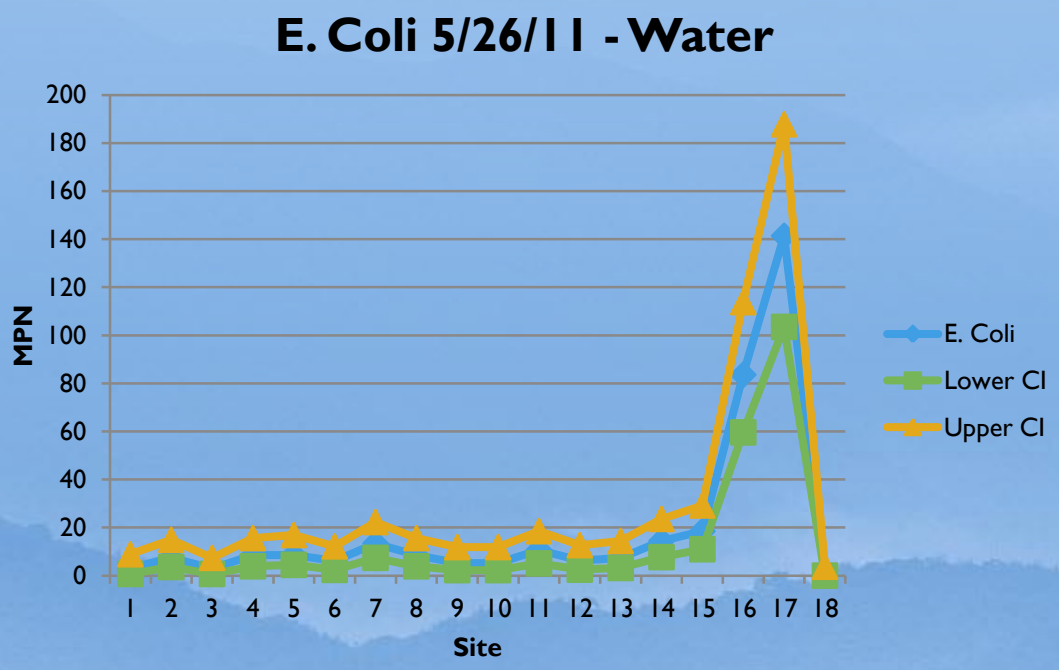
- In situ bacterial concentrations also point to a land-use effect.


1
2
3
4
5
7
8
9
10
11
12
13
14
15
16



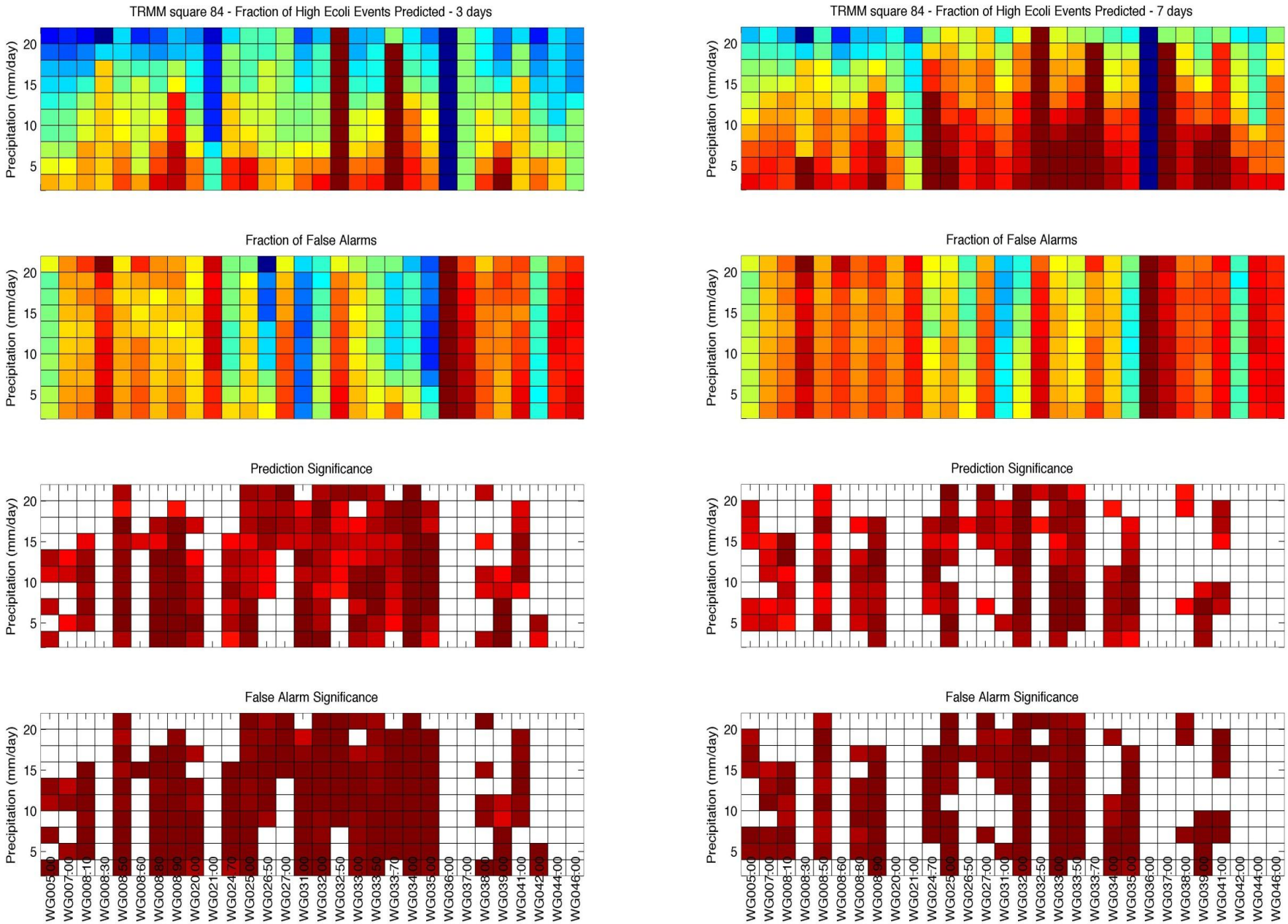
Rain storm

No rain

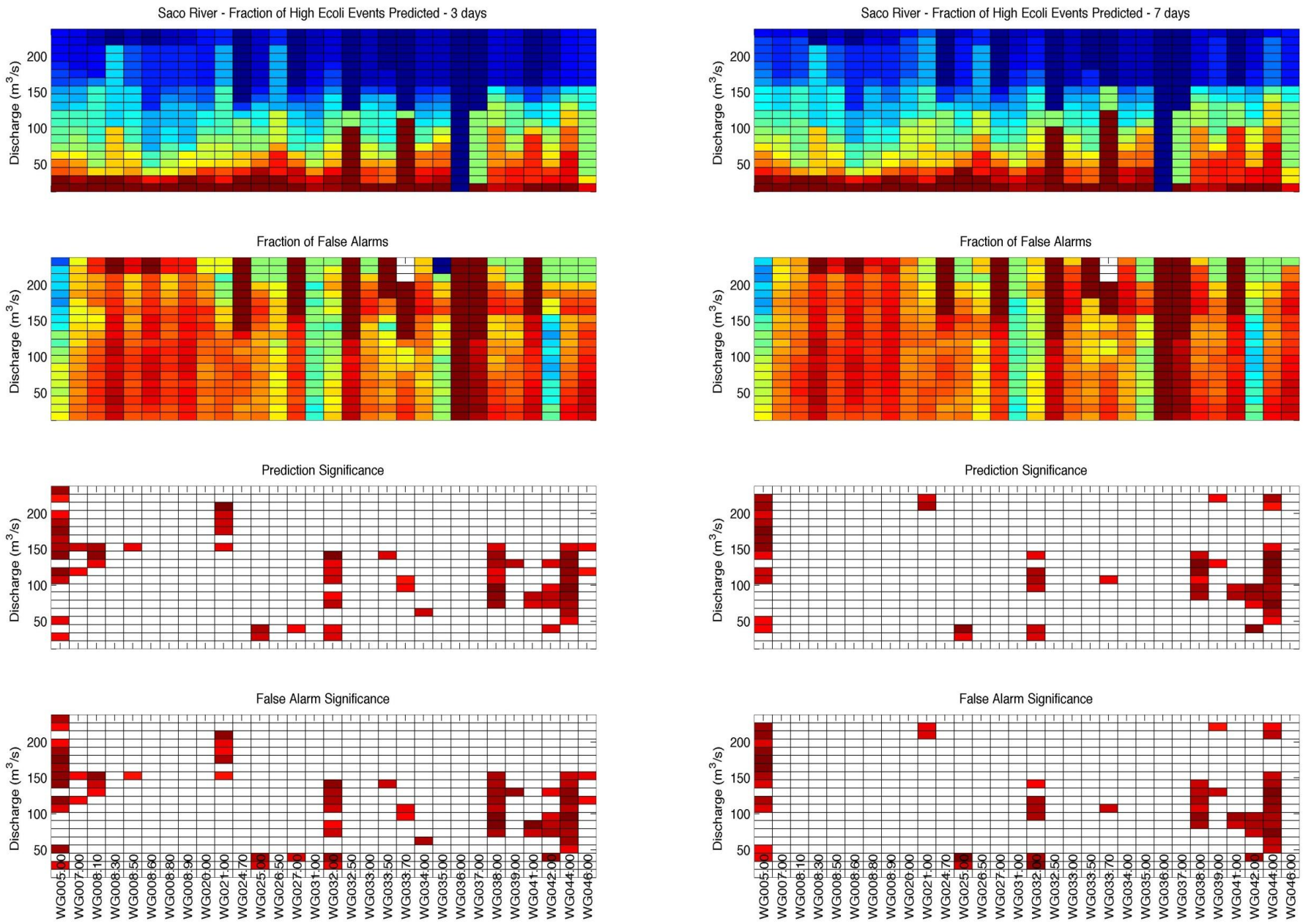


Lets compare to TRMM

- TRMM precipitation is a better predictor than river discharge from gaging stations.

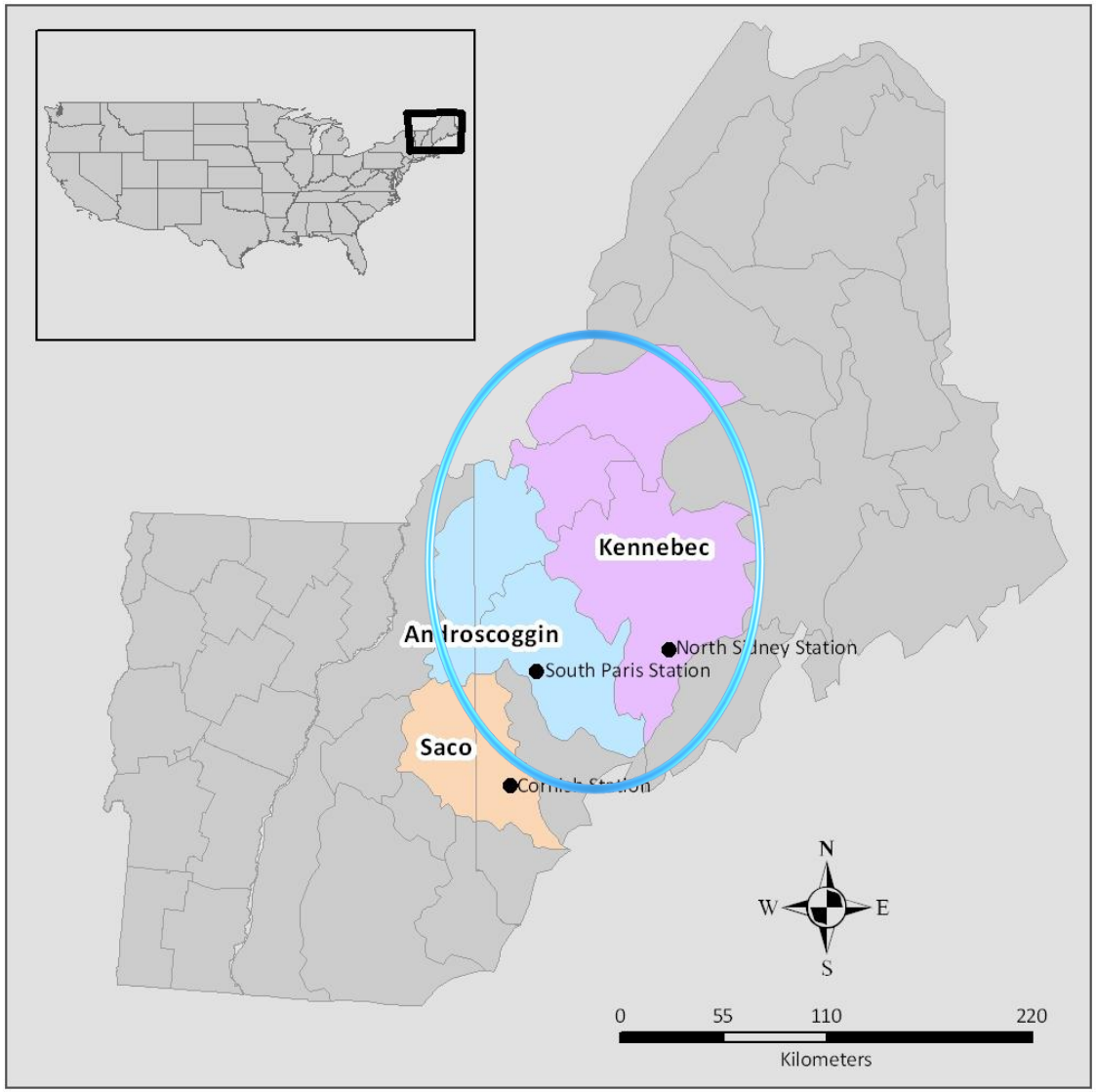


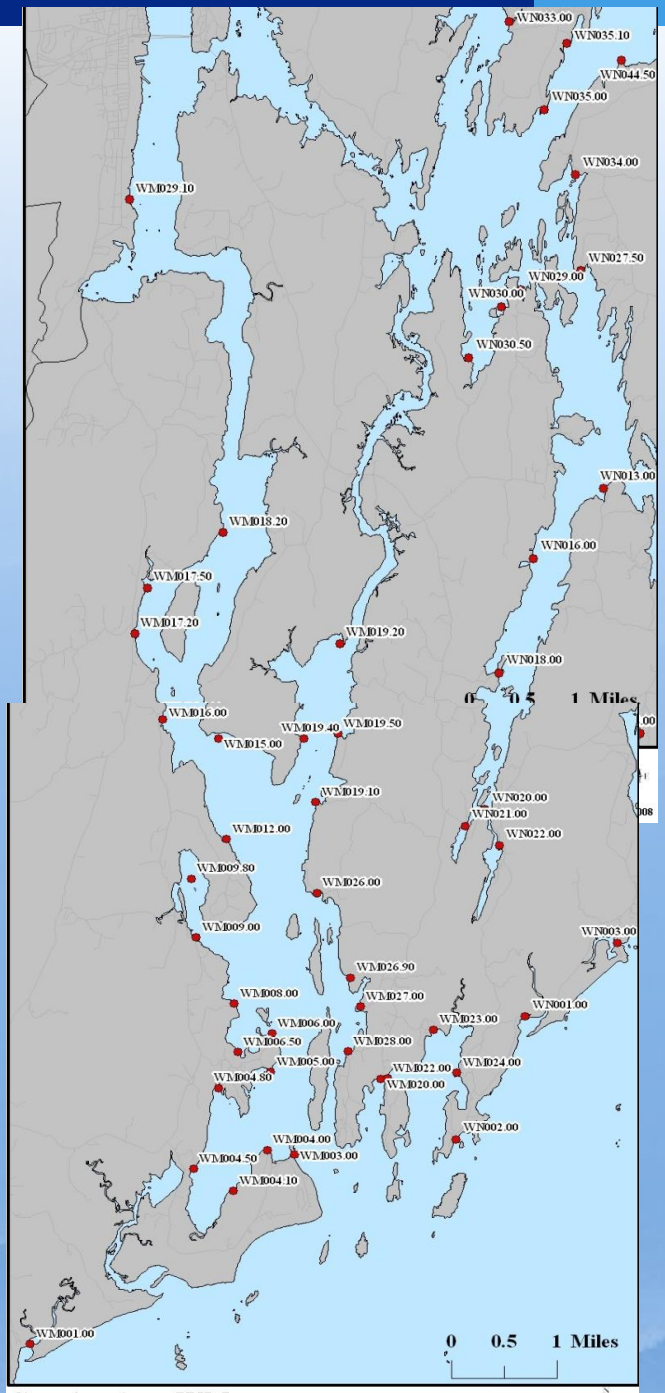
Precipitation based predictions



Discharge based predictions

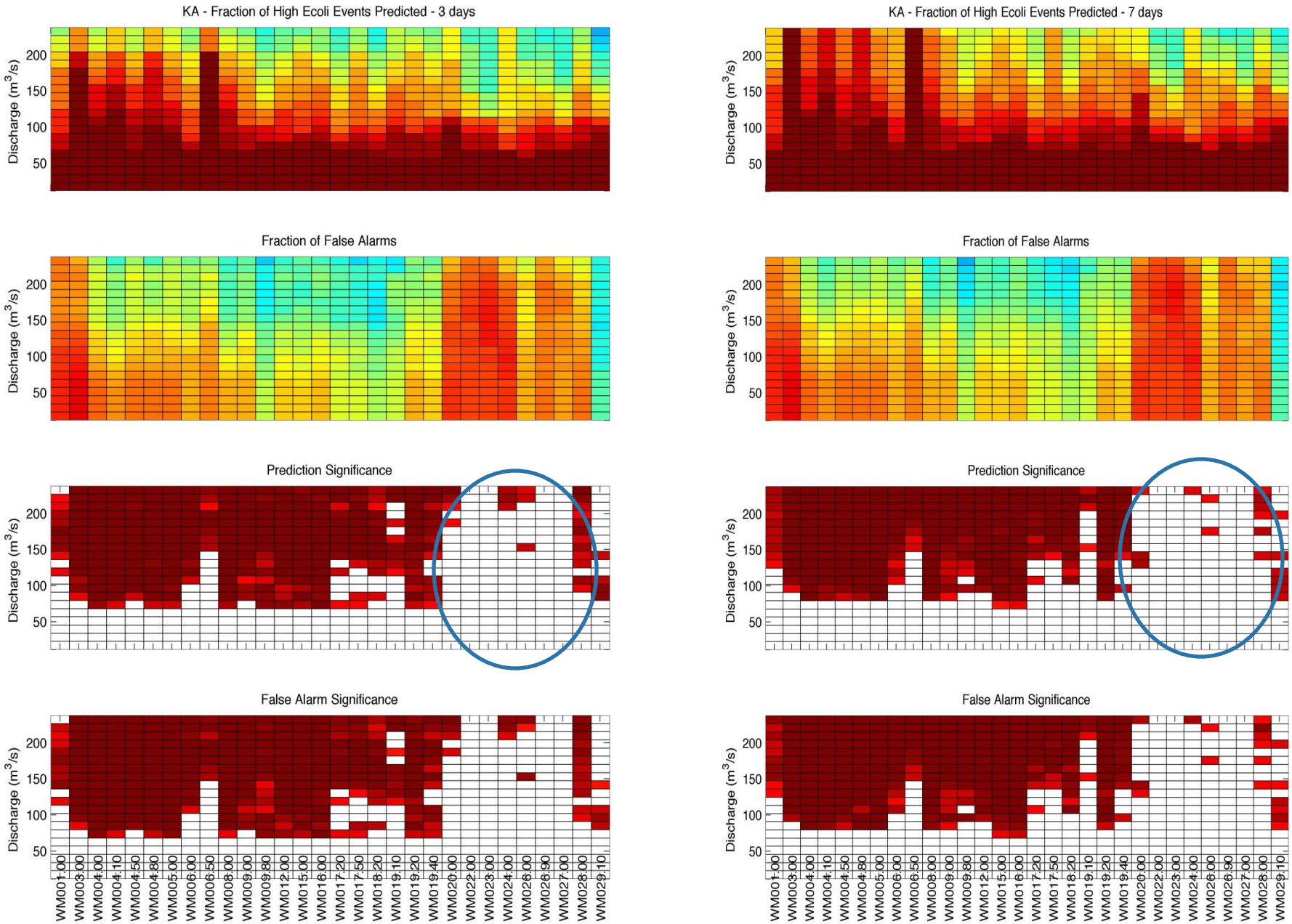
Test Case: Three watersheds in Maine



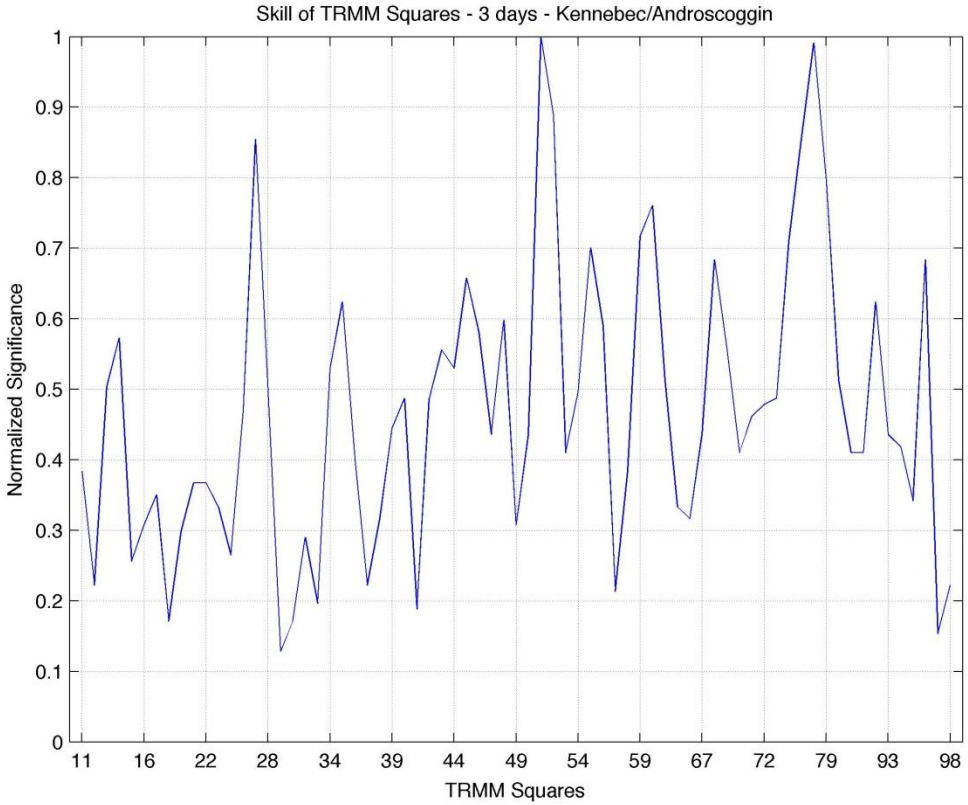


Growing Area WM

See Legal Notice for Current Classifications at:



Discharge predictions


Skill of TRMM Squares - 3 days - Kennebec/Androscoggin
Normalized Significance
TRMM Squares
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
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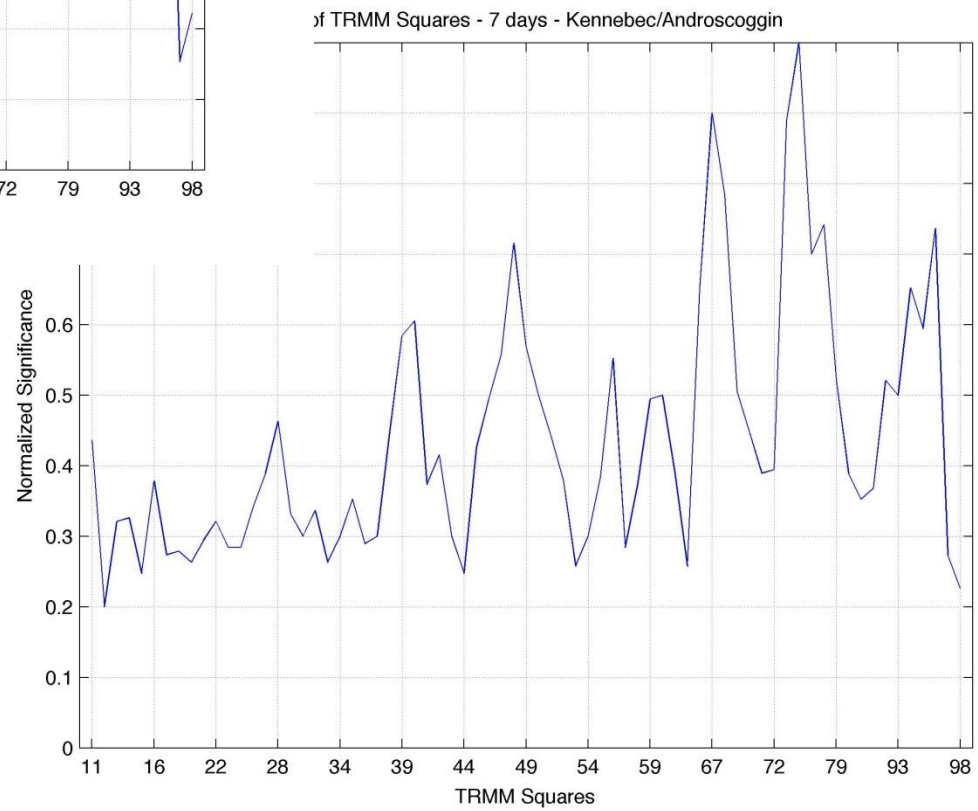
59
67
72
79
93
98


of TRMM Squares - 7 days - Kennebec/Androscoggin
Normalized Significance
TRMM Squares
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0.2
0.3
0.4
0.5
0.6
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39
44
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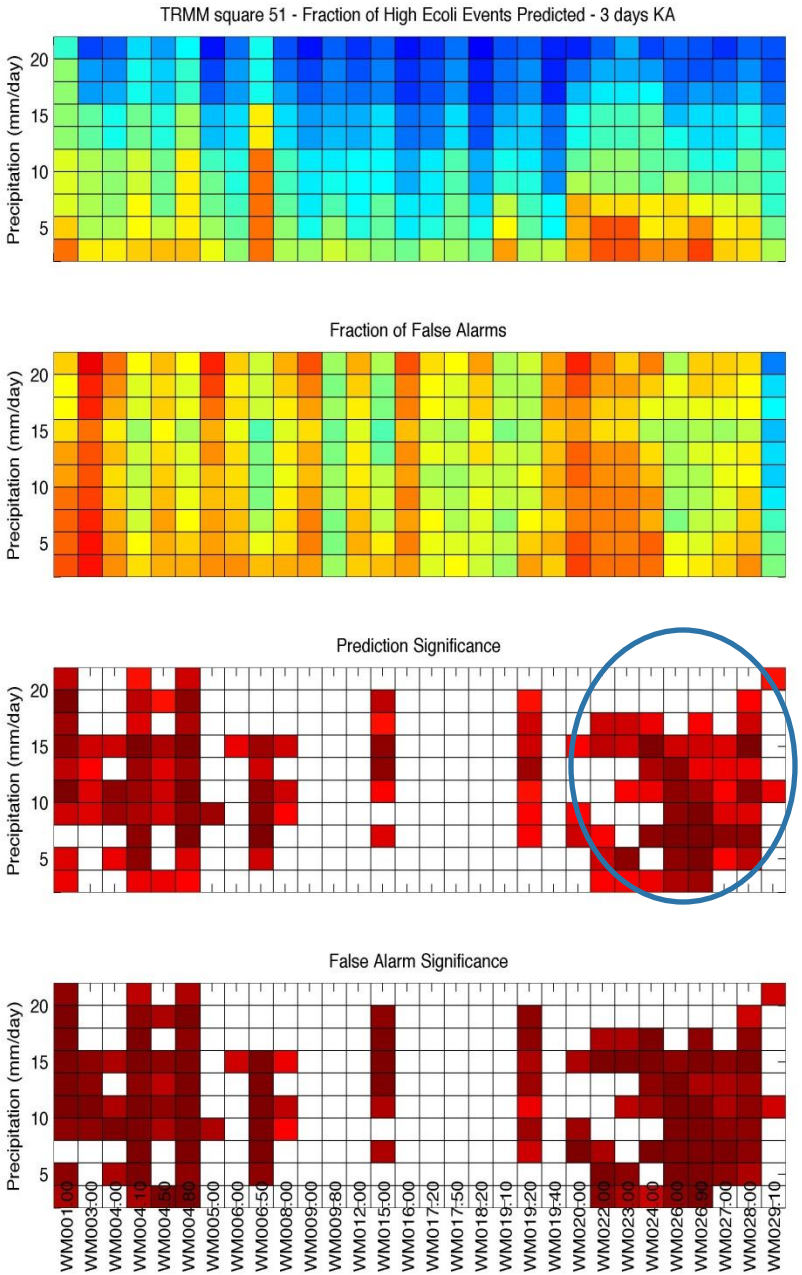
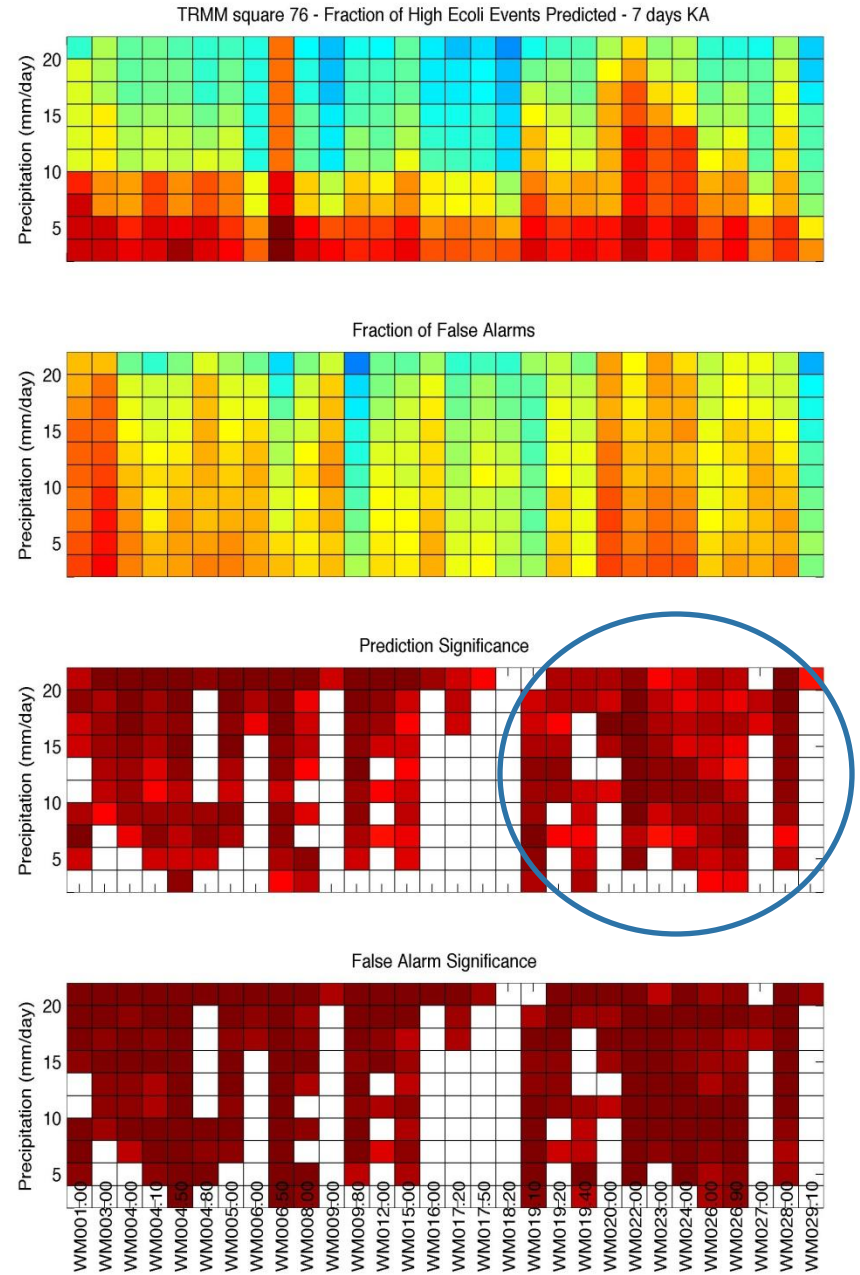
59
67
72
79
93
98

Precipitation based predictions

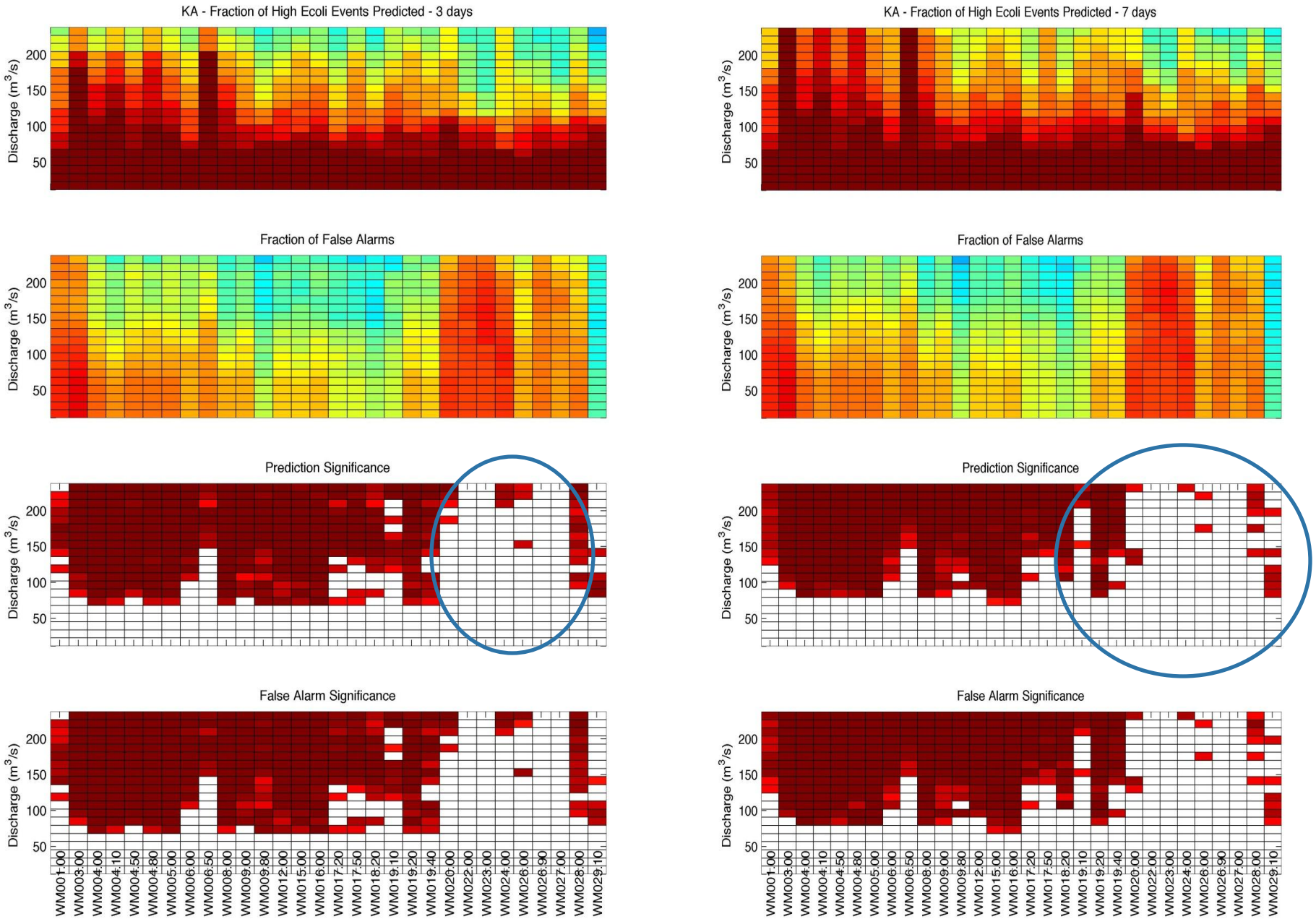


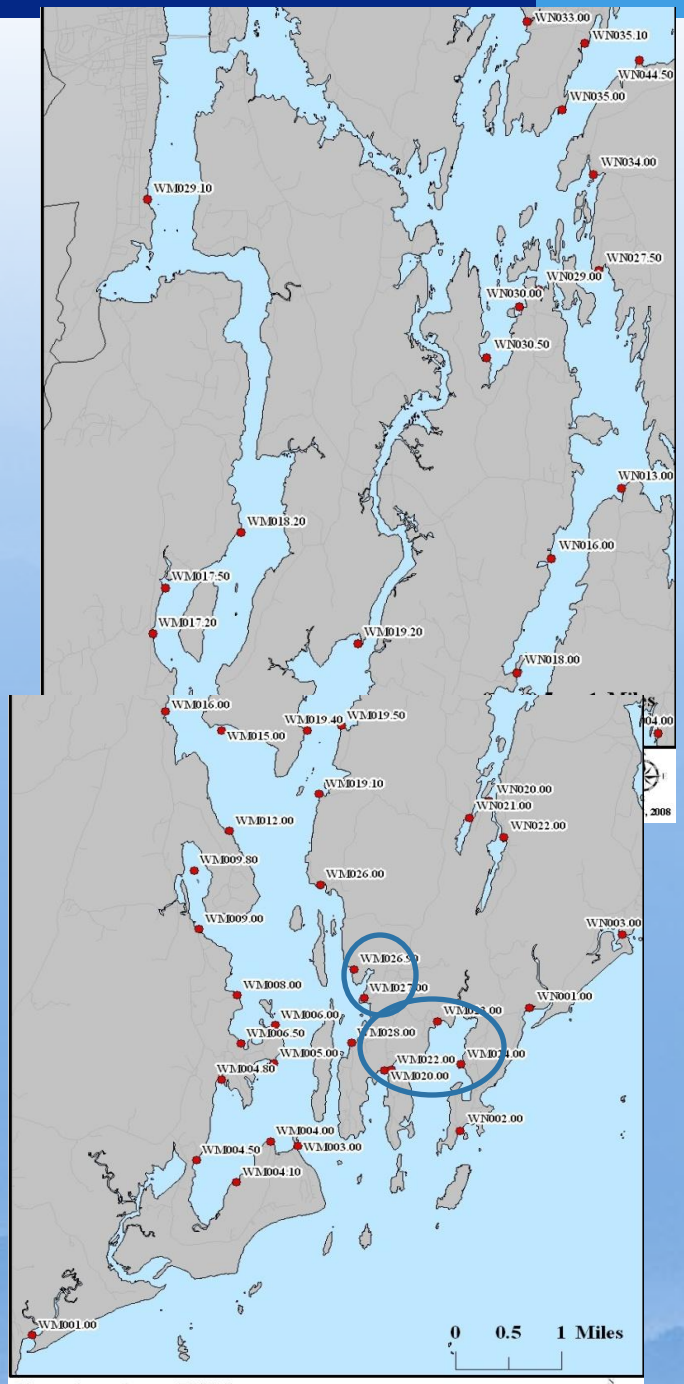
TRMM square 51, 3 day lag



TRMM square 76, 7 day lag

Discharge based predictions





Growing Area WM

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Conclusions

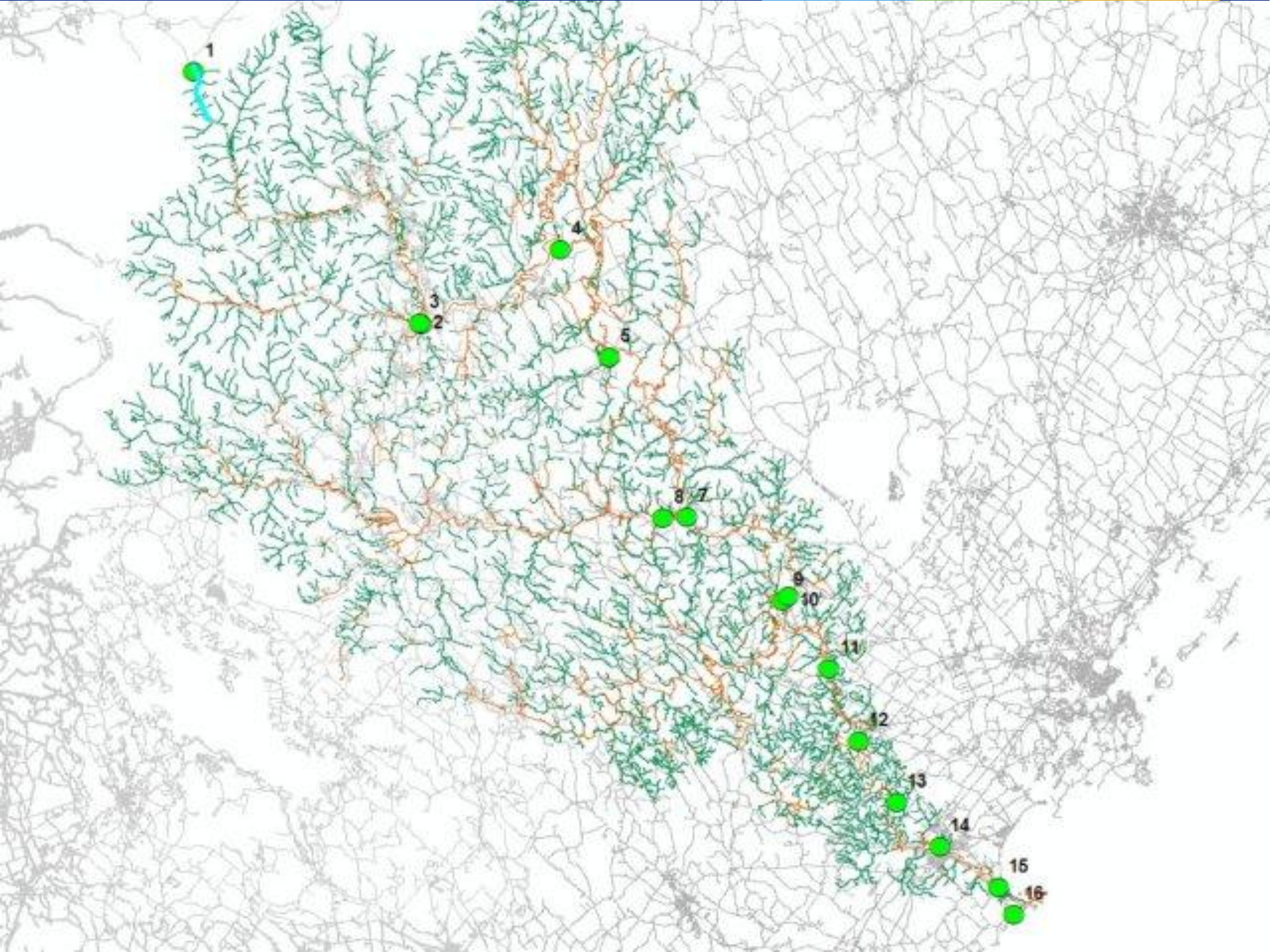
- The use of satellite derived precipitation data was successful in forecasting water quality in the coastal waters of Maine.
  - Use of TRMM is a better predictor of reduced water quality events than Maine's current method.
- The use of precipitation data to forecast water quality at larger (and under-sampled) regions is warranted.
  - Link between land use and reduced water quality is not clear (Yet).
  - Infrequently sampled data hampers validation of predictive model.

Possible Extensions

- The methods can be applied to:
  - Salinity modeling in nearshore waters
  - Transport of other contaminants
  - Studies of other infectious agents (e.g. Vibrio)

Further Areas of Research

- Variability along the stream
- Seasonality
- Survival in the environment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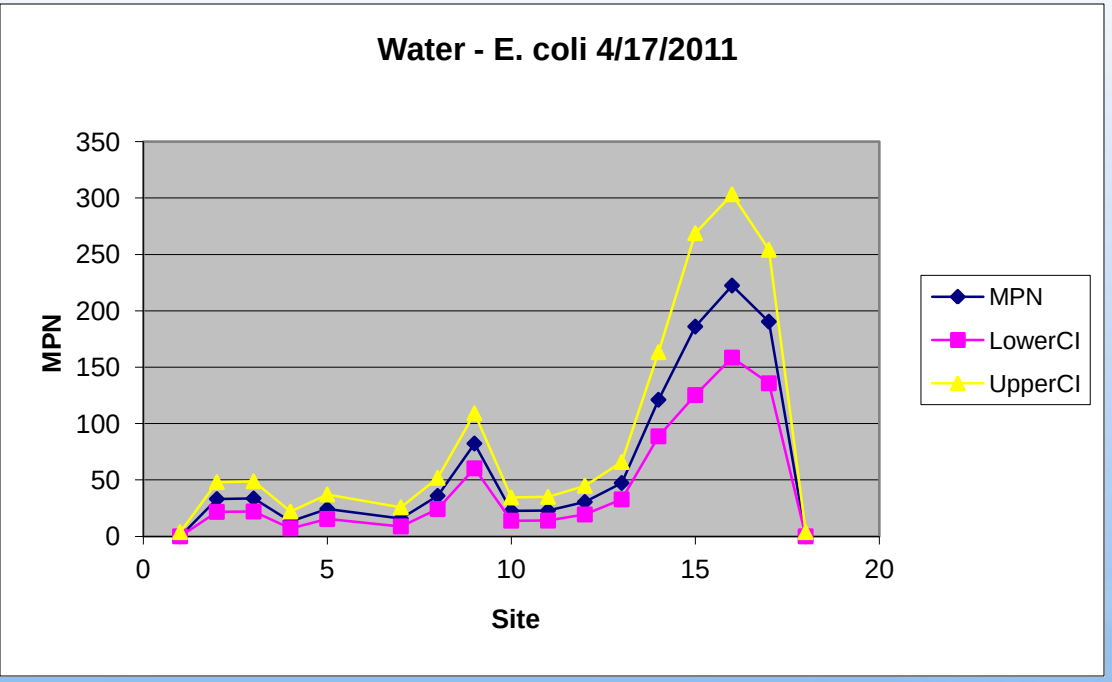
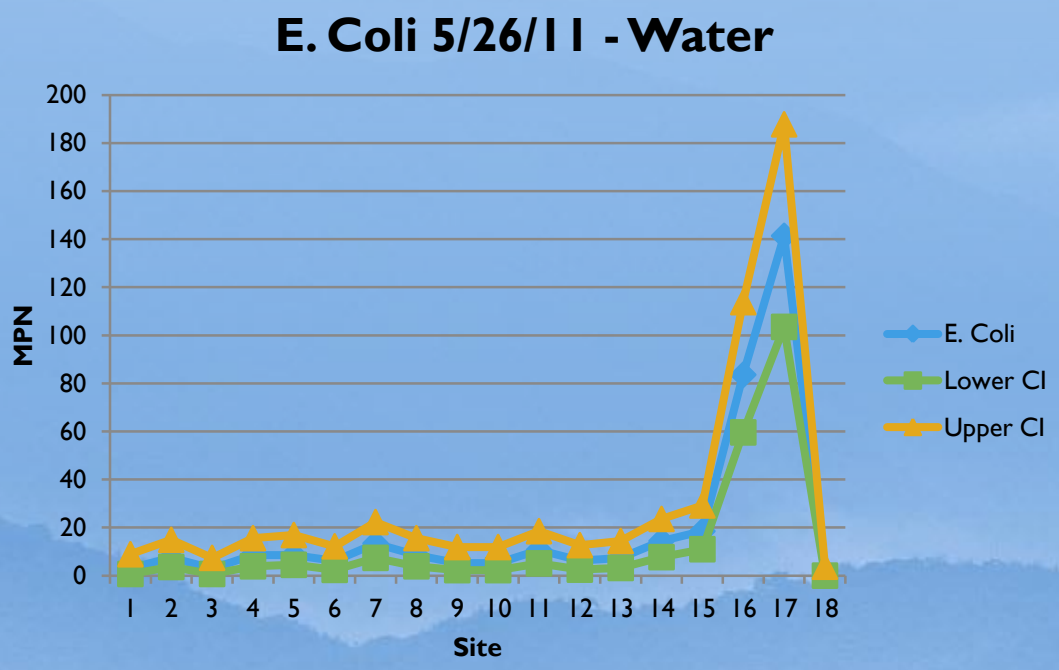
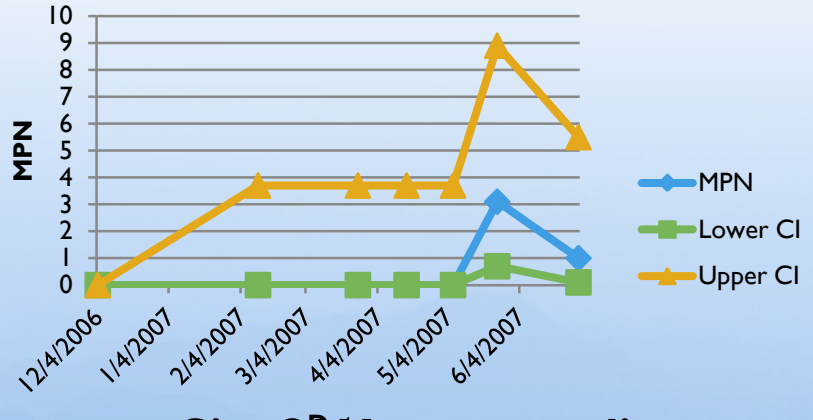


Rain storm

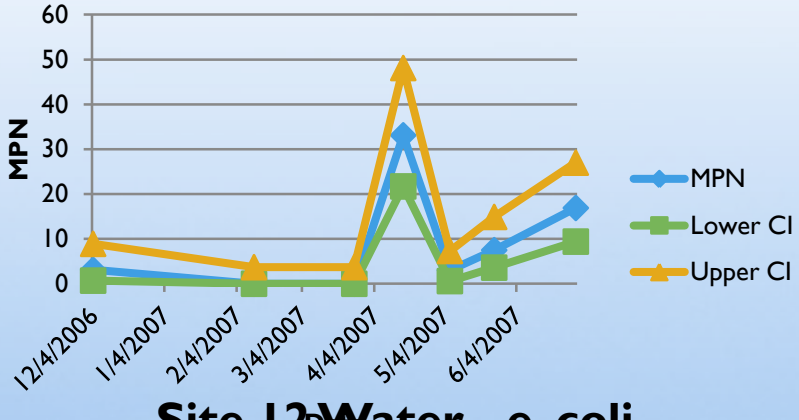
No rain



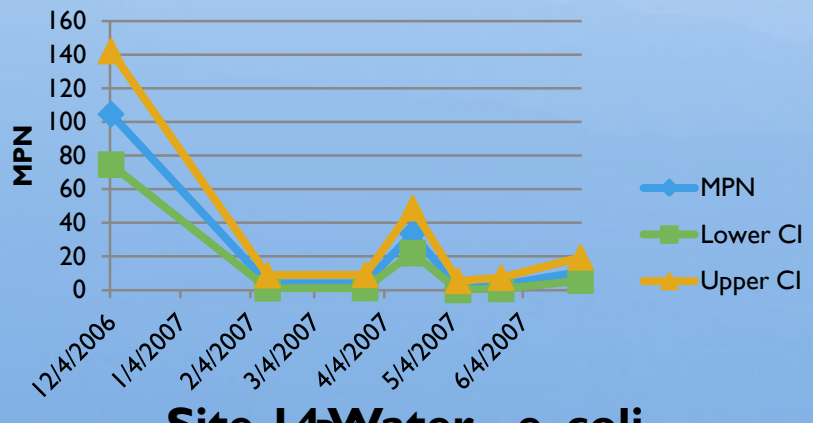
Site 1 Water - e. coli



Site 2 Water - e. coli

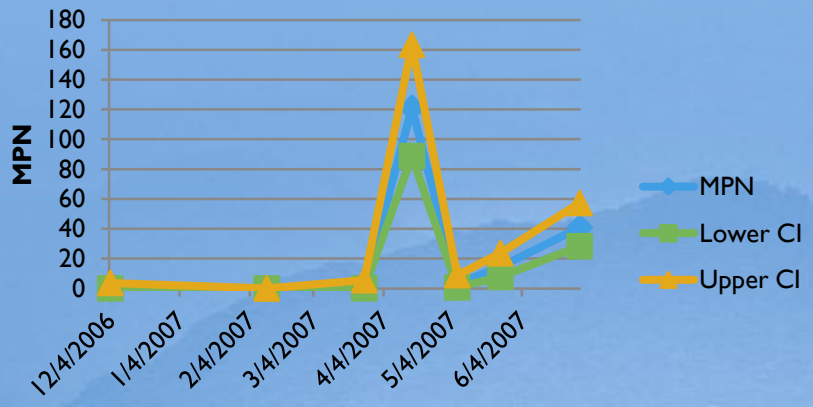


Site 3 Water - e. coli

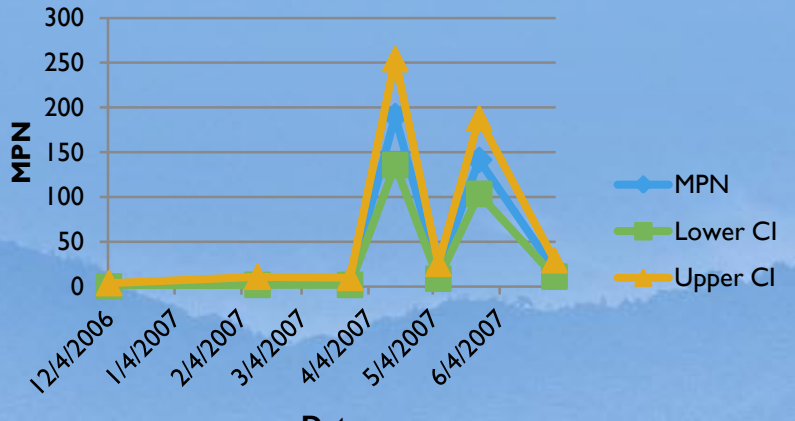


Site 12 Water - e. coli

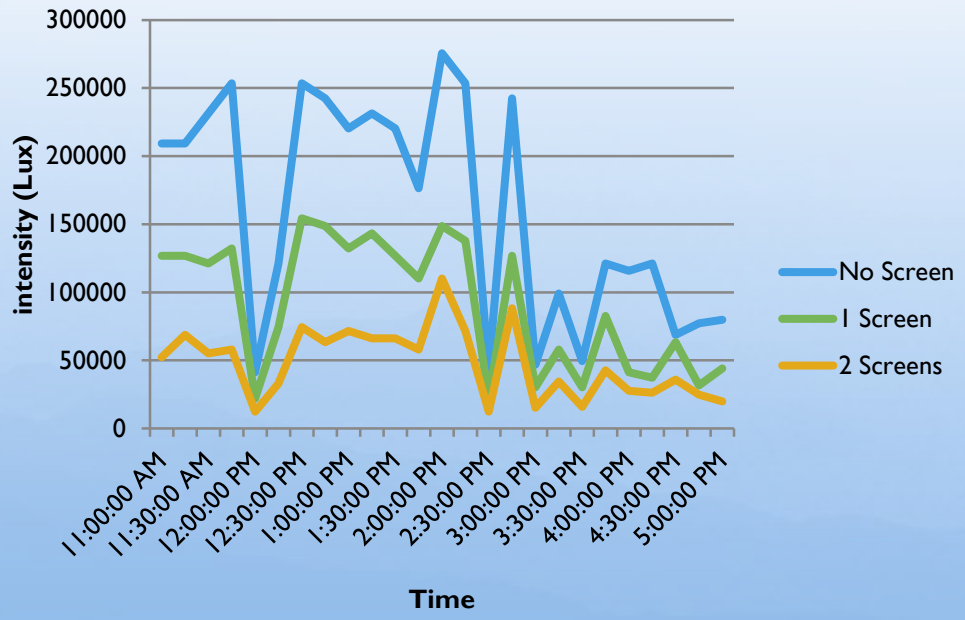
Site 14 Water - e. coli



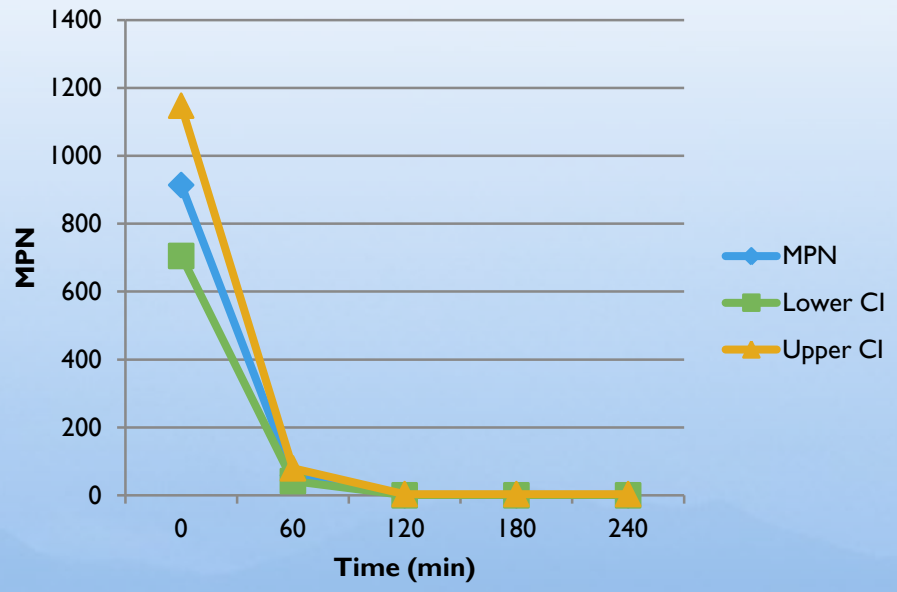
Site 17 Water - e. coli



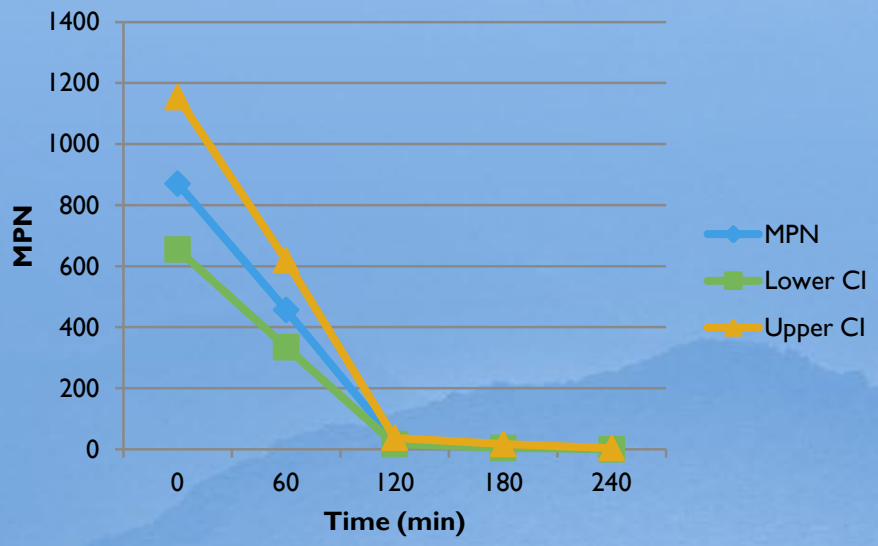
Light Intensity



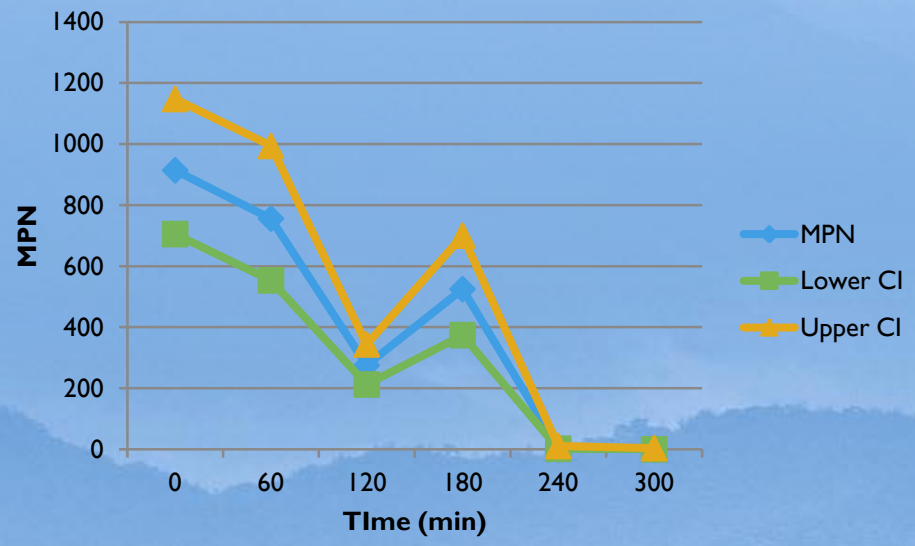
No Screen Total Coliforms



1 Screen Total Coliforms



2 Screens Total Coliforms



Questions?